APPLICATION OF A PROCESS FMEA FOR THE WELDING

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Abstract

This article deals with the use of the FMEA method process in welding processes with the aim to eliminate the causes of defects in welded joints. Welded products and their welds require an improvement in quality, both visual and structural. By increasing the quality of welded joints, we will achieve customer satisfaction and help to reduce costs in terms of the forced repairs of non-conforming pieces. Welding quality is based on the weld joint requirements. It is always based on the business contract, on the order, the relevant standards or technical conditions. The weld must be inspected and evaluated both on the surface and under the surface. Defects in welds are dangerous concentrators of tension that badly affect the limit of fatigue. The application of the process FMEA method aims to minimize defects in the welded joints and improve the resulting quality of the welded parts in the welded joints. To use this method properly, it is important to describe the welding processes, analyse the possibilities of defects and their consequences.

Keywords: PFMEA, defects, welding, quality, welded joint

1. INTRODUCTION

A main trend on the market today is the process of continuous improvement and a quality increase of products and production processes. The aim of the production shops is the continuous increase of the requirements for better efficiency and the quality of the production. These issues are also discussed in the technological processes of welding, to which great demands are placed, mainly concerning the issue of minimizing the occurrence of defects in all welded joints, which can negatively influence the quality of the weld. The FMEA (Failure Mode and Effect Analysis) method is one of the instruments for guaranteeing the quality of production processes with the possibility of carrying out analyses of defects and their consequences.

This contribution deals with the issue of welding high-carbon steels, which is used in a wide range of engineering and transport areas. Namely, it focuses on the mapping out of each kind of defect occurrence, on their consequences and the measures for the renovation of rails for railway and urban transport. For this case the FMEA method was selected, namely the PFMEA (Process Failure Mode and Effect Analysis) method. Thanks to PFMEA a list of occurring defects is made, and an early response to the defects is ensured, and there are rules set up for preventive measures, thanks to which these defects can be detected early enough and their re-occurrence can be minimised, together with all the related costs. [11]

The FMEA method was developed in 1949 in the USA as a military regulation, and in 1963 this method was further developed by NASA, which applied it in practice during its Apollo project. The historical development of the FMEA method is shown in the following table (**Table 1**). [1,7]

Table 1 Historical development of FMEA [1]

The historical development of FMEA			
1963	NASA - Apollo project	1977	Automotive industry
1965	Aeronautics and space flights	1990	Health service
1975	Nuclear technology	1999	Non-technical disciplines

2. THE APPLICATION OF PROCEDURAL FMEA ON ANALYZING THE DISCUSSED ISSUE

2.1. The PFMEA application

The PFMEA method is an important part of the risk management system and it contributes to the continuous improvement of process quality. This is an important and also preventive tool that helps to map out all defects in the welding processes, to analyse possible risks and further define measures necessary to prevent further imperfections. A further reason why it is necessary to introduce FMEA into practice is that this method is recommended in quality standard management ISO 9001:2016, and it is more and more required by customers, who use it to verify whether the manufacturer carefully examined and evaluated all the risks leading to a potential failure of a product. [2,10]

To apply procedural FMEA for welding rails it is first necessary to process all the supporting documents in a form usable to compile the PFMEA form. After processing this data completely, we can move during the second stage to an analysis of defects occurring during the rail welding process. In the framework of the defect analysis, we are searching for the methods, the consequences and causes of these defects. The methods can be defined as the forms of failure during the welding process. After determining how these defects arise a determination of their consequences follows. The determination of the possible consequences includes an analysis of the defects and their severity. The next step is to determine the causes of defects that can be described as activities which can be corrected during the occurrence of defects, and thus prevent them. [3,9]

In the third phase, an analysis of the measures can be included, which contains the identification and assessment of the risks. The determination of the priorities for actions is described by three characteristics, which are classified in accordance with the specified tables in the FMEA manual, published by the Czech Society for Quality. The criteria are within the range "1 - 10", where the grade 10 is unacceptable for all of the characteristics. These features are: Severity (S), Occurrence (O), Detection (D).

After grading all items the assessment of risks follows, using the priority indicator of a risk - RPN (Risk Priority Number). The risk number can be calculated as the product rating the severity, incidence and detection of defects. [4,8]

$$RPN = S * O * D \quad (1)$$

Where RPN - Risk Priority Number

S - Severity

O - Occurrence

D - Detection

The final stage in processing the PFMEA method is optimization, where it is necessary to choose a threshold value first. Any defects which exceed this value with their final figures (or reaching a high number of severity) are further optimized using the measures to reduce their current value (**Figure 1**). Special attention is paid to these defects and special provisions are taken. As the PFMEA is a "live" database it must be constantly developed and updated with new findings. [1]

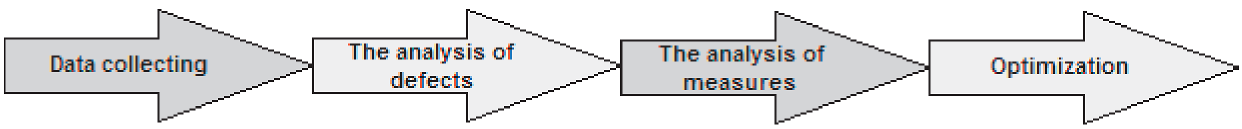

Figure 1 The processing of PFMEA [1]

2.2. The issue of welding rails

The subject here was to apply the procedural FMEA in the matter of rail welding with a view to minimise the occurrence of cracks and to establish measures to avoid their recurrence. Specifically, they are welds on high-carbon steel rails for the rails of railways and urban transport. The method of welding rails is illustrated in the following figure (**Figure 2**).

The rails are manufactured from materials of different chemical compositions from the materials used to manufacture the railway wheels. This often results in the wear of the rails and wheels, and therefore a significant part of the rail surface and the wheels must be renovated. In the case of welding medium and high-carbon steels, it is also necessary to preheat the material from 200 to 400 °C, to avoid tempering structures in the welds and in any heat-affected areas. This preheating for the rails cannot be done in the case of paving or panelling rails. One of the possibilities to substitute this preheating during welding is to ensure an adequate heat intake, which shall ensure the gradual reduction of the weld temperature and of its surrounding areas. Cracking can also be caused by tension conditions (residual tension) in welded joints. [6]

Renovation technology belongs to one of the methods which prolong the service life of parts used in engineering. The parts are welded using a number of technologies, e.g.: a manually coated electrode, an automatic machine under a flux, etc. The rails are manufactured from materials of various chemical compositions, which can have an impact on the resulting weld. A suitable weld is shown in **Figure 3**. [5]

Figure 2 A groove rail with the upper and lower weld [5]

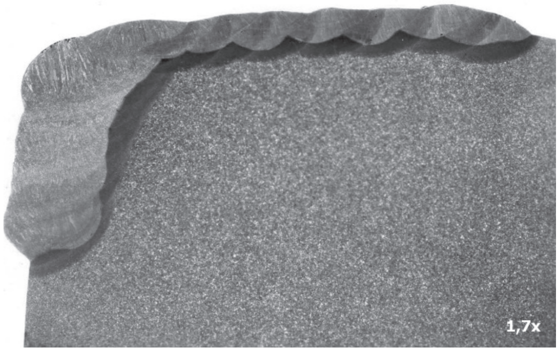

Figure 3 A suitable weld (1.7x) [5]

3. AN ANALYSIS OF THE DEFECTS AND THEIR DETECTION IN THE WELDING PROCESSES

To analyse the occurrence of defects (cracks) for welded rails, individual internal documents containing information on welding rails were at disposal, as well as articles and technological procedures. The incidence of defects, such as cracks during welding, also influences the maximum carbon content in a weld. Any crack on rails and welds is a non-permitted defect (**Figure 4**). [5]

3.1. Occurring defects

Cracks in a weld:

These are defects that can be observed on the open surface as longitudinal cracks in the axis of the weld bead. The cracks in the weld metal were opened by the annealing effect of the heat influence of the side-by-side laid weld beads (**Figure 4**).

Cracks occurring in the basic material:

They were perpendicular to the welding borderline (within the meaning of the heat gradient).

For this defect it was also possible to distinguish the following infringement demonstrations:

- **Transverse cracks intersecting the welding borderline** and affecting both adjacent structural areas. The length of the cracks was linked to structural changes influenced by the heat cycle of the welding process on the side of the welded and even the basic material.
- **Cracks ranging from the lower line of the welding border into the material of a rail**. According to its direction and opening, we could conclude the result of these cracks. A crack lengthwise showed transverse branches, with the influence of the multi-axial state of stress at the place of the weld.
- **Short transcrystalline cracks in the basic material in HIA.** They are oriented perpendicular to the border of the melt, and they belong to traverse cracks. [5]

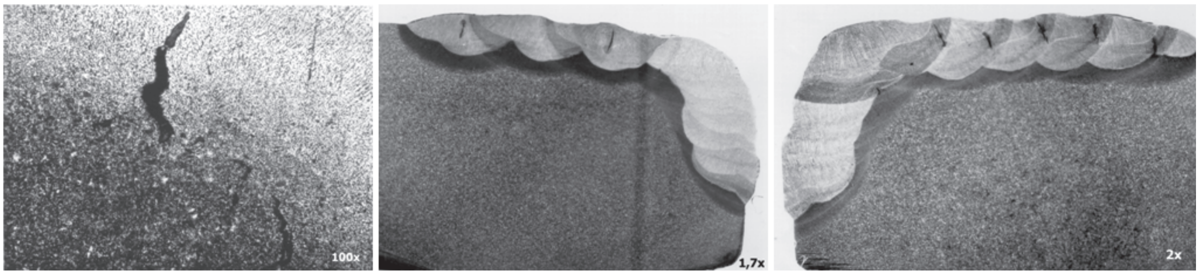

Figure 4 The incidence of cracks in the welds [5]

3.2. Detection of defects

In the framework of detecting the incidence, the total range, and the influence of the individually described defects, other laboratory evaluations were performed:

- A more detailed analysis of microstructures and their changes due to the technology applied,
- Evaluation of the hardness and micro-hardness in areas critical to the quality of the welding,
- An analysis of chemical composition.

The welds can be further checked using non-destructive tests.

When providing these non-destructive tests it is necessary to carry them out in accordance with the applicable standards and procedures. Non-destructive testing of welds - general rules for metallic materials indicates the CSN EN ISO 17635 standard.

- <u>For the detection of surface defects</u>: Visual test (VT) - CSN EN 13018; Capillary / Penetration test (PT) - CSN EN ISO 3452-1; Magnetic method test (MT) - CSN EN ISO 9934-1.
- <u>For the detection of volume defects</u>: Ultrasound test (UT) - CSN EN ISO 16810; Radiographic examination test (RT) - CSN EN ISO 5579. [5]

4. THE PFMEA FORM FOR THE REMOVAL OF DEFECTS IN RAIL WELDING

Based on the analysis of defects and their way of detection, all observations were applied into a standardised PFMEA form, in accordance with the quality manual. The form always contains the particular steps of the process as well as possible ways, causes and consequences of these defects that appear in this area. Everything is subsequently evaluated and the RPN risk value is calculated. In accordance with this number, subsequently, all defects were determined, which were the subjects of further measures. In **Figure 5** a part of the completed PFMEA form can be seen, showing the occurring raptures.

Workplace	Process step / Function	A possible way of defect	A possible consequences of defect	Severity	Possible causes of defects	The current process				RPN
						Prevention management tools	Incidence	Detection management tools	Detection	
Welding Shop	**Welding / welds of upper rail surface**	Transverse cracks intersecting a weld and basic material	Weld bead rupture - loss of resilience for a weld bead and basic material	8	High / Low welding speed	Technological process of welding / operator training	6	Visual test (VT) - each weld bead	6	288
								Capillary / Penetration test (PT) - each weld bead	4	192
					High / Low welding current	Technological process of welding / operator training	6	Visual test (VT) - each weld bead	6	288
								Capillary / Penetration test (PT) - each weld bead	4	192
			Reduction the rail lifetime		The insufficient preparation of material - impurities	Grinding, degreasing, brushing	5	Visual test (VT) - each weld bead	6	240
								Capillary / Penetration test (PT) - each weld bead	4	160

Figure 5 PFMEA form

5. OPTIMIZATION TO PREVENT THE CREATION OF DEFECTS IN RAIL WELDING

The optimisation was performed for those defects which exceed the threshold value above 200 RPN. For these defects, a measure was taken (**Figure 6**) with the aim of minimising the emergence of these defects, and thus consequently reduce the RPN risk number to the lowest value possible.

Workplace	Process step / Function	A possible way of defect	A possible consequences of defect	Severity	Possible causes of defects	The current process				RPN	Recommended measures	Responsible	Resulting measures			
						Prevention management tools	Incidence	Detection management tools	Detection				Severity	Incidence	Detection	RPN
Welding Shop	**Welding / weld of upper rail surface**	Transverse cracks intersecting a weld and basic material	Weld bead rupture - loss of resilience for a weld and basic material	8	High / Low welding speed	Technological process of welding / operator training	6	Visual test (VT) - each weld bead	6	288	Operator training / magnetic method test	Team leader / operator	8	5	4	160
					High / Low welding current	Technological process of welding / operator training	6	Visual test (VT) - each weld bead	6	288	Operator training / magnetic method test	Team leader / operator	8	5	4	160
			The reduction of the rails lifetime		The insufficient preparation of material - impurities	Grinding, degreasing, brushing	5	Visual test (VT) - each weld bead	6	240	Operator training / magnetic method test	Team leader / operator	8	4	4	128

Figure 6 PFMEA form including optimisation

The measures recommended were: to carefully train all operators and welders, who operate the welding equipment, and thoroughly familiarize them with the WPS technological processes, including possible consequences if they fail to comply with them. Other recommendations for the better monitoring and detection of cracks can be seen in providing extended visual and capillary tests together with an ultrasonic examination and the magnetic method.

6. CONCLUSION

The subject of this contribution was to apply the method of procedural FMEA (PFMEA) to the processes of welding, namely for rails. The aim was to minimise the occurrence of different types of defects and establish measures necessary to avoid their recurrence.

The important part was our analysis of various types of defects, which occurred and may occur during welding. For these defects, a proper way of monitoring the welds was defined, in order to determine their frequency of occurrence. After analysing the incidence and the detection of defects, an analysis of their severity was provided, with regard to their final influence on applying them in a customer location.

All the supporting documents obtained in individual analyses have been incorporated into the relevant PFMEA form. Using three characteristics (severity, incidence, detection) these defects were rated according to the specified tables and the risk RPN number was calculated. In conclusion, for the high-risk RPN number defects, it was necessary to optimize them, to prevent their incidence and reduce the final RPN risk number.

The assessment of the measure used in accordance with PFMEA it is apparent that the largest share of defects were cracks, which are mainly occurring as a result of a failure to comply with the speed of welding, or the incorrect adjustment of the welding current. The resulting PFMEA can ensure these mistakes are avoided by consistent compliance with the procedures of the WPS welding by operators and welders. Any technological misbehaviour has a crucial impact on the correct welds. In order to improve the detection of emerging defects, additional tests can be carried out using ultrasonic examination and magnetic methods.

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