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WIDE – RANGING INFLUENCE OF MISCHMETAL ON PROPERTIES OF G17CrMo5-5 CAST STEEL

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Preliminary Note – Prethodno priopćenje

This paper presents influence of rare earth metals (REM) on the mechanical properties, microstructure and morphology of non metallic inclusions as well as the cracking mechanism of G17CrMo5-5 high temperature cast steel. The research has been performed on successive industrial melts. It was found that non metallic inclusions the cracking mechanism of Charpy specimens and the impact strength were all changed. The following properties were tested: mechanical properties (R_m, R_e), plastic properties (A, Z), impact strength (S_{CI}) and the K_{JC} stress intensity factor.

Key words: cast steel, mechanical properties, microstructure, rare earth metals, modification

INTRODUCTION

REM significantly influence on structure parameters (i.e. the grain size, structural constituent fraction, amount and size of non-metallic inclusions, morphology and dispersion level of carbides and others) and on properties such as hardness, impact strength, fracture toughness [1, 2]. REM also play a significant role in increasing the steel corrosion resistance, which is often interpreted as being dependent on the morphology changes of non metallic inclusions, their dispersion and even arrangement in the metallic matrix [3 – 5]. The REM advantageous influence depends on the method of putting them into liquid metal and on their amounts. It was noticed that exceeding the quantity limit of an REM does not improve the metals and alloys properties in any significant way [6, 7].

Information contained in the literature mostly concern REM influence on steel properties. The authors of this paper carried out research, that was aimed at defining the REM influence on the mechanical properties and fracture toughness of two selected grades of G17CrMo5-5 cast steel. The tests were carried out directly on industrial heat melts.

MATERIALS AND EXPERIMENT

In this research G17CrMo5-5 cast carbon steel was selected. The chemical composition from series industrial melts was as follows: 0,18 % C, 0,4 % Si, 0,9 % Mn, 1,2 % Cr, 0,53 % Mo, 0,07 % Ni, 0,041 % Al, 0,015 % S, 0,022 % P.

These cast steels were melted in an electric induction furnace, of 2 000 kg capacity and with a basic lining in the crucible. The deoxidation and desulphurisation baths were carried out in the furnace by means of metallic Mn, ferromanganese FeMn80C01, ferrosilicium FeSi 75 Al 1,5 and calcium silicon SiCa20-3. The final deoxidation of Aluminium A5 was done directly before the tapping of cast steel out of the furnace. The cast steel modification was done by means of an REM mixture (mischmetal) consisting of 49,8 % Ce, 21,8 % La, 17,1 % Nd, 5,5 % Pr, 5,35 % and the rest of the REMs.

After casting and refining the cast, a heat treatment was performed. The were normalized (940 ºC / 1h / air) and tempered (710 ºC / 2h / air). Experiments were carried out on two melts of G17CrMo5-5 cast steel (i.e., non modified and modified with REMs of 1,02 kg/tonne of liquid metal).

RESULTS

– **Microstructure**

The results were verified for two successive melts of the tested cast steels. After the heat treatment the cast exhibited ferrite + carbides microstructure. The modification of cast steels by rare metals caused a decrease of the sulphur content in cast steels by 0,002 – 0,003%. Significant change was decreasing of the grain size of the G17CrMo5-5 cast steel was the important change and there was also a significant decrease of the amount of reduced carbides (Figure 1a,b). In non- modified cast steel in substructure occur ferritic areas with carbides and a large number of dislocations. Ferrite grains showed locally lamellar structure (Figure 2a). Modification caused that these areas were lower and disappeared lamellar structure of subgrain (Figure 2b).

– **Non metallic inclusions morphology tests**

The non metallic inclusions morphology change and an essential decrease of their size (Table 1). In the non

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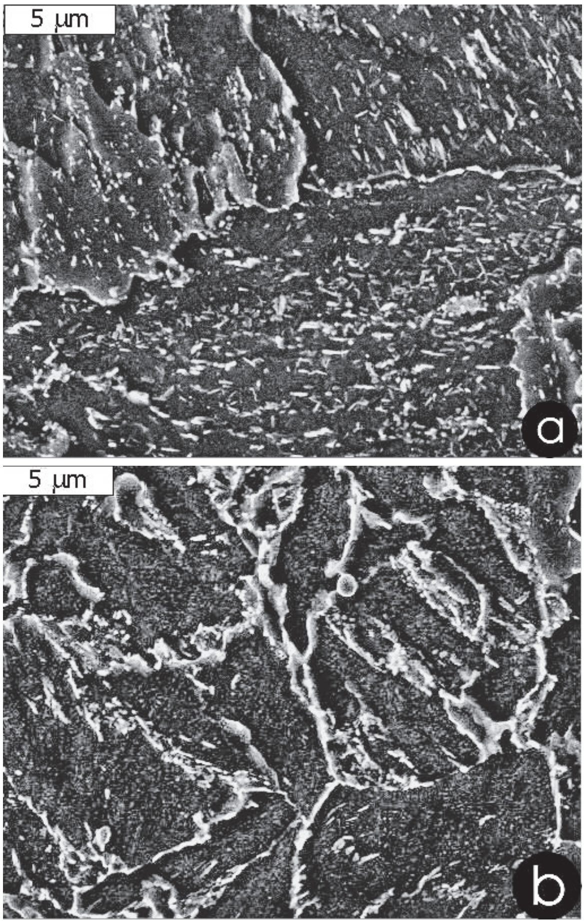

Figure 1 The microstructure: a – non-modified, b – modified, LM

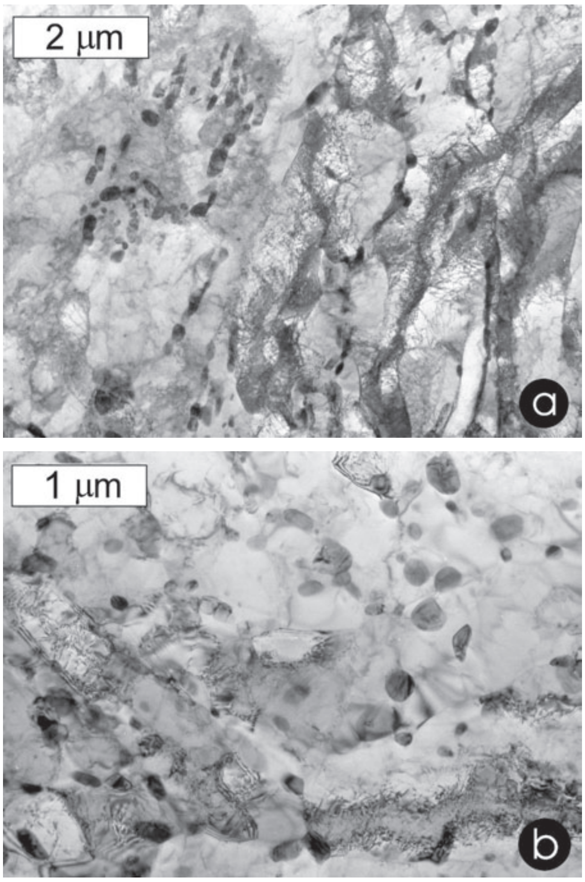

Figure 2 The ferrite dislocation structure: a – non modified, b – modified, TEM

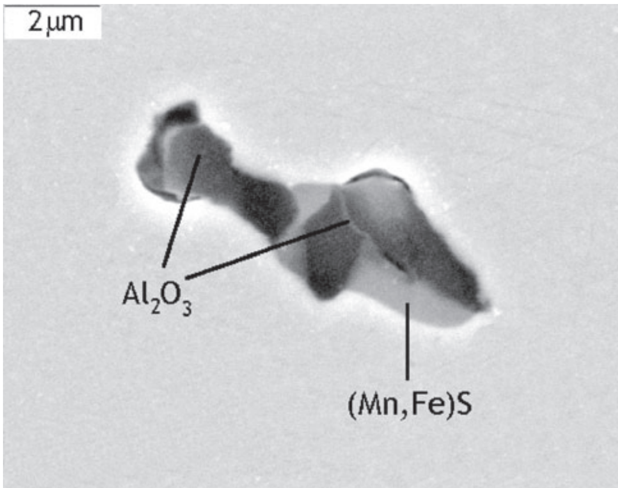

Figure 3 Non metallic inclusions in non modified cast steels. Non etched. SEM

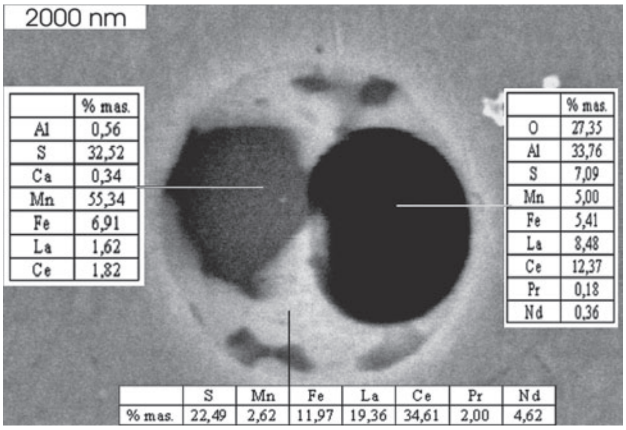

Figure 4 Microanalysis of selected elements in the spherical particles of non metallic inclusions in modified cast steels. SEM, EDS

modified cast steel fractures they are mostly heterogeneous. This was proved by observations done using a scanning electron microscope (SEM) on the non etched metallographic specimen as well as by the microanalysis of the chemical composition. (Mn,Fe)S sulphides crystallize on pads that are most often the Al_2O_3 particles of a large dispersion. Al_2O_3 oxides occured in larger clusters, they are accompanied by (Mn,Fe)S sulphides (Figure 3).

Table 1 **The stereological parameters of the non-metallic inclusions**

Cast steel	Average diameter / µm	Average diameter / %
Non modified	3,13	2,07
Modified	1,78	0,33

The structure and kinds of non-metallic inclusions occurring in REM modified cast steels depend not only on the amount of REM addition but also on the way that they are put into the liquid metal. The way of putting them in influences the amount of REM melting loss and, at the same time, – the amount of REM that actually participates in the process of non-metallic inclusion formation.

REM effectiveness increases when the initial aluminium deoxidation is used and also when the way of REM placement ensures the smallest oxidation loses that appear due to the REM reaction with air, slag and refractories. Meeting these requirements makes the ball-shaped non-metallic inclusions of a large dispersion dominate in the cast steel structure.

Observations in scanning electron microscope prove explicitly that spherical non metallic inclusions occurring in the structure of REM modified cast steels are heterogeneous and of a very complex inner structure. The X- ray microanalysis (Figure 4) results of selected elements reveal that the REM sulphides crystallise on the pads, which are usually Al_2O_3 oxides and (Mn,Fe)S sulphides slightly modified by the REM. The lack of a solid connection of the pads with REM sulphides is the reason of brittleness of these non metallic inclusions.

– **Mechanical properties and crack resistance tests**

The G17CrMo5-5 cast steel modification by REM, which was of 1,02 kg/tonne of liquid metal, caused significant changes in R_e and R_m. The yield point value increased by 44 MPa and the tensile strength increased by 24 MPa, meanwhile the values of elongations and necking were unchanged (changes amounted to about 1 %). The impact strength was also changed, more substantially, from 30 to 99 J/cm^2 (Figure 5). Determination of crack resistance was carried out on flat three-point specimens according to the ASTM E 1737-96 standard. Specimens with the notch and the initial crack opening were selected for the tests. Fracture toughness tests were carried out on specimens taken from the modified and non-modified G17CrMo5-5 cast steel.

The tests proved that the REM modification causes crack resistance increases. When tested, the cast steel underwent a brittle cracking, its stress intensity factor was 116 MPa·m$^{1/2}$. The REM modification made the factor increase to 250 MPa·m$^{1/2}$. The modification process caused a clear plasticization of the material and significant increase of the crack opening length.

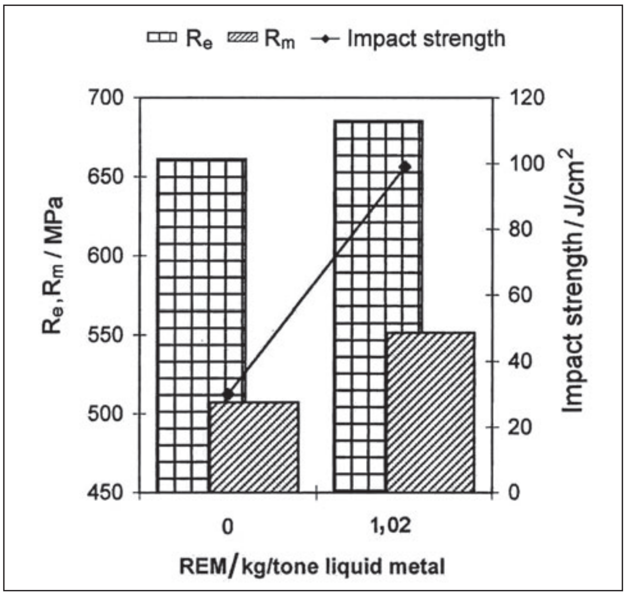

Figure 5 The REM modification influence on the mechanical properties

For the non modified cast steel fracture surface of the Charpy specimens the area of ductile fracture is limited to a narrow (ca 0,1 – 0,2 mm) strip directly under the bottom of the notch of the specimens. The shape and size of non metallic inclusions, as well as the numerous evolutions of a large dispersion of carbides, have a great influence on the mechanism of cracking in this area. The shape and size of non metallic inclusions were responsible for the dimples occurring around them. In the non modified cast steel the size and shape of the occurring dimples were large and irregular (Figure 6a). At the other part of the fracture surface there occurs cleavage fracture with ductile fracture marks mainly at the grain boundaries (Figure 7a). Irregularly shaped non metallic inclusions cause brittle fracture (Figure 7b).

Putting REM into the liquid metal caused the significant change of the shape and size of the non metallic inclusions. They mostly assumed a spherical shape had significantly larger and more differentiated dispersions in comparison with the non modified cast steel and were more evenly arranged in the metallic matrix. This made the amount of occurring dimples in the metallic matrix significantly larger as well. Their sizes were smaller

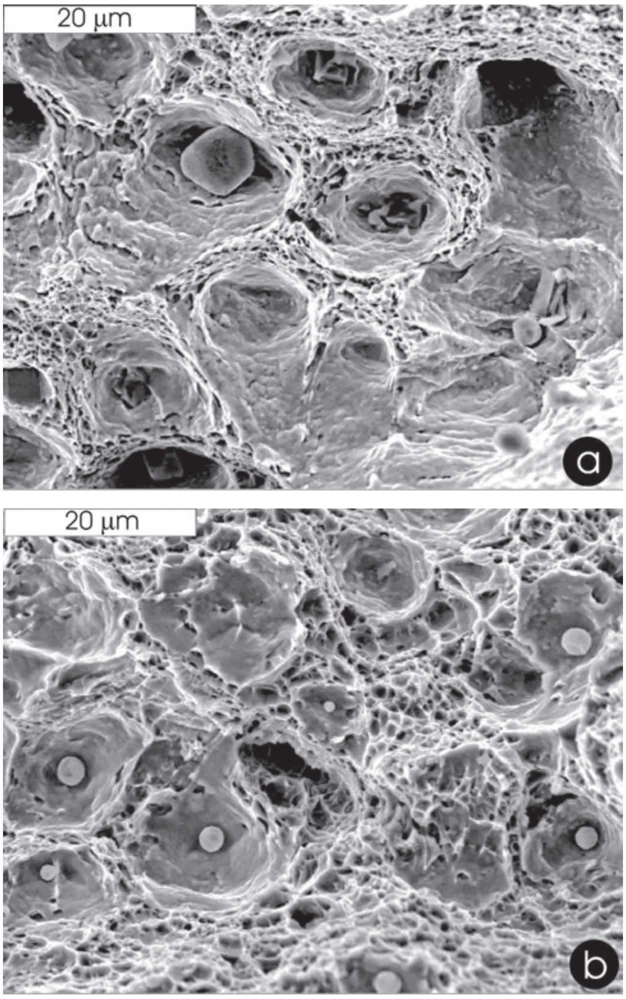

Figure 6 Morphology of the fracture surfaces of Charpy specimens at the area of ductile fracture; a – non modified; b – REM modified. SEM

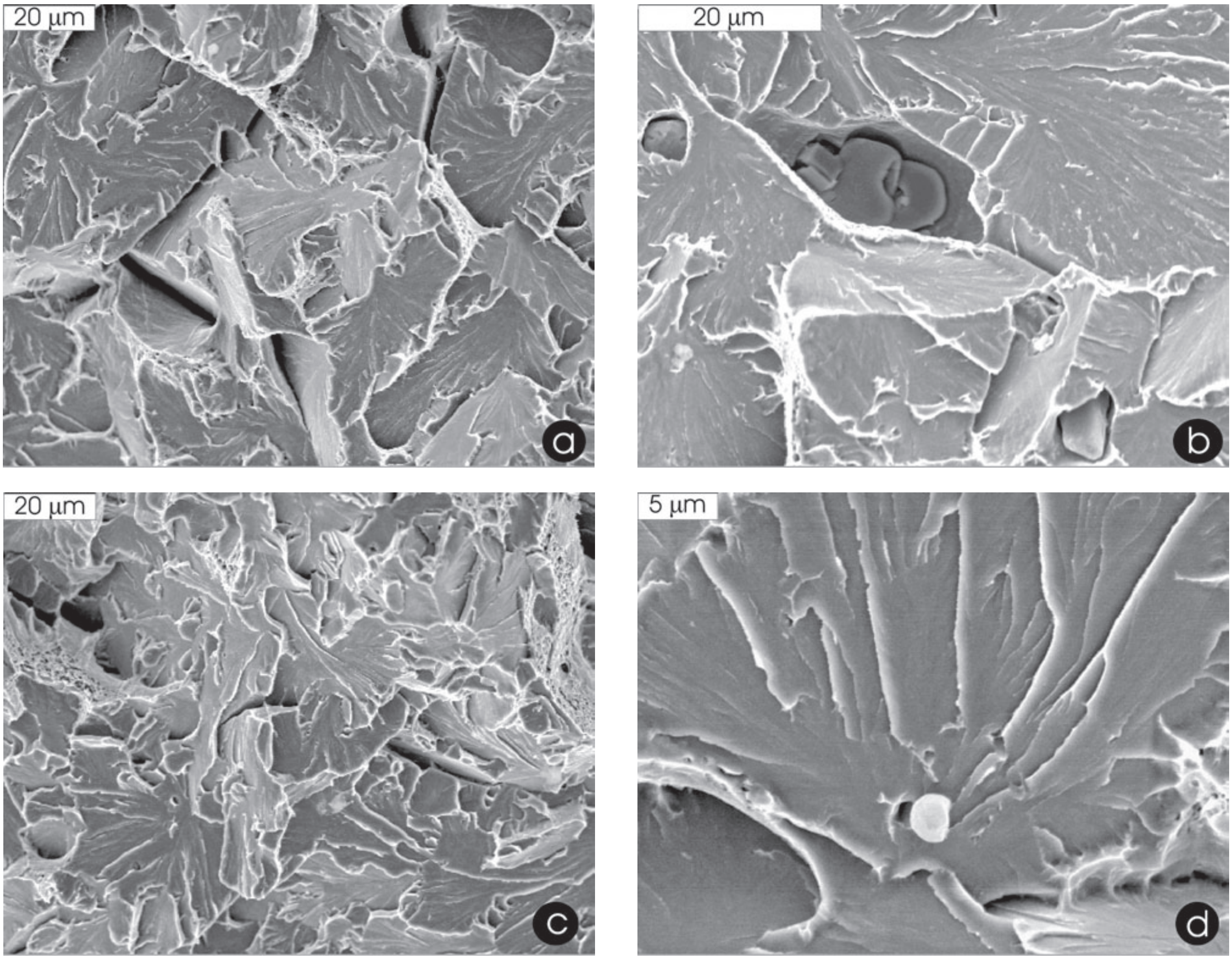

Figure 7 Morphology of fractures of G17CrMo5-5 Charpy specimens at the cleavage fracture area; a, b – non modified; c, d – REM modified. SEM

and shapes were more regular (Figure 6b). The modification causes the increase (to ca 1 mm) of the ductile fracture area under the specimens of the notch bottom. At the areas of cleavage fracture there occurred a significant increase of the changes of cracking directions due to smaller grain sizes (Figure 7c). The share of ductile fracture at these areas was also increased. The difference lies in the fact that after a momentary halt of cracking, the number of new steps increases significantly and the non metallic inclusions are quite often the ductile cracking initiators (Figure 7d).

CONCLUSIONS

Carrying out the REM modification in industry conditions made sulphur quantity decrease by maximum of ca 0,003 %. The essential change of then non metallic inclusion morphology also occurred.

The influence on the static tensile test was very small. Nevertheless the impact strength and fracture toughness, defined by the K_{JC} stress intensity factor, were significantly increased. The performed tests proved that rare earth metals (Ce, La, Nd, Pr) are very effective when increasing the toughness of the cast steels that are used for fittings production in the power industry. It is essential for increasing the life and reliability of pertinent systems. The influence of REM consists in the morphology change of non metallic inclusions, decrease of the casting grain and cracking inhibition. The significant factors, which determine the effectiveness of REM influence, are their form, amount and method of putting them into the liquid metal.

REFERENCES

[1] V. V. Luniov, Przegląd odlewnictwa, 53, (2003) 9, 299-304.
[2] Heon Young Ha, ChanJin Park, HyukSang Kwon, Scripta Materialia, 55, (2006), 991-994.
[3] T. Lis, P. Różański, Hutnik – Wiadomości hutnicze, 5 (2005), 259-264.
[4] Long – Mei Wang, and others, Journal of Alloys and Compounds, 451 (2008), 534-537.
[5] Zhenfeng Zhan, Gaoyong Lin, Shenghua Zhang, Jia Zhou, Materials Science and Engineering A, 457 (2007), 313-318.
[6] S. Kocańda, Fatigues destroying of metals, WNT, Warszawa (1978).
[7] A. Neimitz, Fracture Mechanics, PWN, Warszawa (1998).

Note: The responsible for English language is Lidja Jarosławska, Kielce, Poland