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The Right Evaluation Method - an Enabler for Process Improvement

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Abstract

This paper aims at describing the procedure where an alternative evaluation process was developed to support the improvement of both welding and weld quality evaluation. Welded structures are important when striving for reduced fuel consumption due to vehicle weight. Hence good control of the fabrication process is critical to keep welding performance on target, avoiding waste in terms of added weight and overproduction. The resulting distribution of weld weight has shown to be an important control parameter in the sense of keeping cost down.

To identify the causes for deviations between actual and theoretical weld weight, information about the weld was needed. The currently used evaluation method showed not to be capable of giving the information needed. It was necessary to know the throat size as well as weld geometry. The current evaluation method introduced more variation due to the measurement than the actual fabrication process itself, leading to drift of process target and overproduction.

To fulfil the need of information, that different functions within the company had, a PULL-approach was used. The information need, information presentation and sequence were outlined for each information receiver individually. An alternative measurement method was developed and named WIA – Weld Impression Analysis. The method consists of two parts; creating the replica and analysing the shape in an image analysis program.

The method was tested to see if it was capable of delivering accurate and precise measurements, satisfying repeatability and reproducibility requirements for this particular situation. A thorough measurement system analysis was carried out. The measurement system assigned 98.98% of the total variation to part-to-part variation corresponding to long-term process variation. The variation that stems from taking the impressions and preparing them was as well investigated, also showing satisfying results. Finally it was investigated if the impressions reflect the true shape of the welds accurately. The results showed a tendency of slightly higher cross sectional areas in the range of 0-3 %. This however indicated that the accuracy of the measurement system was sufficient for its purpose.

The PULL-approach generated a sufficient method which enabled the possibility to perform process improvement and gain large production cost savings.

Keywords: weld, evaluation, measurement system analysis, pull, impression, replica, test, quality

1. Background

Reduced fuel consumption by reducing vehicle weight is an important goal within many industries. Welded structures are hence playing an important role in this work. Lower weight can be achieved by using thinner material with increased material strength. A prerequisite, to be able to take that leap, is however to have good process control – in order not to risk breakdowns. Improved processes and process control will increase the fatigue life and reduce scatter in quality.

*1.1 **The Initiating Problem***

The distribution of weld weight could be an important control parameter in the sense of keeping cost down by having a stable, predictable process. Large deviations between actual and theoretical weld weight was identified within a welding industry. An improvement team was started to investigate the causes for the deviation, which is described by Ericson Öberg et al [1]. A part of the investigation was to get more information about the resulting weld, in order to know how to adjust the process.

*1.2 **PULL-approach***

A PULL-approach described by Öberg et al [2] was used to identify the information need, see Figure 1. In the first step the information receiver needs to be identified. It is a great difference if the information is going to be used for a go/no go-decision by the welder or by the manager to make decisions about improvement actions needed.

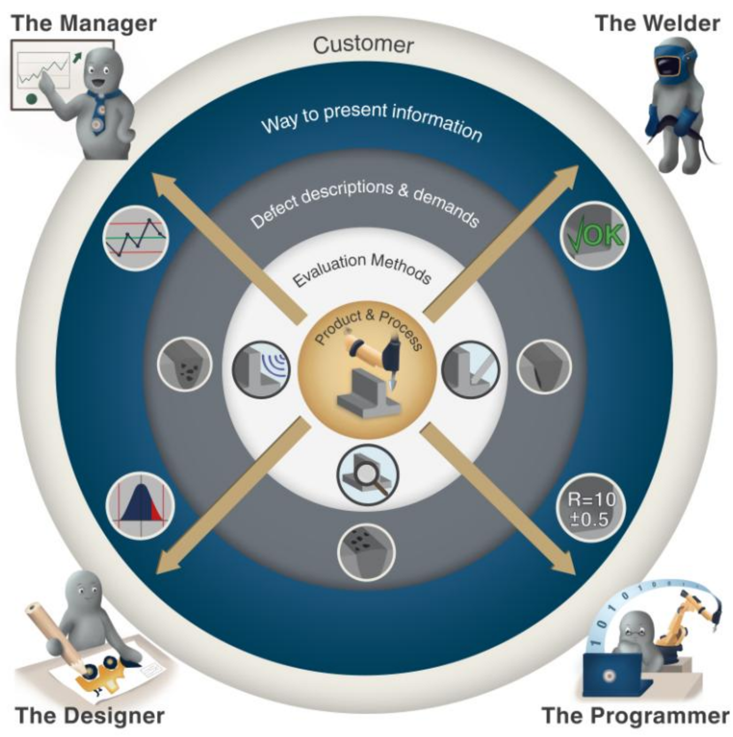

Figure 1: Pull approach when defining evaluation methods.

One of the information receivers in this particular case was the improvement team dealing with the difference between actual and theoretical weld weight. The team needed information about the weld size in order to track down the causes for the deviation. When following the steps in the PULL-approach in Figure 2 the answers for this case became:

1. Who needs to take a decision - the improvement team
2. What information is necessary – difference in weld size
3. How should the data be presented – comparable numbers
4. What are the defects and properties – throat size and geometry

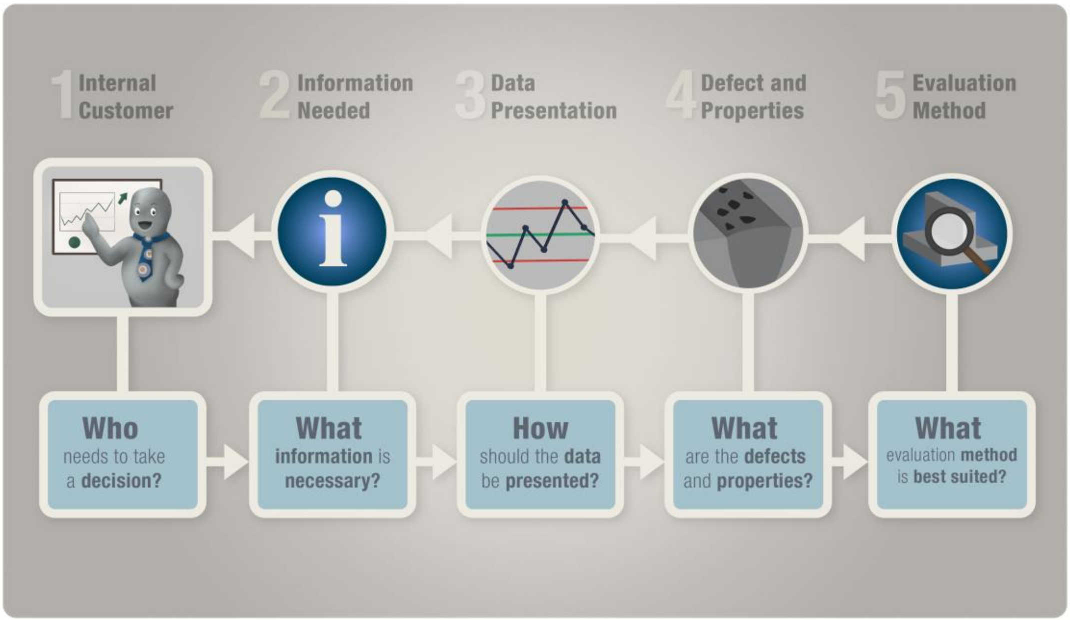

Figure 2: Steps in the PULL-approach.

With the information need clearly defined it is more likely to find an evaluation method that actually delivers the information needed.

2. Evaluation Methods

*2.1. **Measuring Throat Size Using Gauge***

The improvement team started by testing the cheapest and commonly used evaluation method; throat size gauge. The commonly used tool at the plant is shown in Figure 3.

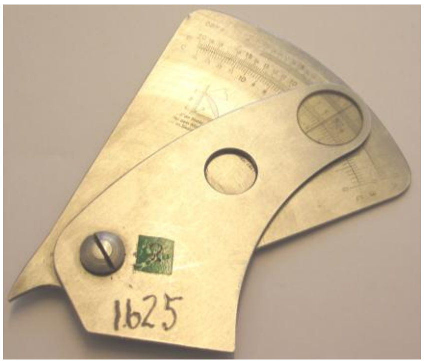

Figure 3: Throat size gauge used at the plant.

The instructions for the usage differ, depending on if the weld shape is concave, straight or convex. Different positioning of the gauge arm is used and the result is read on different scales. Would the currently used method solve the information need? The precision (repeatability and reproducibility) of the method needed to be investigated. The repeatability shows if the operator gets the same result when evaluating the same sample several times. The reproducibility shows if different operators get the same result when evaluating the same parts using the same equipment. The influence of both extrinsic factors (e.g. method and tool) and intrinsic factors (e.g. operator experience and motivation) will thereby be investigated together as a system [3].

MSA 1: A MSA, measurement system analysis, Gauge R&R was performed to see the repeatability and reproducibility of the measurement system. Ten positions on welded test samples were chosen. Three operators performed the measurements. Each of the 30 measurement combinations were repeated three times. The sequence of the measurements was fully randomized.

MSA 2: It was discussed that the main challenge was to determine consistently whether the weld was concave, straight or convex. An extra tool depicted in Figure 4 was therefore used to assist this decision before using the throat size gauge. The MSA was repeated for the changed method.

Figure 4: Tool for deciding weld shape.

2.2. ***Result***

MSA 1: The result showed that the measurement system was not good enough for measuring throat size. The variation of the total Gauge R&R was larger than the part-to-part variation sampled from, concluding that the variation in repeatability and reproducibility contribute far too much to the total variation. This has also previously been shown by Hammersberg and Olsson [4].

MSA 2: MSA 2 got a slightly better result but the conclusion still holds: the measurement system cannot obtain the quality needed for the measurements. However, it was observed that the most experienced operator obtained the most consistent measurements. This indicates that the measurement system can be improved by trained operators even though it was not enough for this purpose.

2.3. ***Other Possible Options***

Other assessment methods needed to be evaluated based on its ability to convey the needed information, cost and availability.

2.3.1. Other Types of Gauges

There are several variants of the previously described throat size gauge, one presented in Figure 5. However, it was concluded that those probably would have the same type of drawbacks as the currently tested ones. They would also not be able to give any more information about the geometry or weld area. The cost for such a gauge is however minor. Other gauges were not currently used at the plant.

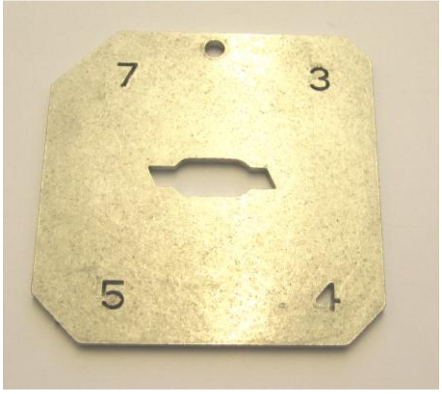

Figure 5: Gauge measuring throat size using corner chamfering.

2.3.2. Macro Sample

A macro sample, see Figure 6, is a destructive test where the actual weld is cut, grinded, polished and etched before it can be measured in a microscope. The amount of information possible to withdraw is substantial and reflects the real situation. A drawback is however the fact that it is a destructive test, meaning the part will be destroyed when tested. The different operations and material needed also makes it an expensive test in comparison. Macro sample is a method already used at the plant.

Figure 6: Macro sample of weld.

2.3.3. Replicas

The weld geometry can be reproduced using an impression method, creating a print of the weld surface as described e.g. by Bowman and Quinn [5]. The replica material is placed on top of the weld. There are several variants from liquid where the replica is created by moulding, two-component silicon based applied with a syringe or a more solid two component clay-like plastic to use. After solidification the replica can be cut and measured. The replica can be magnified using a profile projector, see Figure 7. The information achieved using this method includes for instance the shape of the weld geometry but only represents the result in one particular point. The use of this method within the plant was limited.

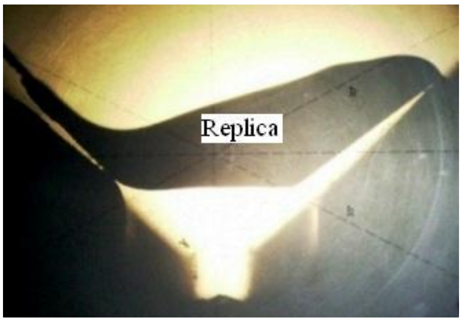

Figure 7: Silicon replica visualized using profile projector.

2.3.4. Scanning device

Another solution could be to scan the weld during or after the welding to get the information, see Figure 8, as described for example by Schreiber et al [6], Barsoum and Jonsson [7], White et al [8], Lindgren and Stenberg [9] and Li et al [10] . The information from such a system could even give continuous data of how the throat size varies along the weld. The information well exceeds the need from the improvement team. The disadvantages with such a system are the cost as well as the lead time to get it at the plant.

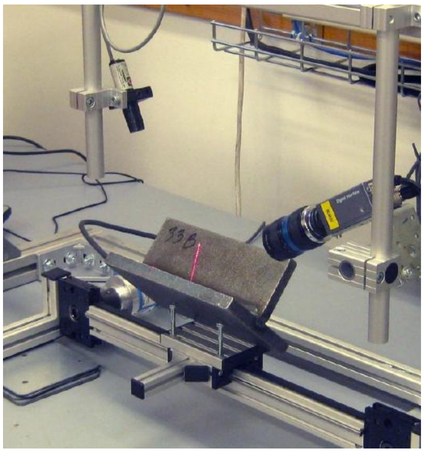

Figure 8: Scanning device for weld samples.

3. The Alternative Method

None of the described methods was suitable for the intended purpose. The gauges did not give the information needed. The macro sample was too expensive and time consuming. Only to use a replica did not give the information needed and the plant did not have any profile projector. The lead time as well as cost for scanning equipment was not realistic for the improvement team.

*3.1. **Description***

A need for an alternative measurement method was identified. For the evaluation information to be used for process development purpose it was desirable to get both throat size, area outside of the throat size as well as weld shape. A method to achieve this was developed and named WIA – Weld Impression Analysis. This method combined impression technique with an image analysis program normally used for macro tests. The plant already used the image analysis program which limited the cost. The method consists of five steps.

1. Apply a two-component polymer to the outside of the weld, see Figure 9
2. Leave for a few minutes until the impression becomes rigid
3. Cut the impression revealing the cross section showing the print of the weld surface
4. Place the impression in the microscope
5. Calculate areas and dimensions using the add-on software for the image analysis program (Picsara), see Figure 10.

Figure 9: Polymer applied to weld to get impressions.

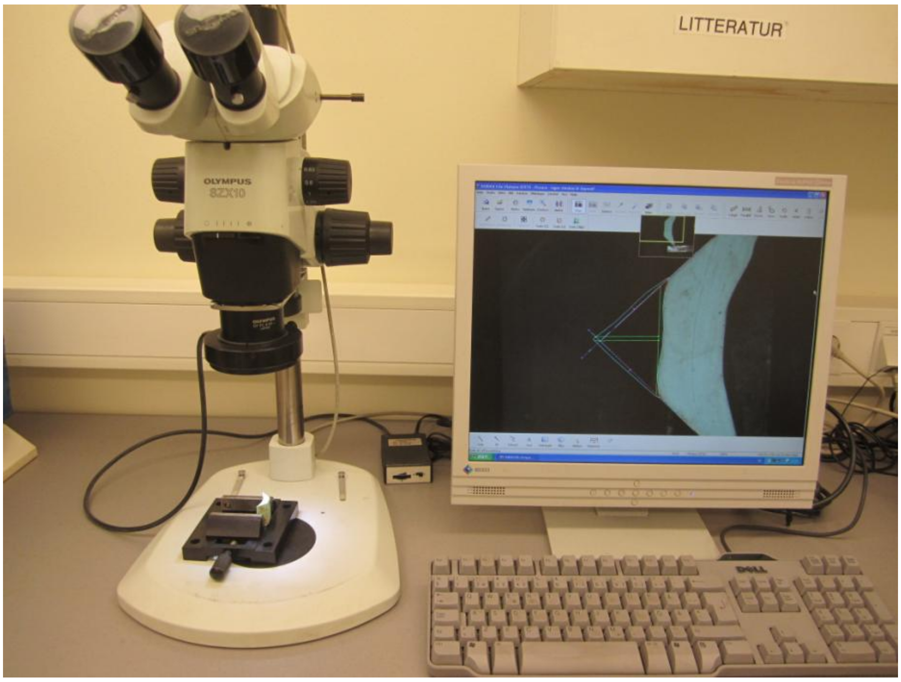

Figure 10: The cut sample is analyzed using Picsara software.

The throat size a and the two weld areas Y1 and Y2 are computed by the program, depicted in Figure 11. Y1 is the triangular weld area corresponding to the true throat size. Y2 is the excess weld seam area outside Y1.

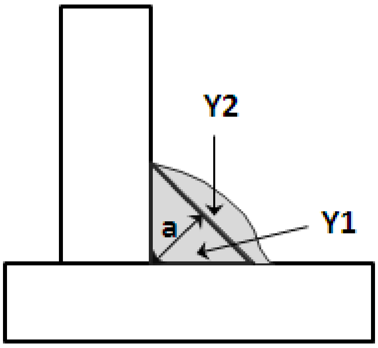

Figure 11: Illustration of area Y1, Y2 and throat size a

The analysis shows the throat size a, area Y1, area Y2, leg length and weld angles as shown in Figure 12. Hence the suggested method delivers the information needed by the process development team.

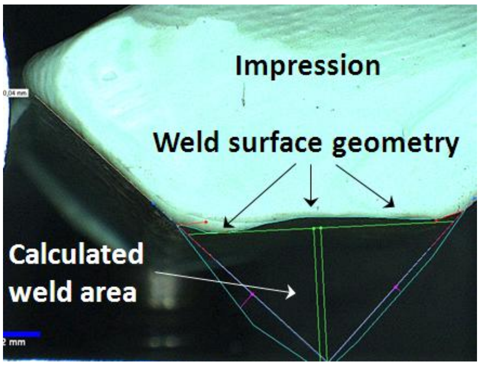

Figure 12: Impression being analyzed in microscope.

*3.2. **Accuracy & Precision***

The accuracy and precision of the method needed to be evaluated in order to decide its suitableness as method used in process development.

3.2.1. Description of Tests Performed

Precision of Analysis: At first it was necessary to investigate the method's repeatability and reproducibility. Measurement System Analysis (MSA) Gauge R&R was chosen for this purpose. A thorough MSA was carried out with 10 samples, investigated by two operators, with three repetitions of each sample for each operator, using a fully randomized measuring sequence.

Precision of Creating Impression: The MSA performed did not include the variation that might stem from the first part of the operation: taking the impressions and preparing them for the microscope by cutting them. In order to investigate this, three similar impressions on four of the welds were performed and analysed.

Accuracy: However, the final and crucial accuracy question was: does the measurement system actually measure the right cross sectional area and throat size? Do the impressions reflect the true shape of the welds accurately? A consistent shrinkage of the impressions could produce inaccurate measurements. To investigate this, impressions were applied on weld test samples that were already cut and prepared for microscope analysis. The cross sections of the impression and the actual weld could then be compared.

3.3. ***Result***

Precision of Analysis: The measurement system assigned 98.98% of the total variation to part-to-part variation for measuring throat size. The corresponding number for measuring Y2 was 99.21%. This result is satisfying for the intended purpose.

Precision of Creating Impression: The result showed that the standard deviation on the four welds, sample size 3, is around 0,05mm for three welds and 0.16mm for the fourth. The variation in the total area (Y1+Y2) is also very good, for the fourth sample as well. This would indicate that the method provides good repeatability also for the moulding step of the method. More work could be done in the future to perform a more extensive analysis since this only provides an indication.

Accuracy: The result showed that there seems to be a tendency that the measurement system generated slightly higher cross sectional areas. However, these deviations were in the range of 0-3 %. This indicates that the accuracy of the measurement system is sufficient for its purpose.

3.4. ***Use of WIA***

The alternative method was used within the project to get data for investigating the causes for weld weight deviations. The cost of the deviations was defined. Several causes were identified, further described by Ericson Öberg et al [1].

4. Discussion

The improvement team decided to use the WIA-method during the project. It provided information about deviations in theoretical and actual throat size as well as the contribution from the weld geometry. The choice of evaluation method clearly supported the process improvement made by the team.

When comparing the WIA-method to the two most commonly used methods at the factory, it becomes clear that the result would not have been the same without it. The scatterplot in Figure 13 shows the result when the same 10 parts were evaluated by three appraisers using gauge, WIA and macro. The variation is increased when using WIA compared to macro, but it is far better than the result from the gauge measurements.

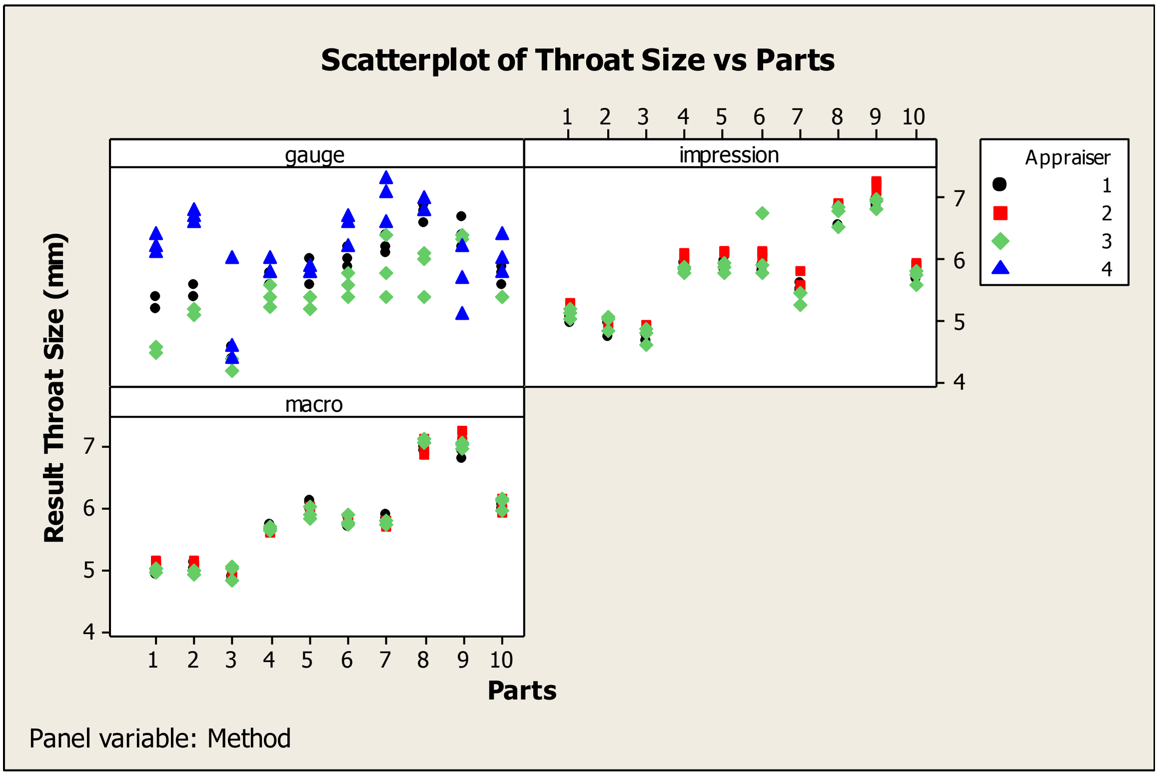

Figure 13: Deviations in results when the same welds are measured using different methods.

When other factors like cost and time are included, as shown in Table 1, WIA is preferable to macro. The method is however more costly than the gauge since polymer, analysis work time and more expensive equipment is necessary. Considering the quality of the data achieved by using the gauge, WIA is the best option.

Table 1: Comparison Between Gauge, Macro and WIA Methods

	DT/NDT	Equipment cost	Testing time	Result delay	Information content	Consumable cost	Precision
Gauge	NDT	Low	Short	Short	Low	None	Low
Macro	DT	High	Long	Long	High	High	High
WIA	NDT	Medium	Medium	Medium	Medium	Medium	High

When choosing evaluation method it might be tempting to select the most advanced method. However, if the extra features or precision is not needed for the task to be solved, it probably leads to waste. In the worst case it might even be that the chosen solution is unsuitable for the exact task it is intended for.

For this particular case the PULL-approach generated a sufficient method which enabled the possibility to perform process improvement and gain large production cost savings.

There are cases when a PUSH-approach could be more suitable. Within certain industries there are regulations controlling which type of equipment to use for certain tasks. In that case, there is no choice but to start already with the method decided. Another example where a PUSH-approach could be suitable is within development of testing equipment. Optimal would be for the PULL-defined need to meet the PUSH-developed solution. Then the receivers, information and presentation need is defined and can be combined with the best matching solution.

Continuous improvements are often made by developing new measures, since existing measures will not drive change. To effectively select the precise measure that drives the current development needs is a complicated interdisciplinary task, often falling between chairs lacking an effective supporting procedure.

5. Conclusions

This paper describes the procedure where an evaluation process was developed, to support the improvement of both welding and weld quality evaluation. The PULL-approach used generated an alternative measurement method that was named WIA – Weld Impression Analysis. The method included creating an impression, using two-component polymer, and analysing the shape using microscope and software. WIA showed to be a sufficient method which enabled the possibility to perform process improvement and gain large production cost savings.

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