A DIFFERENT VIEW OF QUALITY ASSURANCE FOR FATIGUE LOADED STRUCTURES

Anna Ericson Öberg
Chalmers University of Technology/Volvo Construction Equipment
anna.ericson.oberg@volvo.com

Abstract

The basic purpose with quality assurance is to get information about the product or the process in order to make correct decisions. Research performed in the WIQ-project has shown that the insufficient use of that information leads to unnecessary and costly safety margins in each step of production. The outmost consequences of that could be reduced productivity and lost opportunities for product and process development, such as implementing light weight designs. The former focus of the quality assurance at the investigated industries has been of technical character. A need for a different view has been identified. By instead starting with the internal customer's need for information in mind, the drawbacks of the currently used systems could be avoided. A model has been developed based on the internal customer's need for information about the product or the process. Several aspects are highlighted, such as what information is needed and suitable ways to present that information.

Keywords: weld, fatigue, quality, NDT, assurance, inspection, control, information

Introduction

One of the areas heavy welding industries are focusing on is to enable lighter structures. A light weight structure not only reduces the fuel consumption, and thereby the environmental impact, but also has the possibility to increase payload and reduce production cost.

The research project WIQ has aimed at enabling weight reduction by improving the weld quality. To be able to reach that the industries face challenges in several areas. The requirements on the drawings need to be reflecting the actual need to get the necessary fatigue strength. The fabrication should have the correct equipment and procedures to produce accordingly. Last, but not least, assurance that the received quality is according to the specifications needs to be in place.

The focus of quality assurance in this area is often technical such as which equipment or technical solution to use. Conferences are dividing non-destructive testing (NDT) into different techniques such as ultrasonic testing and radiography. It is also a common organizational structure to have experts in certain techniques.

Also the WIQ-project had the traditional view of quality assurance at the beginning. The aim was to find non-destructive tests to be used for evaluating the welded parts especially for toe radius, cold laps and penetration.

Empirical studies

Weld standard

The quality level of the welds is often judged in accordance to a quality system or standard. Among others Karlsson and Lenander [2] and Jonsson [3] has shown that there is no good correlation between the weld class described and fatigue life.

According to Marquis and Samuelsson [4], the weld standards relate to what is good workmanship and easily observed physical characteristics, rather than structural integrity. To solve this issue Volvo Group Standard developed a new standard where the weld acceptance criteria better reflects the fatigue strength [5]. During the WIQ-project the standard has been updated to even better reflect requirements affecting fatigue loaded structures. A new weld class, VE, has been added to suite loading conditions where the root side, instead of the outer geometry of the weld, is critical for the fatigue life. The properties described in the weld standard were the basis for the work with the quality assurance.

Affinity and Interdependence Analysis

An early indication that the quality assurance was not entirely a technical issue, was the result from a KJ Shiba workshop, decribed by Ericson Öberg in [1]. The KJ Shiba, also called Affinity and Interdependence Analysis, is a structured method to identify and group qualitative data. The participants were to answer the question “What are the main obstacles preventing quality assurance in accordance with the weld standard?”. At first the problem was thought of as technical and identified to be somewhere else in the organization. After the workshop the participants concluded that the key factor instead was to assure competence about why it is important to have and follow a standardized way of working in all functions.

Weld characteristics

Weld imperfections and properties often mentioned in connection to fatigue are weld toe radius, penetration, throat size and cold laps, see Figure 1. The work in the WIQ-project has therefore mainly focused on these properties.

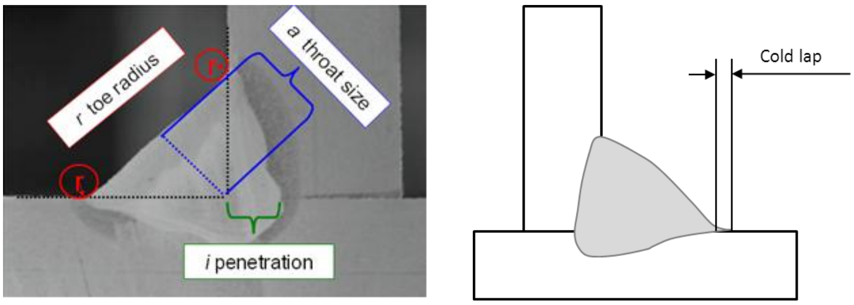

Figure 1: Toe radius, throat size, penetration and cold lap in a fillet weld [1].

The transition radius of the weld toe is one of the most important measures regarding fatigue according to Jonsson, Samuelsson and Marquis [6]. It is necessary to be able to assess if the wanted radius is achieved. Since the toe radius is an invented characteristic there are no obvious evaluation methods in place. Several solutions were tested during the project. The solutions had a wide variety in technical content, level of automation and precision as well as detail level. Lindgren and Stenberg suggested an automated scanning solution in [7]. Ericson Öberg, Hammersberg and Svensson describe a method using impression and microscope to get the weld geometry [8]. The simplest solution, radius gauge and master block is described by Öberg, Hammersberg and Svensson in [9].

The penetration measure describes how deep the fusion between the plates is. When the root side of the weld is critical, the penetration is very influential for the fatigue life. In the research project several tests were performed using phased array ultrasonic testing. The method could be used for checking if sufficient penetration depth is achieved but not to state any exact value of the penetration. That was however sufficient. When there is a need for more detailed values of the penetration, for example when performing process optimization and choosing between parameters, destructive testing is more suitable.

The throat size is, as Figure 1 shows, the height of the greatest inscribed triangle having equal leg length. Previous research has shown concerning problems with the currently used evaluation method. Hammersberg and Olsson [10] describe a measurement system analysis (MSA) performed on throat size gauges. The MSA showed significant variation originating from the measurement system. Studies in the WIQ-project came to the same result. The throat size turned out to be an indicator of over-welding and unstable processes. The issues were caused by both the evaluation method and the handling of weld information. An alternative evaluation method, with very high precision, was developed (Ericson Öberg, Hammersberg and Svensson [8]).

A cold lap is according to Li [11]:" A crack-like imperfection at the weld toe which has a negative influence on the fatigue properties of the weld". There are currently only destructive methods used for identifying cold laps such as macro samples. During the WIQ-project several non-destructive methods were tested. Vibrothermography showed to be the most promising method. Further research is however required.

Visual inspection

An investigation described by Öberg, Hammersberg and Svensson [9] synthesized the currently used evaluation methods at 12 plants. Visual inspection showed to be the most commonly used evaluation method. The precision of the visual inspection method therefore needed to be investigated. This was done by performing an Attribute Agreement Analysis where appraisers got to evaluate several quality characteristics on different welds. The visual inspection showed not have the necessary precision (repeatability and reproducibility) as described by Ericson Öberg and Åstrand in [12].

Weld information

Stable and predictable processes are prerequisites to be able to change weld design to reduce weight. To identify any variation in the process, the deviation between theoretical and actual weld weight was investigated for a number of demonstrator parts. There was a vast variation, which is described by Öberg et al in [13]. The financial impact of this was significant. One cause of the situation highlighted was the handling of the weld quality information. Compensation for gaps was performed in several steps and measurement methods were not capable of giving the information needed. That caused safety margins in several steps, resulting in costly excess throat size. This result is in line with previous research performed by Hammersberg [14]. He states that variation in the approach to robustness and reliability in different organizational functions can be hidden in over dimensioning but needs to be explored to develop cost effective NDT. An important issue to address is how to get the entire organization to look at variation in the same way. That is affected by how the information is presented. Danielsson och Holgård [15], Deming [16] and Wheeler [17] has shown that control charts enable that and can be used for a wide variety of data, such as key performance indicators (KPIs) on management level. A study described in [1] by Ericson Öberg shows promising result when using it on KPIs in a company producing welded components.

Pull approach

The empirical studies showed a problem not only being of a technical kind. There was a missing piece in the jigsaw puzzle connecting the others. The focus had been in specific areas, like analysis, weld parameters or non-destructive testing methods. There was also good result in these areas. However, the areas of expertise needed to be connected or else the benefits would be lost like the empirical studies had shown. A simple and seemingly obvious model was created to describe the necessary approach to weld information, defined by Ericson Öberg [1]. The model, illustrated in Figure 2, is focusing on the information about the product or the process that different functions or people need. The information is necessary to be able to come to the right decision, for example about the weld quality. The people - here represented by manager, welder, designer and programmer – need different information, presented differently. Therefore the suitable evaluation method for providing that information might as well differ between them.

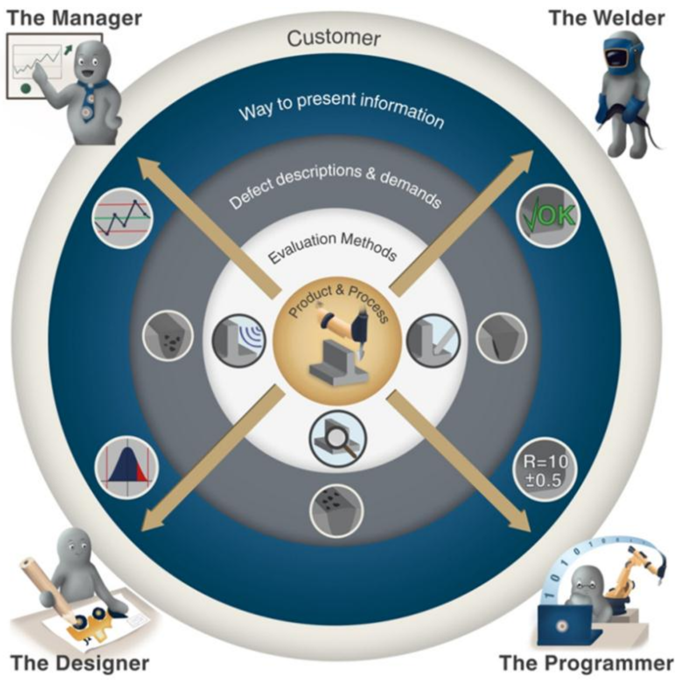

Figure 2: Illustration of components affecting the evaluation system [1].

In traditional lean concepts the customer need is in focus. Parts or information should only be produced when asked for, a pull-approach. The opposite, to push parts or information onto the customer, creates waste. The people affected within the weld process could all be considered internal customers and their information need to be defined in order to create a pull system. Figure 3 shows an approach that can be used for handling weld information. The first step is to identify the internal customer. As previously mentioned that could be anyone within the process needing information to come to a decision, for example the welder or manager. The next step is to find out what information is necessary to be able to come to the decision. Thereafter the best way to present the information should be considered. A graphical data presentation, such as control charts, is often preferred. Based on the information need and data presentation, the defects and properties of interest are defined. Different level of detail can be requested for example only presence of defect or the defect precisely sized and positioned. At the final step the information need is now clearly defined and a suitable evaluation method is to be decided. In many cases there already exists an evaluation method suited for the task. If not, the structured steps have created a definition of what the evaluation system should be able to do.

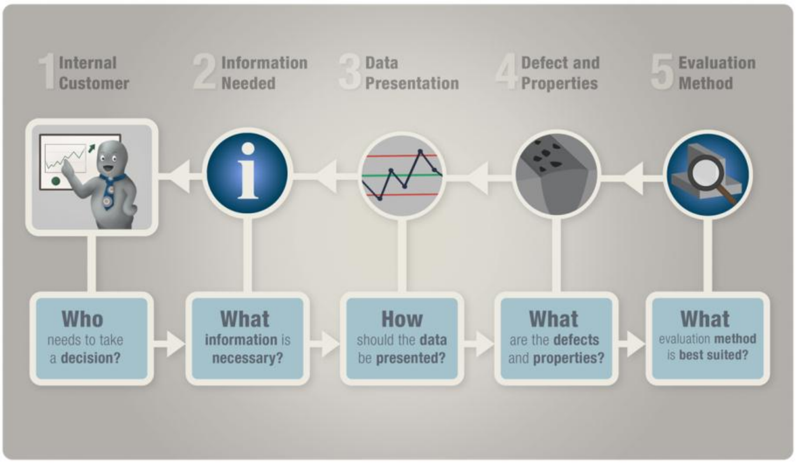

Figure 3: The PULL-approach model for evaluation of welds [1].

Discussion

The WIQ-project at first had a traditional view of quality assurance. The focus was on which non-destructive method to use in order to secure the quality after welding. This research has shown that with a different view of quality assurance the technical aspect is of secondary importance, at least early in the process. Simpler and cheaper methods can be able to retrieve the information needed. The best suited method might even be destructive.

The performed studies regarding the different weld characteristics weld toe radius, penetration, throat size and cold laps clearly illustrate the possibilities when using a pull-approach for choosing evaluation method. For both weld toe radius and throat size, evaluation methods with different level of details could be used depending on the need. For a stop-or-go-decision, for example to decide if the part exceeds a lower limit, simple and cheap solutions were possible to use. When instead the information was needed in process development, a much more detailed and precise method was required, making it possible to fine tune the process. The number of tests needed for that purpose could however be fewer, making it possible to use a more complex and expensive test procedure.

However, there is still a great need of technical solutions. One way of reducing the variation from the operator is for example to replace the operator by a machine. There could also be a need to make the evaluation quicker and thereby cheaper. In that case an automated solution could be the right choice. In other cases there exist no suitable solutions yet. In the case of cold laps there is a need for non-destructive testing. The current destructive methods are time consuming and expensive which makes it inconvenient even in a laboratory setting. The need for technical solutions is however not a contradiction to the pull-approach. By following a structured approach a definition of what the evaluation method should be able to do, is created. The likelihood of succeeding in finding a proper method increases.

By keeping in mind which information the internal customer needs, the entire manufacturing process could be affected. Increased knowledge could enable a move of tests upstream in the process. Instead of evaluating characteristics on the final weld, properties affecting defects to occur could be monitored instead. It would be even better if the characteristics were to be controlled already before the welding takes place. Research creating knowledge about what is causing imperfections to occur and how it can be avoided, rather than only detect them afterwards, is therefore of great importance.

Several evaluation methods might be needed to provide the information for “the same” problem. In the case of throat size measuring, methods with three different technological levels produced information for different purposes. When using a method for the wrong purpose it could be costly or unable to provide the level of details needed, leading to faulty decisions. There is no “one size fits all”-solution, like often believed. The research performed in the WIQ-project has also raised the awareness of the precision of the evaluation methods used at the participating companies. Depending on the information need different reproducibility and repeatability can be accepted.

The performed studies have shown the effect the lack of weld information has on cost. Both short and long term savings can be achieved, even without large investments. Even though the solution might be cheap, it is not always that easy to implement. It can be easier to purchase a technical solution instead of changing the way of working. However, when lacking control of our processes, we get increased weight, cost etc. due to safety margins created in each process step. Long term development and reduced weight of fatigue loaded structures therefore require cross-functional initiatives.

Many of the parts in the research can be considered “old news” for the individuals. However, the difficulties consist of translating that individual knowledge into a common cross-functional understanding within the organization. The way of working described can be counteracted by the common way of organizing the companies’ functions or research projects. Technological push can originate from the fact that the expert has their basis in a certain technology and want to use that, rather than identifying the actual information need. Both previous research and the performed studies in the WIQ-project show the true potential using cross-functional initiatives.

Summary and conclusions

Research performed in the WIQ-project has shown that the insufficient use of evaluation methods and weld information lead to unnecessary and costly safety margins in each step of production. The outmost consequences could be reduced productivity and lost opportunities of implementing light weight designs. A need for a different view of quality assurance has been identified. A model, with a pull-approach, has been developed based on the internal customer’s need for information about the product or the process. Several evaluation methods have been investigated. The research could be concluded into:

- Technical solutions are necessary but not sufficient to get quality assurance and thereby enable light weight structures
- It is necessary to handle quality assessment from an information point of view where the internal customer’s need of information should guide when deciding evaluation methods

- There are several promising evaluation methods for assessing characteristics critical to fatigue loaded structures

Acknowledgment
The WIQ project is partly funded by Vinnova as well as by the participating companies and universities. A great contribution has been made by the staff at Volvo CE.

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