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Mechanical Properties of Tin-Based Babbitt Alloy using the Direct Extrusion technique

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Abstract. Tin Babbitt is an ideal journal bearing material, because of its microstructural properties, which qualifies these alloys as a bearing material. Effect of the Babbitt die casting (ASTM B23 Alloy 2) on its microstructure and the hardness properties were studied. The forward extrusion type was carried out using cosine profile and the five different reduction area such 5%, 10%, 15%, 20% and 40%. The results show that the refinement of hard phases of Cu₆Sn₅ and SbSn led to increasing the hardness value after casting, and after extrusion for all reduction percent, except reduction 40%, the dynamic recrystallization is dominant which led to hardness decrease. The result also shows that the extrusion pressure increases with increasing the reduction value. Moreover, cold deformation improved the hardness properties for Babbitt alloy by refinement of the Cu₆Sn₅ phase.

1. Introduction

Babbitt of Sn–Sb–Cu alloy has been invented and considered as a patented in 1839th for use in journal bearings. Since the combination of these elements is completely compatible with steels, Babbitt alloys (or white metals) are now widely used as a material for sliding bearings [1–2]. Tin Babbitt alloys that contain about 0.5–8%, Cu and less than about 8% Sb are characterized by a solid solution matrix in which are distributed needles of Cu₆Sn₅ copper-rich constituent and fine, rounded particles of precipitated SbSn. The proportion of the copper rich constituent increases with copper content. Alloys that contain about 0.5–8% Cu and more than about 8% Sb exhibit primary cuboids of SbSn, as well as the copper-rich constituent in the matrix [3–6]. In these alloys since the matrix is a supersaturated solution of antimony in the tin, SbSn will tend to precipitate out when bearing stress and sliding contact causes heating of the surface. The presence of either or both of these intermetallic phases has a little influence on the bearing properties. However, the fatigue strength being a maximum when the intermetallic phases are present as very fine dispersals in the matrix [7]. Hardness and tensile strength increase with greater copper and antimony content, while ductility decreases. Low antimony (3–7%) and low copper content (2–4%) provide a maximum resistance to fatigue cracking. Since these low-alloy compositions are relatively soft and weak, a compromise is often made with fatigue resistance and compressive strength [8]. The properties of the Babbitt considerably depend on its chemical composition and structural state. Treatment of a material causes its structural changes and affects physical and mechanical Properties [9]. The size of SbSn-phase has a strong influence on tensile behavior and hardness according to Sadykov et al. [9] it was concluded that when this hard phase refined the wear and fatigue strength increased.

The dellima is related to cold work after casting, which cannot strengthen the Babbitt alloy due to its low recrystallization temperature. The recrystallization occurs at ambient temperature if the cold deformation exceeds up to 20 %, as the result the strength will reduce [10]. However, the study tried to introduce a new approach assessing the effect of the direct extrusion for mechanical properties and the microstructure through provides a proper control of die design after the casting process. Considerable



interest has been focused on this matter during the last decade by using contoured curved dies. Less excessive work, the flow of the metal is smooth and less deformation is the fundamental advantages of using this type of dies. According to Kumar et al. [11] study who conclude an opinion that the cosine and the third order streamlined dies are better than the other die profiles, the investigation was done by using the upper-bound model to study the cold extrusion of different die profiles. Reddy et al. [12] compared eight dissimilar die profiles by combined upper-bound /slab method. It is deduced that amongst all profiles, third and fourth order polynomial and cosine die are the best. Kashaya Kumar Rout [13] recorded that when increasing reduction and friction factor the extrusion pressure increases. This paper aims to study the influence of extrusion using four different cosine dies on the hardness of this alloy, as well as study the microstructural changes occurs during casting and extrusion.

2. Experimental work

2.1. Material Billet Preparation

The preparation of the *material billet* using the tin-based Babbitt alloy (ASTM B23 Alloy 2) has explained as well as the chemical compositions were illustrated in Table 1.

Table 1. chemical analysis of ASTM B23/2

Element	Sn	Ni	Cu	Sb	Al
Standard	88–90	≤ 0.35	3–4	7–8	0.005 max
As-received	88.91	0.12	3.82	7.21	0.1
After die casting	85.17	0.85	3.19	10.39	0.19

In this method, the die-casting was adopted using a cylindrical graphite mold with a dimension of 30×80 mm. The experimental work was conducted by melting the graphite crucible into the graphite mold; while the poured temperature was up to 418°C [14].

2.2. Extrusion tools

Figure 2 illustrates the cosine profile. The extrusion process was conducted using a mechanical press, which is used the instron compressed testing machine. The extruded metal is as in direct contact with the tools such as punch and die. Furthermore, the design of these tools should have a great attention due to these tools are exposed to specific wear and load which can be minimized to a proper design, confirming the requirements design of the piecwork is necessary. Interestingly, Die profile made by CNC machine using MATLAB software using equation (1) below [15] was applied:

$$R_{cos} = \frac{R_o + R_f}{2} + \frac{R_o - R_f}{2} \cos \frac{\pi z}{1} \quad (1)$$

Where:

L is the die length mm, R_o is the input radius mm, while, the R_f is represented the output radius mm, and Z is the effective length mm

The extrusion billets have cylindrical cross-section area of 20 mm diameter and 60 mm length with machined casting of (Ø30x80mm). The extrusion process was carried out at a speed of 5 mm/min, and five dies with cosine profile were used with a dimension of 25 mm input diameter, 15 mm effective length, and different output diameter (23.75 mm, 22.5mm, 21.25 mm, 20 mm and 15 mm) were employed. These diameters were chosen to study influence of extrusion on the mechanical properties, before the recrystallization takes place (23.75 mm, 22.5 mm, and 21.25 mm), at the point of recrystallization (20 mm), and after recrystallization (15 mm).

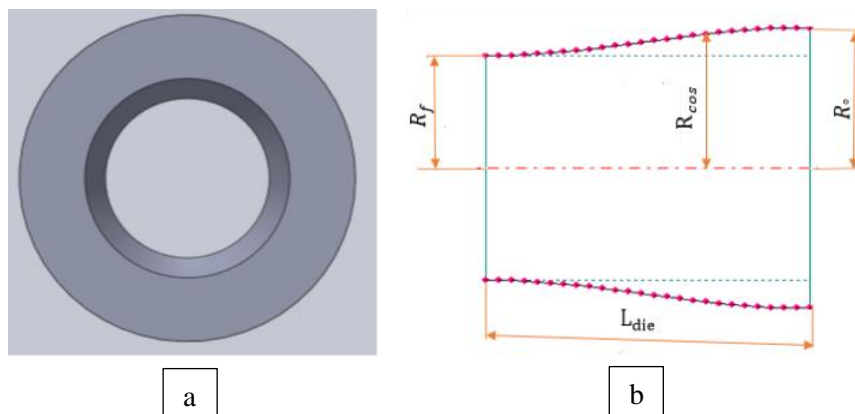


Figure 1. Die Cosine profile; a) top view of Die and (b) cosine profile

The microstructure images of the samples were analysed by the optical microscope SEM.; also, the EDX and the SEM analysis were done using Inspect S50 Scanning Electron Microscope to identify the elements of the constituting at different precipitates.

The microhardness test was carried out using Vickers hardness tester (HVS-1000). The test load and dwelling time were carried out under 100g and 10s loading system, respectively [16]. The measurement of the microhardness was selected at three positions starting from the inner to the outer edge system.

X-Ray diffraction test was carried out for the samples with a diameter of (30 mm) and a height of (5mm) using the x-ray diffraction analysis. This analysis method was performed to investigate the alloy phases which is formed before and after the die casting. More details, the X-ray type of Shimadzu 6100, Cu target, voltage, 40 K.v. and current of 30 micro-Ampere with a scan speed of 5 degrees/min was used for detecting the phases.

3. Results and Discussions

The microstructure of the alloy, as received, shows in figure 2 which illustrates α , β (fine rounded), and γ -phases (needles and asterisks). Figure 3 shows the microstructure after GDC at three positions (at the wall, at the middle distance between the wall and the center. The test determines that the morphology and distribution of the hard phases were changed after the GDC of this alloy.

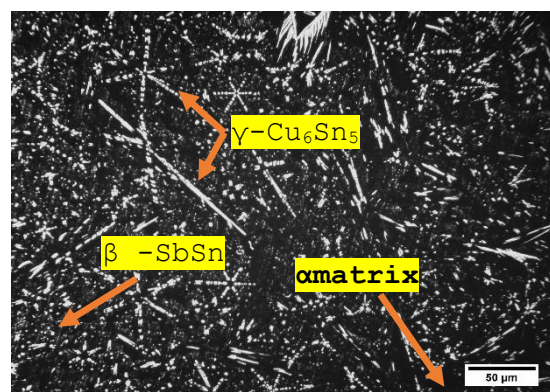


Figure 2. Microstructure examination for the as received Babbitt alloy as received

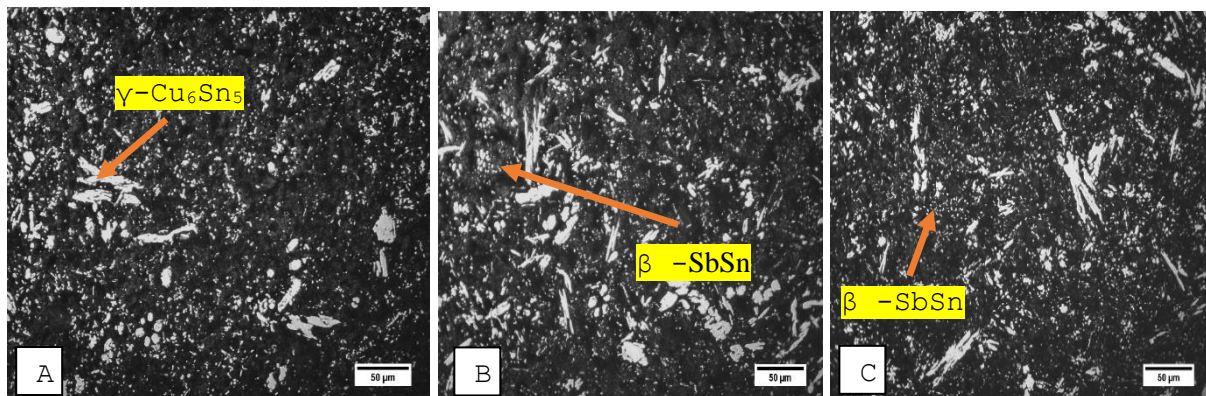


Figure (3). microstructure examination after GDC at three positions
(A) at the wall (B) at the middle (C) at the center

The XRD analysis was carried out after GDC to ensure that the phases are not changed before and after casting, as shown in figure 4. The phases were tested using the MATCH 3 software showing the appearance of SbSn and Cu_6Sn_5 phases.

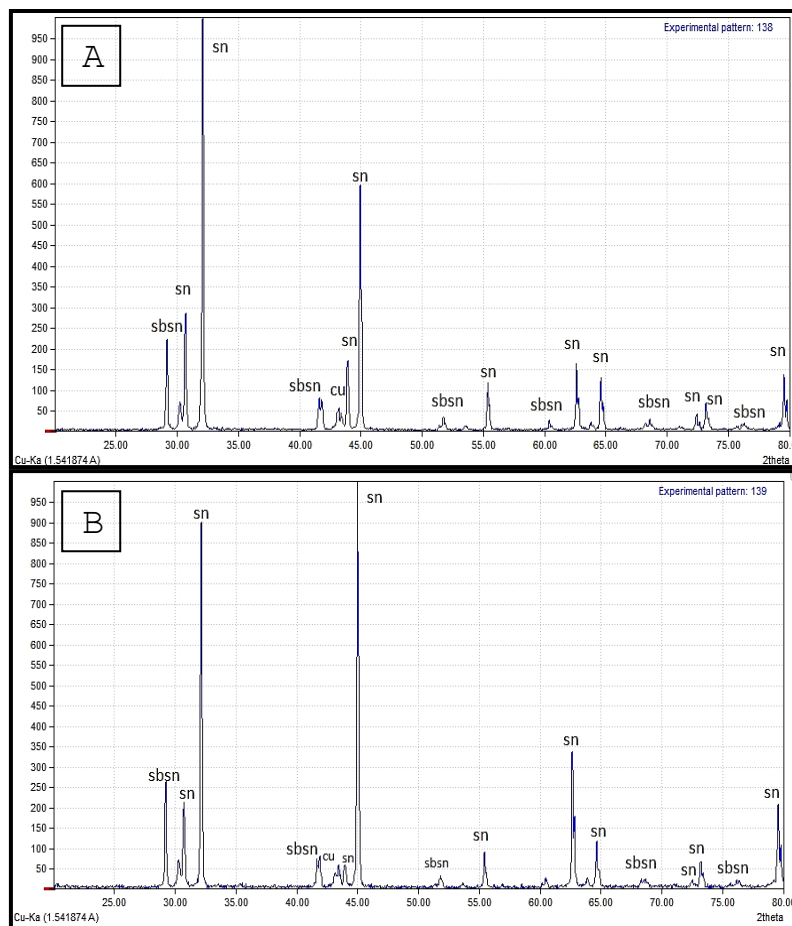


Figure 4. the XRD analysis for alloy (A) as-received (B) as-cast

The grain size measurements using the Image J program were analyzed. The phase with respect to its size and quantity at a specific location was observed. The results show that if the test results are small, it means not only that the particle size is small but also may be the quantity of this phase are small. These tests conducted with the aid of the microstructure examination, as shown in figures (5, 6, 7, 8, 9).

The figures assisted to explain the size and the distribution of these phases. The average primary solid phases were almost recorded its smallest value at the middle distance between the wall and the center (see table 2). These results could attribute in the most deformed metal layers, which is the final product located between the outer surface and the half of the radius of the extruded product [17].

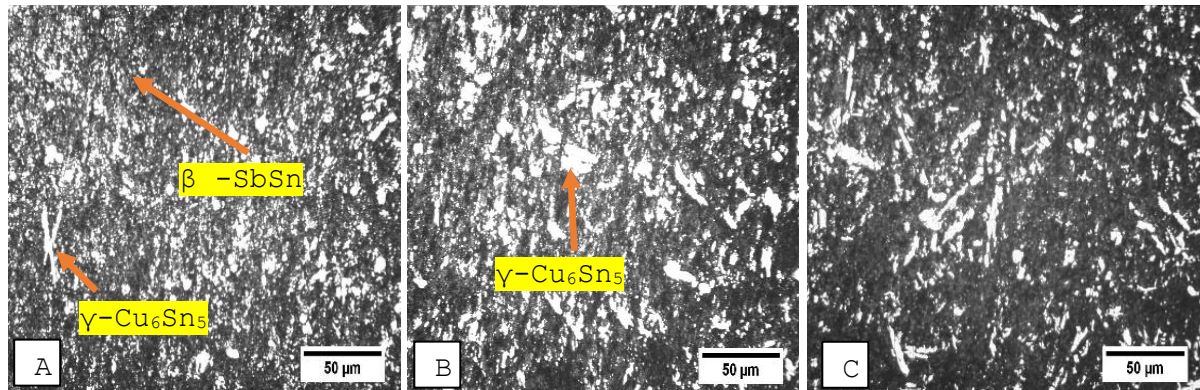


Figure 5. the microstructure of GDC extruded at 5% reduction ratio (a) Near the wall, (b) at the middle and (c) at core of the cross section

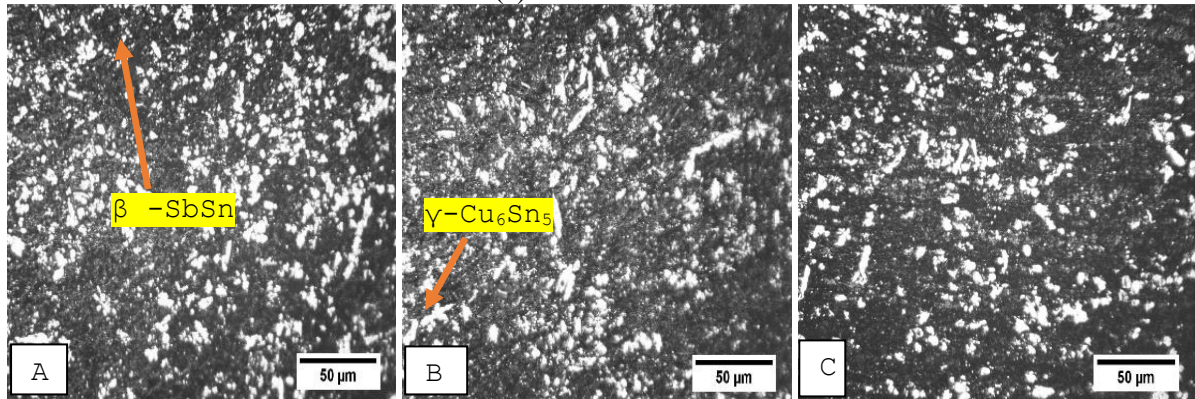


Figure 6. the microstructure of GDC extruded at 10% reduction ratio (a) Near the wall, (b) at the middle and (c) at core of the cross section

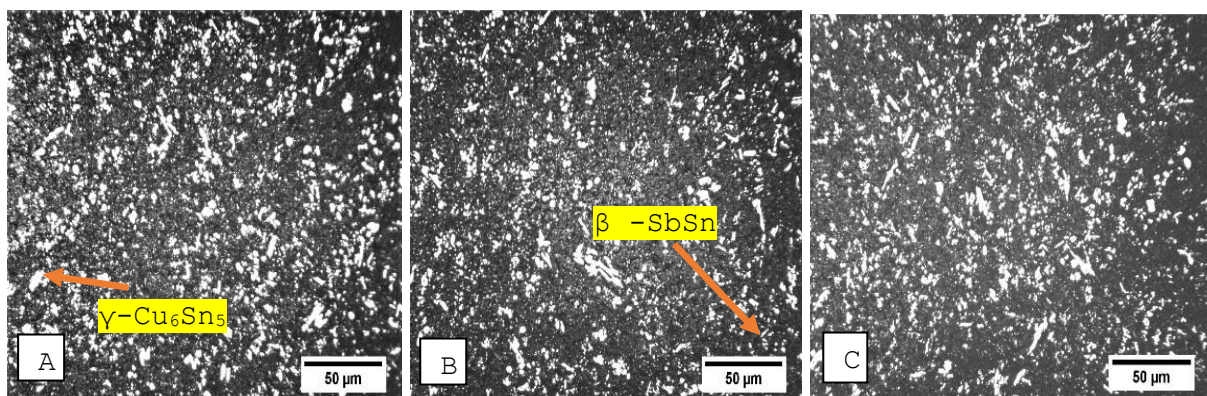


Figure 7. The microstructure of GDC extruded at 15% reduction ratio (a) Near the wall, (b) at the middle and (c) at core of the cross section

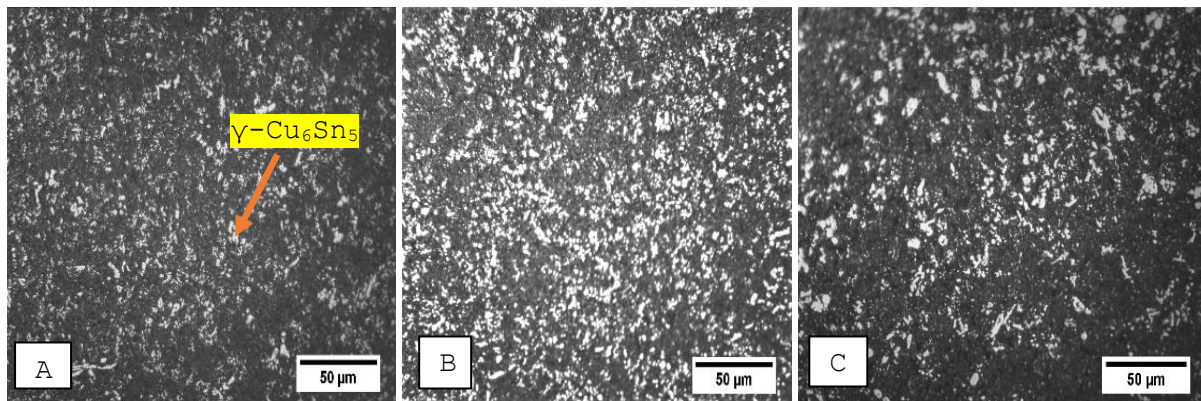


Figure 8. The microstructure of GDC extruded at 20% reduction ratio (a) Near the wall, (b) at the middle and (c) at core of the cross section

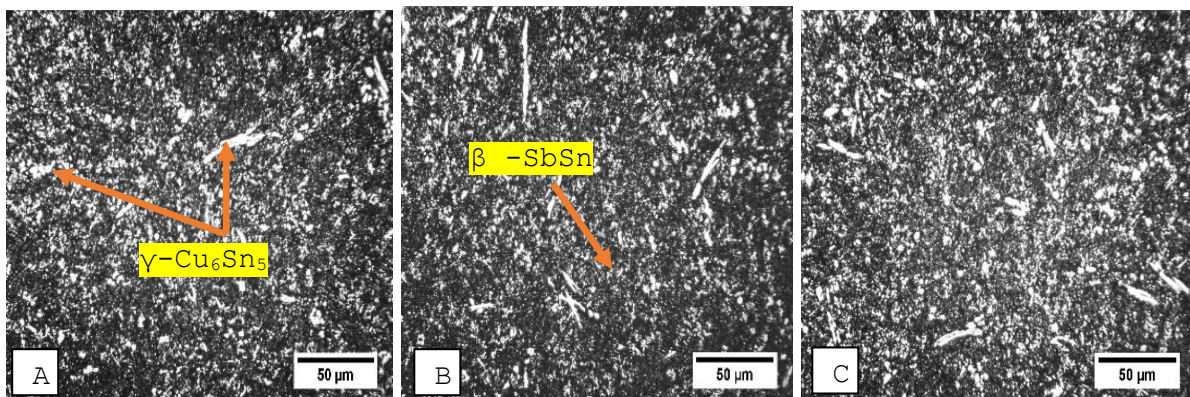


Figure 9. the microstructure of GDC extruded at 40% reduction ratio (a) Near the wall, (b) at the middle and (c) at core of the cross section

Figure 10 shows the three cases: as received, after GDC and after extrusion. It can be concluded that the Vickers microhardness at the wall of the sample was increased after the GDC by 10% compare with the as received alloy. After extrusion, the hardness was increased gradually for 5%, 10%, 15% and 20% by 7%, 9%, 20%, and 17%, respectively. The data shows that the higher value is 26 HV at 15% reduction ratio. The hardness decreases to 25 HV at 20 % reduction ratio due to recrystallization. Moreover, the minimum value of the hardness recorded at a reduction ratio of 40% and it decreases by 11% due to dynamic recrystallization, which occurred consistently. The middle zone, between the edge and the center, appeared as the most deformed layer in the final extruded product. This means that more refinement occurred of the hard precipitates [17], and the hardness value for the cast case increased by 21% compared with the as receive one.

For the extruded case, the hardness value increased by 29%, 13%, 12%, and 10% for 5%, 10%, 15%, and 20% reduction values, respectively. The optimum value was at 5% reduction ratio, as shown in figure 11. This attributed to getting the finest grain size of Cu₆Sn₅, as shown in table 2. Moreover, the recrystallization begins to take place at 20% of the reduction ratio. Therefore, the hardness value starts to decrease as the grain size decreases. For 40% reduction ratio, the hardness value decreased by 8% due to recrystallization. In the middle zone, the hardness of the casted alloy was more than for the as-received one, as shown in figure 11.

This increment in hardness can be attributed to the refinement of the hard precipitates after casting which lead to an increase of the hardness value which conforms to the results as depicted in a study of B. L.Madej [18]. To explain what appears at the center of the sample, 15% reduction area is the optimum value, which can be seen in figure 12. The hardness increased by 20 % because it has the finest grain compared with the other cases, excepting a 40% which the refinement mainly mean that the recrystallization takes place and the hardness value is decreased to 11%. For 5%, 10%, and 20%

reduction area the hardness value increased to 7%, 9% and 17%, respectively. The hardness at the center zone of the as-cast specimen increased to more than 10% compared with the as-received one. This variation in the hardness value was mainly because of the variation in the size, distribution, morphology and the amount of the hard phases in the specific location, which is the hardness property, is attributed [19].

Table 2. the average Grain size measurements of the hard phases

	Cu ₆ Sn ₅			SbSn		
		61			33.3	
	wall	Middle	Center	wall	Middle	Center
As cast	72.1	59.2	59.9	30.3	32.1	31.4
5%	75.11	54.6	70.6	51.14	49.7	40.1
10%	75.9	71.4	55	35.5	48	35.4
15%	57.6	75.18	50.9	44.4	36.87	36
20%	50	52.9	46.4	38	37	38.7
40%	38.6	28	40.8	17.6	20.4	20.3

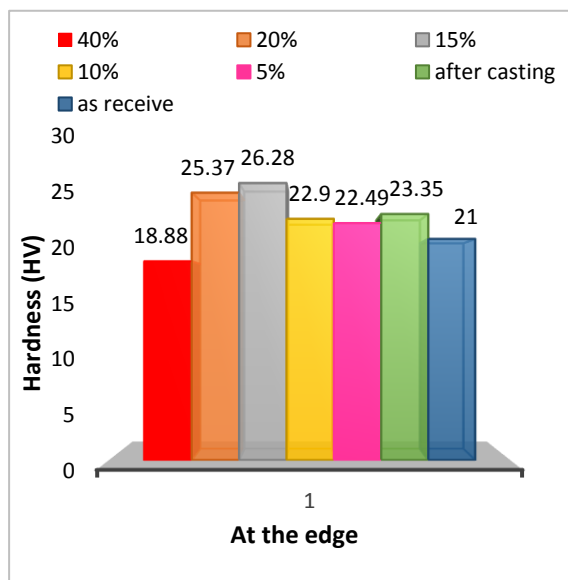


Figure 10. Vickers Microhardness at the edge for as received, as cast and after extrusion samples

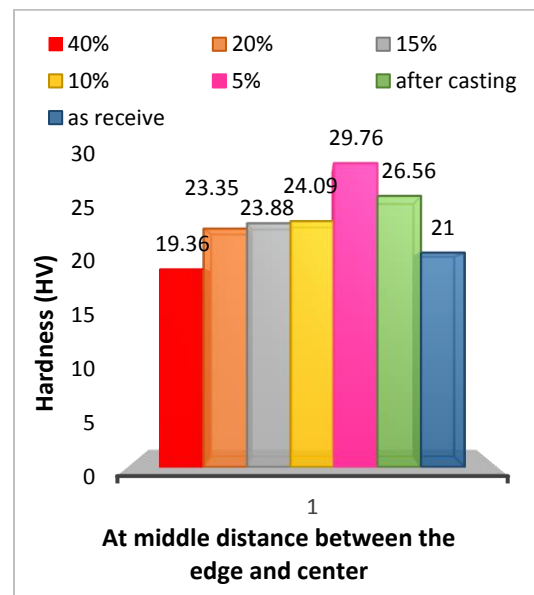


Figure 11. Vickers Microhardness at the middle zone between the edge and the center for as-received, as-cast and after extrusion samples

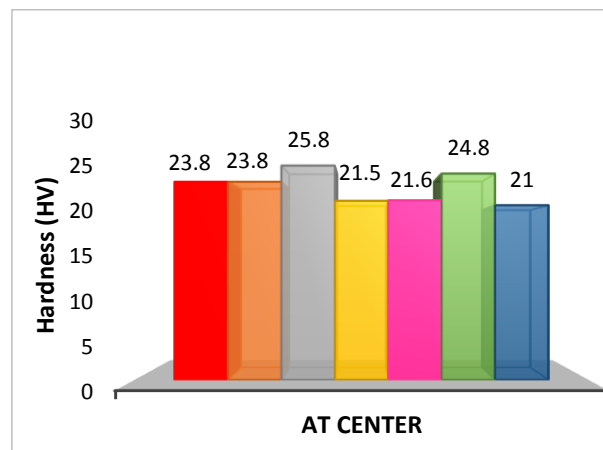


Figure 12. Vickers Microhardness at the center for as-received, as-cast and after extrusion samples

Figure 13 shows that the extrusion load increases with increasing the reduction in area and it has a maximum value at a 40% reduction.

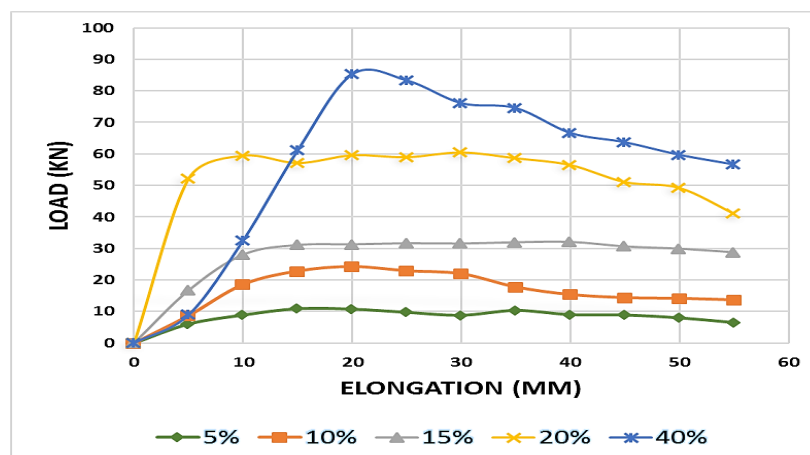


Figure 13. Flow chart of extrusion load-elongation for five extruded Samples at room temperature

4. Conclusions

1. For this understudy, GDC enhances the mechanical properties by making changes in the microstructure (sizes and distribution of the hard precipitates). The hardness value increased to 10%, 21%, and 10% at the wall location, at the middle, and at the center respectively.
2. The best-recorded ratio of reduction was 15% because it has the finest grain size before occurring the recrystallization. Moreover, it gave the maximum hardness value among the other reduction ratios. The hardness increased by 20% at the surface and at the center.
3. The worst reduction percentage was 40% reduction value due to recrystallization.
4. The morphology of the Cu₆Sn₅ hard phase changes from needles and asterisks shape to needles and round like shapes after casting and extrusion that influences the mechanical properties of the alloy.
5. In the extrusion process, the grain size of the hard precipitates, in almost all cases, decreased. Especially, in the area that locates between the wall and the centre, which is the most deformed area.

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