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Repairing of cracks on tooth gear ring of a bucket-wheel excavator

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Abstract

Bucket-wheel excavators are continuously working machines for removal of waste and useful materials in open-pit mines, mainly used for mining of lignite. The purpose of a tooth gear ring is to rotate the excavator using two reducers. Due to this, the structural integrity of such elements is of great importance for the safe and reliable operation of the bucket-wheel excavator as a whole. In order to ensure its proper function, non-destructive testing (NDT) methods (namely magnetic particles testing) was performed after casting of gears. NDT revealed the presence of cracks with varying lengths (10-110 mm), which were located in the gear teeth, its main body and the openings used for connections between segments. For this reason, it was necessary to adopt a repair welding technology which would eliminate the cracks. Since the tooth gear ring was made of GS-40MnCrSi3V low-alloyed cast steel, electrode 42 4 B 42 H5 (designation according to EN 499E) was selected as filler material, due to its exceptional mechanical properties, suitability for welding of low-carbon low-alloyed steels and low hydrogen content. Manual arc welding was the procedure used in this case. Since these repairs were all performed on the surface of the tooth gear ring segments, final NDT included only magnetic particle and penetrant testing, both of which had shown that the repair technology was successfully applied, i.e. not new defects were detected in the repaired gear ring elements.

Keywords: tooth gear ring; repair welding; bucket-wheel excavator; GS-40MnCrSi3V steel

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1. Introduction

If they do not significantly affect the functionality (along with safety) of the part or whole construction, some defects caused by casting can be tolerated. In any other case, these defects could cause serious damage and should be eliminated. Based on the consequences that casting defects can cause, they can be distinguished as:

1. Unrecoverable defects (nor from technological or economical aspects of justification).
2. Defects which can be eliminated by applying additional measures.
3. Defects that can be eliminated in accordance with technical conditions (by welding, impregnation etc.)

Repair welding is a commonly used technique for elimination of any type of defects with the aim of restoring functionality of damaged part, either new or old one [1-7]. The procedure of repairing consists of clearly defined activities, which begin with dismantling, followed by part cleaning and damage analysis, defining of a repair method with techno-economic analysis, followed by technological procedure elaboration, preparation, performing repair welding itself, control and testing, and at the end machining to the final measures and returning repaired part in service with *running-in* period. Among aforementioned activities, damage analysis is among the most important ones, requiring knowledge about material properties, loading condition and damage mechanism to which part is exposed to, and in this particular case that the paper is dealing with - bucket-wheel excavator (BWE).

Bucket-wheel excavators are continuously working machines for removal of waste and useful materials in open-pit mines, mainly used for mining of lignite. Containing tooth gear ring, its purpose is to rotate the excavator using two reducers. Due to this, the structural integrity of such elements is of great importance for the safe and reliable operation of the bucket-wheel excavator as a whole. Several approaches could be applied in order to assess its structural integrity in presence of cracks, e.g. fracture mechanics approach by Arsić et al [8] used on analysis of the gear tooth fracture occurrence and its cause. Some of the studies were based on FEM analysis concerning bucket wheel excavator failure, like Rusinski et al [9] and fracture analysis of shaft, Arsić et al [10] by analyzing the influence of residual stresses in welded joints, Sedmak et al [11] analyzing rotor excavator bearing structure etc. One of the interesting approach is proposed by Petrovic et al [12], introducing the reliability-based analysis of the BWE load-bearing steel structure and quantifying the level of failure, reliability and furthermore delivered reliability index for each failure criteria. Bošnjak et al. [13] performed the fracture analysis of the pulley of a bucket wheel boom hoist system concluding that fracture was the result of the *manufacturing-in* defects, which is also emphasized by Arsić et al [8] pointing-out the role of *manufacturing-in* defects in bucket wheel excavator gears as well. Similar approach by Daničić et al. is presented in papers [14-16].

In this paper the repair-welding technology on tooth gear ring of a BWE is presented, as caused by casting, i.e. repair welding of new part upon delivery. After routine inspection, non-destructive testing (NDT) revealed the presence of cracks on gear ring with varying lengths in range of 10-110 mm, which were located in the gear teeth, its main body and the openings used for connections between segments. For this reason, repair welding technology was developed in order to eliminate cracks caused by inadequate manufacturing process (i.e. casting) taking into account parent material properties, since the tooth gear ring was made of low-alloyed cast steel GS-40MnCrSi3V. Electrode 42 4 B 42 H5 was selected as filler material, and along with it, manual arc welding (MAW) technique. Since these repairs were all performed on the surface of the tooth gear ring segments, final NDTs included only magnetic particle (MT) and penetrant testing (PT) in order to confirm repair-welding technology.

Nomenclature

BWE	bucket-wheel excavator
NDT	non-destructive testing
MAW	manual arc welding
MT	magnetic particle testing (of NDT)
PT	penetrant testing
R_e	yield stress
R_m	tensile strength
A_5	elongation

2. Parent material cast steel GS-40MnCrSi3V

Due to their specific characteristics, cast steels are intended for operation in highly dynamic load conditions. Good wear resistance also characterizes cast steels, and thus they are used for manufacturing of gears. Cast steels have higher casting shrinkage than cast irons, along with higher casting temperature. One of the main problem with cast steels is large influence of the casting thickness (along with its hardening rate) on the mechanical properties, mainly toughness and ductility that decrease with casting thickness increasing [1]. With casting thickness increasing, elongation and contraction of the cross-section (in other words, the deformation properties A_5 and Z) decrease simultaneously. The mechanical properties of cast steel can be improved by heat treatments (normalization or quenching + tempering). For gears production, which are primarily exposed to wear damage mechanism [17-18], Cr-Mn-Si cast steel are used in a thermally treated condition. They contain 0.25-0.45% C, which corresponds to the best ratio of yield stress/tensile strength ratio and good casting properties.

The parent material of BWE gear segments are made is low-alloyed cast steel GS - 40 MnCrSi3V, and its chemical composition and mechanical properties are given in tables 1 and 2, respectively.

Table 1. Chemical composition of low-alloyed cast steel GS - 40 MnCrSi3V [19]

	C	P_{max}	S_{max}	Si	Cr	Mn	Cu_{max}
[%]	0.35-0.45	0.04	0.04	0.5 -0.75	0.5-0.8	0.6 -0.9	0.3

Table 2. Mechanical properties of low-alloyed cast steel GS - 40 MnCrSi3V at 20 ºC [19]

Re [MPa]	Rm [MPa]	A_5 [%]	Z [%]	KCU 3 [J/cm^2]
340	640	10	20	17

3. Damage analysis

Having in mind aforementioned (concerning parent material characteristics), damage analysis was performed. After casting of gear segments, MT of NDT was applied. MT with a fluorescent suspension of particle size 3 µm was performed for defects detection. Surface indications. i.e cracks, were observed on 8 out of 12 gear segments. The lengths of the cracks varied in range 10-110 mm. Cracks were located in the gear teeth, its main body and the openings used for connections between segments as shown in Fig. 1. Surface cracks were probably caused by inadequate manufacturing process (casting or heat treatment), accurately caused by cooling rate causing cracks forming.

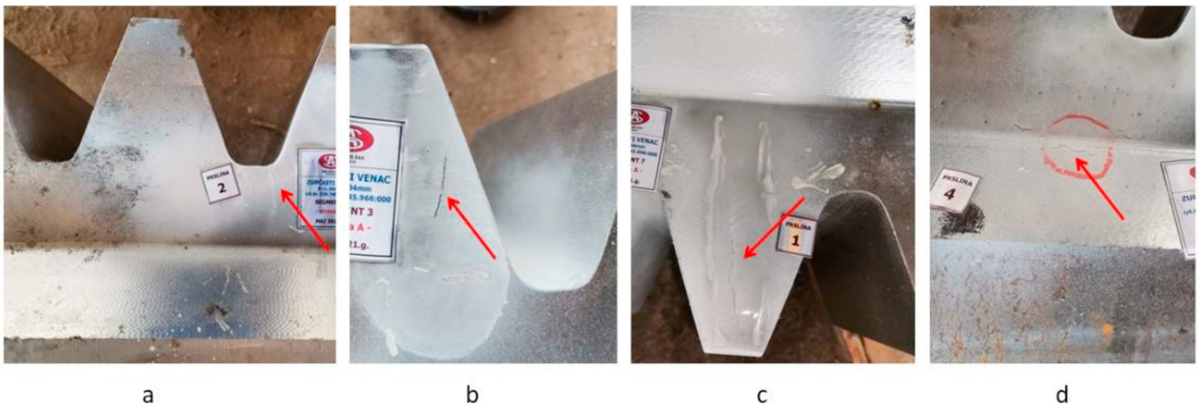

Fig. 1. (a) crack length of 25 mm between gears' teeth; (b) crack length of 30 mm on one of tooth surface; (c) crack length of 110 mm on one of tooth surface; (d) crack length of 10 mm on gear body (ring).

4. Repair-welding technology

Taking into account chemical and mechanical characteristics of gear's parent material (cast steel GS - 40 MnCrSi3V), the requirement concerning mechanical properties of the weld metal (that should not be not lower than the designed one), as well as equipment and conditions in which the repair welding should be carried out, MAW technique was used. Electrode 42 4 B 42 H5 (according to standards EN 499 E and EN ISO 2560-A) was used for filling grooves, and gear repairing in general. This electrode represents coated basic electrode, providing excellent welding characteristics and high metal recovery rate. Welds possess high toughness even at low temperatures, resistant to cracking (> than 47 J at -40 ºC). It is recommended for welding structural steels and cast steel with tensile strength up to 610 MPa as well as fine grained steels with increased yield strength. Deposits have very low hydrogen contents (less than 5 ml/100 g). Chemical composition and mechanical properties of pure welds of used electrode are given in tables 3 and 4, respectively.

Table 3. Chemical composition of electrode 42 4 B 42 H5

	C	Si	Mn
[%]	0.06	0.6	1.0

Table 4. Mechanical properties of electrode 42 4 B 42 H5

R_e [MPa]	R_m [MPa]	A_5 [%]
>440	510-610	>24

After damage analysis and establishing of the repair welding procedure, the discovered cracks were eliminated by grinding, creating the grooves that should be filled with described electrode. Groove depth goes up 60 mm in some cases. Some of the prepared grooves (with U shape) can be seen in Fig. 2. Before repair welding itself, the grooves were tested with MT and liquid penetrants (PT) of NDT as well in order to make sure that the cracks were removed.

Fig. 2. Examples of prepared grooves on different gear segments.

Takin into account parent material's limited weldability, as well as propensity to cold and hot crack of GS - 40 MnCrSi3V [6], preheating at 150°C was necessary. Preheating temperature was determined according Seferian's expression [2, 5-6]. Each electrodes were dried in furnace at 350°C for 2h before usage. Welding parameter for each electrode diameters were shown in table 5. Electrode with Ø2.5 mm was used for root layers, while with Ø3.25 mm for filling rest of the grooves, which was illustrated in Fig. 3.

Interpass temperature between weld layers did not exceed 300°C. Air-cooling were carried after welding, where welded parts are coated with asbestos in order to decrease cooling rate. Fig. 4 shows some of the welds after welding activities. Upon cooling, grinding and polishing of welded joints were carried out to designed geometry.

Table 5. Welding parameter

Layer	Electrode diameter [mm]	Current [A]	Voltage [V]
1-3	Ø2.5	70-85	20
n	Ø3.25	110-140	22

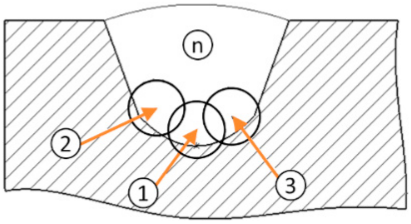

Fig. 3. Filling plan of the grooves: first 3 (root) were filled with electrode diameter Ø2.5 mm; rest were filled with electrode diameter Ø3.25 mm.

In order to verify applied repair-welding technology, PT was carried out on each weld after polishing, and no defects were discovered. Polished repair gear along with PT NDT results method is shown in Fig. 5.

Fig. 4. Filled grooves on gear segments.

Fig. 5. Gear segments after polishing and no surface defects after PT.

5. Conclusion

Necessity of knowing material properties along with knowing the manufacturing technology as well is emphasized. Lower fluidity and significant casting shrinkage led to occurrence of *manufacturing-in* defects on BWE gears, which needed to be repaired. Developed welding technology was confirmed by NDT, confirming the structural integrity of restored gear. The applied NDT methods was primarily dictated by the design and material of the casted parts. Since the examination only included the surface and not the gear volume itself, the MT and PT NDT methods were used.

It was concluded that the repair welding was successfully carried out, and repair gears' segments were put back in service. Monitoring of restored gear is recommended in running-in period.

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