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MECHANISMS OF STRENGTHENING AND FRACTURE IN COMPOSITE MATERIALS

Fifth Progress Report to NASA

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INTRODUCTION

This report describes research activities that were performed during the fifth phase of a program designed to investigate the mechanisms of strengthening and fracture of composite materials. As mentioned in the previous progress reports, (subsequently referred to by PR number), five different programs are being carried out. These are discussed separately in the following paragraphs.

I. The Effect of Drilled Holes on the Notch Toughness of Iron Base Alloys. (With C. A. Rau, Graduate Student).

Two 0.0292" diameter holes, drilled appropriately, have been shown to increase the notch toughness of several iron base alloys. Increased load carry capacity and reduced ductile to brittle transition temperatures have been observed (PR 4 and technical report No. 1*) in slow-bend, tension, and instrumented Charpy tests. Although the elastic stress concentration factor of the notch is reduced only slightly, holes cause a local redistribution of plastic strain and corresponding reduction in plastic stress intensification. Although a general geometric effect, the magnitude of improvement from hole drilling varies with microstructure (PR 4).

During the past six months, we have: (1) employed the instrumented Charpy test to study the effect of more complex geometries on the improvement of notch toughness. It has been shown that in mild steel (a) saw cuts between each hole and the notch side have no effect on the Charpy energy transition curve but cause a slightly lower ultimate load and a markedly lower general yield load compared with the usual drilled sample.

(b) Two larger holes (0.0465", 0.0595" diameter, $\theta = 75°$) reduce the Charpy transition temperature T_D 15 percent more than the two 0.0292" holes. The load carrying capacity is increased only slightly at temperatures below T_D and is markedly decreased above T_D. The general yield load also decreases with increasing hole size.

(c) Four 0.0292" holes located as shown in Figure 1 produce mixed effects. The load carrying capacity of the bar is increased at low temperatures but reduced at high temperatures. The general yield load is lower than that of the two hole samples while the impact energy is modified as shown in Figure 1.

(d) "Stress-relieving" the Charpy notch by machining an additional Charpy notch on each side of it improves the notch toughness. However, only 80 percent of the reduction in T_D obtained with two holes is obtained with the notches, and the general yield load is much lower in the three-notch specimen.

(e) Two 0.0292" holes improve the notch toughness of sharply notched samples (V-notch, $\rho = 0.001"$). The transition temperature is considerably lowered, and a definite bimodal behavior is observed after general yielding. In contrast to the Charpy notch, holes have no measurable effect on load carrying capacity when failure occurs prior to 50 percent of general yield. Above this load, drilled samples are as much as 100 percent stronger.

(2). Employed dislocation etch-pitting to observe the redistribution of local strain caused by four holes (figure 1) in Charpy specimens loaded to various fractions of general yield. Comparison with previous results for two holes is consistent with the observed relative

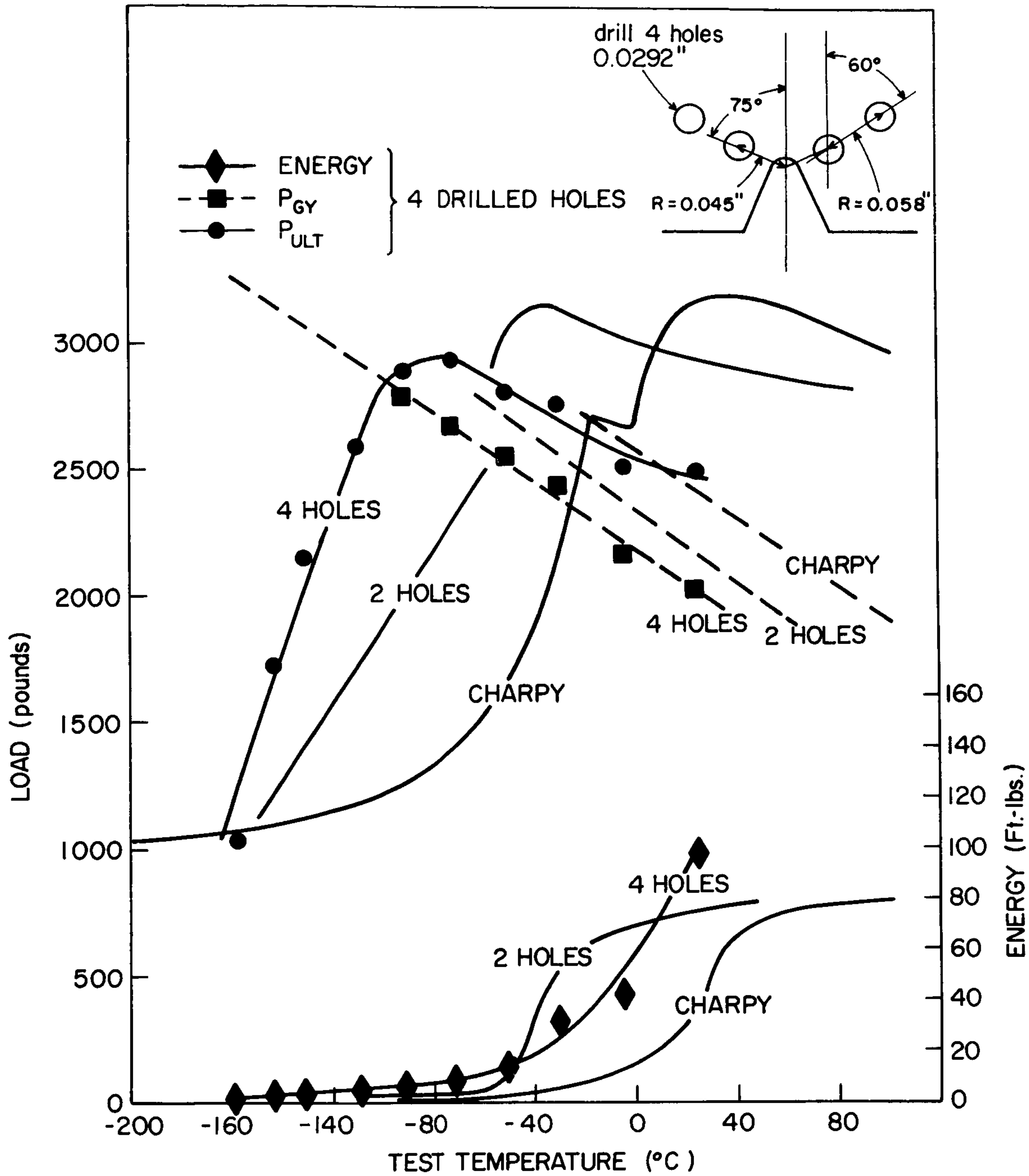

Figure 1 The effect of two and four holes on the Charpy impact transition properties of mild steel.

improvements in fracture properties.

(3). Determined the effect of specimen thickness (plane strain to plane stress) on the improved notch-toughness of drilled Charpy samples. Instrumented Charpy transition curves have been obtained for Fe-3% Si samples at 0.1", 0.2", and standard thickness (0.394"). The shape of the transition curve as well as the transition temperature of standard specimens vary considerably with thickness, but for each thickness the same characteristic improvements observed in the standard samples were noted.

(4). Determined that the drilling strains produced by introducing the holes are not an important factor in obtaining the observed improvement.

II. Fracture Mechanisms in Quenched and Tempered Steels.

(with Darel Hodgson, Graduate Student)

The use of spheroidized, hypo-eutectoid steels in the study of dispersion strengthening is desirable for several reasons. The cementite (Fe_3C) particles formed by quenching and tempering plain carbon steels are nearly ideal in shape and distribution. The amount of this hard, dispersed phase and the size of the particles may be changed easily by using alloys of various carbon contents and by varying the annealing temperature. Yield deformation and fracture properties of the iron matrix are well known, and the ductile-brittle transition allows testing of the dispersions when the matrix acts in either a ductile or brittle manner.

Slow-bend Charpy specimens have been machined from seven alloys of various carbon contents. Curves of yield load, fracture load and plastic bend angle as a function of temperature are being obtained for each alloy. This is done for both the largest and the smallest particle size obtainable with each alloy. The major portion of this testing is completed. It was found in one of the alloys that decreasing the particle size raised the yield stress from 53,000 psi to 122,000 psi while lowering the nil. ductility transition by 100°C.

Tensile specimens of each alloy are also being tested. These specimens have particle sizes corresponding to the slow-bend specimens. Tensile yield strength, work hardening properties and tensile fracture strength are thus obtained as a function of temperature for each dispersion investigated.

Upon completion of the mechanical testing, replica electron microscopy will be used to measure average dimple size and dimple depth when the alloys fracture in a fibrous manner. Techniques for this have already been studied. The number of cracked carbide particles as a function of stress and strain for each dispersion will also be studied.

It is hoped that time will allow a study of the dispersions using transmission electron microscopy. This will determine the types of dislocation arrays (pile-ups, etc.) formed at each test temperature and will allow comparison with the calculations mentioned elsewhere in this report.

III. Strength and Fracture of TiC-Ni-Mo Cermets.

(with F. Darwish, Graduate Student).

The purpose of this work is to evaluate the elastic properties, strength levels, and fracture mechanisms in TiC-Ni-Mo cermets. During the last period the following progress has been made. Transverse rupture strengths of two alloys, whose volume fractions (of hard phase) are 0.5 and 0.73, have been determined. A strength level of 300,000 psi was obtained for the large volume fraction alloy; it appears that the contiguity of the hard pahse is the important factor in controlling the strength of the composite.

Tensile specimens are being prepared by grinding the sintered compacts to required shape and dimensions. For this purpose a set of diamond tensile grips (for holding the tensile specimens in the Instron) have been made in a way to insure good alignment. Misalignment of the specimen with the pull rods would lead to premature failure at stress levels much less than the actual strength of the specimen. Currently, the strength in tension of composites with different composition and particle size is being determined. Microstrain measurements on the tensile specimens to evaluate their elastic properties (E, proportional limit, . . . etc), to determine the microcrack density as function of the microstrain, and to determine the fracture mechanism will be done shortly.

IV. Continuously Distributed Dislocations in Two Phase Systems.

(with D. Barnett, Graduate Student)

Four problems involving stress concentrations in two phase composite materials have been completely investigated using the method of continuously distributed dislocations. Closed form expressions have been obtained for the stress fields associated with:

(1) a screw dislocation pileup at a rigid circular inclusion.

(2) a screw dislocation pileup at a half-plane of finite rigidity.

3. A screw dislocation pileup at a circular inclusion of finite rigidity.

4. An infinite sequence of screw pileups on parallel slip planes against a half-plane of finite rigidity (a model for work-hardening effects).

The effect of the finite size and rigidity of a hard second phase ahead of a pileup is to lower the local stresses by a factor of 3 to 6 from the stresses predicted by homogeneous elasticity theory. A simple analysis is then applied to predict the probability of relieving the local stresses by dislocation cross-slip around the inclusion as a function of inclusion size and rigidity. A more complete relaxation analysis requires:

(1) experimental data on the functional dependence of slip line length upon the distribution of second phases present, and

(2) a statistical study of the distribution of second phases present.

V. Elastic-Plastic Cracks in Two Phase Systems.

(with T. Chou, Graduate Student)

A theoretical approach has been used to investigate the behavior of the elastic-plastic crack in a two phase system. The significance of this problem lies in determining criteria for crack propagation in fiber composites.

A model of a shear crack in a homogeneous material, originally suggested by Bilby, Cottrell and Swiden, is adopted in the investigation. The spread of the plastic region has been calculated for different crack positions and arrangements of the materials.

To date we have solved the cases of an elastic crack at a certain distance from a two phase boundary and an elastic-plastic crack with the plastic region or crack tip connected to the two phase boundary. Owing to the limited method of solutions in the field of singular integral equations and the varying boundary conditions that we have encountered in these problems, an approach leading to a general solution needs further considerations.

We believe that a general solution for this problem may be obtained by employing the numerical solution of singular integral equations. Meanwhile, attempts will also be made to obtain the closed form solutions by considering the minimum energy associated with the cracks, namely, using the variation principle approach.