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INFLUENCE OF INDUCTION HARDENING PARAMETERS ON THE GS30Mn5 WELD PROPERTIES

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This study examines parameters of post-weld heat treatment on the test specimens made of cast steel GS30Mn5. The welding is performed with shielded metal arc welding (SMAW) process. The aim is to obtain the surface without illicit cracks, with hardness ranging from 320 up to 400 HB. After induction heating, the specimens are cooled alternately with air and water. Decreased speed of quenching results in avoiding the occurrence of illicit splashes, while the hardness is maintained within the prescribed limits.

Key words: welding, GS30Mn5, post weld heat treatment, mechanical properties, structure

INTRODUCTION

Damages on castings may occur due to dirt and residual gases, or due to rapid cooling [1]. Welding can repair cracks, corrosion effects and errors in castings. In some cases, new layer can be welded on castings in order to extend the lifetime of a component or equipment [2]. Additional requirements are sometimes set on the welded layer in terms of achieving the appropriate structure and hardness. This paper elaborates welding parameters of specimens made of GS30Mn5 cast steel and effects that subsequent heat treatment has on the structure and hardness of the specimens.

EXPERIMENTAL PART

The GS30Mn5 cast steel is often used in manufacture of large and heavy castings [3], which are exposed to various wear mechanisms. The Table 1 overviews chemical composition of GS30Mn5, and plates used in our experiment were prepared.

Table 1 **Chemical composition of the GS30Mn5 / wt. %**

Element	C	Mn	Si	P	S	Cr	Ni	Cu
Request DIN 17205	0,27 ÷ 0,34	1,20 ÷ 1,50	≤ 0,60	≤ 0,020	≤ 0,015	-	-	-
Test plate	0,31	1,41	0,40	0,014	0,005	0,19	0,25	0,14

In delivered casting conditions, hardness of castings was below 200 HB. For a welder to be able to detect errors in a material, depths and types of cracks, and to determine quality of surface and thickness of welding layer of a material. According to [4], it is defined that surface cracks longer than 2 mm before the hardening and cracks in length up to 5 mm after hardening are acceptable. It is also defined that the hardness after hardening shall range from 320 up to 400 HB.

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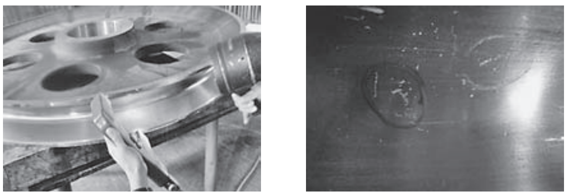
EXPERIMENT RESULTS

Surface dimension and quality shall meet all requirements defined by the technical documentation. Therefore, the machine parts shall apply non-destructive control methods, such as magnet, hardness measuring and fingerprinting of the structure [5]. The Figure 1 shows a characteristic test performed on prisoners dredgers. Control indication of surface cracks is performed with a magnetic method.

Damages may occur in characteristic forms, e.g. as inclusions of dirt, inclusions of residual gases and cracks of different forms due to rapid cooling of castings. If considering the fact that the base material GS30Mn5 has a C_{ekv} = 0,61 %, there is a need for preheating before welding [6]. If multiple layers are welded, then the temperature of the previous layer should be equal to the reheating temperature. If C_{ekv} is greater than 0,6, then it is necessary to overheat the material to a temperature of 200 ÷ 300 °C. Shielded metal arc proce-



a) b)

Figure 1 The characteristic example of determining the formation of cracks indications; a) control indication of surface cracks with magnetic particles; b) the appearance of surface damage dure is applied to repair illicit cracks. The reason for choosing this procedure is the fact that the cracks were only locally present. To check the possibility of improving the damage, coated electrode in diameter ø 2,5 of composition: ≈ 0,06 % C; 1,4 % Mn; 0,3 % Si; 0,015 % P and 0,01 % S [7], is selected as an additional material. Those electrodes are chosen because of their chemical composition and mechanical properties. Declared mechanical properties of the electrodes are shown in the Table 2. It is important to note that the declared content of carbon is very low and that the minimum declared ductility is 28 %. The low content of the carbon is a prerequirement for decreasing excretion of the martensite and the too high hardness. Relatively high ductility should reduce the risk of cracking.

Table 2 **Declared mechanical properties of additional materials [7]**

Yield strength $R_{p0,2}$ / MPa	Tensile strength R_m / MPa	Ductility A_5 / %	Toughness KV (-20 °C) / J
min. 480	min. 580	min. 28	min. 200

Plate in dimension of ~ 50 x 150 x 300 mm is prepared for this experiment. The temperature of preheating plate is 230 °C. Control of target temperature is performed with corresponding digital portable device. After overheating of the plate, welding is performed at three points along the plate length. Welding voltage (*U*) amounted to 23 ÷ 26 V, current welding (*I*) amounted to 110 ÷ 140 A, voltage of idle was 60 V, and energy of efficiency for melting of 0,78 at the speed of welding of 1,5 mm/s. Welding is performed in one, two and in three layers, as of Figure 2. The aim is to cover different sizes (depth) of surface damages. The weld surface is leveled with the milling to the first pure measure. Samples are cut for control of hardness and metallographic analysis. Surface hardness is controlled by the Brinell method ($HB_{2,5/1000/15}$) on three points along the welded layer length and on three points in the heat affected zone. The measured hardness values of the welded layer and of heat affected zones are given in the Figure 2.

Control of the base material and the welded layer is performed in a non-etched condition. Evaluation of the metallurgical cleanliness is performed according to ASTME 45 [8]:

- the base material exhibited the presence of inclusions of type D and globular oxide type, heavy series No. 3;

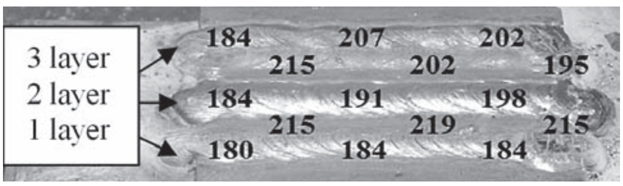
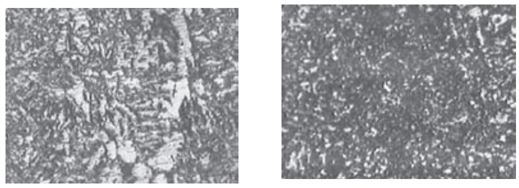


Figure 2 The test plates welded with SMAW process and the results of measurements of surface hardness $HB_{2,5/1000/15}$



a) b)

Figure 3 The characteristic structure of weld (a) and heat affected zone (b), magn. 400 x, etched nital 3 %

- the weld showed inclusions of type D and oxides of globular type – easy series No. 5.

Characteristic structures of the weld and of heat affected zone in etched condition are shown in the Figure 3. The weld structure is fine-grained, dendritic, with no anomalies in the form of micro - and/or macrocracks. Likewise, the structure of the heat affected zone is fine-grained without anomalies.

After analysis of the structure, control of hardness is completed on metallographic samples. The Figure 4 shows the results of control hardness HV10 on the cross-section. Based on the results of hardness measurements, it is concluded that the measured values of the base material and of the welded layer are ranging from 180 to 195 HV and of the heat affected zone from 200 to 220 HV.

Based on these results, it is concluded that the measured values of the base material and weld were below the prescribed value. It is therefore necessary to carry out induction hardening. This procedure leads to overheating of the surface layer to the desired depth, to reduce occurrence of macro deformation to a minimum. In order to continue this experiment, the test plate is cut transversely to the welding direction, and then divided into two equal parts, marked as test plate 1 and test plate 2.

Induction hardening of samples

On the test plate 1, heating of the surface is performed with flat inductor with cooling by water. The following parameters of the induction hardening are obtained: energy *F*, 54 %; feed *S*, 5 mm^{-1}; frequency, 15,4 ÷ 15,5 kHz; generator *F*, 13 %. Appearance of the inductors is shown on Figure 5a.

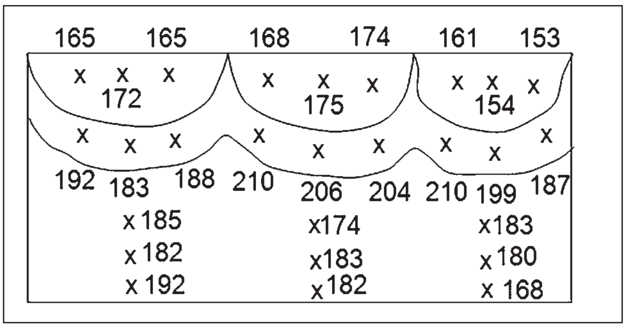
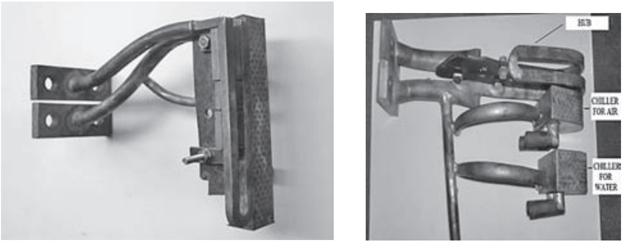
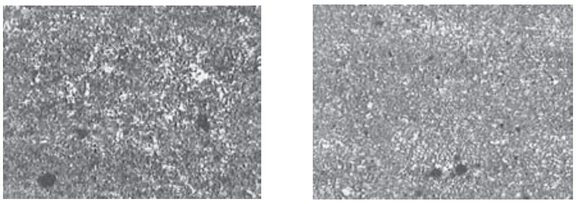


Figure 4 Schedule of measurement places on the sample and the measured hardness HV10 on the cross – section of welds before the induction hardening



a) b)

Figure 5 Inductors for hardening of welded samples



a) b)

Figure 6 The characteristic structure of weld (a) and heat affected zone (b) induction hardened samples cooled with water, magn. 400 x, etched nital 3 %

After induction hardening of the test plate, hardness of surface layer and of base material was measured by the Brinell method. Measured values are ranging from a minimum of 528 HB to a maximum of 560 HB. Based on a comparison with the prescribed or permitted values of groove hardness (320 ÷ 400 HB), it is concluded that the cooling parameters should be changed. Because of the high speed of heat removal, partial elimination of martensite occurred in the surface layer. Probably, regardless of the very low content of carbon contained in the electrodes (C ≤ 0,06 %), as a consequence the additional material is mixing with the base material. The sample surface layer structure is characterized as fine-grained, dendrite without microcracks, as of Figure 6a. Similar structure is observed in the heat affected zone, as of Figure 6b.

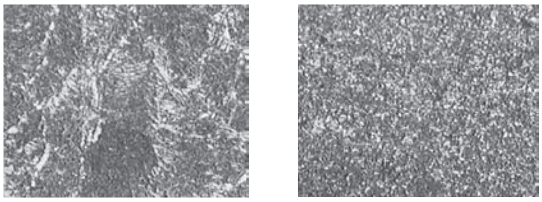
Induction hardening of samples

In order to avoid too high hardness (limits are 320 ÷ 400 HB), it is necessary to choose a slightly slower speed of cooling. Therefore, inductors with two systems for cooling the heated surfaces are developed: the first system cooled the surface by air, and the second system cooled the same surface by water. The systems operated in a very short periods of time, alternately one after another. The appearance of this inductor is shown on Figure 5b. Selected parameters of the induction hardening are the same as for hardening and quenching by only water. After hardening, surface hardness control is performed. Final control shows that the selected parameter of hardening and quenching by combined air and water could achieve satisfactory values of surface hardness, as presented in the Table 3.

The structure is examined after the induction hardening. The Figure 7a presents the structure of the base material. It is characterized by a relatively coarse grain, however, it is evident that the material was subjected to heat treatment. Anomalies in the form of microcracks are not observed in the structure. The structure of heat affected zone is extremely fine-grained, without microcracks, Figure 7b. The structure of the weld is similar to that, as shown in Figure 6a.

Table 3 **The results of hardness control after induction hardening and quenched air/water**

Test place	Hardness $HB_{2,5/1000/15}$
Basic material	373 ÷ 384
Heat affected zone	377 ÷ 379
Welded layers	287 ÷ 312



a) b)

Figure 7 The characteristic structure of the base material (a) and heat affected zone (b), magn. 400 x, etched nital 3 %

CONCLUSION

Hardness in prescribed limits of minimum 320 up to maximum 400 HB is achieved by a cooling with alternation of air and water after induction heating. At the same time, there were illicit cracks and macro deformation avoided. It is necessary to apply scientific methods in the analysis of tribosystem elements and in selection of parameters for welding and heat treatment. The described experiment proves that it was possible to achieve satisfactory structure and hardness without the presence of illicit anomalies that could affect the unacceptability of criteria given by the relevant norms.

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Note: prof. Martina Šuto is responsible person for the translation into English language