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NAVAL AIR ENGINEERING CENTER
PHILADELPHIA, PA. 19112

AERONAUTICAL MATERIALS LABORATORY

REPORT NO. NAEC-AML-2083   DATE 30 Nov 1964

INVESTIGATION INTO THE ELECTRICAL CONDUCTIVITY AND MECHANICAL PROPERTIES OF ALUMINUM ALLOYS SUBJECTED TO ELEVATED TEMPERATURE EXPOSURE

PROBLEM ASSIGNMENT NO. 10-40 UNDER BUREAU OF NAVAL WEAPONS WEPTASK RRMA 02 018/200 1/R007 05 01

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF PLATES

ABSTRACT

The relationship between the electrical conductivity (as measured by Magnatester Conductivity Meter, F100 Series) and strength properties of bare aluminum alloys 7075-T6, 7075-T73, 6061-T6, 7178-T6, 7002-T6, 2024-T81, 2024-T3, 7079-T6, 2020-T6, and 2219-T81 was investigated in an attempt to correlate conductivity with heat damage to aircraft structural alloys.

I. INTRODUCTION

The Bureau of Naval Weapons has expressed concern over heat damage to aircraft structures in locations subject to power plant heating. Since this heat damage occurs at temperatures below that which causes changes in the paint surface appearance, it is necessary to use some other parameter to assess the damage. A method which measures the electrical conductivity of the alloy by means of eddy current techniques has been suggested and is in fact being used to assess damage to aluminum alloy 7075-T6 in the A-4 aircraft. It is the purpose of this investigation to obtain a correlation between conductivity as measured by the Magnatester F100 Series and strength properties of other aluminum alloys.

II. EXPERIMENTAL PROCEDURE

The bare aluminum alloys used in this investigation were 7075-T6, 7075-T73, 6061-T6, 7178-T6, 7002-T6, 2024-T81, 2024-T3, 7079-T6, 2020-T6, 2219-T81.

Tensile test specimens of the above alloys were manufactured from available material. Most of the alloys were in the form of bare sheet of various thicknesses. Several alloys, however, were available only as plate from which round tensile specimens were machined. The form of the test specimens used for each alloy is given with the results in Table 1. For each alloy, the test specimens all had the same orientation with relation to the rolling direction.

Conductivity and hardness measurements were made on each material in the as-received condition. The test specimens were then exposed for various times at temperatures of 400°F, 500°F, and 600°F. Conductivity and hardness measurements were then made on the exposed specimens. Following this, the specimens were tensile tested at a strain rate of approximately 0.035 in/in/min. and the 0.2% yield strength and ultimate tensile strength were calculated.

The conductivity measurements were made using a Magnatester Conductivity Meter (F100 Series), Plate 1. The sensitivity of this instrument was ±0.3% IACS and the accuracy is within ±1-1/2% of scale reading. During calibration of the Magnatester, the standard calibration specimens furnished with the instrument were maintained at the same temperature as the specimens whose conductivity was to be measured, thus eliminating a temperature induced error.

III. RESULTS AND ANALYSIS

The results obtained in this investigation are given in Table 1. Since the yield strength is the most useful of the properties investigated, it is plotted as a function of the conductivity for the various alloys in Plates 1 to 10. Table 2 gives the value of the conductivity and amount of change in the conductivity which corresponds to a 20% loss in yield strength. The amount of change is a measure of the ability of the Conductivity Meter to detect a loss in strength.

From the data in Table 2 and Plates 2, 3, 4, 5, and 6, it is apparent that no useful correlation between conductivity and strength properties is possible for alloys 6061-T6, 2024-T81, 2219-81, 7075-T73, and 2020-T6. In each of these cases, the change in conductivity between the original material and that which has been severely reduced in strength properties by heating is so small that it must be considered nonreproducible.

Alloys 7075-T6, 7178-T6, 7002-T6, and 7079-T6 give useful correlations between conductivity and yield strength as can be seen from Table 2 and Plates 7, 8, 9, and 10.

While alloy 2024-T3, Plate 11, has a very large change in conductivity for a 20% loss in yield strength, it is improbable that a useful correlation can be obtained since only at a high conductivity is a significant loss in strength observed and this loss occurs over a very small conductivity range. A lower conductivity limit could be chosen to eliminate all damaged structures, but in view of the shape of the curve, it could cause a replacement of a large number of structures whose strength was not significantly reduced.

IV. CONCLUSIONS

1. Heat damage to structures can be correlated to conductivity readings obtained using a Magnatester Conductivity Meter (F100 Series) for aluminum alloys 7075-T6, 7178-T6, 7002-T6, and 7079-T6.

2. A similar correlation cannot be made for aluminum alloys 6061-T6, 2024-T81, 7075-T73, 2219-T81, and 2020-T6 due to the small change in conductivity which occurs due to heat damage.

3. The conductivity of alloy 2024-T3 can be correlated, but such a correlation would lead to rejects of many heated but unweakened structures along with those which had been damaged. Above a conductivity of 38%, a high probability exists that this material has been weakened to below the as-received strength and tests of other types should be made.

V. RECOMMENDATIONS

It is recommended that the Magnatester Conductivity Meter (Series F100) be considered for use in detect.ng heat damage to aluminum alloys 7178-T6, 7002-T6, and 7079-T6 in addition to 7075-T6 alloy

RESULTS OF TEST

Alloy & Form	Exposure Temperature	Exposure Time	Conductivity Range, % IACS	Hardness	0.2% Yield Strength	Ultimate Strength
7075-T73 0.065" Sheet	As-Received		37.5	87 R_B	63,500	75,200
	400°F	1 hr.	38.5	84 R_B	58,800	72,600
	400°F	5 hrs.	40.5	68 R_B	43,800	59,500
	510°F	10 min.	41.5	61 R_B	34,600	53,100
	490°F	1 hr.	41.0	65 R_B	37,400	55,800
	600°F	10 min.	39.5	31 R_B	19,500	43,900
	600°F	1 hr.	41.5	75 R_F	18,900	41,700
6061-T6 0.063" Sheet	As-Received		39.0	56 R_B	40,900	46,700
	400°F	1 hr.	40.0	54 R_B	40,000	46,700
	400°F	5 hrs.	40.5	47 R_B	40,800	44,000
	510°F	10 min.	41.0	33 R_B	33,000	38,300
	490°F	1 hr.	41.0	85 R_F	35,000	41,200
	600°F	10 min.	42.3	--	18,700	28,600
	600°F	1 hr.	42.5	58 R_F	16,700	27,700
7178-T6 0.100" Sheet	As-Received		29.5	95 R_B	84,200	91,800
	400°F	1 hr.	36.0	92 R_B	78,800	85,200
	400°F	5 hrs.	41.0	75 R_B	48,000	62,800
	510°F	10 min.	40.5	66 R_B	37,400	55,900
	490°F	1 hr.	41.3	70 R_B	41,800	58,700
	600°F	10 min.	40.5	40 R_B	21,600	45,500
	600°F	1 hr.	41.8	80 R_F	20,000	42,200
2020-T6 0.064" Sheet	As-Received		20.5	91 R_B	73,500	78,666
	400°F	1 hr.	20.5	90 R_B	71,600	76,757
	400°F	5 hrs.	21.0	84 R_B	67,968	73,906
	500°F	1 hr.	21.9	74 R_B	46,400	58,787
	600°F	1 hr.	23.3	46 R_B	28,100	46,099

TABLE 1

Alloy & Form	Exposure Temperature	Exposure Time	Conductivity Range, % IACS	Hardness	0.2% Yield Strength	Ultimate Strength
7079-T6	As-Received		31.0	89 R_B	70,000	80,000
0.088" Sheet	400°F	10 min.	33.0	83 R_B	62,500	74,300
	400°F	1 hr.	34.0	85 R_B	62,500	74,200
	400°F	5 hrs.	36.5	69 R_B	44,600	61,500
	510°F	10 min.	35.8	63 R_B	34,700	56,600
	490°F	1 hr.	36.5	67 R_B	37,900	58,200
	600°F	10 min.	36.0	39 R_B	21,200	48,000
	600°F	1 hr.	37.0	74 R_F	20,800	45,000
7075-T6	As-Received		32.0	93 R_B	79,000	85,500
0.100" Sheet	400°F	1 hr.	37.0	90 R_B	72,400	79,600
	400°F	5 hrs.	41.0	70 R_B	45,000	59,700
	510°F	10 min.	41.5	61 R_B	35,500	54,300
	490°F	1 hr.	41.0	66 R_B	39,200	56,600
	600°F	10 min.	41.5	78 R_F	20,000	44,200
	600°F	1 hr.	42.0	76 R_F	18,600	41,100
2219-T81	As-Received		32.0	77 R_B	52,100	67,290
0.062" Sheet	400°F	1 hr.	32.0	76 R_B	52,100	68,700
	400°F	5 hrs.	32.5	74 R_B	34,900	46,500
	400°F	5 hrs.	32.5	73 R_B	35,500	46,600
	500°F	1 hr.	33.5	68 R_B	40,800	59,200
	600°F	1 hr.	34.6	58 R_B	33,200	51,000
7002-T6	As-Received		33.5	82 R_B	58,900	69,700
0.062" Sheet	400°F	10 min.	35.0	76 R_B	54,200	65,500
	400°F	1 hr.	36.0	79 R_B	54,100	66,800
	510°F	10 min.	37.5	49 R_B	29,600	50,200
	490°F	1 hr.	38.5	58 R_B	32,600	52,200
	600°F	10 min.	37.0	26 R_B	17,300	41,800
	600°F	1 hr.	38.5	73 R_F	16,600	41,200

TABLE 1

Alloy & Form	Exposure Temperature	Exposure Time	Conductivity Range, % IACS	Hardness	0.2% Yield Strength	Ultimate Strength
2024-T81 0.125" Sheet	As-Received		38.0	83 R_B	66,400	72,100
	400°F	1 hr.	37.5	84 R_B	66,300	72,000
	400°F	5 hrs.	38.7	80 R_B	63,800	70,800
	510°F	10 min.	38.8	78 R_B	56,600	67,100
	490°F	1 hr.	39.5	78 R_B	57,500	67,100
	600°F	10 min.	40.0	64 R_B	40,500	57,800
	600°F	1 hr.	41.0	61 R_B	36,600	54,400
2024-T3 0.125" Sheet	As-Received		29.0	77 R_B	45,400	69,600
	400°F	1 hr.	30.0	75 R_B	43,000	67,200
	510°F	10 min.	38.5	76 R_B	56,100	65,000
	490°F	1 hr.	38.8	79 R_B	60,300	68,400
	600°F	10 min.	40.3	64 R_B	41,000	56,500
	600°F	1 hr.	41.5	67 R_B	40,800	57,400
	600°F	3 hrs.	42.5	--	26,600	45,400
	700°F	2 hrs.	42.5	--	15,900	39,600

TABLE 1

CONDUCTIVITY DATA FOR VARIOUS ALUMINUM ALLOYS

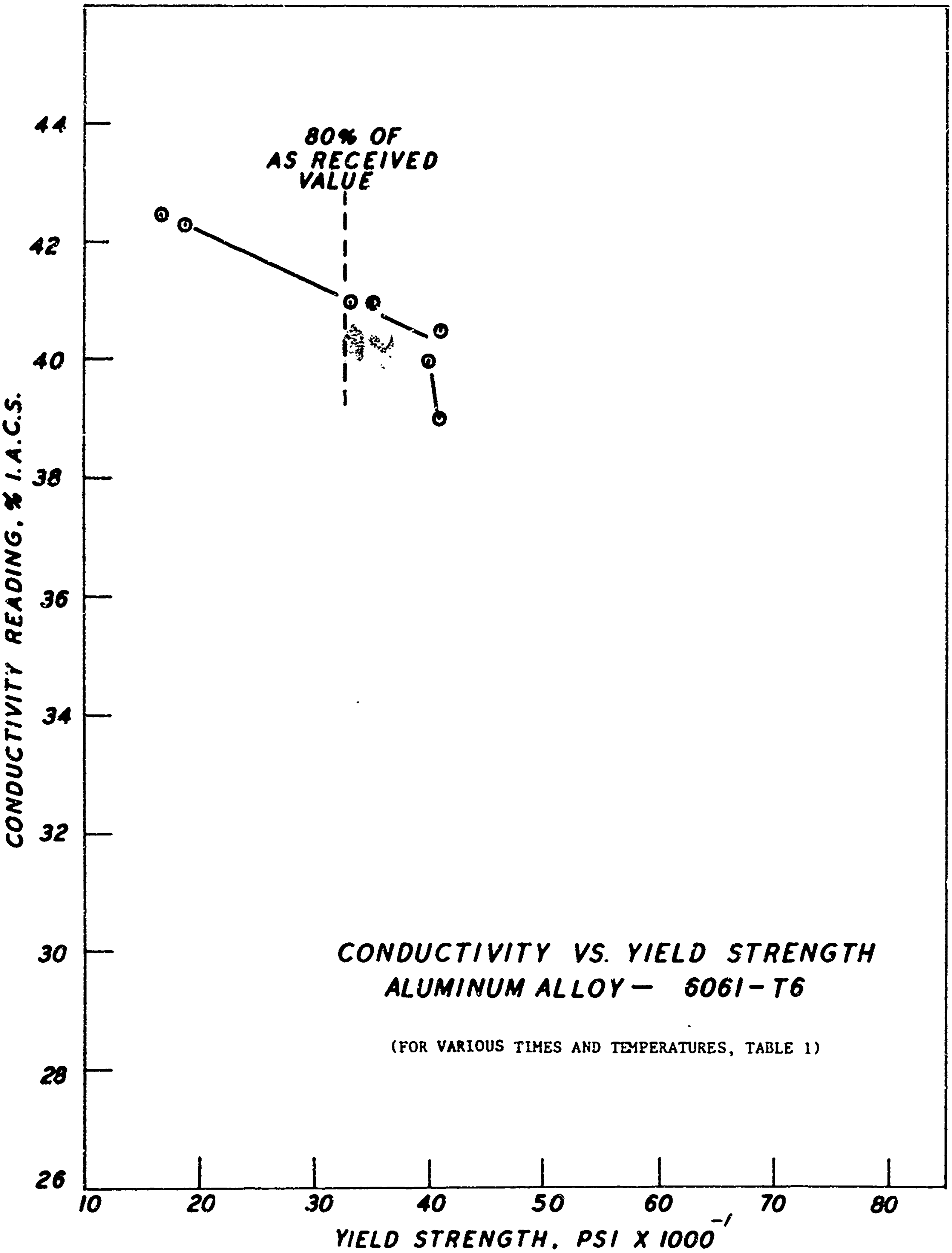
Alloy	Change in Conductivity, % IACS for 20% Loss of Yield Strength	Conductivity at 80% As-Received Yield Strength
2219-T81	1	33.5
7002-T6	3.1	36.6
7178-T6	8.0	37.5
2024-T81	2.0	39.5
7075-T73	2.0	39.5
6061-T6	2.0	41.0
7079-T6	3.5	34.5
2024-T3	12.0	41.0
7075-T6	6.0	38.0
2020-T6	1.0	21.5

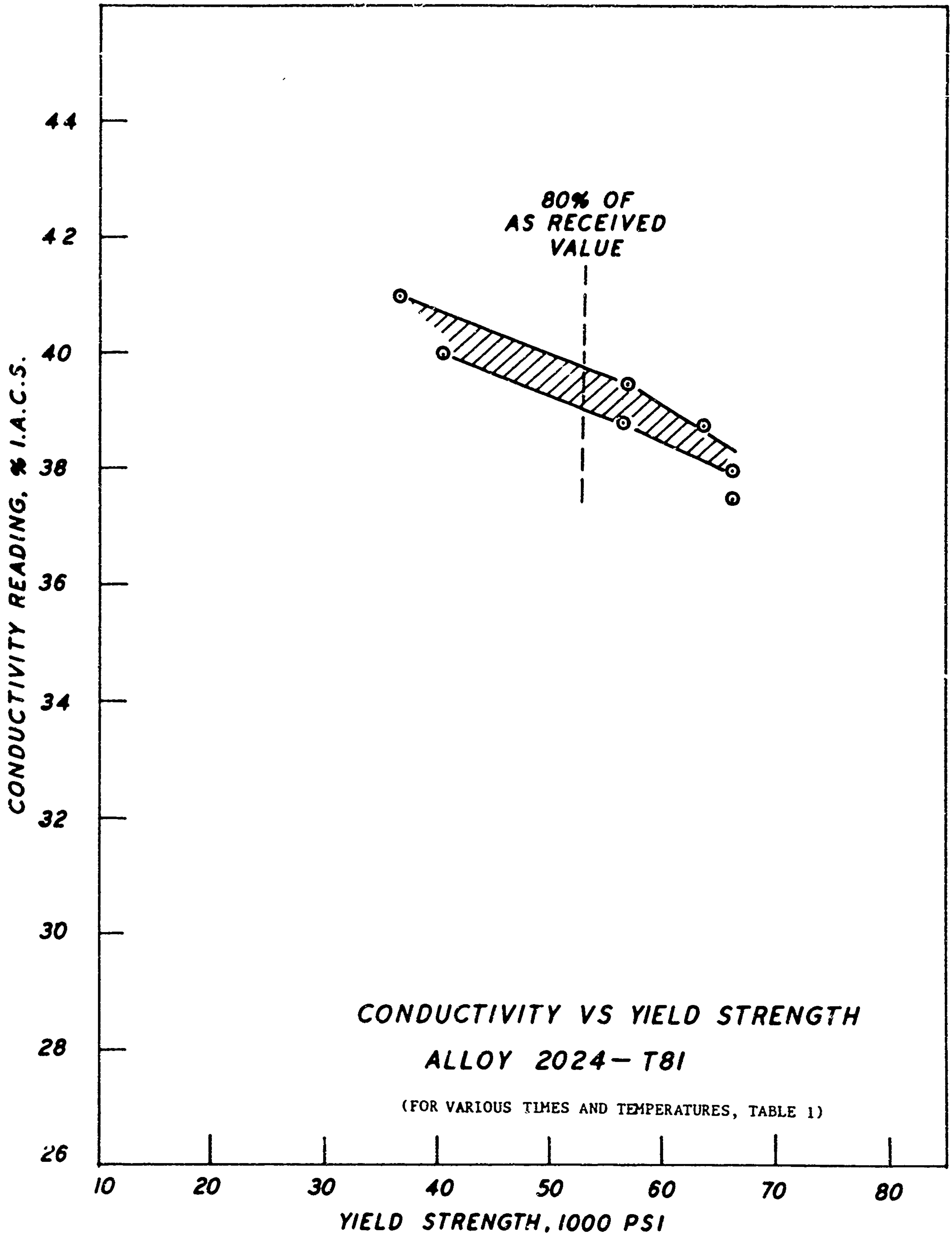
TABLE 2

ELECTRICAL CONDUCTIVITY MEASURING TECHNIQUE

PHOTO NO: CAN-364603(L)-11-64

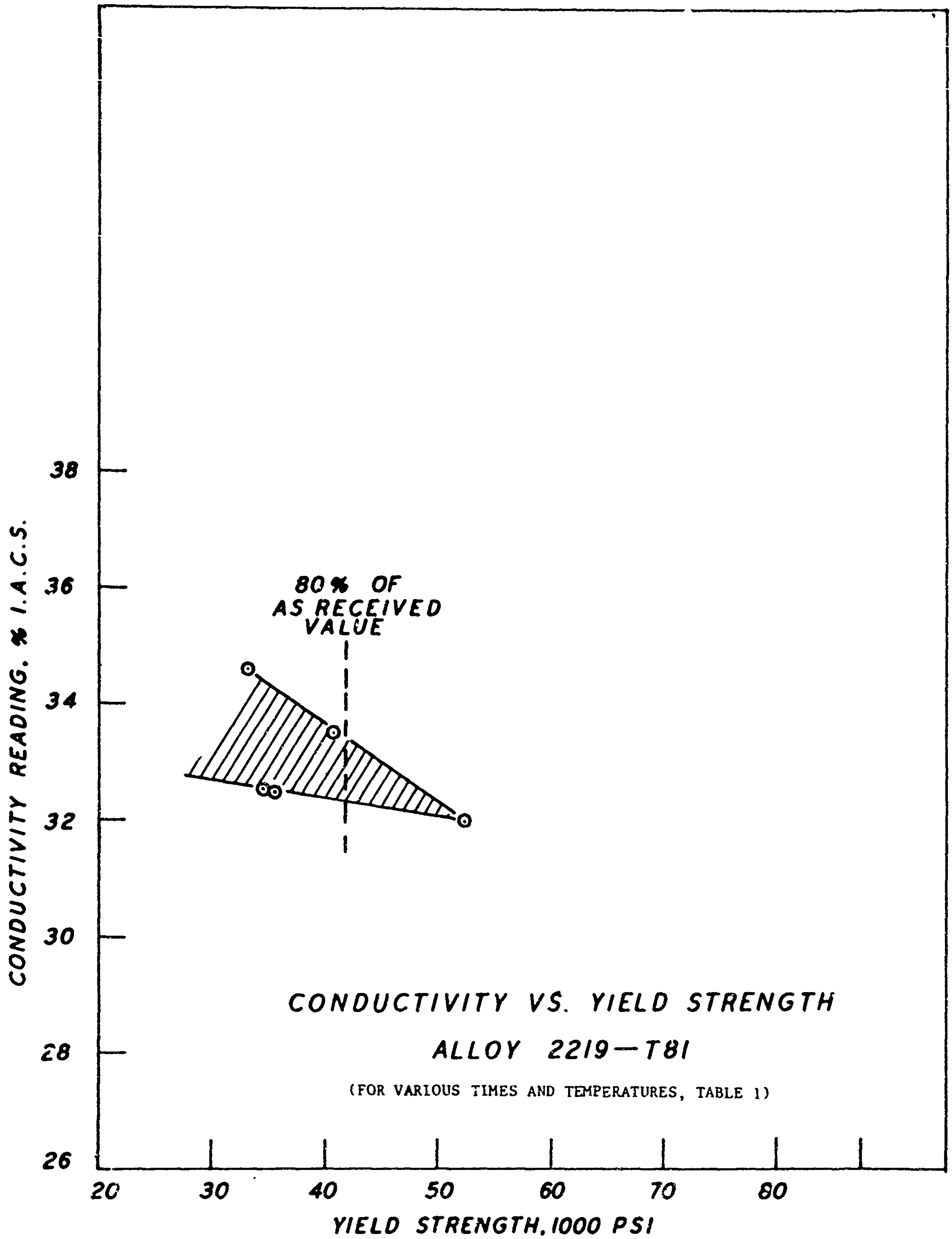
PLATE 1


80% OF
AS RECEIVED
VALUE
CONDUCTIVITY READING, % I.A.C.S.
44
42
40
38
36
34
32
30
28
26
10
20
30
40
50
60
70
80
YIELD STRENGTH, PSI X 1000⁻¹
CONDUCTIVITY VS. YIELD STRENGTH
ALUMINUM ALLOY — 6061-T6
(FOR VARIOUS TIMES AND TEMPERATURES, TABLE 1)



CONDUCTIVITY VS YIELD STRENGTH
ALLOY 2024-T81

(FOR VARIOUS TIMES AND TEMPERATURES, TABLE 1)



CONDUCTIVITY VS. YIELD STRENGTH

ALLOY 2219—T81

(FOR VARIOUS TIMES AND TEMPERATURES, TABLE 1)

PLATE 4

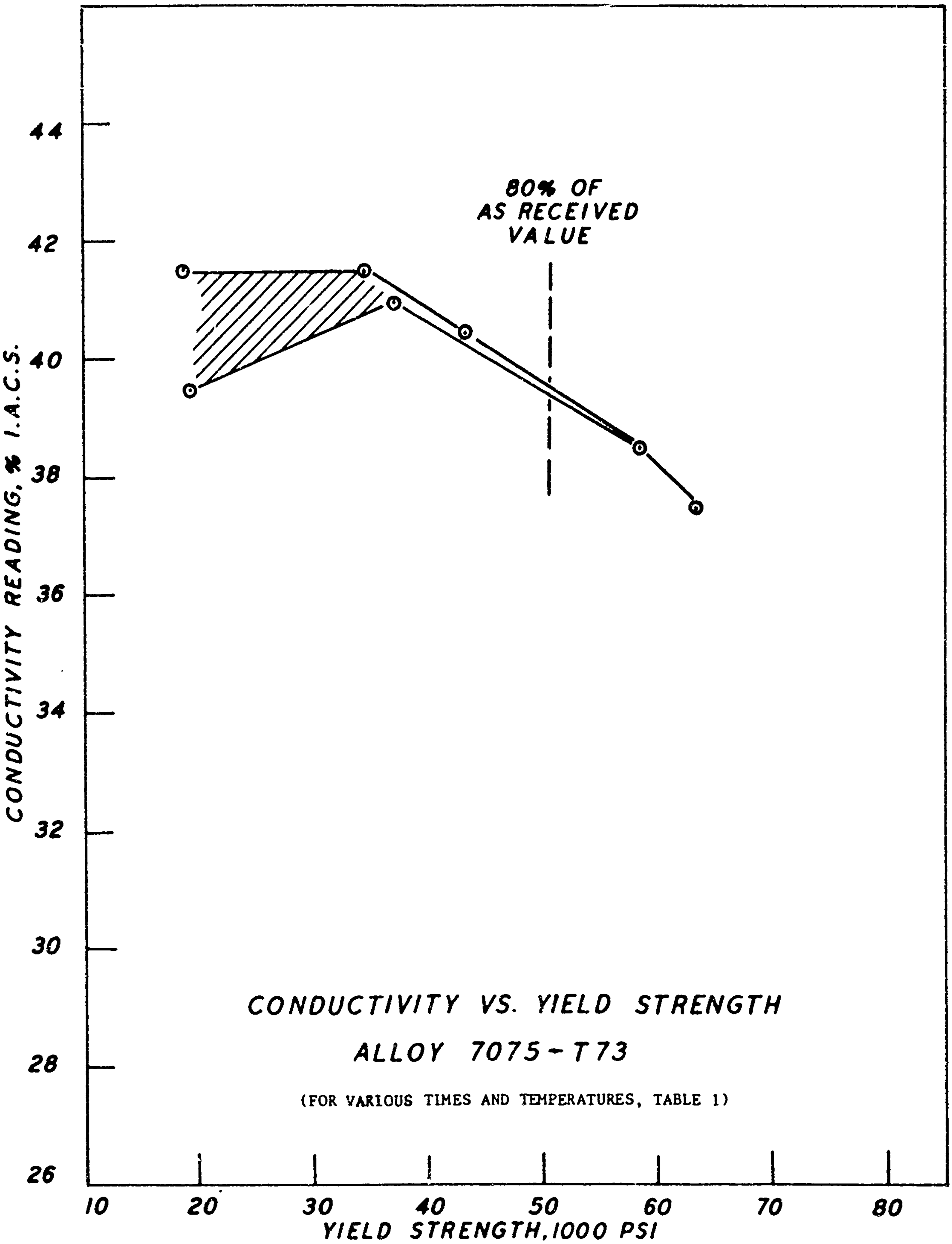
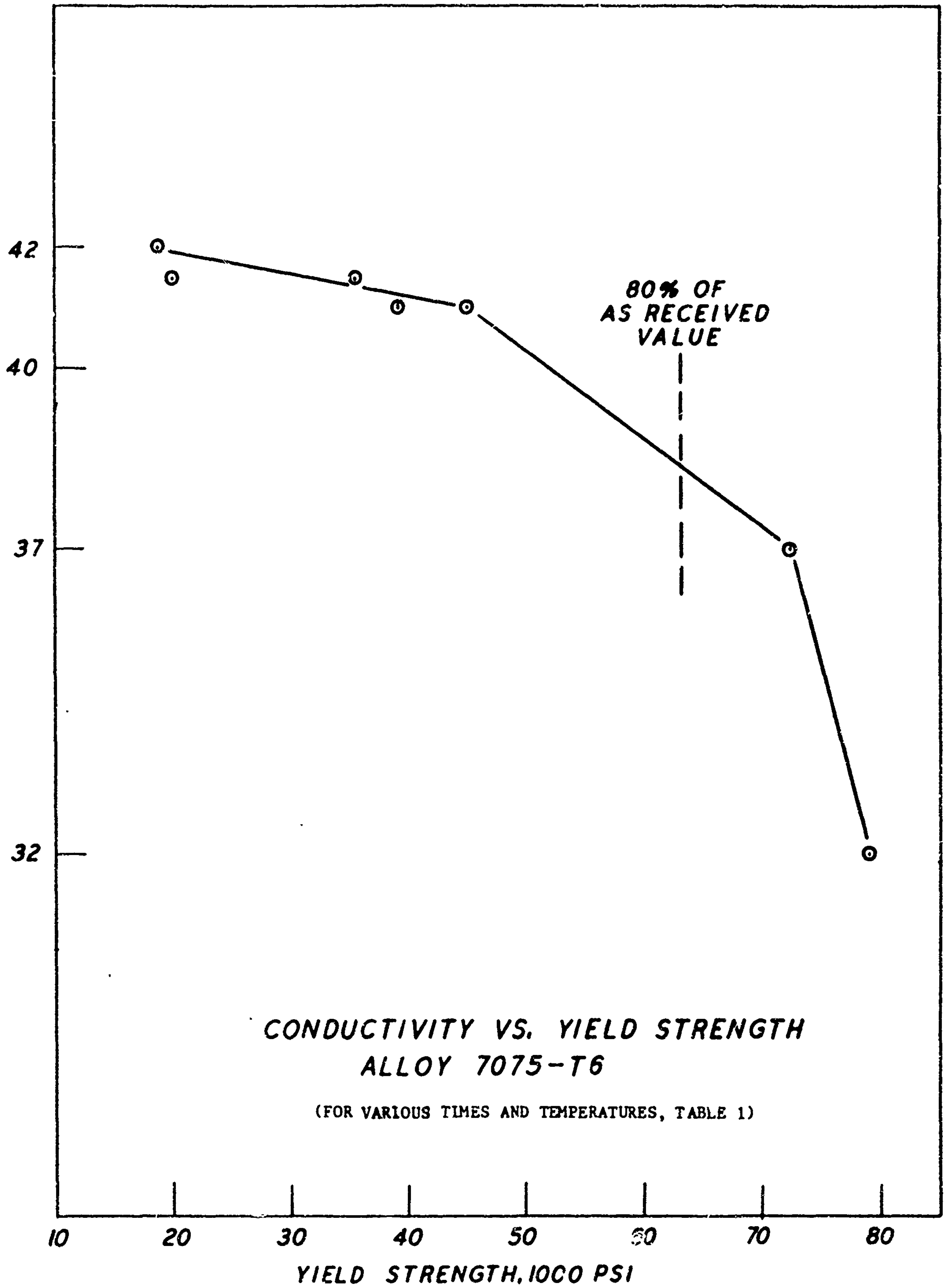

44
42
40
38
36
34
32
30
28
26
CONDUCTIVITY READING, % I.A.C.S.
80% OF
AS RECEIVED
VALUE
CONDUCTIVITY VS. YIELD STRENGTH
ALLOY 7075-T73
(FOR VARIOUS TIMES AND TEMPERATURES, TABLE 1)
10
20
30
40
50
60
70
80
YIELD STRENGTH, 1000 PSI

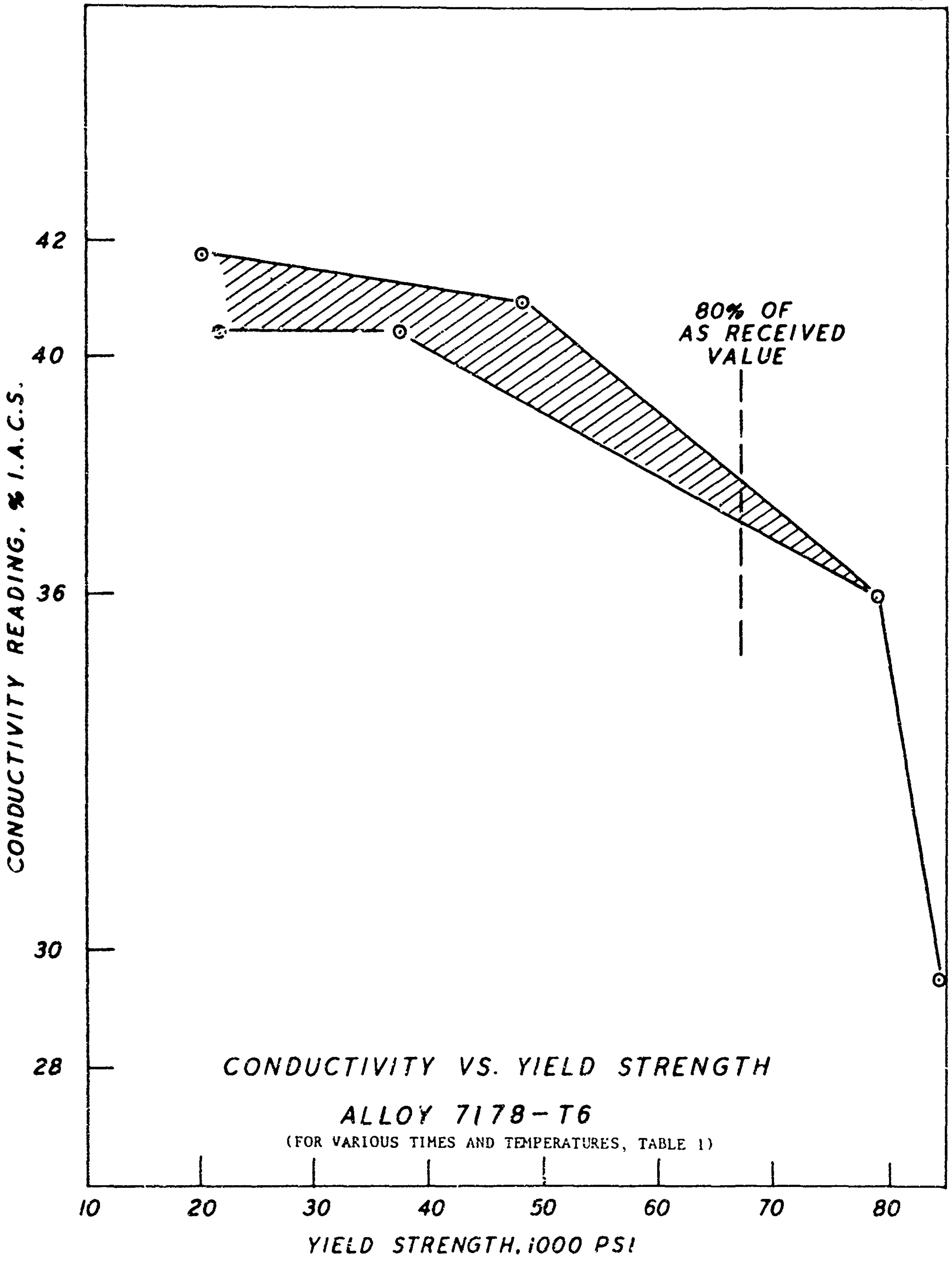
PLATE 5



CONDUCTIVITY VS. YIELD STRENGTH
ALLOY 7075-T6

(FOR VARIOUS TIMES AND TEMPERATURES, TABLE 1)

PLATE 7

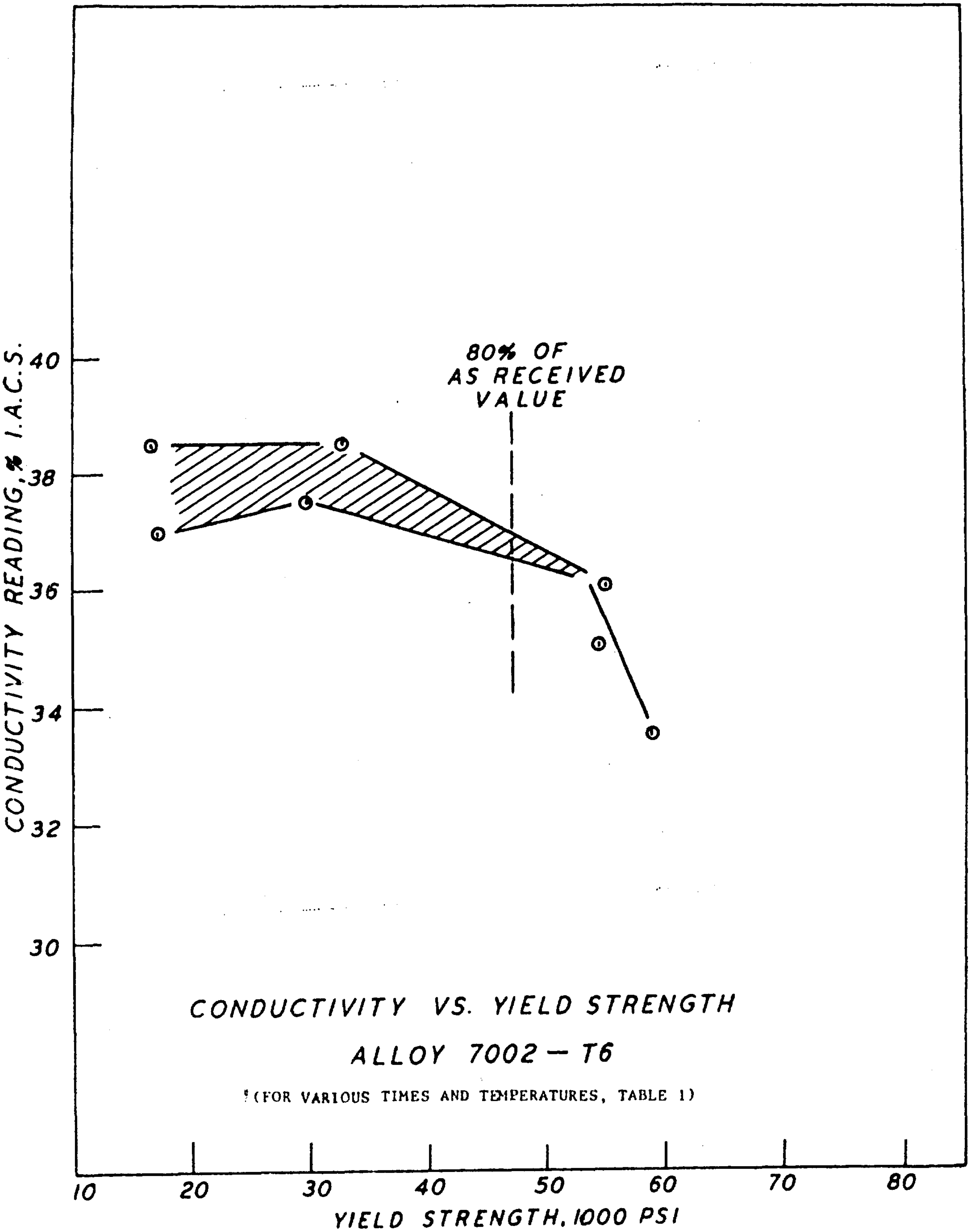


CONDUCTIVITY VS. YIELD STRENGTH

ALLOY 7178-T6

(FOR VARIOUS TIMES AND TEMPERATURES, TABLE 1)

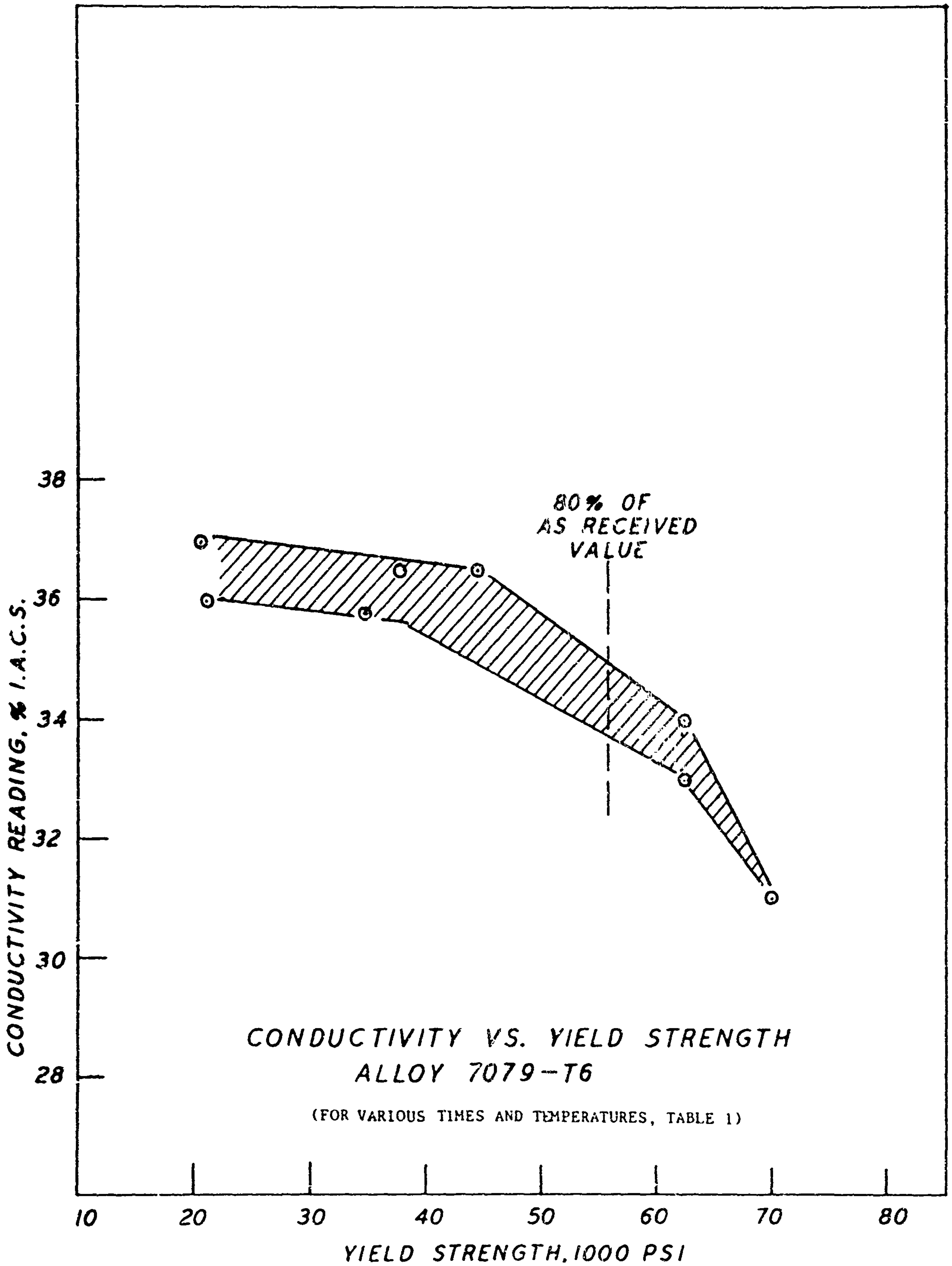
PLATE 8



CONDUCTIVITY VS. YIELD STRENGTH

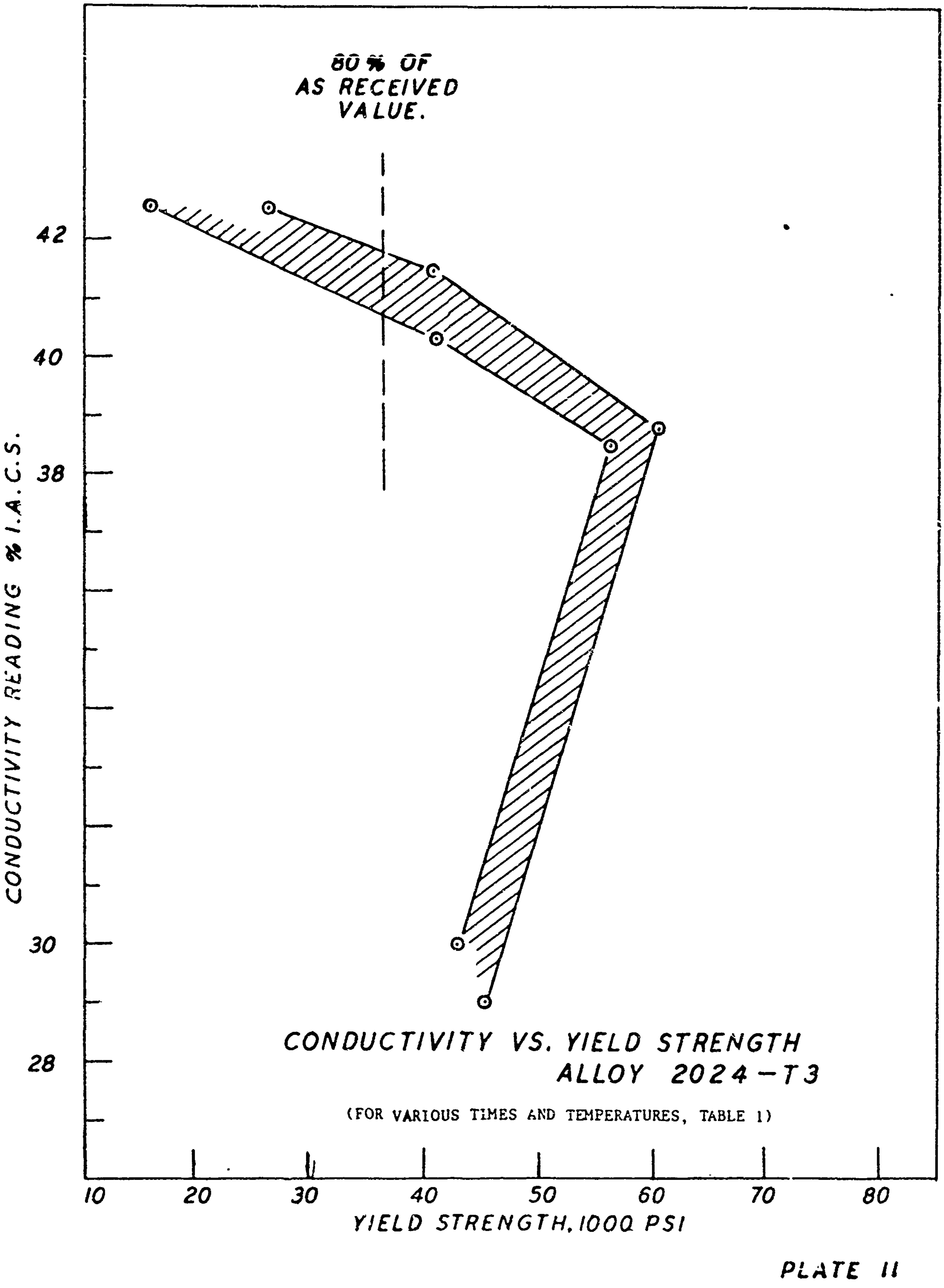
ALLOY 7002 — T6

(FOR VARIOUS TIMES AND TEMPERATURES, TABLE 1)



38
36
34
32
30
28
CONDUCTIVITY READING, % I.A.C.S.
80% OF
AS RECEIVED
VALUE
CONDUCTIVITY VS. YIELD STRENGTH
ALLOY 7079-T6
(FOR VARIOUS TIMES AND TEMPERATURES, TABLE 1)
10
20
30
40
50
60
70
80
YIELD STRENGTH, 1000 PSI

PLATE 10



CONDUCTIVITY VS. YIELD STRENGTH
ALLOY 2024-T3

(FOR VARIOUS TIMES AND TEMPERATURES, TABLE 1)

PLATE II

U. S. NAVAL AIR ENGINEERING CENTER, PHILA, PA.
AERONAUTICAL MATERIALS LABORATORY

1. REPORT NO. NAEC-AML-2083
2. PAN 10-40

Investigation Into the Electrical Conductivity and Mechanical Properties of Aluminum Alloys Subjected to Elevated Temperature Exposure;
W. Allen/R. Mahorter, December 1964,
2 Tables, 11 Plates

The relationship between the electrical conductivity (as measured by Magnatester Conductivity Meter, F100 Series) and strength properties of bare aluminum alloys 7075-T6, 7075-T73, 6061-T6, 7178-T6, 7002-T6, 2024-T81, 2024-T83, 7079-T6, 2020-T6, and 2219-T81 was investigated in an attempt to correlate conductivity with heat damage to aircraft structural alloy.

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ABSTRACT CARD OFFSET MARGINAL GUIDE
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PLATE NO. 583