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2:17-type SmCo magnets prepared by powder injection molding using a water-based binder

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Abstract

2:17-type SmCo permanent magnets by powder injection molding using a water-based binder have been studied. The water-based binder is methylcellulose solution, which consists of deionized water and methylcellulose. When the solution concentration is 0.5 wt%, the carbon content of the sintered magnets is below 0.1 wt% and the magnets have better magnetic properties. The magnetic properties and density of the sintered magnets can be increased through pre-sintering in vacuum (10^{-3} Pa) at 1200 °C. However, the Sm content of the magnets loses obviously in pre-sintering for a long period. The appropriate pre-sintering duration is 20–40 min. The magnetic properties of the magnets are: Br = 0.97 T, H_{cj} = 871 kA/m, BH_{max} = 157 kJ/m^3. The structure of the magnet consists of the matrix phases (2:17 phases) and the precipitate phases (1:5 phases).

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Keywords: 2:17-type SmCo magnet; Powder injection molding; Methylcellulose; Magnetic property

1. Introduction

2:17-type SmCo permanent magnets have excellent intrinsic magnetic properties such as very high Curie temperature, high anisotropy fields and relatively high saturation magnetizations [1,2]. However, the magnets are difficult to form complex, small, precise parts by conventional manufacture process because of their high brittlement. The making cost is very high. These problems can be avoided when the magnets are prepared by powder injection molding (PIM). The PIM process is a newly developed technology, which derives from the traditional shape-making capability of plastic injection molding and the materials flexibility of powder metallurgy [3,4]. Recently, the PIM process has been applied in the fabrication of magnetic materials, such as bond rare-earth permanent magnets, bond ferrites and sintered ferrites [5–8]. But this process is difficult to prepare sintered rare-earth permanent magnets because the magnetic powder is easy to react with oxygen and carbon. There are few investigations on sintered Sm–Co magnets by PIM at present.

In the PIM process, the binder system is a temporary vehicle for homogeneously packing the powder into the desired shape and then holding the particles in that shape until the beginning of sintering. Generally, wax–polyolefin binder systems are used widely in practice, because these binders have quite good rheology and green strength. The binder must be removed by thermal debinding process. Therefore, the magnetic powder is easy to react with oxygen and carbon when rare-earth magnets during debinding. Water-based binder is new binder, which consists of a lot of water and a little organic component. Comparing with wax-based binder, the organic components content of feedstock with water-based binder is very low, which is usually below 1.0 wt%. So there is little residual carbon. Besides, powder and binder can be mixed

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at below room temperature using a water-based binder, which reduces the reaction of powder with oxygen. In 1998, Yamashita [9] adopted methylcellulose solution as binder and prepared sintered Nd–Fe–B magnets using the binder. In this paper, sintered 2:17-type SmCo permanent magnets were prepared by PIM with a water-based binder. The magnetic properties and microstructure of the magnets were also studied.

2. Experimental

Alloys with nominal composition $Sm(Co_{bal}, Fe_{0.17}, Cu_{0.08}, Zr_{0.03})_{7.5}$ were prepared by vacuum induction melting and mold casting. The alloy ingot was milled to powder with an average particle diameter about 4 μm. This process was done in gasoline to prevent oxidation. The binder consists of deionized water and methylcellulose. Various amounts of methylcelluloses were dissolved in deionized water and formed different concentration solutions.

The magnetic powder was surface treated in a stearic acid solution (0.5 wt%) in order to resist oxidation. The treated powder with different concentrations of methylcellulose solutions was mixed in a mixing device at room temperature. The mixture would form compacts at 80–120 °C by reaction of sol–gel. So the mixture was injected into a heat die with 90 °C (shown in Fig. 1). The water of the molded samples was removed in vacuum at room temperature. The methylcellulose was removed in vacuum at about 10^{-3} Pa at 300–400 °C for 1 h. After debinding, the samples were pre-sintered at 1200 °C in vacuum at about 10^{-3} Pa for different periods and sintered at 1200–1220 °C in high-purity argon for 1 h. The sintered samples were solutionized at 1160–1175 °C for 2 h. After the solid solution, the samples were aged at 850 °C for 8 h, followed by a slow cooling to 400 °C at a cooling rate of 0.7 °C/min.

The magnetic properties, namely, remanence Br, intrinsic coercivity H_{cj} and maximum energy product BH_{max}, were measured using a Hysteresisgraph System model NIM-200C. The microstructure was studied using a Rigaku Dmax-RB X-ray diffractometer (XRD) with monochromatic CuKα radiation and a H-800 transmission electron microscope (TEM).

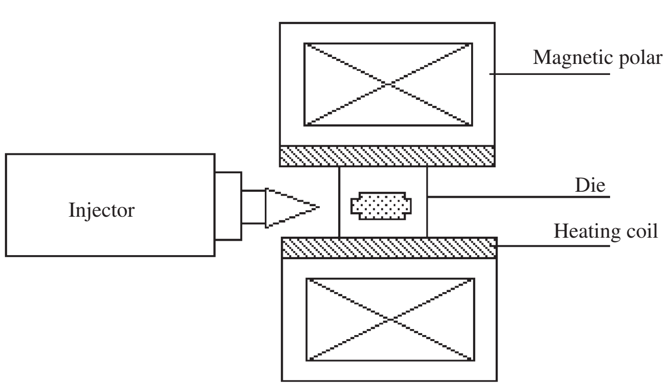

Fig. 1. Sketch of powder injection molding process.

3. Results and discussion

3.1. Binder concentration

The concentration of methylcellulose solution is an important factor that affects directly the PIM process and the magnets' properties. Fig. 2 shows the effect of the solution concentration on the magnetic properties of the magnets. When the concentration is below 0.5 wt%, the magnetic properties (Br, H_{cj} and BH_{max}) increase with increasing concentration. Contrary to that, when the concentration is above 0.5 wt%, the magnetic properties decrease significantly. Therefore, the magnets have better magnetic properties when the concentration is 0.5 wt%: $Br = 0.97\,T$, $H_{cj} = 871\,kA/m$, $BH_{max} = 157\,kJ/m^3$. When the concentration is low (<0.5 wt%), the fluidity of the feedstock is very poor. The friction between the feedstock and the die surface is high so that the injection samples are difficult to remove from mold and have many inner defects. As shown in Fig. 2, the density of the injection sample decreases with increasing concentration when the concentration is below 0.5 wt%. So the magnetic properties of the magnets are poor. However, the carbon content of the magnets increases with the increase of the concentration (see Fig. 3), which results in the deterioration of the magnetic properties. We had researched the effect of carbon on the magnetic properties of 2:17-type SmCo magnets [10]. The results indicated that the magnets had better magnetic properties when the carbon content was not above 0.1 wt%. Only when the concentration is not more than 0.5 wt%, is the carbon content below 0.1 wt% (shown in Fig. 3).

3.2. Pre-sintering

The densities of the injection samples are lesser than those of the compacts by conventional process. The density and magnetic properties of the PIM magnets can be improved

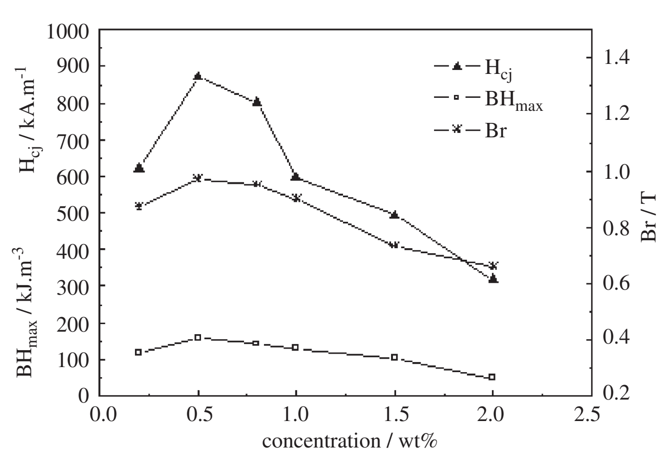

Fig. 2. Effect of the binder concentration on the magnetic properties of the magnets.