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Creep Tests on some Cast Magnesium Alloys

By

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Part I
Creep Tests of 150 hours Duration at 100 deg., 150 deg. and 200 deg. C. on some Cast Magnesium Alloys

Part II
Comparison of the Creep Properties of Three Cast Magnesium Alloys Based on Tests of 1,000 hours Duration

Part III
Effect of Various Heat Treatments on the Short-time Creep Behaviour at 3 ton/sq. in., 150 deg. C., of Four Cast Magnesium Alloys

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Parts I, II and III

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Introduction.—The National Physical Laboratory was represented at a meeting held at the Ministry of Aircraft Production on 21st July, 1943, when certain proposals for research into the properties of magnesium alloys at temperatures up to 200 deg. C. were discussed. It was decided that the N.P.L. should be asked to undertake some short-time creep tests on a number of magnesium alloys with a view to selecting suitable alloys for fuller investigations.

The following series of alloys were selected for the N.P.L. tests :—

Type of alloy			*Condition*
Sand Cast	7·5/8·0% Al, 0·3/0·5% Zn	A8	Fully heat treated
	8·5/9·0% Al, 0·3/0·5% Zn		Annealed. Solution treated. Fully heat treated
	10·5/11·0% Al, 0·3/0·5% Zn	AZ91	Annealed. Solution treated. Fully heat treated
	D.T.D. 350		Annealed
	Zr Zn		As cast
Wrought	AZ 855		As received
	AM 6		As received

It was agreed that creep tests of short duration at 100, 150 and 200 deg. C., and at one stress to be selected for each temperature, should first be undertaken, and that subsequent tests should be made on those alloys which appeared to warrant more prolonged creep testing.

The present report deals with the results of short-time creep tests on the first four alloys in the list.

Material Provided.—At the time of writing the report only the first four alloys in the list have been supplied. Twenty-four bars of each type of heat treated alloy were supplied by request. They were in the form of cast bars approximately 9½ in. long heat treated in accordance with the requirements of the programme. The bars had enlarged ends rather more than 1 in. in diameter and were about 0·8 in. in diameter over about 4½ in. in the centre.

Particulars of the compositions and heat treatments of the alloys are given in Table 1.

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Creep Tests.—Test pieces $0 \cdot 564$ in. in diameter with a gauge length of 5 in. and having screwed ends were machined from the bars.

The following test conditions were selected for the initial short-time creep tests to classify the alloys :—

1 ton/sq. in. at 200 deg. C.
3 ton/sq. in. at 150 deg. C.
4 ton/sq. in. at 100 deg. C.

The tests were continued for 150 hours and the comparison of the alloys has been based on the creep rate at 120 hours (5 days).

Two tests at 150 deg. C. have been continued up to 1,000 hours to ascertain whether, in these cases, the creep rates up to 150 hours were reasonably representative of the creep behaviour up to 1,000 hours.

Results of Creep Tests.—The creep curves obtained are plotted in Fig. 1 (100 deg. C.), Fig. 2 (150 deg. C.), and Fig. 3 (200 deg. C.), and the numerical data are given in Table 1.

Considering first the tests at 100 deg. C. and 4 tons/sq. in. (Table 1, Fig. 1), it is evident that the standard of performance of the four alloys can be very similar. Thus, selecting the best result for each of the two variously heat-treated aluminium-magnesium alloys and the results for the other two alloys it will be seen that the creep strains lie between $0 \cdot 0009$ and $0 \cdot 0013$, and the creep rates between $0 \cdot 7 \times 10^{-6}$ and $1 \cdot 5 \times 10^{-6}$ strain per hour. Judging on the basis of creep rate at 120 hours, full heat treatment produces the best result for the 11 per cent. aluminium alloy and annealing for the $8 \cdot 7$ per cent. aluminium alloy. The difference in behaviour due to change in heat treatment is, however, quite small in the case of the $8 \cdot 7$ per. cent. aluminium alloy. The best individual alloy is that to specification D.T.D. 350 in the annealed condition.

In the tests at 150 deg. C. and 3 ton/sq. in. the disparity between the results for the various materials is much increased. Again the D.T.D. 350 alloy (annealed) is the superior. In their fully heat-treated conditions the 11 per cent. aluminium alloy is better than either of the $8 \cdot 7$ per cent. or $7 \cdot 8$ per cent. aluminium alloys, the superiority appearing to increase with the aluminium content. As at 100 deg. C., the 11 per cent. aluminium alloy is best when in the fully heat treated condition, and the $8 \cdot 7$ per cent. aluminium alloy is best when annealed.

The creep tests on these two materials have been continued up to 1,000 hours, *see* Fig. 4. In both cases the creep rate falls slightly throughout the extended test and the relative creep rates remain about the same as at 120 hours. Thus the superiority at 120 hours of these materials over most of the others may reasonably be expected to be maintained over a considerably longer period.

Under a stress of 1 ton/sq. in. at 200 deg. C. the various materials show less disparity than in the tests at 150 deg. C. However, full heat treatment for the 11 per cent. aluminium alloy and annealing for the $8 \cdot 7$ per cent. aluminium again provide the best respective heat treatments for these alloys, and the D.T.D. 350 retains its superiority over the others. As at 150 deg. C. the superiority of the fully heat treated aluminium-zinc-magnesium alloys appears to increase with the aluminium content.

General Conclusions.—(1) The alloy to specification D.T.D. 350 is superior at all temperatures.

(2) The aluminium-zinc-magnesium alloys can be given nearly similar creep resistance to D.T.D. 350 at 100 deg. C. by suitable heat-treatment.

(3) In the fully heat-treated conditions the aluminium-zinc-magnesium alloys have creep properties at 150 and 200 deg. C. which appear to improve with aluminium content.

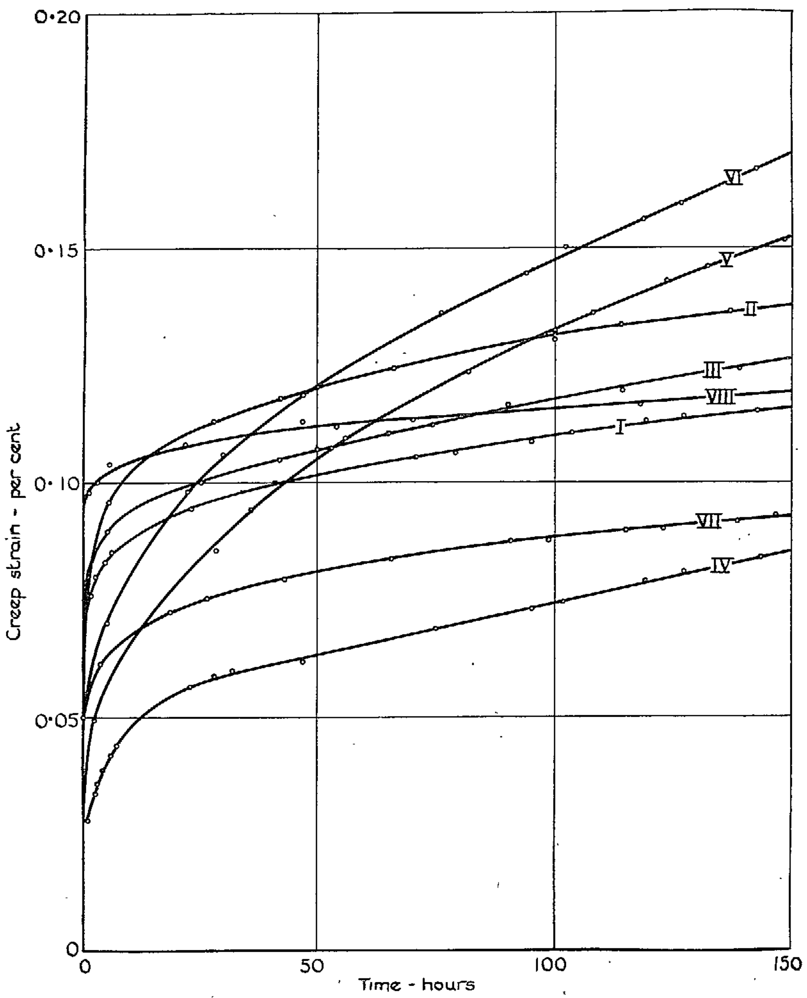
Further Work.—Long-time creep tests are in hand on the D.T.D. 350 alloy at all three temperatures, and on the 11 per cent. and the $8 \cdot 7$ per cent. aluminium alloys at 150 deg. C. in the fully heat-treated and annealed conditions respectively.

TABLE 1

Results of Creep Tests at 100 *deg.*, 150 *deg.*, *and* 200 *deg. C. on some Cast Magnesium Alloys*

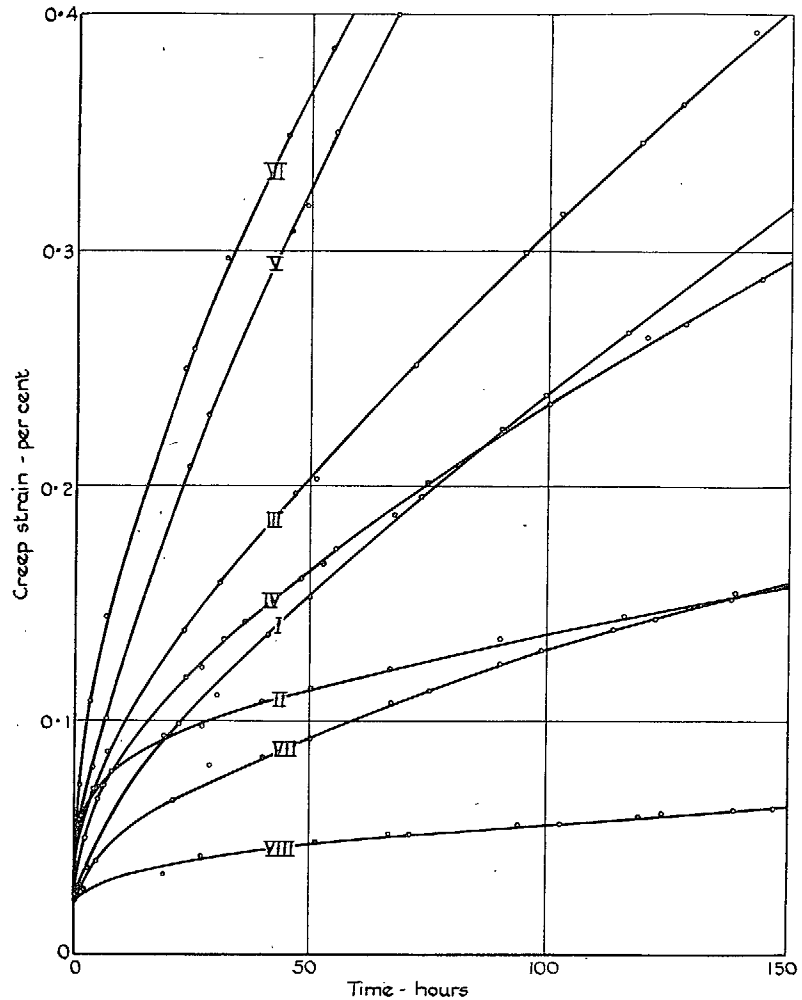
Form of Test Bar

Chemical Composition—per cent. (Remainder is Mg in each case)								Heat Treatment	Tests at 100 deg. C and 4 ton/in.^{2}		Tests at 150 deg. C and 3 ton/in.^{2}		Tests at 200° deg C and 1 ton/in.^{2}	
Al	Zn	Sn	Ag	Mn	Cu	Fe	Si		Creep Strain at 5 days	Creep Rate at 5 days in./in./hr. $\times 10^6$	Creep Strain at 5 days	Creep Rate at 5 days in./in./hr. $\times 10^6$	Creep Strain at 5 days	Creep Rate at 5 days in./in./hr. $\times 10^6$
7·79 to 7·82	0·45	Nil (A8 Alloy)	Nil	0·19	Trace	0·01	0·14	4 hr. at 390 deg. C, followed by 20 hr. at 418 deg. C, and cooled in air. Precipitation treatment 10 hr. at 200 deg. C, cooled in air. (Fully heat treated.)	$0{\cdot}0011_2$	1·3	0·0027	19·0	0·00245	10·0
8·71	0·45	Trace	Nil	0·24	Trace	Nil	0·10	Annealed at 250 deg. C for 4 hr.	$0{\cdot}0013_4$	1·5	0·0015	4·5	0·0012	3·5
8·71	0·45	Trace	Nil	0·24	Trace	Nil	0·10	8 hr. at 390 deg. C, followed by 16 hr. at 410 to 413 deg. C, and cooled in air. (Solution treated.)	$0{\cdot}0012_1$	2·0	0·00345	20·0	0·0016	7·0
8·71	0·45	Trace	Nil	0·24	Trace	Nil	0·10	As above followed by 15 hr. at 200–210 deg. C, and cooled in air. (Fully heat treated.)	$0{\cdot}0007_8$	2·2	0·0026	13·0	0·0018	6·0
10·86 to 10·90	0·42	Nil (AZ91 Alloy)	Nil	0·17	0·14	0·01	0·16	Annealed at 250 deg. C, for 4 hr.	$0{\cdot}0014_1$	4·5	0·0059	3·70	0·0039	18·0
10·86 to 10·90	0·42	Nil (AZ91 Alloy)	Nil	0·17	0·14	0·01	0·16	4 hr. at 390 deg. C, followed by 20 hr. at 418 deg. C, and cooled in air. (Solution treated.)	$0{\cdot}0015_7$	5·0	0·0063	37·0	0·0054	26·5
10·86 to 10·90	0·42	Nil (AZ91 Alloy)	Nil	0·17	0·14	0·01	0·16	As above, followed by precipitation at 200 deg. C for 10 hr., and cooled in air. (Fully heat treated.)	0·0009	1·0	0·0014	7·0	0·0010	5·0
3·54 to 3·37	0·08 to 0·07	5·73 to 6·16 (To Specification D.T.D. 350)	0·9 to 0·97	0·12 to 0·14	Nil	0·018 to 0·025	Nil	Annealed at 300 deg. C. for 4 hr.	$0{\cdot}0011_7$	0·7	$0{\cdot}0009_4$	2·0	0·00052	3·2



I 7½/8% Al, 0·3/0·5% Zr Fully treated
II 8·7% Al, 0·45% Zn Annealed
III 8·7% Al, 0·45% Zn Sol. treated
IV 8·7% Al, 0·45% Zn Fully treated
V 10½/11% Al, 0·3/0·5% Zn Annealed
VI 10½/11% Al, 0·3/0·5% Zn Sol. treated
VII 10½/11% Al, 0·3/0·5% Zn Fully treated
VIII 3% Al, 6% Sn, 1% Ag, 0·2% Mn Annealed

FIG. 1. Creep tests. Temperature 100 deg. C., stress 4 tons/sq. in.



I 7½/8% Al, 0·3/0·5% Zn, Fully treated
II 8·7% Al, 0·45% Zn, Annealed
III 8·7% Al, 0·45% Zn, Sol. treated
IV 8·7% Al, 0·45% Zn, Fully treated
V 10½/11% Al, 0·3/0·5% Zn, Annealed
VI 10½/11% Al, 0·3/0·5% Zn, Sol. treated
VII 10½/11% Al, 0·3/0·5% Zn Fully treated
VIII 3% Al, 6% Sn, 1% Ag, 0·2% Mn, Annealed

FIG. 2. Creep tests. Temperature 150 deg. C., stress 3 tons/sq. in.

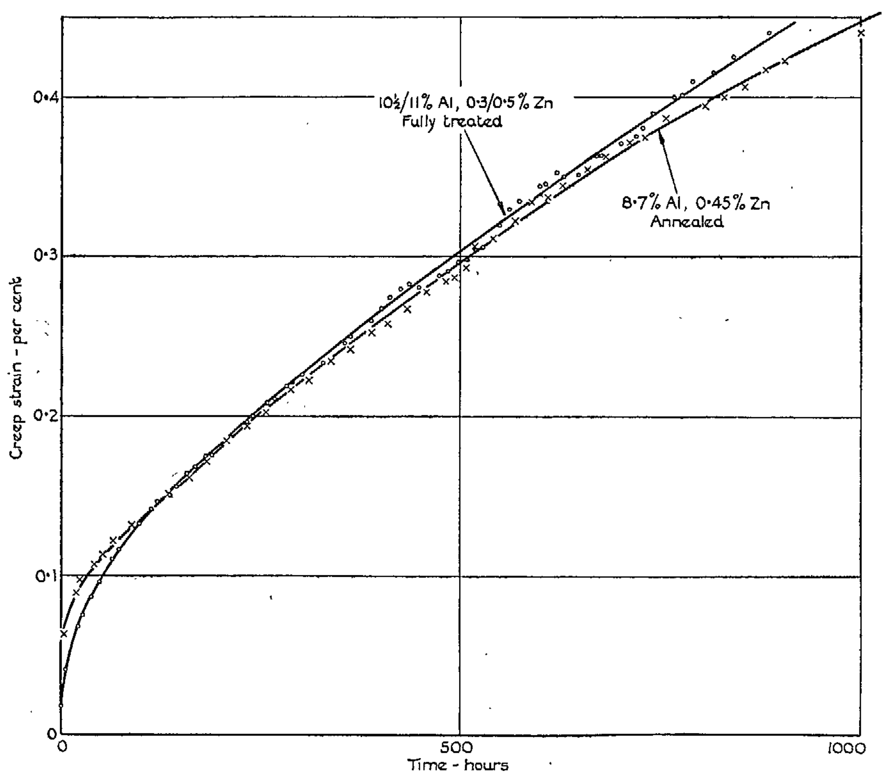
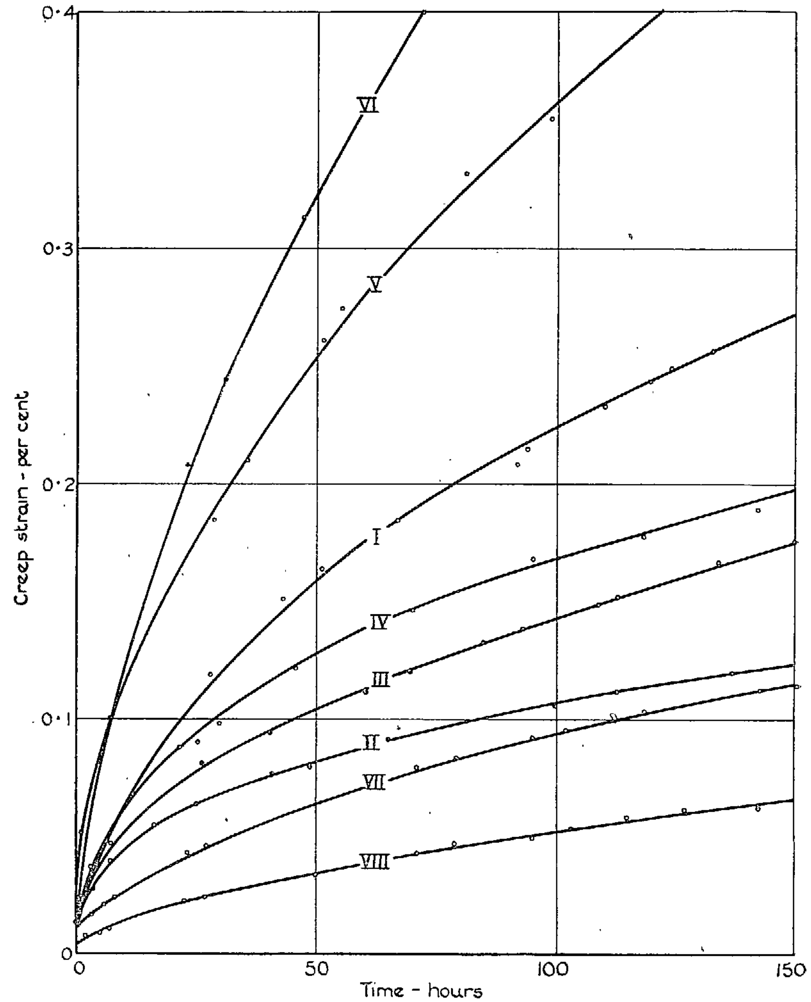


FIG. 4. Creep tests. Temperature 150 deg. C., stress 3 tons/sq. in.



I 7½/8% Al, 0·3/0·5% Zn, Fully treated
II 8·7% Al, 0·45% Zn, Annealed
III 8·7% Al, 0·45% Zn, Sol. treated
IV 8·7% Al, 0·45% Zn, Fully treated
V 10½/11% Al, 0·3/0·5% Zn, Annealed
VI 10½/11% Al, 0·3/0·5% Zn, Sol. treated
VII 10½/11% Al, 0·3/0·5% Zn, Fully treated
VIII 3% Al, 6% Sn, 1% Ag, 0·2% Mn, Annealed

FIG. 3. Creep tests. Temperature 200 deg. C., stress 1 ton/sq. in.

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PART II

Comparison of the Creep Properties of Three Cast Magnesium Alloys based on tests of 1,000 hours duration

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Introduction.—Part I describes the results of short time (150 hours) creep tests at 100 to 200 deg. C. on four cast magnesium alloys made with a view to selecting the best alloys for further investigation. Three of the alloys contained 7·8 per cent., 8·7 per cent., and 10·9 per cent. aluminium, respectively, with about 0·45 per cent. zinc. The fourth alloy, to specification D.T.D. 350, contained approximately 6 per cent. tin, 3·5 per cent. aluminium and 1 per cent. silver.

It was established that the D.T.D. 350 alloy, tested only in the annealed condition, was superior at 100 deg., 150 deg. and 200 deg. C., the 8·7 per cent. aluminium alloy (annealed) and the 10·9 per cent. aluminium alloy (fully heat-treated) being next in order of creep resistance.

Accordingly it was decided to carry out long time (1,000 hours) creep tests on these alloys, the first at 100 deg., 150 deg. and 200 deg. C. and the other two at 150 deg. C. The present paper describes the results of these tests.

Particulars of Materials.—The alloys supplied by the makers were in the form of heat-treated cast bars approximately $9\frac{1}{2}$ in. long with enlarged ends rather more than 1 in. in diameter and about 0·8 in. in diameter over a length of about $4\frac{1}{2}$ in. in the centre.

Particulars of chemical composition and heat-treatment are given in Table 1.

Range of Investigation.—Creep tests at various stresses have been made to provide comparisons based on creep strains up to 0·005 and on creep rates at 1,000 hours from 10^{-4} to 10^{-7} strain/hour. Some of the tests were continued up to periods approaching 4,000 hours for the purpose of obtaining data related to specific creep strains of small order.

Tests to determine the dimensional changes occurring during prolonged heating at zero load have also been made on the D.T.D. 350 alloy at 150 deg. and 200 deg. C. and on the other alloys at 150 deg. C.

Creep and Dimensional Instability Tests.—All the tests were made in 5-ton capacity N.P.L. creep testing machines capable of measuring creep rates of the order of 10^{-8} strain/hour on a 0·564-in. diameter specimen of 5 in. gauge length. The specimen temperature was maintained constant within $\pm\frac{1}{2}$ deg. C. and the temperature gradient along the specimen did not exceed 3 deg. C.

Creep curves for the tests at 100 deg., 150 deg. and 200 deg. C. on the annealed D.T.D. 350 alloy are shown in Figs. 1, 2, 3, respectively. Curves obtained from the instability tests on this alloy at 150 deg. and 200 deg. C. are also included in Figs. 2, 3.

Corresponding curves for the creep and instability tests on the annealed 8·7 per cent. aluminium alloy and the fully heat-treated 10·9 per cent. aluminium alloy are given in Figs. 4, 5, respectively.

Table 2 gives the periods for all stresses at which strains varying between 0·0005 and 0·005 are reached. The stress-strain relations are plotted on a semi-logarithmic basis in Figs. 6, 7, 8 and 9.

Table 3 gives the corresponding strain rates for the alloys at 1,000 hours or the minimum rates where these occur at periods less than 1,000 hours.

Comparisons of the creep properties of the alloys on a stress basis are given in Table 4, which records the stresses to produce specific strains in periods of 100, 300 and 1,000 hours, and in Table 5, which records the stresses producing strain rates of 10^{-5} and 10^{-6} per hour at 1,000 hours. The data in these tables are plotted on a semi-logarithmic basis in Figs. 10, 11.

Discussion of Results.—It will be appreciated that as the alloys show slight dimensional instability at zero load, the strains measured during the tests at various stresses include a measure of instability, but it can not be stated whether the instability is affected by stress so that it would not be legitimate to assume that the true creep strain can be obtained by the subtraction of the strain obtained in the instability test from the strain produced under stress. However, only the latter is of practical significance. The finite value at 1,000 hours of the rate of dimensional change at zero load definitely determines the trend of the stress-log rate curves in Figs. 10, 11 down to zero stress.

(a) *Annealed* D.T.D. 350 *alloy at* 100 *deg.*, 150 *deg. and* 200 *deg. C.*—At all stresses at 100 deg. C. (Fig. 1) the initial plastic strain on loading the specimen exceeds the subsequent strain up to 1,000 hours while at 150 deg. and 200 deg. C. (Figs. 2, 3) the initial plastic strain is relatively small.

Because of the relatively high initial plastic strain at 100 deg. C. no data are given for this temperature in Table 2 and no stress-log time curves have been plotted corresponding to those for 150 deg., C. and 200 deg. C. in Figs. 6, 7, respectively. However, the stresses at 100 deg. C. for various specific strains at 1,000 hours have been deduced from Fig. 1 and are included with corresponding data for 150 deg. C. and 200 deg. C. in Table 4.

For a strain of 0·005 in 1,000 hours the stresses for the temperatures 100 deg., 150 deg., and 200 deg. C. are approximately in the ratio 3 : 2 : 1. At lower strains, *e.g.* at 0·0015, the fall with temperature is greater, the stresses being in the ratio 4·9 : 2·7 : 1.

The change in the creep rate at 1,000 hours between 100 deg. C. and 150 deg. C. is very marked. At 100 deg. C. the creep rate is almost inappreciable at 4 ton/sq. in. (Table 3 and Fig. 10), whereas at 150 deg. C. a stress of 4 ton/sq. in. gives rise to a creep rate of the order of 10^{-5} strain/hour. Between 150 deg. C. and 200 deg. C. the difference in creep rates for stresses up to 2 ton/sq. in. is not particularly marked, but above 2 ton/sq. in. the disparity increases considerably. From Table 5 it will be seen that the stresses producing a creep rate of 10^{-6} strain/hour at 100 deg., 150 deg. and 200 deg. C. are approximately in the ratio 5 : 2 : 1.

The magnitude of the extension in the instability test at 200 deg. C. is about twice that at 150 deg. C. At both temperatures the rate of extension at 1,000 hours somewhat exceeds 10^{-7} strain/hour.

(b) *Annealed* 8·7 *per cent. aluminium alloy and fully heat-treated* 10·9 *per cent. aluminium alloy at* 150 *deg. C.*—Reference to the data for these alloys in Tables 4 and 5 and in Fig. 11 shows that the two alloys have very similar creep properties at 150 deg. C.

As regards the stresses to produce specific strains the latter alloy shows slight superiority at 100 hours and slight inferiority at 1,000 hours (Table 4).

The creep rates at 1,000 hours for stresses up to 4 ton/sq. in. differ very little (Fig. 11) and both alloys show about the same degree of instability, the rate of extension at 1,000 hours being about 10^{-7} strain/hour.

(c) *Comparison of the three alloys at* 150 *deg. C.*—On the basis of creep strain at 1,000 hours (Table 4), the D.T.D. 350 alloy shows superior creep strength for a strain of 0·005 but no superiority for 0·0005 strain as compared with the other alloys. For a strain rate of 10^{-5} strain/hour at 1,000 hours (Table 5), alloy D.T.D. 350 is only slightly superior, but it is seen to be decidedly superior to the other alloys when strengths corresponding to a strain rate of 10^{-6} strain/hour are compared.

Conclusions.—(1) For the annealed D.T.D. 350 alloy the stresses corresponding to a strain of 0·005 at 1,000 hours at 100 deg., 150 deg. and 200 deg. C. are 5·8, 3·7, and 1·9 ton/sq. in. respectively. The stresses giving a strain rate of 10^{-6}/hour at 1,000 hours at 100 deg., 150 deg. and 200 deg. C. are 5·8, 2·35 and 1·2 ton/sq. in., respectively.

(2) Annealed 8·7 per cent. aluminium alloy and fully heat-treated 10·9 per cent. aluminium alloy have very similar creep properties and both are inferior to D.T.D. 350 alloy at 150 deg. C.

(3) The three alloys show only a slight degree of instablity.

TABLE 1

Particulars of Materials

Chemical Composition—per cent. (Remainder is Mg in each case)								Heat treatment
Al	Zn	Sn	Ag	Mn	Cu	Fe	Si	
3·54 to 3·37	0·08 to 0·07	5·73 to 6·16	0·9 to 0·97	0·12 to 0·14	Nil	0·018 to 0·025	Nil	Annealed at 300 deg. C. for 4 hr.
(To Specification D.T.D. 350)								
8·71	0·45	Trace	Nil	0·24	Trace	Nil	0·10	Annealed at 250 deg. C. for 4 hr.
10·86 to 10·90	0·42	Nil	Nil	0·17	0·14	0·01	0·16	4 hrs at 390 deg. C. followed by 20 hr. at 418 deg. C. and cooled in air, followed by precipitation at 200 deg. C. for 10 hr. and cooled in air. (Fully Heat-treated.)
(AZ91 alloy)								

TABLE 2

Times for Specific Strains at Various Stresses

Alloy	Temperature deg. C.	Stress ton/sq in.	Time in Hours for Specific Strain								
			0·0005	0·00075	0·001	0·0015	0·002	0·0025	0·003	0·004	0·005
Mg Alloy 6% Sn 3·5% Al 1% Ag	150	0·75	920	2,100							
		2·0	240	525	815	1,500(E)					
		2·6	60	230	405						
		3·0	0·5	30	150	425	760	1,050	1,360	2,360	
		4·0				5	45	107	180	320	470
		5·0					0·1	0·4	0·9	3·3	8
	200	0·5	125	260	500	1,350					
		1·0	90	195	350	778	1,350				
		1·5	35	80	155	380	710	1,080			
		2·0	8	17	30	73	135	232	340	590	875
		2·5	2	6	12	28	50	78	105	165	245
Mg Alloy 8·7% Al 0·45% Zn	150	1·0	450	800	1,350						
		2·0	30	110	205	415	700	1,050			
		3·0	2	10	33	133	260	387	515	810	1,270(E)
		4·0				2	4	12	26	66	120
		5·0							0·5	3·0	75
Mg Alloy 10·9% Al 0·42% Zn	150	1·0	290	560	960						
		2·0	45	110	180	345	575	890	1,280	2,330	3,750
		3·0	8	27	60	140	245	362	490	765	1,080
		4·0			2	10	30	57	87	160	250

(E) Estimated value.

TABLE 3

Strain Rates at 1,000 hours at Various Stresses

Alloy	Temperature deg. C.	Stress ton/sq in.	Strain Rate/hour $\times 10^{-6}$	Remarks
Mg. Alloy 6% Sn 3·5% Al 1% Ag	100	4·0 4·75 5·25 5·75 6·0	<0·01 0·21 0·32 1·03 1·5	At 1,000 hr. At 1,000 hr. At 1,000 hr. At 1,000 hr. Minimum at 750 hr.
	150	0·00 0·75 2·00 3·00 4·00	0·13 0·3 0·8 1·6 6·9	Instability test at 1,000 hr. At 1,000 hr. At 1,000 hr. At 1,000 hr. Minimum at 500 hr.
	200	0·00 0·5 1·0 1·5 2·0 2·5	0·16 0·6 0·9 1·2 3·4 12	Instability test at 1,000 hr. At 1,000 hr. At 1,000 hr. At 1,000 hr. At 1,000 hr. Minimum at 300 hr.
Mg. Alloy 8·7% Al 0·45% Zn	150	0·0 1·0 2·0 3·0 4·0 5·0	0·09 0·5 1·45 2·4 20·0 100	Instability test at 1,000 hr. At 1,000 hr. At 1,000 hr. At 1,000 hr. Minimum at 100 hr. Minimum at 50 hr.
Mg. Alloy 10·9% Al 0·42% Zn	150	0·0 1·0 2·0 3·0 4·0	0·1 0·7 1·3 3·2 10·8	Instability test at 1,000 hr. At 1,000 hr. At 1,000 hr. At 1,000 hr. Minimum at 300 hr.

TABLE 4

Stresses for Specific Strains in Periods of 100, 300 *and* 1,000 *hours*

Alloy	Temperature deg. C.	Period hr.	Stresses for Specific Strains: ton/sq in.								
			0·0005	0·00075	0·001	0·0015	0·002	0·0025	0·003	0·004	0·005
Mg. Alloy 6% Sn 3·5% Al 1% Ag	100*	1,000	—	—	—	4·54	4·8	5·1	5·3	5·6	5·8
	150	100	2·4	2·8	3·1	3·5	3·8	4·0	4·2	4·3	4·5
		300	1·8	2·4	2·7	3·1	3·4	3·7	3·8	4·0	4·2
		1,000	0·7	1·4	1·9	2·4	2·9	3·1	3·2	3·5	3·7
	200	100	0·9	1·3	1·6	2·0	2·2	2·4	2·5		
		300		0·5	1·1	1·5	1·8	2·0	2·1	2·3	2·5
		1,000				0·9	1·3	1·5	1·6	1·8	1·9
Mg. Alloy 8·7% Al 0·45% Zn	150	100	1·6	2·0	2·5	3·1	3·3	3·4	3·6	3·9	4·1
		300	1·2	1·5	1·8	2·4	2·9	3·1	3·2	3·4	3·6
		1,000	0·8	1·0	1·1	1·5	1·7	2·0	2·6	2·9	3·1
Mg. Alloy 10·9% Al 0·42% Zn	150	100	1·6	2·1	2·6	3·2	3·5	3·7	3·9		
		300	1·0	1·4	1·7	2·2	2·8	3·2	3·3	3·7	3·9
		1,000	0·6	0·8	1·0	1·3	1·6	1·9	2·4	2·3	3·1

*Stresses at 100 deg. C. for 1,000 hr. are derived from Fig. 1. Stresses for 300 hr. are only a little higher than for 1,000 hr.

TABLE 5

Stresses for Specific Strain Rates at 1,000 *hours*

Alloy	Temperature deg. C.	Stress for Strain Rate of 10^{-5}/hr. at 1,000 hr. ton/sq in.	Stress for Strain Rate of 10^{-6}/hr. at 1,000 hr. ton/sq in.
Mg. Alloy 6% Sn 3·5% Al 1% Ag	100	—	5·8
	150	4·1	2·3$_5$
	200	2·4	1·2
Mg. Alloy 8·7% Al 0·45% Zn	150	3·8	1·6
Mg. Alloy 10·9% Al 0·42% Zn	150	4·0	1·6

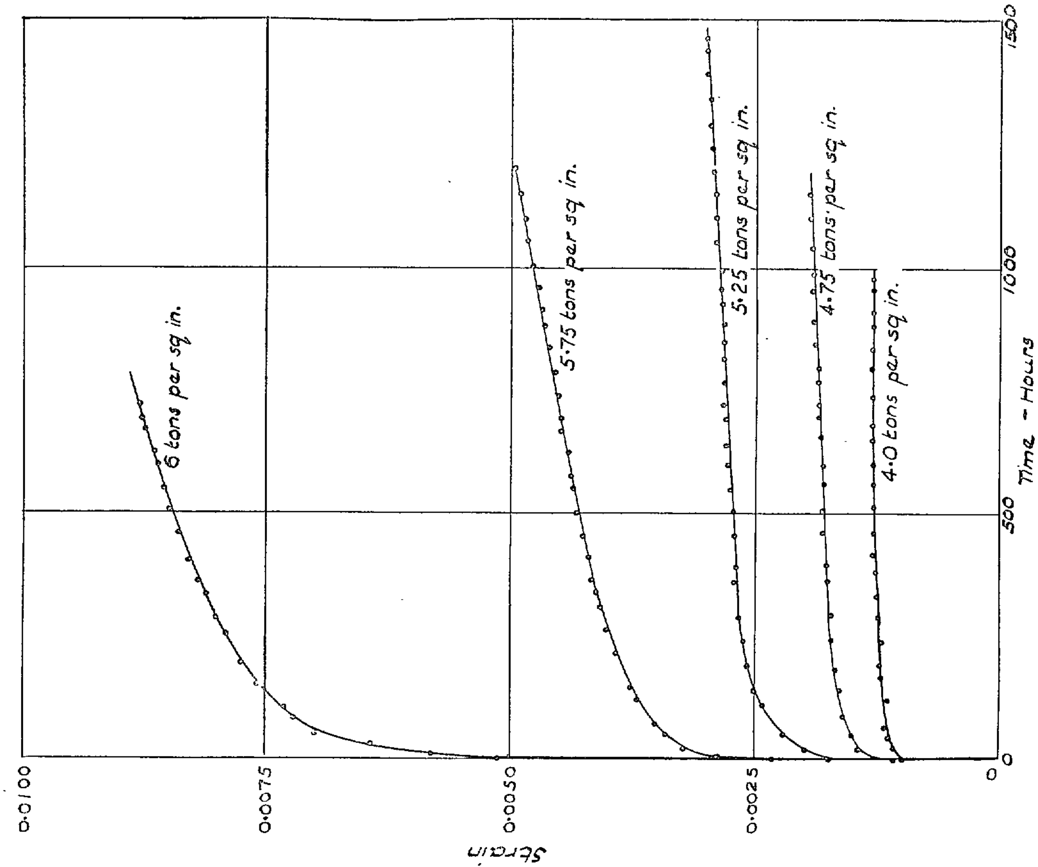

FIG. 1. Strain-time curves for cast annealed alloy D.T.D. 350 at 100 deg. C.

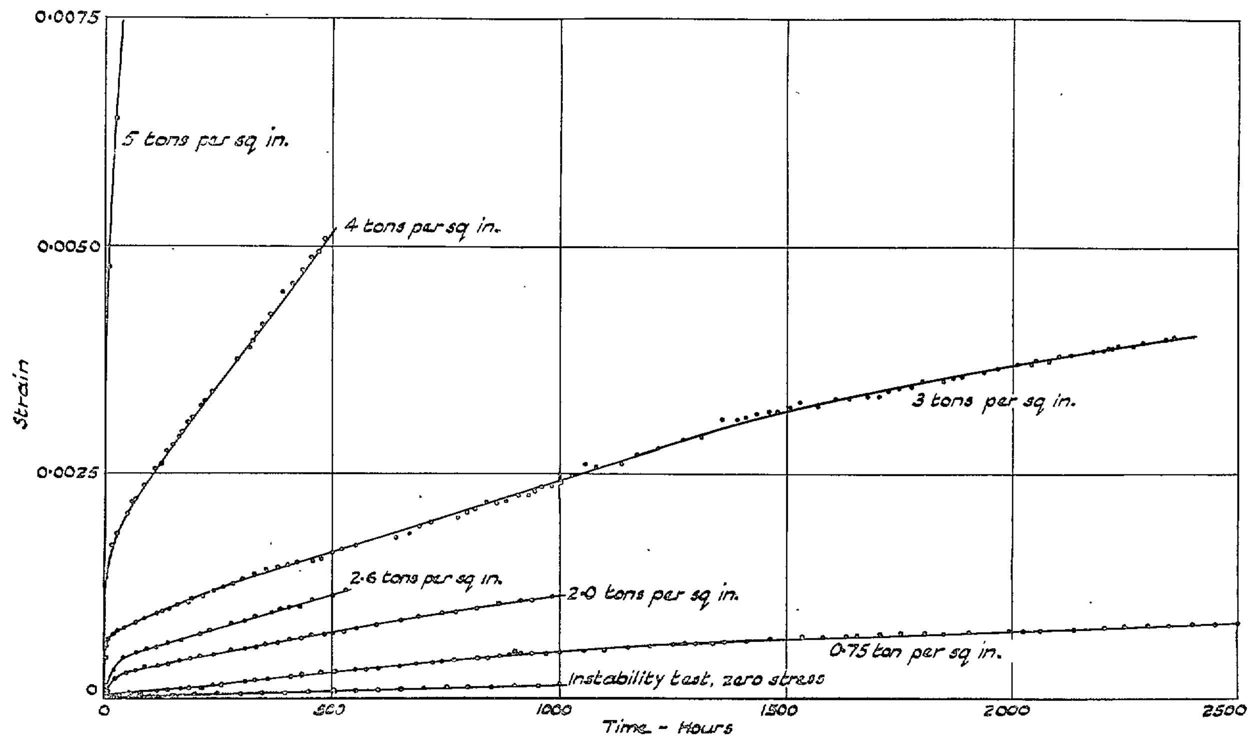

FIG. 2. Strain-time curves for cast annealed alloy D.T.D. 350 at 150 deg. C.

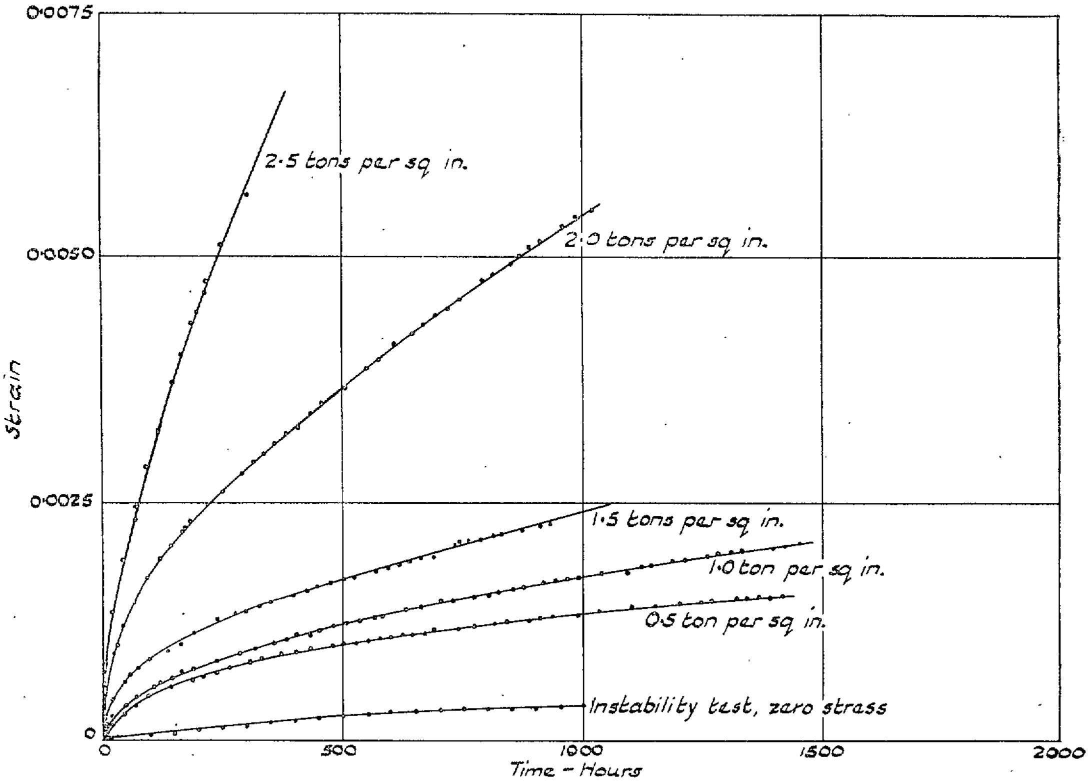

Fig. 3. Strain-time curves for cast annealed alloy D.T.D. 350 at 200 deg. C.

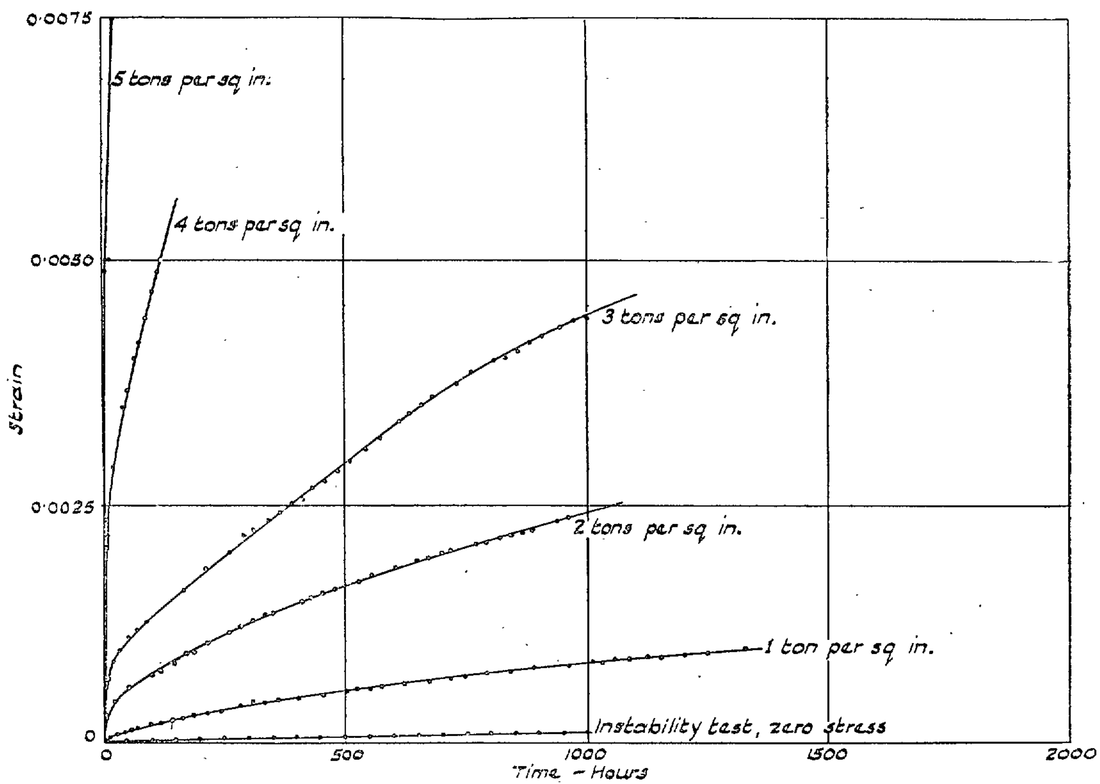

Fig. 4. Strain-time curves for annealed 8·7 per cent. aluminium, 0·45 per cent. zinc. alloy at 150 deg. C.

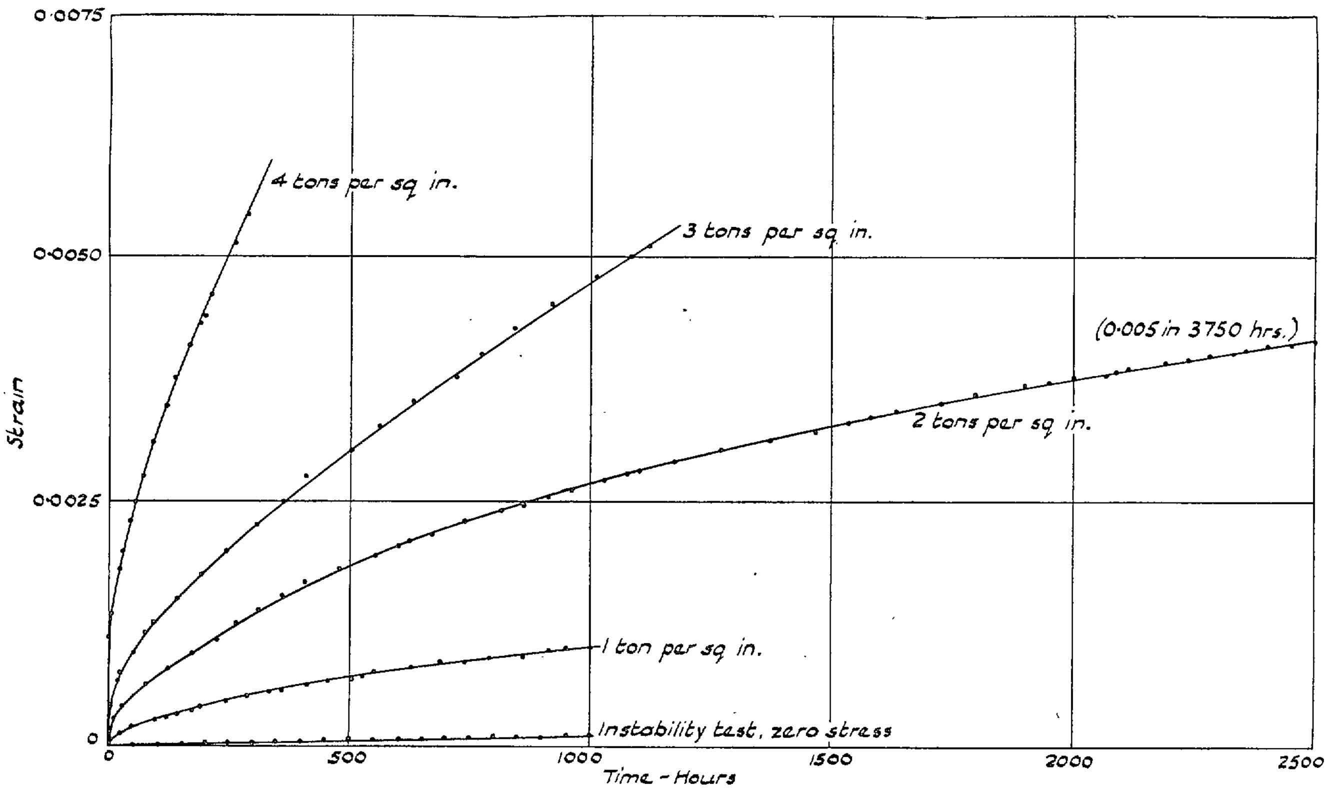

FIG. 5. Strain-time curves for fully heat-treated 10·9 per cent. aluminium, 0·42 per cent. zinc alloy at 150 deg. C.

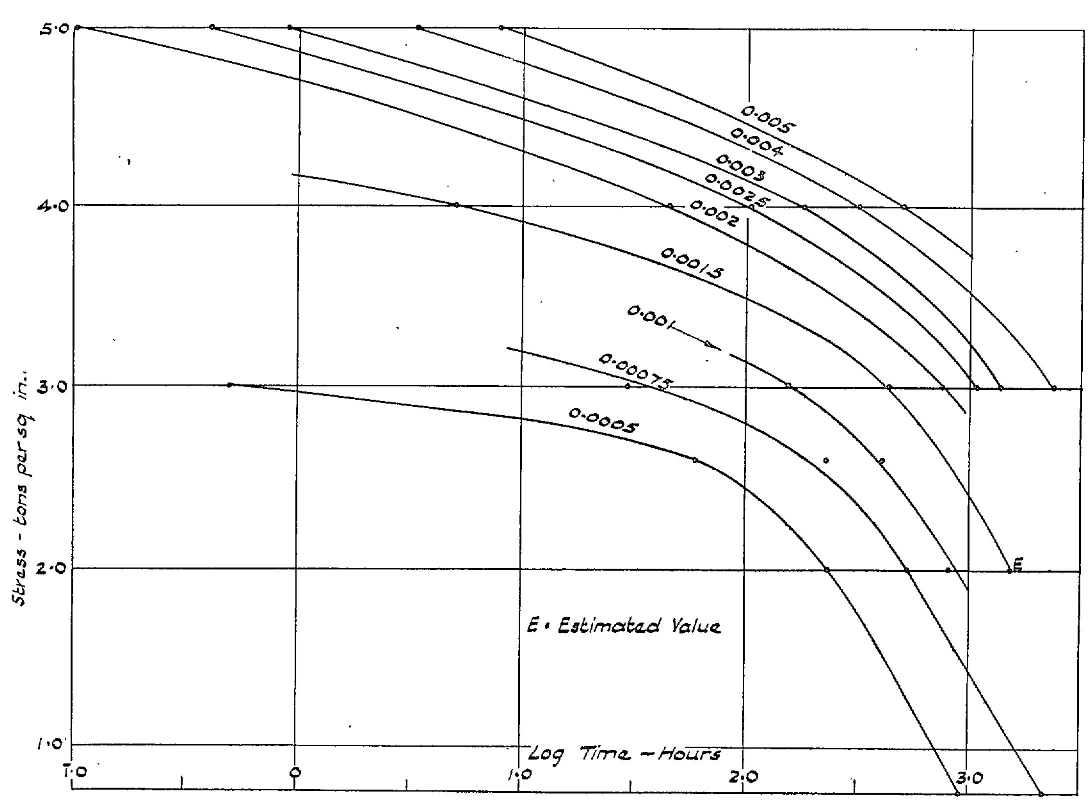

FIG. 6. Stress-log time curves for annealed D.T.D. 350 alloy at various specific strains at 150 deg. C.

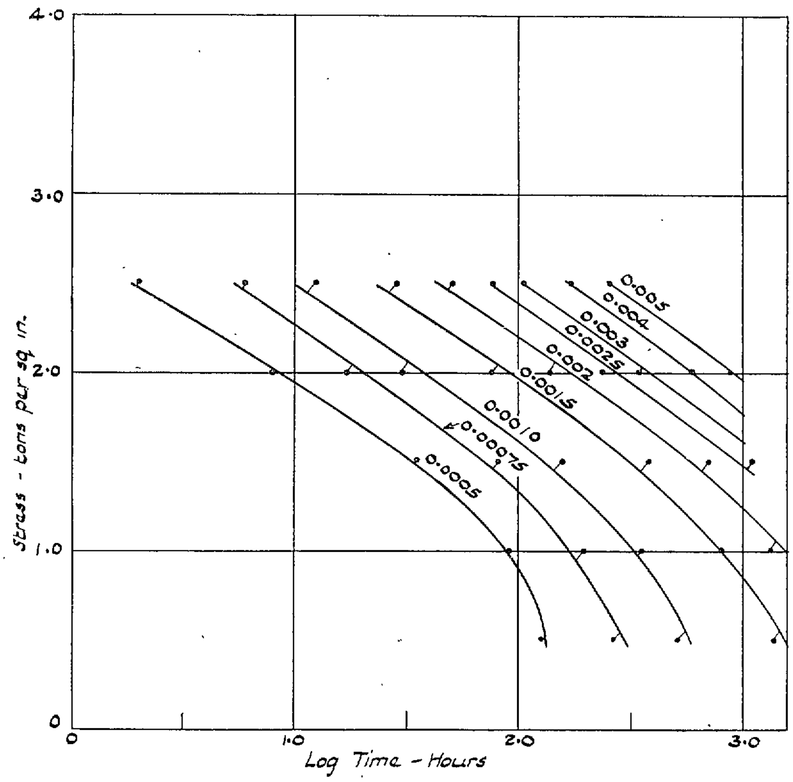

FIG. 7. Stress-log/time curves for annealed D.T.D. 350 alloy at various specific Strains at 200 deg. C.

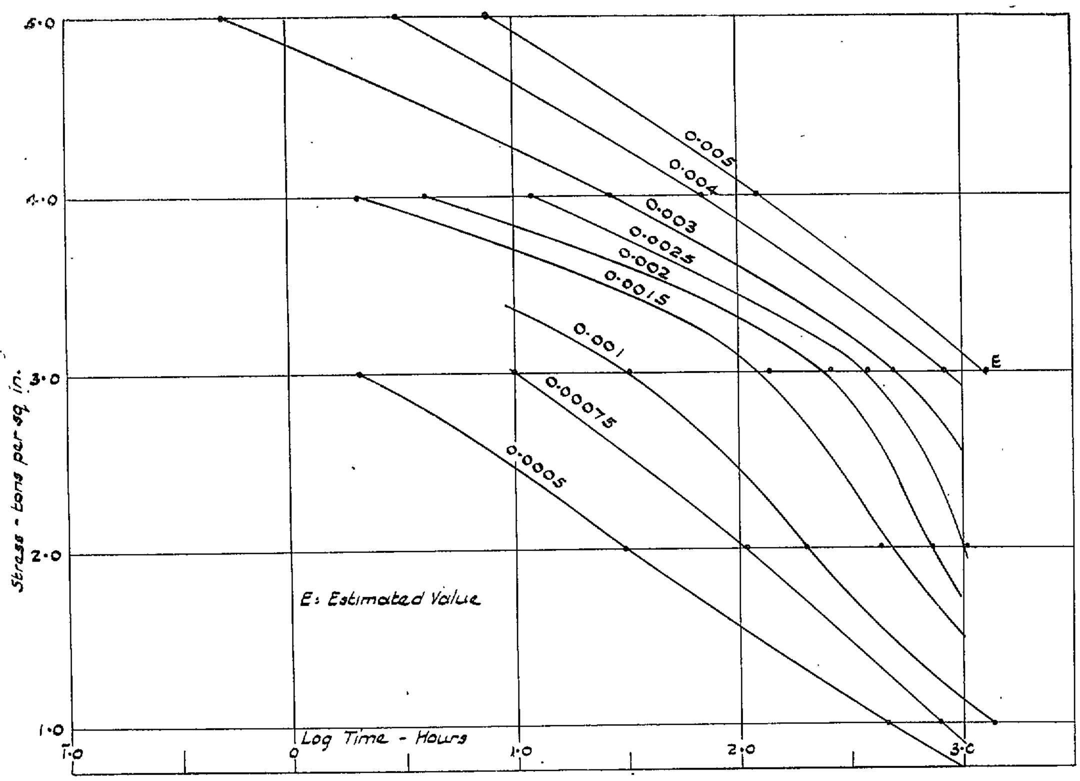

FIG. 8. Stress-log/time curves for annealed 8·7 per cent. aluminium, 0·45 per cent. zinc alloy at various specific strains at 150 deg. C.

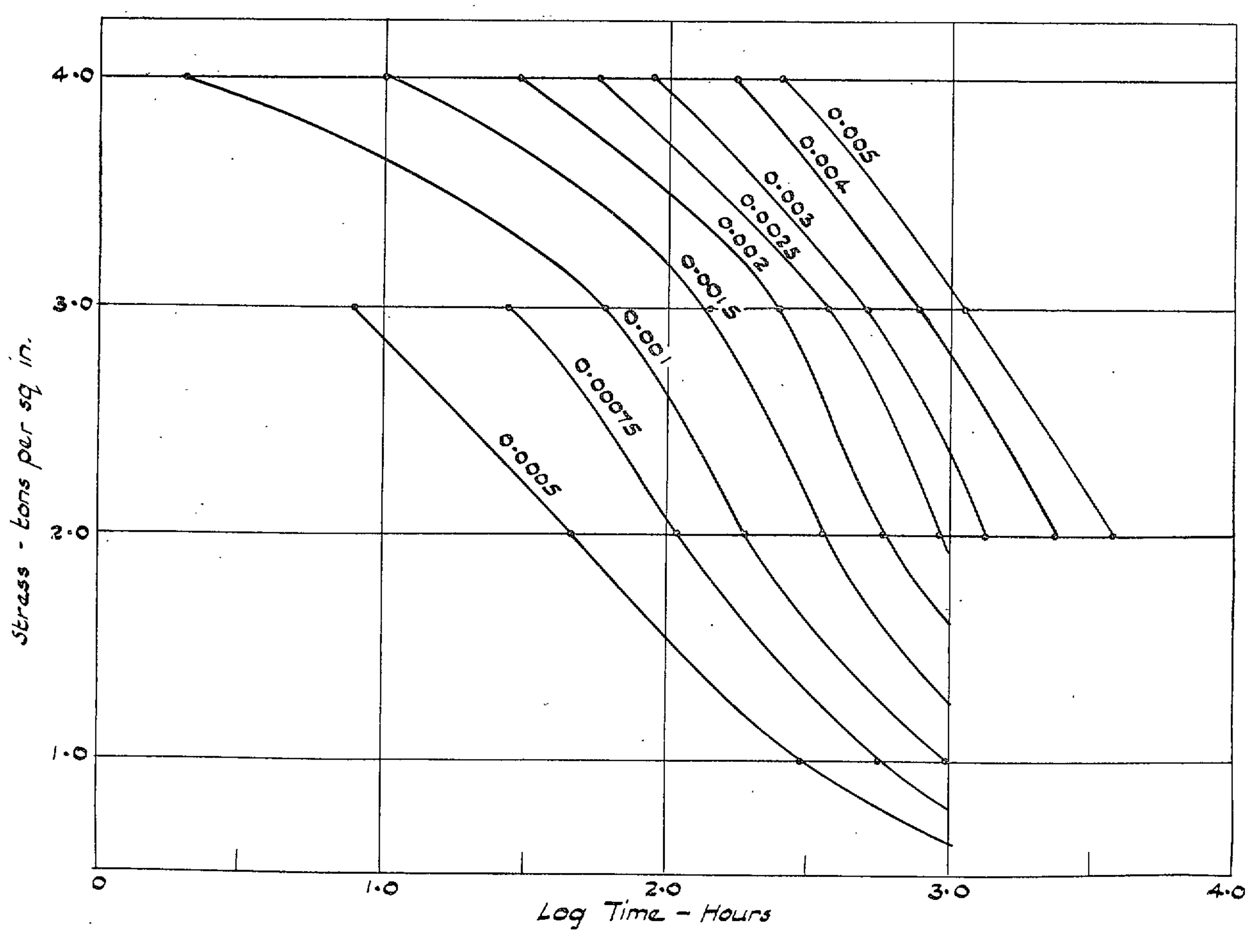

FIG. 9. Stress-log/time curves for fully heat-treated 10·9 per cent. aluminium, 0·42 per cent. zinc alloy at various specific strains at 150 deg. C.

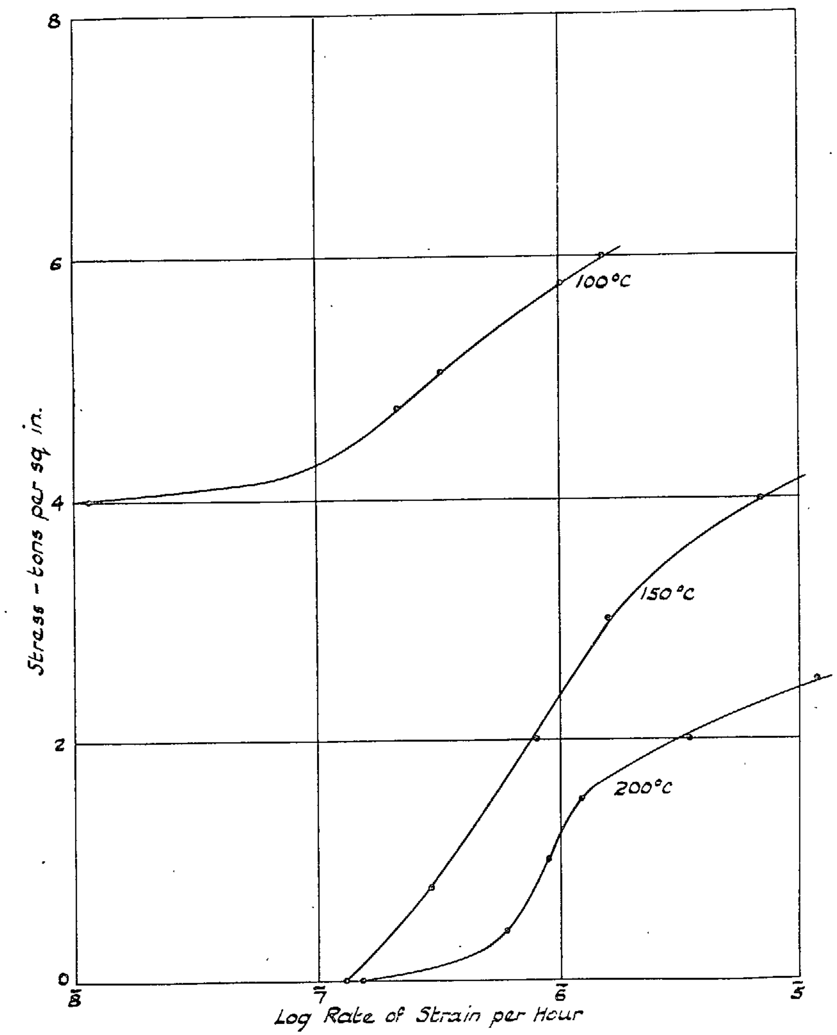

FIG. 10. Stress-log/rate of strain curves at 1,000 hrs. for annealed D.T.D. 350 alloy at 100 deg., 150 deg. and 200 deg. C.

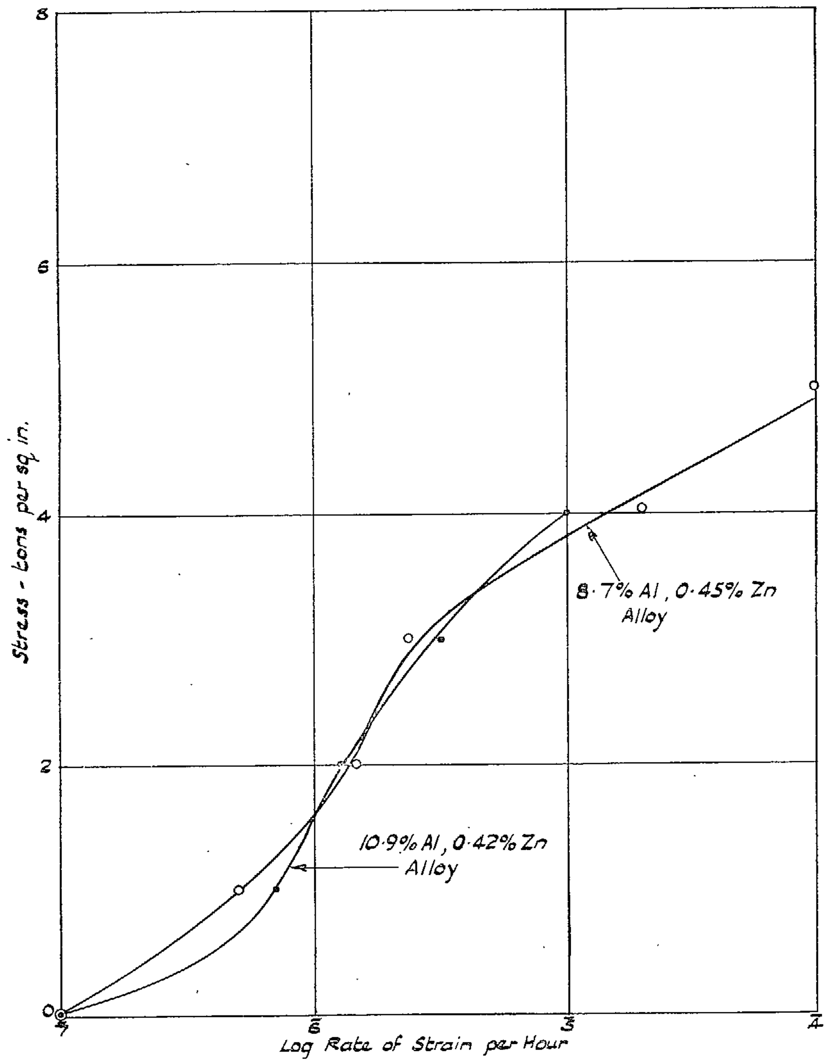

FIG. 11. Stress-log/rate of strain curves at 1,000 hr. for annealed 8·7 per cent. aluminium, 0·45 per cent. zinc. alloy and fully heat-treated 10·9 per cent. aluminium, 0·42 per cent. zinc alloy at 150 deg. C.

PART III

Effect of Various Heat Treatments on the Short-time Creep Behaviour at 3 tons/sq in 150 deg C, of Four Cast Magnesium Alloys

Introduction.—In Part I the results of short-time (150 hours) creep tests at 100 deg., 150 deg. and 200 deg. C. were given on some heat-treated sand cast magnesium alloys, three of these containing, respectively, about 8 per cent., 9 per cent. and 11 per cent. aluminium with $\frac{1}{2}$ per cent. zinc, and a fourth, D.T.D. 350, containing approximately 6 per cent. tin, 3·5 per cent. aluminium and 1 per cent. silver.

The work has been extended to include similar alloys but having different heat treatments from the former. The alloys whose creep behaviour has been investigated are given below, those marked with an asterisk having been tested previously in the heat treated condition indicated.

Alloy	*Condition*
D.T.D. 350 Silver bearing	Annealed 300 deg. C*
,, ,, ,, ...	,, 200 deg. C
D.T.D. 350 Silver free	,, 300 deg. C
,, ,, ,, ...	,, 200 deg. C
7·8% Al 0·45% Zn	Fully heat treated*
,, ,, ...	Annealed 200 deg. C
10·9% Al 0·45% Zn	Solution treated*
,, ,, ...	Fully heat treated*
,, ,, ...	Annealed 320 deg. C
,, ,, ...	Annealed 250 deg. C*
,, ,, ...	Annealed 200 deg. C

Range of Investigation.—Short-time creep tests of 150 hours duration have been made on the new materials at 150 deg. C. with a stress of 3 ton/sq. in., and the results have been compared with those from tests on the former materials at the same temperature and stress. Tensile tests at room temperature have been carried out on all the materials.

Particulars of Materials.—Twenty-four heat treated cast bars of each material were supplied. Each bar was approximately $9\frac{1}{2}$ in. long and had enlarged ends rather more than 1 in. in diameter, and were about 0·8 in. in diameter over about $4\frac{1}{2}$ in. in the middle.

Particulars of the chemical composition and heat treatment of all the materials under consideration are given in Table 1.

Creep Tests.—The tests were made in 5-ton capacity N.P.L. creep testing machines using test pieces 0·564 in. in diameter and having a gauge length of 5 in. The temperature gradient along the specimen did not exceed 3 deg. C. and the mean temperature was maintained constant within $\pm\frac{1}{2}$ deg. C.

One creep test, lasting 150 hours, was carried out on each material at 3 ton/sq. in., 150 deg. C., and the materials were compared on the bases of the creep strain and creep rate at 5 days (120 hr.).

The creep curves obtained for the D.T.D. 350 alloy, the 7·8 per cent. aluminium and the 10·9 per cent. aluminium alloys are plotted in Figs. 1, 2, 3, respectively, and the numerical data are given in Table 1. Corresponding curves and numerical data for the materials previously tested are included.

Considering the results for the D.T.D. 350 silver-bearing alloy, the creep strain at 5 days is less for the material annealed at 300 deg. C. than for the material annealed at 200 deg. C. On the other hand the creep rate at 5 days is greater, so that over a prolonged period of testing at 3 ton/sq. in. the material annealed at 200 deg. C. may show superiority. In the case of the silver-free alloy, annealing at 300 deg. C. again gives rise to smaller creep strain up to 5 days, but greater creep rate at 5 days than annealing at 200 deg. C. For both heat treatments the silver-bearing alloy is superior to the silver-free alloy in creep resistance at 5 days. In both conditions the two D.T.D. 350 alloys are superior to the other materials tested.

The 7·8 per cent. aluminium alloy, tested only in the fully heat-treated and annealed at 200 deg. C. conditions, shows the better creep resistance in the latter condition.

The 10·9 per cent. aluminium alloy shows the least creep strain at 5 days when in the fully heat-treated condition. Its creep resistance at 5 days is, however, a little less than that of the alloy annealed at 200 deg. C. which is the best material based on the creep rate at 5 days. The same alloy annealed at 320 deg. C. is somewhat poorer, and when annealed at 250 deg. C. is much poorer. The material annealed at 250 deg. C. was an earlier supply than the samples annealed at the higher and lower temperatures, and was somewhat harder, as shown below.

Heat treatment of 10·9 *per cent. aluminium alloy*	*Brinell Hardness Number*
Annealed 6 hours at 320 deg. C.	67 ± 2
Annealed 4 hours at 250 deg. C.	82 ± 2
Annealed 16 hours at 200 deg. C.	72 ± 2

These hardness results are in line with the ultimate tensile strengths of the materials at room temperature, as recorded in Table 2. It may be noted that the annealing time at 250 deg. C. is only 4 hours as compared with 6 hours at 320 deg. C. and 16 hours at 200 deg. C. Microscopical examination of the three materials, using the creep specimens for the purpose, has been made in the Metallurgy Division, N.P.L. The specimen annealed at 250 deg. C. showed no coring whereas coring was evident in the other two specimens; this difference in structure may be significant in regard to the differences in creep behaviour. There were no marked differences in grain size.

Tensile Tests at Room Temperature.—Tensile tests have been made on specimens of all the materials, load being applied in steps up to the 0·5 per cent. proof stress, beyond which the stress was increased at a rate of ½ ton/sq. in./min.

The results of the tensile tests are given in Table 2.

Conclusions.—Comparison of the creep properties of the materials at 3 ton/sq. in., 150 deg. C., leads to the following conclusions:—

(1) Both the silver-bearing and silver-free alloys to D.T.D. 350 specification, whether annealed at 200 deg. or 300 deg. C., are superior to the other materials, and the presence of silver appears to effect improvement in creep resistance. With these alloys, annealing at 200 deg. C. results in a slightly lower creep rate at 5 days than annealing at 300 deg. C.

(2) For the 7·8 per cent. aluminium alloy annealing for 16 hours at 200 deg. C. gives improved creep resistance compared with a full heat treatment

(3) Based on the creep rate at 5 days the best heat treatment for the 10·9 per cent. aluminium alloy is annealing for 16 hours at 200 deg. C.

Further Work.—Creep tests at 1 ton/sq. in., 200 deg. C., are well in hand and tests at 4 ton/sq. in., 100 deg. C., have been started.

TABLE 1

Results of Creep Tests at 3 ton/sq. in., 150 deg. C., on some Cast Magnesium Alloys

Chemical Composition—per cent. (Remainder is Mg in each case)								Heat Treatment	Creep Strain at 5 days	Creep Rate at 5 days in./in./hr. $\times 10^6$
Al	Zn	Sn	Ag	Mn	Cu	Fe	Si			
*3·37 to 3·54	0·07 to 0·08	5·73 to 6·16	0·9 to 0·97	0·12 to 0·14	Nil	0·018 to 0·025	Nil	Annealed at 300 deg. C, for 4 hr.	$0{\cdot}0005_8$	2·0
3·28	<0·1	6·16	0·97	0·185	Nil	0·01	Nil	Annealed at 200 deg. C for 16 hr.	$0{\cdot}0010_8$	1·4
3·22	Nil	6·32	Nil	0·15	Nil	Nil	0·06	Annealed at 300 deg. C for 4 hr.	$0{\cdot}0011_2$	2·8
3·22	Nil	6·32	Nil	0·15	Nil	Nil	0·06	Annealed at 200 deg. C for 16 hr.	0·0012	2·2
*7·79 to 7·82	0·45	Nil	Nil	0·19	Trace	0·01	0·14	4 hr. at 390 deg. C, followed by 20 hr. at 418 deg. C. and cooled in air. Precipitation treatment 10 hr. at 200 deg. C. and air cooled. (Fully heat treated)	0·0027	19·0
7·75	0·42	Nil	Nil	0·24	Nil	Nil	0·09	Annealed at 200 deg. C for 16 hr.	0·0020	8·0
*10·86 to 10·90	0·42	Nil	Nil	0·17	0·14	0·01	0·16	4 hr. at 390 deg. C. followed by 20 hr. at 418 deg. C, and air cooled. (Solution treated)	0·0063	37·0
*10·86 to 10·90	0·42	Nil	Nil	0·17	0·14	0·01	0·16	4 hr. at 390 deg. C, followed by 20 hr. at 418 deg. C, and air cooled. Precipitation treatment 10 hr. at 200 deg. C, and air cooled. (Fully heat treated)	0·0014	7·0
10·82	0·45	Nil	Nil	0·19	Nil	Nil	0·08	Annealed at 320 deg. C for 6 hr.	$0{\cdot}0018_8$	10·4
*10·86 to 10·90	0·42	Nil	Nil	0·17	0·14	0·01	0·16	Annealed at 250 deg. C for 4 hr.	0·0059	37·0
10·82	0·45	Nil	Nil	0·19	Nil	Nil	0·08	Annealed at 200 deg. C for 16 hr.	$0{\cdot}0020_2$	5·0

*Reported in Part I.

TABLE 2

Results of Tensile Tests at Room Temperature on Some Cast Magnesium Alloys

Material	Condition	Limit of proportionality ton/sq in.	Proof stresses, ton/sq in.			Ultimate stress ton/sq in.	Elongation $4(\text{Area})^{1/2}$ per cent.	Modulus lb/sq in. $\times 10^6$
			0·1%	0·2%	0·5%			
D.T.D. 350 (Silverbearing)	Ann. 300 deg. C*	—	—	—	—	—	—	—
D.T.D. 350 (Silverbearing)	Ann. 200 deg. C	1·6	3·8	4·7	6·0	10·6	6·0	6·0
D.T.D. 350 (Silver-free)	Ann. 300 deg. C	1·6	4·8	5·7	7·1	10·6	3·8	6·3
D.T.D. 350 (Silver-free)	Ann. 200 deg. C	1·0	3·8	4·7	5·9	8·0	‡	6·3
7·8% Al 0·45% Zn	Fully heat treated	2·1	4·7	5·7	7·4	16·3	11·5	6·1
7·8% Al 0·45% Zn	Ann. 200 deg. C	1·6	5·5	6·7	8·3	11·6	3·2	6·7
10·9% Al 0·45% Zn	Solution treated	3·2	7·6	9·2	†	15·7	3·0	6·6
10·9% Al 0·45% Zn	Fully heat treated	2·2	6·0	7·8	9·4	10·0	1·5	6·5
10·9% Al 0·45% Zn	Ann. 320 deg. C	2·2	6·0	7·4	9·2	10·8	1·5	6·6
10·9% Al 0·45% Zn	Ann. 250 deg. C	3·0	8·4	10·6	13·7	14·8	0·5	6·5
10·9% Al 0·45% Zn	Ann. 200 deg. C	2·1	6·2	7·8	9·8	11·6	1·0	6·4

*Not tested, material exhausted †Not measured ‡Fractured beyond gauge marks
Elongation, not including fracture = 2 per cent.

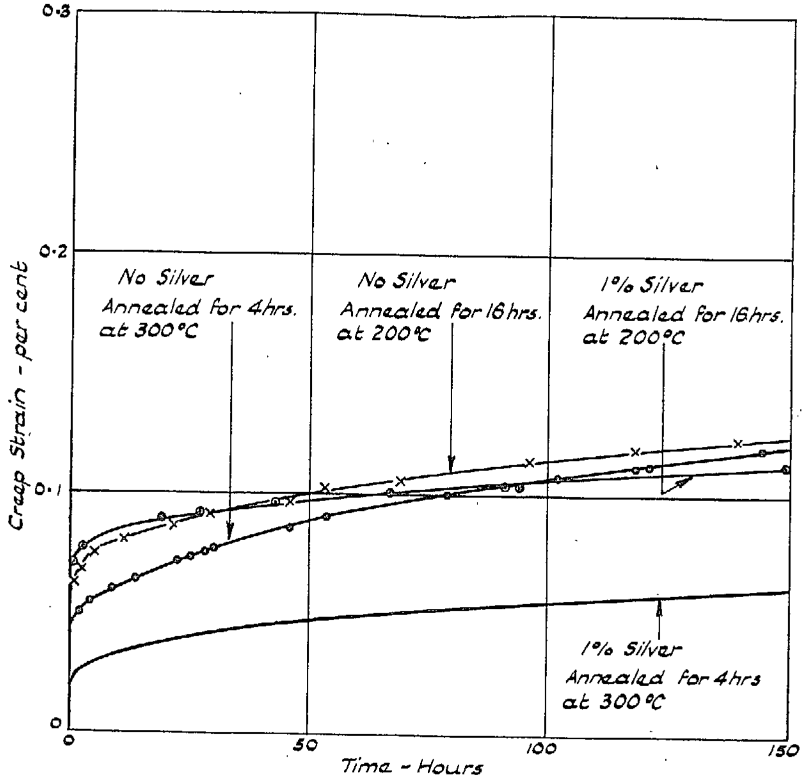

FIG. 1. Creep curves for cast magnesium alloy to specification D.T.D. 350
Temperature 150 deg. C, stress 3 ton/sq in.

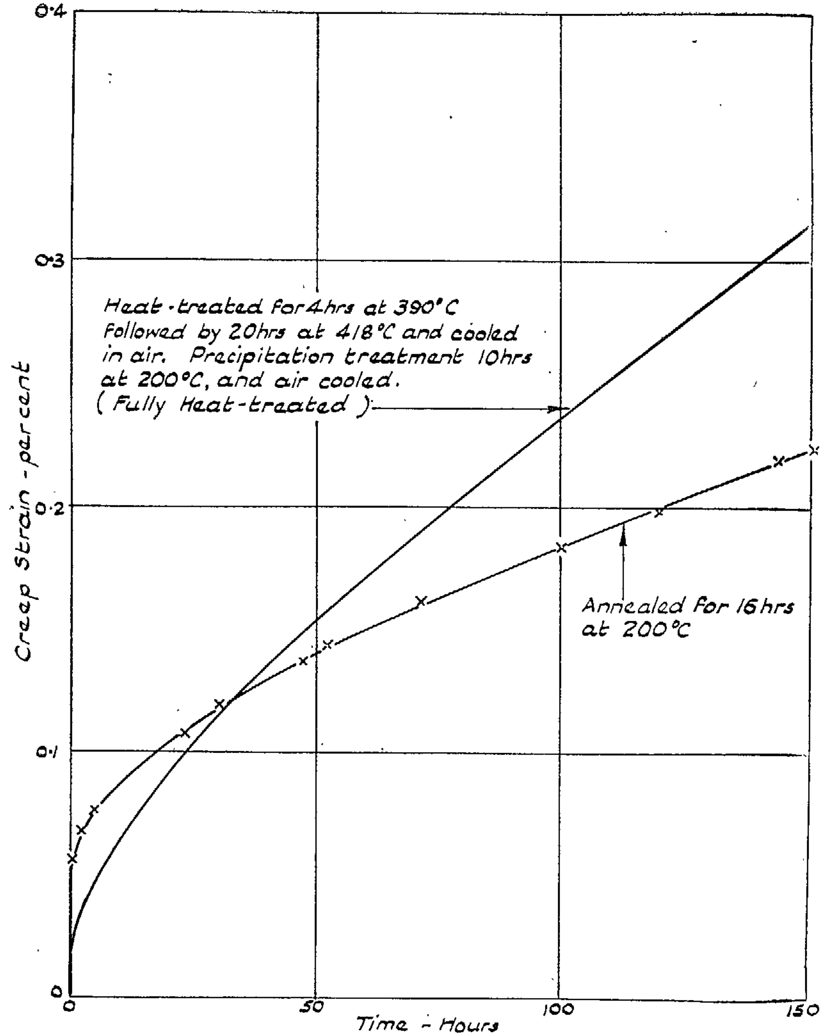

FIG. 2. Creep curves for cast magnesium alloy containing 7·8 per cent. aluminium
Temperature 150 deg. C, stress 3 ton/sq in.

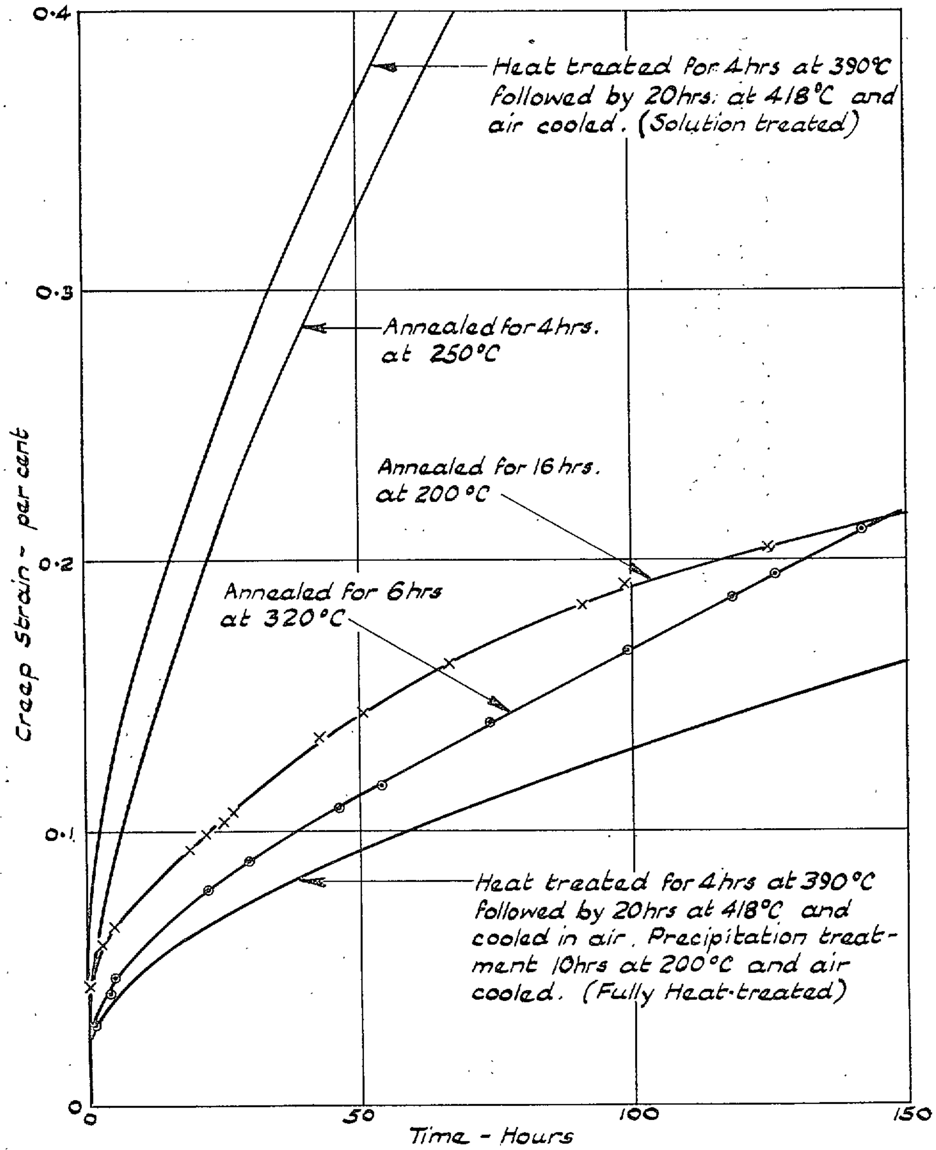

FIG. 3. Creep curves for cast magnesium alloy containing 10·9 per cent. aluminium
Temperature 150 deg. C, stress 3 ton/sq in.

(96736) Wt. 14/655 K.5 6/51 Hw.

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