Effect of sintering temperature on tribological properties of Ni60 matrix self-lubricating composites

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Abstract. Ni60-based self-lubricating composites were prepared by vacuum sintering, and the tribological properties were evaluated against commercial Si₃N₄ ball at room temperature. Apparently, the experimental results show that the prepared composites exhibit excellent lubricating properties at room temperature. The average friction coefficient of the samples is between 0.13 and 0.35 at different sintering temperatures. It can be found that as the sintering temperature increases, the wear rate decreases. Its hardness value showed an upward trend between 900°C and 1000°C, while the temperature achieves 1000°C, the hardness of the composite decreases, because the lubricating phases such as Sr₂MoO₄ and Sr (CrO₄) were produced to increase the porosity.

1. Introduction

Lubrication according to its shape can be divided into solid lubrication, liquid lubrication and gas lubrication. On the current scientific and technological achievements, the application of gas lubrication is still in the study. The liquid lubricant in the high temperature conditions is particularly volatile due to high temperature oxidation resistance is poor, so the liquid lubrication by the working environment temperature constraints, can not work in high temperature environment. However, solid lubrication can be achieved in high temperature environment lubrication. Therefore, the research progress of solid lubrication is also high attention [1]. With the rapid development of science and industry, the traditional lubricating materials have been unable to meet the current needs of science and industry [2,3]. In recent years, domestic and foreign scholars have achieved fruitful results, mainly by the application of self-lubricating materials and development [4-6]. The development of self-lubricating materials is mainly through the synergistic effect, by adding different auxiliary components in the matrix material, processed in different processes [7]. Various auxiliary materials and processes from the self-lubricating body of the friction resistance are different [8-10]. In this paper, Ni60 alloy powder was selected as the test material using vacuum sintering method to study the impact of friction in the different sintering temperature on the self-lubricating composite materials.

2. Experimental details

2.1. Material preparations

The Ni60 matrix solid-lubricating composites were produced by powder metallurgy. The chemical...
composition of Ni60 alloy powder with average particle size about 75 µm was listed in Table 1. The content of Ni60, MoS2, SrSO4, Cr2O3, and BaF2/CaF2 are 60%, 15%, 5%, 10% and 10% respectively. The grain sizes of these are about 35 -40µm.

Table1 The chemical composition of Ni60 alloy powder

| element | wt% |
|---------|-----|
| Cr      | 15.0-17.0 |
| Fe      | <17.0    |
| B       | 3.0-4.0  |
| Si      | 3.5-5.0  |
| C       | 0.6-1.2  |
| Ni      | balance |

The process we fabricated was as follows. The raw powders were milled by the QM-3SP2 planetary ball mill. It lasted 5 h with a rotational speed of 300r/min and the ratio of ball -to- powder in weight is 3: 1. After that, PVA (3% of the polyvinyl alcohol aqueous solution) was added in the mixture, in order to enhance the adhesion of the metal-ceramic powders. Then the compound was placed in the FW-5-type tablet machine, and the loading pressure was 40MPa for 30min. The shaped powders were placed in the DHG series oblast dryers at 200°C for 60 min. When the Vacuum tube furnace evacuated to a dynamic vacuum about 10^-2 Pa, heated the machine at a rate of 8°C/min. The powders were consolidated at 900°C, 950°C, 1000°C and 1050°C, holding 2h. Finally, the samples were taken out from the furnace after naturally cooled to room temperature. Several sinters were fabricated by the same method. After that, the specimens were polished by emery paper before the following tests. The roughness values of the post processing surface were about 3µm.

2.2 Mechanical and tribological tests

The Micro-hardness tests were conducted on HV-1000 Micro Vickers Hardness Tester. And the tests were carried out at least 6 times with a load of 0.3 N and a dwell time of 10 s.

The friction tests were conducted on the HT-1000 ball-on-disk high-temperature tribometer. The samples were cleaned with absolute alcohol and dried in hot air before tested. And the commercial Si3N4 ceramic ball was selected as a counterpart. Meanwhile, the tests were carried out at a sliding speed of 360r/min and an applied load of 10 N for 20 min. Finally, the results of friction coefficient were calculated by detector, and showed on the screen at the same time. The wear rate W is calculated by W = V / SN (S is the sliding distance, and N is the applied load), and was tested by CFT-1 material surface performance tester. The wear tests of the specimens measured in three different locations, and the average results were recorded.

At last, the microstructures, morphologies on the worn surface and phase structure were examined by Quanta FEG-450 Field Emission Environment Scanning Electron Microscope equipped with EDS spectrum and X-ray Diffraction.

3. Results and discussions

The results from mechanical and tribological tests were shown in figure 1-3. Figure 1 presents the micro-hardness of the Ni60 matrix composites at various sintering temperatures. With the increase of the sintering temperature, the hardness of Ni60-based self-lubricating composites increased as a whole, but when the temperature exceeded 1000°C, the hardness of the composites decreased slightly.

The frictional curves at different sintering temperatures were showed in figure 2. It can be found that the friction coefficient of the Ni60 matrix composites is between 0.10 and 0.25, and the friction coefficient of the self-lubricant is the lowest at the sintering temperature of 950°C, and the average friction coefficient is 0.13.

Figure 3 shows the wear rates of the composites. With the increase of sintering temperature, the wear rates of Ni60-based self-lubricating composites under normal temperature showed a decreasing trend. When the sintering temperature was 1050°C, the wear rate was the lowest, and the average wear rate was 5.72 x 10^-5 mm^3/N·m. It can be found that the porosity of the sample is large due to the low hardness of the sample at lower temperature, so that the wear rate is low. With the increase of the sintering forming temperature, the increase of the liquid phase in the sample reduces the porosity, and
the resulting high-temperature lubricating phase is dispersed in the matrix phase and acts as a diffusion strengthening, so the hardness of the sample increases. Its wear rate is reduced.

![Graph](image)

**Figure 1** The micro-hardness of the samples

![Graph](image)

**Figure 2** The friction coefficients at various sintering temperatures

![Graph](image)

**Figure 3** The wear rates of the Ni60 matrix composites at different sintering temperatures

The worn surfaces and wear debris under different sintering temperatures were showed in figure 4. It can be found that a large number of debris that are about to peel off and are observed on the wear surface. The cracks produced on the surface make the abrasive particles loose. With the increase of the sintering temperature, the wear surface is repeatedly broken under the repeated action of the frictional stress to form the massive debris. The abrasive debris is constantly refined during the rubbing process and is gradually flattened to form a surface film on the worn surface.
Figure 4 SEM images of the worn Ni60 matrix composites at different sintering temperatures

Figure 5 presented the phase constituents of the samples identified by XRD. The sample corresponding to the self-lubricating is mainly by (Ni, Fe), Cr₂₃C₆, BaMoO₄, CaMoO₄, NiCr₂O₄ at sintering temperature of 900°C. The glaze layer is formed by these phases, and help to reduce the friction coefficient. When the sintering temperature is increased to 1050°C, the lubricating phases such as Sr₂MoO₄ and Sr₂(CrO₄) are formed by high temperature oxidation, and the dispersion is distributed in the matrix to play a key role in diffusion strengthening, and it will prevent the material from oxidizing and improve the friction performance.

Figure 5 XRD patterns of the sintered Ni60 matrix composites samples

4. Conclusions
This paper presents and discusses the process and performance of Ni60 matrix composites by vacuum sintering. The result shows that the self-lubricating composites prepared at different sintering
temperatures exhibit excellent lubricity at room temperature. It can be found that the friction coefficient of the Ni60 matrix composites is between 0.10 and 0.25, and the friction coefficient of the self-lubricant is the lowest at the sintering temperature of 950°C, and the average friction coefficient is 0.13. With the increase of the sintering temperature, the wear rate decreases. When the sintering temperature was 1050°C, the wear rate was the lowest, and the average wear rate was $5.72 \times 10^{-5}$ mm$^3$/N·m. Furthermore, the hardness of the composites is increasing from 900°C to 1000°C. However, when the temperature exceeds 1050°C, the lubricating phases such as Sr$_2$MoO$_4$ and Sr(CrO$_4$) increasing the porosity results in a decrease in hardness.

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