The properties of some substitute bearing alloys

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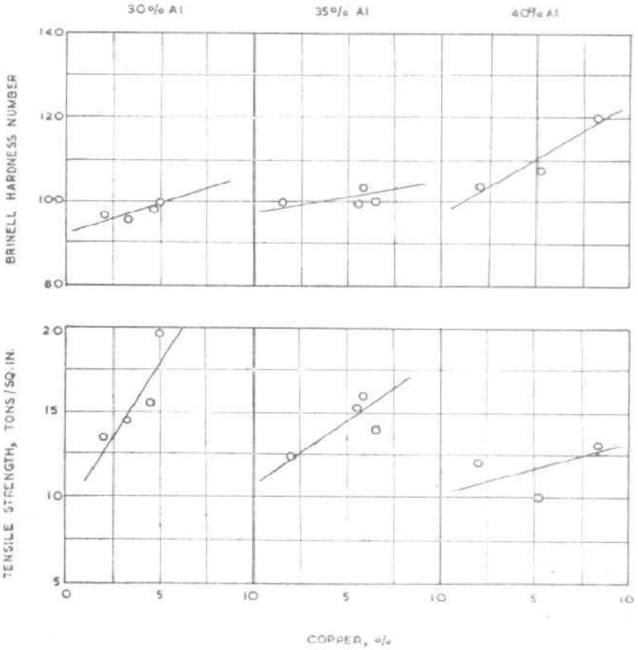
A BEARING is a means for supporting a load between relatively moving surfaces with as little friction as possible.[1] The plain bearings, used in the automobile, aircraft and other engineering industries, consist of two surfaces, the shaft and the bearing, generally separated by a film of lubricant. The so-called bearing alloys utilised for the purpose have to satisfy some primary requirements such as suitable chemical make up giving rise to a hard constituent embedded in a soft matrix, and a certain range of physical (melting point, density, thermal conductivity, etc.) and mechanical (hardness, modulus of elasticity, tensile strength, impact resistance and age-hardening characteristics) properties. Besides these, certain service properties such as wear, seizure-resistance, conformability, embeddability corrosion-resistance, etc. are also to be complied with.

The usual bearing materials of the babbit and the bearing bronze type contain tin as a primary ingredient. As tin is a costly and imported material, references[2,3] can be found in the technical literature of substitute bearing alloys which have little or no tin. Since copper and aluminium are indigeneously available and zinc, though imported, is relatively cheaper in price, they were chosen for the substitute alloys. An attempt was made in the present investigation to further develop the copper-zinc-aluminium alloy, commercially known as the Alzen[3], and to replace partly or fully tin by aluminium and/or zinc in the conventional bearing bronzes.

Preparation of the alloys

The experimental bearing alloys were prepared in the Nernst-Tamman carbon-resistance furnace by employing a suitable melting and alloying technique depending on the melting points of the constituents alloyed. The low temperature melting alloys were covered with a layer of flux skimmings, which was found to be highly suitable by trial and is readily available from the galvanising plant, while the higher temperature melting alloys were melted under a cover of graphite powder to prevent oxidation losses. The melting efficiencies taken for the various elements used in the preparation of the alloys are given in the next column.



I *Effect of variations in the copper content of the Alzen type Cu-Zn-Al alloys on the tensile and hardness at various levels of Al content*

Element	Cu	Zn	Al	Sn	Ni	Sb	Mn	Cr	Pb	P
Efficiency,%	100	90	90	85	100	100	85	100	100	100

The molten alloys after thorough mixing with a graphite rod were cast into cylindrical bars in graphite moulds. The bars having requisite dimensions were turned into Izod and tensile test-pieces. Samples for hardness measurements, heat treatment for age-hardening studies, drillings for chemical analysis and specimens for micropolishing were also cut from the bars cast.

For determining the age-hardening behaviour, the samples of zinc-base and aluminium-base alloys were solution treated at 400°C for 30 min. and water-quenched. Similarly, the copper-base alloys were treated at 800°C. The progressive age-hardening characteristics were stu-

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died at 100, 150, and 250°C for 6, 12 and 18 hr. respectively.

Results and discussions

For the sake of clarity and brevity, the results of the investigation have been divided and discussed in the following six groups :

1. Copper-zinc-aluminum tin-free alloys.
2. Aluminium and aluminium-iron additions to 70 : 30 α brass.
3. Zinc-base alloys.
4. Aluminium-base alloys.
5. Copper-base alloys.
6. Part and full replacement of tin in standard bearing bronzes by aluminium and/or zinc.

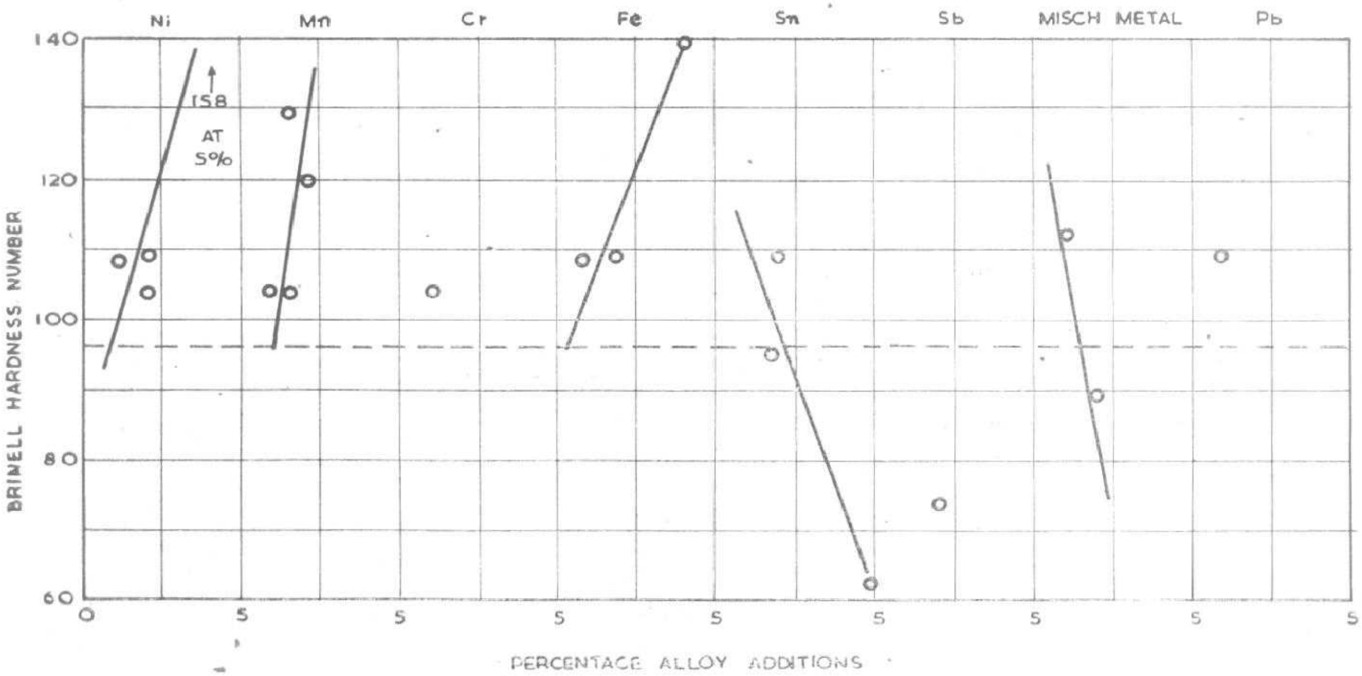
(i) Copper-zinc-aluminium tin-free alloys

The basis for the development of copper-zinc-aluminium tin-free bearing alloys was the patented Alzen 305[3], which was claimed to give desirable bearing properties. It was reported to contain 30-40% aluminium, 5-10% copper and the balance zinc. Some of the physical and mechanical properties of the alloy mentioned were : specific gravity 4·80, yield strength 15 tons/sq. in., tensile strength of 20 tons/sq. in. minimum, elongation 2% minimum and Brinell hardness 100-150. Similar alloys having aluminium from 30 to 45%, copper from 1·5 to 10% and the remainder zinc were made and the relevant physical and mechanical tests carried out are shown in Table I. It can be seen from the table that for the eleven alloys investigated the densities and the hardness are all comparable to the Alzen 305 alloys mentioned earlier while the tensile strength is of a slightly lower order. The effect of variation in copper content from 2 to 10% at various levels (40, 35 and 30%) of aluminium on the hardness and tensile strength of the Cu-Zn-Al alloys is shown in Fig. 1. This graph shows that the hardness has a tendency to increase with increase in copper content and also the level of hardness is somewhat higher at higher aluminium percentages. The tensile strength, however, only shows the former trend but the lower level of tensile values for the 40% aluminium alloys indicates that these sets of alloys are amenable to age-hardening. The percentage elongation obtained for all these alloys is of a lower order. All these alloys have been found to have a duplex micro-structure. But they show poor Izod impact strength. This would restrict their use to bearing applications where impact loading is not an important service factor.

In order to obtain a certain level of toughness, other alloying elements such as nickel, manganese, chromium, iron, tin, antimony and misch-metal were added to Cu-Zn-Al alloys. The resulting physical and mechanical properties are tabulated in Table II. In this connection Fig. 2 reveals that increasing additions of nickel, manganese, chromium and iron to the Alzen, (5% Cu, 35% Al, balance Zn) alloys increase the hardness, whereas additions of tin, misch-metal and anti-

TABLE I Physical, chemical and mechanical properties of Cu-Zn-Al Alzen type of bearing alloys

Sl. No.	Chemical composition % Cu	Zn	Al	Density gm/c.c.	B. H. N.	Tensile tons/sq. in.	Elong. %	Izod ft./lb
E_1	2·00	68·00	30·00	4·45	96·0	13·5	1·56	—
E_2	2·00	58·00	40·00	4·39	104·0	12·3	—	—
E_3	2·00	63·00	35·00	4·68	100·0	14·8	—	—
E_4	3·44	64·40	32·00	3·59	96·3	14·3	1·04	—
E_5	4·64	64·32	30·84	4·93	98·0	16·6	1·04	—
E_6	5·52	57·86	35·55	4·66	100·0	15·7	1·04	—
E_7	5·00	64·48	30·64	5·06	100·0	19·7	1·04	—
E_8	5·36	53·80	40·40	3·47	104·0	10·2	1·04	—
E_9	5·68	59·42	34·70	4·47	104·0	16·1	1·04	—
E_{10}	6·40	57·23	34·75	4·98	100·3	14·0	1·04	—
E_{11}	8·40	47·17	43·75	4·47	121·5	13·1	1·04	—



2 *Effect of alloy additions to the Alzen type (5% Cu) bearing alloys on the hardness*

TABLE II Physical, mechanical and chemical properties of the Alzen type alloys having minor additions of other alloying elements

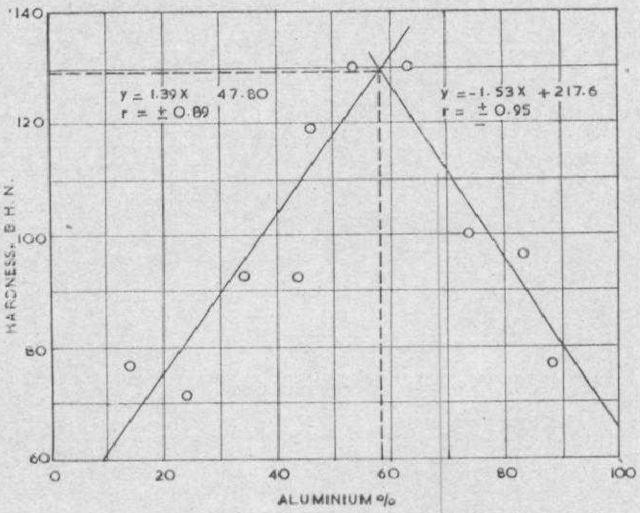
	Chemical composition %								
Sl. No.	Cu	Zn	Al	Other alloying elements	Density gm/cc	B. H. N.	Tensile tons/ sq. in	Izod ft. lb	% Elongation
E_{12}	5·90	56·10	36·30	Sn =1·68	4·42	92·6	—	—	—
E_{13}	5·00	45·00	45·00	Sn =5·00	3·75	63·4	11·80	—	1·56
E_{14}	4·60	64·50	28·00	Ni =1·10 Pb =0·93 Fe =0·80	4·73	109·0	—	—	—
E_{15}	5·00	58·00	35·00	Ni =2·00	4·76	104·0	—	—	—
E_{16}	5·00	53·00	35·00	Ni =5·00	4·38	158·0	—	—	—
E_{17}	5·00	58·00	35·00	Mn =2·00	4·58	120·0	—	—	—
E_{18}	5·00	58·00	35·00	Mn =1·50	4·69	104·0	—	—	—
E_{19}	4·69	56·30	36·50	Mn =1·51	4·48	130·0	—	—	—
E_{20}	5·00	59·00	35·00	Cr =1·00	4·47	104·0	—	—	—
E_{21}	5·00	58·00	35·00	Misch metal =2·00	4·45	89·0	—	—	—
E_{22}	6·00	54·00	36·00	Fe =4·00	4·45	140·0	—	—	—
E_{23}	5·00	58·00	35·00	Sb =2·00	4·41	74·1	—	—	—
E_{24}	5·00	59·50	35·00	Misch metal =1·00	4·56	112·0	—	—	—
E_{25}	5·00	53·00	35·00	Fe =2·00 Ni =2·00 Sn =2·00	4·47	109·0	6·25	—	—

mony lower the hardness. The base hardness (96 B.H.N.) is indicated in the figure with a dotted line. Here also the alloys do not show any Izod impact value and, therefore, they fall into the same category of the Cu-Zn-Al alloys discussed earlier.

Keeping in view the Alzen type Cu-Zn-Al alloy, containing 5% copper, the hardness and other mechanical properties were studied by varying the aluminium content. The results are given in Table III. Even in this case the Izod impact values were quite negligible. However, the hardness (B. H. N.) was seen to bear a tangible relationship with the variations in aluminium content as shown in Fig. 3. The hardness increases linearly with increase in aluminium content up to about 60% after which it decreases linearly. The two regression lines, corresponding to 0–60% Al and 60–100% Al and having co-relation co-efficients of 0·89 and 0·95 respectively, meet to give a maximum hardness value of 129 B.H.N. at 58·5% Al.

TABLE III Physical and mechanical properties and chemical composition of Cu–Zn–Al (5% Cu), alloys

Sl. No.	Chemical composition%			Density gm/cc.	B.H.N.	Izod ft. lb
	Cu	Zn	Al			
E$_{26}$	5·00	6·50	88·50	2·79	76·8	0·5
E$_{27}$	5·00	11·50	83·50	3·05	96·3	0
E$_{28}$	5·00	21·40	73·60	2·83	100·0	0
E$_{29}$	5·00	31·90	63·10	3·43	130·0	0
E$_{30}$	5·00	41·30	53·70	3·75	130·0	0
E$_{31}$	5·00	48·80	46·20	4·00	119·0	0
E$_{32}$	5·00	51·00	44·00	4·06	92·6	0
E$_{33}$	5·00	61·00	34·00	4·50	92·6	0
E$_{34}$	5·00	71·00	24·30	4·82	71·0	0
E$_{35}$	5·00	80·80	14·20	6·78	76·8	0·25



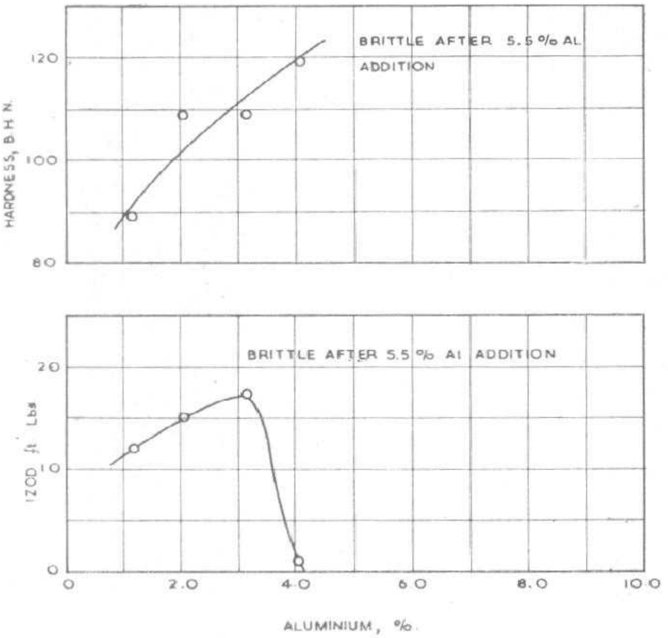
3 *Effect of the aluminium content on the hardness of the Alzen type 5% Cu alloys*

(2) Aluminium and aluminium-iron additions to 70:30 ∝ brass

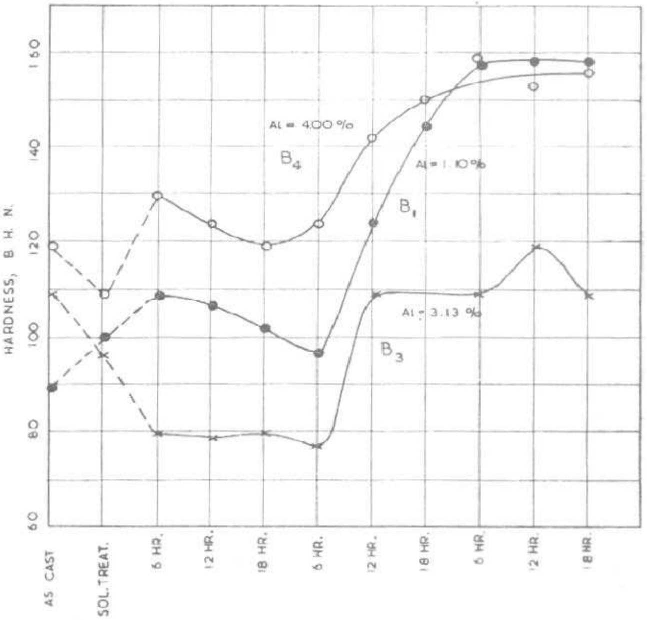
It is well known that the single phase 70 : 30 ∝ brass

TABLE IV Aluminium additions in 70 : 30 ∝ brass

Sl. No.	Chemical composition%			Density gm/cc	B.H.N.	Tensile tons/sq. in.	Elongation %	Izod ft./lb
	Cu	Zn	Al					
B$_1$	68·60	29·94	1·10	8·20	89·0	26·10	7·80	12·0
B$_2$	68·60	29·40	2·00	7·79	109·0	—	—	15·0
B$_3$	65·60	29·55	3·13	8·24	109·0	25·60	20·30	17·4
B$_4$	67·20	28·80	4·00	7·86	119·0	—	—	1·0
B$_5$	65·80	28·70	5·50	7·46	Brittle	—	—	Brittle
B$_6$	64·40	27·66	8·00	7·28	Brittle	—	—	Brittle
B$_7$	63·00	27·00	10·00	7·02	Brittle	—	—	Brittle



4 *Effect of aluminium additions on the hardness and Izod of 70 : 30 ∝ brass*



5 *Age hardening characteristics of B_1, B_3 and B_4 alloys*

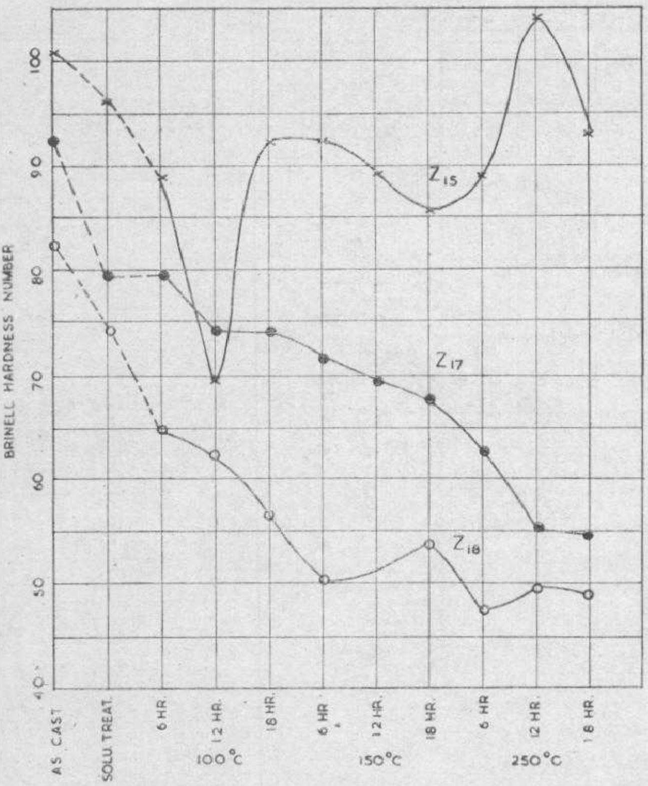
is a tough and ductile material with medium strength. To convert this alloy into one having a duplex microstructure at the same time having a reasonable degree of hardness and impact-resistance, additions of aluminium and aluminium-iron were tried in stages. Progressive additions of aluminium in the alloy had a hardening effect and beyond 5·5% addition, the alloys produced were rendered brittle (Table IV). The Izod impact value was found to increase with increase in aluminium content up to a value of 17·4 ft–lb at 3·13% Al. This suddenly dropped down to 1·0 ft–lb for 3·40% Al in the alloy. The age-hardening behaviour of the alloys B_1, B_3 and B_4, which show some impact resistance, have been plotted in Fig. 5. All these alloys show a definite tendency of age-hardening and also show a duplex microstructure. This indicates that even an addition of 1·10% Al to the single phase 70 : 30 ∝ brass changes it into a duplex alloy having soft and hard constituents.

As the aluminium additions over 5·5% rendered the alloys brittle, it was thought to add aluminium and iron together to the 70 : 30 ∝ brass. The results of adding 3 to 7% aluminium and 1·83%, 3·84% and 4·40% iron are shown in Table V. The Izod impact strength improved with increasing additions and susceptibility to age-hardening was observed in all these alloys.

Thus it can be seen that the addition of aluminium and aluminium-iron to 70 : 30 ∝ brass does produce alloys with primary properties of bearing materials. But taking into consideration that the hardness and toughness are at a reasonable level, the alloys B_1, B_3, B_4 and B_8 can be recommended as bearing materials.

TABLE V Aluminium-iron additions in 70 : 30 ∝ brass

Sl. No.	Chemical composition %				Density gm/cc.	B.H.N.	Tensile tons/sq. in.	Elong. %	Izod ft./lb
	Cu	Zn	Al	Fe					
B_8	61·40	29·51	6·78	1·83	8·16	130·0	—	—	5·84
B_9	58·40	28·31	6·68	3·84	7·60	158·0	—	—	11·25
B_{10}	67·00	26·00	3·00	4·40	8·16	109·0	—	—	11·53



6 *Age-hardening of Z_{15}, Z_{17} and Z_{18} zinc-base alloys*

(3) Zinc-base alloys

Mention has been made in literature on bearing materials of some zinc-base alloys[2] containing mainly copper and aluminium. Keeping this in view, some zinc-base alloys having copper 1 to 10%, aluminium 2·0 to 47·5% and the balance zinc were prepared. Some of the mechanical and physical properties of these alloys are given in Table VI. From the table, it appears that the hardness of these alloys fall within reasonable limits, but most of the alloys do not show any Izod impact resistance except Z14, Z15, Z17 and Z18 alloys. Though these four alloys show a duplex micro-structure, they do not seem to show any age-hardening behaviour as can be seen from Fig. 6. Even minor additions of Sn, Ni, Mn and Fe did not improve their Izod-impact resistance. Apart from this, the Brinell hardness decreases with increasing Zn-content (Fig. 7).

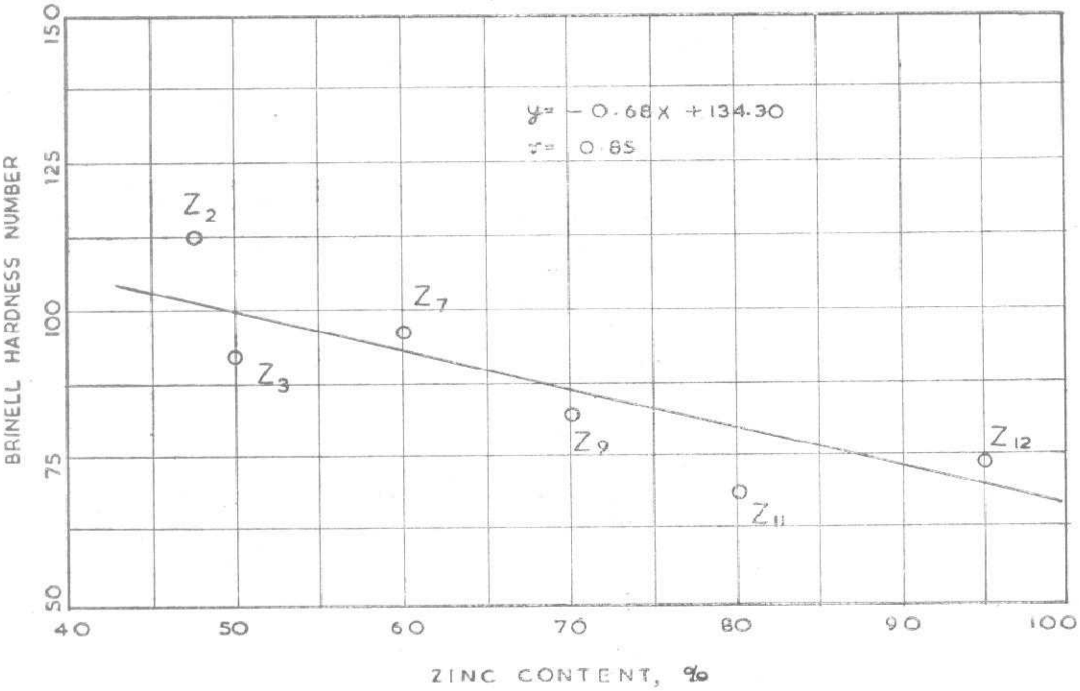
Among the zinc-base alloys discussed, alloys Z_{17} and Z_{18} satisfy the primary requirements of bearing materials. But their application is restricted only to a bearing set up where continuous lubrication and heat-dissipation are possible since they progressively soften with rise in temperature.

(4) Aluminium-base alloys

Aluminium alloys,[4] with mechanical and physical characteristics specially adapted to meet the requirements of modern high-duty bearing service, are of rather recent

TABLE VI Chemical compositions and physical and mechanical properties of zinc-base experimental bearing alloys

Sl. No.	Chemical composition % Cu	Zn	Al	Other elements	Density gm/cc.	B.H.N.	Izod ft. lb
Z_1	5·00	45·00	45·00	Sn = 5·00	3·75	62·5	0
Z_2	5·00	47·50	47·50		4·00	112·0	0
Z_3	5·00	50·00	45·00		4·06	92·6	Brittle
Z_4	5·00	53·00	35·00	Ni = 5·00	4·38	100·0	Brittle
Z_5	5·00	54·00	35·00	Ni = 2·00 Fe = 2·00 Sn = 2·00	4·47	104·0	0
Z_6	6·00	54·00	36·00	Fe = 4·00	4·45	109·0	Brittle
Z_7	5·00	60·00	35·00		4·50	94·1	0
Z_8	23·00	70·00	3·00	Fe = 4·00	7·45	143·0	Brittle
Z_9	5·00	70·00	25·00		4·82	85·0	0
Z_{10}	2·00	80·00	18·00		5·36	100·0	0
Z_{11}	5·00	80·00	15·00		6·78	69·5	0
Z_{12}	10·00	85·00	5·00		6·80	104·0	0
Z_{13}	10·00	88·00	2·00		7·18	96·0	0
Z_{14}	2·00	90·00	5·00	Mn = 1·25 Ni = 1·25	6·57	85·7	0·50
Z_{15}	5·00	90·00	5·00		6·98	101·0	0·25
Z_{16}	1·00	90·00	9·00		6·34	94·5	0
Z_{17}	1·00	92·50	4·00	Mn = 1·25 Ni = 1·25	6·77	92·6	1·50
Z_{18}	1·00	95·00	4·00		6·78	74·1	1·50



7 *Effect of variation in zinc content of the Zn-base alloys on the hardness*

TABLE VII Physical and mechanical properties of Al-base alloys

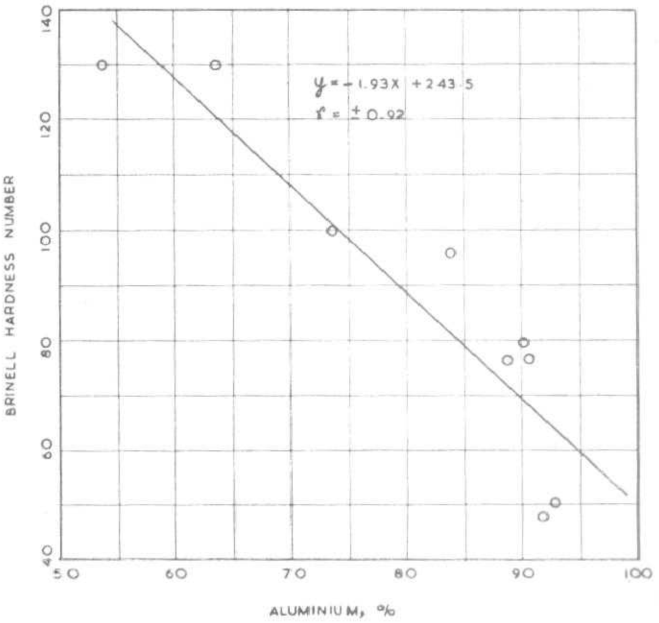
Sl. No.	Chemical composition%				Density gm/cc.	B.H.N.	Tensile tons/ sq. in.	Elong. %	Izod ft. lb
	Cu	Zn	Al	Other elements					
A_1	5·0	41·3	53·7	—	3·75	130	—	—	0
A_2	5·0	31·9	6·31	—	3·43	130	—	—	0
A_3	5·0	21·4	73·6	—	2·83	100	—	—	0
A_4	5·0	11·5	83·5	—	3·05	96·3	—	—	0
A_5	5·6	4·5	88·5	—	2·79	76·8	—	—	0·5
A_6	—	6·9	90·4	Mg = 1·50	2·70	67·8	—	—	0
A_7	2·0	5·0	90·0	Fe = 1·50 Ni = 1·50	3·03	79·6	9·6	1·56	0
A_8	1·77	—	91·6	Mn = 0·45 Sn = 4·22 Ni = 0·63 Mg = 1·46	2·84	47·5	—	—	3·0
A_9	—	—	92·8	Mn = 0·80 Sn = 4·27 Ni = 1·04 Sb = 0·68 Si = 0·47	2·86	50·0	—	—	2·5

TABLE VIII Physical and mechanical properties of copper-base standard and experimental bearing alloys

Sl. No.	Chemical composition%				Density gm/cc.	B.H.N.	Izod ft. lb	Tensile tons/ sq. in.	Elong. %	Micro-hardness V.P.N.	
	Cu	Zn	Al	Orther alloying elements						Soft	Hard
C_1	56·00	33·52	5·54	Mn 2·12 Fe 3·20	7·29	143	—	—	—	202·3	310·0
C_2	56·40	36·46	—	Pb 1·20 Si 0·89	8·46	100	3·00	—	—	118·3	145·4
C_3	57·00	32·26	5·83	Fe 1·20 Mn 3·30	8·07	143	2·70	—	—	197·2	213·1
C_4	58·00	31·15	6·36	Ni 1·57 Mn 2·50 Si 0·37	8·08	143	0·50	27·15	—	197·2	237·4
C_5	58·04	33·74	2·06	Pb 3·30 Fe 0·50 Ni 1·71 Mn 0·07	8·31	130	1·32	—	—	—	—
C_6	58·26	37·30	0·85	Pb 1·66 Fe 0·40 Mn 0·48 Si 1·02	8·29	127	2·25	—	—	174·4	192·3
C_7	58·28	26·73	3·78	Pb 2·54 Sn 0·08 Ni 4·19	8·19	119	3·50	26·80	1·56	115·6	160·4
C_8	62·50	29·00	2·00	Pb 1·50 Fe 3·00 Mn 2·00	8·20	158	1·45	—	—	174·4	237·4
C_9	62·56	26·23	5·32	Fe 2·30 Mn 3·62	7·91	158	1·70	—	—	162·6	244·1
C_{10}	63·00	27·00	10·00	—	7·02	—	Brittle	—	—	—	—
C_{11}	64·40	27·60	8·00	—	7·28	—	Brittle	—	—	—	—
C_{12}	65·00	26·00	5·00	Fe 4·00	7·60	143	11·25	—	—	211·0	233·7
C_{13}	65·60	29·55	3·13	—	8·24	109	17·40	25·60	20·30	85·5	99·8
C_{14}	65·80	28·20	6·00	—	7·46	—	Brittle	—	—	—	—
C_{15}	65·90	23·50	5·14	Fe 4·40	8·20	85·7	18·00	27·60	10·94	80·0	91·5
C_{16}	67·00	26·00	5·00	Fe 2·00	8·16	130	5·84	—	—	94·7	101·7
C_{17}	67·20	28·80	4·00	—	7·86	119	1·00	—	—	—	—
C_{18}	68·29	25·92	0·76	Pb 0·48 Fe 1·02 Mn 3·32	8·03	136	5·00	26·70	6·25	113·4	145·4
C_{19}	68·60	29·40	2·00	—	8·24	119	15·00	25·60	20·30	85·5	99·8
C_{20}	68·60	29·94	1·10	Pb 0·28	8·20	89·0	12·00	26·10	7·80	86·9	101·7
C_{21}	75·00	5·00	15·00	Pb 5·00	8·15	—	Brittle	—	—	—	—
C_{22}	84·40	2·90	10·33	Pb 1·00	7·51	158	0·50	—	—	237·4	284·2
C_{23}	85·00	—	5·00	Sn 5·00 Pb 5·00	8·00	74·1	0·75	—	—	85·5	136·4
C_{24}	87·60	—	10·10	Fe 2·00	7·58	109	13·87	—	—	147·9	209·7

origin. But the alloys commercially reported contain an appreciable amount of tin. As the present investigation was based on obtaining alloys with little or no tin, the aluminium-base alloys tried contained from 0 to 6% copper, 4·5% to 46·0% zinc and the balance aluminium (Table VII). A striking relationship was found between the hardness (B. H. N.) and the aluminium content as indicated in Fig. 8. The regression line, showing a decrease in hardness with increasing percentage of aluminium, had a co-relation co-efficient of 0·92. The tensile strength showed a slight drop with increase of aluminium. Even in this case most of the alloys did not show any Izod impact value except the two standard Rolls Royce alloys A8 and A9, which contained tin and some other minor alloying elements, and the Al-Zn-Cu alloy A5.

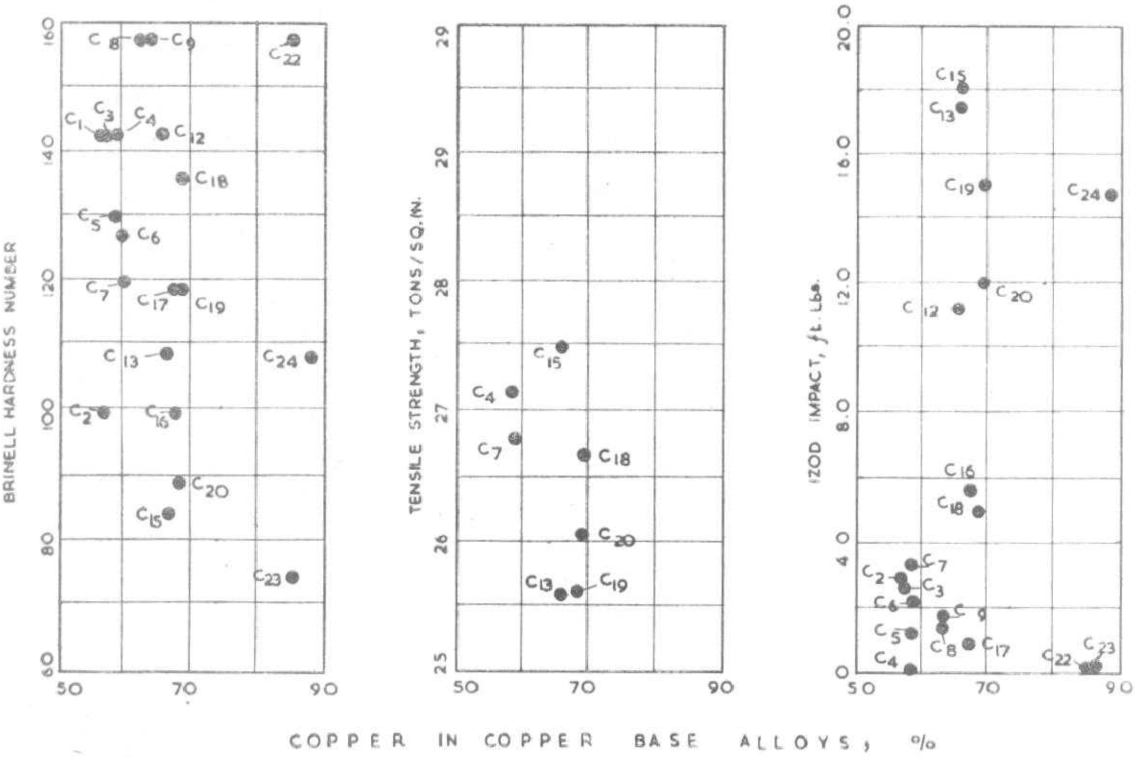
In all these Al-base alloys, the alloy A5, of composition 88·5% Al, 5·6% Cu, 4·5% Zn and having density 2·79 gm/cc. hardness 76·8 B.H.N., Izod-impact 0·5 ft lb and the difference of 52·5 V.P.N. in hard and soft micro-constituents, is the only alloy which could possibly be used as a bearing material.



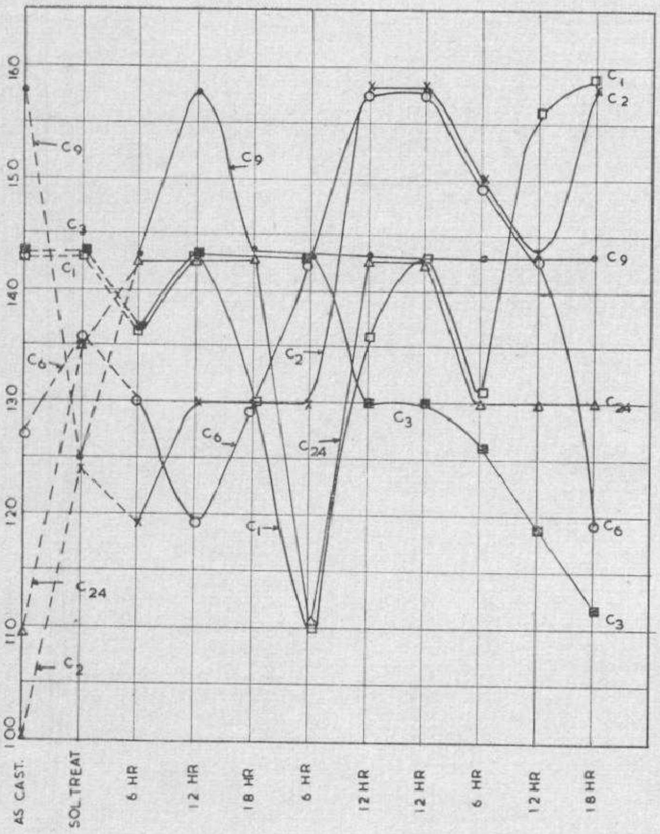
8 *Effect of variation in aluminium content of the aluminium-base alloys on the hardness*

(5) Copper-base alloys

Initially, some standard Cu-base bearing alloys, C1, C2, C3, C6, C9 and C24, found in the alloy digest were made. The chemical compositions and the test-results are given in Table VIII. It can be seen that the hardness (B.H.N.) of these alloys were of a higher order, viz., 100–158 B.H.N., and the Izod impact values ranged from 1·70 to 13·85 ft/lb. Some variations in the minor elements were tried to bring down the hardness and to improve the impact resistance in most of these alloys. Only in few cases where tin and lead were added and also aluminium percentage was decreased, the hardness (Fig. 9) came down and the Izod impact improved slightly. The effect of variation in copper content in these alloys was studied and it was found (Fig. 9) that



9 *Effect of variation in copper of copper-base alloys on the hardness, tensile and Izod-impact values*



10 *Age hardening characteristics of copper base standard alloys*

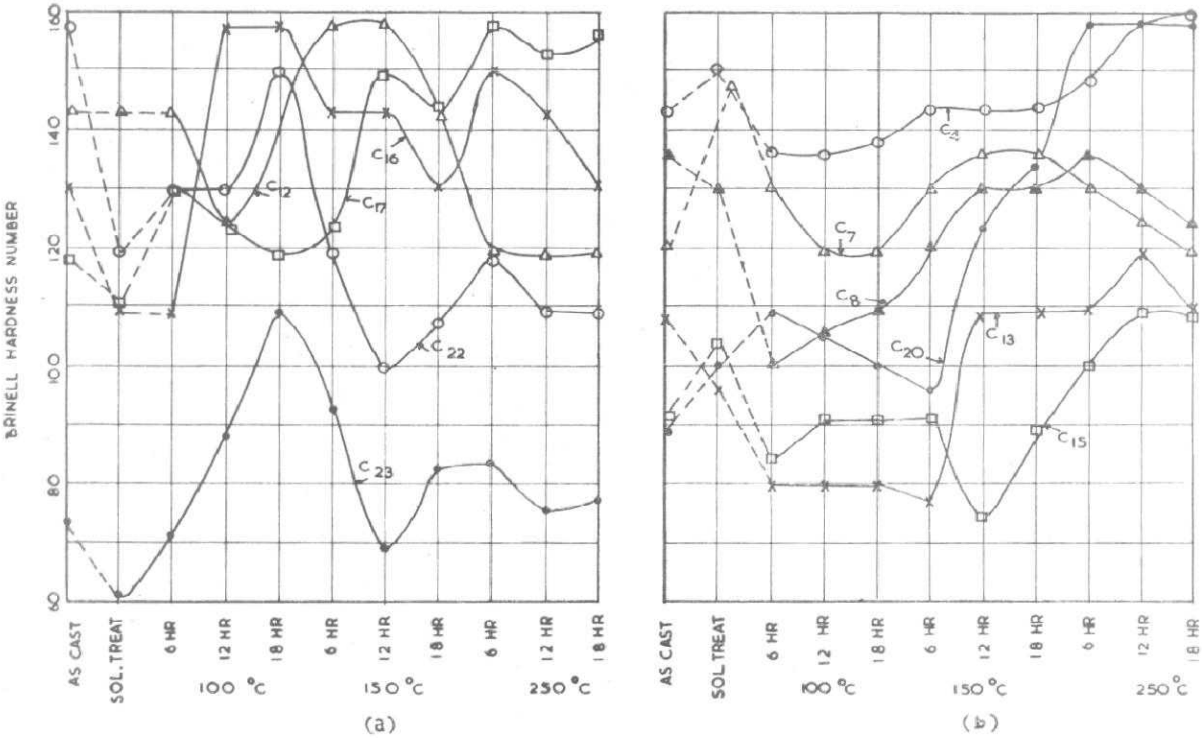
the tensile strength as well as the hardness depended only on the other alloying elements such as nickel, iron and manganese. The Izod impact values varied from 0 to 18 ft-lb and the elongation of 20% maximum was obtained. Most of the alloys showed a duplex micro-structure having a difference of 7 to 63 V.P.N. in the hardness of soft and hard micro-constituents (Table VIII). In Fig. 10, the age-hardening characteristics of the copper-base standard alloys have been plotted to serve as a basis for comparison with the experimental alloys. The age-hardening curves for alloys C12, C16, C17, C22 and C23 are drawn in Fig. 11a. Although all these alloys show age-hardening tendencies, a striking behaviour was observed in the case of the alloy C17, which reaches a maximum hardness of 158 B.H.N. on being treated at 250°C for 6 hours. The as-cast hardness of this alloy was 119 B.H.N. which came down to 109 B.H.N. after solution treatment. Fig. 11b represents the age-hardening characteristics of alloys C4, C7, C13, C15, C18 and C20. It is clear from the figure that all these alloys show a marked age-hardening characteristics. The maximum hardness is achieved after treatment at 250°C for over six hours.

From the above discussion it can be concluded that the copper-base alloys C4, C7, C13, C15, C17, C18 and C20 satisfy all the primary requisites of bearing materials. The applicability of a bearing material depends to a great extent on the hardness-level required of a bearing set-up. These alloys can be suitably used in the hardness range of 80 to 150 B.H.N. The range of chemical composition for these alloys is given below :

Element	Min.,%	Max.,%
Cu	58·20	68·60
Zn	23·04	31·60
Al	0·76	5·14
Ni	1·75	4·19
Mn	2·25	3·32
Fe	1·20	4·40
Pb	0·28	2·75

TABLE IX Chemical composition and physical, mechanical properties of tin-bearing standard bearing alloys

Sl. no.	Chemical composition % Cu	Zn	Al	Sn	Other elements	Density gm/cc,	B.H.N.	Tensile tons/ sq. in.	Elong. %	Izod ft. lb	Micro-Hardness V.P.N. Soft	Hard
TS1	60·20	31·62	3·52	4·08	Ni 1·55 Pb 2·72	8·67	109	25·60	2·03	0·20	118·3	162·6
TS2	83·03	4·72	—	10·00	Pb 1·60	6·11	57·5			2·75	130·8	148·6
TS3	82·20	6·26	—	5·52	Pb 5·80	8·91	69·1			8·75	82·7	123·0
TS4	89·02	—	—	6·88	Pb 2·89 Ni 1·25 P 0·116	8·56	64·6	19·92	14·10	10·25	70·9	121·6
TS5	86·70	—	—	9·50	Pb 1·40 Ni 2·45 P 0·120	8·80	76·8	17·00	4·70	15·00	96·4	155·4
TS6	88·40	—	—	9·60	P 0·120	8·67	75·6	20·32	7·87	4·50	99·9	136·4



11 *Age-hardening characteristics of copper-base experimental bearing alloys*

(6) Part and full replacement of tin in some standard bearing bronzes by aluminium and/or zinc

In the persuit for cheaper bearing alloys it was decided also to modify some of the conventional tin bearing bronzes by replacing the tin by less costly materials like aluminium and/or zinc. The chemical composition and the properties of the standard alloys, TS1, TS2, TS3, TS4, TS5, TS6 already in service as bearings, are entered in Table IX to serve as a basis for comparison with replacement alloys subsequently prepared.

To facilitate discussion this part of the investigation is further subdivided as follows:

(a) Part and full replacement by aluminium.

(b) Part and full replacement by zinc.

(c) Combined replacement by aluminium and zinc.

(6a) Part and full replacement by aluminium

To see the effect of replacement, the tin in the standard alloys, mentioned earlier, was replaced by aluminium in two stages. In the first stage the tin was replaced partly by aluminium. The chemical composition and the physical and mechanical properties of the alloys so produced, viz. TA2, TA4, TA6, TA9 and TA12 are entered in Table X. Fig. 12 depicting the change in mechanical properties of standard and the replaced alloys, reveals that hardness has a definite tendency to increase in four out of the five alloys in which part replacement was attempted. The decrease in hardness observed in case of the fifth alloy TA4 (replacement of TS3), is probably due to its high lead content. The tensile curves mostly follow a similar pattern as hardenss, while the Izod impact and percentage elongation generally show the reverse tendency as expected.

The second stage consisted of full replacement of tin by aluminium. The trend of increase in hardness was found to continue in the same five alloys, mentioned above, while the sixth alloy showed a further decrease in hardness. In all these replaced alloys, the hardness value, even with full replacement, remained within reasonable limit (viz. below 100 B.H.N.) except in the case of alloy TS5 in which, according to this criterion, only up to 75% replacement is permissible. The other mechanical properties such as tensile strength, elongation and Izod impact strength were quite satisfactory. All the replaced alloys showed a duplex microstructure with a difference of micro-hardness of the soft and hard constituents ranging from 8 to 55·6 V.P.N. which is comparable to 18·6 to 59·0 V.P.N. of the standard alloys. The age-hardening behaviour of both standard and replaced alloys are depicted in Figs. 13

TABLE X Chemical compositions, physical and mechanical properties of aluminium-replaced bearing alloys

Sl. no.	Chemical composition% Cu	Zn	Al	Sn	Other elements	Re-placement	Density gm/cc.	B.H.N.	Izod ft. lb.	Tensile tons/ sq. in	Elong. %	Micro-hardness V.P.N. Soft	Hard
TA1	62·00	30·00	4·00	—	Pb 2·50 Ni 1·50	100·0	8·03	158·0	1·00	32·50	1·56		
TA2	85·13	4·91	5·02	4·09	Pb 0·76	59·1	8·30	74·1	4·00	14·55	4·70	111·6	14·45
TA3	86·04	4·50	8·12	—	Pb 1·18	100·0	7·78	92·6	9·50	26·76	4·70	85·5	109·5
TA4	83·50	4·10	2·74	2·56	Pb 5·10	53·7	8·50	56·8	7·50	13·40	15·60	73·9	98·4
TA5	85·20	4·07	6·03	—	Pb 4·40	100·0	8·31	43·6	15·00	12·35	25·00	54·0	107·5
TA6	89·06	—	3·60	3·16	Pb 1·40 Ni 0·94 P 0·144	54·1	7·97	62·5	7·80	6·84	4·70	41·1	85·5
TA7	90·44	—	5·38	—	Pb 3·04 Ni 0·75 P 0·152	100·0	8·51	56·9	11·80	16·20	10·93	55·4	80·0
TA8	85·50	—	8·33	—	Pb 3·40 Mn 0·33 P 0·138	100·0	8·07	60·5	7·35	13·05	9·40	82·1	97·0
TA9	85·10	—	5·25	5·25	Pb 1·25 Ni 3·00 P 0·15	44·8	8·15	79·6	3·24	16·42	6·25	116·0	142·3
TA10	85·10	—	10·50	—	Pb 1·25 Ni 3·00 P 0·15	100·0	7·58	150·0	1·15	32·40	1·56	166·4	174·4
TA11	85·10	—	10·50	—	Pb 1·25 Mn 3·00 P 0·15	100·0	7·47	143·0	1·05	25·50	3·15	123·0	178·6
TA12	90·76	—	3·40	5·25	P 0·09	44·8	8·13	95·6	2·75	14·08	3·13	64·1	96·4

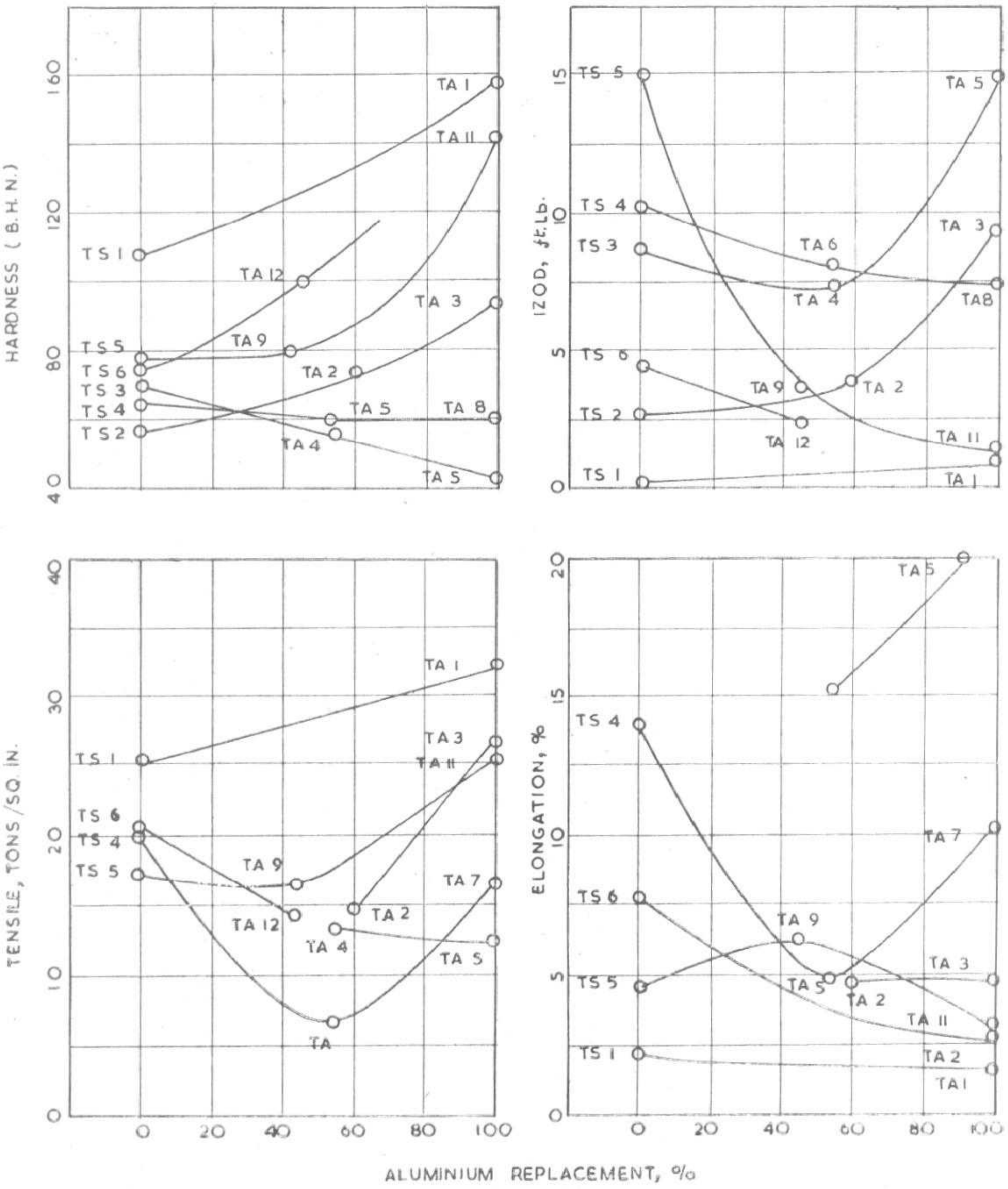
(a) to (f). From these figures it is obvious that both the partly and fully replaced alloys show marked age-hardening characteristics which are seen to be more striking in case of the fully replaced alloys. The hardening effect of aluminium which had been mentioned previously is seen to be more pronounced after treatment.

The standard alloys TS4 and TS5 contained nickel. This was replaced by the same amount of manganese and at the same time tin in the alloys was fully replaced by aluminium. The effect of the replacement of nickel by manganese in the fully aluminium replaced alloys is to decrease the hardness (B. H. N.), tensile strength and the Izod impact value as can be seen in Table 10 for alloys TA7, TA8 TA10 and TA11.

(6b) Part and full replacement by zinc

The replacement of tin by zinc was done in a similar way as for aluminium. In this case the replacement was attempted only for the three standard alloys TS4, TS5 and TS6. The results of the physical and mechanical tests for part and full replacements are given in Table XI. The range invariation of the various mechanical properties obtained are given below:

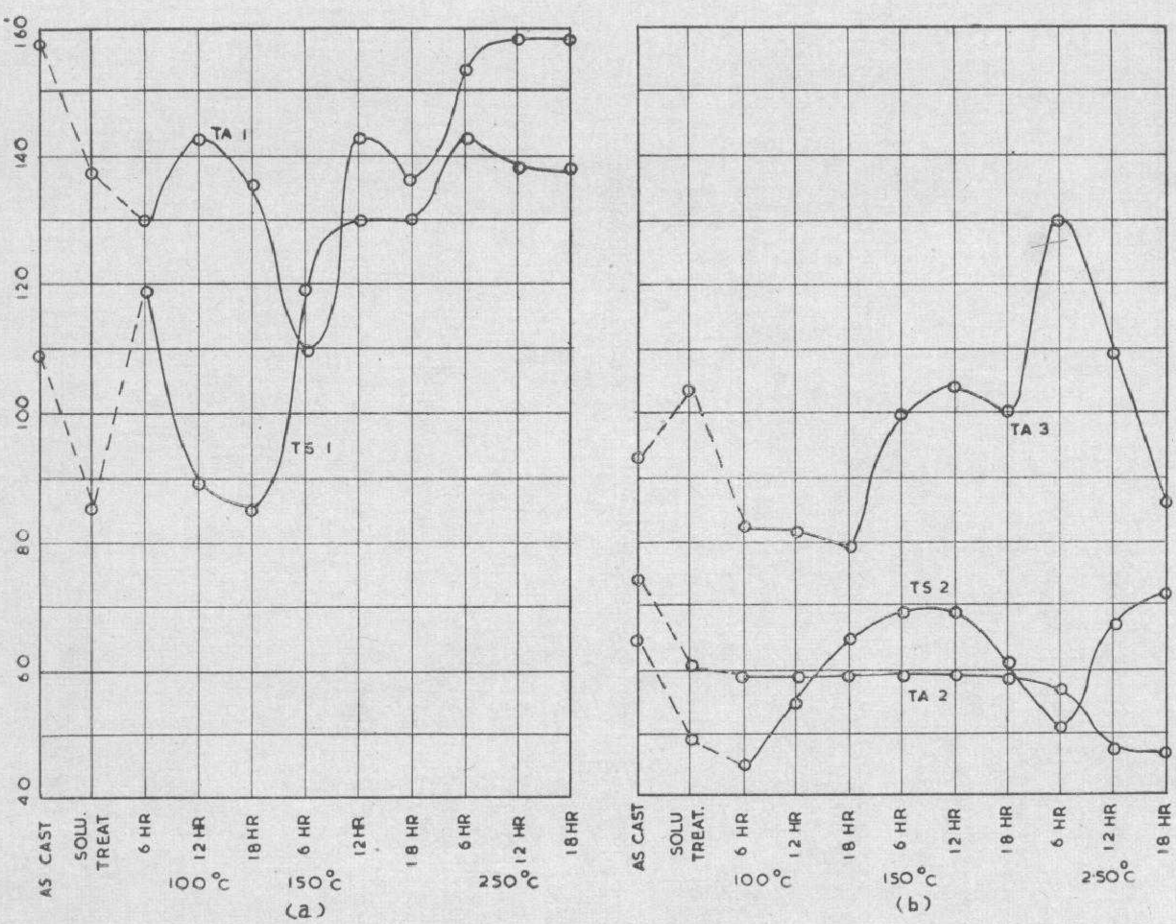
Properties		*Range*
Hardness	...	48·9—76·8 B.H.N.
Izod impact	.	1·5—15·0 ft.-lb
Tensile strength	...	12·7—20·32 tons/sq. in.
Elongation	...	4·69—23·40 per cent
Micro-hardness :		
Soft	...	36·0—99·0 V.P.N.
Hard	...	80·6—183·0 V.P.N.
Difference	...	17·6—112·8 V.P.N.



12 *Effect of Al-replacement on the hardness, Izod, tensile and elongation of the Al-replaced bearing alloys*

The hardness, Izod, tensile and elongation values versus the percentage replacement of tin by zinc have been plotted in Fig. 14. Reference to the figure shows that the hardness has a tendency to decrease with increasing replacement. In the case of TS4, this decrease is slight, whereas for TS5 and TS6, it is considerable. On the other hand, the Izod impact values for TS5 and TS6 increase with increase in replacement but TS4 shows a decrease. The part replacement of tin by zinc tends to decrease the tensile strength with a tendency to regain on full replacement.

The age-hardeding characteristic curves for all these zinc-replaced alloys are plotted in Figs. 15(a) to (c) along with the corresponding standard alloys. From the figure, the replaced alloys TZ1, TZ3, TZ5, TZ6 and TZ8 distinguish themselves as showing marked



13 *(a), (b), Age hardening characteristics of Al-replaced alloys*

TABLE XI Chemical composition, physical and mechanical properties of fully and partly zinc-replaced bearing alloys

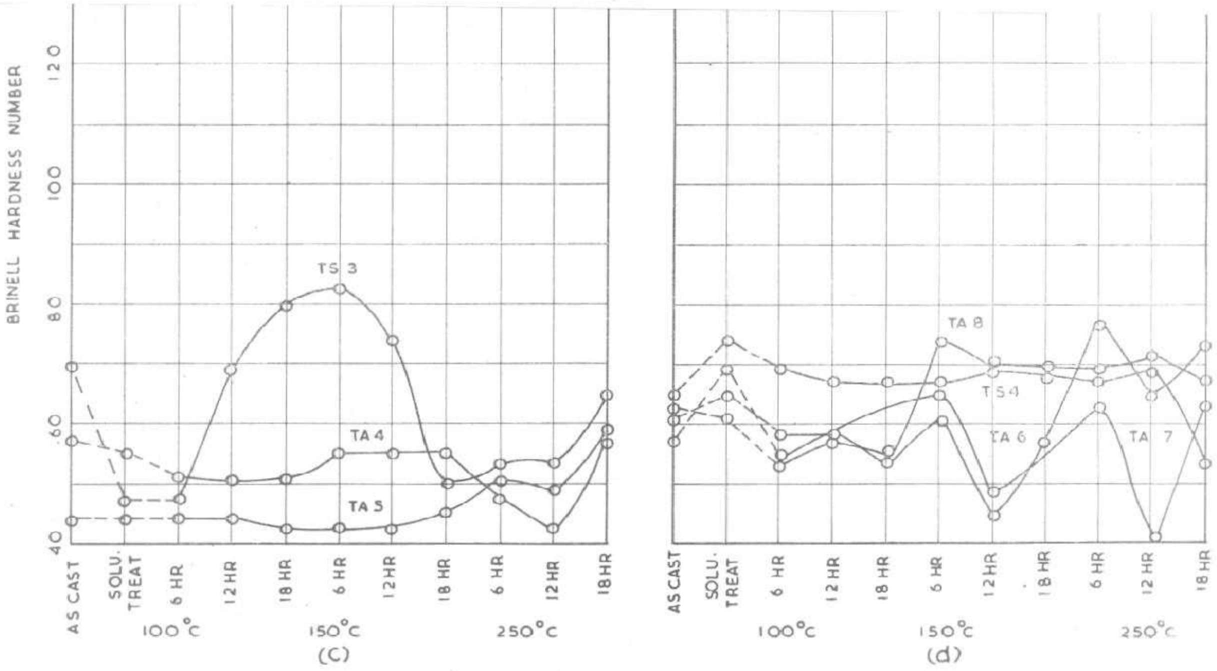
Sl. no.	Chemical composition% Cu	Zn	Al	Sn	Other elements	%Re-placement	Density gm/cc.	B.H.N.	Izod ft. lb	Tensile tons/sq. in.	Elong. %	Micro-hardness V.P.N. Soft	Hard
TZ1	86·80	3·21	—	3·63	Pb 4·90	44·20	8·88	60·5	8·00	15·95	10·93	86·1	155·6
					Ni 0·94								
					P 0·126								
TZ2	88·85	6·50	—	—	Pb 3·50	100·00	8·94	62·5	6·75	16·17	12·50	98·3	121·7
					Ni 1·00								
					P 0·15								
TZ3	86·10	6·25	—	3·15	Pb 3·37	51·60	8·83	76·5	14·50	18·96	12·50	68·1	80·6
					Ni 0·98								
					P 0·15								
TZ4	86·10	6·25	—	3·15	Pb 3·37	51·60	8·91	69·5	9·20	18·05	17·20	66·5	86·3
					Mn 0·98								
TZ5	84·50	5·10	—	3·46	P 0·15								
					Pb 2·10	67·00	8·63	69·1	10·25	13·40	6·25	36·0	116·0
					Ni 2·82								
TZ6	85·10	10·50	—	—	P 0·132								
					Pb 1·25	100·00	8·87	48·9	15·00	17·30	23·40	70·8	115·6
					Ni 3·00								
TZ7	81·75	9·00	—	5·02	P 0·15								
					Pb 1·23	52·20	8·46	72·5	11·30	18·20	12·50	85·5	113·8
					Ni 2·85								
TZ8	80·00	11·14	—	4·00	P 0·15								
					Pb 1·50	61·90	8·46	76·5	6·35	12·72	4·69	94·0	111·6
					Mn 2·30								
TZ9	86·03	8·64	—	4·37	P 0·144								
TZ10	87·86	4·50	—	5·65	P 0·112	56·30	8·86	69·5	15·00	16·24	12·95	89·3	111·5
					Pb 2·70	43·50	8·77	69·1	11·00	22·50	12·00	70·2	183·0

AZ6, produced by replacement of tin fully by aluminium and zinc in the commercial bearing bronzes, hold out great promise as materials for the fabrication of bearings for various engineering industries.

The micro-photographs of some useful experimental bearing alloys are shown in Figs. 17 and 18. The duplex structure is clearly visible after etching with a standard solution of ferric chloride.

Summary

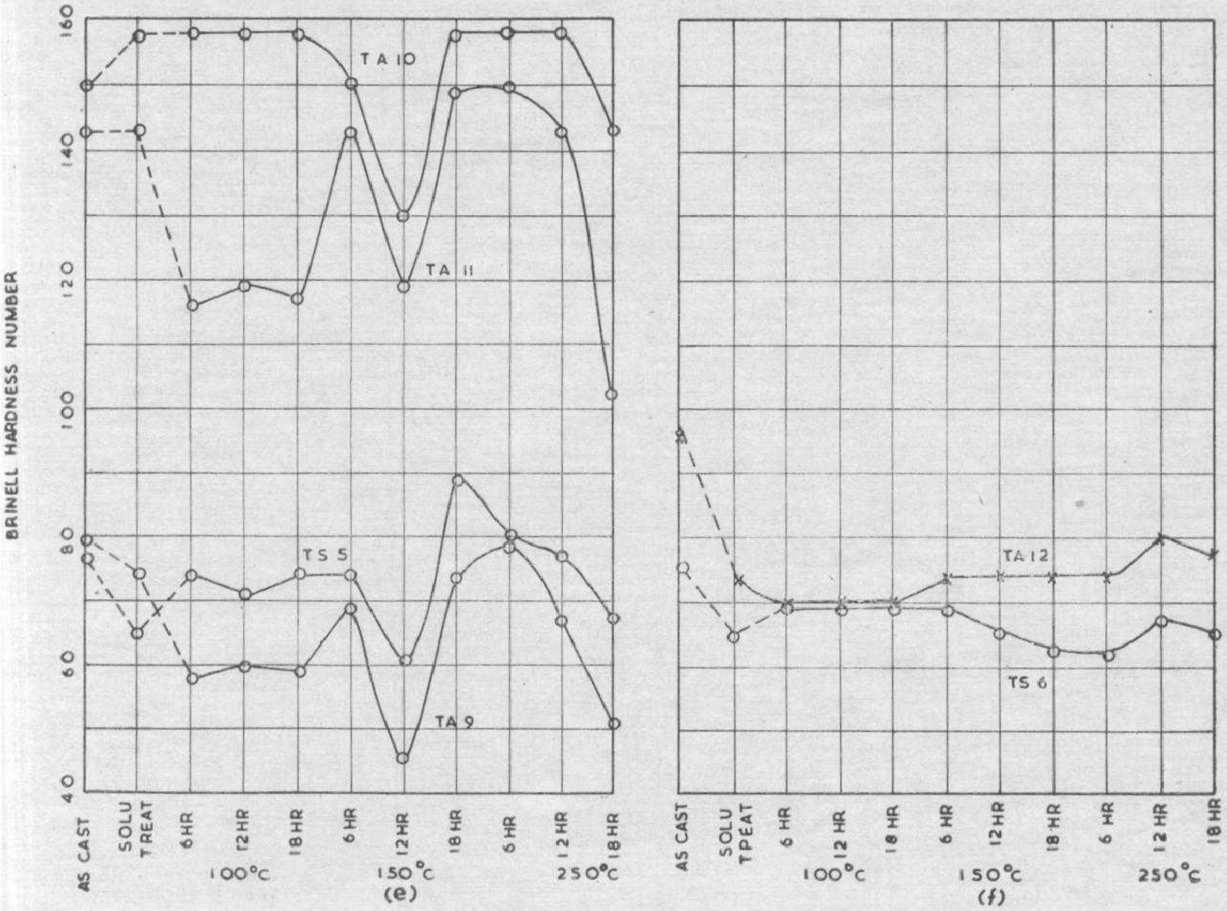
1a. The Alzen type of Cu-Zn-Al alloys investigated showed a duplex micro-structure consisting of a hard ternary eutectic of copper-aluminium-zinc in a relatively soft matrix of zinc-aluminium. They do not show any Izod impact strength. These alloys may be used in bearing applications where



13 *(c), (d) Age hardening charecteristics of Al-replaced alloys*

TABLE XII Chemical composition, physical and mechanical properties of Al-Zn-replacement bearing alloys

Sl. no.	Chemical composition%				Other elements	%Re-place-ment	Density gm/cc.	B.H.N.	Izod ft. lb	Tensile tons/ sq. in.	Elong. %	Micro-hardness V.P.N.	
	Cu	Zn	Al	Sn								Soft	Hard
AZ1	86·10	6·25	3·12	—	Ni 0·98 Pb 3·40 P 0·15	100·0	8·35	69·8	6·30	11·48	8·60	81·1	97·4
AZ2	86·10	6·25	3·12	—	Mn 0·98 Pb 3·40 P 0·15	100·0	8·36	66·5	8·16	12·52	7·81	75·1	82·7
AZ3	81·75	9·02	5·02	—	Ni 2·85 Pb 1·23 P 0·15	100·0	8·03	82·9	10·20	21·35	11·70	91·5	118·3
AZ4	78·00	10·90	6·70	—	Mn 1·90 Pb 1·26 P 1·136	100·0	8·01	84·9	12·75	19·24	14·85	99·9	103·6
AZ5	84·00	10·70	5·05	—	P 0·164	100·0	8·12	63·7	23·00	16·56	14·85	88·4	101·7
AZ6	86·56	5·35	5·80	—	Pb 2·50	100·0	8·09	55·1	34·00	16·35	20·30	85·4	111·6



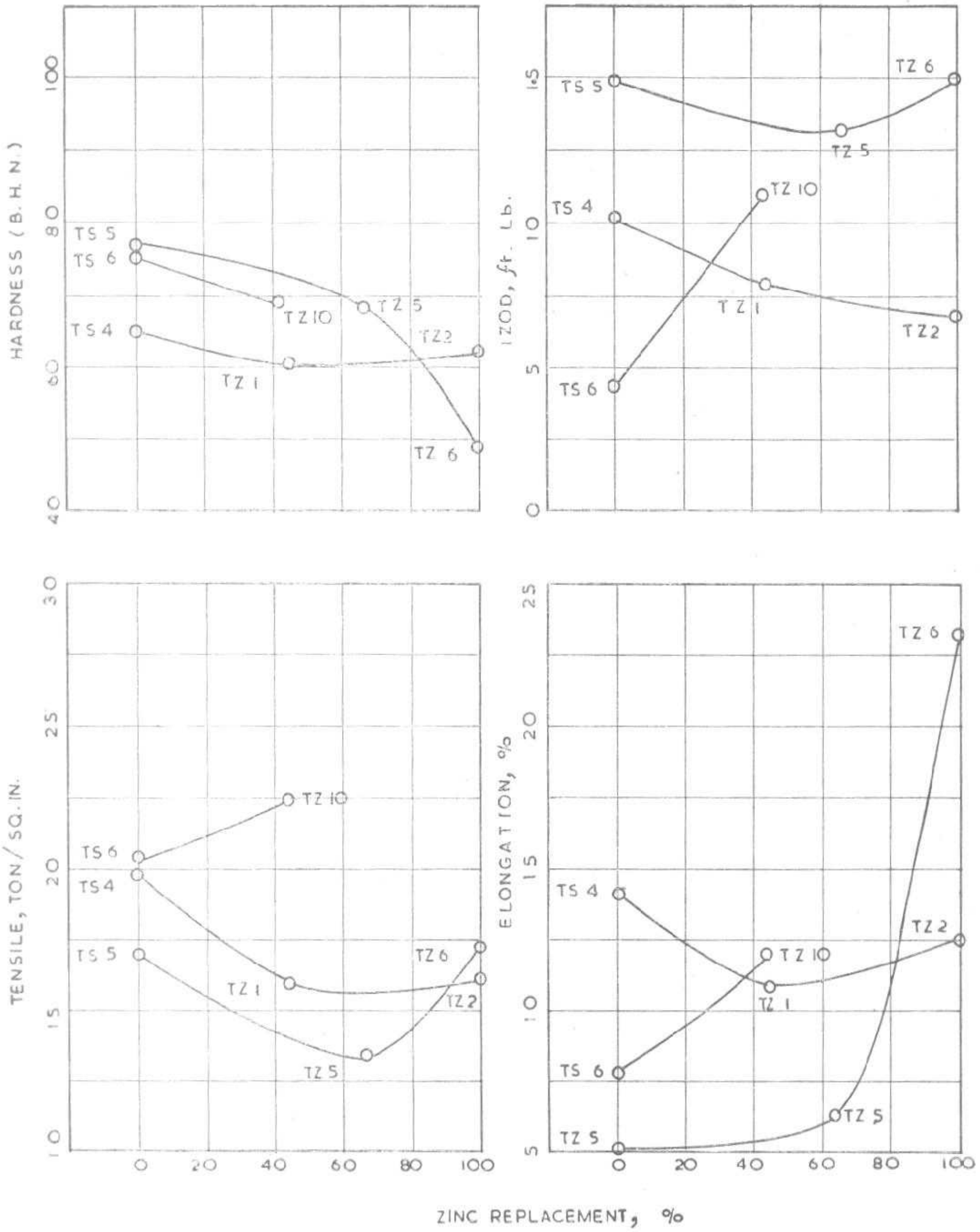
13 *(e), (f) Age hardening characteristics of Al-replaced alloys*

age-hardening behaviour. All these alloys have shown duplex micro-structure.

(6c) Combined replacement by aluminium and zinc

As observed earlier, the hardness of the replaced alloys increases when aluminium is used for replacement while it decreases with zinc used for replacement. So in order to keep the hardness within reasonable limits, it was decided to replace the tin of the standard alloys partly by aluminium and partly by zinc. The results of the physical and mechanical properties obtained after this replacement in the standard alloys TS4, TS5 and TS6 are entered in Table XII. In all these alloys, half of the tin content was replaced by approximately equal amount of aluminium while the other half was replaced by double amount of zinc.[5] In the two standard alloys TS4 and TS5, the nickel in the original alloys has also been replaced by manganese, while in the case of the standard alloy TS6, a replacement alloy AZ6 with equal replacement by aluminium and zinc has also been tried. The lower tin alloy TS4 shows a slight increase in hardness with some decrease in Izod impact, tensile strength and percentage elongation at the same density in both of its replacements, while the higher tin alloy TS5 not only exhibits an increase in hardness but also an appreciable increase in the other mechanical properties even after some reduction in the density. The replacement of the standard 10 PB alloy TS6 produces somewhat lighter alloys of less hardness and tensile strength, but with marked increase in Izod impact value and percentage elongation. A general appraisal of Table XII indicates that the hardness has been achieved at a reasonable level viz., between 55 and 85 B.H.N., the Izod impact strength ranges from 6 to 34 ft. lb, the tensile strength lies between 11·5 and 21·5 tons/sq. in., and the percentage elongation between 7 and 20% with a slightly lower density than that of bearing bronzes. The response to age-hardening of the replaced alloys is drawn side by side with the respective standard alloy in Fig. 16. The increment in hardness on keeping the alloys progressively up to a temperature of 250°C for six hours after solution treatment at 800°C is well brought out by following the aging curves.

The alloys, TA3, TA5, TA7, TA8, TA10, TA11, TZ1, TZ3, TZ4, TZ5, TZ7, TZ9 TZ10, and AZ1 to



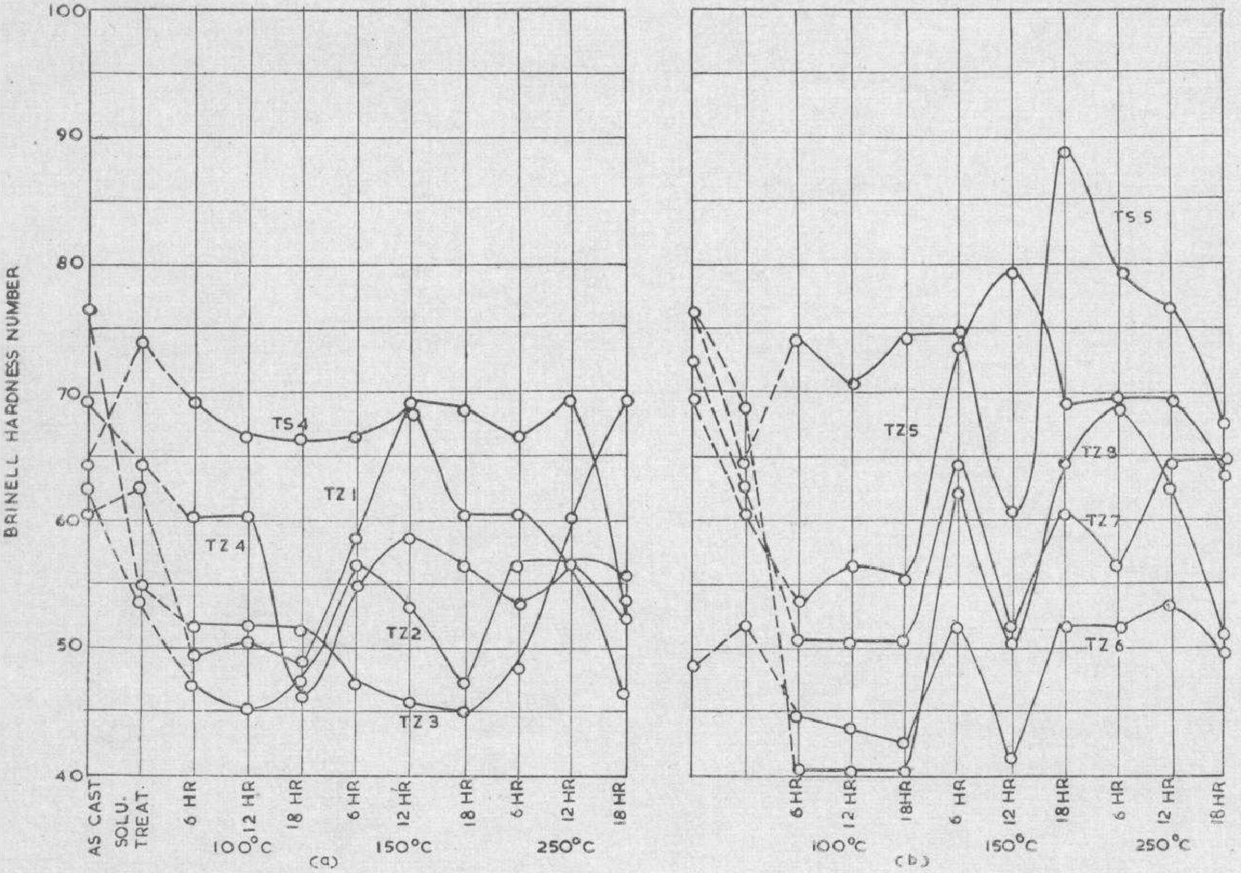
14 *Effect of zinc-replacement on hardness, Izod, tensile and elongation of the zinc-replaced bearing alloys*

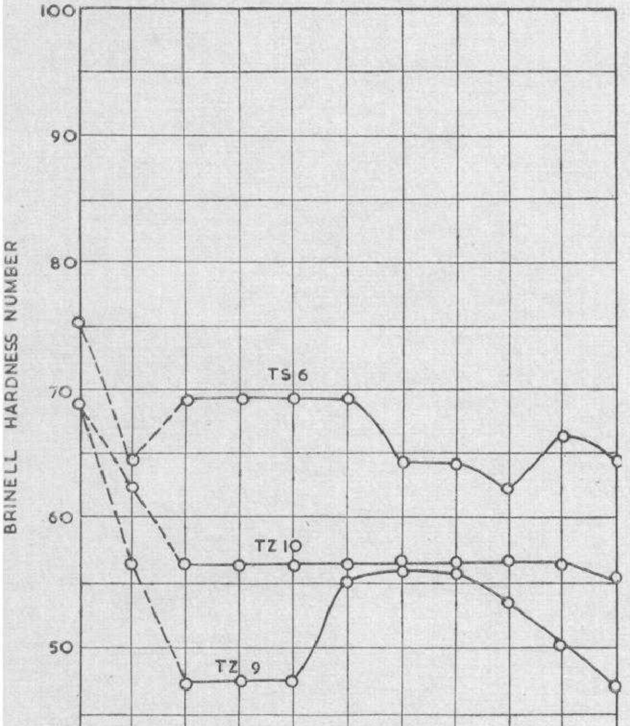
AZ6, produced by replacement of tin fully by aluminium and zinc in the commercial bearing bronzes, hold out great promise as materials for the fabrication of bearings for various engineering industries.

The micro-photographs of some useful experimental bearing alloys are shown in Figs. 17 and 18. The duplex structure is clearly visible after etching with a standard solution of ferric chloride.

Summary

1a. The Alzen type of Cu-Zn-Al alloys investigated showed a duplex micro-structure consisting of a hard ternary eutectic of copper-aluminium-zinc in a relatively soft matrix of zinc-aluminium. They do not show any Izod impact strength. These alloys may be used in bearing applications where





impact loading is not of prime importance.

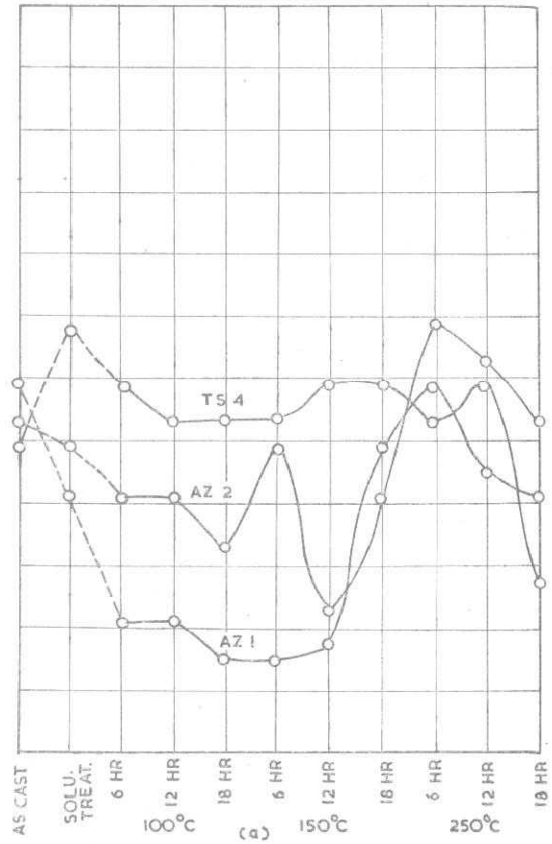
1b. No improvement in Izod impact strength is obtained by adding small amounts of tin, manganese, nickel, chromium, iron, antimony and misch-metal to the 5% copper, 35% aluminium, Cu-Zn-Al Alzen type alloy. Therefore, it falls into the same category as the previous set of alloys.

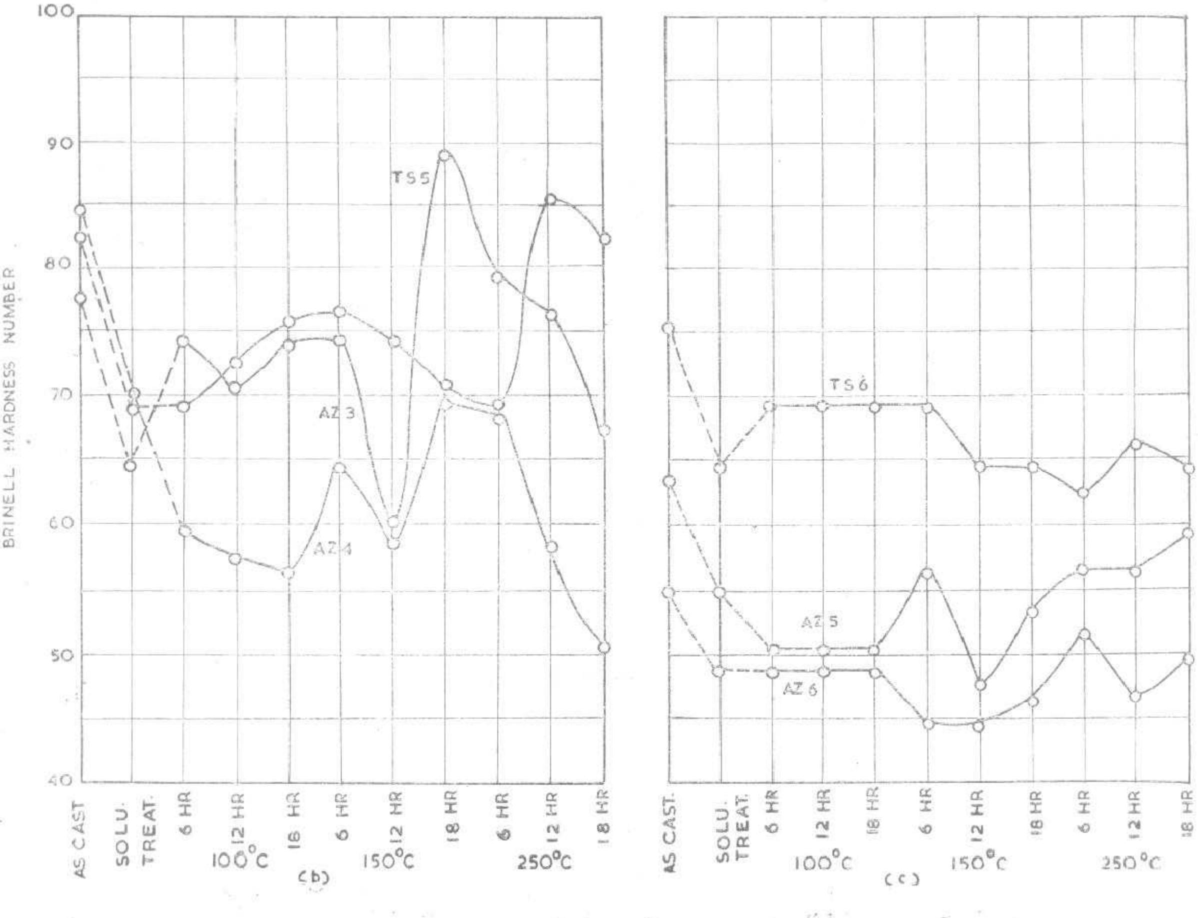
1c. The hardness of the Cu-Zn-Al 5% copper alloys rises with increasing aluminium up to 60% aluminium upto 60% aluminium after which it is found to decrease.

15 *(a), (b), (c) Age hardening characteristics of zinc-replaced bearing alloys*

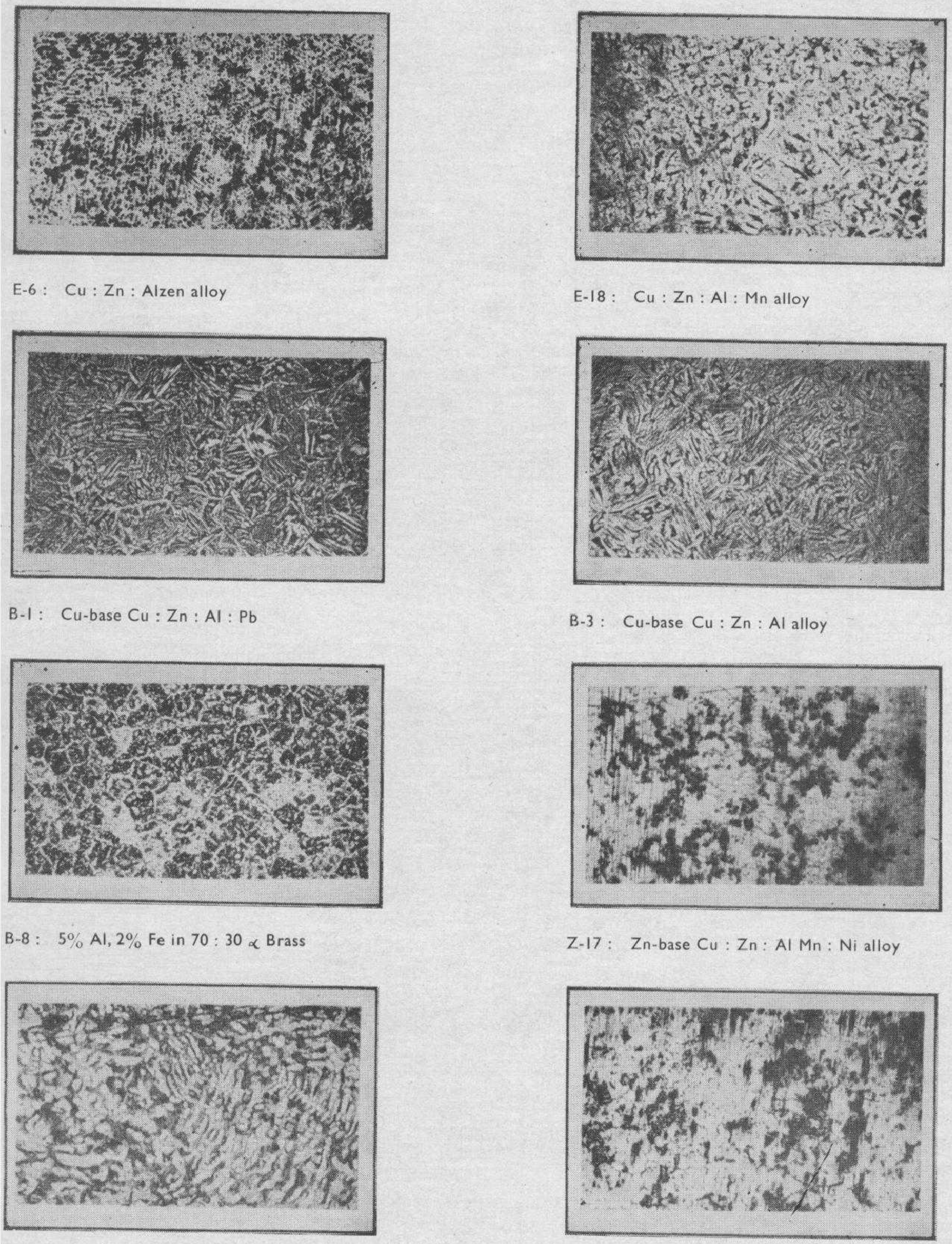
2. Addition of aluminium and aluminium-iron to 70 : 30 ∝ brass does produce alloys having primary requisites of bearing alloys. In this connection, the alloys B1, B3, B4 and B8, possessing reasonable hardness and toughness, are recommended as bearing materials.

3. Among the zinc-base alloys, only alloys Z17 and Z18 containing zinc from 89–95%, copper from 1 to 5% and the balance aluminium, could be utilised as bearing materials. These can be used





16(*a*), (*b*), (*c*) *Age hardening characteristics of Al-Zn-replaced alloys*



E-6 : Cu : Zn : Alzen alloy

E-18 : Cu : Zn : Al : Mn alloy

B-1 : Cu-base Cu : Zn : Al : Pb

B-3 : Cu-base Cu : Zn : Al alloy

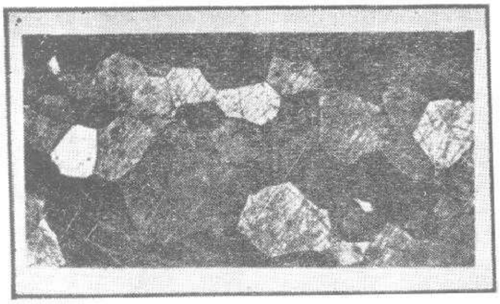
B-8 : 5% Al, 2% Fe in 70 : 30 α Brass

Z-17 : Zn-base Cu : Zn : Al Mn : Ni alloy

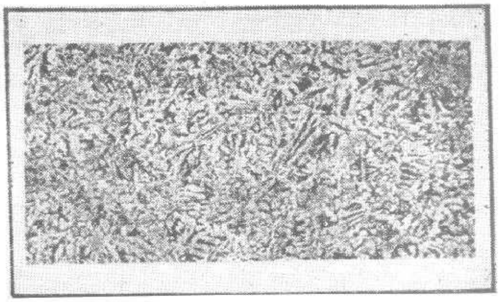
Z-18 : Zn-base Cu : Zn : Al alloy

A-8 : Al-base Cu : Zn : Al alloy

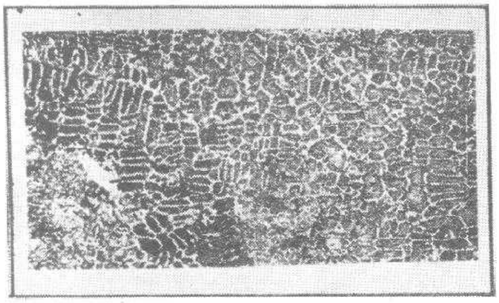
17 *Micro-photographs of some of the bearing alloys etched in ferric-chloride* $\times 100$



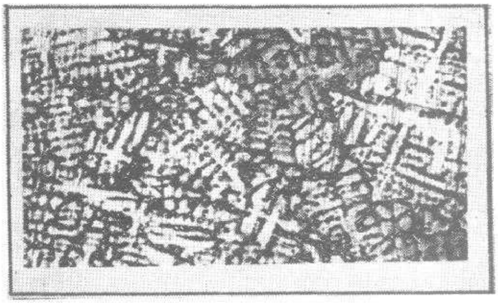
C-14 : Cu-base Cu : Zn : Al alloy



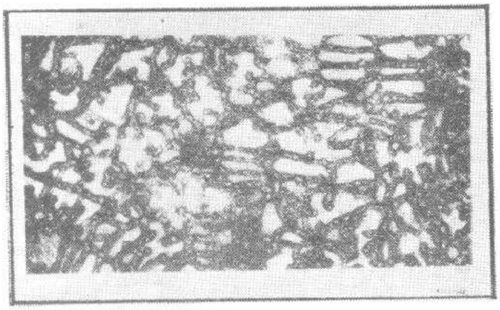
C-19 : Cu-base Cu : Zn : Al : Fe alloy



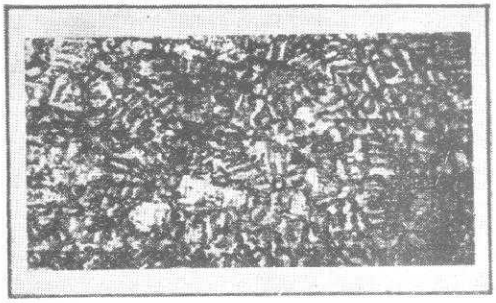
Ta-5 : Al-Replaced Cu-Zn-Al-Pb alloy



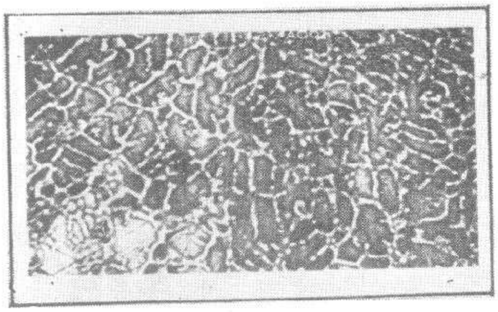
Ta-8 : Al-Replaced Cu : Al : Pb : P : Ni : Sn alloy



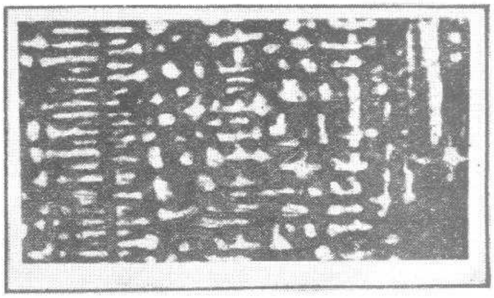
Tz-1 : Zn-Replaced Cu : Zn : Pb : P : Ni : Sn alloy



Tz-5 : Zn-Replaced Cu : Zn : Pb : P : Ni : Sn alloy



Az-1 : Al-Zn-Replaced alloy



Az-6 : Al-Zn-Replaced alloy

18 *Micro-photographs of some of the bearing alloys etched in ferric-chloride* × 100 under conditions of continuous lubrication and heat dissipation.

4. A5 is the only aluminium-base alloy which could possibly find a use as a bearing material.
5. The copper-base alloys which could be chosen as bearing materials are C4, C7, C13, C17, C18, C20 and C25. In their case the hardness level desired for a particular bearing set up is the deciding factor.
6. The replacement of tin by aluminium and/or zinc in some conventional bearing bronzes has been successful in producing as many as twenty alloys viz., TA3, TA5, TA7, TA8, TA10, TA11, TZ1, TZ3, TZ4, TZ5, TZ7, TZ8, TZ9, TZ10, and AZ1 to AZ6, which could be commercially exploited in the fabrication of bearings for automobiles and other modern engineering industries. The primary considerations, viz., the chemical, mechanical and physical properties, required for a bearing material, hitherto discussed, has been found to be satisfactory for several of the alloys investigated, as mentioned above. It is envisaged to carry out wear and other service performance tests to get a proper assessment of these materials as bearings in service under varying conditions of load and speed.

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