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Heat Treatment Effects on Mechanical Properties of (α+β) and Lead-tin Brasses

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Abstract: Commercially available two different compositions of (α+β) brass and lead-tin-brass were annealed, normalized and solution-treated at 815 °C for ½ hr. The tensile test data were analyzed to find the UTS (ultimate tensile strength), elastic modulus, %elongation and reduction in area. The UTS of (α+β) brass with different heat treatments was found to vary between 360.81 to 417.40 MPa with elongation of 8.6-32.0% and between 399.72 to 474.00 MPa with elongation of 4.6-9.9% for lead-tin-brass. The Rockwell hardness (HRF) with these heat treatments was observed to decrease variably for (α+β) brass and also for annealed and normalized samples of lead-tin-brass but increased for solution treated sample.

Key words: Heat treatment effects, Mechanical Properties, Lead-tin Brasses

Introduction

Brasses are essentially alloys of copper {a very important engineering metal not only in pure form but also when combined with other elements to form alloys (Donald's, 1987)} and zinc. Some brasses may have small amounts of alloying elements such as lead, tin, or aluminum to improve their machinability and corrosion resistance. The (α+β)-brass consists 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 had been studied (Suery and Baudelet, 1980) taking into account the nature of deformation of the two individual phases. It was concluded that the brass shows superplastic behavior at higher temperatures due to β phase as β phase becomes softer at these high temperatures while at lower temperatures, dynamic recrystallization was observed (Roberts, 1984).

Typical applications of these brasses include condenser heads, perforated metal, architectural work, hardware, gears, automotive high speed screw machine parts, decorative moldings, grills, welding rods, propeller shafts etc (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. The microstructure of rapidly cooled (α+β)-brass is governed by the isothermal transformation or time-temperature-transformation (TTT) diagram (Higgins, 1991). When (α+β)-brass is heated at about 800 °C, it transforms into a single-phase β (Gupta and Gupta, 1992). Rapid cooling from β phase may suppress the precipitation of most of the α phase. In the present work, effect of different cooling rates on the 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 1 cm thickness were obtained from the local market. Their chemical composition is given in Table 1.

Round bars of 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 heat treated at 815 °C for 30 min. in a tube furnace (GERO, SRAO 70-250, GmbH Germany) at the Department of Materials Science, Bahauddin Zakariya University, Multan and cooled with different cooling rates as shown in Table 2. 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), elastic limit, 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 before and after each heat treatment using Rockwell Hardness Tester (FR-1, Future-Tech, Japan), the depth of impression was also calculated.

Table 1: Chemical Composition of Brasses

	Cu	Zn	Tin	Lead
(α+β)-Brass (at%)	60.00	40.00	-	-
Lead-Tin-Brass (at%)	55.82	39.29	2.48	2.43

Table 2: Heat Treatments and Nomenclature

(α+β) -Brass	Lead-tin-brass	Temp. (°C)	Time Min.	Cooling mode
A_1	B_1	As recvd	-	--
A_2	B_2	815	30	Furnace
A_3	B_3	815	30	Air
A_4	B_4	815	30	Water Quenching

Results and Discussion

Tensile Properties and Microstructure:

Microstructures of as received (α+β)-brass (Fig. 2a) and lead-tin-brass (Fig. 2b) show transgranular and intergranular fracture respectively and consist of α phase (light) present in the β′ (low temperature β phase) matrix with different morphologies. (α+β)-Brass contains lamellar α grains, while lead-tin-brass shows fine α grains (white and pink) alongwith dark globules of lead. As β-phase is considered (Avner, 1974) to be harder than α at room temperature, variations in tensile properties can be related to the distribution of size and fraction of α and β′ phases and to the presence of tin and lead in lead-tin-brass. Lead, as small globules, causes local fracture during machining (Higgins, 1991) and tin (retained in solid solution) improves the corrosion resistance. Addition of small amounts of lead and tin in (α+β)-brass improves UTS with a decrease in its ductility with respect to (α+β)-brass as shown in Fig.1 and Tables 3 and 4.

Microstructure of annealed specimen of (α+β)-brass (Fig. 3a) shows transgranular ductile fracture with coarse and elongated α (light) grains with β (dark) present at grain boundaries. Due to slow cooling (annealing) from β phase, grains of α phase appear in the β matrix at about 770 °C, which grow and become coarse. The larger fraction of α phase (softer) decreases Ultimate Tensile Strength (UTS) by making the specimen very much ductile (Table 3 and Fig.1). The UTS value of annealed (α+β)-brass was found in agreement with literature data (Smithells Metals Reference Book, 1992; Smith, 1990). But microstructure of the annealed sample of lead-tin-brass shows intergranular fracture, due to large α feathers embedded in β matrix (Metals Handbook, 1973) and clustering of lead particles around α feathers (Fig.3b), the annealed sample shows high value of UTS with relatively more elongation as compared to that of B_1 (table 4) but high UTS with less elongation as compared to that of A_1 & A_2 as clear from Fig. 1 and Tables 3 and 4.

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

Heat Treatment	UTS (Mpa)	Elastic Modulus (Mpa)	Elongation (%)	Reduction in Area (%)	Elastic Limit (MPa)	Proof Stress at 0.1% (Mpa)
As Received	389.10	7860.00	8.60	85.30	318.31	357.27
Annealed	360.81	8842.50	29.30	70.00	127.32	141.49
Normalized	410.32	11790.00	32.00	60.00	127.32	169.79
Quenched	417.40	7860.00	27.80	64.00	148.54	191.01

Table 4: Tensile Properties of Lead - tin-brass

Heat Treatment	UTS (Mpa)	Elastic Modulus (Mpa)	Elongation (%)	Reduction in Area (%)	Elastic Limit (MPa)	Proof Stress at 0.1% (Mpa)
As Received	399.72	10105.70	5.25	0.00	367.82	399.78
Annealed	438.63	8842.50	7.15	8.14	318.31	389.10
Normalized	541.21	11790.00	9.90	15.95	353.68	-
Quenched	474.00	10105.71	4.60	3.29	431.49	474.00

Table 5: Rockwell Hardness (HRF) & Depth of Impression for (α+β) brass

	As Received		Annealed		Normalized		Quenched	
	HRF	Depth (mm)	HRF	Depth (mm)	HRF	Depth (Mm)	HRF	Depth (mm)
	96.2	0.068	47.4	0.165	57.8	0.144	64.2	0.131
	92.2	0.074	43.8	0.172	57	0.146	64.9	0.131
	96.4	0.067	44.9	0.170	58.5	0.143	66.7	0.127
	93.5	0.073	41	0.176	57.4	0.145	66	0.128
Mean	94.72	0.070	44.27	0.170	57.67	0.144	65.45	0.129

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

	As Received		Annealed		Normalized		Quenched	
	HRF	Depth (mm)	HRF	Depth (mm)	HRF	Depth (Mm)	HRF	Depth (mm)
	96.9	0.066	89.3	0.081	94.80	0.070	99.3	0.061
	97.6	0.065	88.1	0.083	93.40	0.073	100.2	0.060
	96.8	0.066	89.7	0.081	94.40	0.071	101.1	0.058
	97.4	0.065	90.1	0.080	94.80	0.070	100.5	0.059
Mean	97.17	0.066	89.3	0.810	94.35	0.071	100.3	0.059

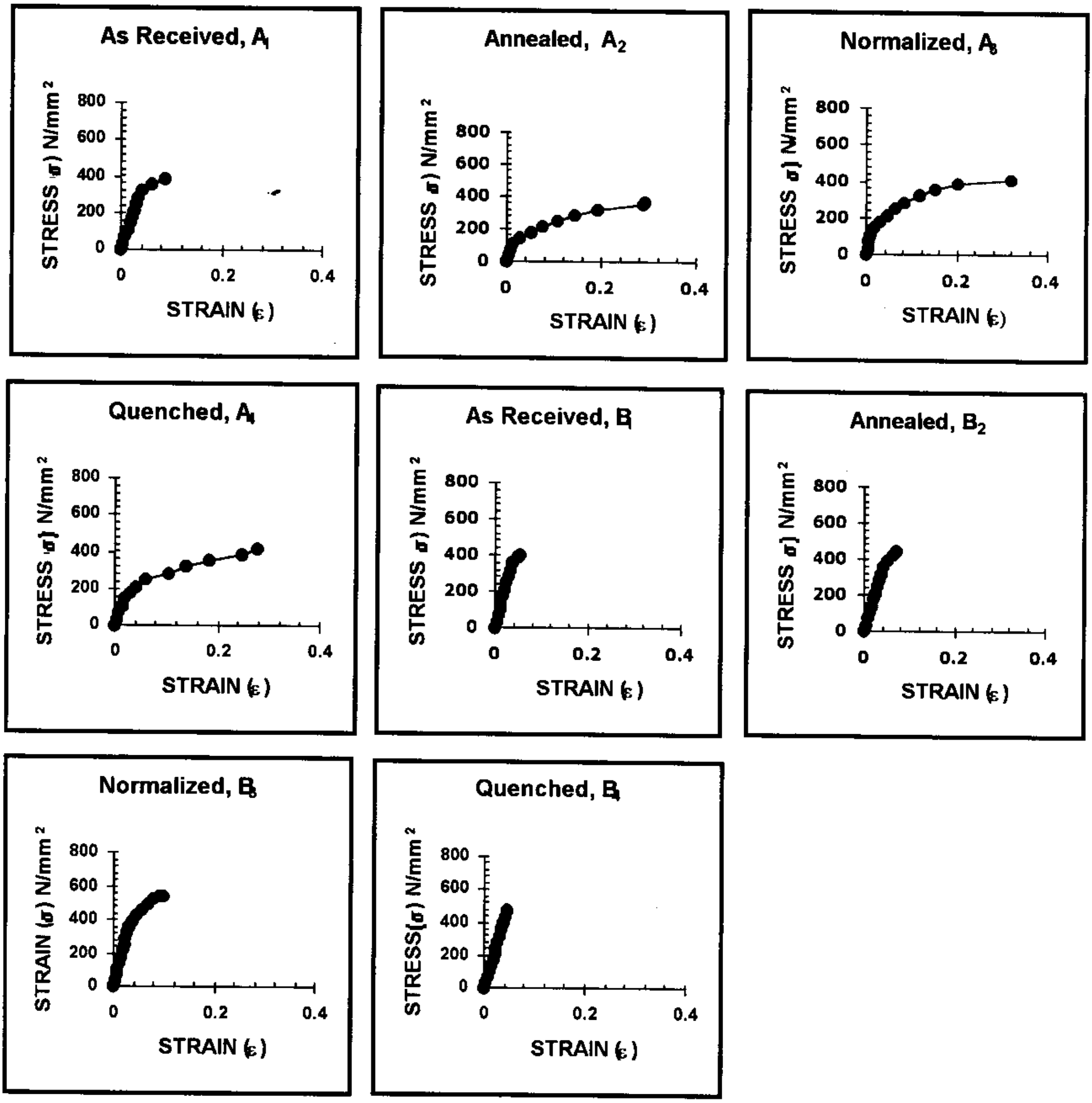

Fig. 1: Stress-Strain plots for (α+β)-brass and lead-tin-brass under different heat treatments (as mentioned in each graph)

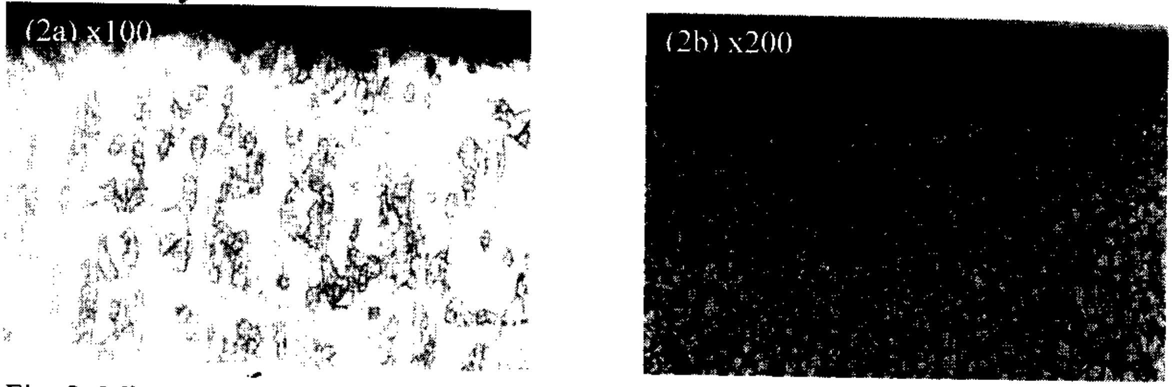

Fig. 2: Microstructure of as received a) (α+β)-brass, b) lead-tin-brass.

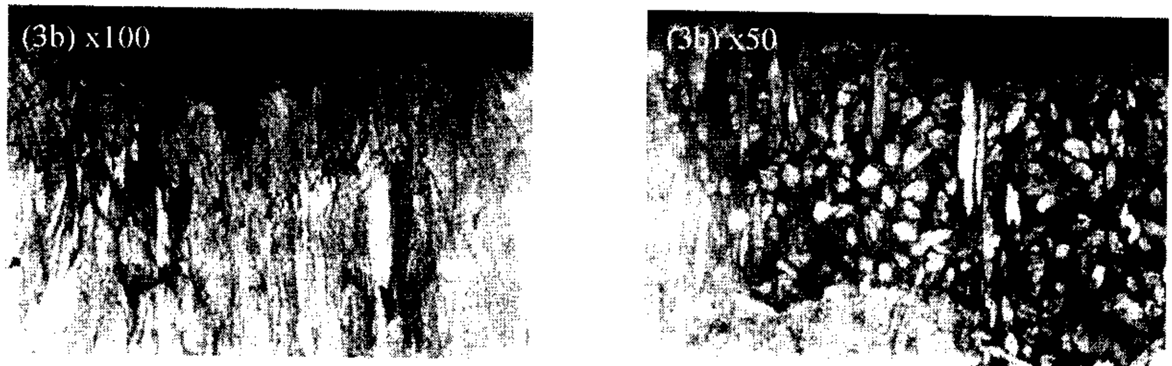

Fig. 3: Microstructure of annealed a) (α+β)-brass, b) lead-tin-brass.

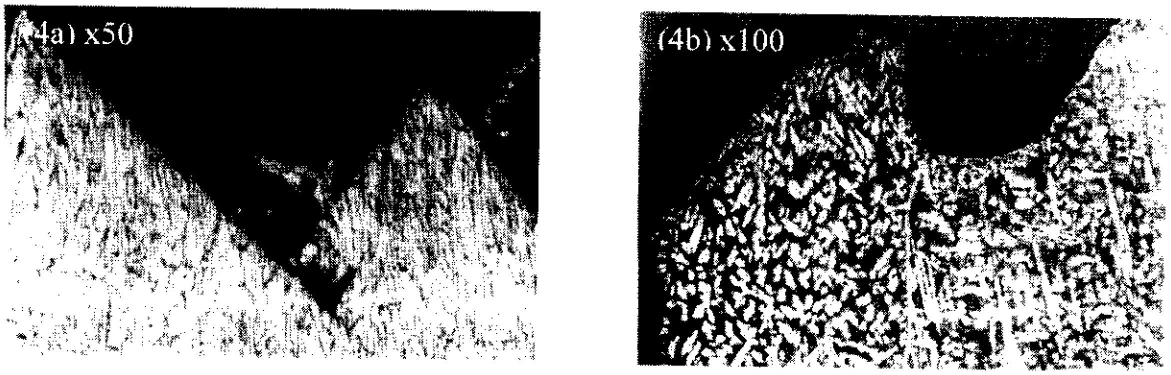

Fig. 4: Microstructure of normalized a) (α+β)-brass, b) lead-tin-brass.

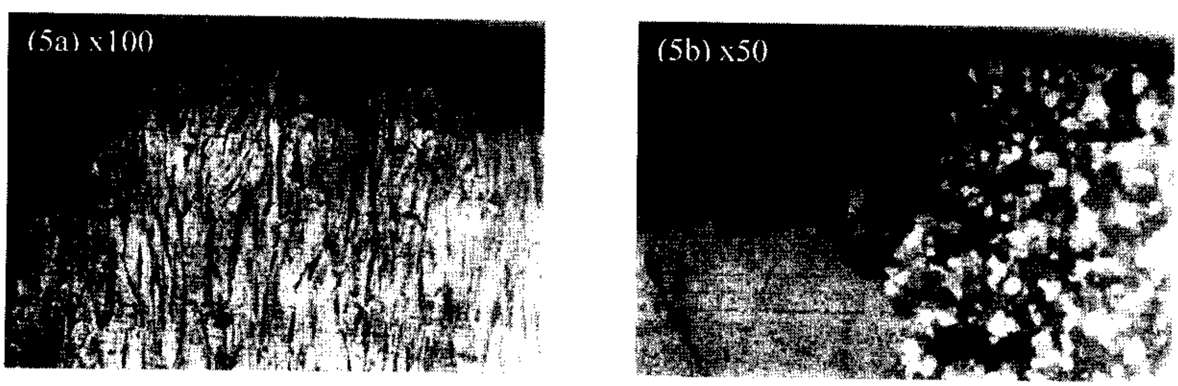

Fig. 5: Microstructure of quenched a) (α+β)-brass, b) lead-tin-brass.

Microstructure of normalized specimen of (α+β)-brass (Fig. 4a) shows sharp cuts at fracture point and elongated α (light) grains with β (dark) present at grain boundaries. Due to relatively fast cooling rate as compared to furnace annealing, the grain size of α is relatively smaller and there is more β phase as compared to that for annealed one. Normalized specimen has high UTS and more elongation (table 3) as compared to A_1 and A_2. This can be attributed to finer interlamellar spacing and precipitation of α particles in the β matrix that produced higher strength in the normalized sample (Khalid *et al.*, 1992; Khalid and Edmonds, 1993). But in lead-tin brass, the α feathers (Fig. 4b) embedded in β matrix increase in number but decrease in size. Also the presence of tin and lead particles at the grain boundaries and inside the grains makes the specimen harder (Table 6). This improves the UTS as compared to as received & annealed samples of both compositions. It is more ductile (showing fibrous and cleavage fracture) than B_1 & B_2 but less ductile than A_2 & A_3 (Fig.1 and Tables 3 and 4).

Microstructure of water quenched (A+B) brass (Fig. 5a) after tensile test shows a transgranular ductile fracture causing elongated grains of α present in β-matrix. Most of the β-phase has been preserved but α-phase has also formed showing not a very fast quench. The α-phase (dark) 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 as compared to that of samples A_1, A_2 and A_3. But in lead-tin brass (Fig. 5b), the microstructure consists of two different 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 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_4 (Fig. 1 and Tables 3 and 4).

Hardness and Depth of Impression: The Rockwell hardness values and corresponding depth of impressions are illustrated in Table 5 for (α+β) brass and in table 6 for lead-tin brass. It can be noted that normalized sample generally exhibits higher hardness as compared to annealed sample. This can be attributed to the finer interlamellar spacing and precipitation of α particles in the β matrix that produced higher strength in the normalized sample (Khalid *et al.*., 1992; Khalid and Edmonds, 1993). 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 solid solution and also 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 (α+β)- and lead-tin-brasses.

Conclusion

It was concluded that:

- (α+β)-Brass shows large variations in hardness with different heat treatments while the addition of lead and tin to (α+β)-brass causes only small changes in it.
- The UTS for as received specimen in (α+β) brass decreases by slow cooling (annealing) but increases with faster cooling i.e. air cooling and sudden cooling in water but its Rockwell hardness (HRF) decreases in all cases.
- The addition of lead and tin improves UTS but decreases ductility. Further improvement in UTS was observed with different heat treatments.
- The best combination of UTS, elongation and Rockwell hardness is obtained in normalized specimens of both brasses.

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