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PART 2

INVESTIGATION OF ALLOYS OF MAGNESIUM AND THEIR PROPERTIES

Part 2. Physical Properties of Mg Base Alloys

THE DOW CHEMICAL COMPANY

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FOREWORD

This report was prepared by The Dow Chemical Company, under USAF Contract No. AF 33(616)-2337. The contract was initiated under Project No. 7351, "Metallic Materials", Task No. 73514, "Improved Magnesium Alloys", formerly RDO No. 615-15, "Improved Magnesium Alloys", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Lt J. D. Wood acting as project engineer and editor of the report.

This report covers work conducted from February 1954 to February 1955.

ABSTRACT

The coefficients of linear thermal expansion have been determined for pure magnesium, AZ31A, AZ31B, AZ63A, AZ81XA, ingot extruded ZK60A, pellet extruded ZK60A, EK30A, EK41A, EZ33A, HK31XA, and HZ32XA using a high precision dilatometer. The electrical conductivities of AZ31A, AZ31B, AZ63A, AZ92A, cast ZK60A, and pellet extruded ZK60A have been determined using a Kelvin Bridge. Values obtained compare favorably with previous determinations. Thermal conductivities of the alloys were calculated from the electrical conductivity data using the Powell and Bungardt equations. The heat capacity and heat fusion of pure magnesium are also reported.

The effects of heat treatment, composition, mechanical history, and working direction on electrical conductivity were noted. There was no significant effect of these variables on thermal expansion.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

R. W. CONNERS
Lt Colonel, USAF
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INTRODUCTION

This is Part Two of the Final Report on Contract Number AF 33(616)-2337, sponsored by the Materials Laboratory, Wright-Patterson Air Force Base, and relates to the determination of the physical properties of magnesium alloys.

This report covers the determination of the electrical conductivity and coefficient of thermal expansion of several magnesium alloys. It also covers the reporting of the heat capacity and heat of fusion of pure magnesium.

SUMMARY OF EXPERIMENTAL RESULTS

1. Coefficients of linear thermal expansion have been determined for pure magnesium, AZ31A, AZ31B, AZ63A, AZ81XA, ZK60A, EK30A, EK41A, EZ33A, HK31XA, and HK32XA alloys for the range 25 to 215C using a calibrated "chronin" metal body specimen as a standard and are shown in Table IV.

2. Coefficients of linear thermal expansion also have been determined for various temperature ranges and thermal treatments for longitudinal and transverse specimens of pellet extruded ZK60A and for cast AZ31A, AZ31B, and AZ63A and are shown in Tables V through IX.

3. The electrical conductivity of cast AZ31A, AZ31B, AZ63A, AZ92A, cast ZK60A, and pellet extruded ZK60A were measured at room temperature using a Kelvin Bridge and an electronic galvanometer. The values appear in Table X.

4. Electrical resistivities (Table X) were calculated by taking the reciprocals of the electrical conductivities.

5. The thermal conductivities were calculated from the Powell and the Bungardt equation relating electrical and thermal conductivity. The average of the two equations is listed in Table X.

6. The heat capacity and heat of fusion of pure magnesium were determined by the Dow Thermal Laboratory and are reported here in Table XI.

CONCLUSIONS

1. The coefficients of linear thermal expansion and electrical and thermal conductivities compare satisfactorily with values previously determined.(1)(2)(3)

2. Thermal treatments have no effect on thermal expansion.

3. There is no difference between AZ31A and AZ31B with respect to thermal expansion.

4. There is no significant difference in thermal expansion properties in the longitudinal and transverse directions for specimens of pellet extruded ZK60A.

5. Thermal treatment has a significant effect on the electrical conductivity of the alloys tested. As compared to the as-cast condition, solution heat treatment decreases the conductivity while aging increases it.

6. Increases in alloy content decrease conductivity significantly.

7. Comparisons between as-cast and extruded material indicate that mechanical history affects the electrical properties.

8. Transverse specimens from as-extruded material have higher electrical conductivity than logitudinal specimens indicating the effect of working direction on electrical conductivity.

9. The heat of fusion of pure magnesium is 88 calories per gram.

EXPERIMENTAL PROCEDURE

The test rods and standard bodies used for the measurement of thermal expansion are of a shape and size as indicated in Figure 1. Test rods of different length may be used but for the sake of simplicity it is advisable to use standards and test specimens of the same dimension.

The camera top box carrying the projection screen is in a fixed position thus yielding a fixed projection distance and a constant magnification of about 200X. In order to increase the sensitivity of the instrument this magnification is enlarged to 800X by the insertion of an optical magnifying system.

The test rod and a standard body of known expansion are carefully inserted into two quartz tubes, the front ends of which are bowl-shaped. These tubes are fastened to the adjusting head of the dilatometer. The shape of the specimens is so selected that the expansions may take place unhindered. By means of special intermediate quartz rods the expansion of the specimen is transmitted to the guiding system through which a prism supported by three points (the measuring bridge) is activated. In order to insure perfect contact of the comparison body and the specimen respectively with the rear wall of the quartz tube and the intermediate quartz rod respectively small quartz bodies of conical and hemispherical shape are interposed.

For accurate temperature control a bore is provided in the comparison body in which the point of the thermocouple is inserted. Since both the comparison body and the test specimen are lying in close proximity to one another the temperature of the test specimen will be accurately known.

The metal bodies are heated by a small tube furnace which has a top temperature limit of 1100C. The furnace is mounted on rollers on a fixed track which runs parallel to the axis of the metal specimen bodies. Heating is accomplished by rolling the furnace back along the track so that it completely encloses the specimens contained in the quartz tubes. Metal radiation shields are used to facilitate temperature control and protect the equipment.

The rays from a 6 volt, 5 amp lamp are led over the guiding prism in the dilatometer head so that the light point, in accordance with the expansion of the metal specimens, moves along the projection surface of the camera and is recorded photographically.

Prior to heating the specimens the origin and vertical axis for the expansion curve is marked on the photographic paper by short exposures of the light beam as it is moved mechanically along the axes. The light beam is then reoriented on the origin and turned off. The specimens are then heated to specific temperatures and allowed to reach equilibrium. At each temperature level the light beam is projected onto the photographic paper for a short time interval thus providing a record of the expansion of the test specimen relative to the standard comparison body at that temperature. The complete photographic record for one test is shown in Figure 2. The photographic record is then transferred to rectangular coordinate paper from which the coefficient of linear thermal expansion is calculated. Figure 3 shows a characteristic plot of expansion of the test rod versus the expansion of the standard body in arbitrary units. The linear coefficient of expansion of the test rod is then determined by the relation:

$$\alpha = \alpha_{st} \left(\frac{1}{\text{slope}}\right)$$

α = coefficient of linear thermal expansion of test rod

α_{st} = coefficient of linear thermal expansion of standard

The slope is obtained from the best straight line drawn through the plotted points for the temperature range concerned.

The resistance to an electric current passing through the specimen was measured using a Kelvin Bridge. As the area of the rod and the distance the current traveled could be measured, it was possible to calculate the conductivity.

Analysis of the alloys is given in Table II.

DISCUSSION OF RESULTS

The coefficient of linear thermal expansion determined on aluminum using the chronin standard is shown in Table III along with the published value of the coefficient for aluminum. The small difference between the values determined in this investigation and the accepted value is an indication of the reliability of the chronin standard.

Data obtained so far do not indicate any significant change in thermal expansion properties following heat treatment, but more extensive testing with other alloys will be needed to determine whether this conclusion is valid in all instances.

Compared to that inherent in the as-cast condition, the electrical conductivity is decreased by a solution heat treatment (-T4) and increased by aging (-T5 and -T6). Alloy content shows its effect on electrical conductivity in the three Al-Zn alloys. Increasing alloy content decreased the conductivity, as had been expected from the literature.[4]

A comparison of the electrical conductivities of as-cast ZK60A and the ingot extruded ZK60A shows a significant increase in conductivity with hot working.

An indication of the effect of working direction on conduction is given by the higher electrical conductivities of transverse specimens of pellet extruded ZK60A as contrasted to those of longitudinal specimens. Orientation effects are responsible for the higher conductivity in the transverse direction.

Values for electrical resistivity and thermal conductivity also appear in Table X. The values of these were calculated from the electrical conductivity for each alloy: the resistivity as the reciprocal of the conductivity and thermal conductivity as the average of the values obtained from the Powell and Bungardt equations[5][6] relating the electrical and thermal conductivities.

The heat capacity and heat of fusion were determined experimentally for pure magnesium by the Dow Thermal Laboratory as part of other research and the results are included here to make the data on physical properties more complete.

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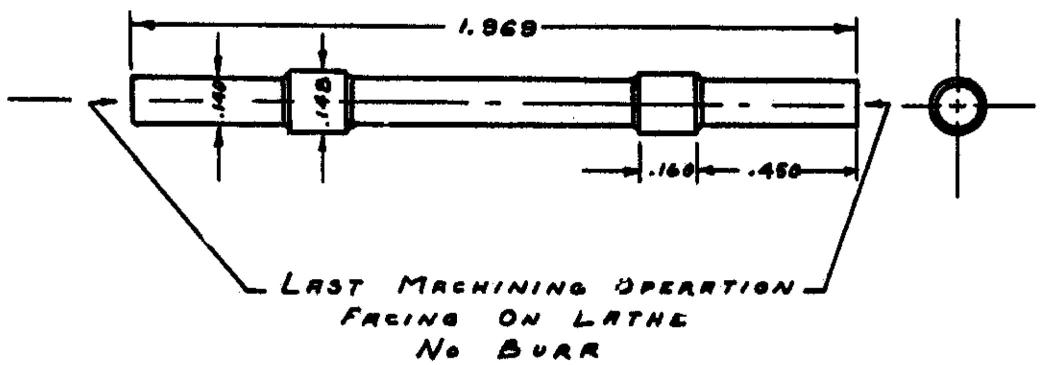
5. Powell, R. W., Philosophical Mag., Volume 27, 1939, page 677.

6. Bungardt, W. and Kallenbach, R., Metallwissenschaft und Technik, Volume 4, 1950.



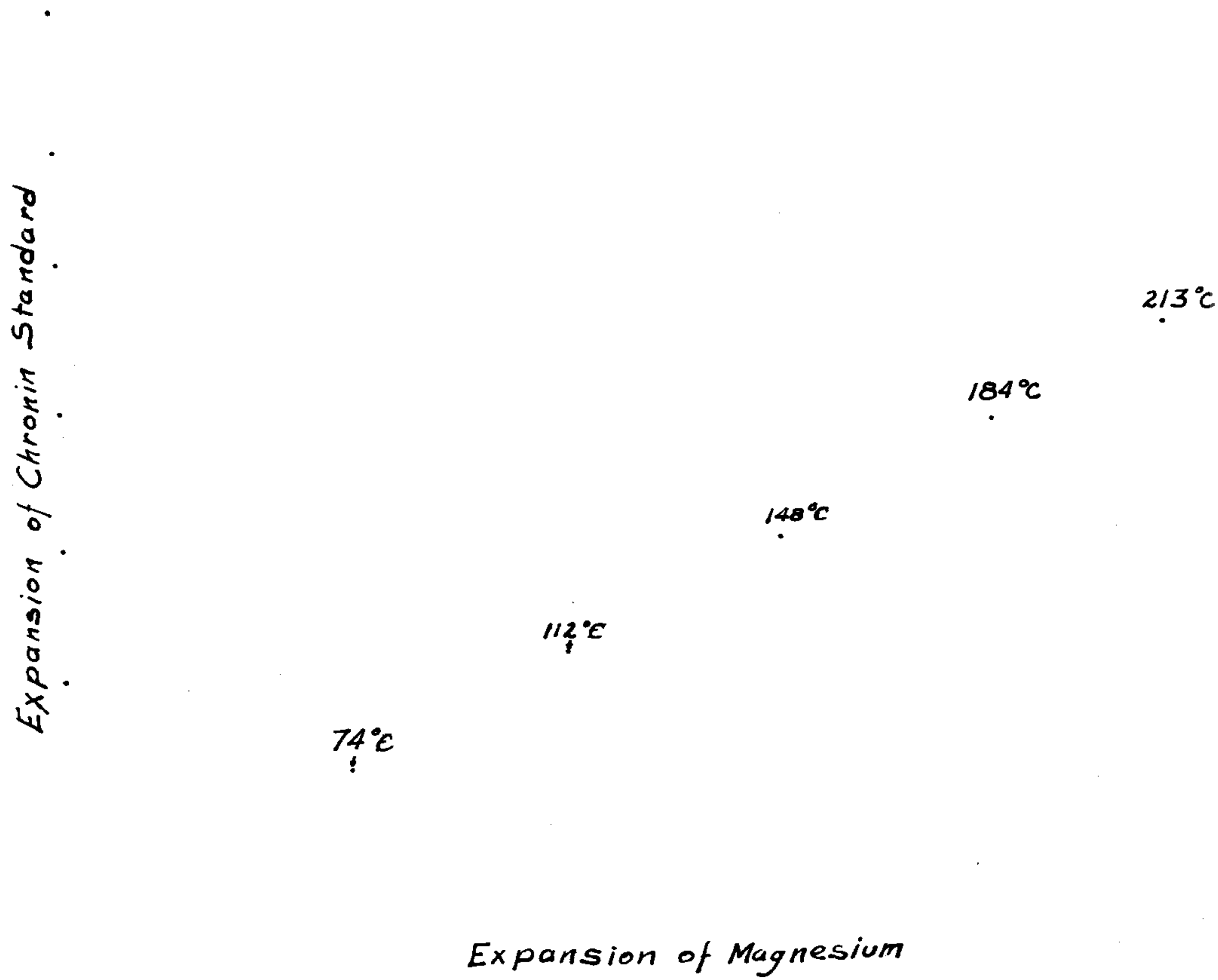
SCALE - 2" = 1"

FIG. 1

DIMENSIONS AND SHAPE FOR TEST AND STANDARD DILATOMETRIC SPECIMEN BODIES

 4M40-172

Figure 2-Photographic Record of Expansion of Pure Magnesium Versus Chronin Standard Arbitrary Units



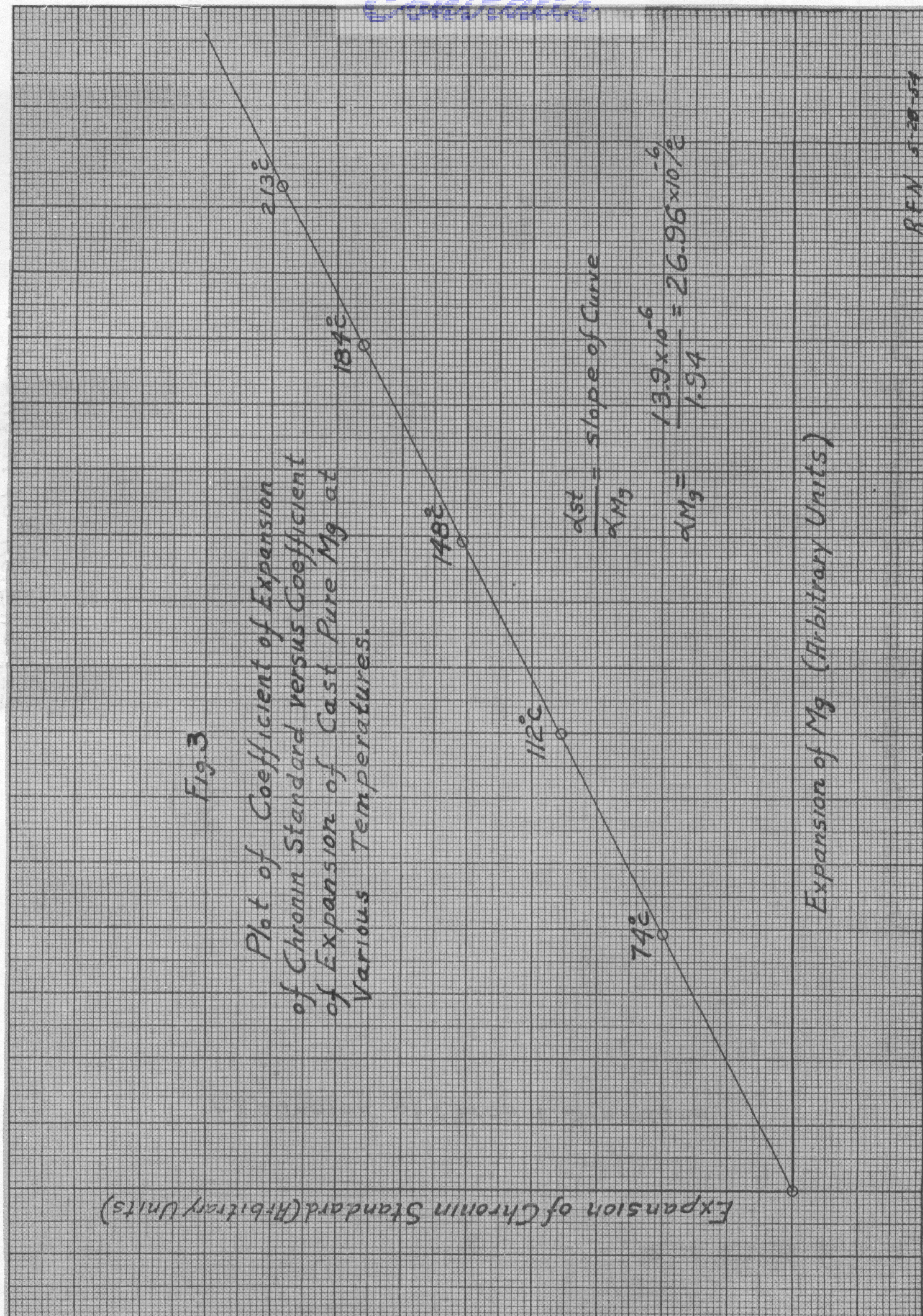


Fig. 3
Plot of Coefficient of Expansion of Chronin Standard versus Coefficient of Expansion of Cast Pure Mg at Various Temperatures.
213°C
184°C
148°C
112°C
74°C
αst / αMg = slope of Curve
αMg = 13.9x10^-6 / 1.94 = 26.96x10^-6/°C
Expansion of Mg (Arbitrary Units)
Expansion of Chronin Standard (Arbitrary Units)
RFN 5-28-54

TABLE I

List of Symbols

-F	As Fabricated
-T4	Solution Heat Treated
-T5	Aged
-T6	Solution Heat Treated plus Artificial Aging
(ℓ)	Longitudinal
(t)	Transverse
α	Coefficient of Linear Thermal Expansion
σ	Root Mean Square Deviation
Cp	Heat Capacity

TABLE II

Analysis of Alloys, %

	Al	Ca	Cu	Fe	Mn	Ni	Pb	Si	Sn	Zn	Zr	TRE	Th
AZ31A	3.12*	0.16*	.001	.0044	.49	<.0005	<.001	<.01	<.01	1.07*	--	--	--
AZ31B	3.14*	<.01	<.001	.0047	.49	<.0005	<.001	<.01	<.01	1.05*	--	--	--
AZ63A	6.02*	<.01	.002	.017	.26	<.001	<.001	<.01	<.01	3.10*	--	--	--
AZ81XA	8.00*	<.01	<.001	.001	.21*	<.001	.003	.01	<.01	0.76*	--	--	--
Ingot ZK60A	<.03	<.01	<.001	<.001	.048	<.001	<.001	<.01	<.01	5.78*	0.74*	--	--
Pellet ZK60A	<.03	<.01	.001	.001	.046	<.001	.006	<.01	<.01	5.3	0.69	--	--
EZ33A	<.03	<.01	.004	<.001	.044	<.001	.005	<.01	<.01	2.39*	0.68*	3.09*	--
HK31XA	<.03	<.01	<.005	.002	.054	<.001	<.001	<.01	<.01	<.02	0.71*	--	3.16*
HZ32XA	<.03	<.01	<.005	.002	.049	<.001	<.001	<.01	<.01	2.11*	0.77*	--	3.04*
AZ92A	9.14*	<.01	.010	.010	.29	<.001	<.001	<.01	<.01	1.90*	--	--	--

*Analysis determined by chemical analysis.
Remainder determined by spectroscopic analysis.

TABLE III

Coefficient of Linear Thermal Expansion of Standard Bodies

Material	Temp. C	(10^{-6}/C)	(10^{-6}/C) Measured Against Chronin
Chronin	20-250	13.90	
Aluminum	20-250	23.98	24.14 ± .20

TABLE IV

Coefficients of Linear Thermal Expansion for Various Magnesium Alloys

(25-215C)

Alloy	Method of Fabrication	Condition	No. of Tests	Coefficient of Expansion $-\alpha$ (10^{-6}/C) α	σ	(10^{-6}/F) α	σ
Pure Mg	Cast	-F	4	26.92	± .06	14.96	± .03
Pure Mg	Ingot Extruded	-F	6	26.47	± .17	14.71	± .09
AZ31A	Cast	-F	6	26.86	± .19	14.93	± .11
AZ31A	Cast	-T4	6	26.73	± .34	14.86	± .19
AZ31B	Cast	-F	6	26.56	± .18	14.77	± .10
AZ31B	Cast	-T4	6	26.72	± .10	14.86	± .06
AZ63A	Cast	-F	10	26.99	± .21	15.01	± .12
AZ63A	Cast	-T4	6	27.26	± .16	15.16	± .09
AZ63A	Cast	-T5	6	26.83	± .26	14.92	± .14
AZ63A	Cast	-T6	6	27.25	± .26	15.15	± .14
AZ81XA	Cast	-T4	4	27.08	± .27	15.04	± .15
ZK60A	Ingot Extruded	-F	4	26.50	± .14	14.72	± .08
ZK60A	Pellet Extruded	-F (ℓ)	6	26.24	± .36	14.59	± .20
ZK60A	Pellet Extruded	-F (t)	6	26.27	± .55	14.61	± .31
ZK60A	Pellet Extruded	-T5 (ℓ)	6	25.82	± .27	14.36	± .15
ZK60A	Pellet Extruded	-T5 (t)	6	25.96	± .56	14.43	± .31
EK30A	Cast	-T6	3	26.70	± .21	14.83	± .12
EK41A	Cast	-T5	4	26.30	± .08	14.61	± .04
EK41A	Cast	-T6	4	26.35	± .14	14.64	± .08
EZ33A	Cast	-T5	4	26.46	± .06	14.70	± .03
HK31XA	Cast	-T6	4	26.74	± .20	14.86	± .11
HZ32XA	Cast	-T5	4	26.32	± .19	14.62	± .11

TABLE V

Coefficients of Linear Thermal Expansion for Various Magnesium Alloys at Several Temperature Ranges

Centigrade Units

Alloy	Method of Fabrication	Condition	Coefficient of Expansion α (10^{-6} in/in/C) 25 - 75C α	25 - 75C σ	25 - 115C α	25 - 115C σ	25 - 150C α	25 - 150C σ	25 - 185C α	25 - 185C σ	25 - 215C α	25 - 215C σ
ZK60A	Pellet Extruded	-F (ℓ)	24.87	± .34	25.08	± .34	25.58	± .35	25.98	± .35	26.24	± .36
ZK60A	Pellet Extruded	-T5 (ℓ)	24.47	± .25	24.68	± .26	25.17	± .26	25.56	± .27	25.82	± .27
ZK60A	Pellet Extruded	-F (t)	24.90	± .52	25.11	± .52	25.61	± .53	26.01	± .54	26.27	± .55
ZK60A	Pellet Extruded	-T5 (t)	24.60	± .53	24.81	± .53	25.31	± .54	25.70	± .55	25.96	± .56
AZ31A	Cast	-F	25.45	± .18	25.67	± .18	26.18	± .18	26.59	± .19	26.86	± .19
AZ31A	Cast	-T4	25.33	± .32	25.55	± .32	26.06	± .33	26.46	± .33	26.73	± .34
AZ31B	Cast	-F	25.17	± .17	25.38	± .17	25.89	± .17	26.29	± .18	26.56	± .18
AZ31B	Cast	-T4	25.32	± .09	25.54	± .10	26.05	± .10	26.45	± .10	26.72	± .10

TABLE VI

Coefficients of Linear Thermal Expansion for Various Magnesium Alloys at Several Temperature Intervals

Centigrade Units

Alloy	Fabrication	Condition	Coefficient of Expansion α (10^{-6} in/in/C)									
			25 - 75C		75 - 115C		115 - 150C		150 - 185C		185 - 215C	
			α	σ	α	σ	α	σ	α	σ	α	σ
ZK60A	Pellet Extruded	-F (ℓ)	24.87	± .34	25.66	± .35	26.14	± .36	27.03	± .37	27.31	± .38
ZK60A	Pellet Extruded	-T5 (ℓ)	24.47	± .25	25.25	± .26	25.72	± .27	26.60	± .28	27.07	± .28
ZK60A	Pellet Extruded	-F (t)	24.90	± .52	25.69	± .53	26.17	± .54	27.06	± .56	27.54	± .57
ZK60A	Pellet Extruded	-T5 (t)	24.60	± .53	25.39	± .54	25.86	± .55	26.75	± .57	27.22	± .58
AZ31A	Cast	-F	25.45	± .18	26.26	± .18	26.75	± .19	27.67	± .19	28.15	± .20
AZ31A	Cast	-T4	25.33	± .32	26.14	± .33	26.62	± .34	27.54	± .35	28.02	± .35
AZ31B	Cast	-F	25.17	± .17	25.97	± .17	26.45	± .18	27.36	± .18	27.84	± .19
AZ31B	Cast	-T4	25.32	± .09	26.13	± .10	26.61	± .10	27.53	± .10	28.01	± .10

TABLE VII

Coefficients of Linear Thermal Expansion for Various Magnesium Alloys at Several Temperature Ranges

Fahrenheit Units

Alloy	Fabrication	Condition	Coefficient of Expansion α (10^{-6} in/in/F) 80 - 170F α ± σ	80 - 240F α ± σ	80 - 300F α ± σ	80 - 360F α ± σ	80 - 420F α ± σ
ZK60A	Pellet Extruded	-F (ℓ)	13.83 ± .19	13.94 ± .19	14.22 ± .19	14.44 ± .19	14.59 ± .20
ZK60A	Pellet Extruded	-T5 (ℓ)	13.61 ± .14	13.72 ± .14	13.99 ± .14	14.21 ± .15	14.36 ± .15
ZK60A	Pellet Extruded	-F (t)	13.84 ± .29	13.96 ± .29	14.24 ± .29	14.46 ± .30	14.61 ± .31
ZK60A	Pellet Extruded	-T5 (t)	13.68 ± .29	13.79 ± .29	14.07 ± .30	14.29 ± .31	14.43 ± .31
AZ31A	Cast	-F	14.15 ± .10	14.27 ± .10	14.56 ± .10	14.78 ± .11	14.93 ± .11
AZ31A	Cast	-T4	14.08 ± .18	14.21 ± .18	14.49 ± .18	14.71 ± .18	14.86 ± .19
AZ31B	Cast	-F	14.00 ± .09	14.11 ± .09	14.39 ± .09	14.62 ± .10	14.77 ± .10
AZ31B	Cast	-T4	14.08 ± .05	14.20 ± .06	14.48 ± .06	14.71 ± .06	14.86 ± .06

TABLE VIII

Coefficients of Linear Thermal Expansion for Various Magnesium Alloys at Several Temperature Intervals

Fahrenheit Units

Alloy	Fabrication	Condition	Coefficient of Expansion α (10^{-6} in/in/F)									
			80-170F		170-240F		240 - 300F		300 - 360F		360 - 420F	
			α	σ	α	σ	α	σ	α	σ	α	σ
ZK60A	Pellet Extruded	-F (ℓ)	13.83	± .19	14.27	± .19	14.53	± .20	15.03	± .21	15.30	± .21
ZK60A	Pellet Extruded	-T5 (ℓ)	13.61	± .14	14.04	± .14	14.30	± .15	14.79	± .16	15.05	± .16
ZK60A	Pellet Extruded	-F (t)	13.84	± .29	14.28	± .29	14.55	± .30	15.05	± .31	15.31	± .32
ZK60A	Pellet Extruded	-T5 (t)	13.68	± .29	14.12	± .30	14.38	± .31	14.87	± .32	15.13	± .32
AZ31A	Cast	-F	14.15	± .10	14.60	± .10	14.87	± .11	15.38	± .11	15.65	± .11
AZ31A	Cast	-T4	14.08	± .18	14.53	± .18	14.80	± .19	15.31	± .19	15.58	± .19
AZ31B	Cast	-F	14.00	± .09	14.44	± .09	14.71	± .10	15.21	± .10	15.48	± .11
AZ31B	Cast	-T4	14.08	± .05	14.53	± .06	14.80	± .06	15.31	± .06	15.57	± .06

TABLE IX

Coefficients of Linear Thermal Expansion For a Magnesium Alloy at Several Temperature Intervals

	Coefficients of Expansion α (10^{-6} in/in/C)							
	AZ63A-F		AZ63A-T5		AZ63A-T4		AZ63A-T6	
	α	σ	α	σ	α	σ	α	σ
25-100C	26.09	± .20	25.94	± .25	26.35	± .15	26.34	± .24
25-150C	26.50	± .20	26.34	± .25	26.76	± .16	26.75	± .25
25-200C	26.99	± .21	26.83	± .26	27.26	± .16	27.25	± .26
25-250C	27.48	± .21	27.32	± .26	27.75	± .16	27.74	± .27
25-300C	27.94	± .22	27.78	± .27	28.22	± .16	28.21	± .28
100-150C	27.10	± .21	26.94	± .26	27.37	± .16	27.36	± .24
150-200C	28.10	± .22	27.94	± .27	28.38	± .17	28.37	± .25
200-250C	29.16	± .23	28.99	± .28	29.45	± .17	29.44	± .25
250-300C	29.90	± .23	29.72	± .29	30.20	± .18	30.18	± .26

	Coefficients of Expansion α (10^{-6} in/in/F)							
80-200F	14.51	± .11	14.42	± .14	14.65	± .08	14.64	± .13
80-300F	14.73	± .11	14.64	± .14	14.88	± .08	14.87	± .14
80-400F	15.01	± .12	14.92	± .14	15.16	± .09	15.15	± .14
80-500F	15.28	± .12	15.19	± .14	15.43	± .09	15.42	± .15
80-600F	15.53	± .12	15.45	± .15	15.69	± .09	15.68	± .16
200-300F	15.07	± .12	14.98	± .14	15.22	± .09	15.21	± .13
300-400F	15.62	± .12	15.53	± .15	15.78	± .09	15.77	± .14
400-500F	16.21	± .13	16.12	± .16	16.37	± .09	16.37	± .14
500-600F	16.62	± .13	16.52	± .16	16.79	± .10	16.78	± .14

TABLE X

Electrical and Thermal Properties of Magnesium Alloys

Alloy	Fabrication	Condition	Electrical Conductivity at 20C ($10^4 ohm^{-1} cm^{-1}$) (1)	Electrical Resistivity at 20C (microhm-cm)	Thermal Conductivity at 20C ($Cal/cm^2/cm/^oC/sec.$) (2)
AZ31A	Cast	-F	10.84 ± .02	9.22	.185
AZ31A	Cast	-T4	10.75 ± .01	9.31	.183
AZ31B	Cast	-F	10.68 ± .08	9.36	.182
AZ31B	Cast	-T4	10.57 ± .06	9.46	.181
AZ63A	Cast	-F	8.12 ± .13	12.32	.143
AZ63A	Cast	-T5	8.88 ± .13	11.26	.154
AZ63A	Cast	-T4	7.05 ± .01	14.19	.126
AZ63A	Cast	-T6	8.48 ± .09	11.79	.148
AZ92A	Cast	-F	7.04 ± .09	14.19	.126
AZ92A	Cast	-T5	7.86 ± .05	12.73	.139
AZ92A	Cast	-T4	5.72 ± .04	17.48	.106
AZ92A	Cast	-T6	7.98 ± .00	12.53	.141
ZK60A	Cast	-F	14.82 ± .14	6.75	.246
ZK60A	Cast	-T5	15.94 ± .04	6.27	.264
ZK60A	Ingot Extruded	-F	16.77	5.97	.280
ZK60A	Ingot Extruded	-T5	17.65	5.67	.294
ZK60A	Pellet Extruded	-F (ℓ)	18.12 ± .04	5.51	.298
ZK60A	Pellet Extruded	-F (t)	18.50 ± .11	5.40	.304
ZK60A	Pellet Extruded	-T5 (ℓ)	18.40 ± .04	5.43	.302
ZK60A	Pellet Extruded	-T5 (t)	18.68 ± .04	5.35	.306

(1) RMS deviation based on 12 determinations using two specimens.
(2) Quoted by Powell as ± 5% maximum deviation.

TABLE XI

Heat Capacity and Heat of Fusion of Pure Magnesium

Temperature		Cp	
°K	°C	cal/mole/deg.	cal/g/deg.
	400	7.02	.289
700		7.09	.292
	450	7.16	.294
750		7.24	.298
	500	7.32	.301
800		7.42	.305
	550	7.50	.308
850		7.61	.313
	600	7.70	.317
900		7.81	.321
	650	7.91	.325
923	650	melting point	
950		7.75	.319
	700	7.81	.321
1000		7.88	.324
	750	7.94	.326
1050		8.01	.329
	800	8.07	.332
1100		8.14	.335

	cal/mole	Cal/g
Heat of Fusion	2140 ± 50	88 ± 2