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Precipitation Hardening in (α+β) and Lead -Tin Brasses

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Abstract: Commercially available two different compositions of (α+β) and lead-tin-brasses were solution treated at 815 °C for ½ hr and aged at 400 and 500° C for ½ and 1 hr. The tensile test data were analyzed to find the UTS (ultimate tensile strength), elastic modulus, %elongation and reduction in area. The UTS for (α+β) brass with different heat treatments was found to vary between 371.42 to 417.40 N/mm^2 with elongation of 25.7-30.15% and between 474.00 to 619.03 N/mm^2 with elongation of 4.60-9.75% for lead-tin-brass. The Rockwell hardness (HRF) with these heat treatments were observed to decrease variably for both (α+β) and lead-tin-brasses.

Keywords: Ultimate Tensile Strength, Ductility, Microstructure, Precipitation, Rockwell Hardness

Introduction

The (α+β)-brasses consist of a softer phase, α and a harder phase, β, therefore, they show different flow behavior (Padmavardhani and Prasad, 1991). The constitute flow behavior in (α+β)-brass has been studied (Suery and Baudelet, 1980) taking into account the nature of deformation of the two individual phases. During β → α + β′ transformation two types of precipitates has been commonly observed and conditions of their transformation depend on the alloy composition and the transformation temperature (Mujahid and Bhadeshia, 1999: Flewitt and Towner, 1967: Hornbogen and Warlimont, 1967: Srinavasan and Hepwarth, 1971: Cornelis and Wayman, 1974: Kostic and Hawbolt, 1979) The α-phase is absorbed into the β phase when 60-40 composition is heated to a point above the (α+β′)/β phase boundary in the region of 750 °C, thus producing a uniform plastic structure of β phase only. The α phase is usually in the process of being precipitated whilst hot working is taking place, so that, a refined granular α+β′ structure is formed again as the temperature falls (Higgins, 1991). Rapid cooling from the β region may suppress the precipitation of most of the α phase. Ageing to a low temperature will allow more of the α phase to come out of the supersaturated solution. The addition of small amounts of alloying elements such as lead, tin, or aluminum to these brasses can improve their machinability and corrosion resistance as well as the microstructure.

Typical applications of such brasses include hardware, gears, ship sheathing, condenser heads, perforated metal, and architectural work. These brasses can also be used for valve stems, brazing rods, and condenser tubes (Avner, 1974).

The objective of this research is to highlight the strong dependence of mechanical properties on microstructure, which in turn is dictated by the heat treatment parameters in (α+β)- and lead-tin-brasses. The selection of a material for hardware applications, particularly for gears must be based on sound metallurgical grounds. In the present investigations, effect of different aging temperatures and time on high temperature β phase was studied to observe variations in the microstructure, tensile strength and hardness of these materials. Variations in mechanical properties of these brasses caused by adding small amounts of tin and lead were also observed.

Materials and Methods

Samples of (α+β)- and lead-tin-brasses in the form of round bars of 1cm thickness were obtained from the local market. Their chemical composition is given in Table 1.

Table 1: Chemical Composition

	Cu	Zn	Tin	Lead
(α+β) Brass (at%)	60	40	-	-
Lead-tin brass (at%)	55.82	39.29	2.48	2.43

Specimens in the form of round bars with gauge diameter 6mm and gauge length 20mm were used for the tensile test. Before tensile test, specimens of (α+β)- and lead-tin-brass were solution treated and aged at different temperatures for different times and then cooled in still air at room temperature as given in Table 2. This research work was conducted at Department of Materials Science, Bahauddin Zakariya University, Multan during the year 1999-2000.

Table 2: Heat Treatments and Nomenclature

(α+β)-Brass	Lead-tin -brass	Temp.(°C)	Time (Min.)	Cooling Mode
A_1	B_1	815		30Water Quenching
A_2	B_2	815+400	30	Water+Air
A_3	-	815+400	60	Water+Air
A_4	B_4	815+500	30	Water+Air
A_5	B_5	815 +500	60	Water+Air

The tensile test were performed using manual tensile test machine "Monsanto Hounsfield Tensometer" at room temperature. The stress-strain curves are shown in Fig.1 for both brasses. The UTS, proof stress (at 0.1% of the gauge length) and elastic modulus were calculated and are given in Tables 3 and 4. Microstructures of these heat-treated tensile samples were examined at fracture point. Metallographic specimens were prepared by grinding and polishing followed by etching with hydrochloric acid and iron chloride, the latter technique resulted in effectively revealing the microstructural features, particularly grain boundaries. Hardness of all samples was measured after each heat treatment using Rockwell Hardness Tester (FR-1, Future-Tech, Japan), the depth of impression was also calculated.

Table 3: Tensile Properties of (α+β) Brass

Heat Treatments	UTS (N/mm^2)	Elastic Modulus (N/mm^2)	Elongation (%)	Reduction in Area (%)	Elastic Limit (N/mm^2)	Proof Stress at 0.1% (N/mm^2)
Quenched (A_1)	417.40	7860	27.80	64.00	148.54	191.01
Aged at 400 °C for ½ hr (A_2)	403.25	10106	30.15	60.90	134.40	173.33
Aged at 400 °C for 1 hr (A_3)	417.40	8842	29.25	62.00	141.47	187.48
Aged at 500 °C for ½ hr (A_4)	385.57	8843	28.70	72.43	134.40	169.79
Aged at 500 °C for 1 hr (A_5)	371.42	11790	29.75	70.65	84.88	148.57

Table 4: Tensile Properties of Lead-Tin-Brass

Heat Treatments	UTS (N/mm^2)	Elastic Modulus (N/mm^2)	Elongation (%)	Reduction in Area (%)	Elastic Limit (N/mm^2)	Proof Stress at 0.1 % (N/ mm^2)
Quenched (B_1)	474.00	10106	4.60	03.29	431.49	474.00
Aged at 400 °C for ½ Hr (B_2)	601.34	11790	9.50	11.31	424.42	516.45
Aged at 500 °C for ½ Hr (B_4)	580.12	7860	9.75	06.54	410.27	495.22
Aged at 500 °C for 1 Hr (B_5)	619.03	11790	9.60	12.87	410.27	509.37

Results and Discussion

Tensile Properties and Microstructure: The microstructure of water quenched (α+β) brass (Fig. 2a) after tensile test shows a transgranular ductile fracture causing elongated grains of α present in a matrix of β. Most of the β-phase has been preserved but α-phase has also formed showing not a very fast quench. The α-phase (darker) is present at grain boundaries and inside the β (light) grains. The directional characteristic of the α forming as plates extending from the boundary into the β grains {a Widmanstatten characteristic (Mujahid and Bhadeshia, 1999; Brick *et.al.*, 1977; Smith, 1993)}is not much visible. As β phase is harder than α, that is why it has high value of UTS (Table 3). But in lead-tin brass, the microstructure (Fig. 2b) consists of two regions. First region consists of very large β grains with fine distribution of discrete, globular lead particles while second portion consists of fine particles of α and β phases with tin on their grains boundaries. Due to hard and greater fractions of β phase, specimen finally fractures in the elastic limit (showing intergranular fracture) and shows brittle behavior. The lead-tin brass possesses high UTS but less elongation as compared to A_1 as clear from Fig. 1 and Tables 3 & 4.

The microstructure of (α+β) brass aged at 400 °C for ½ hr (Fig. 3a) shows transgranular fracture causing elongated grains in the direction of the applied stress. Aging of this specimen allows more of the α (dark) phase to come out of the supersaturated β (light) matrix. The unstable β′ of the quenched alloy changed over to α upon reheating in the low temperature range (Avner, 1974: Brick *et.al,* 1977). The fraction of α phase has been increased with aging as compared to that in quenched sample and made the specimen softer. That is why it has less UTS and more elongation (Table 3) as compared to A_1. But in lead-tin brass (Fig. 3b), the β grains are small in size containing a large number of fine α feathers. α is also present at the grain boundaries. The lead is observed in the microstructure as discrete, globular particles because it is practically insoluble in solid copper. Tin fills the areas between α feathers. This causes very high UTS and less elongation as compared to A_2 & B_2 (Fig. 1 and Tables 3 & 4). The microstructure shows intergranular and fibrous fracture. The microstructure of (α+β) brass aged at 400 °C for 1 hr (Fig. 4a) is of similar type as Fig. 3a but fractions of α has been increased as the aging time has increased. Due to this reason, specimen shows more elongation as compared to A_1 (Fig. 1 & Table 3).

Aging of (α+β) brass at 500 °C for ½ and 1hr (Figs. 5a, and 6a) shows that larger fraction of α (dark) has been precipitated out from the β matrix as compared to samples A_2 and A_3. That is why the specimens show less UTS but more ductility as compared to A_1 (Table 3). But in lead-tin brass, the microstructure (Fig. 5b) shows sharp cuts (cleavage) at the fracture point. Aging to this temperature resulted in the attainment of approximately equilibrium proportions of the two phases. Due to this, it has high UTS as compared to A_1 & B_1 but more elongation with respect to B_1 (Fig. 1 and Tables 3 & 4). But the microstructure of lead-tin brass aged at 500 °C for 1hr (Fig. 6b) shows intergranular and fibrous fracture as it consists of two regions. One region consists of fine β grains containing fine precipitated α grains while other shows small α feathers with lead and tin particles randomly distributed. That is why it has high value of UTS and less elongation with respect to all samples of (α+β) brass (Fig. 1 and Tables 3 & 4).

Hardness and Depth of Impression: The Rockwell hardness values and corresponding depth of impressions

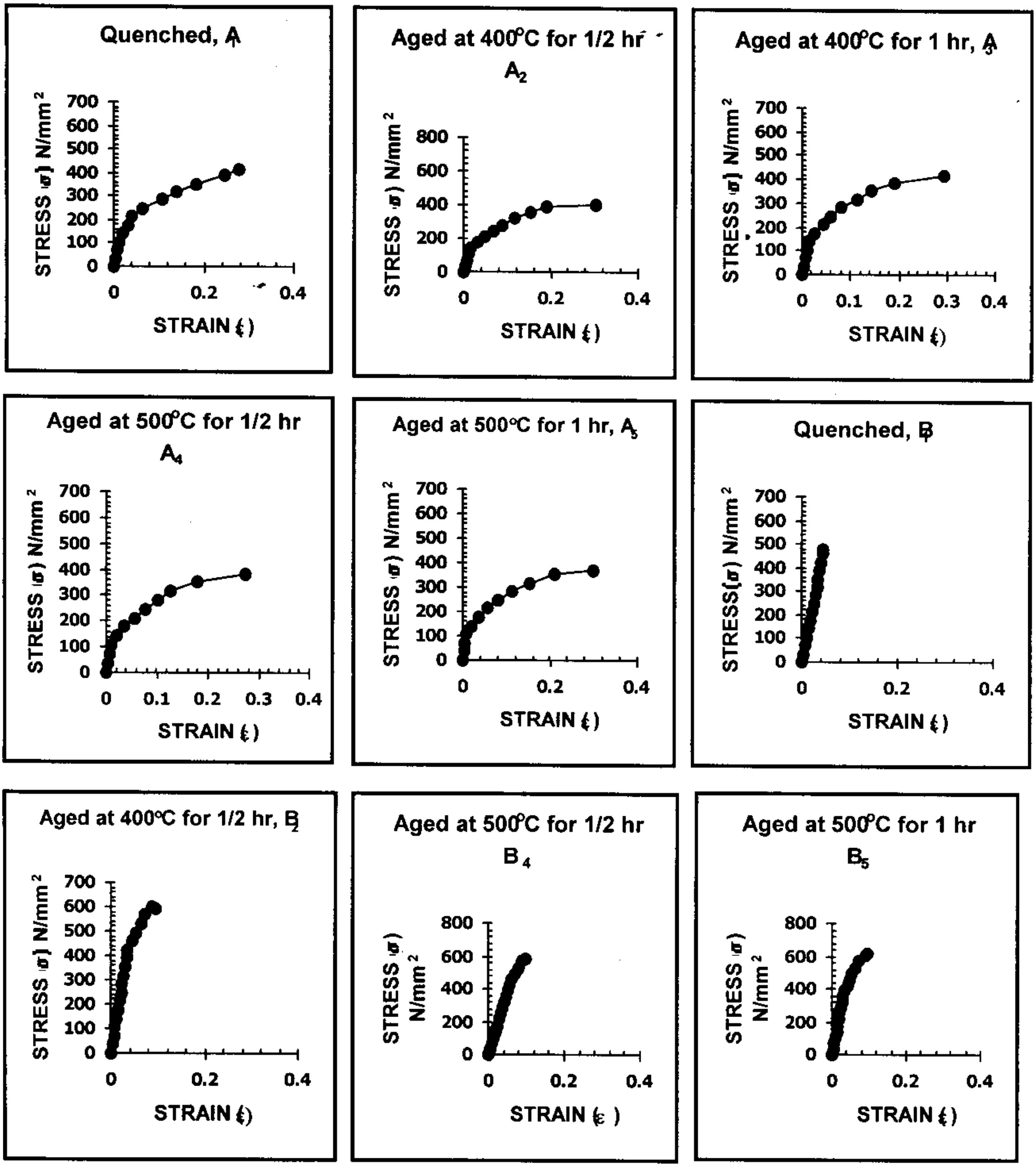

Fig. 1: Stress-Strain plots for (α+β)-brass and lead-tin-brass after different heat treatments (as mentioned in each graph)

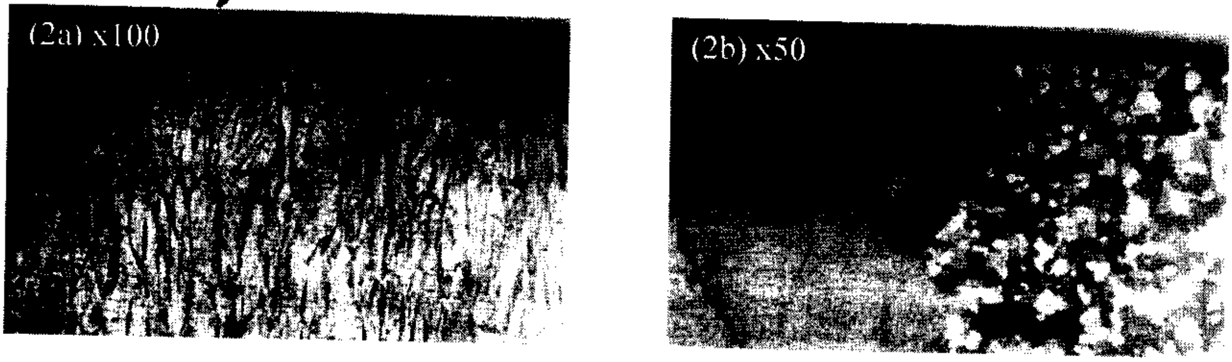

Fig. 2: Microstructure of quenched a) (α+β)-brass, b) lead-tin-brass.

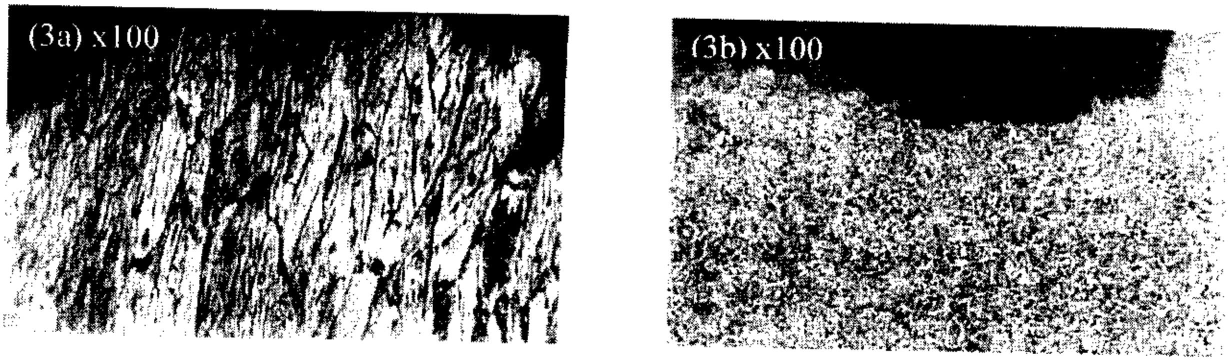

Fig. 3: Microstructure of a) (α+β)-brass, b) lead-tin-brass aged at 400 °C for ½ hr.

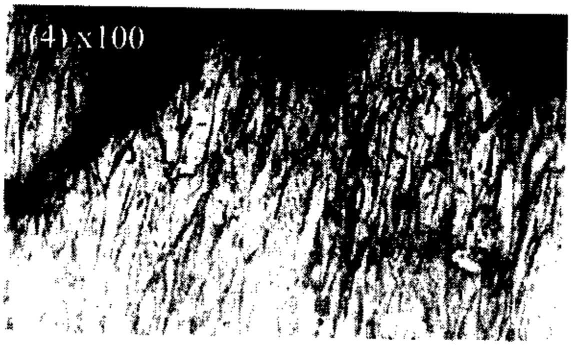

Fig. 4: Microstructure of (α+β)-brass aged at 400 °C for 1 hr.

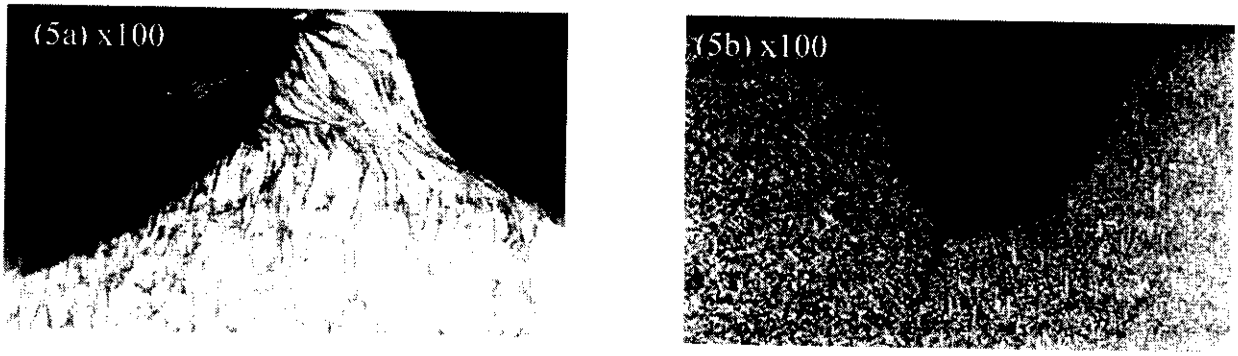

Fig. 5: Microstructure of a) (α+β)-brass, b) lead-tin-brass aged at 500 °C for ½ hr.

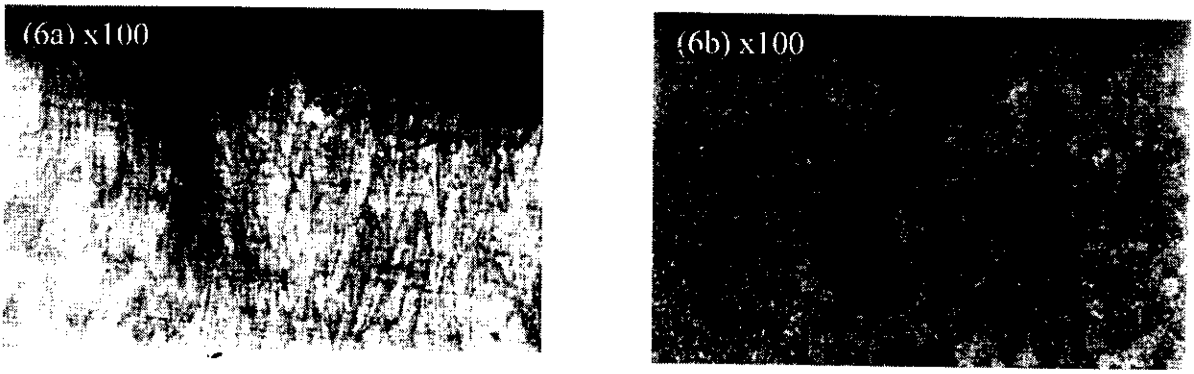

Fig. 6: Microstructure of a) $(\alpha+\beta)$-brass, b) lead-tin-brass aged at 500 °C for 1 hr.

Table 5: Rockwell Hardness (HRF) & Depth of Impression for $(\alpha+\beta)$ brass

	Quenched		Aged at 400 °C for ½ hr		Aged at 400 °C for 1 hr		Aged at 500 °C for ½ hr		Aged at 500 °C for 1 hr	
	HRF	Depth (mm)	HRF	Depth (mm)	HRF	Depth (mm)	HRF	Depth (mm)	HRF	Depth (mm)
	64.20	0.131	63.60	0.132	60.50	0.139	55.50	0.149	56.20	0.147
	64.90	0.131	63.20	0.133	61.10	0.137	57.70	0.144	57.50	0.145
	66.70	0.127	60.50	0.139	63.30	0.133	59.00	0.142	55.90	0.148
	66.00	0.128	61.80	0.136	62.40	0.135	57.90	0.144	52.90	0.154
Mean	65.45	0.129	62.27	0.135	61.82	0.136	57.52	0.145	55.55	0.148

Table 6: Rockwell Hardness (HRF) & Depth of Impression for lead-tin brass

	Quenched		Aged at 400 °C for ½ hr		Aged at 500 °C for½ hr		Aged at 500 °C for 1 hr	
	HRF	Depth (mm)	HRF	Depth (mm)	HRF	Depth (mm)	HRF	Depth (mm)
	99.30	0.061	98.50	0.063	97.40	0.065	98.00	0.064
	100.20	0.060	98.90	0.062	96.50	0.067	97.40	0.065
	101.10	0.058	98.10	0.064	96.50	0.067	99.10	0.061
	100.50	0.059	98.30	0.063	97.00	0.066	96.70	0.067
Mean	100.30	0.059	98.45	0.063	97.00	0.066	97.80	0.064

are illustrated in Table 5 for $(\alpha+\beta)$ brass and in Table 6 for lead-tin brass. A comparison of hardness values (Tables 5 & 6) shows that the addition of tin and lead in $(\alpha+\beta)$ brass has caused a remarkable increase in hardness. Furthermore, higher hardness values of quenched samples are related to the larger fraction of β phase as well as the random distribution of lead and tin in case of lead-tin-brass that are retained in the solid solution and also to the distribution of phases that exhibit higher hardness (Higgins, 1991). Variations in the depth of impression can be attributed to the size and distribution of different phases present in the $(\alpha+\beta)$- and lead-tin-brasses.

Conclusion

It was concluded that:

- The $(\alpha+\beta)$-Brass shows small variations in tensile properties with ageing while the addition of lead and tin to $(\alpha+\beta)$-brass causes large changes in these properties.
- The addition of lead and tin in $(\alpha+\beta)$ brass causes a remarkable increase in hardness.
- The best combination of UTS, elongation and Rockwell hardness (HRF) is obtained by aging $(\alpha+\beta)$ brass at 400 °C for 1 hr and lead-tin-brass at 500 °C for 1 hr.

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