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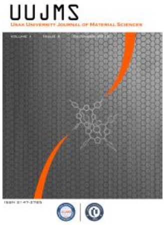

Research article

Hardness improvement of Pb75% - Sb15% - Sn10% bearing alloy through reinforcement with 5% v/v SiO_2 particulates

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Abstract

The work 'Hardness Improvement of Pb75%-Sb15%-Sn10% Bearing Alloy through Reinforcement with 5% v/v SiO_2 Particulates' has been carried out. The research involved the development of the composite. The alloy matrix which was earlier developed in the foundry shop of NMDC was used for the production of the composite through the stir cast method. The bars were prepared into test specimens some of them were solution treated, age-hardened and then they were subjected to hardness test and microstructural examination. The result of the work revealed that the as cast sample had a hardness value of 34 HRB and showed improvement when compared with the hardness value of the matrix alloy used for the development of the composite which had a hardness value of 27.7 HRB. The highest value of 35 HRB occurred after 3 hrs of age-hardening the composite. The microstructural analysis confirmed the changes in the hardness values as it revealed the constituent phases of the composite at different ageing periods. The microstructure also agreed with revelations from Scanning Electron Microscope (SEM) images captured on similar alloys. The improved hardness recorded with the reinforcement of Pb75%-Sb15%-Sn10%alloy with particulate silica clearly confirms that the bearing alloy in the form of a composite can sustain heavier loads.

***Keywords*:** Bearing alloy, composite, particulate, reinforcement, hardness improvement.

1. Introduction

Lead was one of the first metals known to man. All civilization beginning with the ancient Egyptians, Assyrians, and Babylonians, have used lead for many ornamental and structural purposes. Lead possesses good antifriction. Lead base alloys containing copper, antimony and Tin possess excellent casting properties but are used where strength and weight are not important, rather resistance to corrosion is the only consideration [1]. Lead base alloys possess low tensile strength of the order of 600 to 1000 kg/cm^2. Lead base alloys are costlier than zinc base alloys. Lead base alloys being toxic need careful handling. There is a gradualshift from the use of lead based alloy to lead free alloys [2], be it as the case may be a lot of lead bearing alloys are still used in some countries. It is also important to note that every research is important if it is able to solve a problem or to meet a need. A common die-casting lead base alloy contains 15%

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antimony, 5% tin, 0.5% copper, and the remaining lead. Antimony increases hardness whereas tin improves hardness, strength and fluidity of lead base alloys. Applications include accumulator plates, and terminal caps, radiation (X-ray) shielding, battery parts and light duty bearings [1].

Lead and tin alloys are used as bearing materials for antifriction bearings. When antimony is added, they are known as babbit metals. A typical composition of a lead based alloy is 75%Pb, 15%Sb and 10% Sn. Lead based alloys are softer and more brittle than the tin base alloys. They have a higher coefficient of friction as compared to tin based alloys. Lead based alloys are suitable for light and medium loads whereas tin base alloys are preferred for higher loads and speeds. Lead base alloys are used in rail road freight cars. Lead base alloys have a solidus temperature of approximately 240^{0}C. It has a good ability to embed dirt, conformability to journal, corrosion resistance and very good seizure resistance, etc [1]. Despite these properties the low hardness and strength of lead base alloys limit its use as a bearing material to light and medium loads bearings. There is a need to improve the hardness of lead base alloys so that it can be used for higher loads and speeds. This can be done through composite production using the alloy as a matrix. The alloy will be reinforced with particulates to increase both strength and hardness. According to Ihom et al. [3] composites combine the attractive properties of the other classes of materials while avoiding some of their drawbacks. They are light, stiff, and strong, and they can be tough. Metal matrix composites (MMCs) reinforced with ceramics or metallic particles are widely used due to their high specific modulus, strength, hardness and wear resistance. MMCs have been considered as an alternative to monolithic metallic materials or conventional alloys in a number of specialized applications. The majority of such materials are metallic matrices reinforced with high strength, high modulus and often brittle second phase in the form of fibre, particulate, whiskers, embedded in a ductile metal matrix.

Quartz, the second most common of all minerals, is composed of silicon dioxide, or silica, SiO_2. It is distributed all over the world as a constituent of rocks and in the form of pure deposits. It is an essential constituent of igneous rocks such as granite, rhyolite, and pegmatite, which contain an excess of silica. In metamorphic rocks, it is a major constituent of the various forms of gneiss and schist; the metamorphic rock quartzite is composed almost entirely of quartz. Quartz crystallizes in the rhombohedral system. The size of the crystals varies from specimens weighing a metric ton to minute particles that sparkle in rock surfaces. Quartz is also common in massive forms, which contain particles ranging in size from coarse-grained to cryptocrystalline (grains invisible to the naked eye but observable under a microscope). The mineral has a hardness of 7 and specific gravity of 2.65. The luster in some specimens is vitreous; in others it is greasy or splendent (shining glossily). Some specimens are transparent; others are translucent. In the pure form, the mineral is colorless, but it is commonly colored by impurities. Quartz crystals undergo structural transformations when heated. Ordinary, or low, quartz, when heated to 573°C (1063.4°F), is converted into high quartz, which has a different crystal structure and different physical properties. When cooled, however, high quartz reverts to low quartz. Between 870°C and 1470°C (1598°F and 2678°F), quartz exists in the form called tridymite, and above 1470°C (2678°F), the stable form is known as cristobalite. At about 1710°C (3078°F), the mineral melts [4]. Deposits of different varieties of quartz abound in Jos-Nigeria and the clear transparent and lustrous type was selected for this research work based on the properties outlined above the material meets the specification expected of a reinforcing agent [5].

Bearing supports moving parts such as shafts and spindles of a machine or mechanism. Bearings may be classified as rolling contact and plain bearings. Giving an overview of bearing metals by several authors [1-2, 6-7], the authors argued that the mechanical requirements of a bearing metal can only be met by the intelligent use of alloying. Some authors [5-8] argue that it can also be met through composite material. They all however, agree that a bearing must be hard and wear-resistant with a low coefficient of friction but at the same time be tough, shock resistant and sufficiently ductile to allow for 'running in'. These properties of hardness, toughness and ductility cannot be found to the required degree in a single–phase alloy. Thus, intermetallic compounds are hard and have a low coefficient of friction but are extremely brittle, whilst pure metals and solid solutions though ductile are usually soft and with a relatively high coefficient of friction. A suitable combination of mechanical properties can, however, is obtained by using an alloy in which particles of a hard intermetallic compounds are embedded in a matrix of ductile solid solution or in some cases a eutectic of two solid solutions. Alternatively, pure metals or alloys can be used to produce composites with hard particulates embedded in the matrix of the metals and alloys. Pb-Sb-Sb alloy form intermetallic compound of SbSn in the matrix of the eutectic alongside β and α solid solutions [1-9]. Khana [1] in his work found out that during the 'running in' process the soft matrix tends to wear leaving the hard particles standing proud. This not only reduces the overall coefficient of friction of the bearing surface but also provides channels through which lubricant can flow [1-2].

The objective of this paper is to use the composite route to improve on the hardness characteristic of Pb-15Sb-10Sn bearing alloy so that it can be used for heavy duty loading and high speed devices.

2. Materials and Methods

2.1. Materials and Equipment

The materials used for the work were Pb75%-Sb15%-Sn10% alloy with a hardness value of 27.7 HRB produced in the foundry shop of NMDC Jos, pure quartz from Jos deposit at Rukuba, clay, alumina, and silicon carbide powder, and water. The equipment used included, melting crucible furnace, heating oven, specimen lathe, Rockwell hardness tester, computerized metallurgical microscope, grinding and polishing disc, stirring device, electronic weighing balance, permanent mould, tongs, and quenching bath.

2.2. Methods

2.2.1. Composite Production

The composite was produced using Pb75%-Sb15%-Sn10% alloy with a hardness value of 27.7 HRB produced in the foundry shop of NMDC Jos. The charge to produce the composite was calculated based on the dimension of the test specimen which was 20 cm x Ø2cm. The charge was introduced into the crucible furnace which was equipped with a mechanical stirrer. The furnace which was preheated earlier to 300°C had the temperature raised to 500°C after charging. When the alloy was completely melted, 5%v/v of quartz (SiO_2) which was pulverized using laboratory ball mill to 63 microns passing was introduced into the melt. The mechanical stirrer was inserted and the stirring was done at the rate of 315 rpm for 1 minute; to avoid freezing, the temperature was equally raised to 600°C. The melt was then quickly poured into permanent moulds which were sealed at the bottom and by the side with clay to avoid leakage. After cooling the solidified bars were removed; three test bars were produced. Lead is poisonous; therefore, all the workers wore nose mask to avoid inhaling the lead vapor.

2.2.2. Ageing

The bars were prepared into test specimens of 2cm x 2cm using specimen lathe. Some of the specimens were heated to 300°C in the oven and held for 1h and then quenched in warm water. The specimens were then artificially aged in the oven at 100°C, for time ranging from 1 to 4h. They were then subjected to hardness test and microstructural examination.

2.3. Microstructure Examinations

The specimens were ground and polished. A belted grinding machine with grits 240-600 was used. The specimens were then transferred to a pre-polishing disc where alumina powder paste of 1 micron was used for pre-polishing. The specimens were finally polished on the finishing disc; 0.5 micron of alumina paste was used. It was ensured that the surfaces were devoid of scratches and it was thoroughly washed and dried using a hand blower to avoid chemical corrosion. 2% nital solution was used to etch the specimen and rinsing was done using clean water. It was then dried using a blower before transferring to the microscope for viewing and taking of the photomicrograph of the microstructure.

3. Results and Discussion

The results of the work are as presented in Table 1 and Fig. 1.

3.1. Discussion

3.1.1. Hardness Test

Table 1 shows the hardness values of the as cast composite and that of the composites age hardened at various ageing temperatures. The alloy matrix used for the production of the composite had a hardness value of 27.7 HRB. The as-cast composite had a hardness value of 34 HRB; after ageing for 1h the hardness value dropped to 32 HRB, however, It rose to 34 HRB after ageing for 2h and then 35 HRB after 3h of ageing. The hardness then dropped to 32 HRB after 4h of ageing. It is clear from this result that the age hardening of the composite did not result in reasonable increase in the hardness of the composite. This may be because no further phase precipitation or little occurred during the ageing process. The alloy matrix as indicated in works carried out by several authors [1-2, 5-10] has precipitates of SnSb intermetallics; this is responsible for the hardness of the Pb/Sb/Sn alloy. The hardness of the as cast composite increased above that of the alloy matrix indicating that the silica reinforcement used was responsible for the increase in hardness of the composite over that of the alloy used as matrix. This can be explained in terms of solid solution formation with the matrix and dispersion effect. The SbSn precipitate cuboids which are white in colour are dispersed in a matrix of eutectic of tin-antimony and tin-lead solid solution. This result agrees with the result of several works carried out by different authors [2, 9-12].

3.1.2. Ageing Characteristics of the Composite

Table 1 gives the effect of ageing time on the hardness values of Pb75%-Sb15%-Sn10%/5%v/vSiO_2 particulate composite. The table gives that as the ageing time increased to 1h the hardness value dropped from 34 HRB to 32 HRB. The hardness then increased reaching a peak of 35 HRB at 3h of ageing and then dropped to 32 HRB after 4h of ageing. The hardness variation with respect to ageing time can be attributed to reinforcing particulate and precipitate distribution during the ageing process [1, 12-15]. The result of the age hardening process has shown that the best ageing time for better result is 3h of ageing.

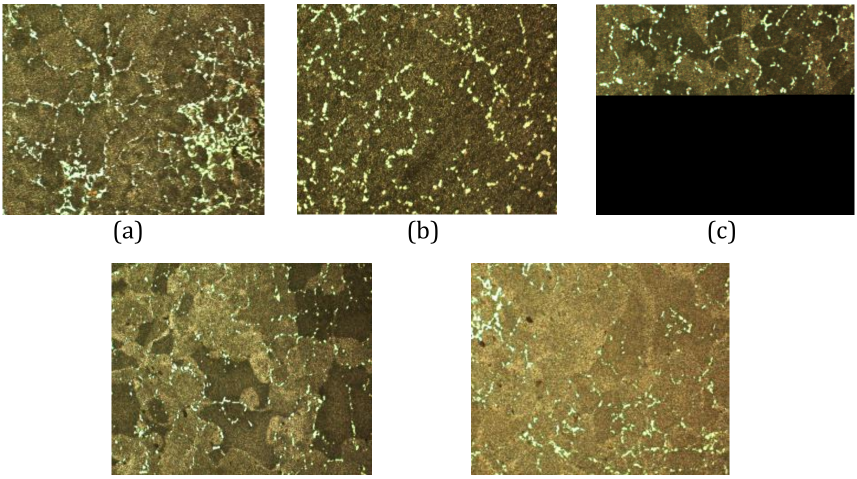
Table 1
Hardness Values of Pb75%-Sb15%-Sn10%/5%v/vSiO_2 particulate composite in HRB

S/No.	Composition	Ageing Time (h)	Hardness Values (HRB)
1.	75Pb-15Sb-10Sn/5%v/v SiO_2	0	34
2.	75Pb-15Sb-10Sn/5%v/v SiO_2	1	32
3.	75Pb-15Sb-10Sn/5%v/v SiO_2	2	34
4.	75Pb-15Sb-10Sn/5%v/v SiO_2	3	35
5.	75Pb-15Sb-10Sn/5%v/v SiO_2	4	32

3.1.3. Microstructural Analysis

Fig. 1 shows micrographs of the as cast sample (sp1), sample aged for 1h (1-1), sample aged for 2h (1-2), sample aged for 3h (1-3), and sample aged for 4h (1-4). The micrograph of the as cast sample labeled sp1, shows the intermetallic phase appearing as white precipitates or cuboids as is commonly called. The intermetallic phase is SbSn, and it precipitates from the grain boundaries in the eutectic matrix. The matrix itself reveals a eutectic structure according to Khanna [1], these properties of hardness, toughness and ductility cannot be found to the required degree in a single–phase alloy.

Thus, intermetallic compounds are hard and have a low coefficient of friction but are extremely brittle. While pure metals and solid solutions though ductile are usually soft and have a relatively high coefficient of friction. A suitable combination of mechanical properties can, however, is obtained by using an alloy in which particles of a hard intermetallic compounds are embedded in a matrix of ductile solid solution or, in some cases a eutectic of two solid solutions. Tin and antimony forms are completely soluble solutions with lead in the liquid state; however, they are partly soluble in each other in the solid state. This is clearly shown in the microstructure which is in Fig. 1, which shows cored-β within some of the grains of the samples. Previous work carried out on similar or related alloys using Scanning Electron Microscope have clearly identified the presence of SbSn intermetallic and β solid solution in the alloy see Fig. 2 and Fig. 3 [9-10]. The microstructure also shows particles which are dispersed within the matrix of the structure. These particles are seen in various quantities and distribution patterns as one view Fig. 1 1-1, 1-2, 1-3 and 1-4. The age-hardening of the samples must have affected the distribution pattern of the reinforcing particles (SiO_2). This may also be responsible for the changes observed in the hardness values of the samples at different ageing times. This fact has been confirmed by several researchers [11-13].


(a) (b) (c)

(d) (e)

Fig. 1 Micrographs (x 1000) show the as cast (SP1) (a), sample aged at 1h (1-1) (b), at 2h (1-2) (c), at 3h (1-3) (d), and at 4h (1-4) (e) (etched using 2%Nital solution)

The distribution of the precipitated phase at the grain boundaries is not so much affected by the ageing process. It must, however, be admitted that it is more concentrated and segregated in the as cast state than the age-hardened samples. This could also be responsible for the variation in hardness values. Some researchers have attested to the nature of distributed precipitates affecting the hardness values of alloys and composites [11-14].

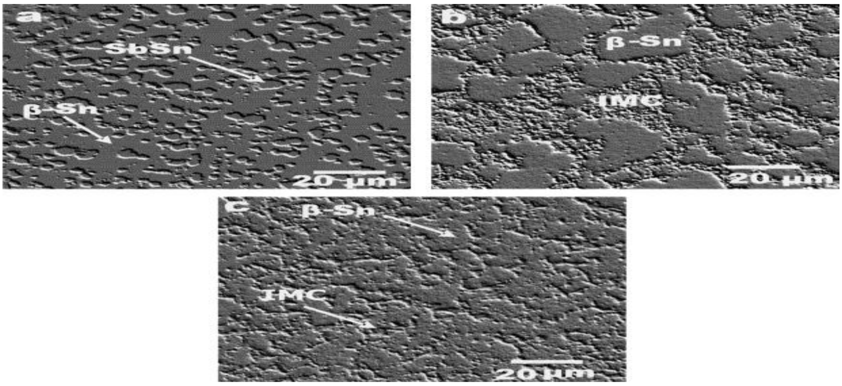


Fig. 2 Microstructure of as-cast solder alloys: (a) Sn–5Sb, (b) Sn–5Sb–3.5Ag and (c) Sn–5 Sb–1.5Au

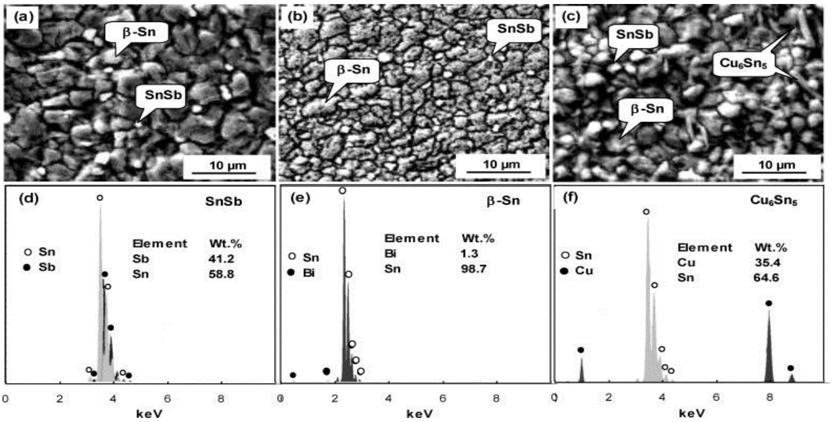


Fig. 3 SEM micrographs of: (a) Sn–5Sb, (b) Sn–5Sb–1.5Bi, (c) Sn–5Sb–1.5Cu, and EDX analyses of (d) SnSb, (e) β-Sn, and (f) Cu_6Sn_5 particles in the respective alloys

4. Conclusion

The paper has been able to X-ray the developed composite which is an attempt to improve the hardness of Pb-Sb-Sn bearing alloy through reinforcement with particulate silica, and the study have come up with the following results:

- The reinforcement (SiO_2) has improved the hardness of the bearing alloy from 27.7 HRB to 35 HRB in the as cast state.
- The ageing-hardening of the composite led to a decrease in the hardness at a certain ageing time before increasing again. However, at all the ageing temperatures the hardness was more than that of the bearing alloy alone.

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