Microstructure Analysis on Beryllium Reflector Blocks of Research Reactors

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1. Introduction

A pure beryllium has a very low mass absorption coefficient; it has been used as the reflector element material in research reactors. The lifetime of beryllium reflector elements usually determined by the swelling [1-6]; the swelling leads to dimensional change in the reflector frame, which results in bending or cracking of the parts. The mechanical interference in between parts should be avoided; the anisotropy of beryllium also needs to be considered. A beryllium has hexagonal close-pack (HCP) crystal structure, which is inherently anisotropic. It has virtually no ductility in one direction. There are two main aspects in the manufacturing of beryllium which will affect its isotropy, and those are the powder morphology and the consolidation process. Powder metallurgy permits the material to be produced in isotropic and fine-grained form, which overcomes the crystal structure problem by distributing loads in low ductility oriented grains to high ductility oriented grains. There are three representative consolidating methods to make beryllium reflector blocks. Traditionally, most powder-derived grades of beryllium have been consolidated by vacuum hot-pressing (VHP). A column of loose beryllium powder is compacted under vacuum by the pressure of the opposed upper and lower punches, bringing the billet to final density [6, 7]. The VHP process is directional in nature; it contributes to the anisotropy of the material properties. Another consolidating method for beryllium powder is hot isostatic pressing (HIPing), which will enhance its isotropy [8]. During HIPing, The argon gas exerts pressure uniformly in all directions on the can containing the beryllium powder. The HIP process is effective to improve the isotropy of the resulting material as well as refinement of grain sizes. The last consolidating method is hot extrusion (HE). A roughly close packed beryllium is subjected to severe plstice defomation, the grains are refined and the tensile strength is enhanced. Since the material is deformed severely along the specific direction, the extruded material has strong anisotropy. It is generally known that the hot extruded HCP materials have $<10\bar{1}0>$ preferred orientation along the extrusion direction (ED).

Mechanical properties of powder-derived beryllium are affected by those consolidation methods and chemical compositions. In this study, microtexture and microstructure of three different beryllium grades are observed and following mechanical properties are discussed.

2. Methods and Results

Chemical compositions of three different grades of beryllium are shown in Table I. A hot isostatic pressed S-65, a vacuum hot pressed S-200-F, and a hot extruded EHP-56 is chosen to be compared. The main difference in chemical composition is the oxide content; it is related to BeO content in material. S-65 has only 0.5 wt% of oxygen, the most pure beryllium in table. S-200-F has 1.2 wt% and EHP-56 has 1.3 wt%, respectively. It is generally known that the higher BeO content will result in higher yield strength, but lower elongation. Mechanical properties of each beryllium grades are shown in Table II, it is estimated that the mechanical properties of powder-derived beryllium is affected by the material's chemical composition, consolidation method.

Table I: Chemical compositions of each beryllium grades

	Be	O	Fe	C	Al	Si	Etc.
S-65, HIP	99.36	0.50	0.06	0.03	0.02	0.02	<0.01
S-200-F, VHP	98.50	1.20	0.10	0.10	0.05	0.03	<0.02
EHP-56, HE	98.30	1.30	0.20	0.12	0.03	0.04	<0.01

Table II: Mechanical properties of each beryllium grades

	TS [MPa]	UTS [MPa]	ε [%]
S-65, HIP	243	369	4.8
S-200-F, VHP	271	364	2.2
EHP-56, HE	294	490	2.5

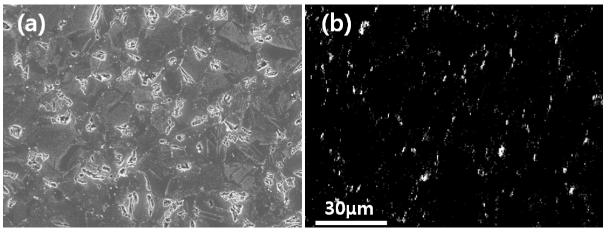
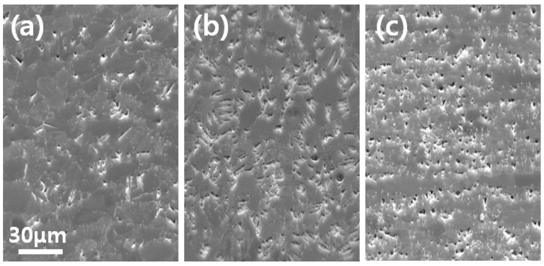


Figure 1. Oxygen content in the S-200-F, VHP sample is investigated. (a) SEM micrograph of chemically etched sample surface, (b) Oxygen signal of EDS analysis is displayed by white dots. Fine BeO particles are distributed along the grain boundaries.

In figure 1, oxygen content in the S-200-F, VHP sample is investigated. The SEM micrograph of sample surface is shown in figure 1(a). Grains sizes are estimated less than 20μm, deep furrows are observed at the grain boundaries with BeO particles inside. The furrows are made during surface etching by 10% perchloric acid. Corresponding oxygen signal of EDS analsys is displayed by white dots in figure 1(b), It is observed that fine oxygen distributed along the grain boundaries. Since the BeO particles are located at grain boundaries, they are known to be the main source of brittle properties of beryllium.

In figure 2, the SEM micrographs of three different sample surfaces are shown. A hot isostatic pressed S-65, a vacuum hot pressed S-200-F, and a hot extruded EHP-56 is shown in figure 2(a), 2(b) and 2(c), respectively. It is observed that the BeO amount of S-65 is smaller than other samples. It is correlated with the oxygen content in Table 1, the oxygen content of S-65 is less than half of others. Except the BeO content, microstructural characteristic of figure 2(a) and 2(b) looks similar. However, the grain shapes and sizes look very unique in figure 2(c). The grains are elongated along hot extrusion direction; BeO distribution is also parallel to that direction.



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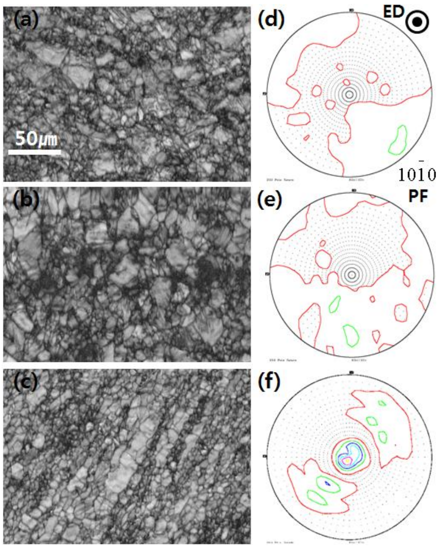

Figure 3. EBSD band contrast map of S-65, s-200-F and EHP-56 are shown in (a), (b), and (c), respectively. Following $10\bar{1}0$ polefigures are observed in (d), (e), and (f), respectively.

In figure 3, microstructure of beryllium samples are observed by band contrast (BC). BC is a qualitative factor of electron back-scattered diffraction (EBSD), which is derived from the intensity of the diffraction bands. The brightness of diffraction pattern can be mapped into a gray scale image, and it shows detailed features of the microstructure such as boundaries. The grain sizes are 10-20μm in S-65, 10-30 in S-200-F, and 1-30μm in EHP-56. The smallest grains are observed in EHP-56, however, the homogeneity of grain is better in S-65.

EHP-56 is suspected to have strong anisotropy along the extrusion direction. The $10\bar{1}0$ pole figures in figure 3(d), 3(e) s suggests that there is no preferred orientation. However, strong preferred orientation is shown in figure 3(f), the $10\bar{1}0$ pole is developed along the extrusion direction.

3. Conclusions

In this study, microtexture and microstructure of three different beryllium grades are observed and following mechanical properties are discussed. It is observed that the BeO distributions, grain sizes, and preferred orientation of powder-derived beryllium are deeply affected by the chemical composition and consolidation method. Preferred orientation of beryllium samples have been evaluated by $10\bar{1}0$ polefigure, strong anisotropy along the extrusion direction is suspected in EHP-56 sample.

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