Design and Simulation Analysis of Micro-Porous Structure in Infiltration-Type Self-Lubrication Composites Matrix

HAN Ying^{1,a}

¹ School of Mechanical Engineering, Shandong Yingcai University, Ji'nan, 250104, China

Abstract. Metal ceramic preforms were fabricated by vacuum sintering method in this work. Ti-Fe-Cr-W-Mo-V powder was used as the basic material, TiH₂ and CaCO₃ were used as the composite pore-forming material and Al₂O₃ was used as dispersal particles. The microstructure and the worn surface morphology of the preforms and the composites were analyzed using scanning electron microscope (SEM) and energy dispersive spectrometer (EDS). The experimental results showed that when the micro-pore shapes are circular and quadrilateral respectively, with the increasing load, the Mises equivalent stress distribution generated by the single cell model is quite different, but it has symmetry, and the maximum stress appears around the interpenetrating micro-pore. Using FeCrWMoV alloy powder as the metal phase and TiC powder as the ceramic phase, the micro-porous matrix was prepared by powder metallurgy sintering with the addition of a certain volume fraction of compound pore-making agent.

1 Introduction

The new type of infiltration self-lubrication composites is prepared by using bionic tribology. Under vacuum pressure, the melt solid lubricant is immersed in the micro-pore matrix. Under the action of high temperature and friction heat, the solid lubricant is precipitated out to the friction interface along the micro-pore structure[1]. The material has good mechanical properties and self-lubricating properties under special working conditions such as high temperature and high pressure, and is widely used in aerospace, electronic machinery and other industries.

The main function of the micro-pore matrix is to bear the load, which affects the mechanical properties and various properties of composite materials[2,3]. How to control the micro-pore structure of the matrix, so that it can store enough lubricant to meet the requirements of lubrication performance[4], and at the same time, it has enough strength to meet the requirements of mechanical performance is the key of this paper.

2 Finite element simulation

2.1 Pore shape

The micro-pore structure of the infiltration self-lubrication composites matrix is complex, which mainly depends on the powder particles and the production process. Micro-pore structure characteristics affect the mechanical properties of the self-lubricating composites, which is the key to determine the number of infiltrated solid lubricant, the uniformity of lubricant distribution and whether the lubrication film can be formed at the

friction interface[5]. Therefore, the micro-pore shape is an important structural characteristic parameter of porous matrix.

The micro-pore matrix was prepared by powder metallurgy sintering, and its internal structure was very complex. In order to facilitate the analysis, the micro-pore structure is assumed as follows: the micro-pore is uniformly distributed; the micro-pore size is equal; the wall thickness is uniform and isotropic. Taking the regular quadrilateral as the basic cell, the structural sections of different micro-pore shapes are shown in figure1.

Figure 1. Micropore section diagram: (a) circular (b)quadrangle

2.2 Finite element simulation

In the process of preparing micro-pore matrix, the size and shape of micro-pore were not the same due to the mutual influence of the size of powder particle, the proportion of pore-forming agent and sintering process parameters. However, from a macroscopic point of view, the micro-pore structure was still arranged periodically and repeatedly. The Mises equivalent stress and strain were analyzed by applying uniformly distributed displacement load to a three-dimensional single cell model in space.

^a Corresponding author: abchanying@126.com

Figure 2 is the equivalent stress distribution cloud map produced by the cellular model with a porosity of 20%. It can be seen from the figure that different micro-pore structure models produce different degrees of deformation and different stress values, but the maximum stress appears around the interpenetrating micro-pore. With the increase of external load, the value of equivalent stress increased gradually. When the loading is the same, the Mises equivalent stress produced by the circular microcellular model is the smallest, followed by the quadrangle.

Figure 2. Cloud map of equivalent stress distribution generated by the single cell model

3 Experimental procedure

3.1 Preparation of sample

The matrix powder was mixed with 80%(volume fraction) in Ti-Fe-Cr-W-Mo-V(the chemical composition as: 20%Ti, 4%Cr, 6%W, 5%Mo, 3%V, Fe in balance) alloy powders (particle size of 15 to 25 μ m) and 20%(volume fraction)Al₂O₃ ceramic powder (particle size of 20 to 25 μ m). And 40%(volume fraction)of TiH₂ and 60%(volume fraction) of CaCO₃ were added as complex pore-forming agent. It was ball-milled for 4h, and then die-pressed into cylindrical specimens of $\varnothing$ 12mm $\times$ 16mm under a 600MPa of compaction pressure. After compaction, sample was vacuum sintered under 0.1 to 0.01Pa and sintering temperature was 1200 $^{\circ}$ C to 1300 $^{\circ}$ C.

3.2 Experimental method

The liquid static equilibrium method is used to test the density, the porosity and the volume of infiltration lubricant of the preform. The micro hardness and crushing strength of samples were tested using HVS-type micro hardness tester and YE-600 type hydraulic testing machine respectively. Friction and wear properties of the composites were investigated using a high temperature XP-5 pin-on-disk wear tester. The pin in the form of 12 mm diameter and 15 mm length was rounded to hemispherical type of 10 mm diameter at one end and surface roughness of 0.2 μ m to 0.8 μ m. The disk was made of Ti-Al ceramic coating materials with geometric size of 55 mm $\times$ 5 mm. The hardness of the disk was HRC 62 to 67 and surface roughness of 0.2 μ m. The friction and wear tester were conducted at temperature of 600 $^{\circ}$ C

and sliding speed of 0.139 m/s. The samples microstructures and worn surface morphology were characterized using scanning electron microscope (SEM) equipped with an energy dispersive spectroscopy (EDS).

4.Results and discussion

4.1 Microstructure

Figure 3 is matrix powder (metal and ceramic phase volume fraction ratio of 80:20) particle size is 55-75 microns, compound pore-forming agent content is 7%, at 1230 $^{\circ}$ C sintering, thermal insulation, after 60 min sintered sample pore structure characteristics of different cross section. As can be seen from figure 3(a), the micro-pore distribution on the surface of the sample is relatively uniform, the pore size is basically the same, and the micro-pore shape is mainly round, square and irregular, etc. As can be seen from figure 3(b), the internal structure of the sample is intersected into a network, similar to the structure of human sweat glands. Fig. 3(c) and (d) are enlarged SEM images with square and circular micro-pore shapes respectively. In the process of actual preparation, the matrix of self-lubricating composite material with thick wall cell structure was obtained by taking metal ceramics as the raw material and using compound hole making agent through secondary hole making. Because of the different sintering process parameters such as sintering temperature, heating speed and heat preservation time, various pore shapes will be formed simultaneously in the sintering matrix, and the porosity percentage of various pore shapes will be different.

Figure 3. Micro-pore structure of sintered sample: (a) surface; (b) axial section; (c) square hole; (d) round hole

4.2 The determination of sintering process parameters

Fig.4 shows the change curve of metal ceramic sintered body about micro hardness and crushing strength. With the increase of sintering temperature, the micro hardness and crushing strength of preform was improved. When the temperature was more than 1230 $^{\circ}$ C, the curve became flat. This situation is not in conformity with the regular

pattern that intensity was dropped according to the index law with the increase of porosity [6]. It was suggested that the preform have corresponding porosity under a certain sintering temperature. With the increase of sintering temperature, the preform tended to be dense and the porosity was decreased. The diffusion speed was accelerated and the activity of powder was enhanced with the increasing of sintering temperature [7, 8]. In consideration of the requirements of pore structure and wear resistance about the preform, the advisable sintering temperature is about 1230°C.

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Figure 4. Influence of sintering temperature on micro hardness and crushing strength of the preform

5 Conclusion

When the micro-pore shapes are circular and quadrilateral respectively, with the increasing load, the Mises equivalent stress distribution generated by the single cell model is quite different, but it has symmetry, and the maximum stress appears around the interpenetrating micro-pore. Using FeCrWMoV alloy powder as the metal phase and TiC powder as the ceramic phase, the micro-porous matrix was prepared by powder metallurgy sintering with the addition of a certain volume fraction of compound pore-making agent. The micro-pore shape is regular (mainly round or square), and the pores are evenly distributed and interspersed into networks.

References

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