N72-20494

NASA TECHNICAL MEMORANDUM

NASA TM X-64645

ZM-21 MAGNESIUM ALLOY CORROSION PROPERTIES AND CRYOGENIC TO ELEVATED TEMPERATURE MECHANICAL PROPERTIES

By J.W. Montana and E. E. Nelson
Astronautics Laboratory

March 14, 1972

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

MSFC - Form 3190 (Rev June 1971)

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. TMX- 64645	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE ZM -21 MAGNESIUM ALLOY CORROSION PROPERTIES AND CRYOGENIC TO ELEVATED TEMPERATURE MECHANICAL PROPERTIES		5. REPORT DATE March 14, 1972 6. PERFORMING ORGANIZATION CODE
7. AUTHOR (S) J. W. Montano and E. E. Nelson		8. PERFORMING ORGANIZATION REPORT #
9. PERFORMING ORGANIZATION NAME AND ADDRESS George C. Marshall Space Flight Center Marshall Space Flight Center, AL 35812		10. WORK UNIT NO. 11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D.C.		13. TYPE OF REPORT & PERIOD COVERED Technical Memorandum 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Astronautics Laboratory, Science and Engineering

16. ABSTRACT

The mechanical properties of bare ZM-21 magnesium alloy flat [0.090-inch (0.229 cm) thick] tensile specimens were determined for test temperatures of +400°F (+204°C), +300°F (+149°C), +200°F (+93°C), +80 °F (+27°C), 0°F (-18°C), -100°F (-73°C), -200°F (-129°C), and -320°F (-196°C). The ultimate tensile and yield strengths of the material increased with decreasing temperature with a corresponding reduction in elongation values.

Stress corrosion tests performed under (a) MSFC atmospheric conditions, (b) 95% relative humidity, and (c) submerged in 100 p.p.m. chloride solution for 8 weeks indicated that the alloy is not susceptible to stress corrosion. The corrosion tests indicated that the material is susceptible to attack by crevice corrosion in high humidity and chemical type attack by chloride solution. Atmospheric conditions at MSFC did not produce any adverse effects on the material, probably due to the rapid formation of a protective oxide coating.

In both the mechanical properties and the stress corrosion evaluations the test specimens which were cut transverse to the rolling direction had superior properties when compared to the longitudinal properties.

17. KEY WORDS	18. DISTRIBUTION STATEMENT STAR Announcement J. W. Montano E. E. Nelson

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE

MSFC - Form 3292 (May 1969)

ACKNOWLEDGEMENT

Acknowledgement is given to Mr. S. H. Hunter for his assistance in elevated and cryogenic temperature tensile testing and Mr. H. L. Gilmore for his thorough survey of the use of ZM-21 alloy. We would also like to acknowledge Mr. F. Sheara of Magnesium Elektron, Inc. for his efforts in obtaining the test material.

LIST OF TABLES

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

ZM-21 MAGNESIUM ALLOY CORROSION PROPERTIES AND CRYOGENIC TO ELEVATED TEMPERATURE MECHANICAL PROPERTIES

SUMMARY

This report presents some mechanical, corrosion and stress corrosion properties of bare ZM-21 magnesium alloy flat tensile specimens cut both longitudinal and transverse to the rolling direction. The mechanical properties were evaluated at temperatures from -320°F (-196°C) to +400°F (+204°C) for 0.090-inch (0.229 cm) thick material. The tensile test data indicate an increasing ultimate tensile and 0.2% offset yield strength with decreasing temperature. Elongation, measured in a 1.0-inch (2.54 cm) gage length, decreases with decreasing temperatures. At all testing temperatures used in this evaluation, the transverse test specimens had better mechanical properties than the longitudinal specimens.

Corrosion and stress corrosion tests were conducted for eight (8) weeks using 0.050-inch (0.127 cm) thick material specimens stressed to 0, 50 and 75 percent of the 0.2% offset yield strength and subjected to the following environments: (a) Marshall Space Flight Center outside atmosphere during the unseasonably wet and mild temperature months of November, December, 1971 and January 1972; (b) humidity cabinet at 100°F (+38°C) with 95% humidity, (c) 100 p.p.m. chloride solution, completely immersed. The atmospheric environment produced no adverse effects on the mechanical properties of the test specimens. Tests performed in the 95% relative humidity environment indicated crevice type corrosion occurring in the test specimen at the contact points of the specimen with the stress jigs. Test specimens immersed in the 100 p.p.m. chloride solution indicated a rather severe chemical attack which preferentially etched tiny pin holes in the material. This alloy was not susceptible to stress corrosion cracking under the conditions of these tests. As in the mechanical properties evaluation at cryogenic and elevated temperatures, the transverse test specimens exposed to the stress corrosion conditions indicated more consistent mechanical properties than the longitudinal test specimens.

INTRODUCTION

ZM-21 magnesium alloy is composed of approximately 97% Mg, 2% Zn and 1% Mn and is a patented alloy developed by Mr. W. H. O. Ziegler of West Germany. Improvements have been made to the alloy by Magnesium Elecktron Ltd. who have used the alloy in the United Kingdom in aerospace applications. The alloy is also being used by the Samsonite Company in Canada for luggage framing. Kaiser Aluminum Company, which is the U.S. licensee of ZM-21, has used the alloy for typewriter frames.

This alloy has low Fe and Si impurities and is reported to have the highest corrosion resistance of all magnesium alloys, good weldability, and excellent damping characteristics. The Bureau of Mines in Rola, Missouri reportsthe damping index to be 38.4.

The Materials Division, Astronautics Laboratory, of MSFC, in a continuing search for new light-weight alloys with resistance to stress corrosion cracking and desirable mechanical properties over a moderate temperature range, evaluated ZM-21 magnesium alloy. The material used in the evaluation consisted of 2 sheets 24 inches X 24 inches (61 cm X 61 cm) each of two different thicknesses, 0.050 inches (0.127 cm) and 0.090 inches (0.229 cm), furnished by Magnesium Elektron, Inc., of Secaucus, New Jersey.

TEST SPECIMENS AND EQUIPMENT

The chemical composition of the material used in this evaluation is shown in Table I. The specimen configuration used for cryogenic and elevated temperature tensile testing is illustrated in Figure 1. This pin-clevis type specimen is 4.75 inches (12.06 cm) overall length by 0.75 inch (1.90 cm) width, with a reduced gage length section of 1.5 inches (3.8 cm) in length by 0.25 inch (0.635 cm) in width. The 0.090-inch (0.229 cm) thick material was utilized for the elevated and cryogenic temperature mechanical property evaluation.

The stress corrosion tests utilized a test specimen of 6.0 inch (15.2 cm) overall length by 0.75-inch (1.90 cm) width by 0.050-inch (0.127 cm) thick, with a reduced gage length section of 2.5 inches (6.35 cm) X 0.50 inch (1.27 cm) wide.

The equipment used in the cryogenic and elevated temperature tensile testing is illustrated in Figure 1 and Figure 2 respectively with the exception of the extensometer attachment. Cryogenic tensile testing utilizes a special extensometer which attaches directly to the specimen gage length. For elevated temperature tensile testing a 3.0 inch (7.6 cm) I.D. class-shell type furnace was used. Figure 2 illustrates the gage length attachment rods which provide for a clamp-on linear differential transformer extensometer outside of the furnace to record strain movement. This test setup enabled us to acquire a modulus value at +400°F (+204°C). However, a deflectometer was used to record the load-strain curves for all elevated temperature tests except the one experimental test performed at +400°F (+204°C).

The corrosion and stress corrosion tests were performed in three different environments:

a. Marshall Space Flight Center (MSFC) atmosphere

b. Humidity cabinet: Temperature 100°F (38°C) and 95% relative humidity

c. 100 p.p.m. chloride solution: Complete immersion of specimen.

RESULTS AND DISCUSSION

The tensile test results of the elevated temperature through cryogenic temperature mechanical properties evaluation are tabulated in Tables II and III, and these properties are plotted in Figures 3-6.

Table II contains test data on longitudinal 0.090-inch (0.229 cm) thick tensile specimens machined from sheet material. As indicated in those test data, there is an increase in ultimate tensile (U.T.S.) and 0.2% yield strengths (Y.S.) and a decrease in elongation with decreasing temperatures.

Table III contains test data on transverse 0.090-inch (0.229 cm) thick tensile specimens machined from sheet material. The test data indicate an increase in U.T.S. and Y.S. and a decrease in elongation with decreasing temperature.

At all testing temperatures employed in the investigation, the transverse test data indicated superior mechanical properties compared to the longitudinal test data. For instance, at +400°F (+204°C) the transverse data showed an approximate 10% and 17% increase in ultimate tensile and 0.2% yield strengths, respectively, over the longitudinal test data; at -320°F (-196°C) the increase in transverse U.T.S. and Y.S. was 14 percent and 29 percent respectively.

Figures 3 and 4 plotted in the Mil-Handbook 5 format indicate the percent of ambient temperature strength retained at test temperature for ZM-21 magnesium alloy specimens. As indicated in these figures, at +400°F (+204°C) there is only about 26% of the ambient temperature U.T.S. and Y.S. remaining in the transverse or the longitudinal test specimens. At -320°F (-196°C) there is an approximate gain of 25% in the longitudinal U.T.S. and Y.S. and a corresponding gain of approximately 40 and 35% for the transverse U.T.S. and Y.S., respectively.

Figures 5 and 6 represent the mechanical properties of the transverse and longitudinal test specimens, respectively. The elongation values have also been plotted using the same scale as the U.T.S. and Y.S. to indicate a clear picture of the effects of temperature on the mechanical properties. There is a vast difference in elongation properties between +200°F (+93°C) and 0 °F (-18°C). The elongation percent in 2.00 inches (5.08 cm) varies from approximately 44 percent to 5 percent over the 200°F (+93°C) temperature span. With this loss in ductility with decreasing temperature there is an increase in the U.T.S. and Y.S. of approximately 43 % and 40 % respectively.

The stress corrosion test data is reported in Tables IV and V indicating the longitudinal and transverse tensile test data after 8 weeks exposure to the following conditions:

a. MSFC atmosphere

	Avg. Temp.	Avg. Relative Humidity	Rainfall
Nov. 17-30, 1971	41.9°F (5.5°C)	75.2%	0.71 in (1.79 cm)
Dec. 1 -31, 1971	50.5°F (10.3°C)	81.1%	9.89 in (25.12 cm)
Jan. 1 -19, 1972	42.1°F (5.6°C)	68.8%	6.61 in (16.79 cm)

b. Humidity cabinet: Temperature +100°F (+38°C) with 95% relative humidity

c. 100 p.p.m. chloride solution: Completely immersed.

As indicated, the mechanical properties were not affected by exposure to the MSFC atmosphere. The tensile test data listed under the MSFC atmosphere represent the average of 3 tests for each stressed condition. Exposure of the test specimen in the 95% relative humidity indicated the ZM-21 material to be susceptible to attack by crevice type corrosion occurring in the specimens at their contact points with the specimen stress jigs. Test specimens completely immersed in the 100 p.p.m. chloride solution indicated a severe chemical attack which preferentially etched tiny holes in the ZM-21 materials. The data indicate a rather severe reduction in elongation values for the specimens which were affected by their environments and their stressed conditions. This phenomenon has also been reported by the inventor of the alloy, Mr. W. H. O. Ziegler, who found the loss in elongation after exposure to stress corrosion conditions to be a sensitive measure of incipient corrosion.

The maximum stress (percent of the 0.2% yield strength) applied to the ZM-21 alloy was 75 percent, due to the specimen configuration. If more material had been available, the specimen lengths could have been increased allowing more stress to be applied by the stress jig.

There were no stress corrosion failures in the transverse or longitudinal test specimens. This lack of failures could possibly be attributed, in part, to the stress relaxation which occurred in the specimens during the test. The stressed test specimens took a permanent set, thereby relieving part of the initially applied stress.

Figures 7, 8, and 9 show the stress corrosion test specimens after 56 days exposure to, (a) MSFC atmosphere (b) 95% relative humidity, (c) 100 p.p.m. chloride solution, respectively. Figure 7 indicates the dark protective oxide coating which formed on the test specimens exposed to the atmosphere. Figure 8 shows the crevice type corrosion which occurred in the test specimens exposed to a 95 % relative humidity. environment. The presence of this type of corrosion can be observed at the contact points of the specimen with the stress jigs. Figure 9 illustrates the general type of corrosion which occurred in the specimen exposed to the 100 p.p.m. chloride solution. Tiny pin holes propagated through these test specimens and an overall chemical attack was observed.

The microstructure of the test material as revealed by Nital etch is illustrated in Figures 10 and 11 indicating the 0.090-inch (0.229 cm) thick material and the 0.050-inch (0.217 cm) thick material, respectively. There appears to be very little difference in the microstructure of the material rolled in either the longitudinal or transverse direction.

CONCLUSIONS

Based upon the results of this evaluation, ZM-21 magnesium alloy properties such as ultimate tensile and 0.2% yield strength are shown to increase with decreasing temperatures while elongation percent in 2.00 inches (5.08 cm) indicatesa corresponding decrease with decreasing temperature.

The stress corrosion resistance of ZM-21, as determined by exposure to the MSFC atmosphere for 56 days, is not affected even when the material is stressed to 75 percent of the 0.2 percent offset yield strength prior to exposure.

Although no failures occurred in the test specimens exposed to either the humidity cabinet or the 100 p.p.m. chloride solution, it is strongly recommended that the AM-21 material be given a protective coating prior to use. The crevice type corrosion in the high humidity environment and the general corrosion experienced under exposure to chloride warrants the use of a protective coating.

Further evaluation is needed to determine the notch sensitivity, fracture toughness, fatigue and impact properties.

TABLE I

CHEMICAL COMPOSITION OF ZM-21 MAGNESIUM ALLOY SHEET*

Mg	Zn	Mn	Si	Fe	Sn	Pb	Cu	Ni	Al
Bal.	1.65	1.20	<0.03	<0.01	<0.01	<0.02	< 0.001	< 0.001	Not Detected

* MSFC Analysis

< Symbol For Less Than

TABLE II

MECHANICAL PROPERTIES OF ZM-21 MAGNESIUM ALLOY
LONGITUDINAL TENSILE SPECIMENS, 0.090-INCH (0.229 cm) THICK

Test Temperature °F	(°C)	Ultimate Tensile Strength ksi	(MN/m^2)	0.2% Offset Yield Strength ksi	(MN/m^2)	Elongation 1.00 Inch (2.54 cm) (%)	Modulus X 10^{-6} psi	(GN/m^2)	No. of Tests
+400	(+204.0)	10.7	(73.8)	8.1	(55.8)	46.3	-	-	3
+300	(+149.0)	18.0	(124.1)	12.0	(82.7)	49.0	-	-	3
+200	(+ 93.0)	26.9	(185.5)	14.8	(102.0)	*47.8	-	-	3
+ 80	(+ 26.7)	37.5	(258.6)	27.4	(188.9)	*18.5	6.0	(41.4)	3
0	(- 17.8)	38.9	(268.2)	30.9	(213.0)	4.0	5.6	(38.6)	3
-100	(- 73.0)	42.1	(290.3)	31.7	(218.6)	3.3	6.2	(42.7)	3
-200	(-129.0)	44.6	(307.5)	34.1	(235.1)	2.8	5.9	(40.7)	3
-320	(-196.0)	48.3	(333.0)	34.3	(236.5)	2.3	6.3	(43.4)	3

* Only Two Tests Valid for Elongation Measurements at +200°F (+93.0°C)

* Only Two Tests Valid for Elongation Measurements at + 80°F (+26.7°C)

All Specimens Soaked for 1/2 Hour Prior to Testing.

TABLE III

MECHANICAL PROPERTIES OF ZM-21 MAGNESIUM ALLOY
TRANSVERSE TENSILE SPECIMENS, 0.090-INCH (0.229 cm) THICK

Test Temperature °F	(°C)	Ultimate Tensile Strength ksi	(MN/m^2)	0.2% Offset Yield Strength ksi	(MN/m^2)	Elongation 1.00-Inch (2.54 cm) (%)	Modulus X 10^{-6} psi	(MN/m^2)	No. of Tests
+400	(+204.0)	11.9	(82.0)	9.8	(67.6)	44.9	*5.6	(38.6)	5
+300	(+149.0)	20.5	(141.3)	12.3	(84.8)	45.2	-	-	3
+200	(+ 93.0)	29.5	(203.4)	24.9	(171.7)	**44.0	-	-	3
+ 80	(+ 26.7)	40.2	(277.2)	34.9	(240.6)	24.3	6.1	(42.0)	3
0	(- 17.8)	44.5	(306.8)	40.3	(277.8)	5.5	6.0	(41.4)	3
-100	(- 73.0)	47.9	(330.2)	42.4	(292.3)	4.7	5.9	(40.7)	3
-200	(-129.0)	52.5	(362.0)	45.2	(311.6)	3.7	5.6	(38.6)	3
-320	(-196.0)	56.4	(388.9)	48.2	(332.3)	3.2	6.2	(42.7)	3

* Only One Test Valid for Modulus at +400°F (+204.0°C)

** Only Two Tests Valid for Elongation Measurements for +200°F (+93.0°C) Test Specimens

All Specimens Soaked for 1/2 Hour Prior to Testing

TABLE IV

MECHANICAL PROPERTIES OF BARE ZM-21 MAGNESIUM ALLOY
LONGITUDINAL TENSILE SPECIMENS [0.050-INCH (0.127 cm) THICK] STRESSED TO 0, 50, AND 75%
OF THE 0.2% YIELD STRENGTH AND EXPOSED TO STRESS CORROSION CONDITIONS FOR 8 WEEKS

Stressed Condition Percent of 0.2% Y.S.	Ultimate Tensile Strength ksi	Ultimate Tensile Strength (MN/m^2)	0.2% Offset Yield Strength ksi	0.2% Offset Yield Strength (MN/m^2)	Elongation 1.00-Inch (2.54 cm) (%)	Environment	No. of Tests
0	38.9	(268.2)	29.4	(202.7)	11.5	MSFC Atmosphere	1
50	39.1	(269.6)	30.4	(209.6)	9.5	MSFC Atmosphere	3
75	38.9	(268.2)	29.1	(200.6)	11.1	MSFC Atmosphere	3
0	39.6	(273.0)	30.2	(208.2)	11.5	Humidity	1
50	22.8	(157.2)	-	-	1.5	Humidity	1
50	38.3	(264.1)	29.3	(202.0)	20.5	Humidity	1
50	28.2	(194.4)	-	-	1.5	Humidity	1
75	26.5	(182.7)	-	-	1.5	Humidity	1
75	23.9	(164.8)	-	-	1.0	Humidity	1
75	38.9	(268.2)	30.1	(207.5)	7.5	Humidity	1
						Complete Immersion	
0	13.9	(95.8)	-	-	0	100 p.p.m - Chloride	1
0	16.2	(111.7)	-	-	0.5	100 p.p.m. - Chloride	1
						Complete Immersion	
50	31.4	(216.5)	29.2	(201.3)	7.5	100 p.p.m - Chloride	1
50	16.9	(116.5)	-	-	1.0	100 p.p.m - Chloride	1
50	10.4	(71.7)	-	-	1.0	100 p.p.m - Chloride	1
						Complete Immersion	
75	23.0	(158.6)	-	-	1.5	100 p.p.m - Chloride	1
75	12.7	(87.6)	-	-	1.0	100 p.p.m - Chloride	1
75	19.6	(135.1)	19.6	(135.1)	1.0	100 p.p.m - Chloride	1

TABLE V

MECHANICAL PROPERTIES OF BARE ZM-21 MAGNESIUM ALLOY TRANSVERSE TENSILE SPECIMENS [0.050-INCH (0.127 cm) THICK] STRESSED TO 0, 50, AND 75% OF THE 0.2% YIELD STRENGTH AND EXPOSED TO STRESS CORROSION CONDITIONS FOR 8 WEEKS

Stressed Condition Percent of 0.2% Y.S.	Ultimate Tensile Strength ksi	Ultimate Tensile Strength (MN/m^2)	0.2% Offset Yield Strength ksi	0.2% Offset Yield Strength (MN/m^2)	Elongation 1.00-Inch (2.54 cm) (%)	Environment	No. of Tests
0	38.9	(268.2)	29.4	(202.7)	11.5	MSFC Atmosphere	1
50	38.2	(263.4)	29.6	(204.1)	7.5	MSFC Atmosphere	3
75	37.1	(255.8)	29.4	(202.7)	5.5	MSFC Atmosphere	3
0	39.1	(269.6)	30.1	(207.5)	15.0	Humidity	1
50	31.4	(216.5)	30.1	(207.5)	1.5	Humidity	1
50	32.8	(226.1)	30.1	(207.5)	1.0	Humidity	1
50	37.3	(257.2)	31.0	(213.7)	4.0	Humidity	1
75	24.6	(169.6)	9.8	(67.6)	1.5	Humidity	1
75	26.6	(183.4)	9.6	(66.2)	1.5	Humidity	1
75	10.7	(73.8)	-	-	0	Humidity	1
0	24.1	(166.2)	22.8	(157.2)	1.0	Complete Immersion 100 p.p.m. - Chloride	2
50	14.5	(100.0)	13.8	(95.1)	1.0	Complete Immersion 100 p.p.m. - Chloride	1
50	17.3	(119.3)	-	-	1.0	100 p.p.m. - Chloride	1
50	21.5	(148.2)	21.5	(148.2)	1.0	100 p.p.m. - Chloride	1
75	23.8	(164.1)	-	-	0.5	Complete Immersion 100 p.p.m. - Chloride	1
75	24.9	(171.7)	24.6	(169.6)	1.0	100 p.p.m. - Chloride	1
75	26.9	(185.5)	25.2	(173.7)	1.0	100 p.p.m. - Chloride	1

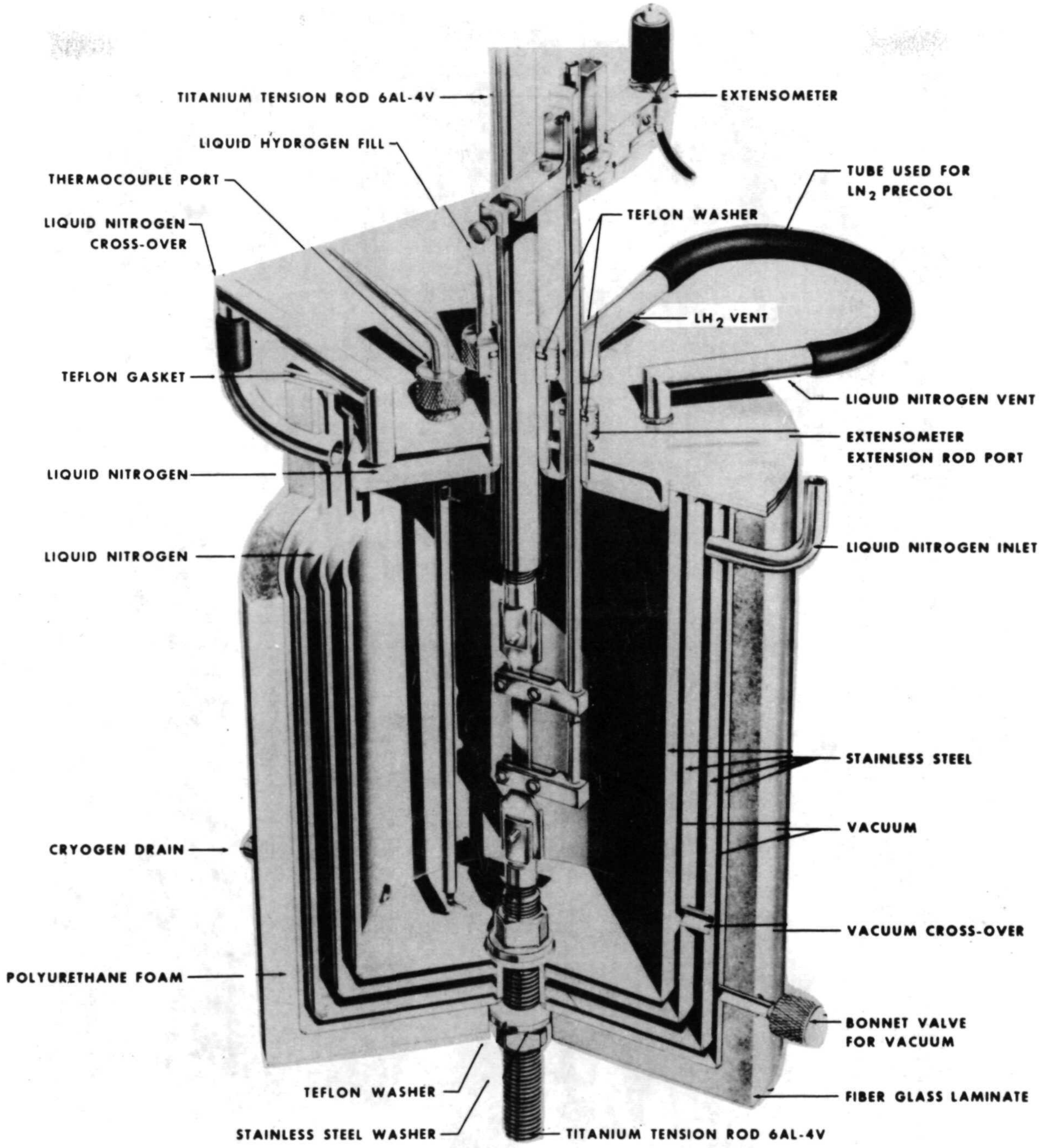


FIGURE 1 - TENSILE CRYOSTAT SHOWING SPECIMEN AND EXTENSOMETER

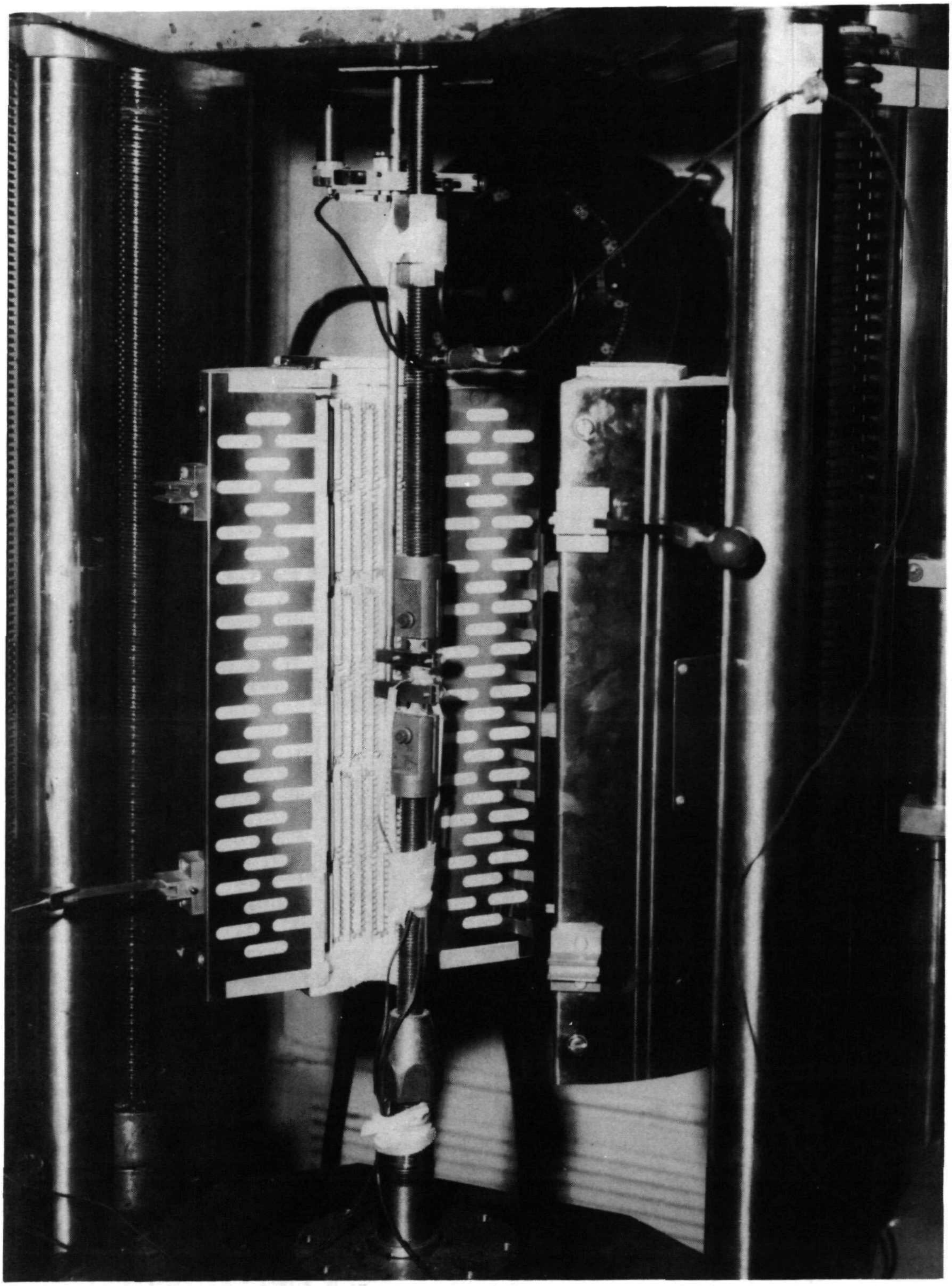


FIGURE 2 - CLAM SHELL TYPE FURNACE USED FOR HIGH TEMPERATURE TESTING OF ZM21 SPECIMENS

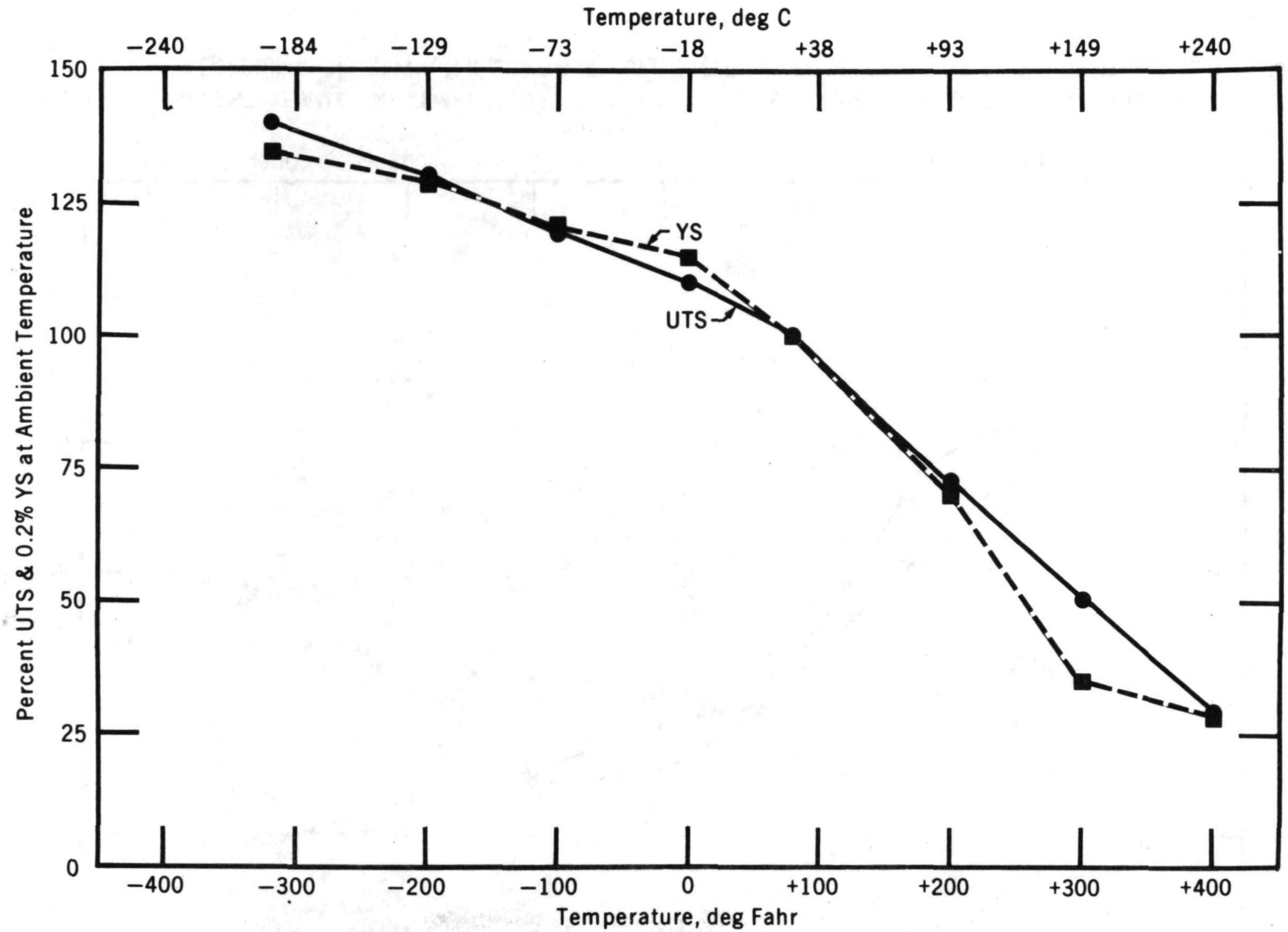


FIGURE 3 - PERCENT OF AMBIENT TEMPERATURE STRENGTH RETAINED IN ZM—21 MAGNESIUM ALLOY TRANSVERSE FLAT SPECIMENS [0.090 INCH (0.229 CM) THICK] TESTED AT TEMPERATURE AFTER 30 MINUTES SOAK

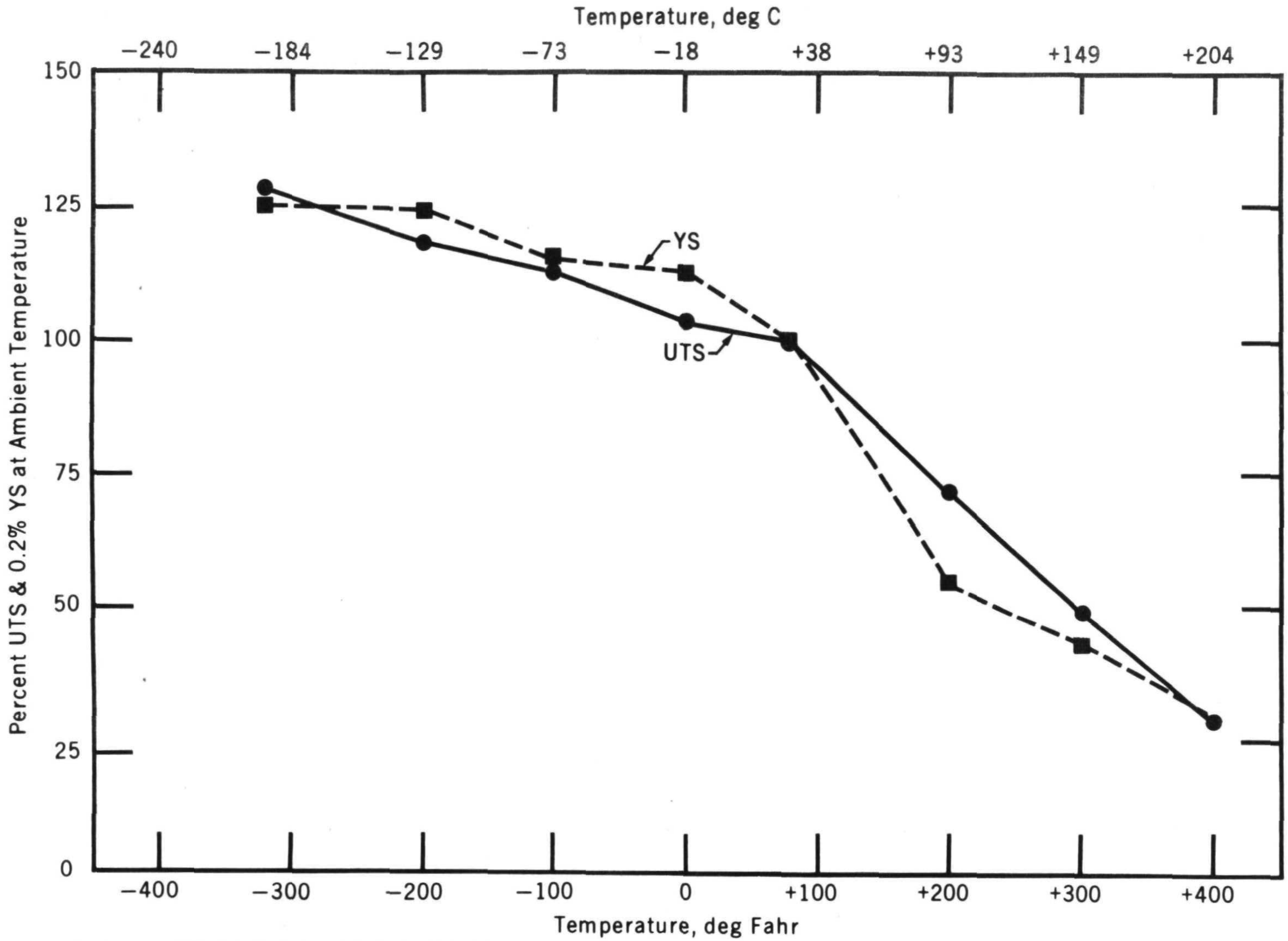


FIGURE 4 - PERCENT OF AMBIENT TEMPERATURE STRENGTH RETAINED IN ZM—21 MAGNESIUM ALLOY LONGITUDINAL FLAT SPECIMENS [0.090 INCH (0.229 CM) THICK] TESTED AT TEMPERATURE AFTER 30 MINUTES SOAK

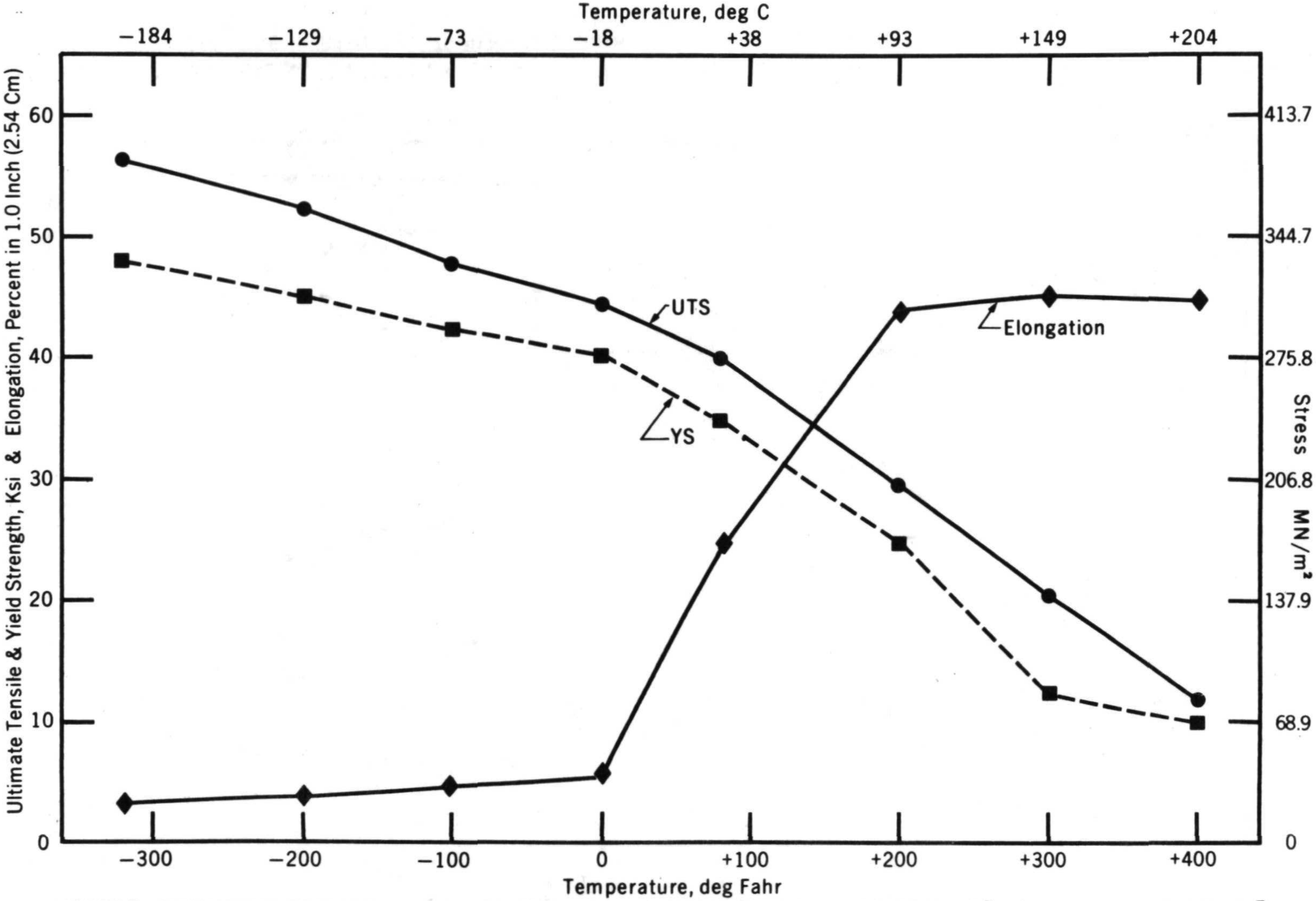


FIGURE 5 - MECHANICAL PROPERTIES OF ZM–21 MAGNESIUM ALLOY TRANSVERSE FLAT SPECIMENS [0.090 INCH (0.229 CM) THICK] TESTED AT TEMPERATURE AFTER 30 MINUTES SOAK

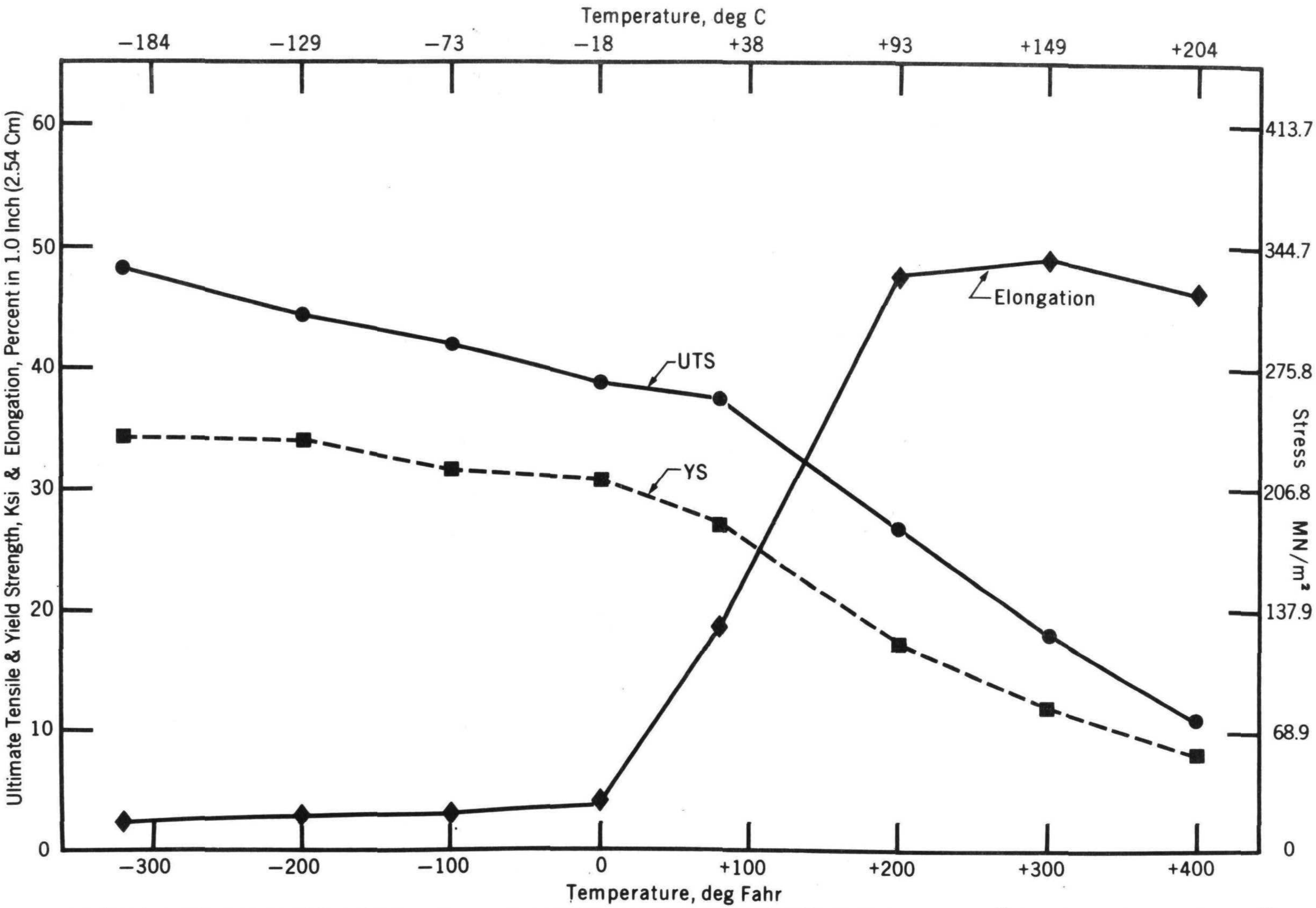


FIGURE 6 - MECHANICAL PROPERTIES OF ZM—21 MAGNESIUM ALLOY LONGITUDINAL FLAT SPECIMENS [0.090 INCH (0.229 CM) THICK] TESTED AT TEMPERATURE AFTER 30 MINUTES SOAK

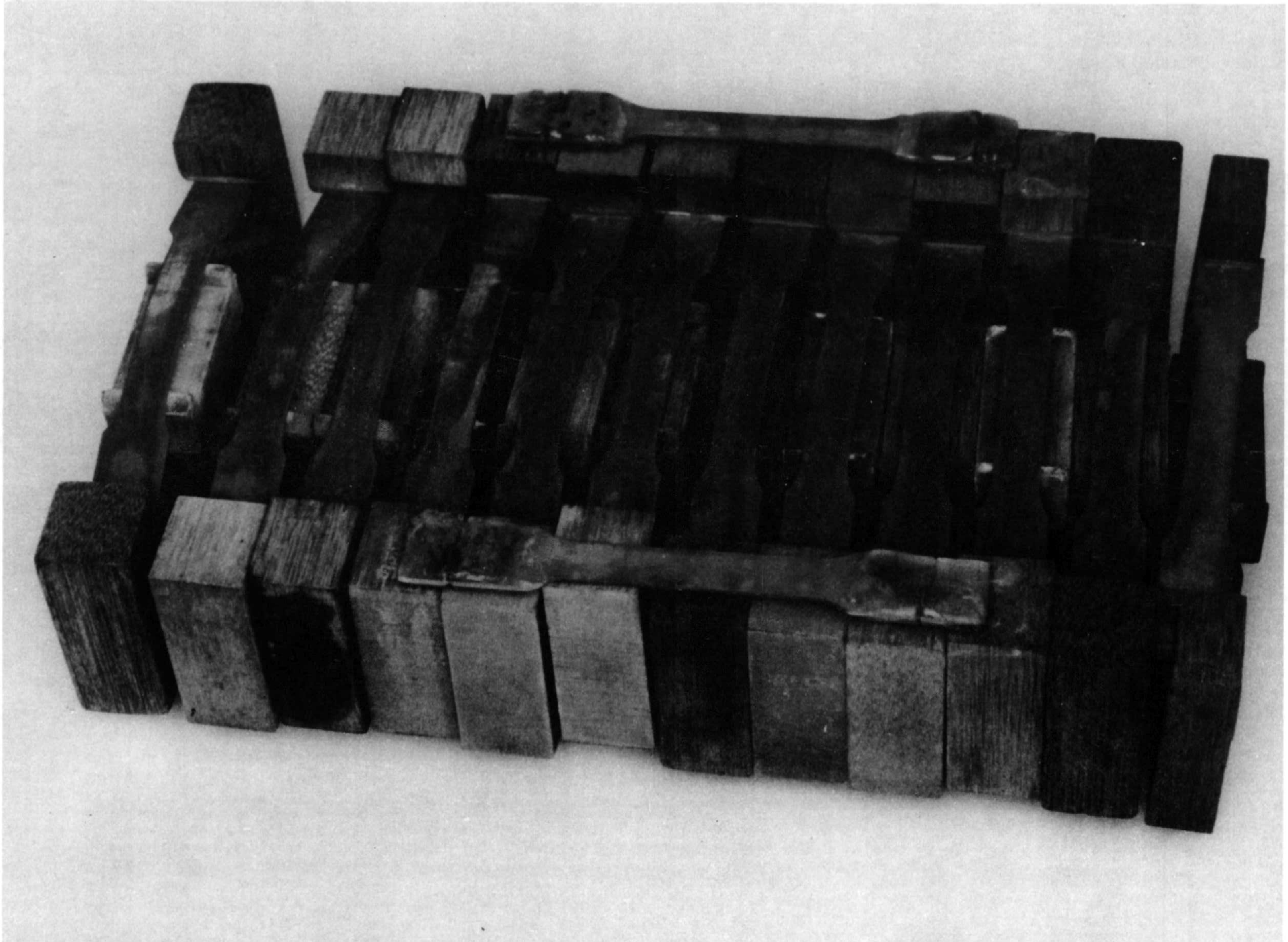


FIGURE 7 - ZM21 TEST SPECIMENS EXPOSED TO THE MSFC ATMOSPHERE FOR 56 DAYS

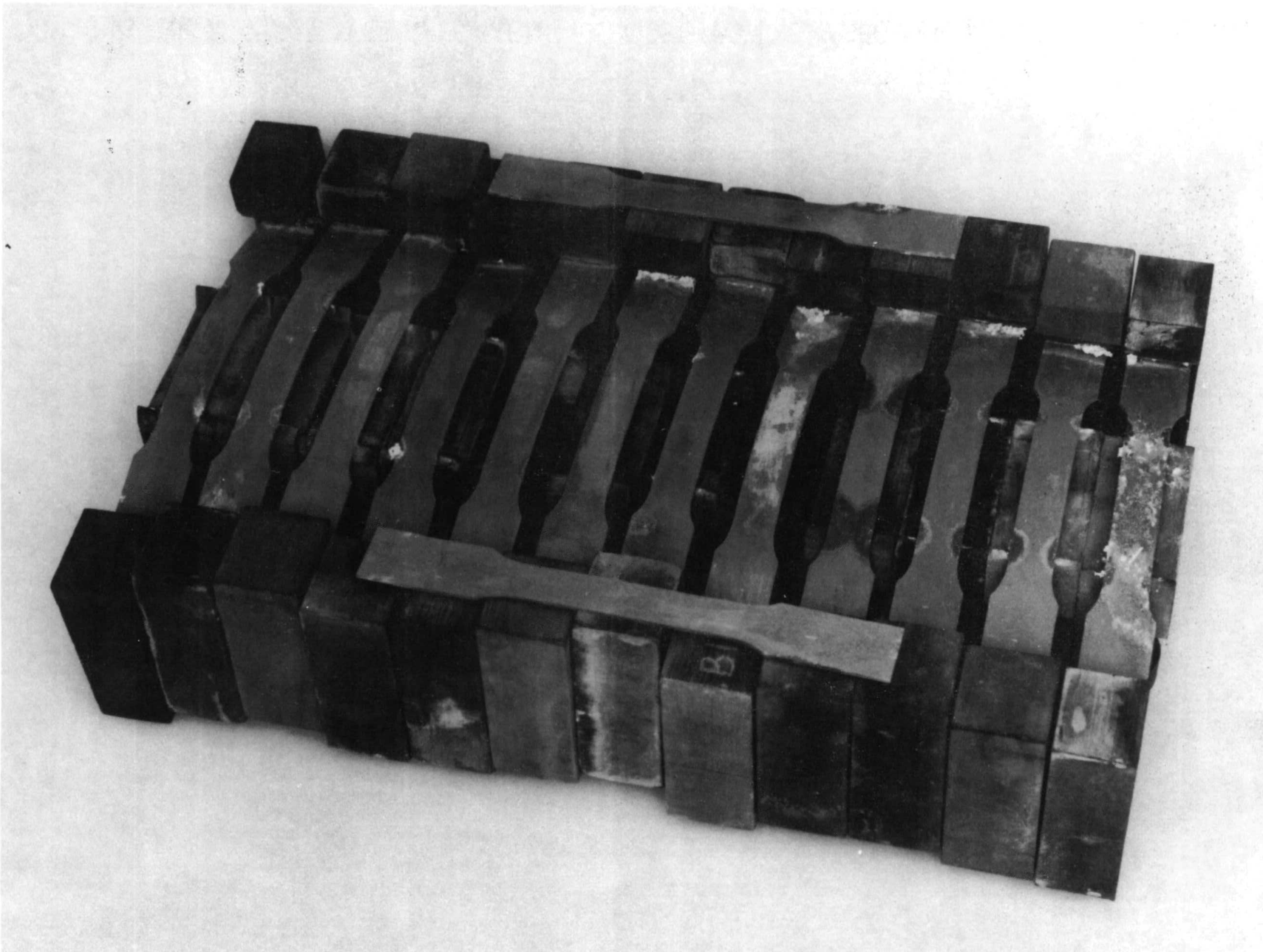


FIGURE 8 - ZM21 TEST SPECIMENS EXPOSED TO 95% RELATIVE HUMIDITY FOR 56 DAYS

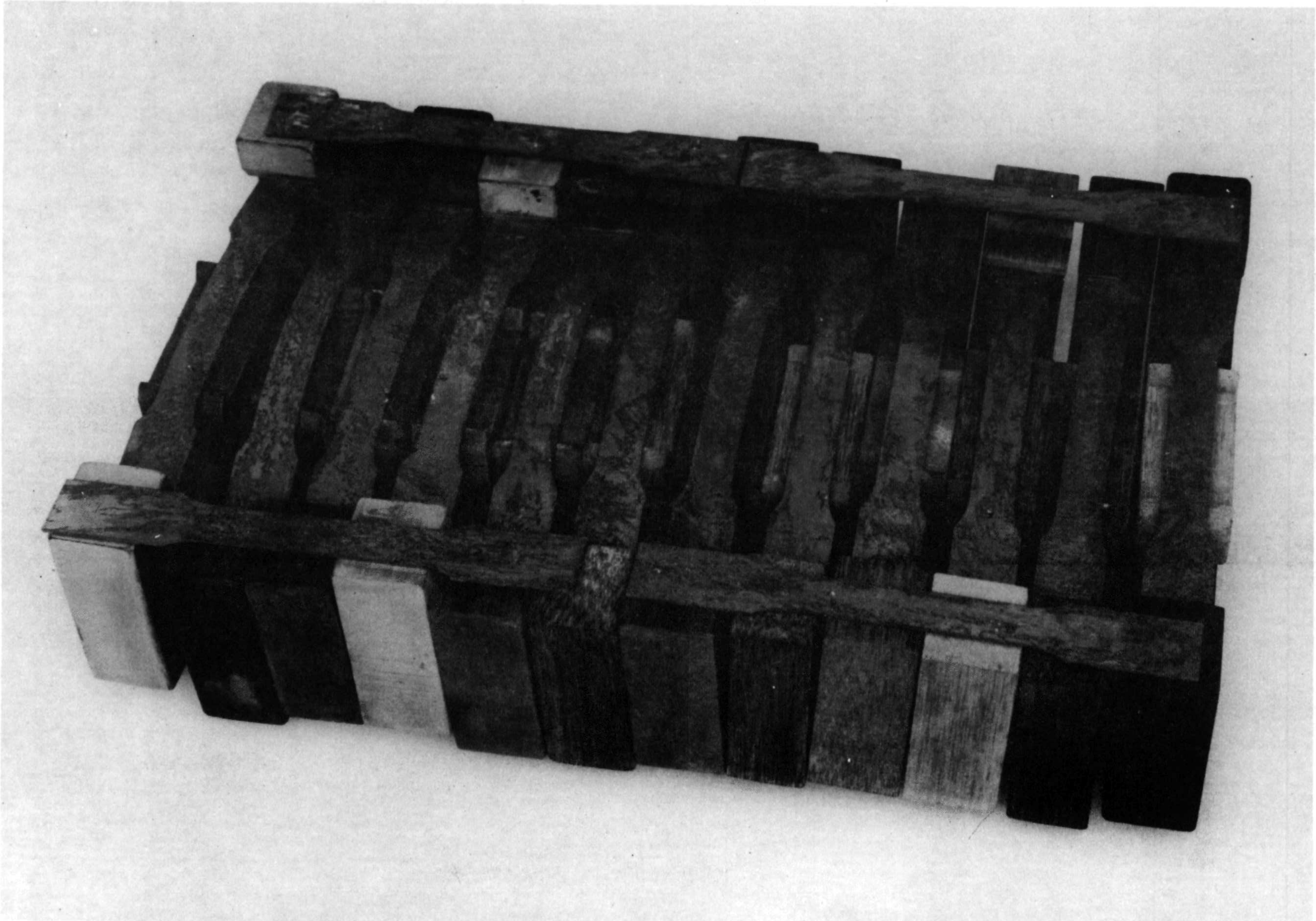
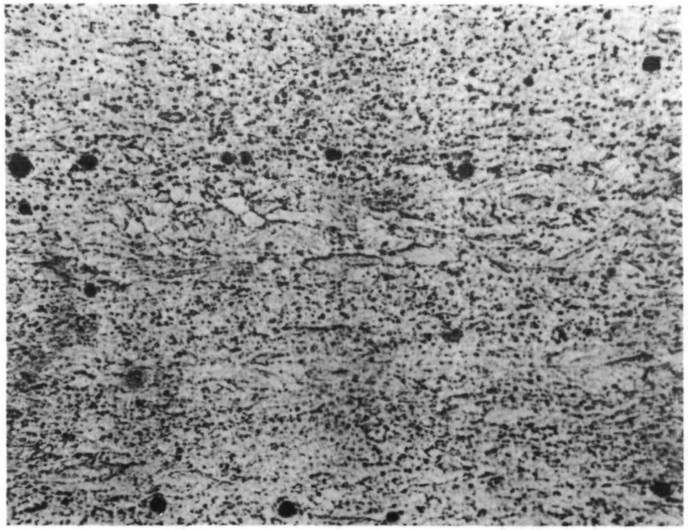
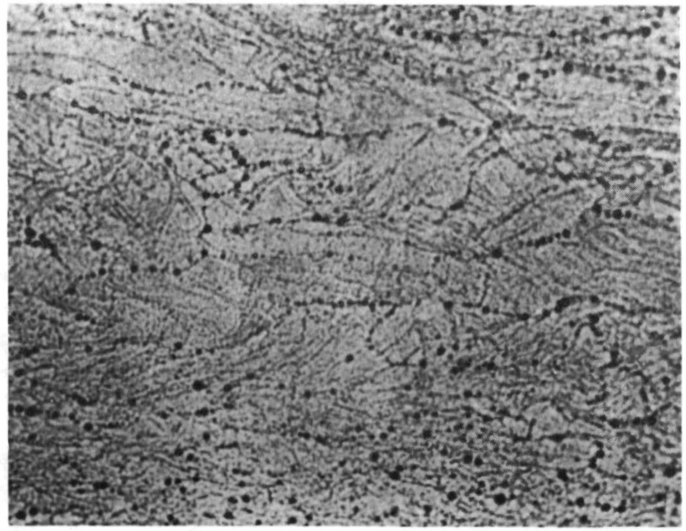
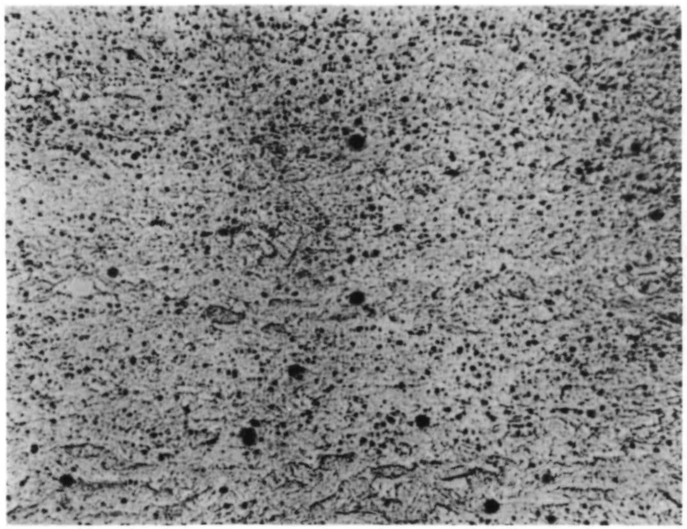


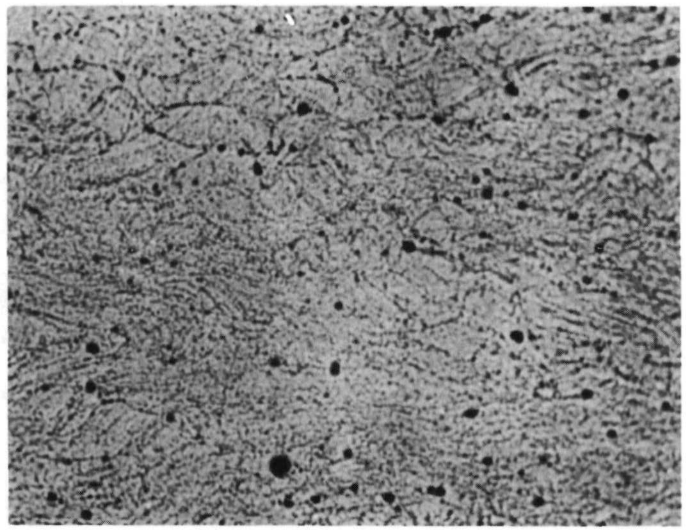
FIGURE 9 - ZM21 TEST SPECIMENS EXPOSED TO 100 ppm CHLORIDE SOLUTION FOR 56 DAYS





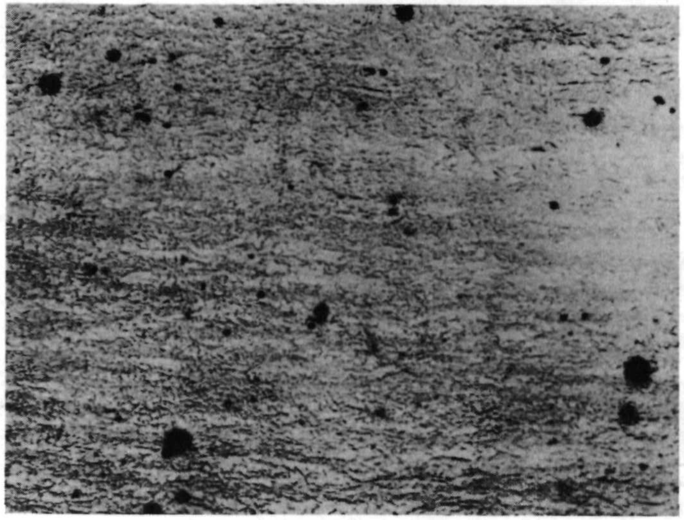
MAG 100X Longitudinal MAG 500X

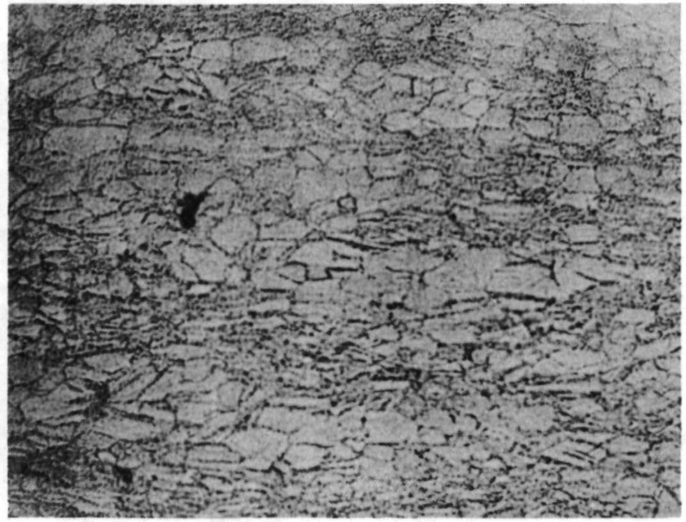




MAG 100X Transverse MAG 500X

FIGURE 10 - MICROSTRUCTURE OF ZM 21 MAGNESIUM ALLOY SHEET [0.090-INCH (0.229 cm) THICK] ETCHANT: NITAL

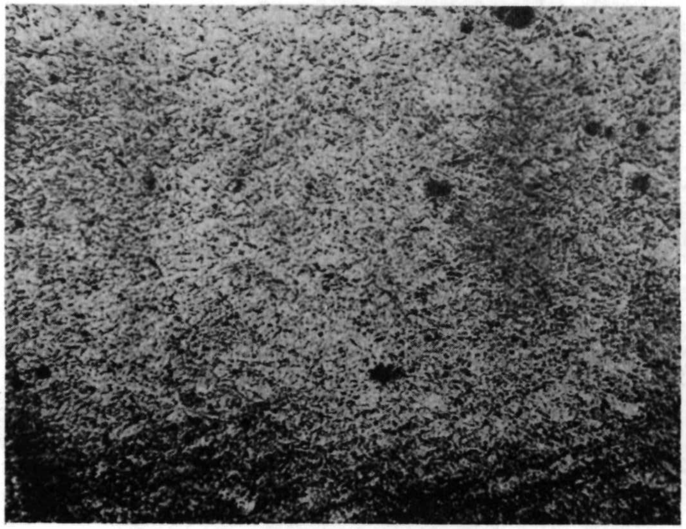


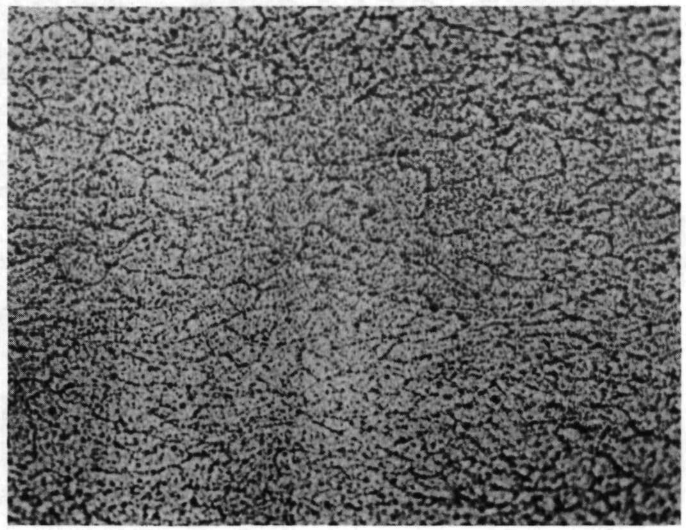


MAG 100X

Longitudinal

MAG 500X





MAG 100X

Transverse

MAG 500X

FIGURE 11 - MICROSTRUCTURE OF ZM 21 MAGNESIUM ALLOY SHEET [0.050-INCH (0.127 cm) THICK]

ETCHANT: NITAL

APPROVAL

ZM-21 MAGNESIUM ALLOY CORROSION PROPERTIES
AND CRYOGENIC TO ELEVATED TEMPERATURE MECHANICAL PROPERTIES

By

J. W. Montano and E. E. Nelson

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

E. C. McKannan
Chief, Metallic Materials Branch

R. J. Schwinghamer
Chief, Materials Division

Karl L. Heimburg
Director, Astronautics Laboratory

DISTRIBUTION

DIR	Dr. Rees
DEP-T	Dr. Lucas
S&E-ASTN-DIR	Mr. Kingsbury
S&E-PE-DIR	Dr. Siebel
S&E-ASTR-DIR	Mr. Moore
S&E-QUAL-DIR	Mr. Grau
S&E-CSE-DIR	Dr. Haeussermann
S&E-CSE-S	Mr. Aberg
S&E-ASTN-M	Mr. Schwinghamer (3)
S&E-ASTN-MX	Mr. Uptagrafft
S&E-ASTN-MX	Mr. Holmes
S&E-ASTN-MR	Mr. Welzyn (3)
S&E-ASTN-P	Mr. Paul
S&E-ASTN-E	Mr. Kroll
S&E-ASTN-MC	Mr. Nunnelley/Krupnick
S&E-ASTN-MM	Mr. McKannan
S&E-ASTN-MN	Mr. Curry
S&E-ASTN-MMM	Mr. Hess
S&E-ASTN-MMP	Mr. Morgan
S&E-ASTN-MMC	Mr. Williamson
S&E-ASTN-MMC	Mr. Nelson (20)
S&E-ASTN-MMP	Mr. Montano (20)
S&E-ASTN-RM	Mrs. Thompson
S&E-ASTN-ASV	Mr. Hurford
S&E-ASTN-S	Mr. Verble
S&E-ASTN-EA	Mr. Prasthofer
S&E-ASTN-EAA	Mr. Genter
S&E-ASTN-ESP	Mr. Franz
S&E-ASTN-SA	Mr. Engler
S&E-PE-D	Mr. Weckwarth
S&E-QUAL-ARM	Mr. Neuschaefer
S&E-PT-MW	Mr. Parks
S&E-PT-MMM	Mr. Woods
A&TS-MS-H	Mr. Akens
A&TS-PAT	Mr. Wofford
A&TS-TU	Mr. Higgins
A&TS-MS-IP	Mr. Remer
A&TS-MS-IL	Miss Robertson (8)

Scientific and Technical Inf. Facility (25)
P. O. Box 33
College Park, MD 20740