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CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

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DEVELOPMENT OF A SAND-CAST MAGNESIUM ALLOY BASEPLATE FOR THE MEDIUM MORTAR. PHASE IV

by

B. LAGOWSKI, J. HARBEC & J.W. MEIER

PHYSICAL METALLURGY DIVISION

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B. Lagowski*, J. Harbec** and J. W. Meier***

SUMMARY

This report describes the work on Phase IV of the development of a cast magnesium alloy baseplate for an 81 mm mortar, carried out during the period of 1963-64 by the Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, for the Army Equipment Engineering Establishment (formerly Army Development Establishment), Department of National Defence, Ottawa, Canada.

This final phase of the investigation included the commercial production of successfully redesigned (A4) magnesium alloy baseplates and the results of metallurgical quality control, simulated service (static breakdown) and dynamic design (firing) tests of these baseplates, as well as of some additional research work on the use of other high-strength magnesium casting alloys for baseplate castings.

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INTRODUCTION

A Summary Report[1] and three progress reports[2-4] were issued on the development of a cast magnesium alloy baseplate for the 81 mm mortar, carried out during the period of 1960-1964 by the Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, for the Army Equipment Engineering Establishment (formerly Army Development Establishment), Department of National Defence, Ottawa, Canada.

The present report describes in detail the work on the final phase (IV) of the investigation (1963-64), which included the procurement of commercially produced magnesium alloy baseplates (final design A4) and the results of metallurgical quality control, simulated service (static breakdown) and dynamic design (firing) tests of these baseplates. In addition, research work was carried out on the use of other high-strength magnesium casting alloys for baseplate castings.

The fourth and final phase of the project was carried out on commercially produced castings. The foundry (Foundry A) was requested to cast 40 ZK61-T6 alloy baseplates to the finally approved design (see Figures 1 and 2, Mines Branch drawing MBP 20-1) and to adhere strictly to the mould design, developed at the Mines Branch (as shown in Figure 3), which was carefully chosen to secure the required mechanical properties in critical areas. Apart from this, standard equipment and routine foundry methods were used. The net weight of the casting (after machining) was 23.5 to 24 lb.

It is worth noting that, while a total of forty-one ZK61-T6 alloy castings were made, only one was rejected after all were closely examined radiographically. This shows that, although metallurgical development of premium-quality castings is time-consuming and costly, once the proper casting conditions are established and strictly adhered to, a very small rejection rate can be achieved in the actual production run.

FOUNDRY PROCEDURES

Contrary to the conditions applying in the first two phases of the project, when the foundries were left a free hand to develop their casting techniques, in the fourth and final phase the commercial foundry (Foundry A) was instructed to produce the castings to strictly specified moulding and casting procedures, established by the Mines Branch and set forth below.

Specified Moulding and Casting Procedures

Patterns:	produced according to Mines Branch drawing MBP 20-1 (Figure 2) in the form of a loose pattern with follow-up board.
Moulding Boxes:	31 x 31 in. - cope 10 in. - drag 4 in.
Runner System:	double runner as shown in Figure 3
Sprue:	1 in. diameter
Screens:	each side of down sprue, 7 sq. in. (two 3-1/2 x 2 in.)
Slot Gates:	four at spades - 1-1/2 in. at the bottom, 1/2 in. at the top
Risers:	Four cylindrical at the ingates - 3 in. at the bottom and 2-1/2 in. at the top, with Feedex on top of risers, and one cylindrical 1-3/4 in. in the centre without Feedex
Chills:	as marked xxx in Figure 3. Cast-to-shape magnesium chills for the tension side of the arms and reinforcing rib (total weight - 5.5 lb); cast-to-shape copper chills for the compression side of arms and the socket between the arms; and a split-type copper chill for the recess in the hub (total weight - 12 lb)
Facing Sand:	57 AFS
Backing Sand:	45 AFS

Mould and Chill Coat:	Foseco No. 825 zircon wash
Pouring Temperature:	770 °C (1420 °F)
Gross Weight of Casting:	42 lb (including risers and gating)
Net Weight of Casting:	25 lb (before machining)
Metal Preparation:	basically the same as described in third progress report(4), with the exception that zirconium was introduced as Mg-40% Zr sintered metal powder pellets and only 3% (by weight of metal charge) of TAM zirconium tetrachloride fused salt was added at the end of the alloying operation
Heat Treating:	solution treatment for 10 hr at 480 °C (900 °F), raising the temperature for 15 min to 500 °C (930 °F), uniform air blast cooling, and ageing for 48 hr at 130 °C (265 °F)

METALLURGICAL EVALUATION OF CASTINGS

All castings were examined radiographically by the Nondestructive Testing Section, including special X-ray shots for the arms and the socket area. Out of forty-one ZK61-T6 alloy castings only one was rejected because of defects detected by radiographic examination.

Table 1 lists the chemical analyses, properties of separately-cast test bars supplied with each melt and the disposition of the castings for simulated service (static breakdown) tests and dynamic design (firing) tests. All castings, which have no disposition annotation, were left for use in additional engineering evaluation tests and for another program of evaluation of surface protection of baseplates.

Table 2 shows the results of tensile tests obtained on test bars cut out of critical areas, designated Class 1 (the most critical areas, location "C" on Figure 3 in the first progress report(2)) and Class 2 (less critical but still important areas, location "D"), as well as of unspecified areas (non-critical locations "E" and "F"). The results are

compared with the minimum requirements for alloy ZK61-T6 in U. S. Military Specification MIL-M-46062 (MR), dated 25 June 1963. Although at time of casting of the A4 design baseplates, this specification was not yet issued, it is interesting to compare our results with the stringent requirements of this specification. Despite the fact that some of the lowest results (YS) were somewhat less than the specified minima, in general the results may be considered as very satisfactory, particularly if the less favourable heat treatment schedule (480 °C (895 °F) instead of 500 °C (930 °F) - which is standard for this alloy), and the small amount of risering and total weight of chills are taken into account. This may be compared with a premium-quality aircraft casting tested recently[8], where 70 lb of magnesium and 78 lb of chills were used for a casting of 10 lb shipping weight.

The table shows also that lower properties in unspecified areas, which from the structural design point of view are not significant, do not affect the results obtained in simulated service (breakdown) tests carried out on whole castings, as may be seen in the last column of Table 2.

Figures 4 and 5 show the typical mode of fractures of the A4 baseplates in simulated service (static breakdown) tests.

SIMULATED SERVICE TESTS

The results of simulated service (static breakdown) tests on A4-type plates, produced in ZK61-T6 alloy, are shown in Table 3 and Figure 6. The tests were described in detail in the first progress report[2]. Baseplates of A4-25X and A4-44X had been cast with thicker supporting spades to prevent chipping before fracture occurred in the 4-point-support test[4].

For this design, the permanent set equivalent to the yield strength of 120,000 lb was slightly greater than 0.03%. This is a considerable improvement over the previous prototype baseplates A2 and B2, for which a yield strength of 70,000 lb was equivalent to a permanent set of 0.1%.

The yield strength of the baseplate is defined as the beginning of a permanent deformation of the plate as determined from the total deflection-load curve. The permanent deformation obtained from this

curve should be that which occurs over the whole plate. However, part of the permanent deformation measured in this manner may occur in the spades at the points of contact with the rollers, particularly in standard production plates whose spades have not been specially increased in thickness for the 4-point-support test. Therefore, the acceptance of the casting, if based on this yield strength, should take these facts into account and baseplates for 4-point-support testing should either be cast with thicker spades, or corrections should be made for any local deformation which may occur at the points of support. The possibility of determining the yield strength of the baseplates by strain gauges placed at appropriate locations in the casting could also be considered.

ENGINEERING (FIRING) TESTS

Nine baseplate castings were selected (see Table 1) for engineering (firing) tests at the Canadian Armament Research and Development Establishment, Defence Research Board, Valcartier, Quebec.

The castings successfully withstood all the rigorous service evaluation tests[9] and it is concluded that the A4-type baseplates are suitable for service use insofar as their ability to withstand overload firing under a variety of support conditions is concerned.

ADDITIONAL WORK ON BASEPLATES IN OTHER MAGNESIUM ALLOYS

Although the program of the present investigation was limited to the design of a baseplate cast in magnesium alloy ZK61-T6, it was considered desirable to test a few baseplates in other high-strength magnesium casting alloys for comparison purposes.

The alloys chosen were:

(a) AZ92-T6 - which has high ultimate tensile strength, medium yield strength and low elongation, but belongs to the most popular group of Mg-Al-Zn casting alloys which have much better casting characteristics than alloy ZK61-T6 and are, therefore, easier to produce.

(b) QE22-T6 - this alloy has a high yield strength, although the ultimate tensile strength and elongation are considerably lower than those obtainable in alloy ZK61-T6.

(c) ZQ64-T6 - one of the new experimental Mg-Zn-Ag-Zr alloy family developed recently at the Mines Branch and which has higher strength than any commercial magnesium foundry alloys and good ductility[5, 6].

Since gating, risering and chilling were designed for alloy ZK61-T6, only a few castings were made in the other three alloys. Castings in AZ92-T6 and QE22-T6 alloys were produced by the commercial foundry, while one casting in the experimental alloy ZQ64-T6 was made at the Mines Branch Experimental Foundry and only heat treated commercially. Table 4 lists the chemical analyses, tensile test results on separately-cast test bars and the disposition of the castings. Test bars were cut out from all castings made in the three alloys and the test results are listed for comparison in Table 2.

Table 2 shows the results obtained on test bars from areas designated as Class 1 and Class 2, and from unspecified areas. The maximum, minimum and average values for each alloy are compared with the minimum requirements of U. S. Military Specification MIL-M-46062 (MR), dated 25 June 1963. Although the castings were not made to this specification (it had not been issued yet), the comparison is interesting, because it shows that, with a few exceptions, the stringent requirements of the MIL specification were met without undue difficulty and that the baseplate castings produced in the fourth and final phase of the present investigation, were of high quality.

Table 2 shows also the static breakdown results obtained in the 4-point-support tests. These results should be compared with those typical for the standard forged aluminum alloy baseplates, which average 195,000 lb[10]. Each of the alloys used, with the exception of AZ92-T6, showed higher strength than the aluminum alloy forging.

Table 5 gives a more detailed account of the results of simulated service (breakdown) tests performed on baseplates produced in the three additional alloys. Figures 7 to 9 show typical load deflection curves for A4 baseplates cast in these alloys.

Especially outstanding are the properties of alloys ZK61-T6 and ZQ64-T6, which in both cases could be even further increased by use of hot water quenching after solution heat treatment (for examples see Table 6, according to recent Mines Branch work[6]). Alloy QE22-T6 exhibits very good yield strength values, but has relatively lower tensile strength and elongation, and shows poorer performance in the simulated service tests. The suitability of alloy QE22-T6 for premium-quality castings is, therefore, more limited, because an ample margin of UTS over YS and good ductility is required to increase reliability of castings from the designer's point of view.

CONCLUSIONS

1. Full cooperation between the designer, end-user, metallurgist and foundryman has resulted in the development of a sand-cast magnesium alloy baseplate which meets the design requirements for the medium mortar with respect to strength and stability.

2. The use of high strength magnesium alloys (ZK61-T6, and especially the recently developed ZQ64-T6) and the application of premium-quality casting methods has now made possible the development of a redesigned magnesium alloy medium mortar baseplate casting which is 10% lighter than the standard aluminum alloy forging and has up to 30% higher strength in 4-point-support tests with twice the rigidity.

3. A comparison of the simulated service test loads required to cause fracture of the cast magnesium and the standard forged aluminum baseplates indicates that the weight of the cast magnesium alloy baseplate (23.5 to 24 lb) could be reduced, with further redesign, by at least 15% without lowering the strength below that of the standard baseplate.

ACKNOWLEDGEMENTS

Work on the development of the magnesium alloy medium mortar baseplate was carried out by a team of staff members of the Physical Metallurgy Division, Mines Branch. Special acknowledgement is due to Messrs. J. O. Edwards, Head, Non-Ferrous Metals Section, and P. J. Todkill, Head, Mechanical Testing Section, for their considerable assistance in all phases of the work and their technical advice; to the Nondestructive Testing Section for their assistance in X-ray evaluation of the castings, and to the Analytical Chemistry Subdivision, Mineral Sciences Division, Mines Branch, for the numerous chemical determinations.

Design work and design calculations on the mortar baseplates were done by Dr. T. W. Wlodek, Senior Scientific Officer, Mines Branch, with the assistance of Mr. J. Harbec.

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BL:JH:JWM:vb

TABLE 1

Chemical Analyses and Properties of Separately-Cast Test Bars

Melt No.	Base-plate No.	Composition Zn %	Composition Zr sol %	Tensile Properties UTS kpsi	Tensile Properties 0.2% YS kpsi	Tensile Properties El %	Weight lb	Disposition of of Casting
KE 170	A4-1	5.92	0.51	44.2	31.9	5.0		Sand
171	-2X*	6.29	0.56	45.2	31.0	5.0		4-point
172	-3X	6.46	0.62	43.8	28.3	4.0		4-point
173	-4	6.45	0.70	45.1	32.5	5.0	24	
174	-5	6.58	0.70	44.9	32.9	5.5	23.7	
175	-6	6.13	0.75	46.9	32.5	6.0		4-point + sand
" -	-7	"	"	"	"	"	24	
176	-8	6.12	0.74	46.3	30.9	6.0	24	
177	-9	6.27	0.78	47.7	32.5	7.5	24	
" -	-10	"	"	"	"	"	23.7	
178	-11	5.99	0.72	46.3	31.9	6.5	24	
" -	-12	"	"	"	"	"	24	firing
179	-13	5.78	0.65	44.9	31.5	6.0	23.5	
180	-15	6.33	0.76	47.3	32.5	7.5	23.5	
" -	-16	"	"	"	"	"	23.5	
181	-18	6.31	0.75	46.7	33.0	5.0		rejected
182	-19	6.43	0.77	45.4	32.2	6.0	23.5	firing
" -	-20	"	"	"	"	"	23.7	firing
184	-21	6.27	0.67	47.4	32.8	6.0	23.7	
185	-23	6.13	0.66	46.8	33.0	5.0	23.5	firing
" -	-24	"	"	"	"	"	23.7	firing
186	-25X	6.1	0.67	47.0	33.1	6.0		4-point
" -	-26	"	"	"	"	"	24	firing
187	-27	6.09	0.72	47.2	33.1	7.0	24	firing
" -	-28	"	"	"	"	"	23.7	firing
188	-29	6.04	0.60	46.4	33.2	5.0	23.5	
" -	-30	"	"	"	"	"	23.5	
189	-31	6.47	0.73	46.8	33.3	4.5	23.7	stress coat
" -	-32	"	"	"	"	"	24	
190	-33	5.9	0.70	48.2	33.3	7.5	23.7	
" -	-34	"	"	"	"	"	23.5	
191	-35	6.07	0.66	48.1	32.8	9.5	23.7	
" -	-36	"	"	"	"	"	24	
192	-37	5.81	0.58	47.8	32.8	8.0	23.7	
" -	-38	"	"	"	"	"	24	
193	-39	6.31	0.69	47.6	33.5	7.0	23.5	firing
" -	-40	"	"	"	"	"	23.7	
194	-41	6.01	0.68	47.8	33.4	8.5	23.7	
" -	-42	"	"	"	"	"	24	sand
195	-43	6.01	0.66	46.1	31.9	5.0	23.7	
" -	-44X	"	"	"	"	"		4-point

* Baseplates designated X were cast with thicker supporting spades for 4-point-support tests.

TABLE 2

Tensile Properties of Test Bars Cut Out of Prototype Castings

Alloy Designation		Designated Areas Class 1				Designated Areas Class 2				Unspecified Areas				Simulated Service Tests** Breaking Load-lb
			UTS, kpsi	YS, kpsi	El, %		UTS, kpsi	YS, kpsi	El, %		UTS, kpsi	YS, kpsi	El, %	
ZK61-T6	max		46.4	33.2	14.0		44.5	30.2	10.0		41.5	29.5	6.5	
	min		44.4	28.3	8.0		43.2	28.2	8.0		38.2	20.0	2.5	
	ave	(10)	45.5	31.8	10.0	(8)	43.9	29.4	9.1	(12)	39.4	25.9	4.0	236,000
	Mil*		42	29	6		37	26	4		30	21	0.25	
AZ92-T6	max		46.2	25.6	4.5		41.8	26.8	4.5		38.9	25.2	2.0	
	min		41.7	20.2	3.5		35.1	21.4	2.5		35.1	20.5	1.0	
	ave	(6)	43.9	22.8	4.5	(5)	36.9	24.0	3.2	(6)	36.6	23.2	1.4	178,000
	Mil*		40	25	3		34	20	1		17	13.5	0.25	
QE22-T6	max		42.2	35.0	5.5		41.2	32.8	5.5		40.1	30.2	3.5	
	min		39.7	30.1	33.5		39.6	31.7	3.5		38.4	25.8	2.5	
	ave	(7)	40.7	33.4	4.3	(6)	40.5	32.3	4.2	(8)	39.3	28.3	2.7	217,000
	Mil*		40	28	4	37		26	2		28	20	2	
ZQ64-T6	max		49.2	40.1	9.5		47.2	31.5	7.5		45.9	30.1	7.0	
	min		48.7	32.8	8.0		44.0	29.9	6.0		39.2	19.1	4.5	254,500
	ave	(3)	49.0	36.0	8.5	(3)	45.7	30.7	6.5	(4)	42.9	26.0	6.0	

* Mil - minimum in Military Specification MIL-M-46062 (MR) dated 25 June 1963.
** - 4-Point-Support Tests.

NOTE: Numbers in brackets give number of specimens tested.
Test bars for Class 1 and Class 2 areas were cut out from 1-1/4-inch-thick sections.

TABLE 3

Results of Simulated Service Tests on Cast Magnesium ZK61-T6 Alloy Baseplates

Base-plate No.	Type of Support	Load for 0.01% Perm.Set, lb	Load for 0.03% Perm.Set, lb	Load for 0.1% Perm.Set, lb	Yield Strength, lb	Breaking Load, lb
A4-25X	4-pt	90,000	115,000	150,000	120,000	224,500
A4-44X	4-pt	95,000	115,000	150,000	120,000	247,500
A4-6	sand	-	-	-	-	237,000
A4-42	sand	-	-	-	-	300,000

NOTE: Loads for permanent sets determined from strain gauges located on the tension side of arms; Yield Strength determined from load-deflection measurements using dial gauge.

TABLE 4

Baseplates Produced from Other Alloys

Melt No.	Plate No.	UTS, kpsi	0.2% YS, kpsi	El, %	Chemical Analysis %			Disposition of Casting
					Al	Zn	Mn	
EX210	A4-45X	39.2	23.5	2.0	8.94	2.03	0.31	4-point
220	-46	40.0	25.3	2.0	8.88	2.08	0.30	sand
					Ag	RE	Zr sol	
QE22-2	-X2	42.9	31.8	4.0	2.56	2.10	0.42	4-point
"	-X3	"	"	"	"	"	"	4-point
-3	-X4	42.7	31.0	4.0	2.64	2.19	0.42	sand
					Zn	Ag	Zr sol	
5038	SG	49.0	33.2	9.5	5.27	3.86	0.78	4-point

TABLE 5

Results of Simulated Service Tests on Cast Magnesium Alloy Baseplates

Alloy Designation	Baseplate No.	Type of Support	Yield Strength, lb	Breaking Load, lb
AZ92-T6	A4-45X	4-pt	85,000	178,000
	A4-46	sand	-	197,000
QE22-T6	A4-X2	4-pt	110,000	208,500
	A4-X3	4-pt	120,000	225,500
	A4-X4	4-pt	110,000	load to yield
	A4-X4	sand	-	240,000
ZQ64-T6	C4-SG	4-pt	120,000	254,500

NOTE: Yield Strength determined from load-deflection measurements using dial gauge.

TABLE 6

Effect of Cooling Rate from Solution Temperature on Mechanical Properties

Alloy Designation	UTS, kpsi	0.2% YS, kpsi	El, % in 4D	Cooling Rate
(a) Separately-Cast Test Bars				
ZK61-T6C	46.8	32.5	11.0	cooled in air blast
ZK61-T6E	48.2	35.0	10.0	quenched in boiling water
ZQ64-T6A	48.9	34.3	10.5	cooled in air blast
ZQ64-T6E	50.6	36.2	10.0	quenched in boiling water
(b) Castings*				
ZK61-T6C	46.5	31.3	18.0	cooled in air blast
ZK61-T6E	47.5	33.2	15.0	quenched in boiling water
ZQ64-T6A	50.1	33.8	7.0	cooled in air blast
ZQ64-T6E	50.8	35.4	10.0	quenched in boiling water

* test bars cut from end-chilled 2-inch thick plates (adjacent to chill).

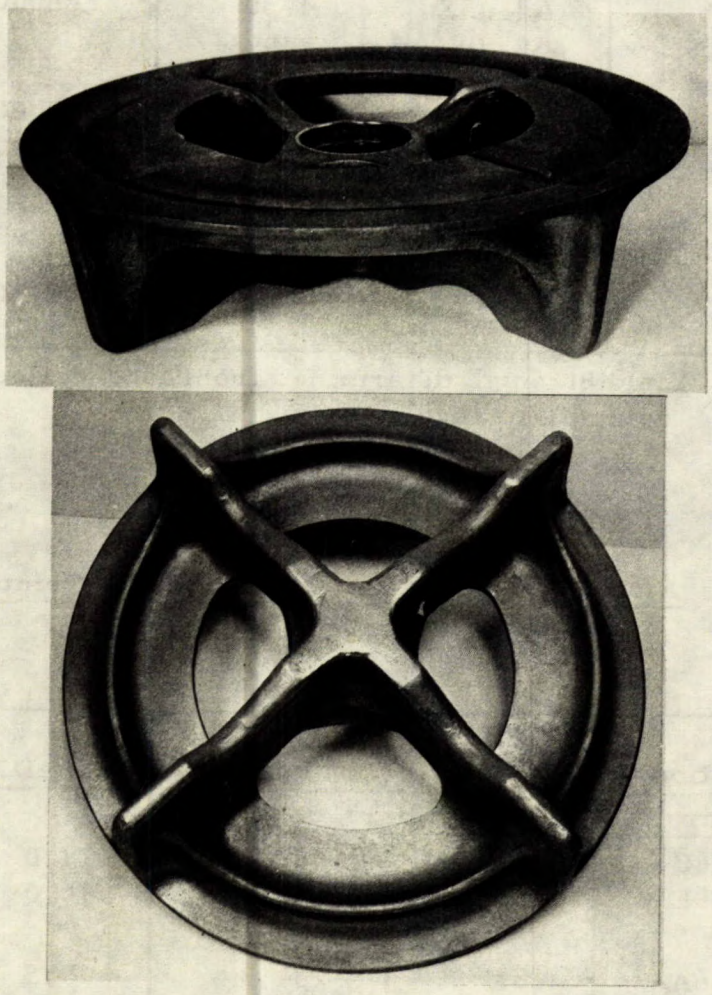

Figure 1. Views of medium mortar base casting.

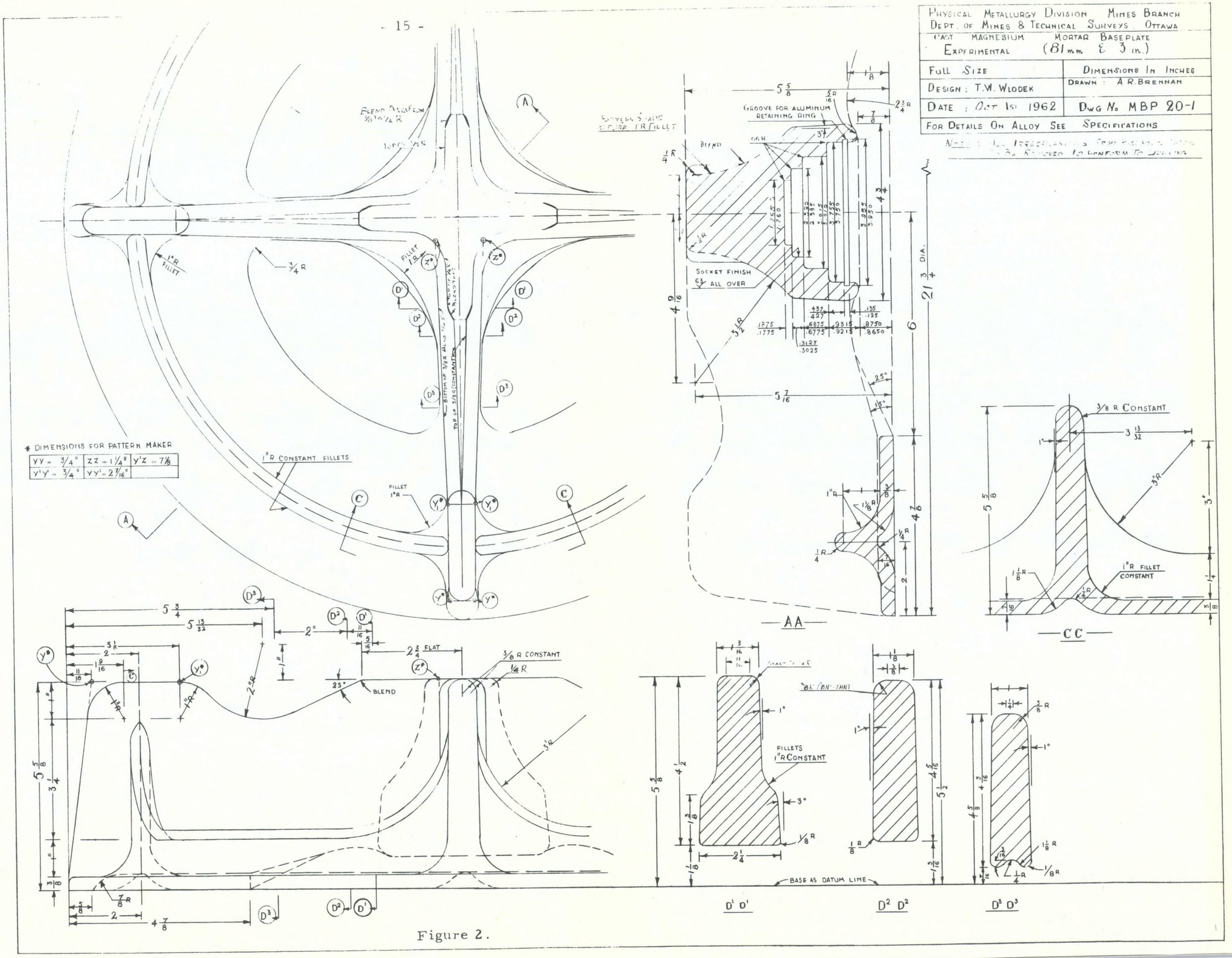
PHYSICAL METALLURGY DIVISION MINES BRANCH
DEPT. OF MINES & TECHNICAL SURVEYS OTTAWA
CAST MAGNESIUM MORTAR BASEPLATE
EXPERIMENTAL (81 mm & 3 in.)
FULL SIZE
DIMENSIONS IN INCHES
DESIGN : T.W. WLODEK
DRAWN : A.R. BRENNAN
DATE : OCT 1ST 1962
DWG No. MBP 20-1
FOR DETAILS ON ALLOY SEE SPECIFICATIONS
* DIMENSIONS FOR PATTERN MAKER
YY = 3/4"
ZZ = 1 1/4"
Y'Z = 7/8
Y'Y' = 3/4"
YY' = 2 7/16"
1"R CONSTANT FILLETS
GROOVE FOR ALUMINUM RETAINING RING
SOCKET FINISH
BLEND
3/8 R CONSTANT
1/4 R
2 3/4 FLAT
FILLETS 1"R CONSTANT
BASE AS DATUM LINE
AA
CC
D1 D1
D2 D2
D3 D3

Figure 2.

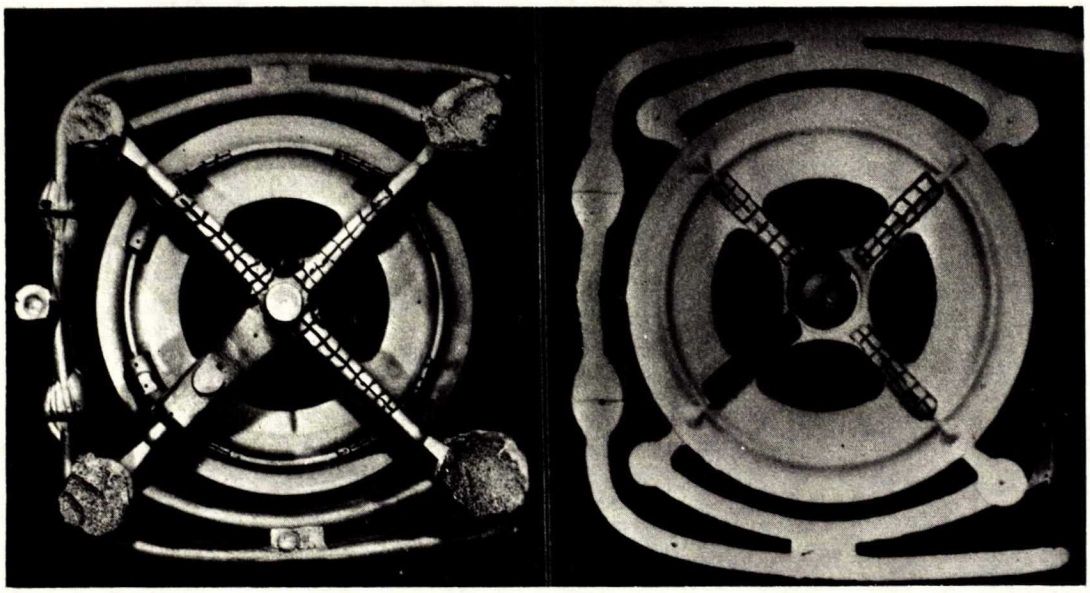

Figure 3. Moulding arrangement in commercial production of the design A4.

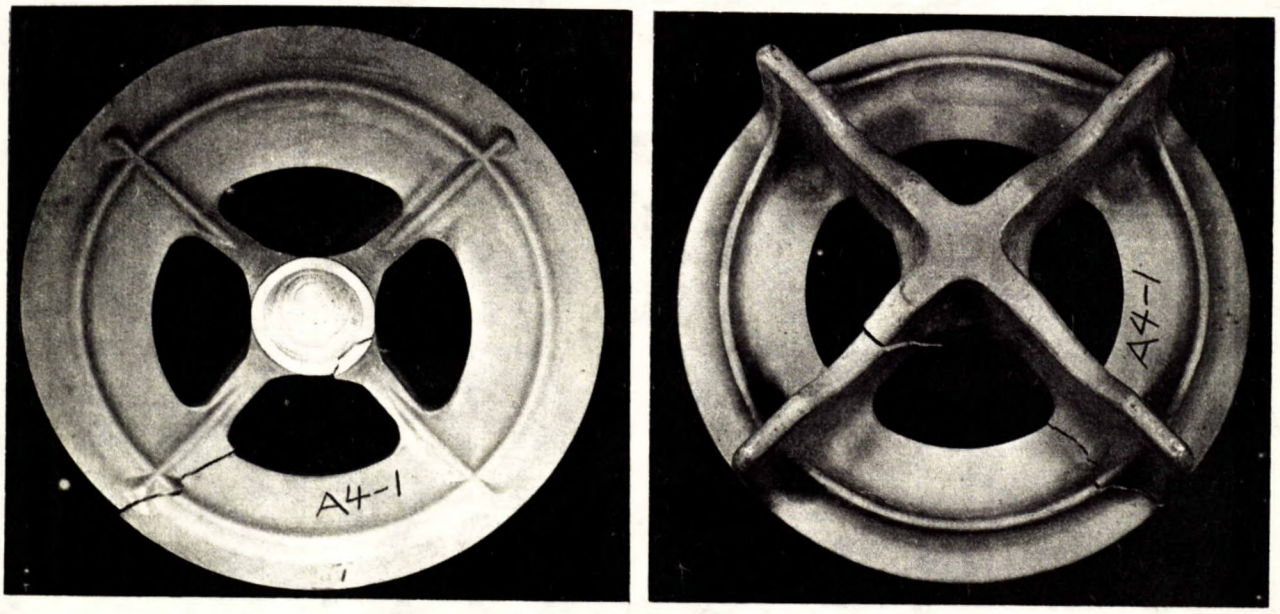

Figure 4. Typical fracture in sand test of A4 design.

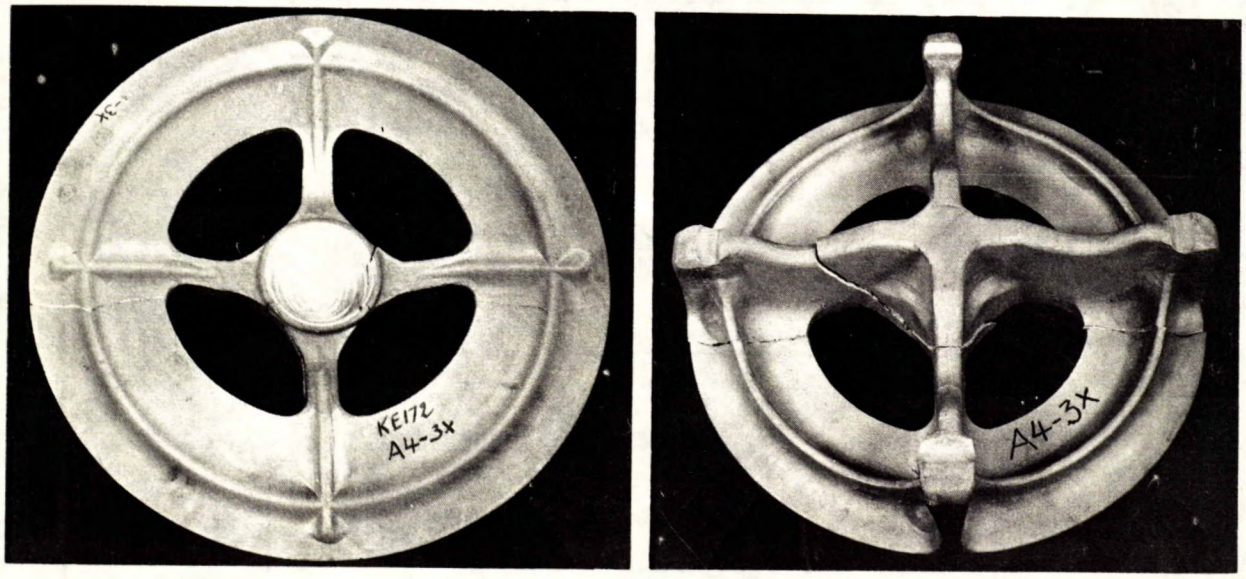

Figure 5. Typical fracture in 4-point-support test of A4 design.

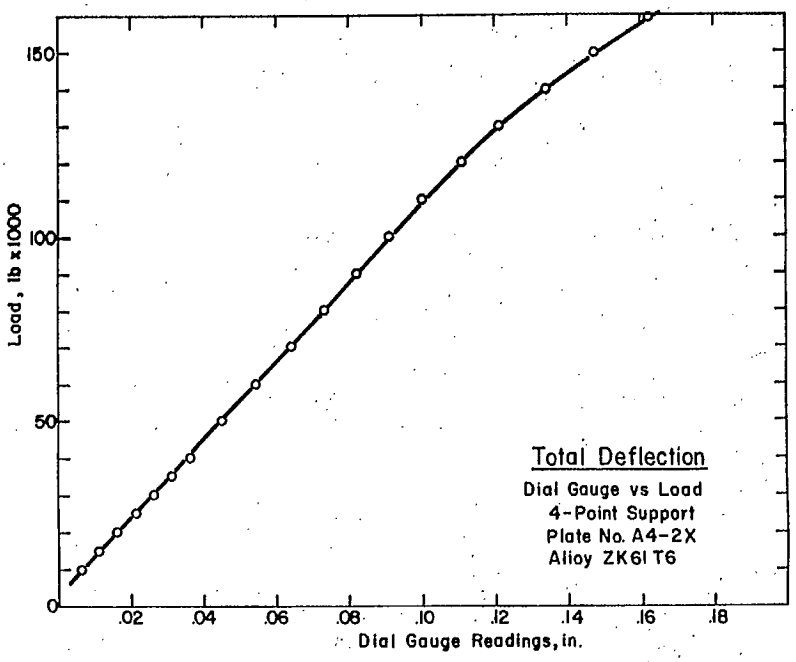

Figure 6. Total strain for 4-point-support test representative of A4 baseplates cast in ZK61-T6 alloy.

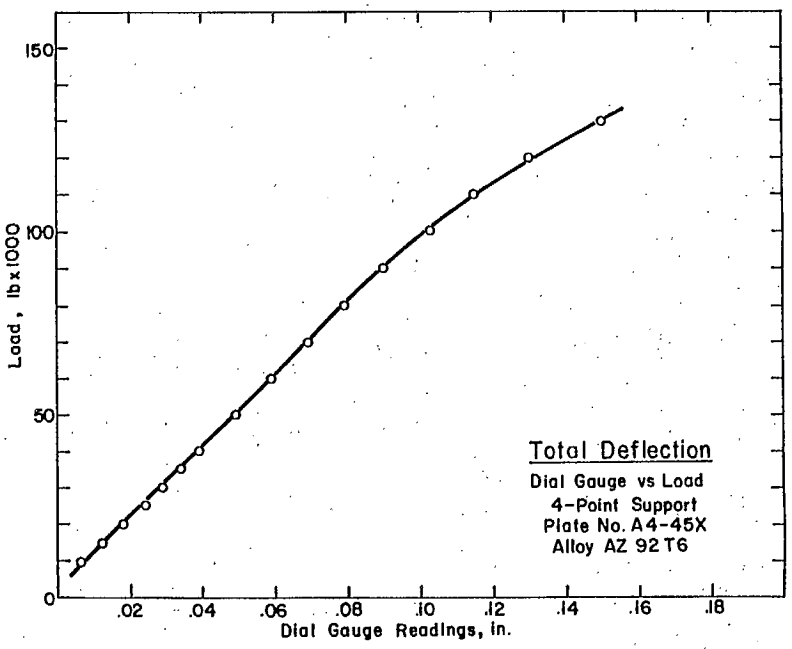

Figure 7. Total strain for 4-point-support test representative of A4 baseplates cast in AZ92-T6 alloy.

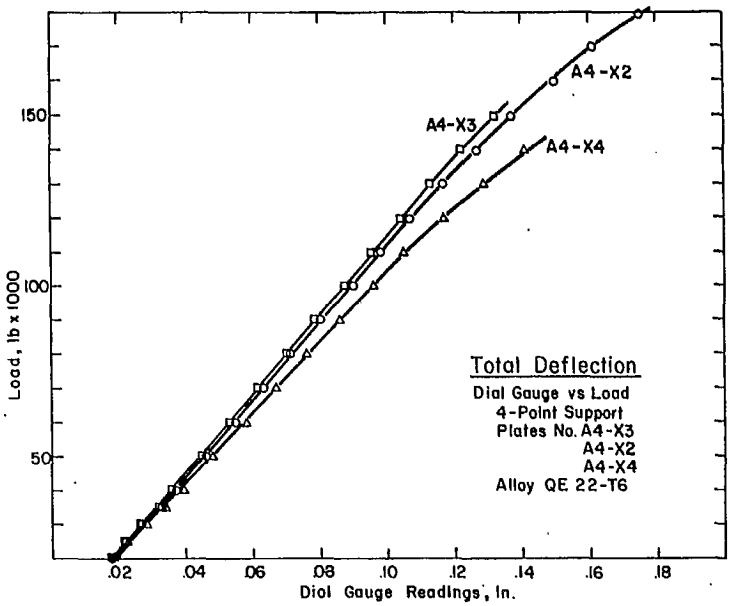

Figure 8. Total strain for 4-point-support test representative of A4 baseplates cast in QE22-T6 alloy.

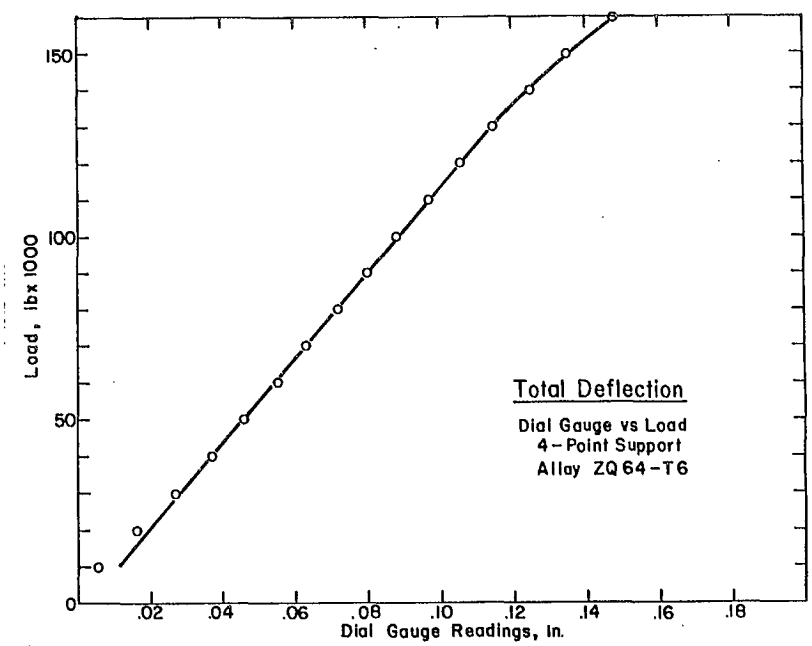

Figure 9. Total strain for 4-point-support test of A4 baseplate cast in ZQ64-T6 alloy.