STUDIES ON SOME PROPERTIES OF SILICON BRASS

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This study reveals that mechanical properties of silicon brass are superior and sea salt corrosion is of the same order as Naval and Admiralty brasses but inferior to aluminium brass. In condenser tube condition, silicon brass has only half the thermal conductivity of Naval or aluminium brasses but corrosion resistance is of the same order. The stress corrosion resistance of silicon brass is much superior.

Edmunds[1] was the pioneer in discovering the superior properties of this alloy in amoniacal atmosphere and since then this system has come under the active consideration of the metallurgists both from the theoretical and practical point of view. The equilibrium diagram of the Cu-Zn-Si system in the copper rich portion was published later and the processing of the system could be analysed. Recently, failure of some established alloys of copper in sea water service has been suspected to be due to stress corrosion cracking. This study has been undertaken to develop an alloy resistant to stress corrosion cracking by adding silicon upto 2 per cent in alpha brass. Its various properties such as melting, alloying, mechanical properties, structural characteristics, work hardening and recrystallisation characteristics, sea salt corrosion, condenser tube corrosion and thermal conductivity have been compared with those of standard brasses used in the marine conditions for different purposes.

STUDY OF PROPERTIES

70-30 Brass containing varying amount of silicon and at different stages of cold work and heat treatment was compared with Naval Brass, Admiralty Brass and Aluminium Brass. The composition of these brasses are given in Table 1.

Melting

All the alloys were melted in heats of 10 kg in an oil-fired crucible furnance. Alpha brass was prepared from the virgin metals in calculated amounts. Copper was melted first and to it zinc was added. The pouring temperature was decided by zinc flare. In some heats, scrap of alloys prepared at preliminary stages was used in the charge and the composition was adjusted suitably. There was no difficulty in getting silicon in solution from a 15% Cu-Si master alloy charged with the virgin ingots or scrap at the initial stages; 4% zinc had to be added to compensate its loss during melting.

Casting

The alloys were cast in $20 \times 12 \cdot 5 \times 8$ cm. blocks in a steel mould. Except for the formation of a thin oxide skin on aluminium brass, no abnormal formation of dross was noted. Silicon brasses had negligible extent of piping and gave the cleanest surface.

Processing

The blocks were homogenized at 650°C for 24 hours. Approximately 0·6 cm thick slabs were sawed off after homogenization and were cold rolled.

Alloys containing more than 2% silicon cracked if rolled beyond 5% cold reduction· Brass containing 1·5 to 2% silicon may crack during cold rolling if oxidation at grain boundary is not prevented during process annealing. With silicon content upto 2% brasses could be cold rolled only upto the extent of 25% in primary stages, because of incomplete homogenization. Cold work helps in dissolution of the second phase during process annealing and these alloys, then can be cold rolled upto 65% reduction. Study on alloys containing beyond 2% silicon was abandoned as they were unworkable.

Heat Treatment and Microstructure

The alloys are single phase with silicon upto 2 per cent and a two phase structure can be obtained by quenching in water from a temperature of 800°C. The phases detected were of F.C.C. and H.C.P. types.

The quenched sample when reheated in the range of 250° to 450°C showed the formation of the equilibrium beta (B.C.C.) phase and elimination of the H.C.P. phase. The amount of beta phase increased to a maximum at 350°C and then found to decrease considerably at 450°C with consequent increase of alpha phase.

Mechanical Properties

The mechanical properties, work hardening and recrystallisation characteristics and other physical properties are given in Table 2 and 3 and Fig. 1 and 2. It is to be noted that addition of silicon improved the tensile strength of 70-30 brass from 20 T/sq. inch to 30T/sq. inch but percentage elongation was reduced from 50 per cent to 25 per cent Maximum hardness obtained for silicon brass in the cold worked state was Vickers (269 *RC* 26) which is slightly more than hardness of Naval or Admiralty brasses (*RC* 20). Though 70-30 brass containing 2·2% silicon cannot be cold rolled, its hardness of casting rises from 120 to 170 V.P.N. after quenching from 800°C due to a martensitic type of phase transformation.

TABLE 1

COMPOSITION OF VARIOUS BRASSES

	Alpha Brass		High Silicon Brass			Low Silicon Brass			Admiralty Brass			Naval Brass			Aluminium Brass		
Analysis	Cu.	Zn	Cu	Zn	Si	Cu	Zn	Si	Cu	Zn	Sn	Cu	Zn	Sn	Cu	Zn	Al
Acutal %	73	27	72·6	25·54	1·86	71·28	27·66	1·06	69·3	29·91	0·79	63	36·04	0·96	69	29·69	1·31
Calculated (%)	74	26	73	25	2	70	28·8	1·5	70	29	1	61	39·2	0·8	70	28	2
Loss or gain (%)	—1	+1	—·4	+·54	+·14	+1·28	—1·14	—·44	—·7	+·91	—·21	+2	—3·16	+·16	—1	+1·69	—·69

TABLE 2

MECHANICAL PROPERTIES OF SILICON BRASS

Material	Condition	Tensile Strength Tons /sq. in	Tensile strength Kg/mm^2	% Elongation
1·86% silicon brass	Annealed	30·0	50·0	25
	50% cold rolled	52·0	86·6	
	Quenched and 50% co d rolled	46·5	77·5	
1.06% silicon brass	Annealed	29·4	49·0	33
	50% cold rolled	49·4	82·3	
	Quenched and 50% cold rolled	50·0	83·3	

TABLE 3

RECRYSTALLISATION CHARACTERISTICS OF THE BRASSES

Temp °C	250					350					450				
% Cold reduction	10	25	50	65	80	10	25	50	65	80	10	25	50	65	80
1·86% Si Brass V.P.N. Hardness	159	178	219	251		159	175	219	251		140	159	205	210	
1·06% Si Brass V.P.N.	159	178	239		269	153	173	224		251	148	129	131		148
2·2% Si Brass V.P.N.	Cannot be cold rolled														
Admiralty V.P.N.	117	138	229		229	106	148	129		145	105	91	100		117
Naval V.P.N.	129	150	224		229	129	148	143		160	105	110	117		131
Aluminium Brass V.P.N.	144	175	197		229	145	165	201		242	127	159	175		162

Temp °C	550					650					Annealed	Cast	Cast & Quenched
% Cold reduction	10	25	50	65	80	10	25	50	65	80			
1.86% Si Brass V.P.N. Hardness	127	130	153	168		115	125	145	143		125	111	
1·06% Si Brass V.P.N.	119	117	113		119	117	110	105		117	113	87	
2·2% Si Brass V.P.N.												120	170
Admiralty V.P.N.	78	83	85		79	80	79	82		79	89	49	
Naval V.P.N.	96	95	93		94	93	98	90		94	106	55	
Aluminium Brass V.P.N.	110	119	133		143	105	119	119		119	110	47	

TABLE 4

LOSS IN WEIGHT (AFTER 33 DAYS) OF BRASSES DUE TO SEA SALT CORROSION

Samples	Heat treatment	Loss in wt. in 33 days (gm)
Naval Brass	Annealed	·0206
	50% cold rolled	·0202
Admiralty Brass	Annealed	·0184
	50% cold rolled	·0196
1·86% silicon Brass	Annealed	·0226
	50% cold rolled	·0250
	15 min. at 800°C soaked, quenched cold rolled	·0272
	30 min. at 800°C soaked, quenched 50% cold rolled	·0270
1·06% silicon Brass	Annealed	0·222
	50% cold rolled	0·208
	15 min. at 800°C soaked, quenched cold rolled	0·210
	30 min. at 800°C soaked, quenched 50% cold rolled	0·194
Aluminium Brass	Annealed	·0054
	50% cold rolled	·0058

TABLE 5

LOSS IN WEIGHT (AFTER 52 DAYS) OF BRASSES DUE TO SEA SALT CORROSION

Samples	Heat treatment	Loss in wt. in 52 days (gm)
Naval Brass	Annealed	·0200
	50% cold rolled	·0212
Admiralty Brass	Annealed	·0252
	50% cold rolled	·0250
1·86% Silicon Brass	Annealed	·0290
	50% cold rolled	·0294
	15 min. at 800°C soaked, quenched cold rolled	·0262
	30 min. at 800°C soaked, quenched cold rolled	·0454
1·06% Silicon Brass	Annealed	·0382
	50% cold rolled	·0296
	15 min. at 800°C soaked, quenched cold rolled	·0296
	30 min. at 800°C soaked, quenched and cold rolled	·0422
Aluminium Brass	Annealed	·0082
	50% cold rolled	·008

CORROSION TESTS AND THEIR RESULTS

Sea Salt Corrosion Test

To test the susceptibility of the brasses to Crevice corrosion in sea salt, cold worked and recrystallised samples were kept for a long period covered in moist sea salt obtained by evaporating natural sea water. Some spots developed in all samples and corrosion rate was determined by loss in weight after washing in distilled water. Aluminium brass suffered least amount of corrosion as shown in Tables 4 and 5.

Condenser Tube Corrosion Test

An experiment was set up as shown in Fig. 3 for investigating the possibility of using silicon brass as a condenser tube alloy.

Weighed pieces of different alloys, rectangular in size, were tightly fitted in rubber pads with openings in the shape of a parallelopiped at the centre. Two such pads were joined with araldite to form a closed box. At the side of the box two glass tubes 'G' were inserted to circulate the cooling water over one surface of specimens. Each such unit was connected with rubber tubes.

The unit was kept within the humidity chamber, where steam was allowed to come in contact with the exposed side of the specimen, the other side of the specimen was kept cool with 1 per cent saline water circulating at a velocity of 30 cm per second. The extent of corrosion was estimated after an exposure period of 32 hours at steam heat for different stretches. This period consisted of exposure from 4 to 5 hours each day for 7 days.

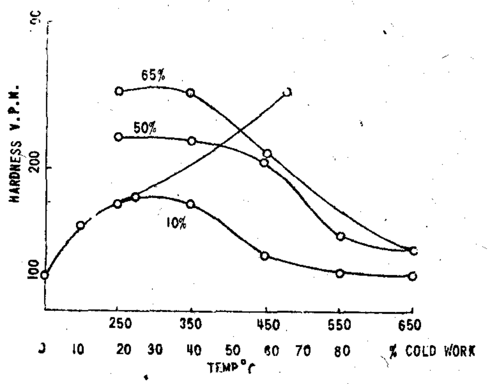

Fig. 1—Work hardening and recrystallisation characteristics of 1·86% silicon brass.

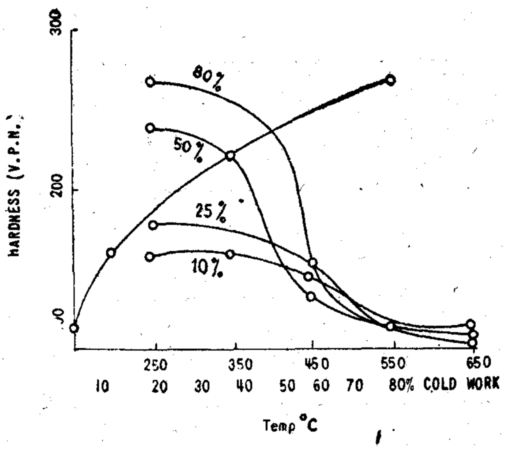

Fig. 2—Work hardening and recrystallisation of 1·06% silicon brass.

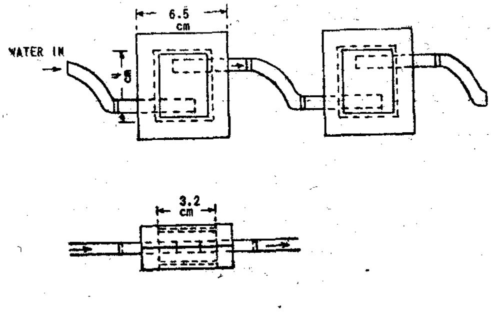

Fig. 3—Set-up for condenser tube alloy testing.

After the completion of the test the samples were washed in water and loss in weight determined. The density of the sample was determined next. The density of the sample was determined once again after removing the oxide layer by nitric acid. The true weight of oxide film was then calculated from these two densities and the measured density of the oxide film. Therefore the true loss in weight could be found from the weight of oxide film formed. A sample calculation is given as follows for the Naval brass.

Density of oxide film $=3\cdot00$

Density of Naval brass $=8\cdot513$.

Density of corroded Naval brass $=8\cdot41$

Initial weight of Naval brass $=15\cdot7378$ gm.

Let x gm of oxide mix with $8\cdot513$ gm of brass in the corroded sample,

$$\text{So} \quad 8\cdot41 = \frac{8\cdot513+x}{1+\frac{x}{3}}$$

this gives $x = \cdot0571$ gm.

$(8\cdot513 + x)$ gm contains $\cdot0571$ gm oxide.

Therefore $15\cdot7378$ gm contains $\cdot1048$ gm oxide.

Therefore total corrosion $= 0\cdot1048 + 0\cdot0962 = \cdot2010$ gm.

TABLE 6

RESULTS OF CONDENSER TUBE CORROSION TEST

Sample	Heat treatment	Loss in wt. in 7 days (gm)	Specific resistance of the annealed sample $X10^{-6}$	Density of corroded sample	Density of acid treated sample	Wt. of oxide film (gm)	Total corrosion in 7 days (gm)
Naval Brass	Annealed	·0962	6·9 ohm cm	8·41	8·513	·1048	·2010
	50% cold rolled	·0380		8·427	8·573	·0765	·1145
Aluminium Brass	Annealed	·0954	8·3 ohm cm	8·25	8·282	0·342	·1296
	50% cold rolled	·0818		8·252	8·30	·0256	·1074
1·86% Silicon Brass	30 mins. at 800°C soaked, quenched 50% cold rolled	·0344	14·9 ohm cm	8·3903	8·4669	·0384	·0728
1·06 % Silicon Brass	30 mins. at 800°C seaked, quenched 50% cold rolled	·0554	14·1 ohm cm	8·2949	8·4173	·0637	·1191

The results for different brasses as given in Table 6 show that the performances of brasses are rather close excepting that of the aluminium brass which develops a very thin oxide film. It may be noted that aluminium brass containing 76 per cent copper 2 percent aluminium, 0·04 percent arsenic and balance zinc is widely used as condenser tubes where sea water is being used as a cooling medium.

Stress Corrosion Test

Stress Corrosion resistance of silicon brass is much superior to other brasses. This resistance can be further improved by quenching the alloy from 800°C in water. The improvement is caused by the appearance of a H. C. P. phase developed at high temperature. The tests were carried out in tensile loaded specimen (·081 cm thick, ·476 cm wide) in an atmosphere of 68·9% air, 27·8% ammonia and 3·3% moisture. The load was 6·7 kg/mm². The time of failure of the specimen denoted its stress corrosion resistance. The results are given in Table 7 and 8.

TABLE 7

STRESS CORROSION RESISTANCE OF ALPHA AND NAVAL BRASS

% Cold reduction	Time to failure (min) average	
	Alpha brass	Naval brass
Annealed	193	210
10—15	172	182
20	155	—
30	256	—
50	290	495
70—80	439	483

TABLE 8

STRESS CORROSION RESISTANCE OF SILICON BRASSES

Condition	Time of failure (Min)	
	1·06% Silicon Brass	1·86% Silicon Brass
Annealed	500	630
50% Cold rolled	1110	2820
Quenched from 800°C after soaking 15 minutes and 50% cold rolled.	>23130	>17280
Quenched from 800°C after soaking 30 minutes	>21600	
Quenched from 800°C after soaking 15 minutes	4695	
Specimen after giving heat treatment No. 4 cold rolled and reannealed at 200°C for 30 minutes	7800	
Specimen after giving heat treatment No. 4 cold rolled and reannealed at 300°C for 30 minutes	1101	
	4685	
Specimen after giving heat treatment No. 4 cold rolled and reannealed at 450°C for 30 minutes	5190	
	7065	(7065)

DISCUSSION

The study of the properties of silicon brass shows that the alloy may be suitable as a marine hardware in lieu of the current brasses in specific cases where the failure of equipment in sea water is suspected to be due to stress corrosion cracking. The comparative stress corrosion resistance of silicon brass and other brasses has been investigated by Edmunds[1]. In the present investigation the heat treatment of the silicon brass was diversified to a greater extent. A phase transformation associated with the quenched silicon brass increases its stress corrosion resistance. This observation is in accordance with the recent[2,3] experiments that a phase trasformation can improve the transgranular stress corrosion resistance in F.C.C. alloys.

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