Rate effects in hardness

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Hardness testing is gaining popularity as a scientific tool for evaluating the deformation properties of materials [1]. Its simplicity and economy are particularly well suited to systematic investigation of the many variables which are manifest in the general deformation response of any given material. Time is one of the more significant of these variables, for it contains the key to the kinetics and dynamics of material behaviour at the micromechanical level. Such rate effects could be an important design consideration where hardness values are taken as a basis for predicting strength, erosion and wear characteristics of solids.

Reports in the literature of rate dependencies in hardness measurements are sparse. The earliest studies, on metals, showed effects which appeared to reflect general creep properties; thus whereas indium showed substantial decreases in hardness with increasing indentation time [2] metals with higher melting points apparently did not, unless the test temperature was raised to a sufficiently high level [3]. Similar indentation creep phenomena were later reported for some ionic solids [4, 5]. A study on a wide range of other nonmetallic solids showed somewhat analogous behaviour for low-load indentations (< 1 N) [6], but the effect disappeared at higher loads; this led the authors of that study to conclude that they were observing a spurious manifestation of surface-adsorbed water. Gunasekera and Holloway [7], in perhaps the most detailed investigation of this kind, found strong rate sensitivities in the hardness of silicate glass, depending on both the environment and the state of the surface; the loads used in their study were sufficiently large (1 to 5 N) for these workers to convince themselves they were not simply recording an artifact of either the experimental procedure or the material.

The results to be described in the present paper represent preliminary findings of a proposed comprehensive programme to investigate time-dependent mechanical properties of selected engineering materials. Specificially, we report on the hardness response of a copper single crystal [(1 1 0) surface orientation], polycrystalline tungsten (grain size $\approx 1\,\mu$m) and crown silicate glass (thermally tempered, to minimize the incidence of radial cracking at the indentation corners); these three candidates were chosen simply to embrace a range of material types.

The hardness testing apparatus used in the study represents a modification of that described by Gunasekera and Holloway [7]. An electromagnetic transducer is used to drive the indenter arm vertically downward onto the surface of a rigidly mounted specimen. The compliance of the mechanical support for the coil in this system is sufficiently small that the load delivered is determined exclusively by the electrical input to the transducer, independent of any indenter movement relative to the specimen surface. In our experiments a sinusoidal signal is used to minimize complications due to inertial effects. The indenter is a standard Vickers diamond pyramid. The indentation load is monitored directly by means of a piezoelectric or strain-gauge-instrumented cell, depending on whether the contact period is less than or greater than ≈ 1 sec. These cells are generally located immediately below the specimen (see below, however). The load-time pulses, along with the corresponding activation pulses from the sine-wave generator, are recorded on an oscilloscope. With this arrangement an accuracy of $\approx 2\%$ in the load measurement is readily attainable. The indentations produced are then measured optically in the usual way, and the hardness evaluated from the averaged impression diagonals on a projected contact area basis.

Initial runs to test the performance of the above system soon revealed difficulties due to

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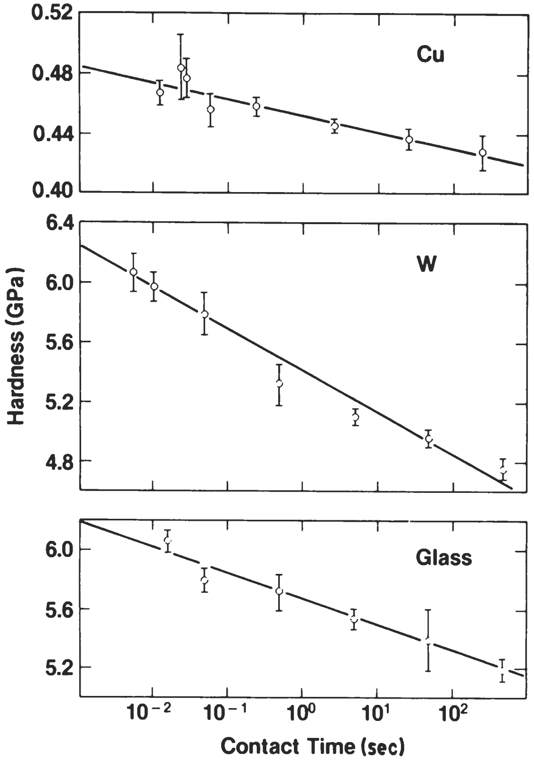

Figure 1 Vickers hardness as function of contact period for three materials. Solid lines are empirical fits to the data.

resonance effects at contact times much less than 10 msec. In this region the load pulse began to reduce in amplitude and to lag in phase relative to the input signal; spurious oscillations also became apparent. The inertia of the indenter drive system was certainly a contributing factor here, as could be demonstrated by removing the piezoelectric load cell from below the specimen and relocating it in the actual indenter arm; the recorded peak load, and thence the hardness evaluation, were much reduced by this interchange. We may note in passing that such artifically low readings could, if not properly accounted for, lead one to conclude that a given material is actually undergoing a rate-induced softening, e.g., due to localized adiabatic heating [8]. In any event, we avoid such potential ambiguities in interpretation here by including only data from indentations whose load pulses were entirely free of any resonance effects.

For the runs proper, indentations were made on mirror-finished surfaces of the three test materials, in air, at loads which could be considered to sample the bulk deformation properties, namely, ≈ 5 N for the metals and 2.5 N for the glass. The results are shown in Fig. 1. Each data point in this figure represents the mean and standard deviation of measurements from five impressions at a fixed input signal setting. Significant increases in hardness are observed with declining contact period for the three months, particularly for the tungsten and the glass. The trend for the latter is commensurate with that observed by Gunasekera and Holloway [7]. It is interesting to note that of the two metals studied it is the one with the lower melting point, copper, which is relatively insensitive to time variations.

The data contained in Fig. 1 are acknowledged to be restricted in several respects: the number of solids investigated is hardly large enough to allow general conclusions to be drawn concerning the role of material parameters in the deformation kinetics; the range of contact times is limited, such that any extrapolations into the realms of either dynamic impact or long-term loading would carry an element of extreme uncertainty; and no attempt has been made to control the environment. Nevertheless, the results serve to confirm that hardness can indeed be subject to rate effects. Furthermore, systematic study of such trends might be expected to throw some light on the micromechanics of the processes which control the deformation properties of materials.

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