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Effect of Phase Transformation and Grain-size Variation on the Dry Sliding Wear of Hot-pressed Cobalt

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Abstract

Effect of phase transformation and grain-size variation of hot-pressed cobalt on its dry sliding wear was investigated. The sliding wear test was carried out against glass (83% SiO_2) beads at 100N load using a pin-on-disk wear tester. Worn surfaces, cross sections, and wear debris were examined by an SEM. Phases of the specimen and wear debris were identified by an XRD. Thermal transformation of the cobalt from the hcp ε phase to the γ (fcc) phase during the wear was detected, which was deduced as the wear mechanism of the sintered cobalt.

Keywords : co, sliding wear, phase transformation, hot pressing

1. Introduction

Cobalt and cobalt-base alloys have been widely employed as the metal bond for a diamond-impregnated sawblade segment, which is normally used for a stone sawing. Cobalt has a superb diamond-holding capability and exhibits proper wear rate to achieve an optimum stone sawing [1]. Wear resistance of the cobalt matrix easily corresponds to the abrasiveness of the workpiece material, which results in an ideal cutting for most workpieces. However, in spite of the excellence of the cobalt as the metal bond in the sawblade segment, the wear mechanism of the cobalt is not fully understood, yet.

Phase transformation of metals is reported to influence their tribo characteristics [2-4]. Hot-pressed cobalt powders normally possess both α (fcc) and ε (hcp) phases. While there is a report that the amount of the ε phase in a cobalt alloy changes during plastic deformation through stress-induced martensitic transformation [2], the effect of phase transformation of cobalt on its wear is not yet reported. The present research was performed with the aim of exploring the effect of phase transformation of cobalt on its sliding wear.

2. Experimental and Results

Cobalt powders with the average size of 1.5 μm were used to fabricate disk specimens for the wear test. The specimens were hot pressed at 800°C under 35 MPa pressure. The sintered disks were annealed at temperatures ranging from 300°C to 750°C for 30 min. Dry sliding wear tests of the disk specimens against SiO_2 beads were carried out in the air at room temperature using a pin-on-disk wear tester with a sliding speed of 0.38 m/sec. Applied wear load and sliding distance were 100N and 600 m, respectively. Worn surfaces, their cross sections, and wear debris of the disk specimens were examined by a scanning electron microscope (SEM). Phases of the cobalt specimen and wear debris were identified by an XRD analysis.

Hardness and wear rates of the sintered cobalt specimens are listed in Table 1, together with their heat treatment conditions. Though the heat treatment hardly changed hardness of the sintered Co, the wear rate of the cobalt specimens varied slightly.

Table 1. Hardness and wear rate of the heat-treated cobalt specimens

	Annealing Condition	Hardness (HRB)	Wear Rate (m^3/m)
Spec. 1	as-sintered	103.5	4.3×10^{-12}
Spec. 2	300°C, 30 min.	104.3	3.1×10^{-12}
Spec. 3	450°C, 30 min.	105.1	3.6×10^{-12}
Spec. 4	600°C, 30 min.	106.0	4.3×10^{-12}
Spec. 5	750°C, 30 min.	103.5	4.2×10^{-12}

Worn surfaces and wear debris of the as-sintered and annealed (at 300°C and 750°C) cobalt specimens slid 600 m at the load of 100N were explored. Worn surfaces of all looked similar. The worn surface is shiny, and composed of long shallow furrows with various width. The surface contained neither cracks nor any significant trace of deformation, which is a typical nature of worn surfaces of most hcp metals. A very thin (less than 5 μm) detaching surface layer with numerous cracks, which is unusal with most metallic materials tested at high loads, was observed from the cross section of the cobalt specimens, especially from the as-sintered cobalt specimen. Most of the wear debris collected from all cobalt specimens were fine particles (diameter less than 5 μm). Coarse (diameter bigger than 50 μm) debris particles were also observed, especially from the specimen heat treated at 300°C. The coarse ones usually contained numerous cracks, which indicates that the fine particles may also be originated from fractured coarse particles.

Phase transformation of the cobalt and its subsequent effect on the wear were explored to explain the unique wear characteristics of the sintered cobalt specimens. Phases of the as-sintered and heat-treated cobalt specimens before the wear test were analyzed to find out that the specimens had both α (fcc) and ε (hcp) phases initially. However, wear debris from the cobalt specimens possessed only the fcc, α phase, which led to the postulation that the original ε phase had transformed to the α (fcc) phase during the wear. Transformation of the ε phase to the α phase is a thermally induced one. There is a slight volume increase when the hcp crystalline structure changes to the fcc structure. The volume change associated with the phase transformation was indirectly confirmed by a dilatometer analysis of the cobalt specimen. It is suggested that the volume change associated with the phase transformation during the wear induced shallow cracks beneath the wearing surface, which propagated to result in the thin detaching surface layer as well as the fine wear debris of the cobalt specimens.

By performing tests with various sliding distances, it was found that the wear rate of the as-sintered cobalt increases with the sliding-distance increase. Such a result is contradictory to usual results that a wear rate normally remains the same or decreases with the increase of sliding distance. The rate-increase with the distance is regarded as another evidence of the thermal-transformation occurring during the wear of the cobalt. As the sliding distance increases, the temperature at the wearing surface rises. The higher temperature would then provide a more favorable condition for the thermal transformation, which results in the higher wear rate with longer sliding distance. In order to substantiate the reasoning that the temperature-increase during the wear is the cause of the transformation, wear tests of the as-sintered cobalt specimens were carried out at low temperature (-50ºC) to suppress the thermal transformation. The result clearly showed that the wear rate measured at -50ºC is much lower, and the rate remained more or less the same with the increase of the sliding distance increase.

The grain size of all heat-treated cobalt specimens was similar, and so it is difficult to evaluate directly the effect of grain size on the wear of the heat-treated specimens. However, the similar wear rates (Table 1) and coinciding grain size of the heat-treated and the as-sintered cobalt specimens suggest a grain-size-dependence of the transformation. Since the lower wear rate of the sintered cobalt specimen annealed at 300°C for 30min than the others could be explained by its higher porosity level, the plausibility of the suggested relationship was further investigated.

Sliding wear tests of wrought cobalt specimens with bigger grain size (about 30μm) were performed under the same condition. The wear rates of the wrought cobalt specimens were around $3.1\text{x}10^{-12}\text{m}^3/\text{m}$, which is slightly lower than that of the sintered specimes. However, worn surface, cross section, and wear debris of the wrought specimen were quite different from those of the sintered specimen. The worn surface showed traces of deformation together with cracks, and the cross section revealed long subsurface cracks, which would form a thick detaching surface layer. Large bellows-like folded wear debris were collected from the wrought specimen. These denote the effect of grain size on the thermally-induced transformation, deformation, and crack propagation, which naturally influence the wear rate. However, further research on the effect is needed.

3. Summary

Dry sliding wear tests of hot-pressure sintered cobalt specimens were carried out, and the effect of phase transformation and grain size of the cobalt on the wear was investigated. The sintered cobalt exhibited distinctive wear characteristics such as worn surfaces with narrow shallow furrows, very thin (less than 5 μm) detaching surface layers, and fine wear debris. Thermal transformation of the Co during the wear was deduced to be the wear mechanism of the sintered cobalt. Wear tests with various sliding distances and at very low temperature (at-50ºC) supported the thermal-transformation-induced wear mechanism of the Co. A connection between the grain size of the sintered cobalt and the transformation was also postulated, and a grain-size-dependence of the transformation was suggested.

4. References

1. J. Konstanty, Cobalt as a Matrix in Diamond Impregnated Tools for Stone Sawing Applications, Wydawnictwa AGH, Krakow (2002).
2. P. Huang and H. Lopez, Materials Letters **39**, p.244 (1999),
3. T. Waitz and H. Karnthaler, ACTA Mater. **45**, p.837 (1997).
4. J. Sort, A. Zhilyaev, M. Zielinska, J. Nogues, S. Surinach, J. Thibault and M.D. Baro, ACTA Mater. **51**, 6385 (2003).