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A comparative investigation on MIM418 superalloy fabricated using gas- and water-atomized powders

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ABSTRACT

Gas atomized (GA) and water atomized (WA) K418 superalloy powders were injection molded, and a detail comparative investigation on microstructure and mechanical properties of MIM418 superalloys was carried out. The GA sample possesses higher sintering density than the WA sample due to its lower oxygen content, narrow pore size distribution and higher packing density. Both superalloys achieve near full dense after HIPing, and increasing HIPing temperature leads to grain growth and leaving carbide particles at the site of the original prior particle boundaries (PPBs) within the new grains. The GA powder leads to finer and more homogeneous γ′ precipitates and carbides, as well as equiaxed grains (31 μm), while the WA powder results in larger γ′ precipitates with higher coarsening rate, higher concentration of PPBs, and smaller grain size (26 μm). The GA sample exhibits satisfactory levels of tensile strength (1425 MPa) and yield strength (1004 MPa) combined with a significantly improved elongation (19.4%), which is suitable for high performance applications. The WA sample has comparable mechanical properties with that of the cast K418 superalloy, which can be used for less critical and low cost demand applications.

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1. Introduction

The K418 superalloy is a precipitation hardened Ni-based superalloy, which has excellent high temperature mechanical properties, good fatigue property, prominent oxidation and corrosion resistance at the temperature below 900 °C [1]. It is commonly used to fabricate turbine wheels in automotive turbocharger [2]. Conventionally, the K418 superalloy components were fabricated by lost wax casting after vacuum induction melting [3,4]. However, casting process cannot bring the mechanical properties of the superalloy into full play because of elemental segregation, shrinkage defects, coarse gain size and undesirable phases [5–7]. The cast superalloy exhibits poor hot workability, which adversely affects the complexity of the superalloy components [8]. These problems have spurred the development of near-net shape forming technique for producing highly alloyed superalloy components. Metal injection molding (MIM) is one of the most important near net shape forming technique, which enables the solution of segregation problems and the fabrication of complicate shaped products with high dimensional accuracy [9–11]. The K418 superalloy prepared by metal injection molding is named as MIM418.

Raw material powder is crucial for the fabrication of MIM418 superalloy. Superalloy powder used in powder metallurgy industry is produced by two common techniques: gas atomization and water atomization. Gas atomization yields spherical particles and high packing density. Water atomization gives irregular particles, which has better shape retention ability and lower cost. Ar gas atomized powder is the most commonly used powder for the fabrication of superalloy components for high temperature and high performance application, and the potential benefits of using gas-atomized powder have been extensively explored [12,13]. However, the widespread use of GA powder is greatly limited by its high cost. As the use of the MIMed superalloy components in automotive and the other industrial fields is growing, there is a need to explore if the less expensive WA powder can be realistically utilized [14]. Up till now, there are no systematic investigations on the microstructure and mechanical properties of the MIM418 superalloys produced from GA and WA powders.

In this work, systematic comparisons on microstructural evolution, characteristics of precipitate phase and mechanical behavior were made between the GA samples and WA samples. This information is beneficial to better understanding and adjusting the microstructure and mechanical properties of MIM418 superalloy.

2. Experimental

The K418 superalloy powder was manufactured by Ar gas atomization or by water atomization. The GA powder was supplied by Beijing

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Table 1
Chemical composition of the GA and WA K418 superalloy powder (wt.%).

Elements	Cr	Al	Ti	Mo	Nb	Ni
Theoretical composition	11.5–13.5	5.5–6.4	0.5–1.0	3.8–4.8	1.8–2.5	Bal.
GA powder	12.62	6.39	0.63	3.83	1.85	Bal.
WA powder	13.15	6.05	0.71	3.95	1.81	Bal.

Institute of Aeronautical Materials. The chemical compositions of the GA and WA powders are given in Table 1. The two kinds of powders have similar chemical compositions close to that of the designed K418 superalloy. Fig. 1 presents the morphology and size distribution of the GA and WA powders, and the powder characteristics are listed in Table 2. The GA powders are spherical, while the WA powders are rounded and irregular in shape. Compared with the WA powder, the GA powder has larger mean particle size, lower specific area and higher packing density, which is in favor of the increase of powder loading. The WA powder shows smaller particle size, better shape retention ability during debinding and sintering [15,16]. The noticeable difference in impurity contents is the higher carbon and oxygen contents of the WA powder than that of the GA powder. The oxygen content of the WA powder is as high as 680 ppm, which is about 3 times that of the GA powder.

Phase transformation temperature of the GA and WA powders is detected by differential thermal analysis (Fig. 2). The heating curve of the GA powder in Fig. 2a shows two weak bulges at 1125 °C and 1189 °C, which corresponds to the dissolution of γ′ phase and carbides, respectively. The maximum peak at 1335 °C indicates the liquidus for the alloy. For the WA powder (Fig. 2b), the dissolution temperature of γ′ phase and carbides shift to 973 °C and 1012 °C, respectively. It is inferred that the thermal stability of γ′ phase and carbides in the GA powder is higher than that in the WA powder. Owing to the higher C content of the WA powder, the liquidus of the powder is located in a relatively large temperature range of 1285–1360 °C.

The feedstock for MIM was produced by mixing K418 superalloy powder and binder in the double planetary mixer at 150 °C. A multicomponent binder system, which consists of paraffin wax, polypropylene, high density polyethylene and stearic acid, is designed. Powder loading of the GA and WA powder is 65%. Dog-bone tensile specimens with gauge dimensions of 18 mm (length) × 2 mm (width) × 1 mm (thickness) were injection molded with a CJ-80E type injection molding machine at 150–160 °C. Prior to sintering, the binder was removed by solvent debinding and thermal debinding. Subsequently, the debinded samples were sintered at 1210–1250 °C for 2 h in vacuum (10^{-3} Pa). Then the sintered samples were HIPed at 1180–1230 °C for 2 h under the pressure of 180 MPa. Subsequently, the HIPed samples were firstly solution-treated at 1200 °C for 2 h, and then aged at 750 °C for 24 h and air cooled.

Thermal analysis was performed on TG-DTA 2000S (Mac Science) and NETZSCH STA 449C at a heating rate of 10 °C/min. The particles were extracted by electroless extraction method by using the solution composed of 10% $CuCl_2$ and 1% tartaric acid. The size of γ′ precipitate was measured by drawing a circle around γ′ particles using image tool software and then taking the diameter of the circle as an equivalent diameter for each precipitate. After electro-polishing and electro-etching, the morphology of carbides and γ′ precipitates was observed on a LEO1450 secondary electron microscopy (SEM). Disks for transmission

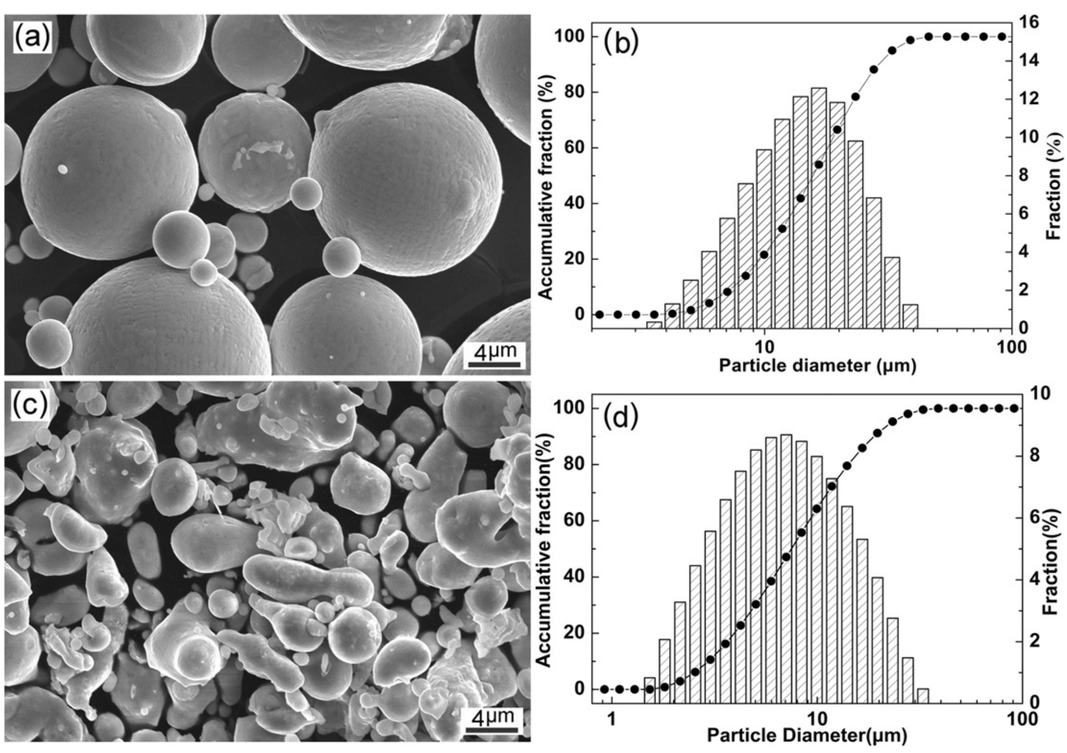

Fig. 1. SEM images and particle size distribution of varied kinds of powders: (a and b) GA powder and (c and d) WA powder.

Table 2
Powder characteristics of Ar-gas and water atomized K418 superalloy.

Powder kinds	D_{10} (μm)	D_{50} (μm)	D_{90} (μm)	Specific area (m^2/cm^3)	Normal distribution 50% (μm)	Tap density (g/cm^3)	Oxygen (wt.%)	Carbon (wt.%)
GA powder	7.51	15.70	28.71	0.534	14.85	5.24	0.019	0.11
WA powder	2.95	7.49	18.83	2.471	7.43	4.83	0.068	0.22

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