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# The Role of Nano Particles Additives on The Wear Properties of Al-Pb alloy

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## Abstract

The Al-Pb alloy is one of the important alloys, especially for bearings materials. The main problem of Al-Pb alloy is the difference in melting point and immiscibility between aluminum and lead. In this research mechanical alloying method was used to produce Al- 10%Pb- 4.5%Cu by mixing the constituent in a ball mill under argon atmosphere for two hours at 150 rpm , then it was pressed with different applied loads (44100, 49000, 53900, 58800 and 63700N) and at three sintering temperatures (350, 450 and 550℃). The results show that sintering temperature was the main factor affecting on the microstructure of alloy. The grain size was reduced with increasing sintering temperature and applied load. The results revealed that the best hardness and compressive strength was obtained with 58800N applied load and 450℃ sintering temperature due to the formation of $CuAl_2$ as well as good distribution of Pb.

Alumina in a form of micro and nano particles size resulted in a decline in hardness and wear resistance, while micro $Al_2O_3$ improved compressive strength and then decreased at high concentration (2wt. %). The addition of micro and nano SiC resulted in reduced hardness. Micro SiC improves wear resistance and slightly improved the compressive strength while nano SiC increased to some extent the compression strength and reduced wear resistance. The grains size decreased with the increase of the percentage of $Al_2O_3$ and SiC (micro and nano) until 1.5% $Al_2O_3$ and 1%SiC addition. X-ray diffraction indicated the formation of new Al-Cu intermetallic compound ($Cu_9Al_4$) in the alloy containing $Al_2O_3$ or SiC associated with disappears of $CuAl_2$.

**Keywords:** Mechanical alloying, Sintering, SEM, EDS, hardness, compressive strength, Wear.

## 1. Introduction

Aluminum-lead alloy considered as bearings materials of the 21st century **[1]**. The use of aluminum alloys for bearing applications has increased considerably in recent years **[2]**. Al-based bearing materials have higher fatigue strength than white metal bearings and can be used at higher working temperatures. **J. An, Y. B. Liu, Y. Lu, J. Wang, and B. Ma (2002) [3]** investigated the wear resistance of many aluminum alloys. The friction and wear properties of Al-Pb alloys fabricated by hot extrusion process with lead contents of 0-25 wt. % and Al-Pb alloys with 20 wt. % lead content prepared by casting technology were tested using a pin-on-disc test under dry-sliding conditions. The results illustrated that the Al-Pb alloys present better friction and wear characteristics than the other alloys. The wear rate and friction coefficient in Al-Pb alloys decrease with increasing Pb content. For a long time, the Al base bearing alloys used are Al–Sn base alloys in most cases. Since Pb is soft and easy to form lubrication film, and it is much cheaper than Sn, many efforts have been made to use Pb to replace Sn in bearing alloys. In recent years, Al–Pb bearing alloys have been used, especially in the automobile industry **[2]**. **K. M. Deol (2006) [4]** was selected two compositions of conventional aluminum based bearing alloys with various amounts of Sn and Pb as a soft phase. Various series of alloys with various amounts of Sn and Pb% were sintered at different sintering temperatures. Powder metallurgy method was employed for the production of the alloys. It is shown that Pb provides better uniformity in structure as compared to Sn for Al based alloys. The hardness characteristics and the structural features indicate that Pb can act as a better bearing material as compared to Sn.

An important way used to improve the mechanical properties of Al-base bearing alloys is to add alloying elements to strengthen the alloys by solid solution strengthening and precipitation strengthening **[2, 5]**. The wearing properties of Al–Pb alloys can be further improved by adding alloying elements, such as Si, Cu and Mg **[2]. M. Zhu, M. Q. Zeng, Y. Gao, L. Z. Ouyang and B.L. Li (2002) [5]** prepared Al- 10% Pb- (0, 2.5, 4.5, 5.5) % Cu alloys by mechanical alloy technique. The addition of Cu resulted in dissolving of part of Cu in Al matrix and the precipitation of $CuAl_2$ phase. The results showed that the wear properties of Al–10wt. % Pb–xwt. % Cu alloys are the best in the composition of Al–10% Pb–4.5% Cu.

Metal matrix composites (MMCs) are another important way to improve the mechanical properties of Aluminum alloy. Al is the most familiar matrix for MMCs because of its low density, good corrosion resistance and high thermal and electrical conductivity. Aluminum matrix composites (AMCs) reinforced with ceramic particulates exhibit high strength, hardness and elastic modulus **[6].** The widely used reinforcement materials are silicon carbide, $Al_2O_3$ etc., which has been observed to improve wear and abrasion resistance **[7]. M. H. Zadeh, M. Razavi, O. Mirzaee and R. Ghaderi (2013) [8]** studied the effect of adding nano-crystalline $Al_2O_3$ to the pure aluminum. Due to the existence of 1 wt. % $Al_2O_3$ hard particles and hence smaller crystalline size, wear resistance, yield strength and hardness of Al–$Al_2O_3$ composite were significantly increased. **R. S. Rana, R. Purohit and S. Das (2013) [9]** investigated and analyzed the effect of nano and micro SiC on the wear properties of AA 5083 alloy. Different weight percent of SiC particles of micron (10 wt. %) and nano (1, 2, 3, and 4 wt. %) were used for synthesis of aluminum matrix composites. The results showed that the wear rate of Al-SiCp composites with micron particles exhibits better wear resistance than composites with nano particles at higher load of (30 N) and higher sliding distance of (1885 m).

The manufacturing process of leaded aluminum alloys had been difficult owing to the big difference in specific gravity and wide immiscibility gap **[1].** Therefore, homogeneous distribution of Pb in Al matrix could not be easily obtained. Different preparing methods, including rapid solidification, stir cast, rheocast, powder metallurgy (P/M) and hot extrusion, have been used to improve microstructure homogeneity and refine the size of Pb phase in Al–Pb alloys **[4]. M. Zhu, Y. Gao , C. Y. Chung, Z. X. Che, K. C. Luo and B. L. Li (2000) [2]** used mechanical alloying (MA), powder metallurgy (PM), casting and stir casting technique for production of Al- (10, 14, 18)% Pb alloys. The results showed that MA is an effective technique of improving the microstructure and the wear properties of Al–Pb alloys.

## 2. Experimental Work

The metal powders (Al, Pb and Cu) and ceramic powders ($Al_2O_3$ and SiC) were examined to determine their purity and particle size (as shown in Table 1, 2) then the base alloy composition of (Al- 10%Pb- 4.5%Cu) were produce by mechanical alloying method. The powders were mixed in ball mill under argon atmosphere for 2 hours and 1:10 ball to weight powder ratio at 150 rpm, then it was pressed at 44100, 49000, 53900, 58800 and 63700N, while it was sintered at 350, 450 and 550℃ under argon atmosphere.

After determining the optimum applied load and sintering temperature, 0.5, 1, 1.5, 2 weight percent of micro and nano $Al_2O_3$ and SiC powders were added to the base alloy to determine their effects on the mechanical properties. The produced alloy was examined by brinell hardness test, compression test and wear test. It should be noted that the microstructure of the produced alloys were examined by Optical Microscope, X-ray Diffraction, Scanning Electron Microscope and Energy Dispersive Spectroscopy.

## 3. Results and Discussion

### 3-1 Introduction

The results concentrated on the microstructure, mechanical properties and wear properties of Al- 10%Pb- 4.5Cu formed at different applied loads and sintering temperatures. The effect of $Al_2O_3$ and SiC on the microstructure, mechanical properties and wear properties of alloy were also investigated.

### 3-2 The Base Alloy (Al- 10%Pb- 4.5%Cu)

### 3-2-1 Microstructure

The production parameters (mixing, pressing and sintering) of Al- 10%Pb- 4.5%Cu alloy have wide effects on the microstructure and as a result on the properties.

#### 3-2-1-1 Sintering at temperature of 350 ℃

The base alloy were firstly pressed at 44100, 49000, 53900, 58800 and 63700N and then sintered at 350 ℃. The microstructure of this alloy is showen in Figure 1. Where the copper is still in its original state and there is no reaction between copper and aluminum to form $Al_xCu_y$ inter metallic compound (Figures 2 and 3).The lead particles don`t expand around , and between the aluminum particles. This is may be due to low sintering temperature. Average grain size of the aluminum is affected slightly by increasing applied load. The average grain size is 67μm at 44100N applied load while it raised to 72μm with 63700N. The reason may be related also to the low sintering temperature.

X-ray diffraction indicated the absence or low content of metals oxides. The appropriate purging process of ball mill vial in the mixing stage and the optimum argon flow rate throughout furnace during sintering stage are the main purpose of preventing forming of metals oxides.

#### 3-2-1-2 Sintering at Temperature of450℃

When the base alloy (Al- 10%Pb- 4.5%Cu) was sintered at 450℃, so several changes in the microstructure took place. When the alloy was pressed at low applied load (44100N) there were copper and lead particle agglomerations. Whereas, when the applied load was increased to 58800N and 63700N the agglomerations disappeared. Increasing pressing loads promote the increase of the interaction between the alloy constituents, so the of $Al_2Cu$ formed as shown in figures (4 and 5). This intermetallic compound had very important effect on the hardness, compressive strength and wear of the alloy, as $Al_2Cu$ is a hard phase **[10]**. In the case of high applied load (63700 N) a deformation appeared in the microstructure as shown in (Figure 6c).

#### 3-2-1-3 Sintering at temperature of 550℃

The microstructure of this alloy where the sintering was at 550℃, showed the distribution of lead around aluminum particles due to the melting of lead (Figures 7 and 8). This manner of distribution caused a reduction in mechanical properties. The grain size was slightly affected, when increasing applied load at sintering temperature (Figure 9).

There was a decrease in grain size when the sintering temperature increased to 450℃ and 550℃ (Figure 9). This behavior was due to the diffusion of Al particles that occurred resulting in nucleation and development of new Al structure **[11].**

### 3-2-2 Effect of Applied Load and Sintering Temperature on Mechanical Properties

Initially hardness increased with the increasing of sintering temperature and then decreased. The decrease in hardness at 350℃ was owing to Pb remaining as a bigger droplet in the matrix of Al, due to it being in a molten state **[31]** , as well as, that there was no reaction between aluminum and copper to form intermetallic compounds. When the sintering temperature went up to 450℃, the hardness increased because of the formation of $Al_2Cu$ (Figure 4). Whereas the hardness decreased due to the expansion of Pb around Al grains after sintering at higher temperature (550℃) **[2].** The effect of increasing sintering temperature on the hardness was greater than the increasing of applied load (Figure 10).

The results showed that high compressive strength were obtained at 450℃ and 58800N in view of the presence of $Al_2Cu$ (Figure 4) and also, the appearance of plastic deformation of Al-grains (Figure 6c). while It seems that there was slight effect of applied load on the compression strength at the same sintering temperature (Figure 11). Compression strength increased with increasing sintering temperature firstly and then decreased with the raising of sintering temperature. The reasons of these behaviors were the same as that in hardness.

### 3-3 Effect of $Al_2O_3$ Additives

### 3-3-1 Microstructure

In all alloys that contain alumina, copper particles and lead, agglomerations reappear in the microstructure. The alumina (micro and nano) particles agglomerations happened because of high contact angle between Al-Pb alloy and alumina particles as well as poor wettability **[40]** (Figures 15 and 16). X-ray diffraction indicates (Figure 17) the formation of a new intermetallic compound $Cu_9Al_4$ and the absence of $CuAl_2$ intermetallic compound.

The average grain size decreased with increasing of $Al_2O_3$ (micro and nano) until 1.5%. The average grain size was 60µm and 54µm for 1.5% micro and nano $Al_2O_3$ respectively (Figure 12). This is owing to alumina particles acting as an obstacle against the grain boundary movement during sintering. While the clustering of alumina at high percent (2 wt.%) reduced its effects on the grain size [**12**].

### 3-3-2 Effect of $Al_2O_3$ on Hardness and Compressive Strength

The Addition of micro and nano-alumina had adverse effect on the hardness of the Al-Pb alloy (Figure 18). This is due to the poor wettability of alumina and the high value of the contact angle between the Al-Pb alloy and alumina**.** The presence of Pb lead to the decrease of the contact angle and increasing pressure threshold **[13]**. The alloy that contains micro alumina gives less reduction in HB value than that contains nano alumina. This is attributed to the small volume fraction of micro alumina that reduces the effect on the mechanical properties of the alloy **[12]**.

As it is known that Micro $Al_2O_3$ improves the compressive strength of the Al-10%Pb- 4.5%Cu alloy. So it increased with the increasing of micro $Al_2O_3$ to 1.5% and then it was reduced with 2%. Further increase in the amount of alumina particles which raised the possibility of clustering and finally initiated the formation of weak regions in matrix (Figure 15)**.** These clusters acted as a failing point in the alloys microstructure **[12]**.

### 3-3-3 Effect of $Al_2O_3$ on Wear Properties

The wear rate increased with increasing of $Al_2O_3$ from 0.5% to 1.5%. When the $Al_2O_3$ percentage increased to 2% the wear rate decreased, but it was still more than that of base alloy (Figure 20). The poor wettability between $Al_2O_3$ and Al-Pb alloy is the main reason for the high wear rate. Alumina particles were separated easily from the microstructure of the base alloy. These particles were working as an assistant to wear and as a result the total wear rate of alloys was raised **[13]**.When adding nano particles the negative effect of the alumina is still clear (Figure 21). The negative effect of nano alumina additives was more than micro alumina. The reason was due to the decrease in the surface roughness as the $Al_2O_3$ particle size increased **[12].**

### 3-4 Effect of SiC Additives

### 3-4-1 Microstructure

Figure 22 indicates the reduction of grain size with the increasing of SiC percent, and then it went up with incremental increase of SiC percent. The behavior of SiC particles as obstacles against grain boundaries movement was the main reason for the grain size reduction (Figure 23 and 24).

At high SiC percent (1.5% and 2%) the agglomeration of SiC particles would reduce its effect on grain growth **[34]**. X-ray diffraction analysis (Figure 26) showed the disappearance of $Al_2Cu$ and the formation of $Cu_9Al_4$ intermetallic compound.

### 3-4-2 Effect of SiC on Hardness and Compressive Strength

Also the addition of micro and nano silicon carbide had adverse effect on the hardness of the base alloy (Figure 27). The clustering of micro and nano SiC particles was the main reason of the reduction in hardness. These clusters are indicated in Figure 25.

When the base alloy with SiC additives was tested in the compression test, there was an increase in the strength of the alloy with micro-SiC. The increase can be related to the interaction between the particulates and dislocations within the matrix **[14].** Where the contact angle between the Al-Pb alloy and SiC was lower than the contact angle between aluminum and SiC **[15]**. The good wettability between Al-Pb alloy and SiC improved the compressive strength. The effects of micro SiC were better than those of nano SiC because of the clustering of nano SiC. The compressive strength increased to 12% with 1% micro SiC. Figure 28 shows the very little effect of nano SiC in all concentrations on the compressive strength.

### 3-4-3 Effect of SiC on Wear Properties

The wear rates of the base alloy with micro silicon carbide in all SiC percent were lower than wear rate of base alloy without additives. This was owing to the high hardness of SiC particles and good wettability between Al-Pb alloy and silicon carbide. The results illustrated that the alloy with 2% micro SiC had lower wear rate than other alloys. Wear rate of this alloy was reduced more than 75% over wear rate of alloy without additives under 10N applied load as an example.

Figures (29 and 30) show that the wear rate of the alloys with micro additives was better than that which contained nano additives. Due to its low bonding strength, nano SiC particles can be easily pulled out from the matrix under dry sliding conditions **[16].** The high volumes of small quantities of nano silicon carbide lead to the clustering of these particles and easy separation from the microstructure of alloy making high wear rate.

### 3.5 Conclusions

From the present work it can be concluded that:

1. Average grain size of Al- 10%Pb- 4.5%Cu is reduced with increasing sintering and applied load.
2. Sintering temperature is the main effect on the properties of the alloy.
3. Nano $Al_2O_3$ depresses alloy properties, hardness, compressive strength and wear resistance, while micro $Al_2O_3$ improves the strength.
4. Adding micro SiC particles reduces the hardness and improves compressive strength and wear resistance.
5. The effects of nano SiC are the same as those of micro SiC except the reduction of wear resistance.

### References

[1] ChV S H S R Sastry and G. R. Jananrdhana. "Densification Behavior of Al-Pb Alloys –Astudy of Effect of Certain Process Parameters" Indian Journal of Engineering & Materials Sciences Vol 17, February, 2010, PP 56-60.

[2] M. Zhu, Y. Gao, C.Y. Chung, Z.X. Che, K.C. Luo and B.L. Li "Improvement of The Wear Behaviour of Al–Pb Alloys by Mechanical Alloying". Wear 242 _2000. 47–53

[3] J. An, Y.B. Liu, Y. Lu, J. Wang, and B. Ma "Friction and Wear Characteristics of Hot-Extruded Leaded Aluminum Bearing Alloys", JMEPEG, 2002, PP433-443.

[4] K. M. Deol "Synthesis and Characterization of Immiscible Aluminum Based Bearing Alloys Through P/M Route", School of Physics and Materials Science, Thapar Institute of Engineering and Technology (Deemed University), 147004, 2006.

[5] M. Zhu, M.Q. Zeng, Y. Gao, L.Z. Ouyang and B.L. Li "Microstructure and Wear Properties of Al–Pb–Cu Alloys Prepared by Mechanical Alloying" Wear 253, 2002, 832–838

[6] Y. Mazaheri, F. Karimzadeh and M. H. Enayati "Nanoindentation Study of Al356-Al2O3 Nanocomposite Prepared by Ball Milling "Materials Sciences and Applications, 2010, 217-222

[7] G. H. Kumar, B. R. R. Bapu, R. Sagar and H. Mohit "The Abrasive Wear Behaviour of Al-SiCp Composites for Automotive Parts" IEEE, 2010, 978-1-4244-9082

[8] M. H. Zadeh, M. Razavi, O. Mirzaee, and R. Ghaderi "Characterization of Properties of Al–Al2O3 Nano-composite Synthesized Via Milling and Subsequent Casting", Journal of King Saud University – Engineering Sciences, 2013, PP75–80.

[9] R. S. Rana, R. Purohit and S. Das "Tribological Behavior of AA 5083/ Micro and Nano SiC Composites Fabricated by Ultrasonic Assisted Stir Casting Process", International Journal of Scientific and Research Publications, Vol. 3, Issue 9, 2013, PP1-7.

[10] M. Aravind, P. Yu, M.Y. Yau and D. H.L. Ng "Formation of Al2Cu and AlCu Intermetallics in Al(Cu) Alloy Matrix Composites by Reaction Sintering "Materials Science and Engineering A 380, 2004, 384–393

[11] S. P. Reddy, B. Ramana, and A. C. Reddy "Sintering Characteristics of Al–Pb/Fly-Ash Metal Matrix Composites", Trans Indian Inst. Met., 2013, PP87–95.

[12] M. Rahimian, N. Parvin and N. Ehsani "Investigation of Particle Size and Amount of Alumina on

Microstructure and Mechanical Properties of Al Matrix Composite Made by Powder Metallurgy", Materials Science and Engineering, A 527, 2010, PP1031–1038.

[13] C. G. Cordovilla "Interfacial Tensions and Threshold Pressure for Infiltration of Packed Ceramic Particulate by Al-Sn and Al-Pb Alloys", Journal of Materials Science Letters 20, 2001, PP405–407.

[14] A.R.I. Kheder, G.S. Marahleh and D.M.K. Al-Jameaa "Strengthening of Aluminum by SiC, Al2O3 and MgO", Jordan Journal of Mechanical and Industrial Engineering, Vol.5, No.6, 2011, PP533 – 541.

[15] E. Candan " Effect of Alloying Elements to Aluminium on the Wettability of AL/SiC System", Turkish J. Eng. Env. Sci., Vol.26, 2002, PP1 – 5.

[16] R. S. Rana, R. Purohit and S. Das "Tribological Behavior of AA 5083/ Micro and Nano SiC Composites Fabricated by Ultrasonic Assisted Stir Casting Process", International Journal of Scientific and Research Publications, Vol. 3, Issue 9, 2013, PP1-7.

**Table 1. Purity, diameter and specific surface area of Al, Cu and lead powders**

| Materials | Purity % | $\bar{D}_s$ (µm) | $\bar{D}_v$ (µm) | $A_w$ ($m^2/g$) |
|---|---|---|---|---|
| **Al** | 99.72 | 23.662 | 32.426 | 0.254 |
| **Pb** | 95.7 | 15.753 | 88.253 | 0.381 |
| **Cu** | 99.97 | 11.328 | 37.262 | 0.53 |

**Table 2. Purity and average particle size of micro, nano $Al_2O_3$ and micro, nano SiC**

| Materials | Purity % | Average particle size (µm) |
|---|---|---|
| **Micro$Al_2O_{3\ alpha}$** | 99.99 | 0.3 |
| **Nano $Al_2O_{3\ gamma}$** | 99.99 | 0.05 |
| **Micro SiC** | 98.79 | 10 |
| **Nano SiC** | 98 | 0.05 |

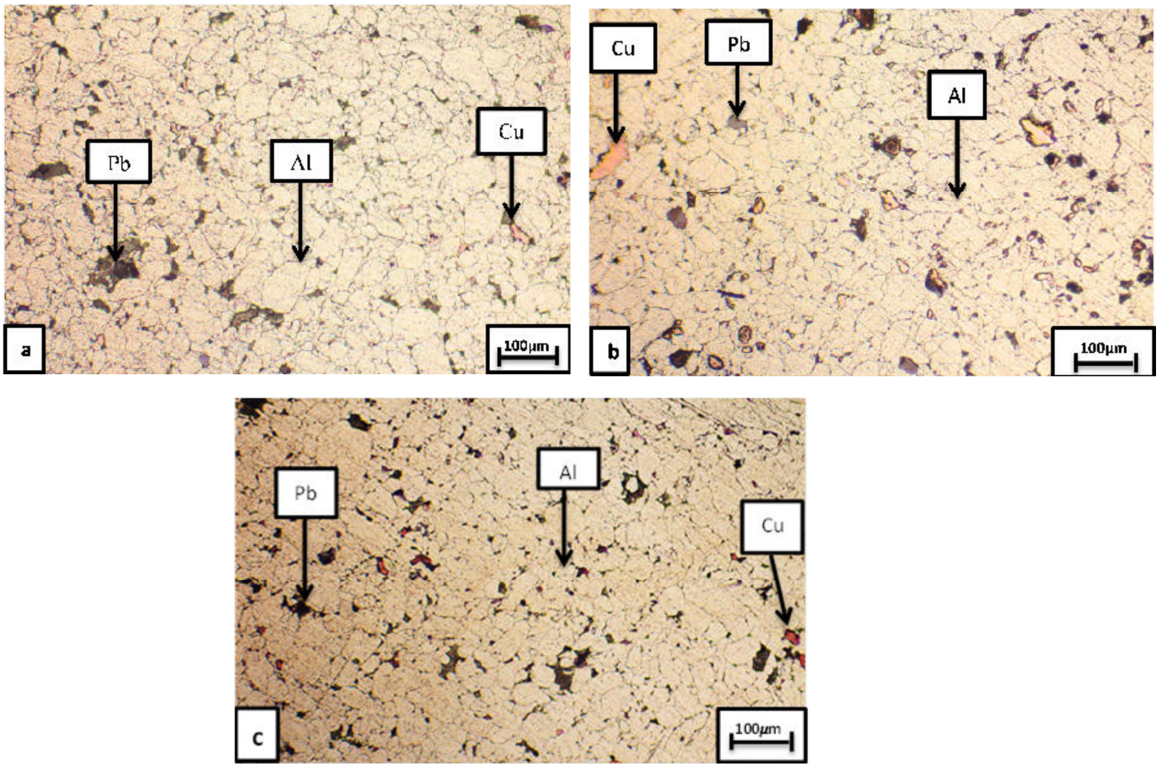

**Figure 1. Microstructure of Al- 10% Pb- 4.5%Cu sintered at 350℃ and pressed at (a) 44100N, (b) 58800N (c) 63700N**

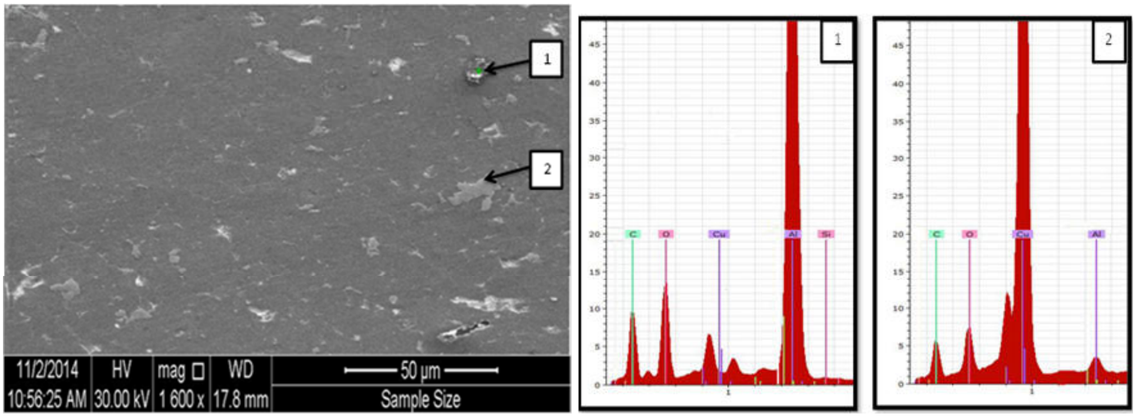

Figure 2. SEM image and EDS analysis of Al -10%Pb -4.5%Cu alloy pressed at 58800N and sintered at 350℃

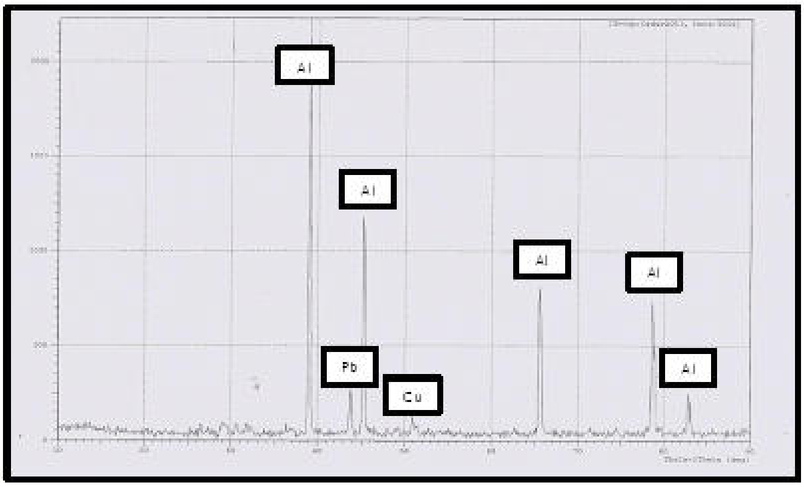

Figure 3. X-ray diffraction of Al- 10%Pb- 4.5%Cu pressed at 58800N and sintered at 350 ℃

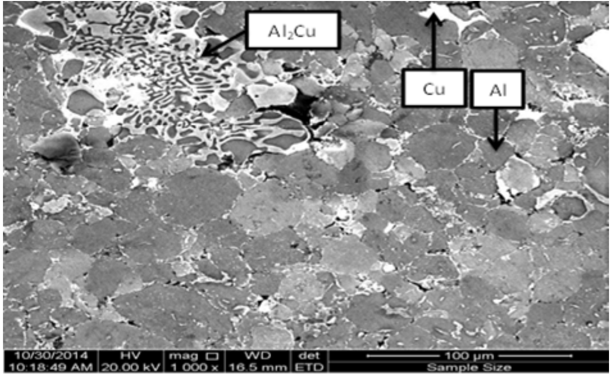

Figure 4. SEM image of base alloy (al-10%Pb- 4.5%Cu) pressed at 58800N and sintered at 450℃

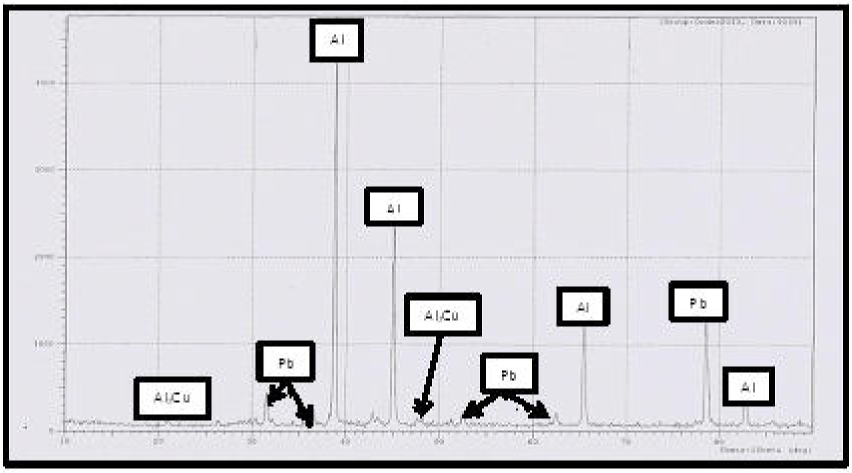

**Figure 5. X-ray diffraction of Al- 10%Pb- 4.5%Cu pressed at 58800N and sintered at 450 ℃**

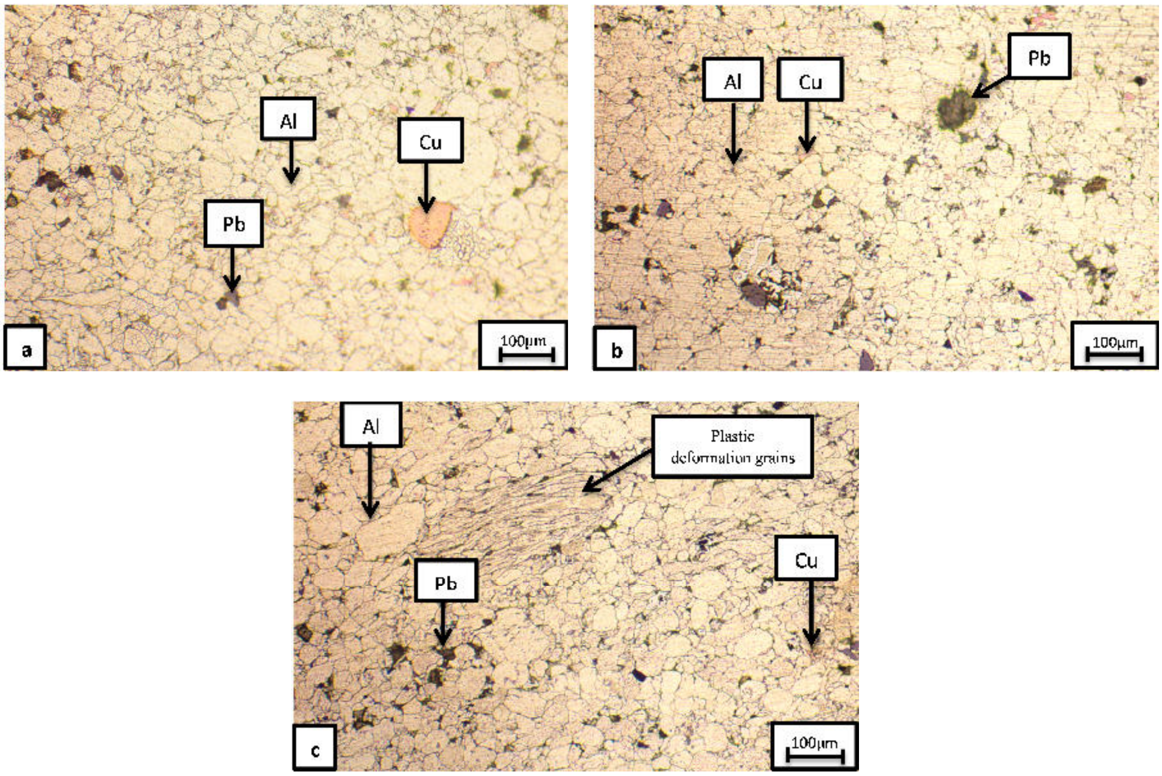

**Figure 6. Microstructure of the base alloy (Al- 10%Pb- 4.5%Cu) sintered at 450 ℃ and pressed at (a) 44100N, (b) 58800N and (c) 63700N**

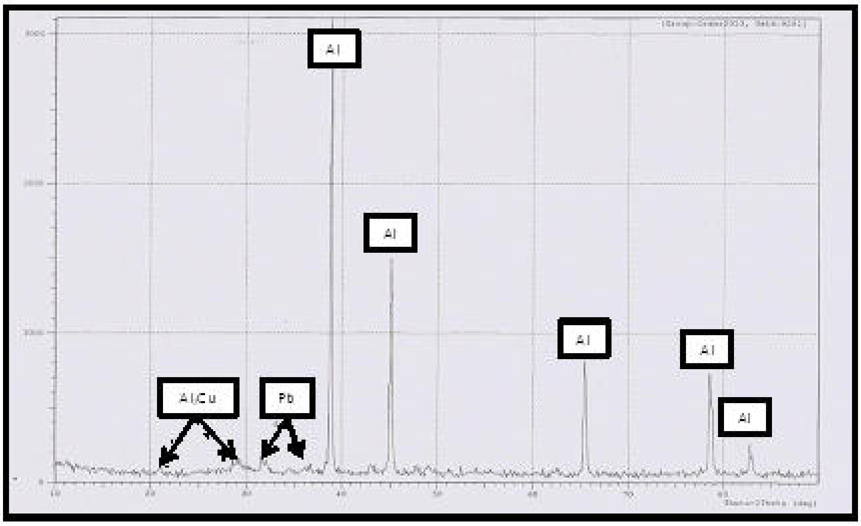

Figure 7. X-ray diffraction of Al- 10%Pb- 4.5%Cu pressed at 58800N and sintered at 550℃

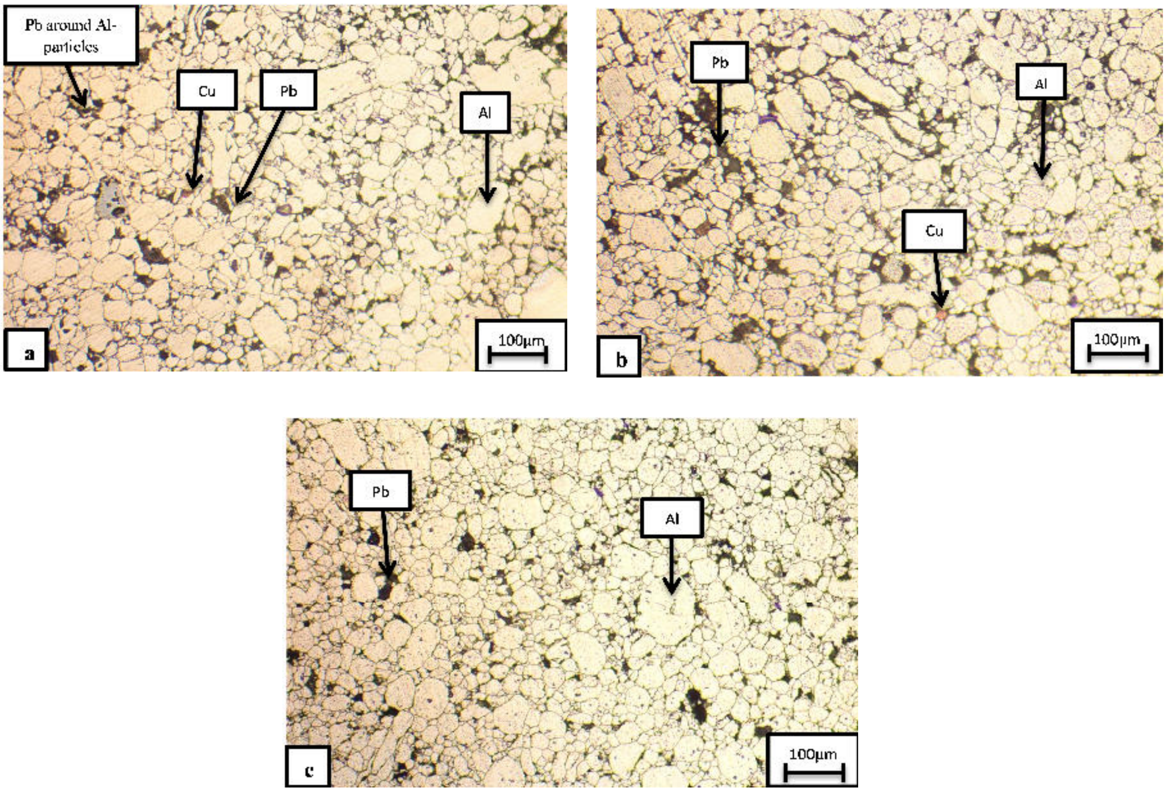

Figure 8. Microstructure of base alloy (Al- 10%Pb- 4.5%Cu) sintered at 550℃ and pressed at (a) 44100N, (b) 58800N and (c) 63700N

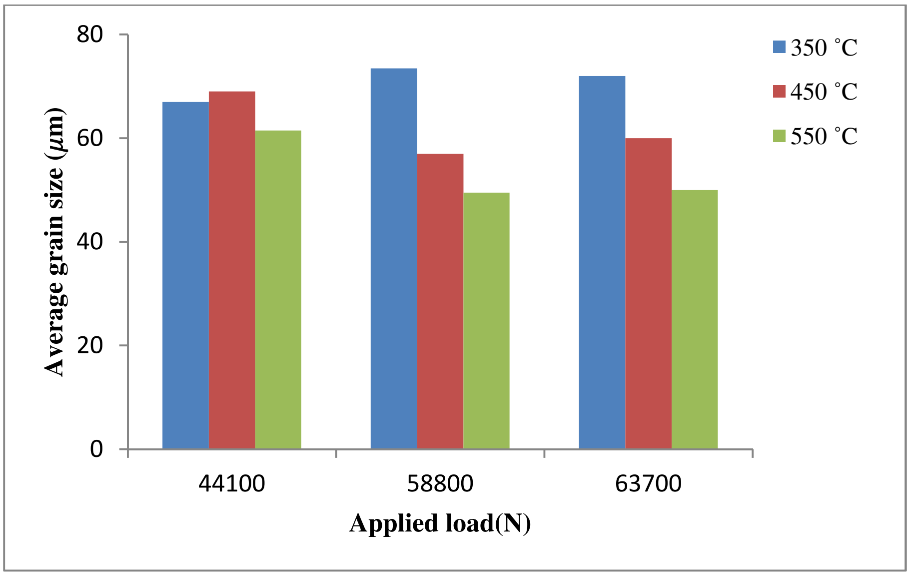

**Figure 9. Effect of applied load and sintering temperature on the average grain size of Aluminum**

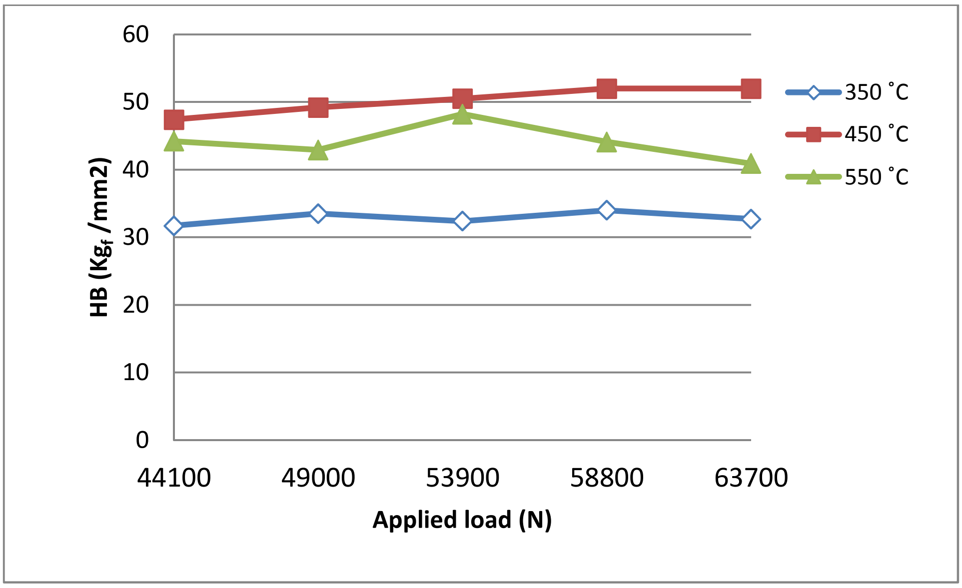

**Figure 10. Effect of applied load and sintering temperature on hardness of Al-10%wt. Pb-4.5%Cu**

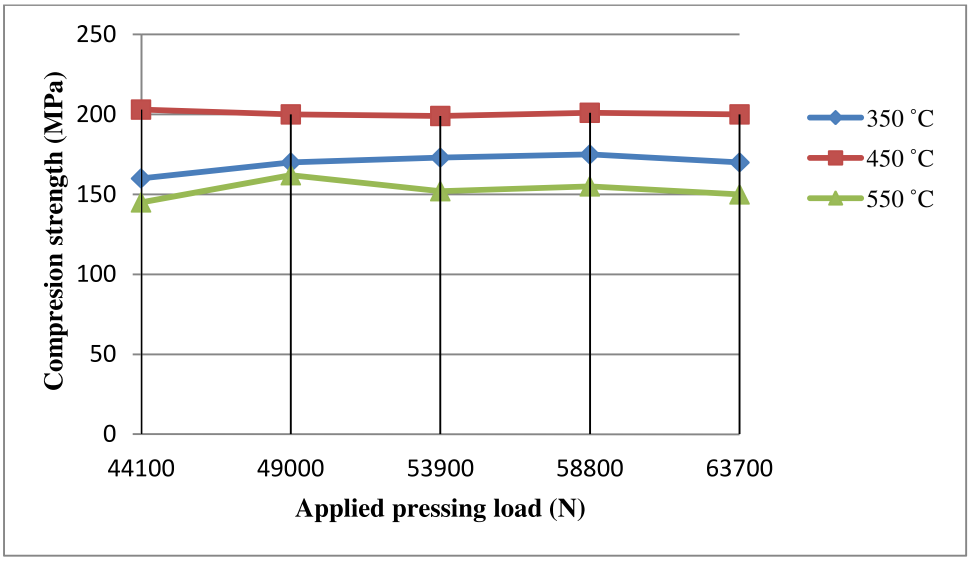

**Figure 11. Effect of sintering temperature and applied load on the compression strength of Al- 10%Pb-4.5Cu alloy**

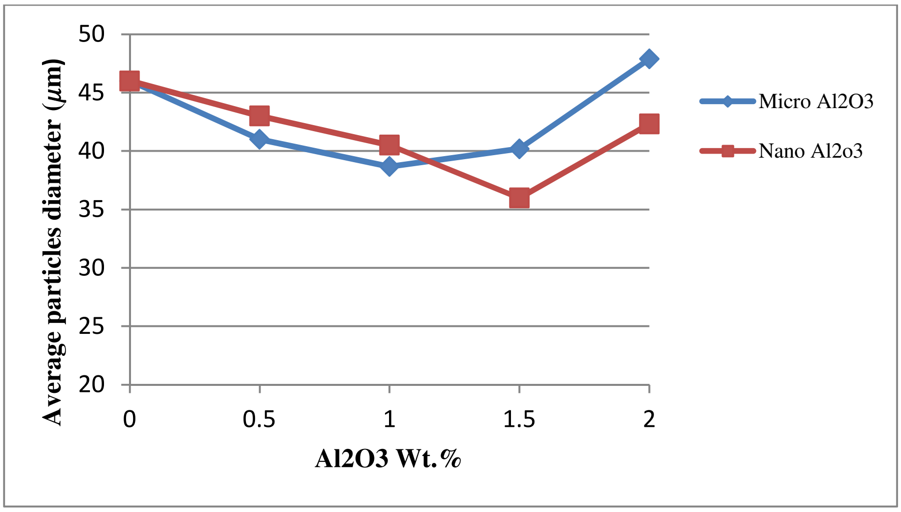

**Figure 12. Effect of $Al_2O_3$ additives on average grains size**

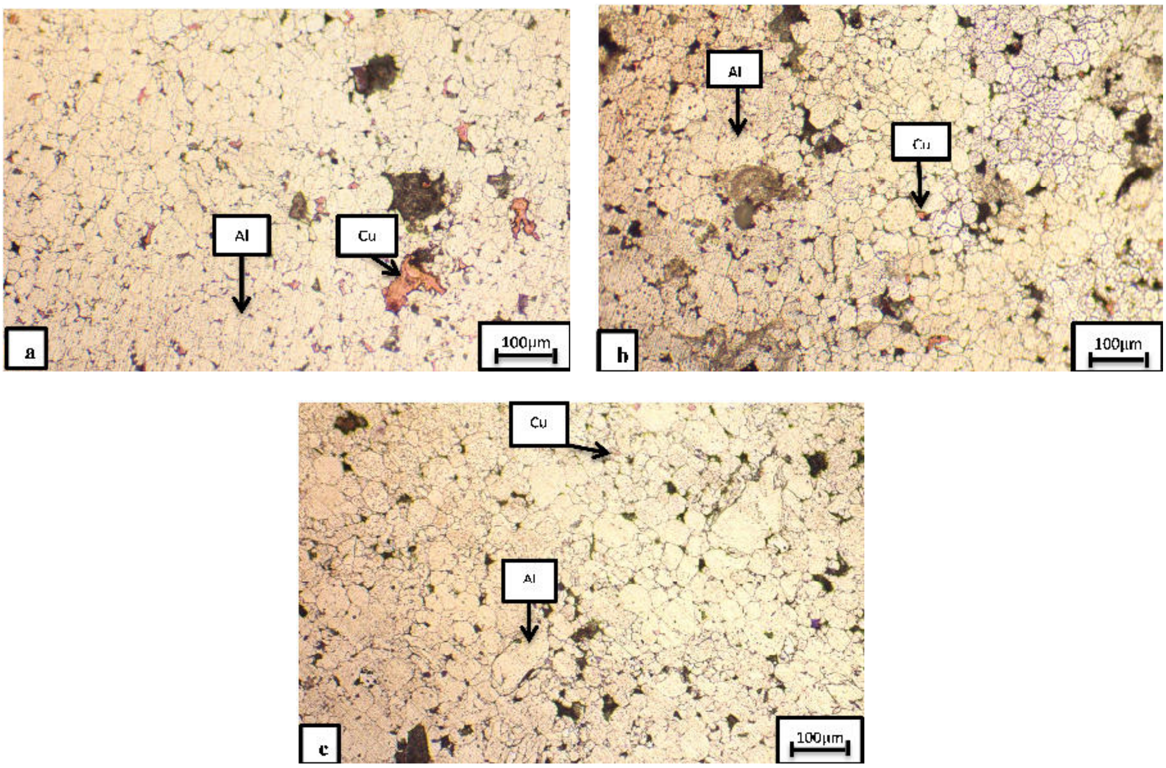

Figure 13. Microstructure of base alloy with (a) 1, (b) 1.5 (c) 2% wt. micro alumina additives

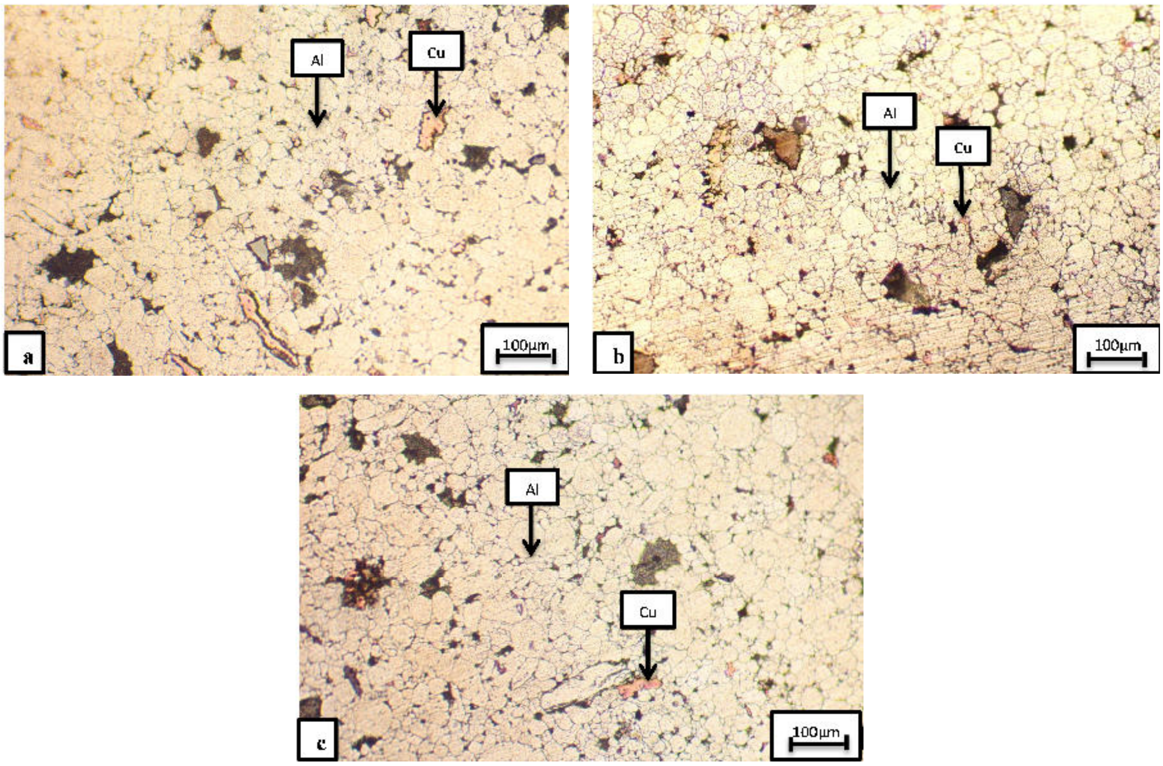

Figure 14. Microstructure of base alloy with (a)1, (b) 1.5, (c) 2% wt. nano alumina additives

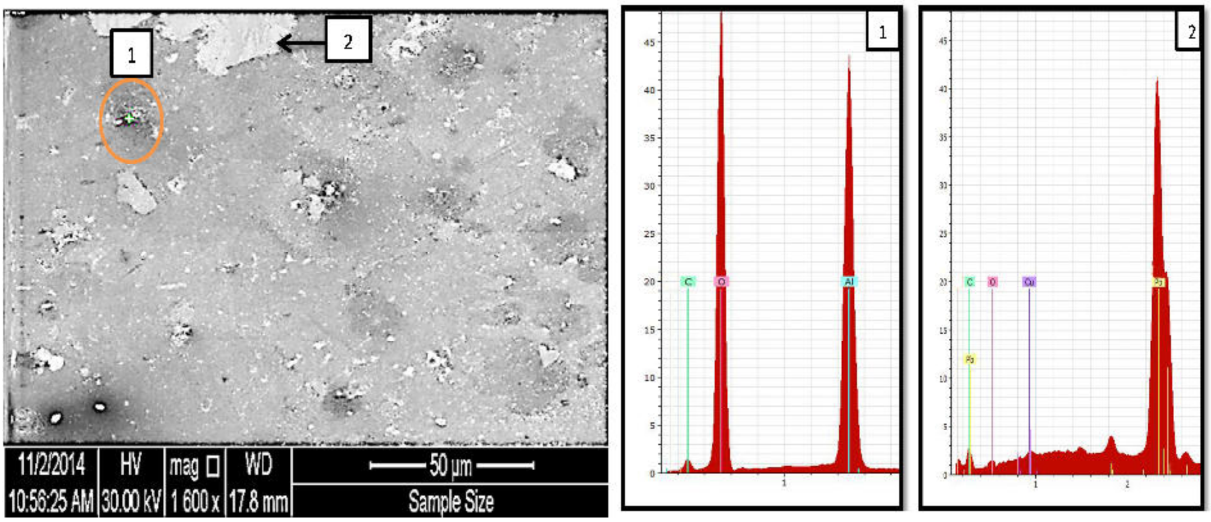

**Figure 15. SEM image and EDS analysis explained the microstructure of Al- 10% Pb- 4.5% Cu with 1.5 % micro $Al_2O_3$ pressed at 58800N and sintered at 450℃**

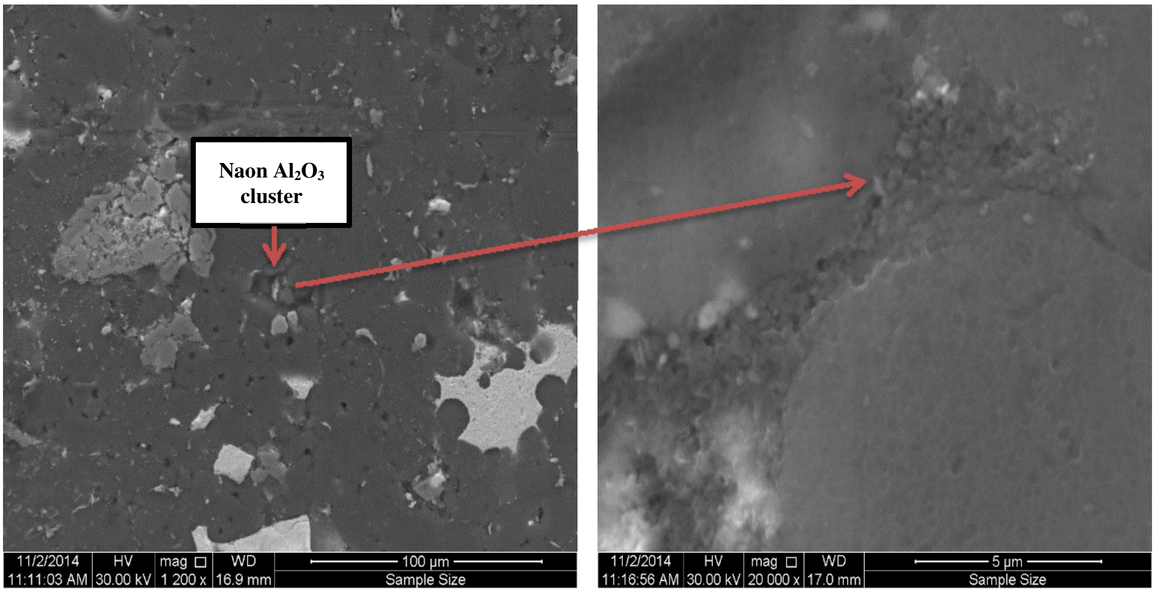

**Figure 16. SEM image of Al- 10%Pb- 4.5%Cu alloy with 1.5% naon $Al_2O_3$ additives pressed at 58800N and sintered at 450℃**

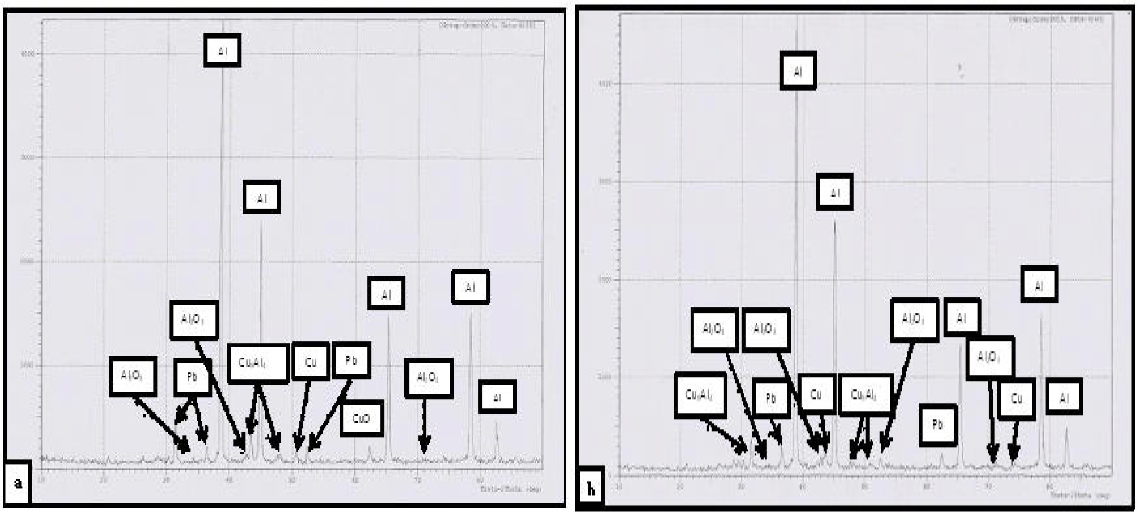

**Figure 17. X-ray diffraction of base alloy with (a) 1.5% micro $Al_2O_3$ and (b) 1.5% nano $Al_2O_3$**

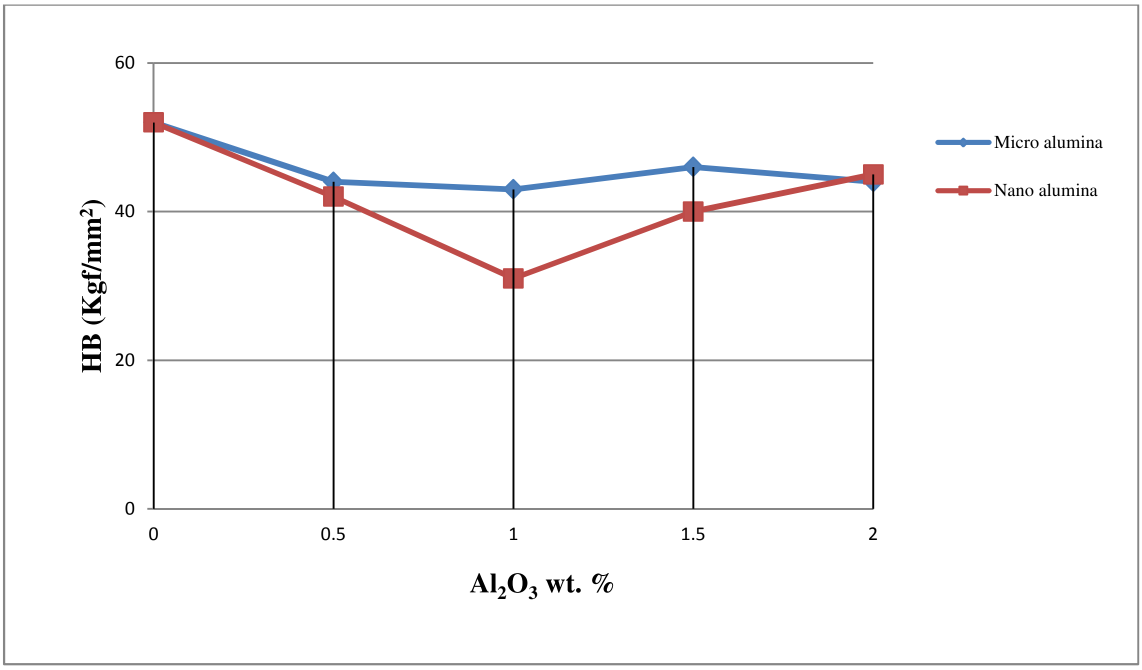

**Figure 18. Effect of micro and nano-alumina on the HB values of Al-10wt%Pb- 4.5wt% Cu.**

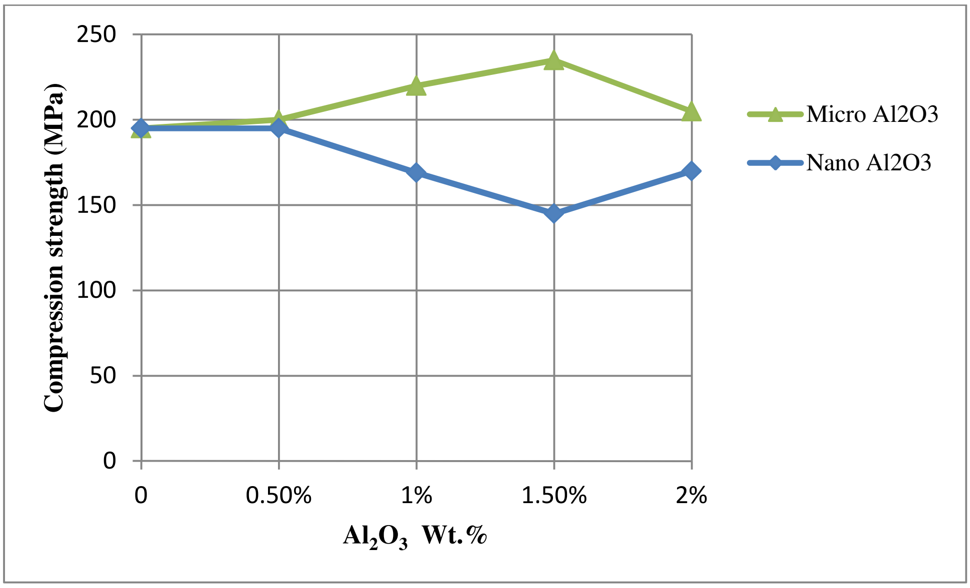

Figure 19. Effect of micro and nano alumina on compression strength of the base alloy

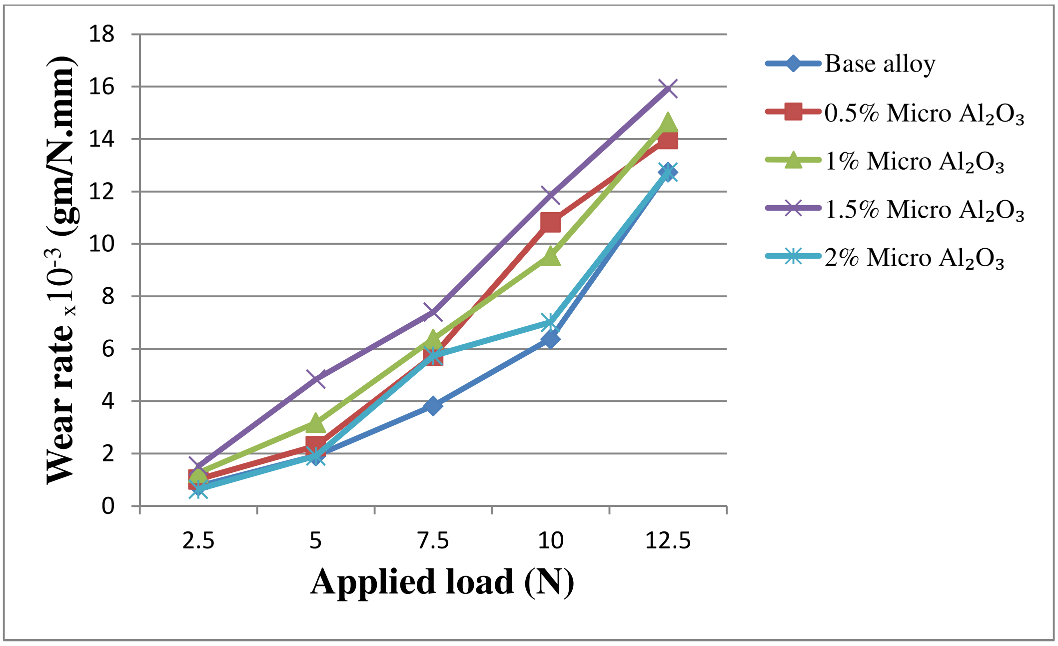

Figure 20. Effect of micro alumina on the wear rate of Al- 10%Pb- 4.5Cu alloy with different micro $Al_2O_3$ percentage

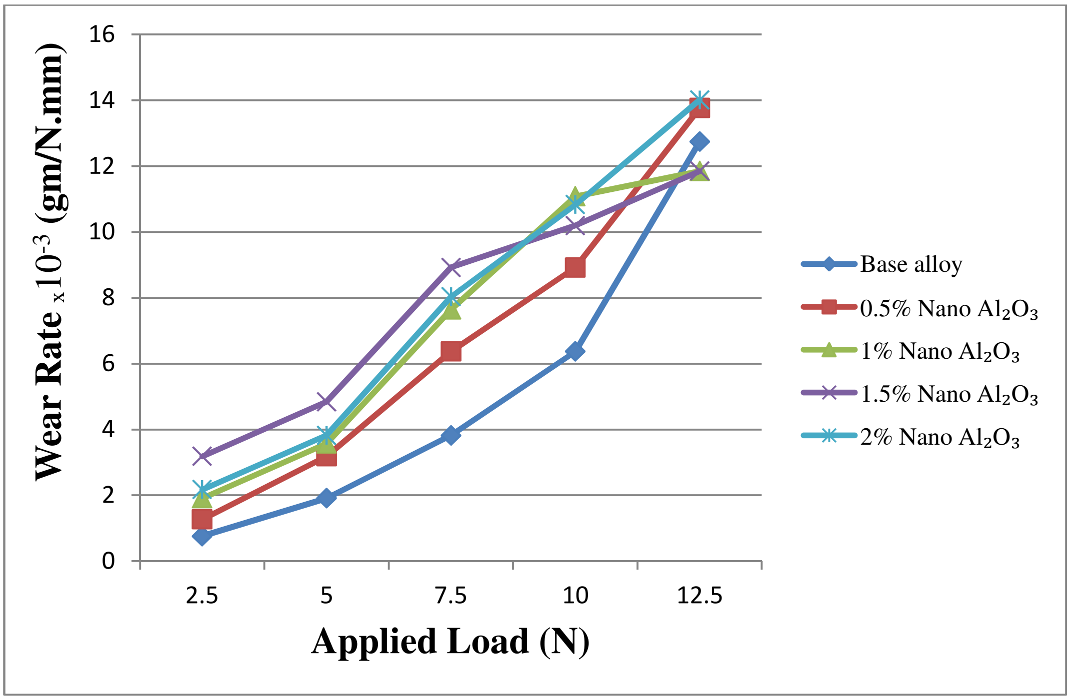

Figure 21. Effect of nano alumina on the wear rate of Al- 10%Pb- 4.5Cu alloy with different micro $Al_2O_3$ percentage

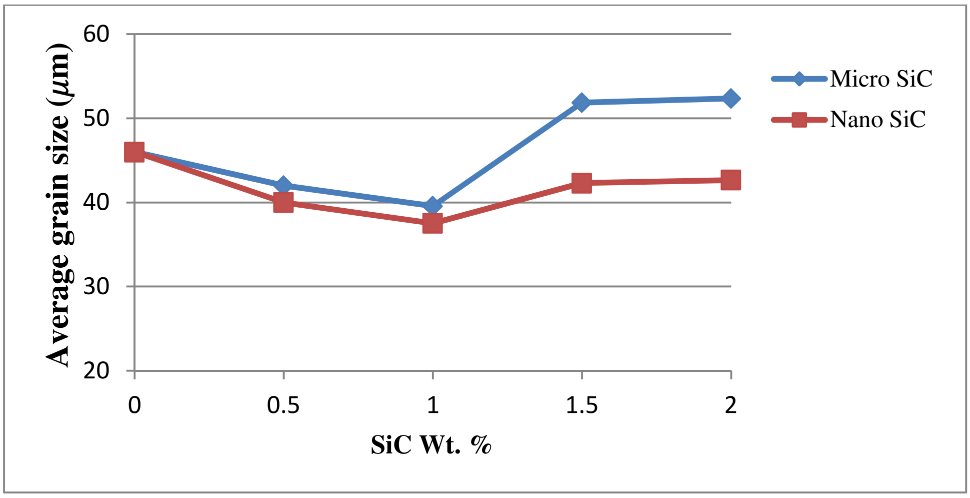

Figure 22. Effect of silicon carbide on the grain size

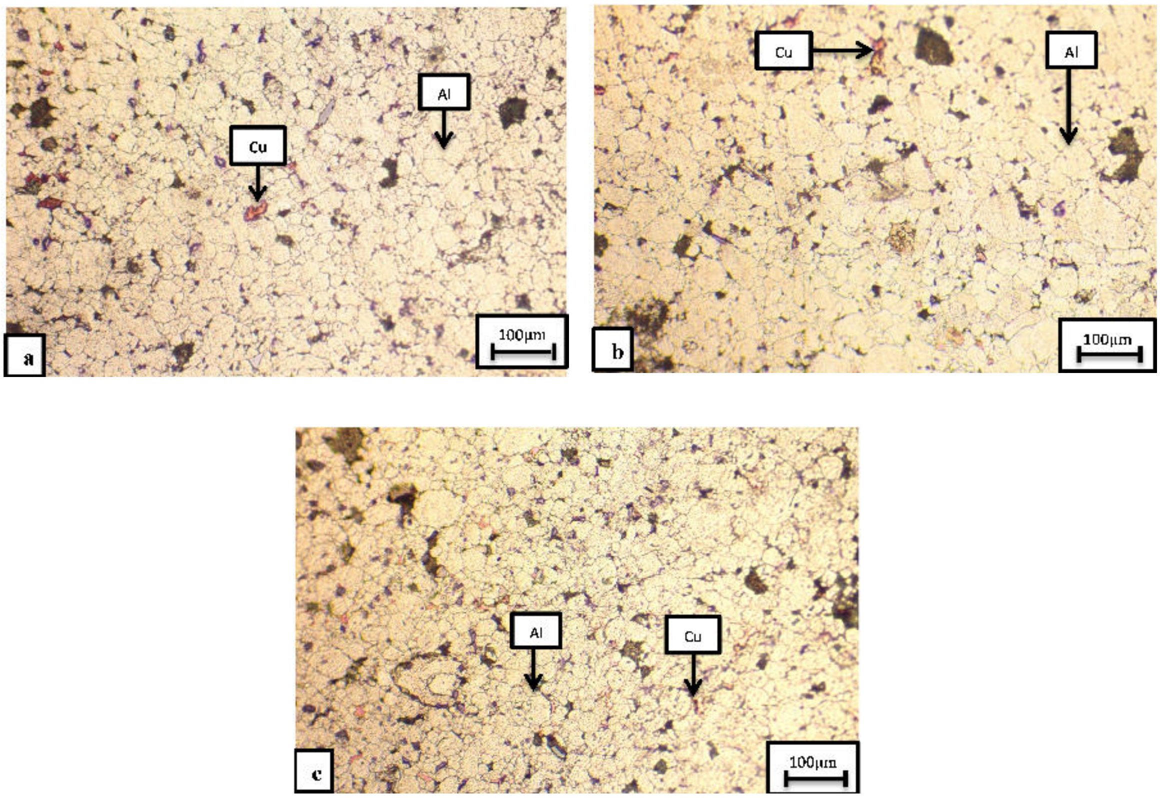

**Figure 23. Microstructure of the base alloy with (a) 1, (b) 1.5 and (c) 2% wt. micro silicon carbide present additives**

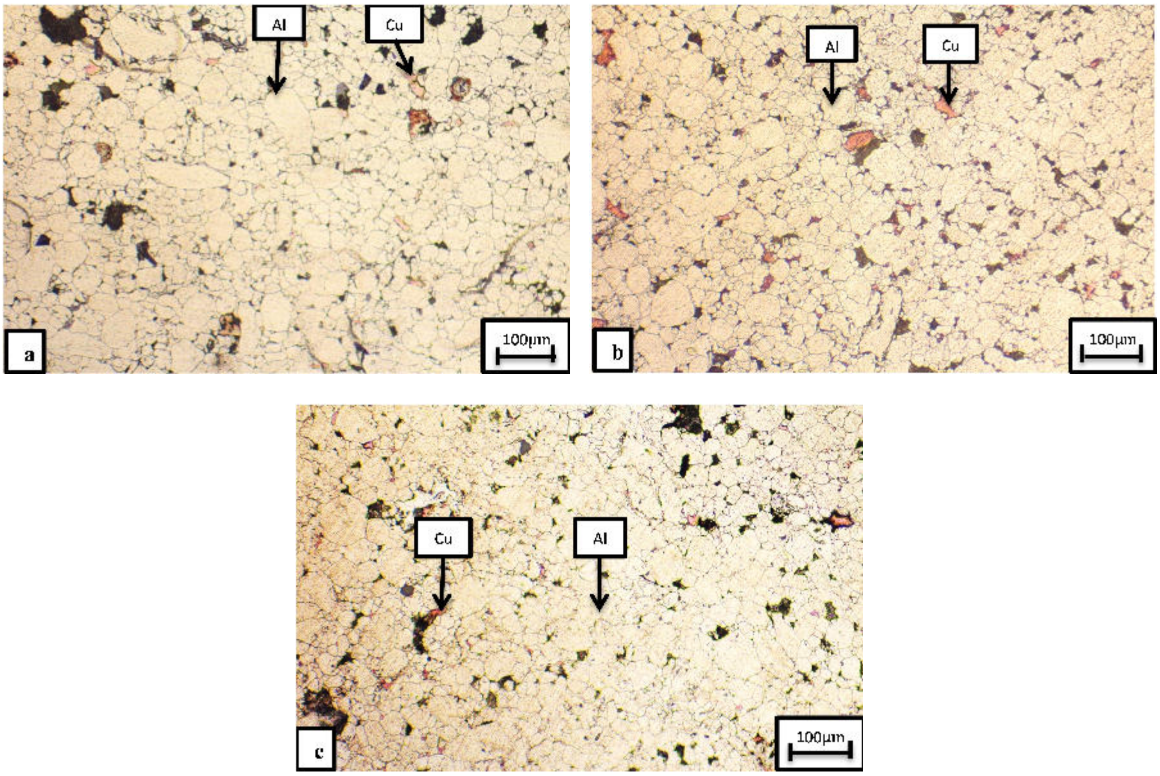

**Figure 24. Microstructure of the base alloy with (a) 1, (b) 1.5 and (c) 2% wt. nano silicon carbide present additives**

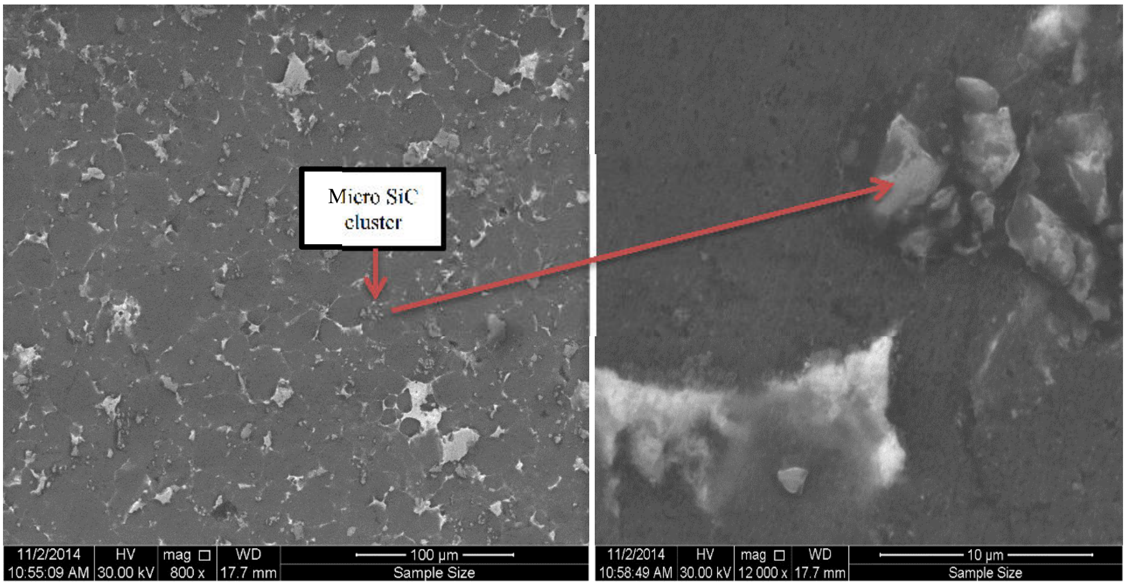

**Figure 25. SEM image of Al- 10%Pb- 4.5%Cu with 1.5%wt. micro SiC pressed at 58800N and sintered at 450℃**

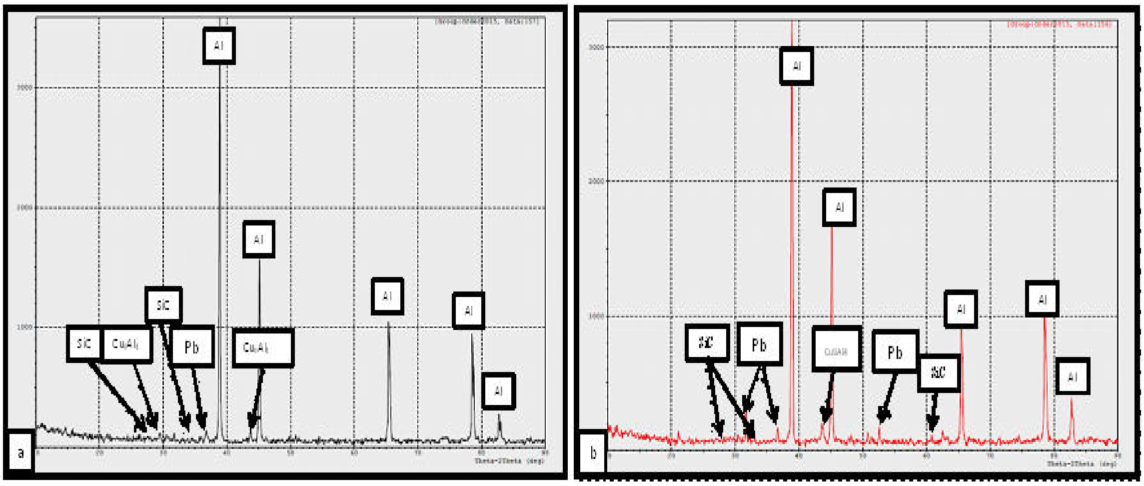

**Figure 26. X-ray diffraction of base alloy with (a) 1.5% micro SiC and (b) 1.5% nano SiC**

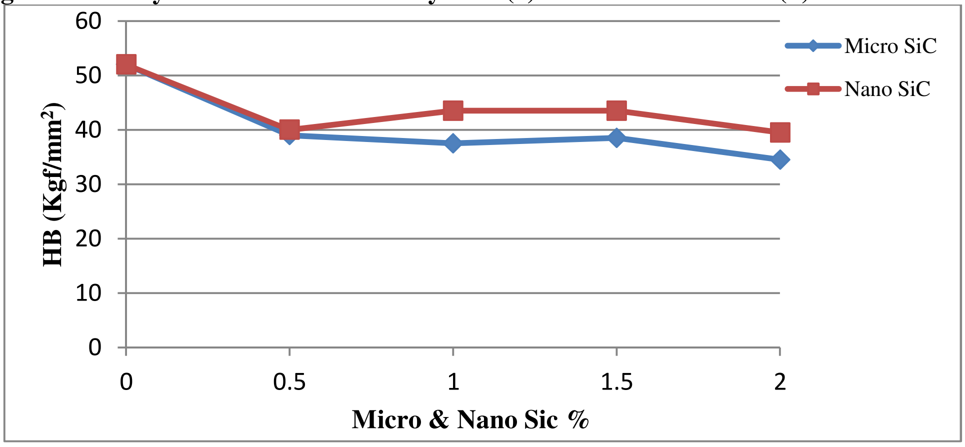

**Figure 27. Effect of micro and nano silicon carbide on the hardness of Al- 10% Pb- 4.5% Cu**

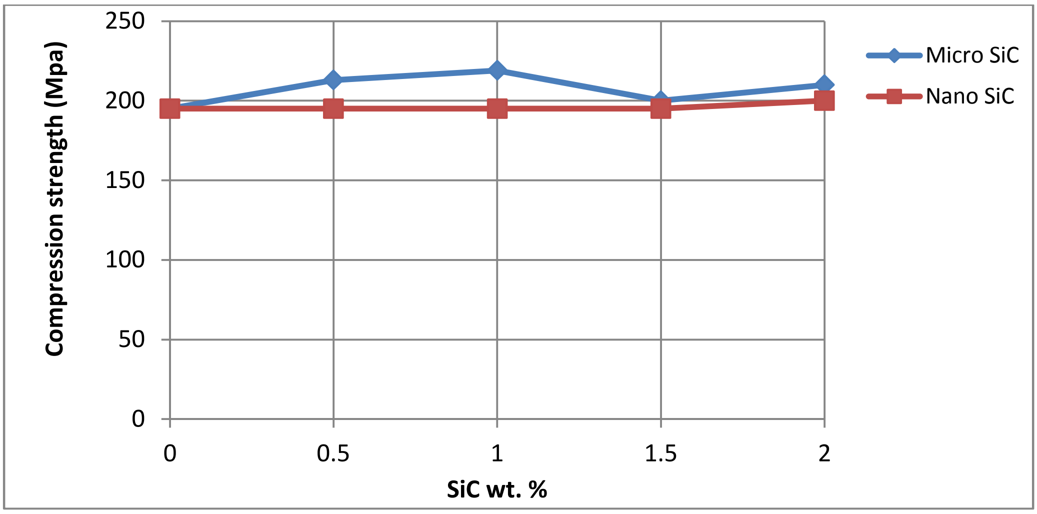

**Figure 28. Effect of silicon carbide additives on the compression strength of alloy**

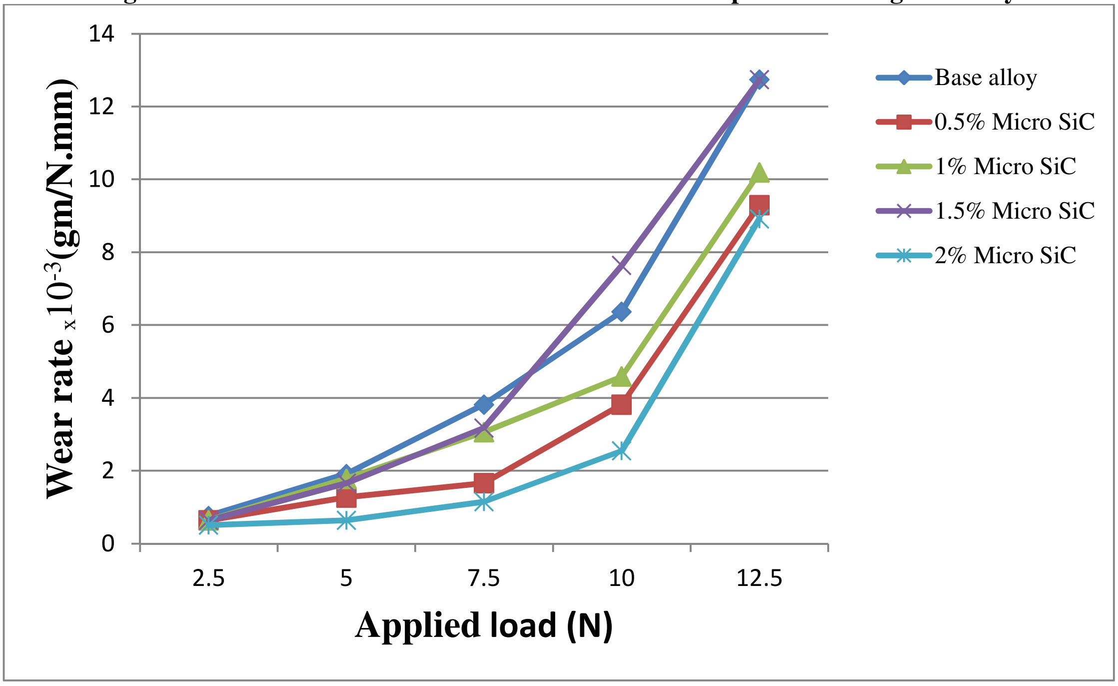

**Figure 29. Effect of micro SiC additives on wear rate of alloy**

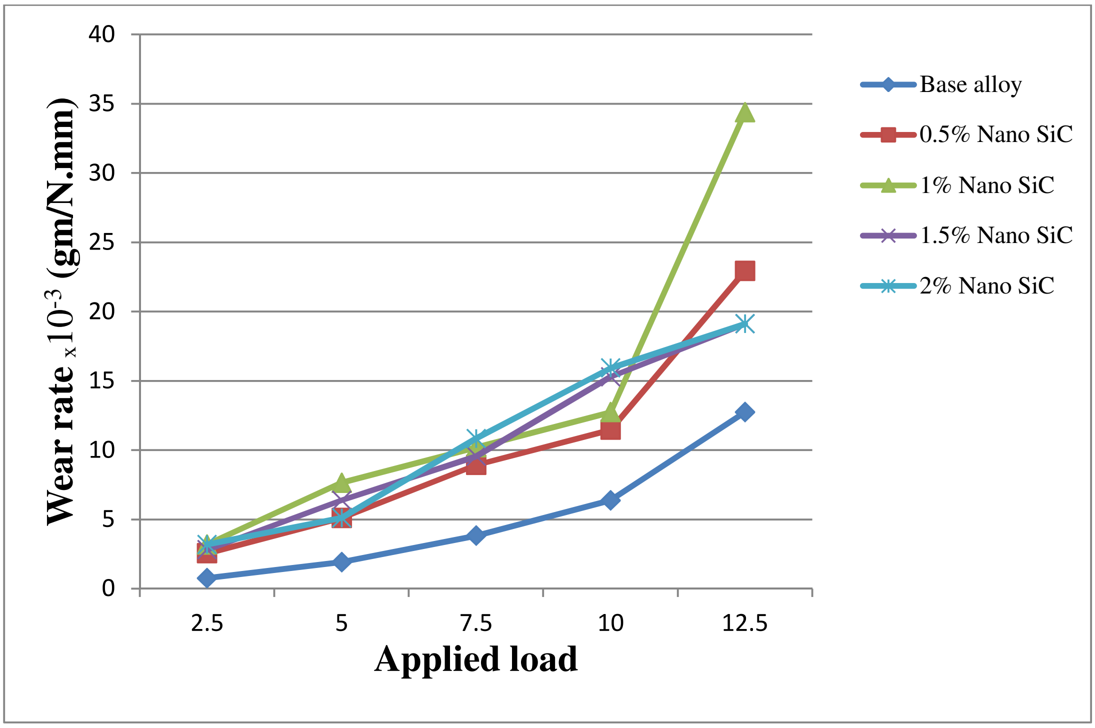

Figure 30. Effect of nano SiC additives on wear rate of alloy