Structure of carbon steels after remelting of the surface layer with the electric arc

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Received 26.02.2009; accepted in revised form: 30.03.2009

Summary

This study presents results of a research on the enhancement of properties of the surface layer of carbon steels by treating it with a concentrated heat stream utilizing the GTAW method. Remelting of the surface layer of studied steels was performed by a welding head moving at a constant speed of 200 mm/min and varying current intensity of the electric arc ranging from 50A to 300A as well as with a constant current intensity of the electric arc and a varying speed of the welding head ranging from 200 mm/min to 800 mm/min. Metallographic evaluations (LM and SEM) of the resulting structure were performed. Correlation between the current intensity of the electric arc and its speed in relation to the treated material sample and the geometry of the remelted layers and their structure was established.

Keywords: steel, remelting, martensite, surface layer, GTAW method

1. Introduction

Durability of mechanical parts depends mostly on the microstructure and properties of their top surfaces. Among a number of surface-modifying methods such as: laser or electron treatments or various coating techniques – PVD, CVD and PLD one method worth considering is the application of concentrated heat stream based on the GTAW process (Gas Tungsten Arc Welding). The advantage of this method is relative easy of application and low-cost equipment requirements. The bigger effective working area achieved with a single heat stream pass, as compared to the laser or electron technologies, also adds to the GTAW method’s advantages. The influence of the treatment process on the resulting material structures can be easily controlled by varying technological parameters of the GTAW process such as the electric current intensity, the heat source’s feed rate (also known as scanning rate) and the composition of the plasma-generating gas [1-6].

By varying parameters of the treatment we can influence properties of the surface layer by attempting to create structures characterized by large fragmentation, increased atomic solubility of additives and increased concentration of defects. Beside the basic structure, other factors influencing usage properties of elements remelted with the electric arc are material’s residual stresses. The design of the heat treatment should attempt to create residual stresses in the surface layer that will lead to increased material durability. In most cases it is desirable for the compressional stresses to appear in material’s surface and for the tensional stresses to appear in material’s core. The type, size and gradient of residual stresses are highly dependant on the quality of the material and on the parameters of the treatment [7-8].

Knowledge of these issues allows for choosing correct parameters for a surface-forming treatment during surface-refinement of machine elements. In this study, analysis of an influence of the GTAW method’s parameters on C15, C45 and C90U steel surface structure and its micro-hardness were performed.
2. Methodology and materials used for the study.

Test samples were cuboids (200x50x20 mm), made of C15, C45 and C90U steel in normalized state (Fig. 1).

The samples were surface-remelted with the electric arc, using a FALTIG 315AC/DC apparatus with parameters as per Table 1. Argon was used as the plasma-generating gas. The processing was conducted in the Founding and Welding Department of University of Technology in Rzeszow.

Table 1. Processing parameters used during the study

<table>
<thead>
<tr>
<th>Current intensity of the electric arc I [A]</th>
<th>Scan rate v [mm/min]</th>
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Microscopic examinations of the resulting structure, as well as measurements of the geometry of the remelted layers were performed in the study. The relationship between the current intensity of the electric arc, geometry of the remelted layers and microstructure of the material was established. Geometric parameters of the strengthened areas were measured with a Neophot 2 microscope, fitted with the Multiscan image analysis system. Metallography was conducted on a Tesla BS-340 scanning electron microscope.

3. Results description

The processing parameters ensured remelting of the material’s surface layer in all test samples, thus creating a zonal cross-section of the surface layer consisting of: the remelted zone, the heat-affected zone and the zone consisting of material heated below the Ac1 temperature (Fig. 2).

Increase in the electric current intensity increases the depth of the remelted zone from 0,60-0,80 mm at I = 50A to 3,8-4,1 mm at I = 300A. The width of the remelted zone increases from 2,8 mm at I = 50A to 8,7 mm (steel C15) and 10,7 mm (steel C45 and C90U) at I=300A. This is caused by a greater amount of heat delivered into the surface layer of the material under the treatment.

Analyzing changes in the depth and width of the remelted zone in relation to the scanning rate of the electric arc we can observe decrease in the depth of the remelted zone from 3,8-4,1 mm at v=200 mm/min to 2,2 mm at v=800 mm/min and the corresponding decrease in the width from 8,7 mm (steel C15) and 10,7 mm (steel C45 and C90U) to 4,4 mm (steel C15) and 6,0 mm (steel C45 and C90U).

As a result of the intensive heat dissipation in the remelted zone a fast crystallization can be observed. Epitaxial growth of the solid-state phase begins at the liquid - solid-state threshold and proceeds in the direction of the moving heat source. During the rapid heat dissipation from the remelted zone facilitated by the „cold“ substrata the tempering of the studied steel occurred. The structure of the C15 steel shows packets of lamellar martensite as well as residual austenite (Fig. 3a,b). The packets of lamellar martensite measured 20-30 µm in size.

Directly under the remelted zone, a zone of a tempered material heated to solidus temperature could be observed. The zone’s structure shows lamellar martensite as well as unmelted during the heating phase particles of cementite. At the bottom of the heat-affected zone, a zone consisting of material heated to the temperature range of Ac1 - Ac3 could be observed. Structure of the material heated to the temperature range of Ac1 - Ac3 included bainite and ferrite (Fig. 3c,d).

As a result of fast crystallization in the remelted zone of C45 steel dendritic cells are formed (Fig 4a). The structure of cells was composed of lamellar martensite packs and residual austenite (Fig 4b). At the dendritic crystal boundaries, cementite was present (Fig. 4a, b). In the heat-affected zone’s structure martensite and residual austenite were found. Ferrite was present at the bottom of the heat-affected zone (Fig. 4c).
Fig. 5. C15 steel microstructure after the GTAW treatment, a,b) structure of the remelted zone: lamellar martensite, residual austenite c,d) structure of the heat-affected zone: structure: lamellar martensite, residual austenite, ferrite.

Fig. 4. The microstructure of C45 steel after the processing using GTAW method, a, b) remelted zone – dendritic cells – the structure: lamellar martensite, residual austenite, the cementite on the cell borders c) heat-affected zone – the structure: martensite, ferrite, residual austenite
In the remelted zone of C90U steel, dendritic crystals were found (Fig. 5). Their structure consisted of plate martensite and residual austenite. At the dendritic crystal boundaries, cementite was present (Fig. 5, 6).

![Fig. 5. C90U steel microstructure after GTAW treatment; remelted zone – dendritic cells, structure: plate martensite, residual austenite, cementite](image1)

![Fig. 6. C90U steel microstructure after GTAW treatment; remelted zone – dendritic cells, structure: plate martensite, residual austenite, cementite](image2)

In the microstructure of remelted zone in the C90U steel samples, treated with electric arc at the current intensity of 200-300A and scanning rate of 200 mm/min, numerous cracks were observed (Fig. 7).

![Fig. 7. C90U steel microstructure after GTAW treatment, remelted zone – visible multiple cracks](image3)

The micro-cracks run along the dendritic crystal boundaries and formed a number of branches (forks) of several hundred micrometers in length. Such micro-cracks did not occur in specimens remelted with electric arc whose current intensity was 50 or 100 A.

In the heat-affected zone’s structure martensite and residual austenite were found. In the vicinity of remelted zone, local remelting of cementite-surrounding structure was noticed. Bainite secretions were found closer to the native material.

### 4. Conclusions

The chosen parameters of the treatment caused the remelting of the surface layer in all the tested samples. The increase of current intensity of electric arc from 50A to 200A caused an increase in the depth and width of material’s strengthened layer. On the other hand, increasing feed rate of the electric arc from 200 mm/min to 800 mm/min caused a decrease in the depth and the width of material’s strengthened layer.

During the rapid cooling of the remelted zone by the cold substrata the steel sample was tempered. The structure of C15 steel shows packets of lamellar martensite measuring 20-30 μm as well as residual austenite.

In the remelting zone of C45 and C90U steel the dendritic cells are formed. The cell structure of C45 steel was composed of lamellar martensite packets and residual austenite. The structure of C90U steel consisted of plate martensite and residual austenite.

The microstructure of remelted zone in the C90U steel samples treated with electric arc at the current intensity of 200-300A and scanning rate of 200 mm/min showed numerous cracks.

### References


