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SHORT TIME ELEVATED TEMPERATURE TENSILE PROPERTIES AND NOTCH TOUGHNESS OF SOME CHROMIUM-IRON ALLOYS *

By Anthony K. Wong[1]

7 June 1957

SYNOPSIS

The Ordnance Corps is sponsoring the development of chromium-iron alloys in the interest of obtaining a strong, ductile, corrosion-resistant alloy. The results of some short time elevated temperature tensile tests and V-notch Charpy impact tests of some recently developed alloys with 40% and 50% chromium are presented in this paper. These data indicate that chromium-iron alloys have now been developed with interesting engineering properties as evidenced by ductility at room temperature and retention of strength at elevated temperatures up to 1000°F.

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* Statements and opinions expressed in this paper are those of the author and not necessarily those of the Ordnance Corps, Department of the Army.

INTRODUCTION

In the interest of developing a strong, ductile, corrosion-resistant alloy, the Ordnance Corps is sponsoring the development of chromium-iron alloys at the Metals Research Laboratories of the Electro Metallurgical Company. Recent work there resulted in some materials which were strong and ductile when tested at room temperature. In order to determine the factors affecting the application of these alloys, it became necessary to know their behavior at high temperatures. Therefore, this investigation was undertaken to determine the short time tensile properties and notch toughness of some of the alloys at elevated temperatures.

MATERIALS AND TEST PROCEDURES

Three heats of chromium-iron alloys were investigated. Sample A and B had nominal chromium contents of 50%; sample C had a nominal chromium content of 40%. These alloys were vacuum melted, cast into 4 inch square ingots, forged to size at 2060°F and heat treated at 1470°F, water quench at the Metals Research Laboratories.

Samples A and C were forged to 1-1/8 inch square; sample B was forged only to 1-1/2 inch. Table I shows the results of chemical analyses of these materials. Samples A and C were used to determine short time elevated temperature tensile properties and notch toughness; sample B was used to study notch toughness only. Some average room temperature tensile properties of these alloys are listed in Table II.

Threaded tensile specimens with a gage section 1 inch long by 0.252 inch in diameter were used in the short time elevated temperature tensile tests. Federal Specification QQ-M-151a describes the specimen in greater detail. The tensile tests were conducted in a 120,000 pound capacity hydraulic-type universal testing machine at a cross-head speed of 0.02 inch per minute within the yield strength range. Thereafter, a cross-head speed of about 0.05 inch per minute was used to fracture. Test specimens were held for about 30 minutes in a resistance-wound furnace capable of maintaining a temperature uniform within ± 3°F over the 1 inch gage length, before application of the tensile load. An averaging, separable, microformer-type extensometer with extension arms attached to the specimen was used in conjunction with an automatic recorder in order to obtain autographic load-extension curves. The temperatures of the tests ranged from room temperature to 1400°F.

Notch toughness of materials A, B, and C was determined by using subsize V-notch Charpy Specimens, 1 inch long by 0.197 inch square prepared with their lengths parallel to the longitudinal axis of the alloy bars. In addition, some standard size V-notch Charpy specimens were machined from material B, for comparison tests. The impact tests were conducted in machines of 16, 217 and 240 foot-pounds capacity. Specimens tested at temperatures up to 1400°F were held at the desired temperature in a box furnace for 45 minutes prior to removal for testing. Subsize test specimens were used in the investigation because of the limited amount of material available and in conjunction with a study of the use of small specimens for evaluation purposes. The dimensions of the subsize impact specimen used in this investigation are shown in Figure 1.

RESULTS AND DISCUSSION

The variation of strengths as a function of temperature is shown by the curves in Figure 2. Here it can be observed that the strengths of the alloys at first decrease as the temperature of test is increased. This downward trend changes in the vicinity of 500°F and as the temperature of test is further increased the yield and tensile strengths rise. At about 1000°F, the strength of the material reaches a maximum which is about the same or slightly greater than the room temperature strength. Above 1000°F, the strength of the alloy decreases markedly.

An effect of chromium content is also shown by Figure 2 wherein it is noted that for these two alloys, which have the same degree of hot working and heat treatment, the strength of the 40% chromium alloy is less than that of the 50% chromium alloy. For example, the room temperature tensile strength of the 40% chromium alloy is nearly 80,000 psi while that of the 50% chromium alloy is about 106,000 psi. The minimum and maximum tensile strengths for these alloys were approximately 63,000 and 88,000 psi and 84,000 and 108,000 psi, for the 40% and 50% chromium alloys respectively. As previously indicated, these minimum and maximum strength values occured in the vicinity of 500°F and 1000°F, respectively. The yield strengths at 0.20% and 0.01% offset show the same general trend as that of the tensile strength.

The ductility of the material, as indicated in Figure 3 by elongation and reduction of area values, in general increases as the strength decreases. At about 1000°F, where the strength is at a maximum, the ductility is at a minimum. At room temperature, the elongation and reduction of area of the 40% chromium alloy are about 30% and 70%, respectively. Corresponding figures for the 50% chromium alloy are 25% and 60%. These limited data indicate that the 40% chromium alloy is more ductile than the 50% chromium alloy under these conditions of testing.

The cause of the high strength and apparent embrittlement at 1000°F is being investigated. Limited room temperature hardness measurements indicate that when these materials are heated in the range of 1000°F for a short period of time, some permanent change occurs and the hardness level of the material is raised. Heating up to 800°F followed by slow cooling raises the hardness level only to a small degree. Initial metallographic examination of specimens from sample A after testing shows all fractures to be transgranular. No metallurgical changes are observed other than twinning only in the specimen tested at 1000°F.

The impact notch toughness of the material is relatively low at room temperature but increases rapidly as the temperature increases. These limited data shown in the impact transition curves of Figure 4 indicate that with the same degree of hot working and heat treatment, the 40% chromium alloy, (Sample C) requires a higher energy to fracture and has a lower transition temperature than the 50% chromium alloy, (sample A). The transition curves of the 50% chromium alloys, (samples A and B), appear to be almost identical. For comparison purposes, the results of tests on sample B using both conventional full size and subsize V-notch Charpy specimens are shown in Figure 5. In this figure the curve for the subsize sample B specimen looks different from its corresponding curve in Figure 4 because of the change in scale. However, no attempt at correlation due to size effects is being made at this time.

The impact data indicate that for this material a phenomena occurs at some high temperature wherein the impact energy to fracture lessens as the temperature of test is much increased above the transition temperature. The reason for this is still under study.

SUMMARY

Short time elevated temperature tensile tests were conducted on a 50% chromium - 50% iron alloy and a 40% chromium - 60% iron alloy which had the same degree of hot working and heat treatment. The strengsths of these materials decreased as the temperature of the tests increased up to 500°F. From 500°F, the strengths commenced to increase as the temperature increased, reaching a maximum at 1000°F with decrease in ductility. Tensile strength as high as 106,000 psi with 25% elongation was observed in the higher chromium alloy. In general, the strength of the 50% chromium alloy is higher than that of the 40% chromium alloy. On the other hand, the notch toughness of the 40% chromium is greater than that of the 50% chromium alloy. Therefore, it is apparent that the mechanical properties of these materials are dependent upon chromium content as well as other factors. The progress indicates that development of an even stronger ductile alloy is feasible.

TABLE I

CHEMICAL COMPOSITION OF CHROMIUM IRON-ALLOYS

SAMPLE	PERCENT				
	Cr	Fe	C	Zr	Be
A	50.03	Bal	0.03	0.21	-
B	50.75	Bal	0.011	-	0.04
C	41.05	Bal	0.015	0.14	-

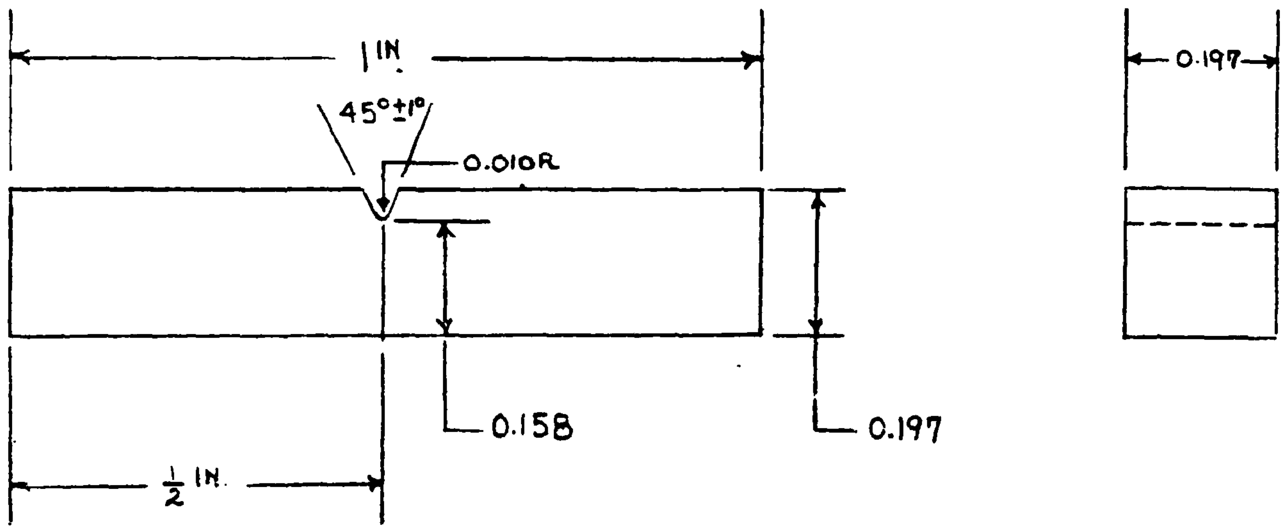
TABLE II

AVERAGE ROOM TEMPERATURE TENSILE PROPERTIES

Material	Direction	Yield Strength Offset 0.01% psi	Yield Strength Offset 0.20% psi	Tensile Strength psi	Elong. %	RA %	Forging and Heat Treatment
A	Longitudinal	84,000	93,000	106,000	25	63	Note (1)
B	Longitudinal	99,000	104,000	106,000	6	7	Note (2)
C	Longitudinal	35,000	55,000	79,000	30	72	Note (1)
A	Transverse	--	83,000	101,000	14	17	Note (1)
B	Transverse	95,000	99,000	105,000	5	5	Note (2)
C	Transverse	--	50,000	78,000	33	66	Note (1)

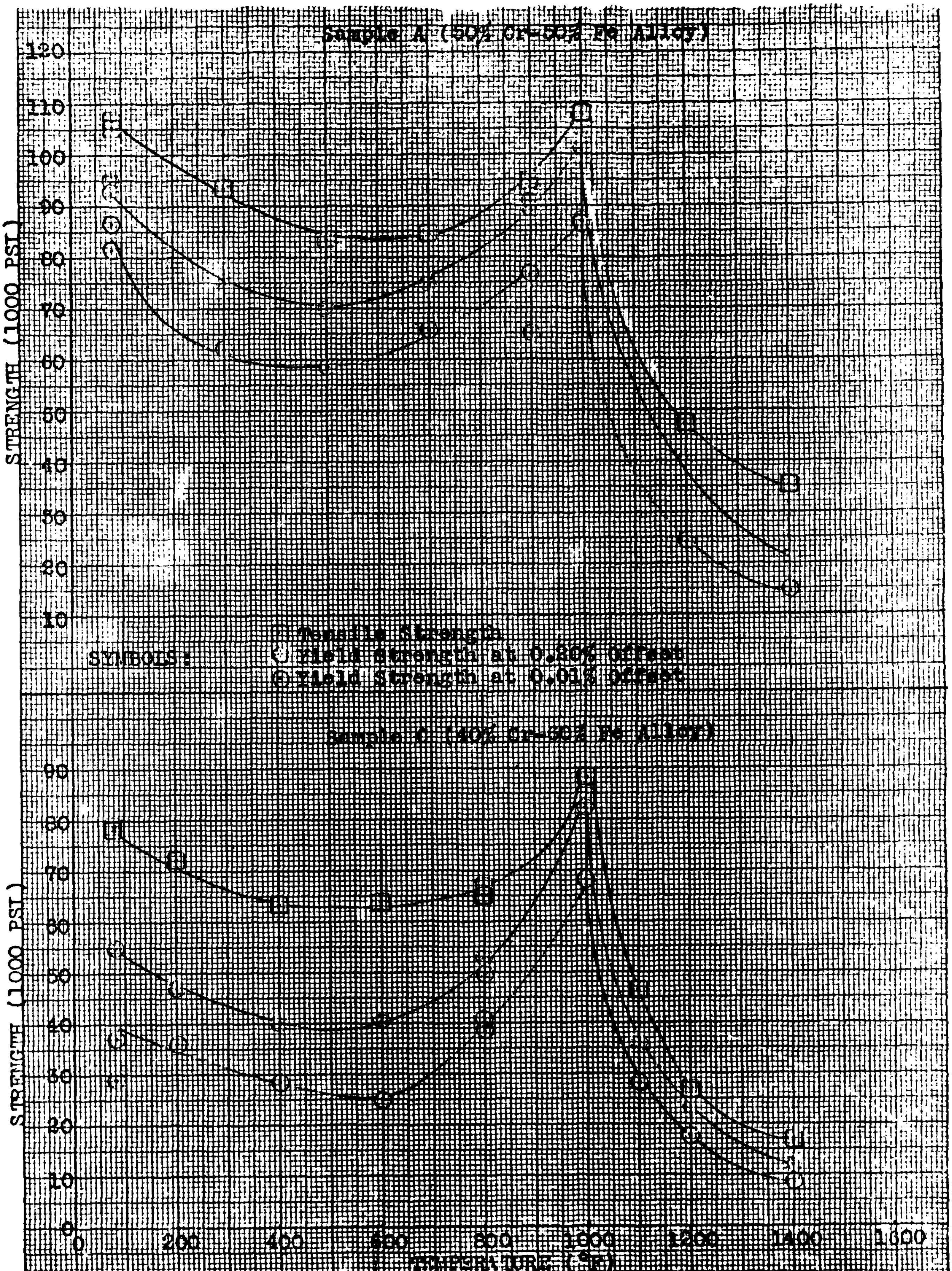
Note (1) Forged from 4 inch ingots to 1-1/8 inch square at 2060°F followed by heat treatment at 1470°F, water quench.

(2) Forged from 4 inch ingot to 1-1/2 inch square at 2060°F followed by heat treatment at 1470°F, water quench.



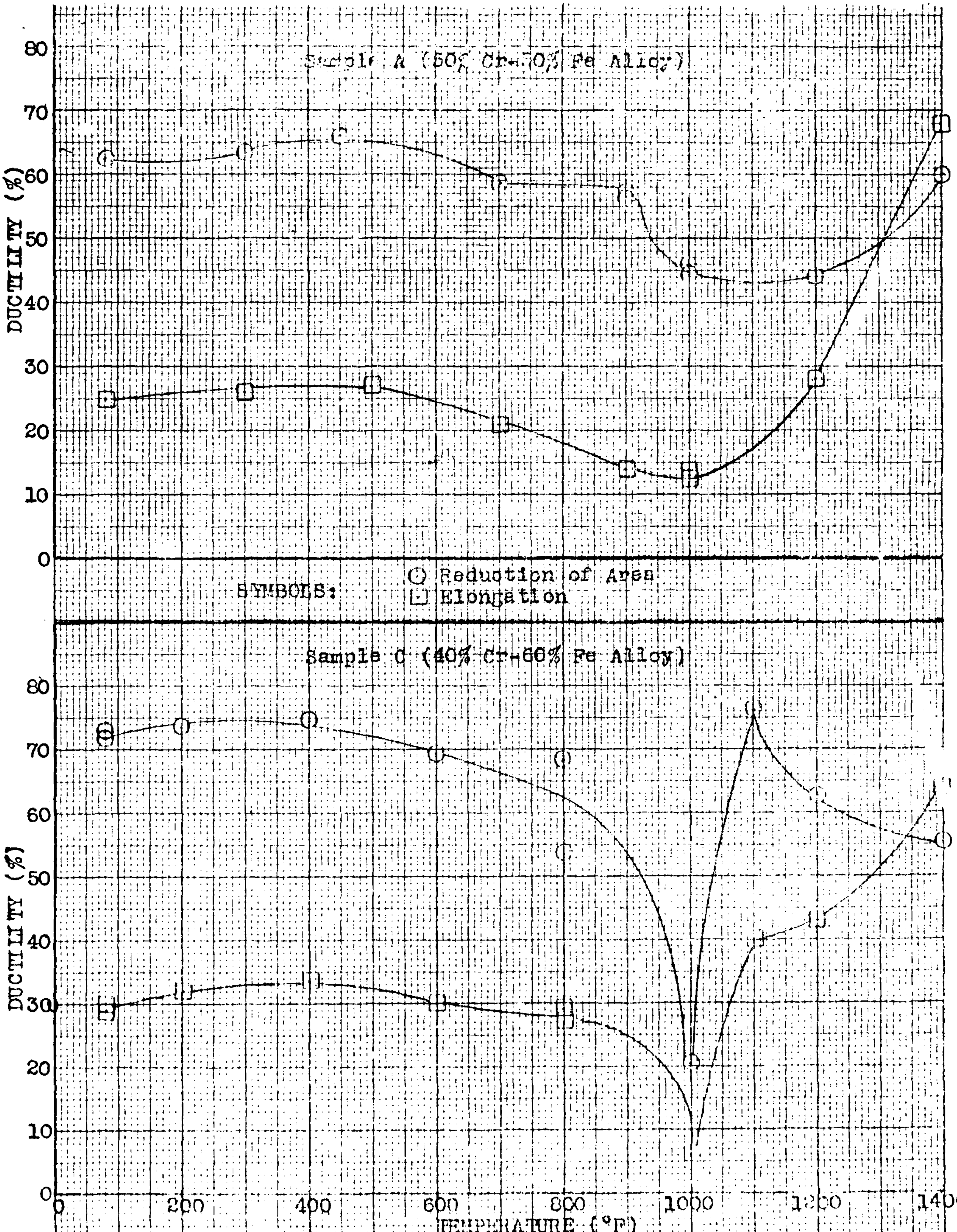
V-NOTCH SQUARE SUBSIZE CHARPY SPECIMEN

Fig. 1



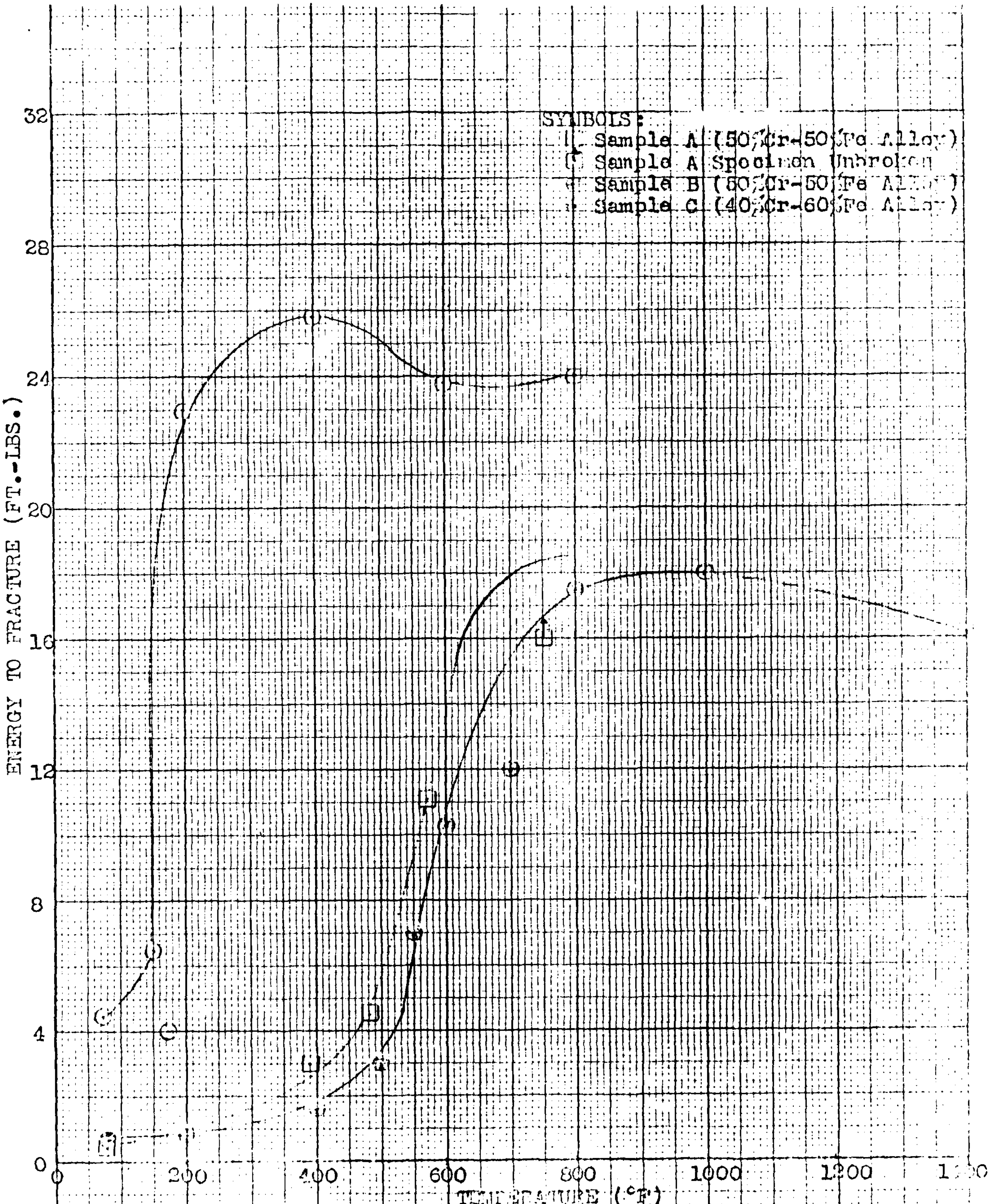
SHORT TIME ELEVATED TEMPERATURE TENSILE PROPERTIES

Watertown Arsenal Laboratories Fig. 2 EE-199



VARIATION OF TENSILE DUCTILITY AS A FUNCTION OF TEMPERATURE

Watertown Arsenal Laboratories FIG. 3 EE-200



IMPACT TRANSITION CURVES OF SOME CHROMIUM-IRON ALLOYS - DATA FROM TESTS OF SUBSIZE V-NOTCH CHARPY SPECIMENS.

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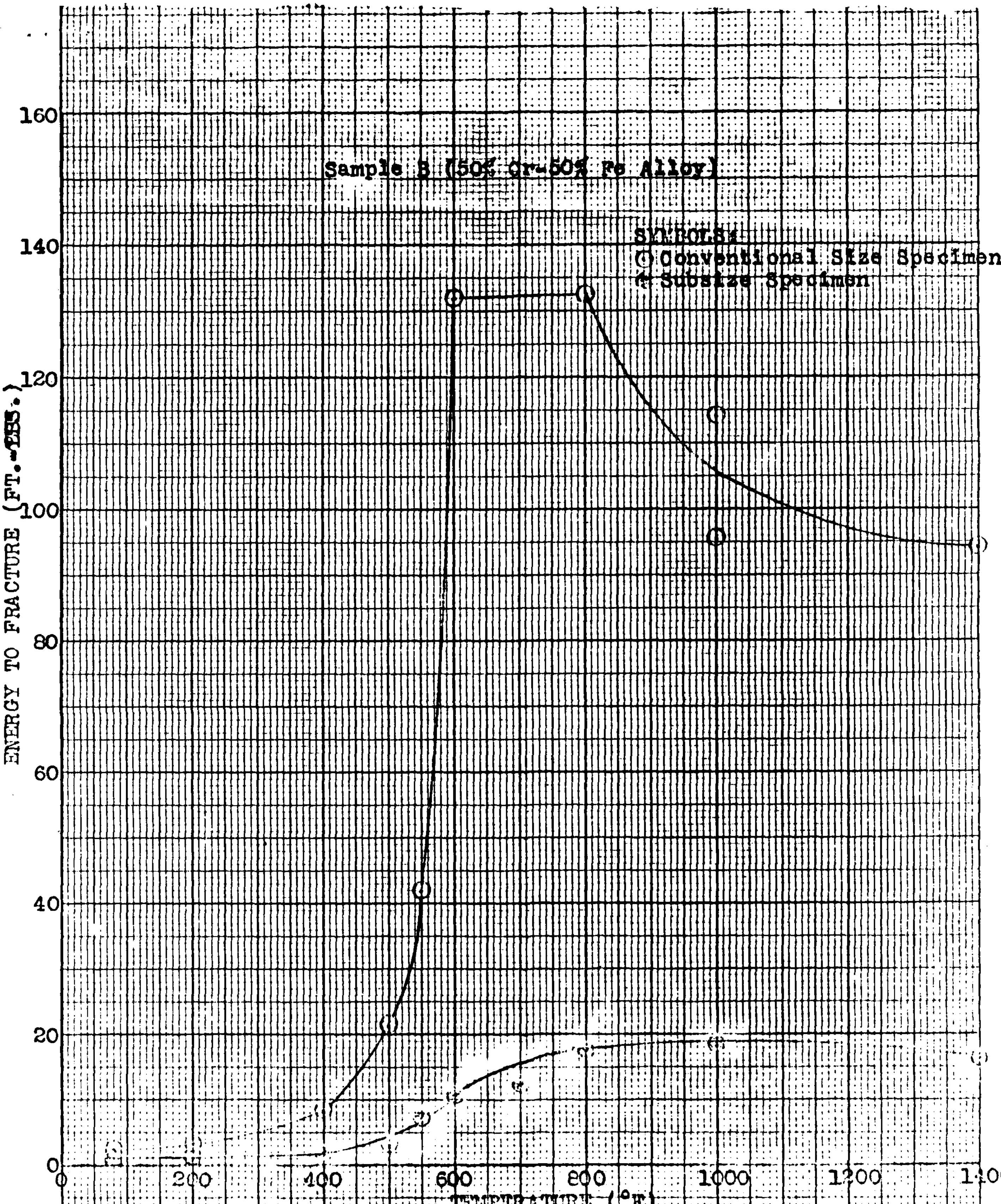
Fig. 4



IMPACT-TRANSITION CURVES OF SAMPLE B ESTABLISHED FROM TESTS ON CONVENTIONAL FULL SIZE AND SUBSIZE V-NOTCH CHARPY SPECIMENS.

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Fig. 5