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The Effects of Heat Treatment on the Microstructure and Mechanical Properties of Nb–V Microalloyed Powder Metallurgy Steels

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In this study, the effects of heat treatment on the microstructures and mechanical properties of powder metallurgy (PM) Nb-V microalloyed steels (Fe + 0.25%C + 0.075%Nb + 0.075%V) were investigated. Argon gas was used as sintering atmosphere. The microstructure and mechanical properties of the Nb-V added PM microalloyed steel were examined by optical microscopy, scanning electron microscope (SEM) and tensile tests. Experimental results showed that microalloyed steels can be produced by PM technology and the heat treatment affects the microstructure and mechanical properties of microalloyed PM steel. Nb–V microalloyed steels were heat treated under different conditions. Microstructures and tensile strengths of the samples were compared.

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1. Introduction

Heat treatment is a process that is applied with the effect of heat to change the inner structures and properties of the products made of metals and alloys as desired [1]. In other words, heating and cooling the material in the proper sequence and time under the solidification temperature in order to obtain a certain state in terms of internal structure and properties is called heat treatment [2]. During the heating and cooling periods, the internal structure of the material changes and this change causes the transformations in mechanical, physical and chemical properties [1].

Powder metallurgy (PM) is the process of converting powders into useful engineering materials. PM processes consist of the synthesis of many techniques such as powder metals, ceramics, particle reinforced composites, plastic moulding and metal forging [3]. Microalloyed steels are widely used from automotive industry to construction due to their high strength, toughness and better weldability [4]. Microalloyed steels are known to gain better properties by heat treatment and controlled milling [5]. Even though MA steels are produced with controlled cooling and controlled rolling techniques, recently there has been an increase in powder metallurgy production. Erden et al. [6] have conducted many studies involving the production of microalloyed steels by powder metallurgy. Although the productions have been carried out with PM, the values of tensile strength of the produced PM steels are lower than that of rolled products.

In this study, it is aimed to improve the tensile strength of Nb–V microalloyed steel produced by PM with different heat treatment methods.

2. Experimental procedure

In this study, iron, graphite, niobium and vanadium powders obtained from Sigma Aldrich were used. The sizes of iron, graphite, niobium and vanadium powders are approximately < 20, ≤ 180, < 45, and < 44 μm, respectively, and their purity values are approximately 96.5%, 99.9%, 99.8% and 99.5%, respectively. The powders were weighed on a scale with a sensitivity of 0.0001 g at the chemical composition ratios (0.25 wt% C – 0.075 wt% Nb – 0.075 wt% V, rest Fe) and Nb–V microalloyed steel was produced by the PM method. The prepared samples were sintered at 1350 °C for 1 h in an argon gas atmosphere and then cooled in the furnace.

TABLE I

Heat treatment cycles of the investigated steels.

Label	Heat treatment parameters			
	T_1 [°C]	t_1 [min]	T_2 [°C]	t_2 [min]
A (original)	–	–	–	–
B	750	5	–	–
C	800	20	400	120
D	800	30	–	–

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Some of the samples except to those of the original samples (A) were cooled in water after annealing at 750 °C for 5 min. (B, 750 °C/5′, H_2O). One part of the water cooled samples was kept at 400 °C for 120 minutes (C, 800 °C/5′, 400 °C/120′, 25 °C). The other samples were cooled in water after annealing at 800 °C for 30 minutes (D, 800 °C/30′, H_2O). The heat treatment routes are given in Table I which were first determined by means of literature [7].

3. Results and discussion

For Nb–V microalloyed steel four different multiphase microstructures labelled A to D were produced. Here, one ferritic/perlitic (A), two dual phase ferritic/martensite, (B, D) and one ferritic/perlitic/bainitic (C) microstructure were developed. The ferritic/martensitic microstructures were a typical as they contained a high amount of martensite and a large martensite island size. This was done on purpose with regard to the fracture investigations. The tensile test results are given in Table II. When the tensile strengths of the samples subjected to different heat treatment are compared, it is seen that the untreated sample has low flow and tensile strength and high percentage elongation. This can be attributed to the formation of the microstructure by the ferrite and perlite phases. When the samples subjected to heat treatment of B and D are compared with each other, the microstructure of both samples has a ferrite and martanite phase. The reason why the sample that was applied D heat treatment shows higher yield, tensile and elongation rates is that in addition to having a smaller grain structure, it also contains higher martensite phase compared to B heat treated samples as well as the dispersion of martensite phase between the fine ferrite grains. When the phase ratios are calculated according to the lever rule [2], the martensite ratio of the B heat treated samples is 34% while the martensite ratio of the D heat treated sample is 64%. Literature studies have shown that increasing the volume fraction of the martensitic phase leads to an increase in the strength values as well [8].

As shown in Fig. 1 and Table III, the strength of the material was increased by the precipitation hardening mechanism due to the presence of NbC (N) and VC (N) precipitates detected at the point EDS analysis. This shows that in addition to the heat treatment, precipitation hardening mechanism is also effective.

TABLE II

Tensile test results of pre- and post-heat treatment of 0.15 (NbV) microalloyed steel.

0.25C + 0.15(NbV) + Fe [wt%]	Yield strength [MPa]	Tensile strength [MPa]	Elongation [%]
A (pre-heat treatment)	240	430	14
B (post-heat treatment)	420	715	7
C (post-heat treatment)	515	690	16
D (post-heat treatment)	588	858	7

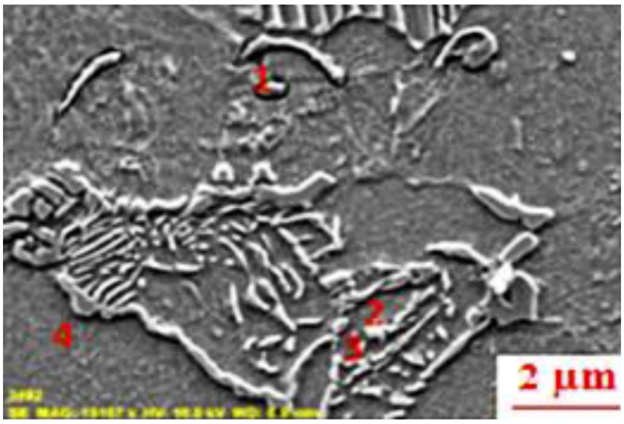

Fig. 1. Measuring points and SEM micrographs.

TABLE III

EDS point scan results of C heat treated sample (composition [wt%]).

Spectrum	C	N	V	Fe	Nb
1	1.77	0.00	0.00	97.97	0.25
2	8.18	0.00	1.05	90.77	0.00
3	6.08	0.25	0.19	93.40	0.09
4	2.10	0.80	0.00	97.10	0.00
mean value	4.53	0.26	0.31	94.81	0.09
sigma	3.12	0.38	0.50	3.35	0.12
sigma mean	1.56	0.19	0.25	1.67	0.06

4. Conclusion

Nb–V Micro-alloyed PM steels were subjected to three different heat treatments. Heat treatments have generally increased the mechanical features of the material. The effects of the applied heat treatment are summarized below.

The strength of samples without any heat treatment was found to be the lowest. The microstructure of the samples subjected to B and D heat treatment are consisted of ferrite and martensite phases at different volume fractions. D heat treated samples showed the highest yield and tensile strengths but lower elongation in comparison with the other heat treated samples. The yield strength, tensile strength, and elongation values of the C heat treated sample increased significantly compared to the non heat treated conditions.

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