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SUITABILITY OF HEAT TREATMENT FOR CRACK RESISTANCE OF MATERIAL IN THE CONNECTION PART OF HEAVY TRANSPORTER FOR LIQUID SLAG

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The post weld heat treatment (PWHT) was used to reduce the level of the residual stresses and increase of the crack resistance of the material in the connection part. The article presents the results of the residual stress measurements immediately after welding and after the stress relaxation by the PWHT.

Key words: weld, heat treatment, residual stress, stress relaxation, crack resistance

INTRODUCTION

Residual stresses (RSs) arise due to local plastic deformation. The plastic deformations always occur during welding by melting. The first such mechanism which generates RSs is hindering contraction resulting from local heating during welding process [1-3]. As a result, RSs arise due to hindering shrinkage. The second cause is the microstructural transformation, where sufficiently heated part of materials are transformed during cooling, so the crystal lattice with surface centred cube changes into crystal lattice with body centred cube [2,4]. The weld metal and part of the heat affected zone areas have tendency to increase their volumes during transformation, but the colder not transformed material in the surrounding area hinder their expansion. As a result, RSs arise due to microstructural transformation. The final level of the RSs depends on interaction of the two mechanisms which generated RSs, temperature when the transformation occurs, heat input during the welding and constraint of the construction during the welding [2]. It is desirable that welded constructions after welding have low level of the RSs, because they can have a harmful influence. Tensile RSs are the most undesirable, because they try to open small welding defects. This can lead to cracks initiation on the welding defects and their further propagation [5,6]. When the level of the RSs is high, various methods are used to reduce the RSs, for example post weld heat treatment (PWHT), vibration during welding, vibration after welding, local plastic deformation etc [2,4]. The PWHT is the one of the most effective methods for relaxation of the RSs, where hardness and yield stress of the material is also reduced and impact toughness is normally increased [2]. The method is appropriate for low alloy construction steels, but more problems occur with its use at micro-alloyed and HSLA steels due to precipitation of carbides. This article deals with RSs measurements on the connection part of the hinge joint of the mobile transporter's construction for transport of liquid slag. It's construction weights 120 tons and can carry 90 tons of liquid slag. During exploitation on the connection part of the transporter crack initiated and propagate until transporter need to be serviced. Figure 1 shows the mobile transporter for liquid slag, the rear part of the transporter and location where crack appeared in exploitation (detail A).

It has been proved during the exploitation that the vital part is the connection part of the hinge joint, which has to be as small as possible to ensure manoeuvrability of the mobile transporter. As a result, it is heavily dynamically loaded, because it connects the front part of the mobile transporter and the rear loading part of the transporter's construction where there is the pot for transport of the liquid slag. High tensile RSs in this part of the mobile transporter's construction are not desirable, because they can have a harmful influence. The PWHT is used on the connection part to relax RSs generated at welding process. The RSs were measured by using magnetic method in the ''as welded'' condition and in the ''PWHT'' condition..

EXPERIMENTAL PROCEDURE

The 40 mm thick material S355 J2 was used for experimental investigation as a base material. MAG welding process was used for welding. The gas mixture of 82 % Ar and 18 % CO_2 and welding filler material VAC 60 ∅1.2 mm were used at welding. Mechanical properties are shown in Table 1.

The connection part during manufacturing by welding is presented in Figure 2.

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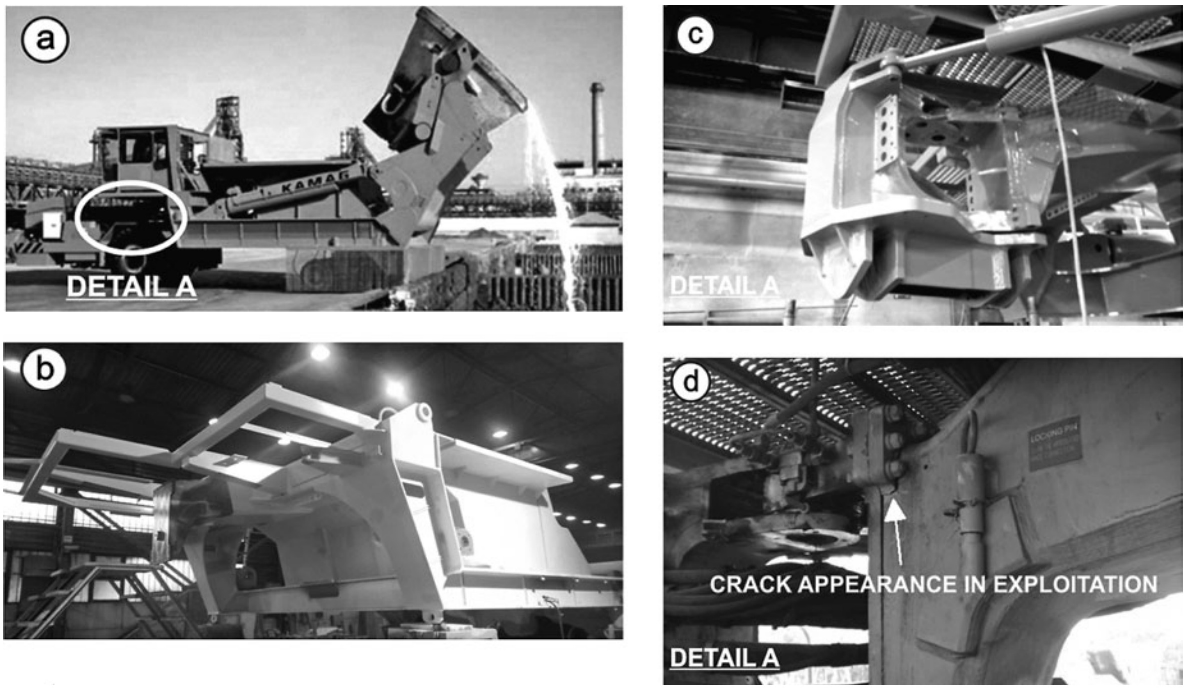

Figure 1 Mobile transporter for slag: a) transporter and detail A where is connection part of the hinge joint located, b) rear part of the transporter, c) connection part and the hinge joint, d) crack in the connection part of the hinge joint in exploitation

Table 1 **Mechanical properties of the base and filler materials**

Material	$R_{p0,2}$ / MPa	R_m / MPa	A_5 / %	KV / J (20 °C)
Base mat.	459	551	25	146
Filler mat.	410	550	22	47

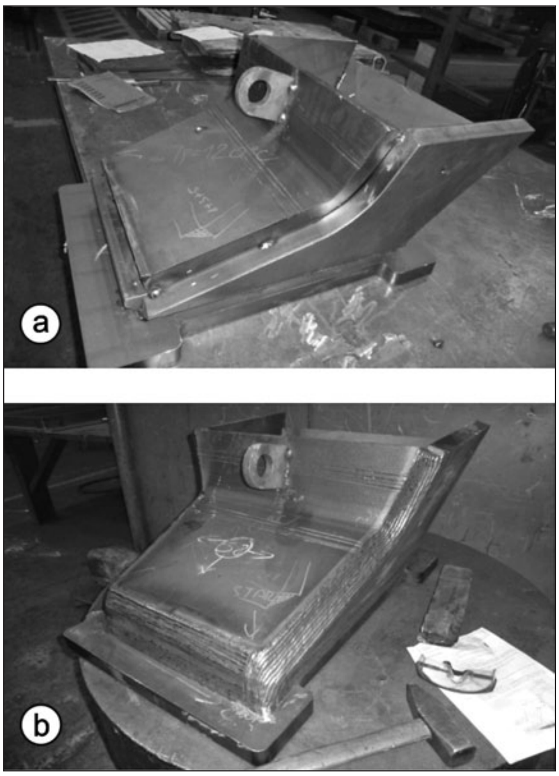

Figure 2 The connection part of the transporter's construction during manufacturing, a) before welding, b) after welding

Post weld heat treatment was performed in the furnace. The heating speed was 140 °C/h. The connection part was held for 2 h at temperature of 590 °C and then it was cool down in the furnace. The cooling speed was 100 °C/h. When the connection part reached 200 °C, it was cooled down in the air. Vickers Hardness HV10 were measured in the in the weld joint in the vicinity where crack initiate and propagate in exploitation in the connection part of the hinge joint. Hardness were measured in "as welded" condition and post weld heat treated condition ("PWHT") as well. Three different magnetic methods exist for measuring of RSs [1]. The first is Induced Magnetic Anisotropy Method, the second is Berkhausen Emissions Method and the last is Magnetic Acoustic Emission Method [7]. The Induced Magnetic Anisotropy Method is used for the experimental measurements. We have measured the difference between principal RSs and their direction. The calibration of the method was necessary to be performed on the same material before measurements. For this purpose the flat tensile specimen (40× 20 mm) was machined from steel S355 J2. The calibration curve is shown in Figure 3.

Firstly, the RSs were measured by the magnetic method on the connection part after manufacturing. They were measured immediately after welding, therefore in ''as welding'' condition. The locations of the measurements are shown in Figure 4 on the left side. Secondly, the connection part was PWHT and then RSs were measured again by using the magnetic method on the same locations to get the level of the RSs in ''PWHT'' condition.

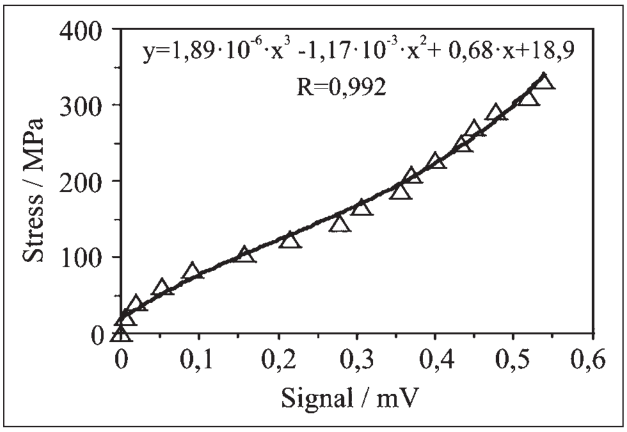

Figure 3 The calibration curve

RESULTS AND DISCUSSION

Results of hardness measurement HV10 are shown in Figure 4. Hardness were measured in weld metal - WM, heat affected zone - HAZ and base material – BM. Figure 4a shows results in ‘’As welded’ ’ condition and Figure 4b shows results in ‘’’PWHT’’ condition. Measurements were performed in weld joint in the vicinity where crack appeared in exploitation.

The influences of macro and micro RSs (I., II. and III. order) together are possible to be measured by the magnetic method, but only the differences of the principal RSs and their directions can be obtained. Figure 5 shows the results of RSs measurements on the connection part of the hinge joint at in the ″as welded″ and the ″PWHT″ conditions. The roman numbers in Figure 5 on the right side corresponds to the measurement paths, which are shown on the left side.

The important is the fact that relaxed RSs are as small as possible in ″PWHT″ condition in some special regions:

- at the position 1 in corners of paths (I. – II and II. – III.),

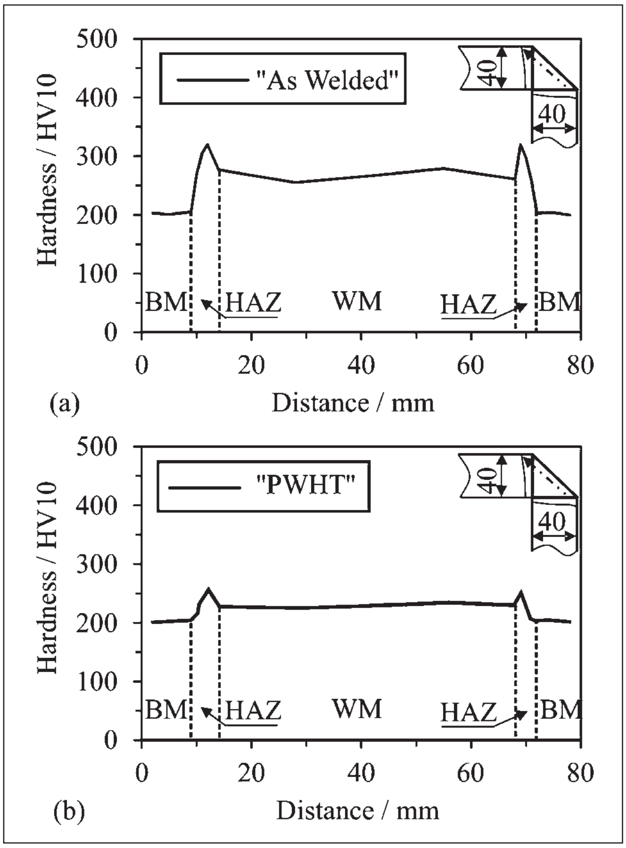

Figure 4 Results of hardness measurements; a) ‘’As welded’’ condition, b) ‘’PWHT’’ conditions

- at the position 2 in the corner of paths (I. – II.),
- at position 3 in corners of paths (I. – II. and IV . – I.),

where the welds are cross each other and those parts of material are heavily dynamically loaded in exploitation. In those regions cracks started to appear on the most heavily loaded mobile transporters in practice, which did not use PWHT for relaxation of the RSs in the connection part of hinge joint. Appropriate results in Figure 5 in

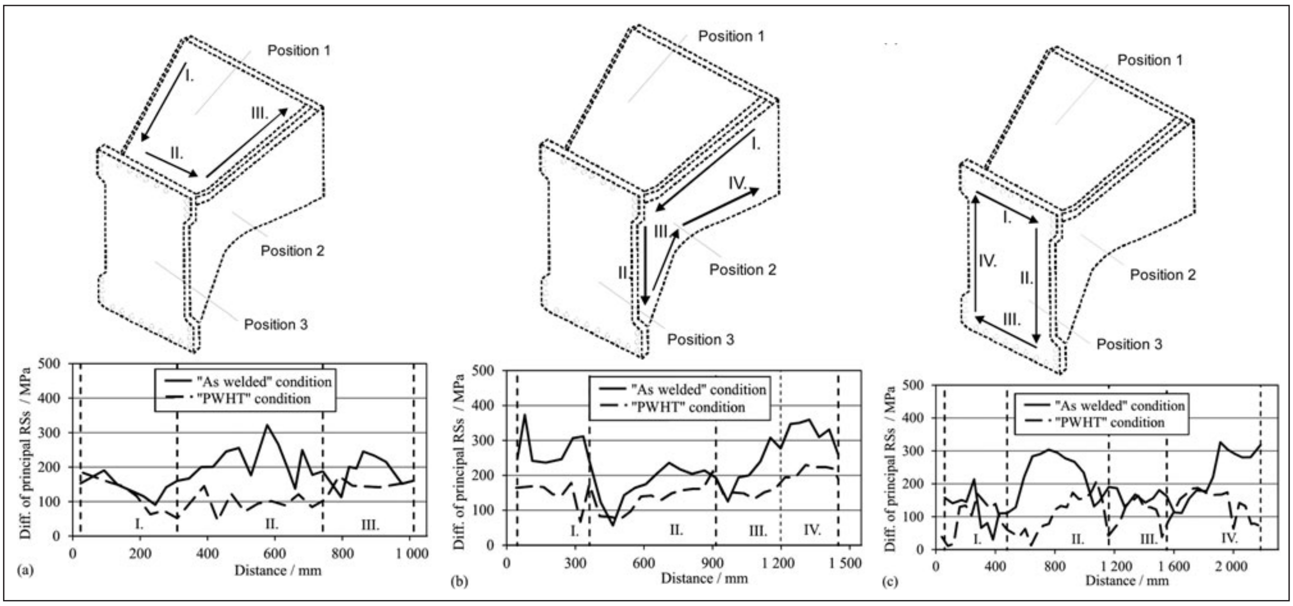

Figure 5 The results of RSs measurements In ″as welded″ and ″PWHT″ conditions; for position 1(a), for position 2(b) and for position 3(c)

those regions show that the RSs relaxed more than 50 % in differences between principal RSs after the PWHT . Hardness in those regions is also reduced by PWHTwhat influence on decreasing of impact toughness and increasing of the crack resistance of the material. The regime of the PWHT for relaxation of RSs is adequate and enables safe operations of the mobile transporter for liquid slag in future. In particular mobile transporter where crack appeared in exploitation, the connection part of the hinge joint was cut and replaced by new one which had been PWHT before. Another safety step which was performed in this mobile transporter are additional ribs which were welded in the positions where cracks appeared before in order to reduce the load and increase the safety and crack resistance of the material of the mobile transporter . Mobile transporter still works in exploitation without any problems.

CONCLUSIONS

The post weld heat treatment (PWHT) was used for RSs relaxation on the connection part of 120 tone mobile transporter for transport of the liquid slag. RSs were measured by magnetic method in the ″as welded″ condition immediately after welding and in ″PWHT″ condition after the heat treatment.The differences of the principal RSs were lowered for more than 50 % in regions where cracks appear in exploitation of the heavily loaded mobile transporter which used connection part in ″as welded″ conditions so the PWHT regime (590 °C/2h) was appropriate. Another safety measure in company is that additional ribs were welded in the positions where cracks appeared before in practice during fabrication of the connection part before PWHT in order to reduce the load and increase crack resistance of the material and safety of the mobile transporter. Particular mobile transporter where crack appeared in exploitation, after two years, still works in practice since it has been serviced and connection part of hinge joint was replaced by new one which had been post weld heat treated before.

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