Influence of Cobalt Content on the Fatigue Strength of WC-Co Hardmetals

Takeshi Nakajima [1,a], Hiroyuki Hosokawa [1,b], and Koji Shimojima [1,c]

[1]Materials Research Institute for Sustainable Development,
National Institute of Advanced Industrial Science and Technology (AIST),
2266-98 Shimo-Shidami, Moriyama-ku, Nagoya 463-8560, Japan
[a]take-nakajima@aist.go.jp, [b]h-hosokawa@aist.go.jp, [c]k.shimojima@aist.go.jp

Abstract

The behavior of hardmetals under cyclic loads is investigated. Unnotched specimens were employed to obtain practical information regarding fatigue in hardmetals. All the tested hardmetals exhibit an increase in the number of cycles until failure with a decrease in the maximum stress, i.e., the hardmetals exhibit a high fatigue sensitivity. The fatigue strength increases with the cobalt content. Although distinct fatigue limits, as observed in metals, cannot be observed, the calculated fatigue limit stress at 10^7 cycles is found to be approximately 70% of the flexural strength, and the stress value exhibits a linear relationship with the flexural stress.

Keywords : fatigue, lifetime, flexural stress

1. Introduction

Hardmetals are mainly used as cutting tools, structural components, and wear parts. The fatigue sensitivity of hardmetals is widely noted; it has been observed that their strength deteriorates under cyclic loads, ultimately resulting in fatigue failure. Therefore, it is necessary to understand the rupture behavior of hardmetals under cyclic loads for their general and practical applications.

The flexural stress of hardmetals under monotonically increasing loads has been well examined by many researchers. Hayashi et al. [1, 2] investigated the flexural stress of hardmetals and found that hardmetals fracture as a result of preexisting microstructural flaws of the materials. They derived a linear relationship between $a^{1/2}$ and $(1/\sigma_d)$, where a is the diameter of the defect and σ_d is nominal stress applied to the defect.

This study aims to obtain practical information regarding the fatigue behavior of hardmetals with varying cobalt content by using unnotched test pieces. All the fatigue tests described in this study were conducted using unnotched specimens. As a result, nearly the same behavior can be expected for the materials when they are used as materials for cutting tools.

2. Experimental and Results

Three grades of WC-Co hardmetals (supplied by Fuji Die Co., Ltd.) were selected for this study. Hot isostatic pressure (HIP) treatment was performed on all the samples after sintering in a vacuum. The mean carbide grain size and Co content are listed in **Table1.** In this table, the flexural stress evaluated by averaging the results obtained from five tests for each material is shown in the right-hand column.

Table 1. Structural parameters and mean flexural stress of the materials under investigation

	Mean carbide grain size, d_{WC} [μm]	Co content [mass%]	Mean flexural stress, σ_F [GPa]
WC-4% Co		4	2.7
WC-6% Co	1.5	6	3
WC-10% Co		10	2.7

Bending fatigue tests were performed on rectangular bars with the dimensions of 40 mm x 4 mm x 3 mm under sinusoidally alternating loads at a stress ratio $R = \sigma_{min}/\sigma_{max} = 0.1$ and a frequency of 20 Hz. In order to eliminate the effect of surface roughness on fatigue lifetime, the specimens were ground and subsequently polished to No. 8000 smoothness. The edges of these samples were chamfered in order to reduce unexpected stress concentrations. All the tests were conducted in air at ambient temperature.

The stress/life (*S*/*N*) curves for the tested materials are shown in **Fig. 1** along with the experimental flexural stress on the $N = 1$ line. The tests were terminated at 10^7 cycles when the fatigue failure did not occur; they are indicated by the plots with attached arrows in **Fig. 1**. However, the plots are scattered, the tested hardmetals exhibit an increase in the number of cycles until failure with a decrease in the maximum stress, σ_{max}. As observed in the figure, distinct fatigue limits, as observed in metals, are not evident. Such an indefinite fatigue limit is often observed in ceramics. The straight lines obtained using linear regression for each material are also shown in the figure. The stress indicated by the intersection of the abovementioned and the $N = 1$ line can be regarded as the *imaginary* flexural stress. A good agreement (factor of the range of 1±0.05) between the *experimental* and *imaginary* flexural stresses suggests the validity of the approximation with the straight line for the scattered plots.

The approximated line is expressed as

$$\sigma_{\max} = P_1 \log N + P_2 \quad (1)$$

where P_1 and P_2 denote the fatigue susceptibility and the strength of each material, respectively. A simple consideration leads to a conclusion that the near-zero value of P_1 indicates an insensivity to fatigue deterioration and a large value of P_2 implies a high innate strength of the materials. **Fig. 2** shows the relationship between the cobalt content and the parameters. Both the parameters reveal a remarkable cobalt-content dependence, i.e., the addition of cobalt increases the fatigue strength.

By substituting $N = 10^7$ in Eq. (1), the fatigue limit stress σ_{limit} can be evaluated. This analysis indicates that σ_{limit} is proportional to the flexural stress and the magnitude of σ_{limit} is approximately 70% of the flexural stress for each material. In the case of metals such as steel, the fatigue limit in the single-cycle tensile (or bending) test is approximately 50% at 10^8 cycles. A similar behavior is observed in many ceramic materials [12]. When compared with metals and ceramics, the higher fatigue limit of the hardmetals under investigation can be attributed to the peculiar structure of the hardmetals.

3. Summary

The current knowledge on the behavior of hardmetals under cyclic loads can be summarized as follows:
(1) All the tested hardmetals exhibit an increase in the number of cycles until failure with a decrease in the maximum stress, i.e., the hardmetals exhibit a high fatigue sensitivity.
(2) The fatigue strength increases with the cobalt content.
(3) The calculated fatigue limit stress at 10^7 cycles is approximately 70% of the flexural strength.

4. Acknowledgment

This work was supported by "Integrated Development of Materials and Processing Technology for High Precision Components" of the New Energy and Industrial Technology Development Organization.

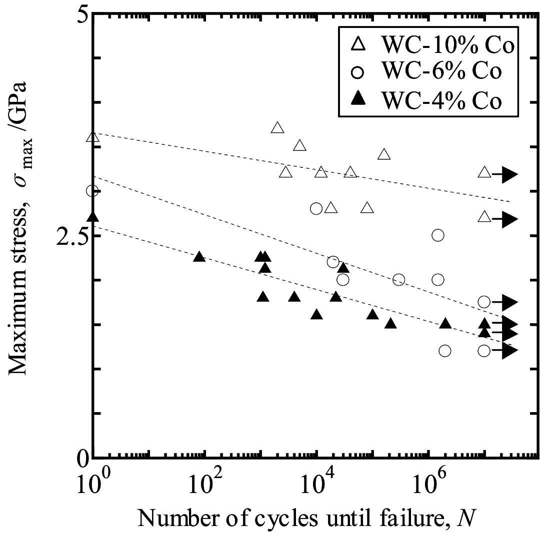

Fig. 1. Stress / life (*S/N*) curves for tested materials. Plots on the line of *N* = 1 indicate mean flexural stress.

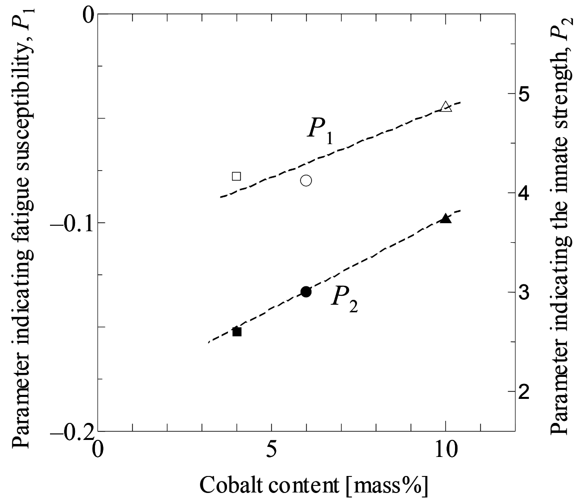

Fig. 2. Dependence of cobalt content on the parameters indicating susceptibility (*P*1) and the innate strength (*P*2).

5. References

[1] H. Suzuki and K. Hayashi: J. Jpn. Inst. Met., 38 (1974), p. 258.
[2] H. Suzuki and K. Hayashi: Planseeberichte fuer Pulvermetallurgie, 23 (1975), p. 24.
[3] R. O. Ritchie and R. H. Dauskardt: J. Ceramic Soc. Jpn., 99 (1991), p. 1047.