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Examination of Cast Iron Material Properties by Means of the Scratch Method

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Abstract

The paper presents results of examination of unalloyed cast iron with diversified structure of the metallic matrix carried out by means of the scratch method. The research work was carried out with cast sample plates and with castings superficially remelted by means of the Gas Tungsten Arc Welding (GTAW) method. The test was carried out with load force of 5 N. Parameters such as the coefficient of friction, penetration depth, and acoustic emission were analysed.

Keywords: Cast iron, Structure, GTAW process, Scratch test

1. Introduction

Cast iron, in view of its low production costs, very good mechanical and service properties, is widely used in the machine and automotive industry as one of the basic materials. For economical reasons, manufacturers are recently more and more interested in the possibility to replace expensive materials with cheaper ones surface of which is subject to improvement. One method of the surface improvement is to form the structure of the material's superficial layer by means of rapid resolidification with the use of a concentrated stream of heat, e.g. laser beam, electron beam, or the Gas Tungsten Arc Welding (GTAW) process. Superficial remelting followed by rapid resolidification gains increasing popularity in the industrial practice [1].

Service properties of superficially remelted castings are examined by means of testing their tribological properties and tests relating to material properties of the microstructure. Tribological tests carried out with the use of conventional methods give results in terms of quantity of the material worn or value of the coefficient of friction. Results of such tests are complemented, if need be, by metallographic analysis and studies on geometrical structure of surface [2–12]. The modern equipment for tests carried out by means of the scratch method provides new additional information that allow to describe the material wear processes better. Currently the method is used mainly to examine metallic, ceramic or plastic films [13–22]. Undertaking research work on the use of the scratch method for examination of iron alloys will allow to extend the knowledge of tribological properties of materials.

2. Methods

2.1. Material for study

The research work was carried out with unalloyed spheroidal cast iron with the following chemical composition: 3,49% C; 2,30% Si; 0,66% Mn; 0,019% S; 0,039% P; 0,17% Cu; 0,01% Ni; 0,084% Mg, analysed by means Q4-TASMAN apparatus by Bruker. For examination with the use of the scratch test, sample castings were prepared in the form of plates with dimensions 200×50×10 mm, on which superficial remeltings were made by means of GTAW method in argon atmosphere, with the welding current intensity of I = 300 A, scanned with electric arc at rate v_s = 200 mm/min. For superficial remelting, TETRIX 351AC/DC machine made by EWM was used. Superficially remelted castings were ground and polished. On samples prepared this way, tests with the use of scratch method were then carried out.

2.2. Scratch test

The scratch method consists in making a scratch on the tested surface by means of a diamond cone moving over the surface under properly selected load. The result is presented in graphical form as the friction force, the acoustic emission and the depth of penetration versus distance travelled by the cone as well as in the form of photographic documentation of the scratch mark. Cast iron scratch tests were carried out on the REVETEST RST tester made by CSM Instruments, according to applicable ASTM standard [23]. For the tests, a head with Rockwell indenter was used with tip radius of 200 μm and angle 120 . The used head allowed to carry out the tests with the loading force in the range from F_N = 0.3 N to F_N = 200 N. The acoustic emission value AE was measured and registered in percentage scale with respect to a standard made of titanium nitride (TiN), the acoustic emission of which equalling AE = 65 dB was assumed to be the reference level corresponding to 100%.Tn the course of testing, the apparatus registered the loading force F_N, the friction force F_T, the coefficient of friction μ, the acoustic emission AE, sample profile P_f and penetration depth P_d. The cast iron scratch tests presented here were carried out with loading force of F_N = 5 and the indenter displacement speed of 5 mm/min. The test set-up is presented in Figure 1.

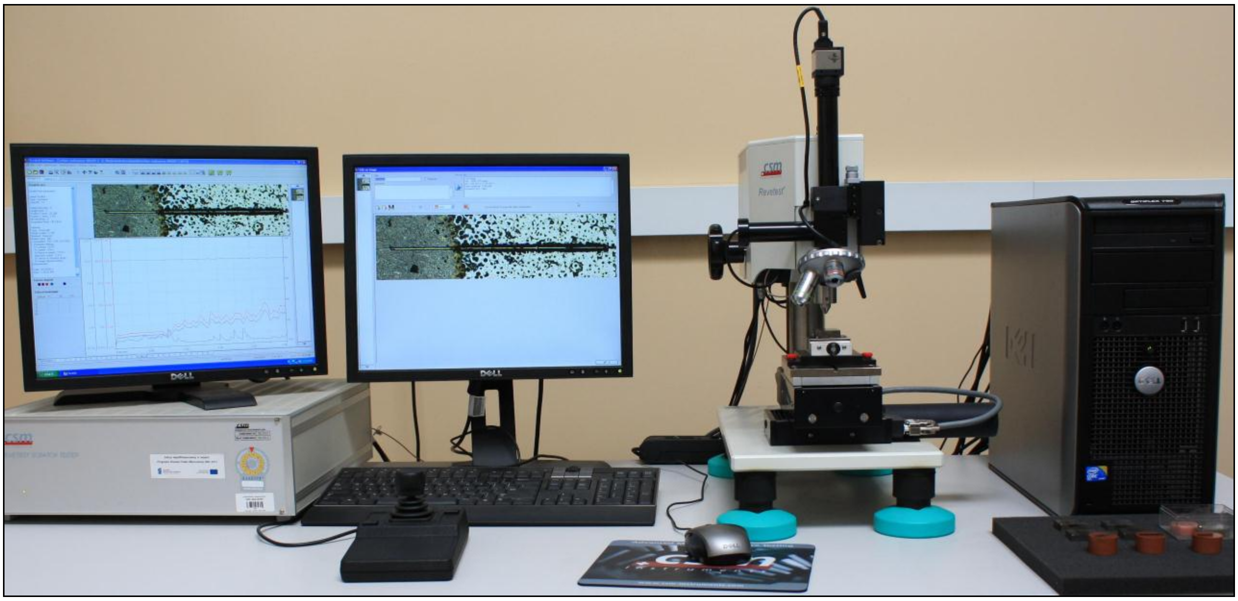

Fig. 1. Stand for testing scratches, REVETEST CSM Instruments

Figure 2 shows results obtained in the course of scratch testing the case iron sample corresponding to transition of the indenter from the area of the material with structure obtained under rapid resolidification conditions to the base material region. The obtained results show that transition of indenter from the area of the material with structure obtained under rapid resolidification conditions though the heat-affected zone to the base material is accompanied by the increase of the acoustic emission AE, friction force F_t and friction coefficient μ.

3. Analysis of results

It can be seen on plots representing variation of individual properties that while the course of the coefficient of friction and the friction force in the remelted area does not show any distinct fluctuations, the acoustic emission picture shows a number of peaks. Diversification of all of the analysed parameters is clearly visible with respect to the areas of the heat-affected zone and the base material. A suspicion then arises that the obtained waveforms result from interaction with the microstructure. The effect is visible especially in scope of different width of the scratch in individual regions of the material (Figure 3).

The obtained results show that the lowest susceptibility to creation of a scratch characterises the material with structure obtained as a result of rapid resolidification; larger — the material from the heat-affected zone (HAZ), and the largest — the base material. In order to explain such smooth course of lines representing variations of the coefficient of friction and the friction force in the superficially remelted area, the material microstructure was subject to assessment, including observation carried out by means of TESCAN VEGA 3 scanning microscope (Fig. 4, 5). The inter-phase distance in cementite eutectic was assessed. In the case of lamellar eutectic it was found to be λ_p = 0,91 μm, compared to λ_w = 0,93 μm for the fibrous eutectic.

It turned out that a characteristic feature of this microstructure was presence of hardening products in the regions of former austenite that, as a result of high rate of cooling down to the ambient temperature, was transformed partly into martensite. Bearing in mind that the indenter tip radius (200 μm) was much larger than the distance between lamellas (1.3 μm) or fibres (1.1 μm) of cementite eutectic and high hardness of cementite eutectic containing hardening products, it must be acknowledged that the natural effect of occurrence such microstructure would consist in smooth course of lines representing variations of values of the coefficient of friction and the friction force.

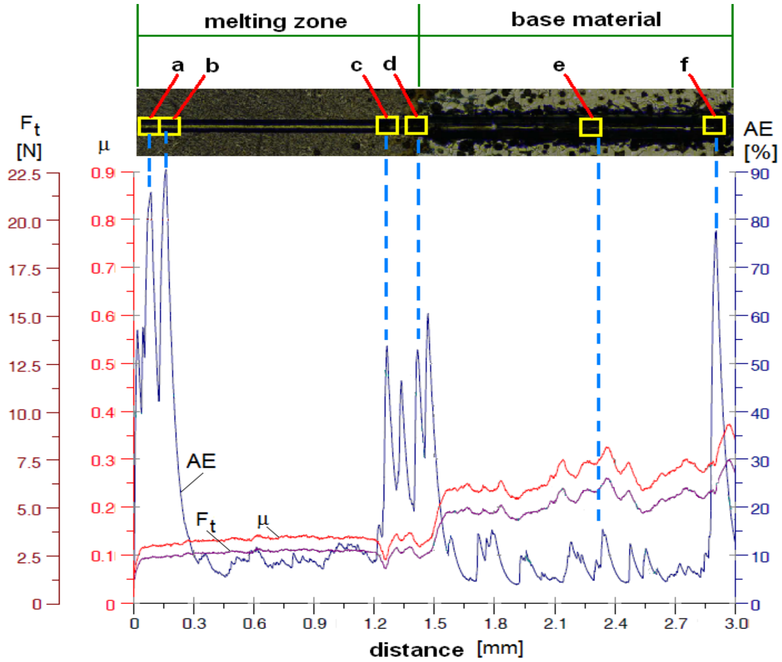

Fig. 2. Scratch test results of cast iron melting by GTAW (left) and in the area without melting (right side). GTAW process parameters: I=300A, v_s=200mm/min, argon. Scratch test was performed under load F_N=20N, the dotted line marked with distinctive elevations or depressions on the course of the changes in the parameters analyzed and the corresponding areas of surface observation features (a-f)

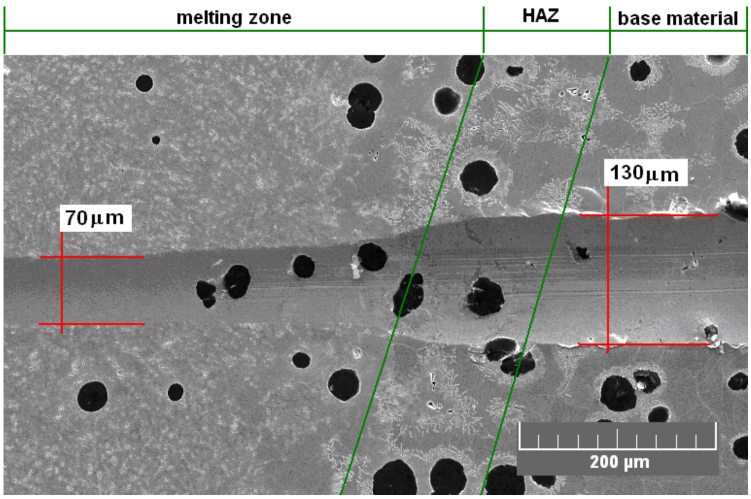

Fig. 3. The results of measurements of a crack in the various areas of material

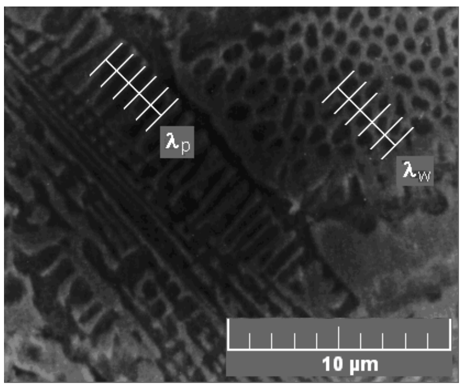

Fig. 4. The distance between the plates in the eutectic λ_p=0.91μm, the distance between the fibers in the eutecticλ_w=0.93μm

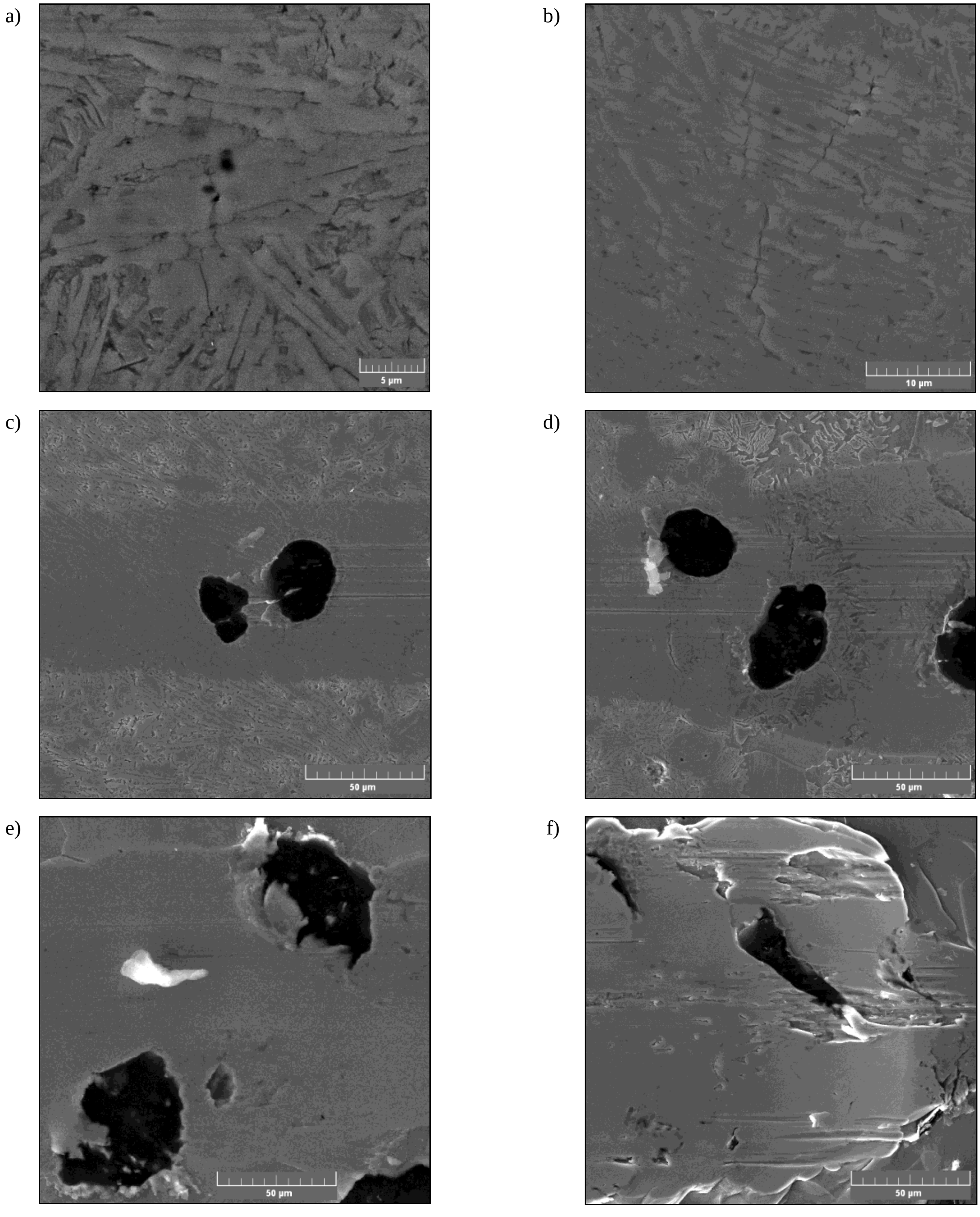

Fig. 5. The results of microscopic observation of clinical features of the cast iron scratch: a, b) in the melting area, c, d) in the zone of influence of heat and partial melting, e, f) in the area without melting (base material)

In this case, indenter glides over surface of the sample without possibility to penetrate deeper into components of the microstructure. Quite different is the picture of the indenter penetration in HAZ and in the base material where soft components of microstructure occur. In order to explain presence of peaks on the line representing fluctuations of the acoustic emission corresponding to the material with the structure obtained as a result of rapid resolidification on one hand, and absence of peaks in the lines representing the course of all the analysed parameters both in HAZ and the base material, observations of the microstructure in selected sections of scratch were carried out. Results of the observations are shown in Figure 5.

The obtained results show that in the case of material improved under rapid resolidification conditions, the peaks on the acoustic emission plot are the signals emitted in the course of creation of micro-cracks (Figure 5a, b). In the case of HAZ and the base material, disturbed waveforms on plots representing variation of the analysed parameters (acoustic emission, coefficient of friction, friction forces) are a result of the indenter entering graphite and hardening products surrounding it in HAZ (Figure 5c, d) penetration into a graphite precipitate and ferrite or pearlite (base material, Figure 5e, f). They represent also a response of material to deformation of structure components caused by displacement of indenter.

4. Conclusions

The obtained results show that the scratch method is a sensitive diagnostic tool for testing of microstructure components oriented at examination of their deformation and cracking in the course of the indenter displacement process. The method is capable to provide information about the effect of individual microstructure components on values of the coefficient of friction, the friction force and the acoustic emission.

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