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New results on the relationship between hardness and fracture toughness of WC–Co hardmetal

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Abstract

Two sets of WC–Co grades were produced, with cobalt content ranging from 3 to 50 wt.%. The mean grain size of the two sets was 2.2 and 6 μm respectively. The two sets of grades were used to investigate the relationship between hardness and fracture toughness. It was found that at constant WC grain size the relationship is linear. It was also found that in the low toughness range, grades of equal toughness have higher hardness if their grain size is finer and vice versa for grades of high toughness.

Keywords: Hardness; Fracture toughness; Grain size

1. Introduction

Fracture toughness and hardness of WC–Co hardmetal vary in opposite ways when the composition and/or the microstructure of the material is varied. However, not all published results agree on the type of relationship existing between fracture toughness and hardness. For example, Ingelström and Nordberg [1] found that the fracture toughness of WC–Co decreases with increasing hardness "almost linearly", which seems to be confirmed by Pickens [2], while Warren and Johannesson [3] and Chermant and Osterstock [4] found clear non-linear relationships.

Chermant and Osterstock and Pickens do not agree even when reporting toughness and hardness results at constant WC grain size. Chermant and Osterstock [4] again found a non-linear relationship while Pickens' relationship [2] could be linear, although the scatter in his results precludes determining this with certainty.

Chermant and Osterstock employed commercial WC Co grades with cobalt content ranging from 5 to 25 wt.%. They measured the WC grain size by linear analysis and divided the grades into three grain sizes: 2.2, 1.1 and 0.7 μm. Six grades were placed into each grain size group but no indication was given of the actual mean grain size of each grade, thus it is not known how much the mean grain size differed among alloys placed into the same group.

Pickens employed alloys from four different sources. In total, he tested 28 alloys, all different in composition and/or microstructure. He measured by linear analysis the WC grain size of each alloy and when he plotted fracture toughness vs. hardness "at constant grain size" he used alloys whose mean grain size appears to have differed by no more than 10%.

This investigation is aimed at establishing if the relationship between fracture toughness and hardness in WC–Co is linear or not, at constant WC grain size. Much effort went into producing grades differing widely in cobalt content (from 3 to 50 wt.%) but with constant grain sizes.

2. Method

2.1. Preparation of the samples

Coarse and fine grain sized sets of WC–Co hardmetal grades were produced from two different starting powders. Two different milling conditions were used to produce the two different sets of grades. The milling parameters were altered to suit the particular grade and the end microstructure required. All the grades were

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milled in a laboratory-scale attritor mill. The mill pots contained 3 kg of 3 mm WC–Co balls. The paddle rotated at ~ 100 rpm, the milling time varied from 3 h for the fine grades to 2 h for the coarse grades. The mill powder charge was 250 g. The powders were wet-milled in hexane with 2% wax. After milling, the powder slurry was screened and then dried and screened again.

Two types of test components were pressed, a test block which measured 45 × 22 × 6 mm for the hardness tests and the microstructural analysis, and K_{IC} test pieces which were 10.0 mm diameter × 16 mm height. A minimum of one test block and three K_{IC} test pieces were pressed from each grade.

The sintering temperature was altered to reduce the effect of grain growth within a specific set of grades with different cobalt contents. All the sintering was done in a laboratory-scale Degussa type VKPgr 10/10/25 sinter-HIP furnace.

The actual sintered grain size was measured in each alloy by linear analysis.

2.2. Testing methods

The hardness testing was done in accordance with the ISO standard 38783 for the determination of the Vickers hardness of hardmetal. A Leco hardness testing machine type V 100-A2 with a 30 kg applied load was used. The resolution of the measuring device was ± 0.5 μm.

The fracture toughness testing was done in accordance with the ASTM B 771 standard. Samples were centerless ground on the outer diameter and surface ground on the ends to dimensional specifications. The samples were slotted using the Terratek slotting machine and tested using the Terratek load distribution machine.

The hardness test results were plotted against the fracture toughness results for each of the two sets of grades.

3. Results

3.1. The samples

Linear analysis showed that the mean WC grain size of the two sets of grades was 2.2 and 6.0 μm respectively, and that the variation in mean grain size within a set of grades was not larger than 15% although the cobalt content varied from 3 to 50 wt.%.

3.2. K_{IC} vs. H_V relationship

Fig. 1 summarizes the results of the fracture toughness and hardness tests. The results from the two sets of grades are plotted together for the sake of comparison. If extrapolated, the two lines in Fig. 1 intersect the axes at different points. They intersect each other at $H_V \simeq$ 1300 kg mm and $K_{IC} \simeq 14.3$ MPa$\sqrt{m}$.

4. Discussion

Fig. 1 shows that the relationship between fracture toughness and hardness is linear, provided that the WC grain size is kept constant.

Pickens' results [2] had already suggested a linear relationship, but the scatter was too large to reveal that the rate of decrease in hardness with increases in toughness varies with grain size. The scatter in Pickens' results was larger than the scatter in the present results probably because of varying material quality (since Pickens obtained his samples from four different sources) or grain size distributions wider than those of the present samples.

The non-linear relationships obtained by Chermant and Osterstock [4] at "constant" grain size were probably owing to a too wide range of grain sizes being included in the same "constant grain size" group (see Introduction). However, Chermant and Osterstock's curves agree with the present results in that they also indicate that the rate of decrease in hardness with increasing toughness is higher in finer material.

Interesting conclusions can be drawn by extrapolating the lines in Fig. 1. By extrapolating them to fracture toughness values of the order of 2–3 MPa$\sqrt{m}$ (the approximate fracture toughness of polycrystalline WC, without binder) one obtains a higher hardness for the fine material than for the coarse one. This is consistent with Lee's results [5], according to which the hardness of hot pressed WC decreases linearly with increases in the square root of the mean crystal size.

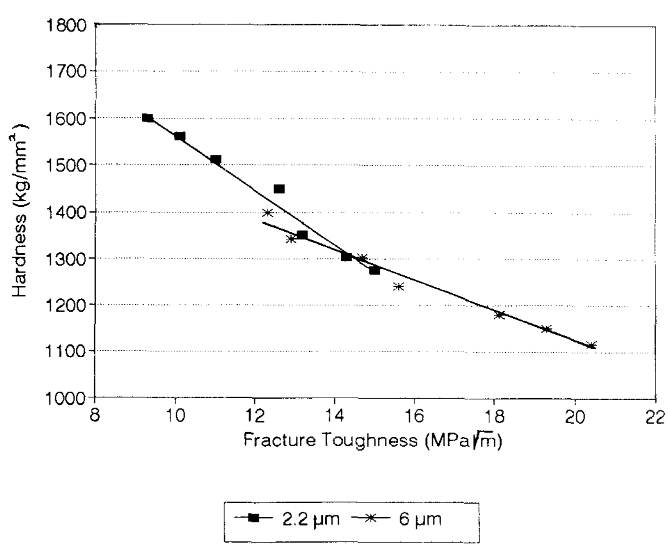

Fig. 1. Plot of the results from the hardness and fracture toughness tests on WC–Co samples with 2.2 and 6 μm grain size and cobalt content varying from 3 to 50 wt.%.

By extrapolating the two lines in Fig. 1 to hardness values of the order of the hardness of the binder (which is 400–500 kg mm^{-2} or higher, according to the binder layer thickness) one obtains a higher fracture toughness for the coarse material than for the fine one. This is consistent with the toughness of the binder being certainly dependent on the amount of tungsten in solution, which is higher in coarse material than in fine one [6]. For example, Rüdiger et al. [6] reported that the tensile strength of the cobalt binder increases with increasing its W content.

An important result of this investigation is that the lines in Fig. 1 intersect each other. This indicates that for hardnesses higher than 1300 kg mm^{-2} the toughness at a particular hardness increases as the grain size decreases. In contrast, for hardnesses lower than 1300 kg mm^{-2} the reverse is true.

Similarly, for material of low toughness (lower than 14.3 MPa$\sqrt{m}$) grades of equal toughness have higher hardness if their grain size is finer and vice versa for grades of high toughness.

5. Conclusions

The present results show that the relationship between hardness and fracture toughness of hardmetal is of the following type:

$H_V = -mK_{IC} + c$

where m and c are functions of the WC grain size (and possibly other microstructural parameters). Work is in progress to extend the investigation to other WC grain sizes in order to determine the functions m and c.

These results show also that for relatively hard grades fine grain sizes provide the best combinations of hardness and toughness, while for relatively soft grades the opposite is true. This is important for material selection.

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