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Influence of Rare Earth Metals on Microstructure and Mechanical Properties of G20Mn5 Cast Steel

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Abstract

The paper describes influence of rare earth metals (REMs) on G20Mn5 cast steel microstructure and mechanical properties. The cerium mixture of the following composition was used to modify cast steel: 49.8% Ce, 21.8% La, 17.1% Nd, 5,5% Pr and 5.35% of REMs. Cast steel was melted in industrial conditions. Two melts of non-modified and modified cast steel were made. Test ingots were subject to heat treatment by hardening (920°C/water) and tempering (720°C/air). Heat treatment processes were also performed in industrial conditions. After cutting flashes off samples of cast steel were collected with purpose to analyze chemical composition, a tensile test and impact toughness tests were conducted and microstructure was subject to observations. Modification with use of mischmetal did not cause significant changes in cast steel tensile strength and yield strength, while higher values were detected for fractures in the Charpy impact test, as they were twice as high as values for the data included in the PN-EN 10213:2008 standard. Observations performed by means of light and scanning microscopy proved occurrence of significant differences in grain dimensions and morphology of non-metallic inclusions. Adding REMs resulted in grain fragmentation and transformed inclusion shapes to rounded ones. Chemical composition analyses indicated that round inclusions in modified cast steel were generally oxysulphides containing cerium and lanthanum. In the paper the author proved positive influence of modification on G20Mn5 cast steel mechanical properties.

Keywords: G20Mn5, Rare earth metals, Modification, Microstructure, Impact toughness

1. Introduction

Low-alloy casts shave been used for decades because of their practical properties and low costs of production. By controlling carbon content or inserting micro additives we can have influence on their properties, such as impact toughness or weldability [1-5]. Among these cast steels we can distinguish manganese cast steels that are often designed to operate in low temperatures or in the off-shore industry. They are used, inter alia, in production of wear-proof elements (rail transport, clutch bodies) or slabs in installations of larger structures or machines operating in high pressure conditions (valve bodies) [6-10]. Besides influence of micro additives (inter alia, niobium and titanium[11,12]) on cast steel properties, including manganese cast steel, the more and more tested factor has been influence of rare earth metals. Most of all, improvement of fracture properties was proven, as well as decreased anisotropy in rolled products. This results in decreased grain dimensions or changes in shape and dimensions of non-metallic inclusions [13 - 21]. In their papers [22 – 25] the authors describe influence of REM additives on carbide spheroidization and dispersion.

2. Materials

Manganese cast steel was smelted in industrial conditions in an industrial induction furnace with volume of 300 kg. Steel scrap and the FeMn and FeSi ferroalloys were used as a charge. Aluminium granules were used for deoxidization. The chemical composition of cast steel being smelted was included in the table 1. The cerium mixture (mischmetal) of the following chemical composition was used for modification: 49.8% Ce, 21.8% La, 17.1% Nd, 5.5% Pr and 5.35% REMs.

2 series of smelts were made and test ingots were manufactured of them (fig. 1). After cutting flashes off they were heat-treated by hardening (920º C/water) and tempering (720º C/air). Heat treatment was performed in a chamber resistance furnace with the hearth dimensions of 2300 x 1300 mm. The process flow for heat treatment being performed was presented at the figure 2.

Influence of modification (REMs) on cast steel mechanical properties was assessed in a tensile test using an Instron 8501 dynamic testing machine. Charpy V-notch tests in the temperature of: -40, -30 and +20ºC. Metalographic tests performed using an Axiovert 200 MAT light microscope and a JSM 7100F electron scanning microscope. Pickling in the following solution: HNO_3 in C_2H_5OH (nital).

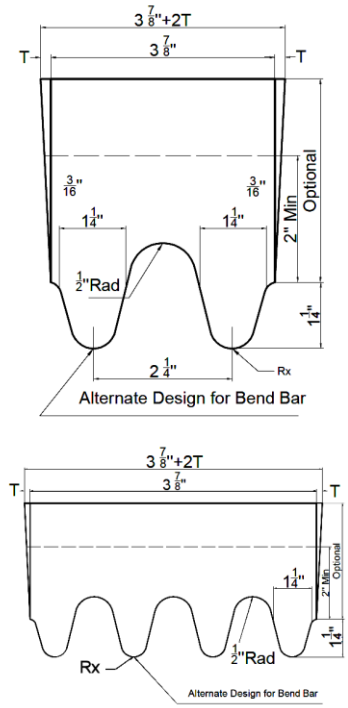

Fig. 1. Scheme of test ingots in compliance with ASTM A370-77

Table 1

Chemical composition of manganese cast steel being tested

Materials	C	Mn	Si	P	S	Cr	Mo	Fe	Ce	La
	wt. %									
Without REMs	0.19	1.14	0.41	0.02	0.018	0.15	0.15	97.80	<0.00500	<0.00100
With REM additive									0.0288	0.0176

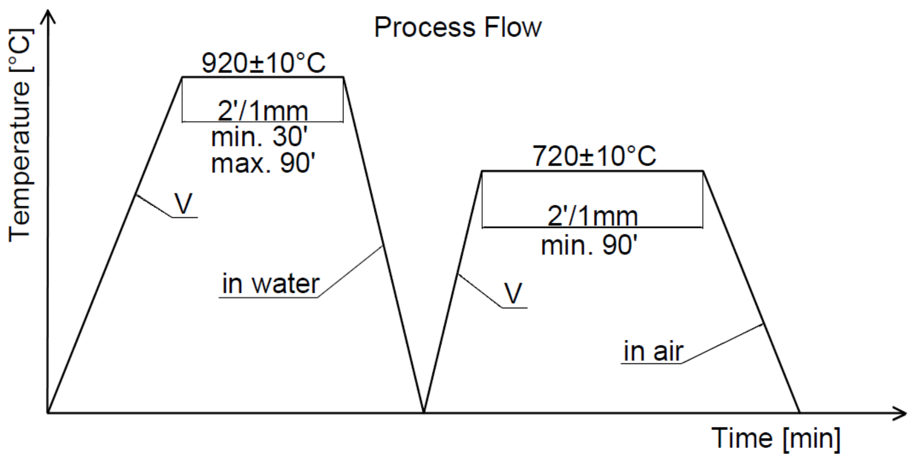

Fig. 2. Process flow of heat treatment

3. Study results and analysis

3.1. Mechanical properties

Performed strength tests proved that adding mischmetal to cast steel did not produce significant impact on a yield strength and tensile strength. Their values for cast steel without REMs were respectively 348 MPa and 545 MPa (average values). After adding REMs a yield strength and tensile strength were respectively 348 MPa and 550 MPa (Fig. 3).
On the other hand, the significant change was observed in case of the impact energy (table 2), especially in the temperature of -40ºC.
Modification of material with rare earth metals might cause increase of material properties such as yield strength and tensile strength. However, it depends on the amount of inserting modifier. In discussed case the impact strength increased, however in other properties no significant changes were observed. Concluding there might be justified to increase the amount of mischmetal inserting into the liquid metal.
Expedient effects of modification depend on many factors. It might be related not only to the change of microstructure or morphology of non-metallic inclusions (paragraph 3.2) but also to the dislocation structure. The amount of particular phases are also have great important (e.g. ferritic matrix, number of carbide precipitates and perlite amount). In the case of cast steel G20Mn5 with a modifier and with the applied heat treatment no change in volume fraction of individual structural elements occurred(carbides / ferritic matrix).

Table 2
Impact toughness of modified and non-modified cast steel

	Without REMs	With the REMs additive
	Impact toughness (J)	
+20 C	113, 113, 123	140, 151, 134
-30 C	58, 67, 66	62, 53, 102
-40 C	48, 48,54	76, 60, 61

3.2. Microstructure

The results of cast steel mischmetal modification influence and its impact on the microstructure of cast steel being tested were presented at the figures 4-6. For as-cast steel with no additives of rare earth metals we can observe larger grain dimensions in the microstructure (Fig. 4a), when compared to the microstructure after modification of cast steel with REMs.
As a result of heat treatment, we produced the tempered martensite structure (Fig. 5, 6). Similarly to the as cast state, inserting REMs resulted in fragmentation of the microstructure.
Besides of decreased grain dimensions, a significant change was obtaining of changed morphology in non-metallic inclusions as a result of modification (Fig. 7). After adding rare earth metals inclusions became smaller. For non-modified cast steel non-metallic inclusions were mainly (Fe,Mn)S sulphides (Fig. 8). After adding the modifier inclusions became more compound. They were mainly oxysulphides, for which the EDS analysis indicated occurrence of cerium and lanthanum (Fig. 9).

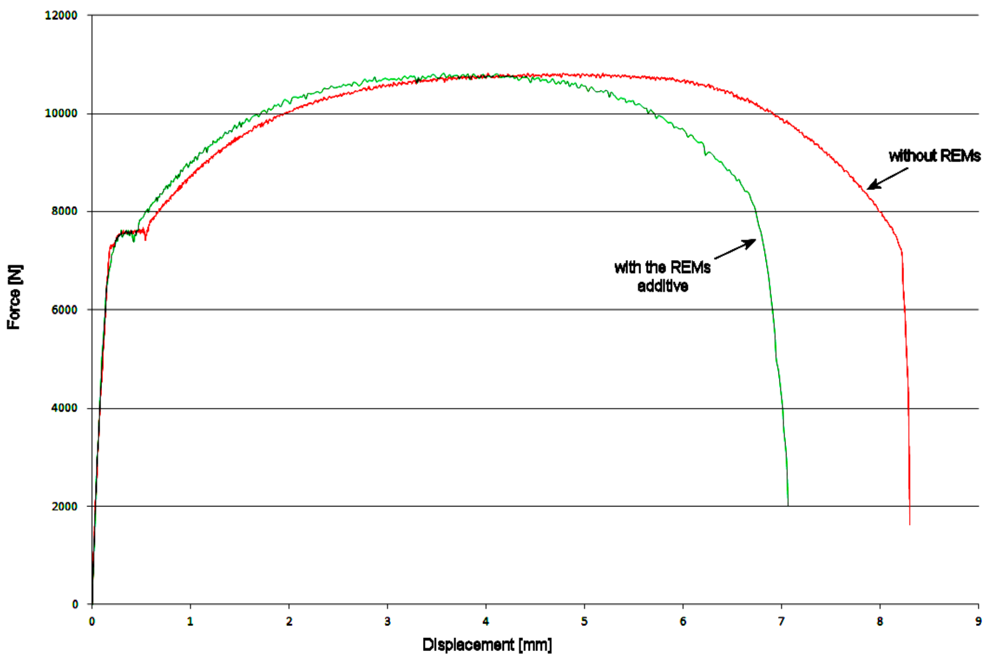

Fig. 3. Examples of tensile test charts for cast steel without REMs and with the REM additive

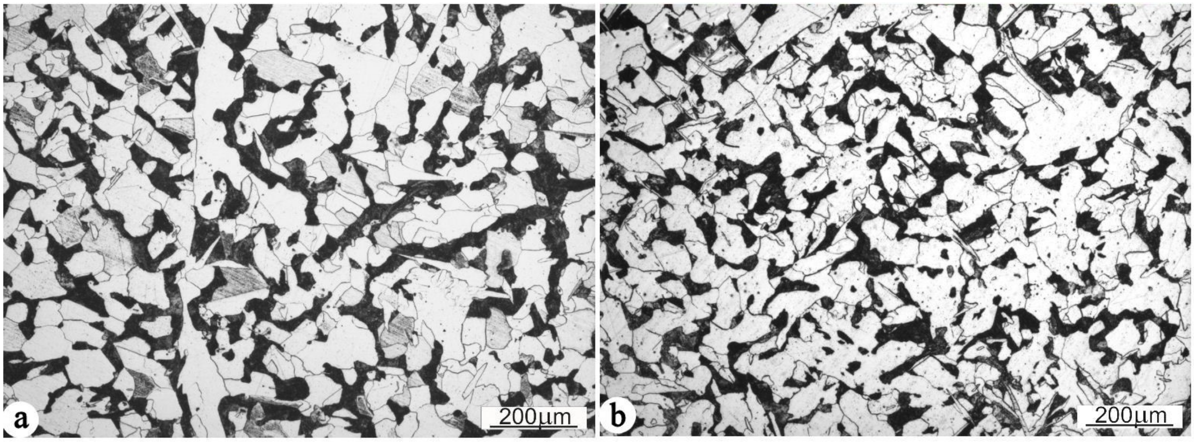

Fig. 4. Microstructure of as-cast steel, a) without REMs, b) with the REM additive, LM; nital etched

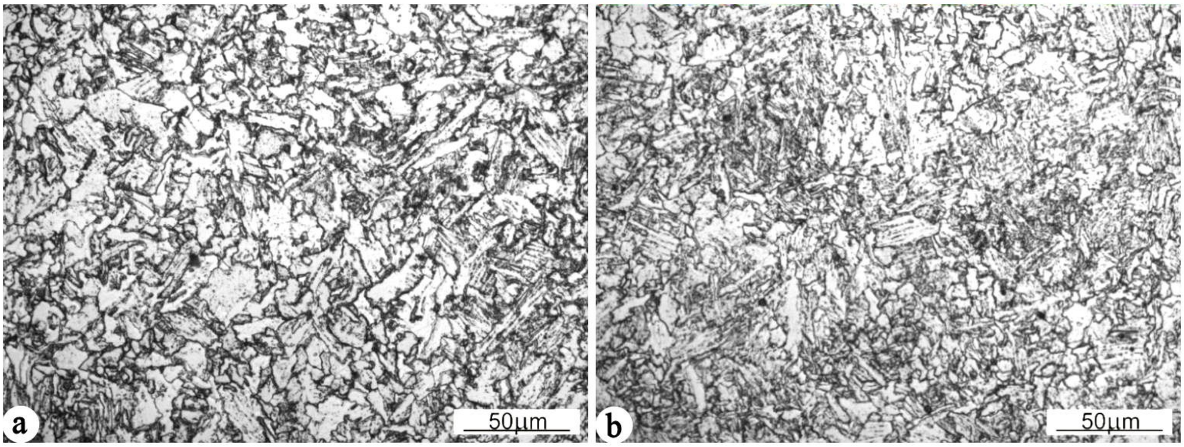

Fig. 5. Microstructure of heat-treated cast steel, a) without REMs, b) with the REM additive, LM; nital etched

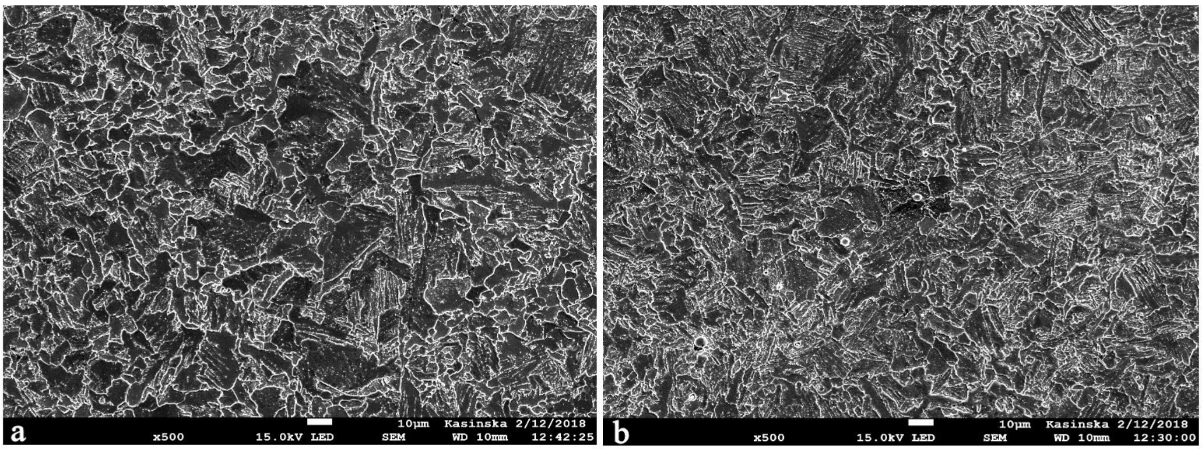

Fig. 6. Microstructure of heat-treated cast steel, a) without REMs, b) with the REM additive, SEM; nital etched

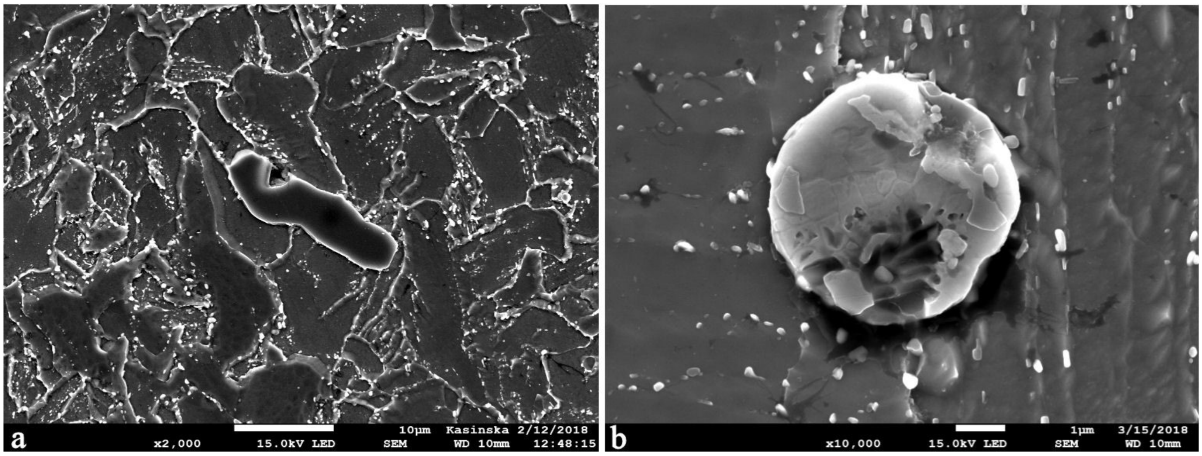

Fig. 7. Microstructure of cast steel with visible non-metallic inclusions, a) without REMs, b) with the REM additive, SEM; pickled with nital.

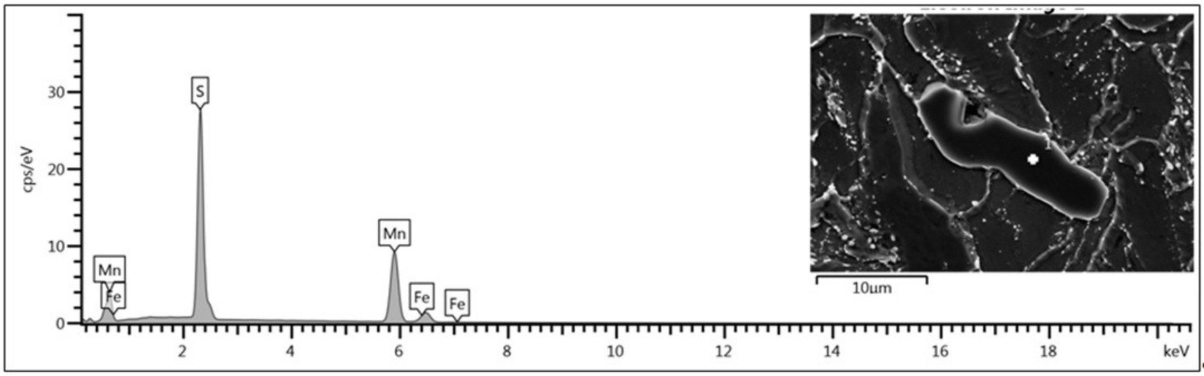

Fig. 8. Characteristic X-ray spectrum of a non-metallic inclusion in modified cast steel, SEM, EDS

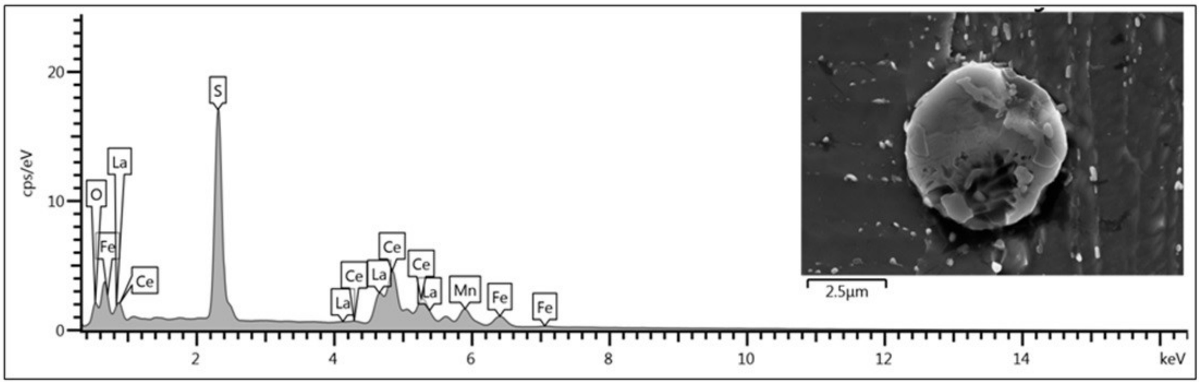

Fig. 9. Characteristic X-ray spectrum of a non-metallic inclusion in modified cast steel, SEM, EDS

4. Conclusions

G20Mn5 cast steel modification with mischmetal resulted in:

- fragmentation of the microstructure both in the liquid and the heat-treated states,
- changed morphology in non-metallic inclusions (after adding REMs inclusion dimensions do not exceed 10 μm),
- increased impact toughness exceeding the requirements included in the standard by over two times. Correctly performed heat treatment processes allow to obtain satisfactory results also for cast steel not modified with

rare earth metals. Modification results in increased impact toughness by another dozen or so percentage points, that is especially significant in lower temperatures.

Modification of cast steel with mischmetal can be performed in industrial conditions with positive and repetitive results.

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