The Effect of Cr and Mo Additions on the Improvement in Microstructural Homogeneity and Mechanical Properties of Ni-containing P/M Steels

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Abstract

The microstructures of Ni-containing P/M steels produced by admixed powders or diffusion alloyed powders are usually heterogeneous. To improve the microstructure homogeneity, the effects of Mo and Cr additions in the prealloyed powder form were examined. The results showed that the microstructural homogeneity was improved and superior mechanical properties were achieved with increases in the alloy content, particularly for the Cr. Such a beneficial effect was attained due to the reduction of the repelling effect between Ni and C, as was demonstrated through thermodynamic analysis using the Thermo-Calc software.

Keywords : sintering, homogenization, sinter-hardening, chromium

1. Introduction

The as-sintered microstructures of Ni-containing P/M steel compacts are usually non-homogeneous and contain many soft Ni-rich ferrites and austenites. These soft phases are located near sintered necks and are susceptible to crack initiation during mechanical testing. Thus, the resultant mechanical properties are unsatisfactory. [1-2] The heterogeneous microstructures are mainly caused by the slow diffusion rate of Ni into Fe. In addition, Wu et al. indicated recently that the presence of carbon in the iron further impeded the diffusion of Ni into the matrix. This was because the chemical potential of C increased when Ni was present.[1] Wu et al. also demonstrated that these heterogeneous microstructures could be improved by adding Cr in the form of 316L stainless steels This was because the addition of Cr alleviated the repulsion between Ni and C, and thus homogeneous microstructures and improved mechanical properties were attained. Since Mo is also extensively employed in P/M steels and is a carbide former, it could provide benefits similar to those of Cr. The objective of this study was thus to identify the role of Mo and Cr on improving the microstructural homogeneity and mechanical properties of Ni-containing steels.

2. Experimental and Results

Table 1 shows the characteristics of the base powders used in this study. The base powders were mixed with 0.7wt% graphite powder and 0.75wt% ethylene bis-stearamide, which is a lubricant, in a V-cone mixer for 30 minutes. The admixed powder was compacted into tensile bars as per MPIF standard No. 10 at a pressure of approximately 500 MPa. The green densities of the tensile bars were maintained at 6.85g/cm^3. The debinding was carried out at 550℃ for 15 minutes to remove the lubricant. After debinding, the specimens were sintered at 1120℃ for 30 minutes or at 1250℃ for 1 hour in a tube furnace, followed by furnace cooling. Both debinding and sintering were performed in an atmosphere of 91%N_2-9%H_2. The dew point of the atmosphere was below -45℃. The average cooling rate of the furnace was about 0.1℃/s in the temperature range of 900℃ to 300℃.

The densities of the sintered specimens were measured using the Archimedes method. Tensile tests were performed using a strain rate of 0.0224/min. The data reported are averages of 8 specimens. For microstructure observations, sintered tensile bars were ground, polished, and etched with a mixed solution of 2% Nital and 4% Picral. The microstructure was examined under an optical microscope.

In order to verify the role of Mo and Cr on improving the homogenization of alloying and microstructures, the Thermo-Calc program and a TCFE3 database were used to calculate the chemical potential of carbon in the steel compacts that were sintered at 1120℃. The results were used to explain the difference in microstructure and Ni distribution in sintered compacts with and without Cr and Mo additions.

The mechanical properties of the sintered prealloy steel compacts are shown in Table 2. As expected, the mechanical properties increased as the sintering temperature increased because

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Table 1. The characteristics of the base powders used in this study.

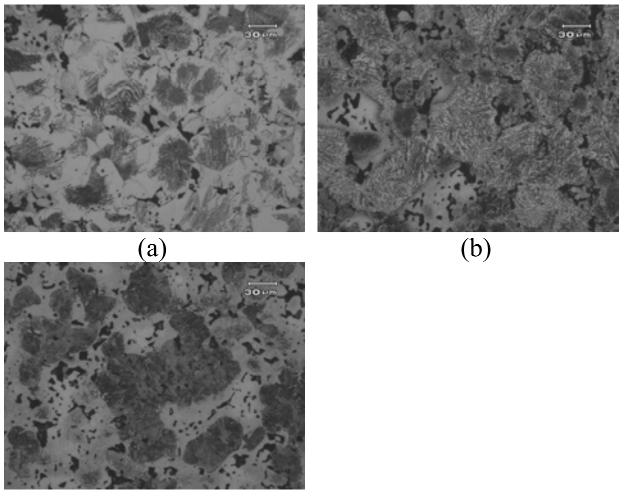
Type	Fe	Fe-1.5Cr-0.2Mo	Fe-1.5Mo	Fe-0.5Mo
Designation	ASC 100.29	CrL	ATOMET 4901	ATOMET 4901
Cr, wt%	-	1.50	-	-
Mo, wt%	-	0.20	1.470	0.497
Mn, wt%	-	-	0.131	0.131
C, wt%	0.002	0.002	0.003	0.004
O, wt%	0.08	0.16	0.080	0.080
Supplier	Höganäs	Höganäs	QMP	QMP

Table 2. The mechanical properties of the sintered steel compacts investigated in this study.

Composition	Temp. (℃)	Density (g/cm^3)	UTS (MPa)	HRC or HRB
Fe-4Ni-0.6C	1120	7.12	400	64.7
Fe-4Ni-0.6C	1250	7.24	485	71.3
Fe-0.5Mo-4Ni-0.6C	1120	6.96	572	81.2
Fe-0.5Mo-4Ni-0.6C	1250	7.09	624	82.2
Fe-1.5Mo-4Ni-0.6C	1120	7.02	668	88.2
Fe-1.5Mo-4Ni-0.6C	1250	7.14	813	92.2
Fe-1.5Cr-0.2Mo-4Ni-0.6C	1120	7.10	851	95.1
Fe-1.5Cr-0.2Mo-4Ni-0.6C	1250	7.29	1178	30.8

high temperature sintering resulted in higher density, rounder pores, and slightly more homogeneous microstructures.

Fig. 1 shows the microstructures of Fe-4Ni-0.6C, Fe-1.5Mo-4Ni-0.6C, and Fe-1.5Cr-0.2Mo-4Ni-0.6C. There were large amounts of Ni-rich areas in the Fe-4Ni-0.6C compacts. In contrast, the microstructures of the Fe-1.5Mo-4Ni-0.6C and Fe-1.5Cr-0.2Mo-4Ni-0.6C compacts were more homogeneous, particularly in the Fe-1.5Cr-0.2Mo-4Ni-0.6C compact. A trace of Ni-rich ferrite was still present in the Fe-1.5Mo-4Ni-0.6C compact. However, there was no Ni-rich ferrite in the Fe-1.5Cr-0.2Mo-4Ni-0.6C compact. This could be explained through thermodynamic analysis using the Thermo-Calc software. As shown in Table 3, the calculation shows that the addition of Mo and Cr decreased the chemical potential of C in the compacts that were sintered at 1120℃, particularly when Cr was added. Therefore, more homogeneous microstructures and better mechanical properties were attained. These results are consistent with those obtained in previous studies. [1]



(a) (b) (c)

Fig. 1. The microstructures of (a) Fe-4Ni-0.6C, (b) Fe-1.5Mo-4Ni-0.6C, and (c) Fe-1.5Cr-0.2Mo-4Ni-0.6C compacts that were sintered at 1120℃.

Table 3. The chemical potentials of carbon in the Ni-containing steels with and without Cr and Mo additions.

	Fe-4Ni-0.6C	Fe-1.5Mo-4Ni-0.6C	Fe-1.5Cr-0.2Mo-4N-0.6C
Chem. Pot. (KJ/mole)	-42.5	-43.2	-44.2

3. Summary

The microstructures of Ni-containing P/M steel compacts are usually heterogeneous. It has been shown that such heterogeneous microstructures can be improved with the addition of 0.5wt%Cr. This study further shows that the addition of 1.5%Cr and 0.2%Mo can improve the microstructure and mechanical properties of Ni-containing P/M steel compacts. The addition of 1.5wt%Mo can also provide similar effect but with less significance. These improvements are attributed to the reduction of the repelling effect between Ni and C, as was demonstrated through thermodynamic analysis using the Thermo-Calc software.

4. References

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