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MODIFICATION INFLUENCE OF MISCHMETAL ON FRACTOGRAPHY FRACTURE OF G17CrMo5-5 CAST STEEL SAMPLES AFTER THE THREE-POINT BENDING TEST

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The article presents the analysis of fracture surfaces after the three-point bending test at a temperature range from + 20 °C to - 80 °C. The author shows a beneficial effect of mischmetal on the cracking mechanism and on the character of fractures. It has been shown that the width of the ductile fracture zone under the bottom of the notch and the nature of the cracking mechanism change with decreasing test temperature.

Key words: G17CrMo5-5 cast steel, rare earth metals (REM), fractography, fracture surface, modification

INTRODUCTION

Fracture surfaces provide information about cracking mechanism. Fractographic examination reveals intrinsic and extrinsic factors that have affected the failure process. Macroscopic observations of failure fractures help infer about the causes of failure in materials, dependent on working and environmental conditions. Microscopic observations pinpoint the causes of crack initiation, i.e., precipitations or types and density of dislocations in the substructure [1, 2].

Analysis of fracture surfaces is essential when dealing with structural steels of high strength at low plasticity [3]. In casting alloys, particular attention is paid to establishing the effect of structural factors on crack initiation and propagation. These factors include casting flaws, types and size of non-metallic inclusions, which testify to hot metal deoxidation, grain size, inter-metallic phases, etc [4 - 8].

A number of casting alloys are modified with the use of micro-additions or through the improvement of technological process, change in crystallization conditions and secondary metallurgy. These factors affect the nature and range of cleavage to ductile transition [9 – 11], as does the test temperature [12, 13].

MATERIALS AND EXPERIMENT

The tests were performed on chromium molybdenum cast steel G17CrMo5-5 non-modified and modified with rare earth metals (REM) in the form of mischmetal (Table 1). Casting was carried out in industrial conditions. Heat treatment consisted of normalizing (940 ºC / 1h / air) and tempering (710 ºC / 2h / air). Previous works indicated effects of the modification on grain size reduction in the ferritic structure and on the change in precipitation processes during tempering and the effect on dislocation structure [14-16]. Figure 1 shows the differences found in the occurrence and size of secondary precipitates. After modification, numerous, significantly dispersed and smaller precipitates of carbides are observed.

The addition of mischmetal increased impact strength of the steel at the same level of plastic properties maintained (Table 2). Assuming that the modification positively influences the material at low operational temperatures, the steel cast was subjected to low temperature strength test.

The tests were performed to ASTM E 1737-96 [17] on specimens under three-point bending at temperatures ranging between + 20 °C to – 60 °C for the non-modified cast steel and between + 20 °C to – 80 °C for the cast steel containing rare earth metals. The cracking resistance, Kjc, (Figure 2) was determined, along with the ductile-brittle transition temperature, T_Q, which was -51,2 °C for the modified cast steel and 1,1 °C for the non-modified cast steel [18].

Table 1 **Chemical composition of G17CrMo5-5 cast steel and mischmetal**

Material	Wt / %						
G17CrMo5-5	C	Si	Mn	Cr	Mo	S	P
	0,18	0,3	0,56	1,2	0,5	0,015	0,018
misch-metal	Ce	La	Nd	Pr	rest of REM		
	49,8	21,8	17,1	5,5	5,35		

Table 2 **Mechanical properties of G17CrMo5-5 cast steel at 20 °C**

G17CrMo5-5	A_5 / %	Z / %	R_e / MPA	R_m / MPA	KV / J
Non-modified	21,4	56,0	443	591	42
Modified	24,8	65,7	446	605	110

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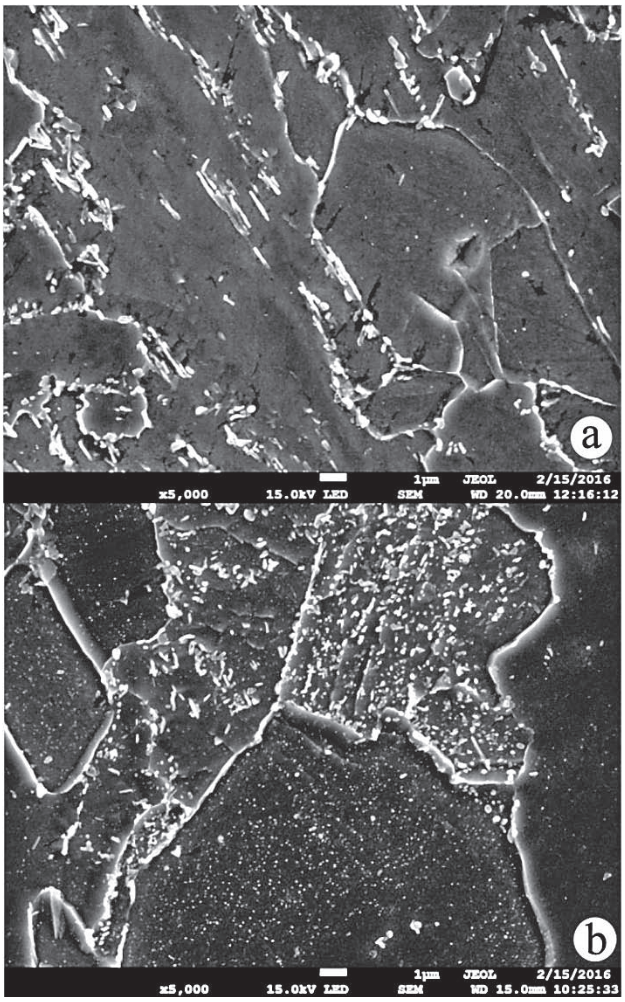

Figure 1 Microstructure of G17CrMo5-5 cast steel: a – non-modified, b – modified, scanning electron microscopy image

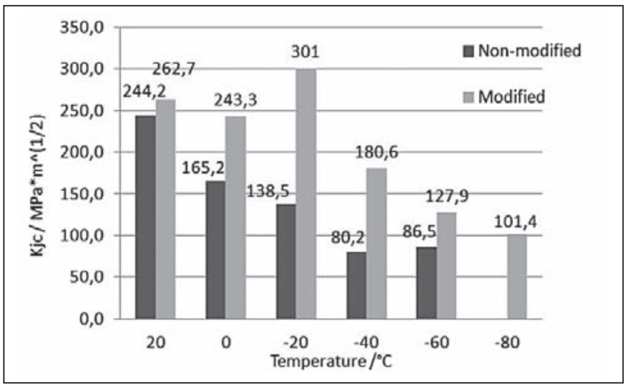

Figure 2 Cracking resistance, K_{jc}, for G17CrMo5-5 cast steel

FRACTOGRAPHIC EXAMINATION OF FRACTURED SURFACES

After strength tests, the fracture surfaces were observed in the scanning electron microscope JSM 7100F. The range of cleavage and ductile transition changed with the test temperature reduction. The ductile fracture occurred mostly just below the notch bottom and had a form of a band. For the specimens tested at + 20 °C and 0 °C, this band was 2 mm in the non-modified cast steel and about 2,5 mm in the steel with the addition of rare earth metals (REM) (Figure 3 a,b). Differences were observed at – 20 °C, when the ductile band in the modified steel was nearly twice as wide, reaching locally 480 mm. At – 40 °C a plastic zone of up to100 mm was observed in the modified cast steel (Fig. 3 c, d). Non-metallic inclusions play an important part in the process of crack growth, plasticizing the zone below the brittle cracking region. Crack initiation in this region is induced by the formation of microvoids at the inclusion-metal matrix interface. No uniform ductile cracking band is observed below – 40 °C. In areas of sharp fracture, bands of ductile cracking occurred locally.

In this region cracking direction changes were observed, with characteristic river patterns and numerous ratchet marks formed at the sites where crack fronts meet. The steel with REM content shows significantly larger number of cracking directions, which is a result of reduced grain size due to modification. Reducing the test temperature affects mainly the change in the ductile to brittle fracture area. As a consequence, transgranular cleavage cracking and brittle cracking at the grain boundaries increase. Inclusions P (Figure 4) influence the progress of cracking, since they are the source of further brittle cracks. At reduced temperatures, ductile cracking bands (D) occur more often in the brittle cracking area of the modified cast steel (Figure 4). At temperatures – 60 °C and – 80 °C, microcracks are observed in the area of ferrite grains of the cast steel with REM (Figure 5).

CONCLUSIONS

Fractographic analysis of the fractured surfaces revealed differences between non-modified and modified cast steel.

Test temperatures affect the width of the ductile cracking band under the notch bottom and the area of plastic to brittle transition range in the sharp fracture region.

The author of this paper attributes the cracking mechanism first of all to the influence of non-metallic inclusions and secondary phase precipitates (carbides). The dislocation structure of materials is also important, since the microcrack focal points are related to the slip bands or foreign phases [1]. Test temperature may have an effect on critical stresses, which increase with decreasing temperature [19]. To analyze the cracking mechanism in more detail, it would be necessary to evaluate the stress field before the cracking front against the structure of fracture surfaces [20].

The fractographic evaluation confirms the fact of coexistence of different cracking mechanisms dependent on the material and test temperature. At low temperatures, a considerable increase in transgranular cracking and brittle cracking along grain boundaries is observed.

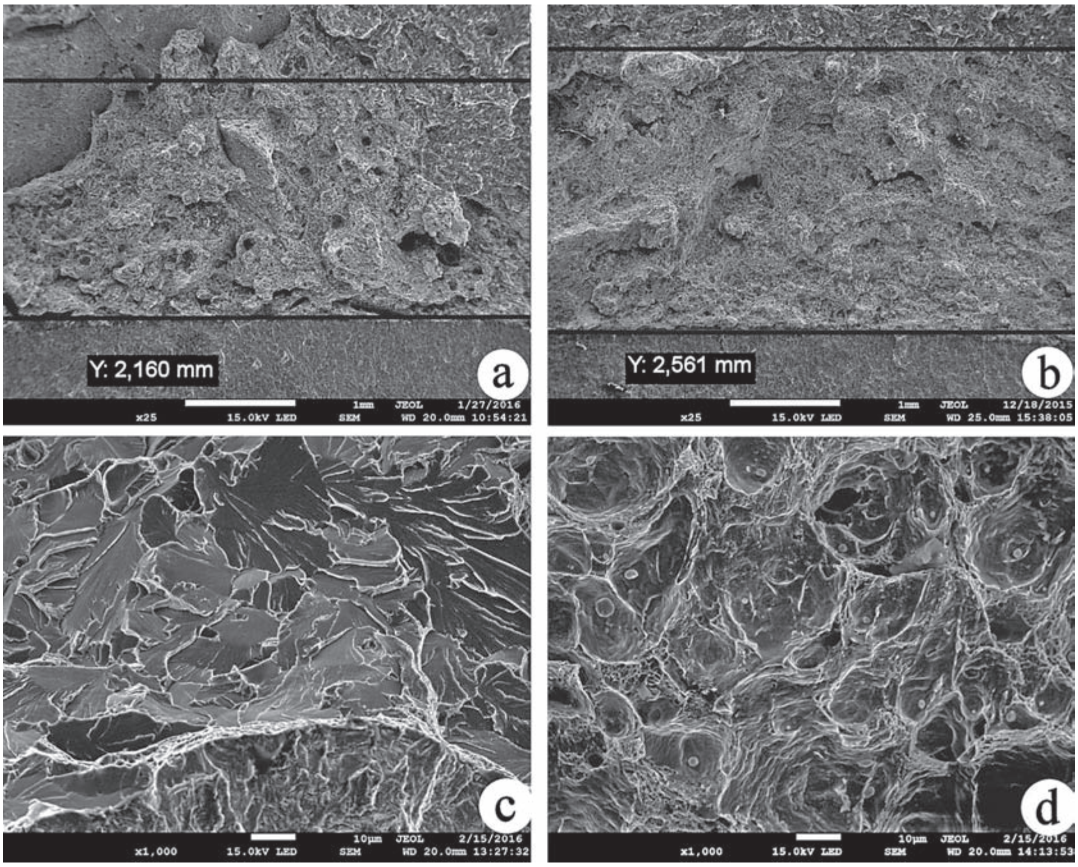

Figure 3 Fracture surface under the notch bottom: a,c – non modified, b,d – modified

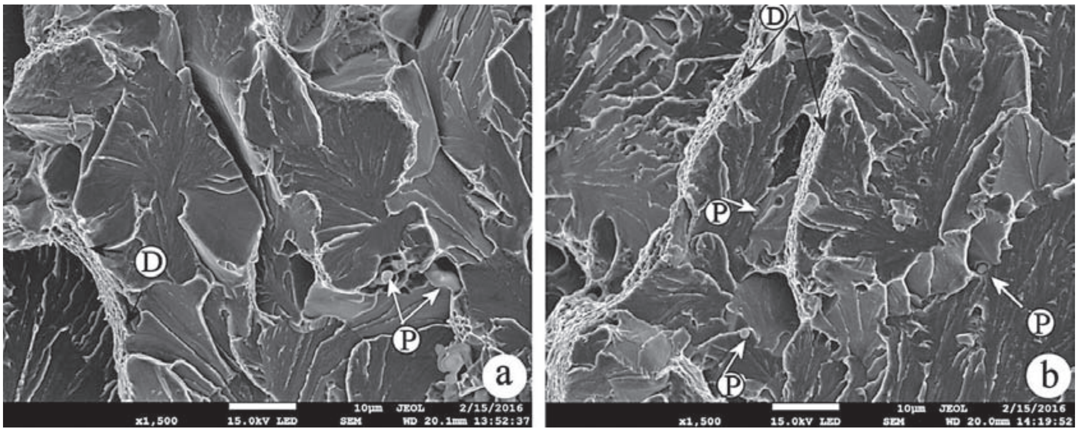

Figure 4 Brittle fracture surface: a – non-modified, b – modified (– 40 °C)

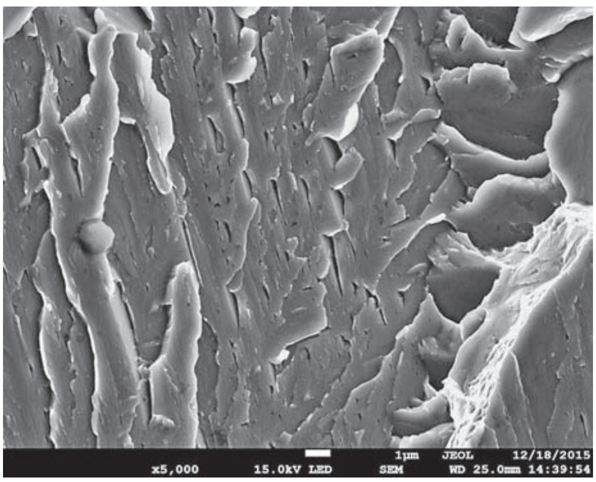

Figure 5 Microcracks in the grain area of the modified cast steel – 60 °C)

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Note: Nina Kacperczyk is responsible for English language, Kielce, Poland