Fatigue of WC–Co Hardmetals Under Tension-compression Loading — the Effects of Co Content and WC Grain Size

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ABSTRACT

Fatigue of WC-Co hardmetals has been investigated under tension-compression cyclic loading at various stress ratios by using a newly developed apparatus. Tests were made under pulsating tension, pulsating compression and at the stress ratios of 0, -1 and - ∞. Materials used for the tests were WC-Co hardmetals whose Co contents are 6%, 12% and 20%, and their WC grain size ranges from 1.1μm to 3.0μm.

For alternating tension-compression (R=-1) and pulsating tension (R=0), all the materials tested have shown about the same value of fatigue limit, regardless of stress ratio, Co content and grain size. In the region of finite life, WC-6% (WC grain size 1.1μm), which is the material with smallest Co content, has shown the longest life, and WC-12%Co (WC grain size 1.4μm) has shown the shortest life. Fatigued specimens under cyclic compression showed a sharp decrease in tensile strength after a certain number of stress cycles.

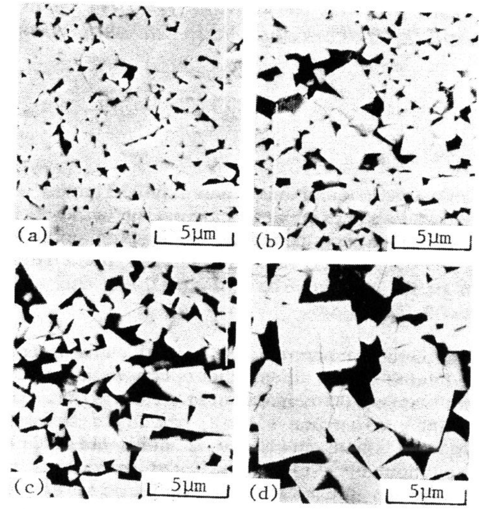
Under R=0 and -1, fatigue cracks were initiated from the inside of the specimens, where cleavage facets and high concentration of Co were always found. These results seem to suggest that the fatigue cracks in these cases were initiated from the cleavage of hcp Co transformed, due to cyclic straining, from fcc Co existing in the as-sintered state. In the specimens fatigued by the cyclic compressive stress, on the other hand, fracture was initiated from the grooves formed by the dropping of the surface layer of the specimens. In this case, no concentration of Co was found by EDX in the area of fracture initiation.

KEYWORDS

WC-Co hardmetal, fatigue, tension-compression fatigue, compression fatigue, WC grain size, fatigue limit

INTRODUCTION

In spite of their importance, the data on WC-Co hardmetals under tension-compression fatigue (Yoshikawa et al., 1984, Otsuka et al., 1987a,b) are very few, though some data obtained by bending fatigue are available (Miyake et al., 1968, Davies and Barhana, 1972, Fujiwara et al., 1980). This is because of the difficulty in carrying out the fatigue tests of hardmetals under axial tension-compression stress with good accuracy. In the present study, tension-compression fatigue tests of WC-Co hardmetals were made at the stress ratio ($\sigma_{min}/\sigma_{max}$) =0,-1 and $-\infty$, by using a newly developed apparatus with the eccentricity of the specimen loading less than 5%. The tests were made on four kinds of HIP treated WC-Co hardmetals, namely, WC-6%, -12%Co, -20%Co with WC grain size 1.2 ∿ 1.4μm (fine grained), and WC-12%Co with WC grain size 3.0μm (coarse grained). Based on the results of the fatigue tests, fractographic studies and EDX analyses, the mechanism of fatigue fracture of WC-Co hardmetals was discussed.



(a) WC-6%Co, WC grain size = 1.1μm
(b) WC-12%Co, WC grain size = 1.4μm
(c) WC-20%Co, WC grain size = 1.6μm
(d) WC-12%Co, WC grain size = 3.0μm

Fig. 1. Micrographs of WC-Co alloys

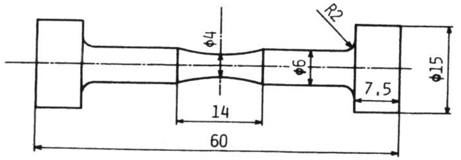


Fig. 2. Specimen

MATERIALS AND EXPERIMENTS

The materials used for the tests were WC-6%Co, -12%Co, and -20%Co hardmetals, whose WC grain sizes were 1.1 ∿ 1.6μm, and coarse grained(WC grain size 3μm) 12%Co material was also used. Their micrographs are shown in figures (a), (b),(c), and (d), respectively, in Fig.1. All the static and fatigue tests were carried out on the specimens shown in Fig.2 after confirming that the eccentricity of the specimen setting to the testing machine is less than 5% at the maximum. The eccentricity of the specimen setting was measured by the strain gages bonded on the specimen along the periphery of the minimum section with equal intervals. One example of the records of the load strain relation obtained from the three gages mentioned above is shown in Fig.3.

RESULTS AND DISCUSSION

Static Tension and Compression Tests

Stress-strain curves obtained from the compression tests are shown in Fig.4 for the four WC-Co hardmetals used in the present research. The fracture points in the tensile tests are designated by X on the curves for compression tests since the stress-strain curves for the tensile tests almost coincide to those for compression tests.

Fatigue Characteristics under Alternating and Pulsating Stress

Fatigue tests were made under alternating tension-compression (R=-1) stress for all the materials tested and under pulsating tension (R=0) for the material of WC-12%, 1.4μm grain size. The results are shown in Fig.5. Open symbols show the results for alternating tension-compression (R=-1) stress, and solid symbols show the results for pulsating tension (R=0). It is noticed that there seems to exist a fatigue limit in the fatigue of the

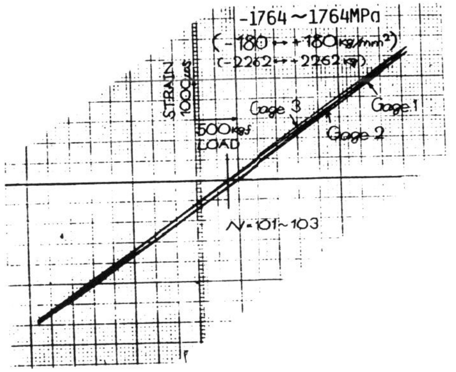


Fig. 3. Records of load-strain relations for a tension -compression (-1764 ∿ 1764MPa) fatigue test. Strain was measured by three strain gages bonded on the specimen along the periphery of the minimum section with equal intervals. Figure shows three curves for gage 1, 2 and 3 for N = 1, 2 and 3, respectively.

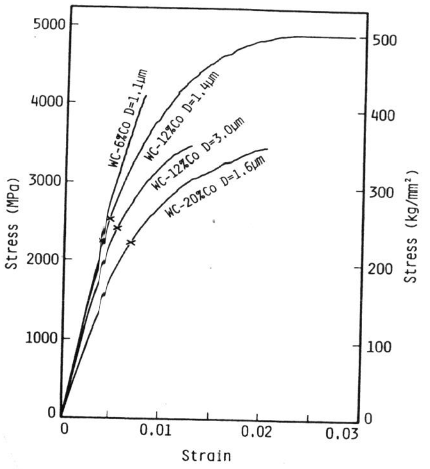


Fig. 4. Stress-strain curves for compression tests on four WC-Co alloys shown in Fig. 1. Ends of each curves are the ends of recording (not the fracture point). x marks show the stress at fracture in tensile tests.

materials tested, and their values are almost the same, regardless of Co content, WC grain size, and stress ratio. In the region of finite life, WC-6%Co specimens show the longest life and WC-12%Co (1.4µm WC grain) specimens show the shortest life. The results of WC-12%Co specimens show that the coarse grained (3.0µm) specimens show longer life than the specimens of smaller WC grain (1.4µm). These results obtained in the present tests on fatigue limit and on the effect of Co content are somewhat different from the former results obtained by bending fatigue (Miyake et al., 1968, Davies and Barhana, 1972, Fujiwara et al., 1980) though direct comparison is not possible because of the differnce in the stress conditions and the materials used.

Fractographs of the Fracture Initiation Zone Fatigued under Alternating and Pulsating Stresses

Figure 6 shows the fractographs of the fracture initiation area in the specimen designated by A in Fig.5. Fracture initiation was always inside the specimen as seen in this figure, and it is also noticed that cleavage-like facets, as seen in figures (b) and (c) in Fig.6, were usually observed in the fracture initiation area. Figure 7 shows the fractographs and EDX analysis of the fracture initiation area of the specimen B in Fig.5. Figure 8 shows the fractographs and relative intensity of Co by EDX at the areas of various distances from the fracture origin, where Co relative intensity means the value of the peak signal count of Co (kα,kβ) devided by the sum of the peak signal count of W (Mα,Lα) and Co (Kα,Kβ). This value was used as a parameter to show the variation of the amount of Co concentration on the fracture surface. From Figs.7 and 8 it is realized that fatigue fracture is initiated in the area of high Co concentration. Cleavage-like facets in the areas of fracture initiation zones seen in Figs.6 ∿ 8 were proved by EDX to

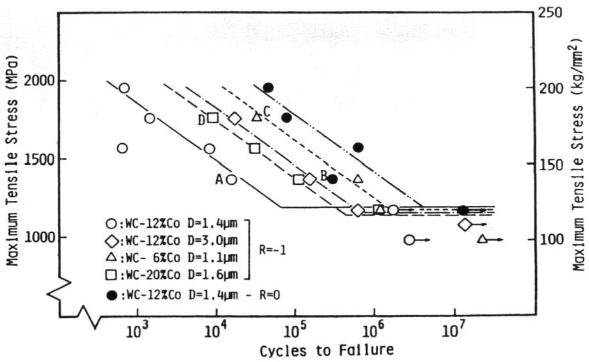


Fig. 5. Maximum tensile stress versus cycles to failure for alternating tension-compression (R = -1) and pulsating tension (R = 0) fatigue tests.

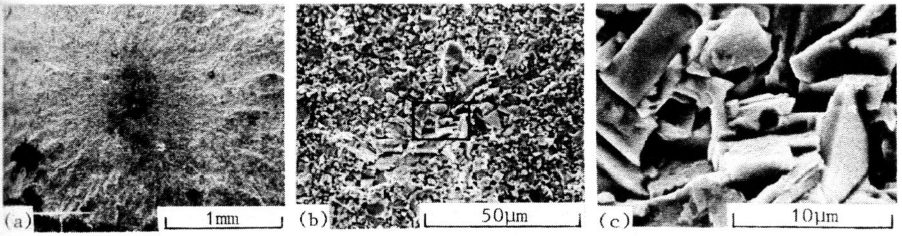


Fig. 6. Fractographs showing the area of fatigue crack initiation in the specimen fractured by pulsating tension fatigue (R = 0, 0 ∿ 1372MPa, N_f = 1.7x10^5), specimen A in Fig. 5. Figures (b) and (c) are the higher magnification views of the areas in the rectangles in figures (a) and (b), respectively.

mainly consist of Co and some WC grains. This observation suggests that fcc Co in as-sintered state transforms to hcp Co due to the cyclic straining by fatigue, and cleavage fracture was initiated in this hcp Co. The result that the values of fatigue limit are about the same for the materials tested, regardless of the Co content, WC grain size and the stress ratio, may be explained from this process of fracture initiation. On the transformation of fcc Co in as-sintered WC-Co to hcp Co, investigations were made by Miyake et al., 1968, Sarin and Johnannesson, 1975, Fujiwara et al., 1980, and Vasel et al., 1985.

Residual Tensile Strength of the Spesimens Fatigued under Cyclic Compressive Stress

In Fig.9 residual tensile strength of the specimens fatigued under cyclic compressive stress is given as a function of the number of cyclic compressive stress. It is seen that the residual tensile strength is reduced very rapidly after the application of certain number of cyclic compressive stress.

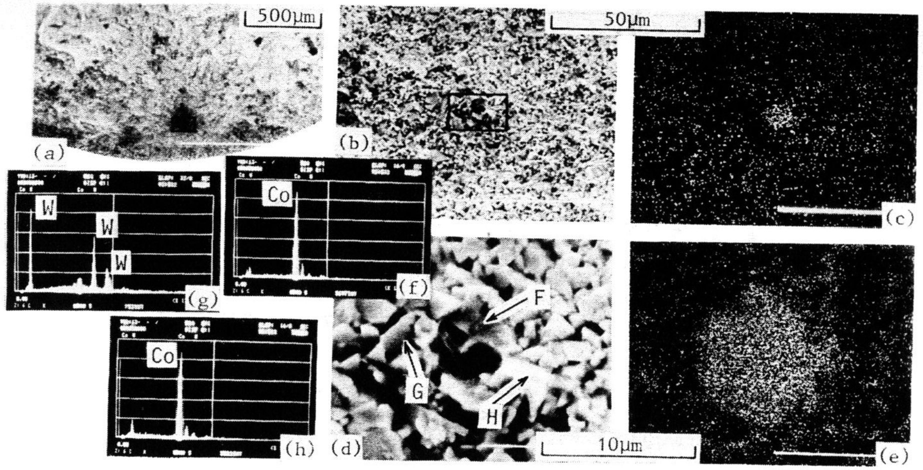


Fig. 7. Fractographs and EDX analysis of the fracture initiation area in the WC-12%Co (WC grain size 1.4μm) specimen shown by B in Fig.5. Figures (b) and (d) are the higher magnification views of the areas shown by the rectangles in figures (a) and (b), respectively. Figures (c) and (e) show Co distribution of the area shown by figures (b) and (d), respectively. Figures (f), (g), (h) are the spot analysis of the points shown by F, G, H, respectively.

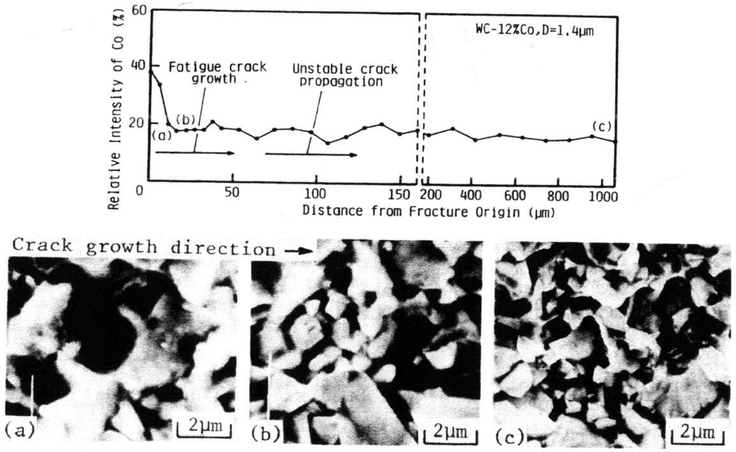


Fig. 8. Fractographs and relative intensity of Co by EDX at various positions from the fracture origin in the specimens shown by B in Fig. 5 (WC-12%Co, WC grain size 1.4μm)

This reduction in tensile strength comes from the grooves formed on the specimen surface by the dropping of surface layer. Some examples of these kinds of the grooves are shown in Fig.10. It is interesting to notice that the material which shows high resistance in tensile fatigue not always shows high resistance in compression fatigue. WC-12%Co, 1.4μm grain material, for

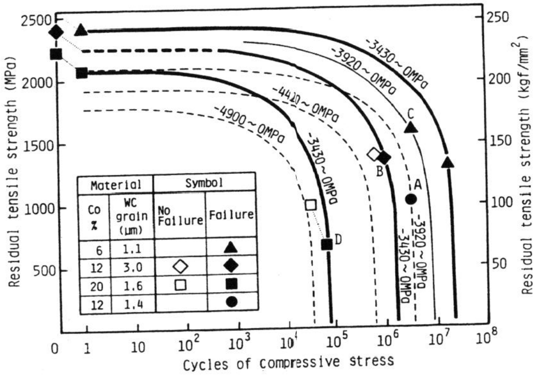


Fig. 9. Residual tensile strength as a function of the number of cyclic compressive stress. Thick solid curves show the results of the specimens subjected to 0 ∿ -3430MPa cyclic compressive stress, and other curves show the results under other loading conditions which are denoted on each curves.

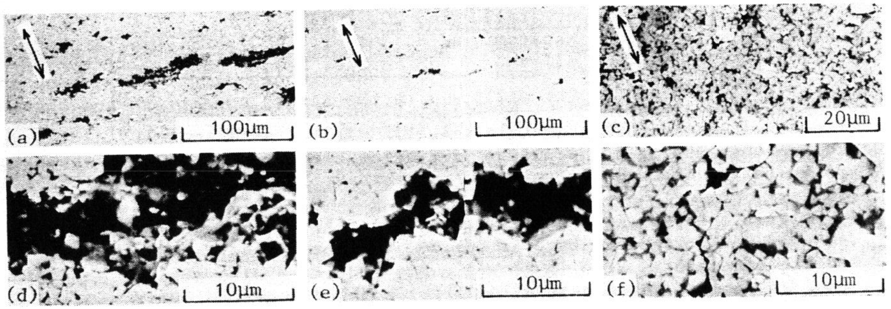


Fig. 10. Surface defects observed on the surfaces of the specimens fractured by tensile loading after the application of zero-compression cyclic loading. Figures (b), (d), (f) show the higher magnification views of the areas shown by the rectangles in figures (a), (c), (e), respectively. Three pairs of figures (a), (c); (c), (d); (e), (f) show the specimens shown by A, B and C, respectively, in Fig. 9. The arrows in figures (a), (b) and (c) show the loading direction.

example, shows lowest fatigue life under tensile fatigue, but it shows relatively long life under compression fatigue. The reduction in residual tensile strength by the application of cyclic compressive stress is larger in the materials with larger Co-content. WC-6%Co material shows highest strength both in tensile fatigue and in compression fatigue, though its tensile strength under monotonic loading shows low level in the materials tested.

CONCLUSIONS

By using newly developed apparatus, tension-compression fatigue tests and compression fatigue tests have been made on WC-6%Co, -12%Co, and -20%Co hardmetals. The main results are summarized as follows:

(1) Fatigue limits were observed in the fatigue under pulsating tension and alternating tension-compression. The values of the fatigue limits were about the same for both stress conditions, if it is expressed in maximum stress.

(2) The values of the fatigue limits mentioned above are about the same for all the materials tested, regardless of Co content and WC grain size.

(3) In the finite life region, WC-6%Co showed the longest life, and WC-12%Co showed the shortest life. For the effect of WC grain size, the larger grained (3.0μm) material showed longer life than the smaller grained (1.4μm) material.

(4) By EDX analysis, a Co-rich region or regions were always observed in the area of fatigue fracture initiation. This result may suggest that fatigue fracture occurs from the cleavage of hcp Co formed by the transformation of as-sintered fcc Co due to cyclic straining.

(5) After application of a certain number of cyclic compression stresses, the residual tensile strength shows sharp decrease. This decrease is due to the grooves formed by the dropping of the surface layer.

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