MECHANISMS OF

STRENGTHENING AND FRACTURE

IN COMPOSITE MATERIALS

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I. Fracture Mechanisms in Quenched and Tempered Steels
(with Darel Hodgson, Graduate Student)

Spheroidized steels are of interest in the study of dispersed composite systems. The matrix undergoes a ductile - brittle transition with decreasing temperature; also, changes in composition and heat treatment yield varying amounts and sizes of hard particles. Thus, changes in material composition, heat treatment and test temperature allow one to investigate independently the effects of particle size, amount of hard particles, and yield strength on the composite's fracture behavior.

It has been determined that fairly large (up to 5 micron), homogeneously dispersed particles are obtained in the steels under investigation using the following heat treatment: Austenitize at 1100°C for one hour, furnace cool to 825°C, oil quench, and anneal at 700°C for 24 hours in static vacuum. Three-point, slow-bend specimens of two steels were given this heat treatment and then tested as a function of temperature at temperatures down to -196°C. The two steels contained 0.80 C, 1.0 Mn and 0.72 C, no Mn respectively. In spite of the same heat treatment and similar carbon contents, the steel containing manganese had a 15% higher lower yield strength and its nil-ductility transition temperature was 75°C lower. Microscopic examination of the structure revealed that the steel containing manganese had an appreciably finer average carbide particle size. This agrees with the qualitative findings of other investigators.

Electron microscope fractography has been used to examine the fibrous and cleavage areas of fracture of both steels which were tested. Numerous photos of dimpled (fibrous) areas have been obtained, and show carbide particles at the bottom of the dimples. Measurements will be made to compare the average dimple size with the interparticle spacing, thus giving a measure of the fraction of particles participating in fibrous fracture for each steel.

Since the aim of this investigation is to define, over as wide a range as possible, the effect of the amount and size of second phase particles on the fracture behavior of dispersion strengthened materials, a number of steels have recently been given a range of heat treatments.

The steels have carbon contents from 0.20 to 0.80 carbon and manganese contents from zero to 1.5%. These steels were austenitized at 1100°C, oil quenched and tempered for 24 hours at temperatures ranging from 450°C to 700°C. Electron microscopy and precise hardness measurements are being used at present to obtain curves of particle size and spacing and specimen hardness versus annealing temperature for each steel. When this data is obtained, further series of slow-bend specimens will be tested to determine quantitative effects of particle size and spacing on fracture initiation and propagation in these steels.

## II. Strength and Fracture of TiC - $Mo_2C$ - Ni Composites

(with F. Darwish, Graduate Student)

The purpose of this work is to determine the strength and fracture behavior of TiC - $Mo_2C$ - Ni composites. The progress that has been made since the last progress report is as follows:

The temperature controlling system for the induction heater has been fixed. The high frequency generator is being driven through a primary saturable core reactor and an SCR driver. The temperature of the final sintering process is controlled by a 3-action current adjusting type electric control that receives the signal from the thermocouple after being amplified and a D. C. reference source, with a range of $0 \rightarrow 30$ mV, that is connected to the thermocouple.

Some of the presintered specimens were final sintered using the molybdenum susceptor and under a vacuum of $2 \times 10^{-5}$ mm Hg. The first specimen was final sintered at $2500^{o}$F for an hour and later it was loaded in three-point bending until it was broken. The fracture stress on the tension side was calculated from knowledge of the load and the dimensions of the specimen and was found to be 240,000 psi. Microscopic investigation revealed the presence of some pores. Other specimens were final sintered at $2560^{o}$F also for an hour; they exhibited a strength of 350,000 psi in the three-point bending test. (Those specimens were given a prolonged pre-sintering treatment.)

Currently specimens made from powder batches of different compositions and milling times are being final sintered. The work to be performed is to diamond grind the final sintered specimens to final shape and size, then polish the specimens with $6\mu$ and $1\mu$ diamond wheels. Micro-strain gauges will be fixed to the specimen while loaded in tension and the density of micro-cracks will be determined as a function of the strain. Electron microscopy of carbon replicas and dislocation etch pitting will also be done.

## III. Theoretical Aspects of Fracture in Composite Materials
(with D. Barnett, Graduate Student)

Exact solutions for the distribution of and the stress fields produced by planar screw dislocation arrays in heterogeneous materials have been obtained for four types of two-phase systems since the last report period.

(1) A pileup against a rigid inclusion of circular cross-section. (Technical Report #2, accepted by Journal of Mechanics and Physics of Solids for publication).

(2) A pileup against a half-plane (semi-infinite second phase) whose shear modulus may have <u>any</u> value relative to that of the parent matrix. (Technical Report #3, submitted to Acta Metallurgica for publication).

(3) A pileup against a rigid laminate (i.e., an infinite strip of finite width).

(4) A pileup against a circular inclusion whose shear modulus may have <u>any</u> value relative to that of the parent phase. (This is the completely general case of (1) and (2).

By coupling the results of the above, the general problem of a screw pileup near a second phase of finite size and finite rigidity may now be discussed more quantitatively.

An investigation of edge dislocation arrays near the same type second phases as in (1) - (4) is now under way. All results will then be incorporated into a treatment of fracture of second phases in heterogeneous materials.

## IV. The Mechanism of Fracture in Composites of Mechanically Drilled Holes and a B.C.C. Metal Matrix
(with Charles A. Rau, Jr.)

Small holes, drilled appropriately have been shown to markedly increase the notch toughness of iron alloys. In PR-3* and Technical

* Progress Report No. 3 to NASA June 1, 1965 - Nov. 30, 1965.

Report No. 1*, slow bend results were reported that showed increased load carrying capacity in drilled samples at low temperatures as well as larger bend angles at higher temperatures. Dislocation etch pitting studies in Fe - 3% Si samples revealed the local redistribution of strain caused by the two holes.

During the past six months, we have:

(1) Obtained Charpy impact transition curves for a series of hypo-eutectoid steels and

  (a) shown that the reduction in ductile-brittle transition temperature through hole drilling is a function of carbon content.

  (b) Shown that holes are most effective in lowering the transition temperature when the carbon content is between 0.1 and 0.25 percent.

  (c) Shown that the percentage increase in shelf (maximum) energy is larger in higher carbon steels.

(2) Successfully instrumented a Charpy impact striker to measure dynamic load-time curves. This equipment was used to show that

  (a) the fracture load of drilled mild steel samples was more than twice as large as simply notched ones over a $60^{\circ}C$ temperature range below the ductile-brittle transition.

  (b) The dynamic general yield load was decreased by two drilled holes.

  (c) The time (plastic bend angle) prior to fracture was

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* Tetelman, A. S., Rau, C. A., Jr., Technical Report #1 (NASA NSG-622), Aug. 1965.

very much larger in drilled samples.

(3) Performed a photoelastic analysis of the standard Charpy and drilled specimen geometry and

   (a) determined that the elastic stress concentration factor of the notch is reduced by only five percent.

   (b) shown that the elastic shear stresses correspond very well with the initial yield patterns observed experimentally in standard and drilled Fe - 3% Si specimens.

(4) Performed sheet tension tests using the Charpy notch and

   (a) shown that two holes increase the nominal fracture stress approximately 30% at temperatures below the transition temperature

   (b) shown that drilled samples have markedly larger elongations prior to fracture above the transition temperature.

   (c) shown that the general yield stress is lowered by drilled holes.

   (d) shown that holes redistribute local strain in a manner <u>similar</u> to that in bending.

   (e) shown that two holes can be effective under plane stress conditions (thin sheets).

Sheet tensile work has confirmed that drilled holes are effective under both tensile loading and plane stress conditions. The magnitude of the improvement appears to be less, but whether this is due to the tension or plane stress conditions is not yet known. Future bend tests on various plate thicknesses should define the relative importance of each effect.

Future instrumented Charpy traces will be used to

(1) obtain quantitative changes in the plastic stress concentration factor below the transition temperature

(2) study a series of important geometrical variables including hole size, notch sharpness, and complex arrays of holes.