Article ID: 1003 - 6326(2000)02 - 0228 - 04

Influence of grain size on mechanical properties of isostatically pressed beryllium materials①

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Abstract: Six kinds of beryllium powders with different particle sizes (4 ~ 15 μm) and low oxygen prepared by impact grinding were compacted and consolidated by cold-hot isostatic pressing (CIP-HIP). The tensile strength, yield strength, elongation and micro-yield strength(MYS) of the materials were tested and it showed that the strength of the materials, especially the yield strength and micro yield strength(MYS) increase obviously with the refinement of grain size. From the XRD and TEM, the second phase is BeO which is finely dispersed in matrix. This is considered to be the main strengthening mechanism for CIP-HIPed beryllium materials with higher purity.

Key words: beryllium; mechanical property; grain size **Document code: A**

1 INTRODUCTION

Beryllium has its own characteristics: low density, high melting point, high elastic modulus, especially high specific stiffness (modulus/density), good dimensional stability, etc. So it is a good material for inertial guidance system and optical system[1~3].

Powder metallurgical process is adopted for beryllium material production[4]. The main methods for producing beryllium powder are disc attritioning and impact grinding. Impact grinding is an advanced method for producing beryllium powder which is very fine and of low oxygen content[5]. And now it is widely used in producing high performance beryllium materials.

The conventional method of consolidating beryllium material is vacuum hot pressing which has a low cost and high efficiency, however, the properties of beryllium material produced are deficient for some applications. Isostatic pressing with higher pressure and lower temperature is able to obtain beryllium materials basically isotropic and providing high performance. It's a good way to produce beryllium materials with high strength and good elongation[6].

It is well known that grain size is the key factor affecting material properties. According to Hall-Petch formula[7]

$$\sigma_y = \sigma_{oy} + K_y d^{-1/2}$$

As grain size decreases, the yield strength increases remarkably. Furthermore, when the deformation/fracture characteristic is basically identical, reduction of the grain size is able to make the differences of fracture stress and yield stress values increase, as a result, elongation of materials is improved. The studies of Turner et al[8] on the influence of particle size on mechanical properties of hot pressed beryllium materials verified the formula very well.

MYS is a main index reflecting the dimensional stability of material. It is a stress to cause 1×10^{-6} plastic strain[9~11]. The index is very important for beryllium material used in inertial parts[12].

Based on above discussion, the purpose of this paper is to determine the relation between grain size and mechanical properties of beryllium materials with different particle sizes made by the use of the CIP-HIP process, so as to establish a foundation for studying and producing beryllium materials with high strength, especially high micro yield strength(MYS) and good elongation.

2 EXPERIMENTAL

2.1 Powder preparation

Six kinds of beryllium powders with different particle sizes of 4.0, 5.2, 7.4, 9.1, 12.1 and 15.0 μm were prepared by the use of cold stream impacting and classifying system. The powders were etched to eliminate impurities such as iron, which brought from grinding. The average particle size was measured and the chemical composition of powders was analyzed with specified standard methods.

2.2 Consolidation

Powders were put into rubber capsules, compacted under the CIP of 260 MPa. The CIPed green compacts were sized and vacuum treated, and welded

① **Received date:** Mar.30, 1999; **accepted date:** Jul.31, 1999

into steel cans which were evacuated before welding. The green compacts were consolidated under the HIP pressure of 120 ~ 140 MPa at 1 050 ℃, 1 h, and the pressure medium is argon.

2.3 Specimens preparation

1) Specimens for MYS and tensile tests

The specimens were cut into single shoulder bars of 10 mm in diameter, 60 mm in length, and the surface of the specimens was chemically etched to remove about 0.1 mm in thickness.

2) Specimens for metallographic observation

By abrading and finishing the transverse fracture surface of tensile specimens.

3) Specimens for TEM observation

The round sheet specimens were finally thinned to 1.5×10^{-7} m with Dual Ion Mill.

2.4 Experimental methods

1) Density

Density of HIPed ingot was measured by method of water displacement.

2) Tensile Tests

The tensile strength, yield strength and elongation were tested in an Instron Testing Machine.

3) MYS tests

Three stain gauges were adhered to each tensile specimen, and then the MYS test was carried out by the method of loading-unloading and recording the plastic strain in an Instron Testing Machine and an MG3800 strain instrument with resolution of 0.1×10^{-6}. The fluctuation of surrounding temperature was strictly controlled within ±0.2 ℃.

4) Metallographic observation

The microstructures of the materials were observed with a metalloscope under polarized light.

5) Second phase particle observation

Second phase particle were determined by XRD and observed with TEM.

3 RESULTS AND DISCUSSION

3.1 Chemical composition

The oxygen contents of six kinds of the powders with different mean particle sizes are all less than 1%, and Fe contents are between 0.040% ~ 0.055%, Al 0.012% ~ 0.013% and Si 0.0085% ~ 0.0122%.

3.2 Mechanical properties

1) Macro-strength

The influence of grain size on tensile strength and yield strength is plotted in Fig.1. As shown in Fig.1, the strength increases in direct proportion with the refinement of the grain size, which is identical with the Hall-Petch Formula.

2) MYS

Fig.2 shows the correlation between MYS and grain size, and it is seen that, the MYS increases

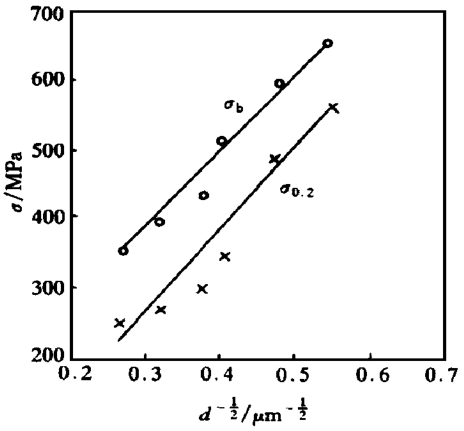

Fig.1 Influence of grain size on tensile strength and yield strength

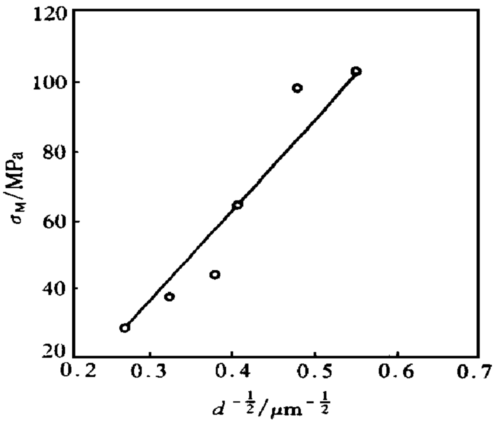

Fig.2 Influence of grain size on MYS

with the refinement of grain size too, which is also identical with Hall-Petch Formula. Fig.1 and 2 indicate that the Hall-Petch Formula is not only suitable for macro-strength, but also extending to the elastic-plastic transitional field between the elastic deformation and plastic deformation.

The finer the grain size is, the more the grain boundary increases, and the more the function of preventing the dislocation motion is, thus both the macro and micro strengths increase.

3) Elongation

Fig.3 shows the relationship between elongation

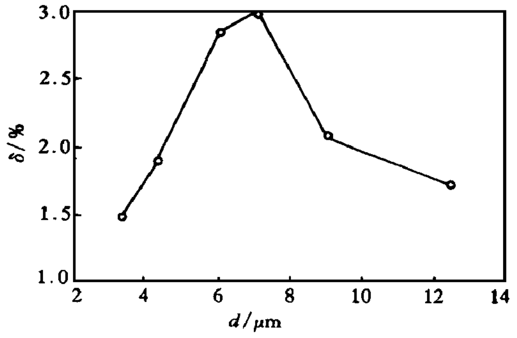

Fig.3 Influence of grain size on elongation

and grain size, and it shows that the value of elongation attains maximum when the grain sizes are 6 ~ 7 μm. The reason is that when the grain size is much coarser, the difference between fracture energy and yield stress decreases, so the ductility becomes poor. In the same way when the grain size becomes much finer, the brittle phase BeO in powders increases, which causes the decrease in the ductility. Upon these experiments, the powders with medium particle size, for example, the powders whose size are 6 ~ 7 μm should be suitable for the high strength and good ductility of beryllium materials.

3.3 Microstructure

The polarized light metallograghs of six kinds of beryllium materials are shown in Fig.4. From Fig.4 (a) to Fig.4(f) grain size decreases in proper order. The main strengthening phase is BeO by XRD analysis (Fig.5). The TEM micrograph in Fig.6 shows the distribution of BeO particles, which are fine

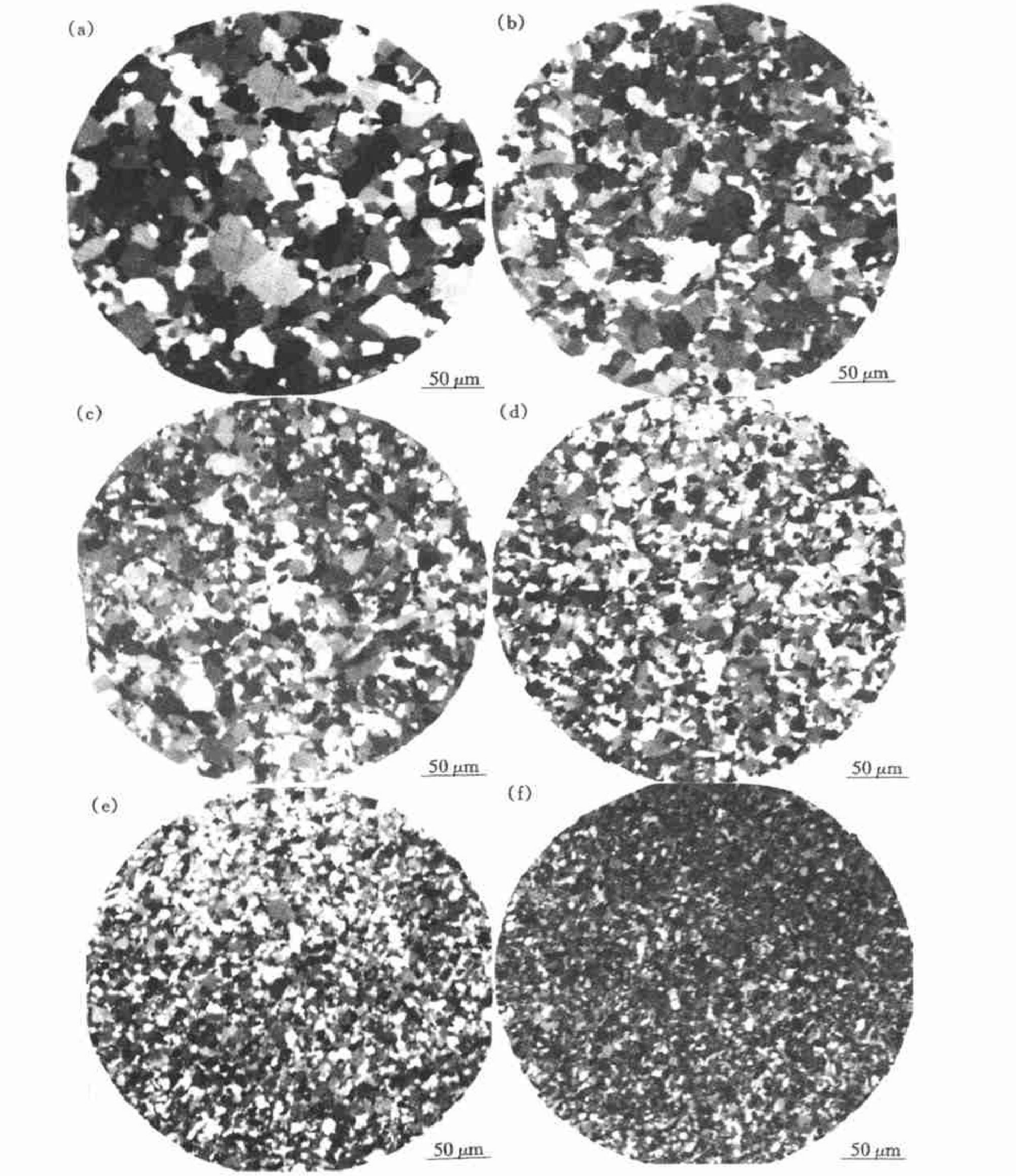

Fig.4 Metallographs of six kinds beryllium materials (Polarized light)

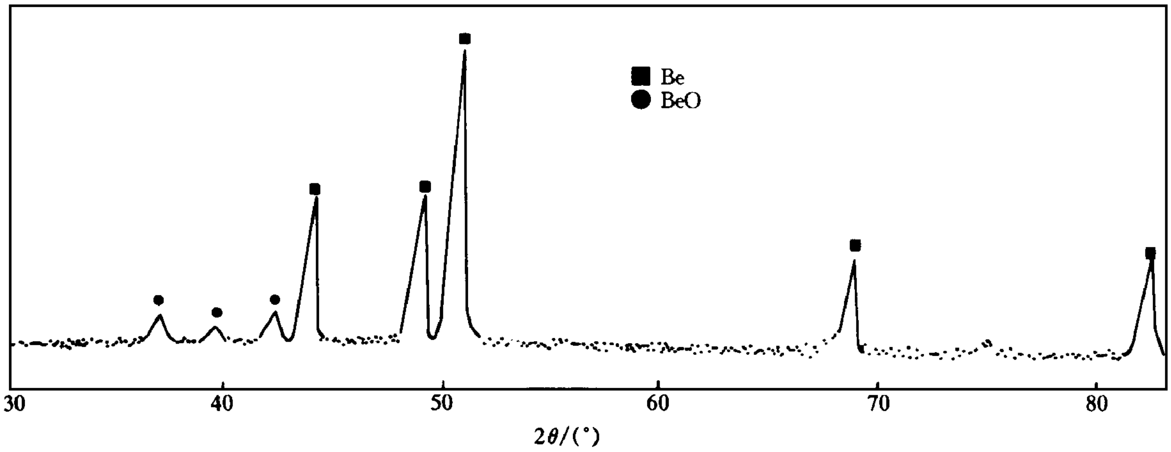

Fig.5 XRD pattern of Be materials

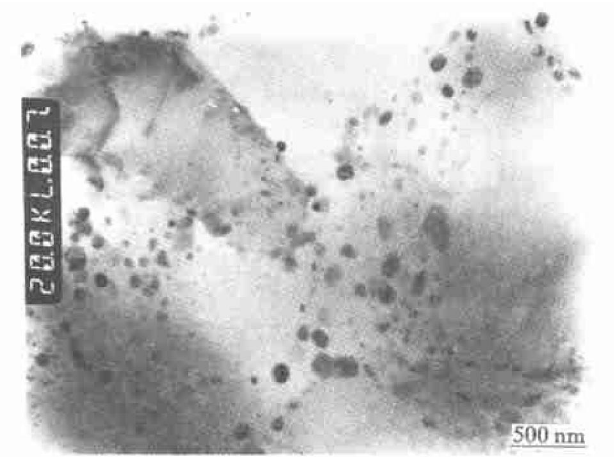

Fig.6 TEM micrograph of BeO distribution conclusions

(about 0.1 μm) and dispersed. This benefits the strength improvement of the materials.

4 CONCLUSIONS

1) The influence of grain size on strength, including MYS, of beryllium materials is evident. The finer the grain size, the higher the strength, which is suitable for Hall-Petch Formula.

2) The particle size of 6 ~ 7 μm is suitable for generally good properties of beryllium materials.

3) The fine and dispersed BeO is the main strengthening factor of the higher purity beryllium materials by isostatic pressing.

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(Edited by HUANG Jin-song)