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Journal of Materials Processing Technology 182 (2007) 462–468

Journal of Materials Processing Technology

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Influence of chromium on microstructure and sintering properties of FeNiMoCu system prealloyed powders

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Received 10 March 2006; received in revised form 6 August 2006; accepted 10 September 2006

Abstract

The chromium was added to the FeNiMoCu system prealloyed powders by using Cr–Fe powders way, powder mixtures were uniaxially pressed at 600 MPa, and then cold pressing sintering, sintering hot-forging, and re-sintering process were respectively carried out. Influence of chromium addition on the microstructure and properties of the FeNiMoCu system prealloyed powders were studied. Results show that chromium can be homogenous diffused into structure, and improved properties of structure by the appropriate sintering process. Oxidation of chromium can be restrained. Microhardness and apparent hardness increase with increasing chromium addition, sintering density and temperature. After hot-forging re-sintering, microstructure and properties of FeCrNiMoCu system PM materials is the better.

Keywords: Prealloyed powders; Cr–Fe powders; Sintering; Microstructure; Hardness

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1. Introduction

Nowadays powder metallurgy (PM) technology develops to multi-alloying and full density sintering. Especially, for powder sintered structural steels, good structure and high density is foundation obtaining high performance. Traditional powder metallurgy steels are made from mixtures powders. However, the structures often are inhomogeneous after sintering, and alloying elements in mixture powders are very limited [1], e.g. Cr, V, Mn, etc. alloying elements are mechanical properties-enhancing element in cast and wrought steels and have a low cost. Because oxidation reaction very easily carried out during sintering, these alloying elements cannot be used in normal mixture powders. A prealloyed powder containing Mo, Ni, Cu (i.e. Distaloy powder) was excogitated by Swedish a company. After sintering, homogeneous structure can be attained [2–4]. However, to manufacture sintered structural steel with Distaloy powders required carbonizing quenching or other treatment way later. Chromium is a hardenability-enhancing element. It has been reported that Cr, Mn, V were introduce into PM materials by using MCM and MVM way, and good effects were obtained [5]. But it was less reported that sintered structural steel was manufactured by prealloyed FeNiMoCu powders with Cr–Fe powder addition. There are three advantages by the Cr–Fe powder: oxidation of Cr element can be restrained, and Cr improves hardenability and mechanical properties, it has a low cost.

In the present work, sintering properties and microstructure of FeNiMoCu system prealloyed powders with Cr addition are investigated using several different sintering approaches. Furthermore pores shape, pores distributing, and diffusion of alloying element is analyzed.

2. Experimental procedure

The compositions of powder mixtures were listed on Table 1. Cr–Fe powder (particle size <70 μm), 0.3 wt.% graphite, and 0.8 wt.% zinc stearate as lubricant were added to Fe–2.0Ni–0.85Mo–1.7Cu and Fe–3.0Ni–0.85Mo–1.7Cu prealloyed powder (particle size 75–150 μm).

All the samples were uniaxially pressed at 600 MPa and the sintering process was performed in an industrial furnace under dissociated ammonia at 1423 K for 60 min. And then a part of specimens cooled with decreasing furnace temperature (i.e. cold pressing sintering process), other one was hot-forged and then oil cooling (i.e. sintering hot-forging process).

To study pore shape, pore distributing, and alloying elements diffusion, after cold pressing sintering and sintering hot-forging, some sintered specimens were re-heated to 1523 K or 1573 K and followed oil cooling (i.e. re-sintering process). The green compacts density and sintered density of the samples were measured by water displacement method. In order to avoid liquid passing into

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0924-0136/$ – see front matter © 2006 Published by Elsevier B.V.
doi:10.1016/j.jmatprotec.2006.09.006

Table 1
The composition of mixture powders

Prealloyed powders	Chromium (wt.%)	Graphite (wt.%)	Sample number
Fe–2.0Ni–0.85Mo–1.7Cu	–	0.3	1
	1.5	0.3	2
Fe–3.0Ni–0.85Mo–1.7Cu	–	0.3	3
	4.0	0.3	4

pores of the samples, a thin layer of paraffin was coated on the sample surfaces. The microstructure, pores, and alloying elements diffusion were analyzed by optical and scanning electron microscopy (SEM). The apparent hardness and microhardness were respectively tested with HRB and $HV_{0.2}$. The testing results are given in Table 2.

3. Results

3.1. Pore morphology and sintered density

Fig. 1 shows pore morphologies of both powder mixtures after cold pressing sintering at 1423 K, and re-sintering at 1523 K, 1573 K. It can be seen that the pores exist in the sintered specimens and porosity increased with increasing chromium addition. After cold pressing sintering at 1423 K, an average density value of 6.8 g/cm^3 was achieved for 1.5% Cr specimens (relative density value is 0.87), and one of 6.7 g/cm^3 was achieved for 4.0% Cr specimens (relative density values is 0.86). A similar trend appears in the sintered hot-forging specimens (see Table 2). Sintered densities have close relation to green porosity. During sintering, the diffusion distance of alloying elements increase with green density decreasing. Yoyoui [2] found that sintering shrink densification extent was in inverse proportion to diffusion distance of alloying elements. Test results show that the green density and sintered density of 1.5% Cr material are more than that of 4.0% Cr material by the measure (see Table 2).

In addition, Fig. 1 shows that pore shape and distribution have greater changed with increasing re-sintering temperature. In generally, PM materials have two type pores, i.e. packing pores and interface pores and that pore shape are irregular [5] (see Fig. 1a and d). After sintering at 1423 K, packing pores and interface pores existed in the samples of 1.5% Cr and 4.0% Cr. Especially, there are an amount of packing pores in the 4.0% Cr sample. However, after re-sintering at 1573 K, most of interface pores and small packing pores have disappeared, a few packing pores were retained (see Fig. 1f). Retained packing pores near spherical shape and the diameter of pores are more than original size. This is the result of pores growth and combination during sintering at higher temperature. Pores diffused driving force come from surface free energy, and the smaller pores have the larger surface energy. Therefore, it first can diffuse to grain interface and follows disappearing during sintering. Similar results were found in Campos et al. investigation report [6]. This viewpoint that temperature on pore changing and densification has greater influence has been generally recognized [7]. In microstructure analysis this problem will be continued discussed.

Fig. 2 shows pore morphologies of both powder mixtures after sintering hot-forging at 1423 K, and re-sintering at 1523 K, 1573 K. Comparing with cold pressing sintering specimens, pores decreased obviously after hot-forging. The as-sintered density of specimens are given in Table 2.The results show that the sintered density up to 7.6 g/cm^3 (relative density of 0.97) from average value of 6.7 g/cm^3 (relative density of 0.85) for 4.0% Cr material, and for 1.5% Cr material sintered density up to 7.7 g/cm^3 (relative density of 0.987) from 6.8 g/cm^3 (a relative density of 0.87). Sintering hot-forging pro-

Table 2
Density and hardness of two materials by the different sintering process

Sintering process	Sample number	Green density, ρ (g cm^{-3})	Sintering temperature, T (K)	Sintered density, ρ (g cm^{-3})	Relative density (%)	Microhardness ($HV_{0.2}$)	Apparent hardness (HRB)
Cold pressing	1	6.58	1423	6.82	87.4	258	88
	2	6.57	1423	6.8	87	283	88
			1523	7.0	90.0	297	98
			1573	7.25	92.9	309	100
	3	6.58	1423	6.82	87.4	260	88
	4	6.5	1423	6.7	86	284	87
			1523	6.9	88.5	304	93
			1573	7.1	91	315	102
Hot-forging	1	6.5	1423	7.4	94.8	258	94
	2	6.57	1423	7.7	98.7	298	103
			1523	7.71	98.8	302	104
			1573	7.71	98.8	325	105
	3	6.5	1423	7.4	94.8	262	95
	4	6.5	1423	7.6	97.4	299	102
			1523	7.63	97.8	308	103
			1573	7.63	97.8	337	105