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Effects of annealing on high velocity compaction behavior and mechanical properties of iron-base PM alloy

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ABSTRACT

High performance PM iron-base alloy was fabricated with annealed powder by high velocity compaction. The effects of powder annealing on densification behavior, variations of stress waves and the resulting mechanical properties of iron-base alloy were studied. The results show that micro-hardness of the powder decreases from 97 Hv to 81 Hv after annealing at 800 °C, facilitating the improvement of powder plasticity and compressibility. Compared with the compacts prepared from unannealed alloy powder, green density of the compacts made from annealed alloy powder is 0.11–0.25 g/cm^3 higher at the impact velocity range of 6.2–9.4 m/s. Green density of the compact made from annealed alloy powder is as high as 7.61 g/cm^3 at 9.4 m/s. The tensile strength, yield strength and hardness of the heat treated specimen reach 1459 MPa, 1185 MPa and 50.2 HRC, respectively.

1. Introduction

Powder metallurgy (PM) iron-base alloys are widely used in automobiles, machinery, chemicals, electronics and other fields because of their technical and economic advantages [1,2]. With the development of automotive, machinery and the other high-end equipment industries, high-performance iron-base components are increasingly demanded [3,4]. The fabrication technology of PM iron-base parts with high strength, high dimensional accuracy has become the research hotspot and the development trend in PM industry [5–7]. For iron-base PM parts, when the density is over 7.2 g/cm^3, their hardness, tensile strength, fatigue strength, toughness, etc. increase exponentially with density [8]. In addition, higher green density results in less shrinkage and distortion during sintering, which means a better dimensional accuracy [9]. So, increase green density is the key to obtain excellent mechanical properties and perfect dimensional accuracy [10].

High velocity compaction (HVC) is an efficient technology for preparing high density PM components. HVC realizes densification within 20 ms by intensive repeated stress waves created by a hydraulically-operated hammer traveling at speeds of 2–30 m/s [7]. The advantages of HVC technique can be seen from the aspects of high density, uniform density distribution, low springback, low ejection force and high cost performance [11–13]. Improving the compressibility of powder is fundamental for the increase of green density. Annealing reduces the contents of the impurity elements in powder, coarsens powder grains appropriately, and lowers work hardening, etc. As a result, micro-hardness of powder reduces and the compressibility improves [14].

In this work, iron-base alloy PM products with high density and high performance were prepared by the combination of powder annealing and high velocity compaction. Effects of annealing on micro-hardness of powder, high velocity compaction behavior and mechanical properties of iron-base alloys were discussed.

2. Experimental

Water atomized iron powder was used as raw material, as shown in Fig. 1. Firstly, the powder was annealed in hydrogen atmosphere at 800 °C and cooled to room temperature at a cooling rate of 2 °C/min. Secondly, alloying elements were mixed with the annealed iron powder and the unannealed iron powder, respectively. Then the unannealed alloy powder and the annealed alloy powder with chemical compositions of Fe–2.0%Ni–1.0%Cu–0.8%Cr–0.5%C were obtained. The two kinds of powders have almost the same apparent density, and they were compacted on the HYP35-2 High Velocity Compaction Machine (Fig. 2). During HVC, powders were first pre-pressed by the hammer under a low pressure of about 15 kN to expel air. Then the hammer rises quickly, and descends again at the set high velocity to finish the compaction. The die diameter is 25 mm, and the filling height is kept at 15 mm. Five specimens were produced in each group at each impact velocity. Cylinder samples with diameter of 25 mm and height of 6 mm are obtained.

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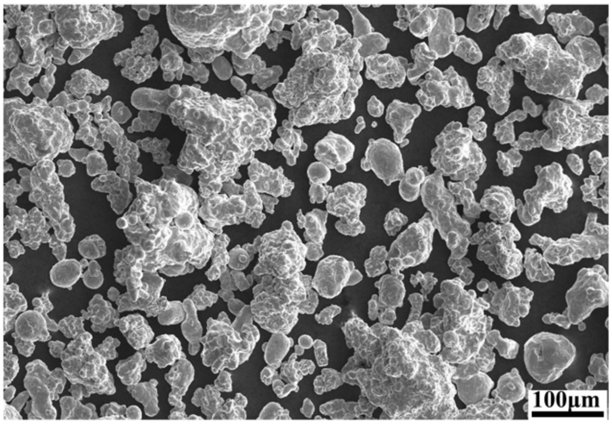

Fig. 1. Morphology of water atomized iron powder.

The compacts were sintered at 1150 °C for 1 h. The sintered samples were austenitized at 850 °C for 2 h, quenched in oil, and then tempered at 180 °C for 2 h.

Densities of samples were measured by Archimedes method. Apparent hardness was determined by TH320 Rockwell hardness tester. Dog-bone tensile specimens with gauge dimensions of 16 mm (length) × 2.5 mm (width) × 2.5 mm (thickness) were tested on Instron5569 mechanical testing machine. Optical microstructure was observed on a MeF3A type metallurgical microscope. Microstructure and fracture appearance were observed on a LEO1450 scanning electron microscope.

3. Results and discussion

3.1. Effect of annealing on the micro-hardness of powder

Fig. 3 shows micro-hardness of the water atomized iron powder annealed at varied temperatures. Micro-hardness of the atomized iron powder is 97 Hv. Micro-hardness of the annealed powder decreases slowly with the increasing annealing temperature. At the annealing temperature of 800 °C, the micro-hardness decreases to 81 Hv. Although micro-hardness of the powder exhibits slightly decrease at 900 °C, a mild sintering phenomenon occurs and the powder is difficult to be broken. Micro-hardness of the powder is influenced by impurity content and lattice defects [15]. After annealing in hydrogen atmosphere, the defect and residual stress of the powder were effectively reduced, oxides in the powder was reduced, and the crystal grains further grew coarse. As a result, powder softens and the micro-hardness reduces [14].

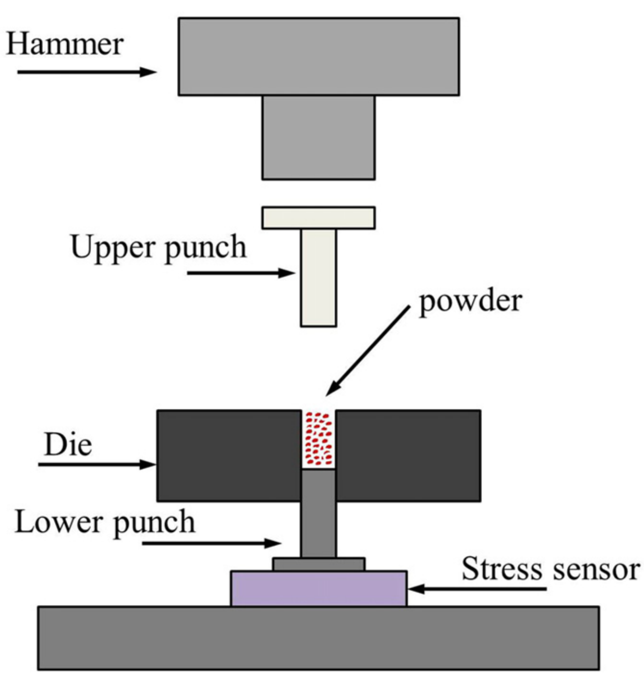

Fig. 2. The schematic diagram of HYP35-2 HVC machine.

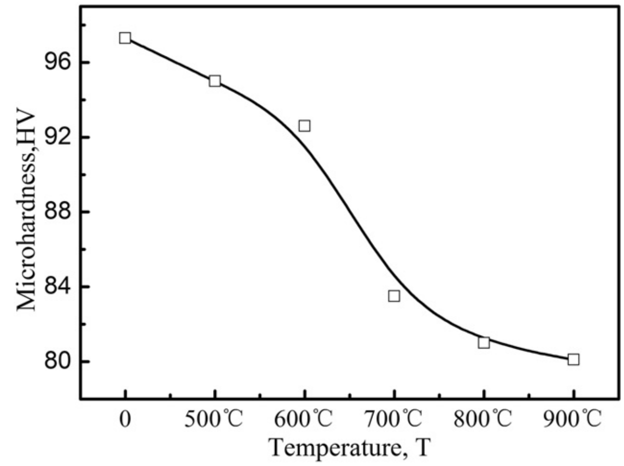

Fig. 3. Micro-hardness of water atomized iron powder annealed at varied temperatures.

3.2. Densification behavior

Fig. 4 displays green densities of the unannealed and annealed samples at different impact velocities. For the unannealed and annealed samples, green density increases with increasing impact velocities. At the impact velocity of 6.2 m/s, green densities of the unannealed and annealed samples are 6.85 g/cm^3 and 7.10 g/cm^3, respectively. At the impact velocity of 9.4 m/s, green densities of the unannealed and annealed samples increase to 7.50 g/cm^3 and 7.61 g/cm^3 (RD = 97.8%), respectively. At the impact velocity range of 6.2–9.4 m/s, green density of the annealed samples is 0.11–0.25 g/cm^3 higher than that of the unannealed samples. The improvement of the green density of the annealed sample is attributed to the reduced micro-hardness and the lowered work hardening of the powder [14].

Fig. 5 presents SEM images of the unannealed and annealed samples compacted at the impact velocity of 9.4 m/s. The unannealed sample exhibits irregular pore morphology, higher porosity content and larger

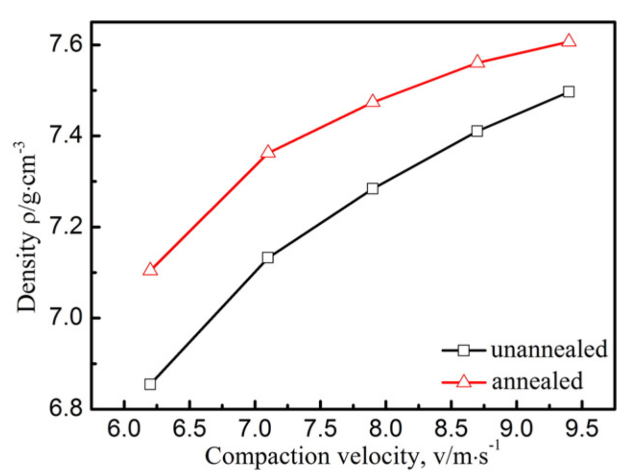

Fig. 4. The influence of impact velocity on green density of the unannealed and annealed samples.