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VALIDATION OF THE FINITE ELEMENT METHOD (FEM) IN CASE OF RECONDITIONING BY WELDING APPLIED TO CRANKSHAFTS

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This paper presents the results of the practical trials carried out based on the calculation assumptions considered within the FEM of the reconditioning by welding of a crankshaft used in the automotive industry. For the validation of the analytical model it was considered the influence of the crankshaft fixing possibility as well as the influence of preheating temperatures on the structure of the deposited zone.

Key words: welding, reconditioning, shielded metal arc welding (SMAW), FEM, crankshaft

INTRODUCTION

The crankshaft is a part that ensures the quality of engine functioning; as the working conditions of the crankshaft are difficult, it must withstand the tensile stress, compressive stress, flexural moment and wearing, which cause the crankshaft journal wearing and fatigue fracture. The life of the crankshaft determines the life of the engine, so the crankshaft is important for the driver's safety. Many engine production enterprises pay great attention to the crankshaft processing, improving the technology of crankshaft processing, in order to improve the quality of crankshaft processing and extend its life [1 - 3].

If the components of equipment are damaged during functioning, they can be replaced or reconditioned so that they can be brought to the initial dimensional value or so that they can regain their initial mechanical properties. If the replacement of the parts is expensive, the parts are reconditioned [4].

The welding deformation is the most important factor that influences the quality of the welding. The welding distortion and residual stress can not only cause the welding cracks, cold cracks and brittle fracture, but also affect the load-bearing capacity, machining precision and dimensional stability of structures.

However, due to numerous factors involved in welding process, it cannot predict welding deformation just depending on experimental data, especially for the large structure. With the development of the computer technology, the numerical simulation for the welding process is an effective method to simulate the welding process, which describes the welding process based on a set of mathematical equations.

The current trend in the field of welded products is to minimize or eliminate the time lost with preliminary tests for the approval of welds, respectively of welding technologies. One of the possible methods to achieve this goal is to simulate the real working conditions by using specialized software. The current research trends are trying to pre-establish the thermal history of the work pieces by using specialized software [5].

The FEM modeling process requires three types of input data: the geometry, the material properties and the loading. In order to determine the operating behavior, a FEM methodology was developed to predict possible material or welds failure locations. Then a solid model is designed and accurate material properties are applied for the crankshaft Figure 1.

EXPERIMENTAL PROCEDURE

The behavior of a crankshaft used in the automotive industry in case it is subject to reconditioning by welding was simulated by taking into account the initial conditions of the studied crankshaft. The base material used to make the crankshaft is EN-GJS-600-3 cast iron according to DIN EN 1564:2012. The mechanical properties and the chemical composition of the base material are presented in Table 1 and 2.

Table 1 **The standardized chemical composition of the base material of EN-GJS-600-3 / wt %**

Base Material	C	Si	Mn	P	S
EN-GJS-600-3	2,5 - 3,6	1,8 - 2,8	0,3 - 0,7	≤ 0,08	≤ 0,02

Table 2 **Material properties measured on test parts according to DIN EN 1563:2012**

Material designation	Tensile strength R_m / N/mm^2	Yield strength $R_{p0,2}$ / N/mm^2	Elongation A / %	Microstructure
EN-GJS-600-3	600	370	3	Pearlite/ ferrite

Starting from the real geometric configuration of the crankshaft as presented in Figure 1 a), it was created its 3D model, which is presented in Figure 1 b).

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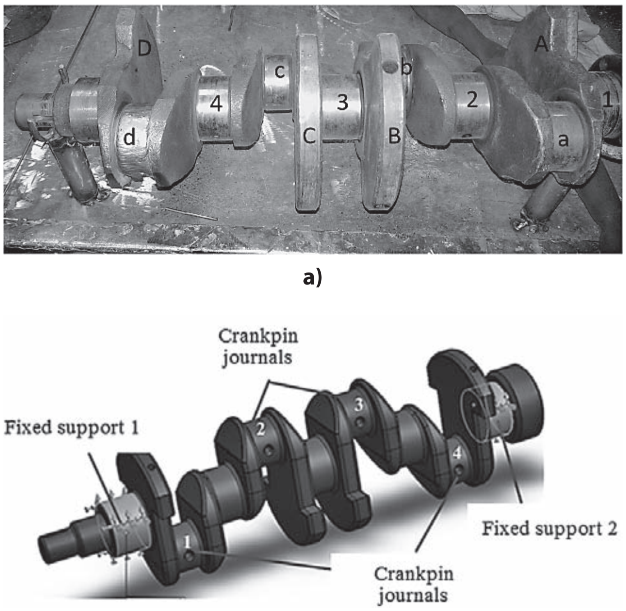


a)

b)

Figure 1 Model of the analyzed crankshaft; a – real model, b – 3D model

In order to reduce the internal strain level and avoid the risk of occurrence of defects after the reconditioning process it was preheated the crankshaft up to a temperature of 200 / ^{0}C [6]. Considering this technological aspect, when will be carried out the simulation it will be applied the thermal load of the crankshaft to the recommended temperature.

During the reconditioning process the crankshaft will be fixed in clamping devices so as to ensure its better stability. From a technological point of view the crankshaft may be fixed at one of the ends or at both ends. The influence of the fixing possibilities is analyzed in the first case study (Figure 1 b).

After inputting the initial data and running the finite element analysis program it was concluded that the highest values of the displacements and stresses occur when the crankshaft is only fixed at one end (Figure 2 and 3).

From the analysis of Figure 2 and 3 it can be observed that the maximum values of the displacements are encountered in the passing zone between the crankpin journal and the adjacent elements of the crankshaft (counterweights), in the technological connection zones, as well as in the oil way zone.

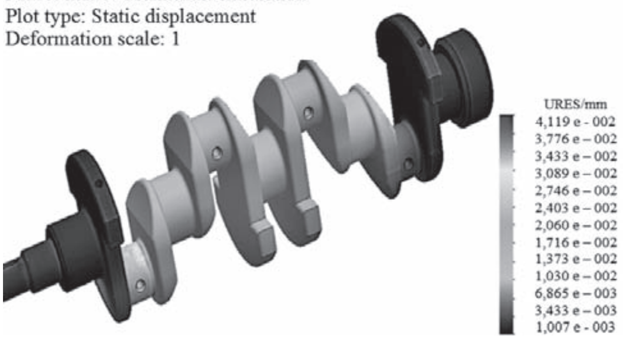


Figure 2 Variation of the displacements in the crankshaft

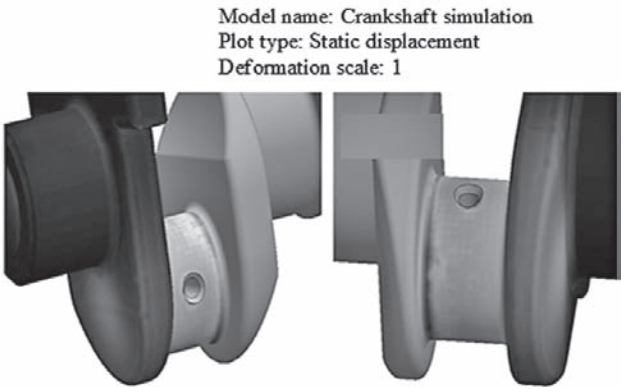


Figure 3 Risk zones with maximum displacements in case journal 1 is reconditioned

In the risk zones it is recommended to deposit a bead at lower values of the welding current intensity before facing the crankpin journals, in order to limit the waving range of the electric arc and the possibility of unintentional touching of adjacent zones [5].

Following the finite element analysis and the interpretation of the results there was elaborated the experimental reconditioning plan for the validation of the analyzed model.

For the depositing process there were chosen two depositing variants that are similar to those used for finite element analysis:

- sample 1 (P 1): the preheating temperature of the crankshaft was the environment temperature: 20 / ^{0}C, the crankshaft was fixed into the device at one end;
- sample 2 (P 2): the preheating temperature of the crankshaft was: 200 / ^{0}C, the crankshaft was fixed into the device at both ends;

The reconditioning technology consisted of [6]:

- visual testing and penetrating liquids testing of the crankpin journals area;
- machining of the surface subject to the depositing process until metallic luster is obtained; - placing the crankshaft into the device, Figure 1 a);
- depositing layers with a width of 3 - 4 / mm to the area where the crankpin journal intersects with the counterweights and around the oil way on the crankpin journal, Figure 4 a), with the parameters mentioned above for both processes [7 - 9];
- depositing the layer by waving with the mentioned parameters, Figure 4 b);
- non-destructive visual and penetrating liquid testing of the deposited areas;
- cutting and machining the samples for the macro and micro-structural examination and the hardness examination.

For the experimental part it was used an inverter based welding power source (Caddy TIG 2200i - ESAB). The polarities used in this experimental procedure were direct current positive polarity (DC+) for SMAW. The values of the main welding parameters were: welding current intensity I_{s1} = 100 / A (for the marginal layers of the crankpin journals) and I_{s2} = 140 / A (for the facing of the crankpin journal surface), arc voltage U_a = 20 - 24 / V.

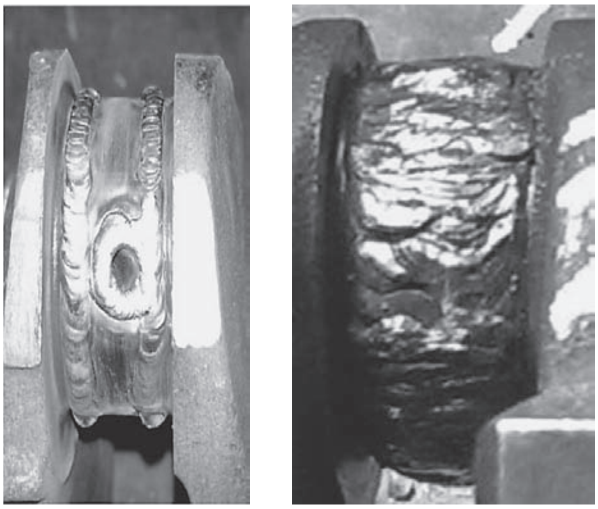
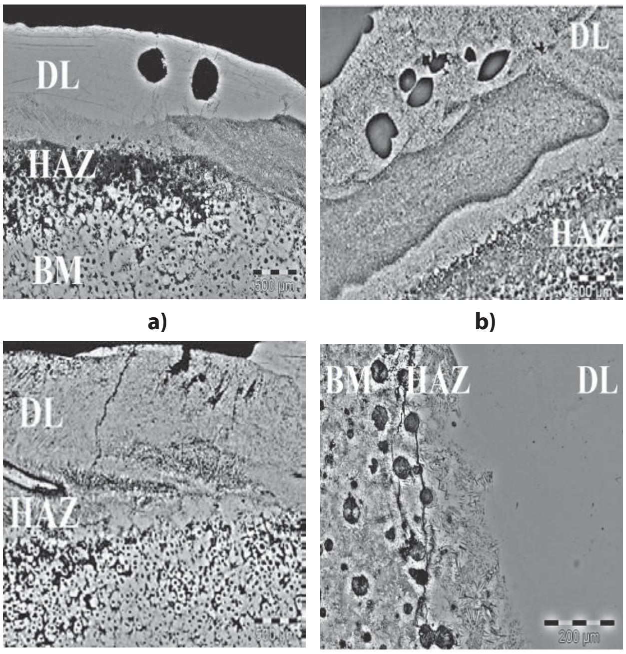

a) b)

Figure 4 Depositing the initial beads on the marginal areas of the crankpin journal a) and on the rest of the crankpin journal area b)

RESULTS AND DISCUSSIONS

After obtaining the samples, they were subject to non-destructive visual and penetrating liquid testing methods. No nonconformities emerged after the testing. From the obtained reconditioned parts samples were taken in order to be subject to micro-structural and macro-structural examinations. All examinations were performed in an accredited laboratory, LAMET. The micrographic images taken over for the two samples are presented in Figures 5 and 6.

After properly processing the obtained samples it was analyzed the micrographic structures obtained in the interest zones of the reconditioning by welding: base material (BM), the heat affected zone (HAZ) and deposited layer (DL).



a) b)

c) d)

Figure 5 Nonconformities occurred for sample P1: a), b) – pores in the deposited material zone, c) – micro-cracks in the deposited material zone, d) – cracks in HAZ

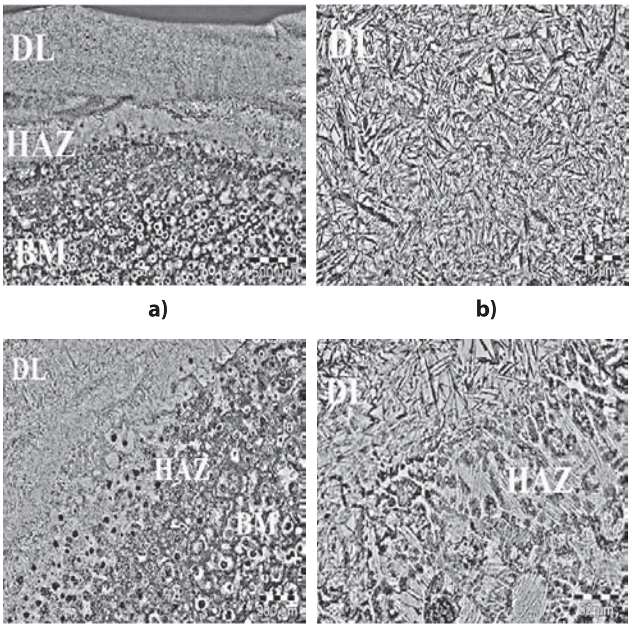
When it was analyzed the metallographic structures presented in Figure 5 it was noticed that in the deposited material zone a series of nonconformities like pores and cracks occurred. Furthermore, the heat affected zone has cracks on large areas – the cracks occurred between the nodular graphite zones in the base material. The cracks occurred especially in the passing zone between the crankpin journals and the counterweights.

When it was analyzed the metallographic structures presented in Figure 6 it was noticed that no cracks occurred following the reconditioning process. Furthermore, Figure 6 reveals that the adherence between the base and the filler material is good, as well as that there are small nonconformities similar to porosities in the deposited material.

When it was analyzed the metallographic structures presented in Figure 6 it was noticed that no cracks occurred following the reconditioning process. Furthermore, Figure 6 reveals that the adherence between the base and the filler material is good, as well as that there are small nonconformities similar to porosities in the deposited material.

CONCLUSION

Following the analysis of the obtained results there can be drawn the following conclusions:



a) b)

c) d)

Figure 6 Microstructure of the deposited material and of the adjacent zones for sample P 2: a) – base material (BM), the heat affected zone (HAZ) and deposited layer (DL); b) – deposited layer (DL); c) – base material (BM), the heat affected zone (HAZ) and deposited layer (DL); d) – the heat affected zone (HAZ) and deposited layer

- the number and position of the fixing points of the product for reconditioning by welding influence the quality of the reconditioning process;
- the preheating temperature reduces the level of the stress input during the heat cycle occurred during the reconditioning by welding process and helps avoiding the occurrence of cracks in the reconditioned material zones;
- the information provided by FEM is an important starting point for the optimization of the reconditioning by welding technologies;
- the results obtained following the deposits carried out according to the recommendations resulted following the FEM lead to the validation of the created model.

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Note: The responsible translator for the English language is Rontescu Aurora Mădălina, Bucharest, Romania