ALUMINUM ALLOY SYSTEM

Filed Aug. 3, 1972 8 Sheets-Sheet 1

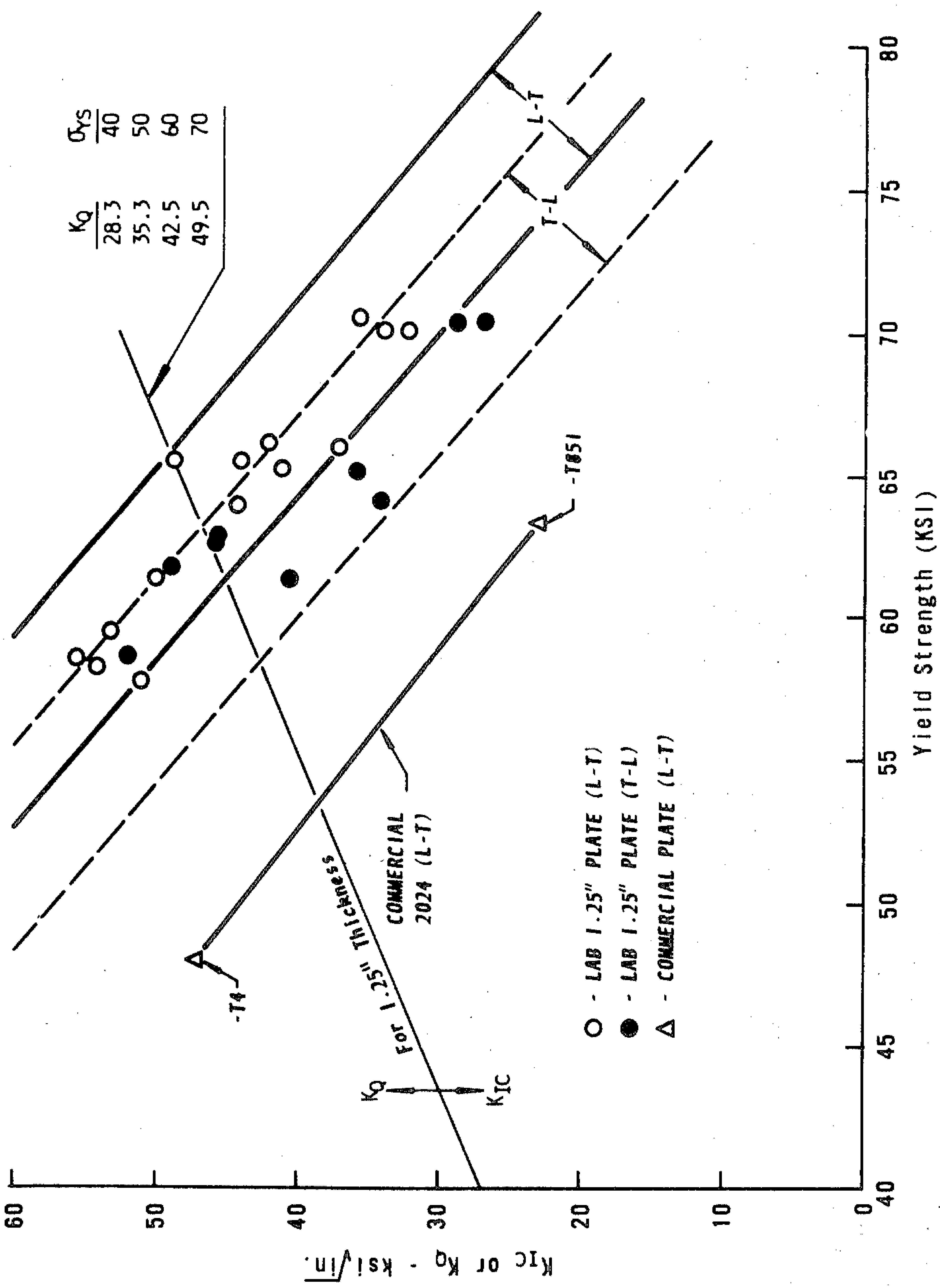


FIG. 1

Plane Strain Fracture Toughness of Laboratory Produced MD-148.

ALUMINUM ALLOY SYSTEM

Filed Aug. 3, 1972 8 Sheets-Sheet 2

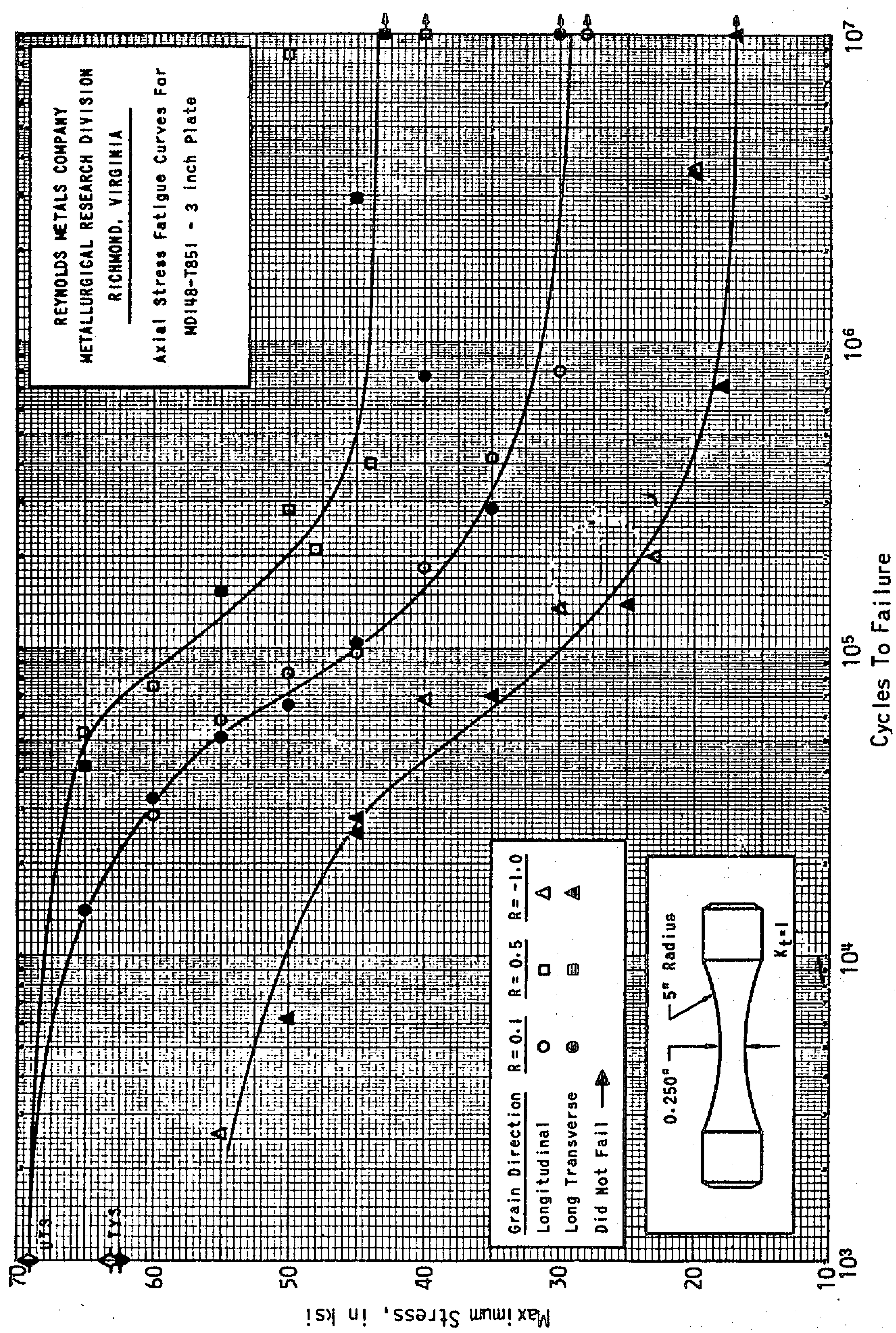


FIG. 2

ALUMINUM ALLOY SYSTEM

Filed Aug. 3, 1972 8 Sheets-Sheet 3

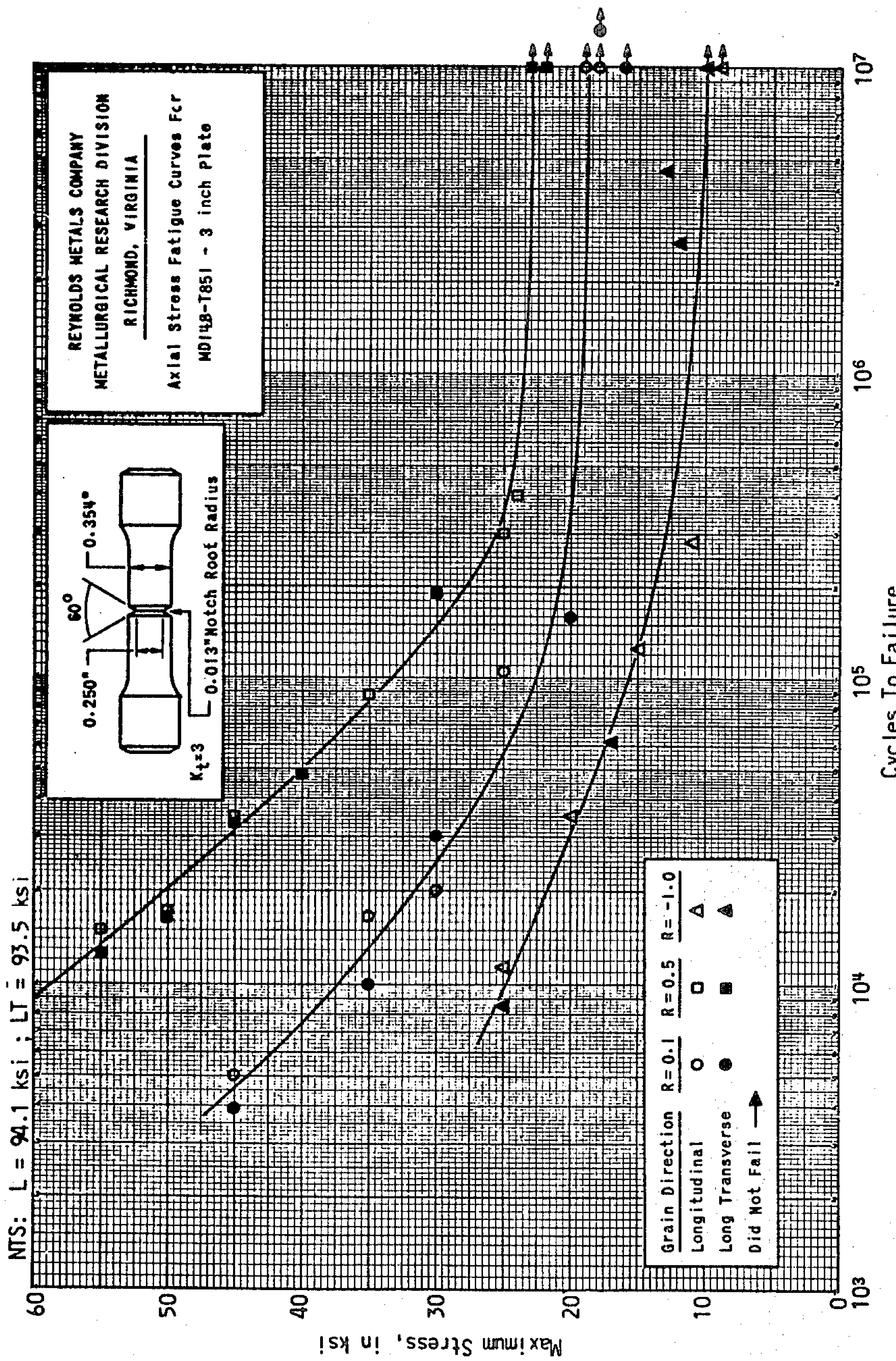


FIG. 3

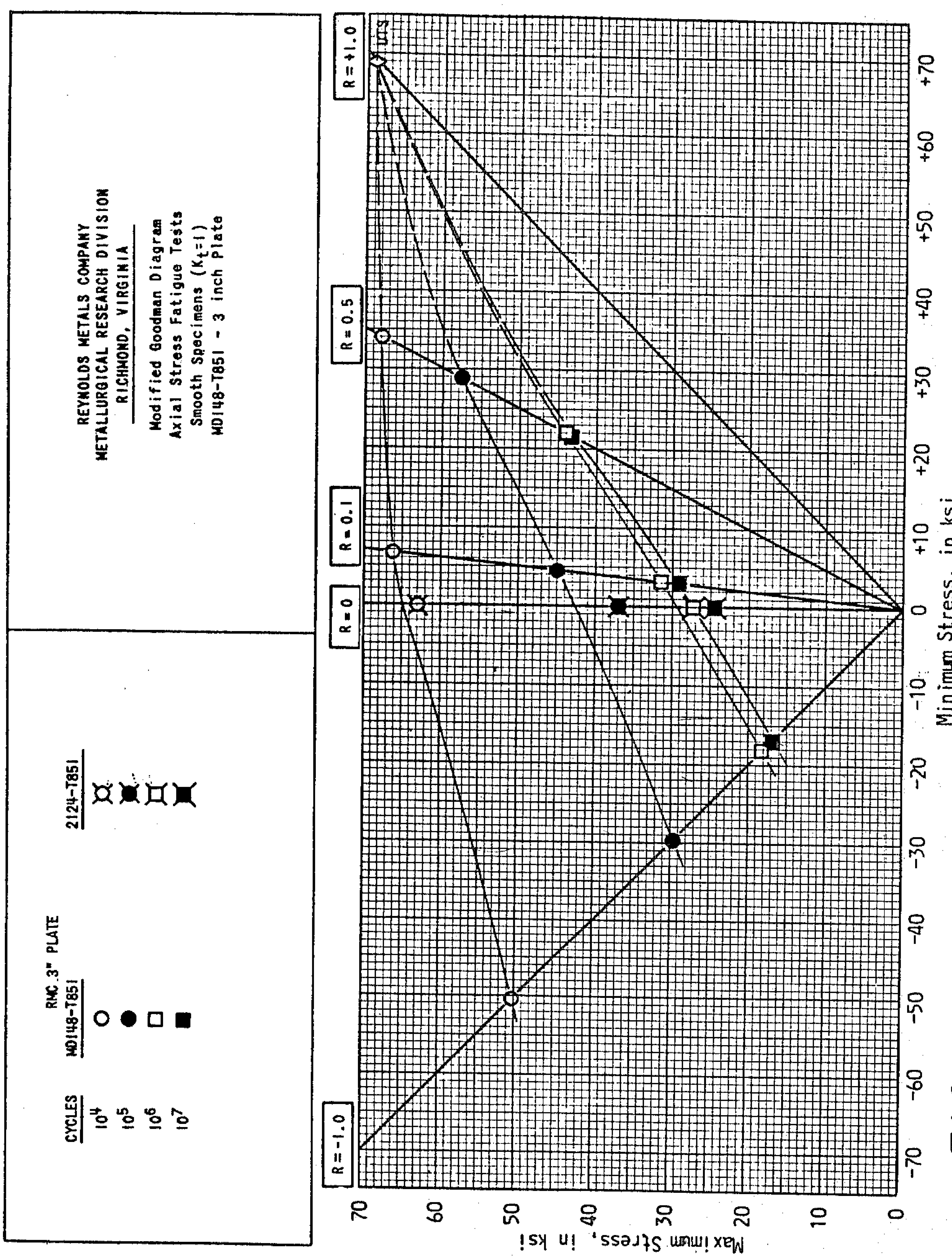

REYNOLDS METALS COMPANY
METALLURGICAL RESEARCH DIVISION
RICHMOND, VIRGINIA
Modified Goodman Diagram
Axial Stress Fatigue Tests
Smooth Specimens (K_t=1)
MD148-T851 - 3 inch Plate
CYCLES
10^4
10^5
10^6
10^7
RMC 3" PLATE
MD148-T851
2124-T851
R=+1.0
R=0.5
R=0.1
R=0
R=-1.0
Maximum Stress, in ksi
Minimum Stress, in ksi

FIG. 4

ALUMINUM ALLOY SYSTEM

Filed Aug. 3, 1972 8 Sheets-Sheet 5

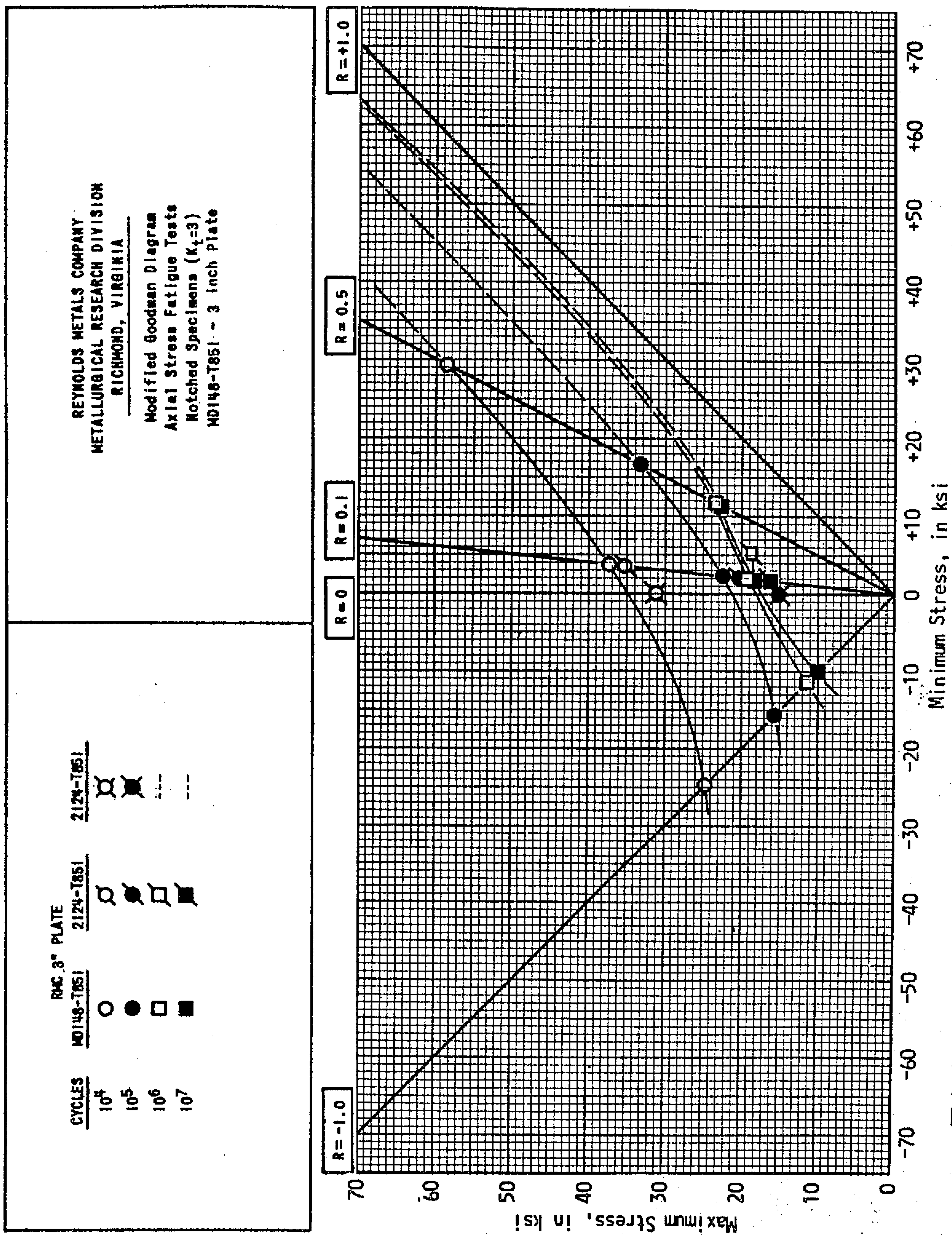


FIG. 5

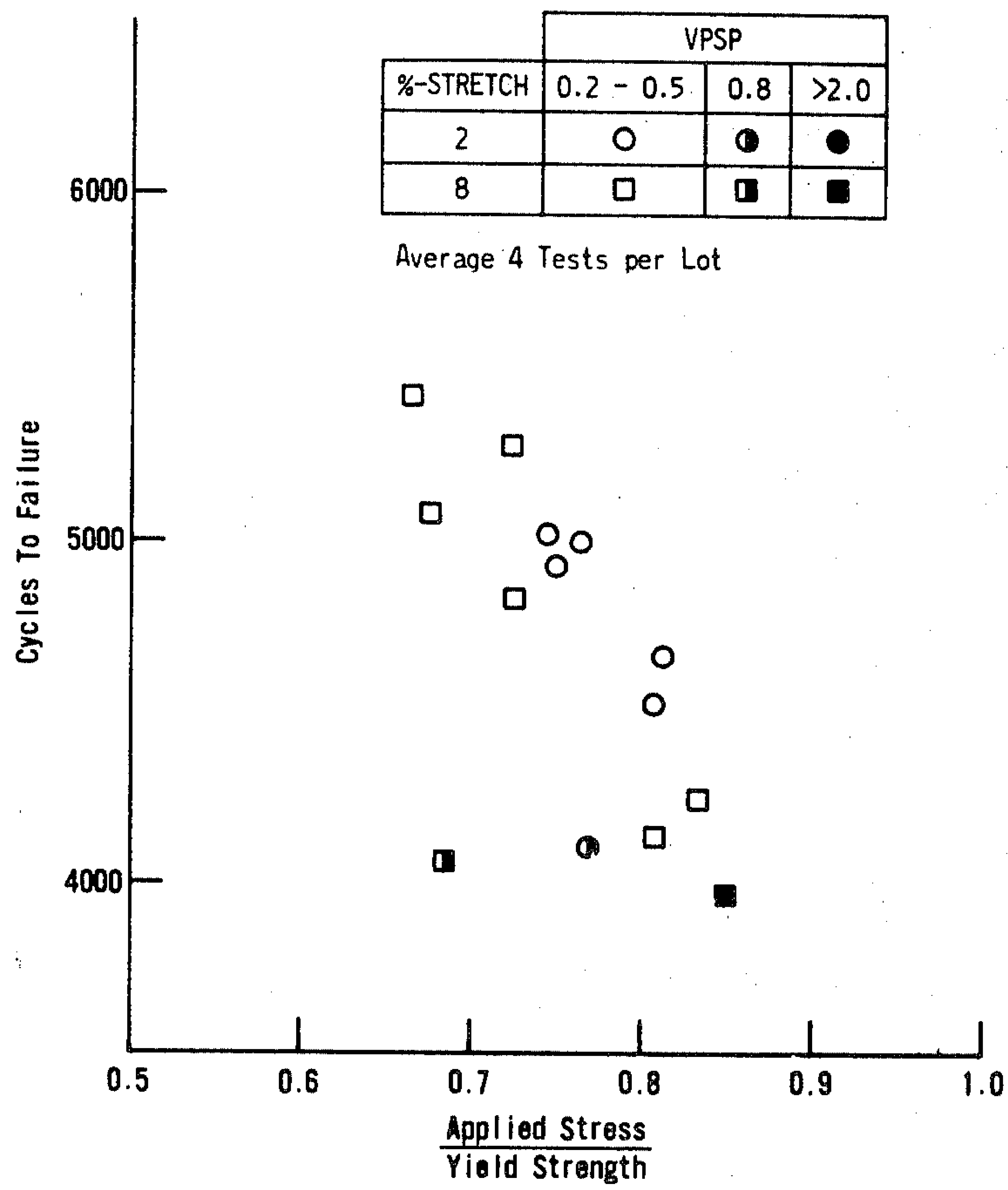
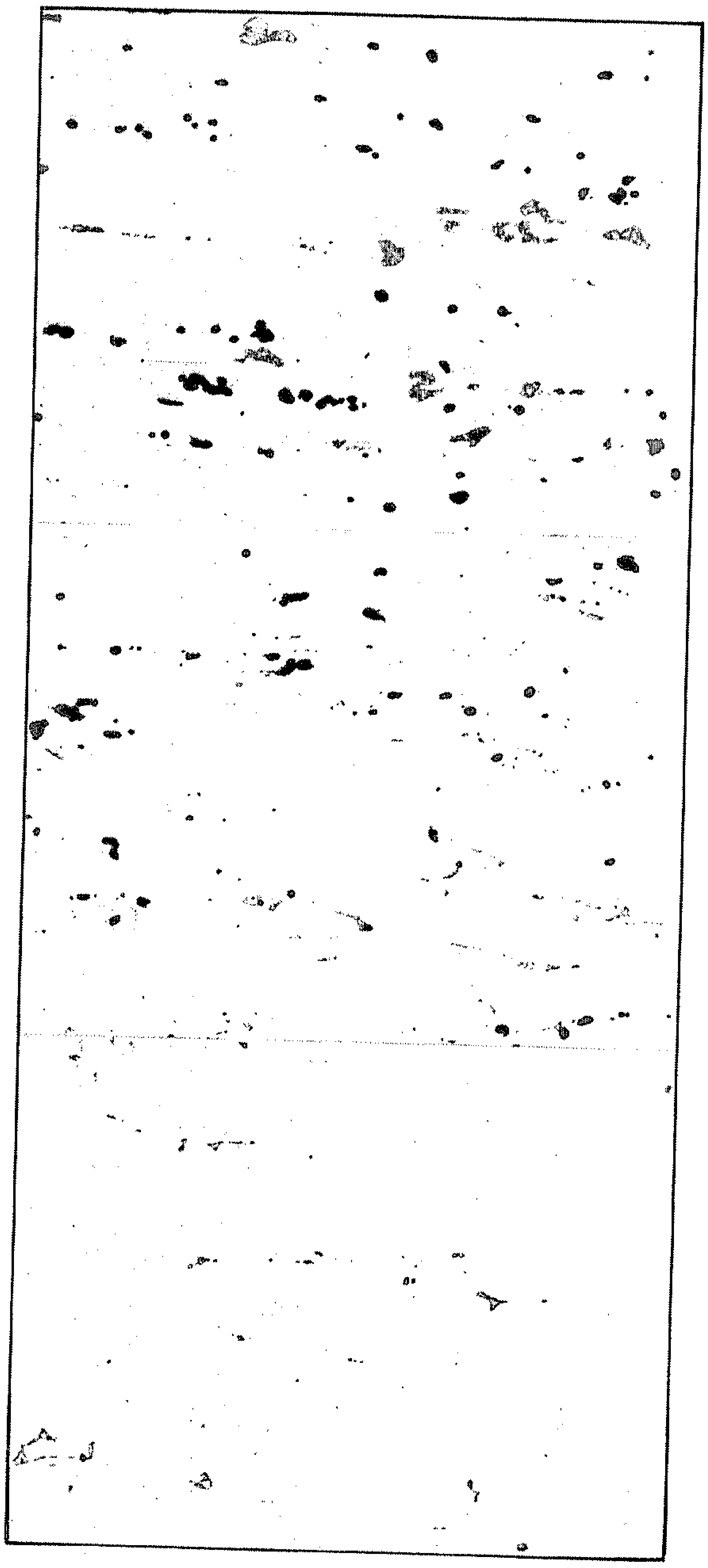


FIG. 6 Short-Transverse Notched Fatigue Behavior of MD-148 at an Applied Stress of 45 ksi. (Laboratory produced 1.25 inch thick plate).

ALUMINUM ALLOY SYSTEM

Filed Aug. 3, 1972 8 Sheets-Sheet 7

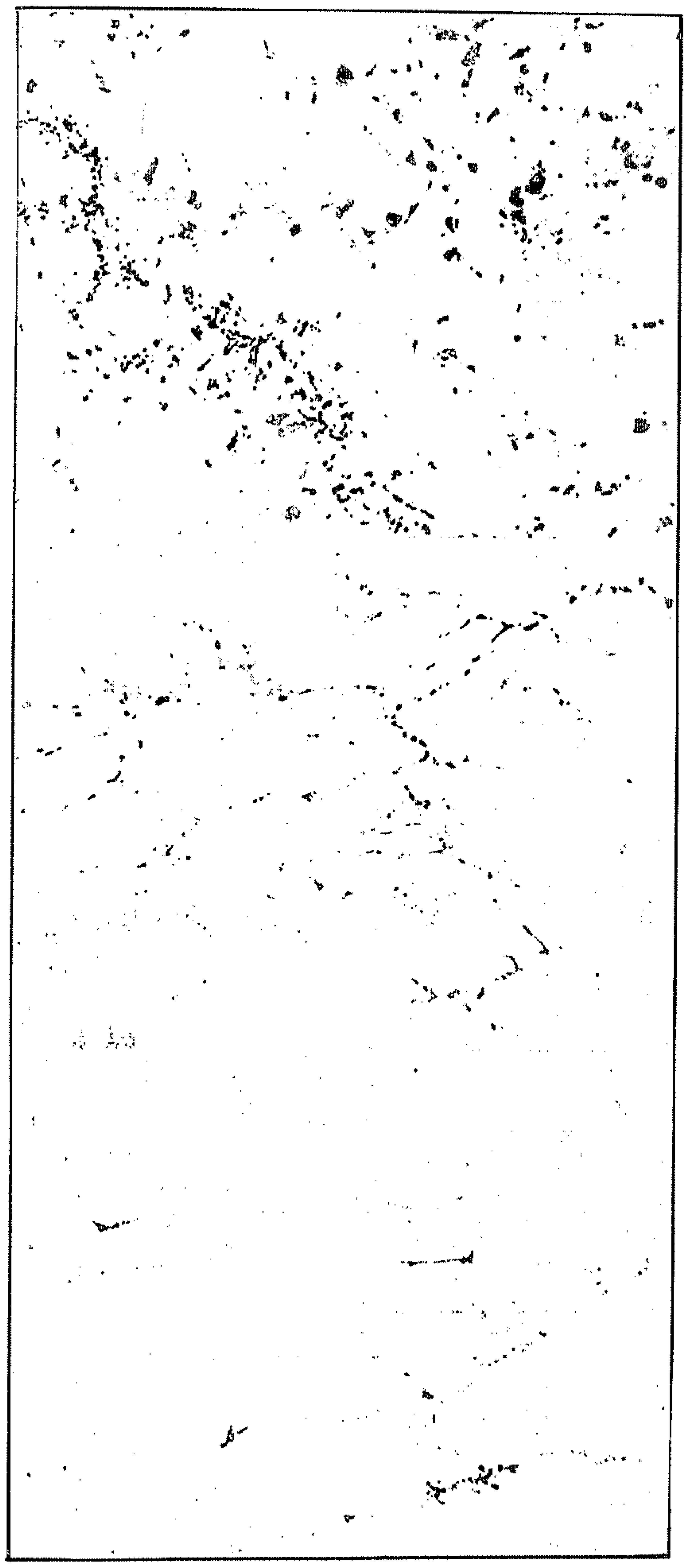


2024
Cu - 4.17%
Mg - 1.51%
Mn - 0.65%
Fe - 0.20%
Si - 0.09%
VPSP ≃ 2.5%

2124
Cu - 4.13%
Mg - 1.39%
Mn - 0.40%
Fe - 0.15%
Si - 0.11%
VPSP ≃ 1.5%

MD-148 (X2048)
Cu - 3.12%
Mg - 1.31%
Mn - 0.38%
Fe - 0.09%
Si - 0.03%
VPSP ≃ 0.5%

FIG. 7A Photomicrographs Illustrating the Relative Levels of Second Phase Particles in 2024, 2124, and MD-148. Longitudinal Section, 250X, Unetched.



2024
Cu - 4.17%
Mg - 1.51%
Mn - 0.65%
Fe - 0.20%
Si - 0.09%
VPSP ≃ 2.5%

2124
Cu - 4.13%
Mg - 1.39%
Mn - 0.40%
Fe - 0.15%
Si - 0.11%
VPSP ≃ 1.5%

MD-148 (X2048)
Cu - 3.12%
Mg - 1.31%
Mn - 0.38%
Fe - 0.09%
Si - 0.03%
VPSP ≃ 0.5%

FIG. 7B Photomicrographs Illustrating the Relative Levels of Second Phase Particles in 2024, 2124, and MD-148. Rolling Plane, 100X, Unetched.

United States Patent Office

3,826,688
Patented July 30, 1974

1

3,826,688

ALUMINUM ALLOY SYSTEM

Sander A. Levy, Richmond, Va., assignor to Reynolds Metals Company, Richmond, Va.

Continuation-in-part of application Ser. No. 105,061, Jan. 8, 1971. This application Aug. 3, 1972, Ser. No. 277,605

Int. Cl. C22f *1/04*

U.S. Cl. 148—2 29 Claims

ABSTRACT OF THE DISCLOSURE

Wrought articles of Al-Cu-Mg alloy containing up to about 5% copper and up to about 2% magnesium as the principal alloying elements by weight, within limits effective to achieve substantially single phase structure, and exhibiting improved fracture toughness in —T8XX condition; also, related practices and improved alloy compositions for making such articles, including plate.

This application is a continuation-in-part of applicant's prior copending application Ser. No. 105,061, filed on Jan. 8, 1971.

The present invention relates to improvements in wrought articles made of an aluminum base alloy containing copper and magnesium as the principal alloying elements by weight, in amounts up to about 5% Cu and up to about 2% Mg, including at least 0.3% magnesium and at least about 3% total of copper and magnesium; and it further relates to practices for making such articles to achieve improved properties, and to alloy compositions of the Al-Cu-Mg type.

Alloy 2024 as currently produced commercially contains a large percentage of second phase particles, such as (i) θ phase—$CuAl_2$, (ii) S phase—Al_2CuMg, and (iii) $FeMnAl_7$' Cu_2FeAl_7 is another probable phase. These particles apparently add little to the strength of the alloy, but tend to impair both ductility and toughness. In addition to 3.8% to 4.9% copper and 1.2 to 1.8% magnesium, alloy 2024 contains 0.3 to 0.9% manganese, with iron up to 0.50%, silicon up to 0.50%, chromium up to 0.10%, zinc up to 0.25%, others, .05% max. each and 0.15% total, balance aluminum. Thus, there are three major sources of second phase particles: the minor addition element Mn, undissolved soluble phases containing Cu and Mg, and trace elements such as Si and Fe. Alloy 2124 is similar, except for lower maximum amounts of silicon and iron.

As far as the reasons for originally including manganese in 2024 alloy are concerned, it seems to have been generally recognized that Mn ties up Fe and so avoids the presence of long $FeAl_3$ needles which tend to cause embrittlement. Manganese may also reduce the amount of Cu tied up by Fe, and so increase the availability of Cu for precipitation. The presence of manganese also tends to inhibit recrystallization, although in other systems it is less effective in this respect than Cr or Zr. Further, manganese contributes to strength of the alloy in two ways, in that the portion in solid solution has a direct influence and its effect on recrystallization may also result in increased strength due to the presence of substructure.

2

In connection with previous work on the Al-Zn-Mg-Cu system, especially 7075 alloy, it has been noted that various properties are improved by using prolonged solution heat treatments and limiting the occurrence of second phases by using higher purity (low Si, Fe, and Mn) aluminum base metal. In trying to apply the same general approach to producing a homogeneous 2024-type alloy, however, it became apparent that use of high purity aluminum and prolonged homogenization alone would not suffice.

As regards Al-Cu-Mg alloys in particular, it has been determined in accordance with the present invention that limitations must be imposed specifically on the major alloying elements copper and magnesium, in order to achieve the desired results. Thus, a first aspect of the invention is providing an aluminum base alloy containing copper and magnesium essentially within their solubility limit, as indicated by a solidus temperature (incipient melting point) of at least about 945° F. or higher in homogenized condition. This criterion alone distinguishes the alloys of the present invention from commercial grades of 2024 alloy, having a solidus temperature of about 935° F. (Metals Handbook, vol. 1, 8th edition, page 938).

A second aspect of the invention involves controlling the impurity and minor alloying elements to an extent sufficient to make possible the attainment of substantially single phase structure. As used herein, a wrought article has "substantially single phase structure" when its VPSP (volume percent second phase) does not exceed 1% on the basis of second phase particles which are visible and resolvable in unetched condition under optical magnification up to 1000×.

As a result of preliminary work it also became apparent that excessive suppression of the minor alloying element manganese could lead to a loss in strength, impaired ductility, and possibily inferior stress corrosion resistance due to inability to maintain an elongated grain structure. Accordingly, a third aspect of the present invention is that of providing Al-Cu-Mg alloys which contain up to about 0.4% manganese in an amount effective approximately to saturate the matrix without producing undesirable amounts of insoluble particles. The use of chromium and/or zirconium in at least partial replacement of or in addition to manganese is also contemplated.

The alloy may further include incidental amounts of silicon, iron, zinc and titanium, ordinarily in minor fractional amounts each, as hereinafter discussed in greater detail, but is substantially free of other impurities (i.e. typically .05 max. each, 0.15 max. total).

When all of the foregoing considerations are taken into account the resulting wrought articles of Al-Cu-Mg alloy in —T8XX temper not only have suitable homogeneity and more nearly isotropic properties, but also exhibit improved fracture toughness at least 50% greater than and up to about double that of conventional 2024–T857 alloy.

In summary, therefore, a wrought article of Al-Cu-Mg alloy in accordance with the present invention is characterized compositionally by containing up to about 5% copper and up to about 2% magnesium as the major alloying elements, and up to about 0.4% manganese, within limits effective to achieve a solidus of 945° F. or higher in homogenized condition; and is further characterized and distinguished by substantially single phase structure. Such articles advantageously are made of alloy compositions affording a yield strength of at least 45,000 p.s.i. in —T8XX temper, preferably at least 52,000 p.s.i. Plate products of this type may exhibit a short transverse yield strength of about 45 to 60 k.s.i., and up to 10% elongation.

Improved alloy compositions of the present invention may include silicon and iron in amounts up to about 0.2% each (typically about .05–0.3% total), as well as minor alloying additions and incidental elements including, for example, up to about 0.2% titanium, up to about 0.2% chromium, up to about 0.4% manganese, up to 0.25% or even somewhat more zinc, and up to about 0.25% zirconium; but all of these elements and other impurities ordinarily will not exceed 1% in the aggregate. Such alloys contain at least about 3% total of copper and magnesium, including at least about 0.6% magnesium, in order to achieve adequate strength, preferably about 4–5.5% total of Cu and Mg when maximum strength is desired, with copper typically in the range of about 3–4.5% by weight. Optimum alloys are those containing at least 1.2% magnesium and less than 3.8% copper, preferably about 2.9–3.7% Cu and about 1.3–1.7% Mg, thus further distinguishing over conventional 2024 alloy.

The accompanying FIGS. 1–6 are graphical representations of certain data discussed in the examples; and FIG. 7 shows a comparison of alloy microstructures hereinafter described.

The following exemplary practices of the invention are provided for purpose of illustration.

EXAMPLE 1

Ingots of various Al-Cu-Mg alloys prepared for processing in accordance with method aspects of the present invention were semicontinuously cast using a "CC" mold. The majority were 50 lb. ingots with a 3 x 8" cross section. A few 400 lb. ingots (4 x 14") were also used. Differential thermal analysis (DTA) samples were taken from replicate chemical analysis buttons. Chemical analyses were performed spectrochemically and the results are presented in Table I.

The ingots were homogenized in dry air (about −40° F. dew point) for 48 hours at about 10° F. below the incipient melting point, as determined by DTA techniques. After homogenization 1/8" was scalped from the two large surfaces of each ingot. The ingots were preheated to 800° F. for rolling. Reductions of 1/4" per pass were taken, with reheating to 800° F. after four passes or when the temperature dropped to 650° F.

The final heat treatments involved solution heat treatment for 5 hours at about 10° below the melting point (DTA basis), and cold water quenching. After a one day incubation at room temperature, portions of the plate were stretched 2% or 8%. The 2% stretch plates then were aged for 12 hours at 375° F. and the 8% plates for 8 hours at 375° F. A controlled heating rate of 25° F./hr. was used to reach the aging temperature. Tensile (standard .505" for L and LT and compact specimens for ST) and compact tension K_{IC} specimens were obtained.

Mechanical properties are listed in Table II, for the compositions indicated by asterisk in Table I.

TABLE I.—ALLOY COMPOSITIONS AND THEIR SOLIDUS TEMPERATURES, AS DETERMINED BY DTA

											Solidus (° F.)	
S No.	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Zr	Cast	Homogenized
24262*	.05	.09	3.83	.30	.29	<.01	<.01	.01	.06	------	1,002	----------
24260	.10	.16	4.23	.40	.64	<.01	<.01	.01	.06	------	987	----------
24261*	.10	.17	3.83	.29	.65	<.01	<.01	.01	.06	------	955	----------
24353*	.01	.03	3.87	.19	.65	<.01	.01	.02	.06	.16	984	----------
25937	.05	.03	3.57	.28	.73	<.02	<.02	<.02	.02	------	961	1,052
25929	.05	.06	3.27	.27	.79	<.02	<.02	<.02	.01	------	956	960
25940	.05	.03	3.19	.27	.80	<.02	<.02	<.02	.01	------	954	1,052
24742*	.04	.02	3.94	.15	.96	<.01	.01	<.01	.02	.14	939	1,006
25938**	.05	.04	3.54	.28	.99	<.02	<.02	<.02	.01	------	930	1,056
23094*	.01	.01	3.87	.17	1.04	<.01	<.01	<.01	.01	------	964	----------
25941	.05	.04	3.24	.27	1.06	<.02	<.02	<.02	.02	------	930	1,027
25930	.05	.06	4.15	.27	1.09	<.02	<.02	<.02	.02	------	938	1,010
23095	.03	.02	3.92	.29	1.10	<.01	<.01	<.01	.02	------	939	----------
25943**	.05	.04	4.02	.27	1.12	<.02	<.02	<.02	.02	------	930	989
25983**	.05	.05	3.90	.39	1.22	<.01	<.01	<.01	.01	------	930	983
25982	.05	.05	4.01	.23	1.22	<.01	<.01	<.01	<.01	------	931	938
25939***	.05	.04	3.59	.28	1.26	<.02	<.02	<.02	.02	------	930	1,029
25942**	.05	.04	3.26	.27	1.36	<.02	<.02	<.02	.02	------	930	1,006
25931	.05	.06	4.13	.26	1.37	<.02	<.02	<.02	.01	------	938	1,023
24259	.10	.16	4.43	.33	1.54	<.01	<.01	.01	.06	------	941	----------
25986	.05	.05	3.27	.32	1.66	<.01	<.01	<.01	.01	------	936	947
25987	.06	.05	3.87	.32	1.68	<.01	<.01	.01	.01	------	934	945
26615	.02	.05	3.70	.34	2.11	<.01	<.01	<.01	.01	------	------	950
26625	.02	.04	4.24	.35	1.56	<.01	<.01	<.01	.01	------	------	940
26626	.03	.04	4.25	.40	1.88	<.01	<.01	<.01	.01	------	------	943

TABLE II.—MECHANICAL PROPERTIES OF HEAT TREATED ALLOYS

S No.	Direction	Percent stretch	UTS	Y.S.	Percent el.	Cu	Jg	Jn	Fe	Zr
24261	ST	2	55.6	44	11.9					
	ST	8	62.4	55.6	9.3	3.83	.65	.29	.17	<.01
	L	2	55.8	45.5	12.1					
	L	8	62.8	58.3	11.4					
24262	ST	2	51.3	39.4	16.6					
	ST	8	54.0	45.9	12.7	3.83	.29	.30	.09	<.01
	L	2	51.4	40.8	15.7					
	L	8	51.0	40.8	14.8					
24353	ST	2	55.7	43.7	15.4					
	ST	8	63.9	55.5	12.9	3.87	.65	.19	.03	.16
	L	2	55.1	45.2	15.5					
	L	8	63.4	58.4	14.0					
23094	L	2	64.9	55.3	10.0					
	L	8	72.6	68.5	9.3	3.87	1.04	.17	.01	<.01
	L	2	62.6	49.1	14.8					
	LT	2	60.8	44.8	12.9					
24742	ST	2	62.6	46.7	11.0	3.94	.96	.15	.02	.14
	L	8	65.2	53.0	12.7					
	LT	8	66.2	52.3	9.1					
	ST	8	64.6	50.4	7.7					

At 0.65% Mg content it may be noted with reference to Table II that the Zr-containing alloy (S No. 24353) is as strong as the Zr-free version (S No. 24261), but exhibits even greater elongation, perhaps due partly to its lower iron content. Also of interest is the relatively high short transverse (ST) elongation obtained in both instances.

At the 1% Mg level the Zr-free alloy had higher strength. On the basis of hardness, however, the effect of Zr does not seem significant on either the rate of aging or the peak hardness.

Fracture toughness tests of ¾-inch plate in —T8XX temper (2% stretch) indicated that these alloys were so tough as to require plate thicknesses of between 1.5 and 1.75 inches for dependable results. Other tests (8% stretch) provided K_Q values considered to be within 10% of the true K_{IC}, and indicating essentially a doubling of toughness over 2024 alloy. Fracture toughness results were determined in accordance with ATSM practice E399–70T, Part 31, May 1970, pages 911–927.

Although the data given in Table I on incipient melting points include results for certain compositions in cast condition, and for others after homogenizing treatment, the latter approach has been found more reliable and more definitive in distinguishing the compositions effective for purposes of the present invention. Such compositions are susceptible to solution treatment at temperatures higher than conventional 2024 alloy.

The following additional data summarize the results of various tests on laboratory produced materials, and also on five plant-produced heats.

EXAMPLE 2

(I) Chemistry and Processing

(a) Laboratory heats.—Several lots of laboratory produced materials were prepared from 4 x 14 x 72 inch ingots of the following compositions:

S No.	Cu	Fe	Si	Mn	Mg	Zn	Ni	Cr	Ti	Zr
26497	3.42	.07	.06	0.30	1.25	<.02	<.02	<.02	.02	<.02
26498	3.60	.06	.05	0.29	1.23	.02	<.02	<.02	.02	0.11
26499	3.46	.07	.04	<.02	1.18	.03	<.02	<.02	.01	0.10
28137	2.68	.08	.04	0.28	0.99	.01	<.01	<.01	.02	<.01
28138	2.76	.08	.04	0.28	1.37	.01	<.01	<.01	.02	<.01

These ingots were stress relieved for 24 hours at 550° F. and then cut into 24 inch long sections. After homogenizing in dry air (about —40° F. dew point) for 48 hours at 925° F., the ingot sections were scalped to 3.25 inch thickness and hot rolled at 800° F. Reductions of ¼ inch per pass were taken, with reheating to 800° F. after four passes or when the temperature dropped to 650° F. Except as otherwise noted these materials were finished at 1.25 inch thickness.

(b) Plant heats.—Five plant produced heats were cast as 16 x 60" ingots. The first three involved alloy variations without Zr (–A) and with Zr (–B). The chemical compositions of these ingots were:

Lot No.	Cu	Fe	Si	Mn	Mg	Ti	Zr
I–A	3.76	0.12	.06	0.33	1.33	.02	--------
I–B	3.66	0.12	.06	0.29	1.28	.02	.06
II–A	3.56	0.12	.05	0.29	1.39	.02	--------
II–B	3.66	0.12	.06	0.29	1.28	.02	.06
III–A	3.34	0.09	.04	0.37	1.11	.02	--------
III–B	3.25	0.09	.05	0.68	1.04	.01	.06
IV–A	3.12	0.09	.03	0.38	1.31	.01	--------
V–A	3.37	0.08	.03	0.33	1.43	.01	--------

The casting and scalping operation involved normal 2024 practice. Lots I–A and I–B were homogenized for 48 hours at 935° F. (about 10° above the normal 2024 ingot homogenizing temperature). All subsequent lots were homogenized for 16 hours at 940 to 960° F. The ability of these alloys to be treated at such high temperatures greatly contributed to their low second phase content and high fracture toughness.

Special care was exercised to cool the ingots directly from homogenization temperature to the hot rolling temperature (approximately 890° F.) to minimize the reprecipitation of second phase particles. Rolling to either 3 or 6 inch plate thickness involved normal 2024 practices. Final solution heat treatment was performed at 910 to 925° F. for 3 hours. The plates were stretched immediately after quenching. For Lot I, both 2 and 6% stretch were used and the final aging time at 375° F. was adjusted according to the level of stretching (see Table VI). For the remaining four heats (Table VII) only 3" plate, 2% stretch, and a final age of 12 to 14 hours at 375° F. were employed.

(II) Mechanical Properties and Fracture Toughness

(a) 1.25" laboratory plate.—Tables III and IV present additional data for laboratory produced heats of the subject alloy, for compositions indicated by a double or triple asterisk in Table I. Typical results for laboratory material are summarized in FIG. 1, compared to 2024 alloy.

(b) Thin gage-K_c values and Kahn tear testing.—While the majority of testing concerned plate products, some testing of thin gage material was conducted. Eight sheets of the first two compositions (S Nos. 26497 and 26498) were rolled to .080 inch for plane stress fracture toughness tests, by hot rolling as noted above to a thickness of ¼ inch, etching and cold rolling to .080 inch.

With some exceptions (as noted) the subsequent thermal treatment of these materials involved a 24 hour solution heat treatment at 925° F. and cold water quenching. After a one day room temperature incubation the samples were stretched. Those pieces stretched 2% were aged 12 hours at 375° F., and those stretched 8% were aged 8 hours at 375° F. A 25° F./hr. heating rate was used in all cases.

The results of .080 gage fracture toughness tests indicate that:

(a) with 2% stretch the alloy is as tough as 2024–T3, but has about 20 k.s.i. higher yield strength;
(b) with 8% stretch its strength and toughness are comparable to 7475–T61;
(c) with 8% stretch there is strength comparable to 2024–T86, as well as about double its toughness.

Kahn tear tests in both the L–T and T–L directions also showed good toughness (see Table V) and only slight directionality of properties.

(c) Plant produced plate.—Results for the first plant heat with two plate thicknesses and two levels of stretch are presented in Table VI. Although a substantial improvement occurred with respect to 2024, the full potential of the alloy system was not realized until the higher ingot homogenization practice was employed, as for the four subsequent heats, cf. Table VII.

(III) Fatigue

Fatigue results, for material taken from Lot II–A, are presented in FIGS. 2–5. These results indicate that the alloy is comparable to 2024 or 2124 in this property. For the short transverse direction, in laboratory produced material, the alloy has even higher fatigue resistance than 2024 or 2124 (cf. FIG. 6), particularly for the low cycle (high stress) range.

(IV) Elevated Temperature Stability

The effect on residual strength of the alloy (Lot I–A and –B) after exposure for 100 hours at 400° F. is presented in Table VIII. This property is important particularly for supersonic aircraft where air friction can cause temperatures to about 275° F. It appears that the present alloy has a comparable advantage regarding thermal stability as 2024 with respect to the 7000 series high strength alloys.

(V) Stress Corrosion

2024–T851 specifications require passing 30 days of alternate immersion in a 3% NaCl solution at 50% of the yield strength, in the ST direction. For alloys of the present invention in its preferred operating range (4.0–5.5% total of copper and magnesium, including at least 1.2% Mg and less than 3.8% Cu) most specimens pass a 90 day exposure (cf. Table VII). Many samples also pass testing at 75% of the ST yield strength. The Zr-free alloy apparently is superior to the Zr-containing alloy in stress corrosion resistance.

TABLE III

Fracture Toughness of 1.25″ Laboratory Produced Plate

S No.	VPSP	Percent stretch	Aging time, 375° F.	Direction	UTS (k.s.i.)	YS (k.s.i.)	Percent el.	K_Q (K.s.i. √in.) L–T	K_Q (K.s.i. √in.) T–L
25938**	.41	2	12	L	66.1	59.7	10.3	54.0	------
				LT	65.8	58.6	9.0	--------	52.0
25942**	.46	2	12	L	68.1	62.5	10.5	49.8	------
				LT	67.9	61.6	8.5	--------	48.6
25943**	.23	2	12	L	70.5	63.6	8.7	42.1	------
				LT	70.6	62.9	6.8	--------	45.3
25983**	.44	8	8	L	76.5	73.9	7.5	35.9	------
				LT	76.2	71.1	5.0	--------	26.8

** For composition see Table I.

TABLE IV

Mechanical propertise and fracture toughness of laboratory produced allows with different Zr and/or Mn additions

S No.	Percent Zr	Percent Mn	Direction	UTS	YS	Percent el.	L–T or (T–L), K_{IC}	VPSP
25499	.10	.02	L	7.00	65.9	7.3	48.1	--------
			LT	66.6	61.1	7.2	(40.2)	.11
			ST	67.5	61.5	5.7	N.D.	--------
25939***	.02	.28	L	69.9	64.0	8.8	44.3	--------
			LT	69.4	62.3	7.9	N.D.	.22
			ST	68.9	61.6	6.0	N.D.	--------
26498	.11	.29	L	70.2	65.9	7.4	37.4	--------
			LT	69.9	65.1	7.1	(35.9)	.53
			ST	70.5	65.1	6.3	N.D.	--------
27913*	.11	.29	LT	68.7	62.5	7.3	(45.8)	.14

* Material originally from ingot No. 26498 but homogenized an extra 24 hours at 925° F. to decrease the VPSP.

*** For composition see Table I.

TABLE V

Kahn Tear Test Data
[MD–148 Compared to other high strength alloys (0.090″)]

Alloy	Direction	Percent stretch	Yield strength (k.s.i.)	UTS (k.s.i.)	Percent el.	UIE	UPE	UTE	T/Y
S No. 26497 (w/o Zr)	L–T	2	66.7	70.1	8.0	605.7	429	1,034.6	1.30
	T–L	2	63.1	68.3	8.0	496.7	531.8	1,028.5	1.32
	L–T	8	71.4	73.8	7.0	362.3	215.3	577.6	1.03
	T–L	8	68.3	72.4	6.0	398.7	218.8	617.5	1.17
S No. 26498 (with Zr)	L–T	2	64.8	69.9	8.0	467.5	446.6	914	1.30
	T–L	2	64.2	69.5	8.0	555.8	559.4	1,115.2	1.35
	L–T	8	71.5	75.1	7.7	377.0	276.4	653.4	1.11
	T–L	8	68.0	72.9	7.0	346.8	211.0	557.8	1.12
2024–T3[1]	L–T	0	52.4	69.6	19.5	--------	710	----------	1.46
	T–L	0	46.4	67.4	19.7	--------	600	----------	1.59
	L–T	0	74.7	79.4	13.0	569.9	369.8	939.6	1.24
7475–T61	T–L	0	73.3	80.2	13.0	505.0	227.1	732.2	1.21
	L–T	0	60.8	70.2	13.0	739.3	796.2	1,548	1.56
7475–T761	T–L	0	59.7	70.7	12.5	672.1	590.2	1,262	1.54

[1] Data of Kaufman and Holt—Fracture Characteristics of Aluminum Alloys (Paper No. 18).

TABLE VI

Plant produced—MD148 (Lot I)

S. No.	VPSP	Plate thickness	Comp.	Percent strength	Hrs. at 375° F.	Test direction	T	Y	E	K_{IC} or K_G, L-T or (T-L)
27660	0.83	3	I-A	2	12	L				31.2
						LT	69.6	64.1	5.0	(24.8)
						ST	68.0	62.8	5.0	
27661	0.83	3	I-A	2	18	L	68.9	63.1	6.5	35.9
						LT	67.6	61.7	5.3	(25.4)
						ST	66.7	60.6	4.0	
27662	0.52	3	I-B	2	12	L	67.9	62.2	9.5	38.3
						LT	67.9	62.0	7.0	(28.4)
						ST	66.1	60.7	4.0	
27663	0.52	3	I-B	2	18	L	69.2	62.9	9.0	
						LT	68.6	63.6	6.5	(26.5)
						ST	66.5	60.8	5.0	
27664	0.83	3	I-A	6	6	L				
						LT	73.4	69.8	3.5	(22.9)
						ST	71.2	67.8	3.0	
27665	0.83	3	I-A	6	8	L				
						LT	71.9	67.8	4.5	(22.9)
						ST	70.1	65.7	3.3	
27666	0.83	3	I-A	6	10	L				
						LT	73.0	69.0	4.0	(22.5)
						ST	71.0	66.9	3.0	
27667	.89C .93 surf	6	I-A	2	12	L				
						LT	66.5	59.1	5.3	(24.3)
						ST	64.0	57.8	4.7	
27668	.89C .93 surf	6	I-A	2	18	L				
						LT	66.2	59.7	4.5	(23.9)
						ST	63.8	57.0	4.3	

TABLE VII

Strength, toughness and stress corrosion resistance of MD-148 plant heats (LOTS II-V)

Alloy	Direction	Yield	Tensile	Percent el.	K_{IC} or (KQ)	SCC 50%	SCC 75%
II-A	L	63.2	69.2	6.5	37.8	3 NF 90 D	86
	LT	62.5	69.2	5.5	34.0		2 NF 90 D
	ST	59.4	66.0	5.7	28.6		
II-B	L	59.6	67.2	9.5	42.8	3 NF 90 D	
	TL	60.5	66.7	7.5	29.2		6, 7, 10
	ST	59.0	65.0	4.0	24.2		
III-A	L	58.4	65.5	10	(47.3)		
	LT	57.9	65.2	8.3	36.0		
	ST	57.1	63.5	6.0	27.1	3, 3, 4	2, 2, 2
III-B	L	55.9	61.6	11	38.2		
	LT	55.2	61.6	8.8	30.7		
	ST	55.4	60.9	5.7	23.2	27, 78, 90	4, 7, 30
IV-A	L	60.4	65.5	10	41.3		
	LT	60 6	66.5	8	33.8		
	ST	59.9	66.7	8	28.0	3 NF	3NF
V-A	L	61.6	67.6	8.0	40.5		
	LT	61.2	67.6	7.3	33		
	ST	58.6	65.5	6.0	27.9	3 NF	3 NF

TABLE VIII

Effect of 100 hr. exposure at 400° F. on mechanical properties; testing at room temperature

Alloy	UTS (k.s.i.)	YS (k.s.i.)	Percent el.
I-A (before exposure)	68.9	63.1	6.5
I-A (after exposure)	61.7	51.7	7.0
I-B (before exspsure)	69.2	62.9	9.0
I-B (after exposure)	59.2	48.0	10.3
2124 (after exposure)	62.2	50.7	7.7
2024-T86*		52	

*ASTM Publication 291.

Finally, in FIG. 7, a comparison is shown between the microstructure of conventional 2024 alloy and a substantially single phase structure obtained in accordance with the present invention.

In conclusion, it has been found that alloy MD-148 (X2048) consisting essentially of aluminum, about 2.9–3.7% copper, about 1.3–1.7% magnesium and about 0.1–0.4% manganese, adapted for homogenizing treatment at 940–960° F., is useful in making wrought articles such as hot rolled plate which, in —T8XX temper, exhibit better strength than 2219 alloy and better fracture toughness than 2024 and 2124 alloys, particularly the combination of a short transverse yield strength of at least 55 k.s.i. and an L-T plane strain fracture toughness value of at least 35 k.s.i.$\sqrt{\text{in.}}$, compared to typical values of 22.5 for 2024 alloy and 28 for 2124 alloy.

While present preferred embodiments of the invention have been described it will be recognized that the invention may be otherwise variously embodied and practiced within the scope of the following claims.

What is claimed is:

1. In the art of processing an aluminum base alloy containing copper and magnesium as the principal alloying elements by weight, including casting the alloy to form an ingot, the method which comprises:

providing an ingot composed of an alloy consisting essentially of aluminum, copper and magnesium, in amounts up to about 5% copper and up to about 2% magnesium not exceeding their limit of solubility, including at least 0.3% magnesium and at least 3% total of copper and magnesium, with no more than one percent total of minor alloying elements and incidental impurities from the group consisting of silicon, iron, manganese, chromium, zinc, titanium and zirconium, including about .05–0.3% total of silicon and iron, others up to about 0.4% in the case of manganese, up to about 0.25% in the case of zinc and zirconium, and up to about 0.2% in the case of chromium and titanium, said alloy being further characterized by a solidus temperature of at least 945° F. or higher in homogenized condition;

heating said ingot to homogenize the alloy; and

hot rolling the ingot to obtain a wrought article exhibiting substantially single phase structure, having a solid solution matrix of copper and magnesium in aluminum and a volume percent of second phase particles not exceeding one percent based on particles that are visible and resolvable in unetched condition under optical magnification up to 1000×.

2. The method of claim **1**, wherein said processing includes solution heat treating the wrought article.

3. The method of claim **1** wherein said processing includes solution heat treating and artificially aging the wrought article.

4. The method of claim **3** wherein said processing includes cold working the solution treated article at least 1½% prior to said aging treatment.

5. The method of claim **1** including homogenizing the ingot at about 940–960° F.

6. The method of claim **5** including cooling the homogenized ingot directly to hot rolling temperature.

7. A wrought article exhibiting substantially single phase structure having a solid solution matrix of copper and magnesium in aluminum and a volume percent of second phase particles not exceeding one percent based on particles that are visible and resolvable in unetched condition under optical magnification up to 1000×, said article being composed of an aluminum base alloy consisting essentially of aluminum, copper and magnesium, in amounts up to about 5% copper and up to about 2% magnesium not exceeding their limit of solubility, including at least about 0.3% magnesium and at least about 3% total of copper and magnesium, by weight, up to about 0.4% manganese and about .05–0.3% total of iron and silicon in amounts up to about 0.2% each.

8. The article of claim **7** in —T8XX temper, and exhibiting at least 50% greater fracture toughness than conventional 2024–T851.

9. The article of claim **8** in the form of plate, having a short transverse yield strength of about 45,000 to about 60,000 p.s.i.

10. An aluminum base alloy in the form of plate prepared by casting and rolling the alloy, including hot rolling the casting, said plate exhibiting substantially single phase structure, having a solid solution matrix of copper and magnesium in aluminum and a volume percent of second phase particles not exceeding one percent based on particles that are visible and resolvable in unetched condition under optical magnification up to 1000×, said alloy consisting essentially of aluminum, copper and up to 2% magnesium, including about 4–5.5% total of copper and magnesium, at least 1.2% magnesium and less than 3.8% copper and about 1.3–1.7% magnesium, in the form of at least 945° F. or higher in homogenized condition.

11. The article of claim **10**, said alloy including up to about 0.4% manganese.

12. The article of claim **10**, said alloy including up to about 0.25% zirconium.

13. The article of claim **10**, said alloy including up to about 0.2% chromium.

14. The article of claim **10**, said alloy including up to about 0.2% titanium.

15. The article of claim **10**, said alloy including up to about 0.2% silicon.

16. The article of claim **10**, said alloy including up to about 0.2% iron.

17. The article of claim **10**, said alloy containing about .05–0.3% total of silicon and iron.

18. The article of claim **10**, said alloy including up to about 0.25% zinc.

19. The article of claim **10**, said alloy containing about 2.9–3.7% copper, about 1.3–1.7% magnesium and about 0.1–0.4% manganese.

20. A solution heat treated, cold worked and artificially aged aluminum base alloy in —T8XX temper, exhibiting substantially single phase structure, having a solid solution matrix of copper and magnesium in aluminum and a volume percent of second phase particles not exceeding one percent based on particles that are visible and resolvable in unetched condition under optical magnification up to 1000×; said alloy consisting essentially of aluminum, about 0.6–2% magnesium by weight, about 4–5.5% total of copper and magnesium, and up to about 0.4% manganese in an amount effective substantially to saturate its matrix.

21. The alloy of claim **20** containing at least about 1.2% magnesium and less than 3.8% copper.

22. The alloy of claim **20** containing about 2.9–3.7% copper and about 1.3–1.7% magnesium, in the form of plate having an L–T plane strain fracture toughness of at least 35 k.s.i.$\sqrt{\text{in.}}$ and a short transverse yield strength of at least 55 k.s.i.

23. The alloy of claim **20** containing about .05–0.3% total of silicon and iron.

24. The method of claim **1** including hot rolling the ingot to a plate thickness of about 3 inches.

25. The method of claim **1** including hot rolling the ingot to a plate thickness of about 6 inches.

26. The method of claim **4** including hot rolling the ingot to plate thickness, wherein said cold working includes stretching the plate about 2%.

27. The method of claim **4** including hot rolling the ingot to plate thickness, wherein said cold working includes stretching the plate about 6%.

28. The method of claim **4** including hot rolling the ingot to plate thickness, wherein said cold working includes stretching the plate about 8%.

29. The article of claim **9** wherein the volume percent of second phase particles is only about 0.5%.

References Cited

UNITED STATES PATENTS

3,333,989	8/1967	Brown et al.	148—12.7
2,252,361	8/1941	Bothmann et al.	75—142
2,228,013	1/1941	Matthaes	75—142

RICHARD O. DEAN, Primary Examiner

U.S. Cl. X.R.

75—141, 142; 148—11.5 A, 12.7, 32, 32.5

PO-1050
(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,826,688 Dated July 30, 1974

Inventor(s) Sander A. Levy

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Claim 10 should read as follows to correct a printing error in the penultimate line:

10. An aluminum base alloy in the form of plate prepared by casting and rolling the alloy, including hot rolling the casting, said plate exhibiting substantially single phase structure, having a solid solution matrix of copper and magnesium in aluminum and a volume percent of second phase particles not exceeding one percent based on particles that are visible and resolvable in unetched condition under optical magnification up to 1000X, said alloy consisting essentially of aluminum, copper and up to 2% magnesium, including about 4-5.5% total of copper and magnesium, at least 1.2% magnesium and less than 3.8% copper, by weight, and having a solidus temperature of at least 945°F. or higher in homogenized condition.

Signed and sealed this 29th day of October 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents