UNIVERSITY OF DENVER
COLORADO SEMINARY

Denver Research Institute
University Park, Denver 10, Colorado

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U. S. Atomic Energy Commission
Chicago Operations Office
9800 South Cass Avenue
Argonne, Illinois

Attention: Mr. Steven V. White, Director
Research Contracts Division

Subject: Contract No. AT(11-1)-742

Gentlemen:

This informal letter report is the sixth in a series of monthly letter reports describing the progress made on the research program, "Study of Factors Influencing Ductility of Iron-Aluminum Alloys", Contract No. AT (11-1)-742.

The objective of the program is to determine the effect of variations of aluminum content, heat treatment, surface preparation and other metallurgical factors upon the room-temperature ductility of Fe-Al alloys. Since alloys containing in excess of 10% aluminum are characterized by order-disorder transformations, heat treatment will provide the means for evaluating the effect of disorder and varying degrees of order upon the mechanical properties of these alloys. With a quantitative knowledge of these effects it may then be possible to improve the room temperature ductility of Fe-Al alloys by suitable control of processing variables.

It is estimated that 40% of the proposed research has been completed during the first six months of the contract period.

Deformation Structures

As a continuation of the metallographic deformation studies reported in the October letter report, two coarse-grained tensile specimens of 13.9-Alfenol were heat treated, electropolished and pulled to fracture. It was believed that electropolishing of the coarse-grained specimens might permit higher degrees of deformation before fracture, thus promoting the display of a complete range of possible deformation mechanisms.

DISCLAIMER

The coarse grains were produced by strain anneal techniques reported previously. The grains varied from about 1/8 to 1/4 inch in diameter.

Two superlattice heat-treatments were employed. The first specimen was heated for 1/2 hour at 650°C, cooled 60°/hour to 300°, held 16 hours at this temperature and air cooled to produce a Fe_3Al ordered condition. The second specimen was given the same ordering treatment and subsequently heated at 550°C for 4 minutes followed by oil quenching. This latter treatment has been successfully employed in attaining high elongations (11 percent), particularly in specimens with a recovered type grain structure. The treatment is also conducive to production of a high electrical resistivity condition in the material, i.e. it corresponds to a peak on the resistivity versus time at temperature curve.

Both of the coarse-grained specimens fractured at a small load and after very little deformation:

	Ultimate Strength	Elongation
Ordered Specimen	80,000 psi	< 0.5 %
Ordered Specimen heated 4 min at 550°C	72,000 psi	1.5 %

The coarse grain size was evidently an opposing factor to the electropolish treatment in promoting ductility. The ordered specimen fractured at the gage scratch, indicating the usual sensitivity to notch effects.

Examination of the microstructures in the vicinity of the fractures (Fig. 1 and 3) reveals that the deformation processes in the ordered specimen were greatly inhibited, as compared with the number of activated traces in the second specimen. The few traces visible in the ordered specimen are very fine slip lines which are uniformly spaced. In the second specimen, the traces appear to be composed of densely clustered slip lines or twins. At high magnification it is possible to resolve the individual traces, and they appear to have finite widths.

The deformed areas surrounding hardness indentations also confirm the improvement in plasticity attained by the additional four minute heat treatment at 550°C over that of the completely ordered material. Figure 2 illustrates a 10 Kg. DPH indentation in the ordered material while Figure 4 shows the effect on deformation of the additional heat treatment. Only one set of parallel slip traces can be seen in the ordered material. Four major sets of slip planes were activated in Figure 4 and near the corners of the indentation the individual slip lines become curved, indicating the tendency for banal slip to occur. These indentations are typical of many, and the degrees of deformation do not appear to be sensitive to grain orientation.

In summary, it is believed that ordering, particularly the Fe_3Al type, inhibits slip, increases the strength and promotes the likelihood of other mechanisms, such as cleavage, to accommodate the applied stresses. The most successful efforts to date to improve ductility have been accomplished by (1) using a fibrous, recovered grain structure whose lattice is less ordered by virtue of the number of imperfections present, (2) alloying to compositions other than the stoichiometric ordered structures and (3) heat treating material to reduce the perfection of both the Fe_3Al and FeAl structures.

Fabrication

It was stated in the Interim Report (6 June 1960) that the sheet material fabricated at DRI uniformly exhibited inferior ductilities and tensile strengths in comparison to that provided by the Naval Ordnance Laboratory. Although isolated data obtained for Thermenol and the Alfenols approached those of the NOL material, it was noted in particular that the properties of DRI alloys containing additions of yttrium were conspicuously poor. Metallographic examination of the warm-rolled yttrium—containing materials indicated that recrystallization had occurred during the final stages of fabrication. In light of subsequent work it has become apparent that superior properties are usually obtained with material in the recovered (non-recrystallized) condition. Recent work has indicated that order-disorder heat treatments are not effective in overcoming the deleterious effects of a recrystallized grain structure. The recrystallization of the material containing yttrium is attributable to insufficient control of temperature during warm-rolling and this factor also is probably responsible for the inferior properties of the other alloys. Non-uniform and low rolling temperatures may contribute towards micro-crack formation and excessive work hardening.

The superiority of the NOL material was believed to be attributable to the use by NOL of a strip heating furnace. This furnace permits the thin sheet to be heated uniformly and pass directly from the furnace through the rolling mill with negligible heat loss. A similar strip heating furnace has been constructed at DRI. The stainless steel hearth of this furnace is 4 × 4 × 48 inches long. A uniform temperature up to 800°C can be maintained in the hot zone, which is 36 inches long.

During the past month the new furnace has been employed for warm-rolling sheet material of 13.9- and 16- Alfenol, Plain Thermenol and Modified Thermol. A further refinement of the rolling technique was the introduction of a sand blasting operation into the procedure between hot and warm rolling. It has been noted in the past that DRI fabricated material frequently had rolled oxide stringers and laps which may have been partly responsible for notch effects during testing. The new material recently fabricated is clean with respect to oxide laps, and metallographic examination indicates that no recrystallization occurred.

Future Considerations

Tensile specimens are currently being machined from the newly fabricated materials and an extensive program of mechanical testing will be conducted during the coming period. Further correlative work to determine the effects of order-disorder heat treatments, microstructure and surface preparation upon ductility and strength will be performed.

It is expected that the X-ray device for quantitative evaluation of order will be ready for initiation of this phase of work during the approaching month. In conjunction with the resistivity measurements, X-ray diffraction studies will permit a better control of atomic ordering variables.

Respectfully submitted,

George P. Rauscher
Graduate Research Assistant

Frank C. Perkins
Research Metallurgist

Joseph F. Nachman
Project Supervisor

Figure 1. Fracture Region of Completely Ordered Tensile Specimen. 200X

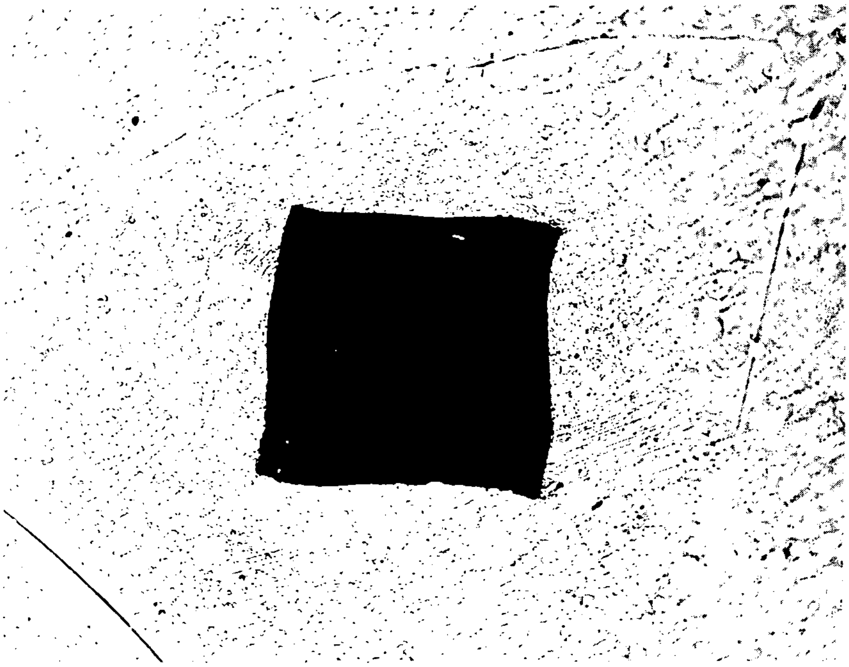

Figure 2. 10 Kg. DPH Indentation in Ordered Tensile Specimen. 200X

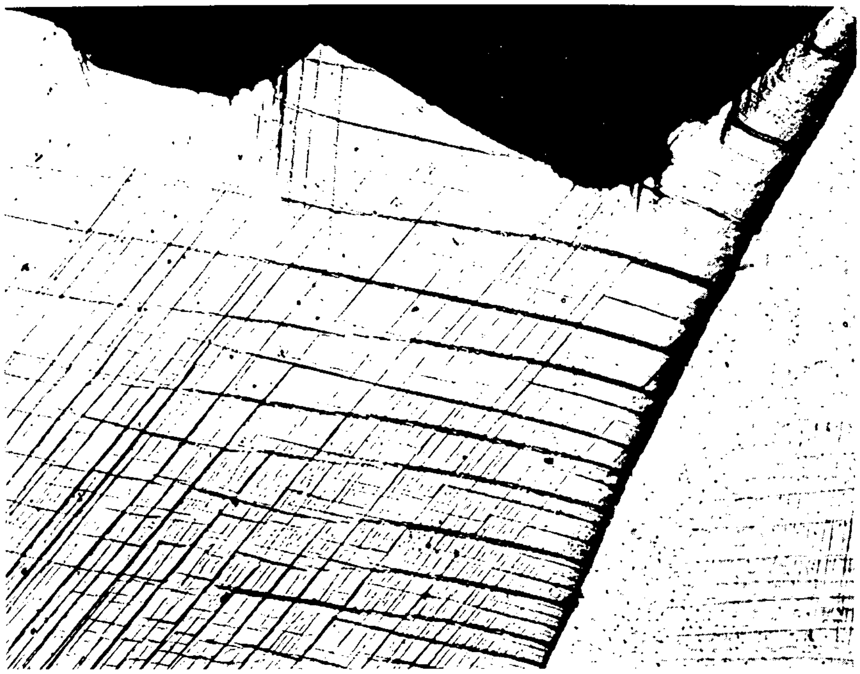

Figure 3. Fracture Region of Ordered Tensile Specimen Heated to 500°C. for 4 minutes. 200X

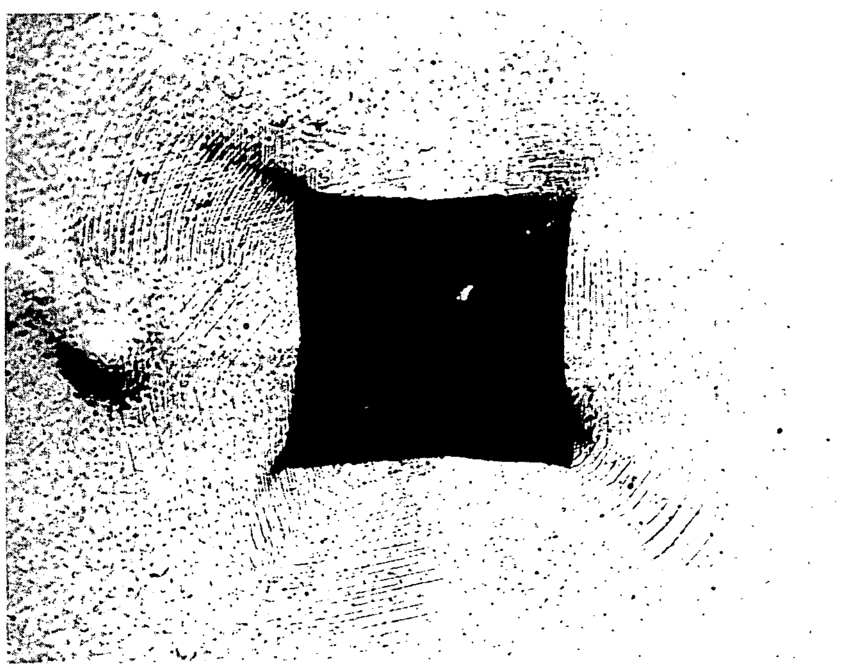

Figure 4. 10 Kg. DPH Indentation in Ordered Tensile Specimen Heated to 550°C. for 4 Minutes. 200X