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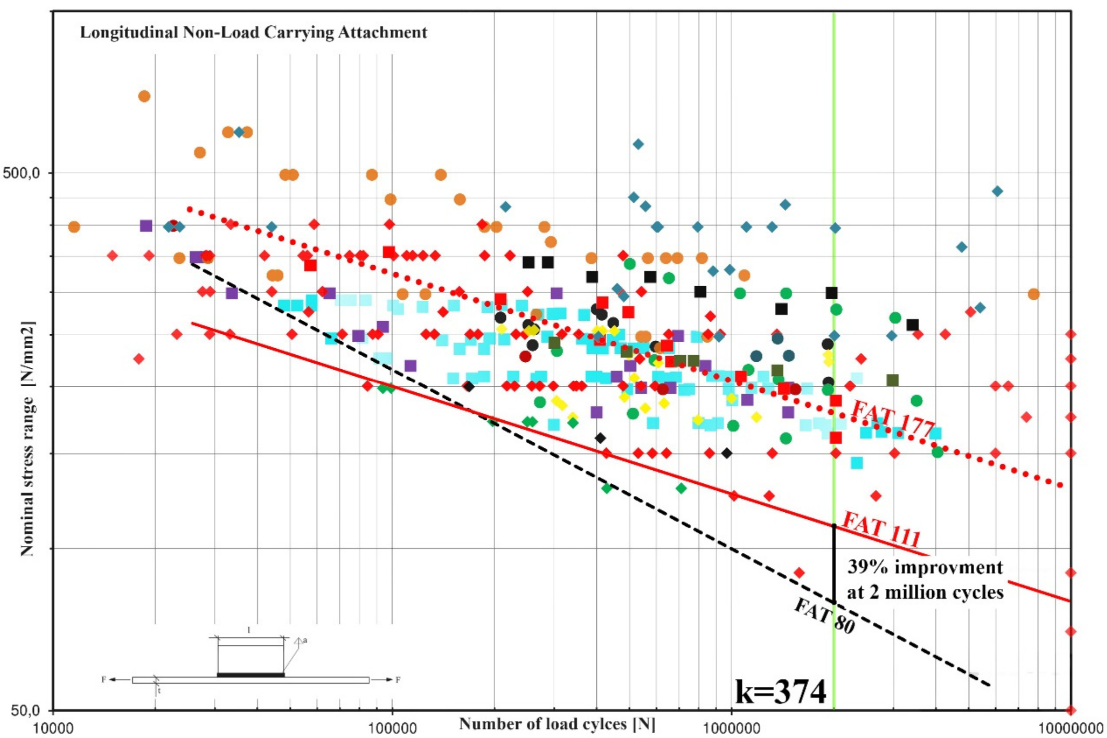

Evaluation of experimental test results of High Frequency Mechanical Impact improved welded details

Master of Science Thesis in the Master's Programme Structural Engineering and Building Performance Design

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover: Picture showing a comparison on different stress ratios concerning longitudinal non-load carrying attachment treated by high frequency mechanical impact technology.

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Abstract

There is a concern regarding fatigue strength of welded steel structures due to high stress concentrations. Over the last century numerous investigations has shown that when welded structures are subjected to cyclic loading, a premature failure occur in the structures before yielding strength is reached. This failure normally takes place in the welded joints due to several factors, such as weld geometrical non-uniformity that causes stress concentrations, material imperfections that act as local stress raisers, and high tensile residual stresses from constraints that appear during the cooling period of the weld. The unfavourable impacts of welded joints significantly decrease the fatigue strength of existing steel structures subjected to cyclic loading.

One option for dealing with this issue is through implementation of various post-weld treatment approaches. HFMI, high frequency mechanical impact treatment, is the most recently developed post-weld treatment technology. The improvement is achieved by removing the weld toe defects and detrimental residual stresses, which occurs at fillet weld throat. Moreover, the high frequency modification method also induces beneficial compressive residual stresses at the weld toe.

The main objective of this paper is to develop a data base by gathering significant information regarding the implementation of the HFMI method on welded steel structure. Accordingly, to support the empirical finding of this project, various published report are assessed and 959 experimental test results are compiled. The multidimensional aspect of welded joint has been narrowed down to three detail categories which are; longitudinal non-load carrying attachments, transverse non-load carrying attachments and butt welded joints.

Moreover, an assessment of the correlation between different steel qualities and stress ratios has been carried out for all three geometries in order to identify fatigue life performance due to these parameters, for samples treated with HFMI. In addition, as a delimitation of the project, the evaluation made in this thesis consists only of samples exposed to constant amplitude and axial fatigue loading.

Keywords: fatigue strength improvement, post weld treatment, High frequency mechanical impact (HFMI), Constant amplitude fatigue loading (CAFL), treatment

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1. Introduction

1.1 Background

In the field of steel science, it is widely acknowledged that the fatigue strength of a base material will improve, as the tensile strength increases (Xianghai et al., 2015). Therefore, the construction industry is persistently introduced to steel types with higher tensile strength. These high strength steels allow engineers to expand their design options to stronger, more lightweight and cost effective structures. Bridges, as well as several other areas of applications within building construction such as towers, wind turbines, masts etc., are continuously exposed to cyclic stresses. Thus, there is a concern regarding fatigue strength of the welded structures with high stress concentration. Over the last century numerous investigations have shown that when welded joints are subjected to cyclic loading a premature failure in the sense of time occurs in the element before yielding strength is reached (Boardman, 1990). This failure normally takes place in the welded joint due to several factors, such as weld geometrical non-uniformity which causes stress concentrations, material imperfections that act as local stress raisers, and high tensile residual stresses from constraints that appear during the cooling period of the weld.

The unfavourable impacts of welded joints significantly decrease the fatigue strength of steel structures subjected to fluctuating loading (Aygul, 2012). One option for dealing with this issue is through implementation of various post-weld treatment methods. Different approaches have been established to insure the industry in terms of increasing the fatigue life for the whole structure and are presented in section 3.1.

1.2 Purpose

The purpose of this master thesis is to gather information of interest concerning implementation of HFMI treatment on welded steel structures. This includes:

- Establish a database of published fatigue test result of HFMI-treated details
- Investigation about the influence of steel quality and stress ratio to the fatigue life of HFMI treated specimens.

1.3 Methodology

To accomplish the purpose of this work, an extensive literature study has conducted at an early stage of the project. This in order to obtain the necessary in regards to understand the fatigue phenomenon in steel and the improvement mechanism of HFMI methods. The literature study was conducted through reviewing a variety of books, reports and scientific articles.

Additionally, a comprehensive overview of experimental data points has been performed by considering HFMI treatments from several published experimental data. Due to a wide variety of the tested specimen geometries and loading conditions an overall evaluation for each type of HFMI treated detail has been carried out to determine a general trend of fatigue life improvement. Finally, the influence of different stress ratios and yield strengths for HFMI-treated specimens has been investigated.

1.4 Limitations

The scope of this thesis is restricted to investigating the fatigue strength improvement for welded steel components treated with HFMI. Furthermore, the diverseness of the welded joint geometries is narrowed down to three Eurocode (EC) recognised detail categories which are; longitudinal non-load carrying attachments, transverse attachments and butt-welded joints. In order to insure the validity of the data collected from the sample size, this theses only take in consideration the samples which have been subjected to constant amplitude loading constant amplitude and axial loading.

2. Fatigue introduction

One of the primary lessons taught hat is taught within engineering is the fact that components that are subjected to a stress higher than the yield strength will be deprived of their structural integrity. Nevertheless, if a material is frequently exposed to fluctuating stress amplitudes, even though the amplitudes are significantly lower than the material yield strength, an accumulated damage due to plastic deformation in material should be expected. This type of failure caused by dynamic loading is known as *fatigue damage*. Several micro-cracks initiate in the material as a result of repeated loading conditions and will further develop a *fatigue crack* with a plastic deformation on the crack tip. These plastic deformations are irreversible and cause permanent structural damage (Totten, 2008).

Within materials science, the phenomenon of fatigue is recognised as a slowly progressive and localised failure process, whereby a material that is subjected to cyclic loading is damaged and followed by a complete fracture after sufficient number of fluctuations (Boardman, 1990).

Fatigue is a harmful and time demanding process, which often is worsened by other unavoidable factors such as corrosion, material imperfections, and manufacturing defects. Furthermore, detrimental tensile residual stresses, which take form in introrespect, in the welded zone during the cooling shrinkage process, have an unfavourable effect on the fatigue strength. By compiling these features with a large number of cycles and complex variable amplitude loading fatigue failure or even worst, brittle failure, will occur significantly sooner than determined for the structure (Halford and Gallagher, 1389).

The total fatigue life of a welded detail is divided in two different phases which are illustrated in figure.1. The first phase, known as initiation phase, is dependent on the number of cyclic loading required to initiate a fatigue crack. In the second phase, the fatigue cracks propagate during cyclic loading period until failure occurs in the element. There are two ways to describe the severity of fatigue loading of the crack initiation and crack propagation phases. The stress concentration factor (SCF) is utilised for the initiation stage. For the crack propagating stage, stress intensity factor (SIF) is used (Al-Emrani and Åkesson, 2013). These two factors are further described in the up-coming sections 2.1-2.2.

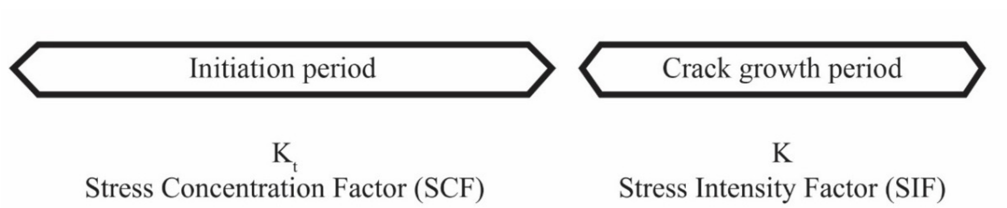


Figure. 1-Different phases of the fatigue life and relevant factors (Schijve, 2001)

2.1 Crack initiation phase

There are no records of the emergence of fatigue failure as an issue before the beginning of the 19th century. At this time, William Albert performed the first methodical analysis concerning material failure due to cyclic stresses (Bhat and Patibandl, 2011). Nevertheless, further observations regarding the crack growth phase of material failure were not made until the mid-20th century when so-called "defect-tolerant design" principles were concluded in the matter of critical fracture growth. These principles indicate that all structures being defective and that crack might occur in a premature stage of service life and grow in a crucial rate (Paris et al., 1961). As illustrated in Figure 2, the lifespan of an element subjected to cyclic loading, from fatigue life point of view, is divided into two phases such as fatigue crack initiation and fatigue crack propagation, where *N* denotes the number of cycles in each phase.

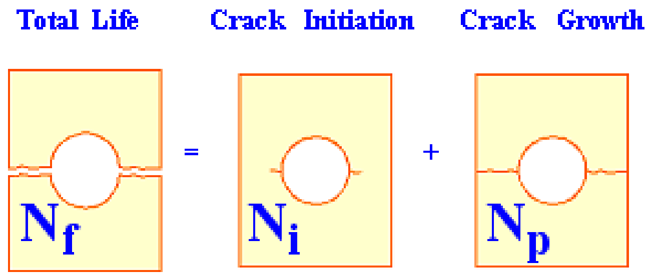


Figure. 2-Fatigue life initiation and propagation phases (Aparicio, 2013).

Application of cyclic stress to a structure results in micro-cracks around notches where the stress concentrations are relatively high (Schijve, 2001). The result of these micro-cracks merging into each other is referred to as a fatigue crack.

Initiation phase describes the part of lifespan where a specimen manages to withstand the applied loading. With other words, crack initiation phase is described by the number of cycles with sufficient number of cycles in order to form the first fatigue crack (Schijve, 2001). In the very end of this phase the dynamic loading causes the formation of the first crack in the region of the surface where the local stress is extensively larger than nominal stresses in surrounding regions (Peeker, 1997).

One type of defect in the crystal structure of metallic materials, from microscopic point of view, is referred to dislocations. A dislocation is an imperfection in the lattice structure that indicates the absence of a couple of ions in the layer (Al-Emrani and Åkesson, 2013). By the action of shear stresses near the dislocation lines, the atomic structure of the material rearranges. Consequently by applying stress, slip plastic deformations take place due to movement of this dislocation, as illustrated in Figure 3. This bahavior, also known as *slip bands*, leads to crystallographic spread of microscopic cracks and subsequently, the formation of fatigue cracks (NDT Education Resource Centre, 2014).

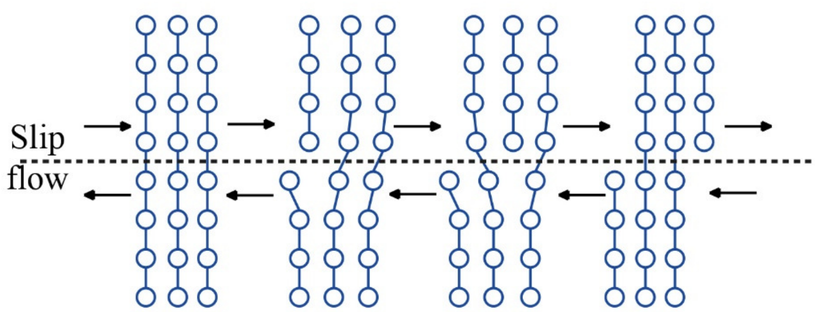


Figure. 3-Dislocation movement in metals (Zaucha, 2006).

When a slip band occurs due to the shear stress, a new part of the surface will be uncovered to the surrounding air (Al-Emrani and Åkesson, 2013). The uncovered surface will immediately react with the atmosphere and be imposed an oxide layer. The dislocation motion is within a crystal structure and it causes intrusion and extrusion at the slip planes, as illustrated in Figure 4. The intrusions and extrusions produced by an irreversible dislocation movement (Bhat and Patibandl, 2011). During the cyclic loading a slight relocation of material takes place at the slip planes which leadsto an intrusion. Nevertheless, as a specimen is under compressive cyclic loading the material is squeezed out at the slip band plastically and does not reverse again to its origin shape which results in extrusion of the material (Fong, 1979).

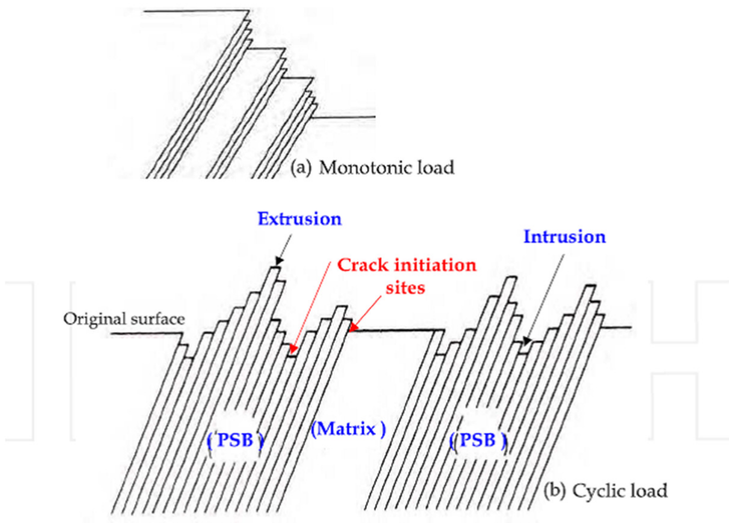


Figure. 4-Extrusion and Intrusion at surface metals due to material movement along slip planes. (Bhat and Patibandl, 2011).

2.1.1 Stress Concentration Factor (SCF)

Any kind of stress flow discontinuity, such as weld process, material defects and cracks leads to a disruption of the stress flow within the welded element and causes high stress peaks locally, which reduce the fatigue strength significantly. The dimensionless stress concentration factor (SCF), K_t, describes the ratio between the maximum stress achieved at the notch area σ_{max} , and the nominal stress at the uniform section of the specimen σ_n. This value depends on the size of the specimen and the shape of the notch in the concentration zone (Dürr, 2007):

$$K_t = \frac{\sigma_{max}}{\sigma_n} \qquad Eq.1$$

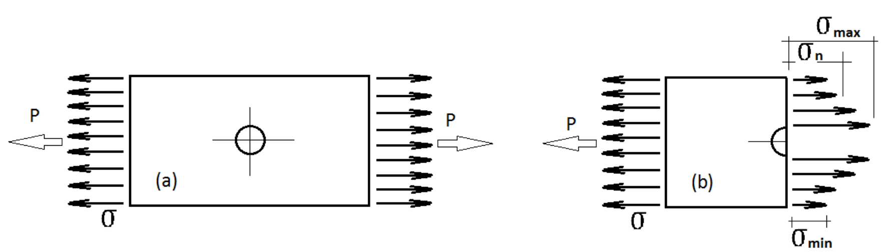


Figure. 5-Stress distribution for a plate subjected to tensile load (a) away from the hole; (b) in the section of central hole. (Santos, 2013).

The nominal stress can be achieved by dividing the axial tension or compression force P to the net cross section A_0 of the element (Santos, 2013):

$$\sigma_n = \frac{P}{A_0} \quad , \qquad A_0 = (w-d)t \qquad Eq.2$$

Where, *w* represents the width of the element, *d* is the diameter of the hole and *t* stand for the thickness of the element.

2.2 Crack propagation phase

The formation and growth of the fatigue crack due to cyclic stress is recognised as the second phase of the total fatigue life, referred to as fatigue propagation or fatigue growth (Peeker, 1997).

According to Totten (2008), the fatigue crack growth phase is subcategorised in these phases:

- Phase I (long cracks): This phase initiates when slips begin to progress in different planes near the crack tip as a consequence of crack growth or higher applied loads. In contrasts to the growth in initiation phase, which is orientated 45 degree in relation to the subjected stress, the direction of propagation in phase I is perpendicular to the load.
- Phase II (final fracture): The other phase of crack propagation is known as unstable crack growth because K_{max} converging to K_{IC} . This phase is highly sensitive with respect to the microstructure, stress ratio, and stress state, and the propagation is determined by static modes of failure.

2.2.1 Stress intensity factor (SIF)

Stress intensity factor (SIF), K is used as a measurement to find fatigue crack propagation rate and the severity of stress concentration around the crack tip zone. Beside the stress range in the exposed detail, SIF is decided by parameters such as loading mode, the geometry of the cracked detail, the boundary conditions and the length of the crack (Al-Emrani and Åkesson, 2013). The presence of higher SIF indicates higher extension of cracks, and has a detrimental effect on the strain (Bradt et al., 2010). Equation 3 expresses the stress intensity factor:

$$K = \sigma_n \cdot \sqrt{\pi a} \cdot f \qquad Eq. 3$$

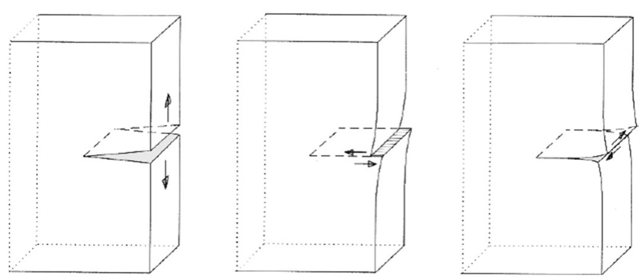


Figure. 6-Different crack opening modes. (Schijve, 2003).

Where, σ_n is the as nominal stress, a represent the length of the crack and f is a function of crack geometry and depends on the position of the crack.

In general, due to the deformation of the crack opening, three different types of crack growth modes are distinguished, as shown in Figure 6. During mode I, opening of the crack takes place due the tensile load, which is considered as the most crucial mode in concern to crack growth. This consideration is based on the high arising effect on the SIF. Mode I is also the most reappeared loading mode in engineering components (Al-Emrani and Åkesson, 2013). Furthermore, crack modes II and mode III result from shear stresses. The opposing displacement of crack surface for mode II and mode III are in same direction as the normal- and tangent vector, respectively. The actual state of a crack taking shape can consist of any type combination from these three presented modes. However, as previously mentioned, mode I is more interesting because fatigue cracks in many cases grow in perpendicular to the tensile stresses (Schijve, 2003). The stress intensity factor is specific for each mode and these are defined as K_I, K_{II} and K_{III} .

Due to an investigation by P.C. Paris et al. (1961), it is proven that the crack growth rate must be a function of stress intensity factor, as presented in following equation:

$$\frac{da}{dN} = C(\Delta K)^n \qquad Eq. 4$$

Where $\frac{da}{dN}$ is the growth rate of the crack, C and n are material constants and ΔK is the range of stress intensity factor, obtained from equation 5.

$$\Delta K = K_{max} - K_{min} \qquad Eq. 5$$

Generally, a standard graph is utilised to represent the interface of the fatigue crack growth rate $\frac{da}{dN}$ and stress intensity factor range ΔK, as shown in Figure 7. Both axes of the graph are logarithmically scaled. The representative curve in the graph is illustrating the fatigue crack propagation behaviour for metals and is divided in three different regions:

Region I illustrates the threshold value, ΔK_{th}, which is the minimum value for stress intensity factors and the fatigue cracks do not propagate in this region (Figure 7).

Region II contains a large amount of data concerning fatigue crack growth rates. The majority of crack development takes place in this section. The crack growth rate increases steadily by increasing stress intensity factor range ΔK. Therefore, one can assume the curve, within limitations of this section, to be a straight line with slope m. Moreover, the crack growth rate in region II is described by Paris-Erdogan law as a function of stress intensity factor (Charles and Crane, 2013).

In Region III the crack growth rate is accelerated to the point where stress intensity factor reaches the critical value ΔK_C, and therefore failure occurs in the component.

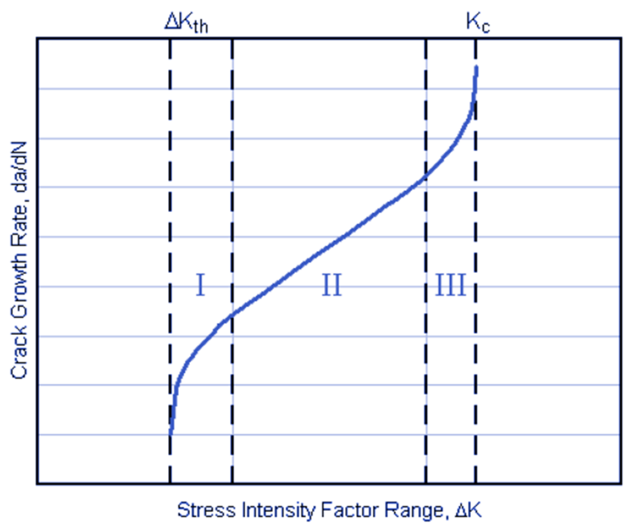


Figure. 7-Three different zones for fatigue crack propagation test. (Fatigue Crack Growth Analysis Review (2015).

2.3 Fatigue failure at welded details

Different weld defects take place at various parts of the weld section and function as local stress raisers, i.e. a position from where fatigue crack could originate. The detectability of weld defects is often a difficult task because of theirs small sizes and often difficult positionings. Some of the most emerging weld defects with a devastating impact on the fatigue strength of welded structure are inclusion, lack of fusion, partial penetration, porosity, and undercut. (Al-Emarani and Åkesson, 2013).

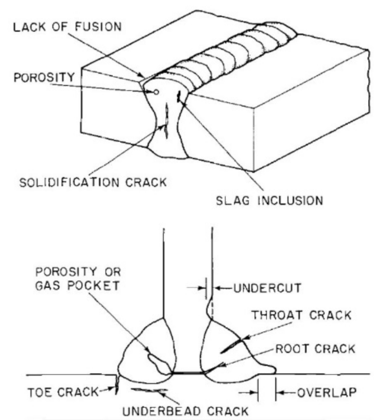


Figure. 8-Imperfections and cracks in welded joints. (Barsom and Rolfe, 1999).

As a consequence of the occurrence of these inconsistencies in the weld joint, a decrement of the service life is often beheld. Mostly, these imperfections initiate due to unconventional design, welding process, selection of material and defective craftsmanship (Yusof and Jamaluddin, 2014). In several scope of practices, several domestic and/or international performance requirements for welding details has been formulated.

2.3.1 Undercut

Undercut is categorised as a geometrical welding imperfection and is detected in almost all kinds of welds at the bordering section between the weld and the base metal, also known as weld toe. The expanse of undercut differs along the length of weld, as illustrated in Figure 9. The permitted amount of undercut is limited but this limitation is highly divergent for various codes and standards. Moreover, several tools are developed in order to detect this welding imperfection, such as Radiographic testing that is a non-destructive testing (NDT) method utilised for monitoring obscured defects in material (NDT Education Resource Center, 2014).

The cause to why of undercut occur is the formation of a groove when the melted welding material fails to fill the entire welding area. According to Karlsson et al. (2011) the characteristics of the melt flow depends on chemistry- and temperature-dependent viscosity as well as surface tension of the melt. Excessive arc length welding, high welding current, inapplicable stick electrodes and overheated base metal are the features causing formation of undercuts during fusion welding procedures, such as shielded metal arc welding.

Undercut at the weld toe is considered as the most detrimental geometrical weld defect. The fatigue performance for butt-welded joints due to this imperfection has been studied by Nguyen and Wahab (1996). A comparison of the fatigue strength for flush-ground welded plates, with and without the absence of undercut, demonstrates an approximately twice as large reduction of the fatigue strength as this imperfection occurs (Nguyen and Wahab 1996).

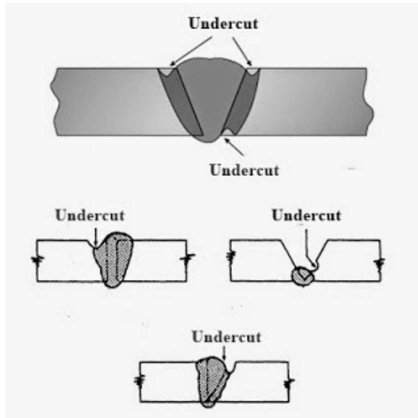


Figure. 9-Undercut defect in butt-welds joint (Effective Ways to Prevent Weld Undercutting, 2013).

2.4 Fatigue resistance

The fatigue resistance in a component is influenced by several factors, such as size of material, type of cyclic loading and surface condition of material. The fatigue endurance of larger samples is lower compared to the smaller ones of the same material. The fatigue cracks nucleate from the weakest link due to under continuing cyclic loading, thereby the crack like-flaws are propagated subsequently in the stress region. Due to this, a higher probability is expected for larger components to reach the weakest link. Also, the character of loading, constant or variable, affect the fatigue life of material, which is discussed in detail in section 2.5. Another factor that influence the fatigue strength, is related to surface condition of material. Any discontinuity in the material surface results in additional stress concentration and residual stresses, which is decreasing crack nucleation phase (Understanding Fatigue Analysis, 2013).

2.4.1 S-N curves

One approach to determine the fatigue strength and service life of materials is by performing SN-testing. During these tests different samples of the same material are exposed to sinusoidal loads with different load amplitudes. In the next step, the results of all tests are plotted in a logarithmic diagram. The horizontal axis of this diagram represents the number of cycles and the vertical axis illustrates the nominal stress range. A statistical evaluation containing all tested specimens data is required to establish a linear regression line in the SN-diagram. The resulting curve from this testing is known as Wöhler-diagram or SN-curve (AL-Emarani and Åkesson, 2013).

The S-N-curve is also divided into three regions which are described as follows:

- In the left part of the SN-diagram, failure of specimens occurs due to high stress ranges but small number of cycle. This area is known as low cycle fatigue (LCF), see Figure 10. In this region, the fatigue resistance is basically characterized by the fact that the yield strength of the material is exceeded during the cyclic loading. The high stress level in this limit lead to plastic deformation in the components.

- The middle region of Figure 10, that is located in-between LCF and fatigue limit, represents high cycle fatigue (HCF). In this area failure take place under cyclic loading with low stress range and high number of cycles. The number of cycles which materials can withstand for a given stress range in this limit allows engineers to design products or structures with maximum performance in term of the material fatigue strength.
- Beneath the fatigue strength limit S_{be} , see Figure 10, the welded steel element endures infinite load cycles. In other words, as long as the stress range is below the stress limit the cracks are not able to propagate in the material. This region is referred to as the cut-off limit.

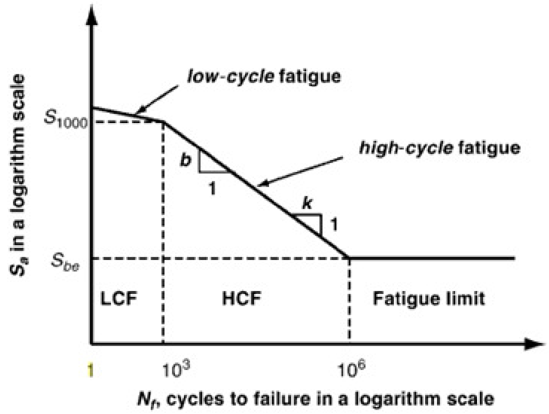


Figure. 10-Typical S-N curve (Mosiello and Kostakakis, 2013).

2.4.2 Stress assessment approaches for welded joints

To evaluate the fatigue strength of metallic structures three different methods are presented in international institute of welding leaflet, such as the nominal stress approach, the structural hot spot stress approach and the effective notch stress approach (Hobbacher, 2008).

2.4.2.1 Nominal stress approach

The nominal stress approach is the most commonly utilised method to evaluate the fatigue strength in welded details and the governing approach for this study. The concept behind this method is based on numerous experimental studies on a variety of structural details and it is mainly related to macro-geometry feature of these details. The local stress concentration in the welded joints, where cracks commonly are developed, is not detected by the calculations (Aygul, 2012).

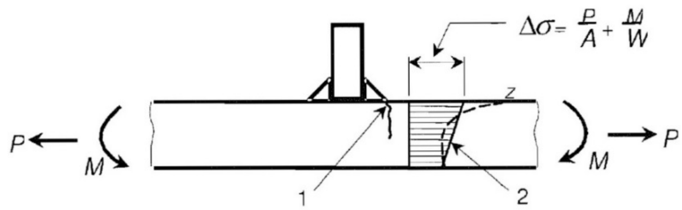


Figure. 11-Local stress concentration at weld toe; 1- crack initiation site; 2 - linear stress distribution, weld toe stress factor at z not calculated (EN 1999-1-3, Eurocode 9, Part 1-3., 2011).

According to Eurocode (EN 1993-1-9, 2005), the nominal stress value is calculated as using the equation below:

$$\sigma_N = \frac{P}{A} + \frac{M}{W} \qquad Eq.6$$

Where, A is the cross section of the element, P is the axial force, M is the bending moment in the section and W is the section modulus.

2.4.2.2 Structural hot spot stress approach

Under the condition where welded details have complex profile, applying the nominal stress method can be significantly complicated and the stress distribution results can no longer be considered as valid

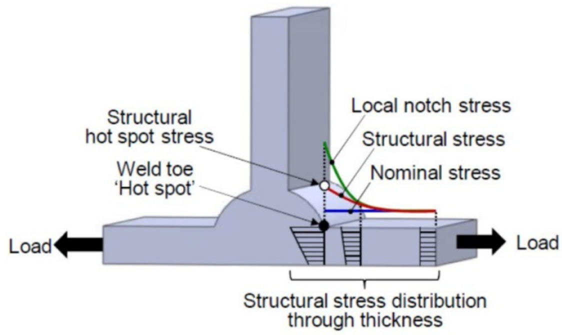


Figure. 12-Structural hot spot stress approach principle (Djavit and Strande, 2013).

data (Aygul, 2012). In these cases, the hot spot stress approach can be considered as an complementary method of the nominal stress approach and should be utilised specifically for welded structures. Noteworthy is that the fatigue life assessment based on this approach consider many different types of welded structures in much fewer S-N curves (Lotsberg and Sigurdsson, 2006). High stress concentrations in welded steel structures with non-uniform stress distribution are commonly occurring in the weld toe region. This is due to notch effect that is causing high local stress concentrations. Consequently, there is a significant potential for crack initiation in this critical region, illustrated by Figure 12.

2.4.2.3 Effective notch stress approach

The assessment of the local stresses at welded elements is normally taking place at the notch area in a section, i.e. the weld toe. Geometrical discontinuities and weld defects on the steel welded structure cause high stress concentration at the weld toe, and therefore the maximum stress accumulate in this region, see Figure 12. The evaluation of the total stress, using effective notch stress approach, is based on the linear elastic behaviour of materials and it is obtained through finite element analyses (Schijve, 2001). One of the main advantages gained by this method, compared to the structural hot spot method which considers just for the weld toe, is its ability to evaluate local stresses at both weld root and weld toe. Nevertheless, the detail geometry of the welded section is required in advance in order to be able to utilise this approach.

2.5 Fatigue loading

The appearance of fatigue load is noticed within many different engineering fields, such as structural-, automotive-, marine-, aircraft engineering, etc. The ultimate fatigue load which causes failure in materials is normally lower than the expected design load. Therefore, for the structures that are aimed to withstand the applied cyclic loading, the detrimental effect by this type of load should be accounted for under the design process (Ashcroft, 2011).

Fatigue failure is a time consuming procedure which takes place under cyclic loading in materials and/or welds. The load spectrum containing both constant and variable amplitude are illustrated in Figure 13. In Figure 13.a the repeated load or stress cycle does not vary in time and is known as constant amplitude cyclic stress. Constant amplitude loading is the most common kind of applied loading in regards to performing laboratory tests. As shown in Figure 13.b, structures subjected to tensile cycle loading do experience both maximum stress σ_{max} and minimum stress σ_{min}. However, the magnitudes of these stresses do not have to be the same for these extremes (Ashcroft, 2011). Constant amplitude loading is not the most common loading pattern experienced by actual structures such as bridges and offshore constructions. The kind of stress cycles subjected to these structures are commonly defined as variable amplitude loading, which has an irregular stress sequence during the lifetime of these structures, as illustrated in Figure 13.c.

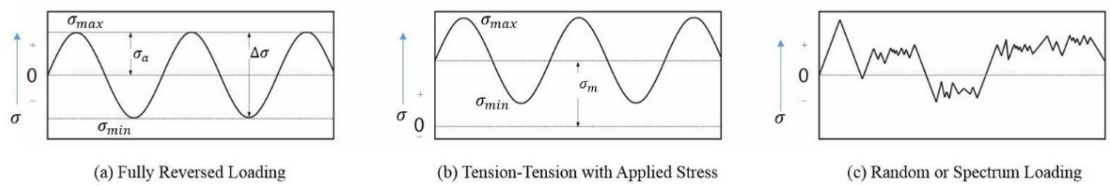


Figure. 13-a) Random or spectrum loading b) Constant amplitude under tension-tension load condition c) Variable amplitude loading spectrum (Campbell, 2008).

By calculating the difference betweeen maximum and minimum stresses, one can express the stress range $\Delta\sigma$ (Campbell, 2008).

$$\Delta\sigma = \sigma_{max} - \sigma_{min} \qquad Eq. 7$$

Cyclic stresses are composed by two parameters, mean stress σ_m, and alternating stress σ_a (Campbell, 2008).

$$\sigma_a = \frac{\Delta\sigma}{2} = \frac{\sigma_{max} - \sigma_{min}}{2} \qquad Eq. 8$$

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} \qquad Eq. 9$$

The stress ratio, R, which has a significant influence on the crack growth rate is another way of describing the mean stress which is frequently used in discussions concerning fatigue loading and failure. This feature can be expressed by calculating the ratio between the minimum to the maximum stresses (Campbell, 2008).

$$R = \frac{\sigma_{min}}{\sigma_{max}} \qquad Eq. 10$$

2.5.1 Constant amplitude fatigue loading (CAFL)

To represent the random-loading spectrum, the determination of fatigue resistance for laboratory test details are commonly performed by using constant amplitude fatigue loading. This in form of sinusoidal waveform (Al-Emrani and Åkesson, 2013). In order to achieve variable amplitude loading in a laboratory environment, several preconditions are required. To create the actual loading situation and also achieving equivalent fatigue damage on the test subject, one should apply several equivalent costant stresses, during the same number of, see Figure.15. The transformation of the fluctuated load spectrum into an equivalent constant amplitude stress histogram is generally accomplished through cyclic counting methods. According to Al-Emrani and Åkesson (2013), two of the most commonly used methods for this purpose are the "rainflow" and the "reservoir" counting methods.

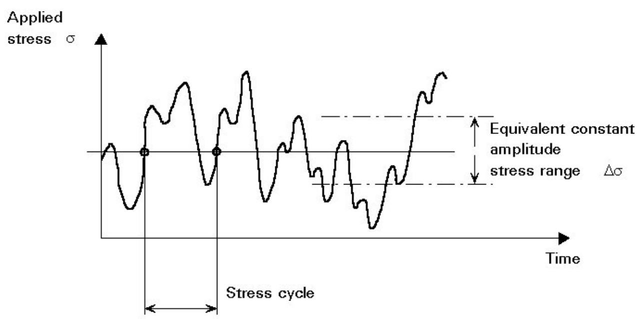


Figure. 15-Variable amplitude stress history (Al-Emarani and Åkesson 2013).

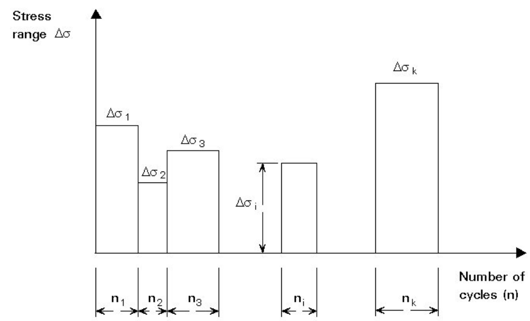


Figure. 14-Stress histogram or stress range distribution (AL-Emarani and Åkesson 2013).

Considering the irregular nature of variable amplitude loading, modelling these significant features is a complex issue. Subsequently, plenty of concepts have been formulated to calculate the fatigue strength of details conducted to variable amplitude loading, such as Wheeler model (Wheeler, 1972), Willenborg et al. model (1971), and the crack-closure measurement method established by Elber (1971) etc.

The results collected from random-load spectrum are reviewed in terms of the equivalent constant amplitude stress range, $\Delta\sigma_E$, in order to simplify assessments with the test outcomes (Huo et al., 2005). This was computed with the assumption based on the Palmgren-Miner rule for calculating the cumulative damage, *D*:

$$D = \frac{n_1}{N_2} + \frac{n_2}{N_2} + \cdots = \sum \frac{n_i}{N_i} \qquad Eq. 11$$

with a number of cycles n_i and the life N_i at stress range $\Delta\sigma_i$ given by the constant amplitude S-N curve achieved with regard to the governing failure factor for the detail. Furthermore, this results in the equivalent constant amplitude stress range $\Delta\sigma_E$ (IIW, 1982) :

$$\Delta\sigma_E = \sqrt[m]{\frac{\sum n_i \Delta\sigma_i^m}{\sum n_i}} \qquad Eq. 12$$

where *m* is the slope of the constant amplitude S-N curve.

2.5.2 Variable amplitude fatigue loading (VAFL)

The discussion concerning constant amplitude loading has brought a lot of attention on the vital mechanisms of fatigue crack propagation properties. The relevancy of variable amplitude loading is more accurate than constant amplitude loading due to more frequent appearance of random-load spectrum in real life engineering structures. Therefore, the ability of comprehending the feature of stress interaction during irregular loading is necessary within life damage calculations and structural design proposals. Due to the magnificence of the topic, numerous researches have been carried out over the last decades (Singh et al., 2011; Huo et al., 2004).

The recognition of the magnitude of variable amplitude loading was made by Ernst Gassner in 1939, who become the first person to formulate a method for simulating variable amplitude loading, The 8 step-blocked program arrangement (Gassner, 1939), as illustrated in Figure 16. Until utilisation of irregular stress sequences using modern servo-hydraulic operating devices in the 1970's, the arrangement by Gassner's was utilized as a norm. Meanwhile, several other constant loading spectrums were established for various application fields (Singh et al., 2011).

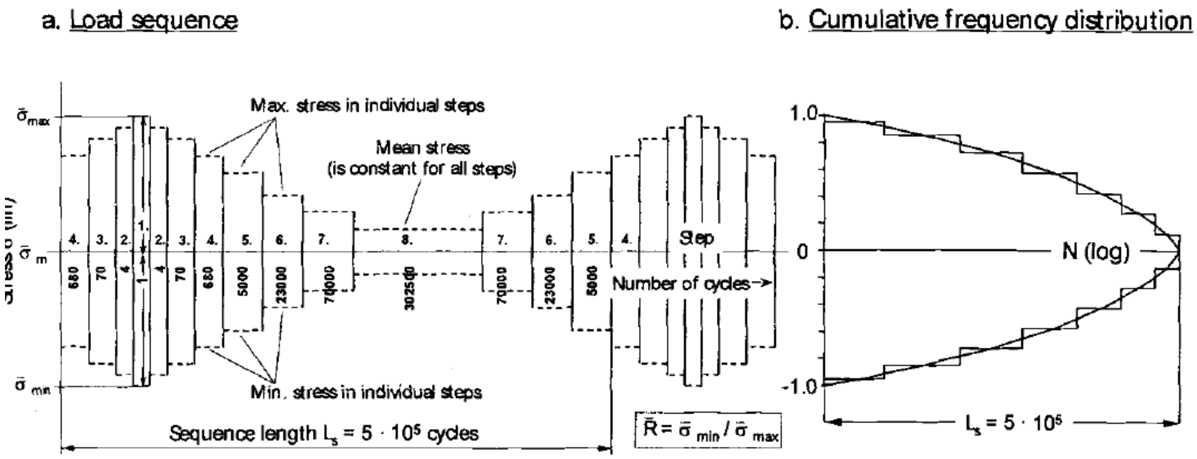


Figure. 16-Gassner's 8 step-blocked program arrangement (Gassner, 1939).

An additional important concern in terms of variable amplitude loading is the technology utilised for laboratory testing as well as managing the outcomes. Experiments are executed by application of stress sequences limiting factors such as the stress ratio, the cycle length, and the progressive frequency distributions pursuant to cycle counting approaches. (Singh et al., 2011). However, the main variable parameter is the stress, which has an impact on the scale of all amplitudes and mean values. These experiments are performed in repeated arrangement of variable stress until the predetermined failure has occurred in terms of a specified crack depth, or total fracture, etc. Moreover, it should be mentioned that a variable amplitude test is considered properly executed as the sequence is repeated by a minimum number of five (Singh et al., 2011).

2.5.2.1 Retardation due to overloading

Engineering structures in service occasionally undergo stress amplitudes which remain constant through the entire service life. Fatigue crack propagation is mostly governed by crack tip plasticity and the permanent nature of plastic strain. Therefore, fluctuation of stress cycles are continuously effecting the ratio of fatigue crack propagation as well as the fatigue enhancement. It is acknowledged that the growth ratio is influenced by factors such as overloads, under-loads, random load spectrum, and block loads (Sadananda et al., 1999).

Several different types of engineering modules experience the phenomenon of overload during their lifetime. Various vital and dominating stress collaborating properties has been recognized in terms of fatigue crack propagation under random load spectrum. The most outstanding property that with needs of being further investigated is the delaying mechanism of crack propagation caused by tensile overloading. This behaviour is nearly associated with residual stresses and deformations caused by the same phenomena (Sadananda et al., 1999).

Overlaying single-peak overloads or spike loads have a delaying effect on crack growth. The delay is influenced by various factors, such as material flow properties, slip planarity, and microstructure. Nevertheless, the most governing factor is the magnitude of the overloads. When the appliance of these features is performed in a periodic manner, the spatial arrangement between the spike loads is considered as an equally vital and dominating factor. By increasing the frequency of overloads, a greater retardation would be achieved. However, too adjacently positioned overloads might result in an acceleration rather than deceleration (Sadananda et al., 1999).

Studies has shown that phase deformation at the crack-tip which is caused by fatigue, results in deceleration for crack propagation ratio (Hornbogen, 1978; Pineau and Pelloux, 1974). This phenomenon is generally mentioned as the transformation-induced Plasticity (TRIP) effect. According to Lee (2009), the phase deformation at the crack-tip is similar to the crack-tip plastic deformation where compressive residual stresses are induced within the nonlinear zone, during cyclic tensile stress. In other words, the mutual factor for these features is that the residual dislocation being remained in the crack wake, and operating towards shutting the crack prematurely at a far-field tensile stress. This matter is mostly affected by dimension and geometry of both the detail and fatigue crack (Lee, 2009).

The impacts from one single-peak tensile overload have been a vital topic within fatigue science. Due to the disadvantageous nature of the subject which can result in a major increment for the fatigue resistance. Extended research has been performed in order to estimate the impact of this feature in terms of the number of detained cycles required to regress to the background steady-state crack propagation ratio. Figure 17 illustrates a schematic of overload impacts due to crack propagation.

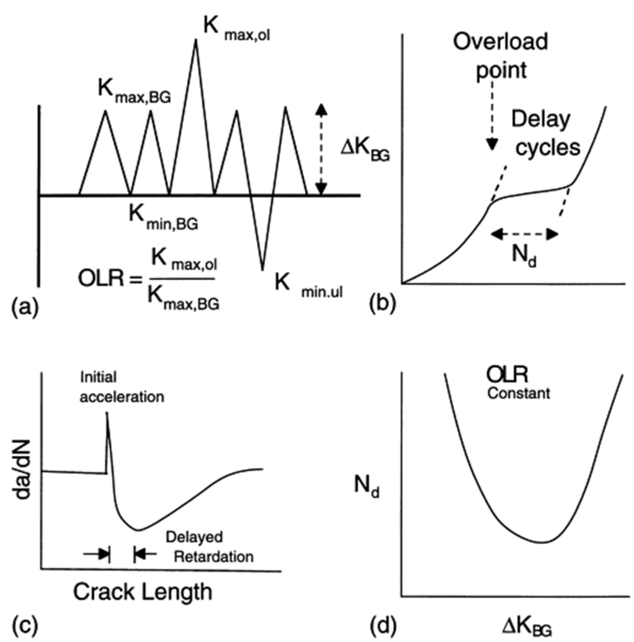


Figure. 17-Schematic illustration of the overload effects on fatigue-crack growth (Sadananda et al., 1999)

2.6 Residual stress

Residual stresses (RS) are described as stress distributions that are left behind in materials after material treating- and/or component assembling-procedures, without any influence by external loads or thermal gradients (Kudryavtsev, 2008). Terms, such as macro- or micro-stresses are often utilised in order to categorise these internal stresses. Schjive (2001) explains the background of the terminology “residual stress” as where the distribution of this feature in a material is often remained as a residue of inhomogeneous plastic distortion.

Nearly all manufacturing procedures, such as casting, welding, machining, heat treatment, etc., result in appearance of RS within the finale product. Other inducing parameters for residual stress are in-service repair and/or modification. Moreover, stress distribution might occur during a later stage of the service-life, for instance by installations, irregular overloads, or dead masses that eventually turn into an integrated component of the assembly (Vishay Precision Group, 2010).

According to Kudryavtsev (2008), RS can substantially influence the engineering characteristics of materials and structural bodies. Giving examples such as the fatigue life, deformation, dimensional stability, corrosion resistance, and brittle fracture. These factors are often resulting in major expenses considering maintenance and renewal of components, installations, and structures. Consequently, consideration of RS becomes an unavoidable phase in the modelling of components, as well as in the evaluation of their trustworthiness under actual service conditions.

With the absence of any external loading, the residual compressive stresses need to be equilibrated with the residual tensile stress (Schijve, 2001), as illustrated by Figure 18:

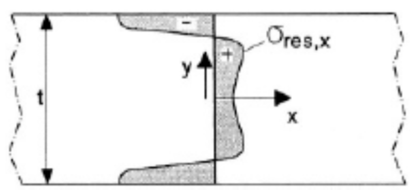


Figure. 18-A residual stress distribution is an equal distribution (Schijve, 2001).

The magnitude of RS has a vital impact in practical issues in the field of fatigue. The impact can either be favourable or disadvantageous, due the significance, path, and distribution of the stress with regard to the load causing the existing stress. Most likely, the impact of these stresses are harmful, and plenty of scientific documentations discuss that residual stresses are predominant parameter causing fatigue and other structural failure (Vishay Precision Group, 2010). The most unreliable character of RS is that its existence usually remains unacknowledged until after failure occurs.

2.6.1 Welding residual stresses

Welding is an important manufacturing procedure within engineering and material science. The procedure of welding engenders residual stresses at often significant levels. Methodical researches indicate that RS caused by welding might result in a radical decrease of the fatigue strength for the welded joints. The occurrence of RS in weld is an outcome of various contractions due to hardening of the melted welding metal while cooling to surrounding temperature. Actually, a high amount of heat contribution enters the welded material, which consequently creates non-uniform heat distributions, plastic distortion, and phase modifications (Rossini et al., 2012). These alterations engender various residual stress patterns in the heat-affected zone (HAZ) as well as rest of the welded region. All of the stress initiating mechanism influences the residual stress distribution uniquely, as illustrated in Figure 19.

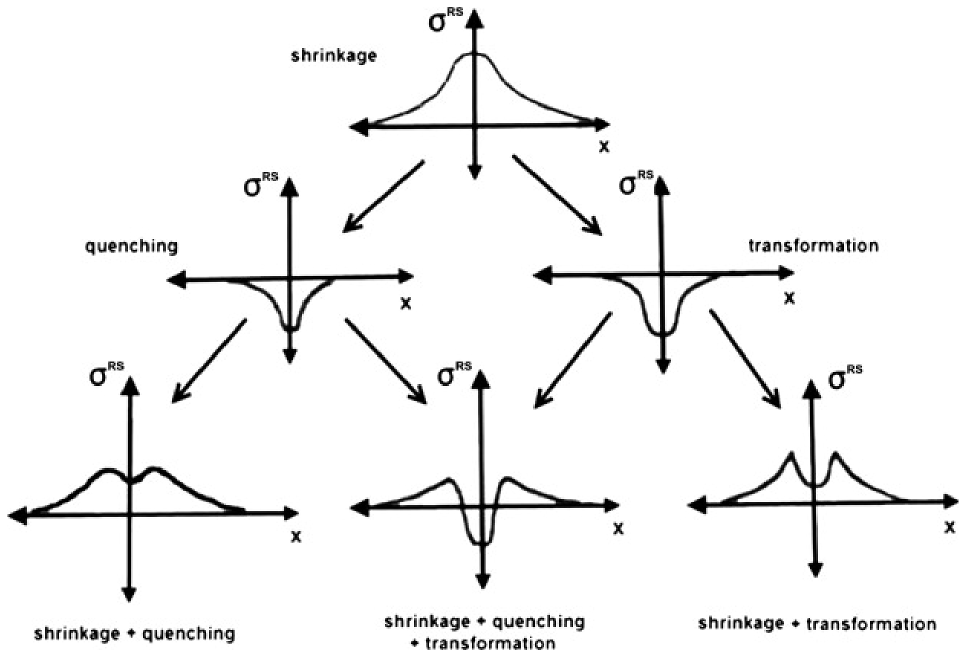


Figure. 19-Change of residual stress due to metallurgical processes during welding (Rossini et al, 2011).

The shrinkage of the melted section results in induction of tensile residual stresses. According to Rossini et al. (2012), transformation inducing residual stresses appear at regions of the HAZ where the temperature arises beyond the critical standards for phase modifications. Furthermore, compressive residual stresses will take form at the point where the influence of phase modifications is dominant.

After a welding operation, the temperature of base material and welded sections are decreased, but the contraction of these two during the cooling stage, are dissimilar due to different crystalline structure. These non-corresponding behaviours of weld and base material generate unfavourable internal tensile stresses, which are captured in the material. Thereby, before the welded elements are subjected to external forces, the tensile residual stresses are presented on the surface of material. Consequently, after appliance of the loading condition, the total stress of the welded profile becomes a summation of the internal and external stresses. The fatigue initiation phase is reduced under this combined loading condition which results in appearance of premature cracks at the weld toe and fracture occurs (Rossini et al., 2012).

By high frequency mechanical impact methods the material in the weld toe are compacted together and the tensile residual stresses are transformed to beneficial compressive residual stresses. In this case when the treated welded joint is subjected to the tensile load, the compressive residual stresses expand the fatigue initiation phase.

3. Post weld treatment

restoration approach considered for the weld in order to obtain fatigue strength improvement, is acknowledged as a post-weld treatment (PWT) method. Investigation concerning this topic shows that these fatigue enhancement methods are strongly dependent on loading conditions (Manteghi and Maddox, 2004). In the intersection region of the weld and base metal at the weld toe, the tensile residual stresses are critical and are causing detrimental effects on the fatigue strength of the component. Furthermore, the generation of invisible cracks in the slip bands, increases the stress concentration in this region. In the conditions where welded elements are subjected to a cyclic load, the fatigue initiation phase decrease drastically (Schijve, 2008).

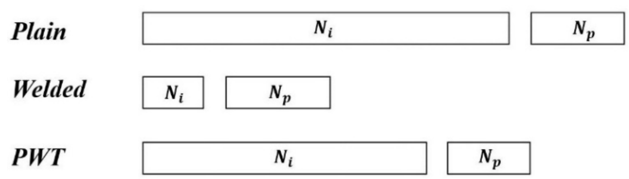


Figure. 20-The benefit of PWT in restoring the crack initiation life of a welded specimen (Mosiello and Kostakakis, 2013).

PWT's are basically classified into two different categories. The main aim for both of these methods is to create a smooth weld by removing the high stress concentration. The first category is recognised as weld geometry enhancement methods which is subdivided in grinding and re-melting methods. During these procedures the weld defects are vanished and a rounded weld profile is established (Ummenhofer et al., 2010).

The second category is a residual stress modification approach. In these methods the weld toe is hardened by different peening techniques such as hammer peening, needle peening, shot peening and high frequency mechanical impact treatment (HFMI). HFMI is a recently developed post-weld technology that enhances fatigue properties. This achievement is induced by beneficial compressive residual stresses that arise due to peening, simultaneously as the weld toe defects and detrimental residual stresses are removed from the fatigue crack-initiation sites. Furthermore, HFMI treatments can be classified according to the device utilised for the operation such as, high frequency impact treatment (HiFIT), ultrasonic impact treatment (UIT), ultrasonic peening treatment (UPT) and pneumatic impact treatment (PIT).

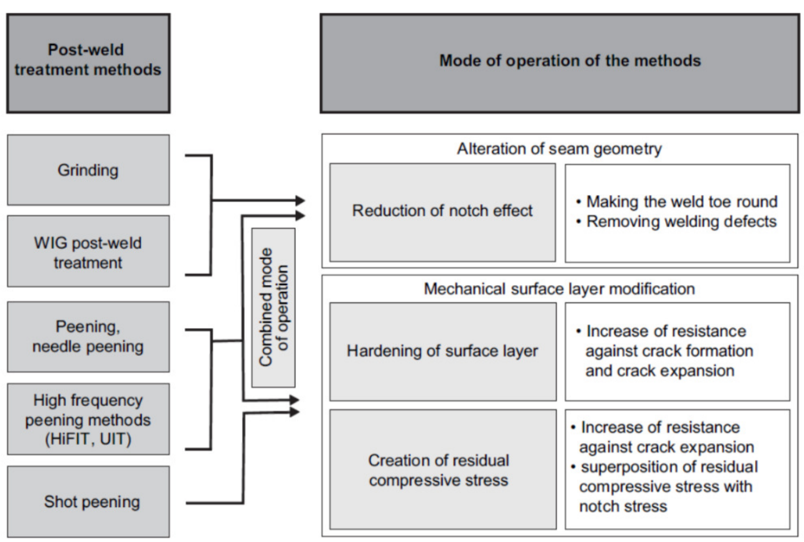
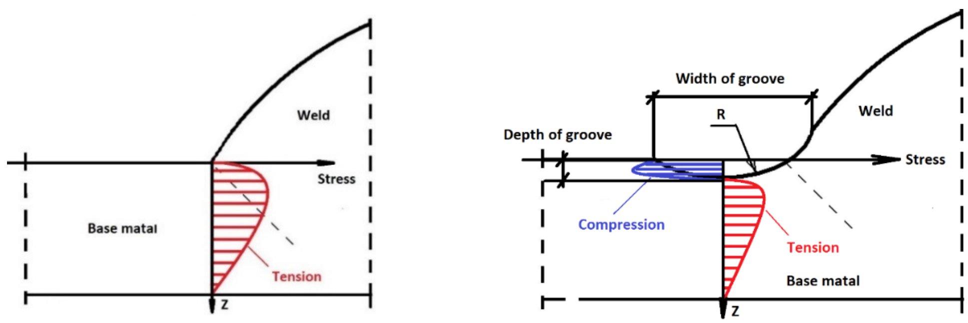


Figure. 21-Post-weld treatment method sub-categorised in different mode of operation (Ummenhofer et al., 2010).

3.1 High Frequency Mechanical Impact treatment (HFMI)

HFMI treatment is a recently developed technology that enhances fatigue performance of welded structures by removing the weld defects and detrimental tensile stresses at the transition zone. This method provides beneficial compressive residual stresses in the surface layer of the weld toe. With other words, HFMI treatment impacts the material at the intersection layer of the weld and base metal by high frequency peening during the operation and induces local plastic deformations in this zone (Kudryavtsev et al. 2009). Thus, a uniformly rounded weld toe profile is achieved, as the outcome of the treatment. Figure 22 is illustrating the before and after distribution condition of tensile and compressive stresses for a HFMI treated welded detail:



(a) (b)

Figure. 22-Stress distributions of the cross section of a welded joint (a) before and (b) after HFMI treatment (Kudryavtsev et al. 2009).

Figure 22.a, shows the distribution of the tensile residual stresses that are originated after welding process in the base metal. Consequently, when a welded element is subjected to an external load, the unfavourable tensile residual stresses are added up and cause unexpected premature failure in the welded joint. Figure 22.b illustrates the post treatment distribution of the compressive and tensile stresses. In this case, the compressive stresses at the surface layer increase the fatigue resistance of material against the external loads (Kudryavtsev et al. 2009).

Although all the HFMI treatment methods have similar operation concepts, they are categorized according to the type equipment that is used for the high frequency peening treatment. Some of these techniques are presented in the following sections.

3.1.1 Ultrasonic Peening Treatment

Ultrasonic peening treatment (UPT) increases fatigue strength by removing the harmful tensile stresses and simultaneously creating compressive residual stress in the welded joints. UPT can be addressed as mechanical surface treatment which changes the formation of surface layers.

The purpose of surface deformation in this treatment is to introduce a groove in the direction of weld toe and eliminate tensile stress and cracks in this part. The treatment process requires frequencies above 20 kHz which is induced by periodic impact peening in the surface of the weld toe. This operation alleviates the stress concentration and modifies the weld geometry in the tensile zone (Galtier and Statnikov, 2013).

Figure. 23-Basic ultrasonic peening system for fatigue life improvement of welded elements and structures. (SINTES-Technology and Equipment for Ultrasonic Impact Treatment (UIT/UP), 2015).

3.1.2 Ultrasonic Impact Treatment

Ultrasonic impact treatment (UIT) is developed at Northern Scientific Technological Foundation in Russia and Paton Welding Institute in Ukraine (E. S. Statnikov, 1996). The rounded head needle for this method, impacts the weld toe through ultrasonic frequency close to 27 kHz. The equipment which is utilised during the operation is put together by an electronic control box and a handled tool (Roy et al., 2003).

Figure. 24-Ultrasonic needle peening system for fatigue life improvement of welded elements and structures (Sonats, 2014).

The technique is a more effective and more environmentally friendly alternative compared to weld treatments mentioned in IIW, such as TIG welding, grinding, air hammer peening, etc. In contrast to the previous methods, UIT is a more effective approach as the technology involves a complex effect of strain hardening, reduction in welding strain, relaxation of the residual stress and reduction in stress concentration (Roy et al., 2003).

3.1.3 High Frequency Impact Treatment

High frequency impact treatment (HiFIT) is a pneumatic high frequent peening procedure which results in a plastic deformation at the as-weld joint. The goal of the treatment is to create a smooth rounded shape at the weld toe and remove the notch sharpness in this part using an air supplied device. One single round shaped intender with a defined radius is applied for this purpose to delay the crack formation and crack propagation at the weld toe (PFEIFER, 2015).

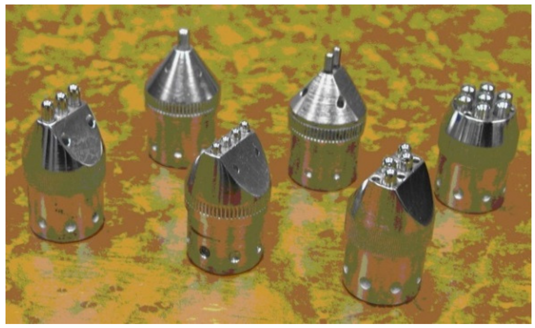


Figure. 25-A set of interchangeable working heads for UIT/UP. (SINTES-Technology and Equipment for Ultrasonic Impact Treatment (UIT/UP), 2015).

HiFIT is applied with various frequencies, 180 – 250 Hz, relying on the surface layer being treated (Ummenhofer et al., 2010). One vital specification for the outcome is the degree of intensity which depends on a combination of process speed, shape of the pin and treatment frequency. According to Ummenhofer et al. (2010), an optimal distortion of the seam geometry and inducing residual compressive stress may be attained by operating with an angle of 60 - 80° combined with one or several pins with a diameter of 3 mm and a depth of groove which is 0.25 mm or smaller. Consequently, the fatigue life of the new treated weld is considerably increased in comparison with the as-weld joint. One of the advantages of this method, which favours it to be considered more reliable, is the visual inspection ability after the welding process.

3.1.4 Pneumatic Impact Treatment

Pneumatic impact treatment (PIT) is a high frequency peening method, which is developed for upgrading fatigue strength and for reducing welding distortion. The method of operation in this treatment consists of mechanical pulses which are transmitted by hardened pins on the weld toe surface. Thus, the material surface will harden and a plastic deformation will take place at the weld toe. Furthermore, uniform compressive residual stresses up to a depth of 2-3 mm can be obtained, depending on the material properties.

Figure. 26-Pneumatic impact treatment system for fatigue life improvement of welded elements and structures. (PITEC, 2013).

PIT does fulfil the diverted requirements of various materials by providing adjustability in term of important parameters, such as the frequency (0-200 Hz), the compressed air, and the impact force while operating. Differing from other PWT devices, the PIT-device operates with low air consumption, approximately about 150-170 l/min, and an air pressure at 4-5 bar (Gerster, 2011). Moreover, this device discharges the exhaust air at the front pin, which gives the disadvantages of having the paint and other impurities removed through air pressure at the same time as no other cooling of the pin is needed. This substantially increases the durability.

4. Statistical analysis

The main purpose of performing fatigue tests for specified specimen is to investigate the correlation between the fatigue enhancement of the specified materials, geometries, or welded profiles, under appliance of a predetermined arrangement of stress amplitudes. Generally, attainment of fatigue test data is executed under appliance of constant amplitude stress on the specimen until failure takes place. The outcome of this type of fatigue life prediction test is illustrated by a graph linking subjected stress, *S*, and the number of cycles, *N*, to failure (Schneider and Maddox, 2013). Due to the improbability of performing tests under the exact same conditions for a geometrically duplicated specimen, the out-coming data are consistently scattered. Furthermore, if the specimens and test conditions are indistinguishable, there are still large amounts of unidentified and unmanageable factors, which lead to a wide scatter in fatigue life.

In terms of providing safety guidelines for all steel structures subjected to fatigue loading, Comité Européen de Normalisation (CEN) emitted Eurocode 3 Part 1-9: Fatigue (EN 1993-1-9, 2005) which today is utilised as standard and commonly settled guidelines by CEN member countries. Consequently, the same statistical techniques are utilised while investigating the connection among fatigue test results (Schneider and Maddox, 2013).

4.1 Analysis of regression line

Regression analysis is one the Eurocode-recommended methods for reviewing fatigue test data. Within statistics, this method is applied in order to evaluate the relation between the independent and the dependent variable. Due to regression analysis, it is possible to make a statement regarding the interacting parameters such as the stress range, *S*, and the number of cycle, *N*.

In terms of analysing the assembled data concerning fatigue life assessment of welded profiles the first step is to create a scatter plot. This graph is utilised to show values for two variables for a set of data, as a collection of points. The stress range is considered as the independent variable in this graph and the dependent variable represent the number of cycle. The equation of the most suitable line passing through the scattered points, expresses the regression line (Little and Ekvall, 1981).

According to Schneider and Maddox (2003), there is an essential linear relationship between $\log \mathrm{S}$ and $\log \mathrm{N}$, in form of:

$$\log \mathrm{N} = \log \mathrm{a} - m \cdot \log \mathrm{S} + \varepsilon \qquad Eq. 13$$

where:

$\log \mathrm{N}$	logarithm of corresponding number of cycles to failure N
$\log \mathrm{a}$	intercept on the log N axis
m	slope of S-N
$\log \mathrm{S}$	logarithm of allowable stress range *S*
ε	sum of unidentified random errors

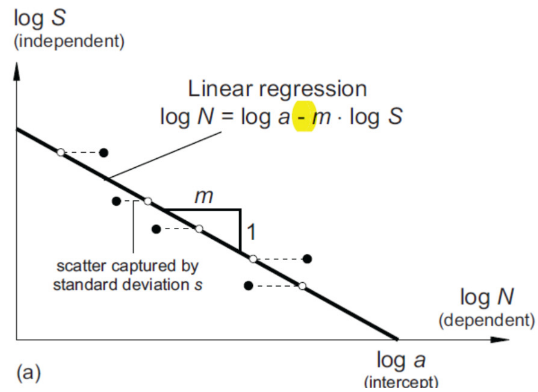


Figure. 27-Linear regression line fatigue (Euler, 2014).

Additionally, the regression line slope m is calculated through:

$$m = \frac{\mathrm{n} \cdot \sum_{\mathrm{i}}(\mathrm{logS_i} \cdot \mathrm{logN_i}) - \sum_{\mathrm{i}} \mathrm{logS_i} \cdot \sum_{\mathrm{i}} \mathrm{logN_i}}{\mathrm{n} \cdot \sum_{\mathrm{i}}(\mathrm{logS_i})^2 - \left(\sum_{\mathrm{i}} \mathrm{logS_i}\right)^2} \qquad Eq. 14$$

where:

I	number of single test
n	sample size

For the intercept log a of the regression line on the on the log N axis it holds:

$$\log a = \frac{1}{\mathrm{n}} \cdot \left(\sum_i \log N + m \cdot \sum_i \log S_i\right) \qquad Eq. 15$$

4.2 Prediction interval

Prediction interval is considered as a range in the scattered graph to represent the data accumulation, in most cases corresponding to 95% of the regression line. In other words, the intervals of the prediction estimates the distribution of individual points on one-sided statistical bound, as shown in Figure.28-a, or two-side statistical interval, Figure.28-b. In terms of fatigue design analysis, for two sided with 95% limitation interval, the prediction ranges are symmetric (Schneider and Maddox, 2003).

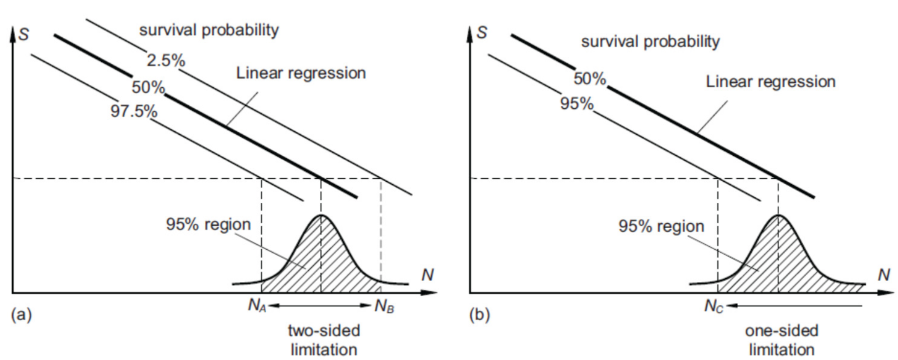


Figure. 28-(a) Two-sided statistical interval, (b) One-sided Statistical bound of the fatigue life N predicted by the regression line for a particular stress range S (Euler, 2014).

The prediction interval of the tested data for one-sided 95% prediction is achieved from Eq.16 (Schneider and Maddox, 2003).

$$\log \mathrm{N}_{95\%} = \log 2 \cdot 10^6 - t_{\alpha,\mathrm{dof}} \cdot s \cdot \sqrt{1 + \frac{1}{n} + \frac{\left(\log \mathrm{S}_{50\%} - \overline{\log S}\right)^2}{\sum\left(\log \mathrm{S_i} - \overline{\log S}\right)^2}} \qquad Eq.16$$

$t_{\alpha,\mathrm{dof}}$ is the student t-distribution which is dependent to number of tested specimen (Appendix 1) and s represents standard deviation, which is obtained from Eq.17.

$$s = \sqrt{\frac{\left(\sum \log \mathrm{N_i} - \left((\log \mathrm{a} - m \cdot \log \mathrm{S_i})\right)\right)^2}{\mathrm{dof}}} \qquad where, \mathrm{dof} = \mathrm{n} - 2 \qquad \mathrm{Eq.\,17}$$

5. Experimental test data

Fatigue test data from several published experimental tests of welded steel joints treated by HFMI methods have been reviewed by the authors and listed in Table 1-3. The total data were assembled from 38 publications containing three types of details which such as longitudinal non-load carrying attachments, butt joint welds and transversal attachments. The gathered data in this work were set according to FAT-classes, steel qualities, stress ratios, the type of HFMI methods and the plate thicknesses. In some references multiple stress ratios and steel qualities were used simultaneously to provide a comparison for the final results. The specimens were loaded under axial and bending loading and presented in the assembled test data. Nevertheless, only the specimens under various conditions of axial loading were evaluated in this study. The data points of each test were presented separately in Appendix 4 as a dot in logarithmical X-Y scatters or line plot. Due to the lack of numerical information, the position for each dot was obtained from a reference using a plot digitalising software WebPlotDigitizer. In all cases the specimens were tested under constant amplitude fatigue loading while the stress ratio was varied in the range between -1.0 and 0.5. In some references, the yield strength for tested material were not reported therefore these values were estimated by studying the steel quality. The specimen thicknesses were also varying from 3 to 30 mm.

Table 1 Experimental fatigue test results for HFMI-treated longitudinal joints under constant amplitude loading

Longitudinal non-load carrying attachment								
No.	References	FAT-EC	Steel Quality	Yield strength [MPa]	Stress ratio	HFMI method	Plate thickness [mm]	Number of specimens
4	Leitner, et al. 2014	71/80	S355/S690/S960	355/690/960	0.1	PIT/HFMI	5	37
6	Polezhayeva, et al. 2014	63	S690	690	0.1	UP	25	3
7	Wu and Wang, 2012	80	Q235B	272	-1.0/0.1/0.45	UP	8	18
8	Lihavainen and Marquis, 2004	63	S355J0	355	0.1	UIT	5-8	10
24	Haagensen, et al. 1998	56	Weldox 700	780	0.1	UIT	6	5
30	Haagensen and Alnes, 2005	56	Domex 355 MC/700 MC	350/700	0.1	UIT/UP	8	20
31	Deguchi, et al. 2012	63	KA36	355	0	UP	16	3
32	Ummenhofer and Weich, 2010	56	S355J2/S690QL	355/690	0.1	HiFIT/UIT	16/30	82
35	Huo, et al. 2005	80	16Mn	390	0.1	UPT	8	6
36	Martinez, et al. 1997	56	Domex 350/Weldox 700	398/780	0.1	UP/UPT	12	12
37	Wang, et al. 2009	80	SS800	700	0.05	UPT	8	8
38	Lihavainen, et al. 2004	63	S355J0	355	0.1/0.46/0.5/0.27/0.28/0.48	UIT	8/5	21
40	Marquis and Björk, 2008	56	S960/Domex700	969/700	-1.0/0.76/0.82/0.1	UIT/UP	6	28
41	Mori, et al. 2012	56	SBHS500	575	0.5	UIT	12	8
52	Vanrostenberghe, et al. 2015	56	S690QL/S960QL/S700MC/S690MC	690/700/960	0.1/0.5	HFMI C1-C2-C3-C4/PIT/UIT	5/10/15/20	113
UP = Ultrasonic Peening, UIT = Ultrasonic Impact Treatment, UPT = Ultrasonic Peening Treatment, HiFIT = High Frequency Impact Treatment, PIT = Pneumatic Impact Treatment								

Table 2 Experimental fatigue test results for HFMI-treated Butt joints welds under constant amplitude loading

Butt welded joint								
No.	References	FAT-EC	Steel Quality	Yield strength [MPa]	Stress ratio	HFMI method	Plate thickness [mm]	Number of specimens
4	Leitner, et al. 2014	90	S355/S690/S960	355/690/960	0.1	HFMI	5	32
13	Ummenhofer, et al. 2011	80	Domex960	960	0.1	HiFIT	6	7
17	Abdullah, et al. 2012	-	Steel 304	349.08	0.1	UP	5	6
18	Li, et al. 2014	-	Q235B	272	0.1	UP	5	13
19	Ummenhofer, et al. 2006	-/76.8	S355J2G/S460TM	407/520	0.1	UIT	8/30	17
23	Hrabowski, et al. 2014	80	S960QL	960	0.1	HiFIT	8	8
26	Huo, et al. 2000	-	Q235B	267.4	0.1	UP	8	15
28	Dong-po, et al. 2004	71	SS400	365	0.5	UP	3	5
32	Ummenhofer and Weich, 2010	90	S355J2/S690QL	355/690	0.1/0.5	HiFIT/UIT	16/30	193
37	Wang, et al. 2009	-	SS800/16Mn	700/390	0.05/0.1	UPT	8	11
47	Janosch, et al. 1996	-	E690	763	0.1	HFMI	9.5	8
50	Kuhlmann and Günther, 2009	-	S355J2	355	0.1	PIT	12	8
UP = Ultrasonic Peening, UIT = Ultrasonic Impact Treatment, UPT = Ultrasonic Peening Treatment, HiFIT = High Frequency Impact Treatment, PIT = Pneumatic Impact Treatment - Not avaliable in the reference								

Table 3 Experimental fatigue test results for HFMI-treated transverse attachments under constant amplitude loading

Transverse attachement								
No.	References	FAT-EC	Steel Quality	Yield strength [MPa]	Stress ratio	HFMI method	Plate thickness [mm]	Number of specimens
4	Leitner, et al. 2014	80	S355/S690S960	355/690/960	0.1	HFMI	5	34
9	Tehrani, 2012	80	350W	450-650	0.1	UIT	9.5	18
11	Statnikov, et al. 2000	80	Weldox 420	461.2	0.1	UIT	20	6
19	Ummenhofer, et al. 2006	80	S460TM	520	0.1	UIT	30	7
20	Shimanuki and Okawa, 2013	80	SBHS500	575	0.1/0.3/0.5	UIT	12	12
21	Yin, et al. 2010	80	Q235/Q345	235/345	-1	UPT	3	28
22	Ermolaeva and Hermans, 2014	71	S690	690	0.1	UIT	20	8
26	Huo, et al. 2000	80	Q235B	267.4	0.25/-0.5	UP	8	12
29	Han, et al. 2009	80	SM490B	352	0.1	PHP	16	7
31	Deguchi, et al. 2012	80	KA36	355	0/0.25/0.5	UP	16/22/30	15
43	Trufiakov, et al. 1998	71	-	420	0.1	UIT	20	8
44	Pedersen, et al. 2010	80	Domex 700	700	0.1	UIT	6	10
45	Galtier and Statnikov, 2004	80	Usiform 700	700	0.1	UIT	5/6	21
46	Statnikov, et al. 2002	80	Weldox 420	468	0.1	UIT	20	7
47	Janosch, et al. 1996	80	E463	579	0.1	HFMI	10	13
48	Kudryavtsev, et al. 2007	80	S260	260	0	UP	20	9
50	Kuhlmann and Günther, 2009	80	S355J2/S690QL	355/690	0.1	PIT	12	18
51	Okawa, et al. 2012	80	AH36	520	-1.0/0.1/0.5	UIT	20	9
53	Kuhlmann, et al. 2005	80	S355/S460/S690	355/460/690	0.1	UIT	12	16
54	Kuhlmann, et al. 2006	80	S690	690	0.1	UIT	12	4
UP = Ultrasonic Peening, UIT = Ultrasonic Impact Treatment, UPT = Ultrasonic Peening Treatment, HiFIT = High Frequency Impact Treatment, PIT = Pneumatic Impact Treatment								

5.1 Overall results

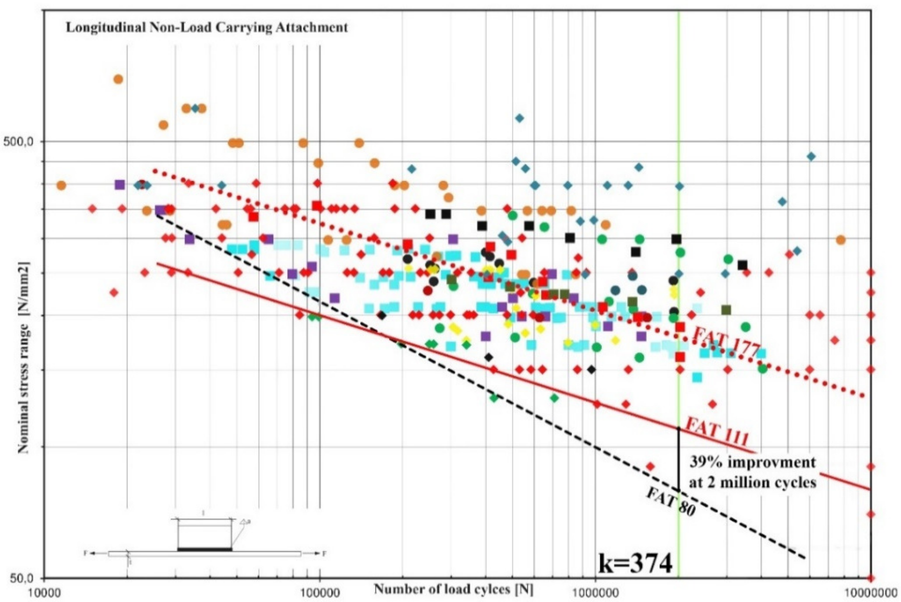
The results of this work has been achieved from a more profound and fundamental evaluation of all the gathered data from the literature study, presented in the early stages of this thesis. According to several published reports (Yildirim, 2013; Yildirim and Marqius, 2012), it is shown that a S-N-curve with fixed slope of $m = 5$ is the most accepted choice in terms of evaluating fatigue test data for welds treated with HFMI and hammer peening. Therefore, the same assumption of applying a fixed slope $m = 5$ has been considered for Plot 1-10 in this report

Plot 1-3 present a holistic overview of test results of HFMI treated specimens for the mentioned detail geometries. The red dashed and solid lines in each SN-graph in these plots illustrate the regression lines for 50%- and 95% survival, respectively. Furthermore, the letter **k** in bottom part of each plot indicates the total number of specimens for each welded geometry.

In order to generate the most reliable level of fatigue life improvements for the investigations made in this section, the SN-graphs achieved by the scatters for each detail geometries has been compared with the highest existing FAT class among the test sets with respect to the as-welded condition:

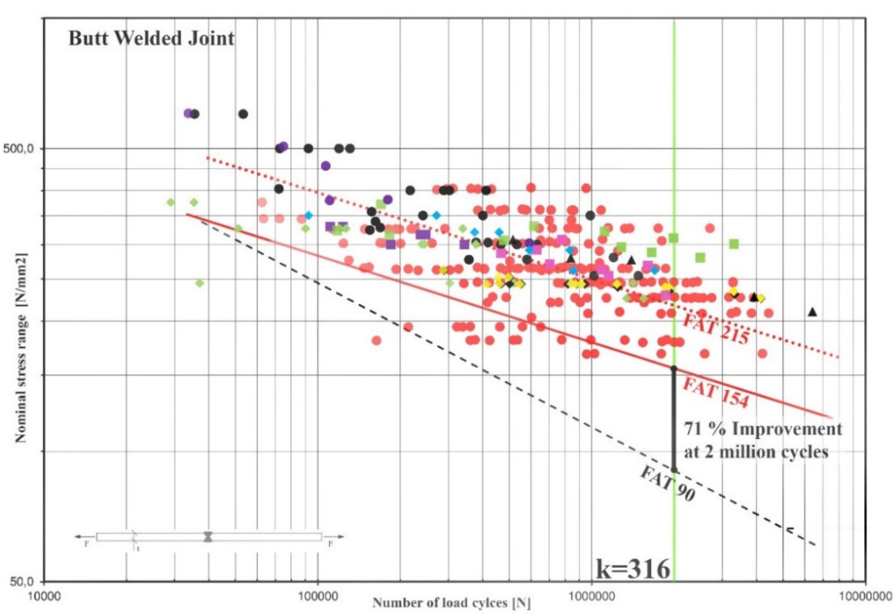
- FAT class 80 for longitudinal non-load carrying attachment
- FAT class 90 for butt welded joints
- FAT class 80 for transversal non-load carrying attachment

A range of the stress ratios between $R = -1$ and $R = 0.5$ is declared. However, by reviewing the legends in Plot 1-3 and charting the marks, it is noticeable that the majority of the current available data have been tested with the stress ratio $R = 0.1$.



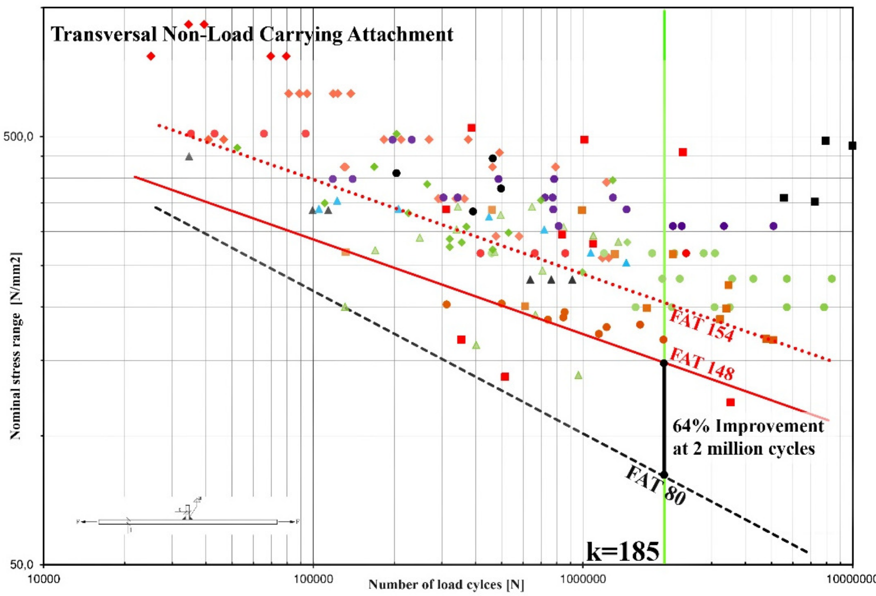
Plot 1 Overall improvement of longitudinal non-load carrying attachment

- Leitner, et al. 2014_fy=355/690/960_R=0.1_t=5_k=37
- Haagensen and Alnes, 2005_fy=350/700_R=0.1_t=8_k=20
- Polezhayeva, et al. 2014_fy=690_R=0.1_t=25_k=3
- Ummenhofer and Weich, 2010_fy=355/690_R=0.1_t=16/30_k=82
- Wu and Wang, 2012_fy=272_R=-1.0/0.1/0.45_t=8_k=18
- Huo, et al. 2005_fy=390_R=0.1_t=8_k=6
- Lihavainen and Marquis, 2004_fy=355_R=0.1_t=5/8_k=10
- Wang, et al. 2009_fy=700_R=0.05_t=8_k=8
- Polezhayeva, et al. 2014_fy=690_R=0.1_t=25_k=3
- Martinez, et al. 1997_fy=398/780_R=0.1_t=12_k=12
- Deguchi, et al. 2012_fy=355_R=0_t=16_k=3
- Lihavainen, et al. 2004_fy=355_R=0.1/0.46/0.5/0.27/0.28/0.48_t=8/5_k=21
- Mori, et al. 2012_fy=575_R=0.5_t=12_k=8
- Vanrostenberghe, et al. 2015_fy=690/700/960_R=0.1/0.5_t=5/10/15/20_k=113
- Marquis and Björk, 2008_fy=969/700_R=-1.0/0.76/0.82/0.1_t=6_k=28



Plot 2 Overall improvement of butt-welded joint attachment

- Janosch, et al. 1996_fy=763_R=0.1_t=9.5_k=8
- Leitner, et al. 2014_fy=355/690/960_R=0.1_t=5_k=32
- Abdullah, et al. 2012_fy=349.08_R=0.1_t=5_k=6
- Hrabowski, et al. 2014_fy=960_R=0.1_t=8_k=8
- Wang, et al. 2009_fy=700/390_R=0.05/0.1_t=8_k=11
- Ummenhofer and Weich, 2010_fy=355/690_R=0.1_t=16/30_k=82
- Huo, et al. 2000_fy=267.4_R=0.1_t=8_k=15
- Ummenhofer, et al. 2006_fy=407/520_R=0.1_t=8/30_k=17
- Li, et al. 2014 _fy=272_R=0.1_t=5_k=13
- Kuhlmann and Günther, 2009_fy=355_R=0.1_t=12_k=8
- Dong-po, et al. 2004_fy=365_R=0.5_t=3_k=5



Plot 3 Overall improvement of transversal attachment

■ Shimanuki and Okawa, 2013_fy=575_R=0.1/0.3/0.5_t=12_k=12
■ Yin, et al. 2010_fy=235/345_R=-1.0_t=3_k=28
■ Okawa, et al. 2012_fy=520_R=-1.0/0.1/0.5_t=20_k=9
◆ Leitner, et al. 2014_fy=355/690/960_R=0.1_t=5_k=34
● Ermolaeva and Hermans, 2014_fy=690_R=0.1_t=20_k=8
● Kuhlmann and Günther, 2009_fy=355/690_R=0.1_t=12_k=18
● Tehrani, 2012_fy=450/650_R=0.1_t=9.5_k=18
▲ Deguchi, et al. 2012_fy=355_R=0/0.25/0.5_t=16/22/30_k=15
▲ Ummenhofer, et al. 2006_fy=520_R=0.1_t=30_k=7
▲ Han, et al. 2009_fy=352_R=0.1_t=16_k=7
◆ Kuhlmann, et al. 2005_fy=355/460/690_R=0.1_t=12_k=16
● Kudryavtsev, et al. 2007_fy=260_R=0_t=20_k=9
● Kuhlmann, et al. 2006_fy=690_R=0.1_t=12_k=4

As observed in Plot 1-3, the degree of improvement for the mentioned details geometries at 2 million cycles differs in a range of 39-71%. Nevertheless, these numbers indicates the minimum possible improvement level achieved by various HFMI treatment due to the fact that the result from each detail geometry has been compared to the highest existing FAT class for the as-weld condition.

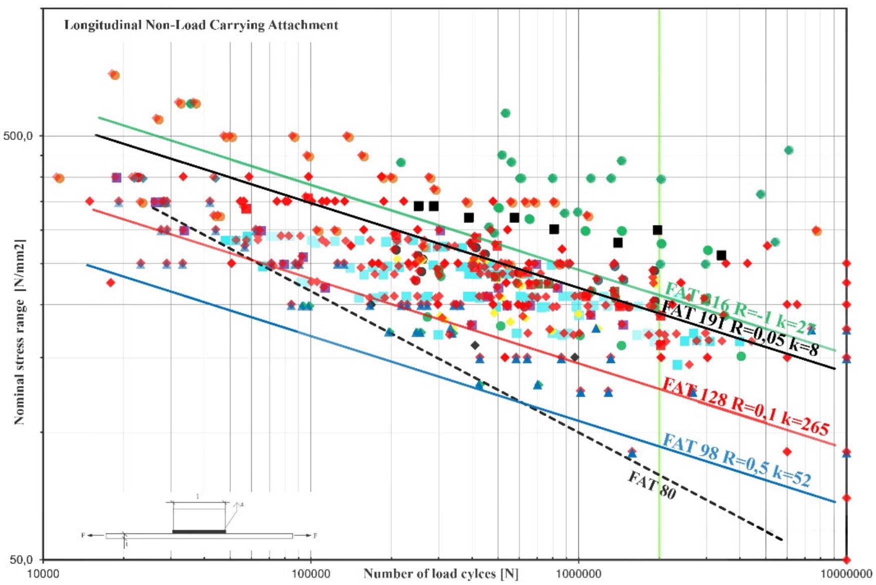
5.2 Influence of stress ratio and steel quality on fatigue life

The results from further investigation based on the influence of two other parameters to fatigue strength, namely stress ratio and yield strength, are shown in Plot 4-8. Moreover, in terms of achieving a more reliable and accurate investigation the geometry types with insufficient number of data points are excluded from the graphs. However, the total number of data points are available in the assembled data base. The dashed line in the graphs represents the as-weld FAT class for each type of specimen geometry. The evaluation is performed for axial loaded specimens in this work.

5.2.1 Comparison of different stress ratios

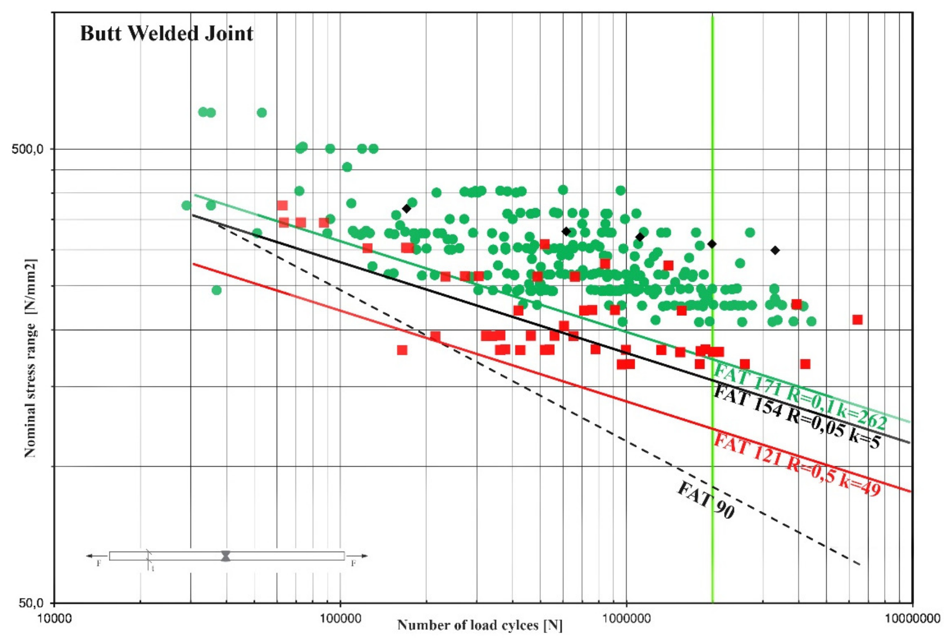
Comparison of different stress ratios has been performed in this section, to identify a clear trend of variation of this parameter based on Eurocode fatigue class recommendations. Therefore, for all HFMI treated geometry types the fatigue data are extracted from the table references in Appendix 2. The results are scattered in Plot 4, 5 and 6.

In plot 4 the fatigue class improvement between 4 different stress ratios are compared to the as-weld condition with FAT 80 for HFMI treated longitudinal attachments. Referring to this graph and the stress ratio $R = 0.1$ with the governing number of fatigue data samples, $k = 265$, it is shown that the fatigue strenght has increased with 60 % at 2×10^6 cycles due to the HFMI treatment. Comparing the results of other stress ratios one can observe that a trend of higher fatigue strength improvement is obtained as the stress ratio is decreased. Notice that the results of improvement are independent of the plate thickness of the specimens.



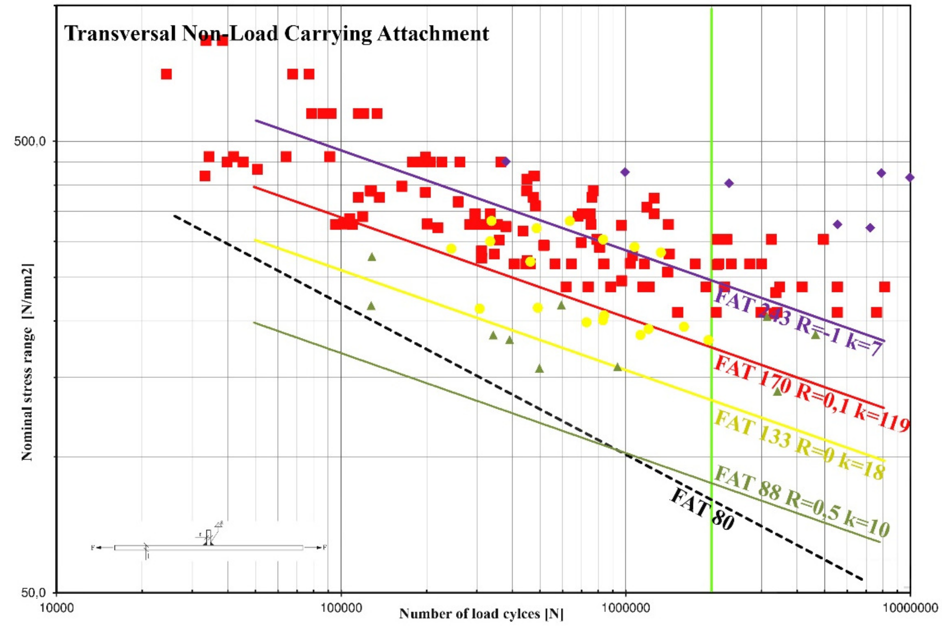
Plot 4 Longitudinal non-load carrying attachment-comparison of different stress ratios extracted from Appendix 2

In Plot 5, three stress ratios of the butt-welded joints are compared with each other. The same trend of fatigue strength improvement has been identified at 2 million cycles for this detail category. In other words, lower level strength ratio for applied loading condition results higher level of fatigue life for butt joints HFMI treated detail.



Plot 5 Butt-welded joint-compression of different stress ratios

The influence of stress ratio on the transversal HFMI-treated details is depicted in Plot 6. In terms of stress ratio, a dissimilar trend was observed after comparing the results to the ones from longitudinal attachments and butt welded joints. The number specimens for transverse attachments at stress ratio other than $R = 0.1$ is too few. Therefore, random errors due to inadequate number of tested specimen can be the main problem for interpretation of graphical data.



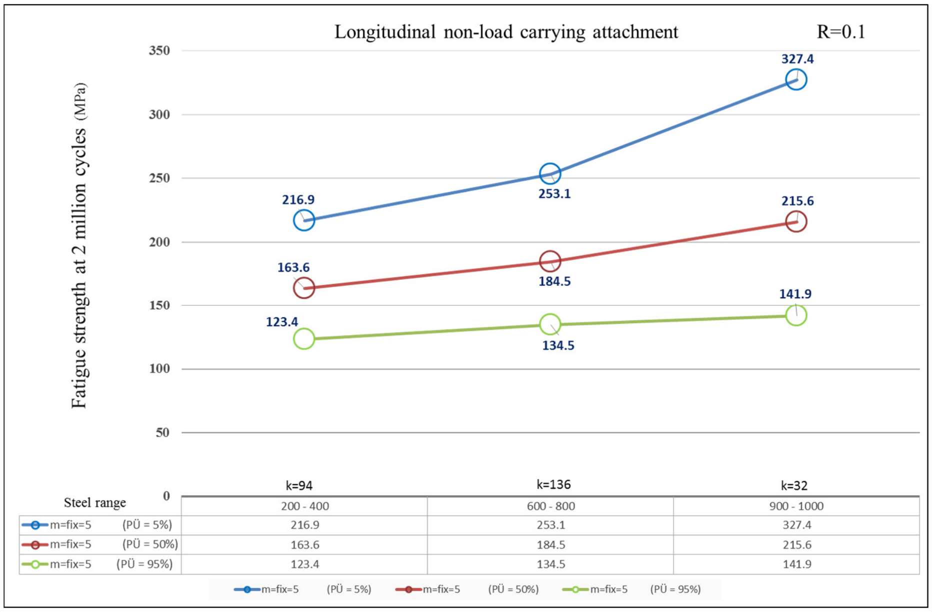
Plot 6 Transverse attachment comparison of different stress ratios

5.2.2 Comparison of different yield strength

In order to examine the influence of yield strength grades for the HFMI-treated specimens, an additional investigation was conducted in this study. Referring to section 4.1, where statistical prediction interval is discussed, the two-sided statistical interval is performed for all tested specimen data points under the stress ratio R=0.1. With other words, the regression line for 5%-, 50%- and 95% survival prediction was also taken into account and used in this investigation. The intersecting value of each line for the corresponding steel range at 2 million cycles have been plotted and formed three curves showing the improvement arrangement. The results are extracted from Appendix 3 in Plot 7-9 for corresponding detail geometries.

In Plot 7 steel yield strength between the range of 200 MPa and 400 MPa the minimum fatigue life is observed for the 50% regression. It is shown that an increase trend of fatigue life improvement exist with greater steel strength.

The degree of fatigue improvement for the two other specimen types are depicted in Plot 8-9. One point of observation based on these data points implies an increasing improvement of the fatigue strength, just about proportionally as the steel quality becomes stiffer. Nevertheless, a number of minor drops can be remarked for some steel qualities. In these cases, the reason might be insufficient number of specimens. However, further investigation would be required in order to fully clarify the main reason causing this dissimilarity.



Plot 7 Longitudinal non-load carrying attachment – comparison of different steel range

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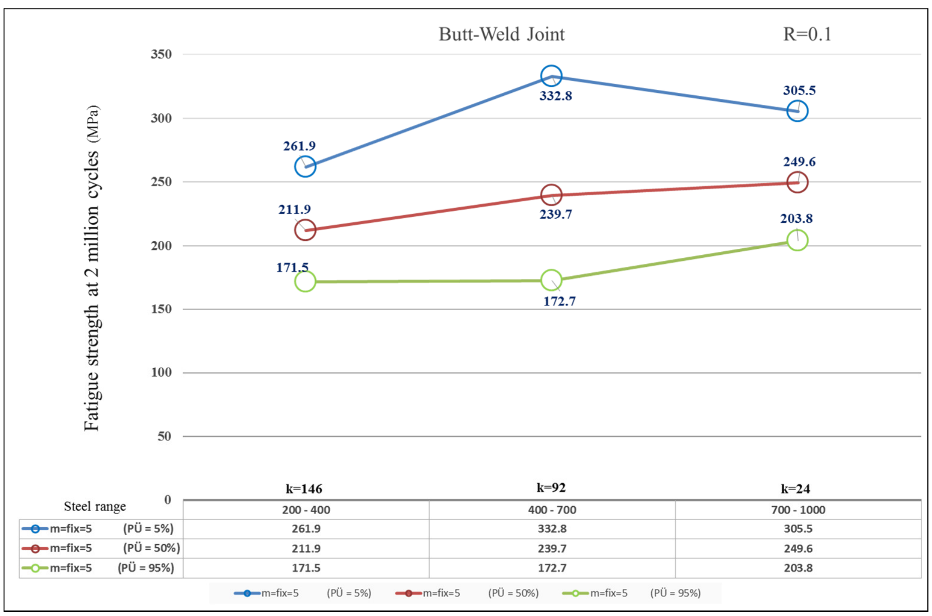
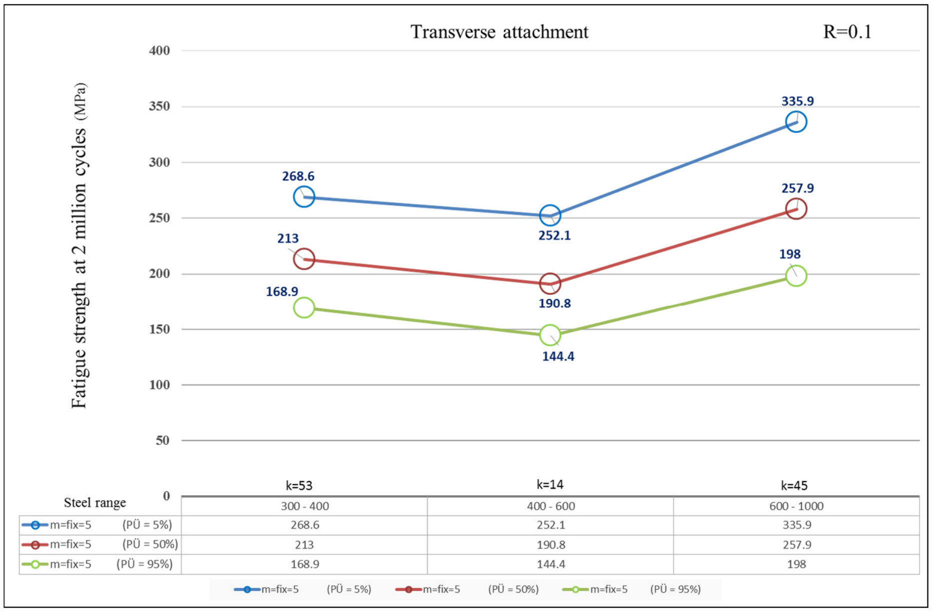


Plot 8 Butt-welded joint – comparison of different steel range



Plot 9 Transverse attachment – comparison of different steel range

6. Conclusion

In the present work, the influence of high frequency mechanical impact (HFMI) methods on the fatigue strength of three types of welded detail geometries has been overviewed from several published experimental data. The compiled database contains approximately 960 specimens modified by HFMI and tested under constant amplitude fatigue loading. However, only specimens subjected to axial fatigue loading have been considered in the evaluation of this work. An overall evaluation for each detail geometry was carried out in order to investigate a general trend of fatigue life improvement caused by HFMI. This investigation resulted in an overall fatigue strength improvement in the range of 39-71% at 2 million cycles.

Furthermore, a comparison of different stress ratio was performed to identify the effect of this parameter on fatigue strength. The comparison for both longitudinal attachments and butt welded joints indicated the same behaviour. The fatigue life improvement for both these geometries increase as the stress ratio decreases. Despite that, dissimilar trends of improvement was noticed by looking at the same comparison concerning transverse attachment. Nevertheless, the numbers of tested specimens in for stress ratios other than $R = 0.1$ were too small and might have been the dissimilarity.

Finally, one other comparison with respect to steel qualities was also executed in order to study the impact on the fatigue life by the variety of the steel stiffness. Due to inadequate number of data points for different range of stress ratios the evaluation was only performed for tested specimens with stress ratio $R = 0.1$. As the plot for the longitudinal attachments was indicating a clear trend of higher level of improvement due to higher yield strength range, some small drops in the plots the two other geometries were disproving this observation.

7. Future work

In order to fully profit from HFMI-treatments, closer investigation based on variation of influencing parameters for example different plate thickness, should be performed. A suggestion for this type of analysis is to perform fatigue enhancement tests on specimens with the same material properties, tested under identical loading condition.

Appendix 1

Student-value t in dependence on the degrees of freedom (dof) and significance level

Dof.	75%	80%	85%	90%	95%	97.50%	99%	99.50%	99.75%	99.90%	99.95%
1	1	1.376	1.963	3.078	6.314	12.71	31.82	63.66	127.3	318.3	636.6
2	0.816	1.08	1.386	1.886	2.92	4.303	6.965	9.925	14.09	22.33	31.6
3	0.765	0.978	1.25	1.638	2.353	3.182	4.541	5.841	7.453	10.21	12.92
4	0.741	0.941	1.19	1.533	2.132	2.776	3.747	4.604	5.598	7.173	8.61
5	0.727	0.92	1.156	1.476	2.015	2.571	3.365	4.032	4.773	5.893	6.869
6	0.718	0.906	1.134	1.44	1.943	2.447	3.143	3.707	4.317	5.208	5.959
7	0.711	0.896	1.119	1.415	1.895	2.365	2.998	3.499	4.029	4.785	5.408
8	0.706	0.889	1.108	1.397	1.86	2.306	2.896	3.355	3.833	4.501	5.041
9	0.703	0.883	1.1	1.383	1.833	2.262	2.821	3.25	3.69	4.297	4.781
10	0.7	0.879	1.093	1.372	1.812	2.228	2.764	3.169	3.581	4.144	4.587
11	0.697	0.876	1.088	1.363	1.796	2.201	2.718	3.106	3.497	4.025	4.437
12	0.695	0.873	1.083	1.356	1.782	2.179	2.681	3.055	3.428	3.93	4.318
13	0.694	0.87	1.079	1.35	1.771	2.16	2.65	3.012	3.372	3.852	4.221
14	0.692	0.868	1.076	1.345	1.761	2.145	2.624	2.977	3.326	3.787	4.14
15	0.691	0.866	1.074	1.341	1.753	2.131	2.602	2.947	3.286	3.733	4.073
16	0.69	0.865	1.071	1.337	1.746	2.12	2.583	2.921	3.252	3.686	4.015
17	0.689	0.863	1.069	1.333	1.74	2.11	2.567	2.898	3.222	3.646	3.965
18	0.688	0.862	1.067	1.33	1.734	2.101	2.552	2.878	3.197	3.61	3.922
19	0.688	0.861	1.066	1.328	1.729	2.093	2.539	2.861	3.174	3.579	3.883
20	0.687	0.86	1.064	1.325	1.725	2.086	2.528	2.845	3.153	3.552	3.85
21	0.686	0.859	1.063	1.323	1.721	2.08	2.518	2.831	3.135	3.527	3.819
22	0.686	0.858	1.061	1.321	1.717	2.074	2.508	2.819	3.119	3.505	3.792
23	0.685	0.858	1.06	1.319	1.714	2.069	2.5	2.807	3.104	3.485	3.767
24	0.685	0.857	1.059	1.318	1.711	2.064	2.492	2.797	3.091	3.467	3.745
25	0.684	0.856	1.058	1.316	1.708	2.06	2.485	2.787	3.078	3.45	3.725
26	0.684	0.856	1.058	1.315	1.706	2.056	2.479	2.779	3.067	3.435	3.707
27	0.684	0.855	1.057	1.314	1.703	2.052	2.473	2.771	3.057	3.421	3.69
28	0.683	0.855	1.056	1.313	1.701	2.048	2.467	2.763	3.047	3.408	3.674
29	0.683	0.854	1.055	1.311	1.699	2.045	2.462	2.756	3.038	3.396	3.659
30	0.683	0.854	1.055	1.31	1.697	2.042	2.457	2.75	3.03	3.385	3.646
40	0.681	0.851	1.05	1.303	1.684	2.021	2.423	2.704	2.971	3.307	3.551
50	0.679	0.849	1.047	1.299	1.676	2.009	2.403	2.678	2.937	3.261	3.496
60	0.679	0.848	1.045	1.296	1.671	2	2.39	2.66	2.915	3.232	3.46
80	0.678	0.846	1.043	1.292	1.664	1.99	2.374	2.639	2.887	3.195	3.416
100	0.677	0.845	1.042	1.29	1.66	1.984	2.364	2.626	2.871	3.174	3.39
120	0.677	0.845	1.041	1.289	1.658	1.98	2.358	2.617	2.86	3.16	3.373
	0.674	0.842	1.036	1.282	1.645	1.96	2.326	2.576	2.807	3.09	3.291

Appendix 2

Stress ratio (R)	Plate thickness [mm]	fy [MPa]	Steel type	m=fix=5 (PÜ = 50%)	m=fix=5 (PÜ = 95%)	Improvement [%]	Number of specimens	Lit. Ref.
The influence of Stress ratio on longitudinal HFMI-treated detail								
-1	-	-	-	305	216	170	27	-
	6	969	S960	355	242	202.5	11	[40]
	8	272	Q235B	271	231	188.75	6	[7]
	8	700	Domex 700	286	193	141.25	10	[40]
0.05	8	700	SS800	254	191	138.75	8	[37]
0.1	-	-	-	179	128	60	265	-
	5	-	-	199	127	58.75	62	-
		355	S355/S355J0	163	123	53.75	18	[4] & [38]
		690	S690	251	209	161.25	12	[4]
		700	S700MC	135	12	-85	6	[52]
		960	S960/S960MC	222	142	77.5	26	[4] & [52]
	5-8	355	S355J0	189	133	66.25	10	[8]
	6	780	WELDOX 700	164	104	30	5	[24]
	8	-	-	173	132	65	43	-
		272	Q235B	187	141	76.25	7	[7]
		350	Domex 355 MC	129	105	31.25	4	[30]
		355	S355J0	200	111	38.75	5	[38]
		390	16 Mn	187	117	46.25	6	[35]
		700	Domex 700/700MC	170	136	70	21	[30] & [40]
	10	-	-	181	115	43.75	37	-
		690	S690QL	172	97	21.25	14	[52]
		700	S700MC	186	102	27.5	17	[52]
		960	S960QL	186	127	58.75	6	[52]
	12	-	-	187	158	97.5	12	-
		398	Domex 350	194	137	71.25	5	[36]
		780	Weldox 700	181	158	97.5	7	[36]
	16	-	-	161	125	56.25	56	-
		355	S355J2	149	115	43.75	32	[32]
		690	S690QL	180	158	97.5	24	[32]
	20	690	S690QL	207	130	62.5	14	[52]
	30	-	-	171	143	78.75	26	-
		355	S355J2	163	127	58.75	13	[32]
		690	S690QL	179	166	107.5	13	[32]
0.5	-	-	-	125	98	22.5	52	-
	5	-	-	121	89	11.25	16	-
		355	S355J0	140	-	-	2	[38]
		700	S700 MC	112	57	-28.75	5	[52]
		960	S960 MC	122	85	6.25	9	[52]
	10	-	-	132	99	23.75	12	-
		700	S700 MC	108	-	-	2	[52]
		960	S960 QL	138	110	37.5	10	[52]
	12	575	SBHS500	109	89	11.25	8	[41]
	15	960	S960 QL	141	116	45	12	[52]
	20	690	S690 QL	125	74	-7.5	4	[52]

The influence of Stress ratio on butt-weld HFMI-treated detail								
Stress ratio (R)	Plate thickness [mm]	fy [MPa]	Steel type	m=fix=5 (PÜ = 50%)	m=fix=5 (PÜ = 95%)	Improvement [%]	Number of specimens	Lit. Ref.
0.05	**8**	**700**	**SS800**	**279**	**154**	**71.1**	**5**	**[37]**
0.1	**-**	**-**	**-**	**224**	**171**	**90.0**	**262**	**-**
	5	-	-	225	173	92.2	51	-
		272	Q235B	208	143	58.9	13	[18]
		349.08	Steel 304	196	94	4.4	6	[17]
		355	S355	213	176	95.6	13	[4]
		690	S690	247	208	131.1	11	[4]
		960	S960	287	254	182.2	8	[4]
	8	-	-	211	149	65.6	38	-
		267.4	Q235B	209	141	56.7	15	[26]
		390	16 Mn	236	83	-7.8	6	[37]
		407	S355J2G	176	89	-1.1	9	[19]
		960	S960QL	243	198	120.0	8	[23]
	9.5	763	E690	230	194	115.6	8	[47]
	12	355	S355J2	227	175	94.4	8	[50]
	16	-	-	239	182	102.2	103	-
		355	S355J2	215	176	95.6	52	[32]
		690	S690QL	266	214	137.8	51	[32]
	30	-	-	207	163	81.1	54	-
		355	S355J2	205	160	77.8	33	[32]
		520	S460TM	195	143	58.9	8	[19]
		690	S690QL	219	164	82.2	13	[32]
0.5	**-**	**-**	**-**	**167**	**121**	**34.4**	**49**	**-**
	3	365	SS400	245	192	113.3	5	[28]
	16	-	-	161	124	37.8	44	-
		355	S355J2	145	107	18.9	23	[32]
		690	S690QL	180	159	76.7	21	[32]

The influence of Stress ratio on transverse HFMI-treated detail								
Stress ratio (R)	Plate thickness [mm]	fy [MPa]	Steel type	m=fix=5 (PÜ = 50%)	m=fix=5 (PÜ = 95%)	Improvement [%]	Number of specimens	Lit. Ref.
-1	-	-	-	405.0	243.0	203.75	7	-
	3	-	-	456.0	169.0	111.25	4	-
		235	Q235	393.0	-	-	2	[21]
		345	Q345	530.7	-	-	2	[21]
	20	520	AH36	344.4	21.0	-73.75	3	[51]
0	-	-	-	186.0	133.0	66.25	18	-
	20	260	S260	161	128	60	9	[48]
	16	355	KA36	241	-	-	2	[31]
	22	355	KA36	230	72	-10	3	[31]
	30	355	KA36	191	85	6.25	4	[31]
0.1	-	-	-	227.0	170.0	112.5	119	-
	5	-	-	245	176	120	34	-
		355	S355	199	179	123.75	13	[4]
		690	S690	265	221	176.25	9	[4]
		960	S960	292	250	212.5	12	[4]
	9.5	350	350W	230	181	126.25	18	[9]
	12	-	-	232	174	117.5	42	-
		355	-	215	148	85	15	-
			S355	188	144	80	6	[53]
			S355J2	235	143	78.75	9	[50]
		460	S460	205	142	77.5	7	[53]
		575	SBHS500	243	184	130	4	[20]
		690	-	263	209	161.25	16	-
			S690	252	162	102.5	7	[53] & [54]
			S690QL	273	227	183.75	9	[50]
	16	352	SM490B	201	125	56.25	7	[29]
	20	-	-	209	165	106.25	11	-
		520	AH36	220	61	-23.75	3	[51]
		690	S690	205	152	90	8	[22]
	30	520	S460TM	175	141	76.25	7	[19]
0.25	16	355	KA36	165.0	22.0	-72.5	3	[31]
0.3	4	575	SBHS500	213.0	158.0	97.5	4	[20]
0.5	-	-	-	144.0	88.0	10	10	-
	12	575	SBHS500	178	78	-2.5	4	[20]
	16	355	KA36	123	43	-46.25	3	[31]
	20	520	AH36	128	19	-76.25	3	[51]

Appendix 3

The influence of yield strength on longitudinal HFMI treated detail									
Stress ratio (R)	Yield Strength Range	fy [MPa]	Steel type	Plate thickness [mm]	m=fix=5 (PÜ = 50%)	m=fix=5 (PÜ = 95%)	Improvement [%]	Number of specimens	Lit. Ref.
0.1	200 - 400	-	-	-	164	123	53.8	94	-
		272	Q235B	8	187	141	76.25	7	[7]
		350	Domex 355 MC	8	129	105	31.25	4	[30]
		355	-	-	162	123	53.75	65	-
			S355	5	169	117	46.25	13	[4]
			S355J0	-	181	132	65	20	-
				5	151	87	8.75	5	[38]
				5-8	189	133	66.25	10	[8]
				8	200	111	38.75	5	[38]
			S355J2	-	153	119	48.75	45	-
				16	149	115	43.75	32	[32]
				30	163	127	58.75	13	[32]
		398	Domex 350	12	194	137	71.25	5	[36]
	600 - 800	-	-	-	184	134	67.5	136	-
		690		-	193	142	77.5	80	-
			S690	-	243	203	153.75	15	-
				5	251	209	161.25	12	[4]
				25	217	94	17.5	3	[6]
			S690 QL	-	183	141	76.25	65	-
				10	172	97	21.25	14	[52]
				16	180	158	97.5	24	[32]
				20	207	130	62.5	14	[52]
				30	179	166	107.5	13	[32]
		700	-	-	172	119	48.75	44	-
			S700 MC	5	135	12	-85	6	[52]
			Domex 700	8	180	111	38.75	5	[40]
			Domex 700 MC	8	166	132	65	16	[30]
			S700 MC	10	186	102	27.5	17	[52]
		780	-	-	175	146	82.5	12	-
			Weldox 700	-	175	146	82.5	12	-
				6	164	104	30	5	[24]
				12	181	158	97.5	7	[36]
	900 - 1000	-	-	-	216	142.0	77.5	32	-
		960	-	-	216	142	77.5	32	-
			S960	5	276	252	215	12	[4]
			S960 MC	5	182	134	67.5	14	[52]
			S960 QL	10	186	127	58.75	6	[52]

The influence of yield strength on butt weld HFMI treated detail

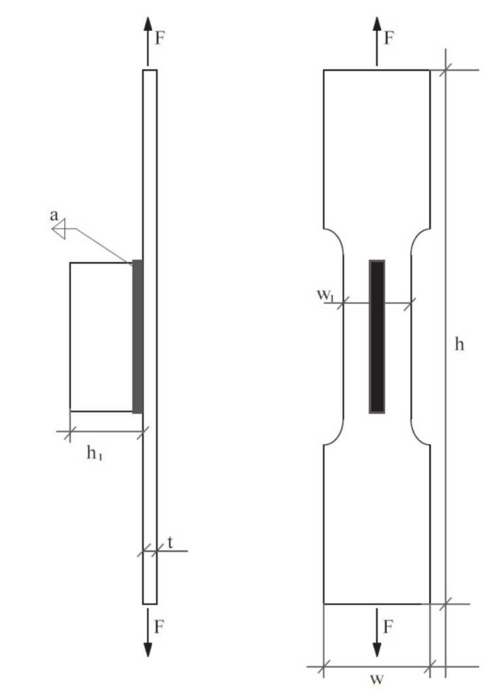
Stress ratio (R)	Yield Strength Range	fy [MPa]	Steel type	Plate thickness [mm]	m=fix=5 (PÜ = 50%)	m=fix=5 (PÜ = 95%)	Improvement [%]	Number of specimens	Lit. Ref.
0.1	200 - 400	-	-	-	212	171	90	146	-
		267.4	Q235B	8	209	141	56.7	15	[26]
		272	Q235B	5	208	143	58.9	13	[18]
		349.08	Steel 304	5	196	94	4.4	6	[17]
		355	-	-	212	174	93.3	106	-
			S355	5	213	176	95.6	13	[4]
			S355J2	-	212	172	91.1	93	-
				12	227	175	94.4	8	[50]
				16	215	176	95.6	52	[32]
				30	205	160	77.8	33	[32]
		390	16Mn	8	236	83	-7.8	6	[37]
	400 - 700	-	-	-	240	173	92.2	92	-
		407	S355J2G	8	176	89	-1.1	9	[19]
		520	S460TM	30	195	143	58.9	8	[19]
		690	-	-	255	201	123.3	75	-
			S690	5	247	208	131.1	11	[4]
			S690QL	-	256	199	121.1	64	-
				16	266	214	137.8	51	[32]
				30	219	164	82.2	13	[32]
	700 - 1000	-	-	-	250	204	126.7	24	-
		763	E690	9.5	230	194	115.6	8	[47]
		960	-	-	261	208	131.1	16	-
			S960	5	287	254	182.2	8	[4]
			S960QL	8	243	198	120.0	8	[23]

The influence of yield strength on transverse HFMI treated detail									
Stress ratio (R)	Yield Strength Range	fy [MPa]	Steel type	Plate thickness [mm]	m=fix=5 (PÜ = 50%)	m=fix=5 (PÜ = 95%)	Improvement [%]	Number of specimens	Lit. Ref.
0.1	300 - 400	-	-	-	213	169	111.25	53	
		350	350W	9.5	230	182	127.5	18	[9]
		352	SM490B	16	201	125	56.25	7	[29]
		355	-	-	208	162	102.5	28	-
			S355J2	12	235	143	78.75	9	[50]
			S355	-	195	174	117.5	19	-
				5	199	179	123.75	13	[4]
				12	188	144	80	6	[53]
	400 - 600	-	-	-	191	144	80	14	-
		460	S460	12	205	142	77.5	7	[53]
		520	S460TM	30	175	141	76.25	7	[19]
	600 - 1000	-	-	-	258	198	147.5	45	-
		690	-	-	247	188	135	33	-
			S690QL	12	273	227	183.75	9	[50]
			S690	-	239	178	122.5	24	
				5	265	221	176.25	9	[4]
				12	252	162	102.5	7	[53] & [54]
				20	205	152	90	8	[22]
		960	S960	5	292	250	212.5	12	[4]

Appendix 4

Construction detail	Longitudinal non-load carrying attachment	
Reference	Leitner, M., Stoschka, M. and Eichlseder, W. (2014) Fatigue enhancement of thin-walled, high-strength steel joints by high-frequency mechanical impact treatment - Welding in the World, vol. 58, no. 1, pp. 29–39, Jan. 2014.	
Material	Denomination	S355
	Plate thickness	5 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	355 MPa
Datail category according to EC		FAT 71
Post-weld treatment	HFMI	PIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	400	11347	1
2	350	23192	1
3	350	28142	1
4	325	43619	1
5	325	45176	1
6	300	123131	1
7	300	105499	1
8	275	261661	1
9	250	549371	1
10	250	834344	1
11	250	532668	1
12	238	605922	1
13	225	50000000	0
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15			
16			
17			
18			
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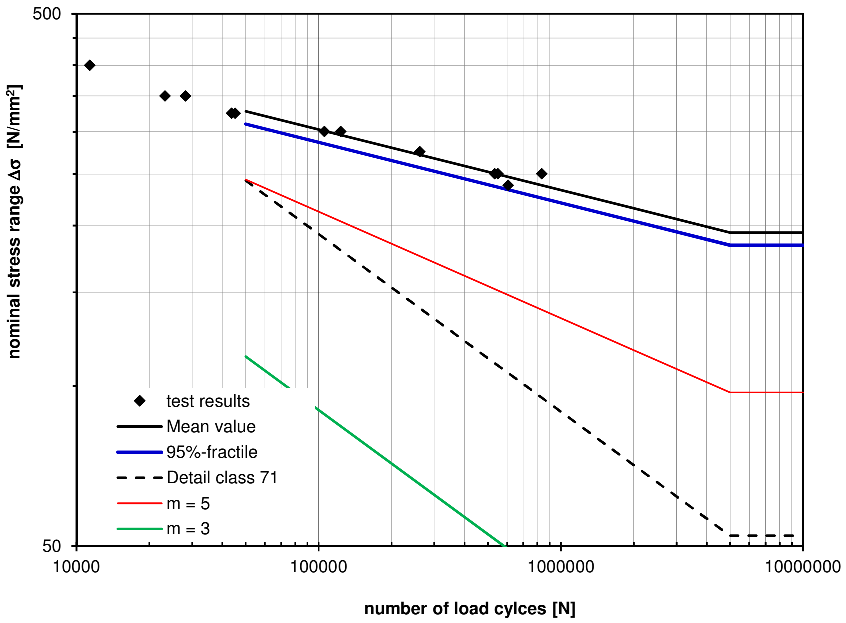
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

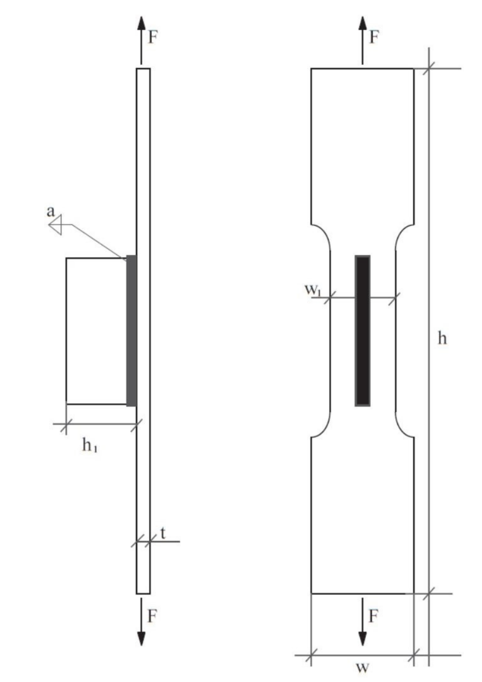


Statistical evaluation of test data according to EN 1993-1-9:2005

slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 8,78	215,4	203,8
m = fix = 3	115,8	33,2
m = fix = 5	**168,8**	**116,7**

Construction detail	Longitudinal non-load carrying attachment	
Reference	Leitner, M., Stoschka, M. and Eichlseder, W. (2014) Fatigue enhancement of thin-walled, high-strength steel joints by high-frequency mechanical impact treatment - Welding in the World, vol. 58, no. 1, pp. 29–39, Jan. 2014.	
Material	Denomination	S690
	Plate thickness	5 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	690 MPa
Datail category according to EC		FAT 71
Post-weld treatment	HFMI	PIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	550	26654	1
2	500	50082	1
3	500	47592	1
4	450	97218	1
5	450	155664	1
6	400	199496	1
7	400	183912	1
8	375	288633	1
9	350	681242	1
10	350	380182	1
11	275	50000000	0
12	275	50000000	0
13			
14			
15			
16			
17			
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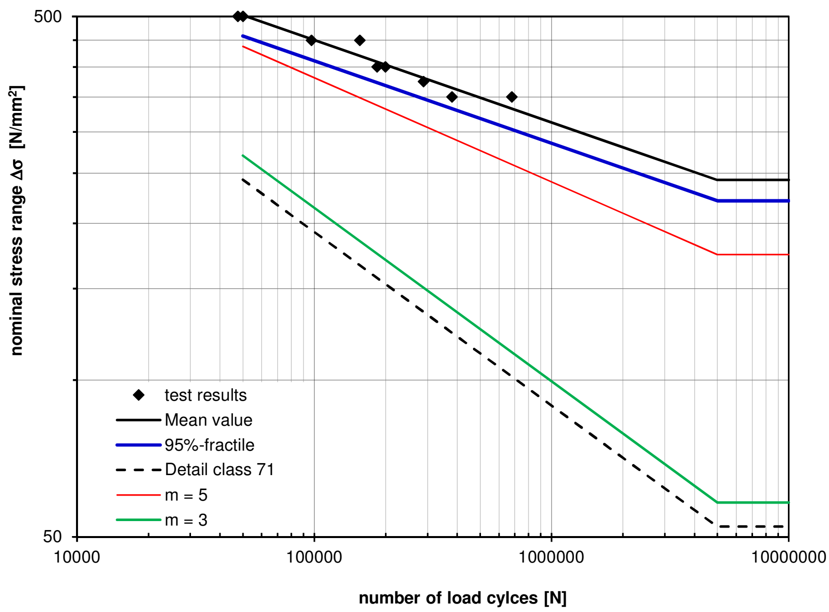
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

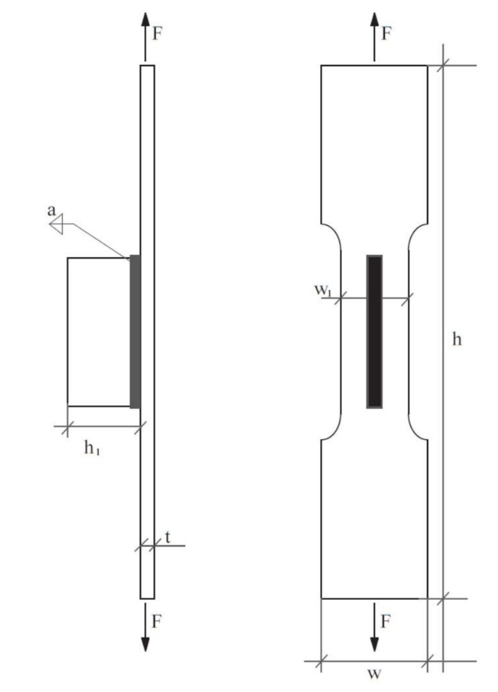


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_{\ddot{U}}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{\ddot{U}}$ = 95%) $\Delta\sigma_C$
m = variable = 6,32	280,3	255,8
m = fix = 3	175,7	79,0
m = fix = 5	**250,8**	**209,3**

Construction detail	Longitudinal non-load carrying attachment	
Reference	Leitner, M., Stoschka, M. and Eichlseder, W. (2014) Fatigue enhancement of thin-walled, high-strength steel joints by high-frequency mechanical impact treatment - Welding in the World, vol. 58, no. 1, pp. 29–39, Jan. 2014.	
Material	Denomination	S960
	Plate thickness	5 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	960 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	-
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	700	18272	1
2	600	32266	1
3	600	36696	1
4	500	136787	1
5	500	85693	1
6	400	276312	1
7	350	630259	1
8	350	557678	1
9	350	804910	1
10	325	1073244	1
11	300	7658700	1
12	275	50000000	0
13			
14			
15			
16			
17			
18			
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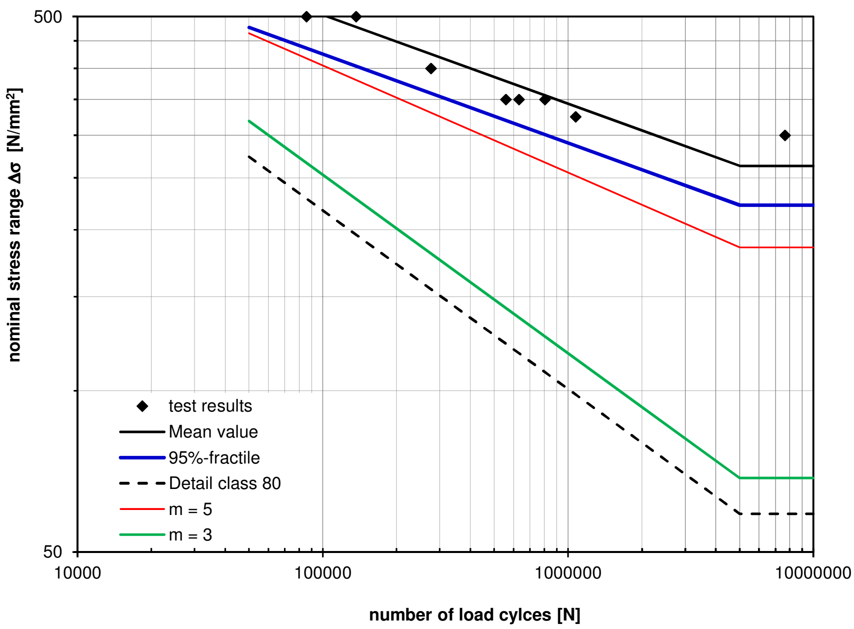
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

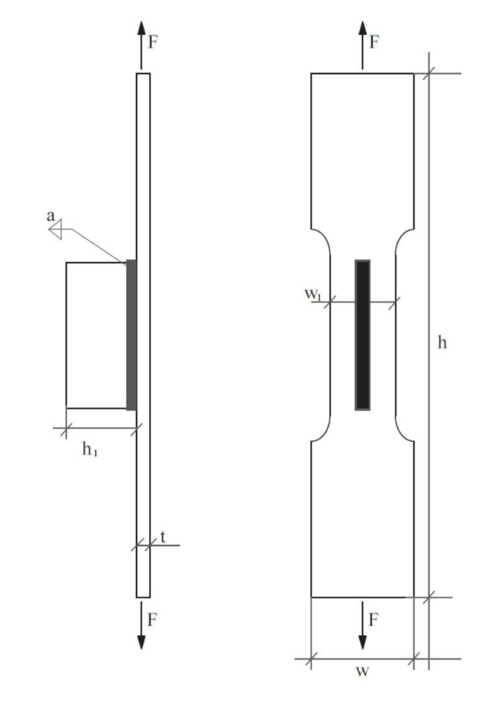
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 6,03	306,3	258,6
m = fix = 3	215,0	93,3
m = fix = 5	**285,0**	**222,5**

Construction detail	Longitudinal non-load carrying attachment	
Literatur	Polezhayeva, H., Howarth, D., Kumar, M., Kang, J.-K., Ermolaeva, N. and Lee, J.-Y. (2014) Effect of Ultrasonic Peening on Fatigue Strength of Welded Marine Structures- Lloyd's Register Research Programme, in The Twenty-fourth International Ocean and Polar Engineering Conference, 2014.	
Material	Denomination	S690
	Plate thickness	25 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	690 MPa
Datail category according to EC		FAT 63
Post-weld treatment	HFMI	UP
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	230,6	1454372	1
2	248,3	1347860	1
3	230,2	1166506	1
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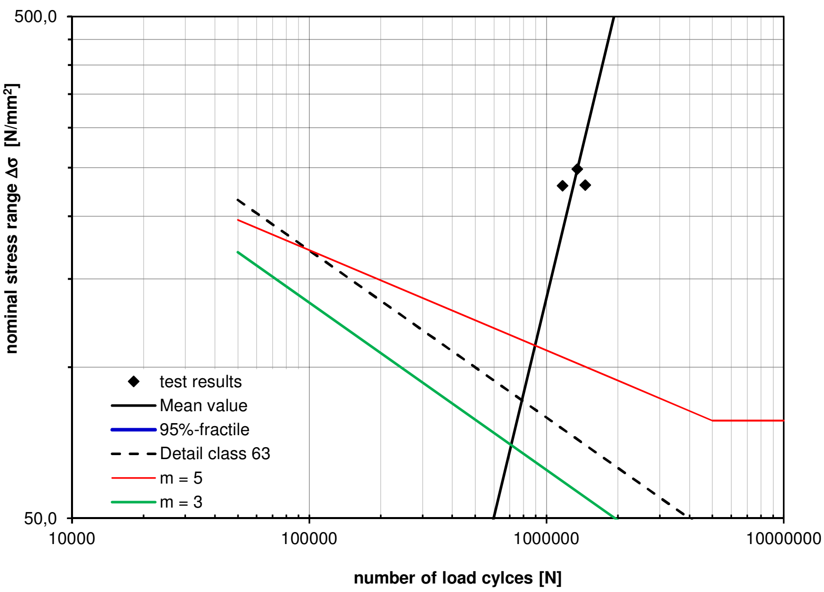
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

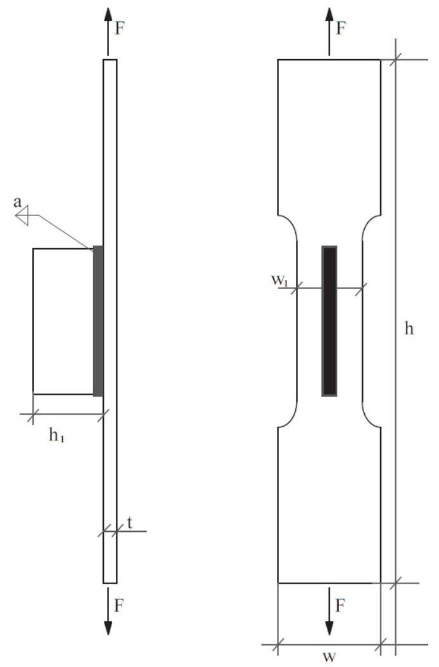
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_{\ddot{U}}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{\ddot{U}}$ = 95%) $\Delta\sigma_C$
m = variable = -0,51	537,6	113888030061360,0
m = fix = 3	205,5	49,6
m = fix = 5	**217,3**	**94,0**

Construction detail	Longitudinal non-load carrying attachment		
Reference	Wu, L.C. and Wang, D.P. (2012) Effect of Welding Residual Stress on Fatigue Performance of the Welded Joints Treated by Ultrasonic Peening. Advanced Materials Research, vol. 418–420, pp. 337–341, 2012.		
Material	Denomination	Q235B	
	Plate thickness	8	mm
Mech. properties	$R_{p0,2}$	435	MPa
	R_m	272	MPa
Datail category according to EC		FAT 80	
Post-weld treatment	HFMI	UPT	
Fatigue loading	Stress ration	-1	[-]
	Type of collective	Constant amplitude	
	Axial/Bending force	Axial	

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	340,1	495742	1
2	320,1	645980	1
3	300,0	1045107	1
4	300,0	1429254	1
5	279,9	2008721	1
6	270,2	2994176	1
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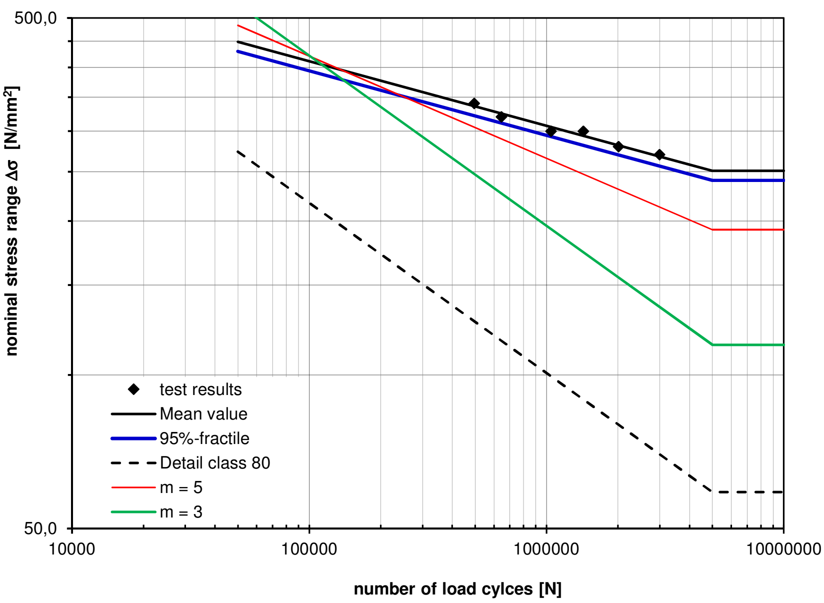
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

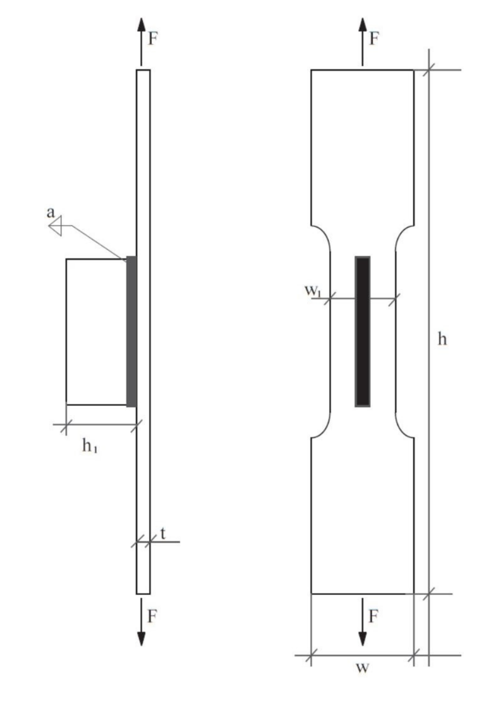
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_{Ü}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{Ü}$ = 95%) $\Delta\sigma_C$
m = variable = 7,92	281,8	269,9
m = fix = 3	253,2	155,5
m = fix = 5	**271,2**	**231,2**

Construction detail	Longitudinal non-load carrying attachment	
Reference	Wu, L.C. and Wang, D.P. (2012) Effect of Welding Residual Stress on Fatigue Performance of the Welded Joints Treated by Ultrasonic Peening. Advanced Materials Research, vol. 418–420, pp. 337–341, 2012.	
Material	Denomination	Q235B
	Plate thickness	8 mm
Mech. properties	$R_{p0,2}$	435 MPa
	R_m	272 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UPT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	234,4	302534	1
2	225,5	585471	1
3	216,3	1107107	1
4	207,3	1357522	1
5	198,1	1896375	1
6	189,1	3460064	1
7	179,9	10175346	0
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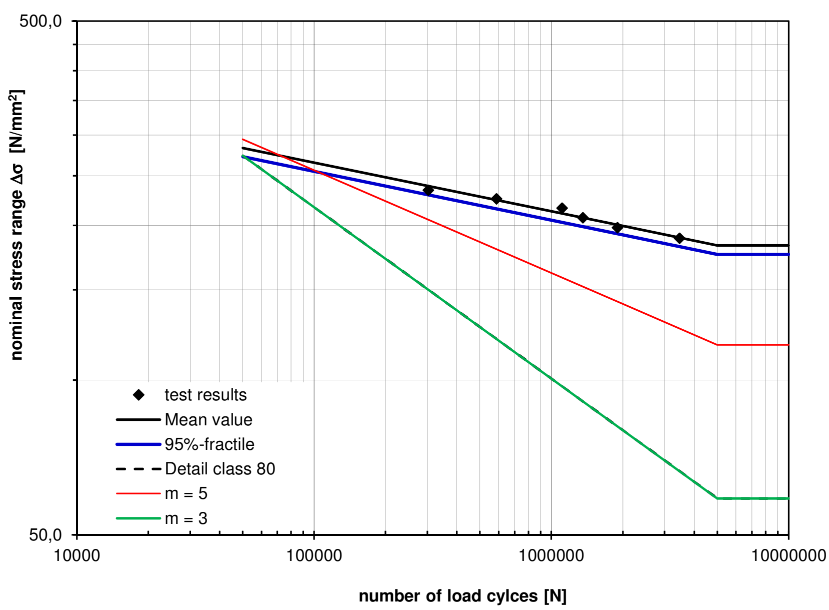
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

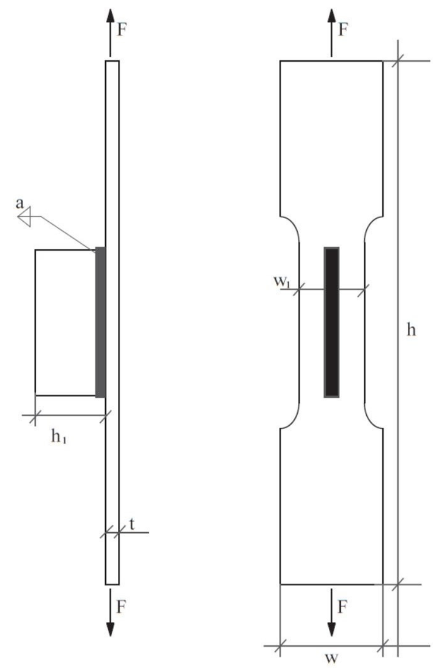
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_{Ü}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{Ü}$ = 95%) $\Delta\sigma_C$
m = variable = 10,54	199,5	191,7
m = fix = 3	172,9	79,9
m = fix = 5	**187,3**	**140,7**

Construction detail	Longitudinal non-load carrying attachment	
Reference	Wu, L.C. and Wang, D.P. (2012) Effect of Welding Residual Stress on Fatigue Performance of the Welded Joints Treated by Ultrasonic Peening. Advanced Materials Research, vol. 418–420, pp. 337–341, 2012.	
Material	Denomination Plate thickness	Q235B 8 mm
Mech. properties	$R_{p0,2}$ R_m	435 MPa 272 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UPT
Fatigue loading	Stress ration Type of collective Axial/Bending force	0,45 [-] Constant amplitude Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	188,0	269761	1
2	179,0	506207	1
3	169,9	998952	1
4	161,1	1427059	1
5	151,9	3989433	1
6			
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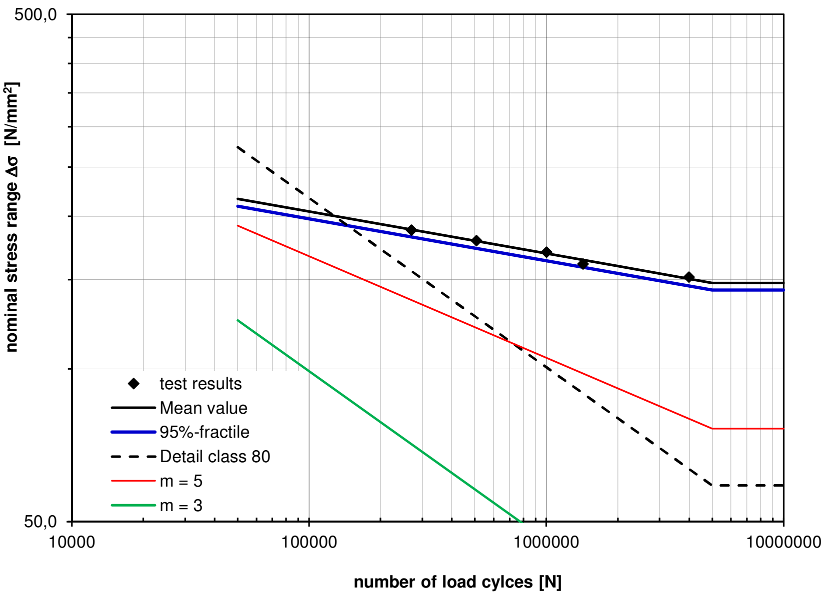
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

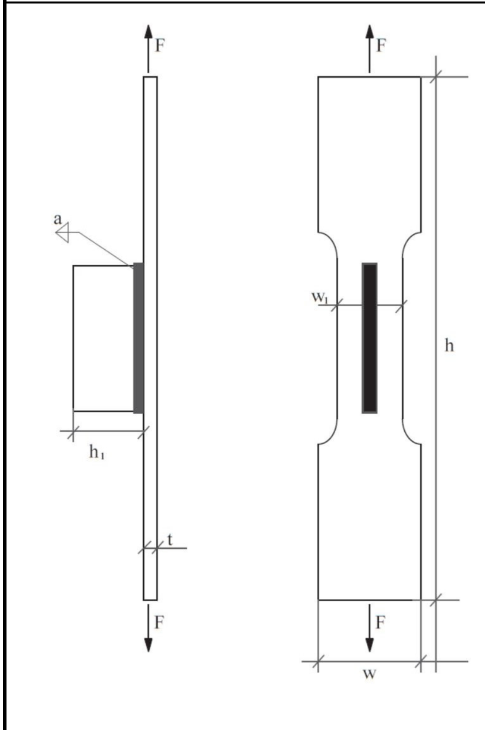
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 12,09	159,4	154,3
m = fix = 3	132,3	36,4
m = fix = 5	**146,1**	**91,6**

Construction detail	Longitudinal non-load carrying attachment	
Literatur	Lihavainen, V.-M. and Marquis, G. (2004) Estimation of fatigue life improvement for ultrasonic impact treated welded joints. In ECF15, Stockholm 2004, 2004.	
Material	Denomination	S355J0
	Plate thickness	5-8 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	355 MPa
Datail category according to EC		FAT 63
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	270,2	205090	1
2	261,8	247513	1
3	256,9	257694	1
4	240,2	254970	1
5	280,0	393816	1
6	273,6	407822	1
7	264,0	440874	1
8	238,7	587715	1
9	241,2	1889888	1
10	204,7	1900587	1
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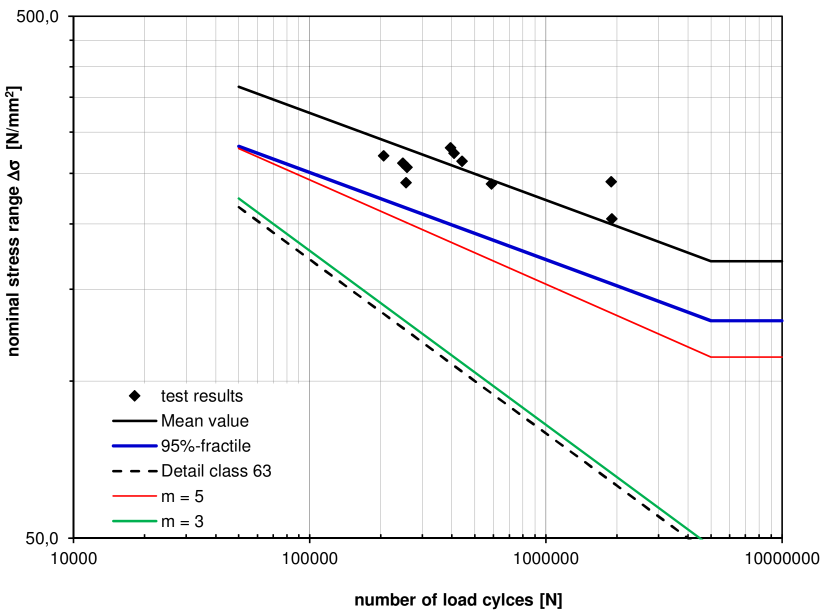
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

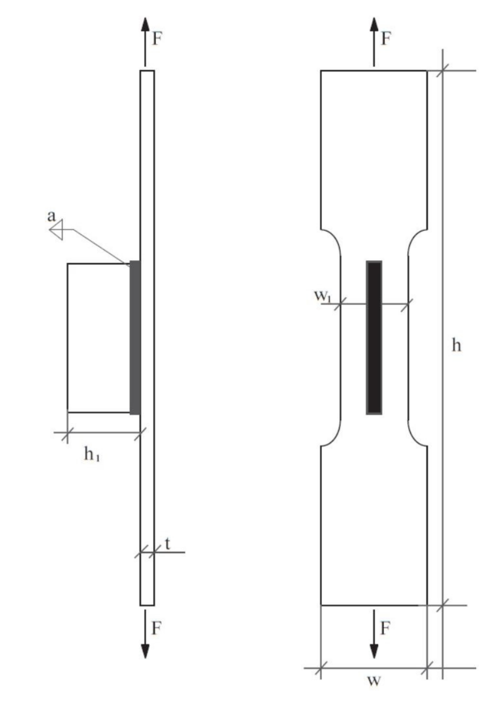
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 5,98	197,8	152,1
m = fix = 3	155,3	65,4
m = fix = 5	**188,6**	**133,5**

Construction detail	Longitudinal non-load carrying attachment	
Literatur	Haagensen, P.J., Statnikov, E.S. and Martinez, L. (1998) Introductory fatigue tests on welded joints in high strength steel and aluminium improved by various methods including ultrasonic impact treatment (UIT). IIW Doc, vol. 13, pp. 1748–98, 1998.	
Material	Denomination Plate thickness	Weldox 700 6 mm
Mech. properties	$R_{p0,2}$ R_m	800 MPa 780 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration Type of collective Axial/Bending force	0,1 [-] Constant amplitude Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	401,5	22279	1
2	229,5	243182	1
3	199	617837	1
4	199	1519004	1
5	179,8	10401842	0
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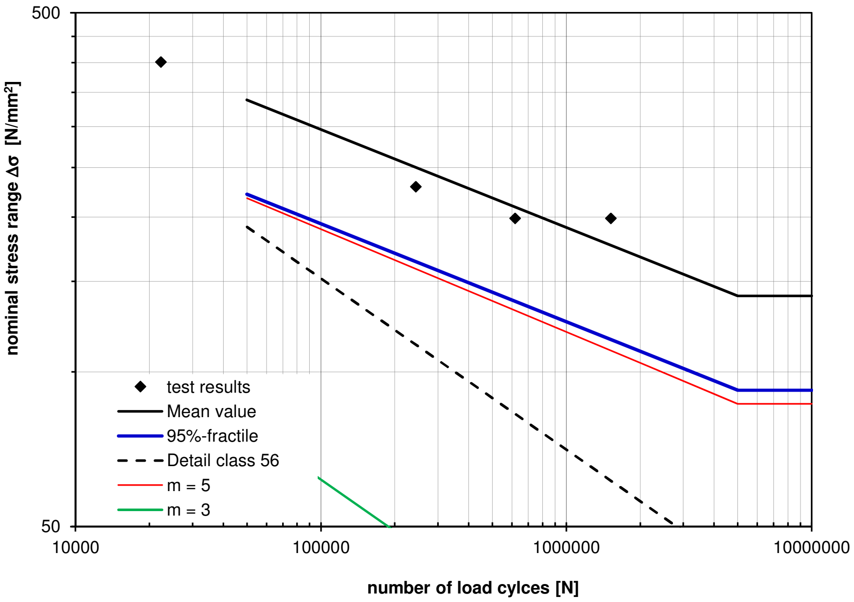
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

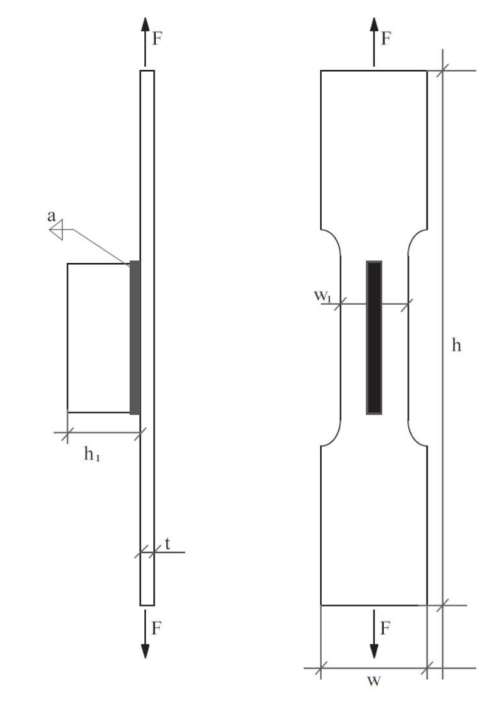
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 5,25	167,5	109,7
m = fix = 3	125,6	22,7
m = fix = 5	**164,3**	**104,1**

Construction detail	Longitudinal non-load carrying attachment	
Literatur	Haagensen, P. J. and Alnes, O. (2005) Progress Report on IIW WG2 Round Robin Fatigue Testing Program on 700 MPa and 350 MPa YS Steels. 2005.	
Material	Denomination	S355
	Plate thickness	8 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	355 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	300	33547	1
2	250	78965	1
3	220	112349	1
4	180	396237	1
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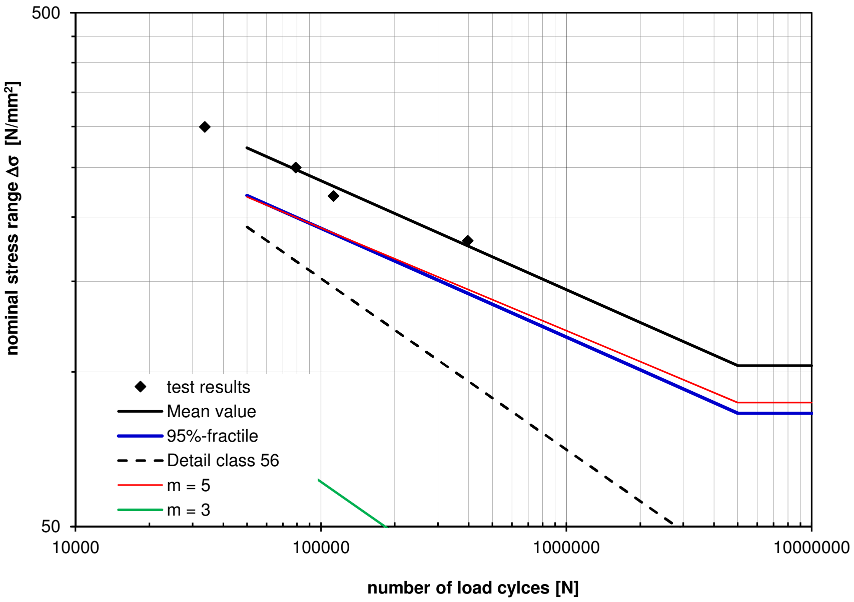
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

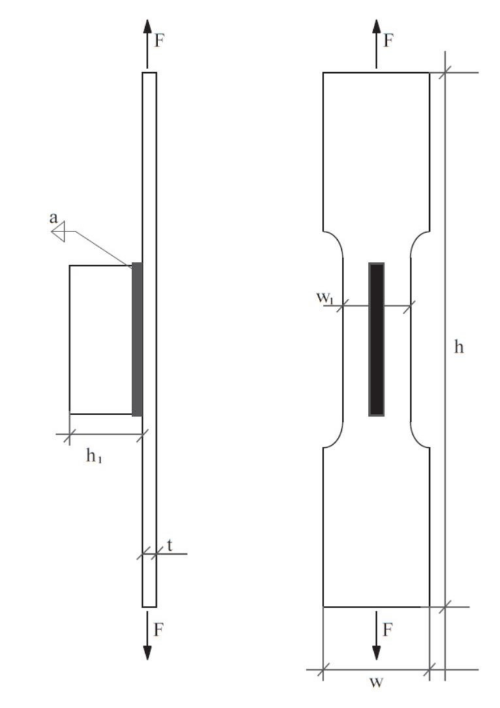
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 4,72	124,9	100,9
m = fix = 3	87,2	22,5
m = fix = 5	**129,3**	**104,7**

Construction detail	Longitudinal non-load carrying attachment	
Literatur	Haagensen, P. J. and Alnes, O. (2005) Progress Report on IIW WG2 Round Robin Fatigue Testing Program on 700 MPa and 350 MPa YS Steels. 2005.	
Material	Denomination	S700
	Plate thickness	8 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	700 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	300	302030	1
2	250	405412	1
3	200	652565	1
4	400	18763	1
5	350	28103	1
6	180	1450588	1
7	220	497616	1
8	210	454200	1
9	190	1099302	1
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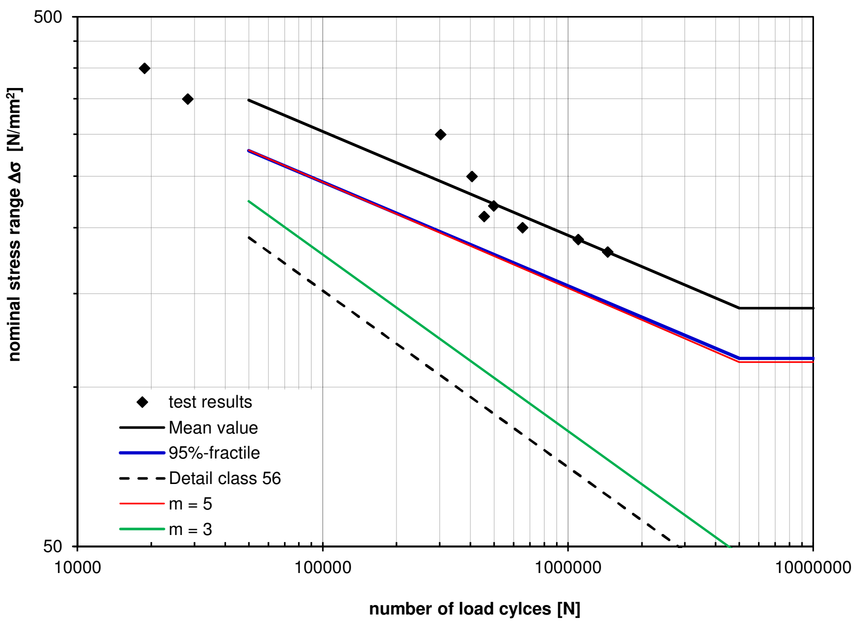
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

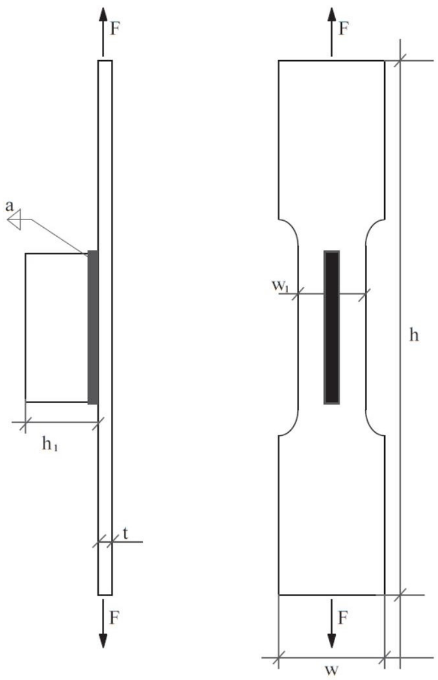


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 5,1	168,7	135,5
m = fix = 3	129,5	65,5
m = fix = 5	**167,5**	**133,8**

Construction detail	Longitudinal non-load carrying attachment	
Literatur	Haagensen, P. J. and Alnes, O. (2005) Progress Report on IIW WG2 Round Robin Fatigue Testing Program on 700 MPa and 350 MPa YS Steels. 2005.	
Material	Denomination	S700
	Plate thickness	8 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	700 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	UP
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	200	535534	1
2	250	687776	1
3	350	26228	1
4	300	64900	1
5	220	826448	1
6	200	1450783	1
7	260	93066	1
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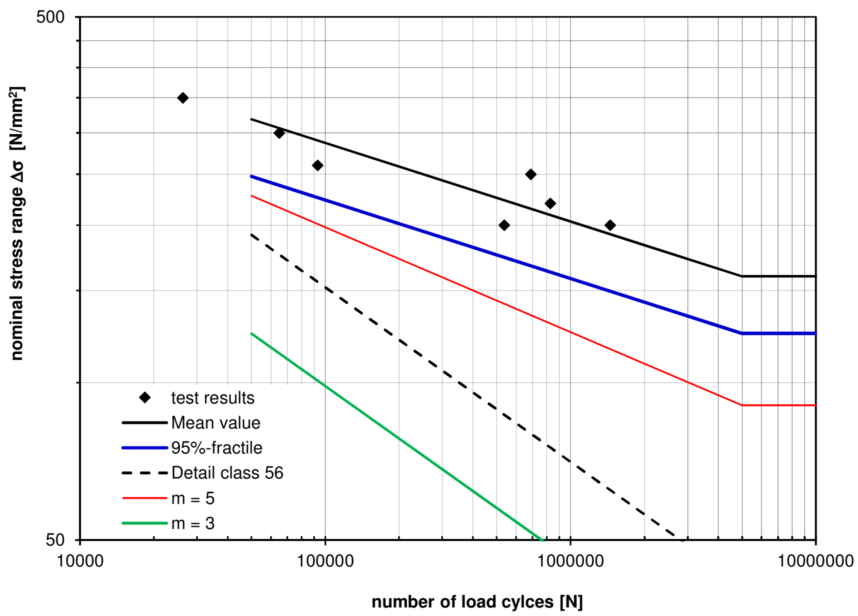
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

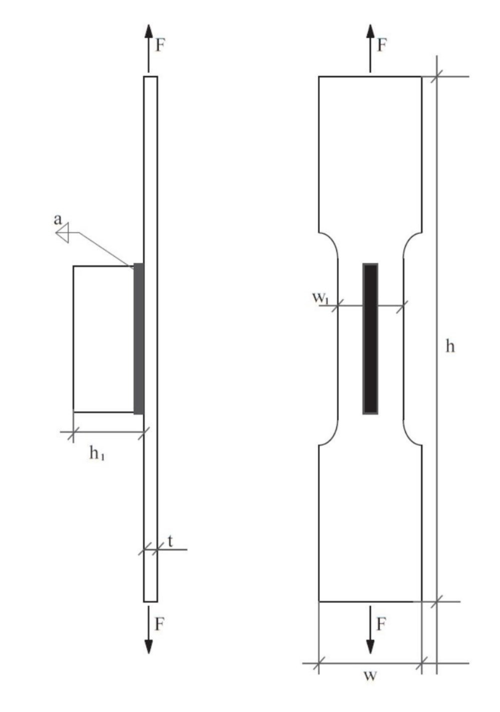
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_{\ddot{U}}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{\ddot{U}}$ = 95%) $\Delta\sigma_C$
m = variable = 6,66	183,1	142,4
m = fix = 3	125,5	36,3
m = fix = 5	**165,2**	**108,7**

Construction detail	Longitudinal non-load carrying attachment	
Literatur	Deguchi, T., Mouri, M., Hara, J., Kano, D., Shimoda, T., Inamura, F., Fukuoka, T. and Koshio, K. (2012) Fatigue strength improvement for ship structures by Ultrasonic Peening. Journal of Marine Science and Technology, vol. 17, no. 3, pp. 360–369, Sep. 2012.	
Material	Denomination	KA36
	Plate thickness	16 mm
Mech. properties	$R_{p0,2}$	490-620 MPa
	R_m	355 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	UP
Fatigue loading	Stress ration	0 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	200,2	169202	1
2	160,8	410355	1
3	150,8	963800	1
4			
5			
6			
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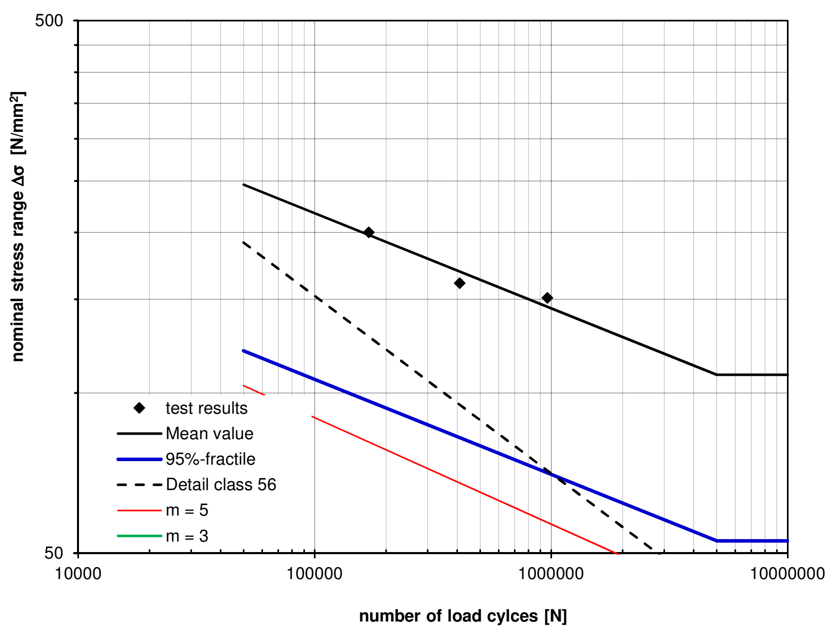
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

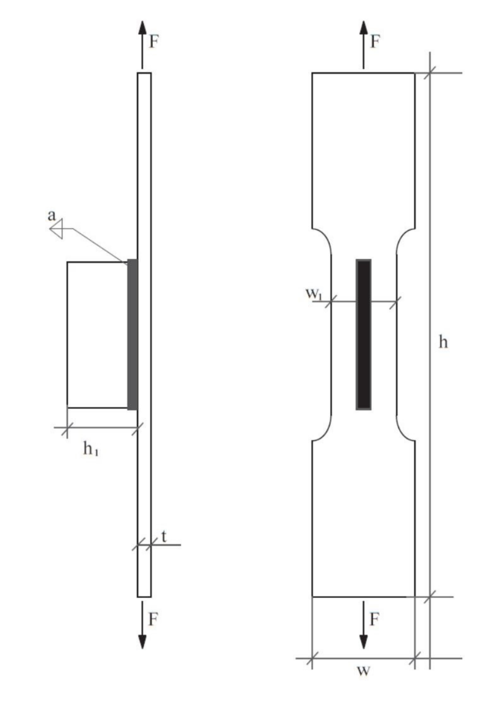
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_{Ü}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{Ü}$ = 95%) $\Delta\sigma_C$
m = variable = 5,6	127,4	62,1
m = fix = 3	99,5	2,2
m = fix = 5	**123,1**	**49,3**

Construction detail	Longitudinal non-load carrying attachment	
Literatur	Ummenhofer, T. and Weich, I.I. (2010) REFRESH – Lebensdauerverlängerung bestehender und neuer geschweiß ter Stahlkonstruktionen, Stahlbau, vol. 75, no. 7, pp. 605–607, 2010.	
Material	Denomination	S355J2
	Plate thickness	16 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	434 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	HiFIT/UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	284,2	81073	1
2	282,6	111687	1
3	240,3	173921	1
4	232,2	217608	1
5	246,7	314497	1
6	206,7	201670	1
7	207,6	253721	1
8	207,9	303330	1
9	208,0	434783	1
10	170,4	652652	1
11	170,6	899083	1
12	170,2	1001356	1
13	209,0	1077043	1
14	208,5	1355069	1
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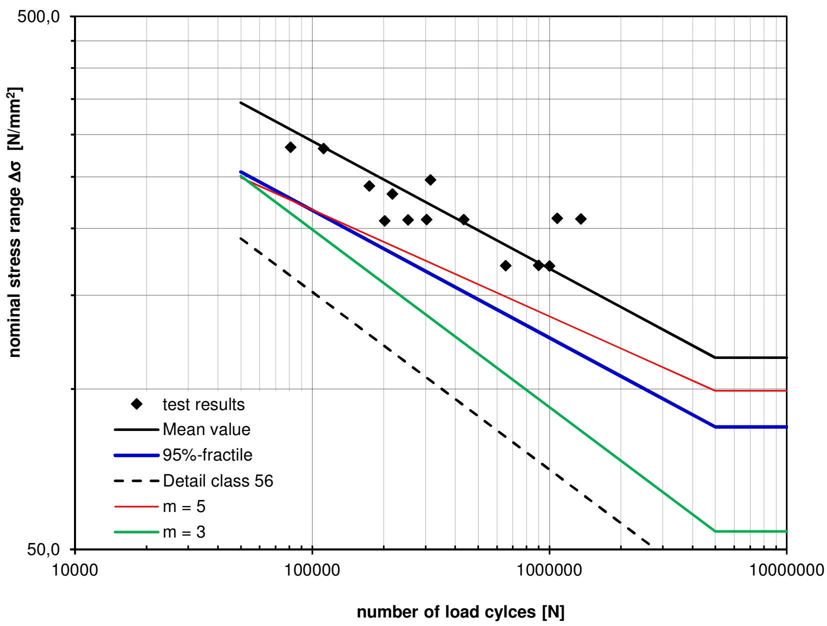
* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

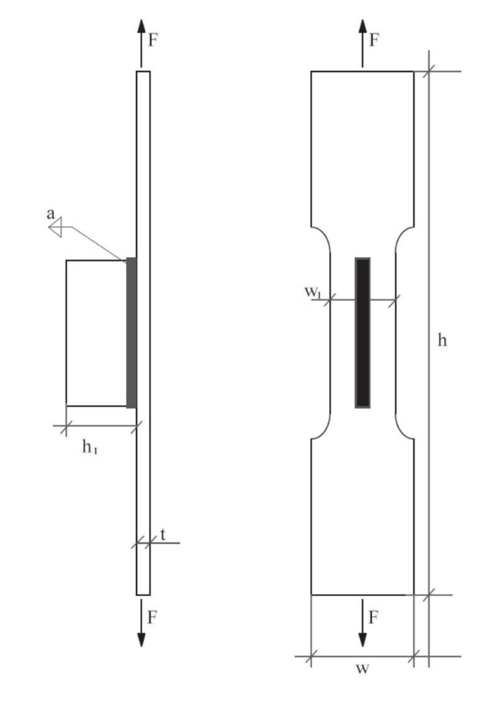
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 4,18	142,5	105,7
m = fix = 3	121,3	73,3
m = fix = 5	**152,4**	**119,2**

Construction detail	Longitudinal non-load carrying attachment	
Literatur	Ummenhofer, T. and Weich, I.I. (2010) REFRESH – Lebensdauerverlängerung bestehender und neuer geschweiß ter Stahlkonstruktionen, Stahlbau, vol. 75, no. 7, pp. 605–607, 2010.	
Material	Denomination	S355J2
	Plate thickness	16 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	434 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	HiFIT/UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	246,9	72945	1
2	247,4	90060	1
3	226,4	101042	1
4	226,4	106000	1
5	207,7	166837	1
6	207,7	189571	1
7	189,0	1108669	1
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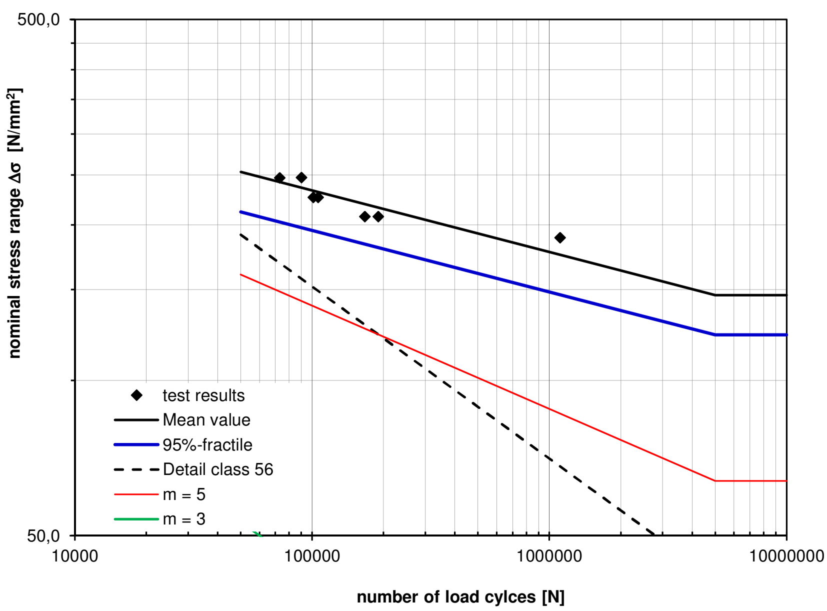
* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

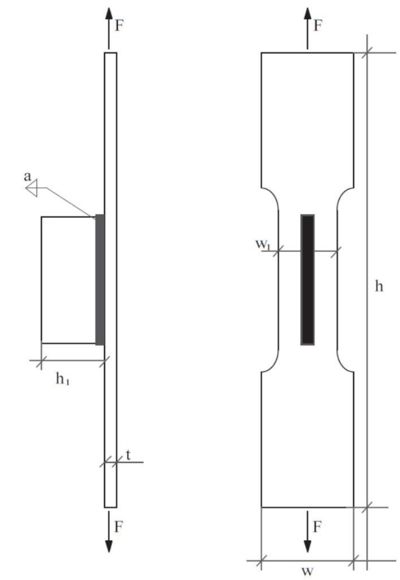


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 8,39	163,1	136,6
m = fix = 3	94,7	15,6
m = fix = 5	**132,9**	**76,7**

Construction detail	Longitudinal non-load carrying attachment	
Literatur	Ummenhofer, T., Herion, S., Rack, S., Weich, I., Telljohann, G., Dannemeyer, S., Strohbach, H., Eslami-Chalandar, H., Kathrin-Kern, A., Pinkernell, D., Smida, M., Rahlf, U. and Senk, B (2010) *REFRESH – Extension of the fatigue life of existing and new welded steel structures.*	
Material	Denomination	S355J2
	Plate thickness	16 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	434 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	HiFIT/UIT
Fatigue loading	Stress ration	0.1 [-]
	Type of collective	Constant amplitude

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	282.2	52967	1
2	282.8	57943	1
3	283.4	64149	1
4	285.1	78864	1
5	284.6	83729	1
6	285.7	93255	1
7	282.2	111599	1
8	234.8	174837	1
9	234.8	207360	1
10	205.4	204892	1
11	205.4	255689	1
12	205.4	302345	1
13	244.7	315283	1
14	169.1	334732	1
15	204.9	424017	1
16	204.9	436899	1
17	169.5	646634	1
18	243.7	880118	1
19	169.8	890718	1
20	169.8	998007	1
21	206.2	1088500	1
22	207.1	1358362	1
23	169.8	2984489	1
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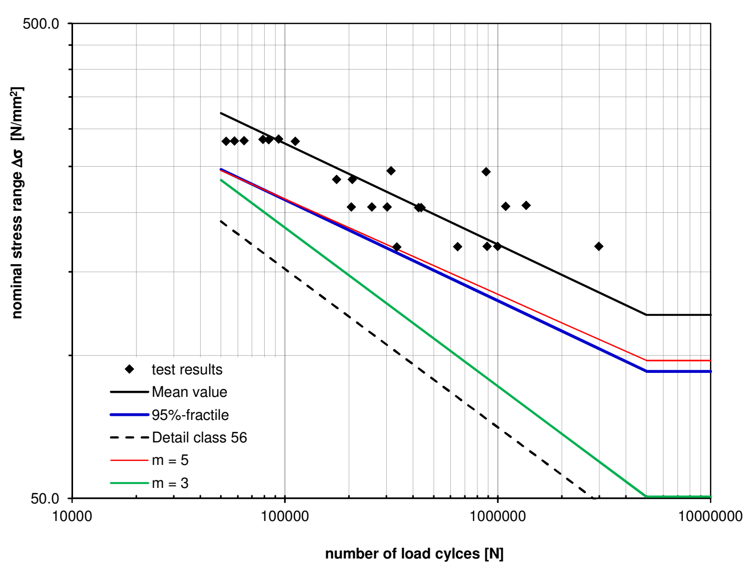
Comments: Some of the data gathered from this reference has been utilised in similar investigations in other reports (Weich and Ummenhofera, 2011; Weich et al., 2009; Weich and Ummenhofer, 2007; Weich, 2008).

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

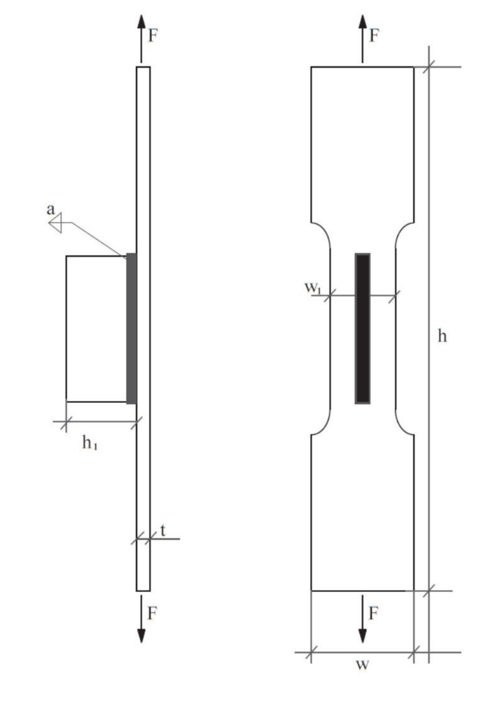


Statistical evaluation of test data according to EN 1993-1-9:2005

slope	an S-N curve ($P_Ü$ = 50 $\Delta\sigma_{50\%}$	characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 4.71	**147.9**	**112.5**
m = fix = 3	116.9	68.4
m = fix = 5	151.5	117.2

Construction detail	Longitudinal non-load carrying attachment		
Literatur	Ummenhofer, T. and Weich, I.I. (2010) REFRESH – Lebensdauerverlängerung bestehender und neuer geschweiß ter Stahlkonstruktionen, Stahlbau, vol. 75, no. 7, pp. 605–607, 2010.		
Material	Denomination	S355J2	
	Plate thickness	30 mm	
Mech. properties	$R_{p0,2}$	- MPa	
	R_m	434 MPa	
Datail category according to EC		FAT 56	
Post-weld treatment	HFMI	HiFIT/UIT	
Fatigue loading	Stress ration	0,1 [-]	
	Type of collective	Constant amplitude	
	Axial/Bending force	Axial	

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	282,8	135565	1
2	284,0	167663	1
3	244,7	154647	1
4	245,3	187858	1
5	246,8	213660	1
6	282,2	210486	1
7	245,8	235840	1
8	207,5	293430	1
9	207,9	470844	1
10	207,9	703159	1
11	169,8	957053	1
12	169,8	1826831	1
13	207,9	2585106	1
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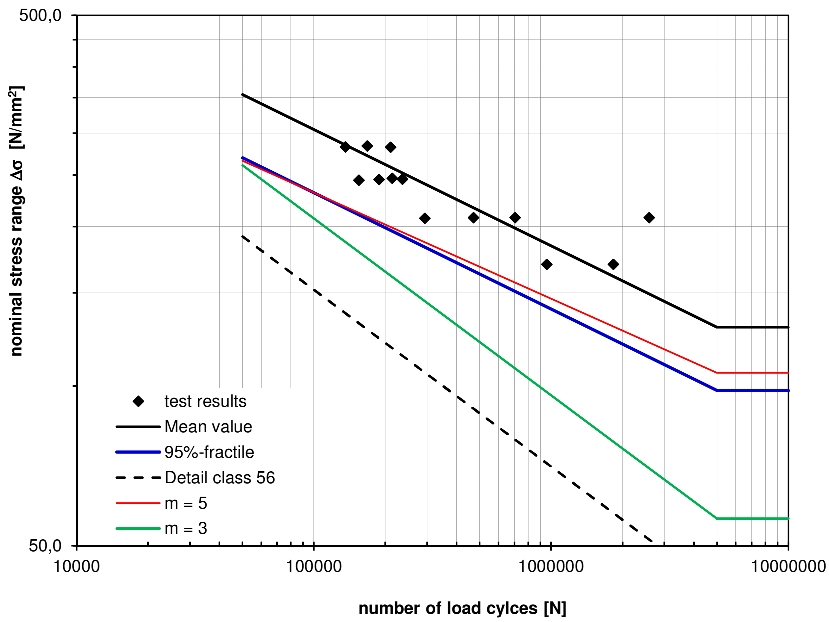
* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

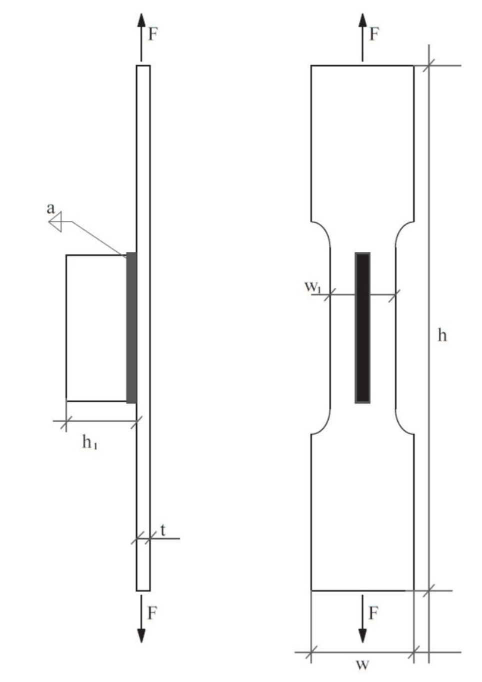


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 4,56	157,9	119,9
m = fix = 3	130,6	76,3
m = fix = 5	**163,1**	**127,3**

Construction detail	Longitudinal non-load carrying attachment	
Literatur	Ummenhofer, T. and Weich, I.I. (2010) REFRESH – Lebensdauerverlängerung bestehender und neuer geschweiß ter Stahlkonstruktionen, Stahlbau, vol. 75, no. 7, pp. 605–607, 2010.	
Material	Denomination	S690QL
	Plate thickness	16 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	719 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	HiFIT/UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	273,4	297273	1
2	274,3	327943	1
3	274,7	345684	1
4	272,9	405854	1
5	250,9	514493	1
6	236,6	430000	1
7	236,4	460853	1
8	236,6	520000	1
9	236,4	567612	1
10	236,8	606979	1
11	236,8	721209	1
12	198,1	543765	1
13	197,5	801513	1
14	198,1	828839	1
15	198,5	1083831	1
16	199,5	1263356	1
17	198,9	1417265	1
18	198,9	1844439	1
19	163,9	2119729	1
20	164,5	2752012	1
21	165,0	3057831	1
22	164,2	3422163	1
23	164,0	4411160	1
24	144,6	2586232	1
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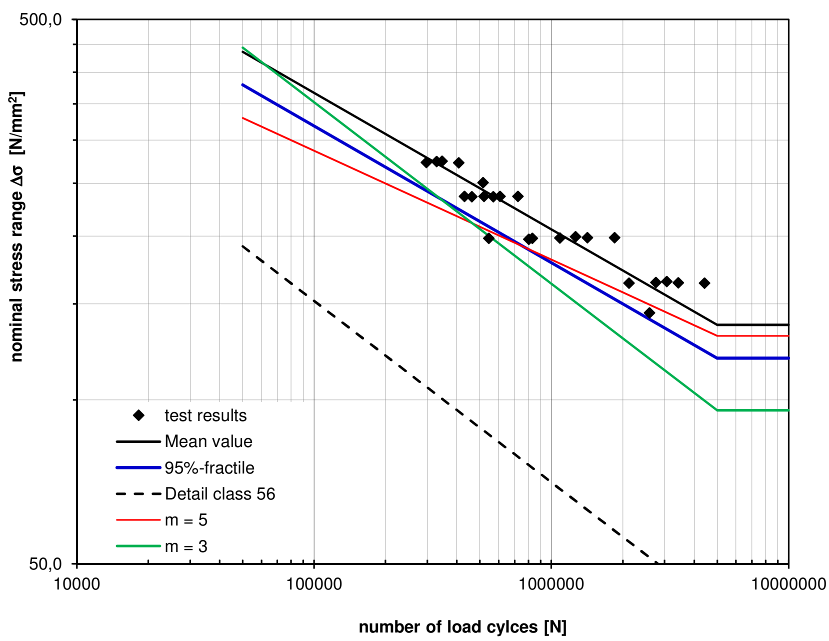
* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

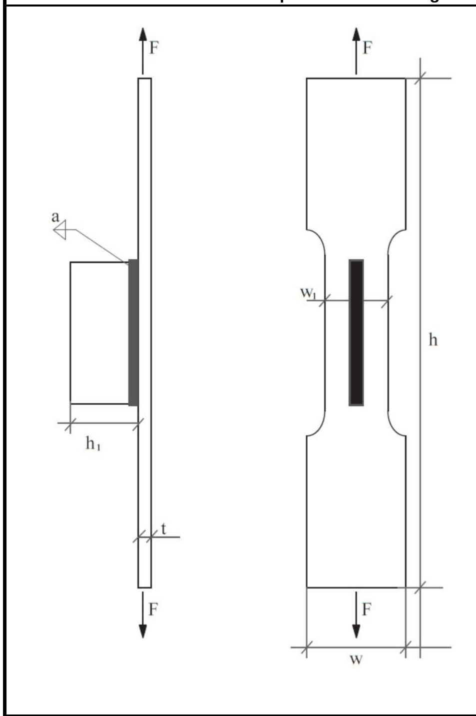


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 3,99	172,9	150,2
m = fix = 3	162,3	129,8
m = fix = 5	**179,8**	**157,5**

Construction detail	Longitudinal non-load carrying attachment	
Literatur	Ummenhofer, T. and Weich, I.I. (2010) REFRESH – Lebensdauerverlängerung bestehender und neuer geschweiß ter Stahlkonstruktionen, Stahlbau, vol. 75, no. 7, pp. 605–607, 2010.	
Material	Denomination	S690QL
	Plate thickness	30 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	719 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	HiFIT/UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	284,9	231721	1
2	283,9	266252	1
3	246,4	400107	1
4	246,0	428885	1
5	245,6	446707	1
6	245,2	492797	1
7	209,2	671298	1
8	208,9	756696	1
9	209,6	968392	1
10	210,0	1011049	1
11	170,8	2316034	1
12	170,0	2094416	1
13	171,4	2001230	1
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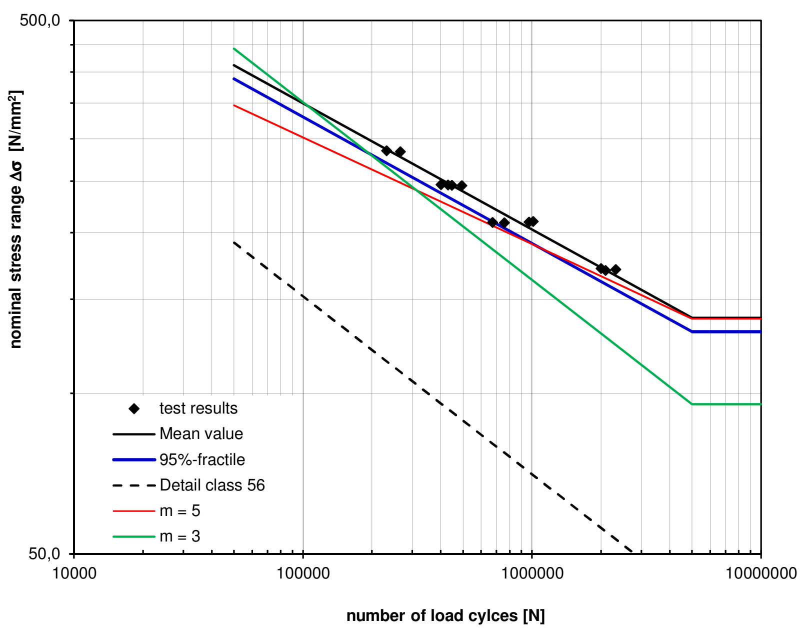
* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

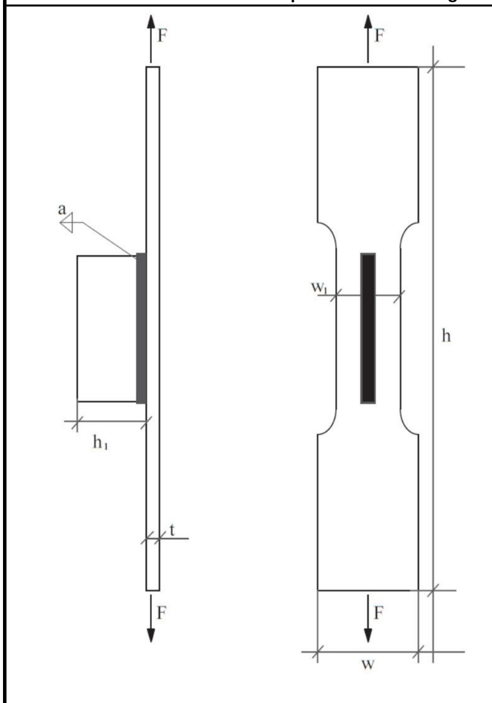


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 4,22	172,0	162,1
m = fix = 3	155,6	129,5
m = fix = 5	**178,7**	**165,8**

Construction detail	Longitudinal non-load carrying attachment	
Literatur	Huo, L., Wang, D. and Zhang, Y. (2005) Investigation of the fatigue behaviour of the welded joints treated by TIG dressing and ultrasonic peening under variable-amplitude load. International Journal of Fatigue, vol. 27, no. 1, pp. 95–101, Jan. 2005.	
Material	Denomination	16Mn
	Plate thickness	8 mm
Mech. properties	$R_{p0,2}$	590 MPa
	R_m	390 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UPT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	243	297000	1
2	234	484000	1
3	225	763000	1
4	225	696000	1
5	216	1347000	1
6	207	2943000	1
7			
8			
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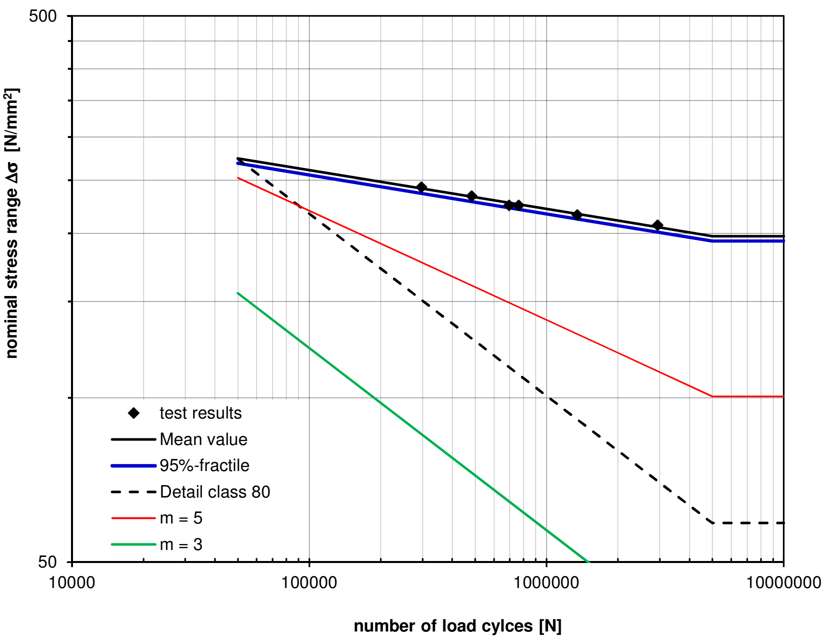
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

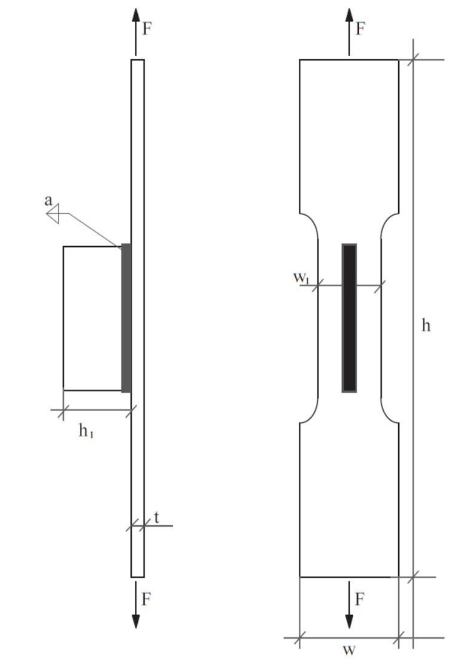
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 14,04	210,9	206,6
m = fix = 3	166,9	45,4
m = fix = 5	**188,0**	**120,8**

Construction detail	Longitudinal non-load carrying attachment			
Literatur	Martinez, L., Blom, A. F., Trogen, H. and Dahle, T. (1997) Fatigue behavior of steels with strength levels between 350 and 900 MPa. - Influence of post-weld treatments.pdf, in Proceedings of the North European Engineering and Science COnference (NESCO), Stockholm, 1997.			
Material	Denomination	S350		
	Plate thickness	12 mm		
Mech. properties	$R_{p0,2}$	503 MPa		
	R_m	398 MPa		
Datail category according to EC		FAT 56		
Post-weld treatment	HFMI	UP/UPT		
Fatigue loading	Stress ration	0,1 [-]		
	Type of collective	Constant amplitude		
	Axial/Bending force	Axial		

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	360	96100	1
2	340	56420	1
3	290	410000	1
4	278	488500	1
5	190	2000000	1
6			
7			
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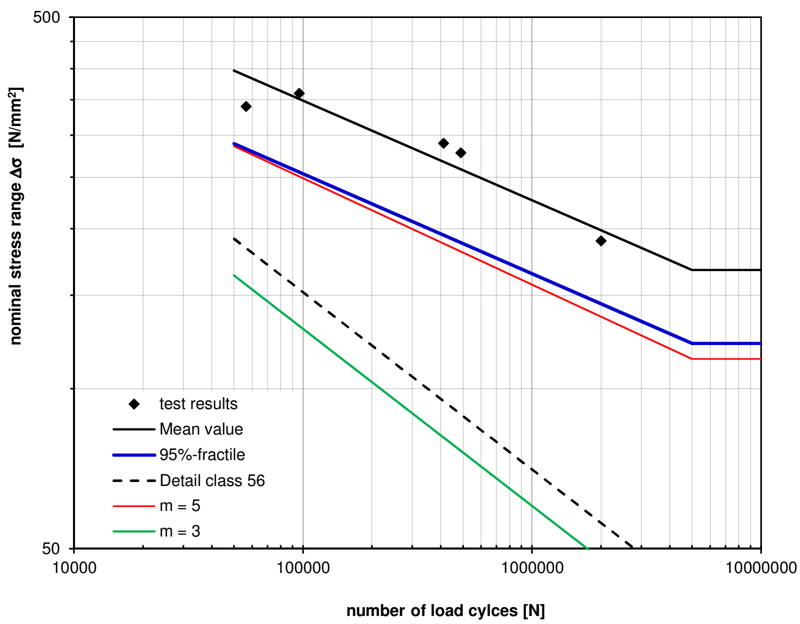
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

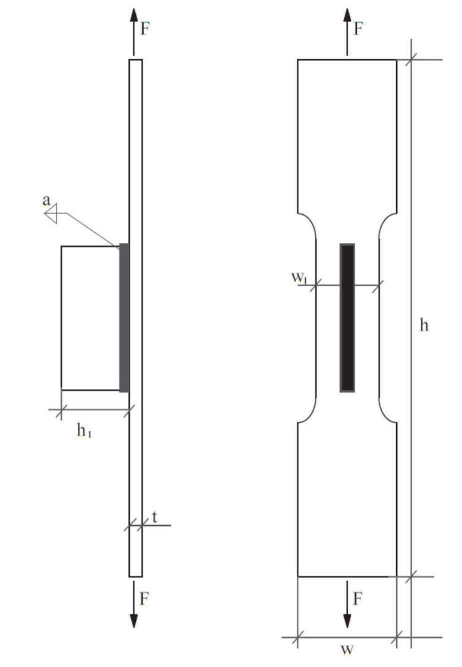


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 5,33	198,6	144,6
m = fix = 3	150,2	47,8
m = fix = 5	**194,0**	**136,7**

Construction detail	Longitudinal non-load carrying attachment	
Literatur	Martinez, L., Blom, A. F., Trogen, H. and Dahle, T. (1997) Fatigue behavior of steels with strength levels between 350 and 900 MPa. - Influence of post-weld treatments.pdf, in Proceedings of the North European Engineering and Science COnference (NESCO), Stockholm, 1997.	
Material	Denomination	S700
	Plate thickness	12 mm
Mech. properties	$R_{p0,2}$	850 MPa
	R_m	780 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	UP/UPT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	294	205200	1
2	247	403000	1
3	241	635000	1
4	225	653000	1
5	211	1050000	1
6	200	1405000	1
7	162	2000000	1
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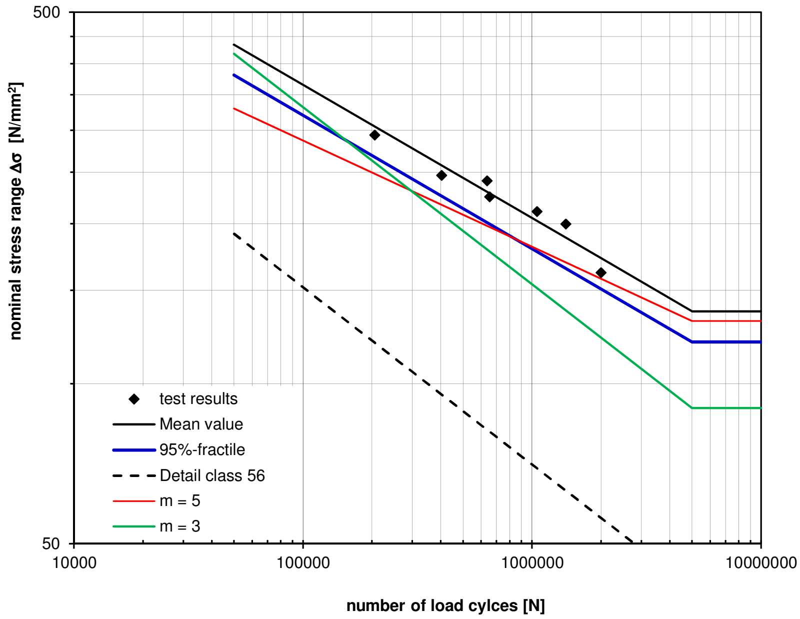
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

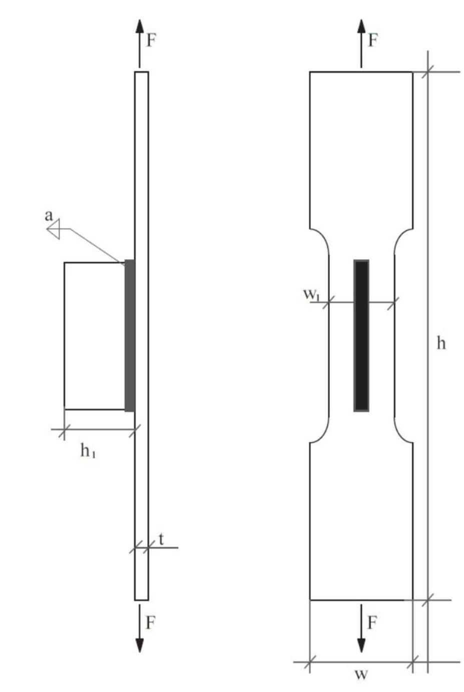


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 3,99	172,2	150,9
m = fix = 3	158,3	122,2
m = fix = 5	**181,4**	**157,7**

Construction detail	**Longitudinal non-load carrying attachment**	
Literatur	Wang, T., Wang, D., Huo, L. and Zhang, Y. (2009) Discussion on fatigue design of welded joints enhanced by ultrasonic peening treatment (UPT), International Journal of Fatigue, vol. 31, no. 4, pp. 644–650, Apr. 2009.	
Material	Denomination	SS800
	Plate thickness	8 mm
Mech. properties	$R_{p0,2}$	830-840 MPa
	R_m	700 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UPT
Fatigue loading	Stress ration	0,05 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	342,9	249878	1
2	342,9	284804	1
3	322,0	384793	1
4	322,0	569747	1
5	302,5	800588	1
6	280,8	1386901	1
7	300,7	1948824	1
8	262,3	3376052	1
9			
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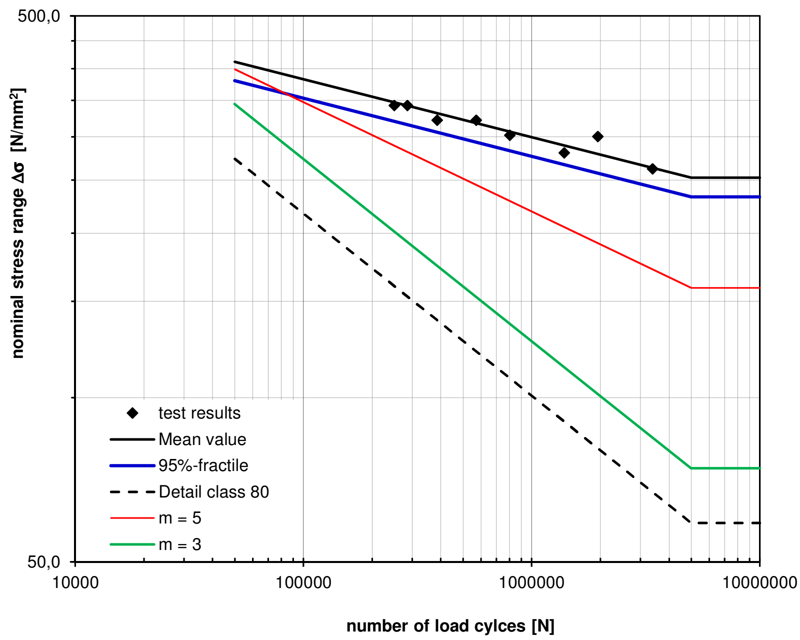
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

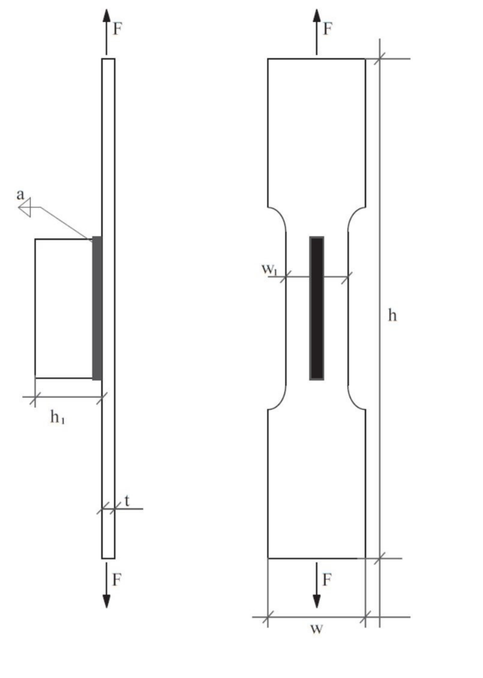
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 9,42	278,3	257,0
m = fix = 3	223,6	100,7
m = fix = 5	**254,2**	**190,6**

Construction detail	Longitudinal non-load carrying attachment	
Literatur	Lihavainen, V.M., Marquis, G. and Statnikov, E.S. (2004) Fatigue Strength of a Longitudinal Attachment Improved by Ultrasonic Impact Treatment. Welding in the World, vol. 48, no. 5–6, pp. 67–73, 2004.	
Material	Denomination	S355J0
	Plate thickness	8 mm
Mech. properties	$R_{p0,2}$	490-630 MPa
	R_m	355 MPa
Datail category according to EC		FAT 63
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	225	1902884	1
2	257	441958	1
3	257	407610	1
4	232	488203	1
5	232	1892369	1
6			
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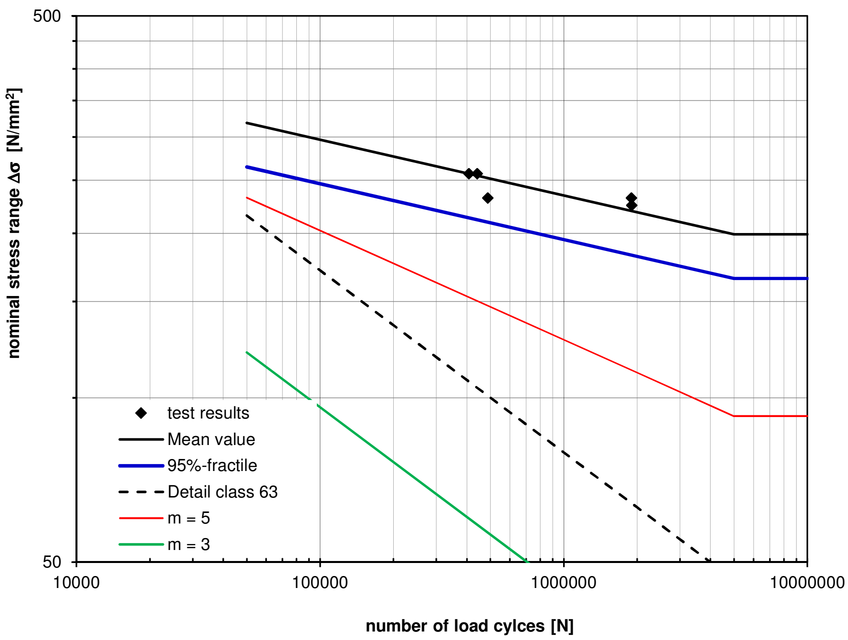
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

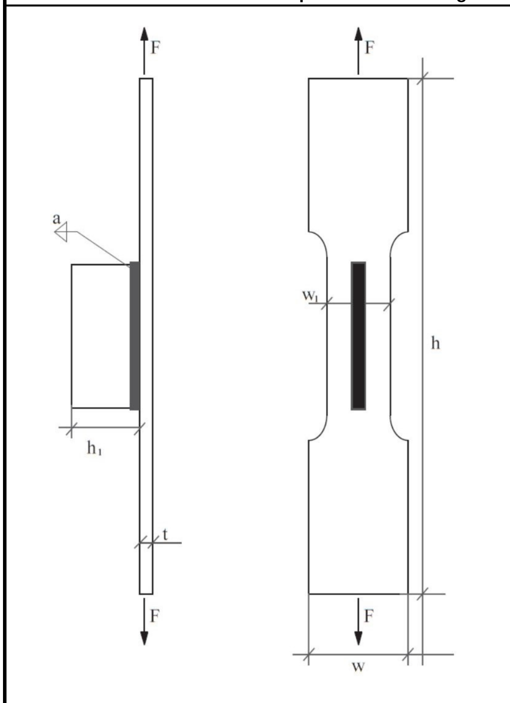
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 9,8	218,6	181,5
m = fix = 3	176,6	35,4
m = fix = 5	**199,7**	**111,1**

Construction detail	**Longitudinal non-load carrying attachment**	
Literatur	Lihavainen, V.M., Marquis, G. and Statnikov, E.S. (2004) Fatigue Strength of a Longitudinal Attachment Improved by Ultrasonic Impact Treatment. Welding in the World, vol. 48, no. 5–6, pp. 67–73, 2004.	
Material	Denomination Plate thickness	S355J0 5 mm
Mech. properties	$R_{p0,2}$ R_m	490-630 MPa 355 MPa
Datail category according to EC		FAT 63
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration Type of collective Axial/Bending force	0,1 [-] Constant amplitude Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	210,0	505913	1
2	186,2	310170	1
3	224,0	596082	1
4	188,0	620074	1
5	175,0	781200	1
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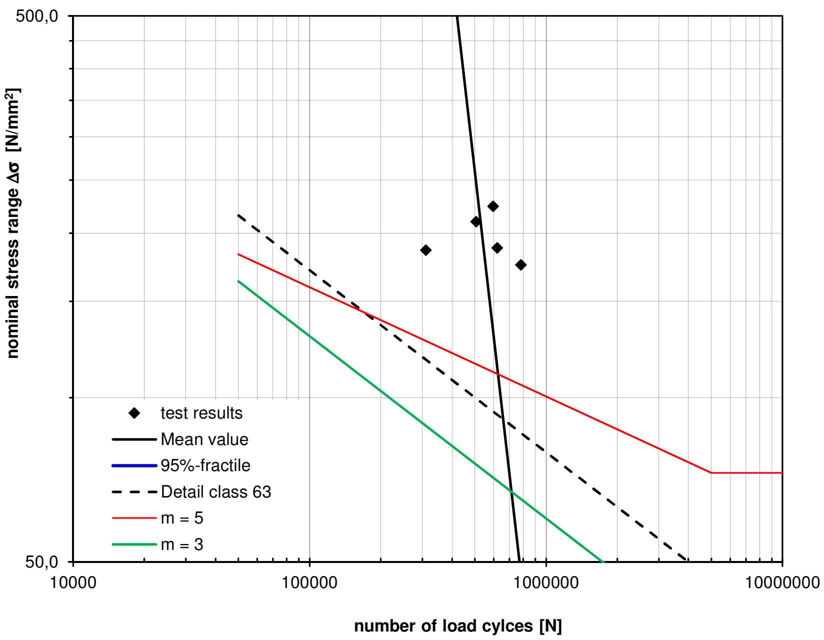
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

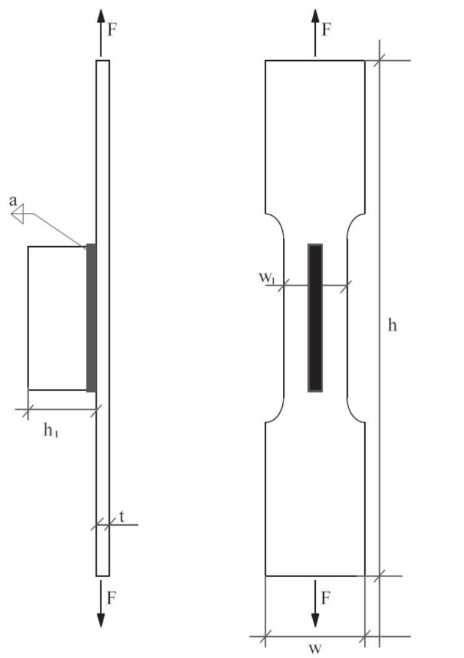
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 0,26	1,4	0,0
m = fix = 3	126,5	47,7
m = fix = 5	**150,7**	**87,5**

Construction detail	Longitudinal non-load carrying attachment		
Literatur	Lihavainen, V.M., Marquis, G. and Statnikov, E.S. (2004) Fatigue Strength of a Longitudinal Attachment Improved by Ultrasonic Impact Treatment. Welding in the World, vol. 48, no. 5–6, pp. 67–73, 2004.		
Material	Denomination	S355J0	
	Plate thickness	5	mm
Mech. properties	$R_{p0,2}$	490-630	MPa
	R_m	355	MPa
Datail category according to EC		FAT 63	
Post-weld treatment	HFMI	UIT	
Fatigue loading	Stress ration	0,46-0,5	[-]
	Type of collective	Constant amplitude	
	Axial/Bending force	Axial	

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	190	298108	1
2	193	473704	1
3	192	980692	1
4	177	333199	1
5	177	1163070	1
6	184	545583	1
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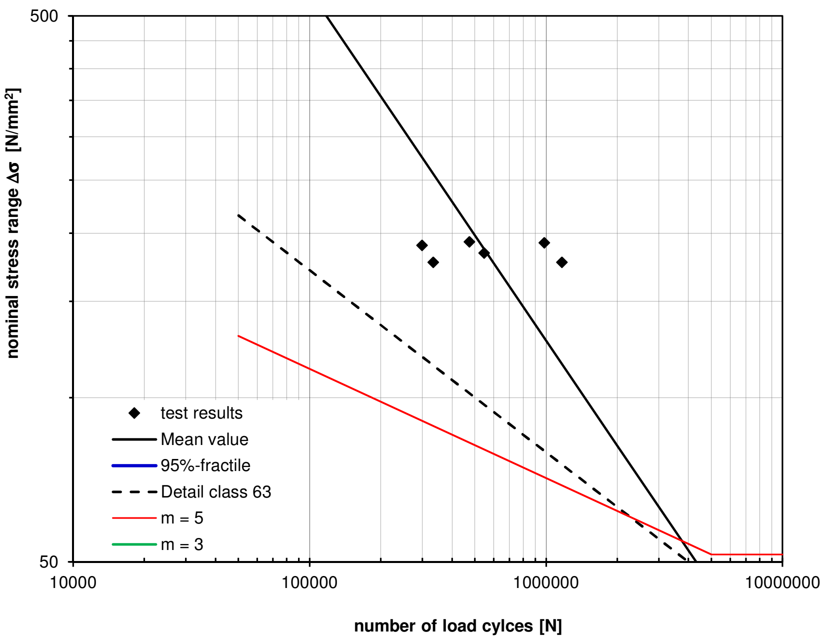
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

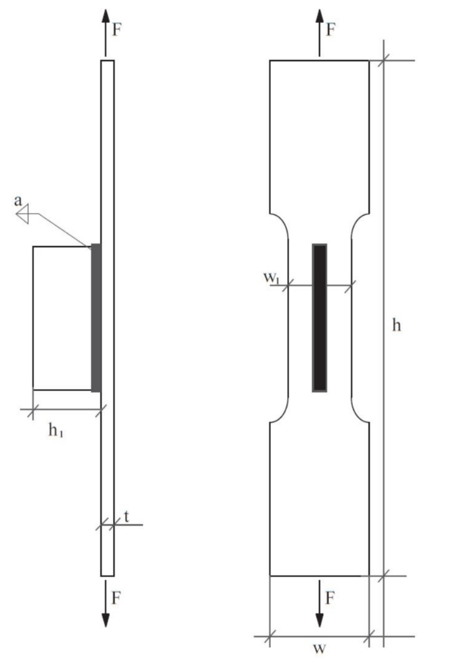
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_{\ddot{U}}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{\ddot{U}}$ = 95%) $\Delta\sigma_C$
m = variable = 1,56	81,7	0,0
m = fix = 3	120,9	13,6
m = fix = 5	**143,5**	**62,0**

Construction detail	Longitudinal non-load carrying attachment		
Literatur	Lihavainen, V.M., Marquis, G. and Statnikov, E.S. (2004) Fatigue Strength of a Longitudinal Attachment Improved by Ultrasonic Impact Treatment. Welding in the World, vol. 48, no. 5–6, pp. 67–73, 2004.		
Material	Denomination	S355J0	
	Plate thickness	5	mm
Mech. properties	$R_{p0,2}$	490-630	MPa
	R_m	355	MPa
Datail category according to EC		FAT 63	
Post-weld treatment	HFMI	UIT	
Fatigue loading	Stress ration	0,27-0,28	[-]
	Type of collective	Constant amplitude	
	Axial/Bending force	Axial	

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	258	256226	1
2	257	393186	1
3	257	247240	1
4	259	205424	1
5	257	254817	1
6			
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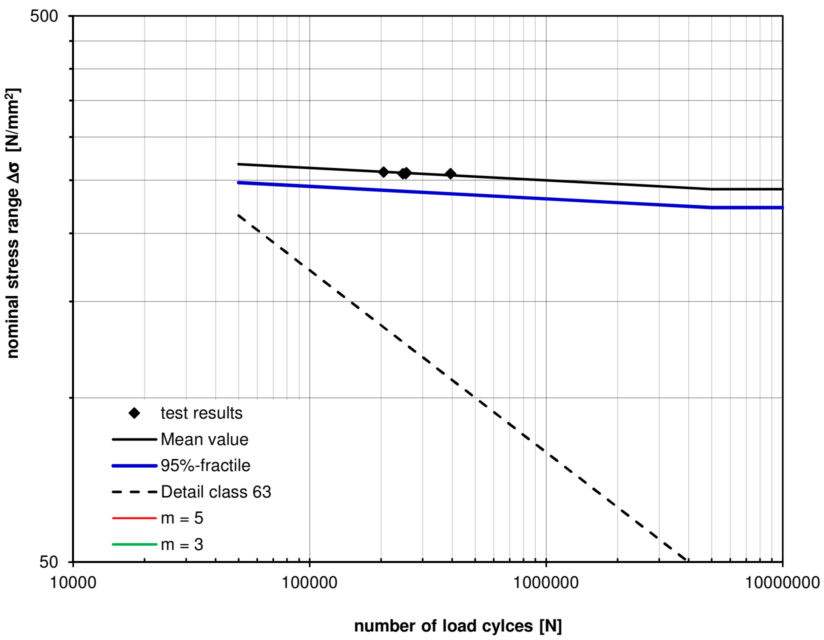
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

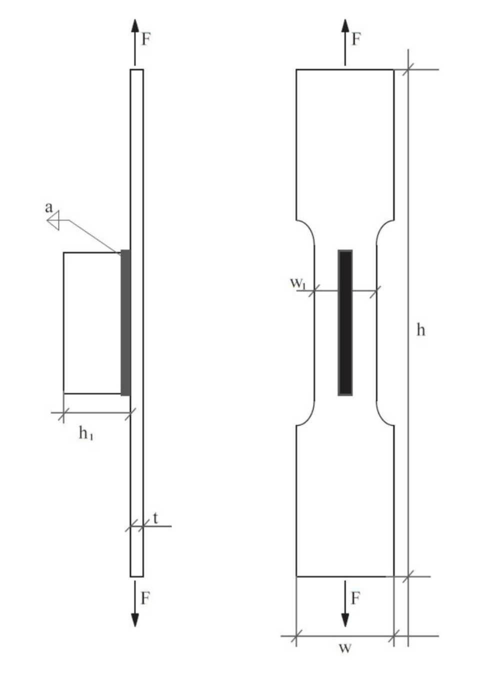
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 43,65	245,9	227,5
m = fix = 3	131,3	0,0
m = fix = 5	**171,9**	**0,1**

Construction detail	Longitudinal non-load carrying attachment	
Literatur	Marquis, G. and Björk, T. (2008) Variable amplitude fatigue strength of improved HSS welds. International Institute of Welding. IIW Document XIII-2224-08, 2008.	
Material	Denomination	S960
	Plate thickness	6 mm
Mech. properties	$R_{p0,2}$	1104 MPa
	R_m	969 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	-1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	600	34923	1
2	570	524316	1
3	466	6002220	1
4	440	1421986	1
5	400	593400	1
6	400	785172	1
7	400	1092356	1
8	400	1300000	1
9	400	600000	1
10	367	4712262	1
11	283	5334812	1
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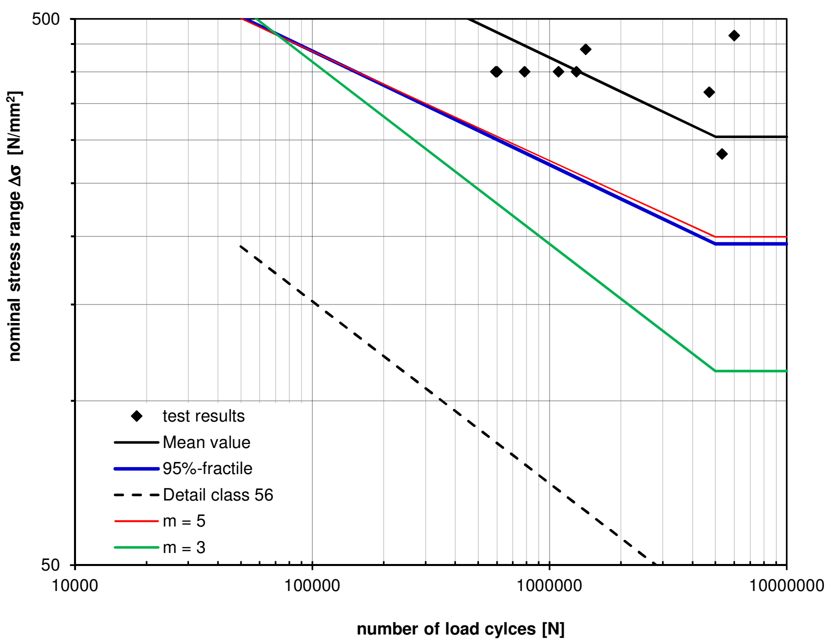
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

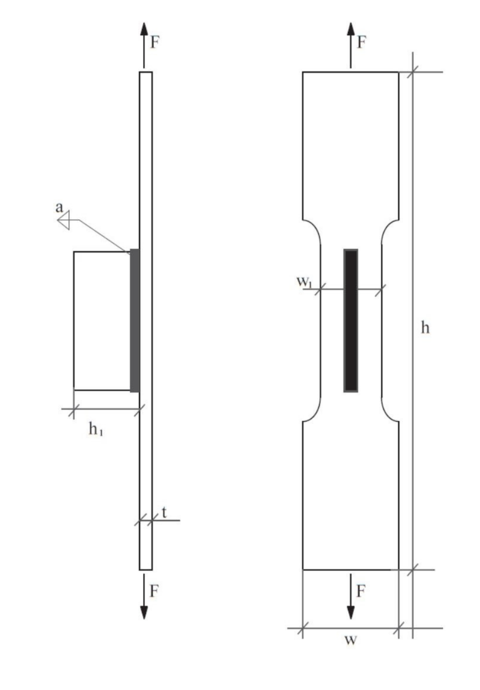
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 4,81	368,0	234,3
m = fix = 3	339,1	153,7
m = fix = 5	**369,9**	**239,6**

Construction detail	Longitudinal non-load carrying attachment	
Literatur	Marquis, G. and Björk, T. (2008) Variable amplitude fatigue strength of improved HSS welds. International Institute of Welding. IIW Document XIII-2224-08, 2008.	
Material	Denomination	Domex 700
	Plate thickness	8 mm
Mech. properties	$R_{p0,2}$	750 MPa
	R_m	700 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	400	43561	1
2	400	21644	1
3	400	23343	1
4	250	906355	1
5	250	400111	1
6			
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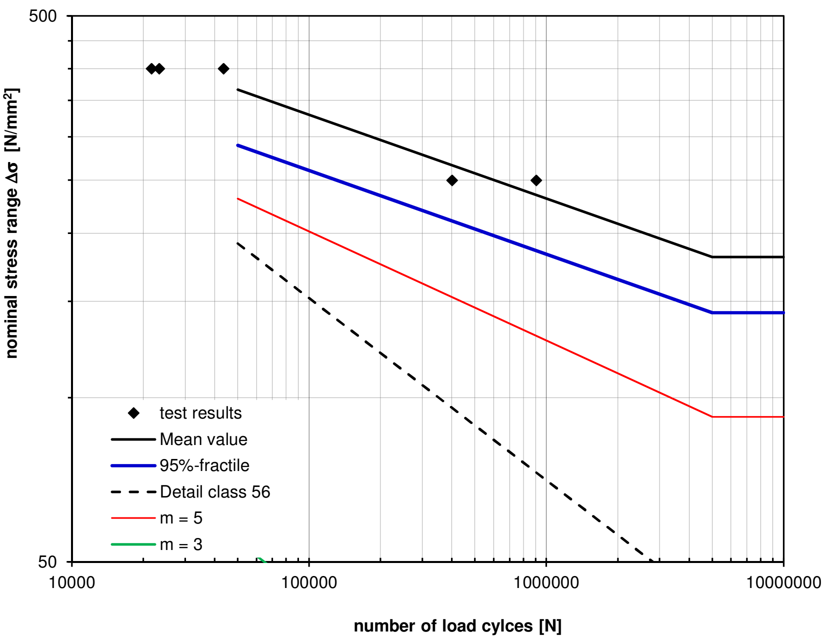
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

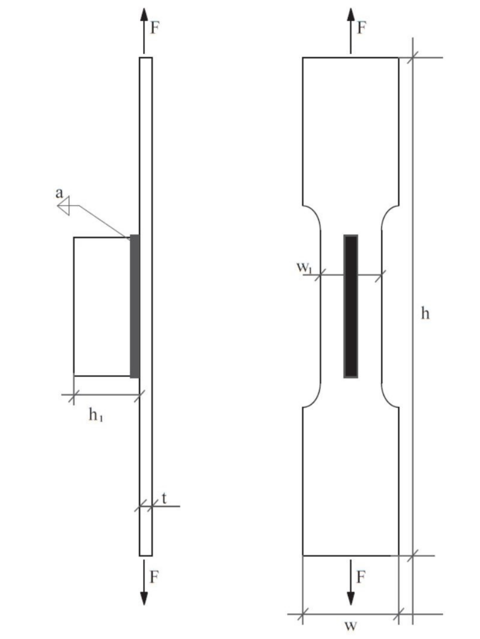


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_ü$ = 95%) $\Delta\sigma_C$
m = variable = 6,53	208,0	164,5
m = fix = 3	120,3	15,9
m = fix = 5	**180,4**	**110,7**

Construction detail	Longitudinal non-load carrying attachment	
Literatur	Marquis, G. and Björk, T. (2008) Variable amplitude fatigue strength of improved HSS welds. International Institute of Welding. IIW Document XIII-2224-08, 2008.	
Material	Denomination	Domex 700
	Plate thickness	8 mm
Mech. properties	$R_{p0,2}$	750 MPa
	R_m	700 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	-1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	307	454407	1
2	297	475387	1
3	398	1997036	1
4	454	508395	1
5	436	213110	1
6	333	975384	1
7	331	871345	1
8	251	2927314	1
9	437	550757	1
10	251	1984437	1
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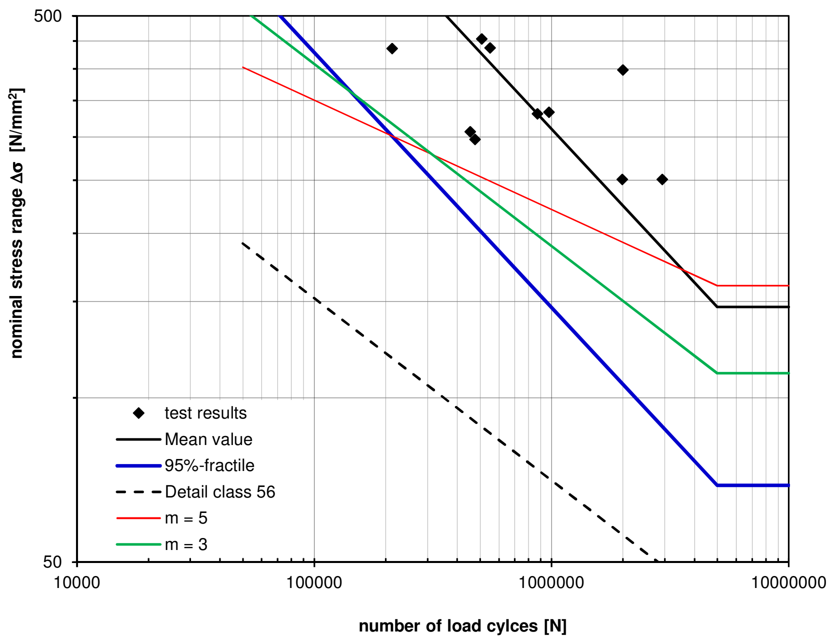
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

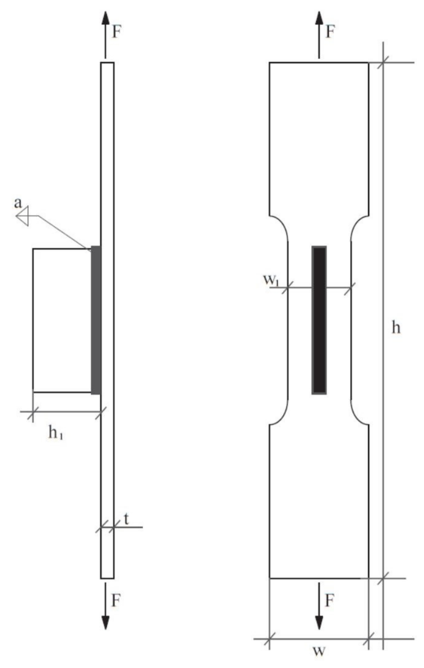


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_{Ü}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{Ü}$ = 95%) $\Delta\sigma_C$
m = variable = 2,14	224,7	106,0
m = fix = 3	253,3	150,4
m = fix = 5	**285,6**	**192,5**

Construction detail	Longitudinal non-load carrying attachment	
Literatur	Mori, T., Shimanuki, H. and Tanaka, M.M. (2012) Effect of UIT on Fatigue Strength of Web-Gusset Welded Joints Considering Service Condition of Steel Structures. Welding in the World, vol. 56, no. 9–10, pp. 141–149, 2012.	
Material	Denomination	SBHS500
	Plate thickness	12 mm
Mech. properties	$R_{p0,2}$	665 MPa
	R_m	575 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	0,5 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	199,8	93132	1
2	199,8	98392	1
3	173,3	195965	1
4	173	247816	1
5	173	256633	1
6	172,2	337765	1
7	130,2	424752	1
8	130,2	703436	1
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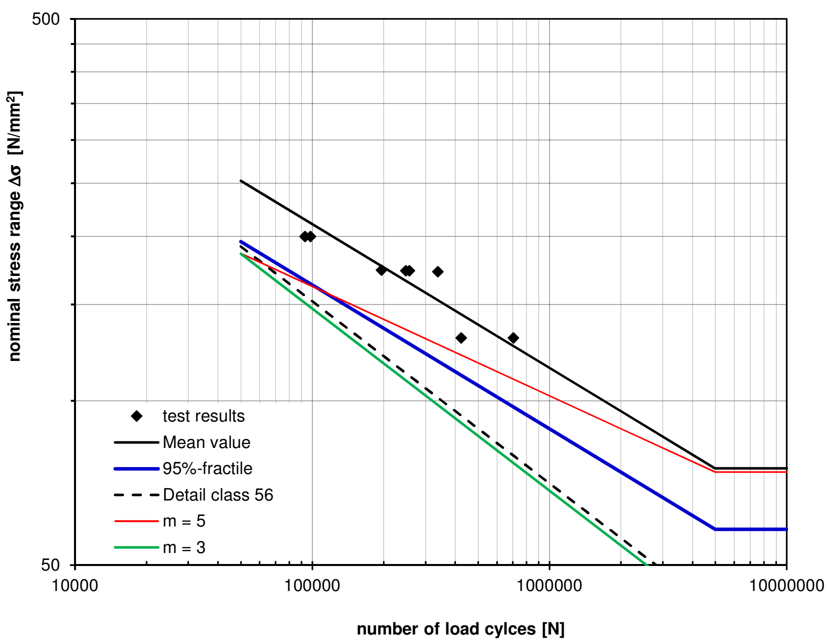
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

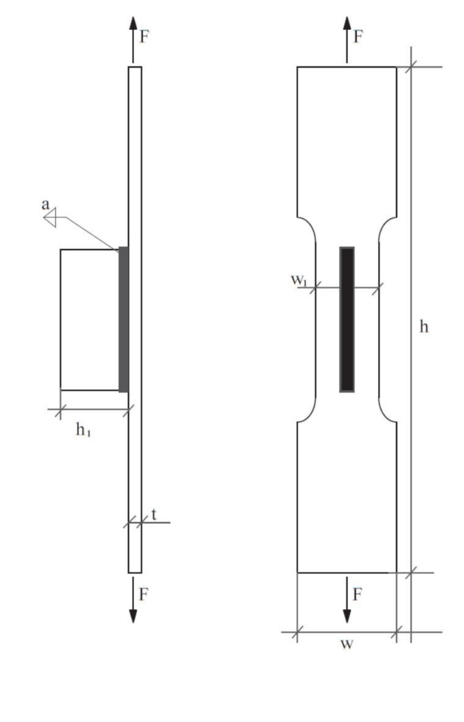


Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_{Ü}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{Ü}$ = 95%) $\Delta\sigma_C$
m = variable = 3,8	95,7	74,0
m = fix = 3	82,5	54,3
m = fix = 5	**109,4**	**88,9**

Construction detail	**Longitudinal non-load carrying attachment**
Reference	Vanrostenberghe, S., Clarin, M., Shin, Y., Droesbeke, B., Van der Mee, V., Doré, M., Marquis, G., Parantainen, J., Kannengiesser, T. and Barsoum, Z. (2015) Improving the fatigue life of high strength steel welded structures by post weld treatments and specific filler material (FATWELDHSS). Final report, Publications Office, Luxembourg, 2015.

Material	Denomination	S700MC
	Plate thickness	5 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	700 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	HFIP C1
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	350	15051	1
2	250	50865	1
3	200	596177	1
4	90	10000000	1
5	70	10000000	0
6	50	10000000	0
7			
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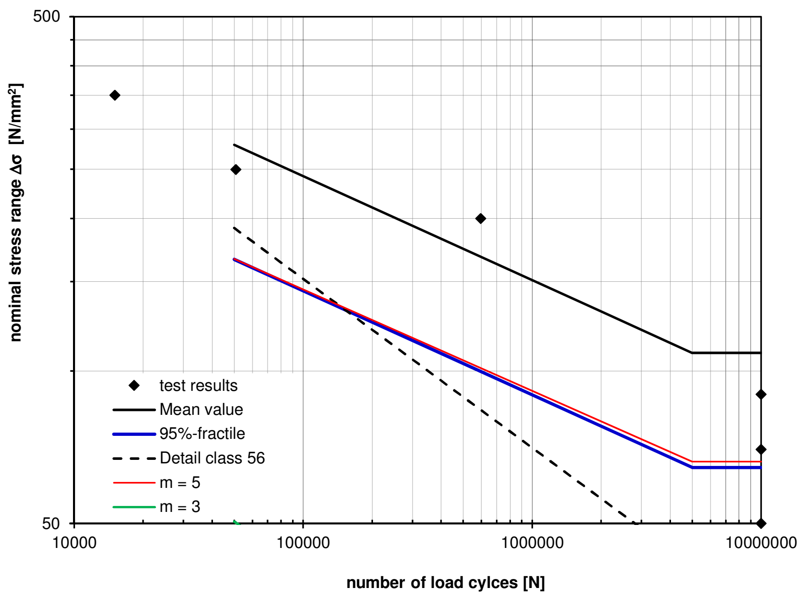
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

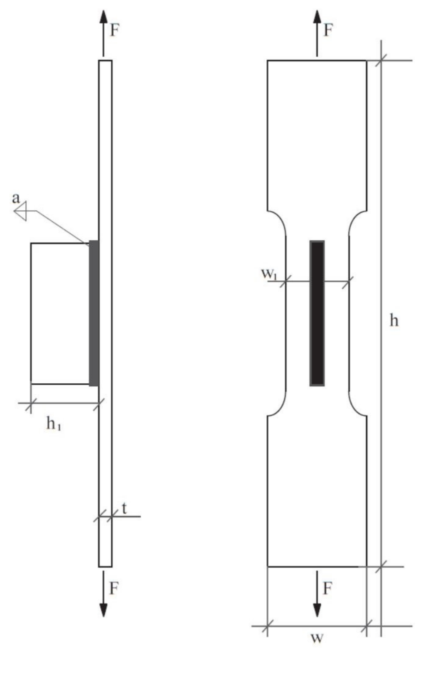
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 4,87	131,0	77,9
m = fix = 3	100,9	14,8
m = fix = 5	**132,5**	**79,6**

Construction detail	**Longitudinal non-load carrying attachment**	
Reference	Vanrostenberghe, S., Clarin, M., Shin, Y., Droesbeke, B., Van der Mee, V., Doré, M., Marquis, G., Parantainen, J., Kannengiesser, T. and Barsoum, Z. (2015) Improving the fatigue life of high strength steel welded structures by post weld treatments and specific filler material (FATWELDHSS). Final report, Publications Office, Luxembourg, 2015.	
Material	Denomination	S700MC
	Plate thickness	5 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	700 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	HFIP C2
Fatigue loading	Stress ration	0,5 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	150	428500	1
2	250	23300	1
3	90	10000000	0
4	200	230000	1
5	250	29100	1
6			
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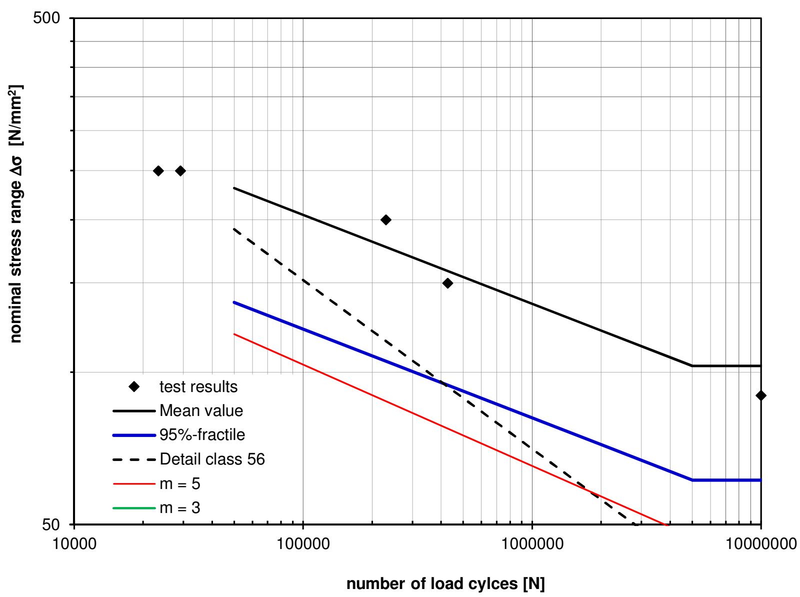
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

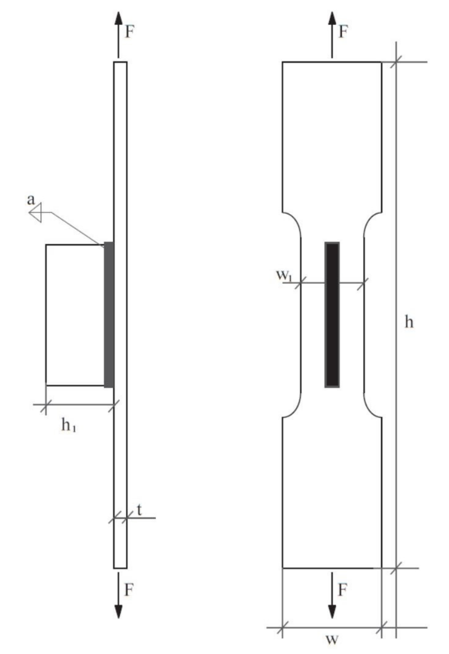
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 5,7	120,8	71,9
m = fix = 3	74,1	5,4
m = fix = 5	**112,0**	**56,9**

Construction detail	Longitudinal non-load carrying attachment	
Reference	Vanrostenberghe, S., Clarin, M., Shin, Y., Droesbeke, B., Van der Mee, V., Doré, M., Marquis, G., Parantainen, J., Kannengiesser, T. and Barsoum, Z. (2015) Improving the fatigue life of high strength steel welded structures by post weld treatments and specific filler material (FATWELDHSS). Final report, Publications Office, Luxembourg, 2015.	
Material	Denomination	S700MC
	Plate thickness	10 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	700 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	PIT vs. UIT / HFIP C1 / HFIP C2 / HFIP
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	400	33600	1
2	270	868600	1
3	90	10000000	0
4	200	10000000	0
5	250	1361300	1
6	350	75100	1
7	300	158200	1
8	150	2031700	1
9	90	10000000	0
10	200	2235000	1
11	250	3547800	1
12	350	101200	1
13	250	855162	1
14	150	6000000	1
15	200	6000000	1
16	350	82506	1
17	225	18010	1
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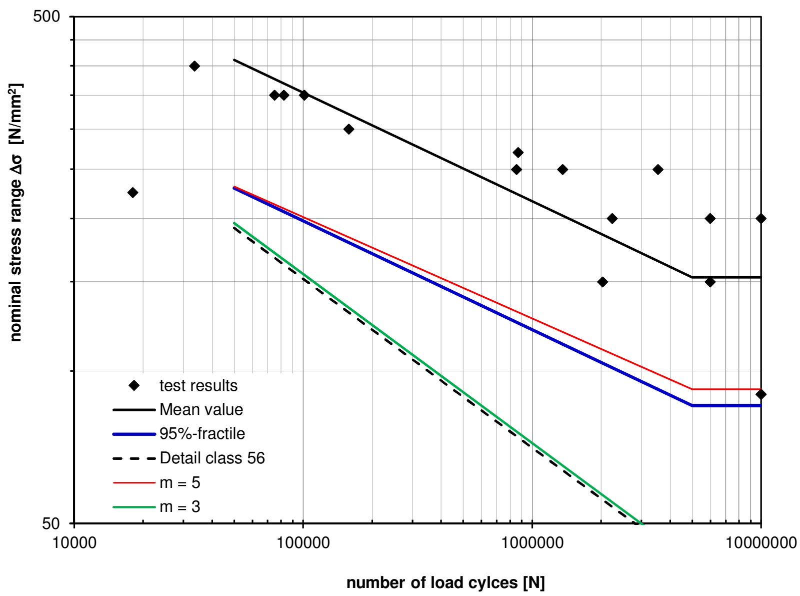
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

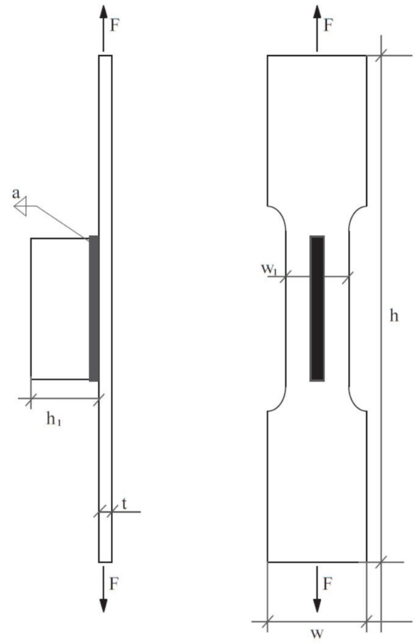
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 4,66	186,3	104,0
m = fix = 3	157,3	57,2
m = fix = 5	**190,2**	**110,6**

Construction detail	Longitudinal non-load carrying attachment	
Reference	Vanrostenberghe, S., Clarin, M., Shin, Y., Droesbeke, B., Van der Mee, V., Doré, M., Marquis, G., Parantainen, J., Kannengiesser, T. and Barsoum, Z. (2015) Improving the fatigue life of high strength steel welded structures by post weld treatments and specific filler material (FATWELDHSS). Final report, Publications Office, Luxembourg, 2015.	
Material	Denomination	S700MC
	Plate thickness	10 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	700 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	HFIP C1 / HFIP C2
Fatigue loading	Stress ration	0,5 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	250	33391	1
2	200	84895	1
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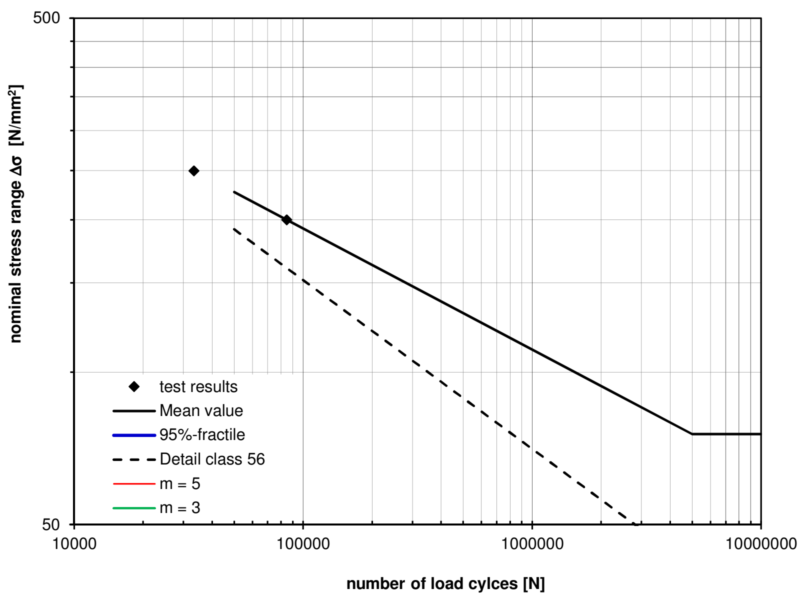
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

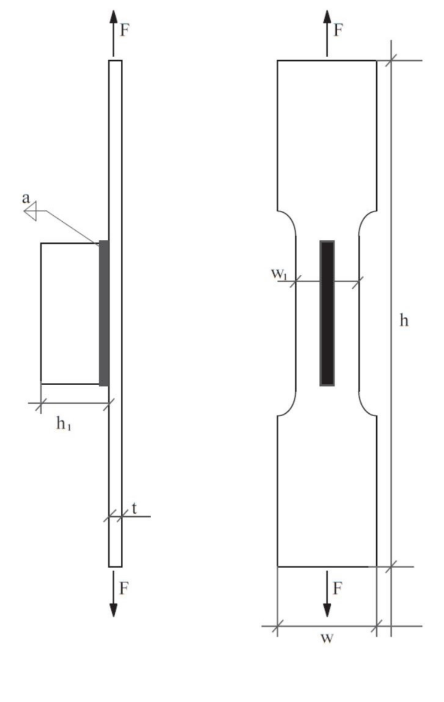


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 4,18	94,0	#DIV/0!
m = fix = 3	66,8	#DIV/0!
m = fix = 5	**108,3**	**#DIV/0!**

Construction detail	Longitudinal non-load carrying attachment	
Reference	Vanrostenberghe, S., Clarin, M., Shin, Y., Droesbeke, B., Van der Mee, V., Doré, M., Marquis, G., Parantainen, J., Kannengiesser, T. and Barsoum, Z. (2015) Improving the fatigue life of high strength steel welded structures by post weld treatments and specific filler material (FATWELDHSS). Final report, Publications Office, Luxembourg, 2015.	
Material	Denomination	S690QL
	Plate thickness	10 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	690 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	HFIP C1 / HFIP C2 / HFIP C3
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	400	98500	1
2	350	187828	1
3	350	223100	1
4	350	134300	1
5	275	141700	1
6	250	317200	1
7	250	179511	1
8	225	10000000	0
9	200	350000	1
10	200	10000000	0
11	200	299234	1
12	175	10000000	0
13	150	532122	1
14	90	6000000	1
15	90	10000000	0
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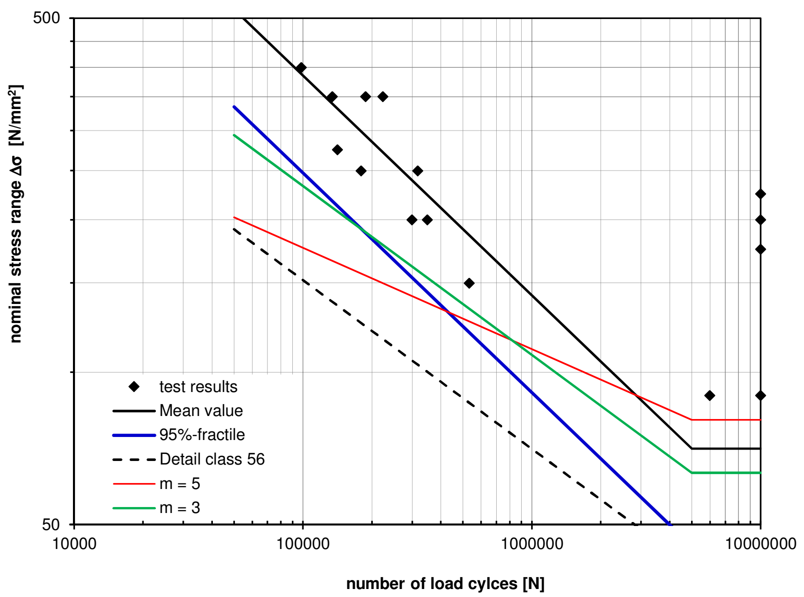
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

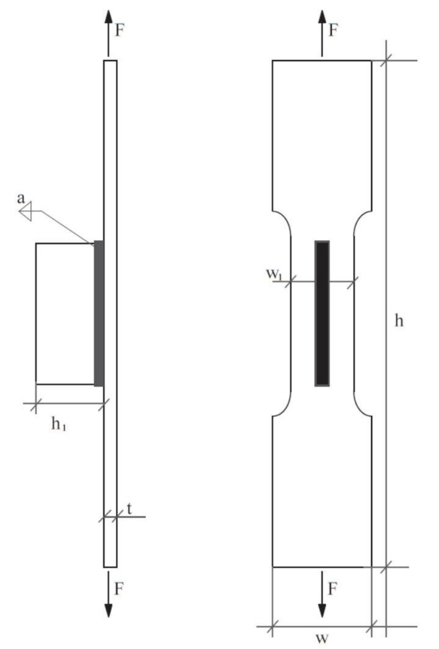
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 2,31	105,1	67,5
m = fix = 3	127,4	85,9
m = fix = 5	**164,4**	**96,7**

Construction detail	**Longitudinal non-load carrying attachment**	
Reference	Vanrostenberghe, S., Clarin, M., Shin, Y., Droesbeke, B., Van der Mee, V., Doré, M., Marquis, G., Parantainen, J., Kannengiesser, T. and Barsoum, Z. (2015) Improving the fatigue life of high strength steel welded structures by post weld treatments and specific filler material (FATWELDHSS). Final report, Publications Office, Luxembourg, 2015.	
Material	Denomination	S690QL
	Plate thickness	20 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	690 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	HFIP C2 / HFIP C3 / HFIP C4
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	275	141700	1
2	400	184642	1
3	350	480227	1
4	350	80830	1
5	350	123655	1
6	300	470640	1
7	275	5068136	1
8	250	4267720	1
9	250	232323	1
10	250	10000000	0
11	225	2411800	1
12	200	480200	1
13	200	2241008	1
14	150	10000000	0
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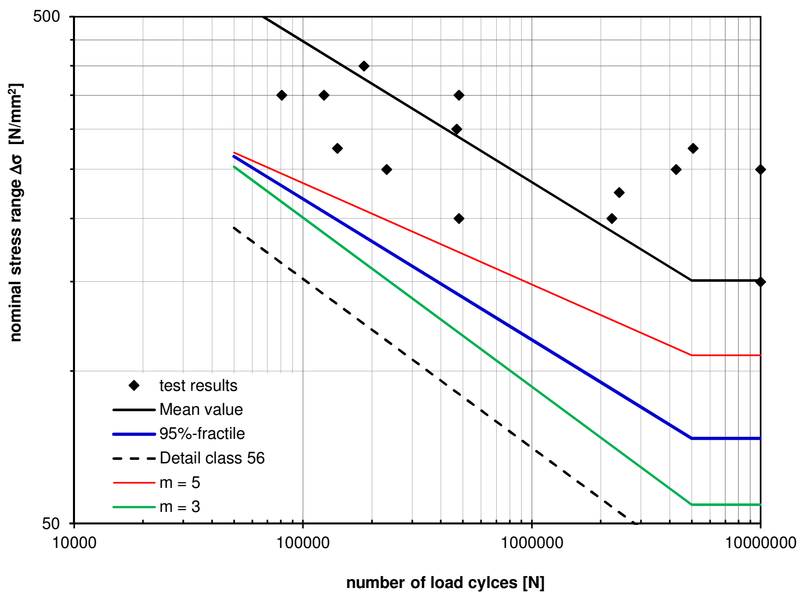
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

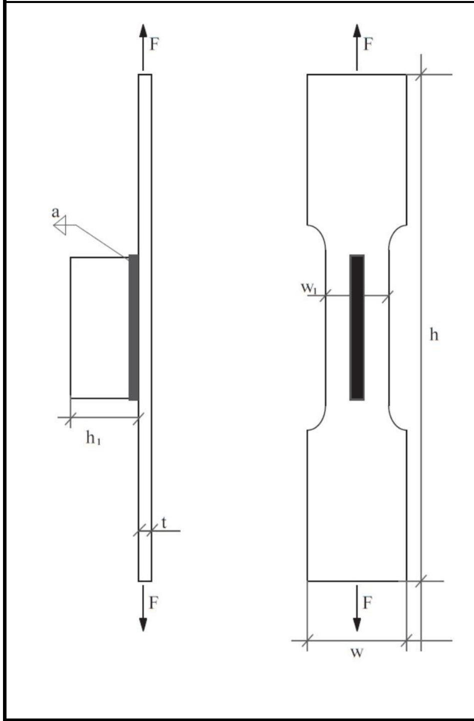
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 3,6	194,6	95,0
m = fix = 3	181,2	73,9
m = fix = 5	**215,2**	**129,0**

Construction detail	**Longitudinal non-load carrying attachment**	
Reference	Vanrostenberghe, S., Clarin, M., Shin, Y., Droesbeke, B., Van der Mee, V., Doré, M., Marquis, G., Parantainen, J., Kannengiesser, T. and Barsoum, Z. (2015) Improving the fatigue life of high strength steel welded structures by post weld treatments and specific filler material (FATWELDHSS). Final report, Publications Office, Luxembourg, 2015.	
Material	Denomination	S690QL
	Plate thickness	20 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	690 MPa
Detail category according to EC		FAT 56
Post-weld treatment	HFMI	HFIP C2 / HFIP C3 / HFIP C4
Fatigue loading	Stress ration	0,5 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	200	343210	1
2	125	1019256	1
3	150	644530	1
4	275	56926	1
5			
6			
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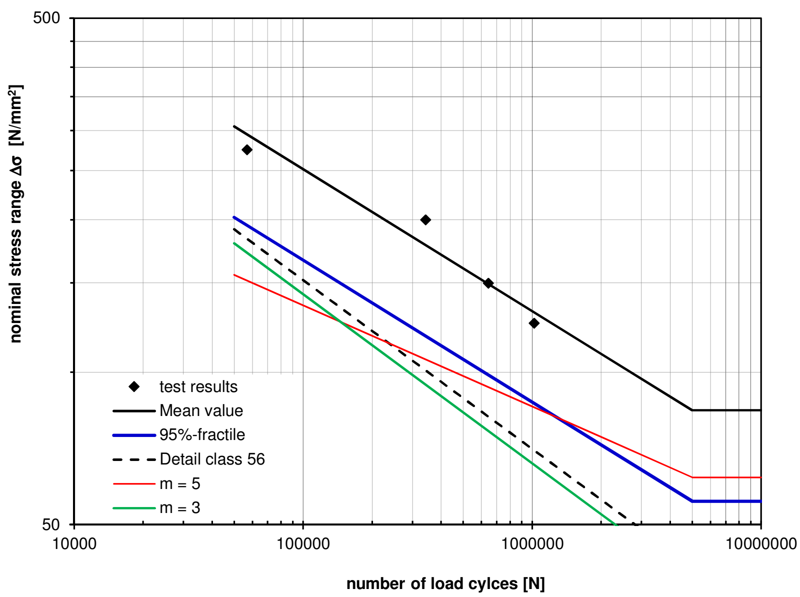
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

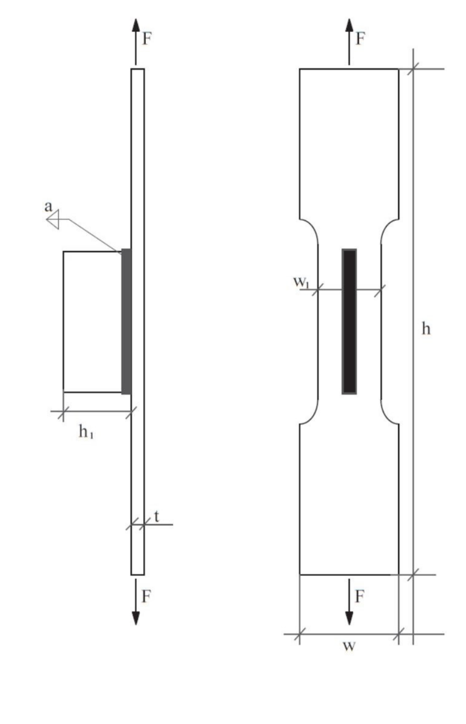


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 3,57	108,8	71,9
m = fix = 3	98,9	52,5
m = fix = 5	**125,5**	**74,5**

Construction detail	Longitudinal non-load carrying attachment	
Reference	Vanrostenberghe, S., Clarin, M., Shin, Y., Droesbeke, B., Van der Mee, V., Doré, M., Marquis, G., Parantainen, J., Kannengiesser, T. and Barsoum, Z. (2015) Improving the fatigue life of high strength steel welded structures by post weld treatments and specific filler material (FATWELDHSS). Final report, Publications Office, Luxembourg, 2015.	
Material	Denomination	S960MC
	Plate thickness	5 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	960 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	HFIP C1 / HFIP C3 / HFIP C4
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	350	56434	1
2	350	110774	1
3	350	54826	1
4	300	251361	1
5	300	544018	1
6	250	247082	1
7	250	928997	1
8	250	654488	1
9	250	170197	1
10	200	542295	1
11	200	10000000	0
12	150	3025780	1
13	150	10000000	0
14	90	10000000	0
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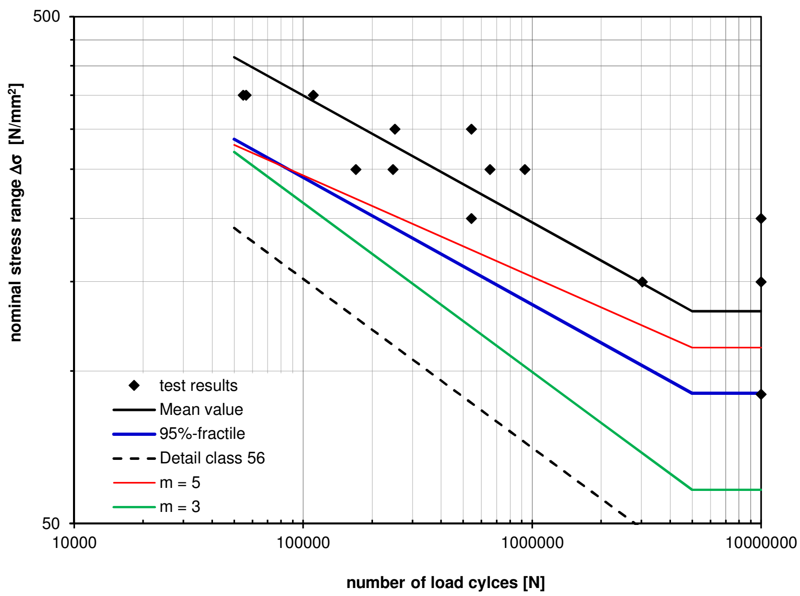
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

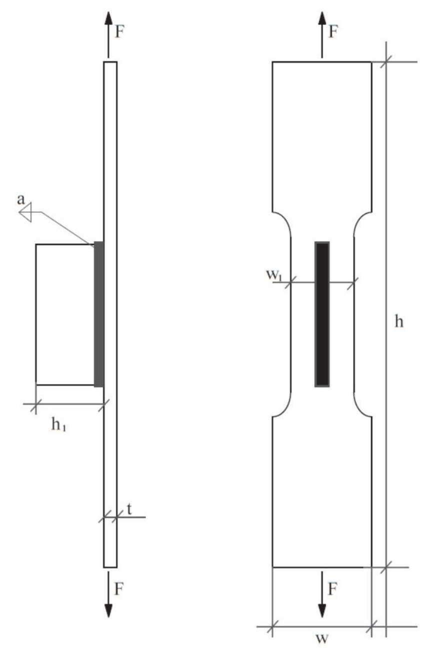


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 3,99	165,1	113,7
m = fix = 3	141,2	79,1
m = fix = 5	**181,7**	**133,6**

Construction detail	Longitudinal non-load carrying attachment	
Reference	Vanrostenberghe, S., Clarin, M., Shin, Y., Droesbeke, B., Van der Mee, V., Doré, M., Marquis, G., Parantainen, J., Kannengiesser, T. and Barsoum, Z. (2015) Improving the fatigue life of high strength steel welded structures by post weld treatments and specific filler material (FATWELDHSS). Final report, Publications Office, Luxembourg, 2015.	
Material	Denomination	S960MC
	Plate thickness	5 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	960 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	HFIP C1 / HFIP C2
Fatigue loading	Stress ration	0,5 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	350	19300	1
2	300	29200	1
3	300	27733	1
4	250	71500	1
5	200	167000	1
6	150	1320700	1
7	125	1293200	1
8	90	1585900	1
9	90	10000000	0
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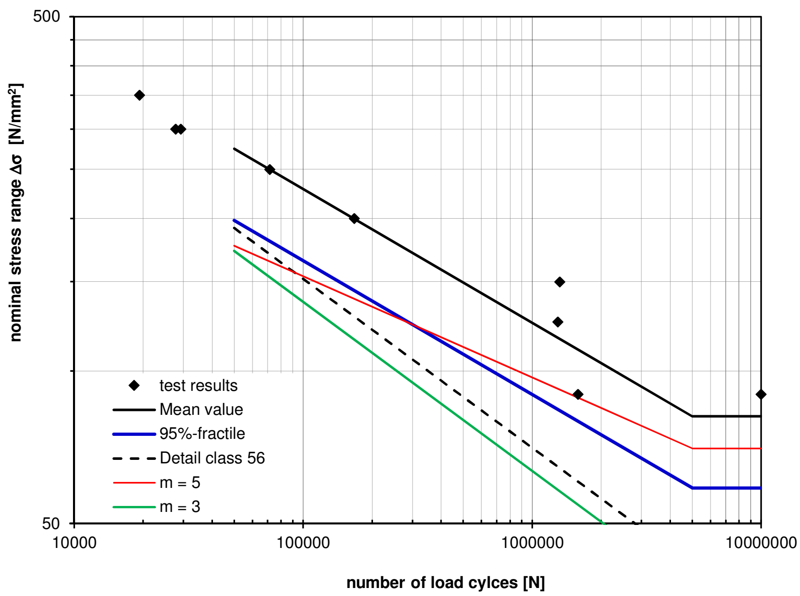
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

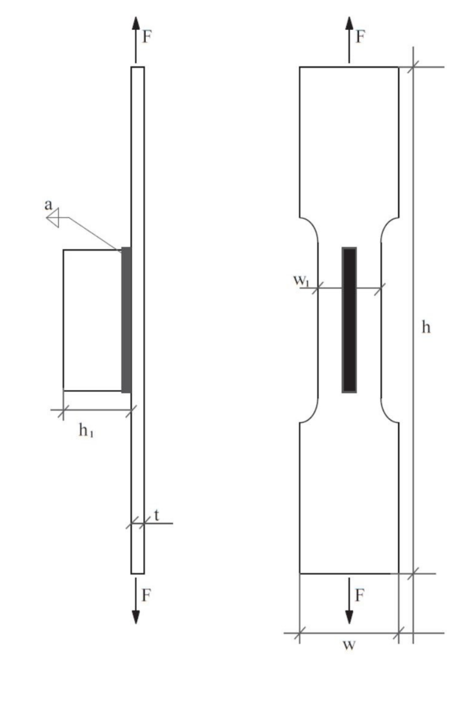
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 3,79	103,7	74,9
m = fix = 3	87,2	50,5
m = fix = 5	**121,7**	**84,5**

Construction detail	**Longitudinal non-load carrying attachment**	
Reference	Vanrostenberghe, S., Clarin, M., Shin, Y., Droesbeke, B., Van der Mee, V., Doré, M., Marquis, G., Parantainen, J., Kannengiesser, T. and Barsoum, Z. (2015) Improving the fatigue life of high strength steel welded structures by post weld treatments and specific filler material (FATWELDHSS). Final report, Publications Office, Luxembourg, 2015.	
Material	Denomination	S960QL
	Plate thickness	10 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	960 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	HFIP C4
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	400	59100	1
2	350	115200	1
3	250	355400	1
4	225	537500	1
5	200	6540000	1
6	90	10000000	1
7			
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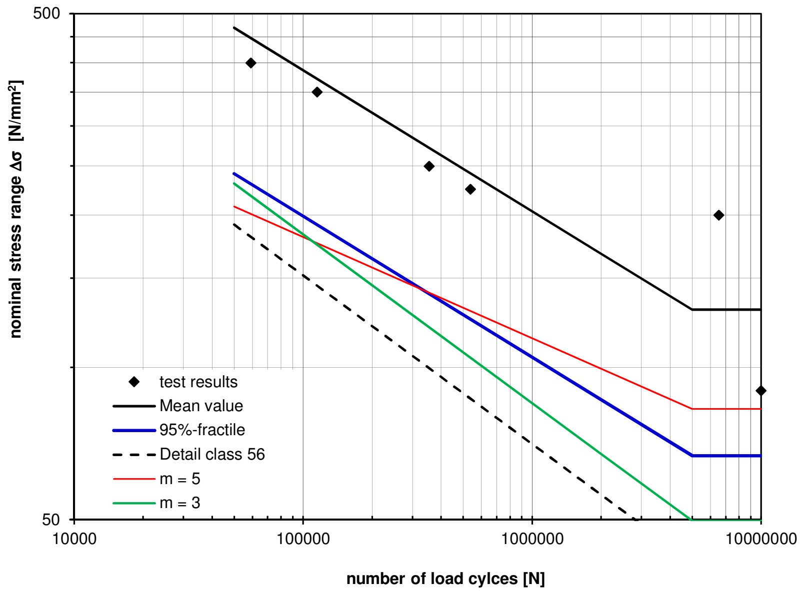
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

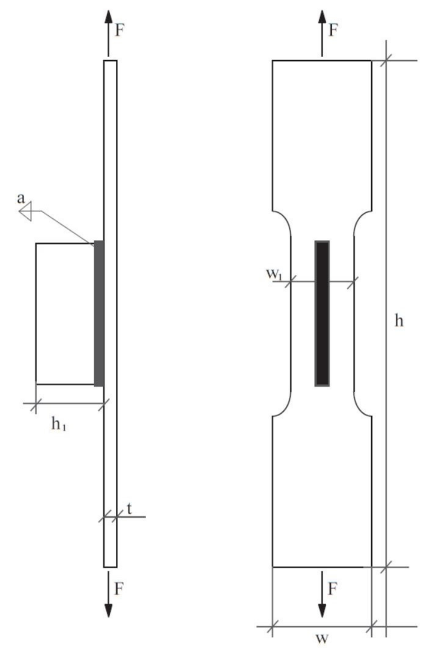
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_{\ddot{U}}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{\ddot{U}}$ = 95%) $\Delta\sigma_C$
m = variable = 3,59	167,9	86,4
m = fix = 3	158,0	67,5
m = fix = 5	**183,1**	**99,5**

Construction detail	Longitudinal non-load carrying attachment	
Reference	Vanrostenberghe, S., Clarin, M., Shin, Y., Droesbeke, B., Van der Mee, V., Doré, M., Marquis, G., Parantainen, J., Kannengiesser, T. and Barsoum, Z. (2015) Improving the fatigue life of high strength steel welded structures by post weld treatments and specific filler material (FATWELDHSS). Final report, Publications Office, Luxembourg, 2015.	
Material	Denomination	S960QL
	Plate thickness	10 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	960 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	HFIP C1 / HFIP C2
Fatigue loading	Stress ration	0,5 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	350	42233	1
2	350	28527	1
3	250	133605	1
4	250	126225	1
5	200	258601	1
6	200	272791	1
7	150	585456	1
8	150	863000	1
9	125	2667460	1
10	90	10000000	0
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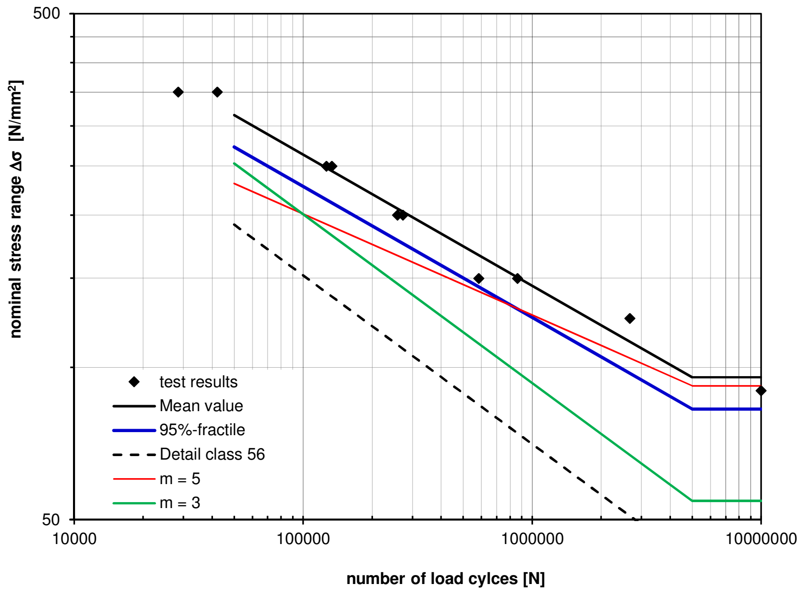
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

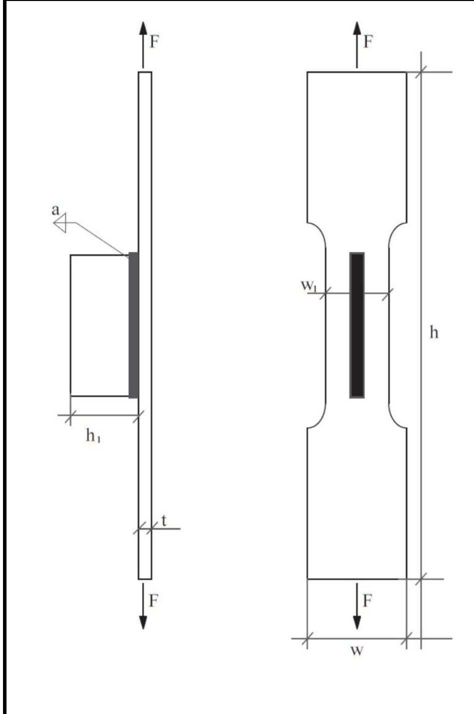


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 3,86	121,2	104,9
m = fix = 3	103,3	74,0
m = fix = 5	**137,7**	**110,5**

Construction detail	Longitudinal non-load carrying attachment	
Reference	Vanrostenberghe, S., Clarin, M., Shin, Y., Droesbeke, B., Van der Mee, V., Doré, M., Marquis, G., Parantainen, J., Kannengiesser, T. and Barsoum, Z. (2015) Improving the fatigue life of high strength steel welded structures by post weld treatments and specific filler material (FATWELDHSS). Final report, Publications Office, Luxembourg, 2015.	
Material	Denomination	S960QL
	Plate thickness	15 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	960 MPa
Datail category according to EC		FAT 56
Post-weld treatment	HFMI	HFIP C1 / HFIP C2
Fatigue loading	Stress ration	0,5 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	350	28287	1
2	350	29129	1
3	300	44361	1
4	300	62521	1
5	250	91133	1
6	250	87883	1
7	200	362809	1
8	200	218365	1
9	175	10000000	0
10	175	7399780	1
11	150	10000000	0
12	150	10000000	0
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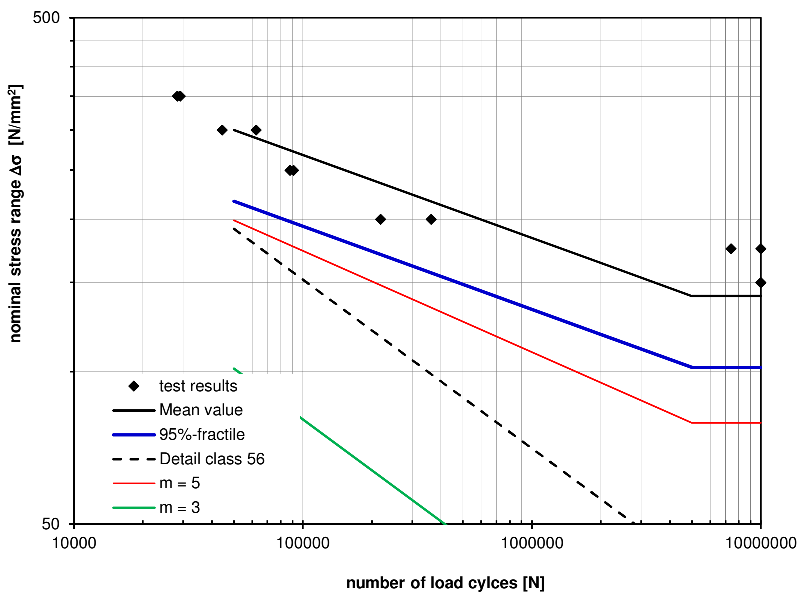
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

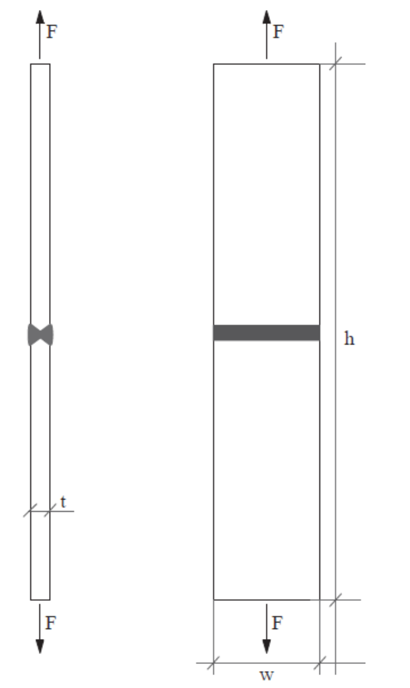


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_{Ü}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{Ü}$ = 95%) $\Delta\sigma_C$
m = variable = 6,1	164,0	118,5
m = fix = 3	103,2	29,6
m = fix = 5	**148,6**	**95,2**

Construction detail	Butt welded joint attachment	
Reference	Leitner, M., Stoschka, M. and Eichlseder, W. (2014) Fatigue enhancement of thin-walled, high-strength steel joints by high-frequency mechanical impact treatment - Welding in the World, vol. 58, no. 1, pp. 29–39, Jan. 2014.	
Material	Denomination	S355
	Plate thickness	5 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	355 MPa
Datail category according to EC		FAT 90
Post-weld treatment	HFMI	-
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	403,5	69406,1	1
2	357,2	151145,8	1
3	339,2	156038,6	1
4	324,1	149096,1	1
5	328,4	162562,9	1
6	276,9	342912,6	1
7	303,2	363813,8	1
8	303,2	402128,0	1
9	277,1	558058,0	1
10	254,1	981244,8	1
11	280,1	1155938,8	1
12	254,2	1425142,6	1
13	225,0	50000000,0	0
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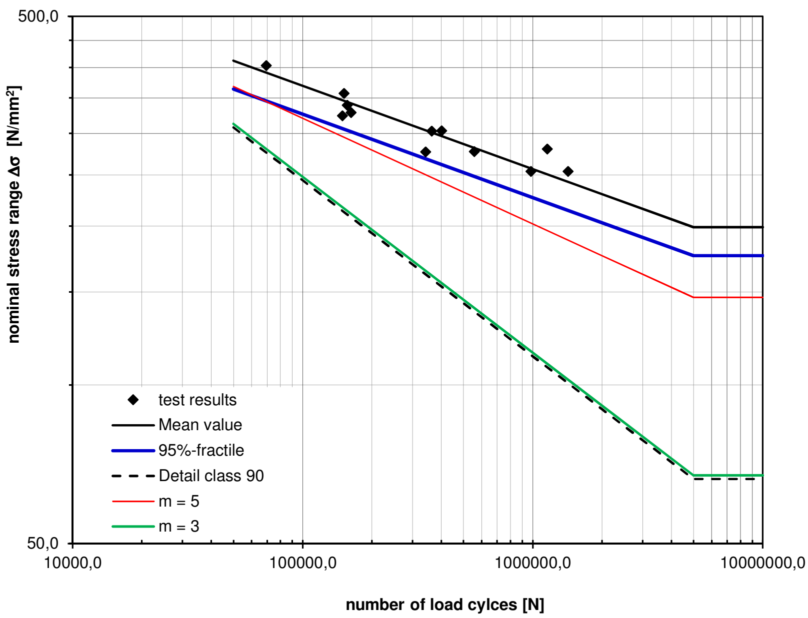
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

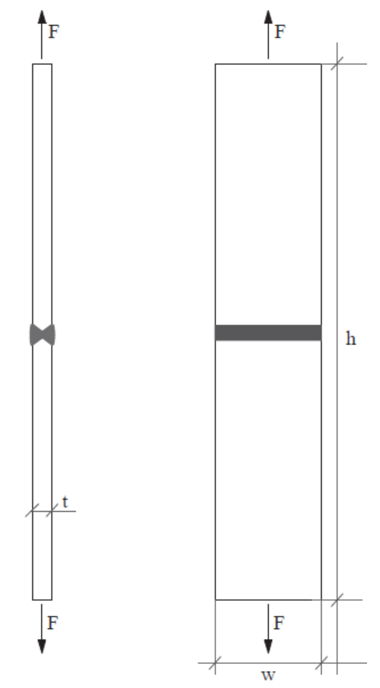


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	mean S-N curve ($P_{Ü}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{Ü}$ = 95%) $\Delta\sigma_C$
m = variable = 6,33	230,1	203,2
m = fix = 3	168,0	91,5
m = fix = 5	**213,4**	**176,0**

Construction detail	Butt welded joint attachment
Reference	Leitner, M., Stoschka, M. and Eichlseder, W. (2014) Fatigue enhancement of thin-walled, high-strength steel joints by high-frequency mechanical impact treatment - Welding in the World, vol. 58, no. 1, pp. 29–39, Jan. 2014.
Material	Denomination S690 Plate thickness 5 mm
Mech. properties	$R_{p0,2}$ - MPa R_m 690 MPa
Datail category according to EC	FAT 90
Post-weld treatment	HFMI -
Fatigue loading	Stress ration 0,1 [-] Type of collective Constant amplitude Axial/Bending force Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	600,0	34108,0	1
2	500,0	69884,0	1
3	500,0	88929,0	1
4	400,0	277182,0	1
5	400,0	209163,0	1
6	350,0	385506,0	1
7	350,0	232637,0	1
8	300,0	448500,0	1
9	300,0	606954,0	1
10	300,0	513201,0	1
11	275,0	50000000,0	0
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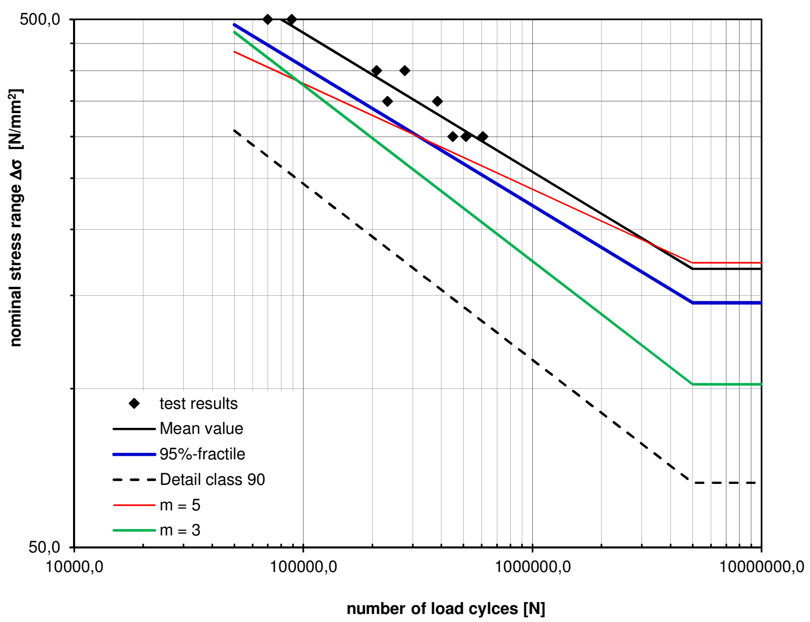
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

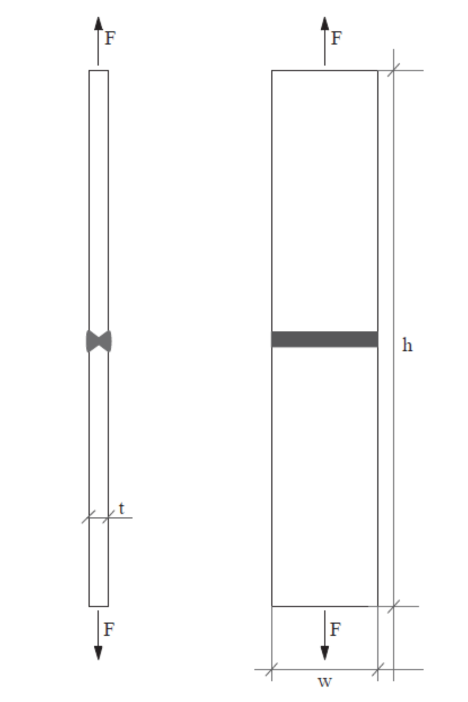


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	mean S-N curve ($P_{Ü}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{Ü}$ = 95%) $\Delta\sigma_C$
m = variable = 3,8	214,5	185,0
m = fix = 3	183,0	138,3
m = fix = 5	**247,5**	**207,8**

Construction detail	Butt welded joint attachment	
Reference	Leitner, M., Stoschka, M. and Eichlseder, W. (2014) Fatigue enhancement of thin-walled, high-strength steel joints by high-frequency mechanical impact treatment - Welding in the World, vol. 58, no. 1, pp. 29–39, Jan. 2014.	
Material	Denomination	S960
	Plate thickness	5 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	- MPa
Datail category according to EC		FAT 90
Post-weld treatment	HFMI	-
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	600,0	51391,0	1
2	500,0	126047,0	1
3	500,0	114960,0	1
4	400,0	396154,0	1
5	400,0	290788,0	1
6	350,0	951175,0	1
7	325,0	17888401,0	0
8	300,0	50000000,0	0
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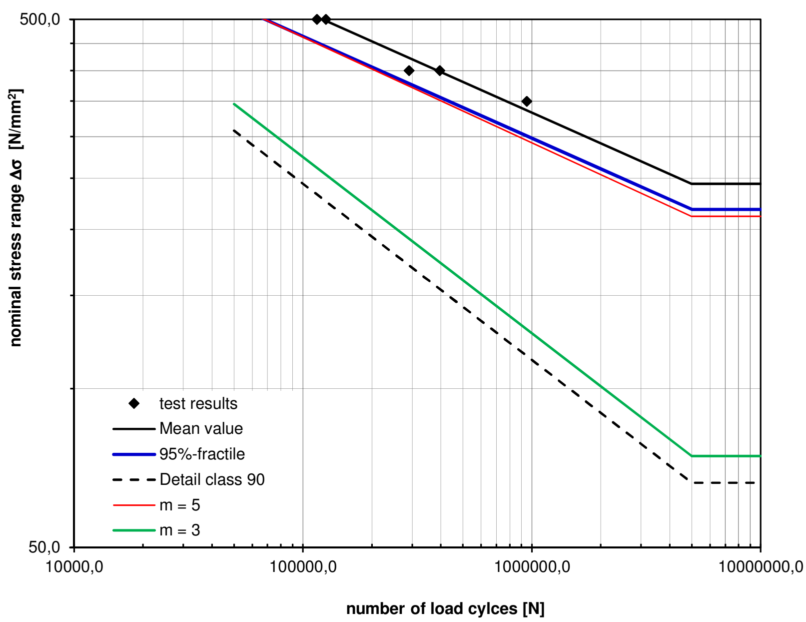
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

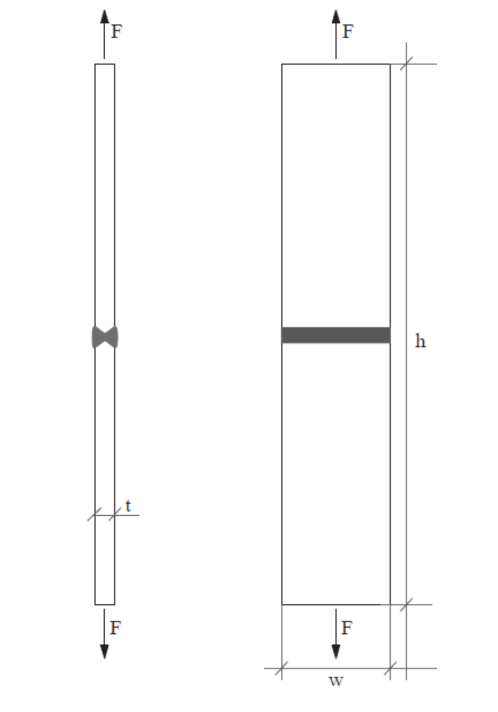


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 5,18	291,4	260,7
m = fix = 3	212,1	101,1
m = fix = 5	**286,8**	**254,4**

Construction detail	Butt welded joint attachment		
Reference	Ummenhofer, T., Herion, S., Puthli, R. and Weidner, P. (2011) Effects of Post Weld Treatment and Loading Condition on the Fatigue Life of Ultra High Strength Steels. International Offshore and Polar Engineering Conference Maui, Hawaii, June, 2011, pp.269-275.		
Material	Denomination	DOMEX960	
	Plate thickness	6	mm
Mech. properties	$R_{p0,2}$	-	MPa
	R_m	960	MPa
Datail category according to EC		FAT 80	
Post-weld treatment	HFMI	HiFIT	
Fatigue loading	Stress ration	0,1	[-]
	Type of collective	Constant amplitude	
	Axial/Bending force	Bending	

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	927,3	15771	1
2	885,0	16154	1
3	897,3	22986	1
4	749,6	51445	1
5	811,3	57096	1
6	627,5	178219	1
7	543,0	311105	1
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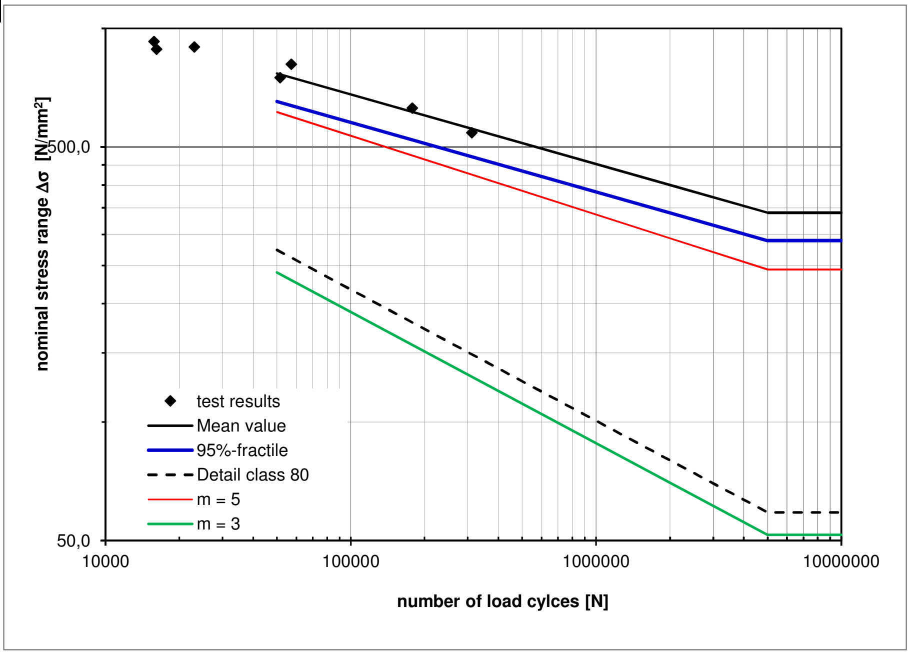
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

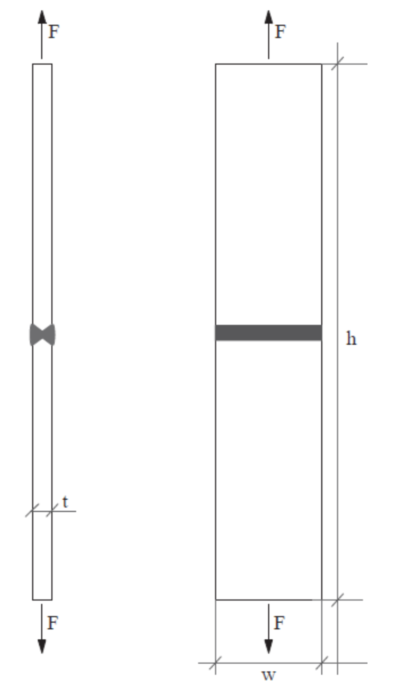


Statistical evaluation of test data according to EN 1993-1-9:2005

slope	mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 5,66	400,2	339,9
m = fix = 3	225,7	70,2
m = fix = 5	**367,6**	**293,2**

Construction detail	Butt welded joint attachment	
Reference	Abdullah, A., Malaki, M. And Eskandari, A. (2012) Strength enhancement of the welded structures by ultrasonic peening. Materials & Design, vol. 38, pp. 7–18, Jun. 2012.	
Material	Denomination	Steel304
	Plate thickness	5 mm
Mech. properties	$R_{p0,2}$	515 MPa
	R_m	349 MPa
Datail category according to EC		FAT 80 (*)
Post-weld treatment	HFMI	UPT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	300,0	329753	1
2	300,0	177903	1
3	316,0	228433	1
4	316,0	238235	1
5	330,0	106782	1
6	330,0	118691	1
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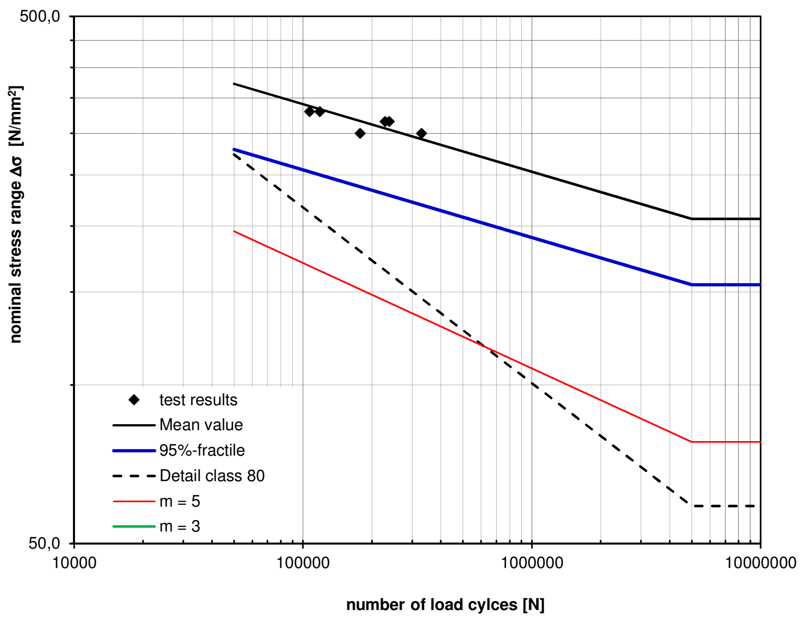
Comments: (*) The value has been assumed by the authors

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

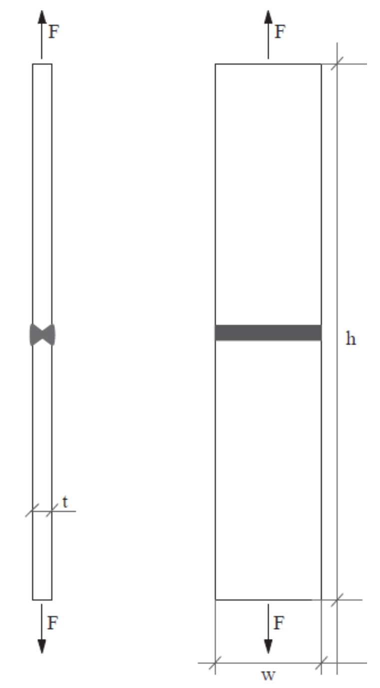


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 7,8	232,3	174,2
m = fix = 3	142,6	14,2
m = fix = 5	**195,8**	**93,6**

Construction detail	Butt welded joint attachment	
Reference	Li, C.R., Cao, Z.P. and Fang, Z.T. (2014) Research on Methods of Improving Fatigue Property of Low-Strength Steel Welded Joints. Applied Mechanics and Materials, vol. 538, pp. 48–53, Apr. 2014.	
Material	Denomination	Q235B
	Plate thickness	5 mm
Mech. properties	$R_{p0,2}$	430 MPa
	R_m	272 MPa
Datail category according to EC		FAT 80 (*)
Post-weld treatment	HFMI	UPT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	225,0	3996000	1
2	230,0	3210000	1
3	234,0	1848000	1
4	239,0	1836000	1
5	239,0	1199000	1
6	243,0	910000	1
7	243,0	848000	1
8	243,0	789000	1
9	243,0	533000	1
10	243,0	448000	1
11	243,0	483000	1
12	252,0	483000	1
13	261,0	278000	1
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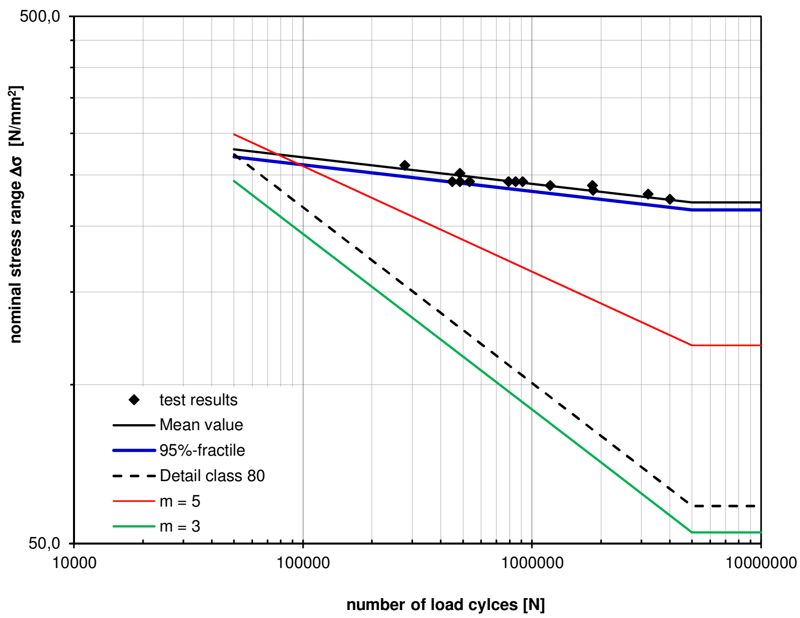
Comments: (*) The value has been assumed by the authors

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

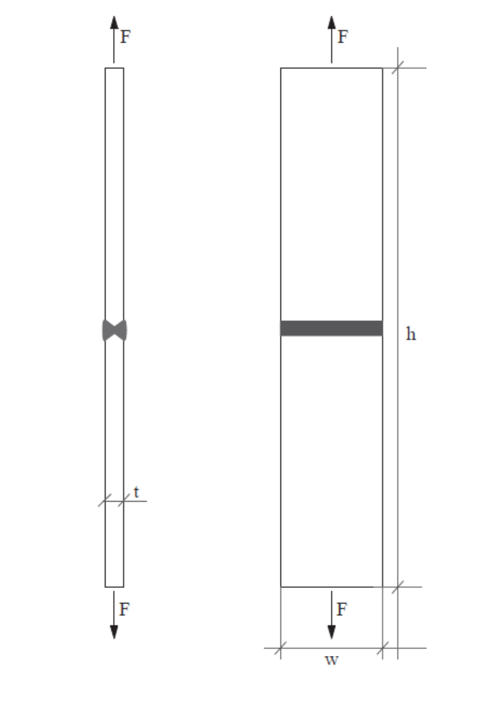
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 19,82	232,3	224,6
m = fix = 3	188,0	71,2
m = fix = 5	**207,7**	**142,7**

Construction detail	**Butt welded joint attachment**	
Reference	Ummenhofer, T., Weich, I.I., and .Nitschke-Pagel, T. (2006) Extension of Life Time of Welded Fatigue Loaded Structures. International Offshore and Polar Engineering Conference San Francisco, California, USA, June, 2006, pp.98-105.	
Material	Denomination	S355J2G3
	Plate thickness	8 mm
Mech. properties	$R_{p0,2}$	555 MPa
	R_m	407 MPa
Datail category according to EC		FAT 80 (*)
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	244,0	292536	1
2	244,0	35714	1
3	244,0	500753	1
4	244,0	1365375	1
5	326,0	49437	1
6	326,0	86965	1
7	326,0	115992	1
8	326,0	122285	1
9	326,0	326668	1
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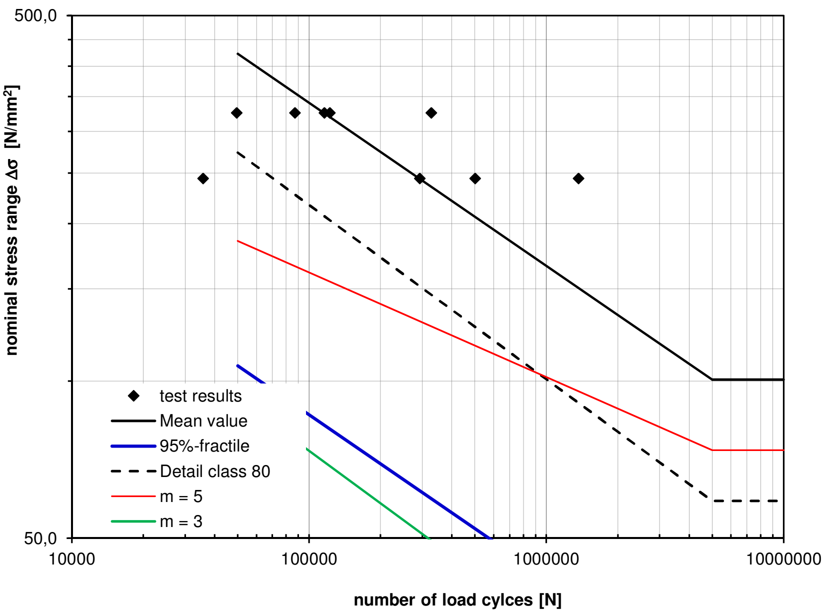
Comments: (*) The value has been assumed by the authors

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

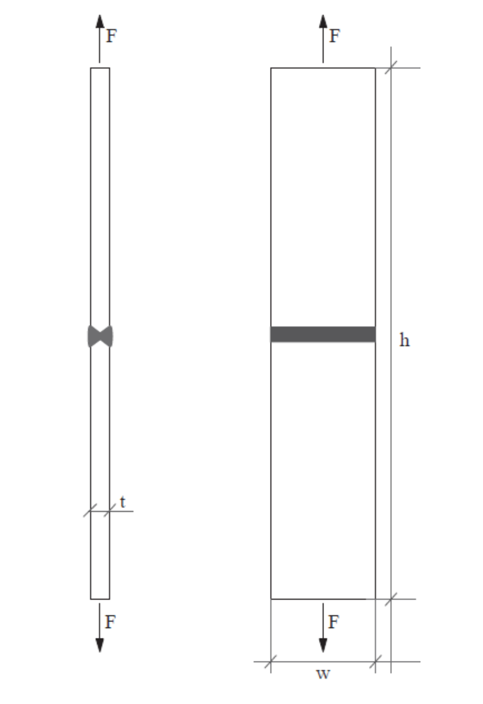


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	mean S-N curve ($P_{\ddot{U}}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{\ddot{U}}$ = 95%) $\Delta\sigma_C$
m = variable = 3,21	133,7	33,8
m = fix = 3	126,9	27,0
m = fix = 5	**175,8**	**88,6**

Construction detail	Butt welded joint attachment	
Reference	Ummenhofer, T., Weich, I.I., and .Nitschke-Pagel, T. (2006) Extension of Life Time of Welded Fatigue Loaded Structures. International Offshore and Polar Engineering Conference San Francisco, California, USA, June, 2006, pp.98-105.	
Material	Denomination	S460TM
	Plate thickness	30 mm
Mech. properties	$R_{p0,2}$	605 MPa
	R_m	520 MPa
Datail category according to EC		FAT 76,6
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	300,0	364620	1
2	225,0	1291470	1
3	225,0	1781610	1
4	375,0	34130	1
5	375,0	28050	1
6	300,0	231100	1
7	300,0	236700	1
8	225,0	1492280	1
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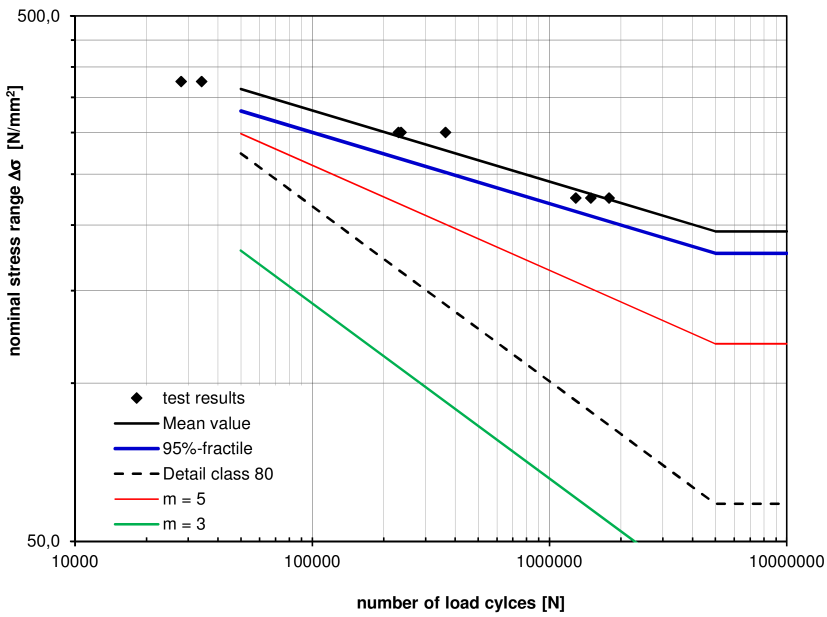
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

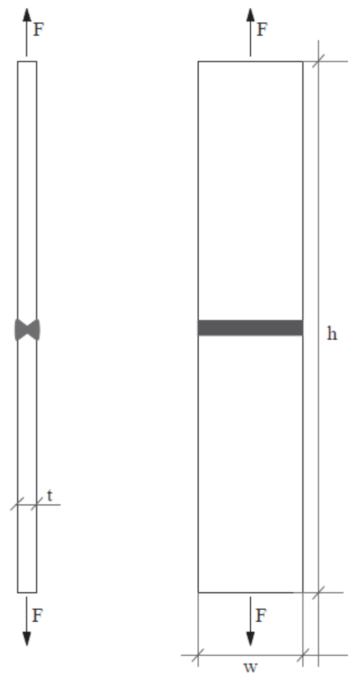
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	mean S-N curve ($P_{\ddot{U}}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{\ddot{U}}$ = 95%) $\Delta\sigma_C$
m = variable = 7,38	220,2	200,0
m = fix = 3	151,3	52,3
m = fix = 5	**194,9**	**142,7**

Construction detail	Butt welded joint attachment			
Reference	Ummenhofer, T., Weich, I.I., and .Nitschke-Pagel, T. (2006) Extension of Life Time of Welded Fatigue Loaded Structures. International Offshore and Polar Engineering Conference San Francisco, California, USA, June, 2006, pp.98-105.			
Material	Denomination	S460TM		
	Plate thickness	30	mm	
Mech. properties	$R_{p0,2}$	605	MPa	
	R_m	520	MPa	
Datail category according to EC		FAT 80 (*)		
Post-weld treatment	HFMI	UIT		
Fatigue loading	Stress ration	0,1	[-]	
	Type of collective	Constant amplitude		
	Axial/Bending force	Axial		

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	300,0	364620	1
2	225,0	1291470	1
3	225,0	1781610	1
4	375,0	34130	1
5	375,0	28050	1
6	300,0	231100	1
7	300,0	236700	1
8	225,0	1492280	1
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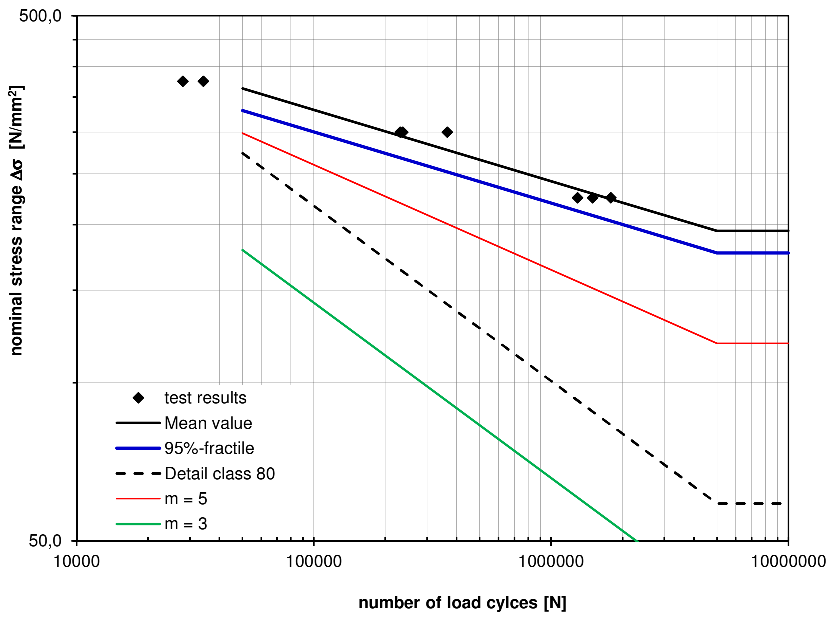
Comments: (*) The value has been assumed by the authors

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

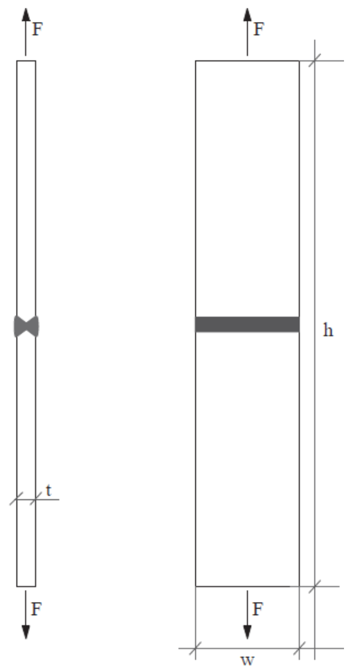


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 7,38	220,2	200,0
m = fix = 3	151,3	52,3
m = fix = 5	**194,9**	**142,7**

Construction detail	Butt welded joint attachment		
Reference	Hrabowski, J., Herion, S. and Ummenhofer, T. (2014) Low-cycle Fatigue of Post Weld Treated Butt Welds Made of High-strength Steels. International Ocean and Polar Engineering Conference Busan, Korea, June 15-20, 2014, pp. 158-163		
Material	Denomination	S960QL	
	Plate thickness	8	mm
Mech. properties	$R_{p0,2}$	-	MPa
	R_m	960	MPa
Datail category according to EC		FAT 80	
Post-weld treatment	HFMI	HiFIT	
Fatigue loading	Stress ration	0,1	[-]
	Type of collective	Constant amplitude	
	Axial/Bending force	Axial	

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	812	6667	1
2	756	6594	1
3	602	32040	1
4	505	71418	1
5	455	101982	1
6	379	105445	1
7	381	172091	1
8	302	566349	1
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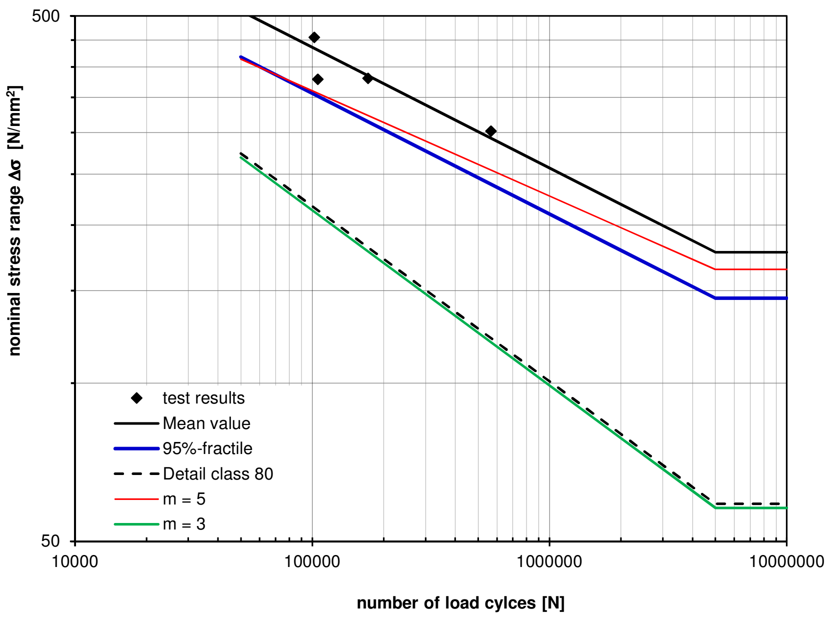
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

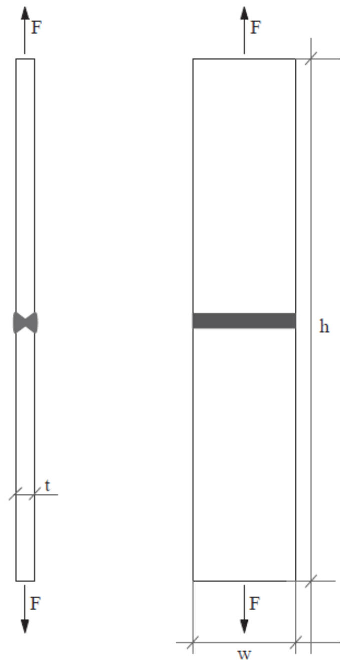
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	mean S-N curve ($P_{\ddot{U}}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{\ddot{U}}$ = 95%) $\Delta\sigma_C$
m = variable = 4,36	219,1	179,1
m = fix = 3	151,4	78,6
m = fix = 5	**243,4**	**197,8**

Construction detail	Butt welded joint attachment			
Reference	Huo, L.X.., Wang, D., Zhang, Y.F. and Chen, J.M. (2000) Investigation on Improving Fatigue Properties of Welded Joints by Ultrasonic Peening Method. Key Engineering Materials, vol. 183–187, pp. 1315–1320, 2000.			
Material	Denomination	Q235B		
	Plate thickness	8 mm		
Mech. properties	$R_{p0,2}$	436 MPa		
	R_m	267 MPa		
Datail category according to EC		FAT 80 (*)		
Post-weld treatment	HFMI	UPT		
Fatigue loading	Stress ration	0,1 [-]		
	Type of collective	Constant amplitude		
	Axial/Bending force	Axial		

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	261,4	276594	1
2	252,2	479422	1
3	243,2	444561	1
4	243,5	810336	1
5	243,0	1190480	1
6	239,4	1839234	1
7	233,9	3176520	1
8	225,2	3969639	1
9	251,9	439792	1
10	242,9	399110	1
11	242,9	526395	1
12	243,0	839997	1
13	243,0	883356	1
14	239,3	1787091	1
15	233,7	3176520	1
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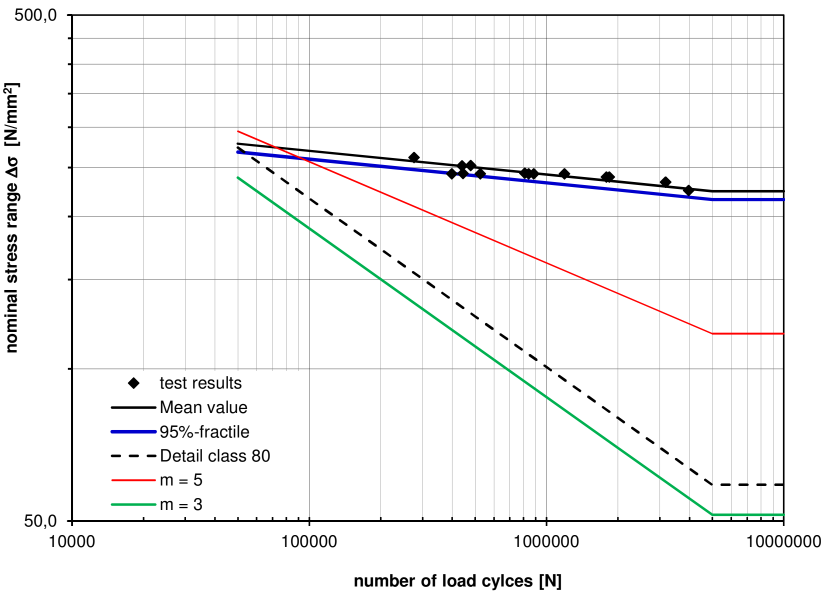
Comments: (*) The value has been assumed by the authors

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve



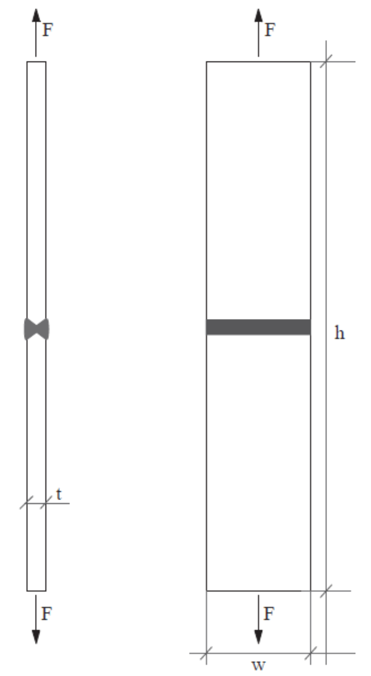
Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	mean S-N curve ($P_{\ddot{U}}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{\ddot{U}}$ = 95%) $\Delta\sigma_C$
m = variable = 21,29	234,2	225,4
m = fix = 3	189,6	69,8
m = fix = 5	**209,2**	**140,9**

Construction detail	**Butt welded joint attachment**
Reference	Dong-po, W., Ting, W., Li-xing, H. and Yu-feng, Z. (2004) Improving the Fatigue Performance of the Welded Joints of Ultra-Fine Grain Steel by Ultrasonic Peening. Transactions of Tianjin University, vol. 10, no. 2, 2004.

Material	Denomination	SS400
	Plate thickness	3 mm
Mech. properties	$R_{p0,2}$	480 MPa
	R_m	365 MPa
Datail category according to EC		FAT 71
Post-weld treatment	HFMI	UP
Fatigue loading	Stress ration	0,5 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	308,2	497202	1
2	279,4	807826	1
3	276,6	1344631	1
4	227,3	3776252	1
5	210,2	6165255	1
6			
7			
8			
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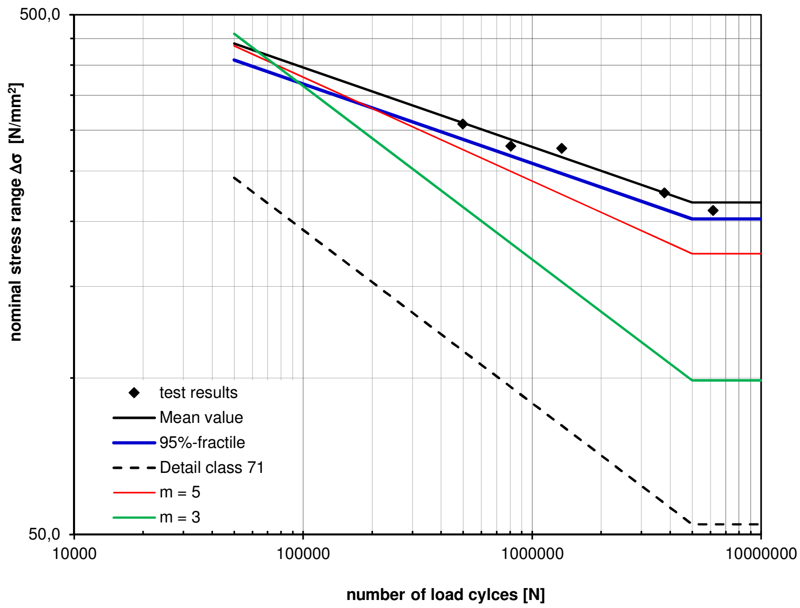
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

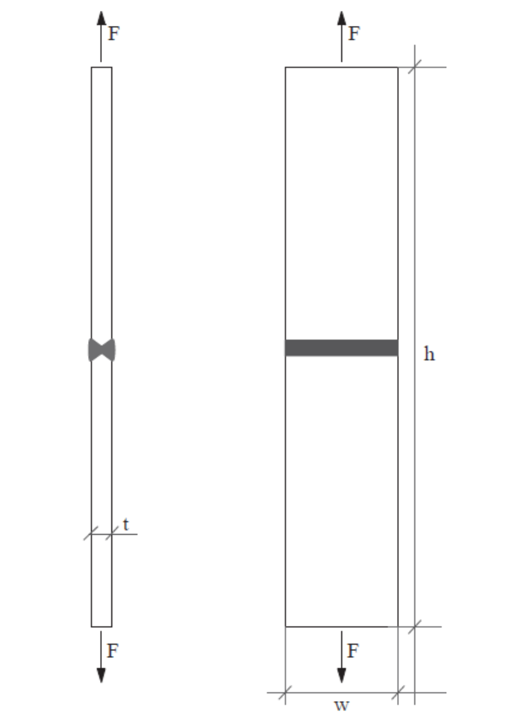


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	mean S-N curve ($P_{Ü}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{Ü}$ = 95%) $\Delta\sigma_C$
m = variable = 6,54	250,5	232,9
m = fix = 3	242,2	134,4
m = fix = 5	**248,3**	**208,4**

Construction detail	Butt welded joint attachment	
Reference	Ummenhofer, T. and Weich, I.I. (2010) REFRESH – Lebensdauerverlängerung bestehender und neuer geschweiß ter Stahlkonstruktionen, Stahlbau, vol. 75, no. 7, pp. 605–607, 2010.	
Material	Denomination	S355J2
	Plate thickness	16 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	434 MPa
Datail category according to EC		FAT 90
Post-weld treatment	HFMI	HiFIT/UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



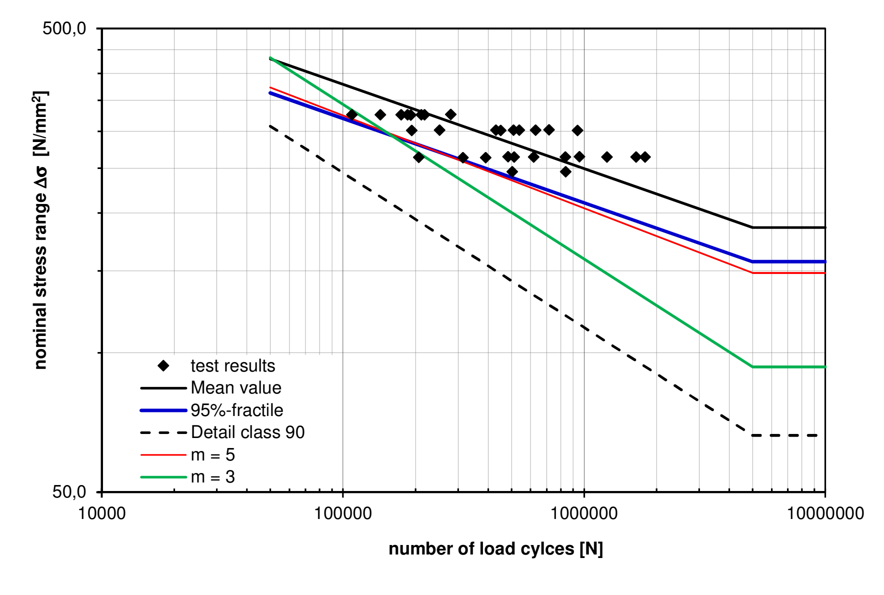
Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *	n	stress range Δσ	load cycles N	Com. *
1	325,8	108843	1	31	245,1	928632	1
2	325,8	142973	1	32	245,5	962150	1
3	325,9	174471	1	33	245,8	996877	1
4	325,9	185261	1	34	245,5	1488567	1
5	325,4	191425	1	35	245,9	1753236	1
6	325,9	211174	1	36	245,9	1918359	1
7	325,9	218200	1	37	246,3	2340998	1
8	326,4	280435	1	38	226,1	837204	1
9	301,5	192997	1	39	226,1	926103	1
10	302,0	251450	1	40	225,8	1090765	1
11	302,1	431509	1	41	225,8	1331074	1
12	301,2	450756	1	42	225,5	1589268	1
13	301,6	509620	1	43	225,8	2116281	1
14	301,6	538191	1	44	225,8	2366678	1
15	301,7	628717	1	45	226,2	2639493	1
16	302,1	716660	1	46	226,2	3364683	1
17	301,3	939192	1	47	226,2	3752542	1
18	263,6	206054	1	48	265,9	148160	1
19	263,5	314730	1	49	265,8	369040	1
20	263,2	391153	1	50	265,7	566303	1
21	264,4	483882	1	51	226,7	3053206	1
22	264,1	512407	1	52	226,8	1934574	1
23	264,1	618512	1	53			
24	264,1	837204	1	54			
25	264,5	956916	1	55			
26	264,2	1243337	1	56			
27	264,2	1642145	1	57			
28	264,2	1791912	1	58			
29	245,4	504090	1	59			
30	245,5	839491	1	60			

Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

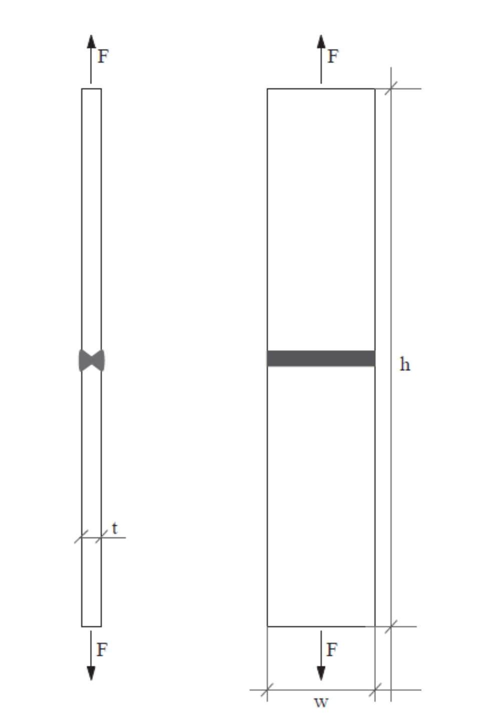


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 5,5	219,8	185,5
m = fix = 3	185,9	126,4
m = fix = 5	**215,5**	**178,4**

Construction detail	Butt welded joint attachment	
Reference	Ummenhofer, T. and Weich, I.I. (2010) REFRESH – Lebensdauerverlängerung bestehender und neuer geschweiß ter Stahlkonstruktionen, Stahlbau, vol. 75, no. 7, pp. 605–607, 2010.	
Material	Denomination	S690QL
	Plate thickness	16 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	719 MPa
Datail category according to EC		FAT 90
Post-weld treatment	HFMI	HiFIT/UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



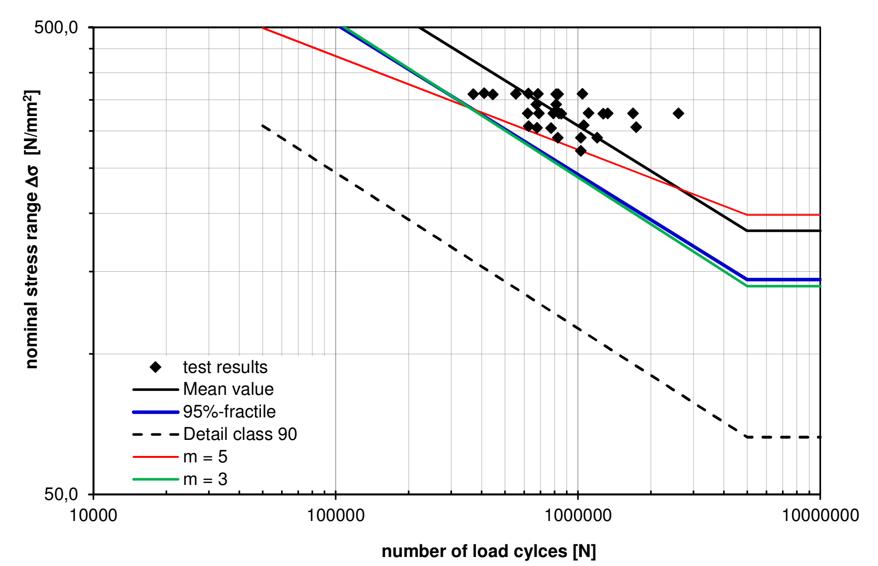
Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *	n	stress range $\Delta\sigma$	load cycles N	Com. *
1	272,0	1028508	1	31	361,3	463251	1
2	290,0	825429	1	32	362,1	537785	1
3	290,0	1028508	1	33	401,9	261984	1
4	290,0	1200860	1	34	402,8	369655	1
5	304,3	774939	1	35	402,8	414607	1
6	304,6	676534	1	36	403,7	286079	1
7	306,0	1737051	1	37	404,1	300091	1
8	307,0	626704	1	38	404,1	349041	1
9	308,7	1056421	1	39	404,6	918751	1
10	326,6	854343	1	40	405,9	578328	1
11	326,6	1271782	1	41			
12	327,0	619553	1	42			
13	327,0	1326439	1	43			
14	327,0	1684697	1	44			
15	327,0	2600669	1	45			
16	327,0	690919	1	46			
17	327,0	789904	1	47			
18	327,0	834957	1	48			
19	327,7	1106046	1	49			
20	341,7	674314	1	50			
21	341,7	813333	1	51			
22	359,3	445864	1	52			
23	359,7	369655	1	53			
24	359,7	813278	1	54			
25	359,7	827278	1	55			
26	360,1	1042371	1	56			
27	360,5	554497	1	57			
28	360,5	684343	1	58			
29	360,9	623119	1	59			
30	361,3	410661	1	60			

Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

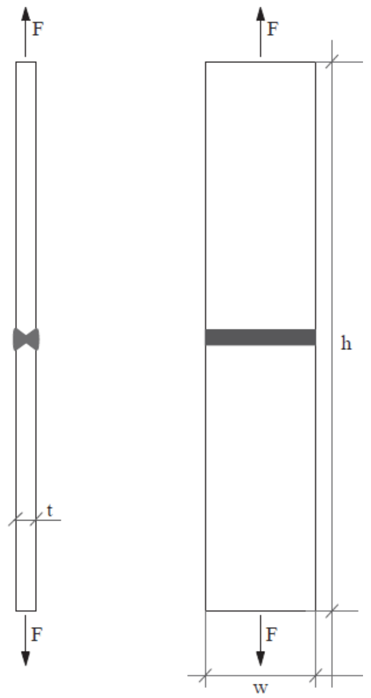


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 3,11	246,3	193,7
m = fix = 3	243,4	189,5
m = fix = 5	**279,4**	**238,3**

Construction detail	Butt welded joint attachment	
Reference	Ummenhofer, T. and Weich, I.I. (2010) REFRESH – Lebensdauerverlängerung bestehender und neuer geschweiß ter Stahlkonstruktionen, Stahlbau, vol. 75, no. 7, pp. 605–607, 2010.	
Material	Denomination	S690QL
	Plate thickness	16 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	719 MPa
Datail category according to EC		FAT 90
Post-weld treatment	HFMI	HiFIT/UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



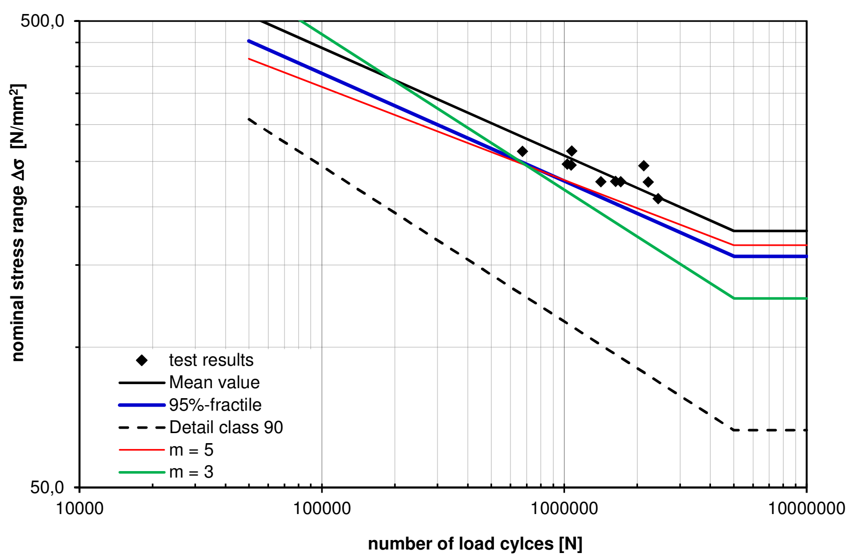
Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *	n	stress range $\Delta\sigma$	load cycles N	Com. *
1	262,6	673945	1	31			
2	246,4	1031412	1	32			
3	245,3	1068358	1	33			
4	263,2	1075217	1	34			
5	226,0	1415780	1	35			
6	226,5	1629804	1	36			
7	226,0	1709930	1	37			
8	244,7	2132338	1	38			
9	225,5	2222900	1	39			
10	207,8	2439025	1	40			
11				41			
12				42			
13				43			
14				44			
15				45			
16				46			
17				47			
18				48			
19				49			
20				50			
21				51			
22				52			
23				53			
24				54			
25				55			
26				56			
27				57			
28				58			
29				59			
30				60			

Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

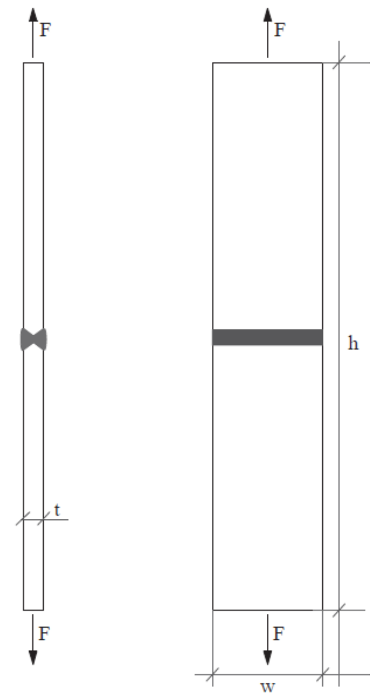


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 4,33	219,2	193,4
m = fix = 3	211,9	172,6
m = fix = 5	**221,5**	**198,5**

Construction detail	Butt welded joint attachment	
Reference	Ummenhofer, T. and Weich, I.I. (2010) REFRESH – Lebensdauerverlängerung bestehender und neuer geschweiß ter Stahlkonstruktionen, Stahlbau, vol. 75, no. 7, pp. 605–607, 2010.	
Material	Denomination Plate thickness	S355J2 30 mm
Mech. properties	$R_{p0,2}$ R_m	- MPa 434 MPa
Datail category according to EC		FAT 90
Post-weld treatment	HFMI	HiFIT/UIT
Fatigue loading	Stress ration Type of collective Axial/Bending force	0,1 [-] Constant amplitude Axial

Sketch and dimension of test specimen and loading



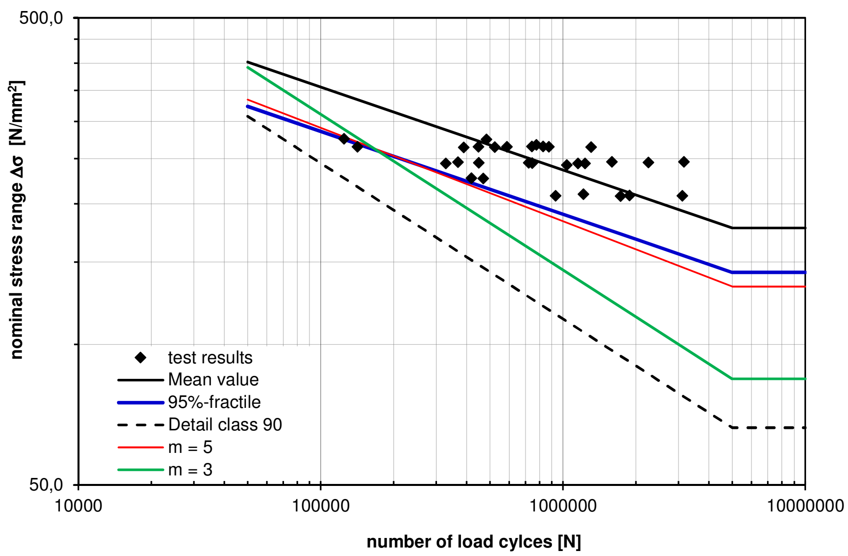
Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *	n	stress range $\Delta\sigma$	load cycles N	Com. *
1	275,7	124918	1	31	209,8	3244109	1
2	274,7	483872	1	32	208,3	3689791	1
3	264,8	142084	1	33	208,3	4262001	1
4	264,0	390000	1	34			
5	264,8	447924	1	35			
6	264,4	522744	1	36			
7	264,8	586950	1	37			
8	265,3	743811	1	38			
9	267,1	777082	1	39			
10	265,3	827730	1	40			
11	264,8	874786	1	41			
12	264,4	1307137	1	42			
13	243,9	328905	1	43			
14	245,6	368351	1	44			
15	244,7	449112	1	45			
16	244,7	723099	1	46			
17	244,3	747710	1	47			
18	242,2	1036887	1	48			
19	243,9	1152310	1	49			
20	243,9	1232081	1	50			
21	246,0	1590790	1	51			
22	245,2	2250426	1	52			
23	246,0	3161174	1	53			
24	227,0	418985	1	54			
25	226,6	469239	1	55			
26	208,0	933156	1	56			
27	209,8	1216498	1	57			
28	207,6	1726526	1	58			
29	208,3	1879611	1	59			
30	208,0	3113221	1	60			

Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

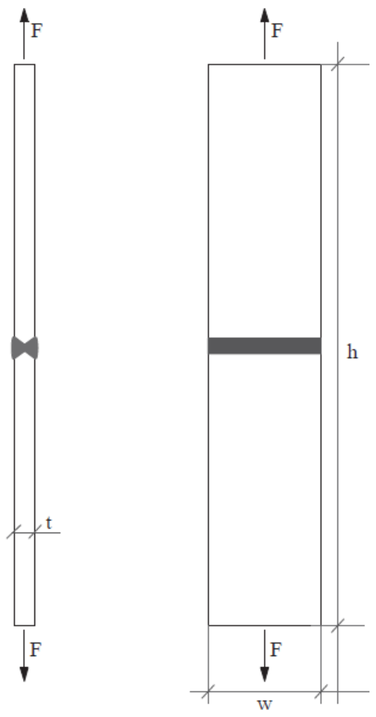


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 5,63	208,9	167,7
m = fix = 3	183,8	114,5
m = fix = 5	**205,1**	**159,7**

Construction detail	Butt welded joint attachment	
Reference	Ummenhofer, T. and Weich, I.I. (2010) REFRESH – Lebensdauerverlängerung bestehender und neuer geschweiß ter Stahlkonstruktionen, Stahlbau, vol. 75, no. 7, pp. 605–607, 2010.	
Material	Denomination	S690QL
	Plate thickness	30 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	719 MPa
Datail category according to EC		FAT 90
Post-weld treatment	HFMI	HiFIT/UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



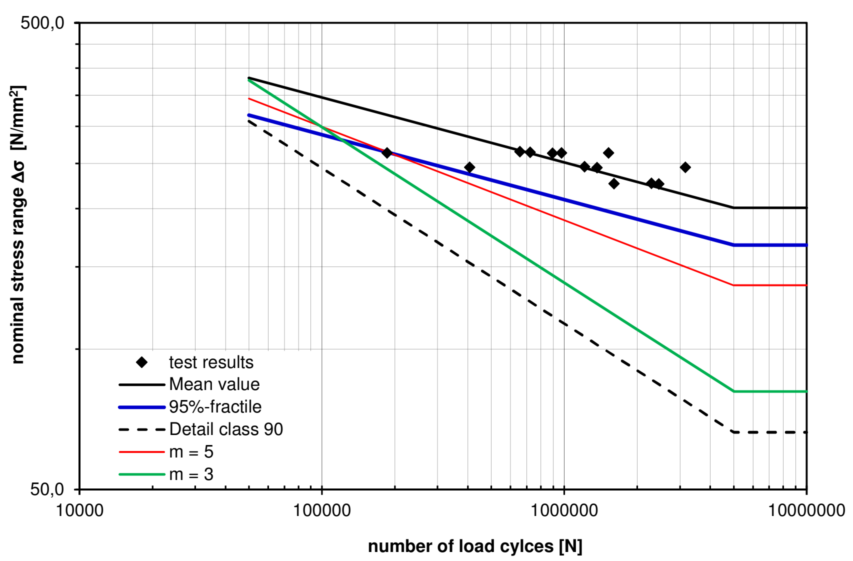
Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *	n	stress range $\Delta\sigma$	load cycles N	Com. *
1	263,0	186083	1	31			
2	245,0	407438	1	32			
3	264,7	656326	1	33			
4	263,9	724462	1	34			
5	262,7	896060	1	35			
6	263,1	976428	1	36			
7	245,9	1215442	1	37			
8	244,7	1364868	1	38			
9	263,1	1522929	1	39			
10	226,2	1606697	1	40			
11	226,6	2289847	1	41			
12	245,2	3160249	1	42			
13	225,9	2457988	1	43			
14				44			
15				45			
16				46			
17				47			
18				48			
19				49			
20				50			
21				51			
22				52			
23				53			
24				54			
25				55			
26				56			
27				57			
28				58			
29				59			
30				60			

Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

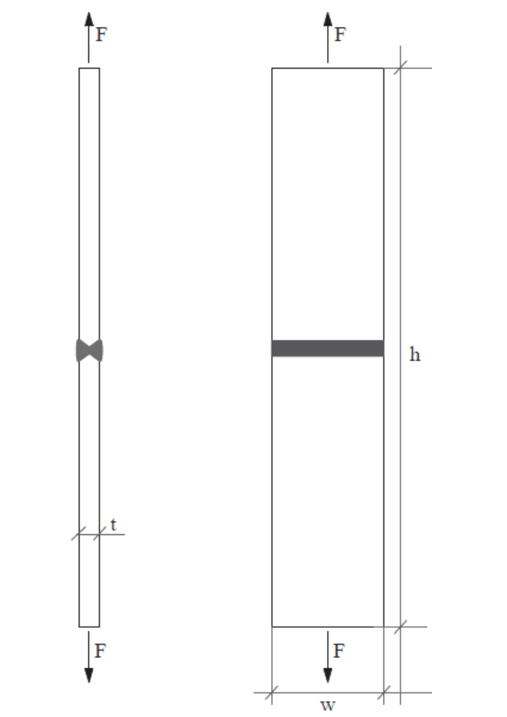


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 7,19	227,9	189,7
m = fix = 3	201,7	110,1
m = fix = 5	**219,3**	**164,5**

Construction detail	Butt welded joint attachment	
Reference	Ummenhofer, T. and Weich, I.I. (2010) REFRESH – Lebensdauerverlängerung bestehender und neuer geschweiß ter Stahlkonstruktionen, Stahlbau, vol. 75, no. 7, pp. 605–607, 2010.	
Material	Denomination	S355J2
	Plate thickness	16 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	434 MPa
Datail category according to EC		FAT 90
Post-weld treatment	HFMI	HiFIT/UIT
Fatigue loading	Stress ration	0,5 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



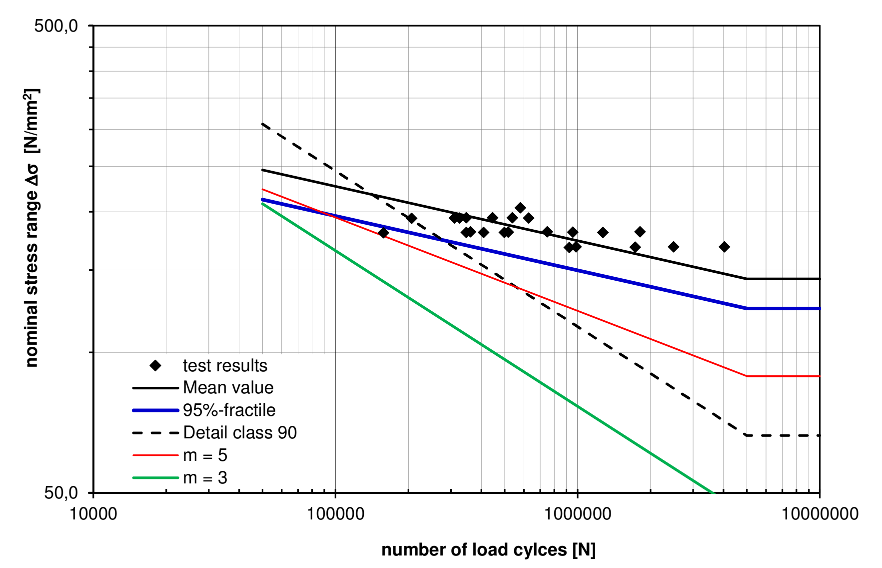
Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *	n	stress range $\Delta\sigma$	load cycles N	Com. *
1	180,1	157928	1	31			
2	193,4	206008	1	32			
3	193,7	310033	1	33			
4	193,5	325155	1	34			
5	194,0	347158	1	35			
6	180,4	347202	1	36			
7	180,8	361256	1	37			
8	180,2	408552	1	38			
9	193,8	444887	1	39			
10	193,8	538245	1	40			
11	203,7	580350	1	41			
12	193,6	627100	1	42			
13	180,4	498223	1	43			
14	180,6	516339	1	44			
15	180,9	748316	1	45			
16	180,5	955179	1	46			
17	167,5	923614	1	47			
18	167,9	986114	1	48			
19	180,4	1271102	1	49			
20	180,8	1809564	1	50			
21	167,8	1729056	1	51			
22	167,8	2491007	1	52			
23	167,9	4042471	1	53			
24				54			
25				55			
26				56			
27				57			
28				58			
29				59			
30				60			

Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

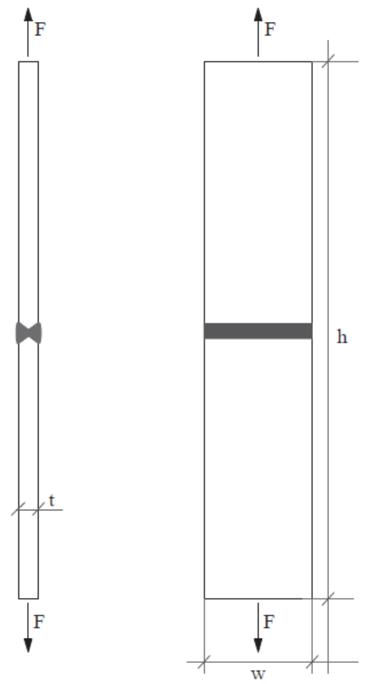


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 8,58	159,8	138,1
m = fix = 3	124,8	60,8
m = fix = 5	**145,3**	**106,7**

Construction detail	Butt welded joint attachment
Reference	Ummenhofer, T. and Weich, I.I. (2010) REFRESH – Lebensdauerverlängerung bestehender und neuer geschweiß ter Stahlkonstruktionen, Stahlbau, vol. 75, no. 7, pp. 605–607, 2010.
Material	Denomination S690QL Plate thickness 16 mm
Mech. properties	$R_{p0,2}$ - MPa R_m 719 MPa
Datail category according to EC	FAT 90
Post-weld treatment	HFMI HiFIT/UIT
Fatigue loading	Stress ration 0,5 [-] Type of collective Constant amplitude Axial/Bending force Axial

Sketch and dimension of test specimen and loading



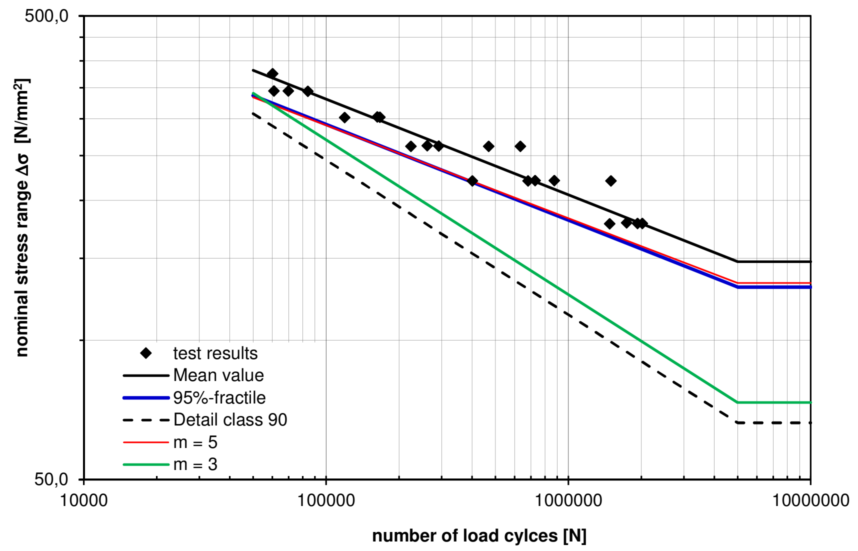
Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *	n	stress range Δσ	load cycles N	Com. *
1	375,5	60275	1	31			
2	344,2	60997	1	32			
3	344,2	69772	1	33			
4	343,6	84058	1	34			
5	301,9	119464	1	35			
6	302,8	162698	1	36			
7	302,4	166581	1	37			
8	261,6	223724	1	38			
9	262,4	261396	1	39			
10	262,0	292031	1	40			
11	261,5	469098	1	41			
12	220,4	401582	1	42			
13	261,5	632874	1	43			
14	220,3	682629	1	44			
15	220,7	729218	1	45			
16	220,7	874397	1	46			
17	220,3	1496897	1	47			
18	178,3	1479765	1	48			
19	179,1	1741203	1	49			
20	178,5	1927015	1	50			
21	178,5	2020068	1	51			
22				52			
23				53			
24				54			
25				55			
26				56			
27				57			
28				58			
29				59			
30				60			

Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

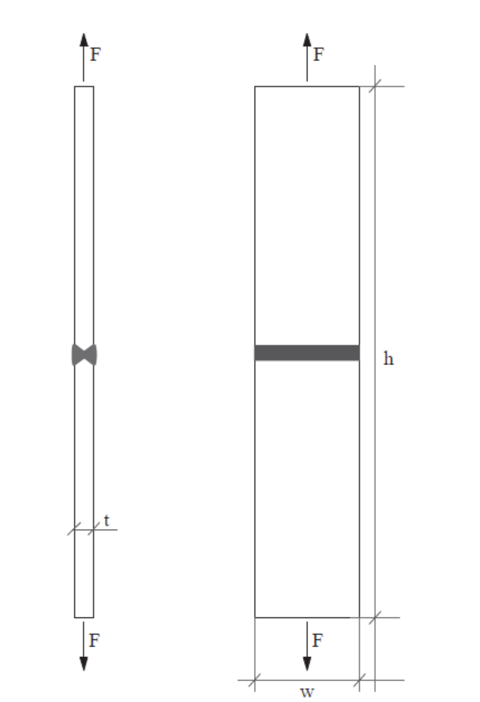


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	mean S-N curve ($P_{Ü}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{Ü}$ = 95%) $\Delta\sigma_C$
m = variable = 4,85	178,3	157,2
m = fix = 3	143,9	99,5
m = fix = 5	**180,2**	**159,4**

Construction detail	Butt welded joint attachment		
Literatur	Wang, T., Wang, D., Huo, L. and Zhang, Y. (2009) Discussion on fatigue design of welded joints enhanced by ultrasonic peening treatment (UPT), International Journal of Fatigue, vol. 31, no. 4, pp. 644–650, Apr. 2009.		
Material	Denomination	SS800	
	Plate thickness	8 mm	
Mech. properties	$R_{p0,2}$	830-840 Mpa	
	R_m	700 MPa	
Datail category according to EC		FAT 80 (*)	
Post-weld treatment	HFMI	UPT	
Fatigue loading	Stress ration	0,05 [-]	
	Type of collective	Constant amplitude	
	Axial/Bending force	Axial	

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	371	163955	1
2	331	592934	1
3	322	1073186	1
4	310	1915176	1
5	301	3184692	1
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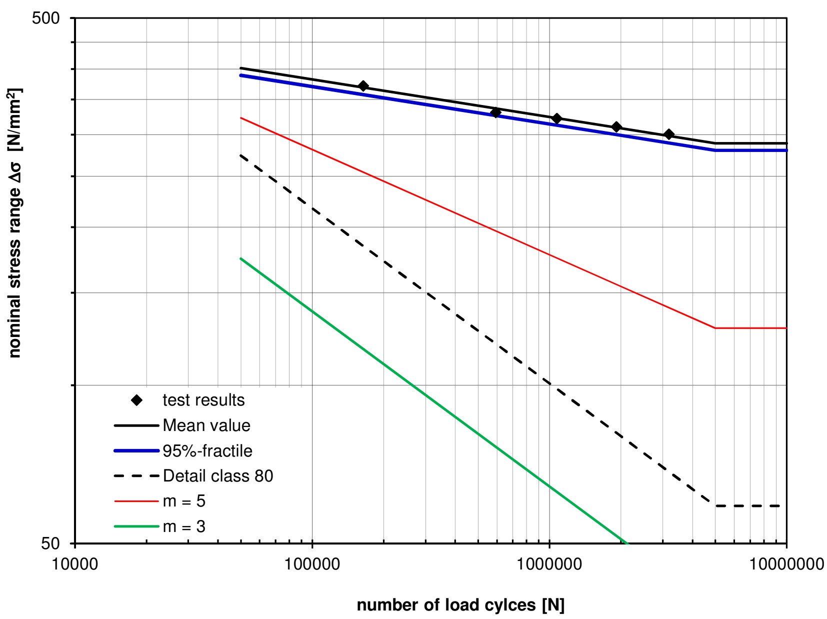
Comments: (*) The value has been assumed by the authors

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

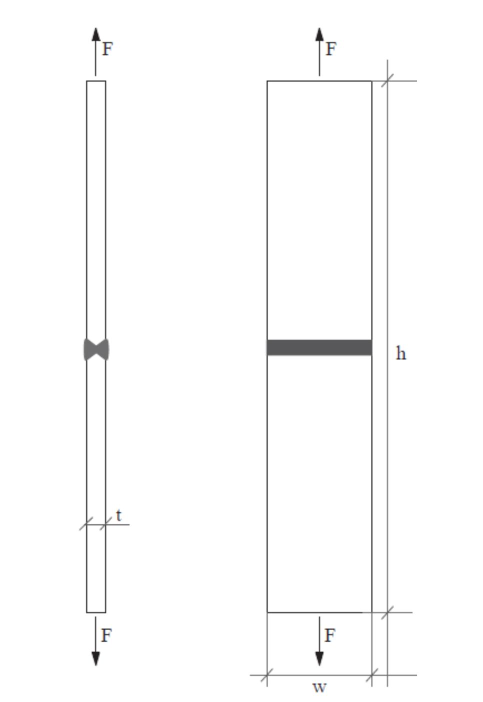


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 14,01	308,4	298,9
m = fix = 3	251,2	50,9
m = fix = 5	**278,8**	**154,3**

Construction detail	Butt welded joint attachment	
Literatur	Wang, T., Wang, D., Huo, L. and Zhang, Y. (2009) Discussion on fatigue design of welded joints enhanced by ultrasonic peening treatment (UPT), International Journal of Fatigue, vol. 31, no. 4, pp. 644–650, Apr. 2009.	
Material	Denomination	16Mn
	Plate thickness	8 mm
Mech. properties	$R_{p0,2}$	591 MPa
	R_m	390 MPa
Datail category according to EC		FAT 80 (*)
Post-weld treatment	HFMI	UPT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	323	113557	1
2	315	175954	1
3	307	459808	1
4	296	1236017	1
5	288	1593874	1
6	280	2400867	1
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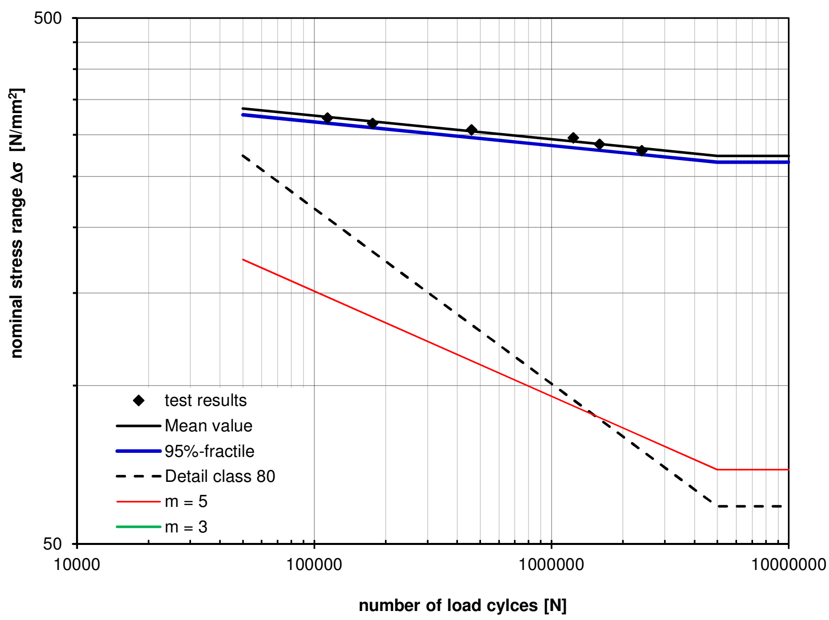
Comments: (*) The value has been assumed by the authors

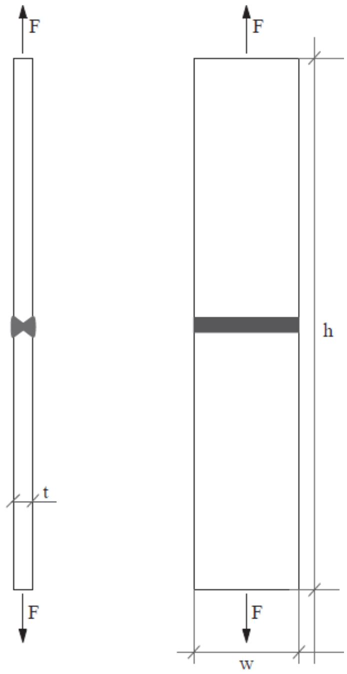
* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	mean S-N curve ($P_{\ddot{U}}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{\ddot{U}}$ = 95%) $\Delta\sigma_C$
m = variable = 22,21	285,0	277,2
m = fix = 3	200,7	10,3
m = fix = 5	**236,0**	**83,1**

Construction detail	Butt welded joint attachment	
Literatur	Janosch, J.J., Koncczny, H., Debiez, S., Statnikov, E.C., Troufiakov, V.J. and Mikhee, P.P. (1996) Improvement of fatigue strength in welded joints (in HSS and in aluminium alloys) by ultrasonic hammer peening. Welding In the World-London-, vol. 37, pp. 72–83, 1996.	
Material	Denomination	E690
	Plate thickness	9,5 mm
Mech. properties	$R_{p0,2}$	836 MPa
	R_m	763 MPa
Datail category according to EC		FAT 80 (*)
Post-weld treatment	HFMI	UPT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	286	450377	1
2	291	606573	1
3	270	677745	1
4	308	750438	1
5	262	1048492	1
6	254	1110198	1
7	268	1545142	1
8	229	1796799	1
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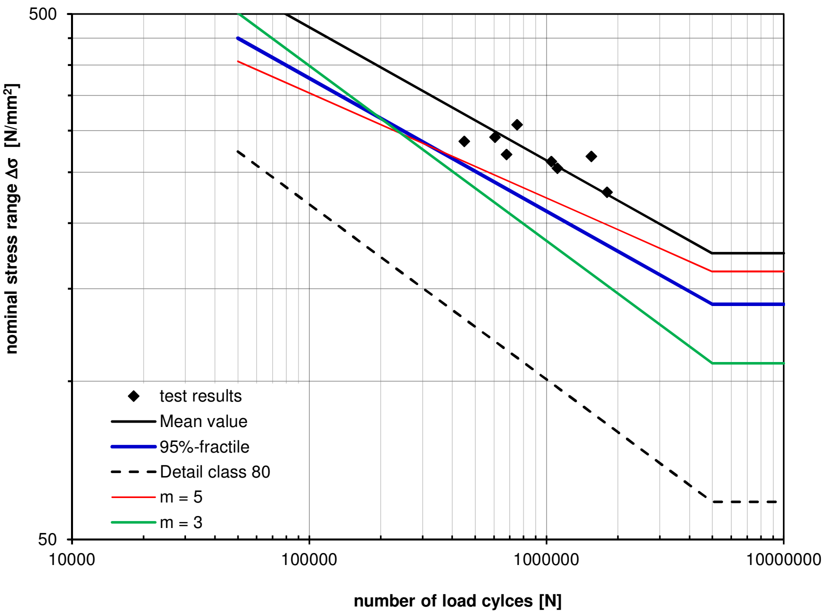
Comments: (*) The value has been assumed by the authors

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

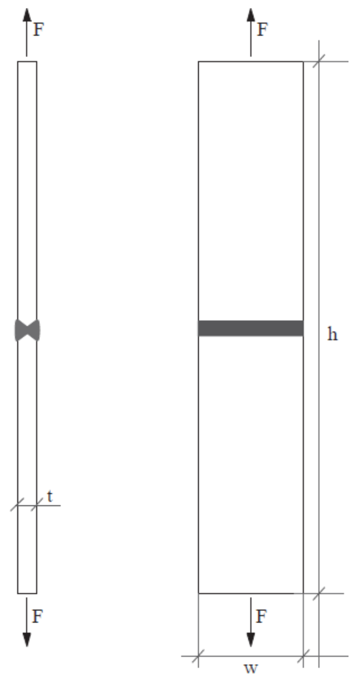
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 3,95	221,0	176,7
m = fix = 3	207,4	146,8
m = fix = 5	**230,5**	**194,3**

Construction detail	Butt welded joint attachment	
Literatur	Kuhlmann, U and Günther, H. P. (2009) Experimentelle Untersuchungen zur ermüdungssteigernden Wirkung des PIT Verfahrens. Versuchsbericht, Universität Stuttgart, Institut für Konstruktion und Entwurf, 2009.	
Material	Denomination	S355J2
	Plate thickness	12 mm
Mech. properties	$R_{p0,2}$	470-630 Mpa
	R_m	355 MPa
Datail category according to EC		FAT 80 (*)
Post-weld treatment	HFMI	PIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	320	441966	1
2	320	359971	1
3	350	89025	1
4	350	261245	1
5	291	570704	1
6	291	801626	1
7	261	824437	1
8	261	1634772	1
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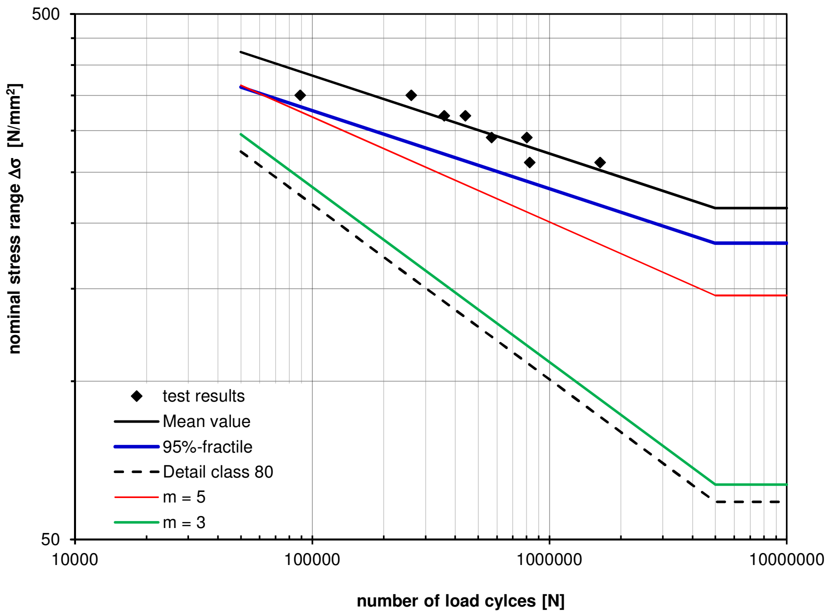
Comments: (*) The value has been assumed by the authors

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

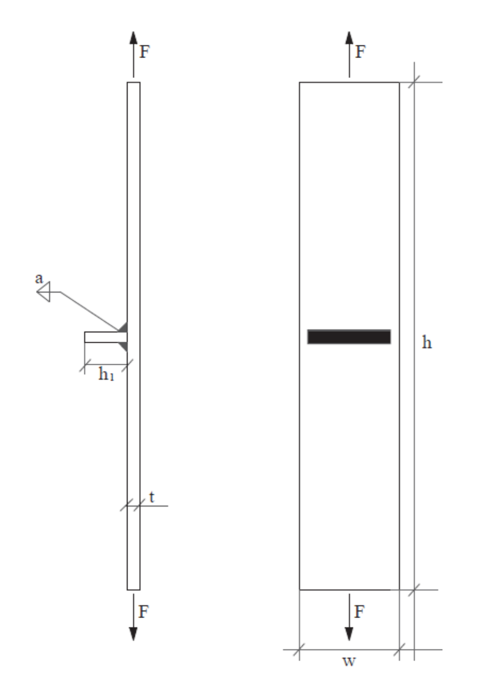


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 6,73	244,7	209,8
m = fix = 3	187,1	86,3
m = fix = 5	**227,1**	**174,9**

Construction detail	**Transversal non-load carrying attachment**	
Reference	Leitner, M., Stoschka, M. and Eichlseder, W. (2014) Fatigue enhancement of thin-walled, high-strength steel joints by high-frequency mechanical impact treatment - Welding in the World, vol. 58, no. 1, pp. 29–39, Jan. 2014.	
Material	Denomination	S355
	Plate thickness	5 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	355 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	PIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	400,0	45762	1
2	400,0	40219	1
3	350,0	127859	1
4	350,0	129313	1
5	300,0	331773	1
6	300,0	292273	1
7	300,0	357196	1
8	300,0	285857	1
9	250,0	467515	1
10	250,0	569303	1
11	225,0	1159771	1
12	225,0	1224537	1
13	200,0	50000000	0
14			
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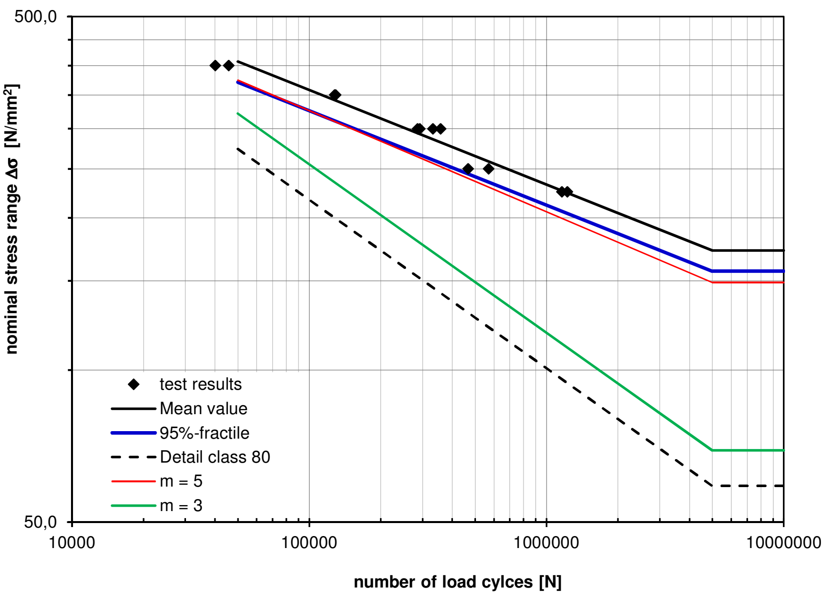
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

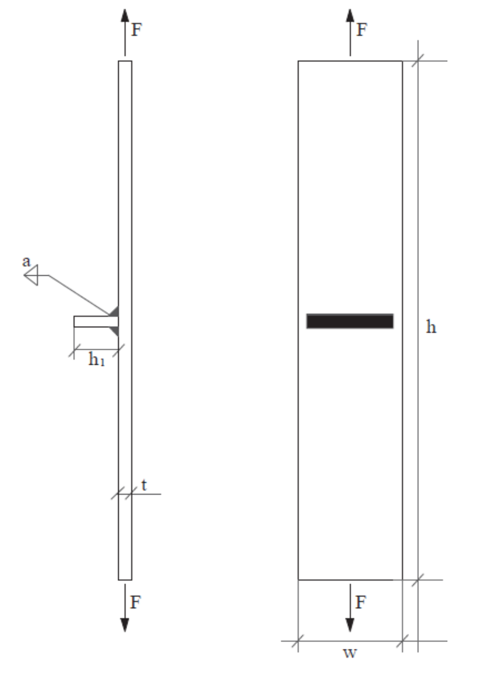


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 5,35	204,5	186,1
m = fix = 3	152,0	94,0
m = fix = 5	**199,1**	**178,9**

Construction detail	Transversal non-load carrying attachment	
Reference	Leitner, M., Stoschka, M. and Eichlseder, W. (2014) Fatigue enhancement of thin-walled, high-strength steel joints by high-frequency mechanical impact treatment - Welding in the World, vol. 58, no. 1, pp. 29–39, Jan. 2014.	
Material	Denomination	S690
	Plate thickness	5 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	690 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	PIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	600,0	24590	1
2	500,0	79746	1
3	500,0	87332	1
4	400,0	208053	1
5	400,0	179853	1
6	350,0	453600	1
7	350,0	776715	1
8	325,0	1201199	1
9	300,0	50000000	0
10			
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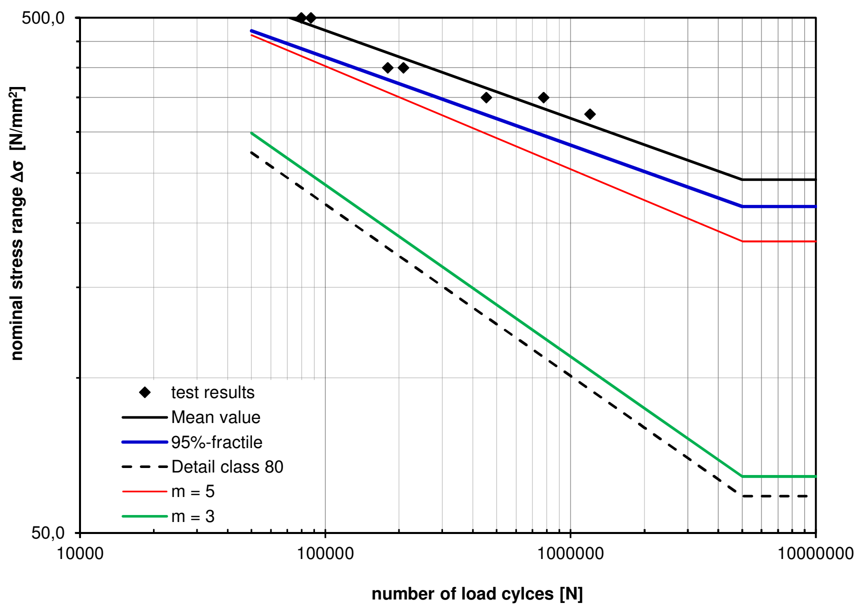
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

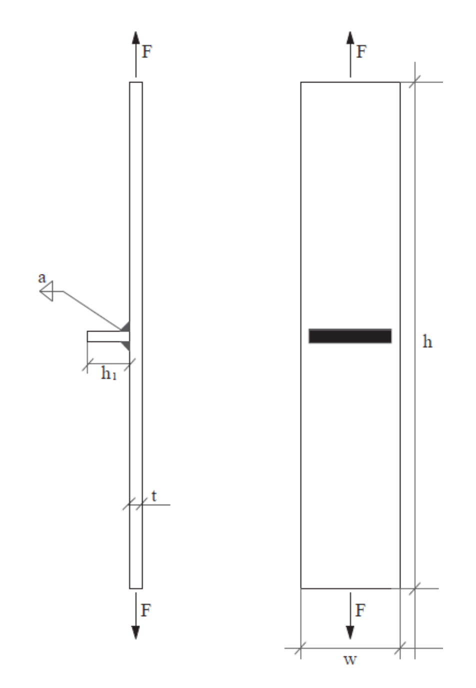


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 5,86	283,5	251,4
m = fix = 3	195,1	87,4
m = fix = 5	**264,9**	**221,1**

Construction detail	**Transversal non-load carrying attachment**	
Reference	Leitner, M., Stoschka, M. and Eichlseder, W. (2014) Fatigue enhancement of thin-walled, high-strength steel joints by high-frequency mechanical impact treatment - Welding in the World, vol. 58, no. 1, pp. 29–39, Jan. 2014.	
Material	Denomination	S960
	Plate thickness	5 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	960 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	PIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	700,0	38777	1
2	700,0	33922	1
3	600,0	68315	1
4	600,0	78002	1
5	500,0	93213	1
6	500,0	121296	1
7	500,0	135449	1
8	500,0	116512	1
9	400,0	368640	1
10	400,0	264182	1
11	375,0	481572	1
12	325,0	50000000	0
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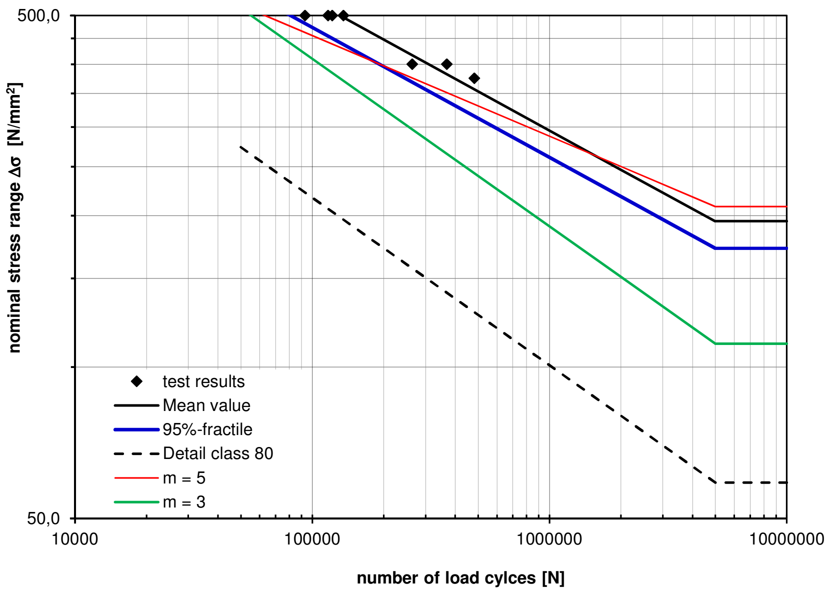
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

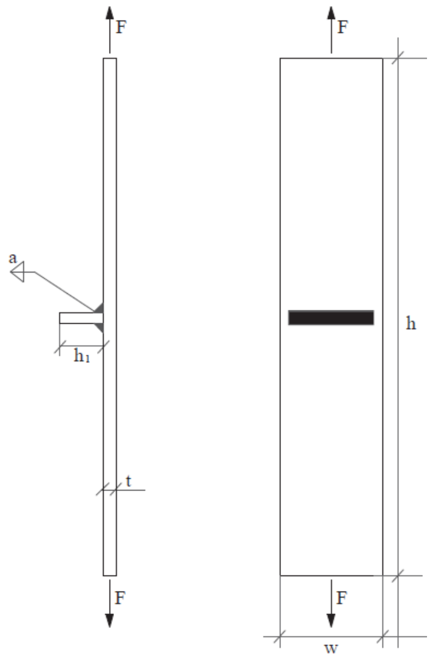
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 3,87	247,0	218,2
m = fix = 3	199,8	151,1
m = fix = 5	**291,6**	**250,4**

Construction detail	Transversal non-load carrying attachment	
Reference	Tehrani Yekta, R. (2012) Acceptance Criteria for Ultrasonic Impact Treatment of Highway Steel Bridges. Canada: University of Waterloo, 2012.	
Material	Denomination	350W
	Plate thickness	9,5 mm
Mech. properties	$R_{p0,2}$	450-650 MPa
	R_m	350 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	200,0	2099320	1
2	225,0	3510188	1
3	250,0	1773851	1
4	200,0	1537837	1
5	225,0	8210202	1
6	250,0	3031499	1
7	200,0	3436785	1
8	225,0	1932685	1
9	250,0	450647	1
10	200,0	3021835	1
11	225,0	2244137	1
12	250,0	2753812	1
13	200,0	7692074	1
14	225,0	4207209	1
15	250,0	1175500	1
16	200,0	5598137	1
17	225,0	5600000	1
18	250,0	2143443	1
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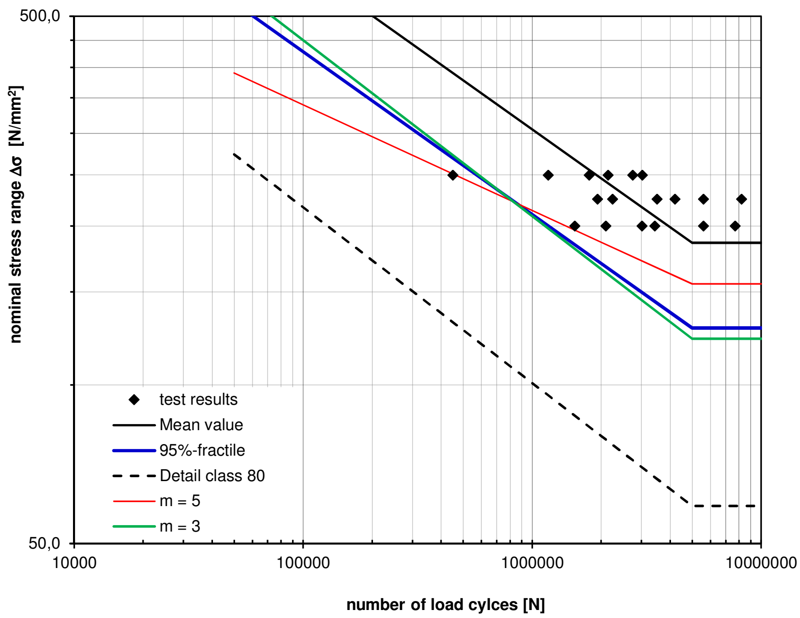
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

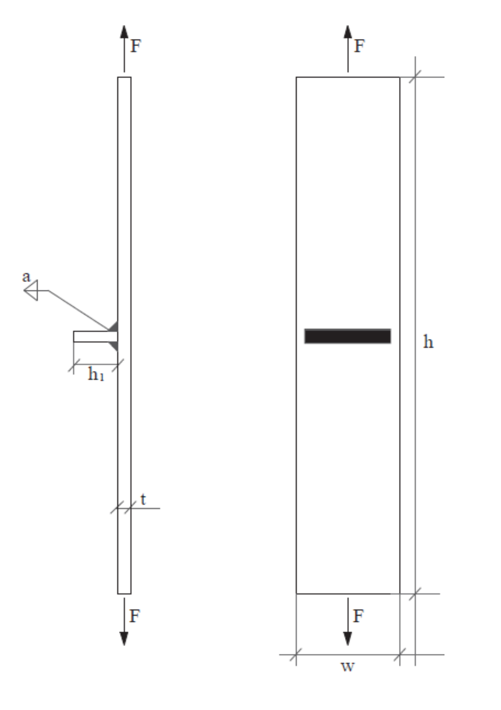


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 3,24	246,7	170,1
m = fix = 3	248,6	166,0
m = fix = 5	**238,5**	**186,6**

Construction detail	Transversal non-load carrying attachment	
Reference	Statnikov, E.S., Muktepavel, V.O., Trufyakov, V.I., Mikheev, P.P., Kuzmenko, A.Z. and Blomqvist, A. (2000) Efficiency Evaluation of Ultrasonic Impact Treatment (UIT) of Welded Joints in Weldox 420 Steel in accordance with the IIW Program. Applied Ultrasonics, IIW/IIS-Document, vol. 13, pp. 1817–00, 2000.	
Material	Denomination	WELDOX 420
	Plate thickness	20 mm
Mech. properties	$R_{p0,2}$	573 MPa
	R_m	461 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Bending

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	400,0	66000	1
2	400,0	93600	1
3	400,0	210000	1
4	370,0	83500	1
5	370,0	156000	1
6	370,0	232400	1
7			
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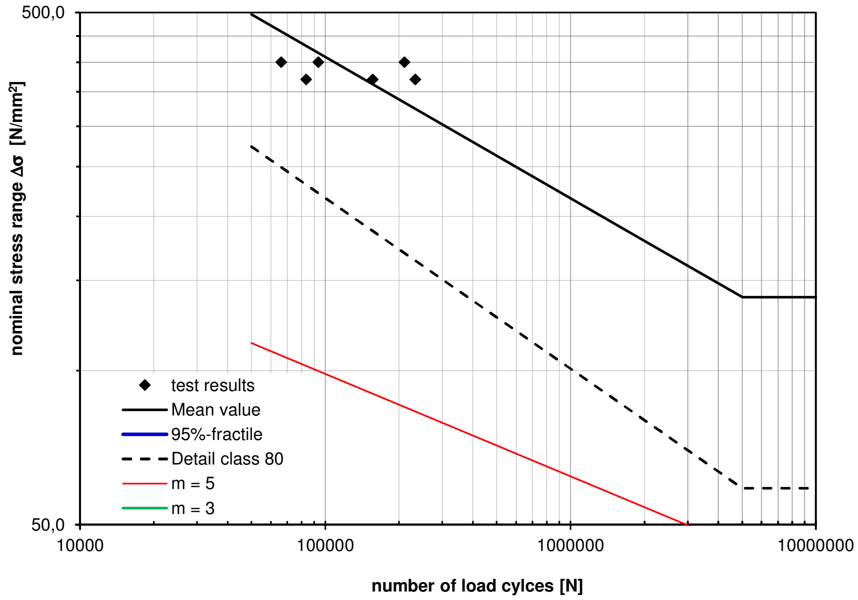
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

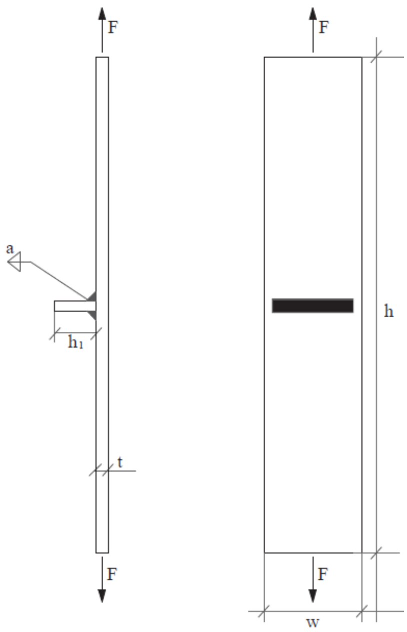


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_{Ü}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{Ü}$ = 95%) $\Delta\sigma_C$
m = variable = 3,62	179,2	12,8
m = fix = 3	152,9	3,3
m = fix = 5	**221,2**	**54,1**

Construction detail	Transversal non-load carrying attachment		
Reference	Ummenhofer, T., Weich, I.I., and .Nitschke-Pagel, T. (2006) Extension of Life Time of Welded Fatigue Loaded Structures. International Offshore and Polar Engineering Conference San Francisco, California, USA, June, 2006, pp.98-105.		
Material	Denomination	S460TM	
	Plate thickness	30	mm
Mech. properties	$R_{p0,2}$	605	MPa
	R_m	520	MPa
Datail category according to EC		FAT 80	
Post-weld treatment	HFMI	UIT	
Fatigue loading	Stress ration	0,1	[-]
	Type of collective	Constant amplitude	
	Axial/Bending force	Axial	

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	300,0	96810	1
2	300,0	110720	1
3	225,0	893780	1
4	375,0	33640	1
5	225,0	624170	1
6	225,0	746250	1
7	190,0	5000000	1
8			
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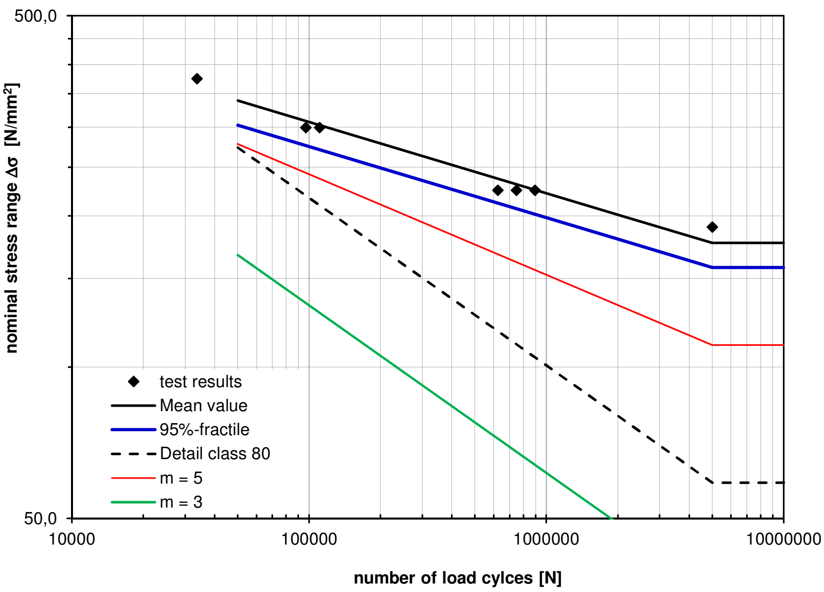
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

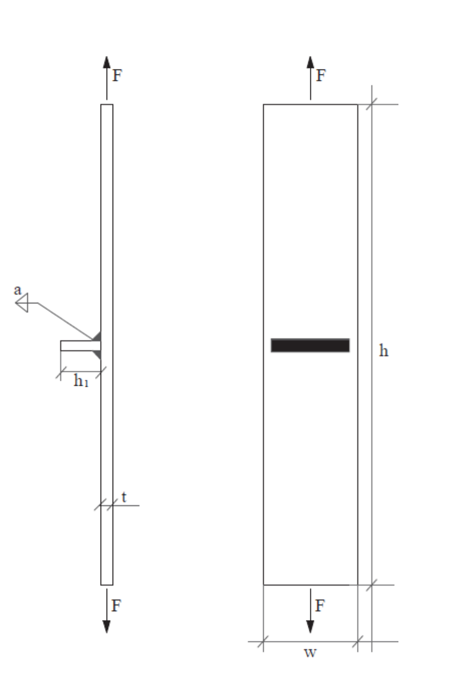


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 7,07	201,1	179,7
m = fix = 3	144,5	48,9
m = fix = 5	**181,8**	**132,9**

Construction detail	Transversal non-load carrying attachment	
Reference	Shimanuki, H. and Okawa, T. (2013) Effect of Stress Ratio on the Enhancement of Fatigue Strength in High Performance Steel Welded Joints by Ultrasonic Impact Treatment. vol. 13, no. 1, pp. 155–161, Mar. 2013.	
Material	Denomination	SBHS500
	Plate thickness	12 mm
Mech. properties	$R_{p0,2}$	665 MPa
	R_m	575 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	298,6	975320	1
2	249,0	2116320	1
3	219,2	3402381	1
4	198,9	3342189	1
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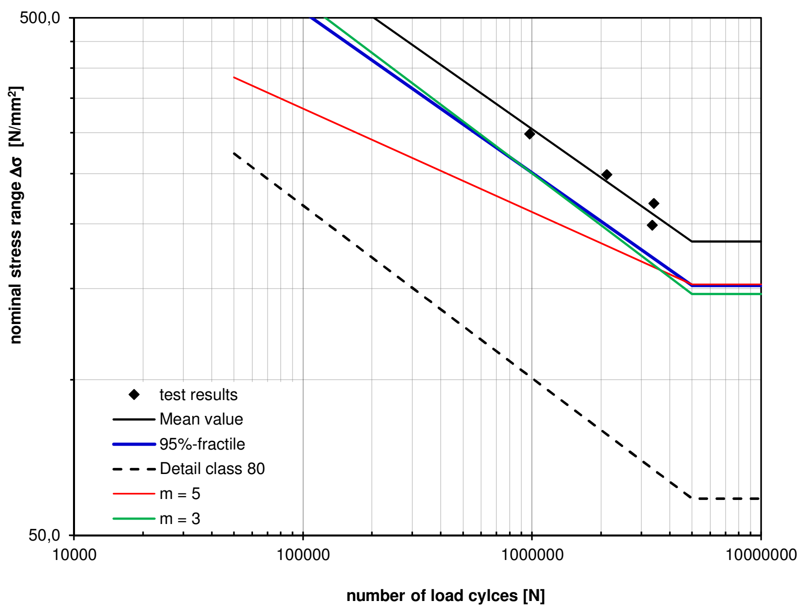
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

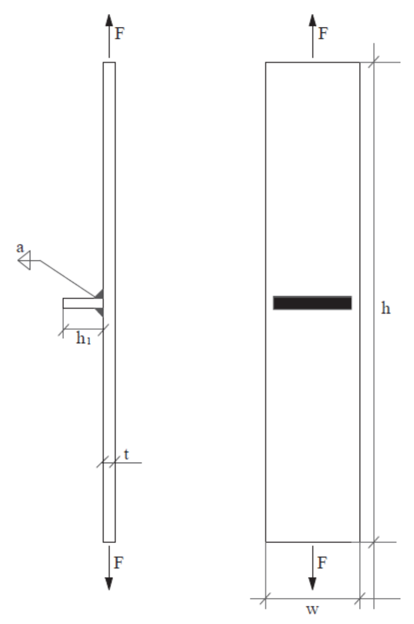
S-N curve



Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 3,21	245,8	202,3
m = fix = 3	246,4	198,8
m = fix = 5	**243,2**	**183,6**

Construction detail	Transversal non-load carrying attachment	
Reference	Shimanuki, H. and Okawa, T. (2013) Effect of Stress Ratio on the Enhancement of Fatigue Strength in High Performance Steel Welded Joints by Ultrasonic Impact Treatment. vol. 13, no. 1, pp. 155–161, Mar. 2013.	
Material	Denomination	SBHS500
	Plate thickness	12 mm
Mech. properties	$R_{p0,2}$	665 MPa
	R_m	575 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	0,3 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	298,8	452704	1
2	249,1	1288480	1
3	199,4	1696123	1
4	174,7	4985106	1
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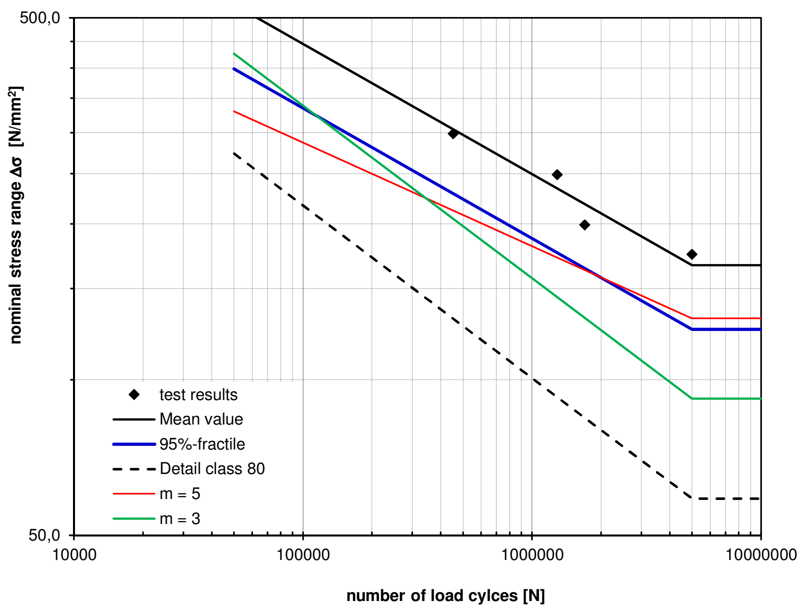
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

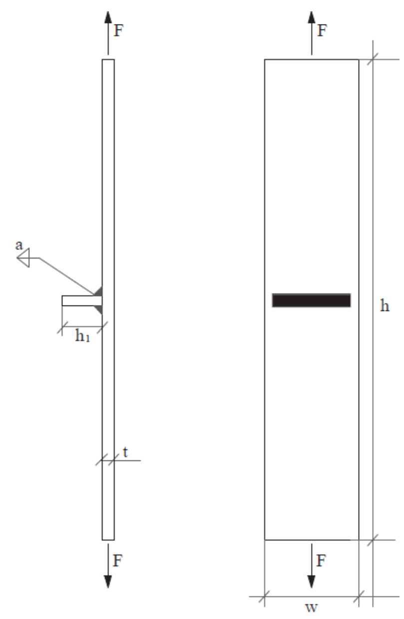
S-N curve



Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 3,98	209,6	157,6
m = fix = 3	204,6	124,7
m = fix = 5	**212,8**	**157,8**

Construction detail	Transversal non-load carrying attachment	
Reference	Shimanuki, H. and Okawa, T. (2013) Effect of Stress Ratio on the Enhancement of Fatigue Strength in High Performance Steel Welded Joints by Ultrasonic Impact Treatment. vol. 13, no. 1, pp. 155–161, Mar. 2013.	
Material	Denomination Plate thickness	SBHS500 12 mm
Mech. properties	$R_{p0,2}$ R_m	665 MPa 575 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration Type of collective Axial/Bending force	0,5 [-] Constant amplitude Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	251,1	129771	1
2	200,7	600198	1
3	190,3	3167927	1
4	175,4	4691566	1
5			
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7			
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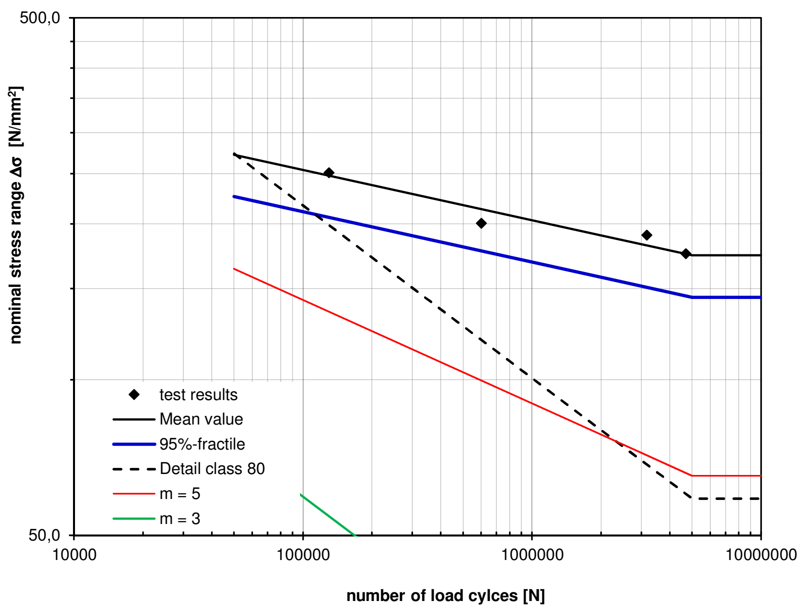
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

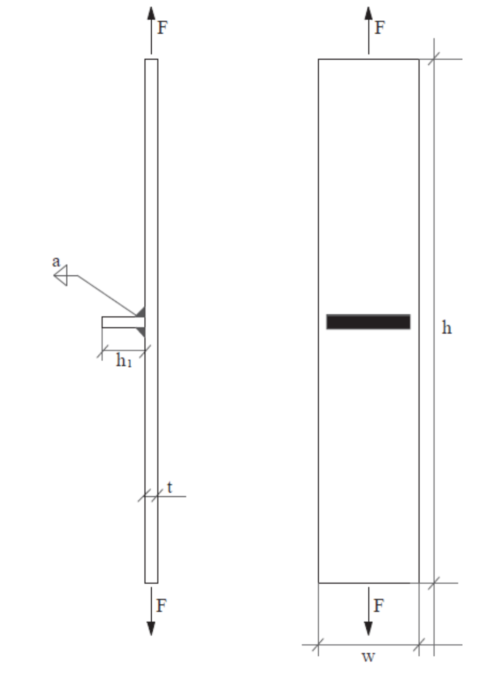
S-N curve



Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 10,28	190,0	157,8
m = fix = 3	162,7	21,9
m = fix = 5	**177,6**	**78,4**

Construction detail	Transversal non-load carrying attachment		
Reference	Yin, D., Wang, D., Jing, H. and Huo, L. (2010) The effects of ultrasonic peening treatment on the ultra-long life fatigue behavior of welded joints. vol. 31, no. 7, pp. 3299–3307, Aug. 2010.		
Material	Denomination	Q235	
	Plate thickness	3	mm
Mech. properties	$R_{p0,2}$	-	MPa
	R_m	235	MPa
Datail category according to EC		FAT 80	
Post-weld treatment	HFMI	UPT	
Fatigue loading	Stress ration	-1	[-]
	Type of collective	Constant amplitude	
	Axial/Bending force	Axial	

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	314,4	5524919	1
2	309,5	7193579	1
3	304,7	10626297	1
4	274,6	23999717	1
5	278,1	50597569	1
6	247,5	109777108	1
7	264,4	160311719	1
8	272,0	299614410	1
9	214,8	390105249	1
10	266,1	399161524	1
11	230,9	901514759	1
12	221,6	1040556888	1
13	214,1	1528308523	1
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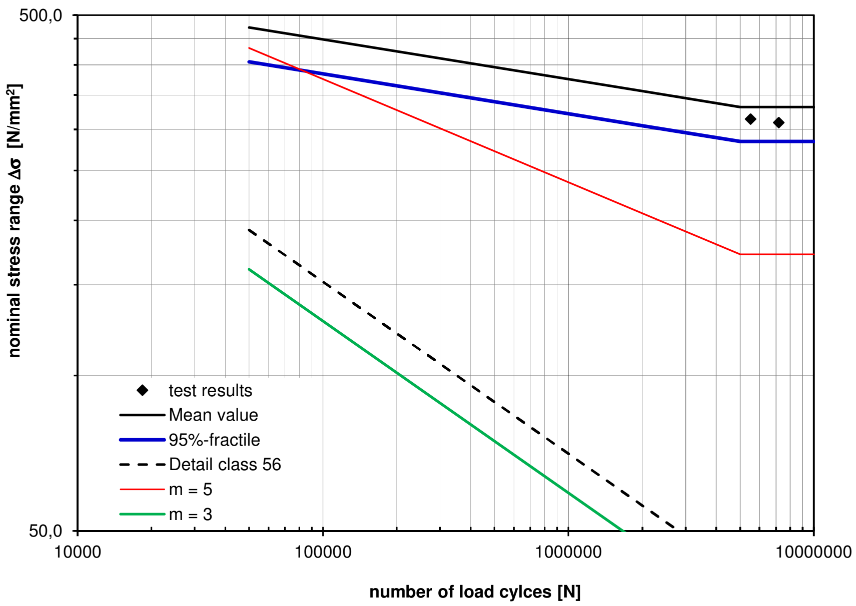
Comments:

* use "0" for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

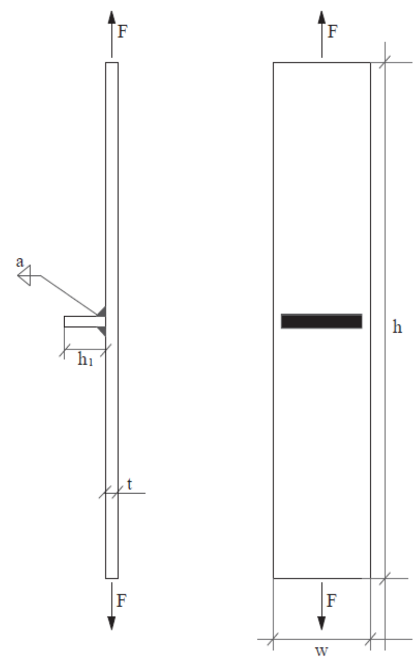
S-N curve



Slope	Mean S-N curve ($P_{Ü}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{Ü}$ = 95%) $\Delta\sigma_C$
m = variable = 12,97	355,8	305,2
m = fix = 3	1004,3	47,0
m = fix = 5	**585,2**	**206,3**

Construction detail	Transversal non-load carrying attachment	
Reference	Yin, D., Wang, D., Jing, H. and Huo, L. (2010) The effects of ultrasonic peening treatment on the ultra-long life fatigue behavior of welded joints. vol. 31, no. 7, pp. 3299–3307, Aug. 2010.	
Material	Denomination	Q345
	Plate thickness	3 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	345 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UPT
Fatigue loading	Stress ration	-1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	398,3	7876718	1
2	390,2	9918892	1
3	355,5	10524653	1
4	326,1	13607167	1
5	336,5	21435963	1
6	344,8	29213731	1
7	307,7	38778321	1
8	294,4	238830680	1
9	288,5	522987074	1
10	287,5	581111052	1
11	261,9	604536048	1
12	287,6	1168081993	1
13	287,6	1332550124	1
14	262,9	1540333645	1
15	246,3	2976226148	1
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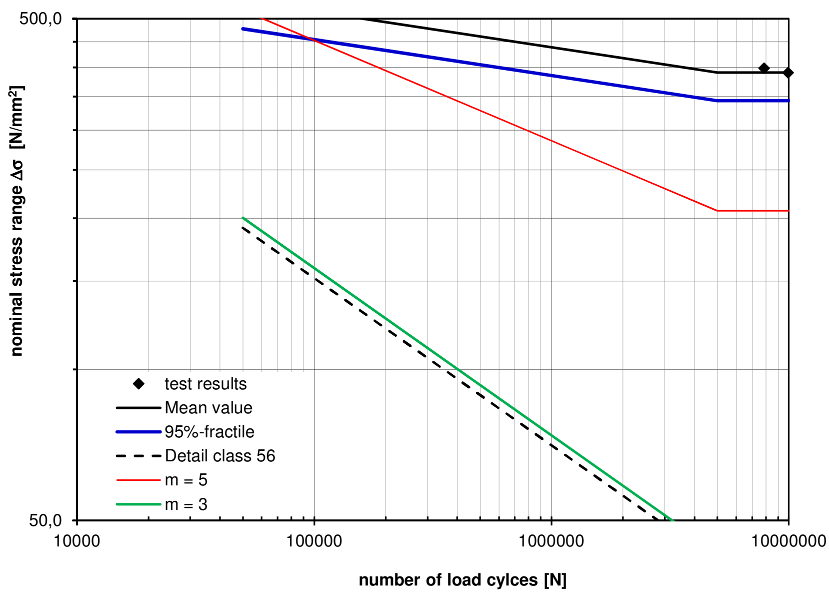
Comments:

* use "0" for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

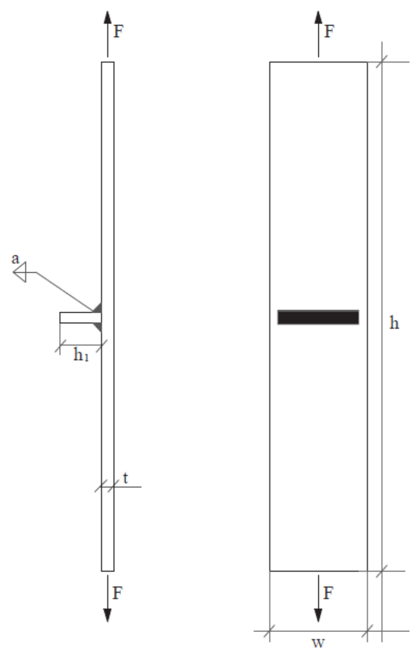
S-N curve



Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 13,95	417,4	366,6
m = fix = 3	1255,3	58,6
m = fix = 5	**716,2**	**248,7**

Construction detail	**Transversal non-load carrying attachment**	
Reference	Ermolaeva, N.S. and Hermans, M.J.M. (2014) Research on Post-weld Impact Treatments of High-strength Steel. International Ocean and Polar Engineering Conference Busan, Korea, June, 2014, pp.410-417.	
Material	Denomination	S690
	Plate thickness	20 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	690 MPa
Datail category according to EC		FAT 71
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	250,0	410556	1
2	250,0	651559	1
3	250,0	845913	1
4	410,0	34729	1
5	410,0	42453	1
6	410,0	64721	1
7	250,0	2371374	1
8	410,0	92282	1
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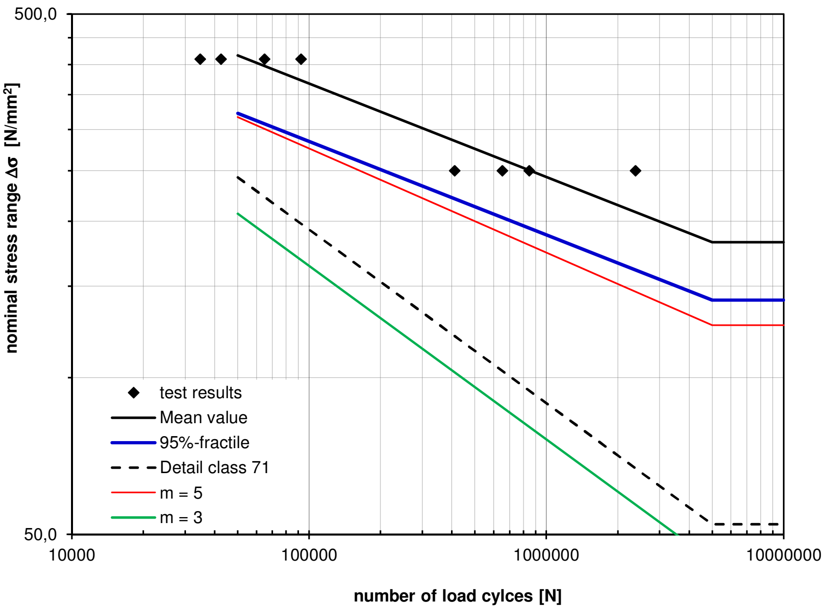
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

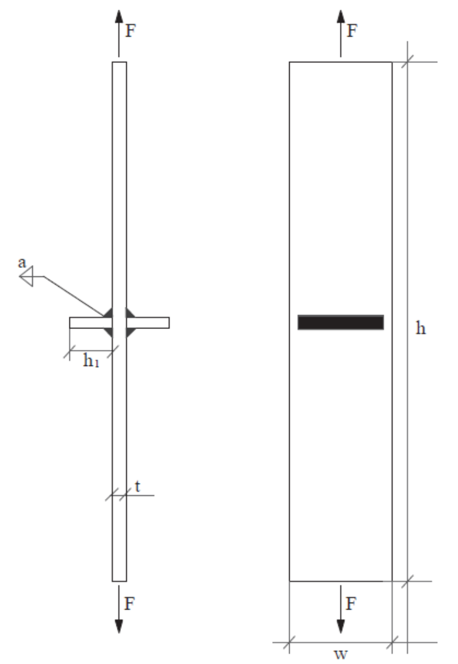
S-N curve



Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 5,57	214,7	166,2
m = fix = 3	152,4	60,4
m = fix = 5	**205,1**	**151,5**

Construction detail	Cruciform welded joint attachment	
Reference	Huo, L.X.., Wang, D., Zhang, Y.F. and Chen, J.M. (2000) Investigation on Improving Fatigue Properties of Welded Joints by Ultrasonic Peening Method. Key Engineering Materials, vol. 183–187, pp. 1315–1320, 2000.	
Material	Denomination	Q235B
	Plate thickness	8 mm
Mech. properties	$R_{p0,2}$	436 MPa
	R_m	267 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UPT
Fatigue loading	Stress ration	0,25 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Bending

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	272,6	393391	1
2	262,6	655175	1
3	250,7	620708	1
4	250,9	1304280	1
5	239,4	1558383	1
6	228,6	3355797	1
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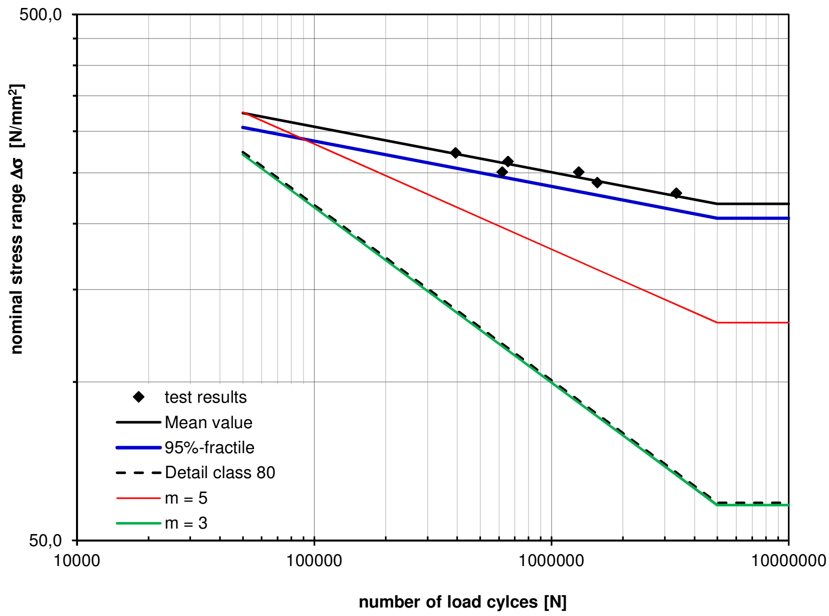
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

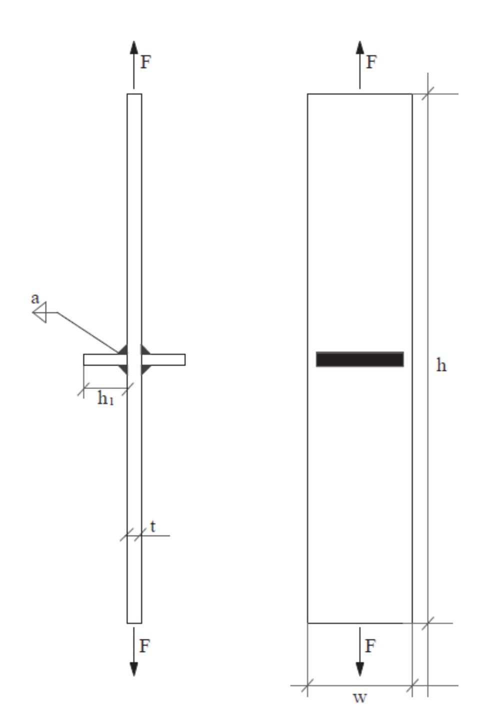
S-N curve



Slope	Mean S-N curve ($P_ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_ü$ = 95%) $\Delta\sigma_C$
m = variable = 11,59	236,1	221,8
m = fix = 3	199,7	79,2
m = fix = 5	**218,6**	**155,7**

Construction detail	Cruciform welded joint attachment		
Reference	Huo, L.X.., Wang, D., Zhang, Y.F. and Chen, J.M. (2000) Investigation on Improving Fatigue Properties of Welded Joints by Ultrasonic Peening Method. Key Engineering Materials, vol. 183–187, pp. 1315–1320, 2000.		
Material	Denomination	Q235B	
	Plate thickness	8 mm	
Mech. properties	$R_{p0,2}$	436 MPa	
	R_m	267 MPa	
Datail category according to EC		FAT 80	
Post-weld treatment	HFMI	UPT	
Fatigue loading	Stress ration	-0,5 [-]	
	Type of collective	Constant amplitude	
	Axial/Bending force	Bending	

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	343,9	303736	1
2	320,8	574795	1
3	309,8	932306	1
4	297,4	1332937	1
5	287,4	1621981	1
6	274,8	2318979	1
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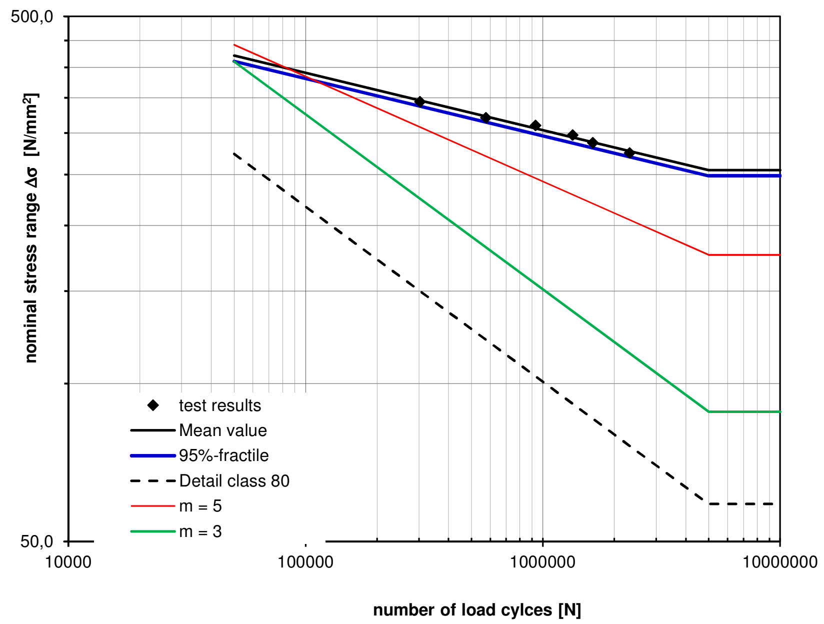
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

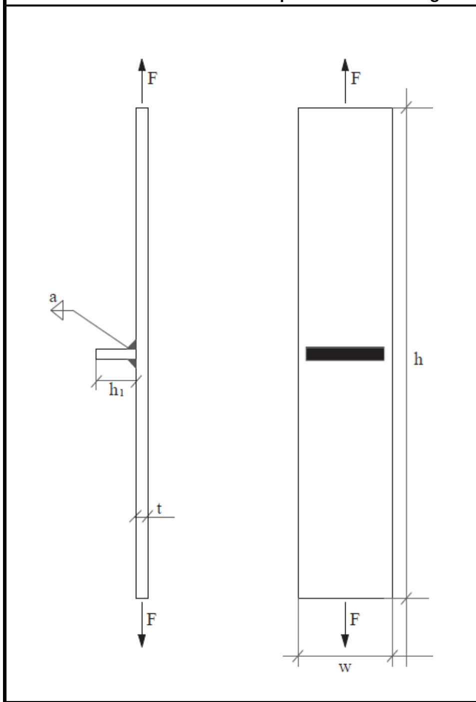


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 9,18	281,6	274,7
m = fix = 3	239,2	120,0
m = fix = 5	**263,6**	**211,1**

Construction detail	**Transversal non-load carrying attachment**	
Reference	Han, S.H., Han, J.W., Nam, Y.Y. and Cho, I.H. (2009) Fatigue life improvement for cruciform welded joint by mechanical surface treatment using hammer peening and ultrasonic nanocrystal surface modification. Fatigue & Fracture of Engineering Materials & Structures, vol. 32, no. 7, pp. 573–579, Jul. 2009.	
Material	Denomination	SM490B
	Plate thickness	16 mm
Mech. properties	$R_{p0,2}$	514 MPa
	R_m	352 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	PHP
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	300,7	102916	1
2	311,0	120389	1
3	300,7	203050	1
4	290,8	440135	1
5	275,8	704531	1
6	250,6	1048169	1
7	240,6	1419383	1
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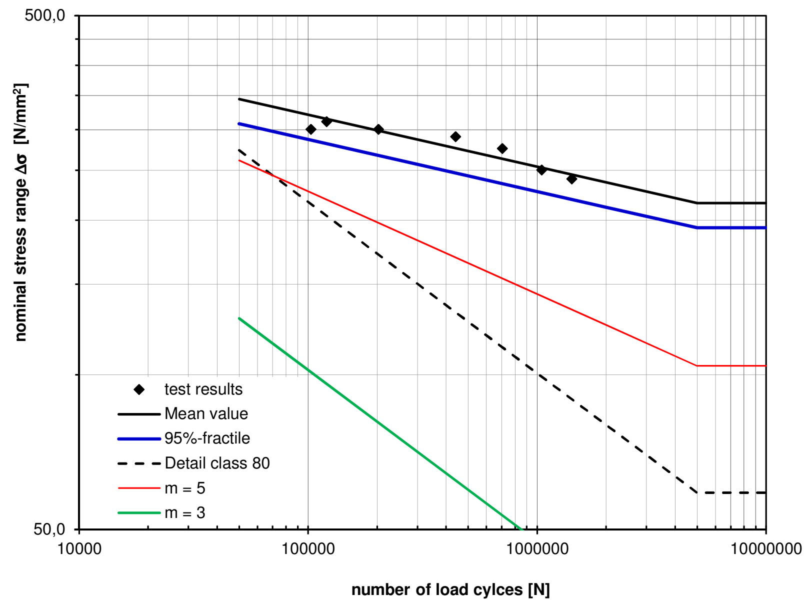
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

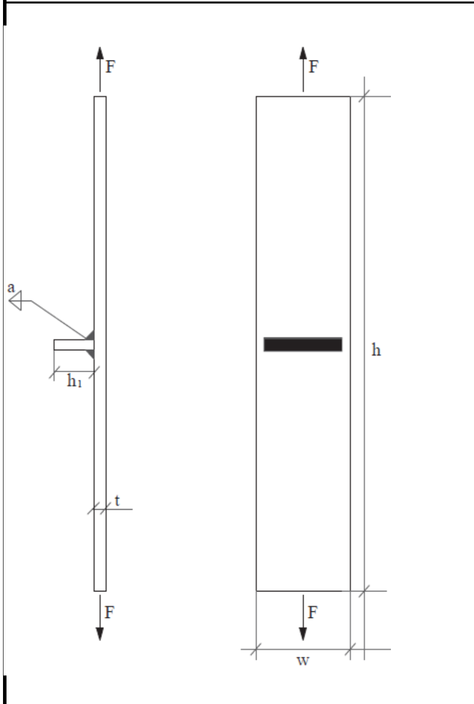
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 9,88	237,0	212,1
m = fix = 3	161,3	37,7
m = fix = 5	**201,2**	**125,0**

Construction detail	Transversal non-load carrying attachment		
Literatur	Deguchi, T., Mouri, M., Hara, J., Kano, D., Shimoda, T., Inamura, F., Fukuoka, T. and Koshio, K. (2012) Fatigue strength improvement for ship structures by Ultrasonic Peening. Journal of Marine Science and Technology, vol. 17, no. 3, pp. 360–369, Sep. 2012.		
Material	Denomination	KA36	
	Plate thickness	16 mm	
Mech. properties	$R_{p0,2}$	490-620 MPA	
	R_m	355 MPa	
Datail category according to EC		FAT 80 (*)	
Post-weld treatment	HFMI	UPT	
Fatigue loading	Stress ration	0 [-]	
	Type of collective	Constant amplitude	
	Axial/Bending force	Axial	

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	303,0	636091	1
2	262,1	1328459	1
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6			
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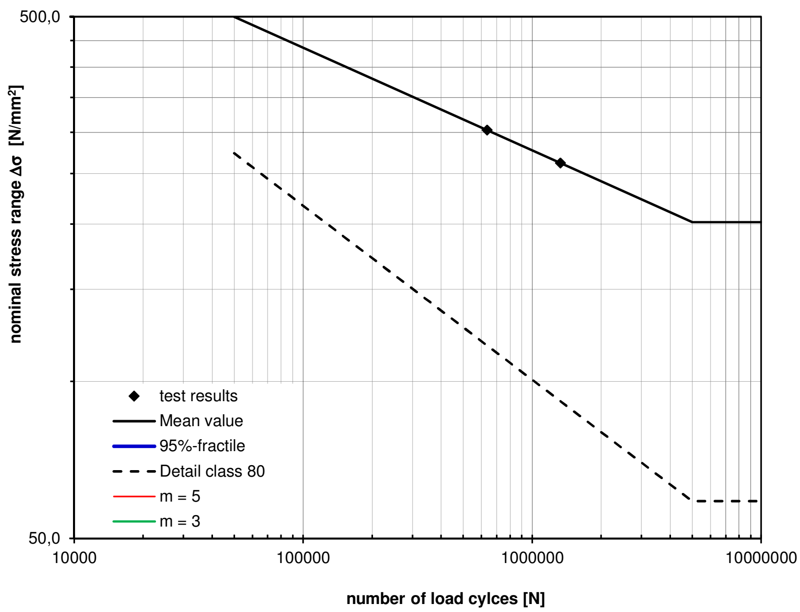
Comments: (*) The value has been assumed by the authors

* use "0" for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

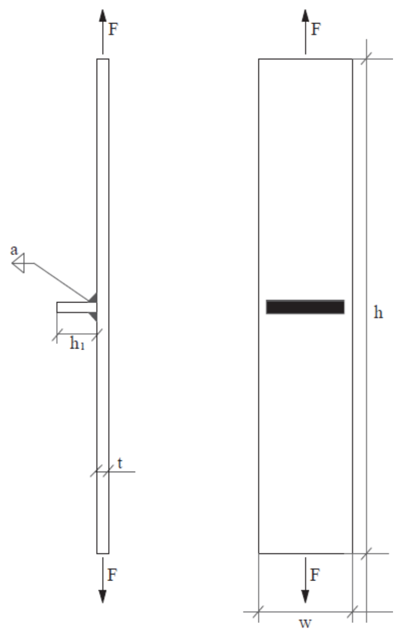


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 5,08	241,8	#DIV/0!
m = fix = 3	217,5	#DIV/0!
m = fix = 5	**241,3**	**#DIV/0!**

Construction detail	Transversal non-load carrying attachment	
Literatur	Deguchi, T., Mouri, M., Hara, J., Kano, D., Shimoda, T., Inamura, F., Fukuoka, T. and Koshio, K. (2012) Fatigue strength improvement for ship structures by Ultrasonic Peening. Journal of Marine Science and Technology, vol. 17, no. 3, pp. 360–369, Sep. 2012.	
Material	Denomination	KA36
	Plate thickness	22 mm
Mech. properties	$R_{p0,2}$	490-620 MPA
	R_m	355 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UPT
Fatigue loading	Stress ration	0 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	292,9	486659	1
2	278,3	833115	1
3	268,9	1073586	1
4			
5			
6			
7			
8			
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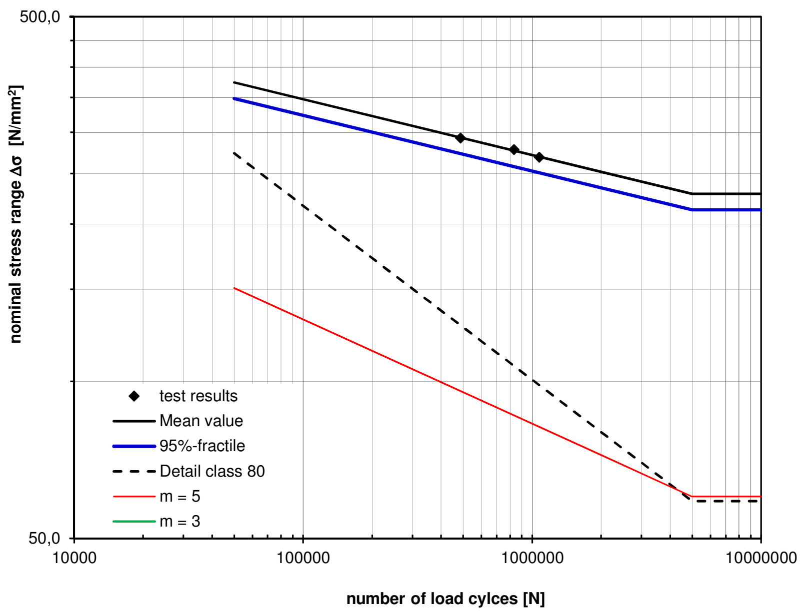
Comments:

* use "0" for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

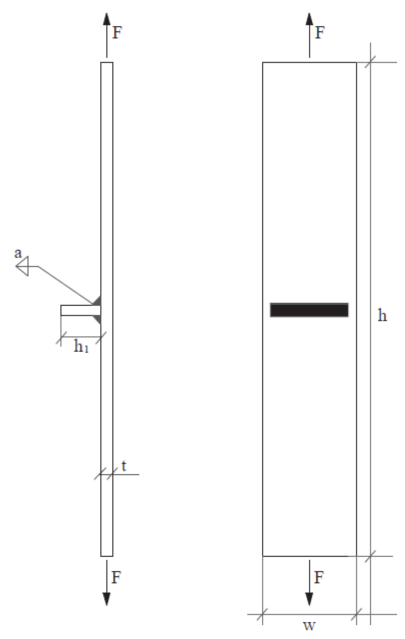


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_{Ü}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{Ü}$ = 95%) $\Delta\sigma_C$
m = variable = 9,37	252,3	235,1
m = fix = 3	202,5	2,3
m = fix = 5	**230,5**	**72,2**

Construction detail		Transversal non-load carrying attachment
Literatur	Deguchi, T., Mouri, M., Hara, J., Kano, D., Shimoda, T., Inamura, F., Fukuoka, T. and Koshio, K. (2012) Fatigue strength improvement for ship structures by Ultrasonic Peening. Journal of Marine Science and Technology, vol. 17, no. 3, pp. 360–369, Sep. 2012.	
Material	Denomination	KA36
	Plate thickness	30 mm
Mech. properties	$R_{p0,2}$	490-620 MPA
	R_m	355 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UPT
Fatigue loading	Stress ration	0 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	266,6	244155	1
2	275,9	334371	1
3	303,0	337780	1
4	251,2	462592	1
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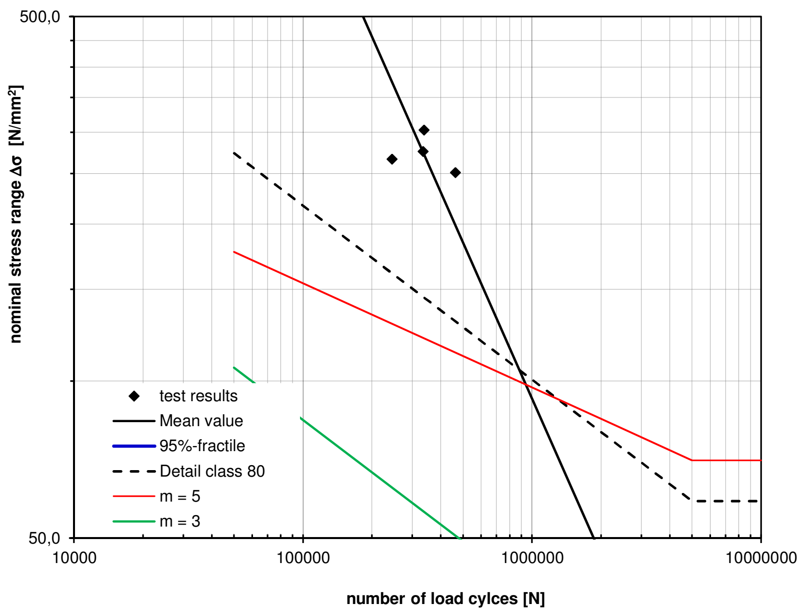
Comments:

* use "0" for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

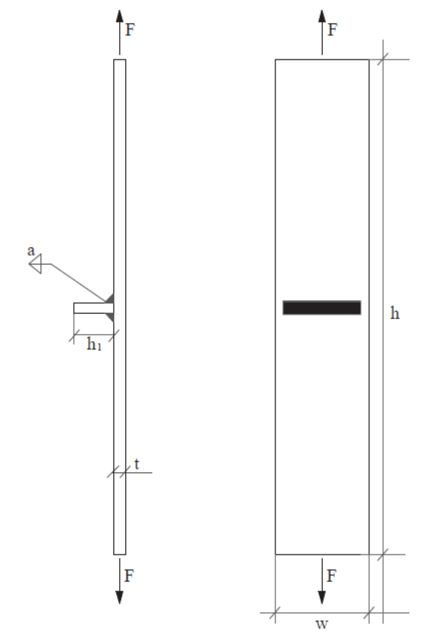
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 1,01	46,5	0,0
m = fix = 3	151,0	31,1
m = fix = 5	**191,5**	**84,7**

Construction detail	**Transversal non-load carrying attachment**
Literatur	Deguchi, T., Mouri, M., Hara, J., Kano, D., Shimoda, T., Inamura, F., Fukuoka, T. and Koshio, K. (2012) Fatigue strength improvement for ship structures by Ultrasonic Peening. Journal of Marine Science and Technology, vol. 17, no. 3, pp. 360–369, Sep. 2012.
Material	Denomination KA36 Plate thickness 16 mm
Mech. properties	$R_{p0,2}$ 490-620 MPA R_m 355 MPa
Datail category according to EC	FAT 80
Post-weld treatment	HFMI UPT
Fatigue loading	Stress ration 0,25 [-] Type of collective Constant amplitude Axial/Bending force Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	253,1	166871	1
2	232,9	695314	1
3	193,9	655173	1
4			
5			
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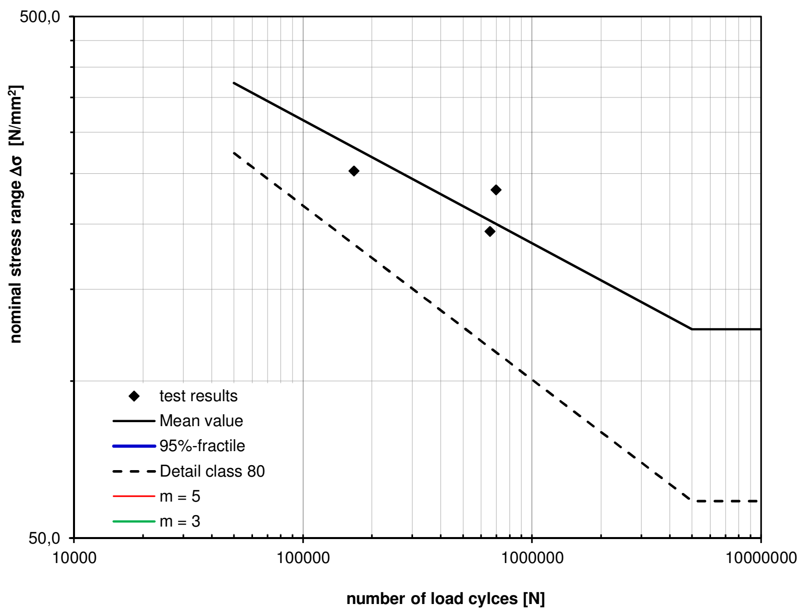
Comments:

* use "0" for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

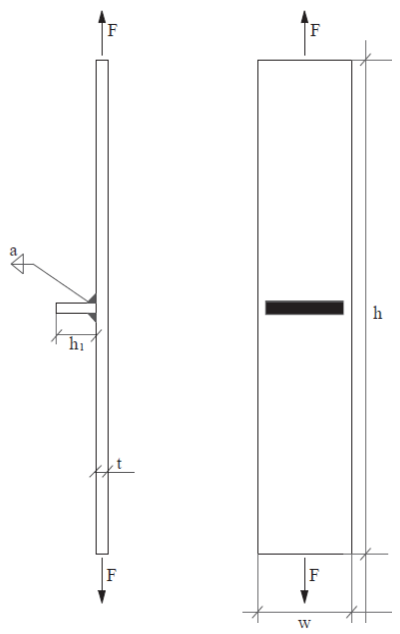


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 4,24	156,1	11,1
m = fix = 3	134,3	0,8
m = fix = 5	**165,1**	**21,7**

Construction detail	Transversal non-load carrying attachment	
Literatur	Deguchi, T., Mouri, M., Hara, J., Kano, D., Shimoda, T., Inamura, F., Fukuoka, T. and Koshio, K. (2012) Fatigue strength improvement for ship structures by Ultrasonic Peening. Journal of Marine Science and Technology, vol. 17, no. 3, pp. 360–369, Sep. 2012.	
Material	Denomination	KA36
	Plate thickness	16 mm
Mech. properties	$R_{p0,2}$	490-620 MPA
	R_m	355 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UPT
Fatigue loading	Stress ration	0,5 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	200,4	128965	1
2	171,1	395224	1
3	151,0	945387	1
4			
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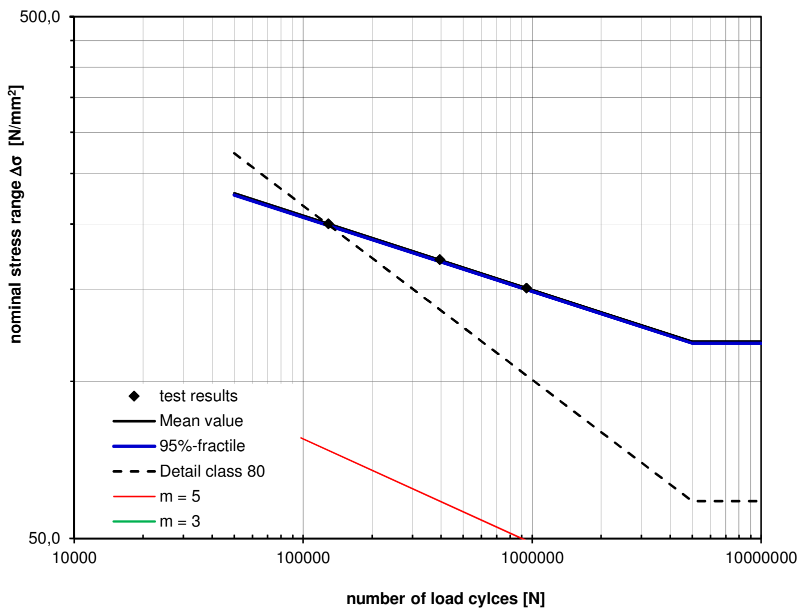
Comments:

* use "0" for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

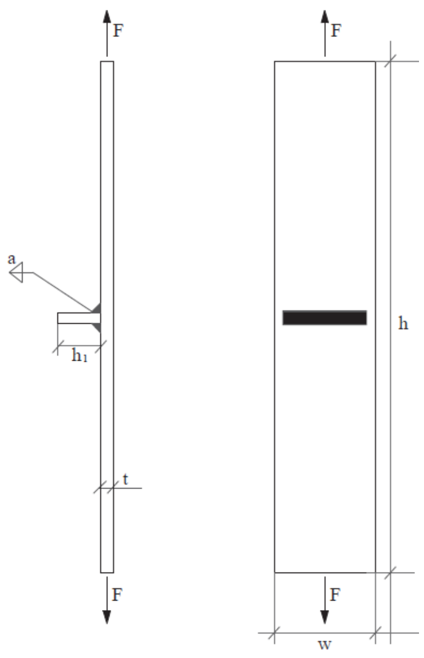


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_{Ü}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{Ü}$ = 95%) $\Delta\sigma_C$
m = variable = 7,04	135,8	134,7
m = fix = 3	98,0	0,5
m = fix = 5	**123,1**	**42,6**

Construction detail	Transversal non-load carrying attachment	
Reference	Trufiakov, V.I., Statnikov, E.S., Mikheev, P.P. and Kuzmenko, A.Z. (1998) The Efficiency of Ultrasonic Impact Treatment for Improving the Fatigue Strength of Welded Joints. IIW Document, vol. 13, pp. 1745–98, 1998.	
Material	Denomination	S420
	Plate thickness	20 mm
Mech. properties	$R_{p0,2}$	490 MPa
	R_m	420 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Bending

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Ds	load cycles N	Com. *
1	400	345000	1
2	400	450000	1
3	400	392000	1
4	400	585000	1
5	370	958000	1
6	370	1550000	1
7	370	850000	1
8	370	1100000	1
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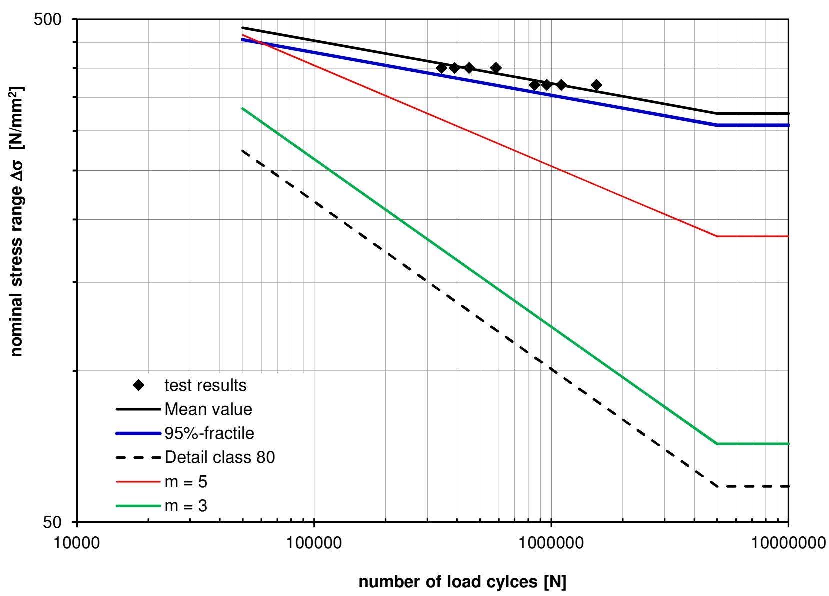
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

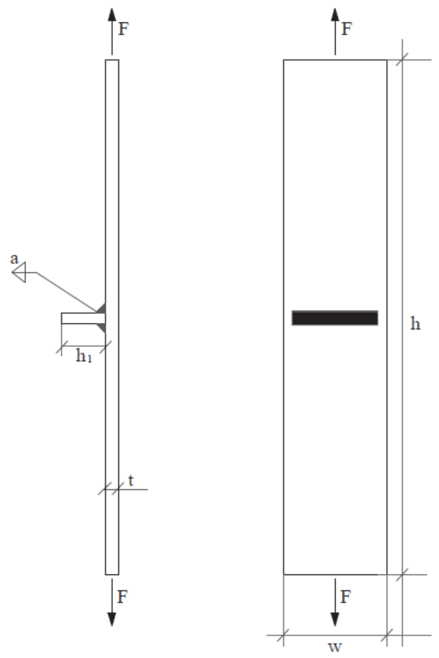
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_{Ü}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{Ü}$ = 95%) $\Delta\sigma_C$
m = variable = 11,75	351,2	332,7
m = fix = 3	269,4	97,1
m = fix = 5	**310,7**	**222,3**

Construction detail	Transversal non-load carrying attachment	
Reference	Pedersen, M.M., Mouritsen, O.Ø., Hansen, M.M.R., Andersen, M.J.G. and Wenderby, M. J (2010) Comparison of Post-Weld Treatment of High-Strength Steel Welded Joints in Medium Cycle Fatigue. Welding in the World, vol. 54, no. 7–8, pp. R208–R217, 2010.	
Material	Denomination	S700
	Plate thickness	6 mm
Mech. properties	$R_{p0,2}$	750 MPa
	R_m	700 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Bending

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Ds	load cycles N	Com. *
1	778	27413	1
2	776	35199	1
3	774	15562	1
4	732	48833	1
5	708	45417	1
6	668	83970	1
7	666	73094	1
8	659	72024	1
9	648	166486	1
10	547	244956	1
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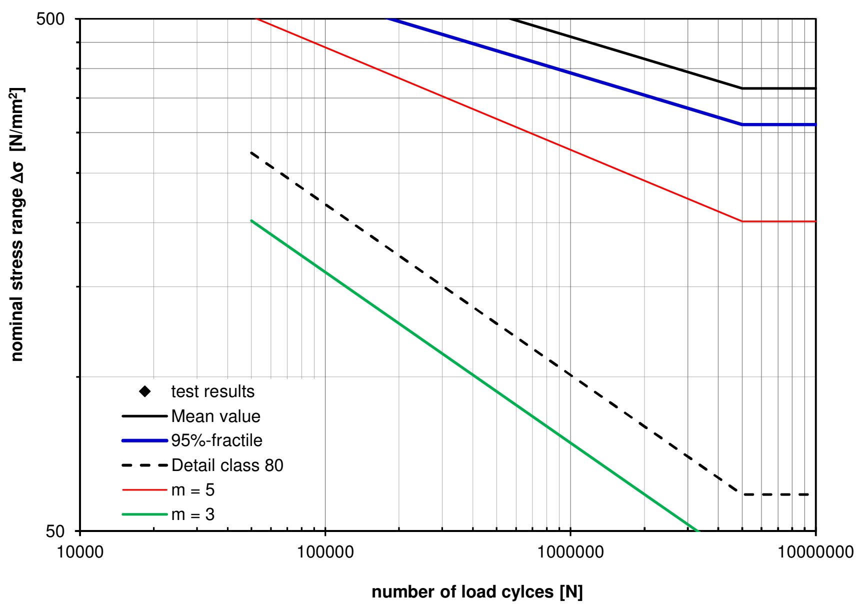
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

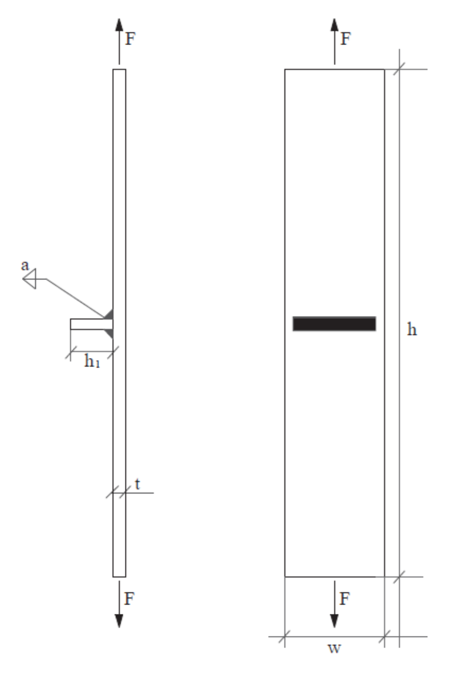


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 6,94	417,5	354,8
m = fix = 3	215,0	59,0
m = fix = 5	**343,1**	**241,5**

Construction detail	Transversal non-load carrying attachment	
Reference	Galtier, A. and Statnikov, E.S. (2004) The Influence of Ultrasonic Impact Treatment on Fatigue Behavior of Welded Joints in High-Strength Steel. Welding in the World, vol. 48, no. 5–6, pp. 61–66, 2004.	
Material	Denomination	Usiform 355
	Plate thickness	5 mm
Mech. properties	$R_{p0,2}$	355 MPa
	R_m	500 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Bending

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	520	111741	1
2	480	243920	1
3	480	308952	1
4	440	646047	1
5	440	800898	1
6	419	1266613	1
7	400	1179070	1
8	380	1773510	1
9	380	2091093	1
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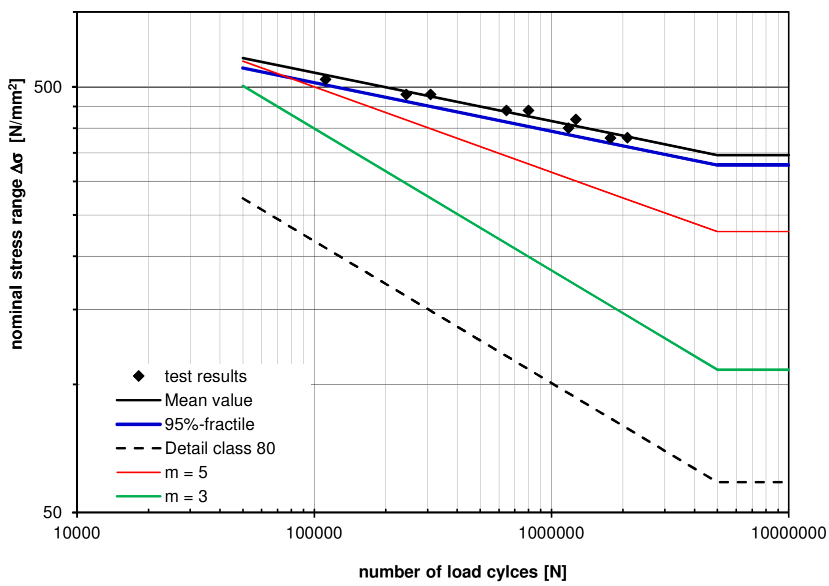
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

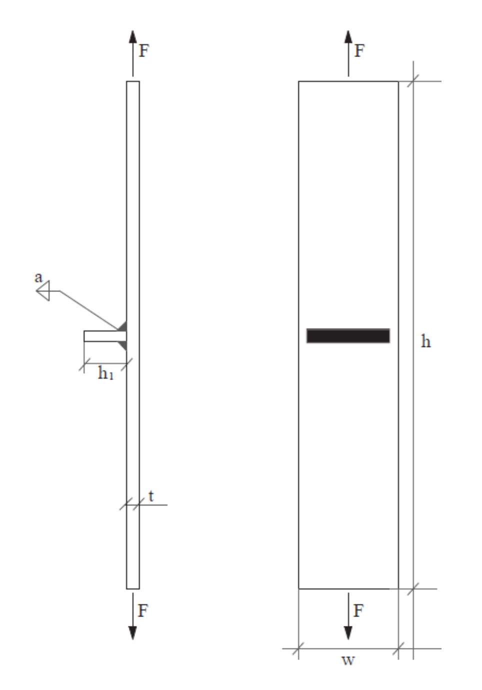
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 8,78	383,9	363,7
m = fix = 3	301,1	147,0
m = fix = 5	**349,0**	**274,7**

Construction detail	Transversal non-load carrying attachment	
Reference	Galtier, A. and Statnikov, E.S. (2004) The Influence of Ultrasonic Impact Treatment on Fatigue Behavior of Welded Joints in High-Strength Steel. Welding in the World, vol. 48, no. 5–6, pp. 61–66, 2004.	
Material	Denomination	Usiform 700
	Plate thickness	5 mm
Mech. properties	$R_{p0,2}$	750 MPa
	R_m	700 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Bending

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	680	59497	1
2	681	163329	1
3	641	81537	1
4	641	225441	1
5	601	495654	1
6	601	1196081	1
7	561	830097	1
8	561	481656	1
9	520	724488	1
10	520	860362	1
11	520	1851382	1
12	480	2804791	1
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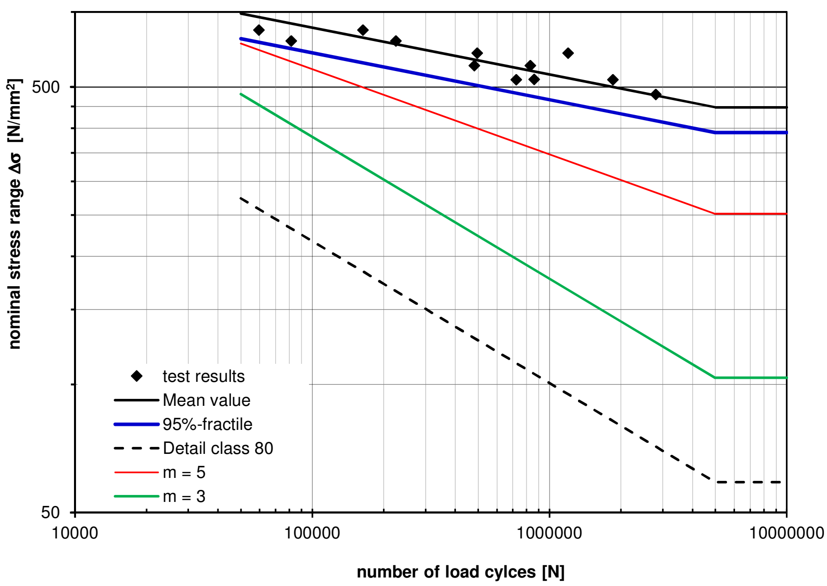
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

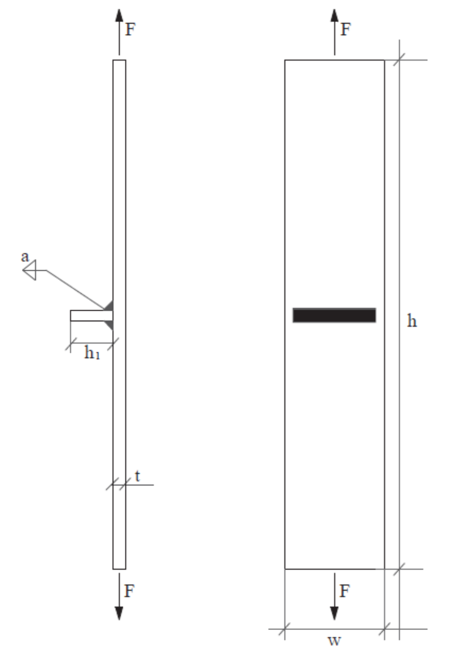


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 9,07	495,4	432,2
m = fix = 3	359,7	140,6
m = fix = 5	**435,6**	**302,3**

Construction detail	Transversal non-load carrying attachment	
Reference	Statnikov, E. S., Muktepavel, V. O. and Blomqvist, A. (2002) Comparison of Ultrasonic Impact Treatment (UIT) and Other Fatigue Life Improvement Methods, Weld World, vol. 46, no. 3–4, pp. 20–32, 2002.	
Material	Denomination	Weldox 420
	Plate thickness	20 mm
Mech. properties	$R_{p0,2}$	587 MPa
	R_m	468 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Bending

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	400	556900	1
2	400	508200	1
3	400	385000	1
4	370	772000	1
5	370	1092100	1
6	370	715300	1
7	370	895000	1
8			
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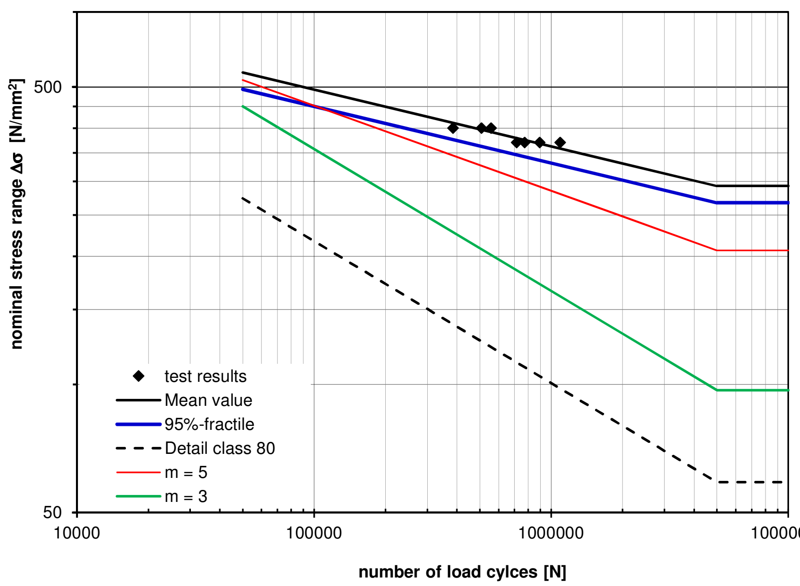
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

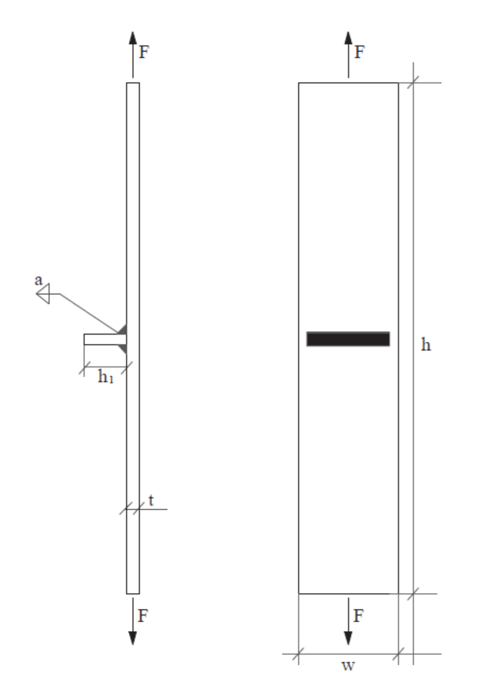


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_{\ddot{U}}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{\ddot{U}}$ = 95%) $\Delta\sigma_C$
m = variable = 7,5	330,5	301,8
m = fix = 3	265,3	131,6
m = fix = 5	**307,1**	**248,1**

Construction detail	Transversal non-load carrying attachment	
Reference	Kudryavtsev, Y., Kleiman, J., Lugovskoy, A., Lobanov, L., Knysh, V., Voitenko, O. and Prokopenko, G. (2005) Rehabilitation and Repair of Welded Elements and Structures by Ultrasonic Peening. Weld World, vol. 51, no. 7–8, pp. 47–53, Jul. 2007.	
Material	Denomination	E460
	Plate thickness	10 mm
Mech. properties	$R_{p0,2}$	579 MPa
	R_m	614 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	-
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Bending

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	428	344096	1
2	419	364527	1
3	387	516324	1
4	341	470613	1
5	327	598875	1
6	347	601347	1
7	363	704713	1
8	335	765239	1
9	332	797425	1
10	320	893089	1
11	322	1254611	1
12	337	1715904	1
13	313	1730101	1
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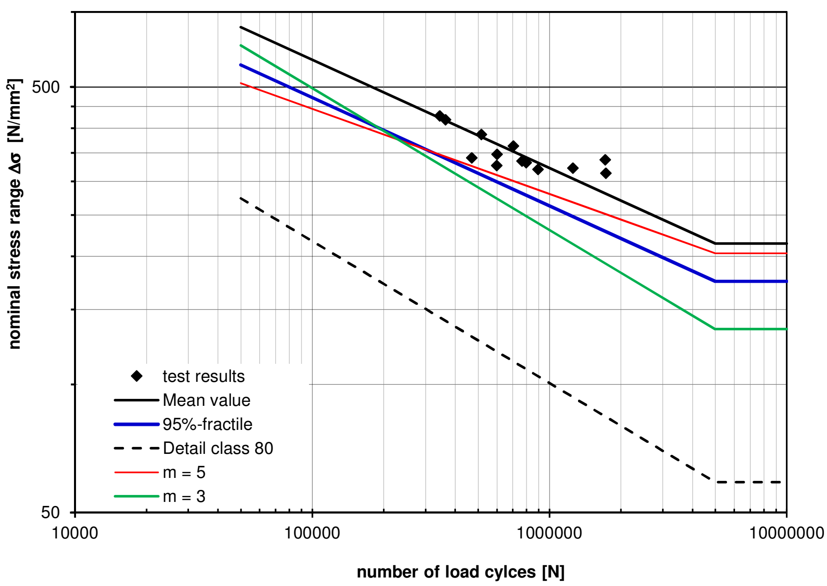
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

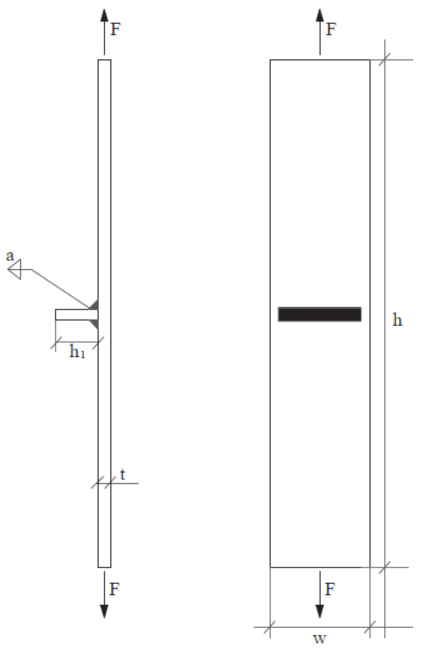


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_{Ü}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{Ü}$ = 95%) $\Delta\sigma_C$
m = variable = 3,93	270,5	220,5
m = fix = 3	249,7	183,0
m = fix = 5	**285,8**	**244,0**

Construction detail	Transversal non-load carrying attachment	
Reference	Kudryavtsev, Y., Kleiman, J., Lugovskoy, A., Lobanov, L., Knysh, V., Voitenko, O. and Prokopenko, G. (2005) Rehabilitation and Repair of Welded Elements and Structures by Ultrasonic Peening. Weld World, vol. 51, no. 7–8, pp. 47–53, Jul. 2007.	
Material	Denomination	S260
	Plate thickness	20 mm
Mech. properties	$R_{p0,2}$	465 MPa
	R_m	260 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UPT
Fatigue loading	Stress ration	0 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	202,3	306993	1
2	203,1	491316	1
3	196,1	840110	1
4	191,8	831376	1
5	190,0	728300	1
6	179,2	1125676	1
7	184,2	1202700	1
8	186,1	1600328	1
9	175,0	1951822	1
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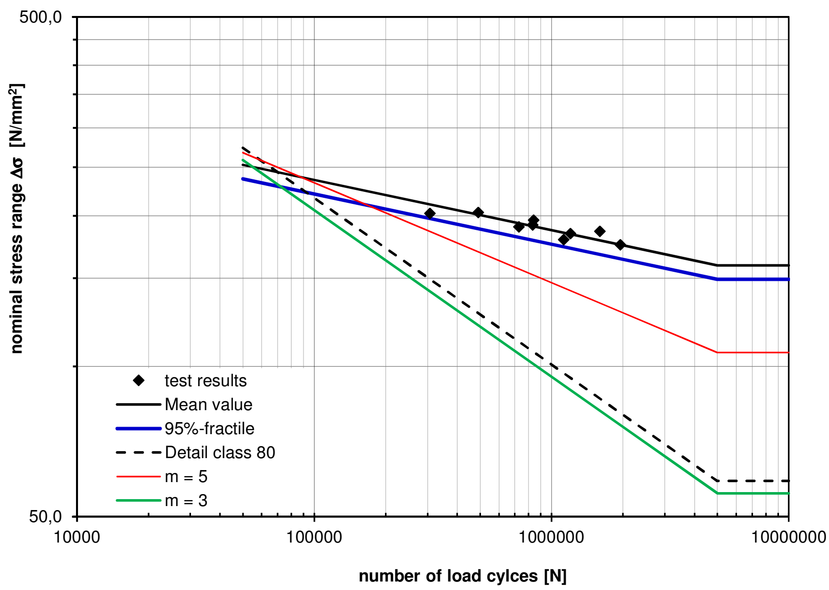
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

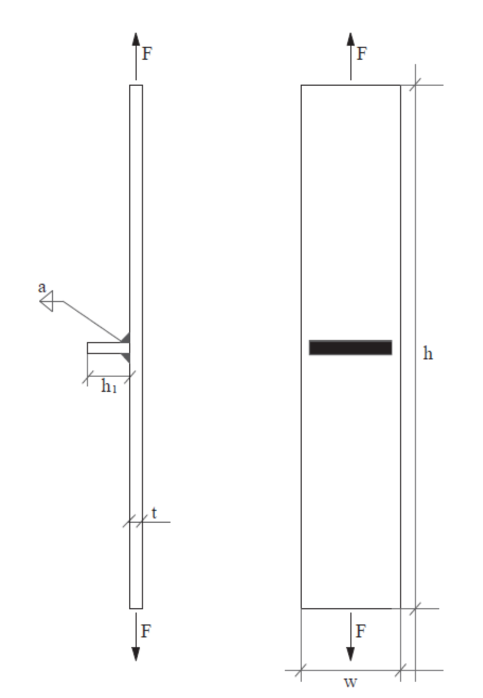


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 9,95	174,6	163,7
m = fix = 3	144,3	75,6
m = fix = 5	**160,9**	**127,9**

Construction detail	Transversal non-load carrying attachment		
Literatur	Okawa, T., Shimanuki, H., Funatsu, Y., Nose, T. and Sumi, Y. (2012) Effect of preload and stress ratio on fatigue strength of welded joints improved by ultrasonic impact treatment, Welding in the world, vol. 57, no. 2, pp. 235–241, 2012.		
Material	Denomination	AH36	
	Plate thickness	20	mm
Mech. properties	$R_{p0,2}$	580	MPa
	R_m	520	MPa
Datail category according to EC		FAT 80	
Post-weld treatment	HFMI	UIT	
Fatigue loading	Stress ration	0,1	[-]
	Type of collective	Constant amplitude	
	Axial/Bending force	Axial	

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	270,0	818000	1
2	260,0	1067000	1
3	300,0	304000	1
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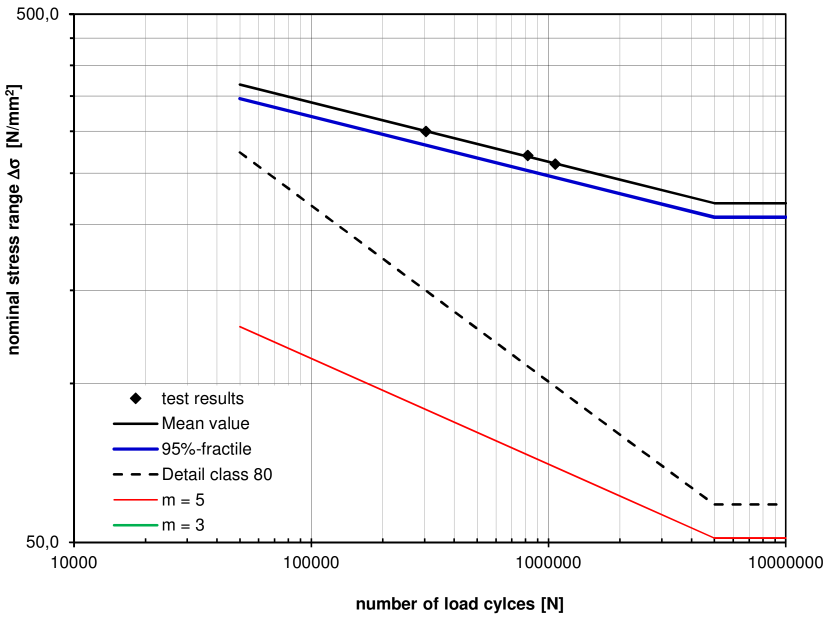
Comments:

* use "0" for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

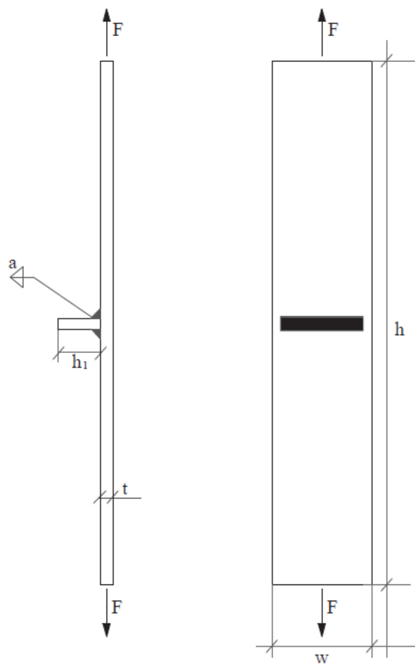


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_{\ddot{U}}$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_{\ddot{U}}$ = 95%) $\Delta\sigma_C$
m = variable = 8,91	243,1	228,7
m = fix = 3	189,1	1,3
m = fix = 5	**220,1**	**61,2**

Construction detail	Transversal non-load carrying attachment	
Literatur	Okawa, T., Shimanuki, H., Funatsu, Y., Nose, T. and Sumi, Y. (2012) Effect of preload and stress ratio on fatigue strength of welded joints improved by ultrasonic impact treatment, Welding in the world, vol. 57, no. 2, pp. 235–241, 2012.	
Material	Denomination	AH36
	Plate thickness	20 mm
Mech. properties	$R_{p0,2}$	580 MPa
	R_m	520 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	0,5 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	175,0	346000	1
2	150,0	503000	1
3	135,0	3450000	1
4			
5			
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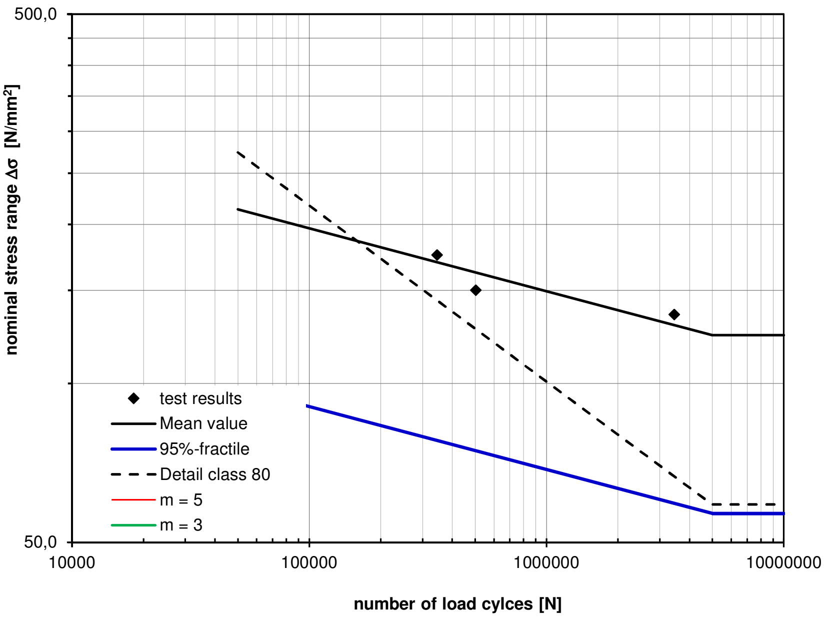
Comments:

* use "0" for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

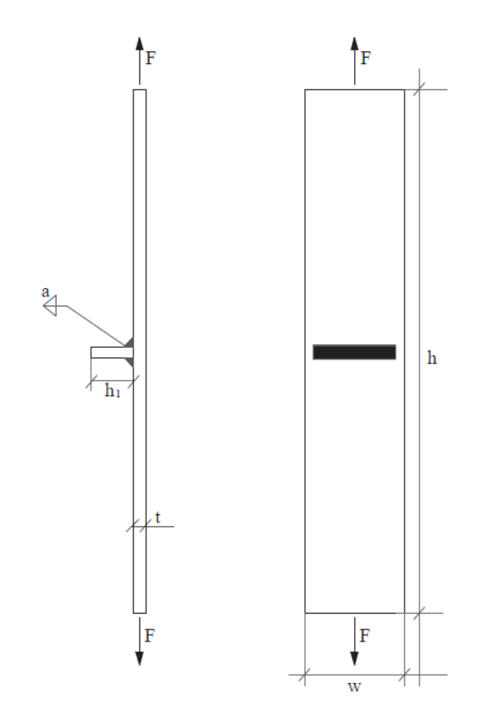


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 8,39	137,6	63,2
m = fix = 3	114,3	0,6
m = fix = 5	**128,3**	**18,9**

Construction detail	Transversal non-load carrying attachment	
Literatur	Okawa, T., Shimanuki, H., Funatsu, Y., Nose, T. and Sumi, Y. (2012) Effect of preload and stress ratio on fatigue strength of welded joints improved by ultrasonic impact treatment, Welding in the world, vol. 57, no. 2, pp. 235–241, 2012.	
Material	Denomination	AH36
	Plate thickness	20 mm
Mech. properties	$R_{p0,2}$	580 MPa
	R_m	520 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	-1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	420,0	378000	1
2	400,0	990000	1
3	380,0	2295000	1
4			
5			
6			
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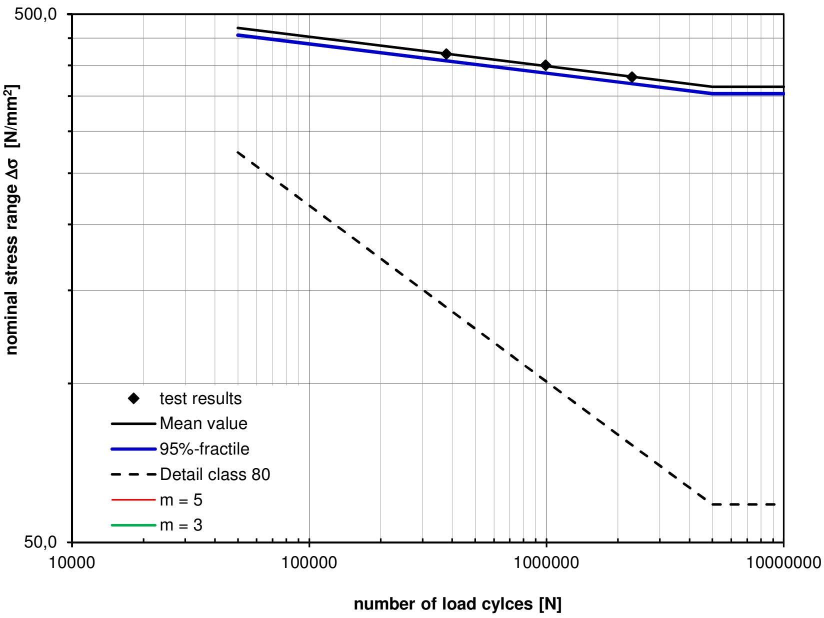
Comments:

* use "0" for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

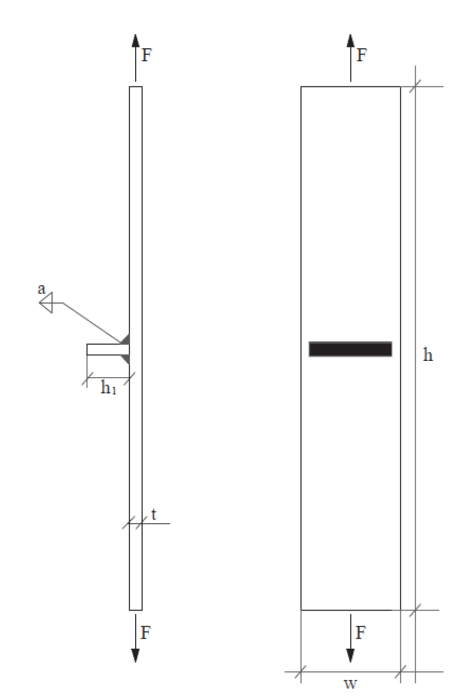
S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 18,01	383,5	371,8
m = fix = 3	311,9	0,1
m = fix = 5	**344,4**	**21,0**

Construction detail	**Transversal non-load carrying attachment**	
Literatur	Kuhlmann, U., Bergmann, J., Dürr, A., Thumser. R., Günther, H.P.and Gerth, U. (2005) Erhöhung der Ermüdungsfestigkeit von geschwei\s sten höherfesten Baustählen durch Anwendung von Nachbehandlungsverfahren, Stahlbau, vol. 74, no. 5, pp. 358–365, 2005.	
Material	Denomination	S355
	Plate thickness	12 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	355 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	307,8	108429	1
2	265,4	315067	1
3	261,7	349246	1
4	279,2	363666	1
5	254,1	455142	1
6	231,3	978172	1
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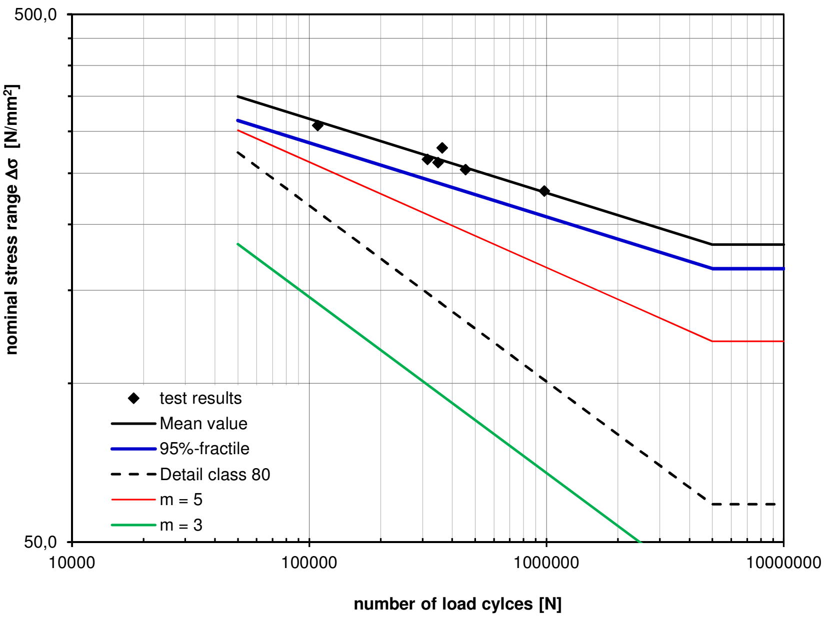
Comments:

* use "0" for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

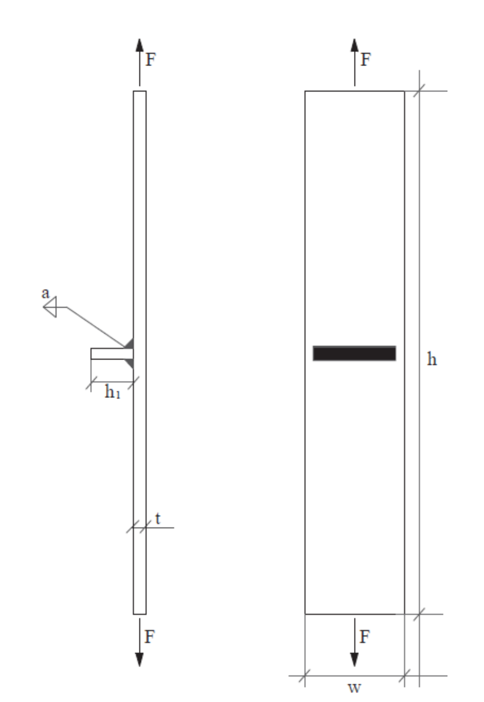


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 7,12	208,2	187,5
m = fix = 3	149,0	53,6
m = fix = 5	**187,7**	**144,2**

Construction detail	Transversal non-load carrying attachment		
Literatur	Kuhlmann, U., Bergmann, J., Dürr, A., Thumser. R., Günther, H.P.and Gerth, U. (2005) Erhöhung der Ermüdungsfestigkeit von geschwei\s sten höherfesten Baustählen durch Anwendung von Nachbehandlungsverfahren, Stahlbau, vol. 74, no. 5, pp. 358–365, 2005.		
Material	Denomination	S460	
	Plate thickness	12	mm
Mech. properties	$R_{p0,2}$	-	MPa
	R_m	460	MPa
Datail category according to EC		FAT 80	
Post-weld treatment	HFMI	UIT	
Fatigue loading	Stress ration	0,1	[-]
	Type of collective	Constant amplitude	
	Axial/Bending force	Axial	

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range Δσ	load cycles N	Com. *
1	357,6	165447	1
2	387,1	51448	1
3	332,9	260287	1
4	295,4	221555	1
5	256,7	315168	1
6	272,4	521436	1
7	261,9	1436926	1
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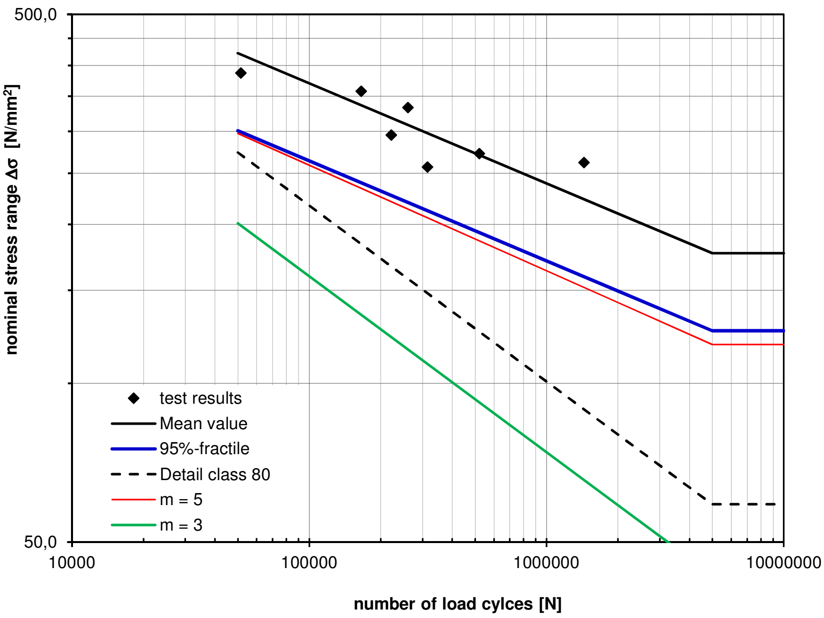
Comments:

* use "0" for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

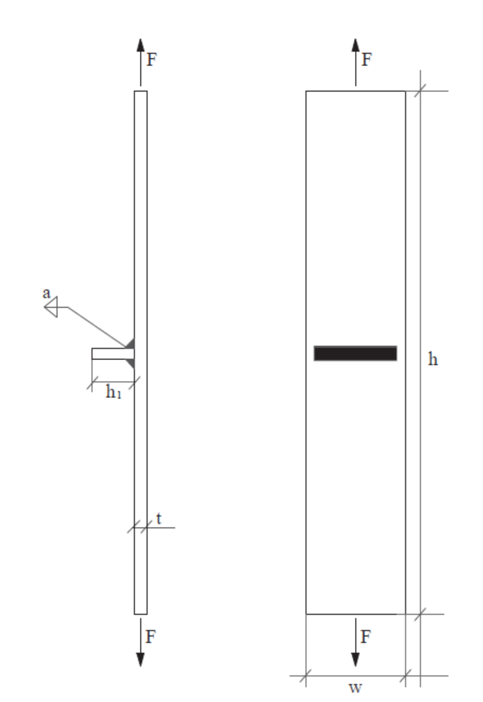


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 5,28	209,8	149,5
m = fix = 3	157,6	58,7
m = fix = 5	**205,4**	**142,2**

Construction detail	**Transversal non-load carrying attachment**	
Literatur	Kuhlmann, U., Bergmann, J., Dürr, A., Thumser. R., Günther, H.P.and Gerth, U. (2005) Erhöhung der Ermüdungsfestigkeit von geschwei\s sten höherfesten Baustählen durch Anwendung von Nachbehandlungsverfahren, Stahlbau, vol. 74, no. 5, pp. 358–365, 2005.	
Material	Denomination	S690
	Plate thickness	12 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	690 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	409,6	200295	1
2	311,6	687435	1
3	338,5	1269346	1
4			
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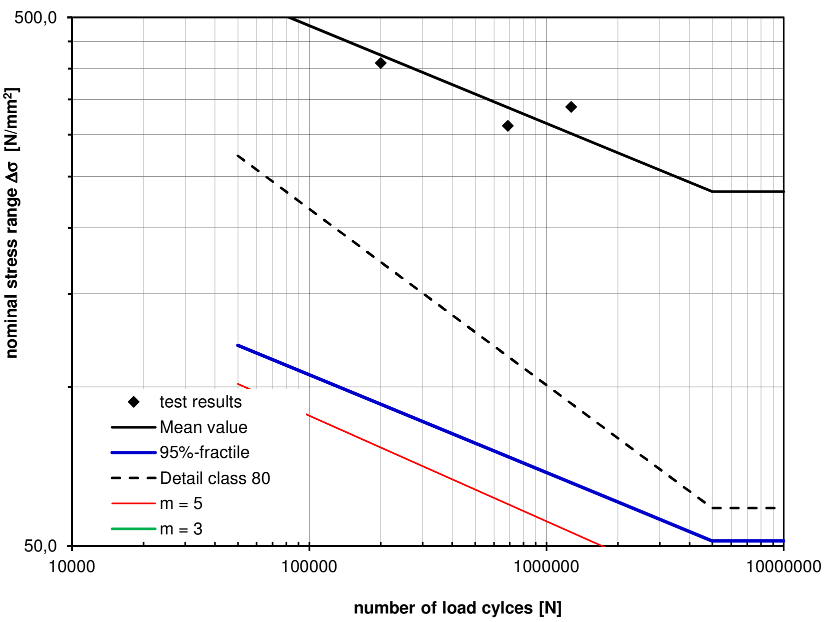
Comments:

* use "0" for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve

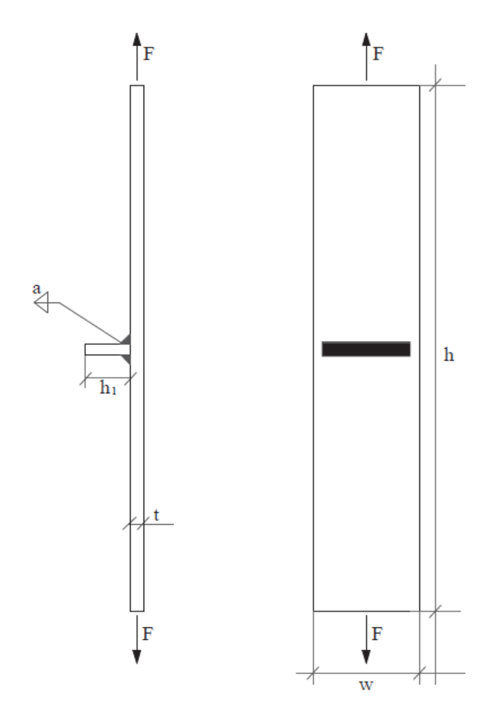


Statistical evaluation of test data according to EN 1993-1-9:2005

Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 5,41	277,2	60,5
m = fix = 3	229,4	2,1
m = fix = 5	**271,9**	**48,4**

Construction detail	Transversal non-load carrying attachment	
Reference	Kuhlmann, U., Dürr, A. and Günther, H.P. (2006) Improvement of fatigue strength of welded high strength steels by application of post-weld treatment methods. In IABSE Symposium Report, 2006, vol. 92, pp. 25–32.	
Material	Denomination	S690
	Plate thickness	12 mm
Mech. properties	$R_{p0,2}$	- MPa
	R_m	690 MPa
Datail category according to EC		FAT 80
Post-weld treatment	HFMI	UIT
Fatigue loading	Stress ration	0,1 [-]
	Type of collective	Constant amplitude
	Axial/Bending force	Axial

Sketch and dimension of test specimen and loading



Versuchsergebnisse

n	stress range $\Delta\sigma$	load cycles N	Com. *
1	348,0	199578	1
2	297,0	383799	1
3	369,9	454298	1
4	326,7	487281	1
5			
6			
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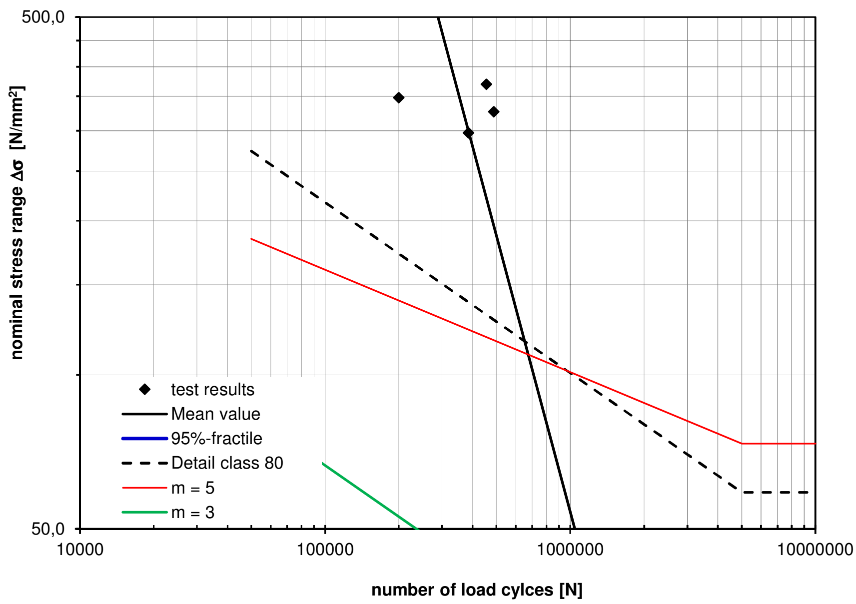
Comments:

* "0" used for a run-out that should not be taken into account for the statistical evaluation, "1" elsewhere

S-N curve



Statistical evaluation of test data according to EN 1993-1-9:2005		
Slope	Mean S-N curve ($P_Ü$ = 50%) $\Delta\sigma_{50\%}$	Characteristic S-N curve ($P_Ü$ = 95%) $\Delta\sigma_C$
m = variable = 0,56	15,5	0,0
m = fix = 3	188,9	24,5
m = fix = 5	**237,4**	**88,1**

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