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SURFACE HARDENING OF PLAIN DUCTILE CAST IRON

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Abstract

The GTAW method was used to surface remelt samples of plain (unalloyed) ductile cast iron with ferritic/pearlitic structure. The cold remelting, hot remelting and multiple remelting techniques were used. Samples underwent penetrant tests, macro- and microscopic tests, x-ray diffraction tests and hardness tests.

Keywords: *ferritic/pearlitic plain ductile cast iron, surface hardening, GTAW method*

1. Introduction

Service conditions of cast iron castings very often require high abrasion resistance and resistance to wear caused by flaking and pitting of selected surfaces. Typical examples include surfaces of cast iron sliding or rolling guides, surfaces of cams, followers etc. High abrasive and contact wear resistance can be obtained through surface hardening. Hardness of surface hardened cast iron guides of machine tools should be within 48÷53HRC [10].

The required hardness of cast iron can be obtained with the same heat treatment methods as those used for steel, i.e. induction or flame surface hardening or heat/chemical treatment, e.g. nitriding [6].

Authors of article [3] present results of surface hardening of plain ductile cast iron based on the casting method, i.e. with the use of chills in moulds. Hardness of the white layer obtained, up to 12mm thick, is within 40÷50HRC, which extends life of the casting many times.

Hardness and tribological properties of cast iron surfaces can be further improved by modern methods based on a concentrated heat stream. The heat source may be either electric arc plasma (GTAW method) or a laser beam [2].

Comprehensive and extensive research into those promising methods have been conducted by authors of [4,5,7]. Depending on parameters of GTAW-based remelting of plain ductile cast iron, surface hardness of the remelted layer is within 54÷60HRC and the layer thickness – 2.5mm [3].

The research into the influence of current intensity and scanning rate on micro-hardness μHV0.1 of the partial melting area showed that depending on the process parameters, micro-hardness is within 773÷902μHV. Abrasive wear, depending on micro-hardness, is approximated with very high correlation coefficient by a decreasing linear function [4]. In the remelted zone, there is a cementitic fibrous eutectic or plate eutectic cementite [5]. The author of [7] found out that a diffusionless transformation of austenite occurs in the remelted zone and heat affected zone.

Hardness of cast iron and consequently its abrasive wear resistance may also be improved by cold plastic forming [8].

The research described in [9] shows that macro- and micro-cracks of various intensity, depending on the cast iron grade and remelting parameters, occur in the remelted layer. Their presence, particularly in case of contact stresses, may cause faster wear of the hardened layer.

Induction or flame surface hardening is a method commonly used for surface hardening of cast iron. In case of predominance of ferrite in the cast iron matrix, the hardening effect is not sufficient [6], and results of surface remelting should not depend on the matrix structure.

This research is aimed at producing and analysing layers hardened with the surface remelting process in the ferritic/pearlitic cast iron using the GTAW method.

2. Material, programme and research object

Ferritic/pearlitic ductile cast iron with chemical composition given in table 1 was used for the tests.

Table 1. Chemical composition of cast iron, % mass

C	Si	Mn	P	S	Cr	Cu	Ti	Mg
3.82	3.41	0.19	0.057	0.02	0.04	0.04	0.019	0.05

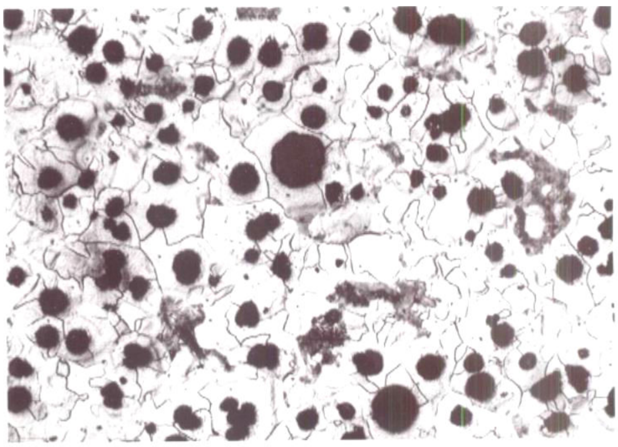

Fig.1. Structure of cast iron, as-cast state, microscope magnification 200x, etching with 2% HNO_3

Cast iron shown in figure 1 in as-cast state has a ferritic/pearlitic structure (approx. 15% pearlite content). Based on a tensile test, it has been classified as EN-GJS-400-15 grade.

YII samples were cast in green-sand moulds. From the bottom part of YII wedge, 30x75x16mm cuboidal samples were cut out for remelting.

The GTAW method was applied for surface remelting of cast iron. A 2.4mm diameter tungsten electrode was used. Argon 4.0 was used as shielding gas. Travel speed of a nonconsumable electrode was 200mm/min and current intensity – 80; 120; 160 or 200A.

The following three methods of GTAW-based surface hardening were applied:

- remelting of samples of room temperature (cold),
- remelting of cast iron pre-heated to 450°C (hot),
- multiple (repeated) remelting of samples of room temperature with 160A current.

The phase composition of the remelted layer was determined by x-ray diffraction. Measurements of hardness on the remelted surface were performed using the Rockwell method, C scale. The structure of remelted layers was evaluated and distribution of HV3 hardness by layer depth was determined on lateral metallographic microsections etched with nital. Penetrant tests were conducted to reveal micro-cracks.

3. The results of the research and their analysis

In „cold” remelting, the remelted layer consists of two phases: cementite and martensite. Regardless of current parameters of the remelting process, the phase composition remains the same. As an example, a diffractogram for the surface of cast iron remelted with 160A current is shown in figure 2. The average hardness for nine measurements made on the remelted surface of cast iron is 66÷68HRC.

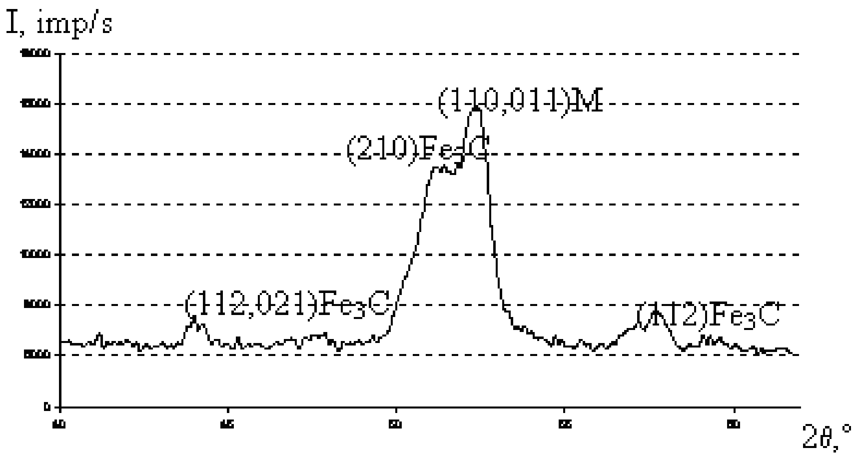

Fig.2. Diffractogram of melted surface

A distribution of hardness of the hardened layer depending on the depth and current is shown in figure 3. Based on the distribution of hardness, thickness of the remelted zone and thickness of heat affected zone can be determined. As the current increases from 80÷200A, so is thickness of the remelted zone from 0,7÷2,0mm, while thickness of the heat affected zone is within 0,5÷1,0mm.

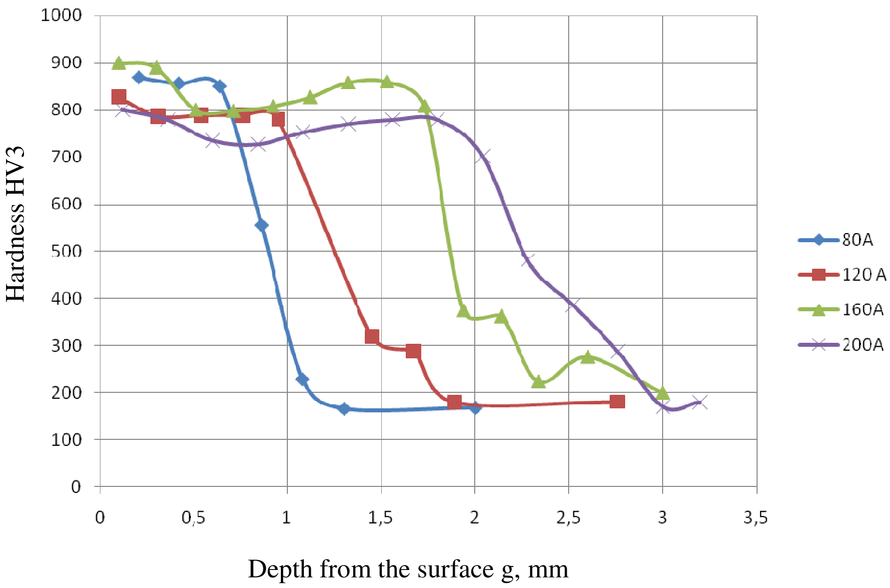

Fig.3. Distribution of hardness in the hardened zone

Figure 4 shows results of penetrant tests. The tests revealed micro-cracks positioned across the remelted layer. The number of cracks increased with an increase of current.

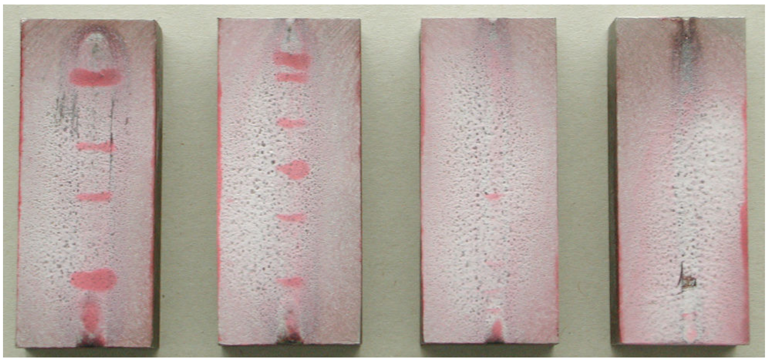

Fig.4. Macro-structure of remelted layers depending on current

Macro-cracks occur in the remelted layer as a result of stresses caused by the martensitic transformation. An example of the remelted layer structure with macro-cracks is shown in figure 5.

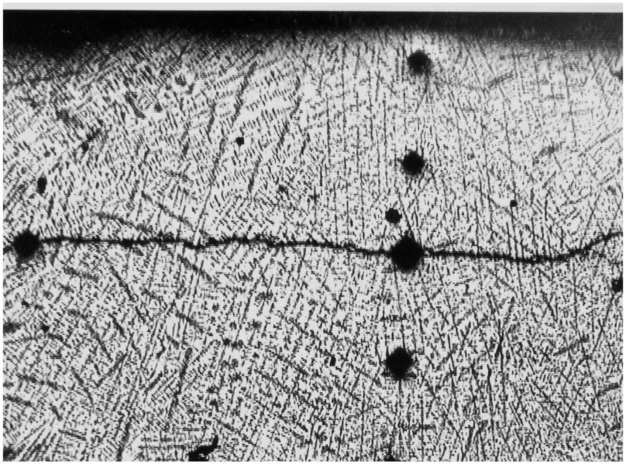

Fig.5. Macro-cracks in melted layer, current intensity 160A, magnification 70x

Micro-cracks in the transitional layer, between the remelted layer and the base material usually occur along the boundaries of eutectic grains (fig. 6).

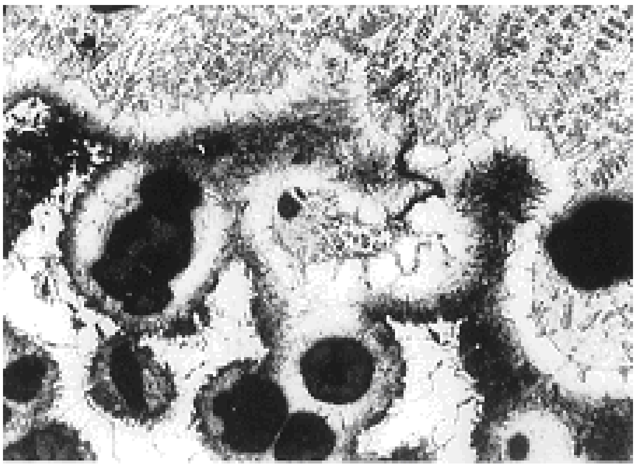

Fig.6. Micro-structure of transitional layer, melted layer-base material, magnification 175x

In order to eliminate cracks caused by the martensitic transformation, “hot” remelting was used. The phase composition of the remelted layer includes ferrite and cementite. Regardless of the remelting conditions, the phase composition is the same. A diffractogram for the surface of the layer “hot” remelted with 160A current and travel speed of a nonconsumable electrode of 200mm/min is shown in figure 7.

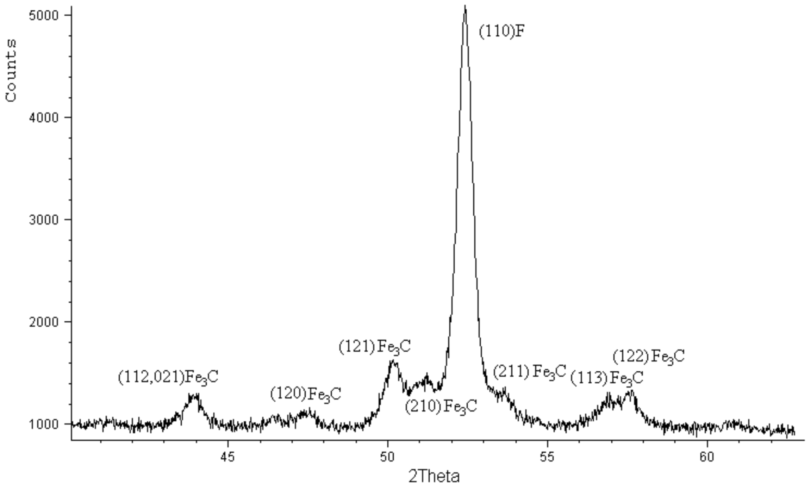

Fig.7. Diffractogram for surface of hot remelted layer, current intensity 160A

Pre-heating has completely eliminated micro- and macro-cracks, however, hardness measured on the surface decreased by approx. 8÷10HRC as compared to „cold” remelting. Cast iron pre-heating increases the costs of the hardening technology based on surface remelting.

In this article, it was proposed to harden the surface by multiple remelting of the layer using the GTAW method. The purpose of multiple remelting is to reduce the temperature gradient between the remelted layer and the hardened cast iron. It was assumed that multiple remelting would prevent the martensitic transformation that causes cracks.

The phase composition of surface layers subjected to multiple remelting, where no macro-cracks were observed, include ferrite and cementite, which is shown in diffractogram in figure 8.

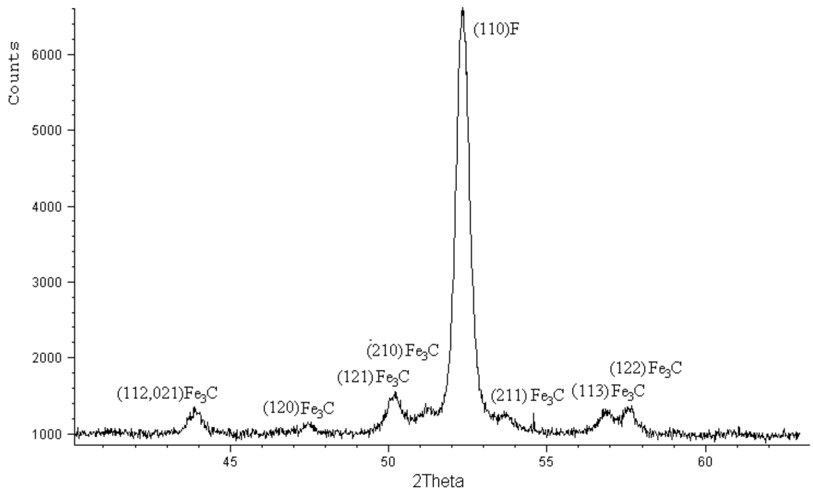

Fig.8. Diffractogram for surface of hot remelted layer, current intensity 160A

Results of penetrant tests are shown in figure 9, where: a – cast iron remelted 4 times, b – cast iron remelted 6 times.

a) b)

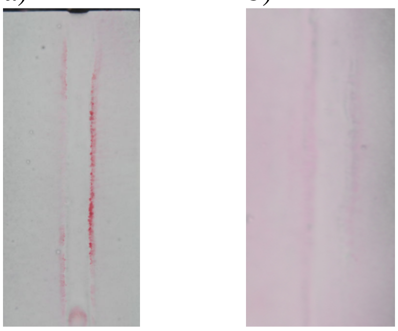

Fig.9. Penetrant tests of repeatedly remelted layers

The structure of layer remelted 6 times is transformed ledeburite. Under the remelted layer, there is a normalization zone consisting of dense pearlite with grid cementite shown in figure 10.

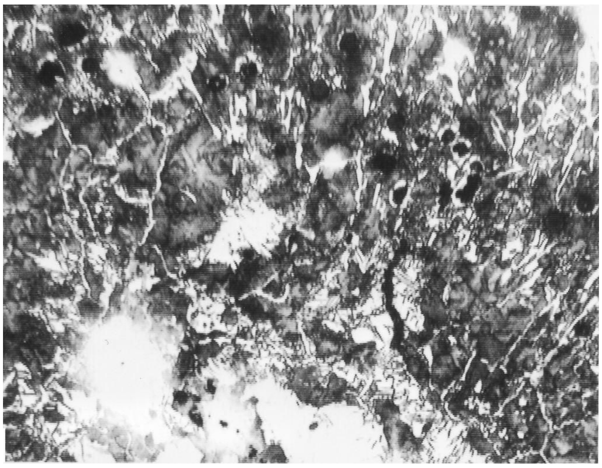

Fig. 10. Structure of normalization zone, magnification 170x

Hardness of ferritic cast iron remelted 6 times is approximately 60HRC.

4. Conclusion

The GTAW remelting method is an effective means of increasing the surface hardness of ferritic/pearlitic plain ductile cast iron. Macro and micro-cracks occur in the hardened surface as an adverse effect of the remelting process, with reference to usage and in particular with regard to contact loads. The frequency of crack occurrence depends on both the remelting process parameters and cast iron matrix structure. The best way to eliminate cracks in the hardened surface is to remelt cast iron preheated to a temperature higher than the martensitic transformation temperature, as the sources of cracks originate from the martensitic transformation of austenite being a component of ledeburite.

The remelted layer of cast iron that was preheated above the M_s temperature has the structure of transformed ledeburite and hardness approximately 8÷10HRC lower than cold remelted cast iron. For technical and economic reasons preheating cast iron makes the surface remelting method without equal when compared with alternative hardening methods. Using standard welding equipment it is possible to obtain hardened layers by multiple remelting of the same layer. The purpose of multiple remelting is to reduce the temperature gradient and avoid martensitic transformation. In case of cast iron with ferritic structure, application of the multiple remelting method entirely eliminates the occurrence of macro-cracks, with an insignificant number of micro-cracks still occurring within the remelted material/base material transitional zone. Further research on surface hardening processes employing the GTAW method ought to concentrate on the selection of current parameters, nonconsumable electrode feed rate, as well as the manner of moving the nonconsumable electrode during remelting. Until now, the electrode has only been moved longitudinally, at the same rate. The possibility of reducing the temperature gradient between the remelted layer and the base material would allow transverse movements to the remelting direction.

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