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TENSILE FRACTURE OF FREE MACHINING BRASS AS A FUNCTION OF HYDROSTATIC PRESSURE*

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The effects of hydrostatic pressures in the range 0.1 to 600 MPa on the tensile fracture of a free machining brass have been studied. In agreement with the results of earlier workers, the natural strain to fracture was found to increase rapidly with pressure for pressures up to 300 MPa, but to increase less rapidly at the higher pressures. The rapid increase in ductility under confining pressures up to 300 MPa is shown to be due to the suppression of void development, by the pressure, until later stages of deformation. The decrease in slope of the fracture strain pressure relationship above 300 MPa pressure was found to coincide with the localization of void formation to a narrow region at the centre of the neck.

ÉTUDE DE LA RUPTURE PAR TRACTION DU LATION NON USINÉ EN FONCTION DE LA PRESSION HYDROSTATIQUE

Les auteurs ont étudié l'influence de la pression hydrostatique (entre 0,1 et 600 MPa) sur la rupture par traction du laiton non usiné. Les auteurs trouvent que la déformation naturelle à la rupture augmente rapidement avec la pression, jusqu'à 300 MPa, mais augmente moins rapidement pour les pressions plus élevées, ceci étant en accord avec les résultats obtenus antérieurement par d'autres chercheurs. Les auteurs montrent que l'accroissement rapide de la ductilité pour des pressions comprises entre 0,1 et 300 MPa est dû à la suppression du développement des cavités par la pression, jusqu'aux derniers stades de la déformation. Les auteurs trouvent que la décroissance de la pente de la relation existant entre la pression et la déformation à la rupture pour les pressions supérieures à 300 MPa coincide avec la localisation de la formation des cavités dans une région étroite située au centre de la zone de striction.

DAS BRUCHVERHALTEN VON BEARBEITETEM MESSING IM ZUGVERSUCH UNTER HYDROSTATISCHEM DRUCK

Der Einfluß eines hydrostatischen Druckes zwischen 0,1 und 600 MPa auf das Bruchverhalten von bearbeitetem Messing im Zugversuch wurde untersucht. In Übereinstimmung mit Ergebnissen früherer Arbeiten ergab sich eine starke Zunahme der Bruchdehnung mit dem Druck bei 300 MPa. Die Zunahme war bei höheren Drucken geringer. Die rasche Zunahme der Duktilität unter dem Einfluß des hydrostatischen Druckes bis zu 300 MPa ist eine Folge der Verschiebung der Hohlraumbildung in ein späteres Verformungsstadium durch den Druck. Die geringere Abhängigkeit der Bruchdehnung vom Druck oberhalb 300 MPa tritt gleichzeitig mit der Beobachtung einer Hohlraumbildung in einem kleinen Bereich in der Mitte des Bruchhalses auf.

INTRODUCTION

Voids or cavities frequently form at inclusions or grain boundaries in ductile metals under axial tensile stress at an advanced stage of straining during necking. With increasing strain in the necked region the voids grow and coalesce to form a transverse cavity which, with only a small additional strain leads to rapid failure of the material by shear tearing.$^{(1-3)}$ The form of the stress state during plastic deformation has a substantial effect on the ductility of metals. During tensile tests under ambient pressure, the triaxial tensile stress developed in the centre of the necked region is such as to assist the growth of voids. However, the stress distribution in the presence of an external hydrostatic pressure is initially compressive,$^{(4)}$ and the formation of voids is delayed until a sufficiently large tensile component of stress is introduced. The greater the external pressure the greater the degree of necking required to overcome the compressive stress (within the neck) which counteracts the formation of voids and hence the greater the strain which can be withstood before fracture.

The natural strain to fracture of many metals subjected to tension under an external hydrostatic pressure has been found to increase linearly with pressure at a rate which is a characteristic of the particular metal. The work in this field has been reviewed recently by Brandes.$^{(5)}$ However, some metals are anomalous as regards their ductility–pressure characteristics in that, above a critical pressure the rate of increase of ductility with pressure may decrease, or the ductility may even be unaffected by further increase in pressure.$^{(6,7)}$ Brass is of particular interest in that the critical pressure is relatively low compared to that of steels. Yajima *et al.*$^{(7)}$ attribute this to the rapid reduction of stacking fault energy of the Cu–Zn and Cu–Ge alloys with increasing alloy content. However, since void formation is an important component of the fracture process, this aspect of the problem deserves closer attention.

In an attempt to find an explanation of the anomaly a series of tensile tests under pressure was made on a commercial free-machining brass which contained

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lead inclusions. A scanning electron microscope (SEM) was used to examine both the fracture surfaces and the void populations in polished longitudinal sections of the brass specimens. The dimensions of the necks formed under pressure at increasing degrees of strain were also measured and the stresses in the neck regions calculated. A brass material containing a fine dispersion of lead particles was chosen in order to provide a structure having a large population of cavity nuclei.

EXPERIMENTAL

Material

Tensile test specimens of 10 mm gauge length and 4 mm diameter with threaded ends were machined from an 8 mm diameter rod of composition—57.5 wt % Cu, 39.6 wt % Zn, 2.9 wt % Pb, plus trace impurities only. All specimens were annealed at 600°C for one hour, the ultimate tensile strength being 390 MPa.

Equipment

The high pressure straining apparatus consisted of a pressurized chamber and associated gear drive, as designed by Heard.(8) Minor modifications were made to this equipment, notably in the use of 0-ring seals, in the method of housing the linear transducer on the load column, and in the addition of a tensile straining attachment.

The pressure chamber had a 15 mm diameter × 60 mm long work space, fitted with a hollow load column at one end (effectively, an internal load cell) and a movable piston sliding through an O ring seal at the other. Threaded adapters were fitted to the ends of the piston and the load column to accommodate the test specimen. The movable piston was connected to a gear train driven by a variable speed motor. The pressure medium was ethanol. Pressures were maintained to better than 0.5 per cent of the indicated pressures in all tests, as monitored by a Manganin gauge. The load on the specimen was continuously recorded by a Sanborn linear transducer mounted in an Invar housing (to minimize thermal effects) on the load column assembly.

Test methods and procedures

The tensile specimens were screwed into the threaded adapters on the load column and the top piston, care being taken to prevent damage by prestraining of the specimens during assembly or during pressurization. The strain rate in all tests was 1 mm/min. Continuous records of load against time were made during the experiments.

The experiments carried out can be classified into two series. Series I consisted of straining samples to fracture at various pressures within the range 0.1 MPa (atmospheric pressure) to 600 MPa. Series II consisted of straining samples by increasing amounts to just below the fracture strain at pressures of 200 MPa and 500 MPa.

With Series I specimens the minimum neck diameter was measured and the fracture surface of one part of the specimen was examined using an SEM. The other part of the specimen was sectioned longitudinally, polished, and examined optically and with the SEM. With Series II specimens the minimum neck diameter and the radius of curvature of the contour of the neck were obtained from tracings made of projections of the neck contours at magnifications of × 10 or × 50. These specimens were then sectioned longitudinally, polished and examined in the SEM. The metallographic preparation of longitudinal sections of specimens was such as to try to prevent microstructural features such as voids from being obscured (see Samuels(9)).

RESULTS

(a) *Series I*

The natural strain at fracture (ε_f) of the specimens fractured whilst under various hydrostatic pressures was calculated using the formula

$$\varepsilon_f = \ln \frac{A_0}{A_f} \tag{1}$$

where A_0 is the original cross-sectional area and A_f the final cross-sectional area at the neck. In Fig. 1 the ε_f values are plotted against hydrostatic pressure. This

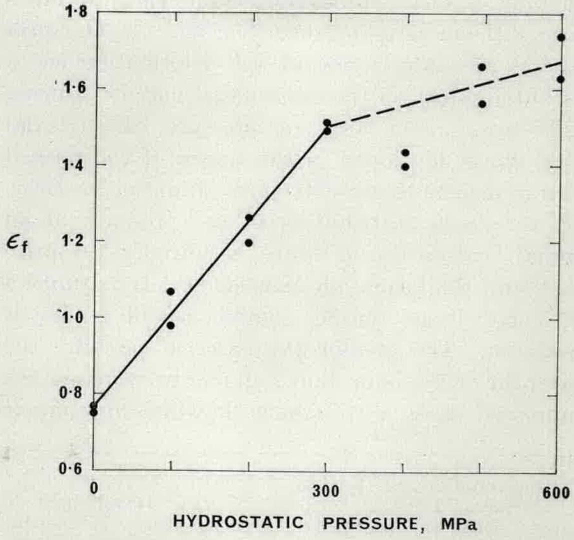

FIG. 1. The variation of natural strain to fracture (ε_f) with hydrostatic pressure.