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Exploitation of rare earth metals in cast steel production for power engineering

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Abstract

The paper presents results of experiments carried out on industrial melts. There has been tested the REM influence on carbon properties (0.20%C) as well as austenitic cast steel Cr-Ni 18/8+Ti type.
It was found that REM cause an essential improvement of cast steels impact strength and in case of austenitic cast steel – also the corrosion resistance improvement in boiling 65%HNO3 (Huey test).

Keywords: REM (rare earth metals), Modification, Cast carbon steel, Austenitic cast steel

1. Introduction

The metallic materials have to satisfy growing demands, it refers especially to strong alloys for power and chemical industries (fittings, pipelines, boilers, etc.)and therefore better and better options have been searched for [1].
One of them is the application of rare earth metals in order to modify steels and alloys and improve their microstructure and properties. REM essentially affect the contents and morphology of sulfides and oxides. Thus the special purpose steels, duplex steels [3] and others have been modified. This process of modification has been widely used in metallurgy of non-ferrous metals and their alloys [4-6].

2. Research methods

In industry conditions the researches were carried out on cast carbon steel of 0.20%C content and Cr-Ni austenitic cast steel of 18/9+Ti type. Melts were made in the electric induction furnace of 2000kg and the basic furnace lining. Metallic Mn, FeMn80CO1, FeSi75 A11 – 11 and SiCa 20-3 were applied in the process of melting for deoxidation and desulphurizing. The final deoxidation was made in the furnace using A5 aluminium.

The modification was performed during tapping cast steel out of the furnace putting into the ladle REM ceric mixture containing 49,8% Ce, 21,8% La, 17,1% Nd, 5,5% Pr and 5,35% and the rest was REM. For cast carbon steel tests were used three different amounts of REM i.e. 0,27, 0,80 end 1,35 kg/ton liquid metal. For Cr – Ni 18/8+Ti type tests, the modification was performed by means of REM at the content of 2,5 kg/1000kg of liquid metal.

Samples for examinations were taken from test coupons after heat treatment. Test coupons from cast carbon steel were normalized at 940^{o}C. For Cr-Ni 18/9+Ti there were used: solution heat treatment (1050^{o}C/h/water), stabilizing (860–880^{o}C/2h/air) and sensitisation (650^{o}C/1h/air).

3. Results

3.1. Cast carbon steel modification

The essential effects of modification appeared only when 0.8kg REM/ton of liquid metal were added. The sulphur content was reduced by 0.002% - 0.03% (Tab. 1). the morphology of the quantity dominating sulfides was changed. In cast steel without modification these are the sulfides (Mn, Fe)S (Fig. 2a, Tab .2) of irregular shapes(Fig 1a, 3a) while in modified cast steel they are ball –shaped sulfides (Ce, La, Nd, Pr, Fe, Mn)S (Fig. 2b, tab. 2) and (Fig. 1b, 3b).

There was an important change of the impact strength KV which increased from 100.5 J/cm^2 for unmodified cast steel to 150.5 J/cm^2 for REM modified cast steel at the content of 0.8kg/ton of liquid metal.

Increase of REM content to 1.35kg/ton liquid metal does not cause any further essential increase of the impact strength with the value of 153.5 J/cm^2.

Adding this amount of REM causes increase of tensile strength of about 10-20 MPa and reduction of the narrowing by 4%. Other indices (Re, As) remain unchanged.

At impact strength sample fractures there appear cleavage and ductile intercrystalline cracking areas.

At unmodified cast steel samples the cleave cracking area covers about 50% of the fracture area while at modified cast steel samples – this area is decreased by ca 10 – 15%. The morphology of impact strength samples fractures at ductile cracking areas is the result of the influence of size and shape of sulfides (Fig. 3).

The impact strength increase is accompanied by the 26% growth of the crosswise shortening of the impact strength samples at the notch bottom.

3.2. Austenitic cast steel modification

Making use of Cr-Ni austenitic cast steels in chemically aggressive medium depends on their intercrystalline corrosion resistance. One of the ways of increasing this resistance is the chemical composition correction in order to obtain the diphase austenitic-ferritic microstructure in cast steels.

However, the advantageous Feδ interaction depends on its morphology. Coarse-grained Feδ particles are especially disadvantageous at dendritic systems [7, 8]. Particles of chromium carbides in austenitic ferritic cast steel after sensitisation are concentrated mainly at phase boundries by tapping chromium from the ferrite enriched in this element to 23% and in smaller quantities at austenitic grain boundaries in case of austenitic cast steels. If Feδ does not appear as an irregular system and its particles are not uniformly distributed in matrix, then the carbide particles do not occur as the continuous system.

Feδ grains surrounded by carbide particles are not bonded with each other and if as a result of dechromizing there appear corrosion then the latter does not spread. Delta ferrite occurence causes the increase of yield point of cast steels and reduction of their high temperature crack sensitivity. Obtaining the advantageous Feδ morphology is possible due to the modification process preferably using REM.

The carried out tests revealed that modification caused reduction of sulphur content in cast steel by ca 0.005% (Tab. 3) and removal of Feδ dendritic system (Fig. 4) Mechanical properties were vitally improved as well.

For these cast steels (Tab. 3) after solution heat treatment with the microstructure shown at Fig.4, the yield point increased from 212 to 242 MPa, the tensile strength increased from 492 to 525 MPa and the impact strength KCU2 from 112 to 168 J/cm^2. There appeared an essential change in the morphology of fractures of the impact resistance samples. At unmodified cast steel samples – the cleavable cracking was prevailing while at modified cast steel – ductile cracking was dominating (Fig. 5).

Growth of crystalline corrosion in Huey test (samples were boiling in 65% HNO3, Fig. 6) with the limitation of corrosion spread into the cast steel sample depth was a particularly essential change (Fig. 7).

4. Conclusions

1. REM can be successfully used for improving the cast steel properties for power industry devices.
2. Cast steel modification by means of REM improves mechanical properties and in case of Cr – Ni austenitic cast steel it can also increase their corrosion resistance.
3. Achieving positive results of REM modification depends on the method of their adding and the right deoxidation of the liquid cast steel in the furnace before the tapping.

Table 1.
Chemical composition of cast carbon steel

Melt		content [at %]					
		C	Mn	Si	P	S	Al
unmodified	without oxidation of Al	0.20	0.72	0.34	0.021	0.015	0.003
	after oxidation of Al	0.21	0.71	0.40	0.020	0.015	0.049
modified	without oxidation of Al	0.21	0.64	0.36	0.022	0.016	0.003
	after oxidation of Al and after modification of REM (1,35 kg/1000 kg of liquid metal)	0.21	0.69	0.43	0.022	0.013	0.037

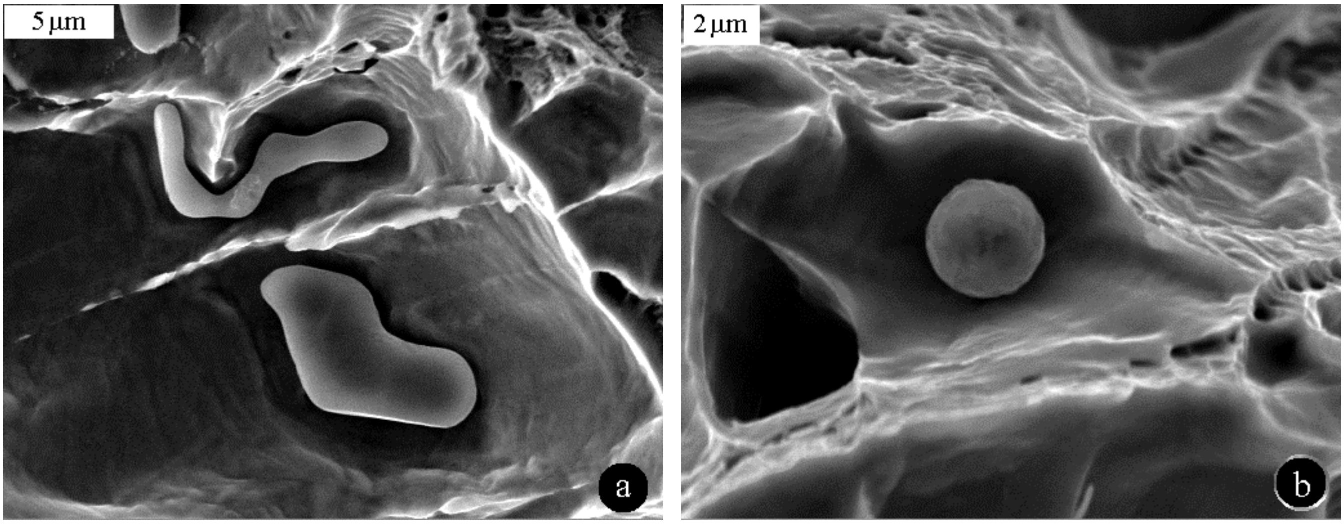

Fig. 1. Morphology of sulfides a – unmodified, b - modified

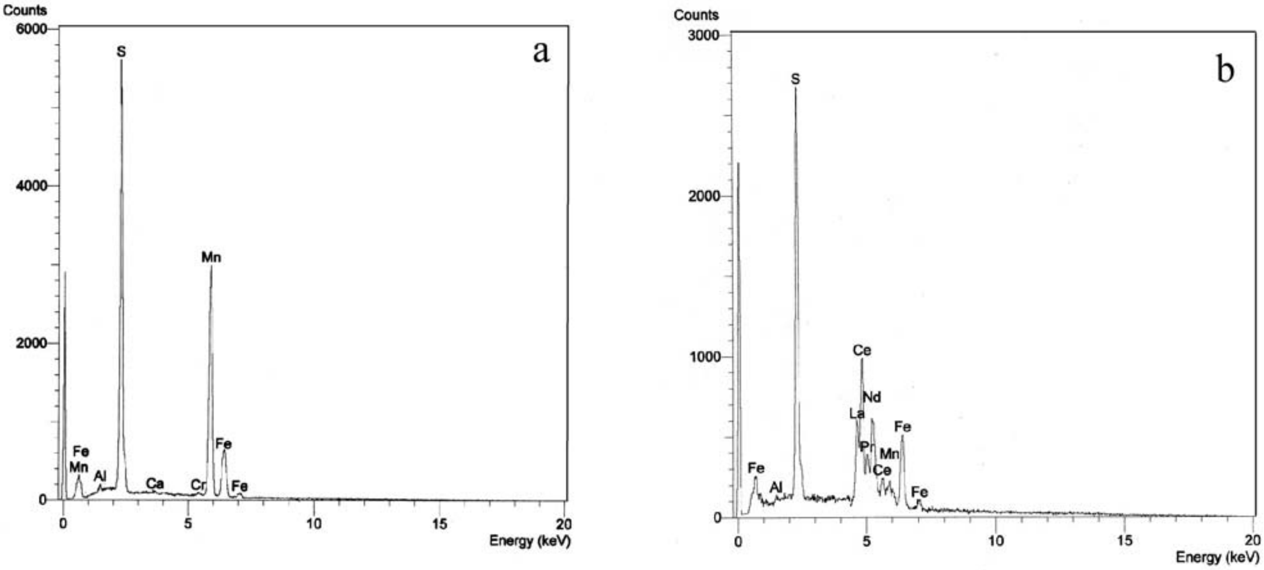

Fig. 2. X – Ray spectrum of sulfides: a – unmodified melt, b – modified melt

Table 2.
Chemical composition of sulfides

Melt	content [at. %]									
	S	Mn	Fe	Cr	Al	Ca	Ce	La	Nd	Pr
unmodified	47.71	44.02	6.63	0.34	1.05	0.25	—	—	—	—
modified	49.70	3.37	15.18	—	1.11	—	17.49	9.87	2.27	1.01

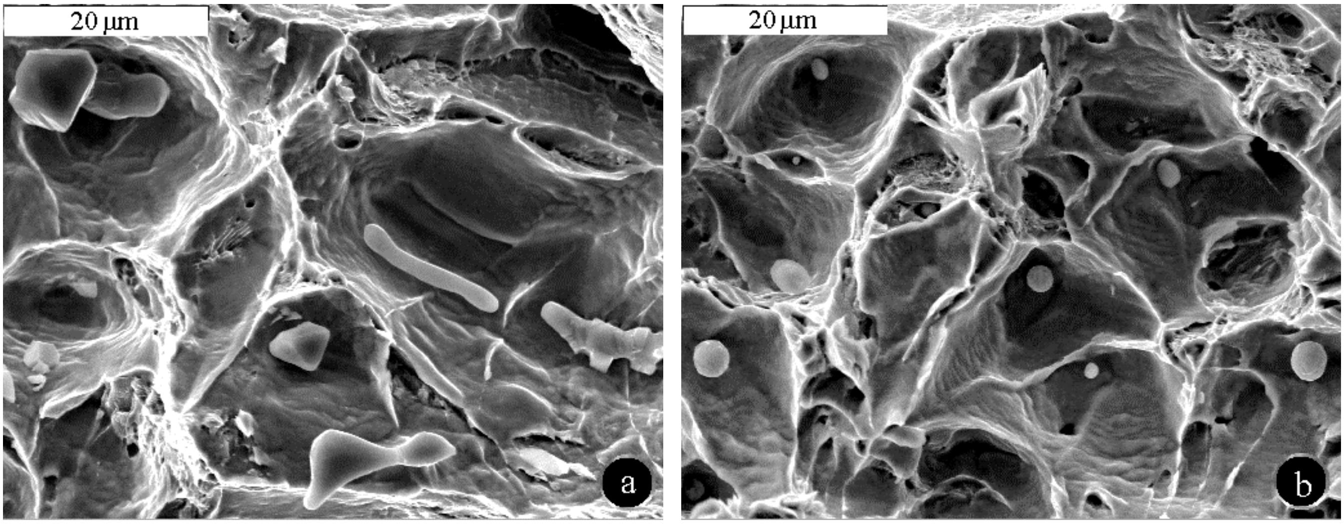

Fig. 3. Morphology of impact strength fracture samples: a – unmodified, b – modified

Table 3.
Chemical composition of commercial melts Cr – Ni cast steel of 18/8 + Ti and the amount of δ ferrite in the casting microstructure determined with a magnetic method

content [wt. %]								O_2 [ppm]	δ ferrite amount [%]
C	Mn	Si	P	S	Cr	Ni	Ti		
unmodified melts									
0.080	1.50	0.69	0.014	0.015	18.0	9.6	0.59	67	5.0
melts modified with cerium mixture									
0.073	1.68	0.65	0.018	0.010	18.9	9.8	0.51	49	7.0

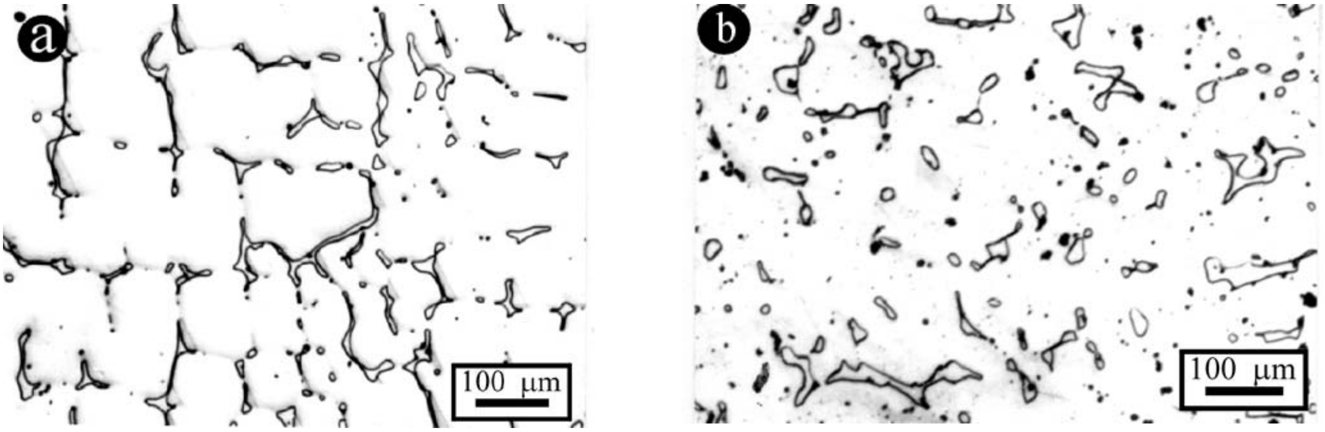

Fig. 4. Microstructure of Cr – Ni cast steel, a – unmodified melt, b – modified melt

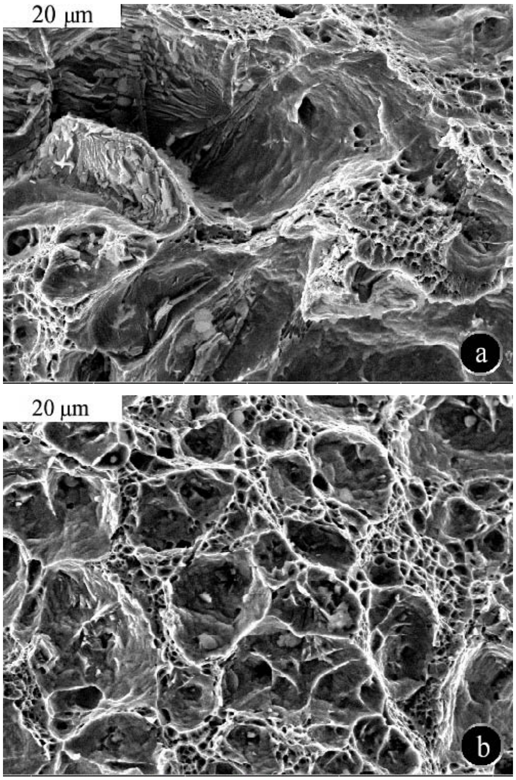

Fig. 5. Impact sample scraps in commercial melts Cr – Ni cast steel of 18/8 + Ti type. Heat treatment: solution heat treatment + stabilization: a – melts without modification, 0.62%Ti, 6.5% Fe – δ, b – melts modified with cerium mixture, 0.51%Ti, 7.0% Feδ

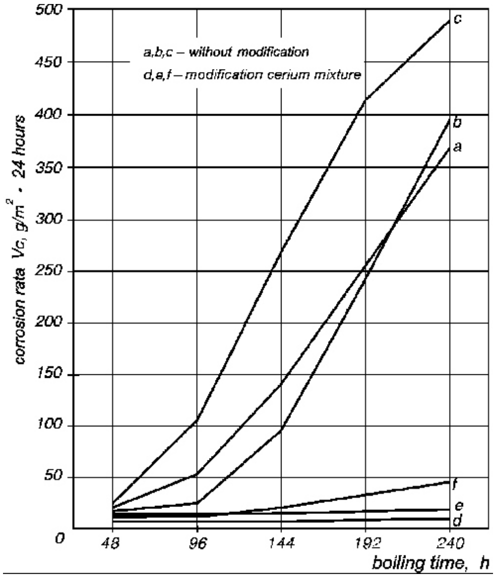

Fig. 6. Expansion of corrosion in commercial melts Cr-Ni cast steel of 18/8 + Ti type. Heat treatment: solution heat treatment + stabilization + sensitization: a – 0.07%C, 0.72%Ti, 17%Fe – δ; b – 0.08%C, 0.59%Ti, 5.0%Fe – δ; c – 0.10%C, 0.62%Ti, 6.5%Fe – δ; d – 0.07%C, 0.55%Ti, 11.5%Fe – δ; e – 0.07%C, 0.51%Ti, 7%Fe – δ; f – 0.12%C, 0.44%Ti, 6.5%Fe – δ

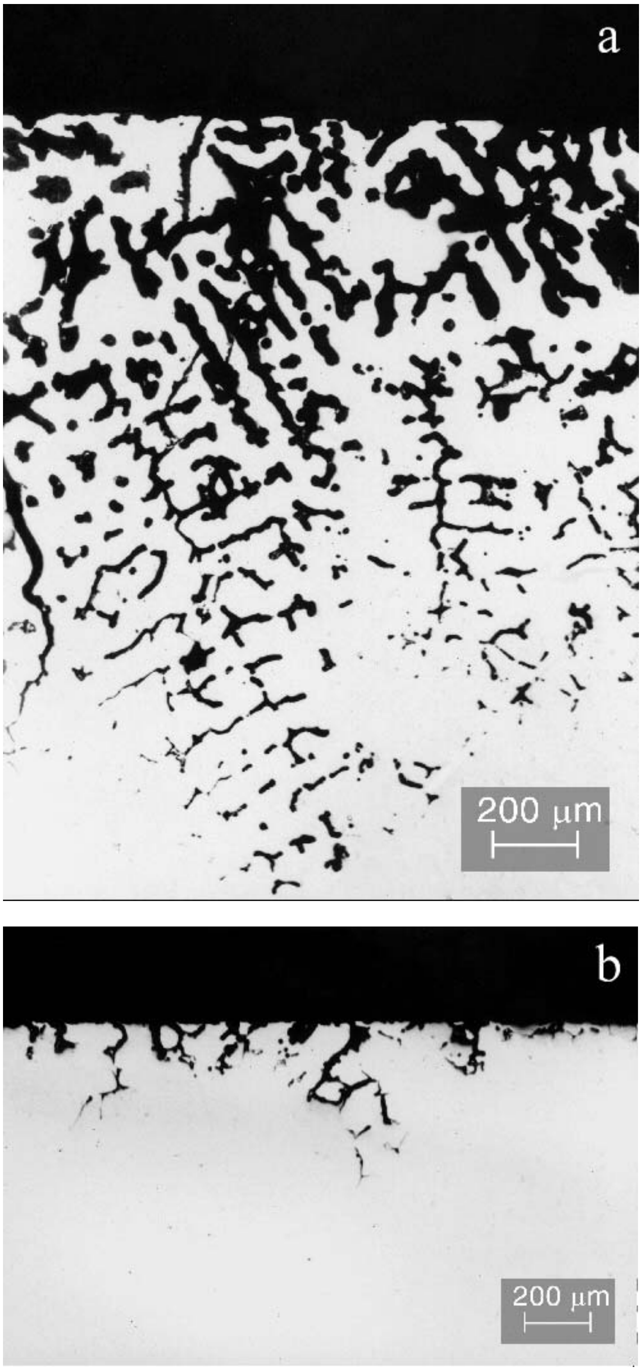

Fig. 7. Expansion of corrosion in Cr – Ni cast steel: a – unmodified, b – modified

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