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Fractographic and structural peculiarities of laser weld-on layers with a maraging alloy

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ABSTRACT

Purpose: Purpose of the present paper is to investigate the fractographical peculiarities of the layers welded-on the surface of 30CrMoV12-28 (DIN) tool steel by laser with additional material of marraging alloy.

Design/methodology/approach: The operation was accomplished on an AL 200 automatic weld-on machine with an Nd:YAG pulse resonator providing a beam of 1064 nm wavelength. The mean power output of the pulse was 200 W and the maximum peak power output was 10 kW. The operating frequency was 20 Hz. The diameter of the laser beam focused on the sample surface was 0.6 mm. The weld-on maraging alloy featured contents of 0.02C - 0.2Si - 0.2Mn - 2Cr - 19.3Ni - 0.4V - 4.7Mo - 14.5Co - 0.25Al, wt%. Studied were the fractures obtained at three - point bending of the layer upon weld-on followed by two - hour age hardening at temperatures of 550 and 600°C.

Findings: The nature of deformation along the weld-on layer under tensile impact strains was studied, the destruction being trans-crystalline determined by the prevailing plastic deformation.The destruction after age hardening at temperatures of 550 and 600°C was of the mixed and trans-crystalline type. The results of the processes of dispersion hardening and those of the beginning of coherent phase formation were connected with the main matrix of the inter-metallic compounds based on NiAl and NiMo. The condition of the structure was characterized by the so called “pit” curved surface of the destruction. The analysis of the fractures along with the EDS analysis showed that the inter-metallic phases formed in the process of secondary hardening of the material in the weld-on layer were of the NiAl, NiMo and Ni_3Mo type.

Research limitations/implications: For more correct determination of phase contents in depth of hardened layers have to be used XRD techniques.

Practical implications: Taking into account the high value of the materials used for producing press-forming dies it is of vital importance to find possibilities for considerable increase of the lifecycle of casting moulds. Laser surface welding-on by using of maraging alloy as additional material is cost effective technology for repairing of press-forming dies.

Keywords: Tool materials; Maraging alloys; Laser surface treatment; Inter-metallic compounds

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MATERIALS

1. Introduction

The advancements in material surfacing techniques, such as ion-nitriding [1,2], boron surface treatment [3] and concentrated energy flows, and especially those with maraging alloys, allowed more extensive implementation of this type of alloys in industry. Of special interest is the possibility of machine part welding-on by a laser, an electron beam or an arc.

The use of concentrated energy flows for welding-on especially in reconditioning machine and tool parts made of other types of steel [4-10], a process in which the maraging alloys are an additional material, has some peculiarities which make their implementation very efficient. The locality of impact allows a certain defective area to be surfaced without any further deformation of the whole part. Surfacing of construction or tool steels by using an additional material of a maraging alloy of particular contents determined by specific needs allows, in turn, further heat treatment depending on the application of the reconditioned part itself.

One of the issues connected with the process of welding-on with an additional maraging alloy of the working surfaces of die casting press moulds and deserving consideration, is their thermal and fatigue durability [11,12]. The classical fatigue destruction of the high-strength maraging alloy is caused by the appearance of a crack originating from the non-metallic phases of Al_2O_3 type [13], the so called “fish eyeball” effect. Fractographic studies of laser sintered samples from maraging alloy are given in [14]. According to these studies, the destruction technique, either of a plastic or mixed type, is determined by the initial condition of the material, with or without ageing upon sintering.

Despite the comprehensiveness of the analyses presented so far, it is necessary to study profoundly the process of laser welding-on with additional material of maraging alloy on the surface of tool steels for die casting press moulds along with their peculiarities which is the purpose of the paper.

2. Methodology

In prismatic samples made of 32CrMoV12-28 tool steel (DIN) have been laser welded-on after preliminary bulk heat treatment including quenching and tempering to hardness of 400-420 HV. A passage (5x0.5 mm) has been welded-on through the length of a sample with dimensions 10x10x5 mm. The chemical contents of the basic material is: 0.3 C, 0.4 Si, 0.36 Mn, 3.23 Cr, 0.21 Ni, 0.6 V, 2.95 Mo, wt%. The chemical contents of maraging alloy used as additional material is: 0.02 C, 0.2 Si, 0.2 Mn, 2 Cr, 19.3 Ni, 0.4 V, 4.7 Mo, 14.5 Co, 0.25 Al, wt%. The laser welding-on was accomplished with an AL 200 automatic weld-on system with an Nd:YAG pulse resonator providing a beam of 1064 nm wavelength. The mean power output of the pulse was 200 W and the maximum peak power output was 10 kW. The operating frequency was 20 Hz. The diameter of the laser beam focused on the sample surface was 0.6 mm.

For the purposes of an electron-microscope analysis, the samples were destructed by three-point bending (Fig. 1). It was accomplished in such a way that the fracture surface was transverse to the sample and made it possible to use a scanning electron microscope (SEM) with a high depth of focus for micrographic and EDS analysis. Three samples from 32CrMoV12-28 (DIN) steel were analyzed after welding-on with maraging alloy followed by ageing at 550°C and 600°C with two-hour soaking. It is necessary to emphasize that the experiment carried out was not a standard one and was used only for obtaining the fracture surface needed for the scanning microscope analysis.

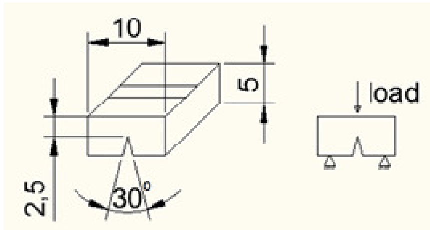

Fig. 1. Form and dimensions of the samples undergone bending after laser weld-on. Three-point bending scheme

The electron microscope analyses of the fractures were carried out by means of a “TESCAN” LYRA-3XM electron microscope with ”Bruker” EDS attachment. The accelerating voltage applied was 30 kV. The distribution of the chemical elements in the fracture surfaces studied was mapped. The microhardness was measured with Hanemann attachment by Vickers method with 1 N load.

3. Results and analysis

In Figure 2a shows the macrofracture graphic condition of the samples studied in final condition upon weld-on and Fig. 2b shows the one upon ageing at 550°C with two-hour soaking. Three main zones into which the macrostructure is divided in the weld-on area are clearly visible: 1) - a weld-on layer with maraging alloy in its contents described in

Methodology; 2) - a boundary zone; 3) - 32CrMoV12-28 steel (DIN) - basic material. What is characteristic of the fracture at destruction after ageing is its visibly lighter colour obtained as a result of destruction from supposedly more brittle condition. The macrostructure condition is clearly differentiated. The contents of the additional weld-on material from maraging alloy require the accomplishment of dispersion hardening at elevated temperatures. Taking into account the presence of elements such as Ni, Al, Mo it could be assumed that this process is connected with the formation of inter-metallic compounds of NiMo type [15].

Despite the high degree of multiplication in the micrographs in Figs 3a,b no direct conclusions can be made about the likelihood of the dispersion hardening mentioned above.

The microstructure is characterized by the so called pit "rippled" surface. Formations of inter-metallic compounds in the fracture surface of the weld-on layer are not visible. Therefore, it is logical to conclude that such compounds are missing in the original weld-on layer without ageing at high temperatures. The fracture is typically plastic; the trans-crystalline destruction is basic and is typical of the technique with a prevailing amount of the work necessary for the plastic destruction of the material.

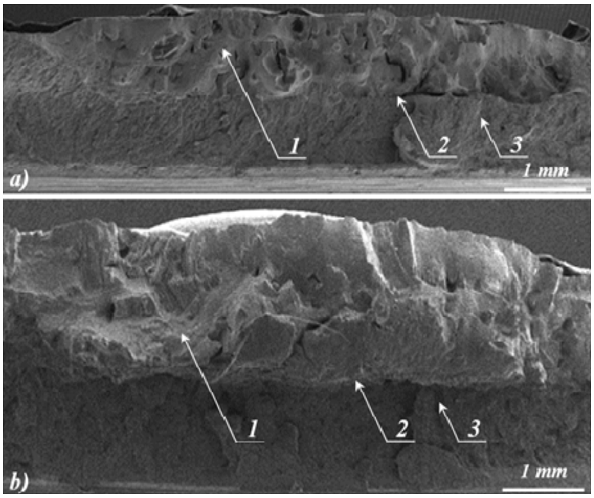

Fig. 2. Macrofracture condition of the original weld-on layer - a); macrofracture condition of the weld-on layer upon two-hour ageing at 550°C - b); 1) - weld-on layer with maraging alloy in its contents; 2) - boundary zone; 3) - basic steel material

Phases of inter-metallic compounds are likely to appear right in the areas of the so called pits. This type of "rippled" surface is obtained in the process of plastic deformation around such phases. Supposedly, they are of the NiAl type and are typical of the initial formation of inter-metallic compounds in the weld-on alloy of this content.

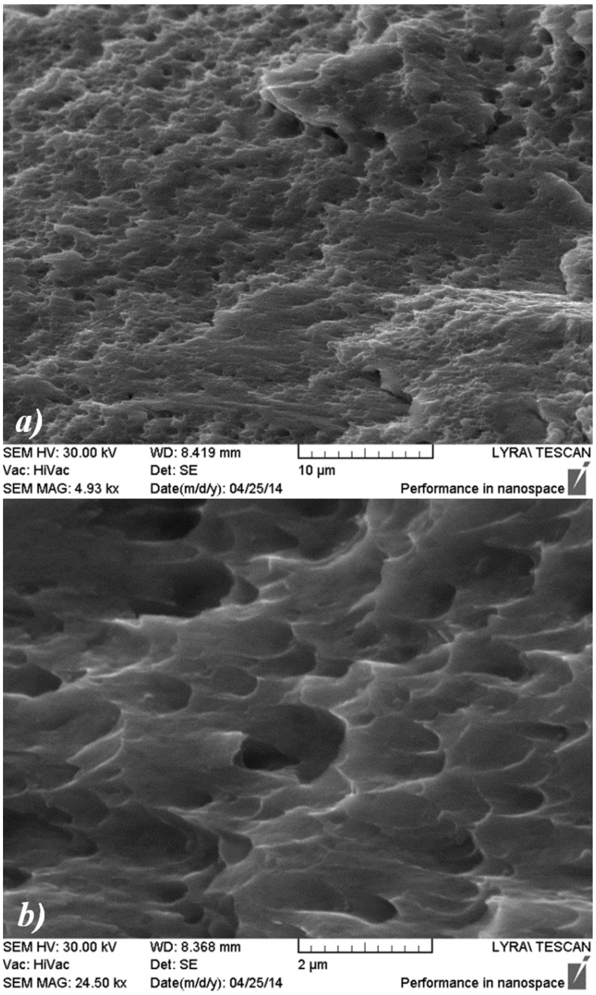

Fig. 3. Microfracturegraphy of the initial weld-on layer: a) - fracture of tough destruction with so called "rippled" surface; b) - fracture determined by the "pits" formed in the areas of inter-metallic compound formations at plastic deformation

The results described have been verified by those given in Fig. 4. The fracture of a sample at destruction upon ageing at 550°C with two-hour soaking was of the mixed inter-metallic/trans-crystalline structure. Clearly visible were the areas with brittle destruction around the grain boundaries in the areas denominated 1. Lines typical of slippage in the process of prevailing plastic deformation in the areas denominated 2 could be observed in Fig. 4a,b.

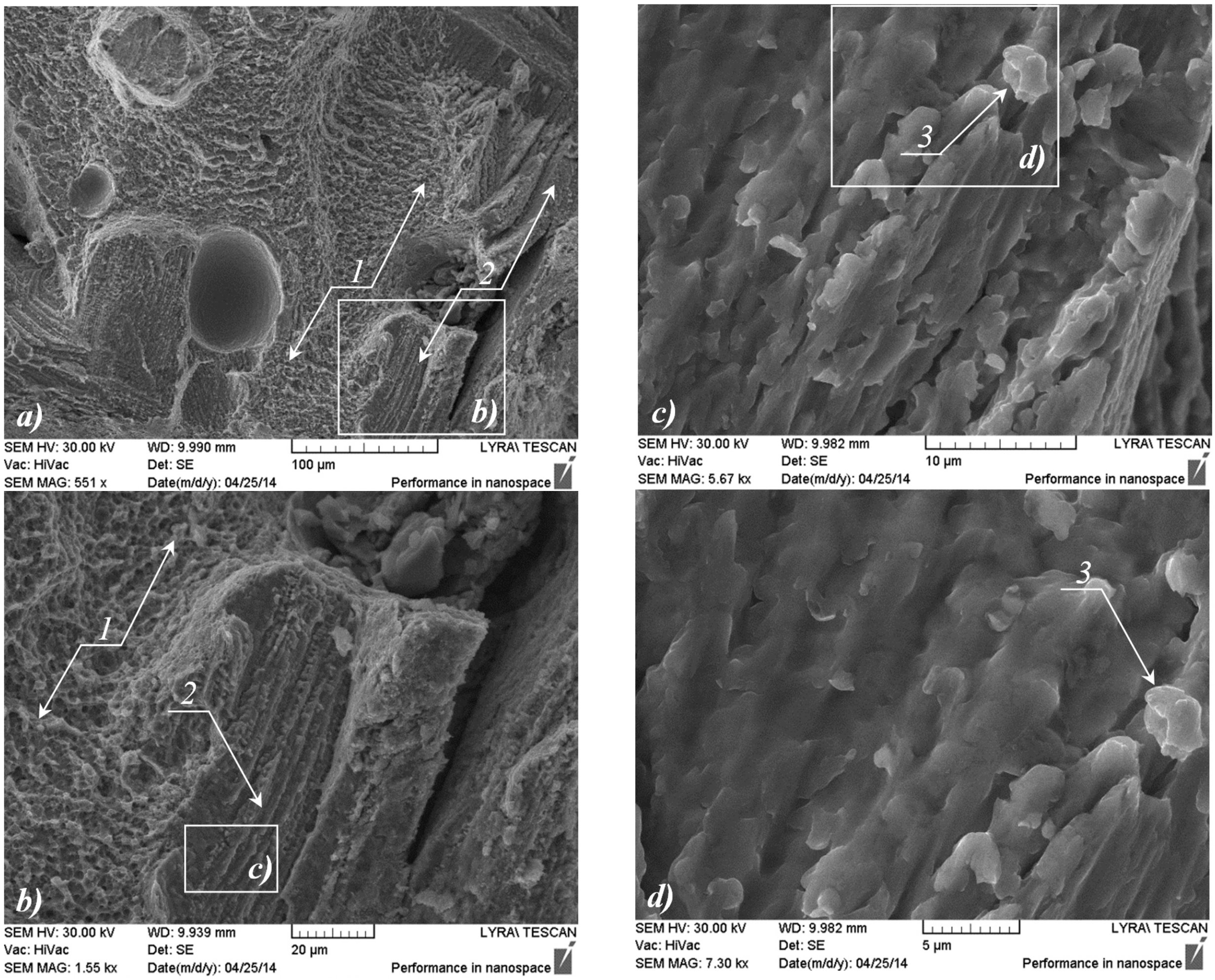

Fig. 4. Microfractography of a weld-on layer upon two-hour ageing at 550°C - a),b): trans-crystalline destruction; planes of slippage at destruction - c), d)

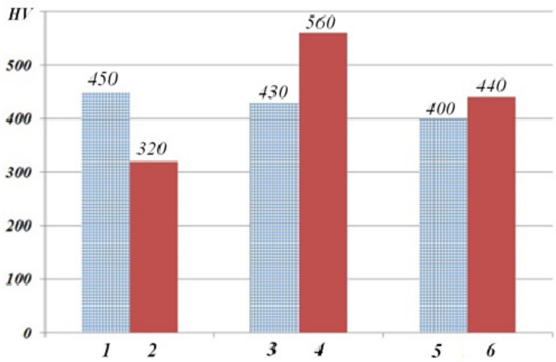

Fig. 5. Mean value of the welded-on layer hardness - 1,2; after two-hour ageing at 550°C - 3,4; after two-hour ageing at 600°C - 5,6. Maraging alloy 2,4,6; basic material from 32CrMoV12-28 steel - 1,3,5

This suggested the appearance of dispersion hardening in ageing accompanied with considerable improvement of the strength properties of the maraging alloy used as an additional material. The areas with visibly trans-crystalline destruction provided us with the opportunity for more profound studies of the properties of the inter-metallic compounds formed. In order to obtain fracture of the mixed inter- and trans-crystalline type featuring improved hardness and brittleness of the studied structure respectively, it is necessary for the secondary phases to have preserved their coherent connectedness with the main mould. Such dispersed phases are likely to be observed along the slippage lines formed at plastic deformation: zones 3 in Fig. 4c,d. No coagulation of the inter-metallic compounds discussed takes place which determines the improved hardness of the structure studied.

The durometric analysis in Fig. 5 has verified all the above mentioned. The hardness in the initial layer upon weld-on is within 295-320 $HV_{0.1}$.

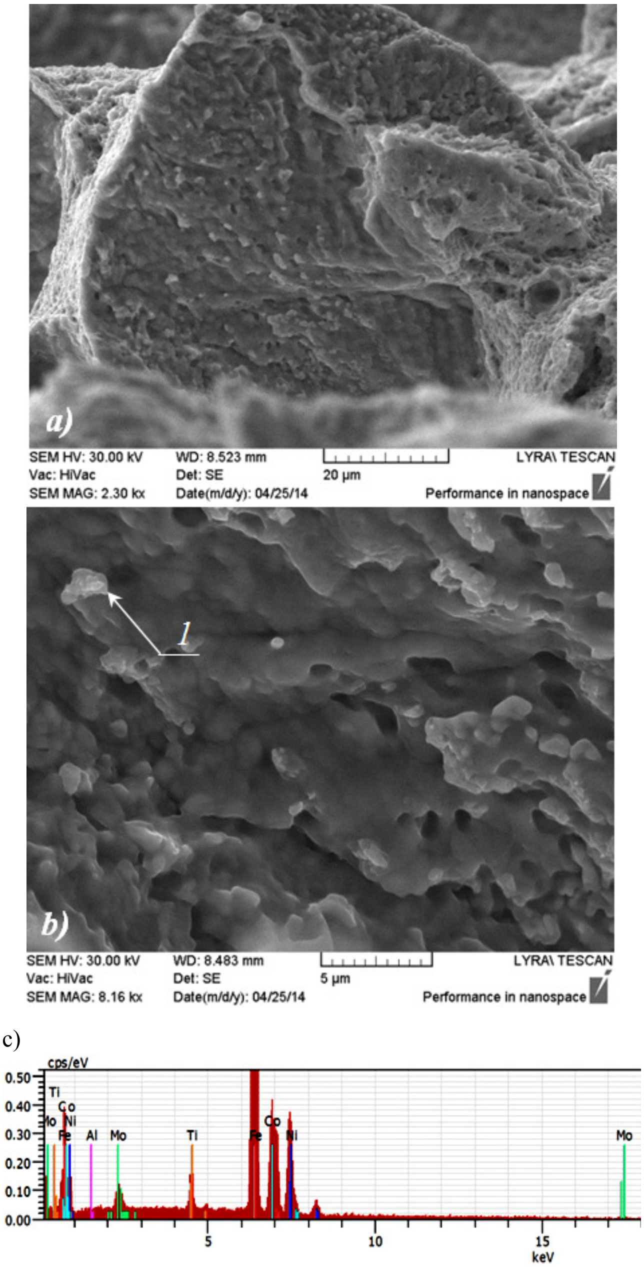

Fig. 6. Microfractography of the weld-on layer upon two-hour ageing at 600°C: a) - trans-crystalline destruction; b) - inter-metallic phase coagulation; c) EDS analysis of the inter-metallic compounds in zone 1(↑). Chemical composition: 28.1 Ni, 18.3 Mo, 2.75 Ti, 0.45 Al, 12.9 Co, rest Fe, wt%

This value is about 100 $HV_{0.1}$ lower than that of 32CrMoV12-28 steel (DIN) after the volumetric heat treatment involving quenching and tempering to 420-450 $HV_{0.1}$. The hardness of the layer welded-on with maraging alloy provided the opportunity for surfacing in order to obtain the desired form of the working surfaces of press moulds.

Hardness has improved considerably - up to 550-570 $HV_{0.1}$ after ageing with two-hour soaking. This was the effect of the secondary hardening of the maraging alloy described above. Due to the dispersity of the inter-metallic phases, in this case it was impossible for their type to be clearly defined. The hardness of the basic material of 32CrMoV12-28 steel remained unchanged within 420-450 $HV_{0.1}$ at temperatures in the range of 550-600°C.

Upon ageing at 600°C, two-hours of soaking, hardness was within 430-450 $HV_{0.1}$, Fig. 5. This suggests that apart from the dispersion hardening accompanied with inter-metallic phase formation, phase coagulation has also taken place which, in turn, resulted in a lower durometric value in comparison with that at 550°C.

This was verified by the micrographic condition of the weld-on layer after ageing at 600°C given in Fig. 6a,b. The fracture in this case was also of the mixed inter-metallic/trans-crystalline type. In the areas with trans-crystalline destruction, a prevailing number of coagulated inter-metallic phases could be observed. The EDS analysis of one of the likely coagulated phases (Fig. 6c) showed that the stechiometric type of the hardening compounds is the Ni_3Mo type with chemical composition 28.1 Ni, 18.3 Mo, 2.75 Ti, 0.45 Al, 12.9 Co, rest Fe, wt%.

The process of inter-metallic phase formation is connected with the initial formation of phases of the NiAl type. It is them that are the cause of the pit "rippled" character of the structural condition of the original weld-on layer shown in the microfractographs in Figure 3. Consequently, at elevated temperatures of ageing at 550°C Al is replaced with Mo forming NiMo and Ni_3Mo inter-metallic compounds resulting in improved hardness.

4. Conclusions

The analyses have shown a trans-crystalline type of the destruction at three-point bending of the layer welded-on with maraging alloy on the surface of 32CrMoV12-28 tool steel. This was determined by the high amount of the work necessary for the plastic deformation of the structure featuring contents with a great quantity of Ni and Co. Upon ageing at 550 and 600°C, destruction was of the mixed inter-metallic/trans-crystalline type determined by the process of dispersion hardening of the maraging alloy at these temperatures which, in turn, led to decrease in the relative part of the material destruction by prevailing plastic deformation.

The micro X-ray spectral analysis has shown that the inter-metallic phases formed in the course of secondary hardening of the weld-on layer were of the NiAl, NiMo, Ni_3Mo type.

The experiments described in the paper give us grounds to recommend the technological process of welding-on with maraging alloy of the chemical contents discussed for repairing of the working surfaces of die casting press moulds.

Additional information

Selected issues related to this paper are planned to be presented at the 22nd Winter International Scientific Conference on Achievements in Mechanical and Materials Engineering Winter-AMME’2015 in the framework of the Bidisciplinary Occasional Scientific Session BOSS'2015 celebrating the 10th anniversary of the foundation of the Association of Computational Materials Science and Surface Engineering and the World Academy of Materials and Manufacturing Engineering and of the foundation of the Worldwide Journal of Achievements in Materials and Manufacturing Engineering.

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