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PROPERTIES OF SAND-CAST MAGNESIUM ALLOYS

Part V: Mg-Zn-Ag-Zr Alloys

B. LAGOWSKI & J. W. MEIER

PHYSICAL METALLURGY DIVISION

OCTOBER 1964

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PROPERTIES OF SAND-CAST MAGNESIUM ALLOYS

Part V: Mg-Zn-Ag-Zr Alloys

by

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

SUMMARY

start

An earlier investigation of Mg-Ag-Zn-Zr casting alloys showed a promising group of alloys in this system. Additional work on the development of proper foundry and heat treating techniques resulted in the introduction of several high-strength, high-ductility Mg-Zn-Ag-Zr casting alloys which offer attractive possibilities for use in structural applications where economic considerations are not critical.

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* Senior Scientific Officer and ** Principal Metallurgist (Non-Ferrous Metals), Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa, Canada.

Part of the results reported here were used in a paper presented at the 68th Castings Congress, American Foundrymen's Society, Atlantic City, N. J., April 27, 1964, and published in Trans. AFS 72, 310-320 (1964).

Direction des mines

Rapport de recherches R 140

PROPRIÉTÉS DES ALLIAGES DE MAGNÉSIUM COULÉS EN SABLE

5e partie: Alliages de Mg-Zn-Ag-Zr

par

B. Lagowski* et J. W. Meier**

RÉSUMÉ

Des recherches précédentes sur les alliages au Mg-Zn-Ag-Zr ont indiqué l'existence d'un groupe d'alliages intéressant dans ce système. Des travaux additionnels sur la mise au point de techniques efficaces de fonderie et de traitement thermique ont permis d'élaborer plusieurs alliages au Mg-Zn-Ag-Zr très résistants et très ductiles et offrant d'intéressantes possibilités d'emploi en construction, là où les considérations économiques n'entrent pas en ligne de compte.

*Agent scientifique senior et **métallurgiste principal (métaux non ferreux), Division de la métallurgie physique, Direction des mines, ministère des Mines et des Relevés techniques, Ottawa, Canada.

Une partie des résultats consignés ici ont été utilisés dans un mémoire présenté au 68e Congrès de Fonderie, American Foundrymen's Society, Atlantic City (N.J.), le 27 avril 1964, et publié dans les Trans. AFS 72, pp. 310-320 (1964).

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INTRODUCTION

An investigation of magnesium-silver and magnesium-silver-zirconium casting alloys, reported earlier(1), revealed that age-hardenable alloys could be obtained by the addition of zinc. Preliminary work on the zinc-containing alloys disclosed a range of casting alloys of remarkably high properties. An additional investigation was, therefore, carried out to develop proper heat treating conditions to improve the response of solution heat treated material to age-hardening and to explore various foundry characteristics of the alloys finally selected.

FIRST ALLOY SERIES

After closer study of the effect of alloy content on the mechanical properties, reported in the earlier investigation(1), it was decided to start the study with 14 alloy compositions in the magnesium-zinc-silver-zirconium system, as listed in Table 1. The selection of these alloys was based on the following criteria:

(a) The most promising zinc range appeared to be 4-7% Zn (alloys with higher zinc contents have much lower solidus temperatures and show decreasing ductility; alloys with lower zinc contents have lower tensile and yield strengths).

(b) The most promising silver range was indicated to be 2-5%, but considerations of its costs led to the choice of 1-4%.

(c) The sum of Ag + Zn was to be less than 10%, to avoid too high density, too low ductility, and further decrease of the solidus temperature.

The materials and the experimental procedure used were the same as described in the earlier report(1).

Solution heat treating temperatures were selected, in the absence of any detailed data, as the highest temperature at which test bars of each alloy suspended in the furnace showed no warping; these temperatures are listed in Table 1*. Two solution heat treating times were chosen: 5 hours,

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* Alloy and temper designations throughout the report are used according to Canadian Standards CSA.H.1.1.-1958 and CSA.H.1.2.-1958.

and 16 hours. Cooling from the solution temperature was by air blast from an electric fan designed to give uniform flow of air between the separately suspended test bars. Ageing for 48 hours at 130 °C (265 °F) or 150 °C (300 °F) was used. Table 2 lists the various temper designations and heat treating

Three melts of each composition were prepared and cast-to-shape test bars were tested in the "as-cast" and various heat treated conditions. Table 3 lists the test results in the "as-cast" condition for each individual melt, and Table 4 the average results for each composition in the four heat treated tempers.

SECOND ALLOY SERIES

After the results on the first 14 alloys were available and plotted in ternary diagrams showing the effect of zinc and silver contents on tensile properties, it became obvious that further alloy compositions had to be investigated for a better evaluation of the alloy group. The second series consisted of 16 additional alloys covering the higher zinc and silver levels as listed in Table 5.

Since all four tempers used for the first series of alloys (see Table 2) showed the same general trend in the tensile test values obtained, only heat treatment T6A was used for the second and third series of alloys. Test results are presented in Table 6.

THIRD ALLOY SERIES

The selection of zinc contents for the first alloy series was limited to 7% Zn, but the properties obtained in the second series on alloys containing 9% Zn showed the necessity of exploring the higher zinc range somewhat further. Five additional alloys (ZQ92, ZQ101, ZQ102, ZQ111 and ZQ112) were, therefore, added to the program as a third alloy series (see bottom of Table 5). The tensile properties of these alloys are listed at the bottom of Table 6. to p3

DISCUSSION OF RESULTS

The results of all 35 alloy compositions in the T6A condition are presented in the ternary diagrams in Figure 1. The graph for ultimate strength shows increasing values with a maximum average tensile strength of 49.5 kpsi for the higher zinc and 50 kpsi for the higher silver composition; examples of these are alloys ZQ71 and ZQ64, with very liberal chemical composition tolerances. The yield strength also increases with rising zinc content and reaches a maximum of 35.5 kpsi for the same alloys. Elongation, as is usual, decreases with the increase in the alloying content, but is still about 8% in the composition ranges of maximum UTS and YS values.

The results show that the investigation on some of the Mg-Zn-Ag-Zr casting alloys was very fruitful and that compositions were found having tensile properties much higher than those obtainable on any currently available commercial magnesium casting alloys.

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Although the detailed metallographic study of the alloys investigated is not yet completed, the microstructures of three selected alloys are presented in Figures 2 to 4. They show that alloy ZQ43 does not have any second phase in either the F or the T6A condition, while alloys ZQ64 and ZQ71 both show the second phase in the as-cast condition, which dissolves nearly completely during solution heat treatment.

Further work on these alloys, especially on their foundry characteristics and the determination of data other than tensile properties, has been started and will be reported in due course. Early results[2] on some test castings (1-inch and 2-inch thick plates) and prototype castings[3] confirm the high level of properties of experimental alloy ZQ64-T6 (50 kpsi UTS, 33 kpsi 0.2% YS, and 8-10% elongation).

Additional work on thin-walled castings[4] also showed very good foundry characteristics (mould filling capacity, less susceptibility to microporosity) with retention of the high tensile properties of alloy ZQ91-T6.

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CONCLUSIONS

1. Some alloys of the Mg-Zn-Ag-Zr system (e.g. ZQ64-T6, ZQ71-T6), on suitable heat treatment, give unusually attractive tensile properties, approaching 50 kpsi UTS and 35 kpsi 0.2% YS and having 8-10% elongation. The combination of these properties is much superior to that obtainable on any of the present commercial casting alloys.

2. Some of the lower alloy-containing compositions in the Mg-Zn-Ag-Zr series, e.g., ZQ42-T6 or ZQ52-T6, show very high ductility while retaining considerable tensile strength values. It appears that a high-strength magnesium casting alloy with high ductility offers attractive possibilities for some structural applications where economic considerations are not critical.

ACKNOWLEDGEMENT

The assistance of Mr. R. I. Hamilton in the heat treating operations and metallographic examinations, as well as of Mr. A. E. LaRochelle, Mineral Sciences Division, in the numerous determinations of chemical analysis, is gratefully acknowledged.

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TABLE 1

Nominal Compositions and Solution Heat Treating Temperatures - Alloy Series I

Experimental Alloy Designation	Nominal Composition, %			Solution H. T. Temperature	
	Zn	Ag	Zr (sol)	°C	°F
ZQ42	4	2	0.7	500	930
ZQ43	4	3	0.7	500	930
ZQ44	4	4	0.7	480	895
ZQ51	5	1	0.7	500	930
ZQ52	5	2	0.7	485	905
ZQ53	5	3	0.7	460	860
ZQ54	5	4	0.7	460	860
ZQ61	6	1	0.7	480	895
ZQ62	6	2	0.7	460	860
ZQ63	6	3	0.7	460	860
ZQ64	6	4	0.7	455	850
ZQ71	7	1	0.7	460	860
ZQ72	7	2	0.7	460	860
ZQ73	7	3	0.7	460	860

TABLE 2

Experimental Heat Treating Cycles

Experimental Temper Designation	Solution H. T.		Ageing		
	Temperature	Time, Hours	Temperature °C	Temperature °F	Time, Hours
T6A	See Table 1	5	130	265	48
T6B		5	150	300	48
T6C		16	130	265	48
T6D		16	150	300	48

TABLE 3

Mechanical Properties in the "As-Cast" Condition - Alloy Series I

Alloy	Melt	Chemical Composition, %			As-Cast Properties		
		Zn	Ag	Zr (sol)	UTS, kpsi	0.2% YS, kpsi	El., %
ZQ42	QU	3.97	2.14	0.73	39.7	21.3	16.5
	QV	4.02	2.14	0.70	40.4	21.5	15.0
	QW	4.02	2.17	0.74	39.3	20.9	15.0
ZQ43	QR	3.75	3.14	0.70	40.6	21.5	12.5
	QS	3.99	3.23	0.72	40.0	21.7	12.5
	QT	3.89	3.24	0.71	38.8	21.5	9.0*
ZQ44	QO	4.00	4.32	0.71	34.3	20.7	6.0*
	QP	3.94	4.20	0.69	40.3	23.0	10.5
	QQ	3.95	4.32	0.71	39.3	21.4	9.5
ZQ51	QI	5.08	1.13	0.77	39.3	22.5	9.5
	QJ	5.07	1.11	0.82	39.0	21.3	11.0
	QK	4.88	1.09	0.78	39.4	22.4	10.5
ZQ52	PF	4.95	2.13	0.83	38.3	21.5	8.0
	PG	5.04	2.10	0.83	42.0	22.8	12.0
	PH	4.88	2.13	0.86	38.8	22.2	9.0
ZQ53	PC	4.91	3.08	0.72	42.5	24.3	12.5
	PD	4.74	3.11	0.75	40.4	23.8	11.5
	PE	5.07	3.11	0.76	36.5	22.6	7.0*
ZQ54	OZ	5.40	4.18	0.65	39.3	23.4	8.5
	PA	4.62	4.02	0.76	36.9	21.3	8.5*
	PB	4.70	4.02	0.71	40.9	22.9	10.5
ZQ61	QL	6.22	1.13	0.80	40.0	22.9	10.5
	QM	5.98	1.09	0.82	38.8	24.1	8.5
	QN	6.17	1.11	0.82	40.9	23.3	10.5
ZQ62	PO	6.46	2.35	0.81	37.0	20.6	8.0
	PP	6.50	2.34	0.80	35.8	21.4	7.0
	PQ	6.34	2.30	0.79	36.8	21.2	7.5
ZQ63	PU	6.26	3.19	0.80	35.8	22.2	6.0
	PV	6.23	3.14	0.80	34.0	21.5	6.0
	PW	6.19	3.11	0.79	34.0	20.1	7.0
ZQ64	PR	6.14	4.23	0.79	34.2	21.7	6.0
	PS	6.10	4.22	0.78	35.9	22.5	7.0
	PT	6.14	4.20	0.77	31.4	20.7	5.0*
ZQ71	QF	7.27	1.16	0.81	40.7	23.4	10.5
	QG	6.88	1.09	0.81	40.9	26.3	10.5
	QH	7.00	1.09	0.80	40.4	23.4	10.0
ZQ72	QC	6.93	2.23	0.78	38.3	21.9	10.0
	QD	6.81	2.15	0.74	35.9	22.7	7.0*
	QE	6.95	2.23	0.78	38.2	22.6	7.5
ZQ73	PZ	6.88	2.96	0.78	33.5	20.5	6.5
	QA	6.69	2.89	0.70	34.7	21.2	6.5
	QB	6.74	2.89	0.72	33.2	20.5	6.5

* Flaw in fracture.

TABLE 4

Effect of Heat Treatment Conditions on Mechanical Properties - Alloy Series I
(Average results of six test bars)

Temper	T6A			T6B			T6C			T6D		
Alloy	UTS, kpsi	YS, kpsi	El.,% in 2 in.	UTS, kpsi	YS, kpsi	El.,% in 2 in.	UTS, kpsi	YS, kpsi	El.,% in 2 in.	UTS, kpsi	YS, kpsi	El.,% in 2 in.
ZQ42	44.1	26.3	17.1	44.6	27.4	14.4	44.2	27.1	16.0	44.4	28.2	15.0
43	45.6	27.7	14.7	46.3	29.5	15.3	45.8	29.0	14.9	46.3	30.1	13.5
44	46.4	26.7	13.2	49.3	30.3	10.1	46.1	27.5	17.1	48.4	30.6	9.0
ZQ51	46.2	30.6	12.8	46.4	31.5	11.4	46.5	31.8	12.9	46.3	31.6	13.6
52	45.5	30.4	13.1	45.3	30.4	13.1	46.0	30.8	15.9	46.4	32.2	11.9
53	47.6	32.3	13.2	48.7	32.7	11.1	47.9	32.8	10.8	48.5	33.5	10.0
54	47.6	32.4	12.0	49.4	32.5	8.5	48.9	32.0	13.0	50.2	32.9	7.3
ZQ61	48.2	34.4	10.1	48.1	33.5	10.5	48.4	34.7	9.5	48.4	34.7	8.9
62	47.6	33.1	9.2	47.4	32.2	9.0	48.3	33.2	10.7	47.2	31.9	9.4
63	48.3	34.1	9.5	49.7	31.8	8.5	48.6	34.1	9.6	49.4	32.4	7.7
64	50.1	34.1	8.6	50.0	33.3	5.5	49.6	33.7	8.5	50.7	33.0	5.7
ZQ71	49.7	35.6	8.0	49.6	34.7	8.2	49.5	36.2	7.5	49.6	34.8	8.4
72	49.6	35.1	8.3	49.1	34.5	7.1	48.2	35.1	8.3	47.5	32.8	7.5
73	49.1	34.4	7.8	48.8	33.7	7.2	46.4	33.8	5.7	47.9	33.0	6.1

TABLE 5

Nominal Compositions and Solution Heat Treating Temperatures - Alloy Series II and III

Experiment Alloy Designation	Nominal Composition, %			Solution H. T. Temperature	
	Zn	Ag	Zr (sol)	°C	°FV
ZQ31	3	1	0.7	500	930
ZQ32	3	2	0.7	500	930
ZQ33	3	3	0.7	500	930
ZQ41	4	1	0.7	500	930
ZQ45	4	5	0.7	500	930
ZQ46	4	6	0.7	455	850
ZQ55	5	5	0.7	475	880
ZQ56	5	6	0.7	455	850
ZQ65	6	5	0.7	450	840
ZQ66	6	6	0.7	435	815
ZQ74	7	4	0.7	450	840
ZQ75	7	5	0.7	420	790
ZQ81	8	1	0.7	450	840
ZQ82	8	2	0.7	400	750
ZQ83	8	3	0.7	400	750
ZQ91	9	1	0.7	400	750
ZQ92	9	2	0.7	370	700
ZQ101	10	1	0.7	370	700
ZQ102	10	2	0.7	370	700
ZQ111	11	1	0.7	370	700
ZQ112	11	2	0.7	370	700

TABLE 6

Chemical Compositions and Tensile Properties of Heat Treated Mg-Zn-Ag-Zr Alloys - Alloy Series II and III
(Average results from three test bars)

Alloy	Chemical Composition, %			T6A Condition		
	Zn	Ag	Zr (sol)	UTS, kpsi	0.2 YS, kpsi	El.,% in 2 in.
ZQ31	3.00	1.10	0.71	35.7	16.0	18.5
31	3.01	1.10	0.71	35.1	14.5	19.5
32	3.05	2.02	0.71	37.8	17.8	20.5
32	2.89	2.03	0.71	37.3	17.8	20.5
33	2.93	2.92	0.70	38.9	18.7	20.0
33	2.97	3.03	0.69	39.3	18.9	20.0
ZQ41	4.02	1.10	0.74	40.0	21.1	15.0
41	3.99	1.04	0.74	39.4	20.5	14.5
45	4.12	4.98	0.72	47.0	29.2	12.5
45	3.78	4.95	0.69	47.0	29.4	14.0
46	4.26	6.23	0.70	48.0	29.6	8.5
ZQ55	4.92	4.98	0.71	50.3	33.6	12.0
55	4.80	5.00	0.74	50.1	33.2	11.0
56	5.23	6.39	0.69	50.3	32.6	8.5
ZQ65	5.85	4.92	0.73	49.1	34.7	7.0
65	5.86	4.94	0.72	49.6	34.3	7.5
66	5.97	6.11	0.72	47.4	33.7	5.0
ZQ74	6.74	4.23	0.70	47.5	36.1	6.5
74	6.58	4.17	0.76	47.5	35.3	5.5
75	7.15	5.08	0.70	47.8	35.2	4.5
ZQ81	4.97	1.14	0.68	48.7	35.0	8.5
81	7.82	1.07	0.68	48.2	34.7	9.5
82	7.74	2.10	0.72	49.7	33.2	9.0
83	7.95	3.12	0.72	48.6	35.3	6.5
ZQ91	8.80	1.03	0.68	49.3	33.8	7.5
92	8.77	1.99	0.70	41.9	33.4	3.5
ZQ101	9.82	1.03	0.74	46.7	35.0	3.0
102	9.88	2.03	0.74	40.5	33.5	2.5
ZQ111	10.57	1.06	0.85	40.2	31.8	3.5
112	10.88	2.05	0.80	39.2	34.7	2.5

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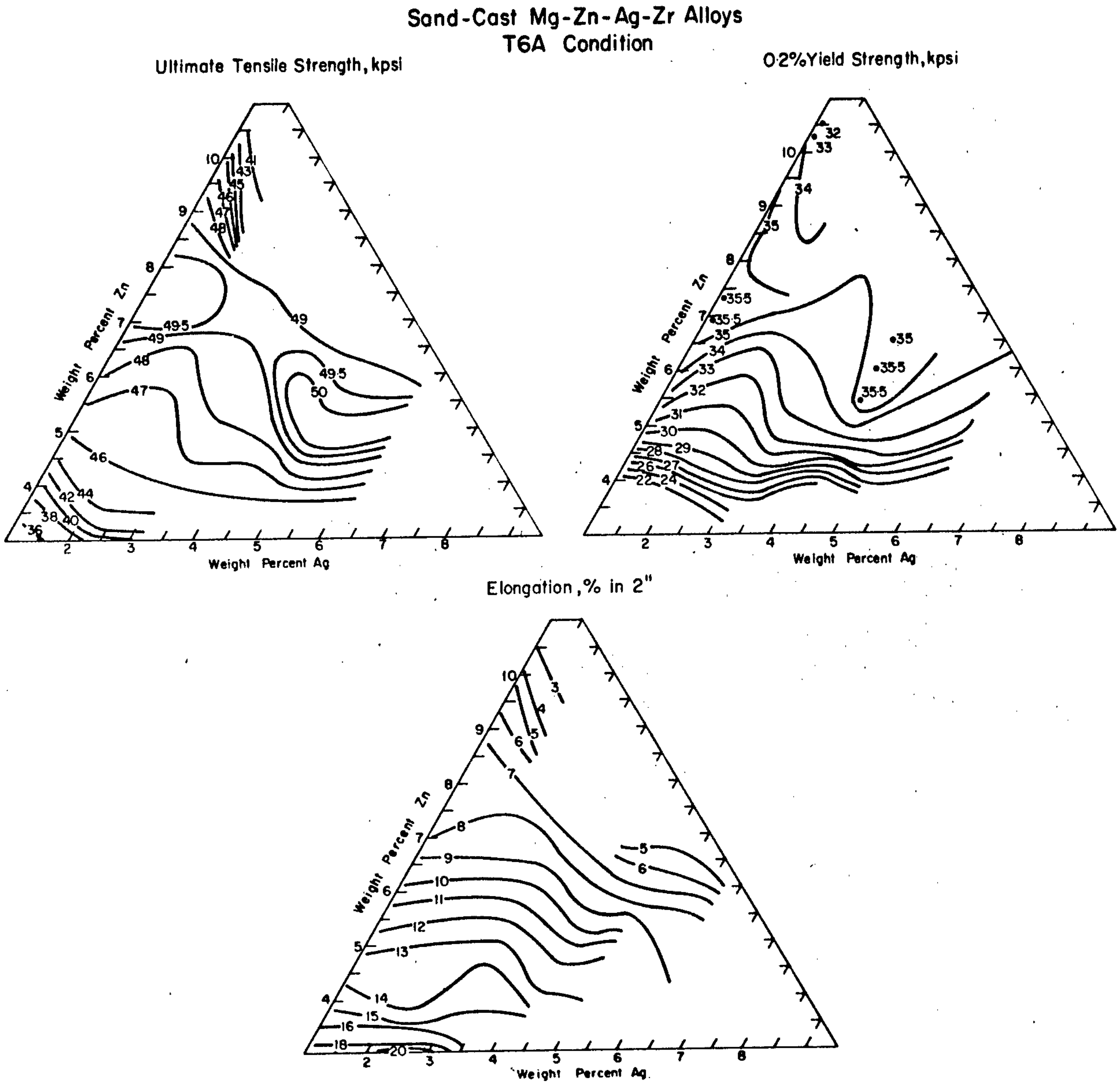
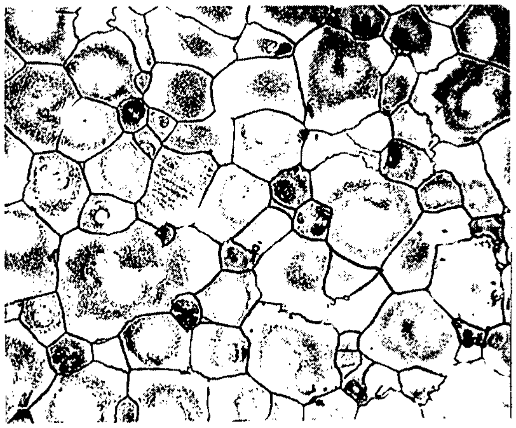
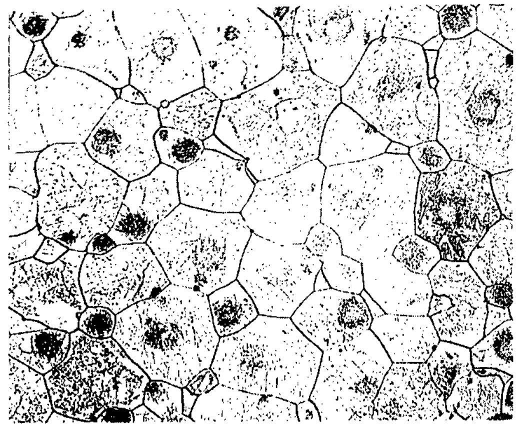
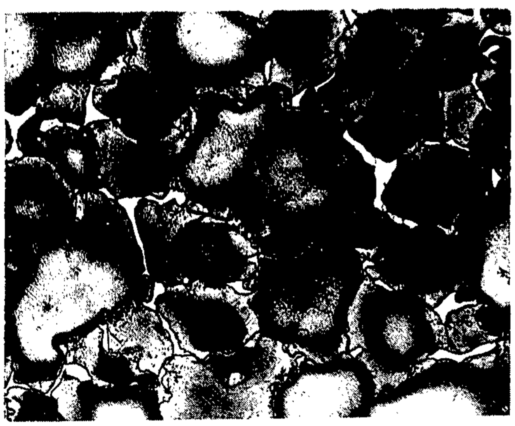


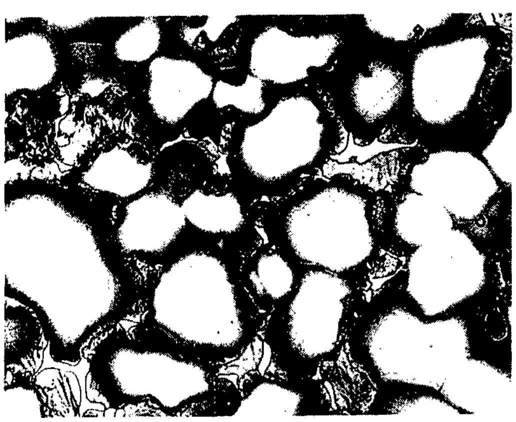
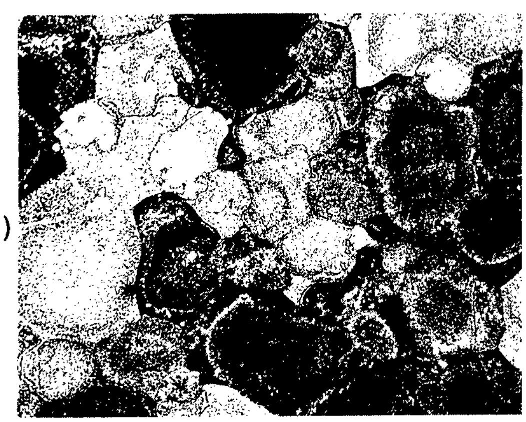
Figure 1. Average tensile property values for fully heat treated ZQ-type alloys, obtained on separately-cast test bars.

a)  b)  Figure 2

ZQ43-F ZQ43-T6A

a)  b)  Figure 3

ZQ64-F ZQ64-T6A

a)  b)  Figure 4

ZQ71-F ZQ71-T6A

Figures 2-4. Microstructures of selected alloys. Etched in 0.5% HF solution. X250.