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

Attention: Mr. Fred C. Mattmueller, Director
Research Contracts Division

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

Gentlemen:

This informal letter report is the first in a series of monthly letter reports for the contract period, 1 June 1961 to 30 November 1961, 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 study 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 in excess of 10% aluminum are characterized by order-disorder transformations, heat treatment will provide the means for studying 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 10% of the proposed research has been completed during the first month of the contract period.

X-Ray Diffraction Study of Long Range Order

During the past month the variation of Fe_3Al order is a function of temperature for 13.9-Alfenol was redetermined under constant instrumental conditions. The data from this determination, together with the previously reported (10 June 1961) variations in Fe_3Al order with temperature for the 16-Alfenol and Thermenol compositions are summarized in Figure 1.

DISCLAIMER

For an AB structure with partial long range order, the structure factor, as previously cited (12 May 1961), is given by

$$F = [f_{B\beta} + f_A (1 - r_\beta)] + [f_{A\alpha} + f_B (1 - r_\alpha)] \times \exp. [\pi i (h + k + \ell)]$$

For the superlattice reflections the sum of h, k, and ℓ is an odd integer and hence the structure factor for these reflections becomes

$$F = (f_B - f_A) (2 r_\alpha - 1) = (f_B - f_A) S$$

where S is the Bragg and Williams long range order parameter. The integrated intensity of a diffraction line is proportional to F^2, and hence a measurement of the integrated intensity of a superlattice reflection permits calculation of the long range order parameter S.

The superlattice reflections of the **FeAl** structure, i.e. those planes whose Miller indices give odd sums, become, in the Fe_3Al structure, fundamental diffracting planes which have Miller indices whose sums are even (see Interim Report, 6 June 1960, page 21). Therefore, below Tc for the Fe_3Al superlattice ($\approx$ 550°C) the expression for the structure factor for a diffracting plane common to both the FeAl and Fe_3Al structures will retain the exponential term, and there should be exhibited no variation in integrated intensity with annealing temperature. Above Tc for Fe_3Al, it would be expected that the integrated intensity of a FeAl superlattice line, and hence the order parameter S with respect to the FeAl superlattice, would decrease in a manner analogous to that observed for Fe_3Al.

Figure 2 illustrates the variation of the electrical resistivity of the three alloys under consideration with temperature upon slow cooling (or heating). For comparative purposes, Figure 3 shows the equilibrium integrated intensities of the (210) plane (a plane common to both the FeAl and Fe_3Al structures) as a function of temperature plotted on the same abscissa. The data for each alloy were obtained from a single crystal of unique orientation, and therefore, the absolute values of integrated intensity for the different alloys are not comparable. However, the variations of intensity with temperature for an individual alloy are significant. It is noted that for the 16-Alfenol and Thermenol compositions, there is, as predicted, no variation of the integrated intensity of the (210) plane with increasing temperature until Fe_3Al critical temperature for each alloy is attained. Above the critical temperature there is indicated a continuous decrease in integrated intensity which corresponds to a reduction in long range FeAl order. The similarity between the shapes of the resistivity vs. temperature curves obtained upon slow cooling (or heating) each of these alloys(Figure 2) would indicate that the alloys disorder in a similar

manner. The regular curvature of the plot of resistivity vs. temperature in the vicinity of T_C for these alloys would also indicate a gradual diminution of long range order.

A remarkable anomaly in the disordering process near the $Fe_3Al \rightarrow FeAl$ transformation temperature is manifested in the stoichiometric Fe_3Al (13.9 Alfenol) alloy. Above a temperature of 490°C, corresponding to the peak on the resistivity vs. temperature curve for this composition (Figure 2), there is a rapid decrease in the integrated intensity of the (210) FeAl superlattice reflection. This decrease continues through the minimum electrical resistivity region and up to the $Fe_3Al \rightarrow FeAl$ transformation temperature (approximately 560°C). Between 560°C and 600°C the integrated intensity of the (210) reflection is maintained constant, manifesting a condition of maximum long range FeAl order in the absence of Fe_3Al order. Above 600°C there is evidenced a steady decrease in FeAl order.

The best ductilities obtained to date for the binary Alfenols have corresponded with heat treatments which involve slow cooling to produce a high degree of Fe_3Al order and subsequent annealing of the ordered material for short periods of time near the $Fe_3Al \rightarrow FeAl$ transformation temperature. This treatment produces a high electrical resistivity condition. Specimens heat treated in this manner frequently manifest a non-crystallographic or banal mode of deformation. It was conjectured that since a transformation from crystallographic to banal mode of deformation tends to occur, the peak resistivity condition may correspond to a quasi-disordered condition in the vicinity of the Fe_3Al critical temperature.

X-ray diffraction determinations of long range order parameters have been performed on single crystals which were heat treated to correspond to maximum ductility conditions (13.0 to 14.0 percent elongation at fracture) for each of the binary compositions. The results of these determinations are tabulated below. It will be noted that the heat treatment employed to produce

Alloy	Heat Treatment	S_{Fe_3Al} observed	S_{Fe_3Al} equilibrium	S_{FeAl} observed	S_{FeAl} equilibrium
13.9-Alfenol	Fe_3Al ordered. 4 Min. @ 550°C, oil quenched	0.0	0.0	0.72	1.0
16-Alfenol	Fe_3Al ordered. 1 hr @490°C, oil quenched	0.49	0.49	-	-

maximum ductility in 13.9-Alfenol results in a significant reduction of long range

FeAl order compared to that obtained upon equilibrating the material at the isothermal annealing temperature. In the instance of 16-Alfenol it is apparent that the best ductilities obtained to date correspond to an equilibrium condition of considerable long range Fe_3Al order. The beneficial effects of long range order on the plastic flow properties of this alloy are not yet understood.

Future Considerations

It was indicated in the previous report that further improvement in the room temperature ductility of Thermenol may correspond to heat treatments designed to further reduce the degree of FeAl ordering, i.e. the as-rolled material must be quenched from a higher temperature. In order that a recovered grain structure may be retained at elevated temperatures it is necessary to produce sheet material having a high recrystallization temperature.

During the past month three experiments involving variations in fabrication procedures were performed on the Thermenol alloy. The experiments were designed to produce a sheet material having a higher recrystallization temperature than the material produced by the NOL rolling schedule.

The fabrication variations employed were (1) hot rolling at a temperature of 1050°C to a thickness of 0.060 inch, and subsequently warm rolling at 575°C to a thickness of 0.035 inch, (2) hot rolling at 1050°C to 0.125 inch and then warm rolling at 700°C to a thickness of 0.035 inch, (3) hot rolling at 1050°C to a thickness of 0.060 inch and warm rolling at 700°C to 0.035 inch. Tensile specimens are currently being machined from the sheet material produced by these three fabrication procedures. Major efforts during the coming month will be concerned with evaluating the mechanical properties of these materials after various annealing treatments.

Respectfully submitted,

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Graduate Research Assistant

Joseph F. Nachman
Project Supervisor

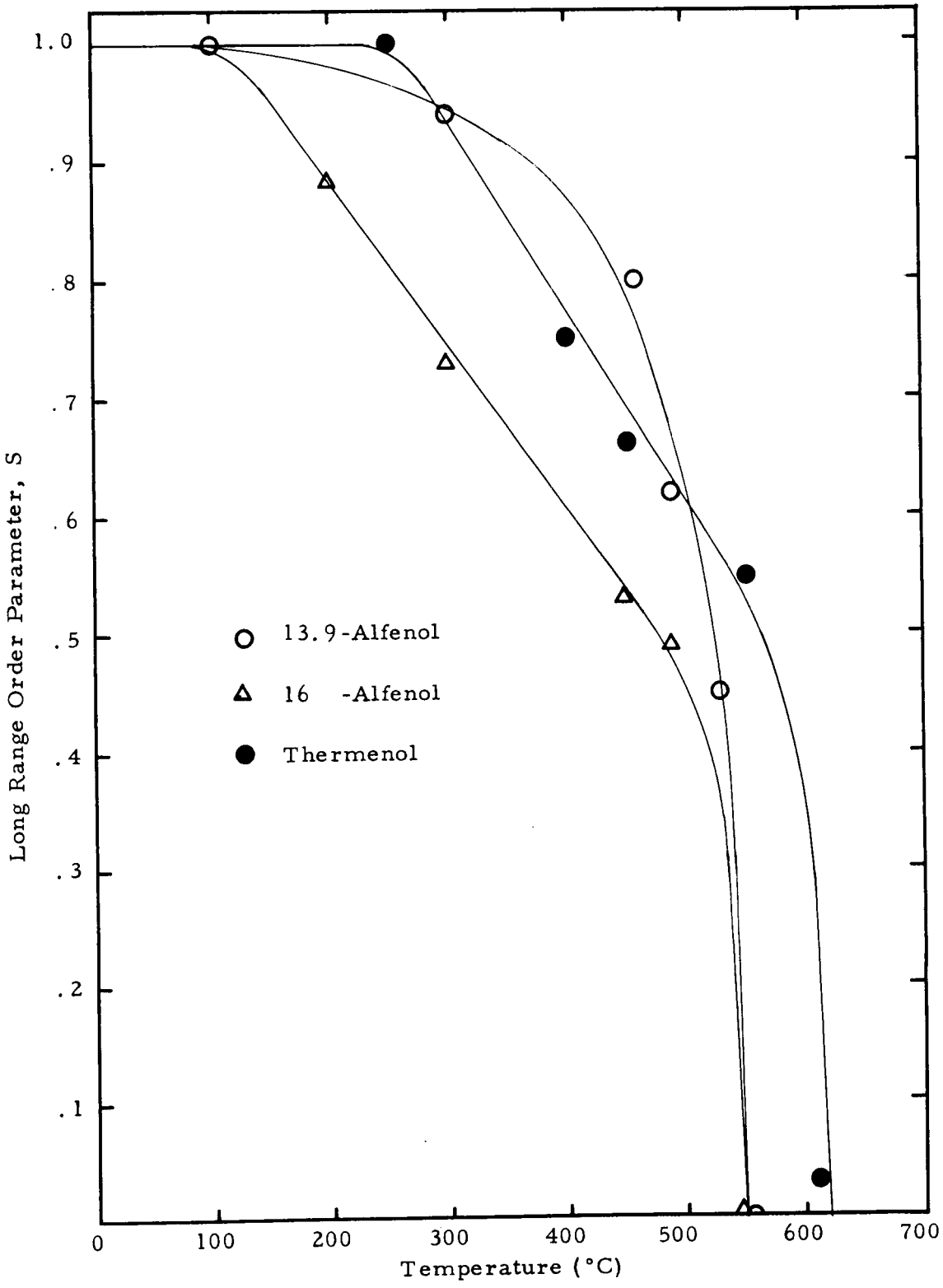

Figure 1. Equilibrium Degree of Fe_3Al Order as a Function of Temperature in Three Iron-Aluminum Alloys.

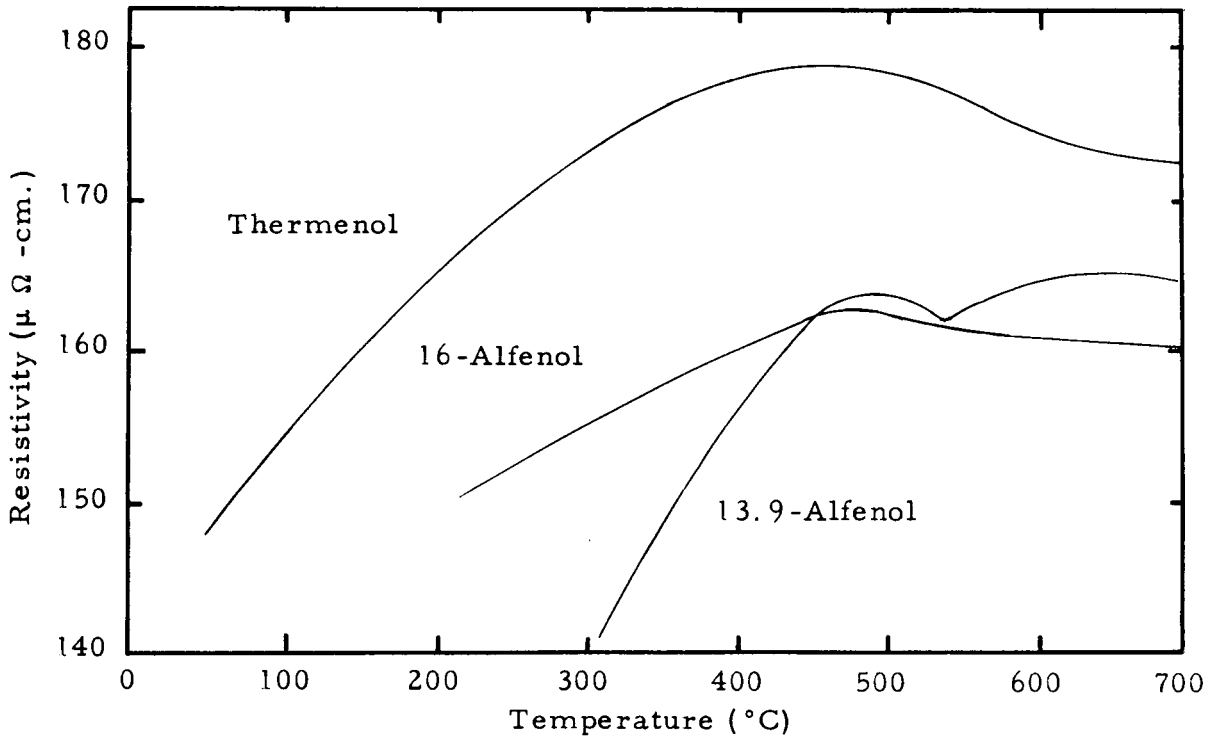

Figure 2. Resistivity as a Function of Temperature on Slow Cooling (30°/hr).

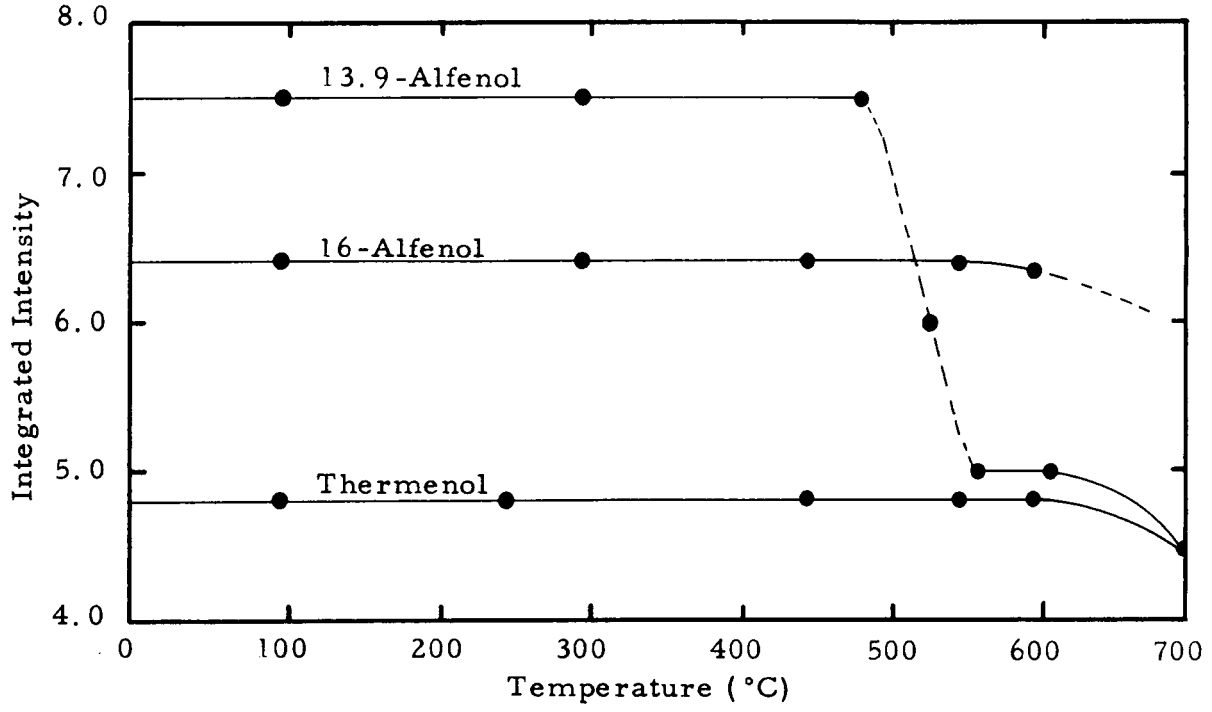

Figure 3. Variation in Integrated Intensity of the (210) Superlattice Reflection as a Function of Temperature.