Some Mechanical Properties of Solids Tested under Superposed Hydrostatic Pressures

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If a hydrostatic pressure, H, and a tensile stress, σ, are applied to a homogeneous and isotropic solid specimen the nett tensile stress will be $\sigma - H$ and the maximum shear stress $\frac{1}{2}\sigma$, i.e. the same as if there was no superposed hydrostatic pressure. Should elastic discontinuities be present, even in cubic solids, localized shear stresses will result through the application of the hydrostatic pressure alone and these stresses can be relieved by microscopic plastic flow. The pressurization-induced dislocations and their effect on subsequent mechanical properties at atmospheric pressure have been recently studied in cubic metallic and ionic solids. It has been found that generally some threshold pressure, usually in excess of 300 MN/m^2, must be exceeded for pressurization-produced phenomena to be detected in any particular system[1]. In the materials chosen for the investigation described: epoxy resin, Fe-49 wt % Co-2 wt % V, 54% V_f carbon fibre-epoxy resin and 53% V_f carbon fibre-nickel, we have no evidence of irreversible effects of 300 MN/m^2 hydrostatic pressure on their mechanical

properties.

This communication thus will deal only with the effects of H, ranging up to ~ 300 MN/m^2, on yielding and fracture of these materials assuming that shear-operated mechanisms, such as yielding and crack nucleation in crystalline solids, are unaffected by the application of H. Processes depending on the tensile stress, e.g. crack propagation, are directly affected by H, which diminishes the relevant normal stress from σ to σ-H. Should the material deform plastically under super-posed pressure, the (nett) crack propagation stress can, however, be increased as greater crack blunting may result from the extra work hardening which had taken place. Further, for the case of polymeric solids it has been suggested[2] that pressure may change the properties, and hence the shear-operated yield stress, of the material.

The tensile tests were carried out at room temperature on a Universal Hedeby machine fitted with a Coleraine pressure cell at extension rates of 10^{-4} or 10^{-3} mm/sec. Miniature specimens with no reduced gauge length (5 mm in the case of Fe-Co-V) and gauge diameters ranging from 1.5 to 2.0 mm were used. Epoxy resin rods were cast, carbon fibre-resin rod was pultruded, carbon fibre-nickel plates were prepared by hot pressing carbon fibres on which nickel had been electro-deposited. Carbon fibres were Harwell Type II surface treated with a mean strength of 2.24 GN/m^2 and a mean diameter of ~ 9 μm. The Fe-Co-V specimens, with the as-extruded banded microstructure of mean

grain diameter ~ 6 μm, were cooled from 1073 to 573°K at $\sim 4^\circ$K/hr to yield the fully ordered state. Tests at atmospheric pressure on this alloy in the temperature range 77 - 373°K showed that the fracture stress increased approximately linearly with increasing strain (in the range 3 - 20%) and accordingly fracture stresses of Fe-Co-V specimens tested under pressure have all been adjusted to the atmospheric strain-to-fracture, 19%, from values ranging up to $\sim 26\%$.

Fig.1 summarizes the tensile properties data and it should be noted that H does not affect the yield stress of the alloy (as also of nickel). There was appreciable scatter in the values of the yield and fracture stresses of Fe-Co-V: this is ascribed to the banded microstructure. The ultimate tensile strength of the resin specimens (which was the upper yield stress at pressures inferior to ~ 100 MN/m^2) varies linearly with H: the slope of the shear strength - hydrostatic pressure line, ~ 0.1, corresponds well to a value obtained, using a different technique, by Bowden and Jukes[2] who discuss the plastic flow of isotropic polymers. The dependence on H of the fracture strength of the resin matrix composite is complex below 100 MN/m^2, above which pressure it appears to be linear with the slope not significantly greater than the 0.2 of the resin. Maximum strength appears to be reached when H ≈ 30 MN/m^2 and this corresponds to $\sim 95\%$ of the theoretical strength of this composite whilst only $\sim 80\%$ is achieved at atmospheric pressure. It is suggested that
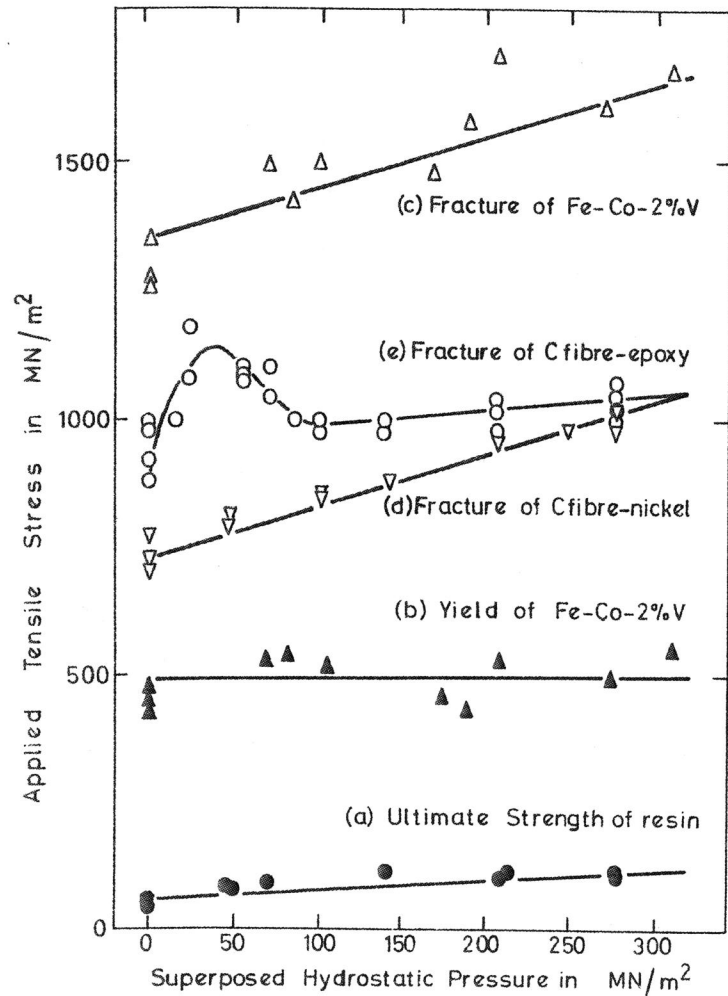
Fig. 1.   The variation with superposed hydrostatic pressure of (a) the ultimate tensile strength of an epoxy resin, (b) and (c) the yield and the ductile fracture stresses of Fe-Co-2% V and (d) and (e) the strengths of continuous carbon fibre - nickel and epoxy resin composites.

friction may play a role in the strengthening of the resin matrix composite at superposed pressures below 100 MN/m^2.

The slopes of the fracture stress - hydrostatic pressure lines for Fe-Co-V and the C-Ni composite are both approximately 1, indicating that the critical stages of their failure processes were operated by tensile stresses.   In the case of the alloy this was crack propagation[3]; observation of non-propagating microcracks in specimens which had been strained beyond the yield point illustrates that crack nucleation is easier than crack propagation in the ductile cracking (cleavage) of Fe-Co-V, in contrast to the conclusion of other workers[4].   For the metal matrix composite the critical stage in the brittle fracture is the failure of the carbon fibres, nickel subsequently flows plastically and necks to fail by transgranular shear at pressures below $\sim$140 MN/m^2 and by intergranular parting at higher pressures.   The fracture strength of the composite (at all pressures), according to the law of mixtures, evaluates to $\sim$56% of the theoretical strength.

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