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An Empirical Ranking of a Wide Range of WC–Co Grades in Terms of their Abrasion Resistance Measured by the ASTM Standard B 611-85 Test

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Abstract: This paper reports the results of a comprehensive investigation into the abrasion resistance of WC–Co alloys, as measured by the ASTM Standard B 611-85 test. The alloys ranged from 3 to 50 wt% and from 0·6 to 5 μm average grain size. Careful control of the grain size has led to new results and new insight into the relationships between abrasion resistance, hardness, cobalt content, grain size and mean free path. © 1997 Elsevier Science Limited

1 INTRODUCTION

The aim of the present investigation was to rank WC–Co grades ranging in cobalt content from 3 to 50 wt% and in mean grain size from 0·6 to 5 μm, on the basis of their abrasion resistance. The abrasion resistance was measured by means of the ASTM Standard B 611-85 test. Its aim was also to determine within which limits is the hardness a reliable indication of abrasion resistance.

2 METHOD

2.1 Materials

Coarse (C), medium (M), fine (F) and ultrafine (UF) sets of WC–Co hardmetal grades ranging from 3 to 50 wt% Co were produced from four different starting powders. The mean grain size of each set of grades, as measured by linear analysis, was the following: 5·1 μm for the coarse grades, 3 μm for the medium grades, 1·1 μm for the fine grades and 0·6 μm for the ultrafine grades.

The milling conditions were adjusted to suit the particular set of grades and the end microstructure required. The mill pots contained 3 kg of 3 mm WC–Co balls. All the grades were milled in a laboratory scale attritor mill. The milling time varied from 4 h for the UF grades down to 1 h for the C grades. After milling, the powder slurry was screened and then dried and screened again.

Test blocks measuring 45 × 22 × 6 mm were pressed from each grade. The blocks were then sintered in a laboratory scale Degussa type VKP gr 10/10/25 sinterHIP furnace. The sintering temperature was adjusted according to the cobalt content in order to reduce the effect of grain growth within a specific set of grades.

The test blocks were ground flat on both surfaces and polished to a 1 μm diamond grit finish on one surface. This surface was used for both the hardness tests and the microstructural analysis. The unpolished surface was used for the abrasion testing.

2.2 Hardness tests

The hardness testing was carried out in accordance with the ISO standard 38783 for the determination of the Vickers hardness of hardmetal. Five indentations were made on each test block and an average of 10 readings was then determined. A Leco hardness testing machine type V-100-A2 with a 30 kgf applied load was used. The resolution of the measuring device was ±0·5 μm.

2.3 Abrasion tests

The abrasion testing for all the grades was carried out in accordance with the ASTM Standard B 611-85 for the abrasion testing of cemented carbides.

The abrasion tester consists of a wheel of diameter 169 mm and width 13 mm. The wheel rotates at a speed of 100 rpm, which gives a peripheral speed of 0·88 m/s. The wheel rotates in a bucket which is filled with Al_2O_3 to within 25 mm below the centre of the wheel. The grit used was Cumar Abrasives Al_2O_3 grit size 24# (BS410+600 μm). Water is added to the grit in accordance with the standard, 4 g of grit to 1 cm^3 of water. This results in sufficient water to wet the grit with little or no excess water on the surface.

The sample holder with sample was held against the wheel with a 10 kg load at the end of a 2:1 lever ratio to give an effective constant load of 20 kgf. The test runs for 1000 revolutions (10 min) which gives a wear path length of 630 m. The test block was weighed before and after the abrasion test. A Shimadzu electronic balance was used and readings were taken to 0·1 mg.

The abrasion resistance was determined in accordance with the standard, i.e. it was calculated from the volume loss. The volume loss was calculated from the mass loss of the sample and the density of the test block. Each grade was tested once, in accordance with the standard.

2.4 Microstructure characterization

Five scanning electron micrographs were taken of each grade and analysed in the following manner. The micrographs were enlarged onto 190 × 240 mm paper. A grid of vertical lines was placed on the micrograph and the number of WC intercepts and Co intercepts counted. From these measurements the average grain size, the true mean free path and the contiguity were determined.[1]

3 RESULTS

3.1 Characterization of the samples

Figure 1 gives the average grain size of each grade in each set of grades. It shows that the average measured grain size varied within a set by no more than ±15%. The apparent variation may be linked to the uncertainty in the grain

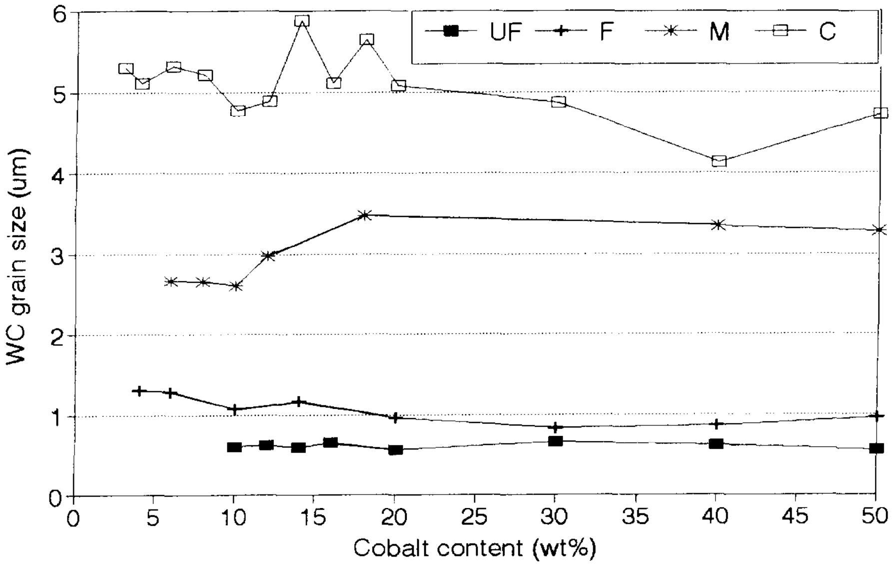

Fig. 1. Summary of the measured carbide grain size and the cobalt content of the WC–Co grades tested. The grades are divided into four sets of nominally constant grain size.

size determination because it has approximately the same value for all the sets of grades.

Figure 2 shows the variation of the measured true mean free path with cobalt content for each set of grades and Fig. 3 shows the variation of contiguity with mean free path. Although the scatter is large, Fig. 3 shows that for equal mean free path, finer grades have lower contiguity, at least in the mean free path range of commercial alloys.

3.2 Mechanical tests

Figures 4 and 5 show, respectively, the variation in hardness and abrasion resistance with cobalt content for each set of grades. For equal cobalt content, hardness and abrasion resistance increase with decreasing grain size.

Figures 6 and 7 show the variation in hardness and abrasion resistance with mean free path. The finest grained material is the softest

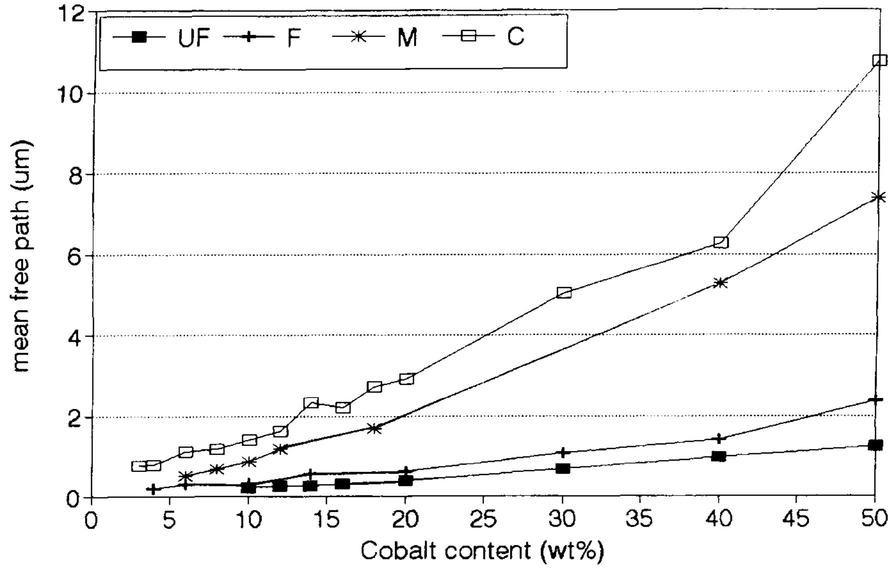

Fig. 2. Plots of the measured (true) mean free path vs the cobalt content of the WC–Co grades tested, at approximately constant grain size.

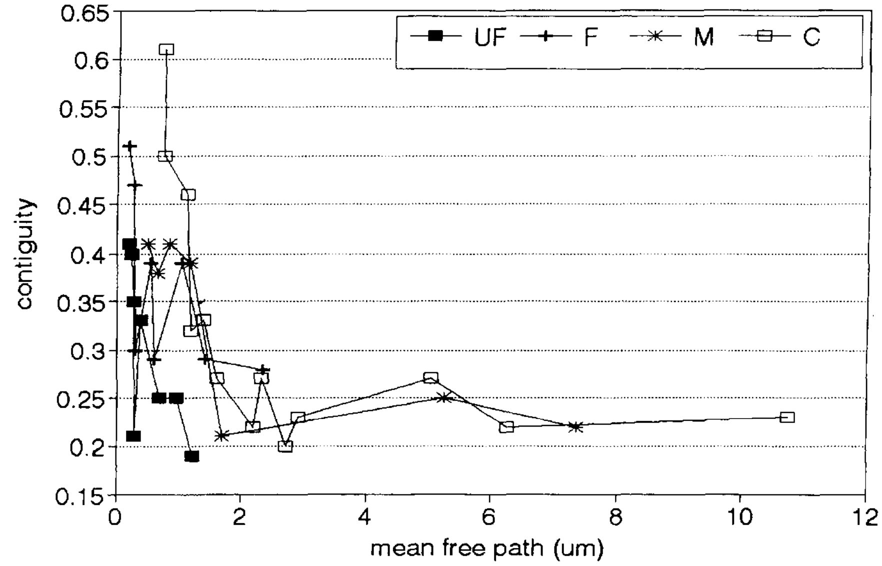

Fig. 3. Plots of the contiguity vs the measured mean free path of the WC–Co grades tested, at approximately constant grain size.

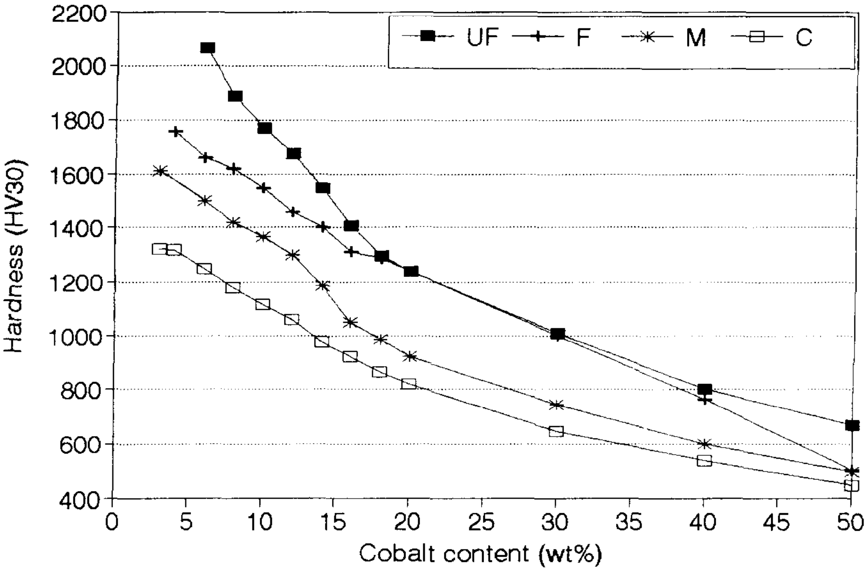

Fig. 4. Plots of the hardness of the sets of WC–Co grades tested, vs the cobalt content, at approximately constant grain size.

and the coarsest the hardest, and the finer grained materials exhibit lower wear resistance.

Figure 8 is a plot of abrasion resistance versus hardness for each set of grades. It shows that at hardnesses lower than ~1000 H_V the abrasion resistance does not vary with grain size while between 1000 and 1600 H_V, coarser grades have higher abrasion resistance than finer grades of equal hardness.

4 DISCUSSION

Figure 1 shows that the size of the WC grains did not vary by more than 15% within the same set of grades. The largest variation appears to be in the set of coarse grades, but this is due to the measuring conditions. Grain size was measured in all sets on micrographs having the same magnification, thus a much smaller number of

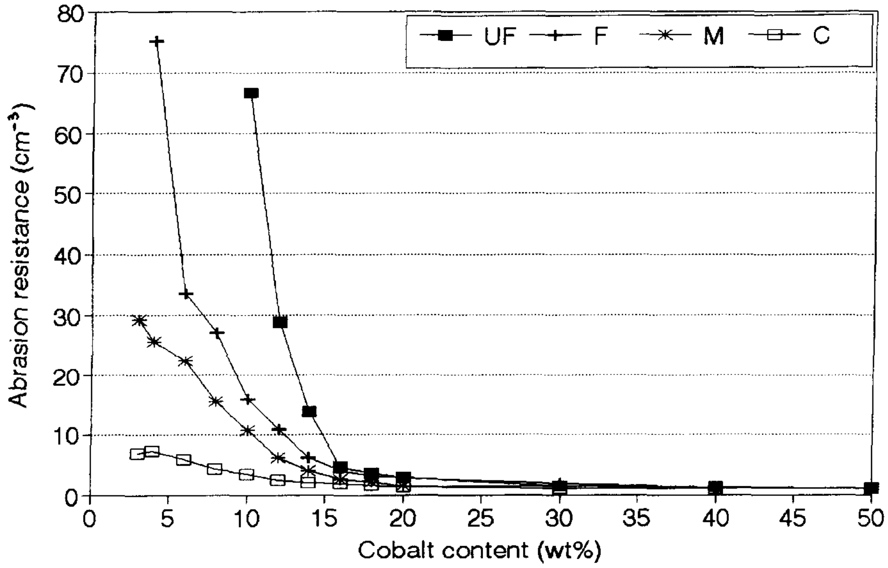

Fig. 5. Plots of the abrasion resistance of the sets of WC–Co grades tested vs the cobalt content, at approximately constant grain size.

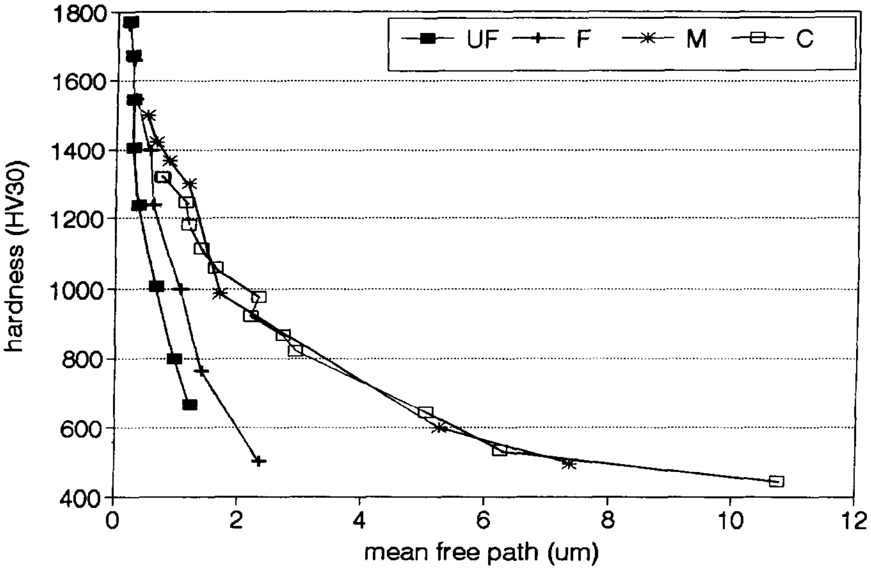

Fig. 6. Plots of the hardness of the sets of WC–Co tested vs the true mean free path, at approximately constant grain size.

grains was measured in the case of coarse grades than in finer grades.

Figure 4 confirms that the hardness of WC–Co decreases with increasing cobalt content and with increasing grain size. This has been reported by many authors[2,3] but none of the previous investigations covered a range of grades as wide as the present one. Similarly, Fig. 5 confirms that the abrasion resistance decreases with increasing cobalt content and with increasing grain size,[4,5] but, again, none of the previous investigations covered such a wide range of grades.

By extrapolating the curves in Fig. 4 to zero cobalt content it can be shown that the hardness of polycrystalline WC increases with decreasing size of WC grains, which confirms Lee and Gurland's results.[6] The abrasion resistance of polycrystalline WC (obtainable by extrapolating the curves in Fig. 5) also appears to increase with decreasing WC grain size, which has not been reported previously.

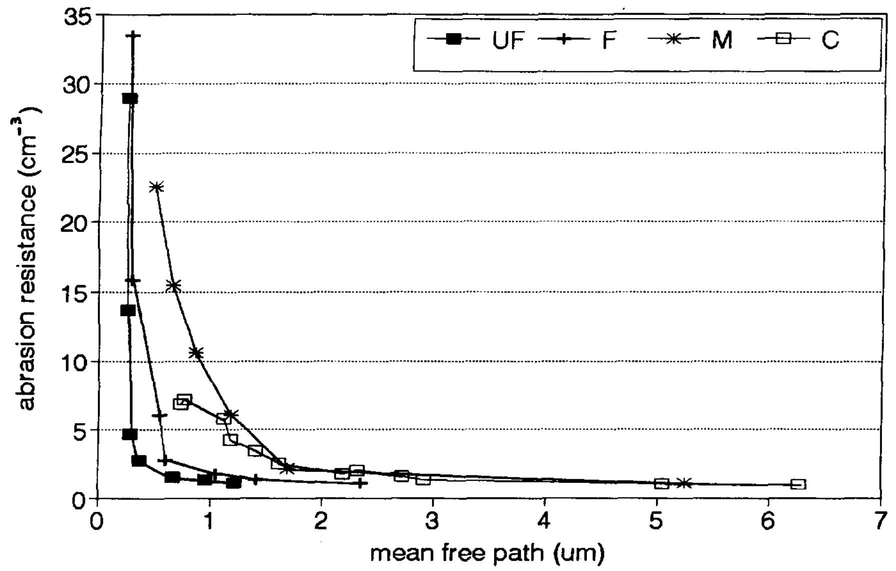

Fig. 7. Plots of the abrasion resistance of the sets of WC–Co grades tested vs the true mean free path, at approximately constant grain size.

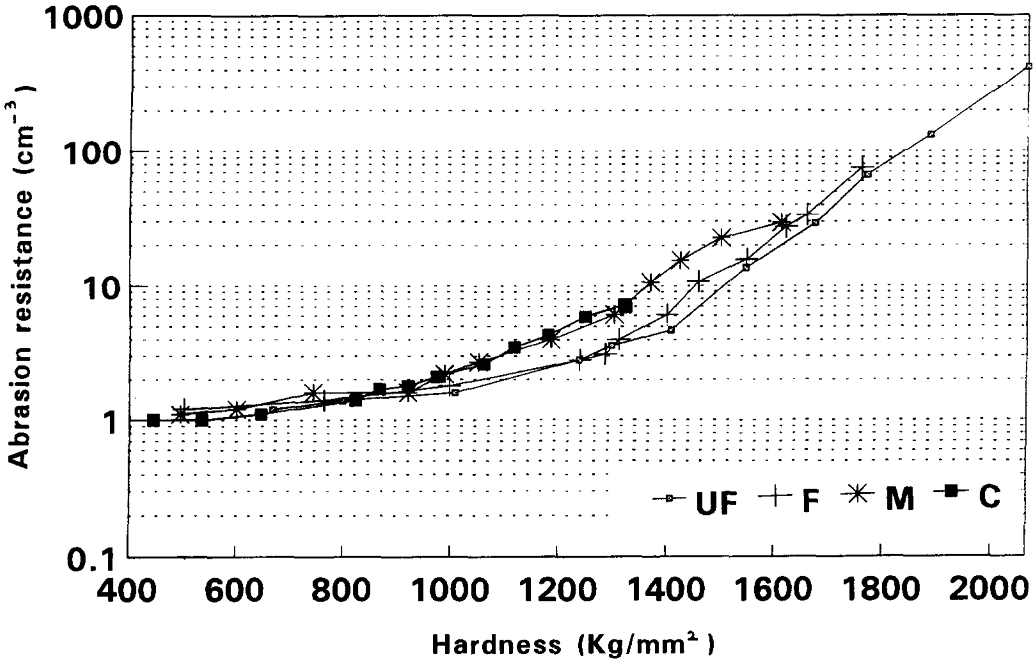

Fig. 8. Plots of the abrasion resistance of the sets of WC–Co grades tested vs their hardness, at approximately constant grain size.

The results in Fig. 6 are in general agreement with results of Keshavan & Jee,[7] although those authors could not differentiate between grades of different grain size. From Fig. 6 it appears that the dependence of hardness on grain size decreases with decreasing mean free path. By extrapolating the curves in Fig. 6 to zero mean free path it is possible to show that Fig. 6 agrees with Fig. 4 in that at zero mean free path finer grained materials have higher hardness, in agreement with Lee and Gurland's results.[6]

Figure 7 shows that the behaviour of abrasion resistance differs from the behaviour of hardness in that the abrasion resistance appears to be more sensitive to changes in grain size at low mean free path values than at high ones.

The results in Fig. 8 are also in general agreement with the literature,[7–9] in that at high hardness, small hardness increments yield large improvements in abrasion resistance. However, previous investigators could not differentiate between different grain sizes. Figure 8 shows that there is a one-to-one correspondence between hardness and abrasion resistance, without dependence on grain size, only up to a hardness of about 1000 H_V. Above 1000 H_V, coarser grades have a higher abrasion resistance than finer grades, up to a hardness of about 1600 H_V, where the curves in Fig. 8 would intersect and finer grades would acquire the higher abrasion resistance that was observed by Perrott.[9] This implies that the abrasion resistance increases with increasing hardness at a higher rate for finer materials.

The results in Fig. 8 suggests that up to 1000 H_V, the main wear mechanism is plastic deformation, which is affected only by the hardness of the material, while above that hardness microfracture sets in. The resistance to microfracture depends on the toughness of the material and, in fact, it has been shown that coarser grades are tougher than finer grades of equal hardness up to a critical hardness whose value depends on the grain size of the materials being compared.[10] Above that critical hardness, which in this case would be 1600 H_V, finer grades are tougher.[10] These results, then, suggest that microfracture (due to Hertzian and/or Palmqvist cracks being produced by the pressure of the abrasive particles onto the WC–Co surface)[11] causes a smaller volume loss than plastic deformation.

The critical hardness values at which changes occur in the wear mechanisms and in the ranking of the materials, must depend on the experimental conditions, particularly on the hardness of, and the pressure applied to, the abrasive particles.

It has been reported in the literature that the abrasion resistance of WC–Co turns from 'low' to 'high' at a critical H_a/H_{wc-co} ratio,[12] H_a being the hardness of the abrasive and H_{wc-co} the hardness of the WC–Co alloy. The value of the critical H_a/H_{wc-co} ratio appears to depend on grain size, since in Fig. 8 the abrasion resistance of fine grained materials turns from 'low" to 'high' at a higher hardness than that of coarse grained materials, although the hardness of the abrasive was the same.

5 CONCLUSIONS

The present investigation allows one to rank a wide range of commercial WC–Co grades on the basis of their abrasion resistance. Figure 5 can serve as a guide in the selection of the cobalt content and carbide grain size of WC–Co grades used for applications that are simulated by the ASTM Standard B 611-85 test.

It is important to emphasize, however, that this ranking may be valid only under the experimental conditions prescribed by the ASTM Standard B 611-85. The ranking may be affected by a number of factors, such as the size and nature of the abrading particles,[13] the speed at which the surface moves relative to the abrasive,[14] or the pressure on the abrasive particles.[14]

Hardness can be used as an indirect measure of abrasion resistance only at low hardness values (Fig. 8), i.e. when the wear process occurs predominantly by means of plastic deformation. At higher hardness values, i.e. when microfracture plays an important role in the wear process, abrasion resistance depends also on the carbide grain size, so that grades of equal hardness but different grain size have, in general, different abrasion resistance. Within the range of grades tested and under the present experimental conditions, coarser grades have a higher abrasion resistance in the ~1000–1600 H_V hardness range while finer grades are expected to have a higher abrasion resistance at hardness values higher than 1600 H_V.

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