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A friction effect in low-load hardness testing of copper and aluminium

H. SHI, M. ATKINSON
Department of Metallurgy and Materials Engineering, The University of Wollongong, PO Box 1144, Wollongong, New South Wales, Australia 2500

Vickers hardness tests were conducted on samples of copper and aluminium in a cold rolled or annealed condition to determine the apparent hardness variation in the load range 15 g to 20 kg. The variation was greatest for the soft specimens. Lubrication with an extreme-pressure lubricant was effective in reducing the hardness values to a virtually constant level for each metal. It is therefore reaffirmed that the hardness variation is attributable to friction and that strain hardening propensity is important in governing the magnitude of the variation. Comparison of these findings with data previously reported for similar tests on iron suggests that the phenomenon is probably an indentation size effect.

1. Introduction

Microindentation hardness testing is a convenient means of investigating the mechanical properties of a small volume of material [1, 2], but variation of the hardness value with load is widely reported. Buckle [3] has identified three ranges of Vickers hardness testing conditions: "microhardness" (< 200 g), "low-load hardness" and normal hardness (> 2 kg load). At that time only the "low load" conditions were definitely associated with increasing hardness for lower load. However, recent reviewers [4–6] have recognized that the effect extends to much lower load, and have also preferred to describe the phenomenon as an indentation size effect.

The cause of the hardness variation remains uncertain. Perhaps the most popular explanation is based on error in measurement of the indentation size arising from limited optical resolution [4]. This does not seem to be an adequate explanation for hardness variation in the "low-load" range when the indentations may be fairly large.

Recent tests on iron [7] have established that lubrication may have a marked effect in reducing the hardness variation, from which it was deduced that friction is the main factor causing the variation. Strain hardening was also thought to contribute to the magnitude of the variation. There appears to be no independent support for these findings. This paper reports further tests on different metals which show similar effects.

2. Experimental procedure

Commercially pure aluminium and copper were chosen as the test materials. The former was cut from a warm-rolled plate about 6 mm thick, the latter from a bar with approximately the same thickness. One specimen of each was annealed to restore the strain hardening propensity. All specimens were polished to metallographic standard.

Two hardness testing machines, a standard Vickers machine and a Leitz low-load hardness tester, each with a Vickers indenter, were used. These are the same machines used for the tests on iron reported previously [7]. As noted then, the hardness values obtained with 1 kg load on either machine could not be separated and the variation of indentation size through the combined load range of 15 g to 20 kg appeared to be continuous.

Indentation tests with several loads revealed the expected load dependence of hardness values for both copper and aluminium. The effect was greater for the soft specimens, which showed significant hardness variation well into the normal Vickers load range. These results are shown graphically in Figs 1 to 4, where averaged results of five repeat tests are plotted. It is of practical interest to note that hardness values for the hard and soft copper specimens were very similar when tested at 15 g load.

A similar series of tests was conducted with the specimens lubricated. The same polybutene-based drawing lubricant chosen previously [7] as being likely to function effectively in the high pressure conditions of indentation was used in these tests. This was applied as a thin film by smearing it on the surface of the test piece and then wiping to remove excess. The hardness variation obtained with lubricated specimens was much smaller than for dry tests: in fact the hardness values are virtually constant. Averaged data from these tests are superimposed in Figs 1 to 4.

3. Discussion

The observed load dependence, or indentation size dependence, of hardness for tests on copper and aluminium is similar to that observed in the earlier tests on iron [7]: i.e. the hardness value increases most rapidly at the lowest loads. Although indentation of cold-rolled iron using 15 g load produced a small impression with diagonal length of only 10 μm, the smallest indentation in the soft aluminium was much larger with a diagonal length of 30 μm. It is difficult to believe that limited optical resolution could account

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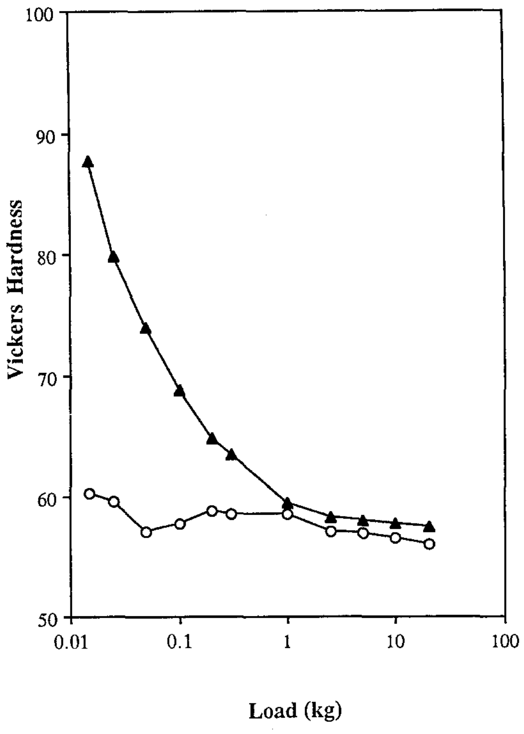

Figure 1 Affect of lubrication in suppressing the variation of hardness with test load, for soft copper (▲ dry,○ lubricated).

for the apparent hardness variation in these tests on aluminium.

The effects of lubrication and of prior deformation in reducing the hardness variation are also very similar. Hardness values for the lubricated specimens are virtually constant and coincident with the hardness values determined for dry specimens using 20 kg test load. These observations clearly support the proposition [7] that friction is the main factor governing the phenomenon. The greater hardness variation for the annealed specimens affirms the suggestion that strain hardening propensity is an important secondary factor controlling the magnitude of the hardness variation.

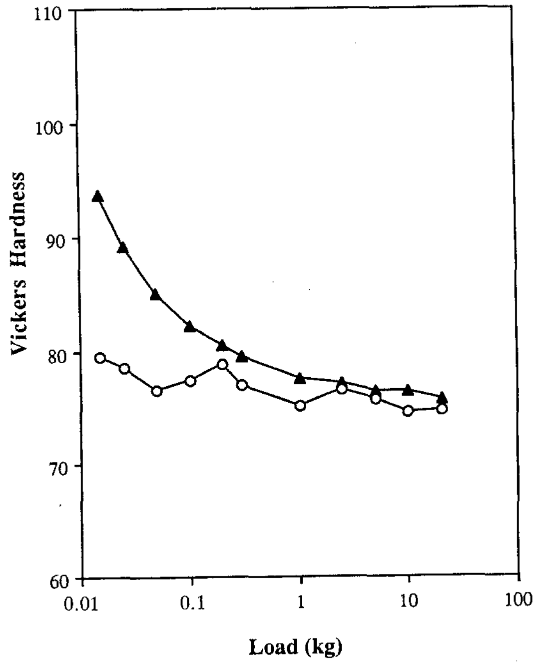

Figure 2 Affect of lubrication in suppressing the variation of hardness with test load, for hard copper (▲ dry, ○ lubricated).

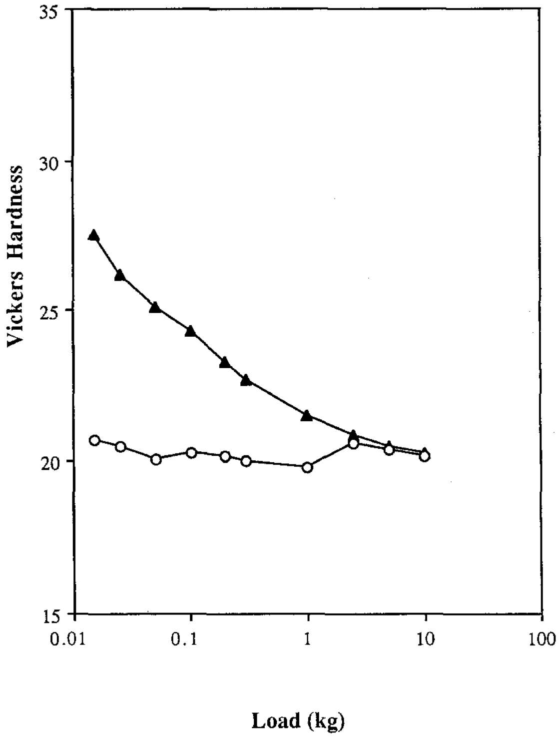

Figure 3 Affect of lubrication in suppressing the variation of hardness with test load, for soft aluminium (▲ dry, ○ lubricated).

A generalized view of the hardness variation can be obtained by comparing the data now available for three metals. In each case the hardness values tend asymptotically to a low level for large test load. It seems reasonable to estimate the minimum, which may be described as H_0, as equal to the value at 20 kg load. The variation of hardness from the minimum, ΔH, may then be normalized by reference to H_0, giving the dimensionless parameter $\Delta H/H_0$ as a basis for comparison.

The normalized hardness variations are found to fall into two distinct groups. For the soft specimens,

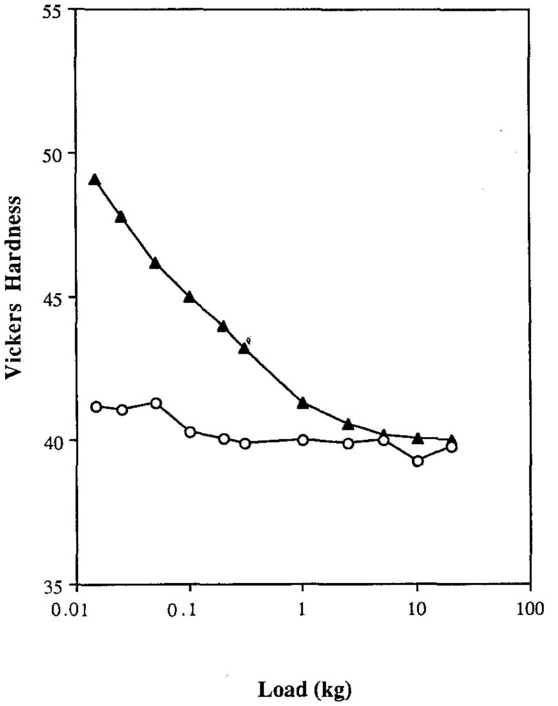

Figure 4 Affect of lubrication in suppressing the variation of hardness with test load, for hard aluminium (▲ dry,○ lubricated).

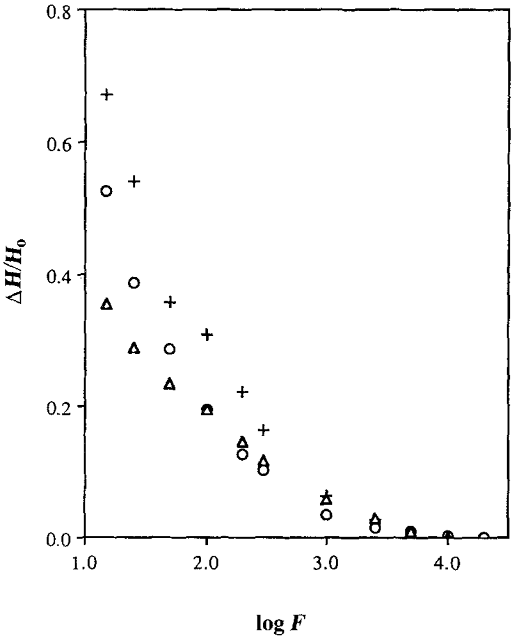

Figure 5 Relationships between normalized hardness variation and test load, for soft specimens (+ iron, ○ copper, △ aluminium).

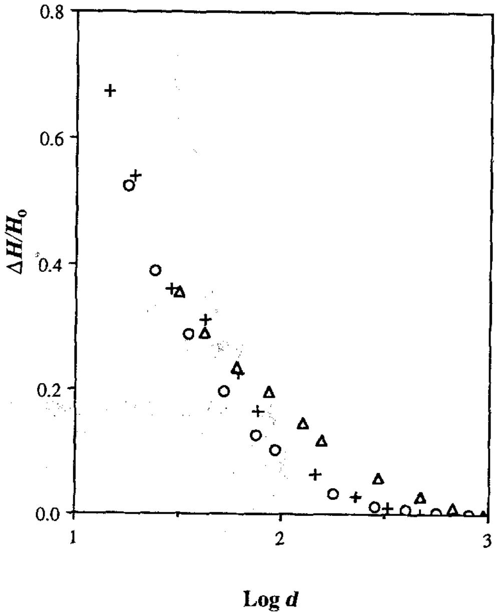

Figure 7 Relationships between normalized hardness variation and indentation size, for soft specimens (+ iron, ○ copper, △ aluminium).

which presumably have rather similar strain hardening propensities, the variation is large and the relationship with test load is distinct for each metal. This is illustrated in Fig. 5. For the hard specimens, the variation is much less and the relationships with test load are rather similar, see Fig. 6. This is curious because the processing histories of the metals are presumed to be sufficiently different to deny a common condition.

When the hardness variations are compared on the basis of indentation size a different picture emerges: now the soft specimens are seen to be similar and the hard specimens appear to respond differently. These relationships are shown in Figs 7 and 8. This comparison is probably more informative because there are stronger grounds for believing that it is the soft specimens which are in a similar condition and likely to behave similarly. It would follow that the phenomenon is better described as an indentation size effect, but it also seems that a rigorous proof might be difficult. Nevertheless, it seems clear that strain hardening is an important factor governing the magnitude of the hardness variation in low-load testing.

4. Conclusions

Vickers indentation tests on copper and aluminium in a cold rolled or an annealed condition, using loads in the range 15 g to 20 kg, indicate higher hardness at low load. A continuous trend in hardness values was observed throughout this load range.

Similar tests conducted in the presence of a polybutene based drawing lubricant markedly reduced the variation of hardness with load.

These observations are similar to those reported

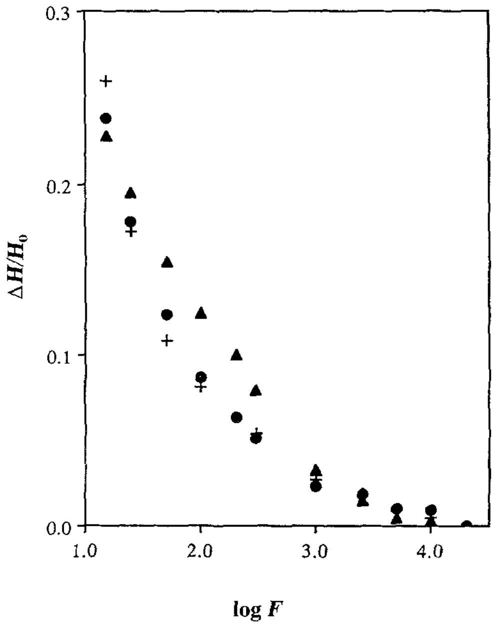

Figure 6 Relationships between normalized hardness variation and test load, for hard specimens (+ iron, ● copper, ▲ aluminium).

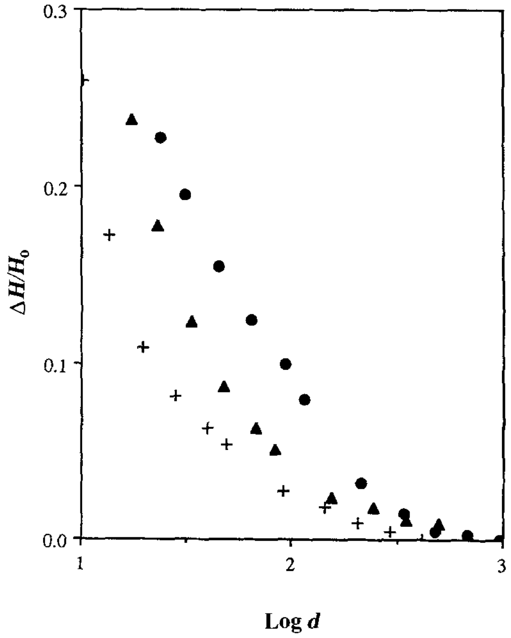

Figure 8 Relationships between normalized hardness variation and indentation size, for hard specimens (+ iron, ▲ copper, ● aluminium).

previously for tests on iron and support the view that friction is the principal factor causing load-dependence of hardness values in low-load testing.

The greater hardness variation for annealed specimens appears to confirm the importance of strain hardening propensity.

It seems likely that the phenomenon is an indentation size effect rather than a load effect.

Acknowledgement

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