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MICROSTRUCTURE STRENGTH RELATIONSHIP IN MICROALLOYED CAST STEELS

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Abstract. The staircase test block with 20, 45 and 75 mm wall thickness were performed on low alloyed Mn-Ni cast steels microalloyed by V or V + Nb additions. Precipitations of carbonitrides in these alloys are related to the different cooling rate and segregation during solidification process. The effects of V + Nb nanoparticles and heat treatments increased yield strength up to 850-950 MPa at the elongation above 8-10%. Particle size changes from 10 nm (in thin sections) to 60 nm (in 60-75mm wall thickness) and depends on the cooling rates (0.15–0.9 °C/s) and the process of microalloying.

1. INTRODUCTION

The work presents the results of investigations of structure and mechanical properties of two invented Mn-Ni cast steel. Applying of V, Nb as microalloying components in these steels leads to formation of carbide and carbonitrides particles and consequent increase yield strength, ultimate tensile strength after proper heat treatment of castings [1-3].

The excellent combination of mechanical properties in steel castings with different sections is related to their cooling rate during solidification and heat treatment. Understanding and advancing the physical metallurgy of these cast steels (segregation of elements in matrix and precipitation of carbonitrides) are characterized by particles morphology. The effect of volume fractions and particles size in low carbon steels have been presented by T. Gladman [2,4]. The increase in yield strength shows an agreement with Ashby – Orowan equation, and can be used to produce steels of given properties [4,5].

The results of a previous investigations indicate that in similar grades of cast microalloyed steels (0.2%C-2%Mn-1.3%Si) [6], the yield strength increased to 620-700 MPa by introduction of V or V+Nb additions. A strengthening phenomenon values in the keel shaped blocks occurred by fine precipitation in the ferrite matrix, and by fine interlamellar spacing of the pearlite.

Experimental works with the cast C-Mn-Cr microalloyed steels [7] reported the improved yield strength and ultimate tensile strength after microalloying by 0.035%Nb + 0.11%V + 0.01%Ti. The highest mechanical properties obtained after quenching and tempering at 500 °C due to the grain refinement and precipitation hardening effects.

Although cast microalloyed steel indicate a good strength – ductile relationship, there is a need to study the characteristics of this group of steel, according to their mode of solidification and variations in the solubility of the basic elements. All these processes modify the size and distribution of precipitates which, response on the strengthening of the alloy.

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Table 1. Chemical compositions of cast steel (wt.%).

No	C	Mn	Si	Cr	Ni	Mo	V	Nb	Al	N
A	0.21	1.13	0.39	0.11	0.91	0.18	0.09	–	0.035	0.0148
B	0.20	1.24	0.52	0.41	0.76	0.29	0.09	0.035	0.007	0.0150

2. EXPERIMENTAL MATERIALS AND PROCEDURE

The study was carried out on two cast steels with chemical composition given in Table 1. This work aimed to investigating microstructural and mechanical strengths changes that take place in Mn-Ni cast steels with additions of V/V+Nb. The steel was melted in electric arc furnace with 6 t capacity. The molten steel was deoxidized in the ladle by Al (0.8 kg/t) and Fe-CaSi (1.5 kg/t) additions. Modification was carried out in the ladle by addition of Fe-V or/ and FeNb after deoxidation of the steel.

The materials were obtained as a stepped ingot (Fig. 1a; 1,2,3 – thermocouple) with three sections (20, 45 and 75 mm). In the middle of each step controlled the cooling rate during solidification (Fig. 1b;). Typical microstructure in the as-cast conditions is shown in Fig. 1c.

The separated steps were hardened by water quenching from 920 °C (Fig. 2) and tempering 580 °C for 1-3 (75 mm sections) hrs.

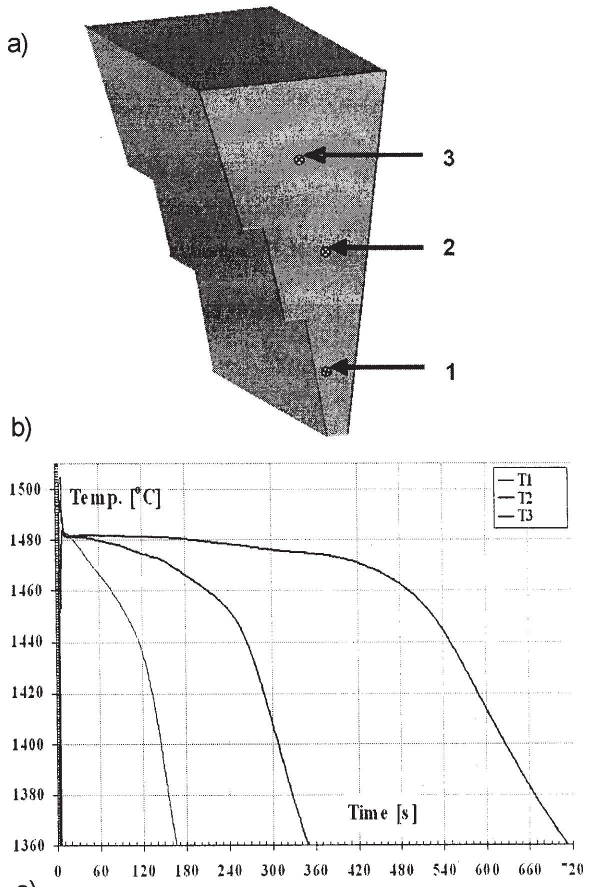
Tensile samples were prepared from selected heat – treated cast steels and tested in a universal tension test machine (ZWICK Z250). The Vickers scale were used for microhardness measurements (500 g load). The fracture surfaces were examined by SEM for observation of the morphology of particles.

Carbon extraction replicas were prepared metallographically for observation and identification of particles. The replicas were placed on copper grids before examination in the TEM with EDX LINX analyzer.

3. RESULTS AND DISCUSSION

Vanadium additions in as cast conditions slightly affect the grain size of ferrite. Fig.1c shows this behavior with the refinement of ferrite grain size with decreasing of wall thickness. The volume ferrite grain size in 20 mm section is 12.7-14.8% and 18-20.% in 75 mm section.

The mechanical properties of the as quenched and tempered cast steels are reported in Table 2. A



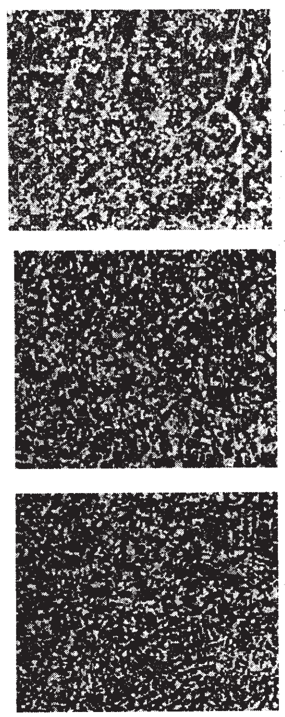


Fig. 1. The shape of cast ingot (a), the cooling curves (b) and microstructures of the cast steel (grade A) in each step; Magn. 100x, (c).

Table 2. The average mechanical properties of cast steel – grade A.

Treatment	wall thickness	$R_{0.2}$ [MPa]	R_m [MPa]	A_5 [%]	Z [%]	$R_{0.2}/R_m$
Normalization: 920 °C	20	487.0	807,0	14,1	25,5	0,60
	45	489.0	805,0	13,4	20,6	0,61
	75	470.2	757,8	9,4	19,5	0,62
920 °C cooling in air from 920 °C to 720 °C; from 720 °C cooling in water	20	1098.3	1480.9	4.3		0.74
	45	966.2	1216.1	11.8		0.79
	75	963.8	1105.2	4.4		0.87
Quenching: 920 °C Tempering: 580 °C	20	958,0	1026,0	9,6	14,6	0,93
	45	916,0	1025,0	10,2	24,5	0,89
	75	867,5	992,8	11,7	30,4	0,87
Homogenization: 1100 °C Quenching: 920 °C Tempering: 580 °C	20	984.0	1034.5	3.7	12.1	0.95
	45	955.3	1047.3	7.7	23.7	0.91
	75	850.2	984.4	12.3	37.1	0.86

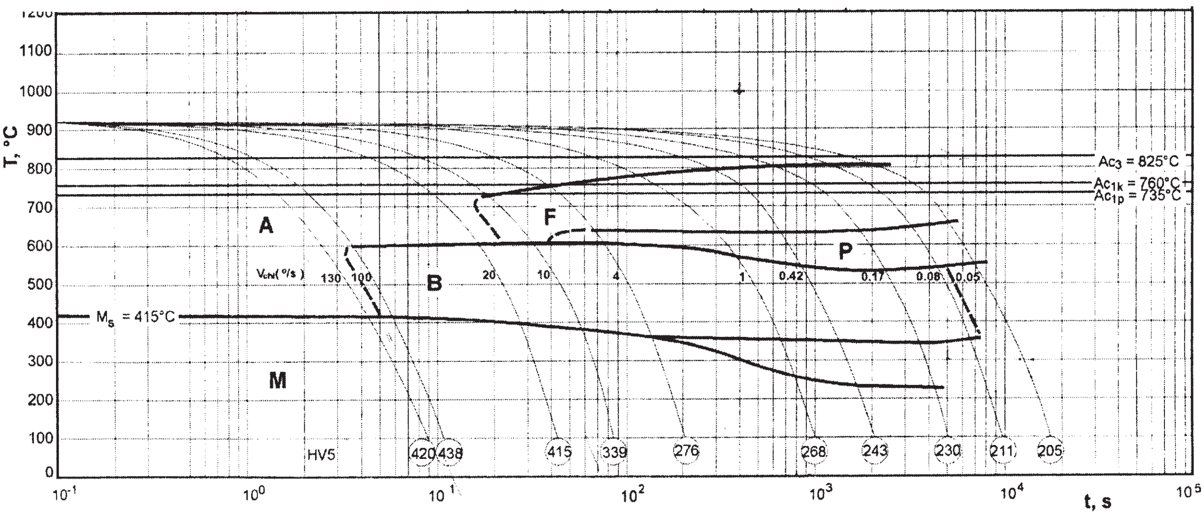


Fig.2. CCT diagrams for the cast steel Mn-Ni with V (grade A), made by means of the dilatometric method for T_A = 920 °C [6].

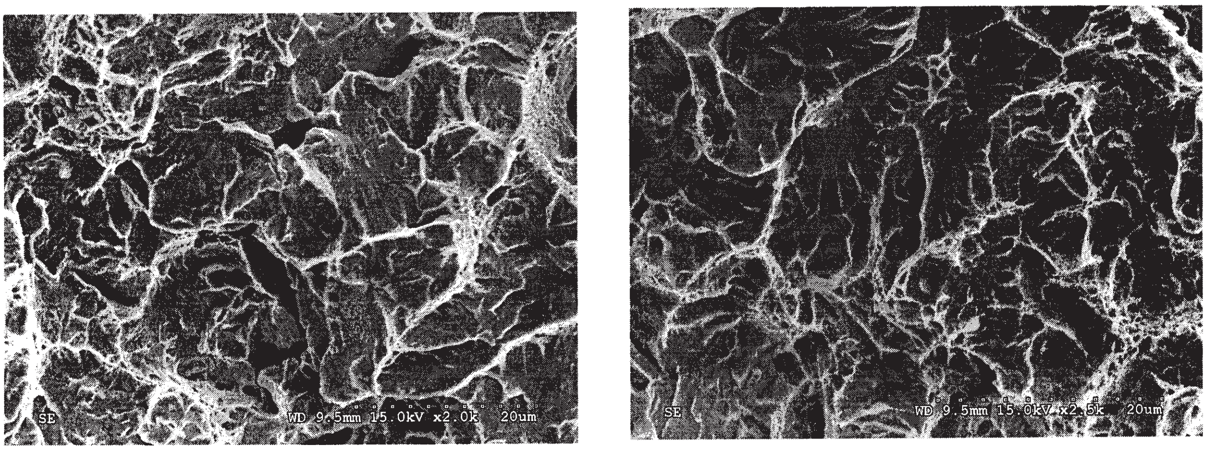
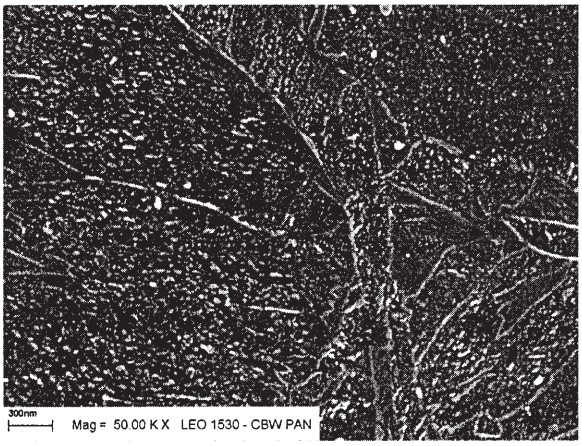


Fig.3. SEM fractograph of A – grade; normalized at 920 °C; sample with A_5=9.4% (a) and A_5=14% (b).



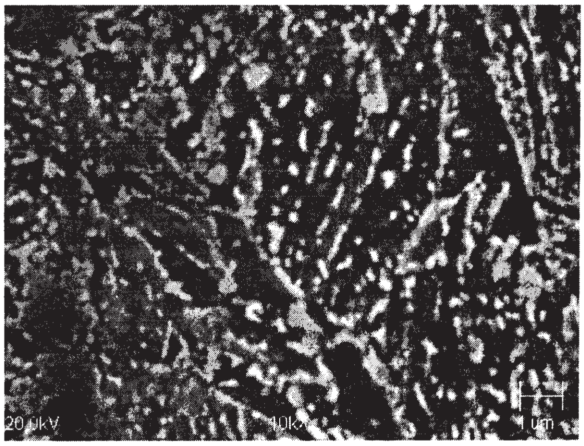


Fig. 4. SEM photograph of A grade (a) and B grade (b); after heat treatment: 920 °C cooling in air from 920 °C to 720 °C; from 720 °C cooling in water.

low carbon content (approx. 0.2 %) permitted realization of high yield strength (above 850-900 MPa) coupled with adequate ductility. The results given in Table 2 suggest that yield strength decreases with higher sections of the test probe. However, at 867 MPa of yield strength in 75 mm wall thickness obtained 11-12% of elongation. In normalized samples the same parameters are 470 MPa and 9.4%. The lower ductility may be attributed to the shrinkage pores found in thick wall thickness (Fig. 3). The improvement in strength was achieved by introduction of 0.09%V to realize the precipitation strengthening by carbonitrides of vanadium (Fig. 4a) or V+Nb(C,N) precipitates (Fig. 4b). The particles were extremely fine (10-30 nm) and hence it was not possible to avoid emission from the ferrous matrix during EDX analysis. This is reflected in the Fe content in the spectrum of precipitates in Fig. 5; (EDX analysis will be conducted on extraction replicas).

4. CONCLUSIONS

- The obtained results indicate possibility of significant strengthening of Mn-Ni cast steel through dispersive precipitation of carbide and carbonitrides particles;
- These steels containing small additions of V and V+Nb and N are susceptible to dispersion strengthening after which their yield strengths increase above 850 MPa and ultimate tensile strength 1000 Mpa;
- Mixed compounds of V+Nb(C,N) form inside the ferritic grains;
- The $R_{0.2}/R_m$ ratio in the cast steel is usually very high (>0.74);
- The benefit of microalloying by V or V+Nb obtained mainly after quenching and tempering at 580 °C.

ACKNOWLEGDEMENT

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