A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 59 2014 Issue 3
DOI: 10.2478/amm-2014-0166

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INFLUENCE OF RARE EARTH METALS ON MICROSTRUCTURE AND INCLUSIONS MORPHOLOGY G17CrMo5-5 CAST STEEL

WPŁYW METALI ZIEM RZADKICH NA STRUKTURĘ I MORFOLOGIĘ WTRĄCEŃ W STALIWIE G17CrMo5-5

This paper presents influence of rare earth metals (REM) on the microstructure and morphology of non-metallic inclusions of G17CrMo5-5 cast carbon steel The research has been performed on successive industrial melts. Each time about 2000 kg of liquid metal was modified. The REM was in the form of mishmetal of the composition 49,8% Ce, 21,8% La, 17,1% Nd, 5,5% Pr and 5,35% the rest of REM. The rare earth metals were put into the ladle during tapping of heat melt from the furnace.
Keywords: Cast steel, modification, rare earth metals, non-metallic inclusions, cerium

W artykule przedstawiono rolę metali ziem rzadkich na strukturę i morfologię wtrąceń niemetalowych w staliwie węglowym G17CrMo5-5. Badania prowadzono na seryjnych wytopach przemysłowych. Każdorazowo modyfikacji poddawano po około 2000 kg ciekłego metalu. Metale ziem rzadkich wprowadzono w postaci miszmetalu o składzie: 49,85% Ce, 21,8% La, 17,1% Nd, 5,5% Pr i 5,35%. Metale ziem rzadkich wprowadzono do kadzi podczas spustu ciekłego metalu z pieca.

1. Introduction

It was shown previously that the rare earth elements are surace-active elements in liquid iron [1]. Besides the unquestionable advantages the structure of an REM is also a main obstacle in their winning and during purification. REMs actively react with sulfur, nitrogen, carbon, and other impurities in steel and the compounds being formed as oxides, sulfides and oxysulfides [2]. Therefore they are used for reducing the amount of these named elements in metal alloys [3]. The addition of rare earth elements changes the amount, the nature, and the distribution of nonmetallic inclusions. Therefore, REM compounds, e.g., michmetal, are used [4, 5].

REMs 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 [6, 7]. REMs 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 [8, 9, 10]. The REMs' 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 [11,12].

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 cast steels. The tests were carried out directly on industrial heat melts.

2. Materials and experiment

In this research G17CrMo5-5 cast carbon steel was selected. The chemical composition according to EN – 10213 – 2:1999: TABLE 1.

These cast steels were melted in an electric induction furnace, of 2000 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 casts from the G17CrMo5-5 cast steel were normalized (940°C / 1 h / air) and tempered (710°C / 2 h / air).

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TABLE 1

Chemical composition of G17CrMo5-5 from series industrial melts

Melt designation	The stage at which samples were taken for analysis	Content (mass %)									Content (ppm)
		C	Si	Mn	P	S	Cr	Mo	Ni	Al	O
0	—	0.18	0.40	0.90	0.022	0.015	1.20	0.53	0.07	0.041	63
1	Before Al deoxidation and REM addition	0.17	0.28	0.57	0.024	0.016	1.13	0.54	0.11	0.004	—
	After Al deoxidation and REM addition	0.16	0.37	0.62	0.022	0.013	1.22	0.53	0.12	0.050	64

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). These compositions were determined from the cast steel specimens taken from the furnace directly before the final aluminium deoxidation. The chemical compositions of the cast steels, following aluminium deoxidation and the addition of the REMs, were defined from specimens taken from the test coupons.

3. Results

3.1. Microstructure

The results were verified for two successive melts of the tested cast steels .After the heat treatment the cast from G17CrMo5-5 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% <Tab. 1>. Significant change was decreasing of the grain size of the G17CrMo5-5 cast steel <Fig. 1a,b>and there was also a significant decrease of the amount of reduced carbides <Fig. 2a,b>, primarily for M_3C and Mo_2C.

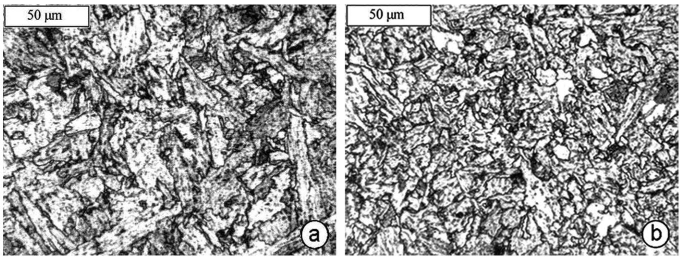

Fig. 1. The microstructure: a – non-modified, b – modified, LM

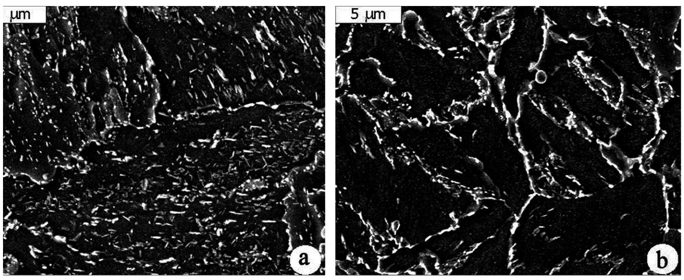

Fig. 2. The microstructure a – non-modified, b – modified, SEM

In non- modified cast steel in substructure occur ferritic areas with carbides and a large number of dislocations. Ferrite grains showed locally lamellar structure <Fig. 3a>.

Modification caused that these areas were lower and disappeared lamellar structure of subgrain <Fig. 3.b>.

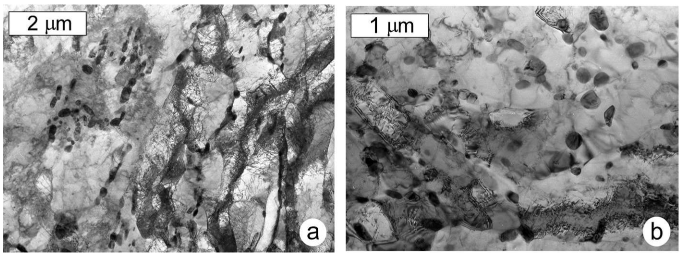

Fig. 3. The ferrite dislocation structure: a – non modified , b – modified, TEM

3.2. Non metallic inclusions morphology tests

Non metallic inclusions morphology change and an essential decrease of their size <Fig. 4a,b,>. The measurements of the non metallic inclusions were carried out by an automatic method using the MetIlo computer program for the picture analysis of the G17CrMo5-5 cast steel specimens.

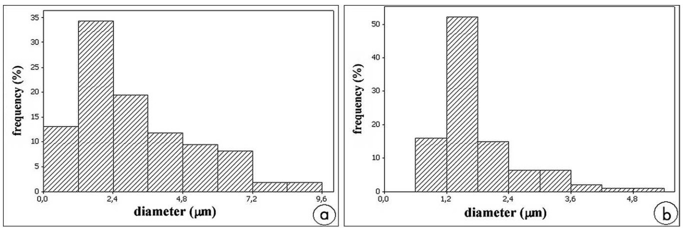

Fig. 4. The bar charts for the non-metallic inclusions diameters: a – non modified and b – modified

Non metallic inclusions occurring in the non modified cast steel fractures are mostly heterogeneous. This was proved by observations done using a scanning electron microscope 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 <Fig. 5a>. Al_2O_3 oxides occured in larger clusters, they are accompanied by (Mn,Fe)S sulphides <Fig. 5b>.

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.

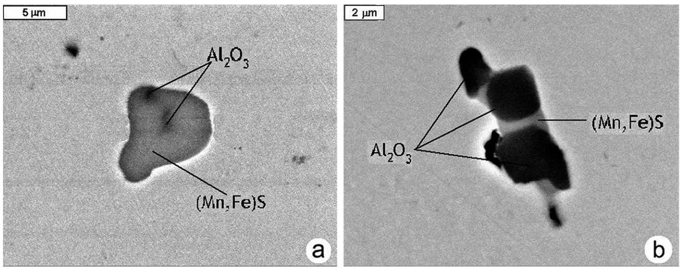

Fig. 5. (a, b). Non metallic inclusions in non modified cast steels. Non etched. SEM

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.

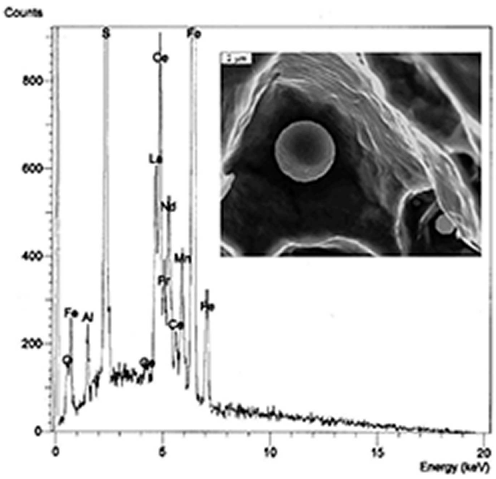

Fig. 6. X-ray spectrum emitted by spherical non-metallic inclusions occurring for Charpy specimens, with fractured surfaces, – from modified cast steels,SEM, EDS

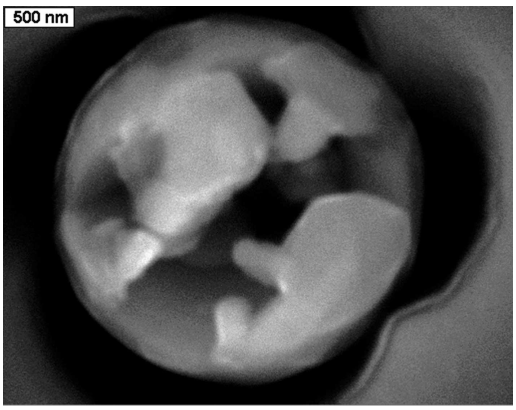

Fig. 7. Spherical non metallic inclusions in REM modified cast steels after etching by 4% HNO_3 in C_2H_5OH; SEM

The X-ray spectrum emitted by spherical non-metallic inclusions occurring on the Charpy specimens, with fractured surfaces, of modified cast steels, was also analysed. In addition to the appearance of the sulphur and REM peaks, there were also oxygen, aluminium, manganese and iron peaks of various intensity <Fig. 6>. The particles of spherical non metallic inclusions observed at the Charpy specimen, fracture and are prone to brittle cracking. For the metallographic specimens etched by 4% HNO_3 in C_2H_5OH some areas of the inclusions were etched whereas others remain untouched <Fig. 7>. By means of the scanning electron microscope it can be seen that on the non-etched metallographic specimens there appears a strong composition contrast inside of these inclusions <Fig. 8>.

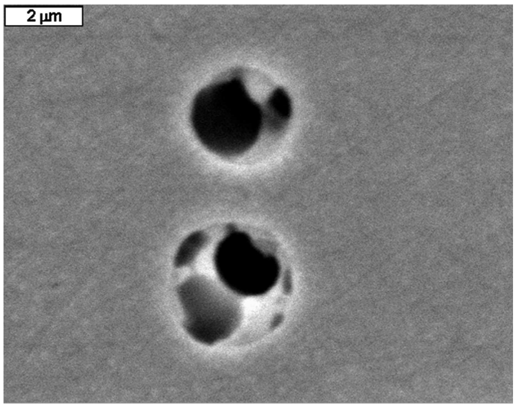

Fig. 8. Spherical non metallic inclusions in REM modified cast steels, SEM

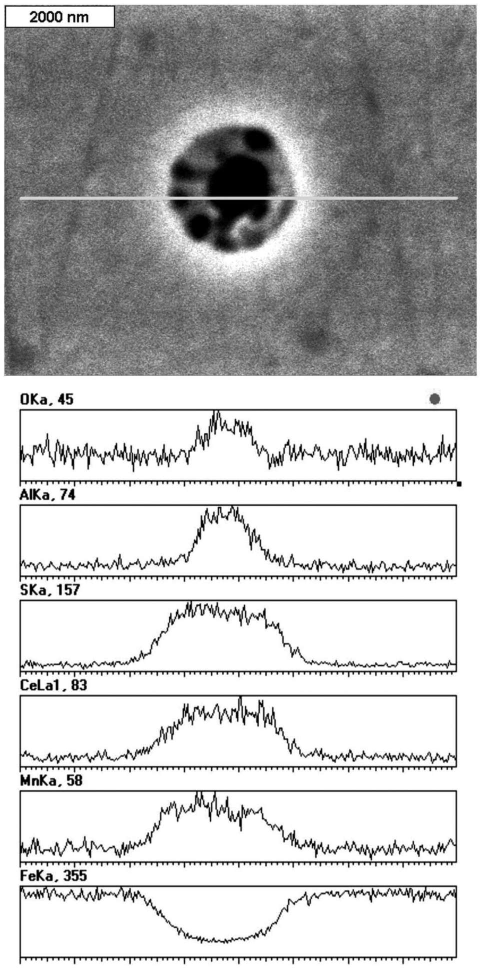

Fig. 9. Linescans of selected elements in the spherical particle of non metallic inclusions in modified cast steels. SEM, EDS. Composition contrast. SEM

All these tests results 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. Linescans <Fig. 9>and microanalysis <Fig. 10>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 REMs. The lack of a solid connection of the pads with REM sulphides is the reason of brittleness of these non metallic inclusions.

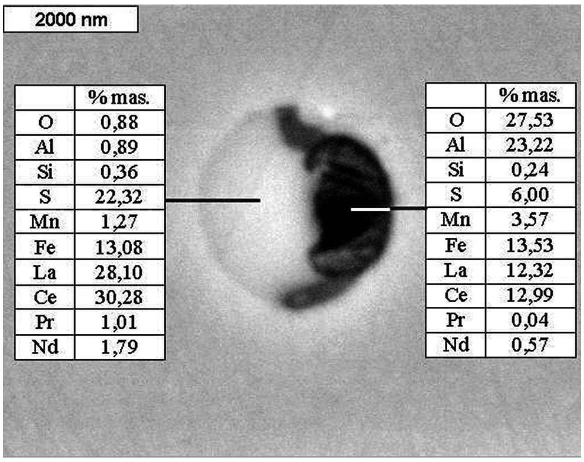

Fig. 10. Microanalysis of selected elements in the spherical particles of non metallic inclusions in modified cast steels. SEM, EDS

4. Conclusions

The modification of cast steels by rare metals caused:

1. In industry conditions sulphur quantity decrease by maximum of ca 0.003% m; This fact cannot be main to changing of structure or property modified cast steels.
2. The decreasing of grain size taking into account the appropriate amount of REM.
3. The essential change was of then non metallic inclusion morphology. This change can be the most important in verification of mechanical properties.
4. The most important result is repeatability in industrial conditions.

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Received: 10 February 2014.