THE EFFECT OF HYDROSTATIC PRESSURE ON THE TENSILE FRACTURE OF α-BRASS*

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A detailed study has been made of the effects of hydrostatic pressures in the range 0.1–600 MPa on the tensile fracture strain of an α-brass. Fracture strain has been found to increase linearly with pressure up to 350 MPa, to decrease between pressures of 350 and 375 MPa and to then increase to a constant value at pressures greater than 450 MPa. The abrupt change from linearity of the fracture strain–pressure relationship at a pressure of 350 MPa was found to coincide with the suppression of large scale void development. At pressures below 350 MPa, fracture was found to occur by the conventional mechanism involving void coalescence whereas at higher pressures fracture occurred entirely by a shear process. Calculations of the increase of the resultant triaxial stress component in the necked region of specimens with strain have shown that, at pressures up to 350 MPa, fracture occurs when this stress reaches a critical value of about 325 MPa.

INFLUENCE DE LA PRESSION HYDROSTATIQUE SUR LA RUPTURE PAR TRACTION DU LAITON α

On a étudié en détail l'influence des pressions hydrostatiques (de 0,1 à 600 MPa) sur la déformation à la rupture par traction d'un laiton α. La déformation à la rupture augmente linéairement avec la pression jusqu'à 350 MPa, puis décroît entre 350 et 375 MPa et enfin augmente et atteint une valeur constante pour les pressions supérieures à 450 MPa. Le changement brutal dans la relation entre la pression et la déformation à la rupture, observé à 350 MPa, coïncide avec l'arrêt du développement des cavités. Pour les pressions inférieures à 350 MPa, la rupture est produite par le mécanisme habituel de coalescence des cavités, alors qu'aux pressions plus élevées elle est produite uniquement par un processus de cisaillement. Les calculs de la variation des composantes triaxiales de la contrainte résultante en fonction de la déformation dans la zone de striction montrent que, pour les pressions alllant jusqu'à 350 MPa, la rupture se produit quand cette contrainte atteint une valeur critique de 325 MPa environ.

EINFLUß DES HYDROSTATISCHEN DRUCKES AUF DEN BRUCH VON ZUGVERFORMTEM α-MESSING

Der Einfluß des hydrostatischen Druckes im Bereich 0,1 bis 600 MPa auf die Bruchspannung von α-Messing wurde ausführlich untersucht. Die Bruchspannung nimmt mit dem Druck bis 350 MPa linear zu, zwischen 350 und 375 MPa wieder ab und schließlich bei höheren Drucken wieder zu, bis sie bei 450 MPa einen konstanten Wert erreicht. Die abrupte Abweichung des Zusammenhangs zwischen Bruchspannung und Druck von der Linearität bei einem Druck von 350 MPa erfolgt gleichzeitig mit der Unterdrückung der Entstehung großer Hohlräume. Bei Drucken unterhalb 350 MPa erfolgt der Bruch durch den konventionellen Mechanismus (aneinanderlagern von Hohlräumen). Bei höheren Drucken ist jedoch ein Scherprozeß der bestimmende Mechanismus. Eine Berechnung der Zunahme der resultierenden triaxialen Spannungskomponente im Bereich des Bruchhalses der Proben als Funktion der Spannung zeigt, daß bei Drucken bis 350 MPa der Bruch erfolgt, wenn diese Spannung einen kritischen Wert von etwa 325 MPa erreicht.

INTRODUCTION

The increase in fracture strain of various brasses when strained in tension under increasing external hydrostatic pressures has been shown to be a substantially linear relationship with pressure up to a critical pressure of 300–400 MPa.[1–3] This increase in fracture strain is due to the effect of external hydrostatic pressure on the stress system in the necked region of tensile specimens.[4] In tests under ambient pressure conditions a tensile triaxial stress is produced in the necked region of the specimen and this enhances void development which leads to fracture. However, in tests in the presence of external hydrostatic pressure the triaxial stress in this region of the specimen will be compressive until the neck is well developed, thus retarding the development of voids and allowing the necking to proceed further before fracture occurs.

At pressures above the critical pressure the fracture strain of brasses either increases much less rapidly with pressure[3,5] or is constant.[1,2] This type of behaviour (also found to occur in copper–germanium alloys[2]) has been attributed to a number of causes. Yajima *et al.*[2] suggested that, in metals with low stacking fault energy such as brasses, the process of ductile fracture might be dominated by the shear stress rather than by the triaxial stress component. Beresnev *et al.*[5] have suggested that in two phase brasses the behaviour may be related to changes in phase composition due to pressure. French, Weinrich and Weaver[3] have found that, in a leaded two phase brass at pressures above the critical pressure, void development occurs only in a narrow region of the neck of the specimen very late in the deformation process. They therefore suggest that the decrease of pressure sensitivity of the fracture strain is attributable to the suppression of void development.

As far as is known, the only previous work on the effects of pressure on the fracture of single phase

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brasses was done by Yajima *et al.*[2] However, no detailed examination of the effects of pressure on void development or calculations of the stress conditions in the neck regions have been made for such brasses. Accordingly, for the purpose of studying further the anomalous behaviour of fracture strain with increasing pressure, a single phase brass of low inclusion content was used. In seeking an explanation for the variation of fracture strain with pressure, void distributions in fractured specimens were measured and the stress situations in the central neck regions of specimens strained to varying degrees in the pressure range 0.1–600 MPa were calculated.

EXPERIMENTAL

Tensile test specimens of 10 mm gauge length and 4 mm dia. with threaded ends were machined parallel to the rolling direction from one piece of 13 mm thick rolled brass plate of composition 70.1 wt.% Cu, 29.9 wt.% Zn plus trace impurities only. Prior to testing all specimens were annealed at 600°C for 1 hr; the ultimate tensile strength was 310 MPa and the mean grain dia. 0.07 mm. The high pressure apparatus and method of use have been described previously.[3] All tests were made at room temperature using ethanol as a pressure medium, at a deformation rate of 1.7×10^{-2} mm/s.

Two types of experiment were carried out. In the first type specimens were strained to fracture at pressures within the range 0.1–600 MPa and their minimum neck diameters measured. The fracture surfaces of these specimens were examined using a Scanning Electron Microscope (S.E.M.) and polished longitudinal sections through the fractures were examined optically. The second type of experiment involved straining specimens by various amounts to just below the fracture strain at a number of pressures. Measurements of the minimum neck diameter and radius of curvature of the contour of the neck of each of these unfractured specimens were obtained from tracings made of projections of the neck contours at magnifications up to $\times 50$.

RESULTS

(a) *Fracture experiments*

Specimens were strained to fracture at pressure intervals of 50 MPa between atmospheric pressure and 600 MPa with duplicate tests being made at pressures of 0.1, 300, 400 and 500 MPa. The natural strain to fracture (ε_f) of the specimens was calculated from the relationship $\varepsilon_f = \ln A_0/A_f$ where A_0 and A_f are the initial and final minimum cross-sectional areas of the specimens. The resulting variation of ε_f with pressure is shown in Fig. 1. This figure shows that ε_f increases linearly with pressure for pressures up to about 350 MPa. At pressures between 450 and 600 MPa, the fracture strain is approximately constant. The experiments at a pressure of 400 MPa yielded lower ε_f values than those for specimens tested at either 350 or 450 MPa. To check the extent of this effect further experiments were carried out at pressures of 375 and 425 MPa. The fracture strain values from these experiments were also lower than expected as shown in Fig. 1.

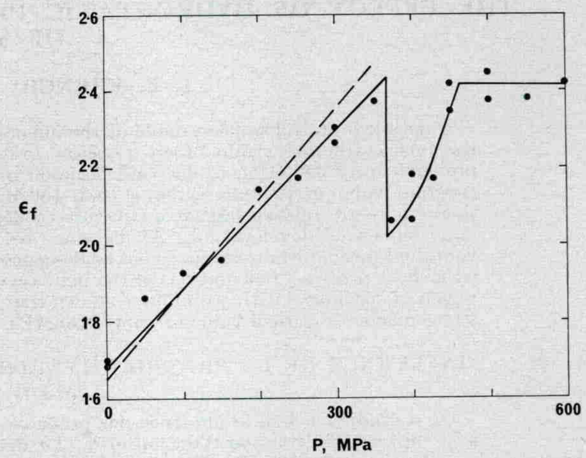

Fig. 1. Variation of natural strain to fracture (ε_f) with pressure (P).

Metallographic examination of longitudinal sections through one part of these fractured specimens showed that voids were present near the fracture surfaces of specimens fractured at pressures up to 350 MPa but that no voids could be seen in specimens fractured at higher pressures. The average area fraction of voids in the longitudinal sections of the regions of these specimens close to the fracture surfaces was determined using a Quantimet Image Analysing System. This was done by measuring the average area fraction of voids and inclusions near the fracture surface then subtracting the average area fraction of inclusions in the undeformed material. The resulting values of area fraction of voids are plotted against pressure in Fig. 2. This figure shows that the area fraction of voids decreases with increasing pressures up to about 350 MPa and is zero (within the limits of measurement) at higher pressures.

The surfaces of specimens fractured at pressures up to 350 MPa were made-up of a rough central region caused by void coalescence and a smoother outer region caused by shear tearing (see Fig. 3a). The fracture surfaces of specimens fractured at pressures above 350 MPa were found to consist entirely of the