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Reparation of the fractured mandrel axle-shaft by welding

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ABSTRACT: Problems of reparatory welding of the broken mandrel axle-shaft are considered in this paper. After visual inspecting of the damaged part and analysis of the crack position and static and dynamic loads, which caused the fracture, it was estimated that the broken part could be repaired, but by a very complex welding procedure combined with heat treatment. The prescribed reparation procedure consisted of proposing the welding procedures, selecting the filler metals and way of groove preparation, welding with the so-called EB insert, defining the welding parameters, prescribing the heat treatment before and during the welding, defining the welds deposition order, selecting the additional machining and defining the control type. The axle-shaft was successfully repaired and the spinner was capable of operating. The downtime was significantly decreased and the costs of procuring/manufacturing the new part avoided. The reparation procedure was done in own plant what provided for significant techno-economic benefits.

1 INTRODUCTION

In this paper, a special emphasis was placed on selection of technology for welding by which the broken axle-shaft could be repaired. These authors have already dealt with the similar problems, when the optimal technology for reparation of certain machine parts and devices had to be prescribed, Jovanović and Lazić (2008a), Lazić et al. (2009), Lazić et al. (2015), Lazić et al. (2012a). In addition, certain research has been done, related to steel's weldability, based on which the welding technology should be prescribed, Mutavdžić et al. (2008), Lazić et al. (2012b), Arsić et al. (2015).

After the detailed analysis of weldability of the steel that the axle-shat was made of and of the fracture surface and operating conditions of this, dynamically loaded part, the complete reparation technology was prescribed, Jovanović et al. (2008). It consisted of proposition of the welding procedures (TIG and MMAW), selection of the filler metals, ways of groove preparation at the place of fracture, welding execution with the so-called EB insert, calculation of parameters for the selected welding procedures (TIG – TIG for the root welds and MMAW for the filling and finishing passes), prescribing the heat treatment (prior to and concurrent with welding), weld passes deposition order, selecting the final machining type, current and finishing control, etc. The prescribed technology was executed to an extent that was possible in the production conditions. For the cover passes, the MMAW procedure was selected due to its higher productivity with respect to the TIG method, Chen et al. (2014), Ericsson and Sandström (2003).

2 CHEMICAL COMPOSITION ANALYSIS OF THE AXLE-SHAFT BASE METAL

Chemical analysis has shown that the axle material was the low-alloyed steel (single alloyed by manganese) what approximately corresponds to steel Č3100 – SRPS (EN – E 355N, DIN – ST52.4). Percentage content of individual elements is shown in Table 1, Jovanović and Lazić (2008a), ASM – Metals Handbook (1979), while the mechanical properties of this steel, for thickness s = 16–40 mm are the following: $R_m = 470–560$ MPa, $R_{0.2} = 280$ MPa, $A_5 = 22\%$. The low-alloyed steel of this class has very low carbon content and it is well weldable. However, due to axle-shaft purpose, the

Table 1. Prescribed and analyzed chemical composition of the mandrel axle-shaft steel (Č3100 – E 355N).

Chemical composition, %						
	C	Si	Mn	Cr	S	P
Prescribed	0.14–0.20	0.20–0.40	0.90–1.20	–	0.050	0.050
Analyzed	0.15	–	0.85	0.090	0.020	–

preheating is recommended up to 200°C, Jovanović and Lazić (2008a), ASM – Metals Handbook (1979), Jovanović et al. (1996), Jovanović et al. (2007).

3 THE BASE METAL OF THE AXLE-SHAFT WELDABILITY ESTIMATE

Though the hollow axle-shaft is made of steel that belongs into a class of relatively well weldable materials, due to the shaft's purpose, especially its length and the wall thickness, certain precautionary measures must be taken in order to equalize the metallurgical-mechanical properties of all the zones of the welded joint. Those measures are related to preheating, additional heating and, if necessary, heating through (both the complete welded joint and the zone in its immediate vicinity). Weldability was estimated based on various expressions from references, Lazić et al. (2012a), Mutavdžić et al. (2008), Lazić et al. (2012b), ASM – Metals Handbook (1979), Jovanović et al. (1996). With great simplifications, neglecting a series of influential factors, it could be accepted that the steel is weldable if the final hardness within the heat-affected zone (HAZ) does not exceed 350 HV. It is considered that up to this value martensite would not be created during the welded joint cooling phase. This limiting hardness corresponds to chemically equivalent carbon content of $CE = 0.45\%$. It is thus adopted that steels with $CE < 0.45\%$ are weldable without application of special measures, while the steels with $CE > 0.45\%$ are conditionally weldable or not weldable at all. The obtained values of equivalent carbon for this steel (according to different expressions) were: $CE_{(1)} = 0.31\%$, $CE_{(2)} = 0.31\%$ and $CE_{(3)} = 0.16\%$. Though those obtained values were well below the adopted critical limit ($CE = 0.45\%$), it was necessary to apply prior and concurrent heat treatment, due to structural inhomogeneity of the zone around the circular weld and the operating conditions of the axle-shaft.

Majority of steels, during the welding, are prone to appearance of cold and hot cracks, as well as to numerous interior flaws. The measures to prevent all the flaws consist in application of such welding technologies that would eliminate the transition brittleness. Cold cracks would appear if the martensite or low-bainite structure would be created within the heat-affected zone and if simultaneously appeared large quantities of diffused hydrogen, as well as the internal tensile stresses. The last two factors are caused by the design-technological solutions, so they cannot be influenced. This is why the only possibility left is to prevent the quenching structures to appear during the transformation. That is generally achieved by increase of the driving energy of welding or by preheating. That implies reducing the cooling speed within the area of the least stability of austenite.

The most used method for calculation of the preheating temperature for this class of steel is the method by Seferian, Jovanović et al. (1996), Jovanović and Lazić (2007). By entering data into the Seferian's formula, the preheating temperature of about 70°C was obtained for the thickness of $s = 27.5$ mm. Taking into account that the preheating temperature must not be higher than the M_s temperature (circa 440°C, CCT diagram), Jovanović and Lazić (2008b), and the mentioned operating conditions of the axle-shaft, the preheating temperature was adopted to be within range $T_p = 150–200 \pm 10$°C. There, it had to be kept in mind that the own thermal stresses (transition and residual ones) must be kept at the minimum level.

4 THE FILLER METAL SELECTION

For filling the groove, after the root pass was deposited by the TIG procedure, it is recommended to apply the MMAW procedure and electrode EVB 50, Jovanović and Lazić (2008a). The

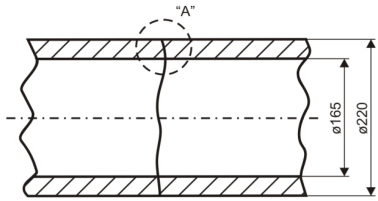

Figure 1. Schematic details for welding the axle-shaft.

Table 2. Recommended electrodes and welding parameters.

Technological parameters of the TIG procedure					Heat treatment	
Electrode mark	d_e [mm]	I [A]	Current type	Electrode drying	Prior T_p [°C]	Current $T_{heat\text{-}through}$ [°C]
EVB 50	3.25	110–140 A	= (+)	400°C/1 h	150–200	150–200
	4.00	140–180 A	= (+)	400°C/1 h	150–200	150–200

recommendations are that the few initial passes should be executed by the TIG procedure (Fig. 1), the filling passes close to the root pass by the MMAW procedure and with electrode of diameter $d_e = 3.25$ mm, while the rest of the filling and the cover passes to be executed with the electrode of diameter $d_e = 4.0$ mm. In Table 2 are presented the recommended welding parameters. Selection of the filler metal has the strong influence on final mechanical properties of the welded joint, what was shown by Mazur et al. (2014). The filer metals are chosen from certain catalogues of the filer metals manufacturers, (Catalogues and prospects, 2014).

5 THE WELDING TECHNOLOGY SELECTION

One starts from preparation for making the circular V-groove by mechanical machining. All the noticed cracks must be ground, i.e., the "liberation" of all the flaws is done and the groove is formed for welding. It is recommended that the design and preparation of the groove should be done according to Figure 1 and to make the so-called the EB-insert in order to deposit the root pass by the TIG procedure, Jovanović and Lazić (2008a). The method of the melting insert with the root pass was originally applied for the very responsible structures and was mainly developed for assemblies accessible from one side only, when the smooth interior surface without underfills is needed and when the root pass of unconditionally high quality is required (pipes joints).

It is assumed that the insert is completely melted by the TIG welding procedure. Deposition of the root pass, which is smooth and uniform, is enabled even when welding is done from one side only. The insert provides for complete welding-through of the root in grooves, which are accessible from the top side only. The melting insert must be precisely positioned and fixed and it serves as the underlying ring, what is often specified in welding of pipes. In many cases of execution of responsible and multi-pass welds with the melting insert, the TIG procedure is applied, but only for the joining (staple) welds and the root pass.

The typical procedure for application of the melting inserts is joining of two pipes of different cross-sections, in the horizontal position and it consists of the following activities:

- careful placement of circular melting EB inserts into the previously prepared V-groove;
- careful execution of the stapling welds by joining the EB inserts and the pipe walls by application of the TIG burner;
- after the partial joining of the melting semi rings and the pipes walls, it is necessary to carefully execute the root pass by application of the previously determined welding parameters (tungsten electrode diameter 2.4 to 3.2 mm, welding current 100 to 180 A, working voltage 12 to 17 V,

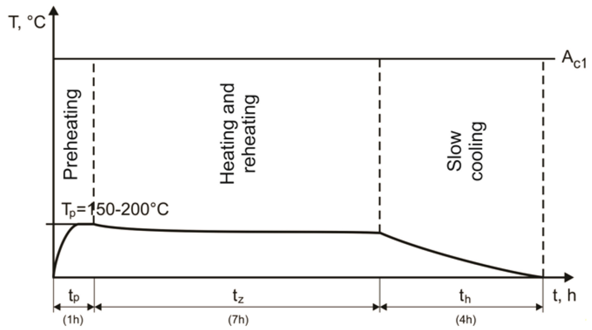

Figure 2. Complete heat treatment cycle of the axle-shaft reparation.

Table 3. Welding parameters for the TIG procedure and estimated characteristics of the HAZ.

d_e [mm]	I [A]	U [V]	v_z [mm/s]	q_l [J/mm]	$t_{8/5}$ [s]	HAZ microstructure	HAZ hardness
3.25	110	24.5	≈1.24	1738.7	11.2–14.15	B + F	210 < HV < 285
4.0	170	27	≈1.60	2295.0	13.46–17.00	B + F	210 < HV < 245

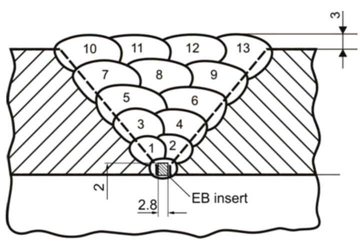

Figure 3. Deposition of the passes by the MMAW procedure (1 to 4-$d_e = 3.25$ mm; 5 to 13-$d_e = 4.0$ mm).

polarity E-, welding speed ≈180 mm/min, protective gas flux ≈10 lit/min, nozzle size 9.5 to 11 mm);
- EB insert should be made of low carbon steel (e.g. Č0146 – EN-DC01) or austenitic stainless steel.

In manufacturing the semi rings one should predict the extensions for easier placing, which would be cut off or melted after placing the semi rings into the groove. Based on the obtained results, one can conclude that the relatively favorable microstructure in the HAZ is obtained (B + F) and relatively low hardness. This is why additional tempering was not necessary, since the unfavorable brittle structures did not appear. In addition, the convenient circumstance is that the following passes relax the previous ones, and the finishing, non-tempered layers are additionally mechanically processed. It is recommended that the fractured zone of the axle should be first preheated. Thus, this zone should be heated slowly until the preheating temperature is reached, then it should be held at that temperature for a certain time – heating through, until the whole cross-section wall does not reach that temperature 150 to 200°C, Figure 2.

After the preheating, one should deposit the root pass by the TIG procedure (Table 3) with the EB insert; then the groove filling should be executed by the MMAW procedure (Fig. 3).

During the whole reparation time, it is necessary to maintain the required preheating temperature, i.e., the part should be constantly reheated by special heaters or the gas burner. It is necessary to provide the most favorable position for the welder, what is achieved by utilities (holders, positioning tools, lunette, turning by the angular velocity adjusted to the prescribed welding speed for the given electrode diameter, etc.). Welding should be done according to the proposed order, Figure 3.

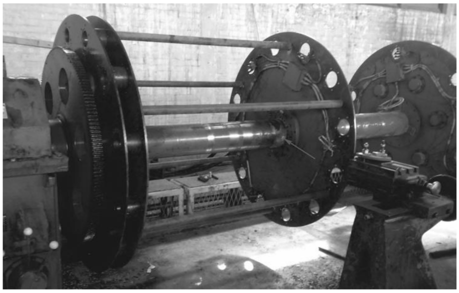

Figure 4. Appearance of the repaired mandrel axle-shaft.

Order of operations in the reparation procedure should be as follows:

- Prepare the groove;
- Make the two-part EB insert according to the given dimensions from the recommended material – the low carbon steel (e.g. Č0146 (EN – DC01), Č0147 (EN – DC03), ...) or from the austenitic steel;
- Secure the two welding devices: the TIG apparatus for the root pass deposition and the MMAW apparatus with direct current for the filling passes deposition;
- Procure the basic electrodes (EVB 50) of diameters 3.25 mm and 4.0 mm, dry them out according to the prescribed regime to eliminate the moisture from the coating (at least one whole package of each of the given diameters, at least 5 kg each);
- Deposit the root pass by the TIG procedure with help of the EB insert, then the filling passes by the proposed electrodes, first of diameters 3.25 and then 4.0 mm (Fig. 3);
- Apply the adequate technology of block-sequences in welding-filling the groove and during depositing the finishing passes (Fig. 3);
- Immediately after the deposition of each layer, it should be mildly forged at temperature above 480°C in order to preserve the impact toughness;
- The slag should be completely removed by the steel brush after each pass and finally it should be blown away by the compressed air;
- The preheating temperature should be constantly controlled;
- It is necessary to heat additionally, occasionally or constantly, the welded area to maintain the prescribed temperature; (it is the best to do it by the propane burner)
- After the complete reparation procedure was executed, the regenerated part should be heated through for a shorter time and then slowly cooled down to room temperature; (the whole welded area should be covered by asbestos or the hot sand).

For this type of joints, the control is mandatory. The prior control consists of checking of the base and filler metals, evaluation of the welding equipment condition, insight into the welders' qualifications and checking of the groove dimensions and coaxiality of both parts of the broken pipe. The current control consists of: checking whether the prescribed electrodes are properly used, whether the voltage was adequately selected, whether the order of individual passes is being respected, whether the slag is regularly removed after each pass. The final control enhances the visual control, the control with the magnifying glass, the control by magnetic flux, penetrant liquids and ultrasound defectoscopy. Appearance of the repaired part is presented in Figure 4.

6 CONCLUSION

By executing the prescribed technology the mandrel axle-shaft was successfully regenerated and the machine – the spinner successfully repaired for work. The downtime of the machine was significantly reduced, the supply costs lowered as well costs of making the new axle-shaft, the reparation procedure costs were also lower since the whole job was done in own plant, i.e., the significant techno-economic benefits were realized.

The whole reparation procedure of the broken mandrel axle-shat enabled modeling of a complex procedure for some future reparation tasks for parts of the similar shape and dimensions. However, despite this fact, each reparation procedure must be approached in a special way. By application of the new knowledge, modern technologies and filler metals, it is realistic to expect multiple positive effects of the part regeneration, which are reflected primarily in saving of the expensive imported parts – the base metal, shortening the downtimes of machinery, reconstruction of some technical solutions, etc.

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