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Microstructural Evolution and Mechanical Properties of $ZA27/Al_2O_3/MoS_2$ Metal Matrix Hybrid Nanocomposites

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Keywords：ZA27 alloy, Nano particles, Stir Casting, Hybrid Nanocomposites, Mechanical Properties

ABSTRACT

Metal matrix hybrid nanocomposites are widely used due to their good strength and wear resistance properties. Because of its light weight and excellent mechanical properties, the ZA-27 alloy is used in industrial and automobile applications. The research article is focused on manufacturing of ZA-27 matrix material reinforced by 1.5 wt. % of Aluminium Oxide (Al_2O_3) and 0.5 wt.% of Molybdenum Disulphide (MoS_2) hybrid micro and nanocomposites by using stir casting followed by ultrasonic assisted technique. The hybrid micro and nanocomposite samples were studied for chemical composition by using EDS analysis. Microstructure investigation of ZA27/ Al_2O_3/MoS_2 nanocomposites was carried out with help of SEM. The hardness, tensile strength and yield strength are mechanical properties of $ZA27/Al_2O_3/MoS_2$ hybrid micro and nanocomposites samples were tested. The uniform dispersion of Al_2O3 and MoS_2 nanoparticles in matrix alloy were observed in the microstructural analysis of hybrid micro and nanocomposites. From results it is observed that hardness of hybrid nanocomposites was increased 20% and 8% equated to base alloy and hybrid composites. The tensile properties were increased 19.4% and 7.1% related to ZA-27 alloy and hybrid composites.

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INTRODUCTION

Zinc and aluminum (ZA) alloys have seen a substantial increase in industrial use because of their superior wear resistance, strength, and castability. ZA-27 alloy is categorized as a high strength alloy among these sorts of ZA-8, ZA-12 and ZA-27, having tensile strength that is higher than that of a typical cast aluminum alloy (T.S. Kiran. et al.,2013, 2014; Srimant Kumar Mishra et al., 2014). As weight percentage of filler particles increases in ZA-27 base material the mechanical behavior of composites increases as compared to the matrix material (I. Bobic et al., 2003; K. H. W. Seah et al., 1996). Graphite particles are reinforced in base alloy composites were investigated and results observed that mechanical behavior such as tensile strength increases and hardness of composites decreases as weight percentages of graphite increases in ZA-27 alloy (B.M. Girish et al., 2011; K. H. W. Seah et al., 1996). The homogeneous dispersion of nano particles in base metal is attained by using ultrasonic assisted stir casting technique. The results of composites reinforcement of SiC nanoparticles in aluminum alloy were produced by using ultrasonic assisted casting method showed that nanoparticles were distributed uniformly throughout the microstructure and hardness of nanocomposites improved with increase of nanoparticles (Xiaochun Li et al., 2004; R. S. Rana. 2013). Stir casting was used to create aluminum alloy reinforced with Gr and SiC particles in equal weight percentages of metal matrix hybrid composites. The findings showed that as the percentage of reinforcement rises hardness of hybrid composites reduces. The hybrid composites friction coefficient is influenced by both sliding speed and applied load (S. Suresha et al., 2012; C.S. Ramesh et al., 2009; Cheng-jin HU et al., 2016). The hybrid composites are used in industrial and automotive applications due to less weight, good strength, excellent mechanical properties and higher wear resistance related to metal matrix composites materials. Numerous studies have demonstrated that as compared to pure alloys, hybrid composites have better hardness, good tensile strength, higher wear resistance, and a lesser friction coefficient. (Slobodan M et al., 2011). Mechanical properties of Al6063 reinforced with the Aluminium oxide (10 wt. %) and molybdenum disulphide (3, 5, 7, and 9 wt. %) particles hybrid composites were fabricated by means of stir casting technique. The result shows that hardness of hybrid composites increases slightly compare to the Al 6063. The tensile strength of composites decreases because of reinforcement of molybdenum disulphide particles varying from 3 % to 9 % by weight (Mitesh Kumar et al., 2014).

The SiC particles varying from 0-9% and graphite with 3% by weight are added in ZA-27 alloy hybrid composites were used to study mechanical properties. The results reveal that, as SiC particles were increased tensile strength and hardness of hybrid composites increased (Kiran, T. S et al., 2013). The mechanical and tribological characteristics were examined on copper-based hybrid composites reinforced with SiC particles that varied from 3wt % to 10wt % and graphite particles with 1 wt. % for preparation of composites. The tensile strength and hardness of hybrid composites improves as weight percentage of SiC particles increases. The presence of graphite content in the hybrid composites reduces wear rate and the coefficient of friction compared to the copper alloy (C.S. Ramesh et al 2009). Mechanical and wear properties of mica and SiC ceramic particle with varying weight percentages were reinforced into the Al 356 alloy hybrid composites. Better hardness and strength of alloys are attained with Al 356 alloy reinforced with 10 wt. % SiC and 3 wt. % mica hybrid composites. The increase wear resistance of hybrid composites due to the increase in weight percentages of mica (T. Rajmohan et al., 2013). The behavior of wear resistance and strength is widely studied using aluminum hybrid composites reinforced with same quantity of graphite and SiC. The outcome indicates that composites hardness will decrease as the reinforcement content increases. The significant influence of friction coefficient is reinforcement content, load, sliding speed and distance, the most influencing parameters being sliding speed and load whereas sliding distance and reinforcement content do not affect friction coefficient (S. Suresha et al., 2012). The study examined mechanical behavior and wear of aluminum matrix reinforced with SiC particulates and rice husk ash at equal weight percentages of hybrid composites were processed using stir casting process. Compared to matrix alloy, the hybrid composites reinforced with distinct particles show greater wear resistance. The mechanical properties of hybrid composites increase as weight percentages of reinforcement particles increase, but their elongation decreases (D Siva Prasad et al., 2014). The investigation of mechanical behavior for the hybrid composites reinforced with 5 weight percent to 10 weight percent SiC and 3 weight percent to 6 weight percent graphite in Al2024 alloy were fabricated. According to the results, Gr and SiC particles added to Al2024 matrix decrease tensile strength and elongation. The Gr particles have a superior detrimental effect on elongation than SiC particles in the hybrid composites (Cheng-Jin Hu et al., 2016; T.S. Kiran et al., 2014). The work was carried out to investigate mechanical characteristics of hybrid composites made of aluminum incorporated with SiC and groundnut shell ash with different weight percentages. Comparing the composites to hybrid composites, the outcomes indicate that hardness, tensile strength, and specific strength of specimens reduced slightly with a rise in groundnut shell ash during the reinforcing phase. The fracture toughness and percentage elongation of hybrid composites increases when increasing the reinforcement content of groundnut shell ash (K K Alaneme et al., 2016). By using the stir casting method, the mechanical characteristics of Al6061-SiC and Al6061-SiC/Graphite hybrid composites with varying percentages were examined. Microstructures of composites revealed uniform dispersion of particles and density of composites decreases as reinforcement content increases in composites. The enhancement in tensile strength of hybrid composites occurred as filler content of graphite and SiC particles increases in Al6061 alloy (M. Vamsi Krishna et al., 2014). The study is focused on processing of ZA-27/Al_2O_3/ MoS_2 micro and nano hybrid composite by using stir casting process with ultrasonification technique. Microstructure analysis of ZA-27/Al_2O_3/ MoS_2 hybrid micro and nanocomposites was studied using SEM. The chemical composition of the hybrid nanocomposites was tested with the help of EDS ZA-27/Al_2O_3/ MoS_2 hybrid micro and nanocomposites samples were subjected to mechanical tests such as hardness, tensile strength and yield strength in accordance with ASTM guidelines.

MATERIALS AND METHODS

Fabrication of Nanocomposites

For the fabrication of the hybrid nanocomposites, the ZA-27 alloy is used as matrix material with chemical configuration as per the standard which is shown in the table 1. The alumina (Al_2O_3) nanoparticles of 50 nm size and MoS_2 nanoparticles of 80 nm were used as reinforcement material for fabrication of hybrid nanocomposites.

Table 1. Chemical configuration of ZA-27 material

ZA-27 as a matrix material is placed in a graphite crucible and heated above its melting temperature of 800^0C in electric resistance furnace. After melting matrix alloy stirring is done by using a mechanical stirrer for 3 minutes for homogenization of the base alloy. The Al_2O_3 and MoS_2 nano particles of weight percentages 1.5 wt. % & 0.5 wt. % are stacked like pallets inside aluminum foil which are pre-heated upto 500^0C to avoid moisture and thermal stability of melt of the base alloy. Add the previously heated nanoparticles (Al_2O_3 and MoS_2) while the mixture is being stirred and continue for 5 minutes for homogeneous mixing of the nanoparticles in base alloy. Once the ZA-27 alloy and nano particles are dispersed in the molten metal then stop the stirring process and continue the process with ultrasonification of the hybrid nanocomposites with the help of an ultrasonic probe for three minutes was done. After successful addition of nanoparticles in ZA-27 alloy the hybrid nanocomposite melt was pour into the shape of cylindrical rods in a mild steel die and wait for some time to solidify the melt. After solidification the samples are taken out from die and standard specimens of the hybrid micro and nano composites were ready for the characterization and analysis. The cast hybrid nanocomposites specimen was given in figure 1.

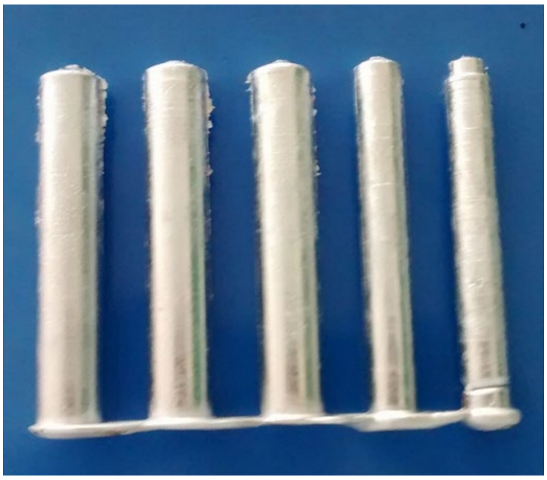


Fig.1. ZA-27 Hybrid nanocomposites

Microstructure and EDS Studies of Hybrid Nanocomposite

The $ZA27/Al_2O_3/MoS_2$ hybrid nanocomposites specimens were polished using various SiC abrasive paper grades, and then disc polishing was performed using cloth and Al_2O_3 particles. The hybrid nanocomposite samples were surface-treated with Palmerton reagent as etching agent in order to reveal microstructure. The microstructures of $ZA27/Al_2O_3/MoS_2$ hybrid micro and nanocomposites samples were observed using a Zeiss Scanning Electron Microscope (SEM). In order to analyze

Material	Mg	Cu	Al	Zn
Weight percentage	0.01-0.02	1 - 2.5	25-28	Balance

chemical composition of $ZA27/Al_2O_3/MoS_2$ hybrid micro and nanocomposites, chemical composition studies were conducted on the Energy Dispersive Spectroscopy (EDS).

Mechanical Behavior of Hybrid Nanocomposites

The microhardness tests of the $ZA27/Al_2O_3/MoS_2$ hybrid nanocomposites were tested by means of microhardness tester. The microhardness test was conducted using a diamond indenter with an applied load of 200 g and a time period of 10s. For every composite, about ten measurements were made, and the average hardness value was taken into account. The ASTM E8M standard was followed in the preparation of the flat tensile samples, which had gauge widths of 6 mm and gauge lengths of 25 mm as shown in figure 2. An electro-mechanical tensile testing machine were used to conduct the tensile test at room temperature. For every composite material, three tensile samples were tested; the average values and standard deviation were computed and reported.

Fig 2. Tensile Samples of ZA-27 hybrid nanocomposites

RESULTS AND DISCUSSIONS

Microstructure and Chemical Analysis

Microstructural analysis of ZA-27 hybrid micro and nano composites are significantly impacted with dispersion of filler particles. Figure 3 (a) through (c) displays SEM micrographs with 1.5 wt. % of Al_2O_3 and 0.5 weight percentages of MoS_2 micro and nano particle reinforcement in the ZA-27 alloy. Figure 3(a) illustrates the coarse dendritic structure of primary α phase (Al rich) dendrites in the ZA-27 alloy, which are encircled by the intermetallic α phase (Cu-rich) and the eutectoid α+η in the interdendritic areas. As the Al_2O_3 and MoS2 micro and nano particles added in matrix alloy the refined grain structure was obtained and particles were invariably located at grain boundaries of hybrid. The overall performance of the hybrid composite based on ZA-27 alloy is significantly influenced by the microstructure analysis. Figure 3(b) & 3(c) displays microstructure of matrix material reinforced with micro/nano sized Al_2O_3 and MoS_2 particles in the hybrid composite. Because of stir casting followed by the ultrasonic assisted technique, the filler particles in base material were uniformly distributed.

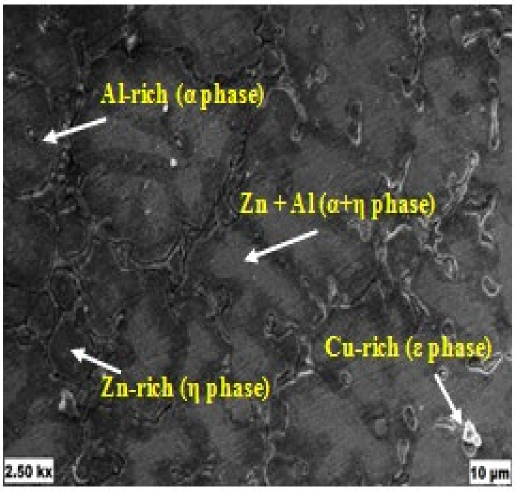


Fig.3(a). Base Material

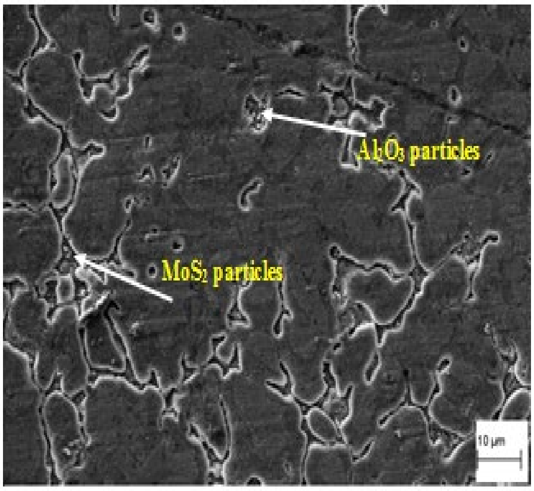


Fig. 3 (b) Hybrid composite (ZA-27+1.5wt% Al_2O_3 (µm) + 0.5 wt. % MoS_2 (µm))

The Al_2O_3 and MoS_2 nanoparticles were situated at the interdendritic regions of ZA-27 hybrid micro and nanocomposite, in which Al_2O_3 micro and nanoparticles were detected white in colour and molybdenum disulphide micro and nano particles as shady black colour through fine cored dendrites of Al phase and Zn phase. It was observed from the microstructure that the particle clustering was more in the case of hybrid nanocomposites because of increasing surface area and the surface energy nanoparticles. The porosities were observed in the ZA-27 hybrid nanocomposites at matrix and nanoparticle interfaces, which weaken the bonding between ZA-27 alloy and reinforcement particles.

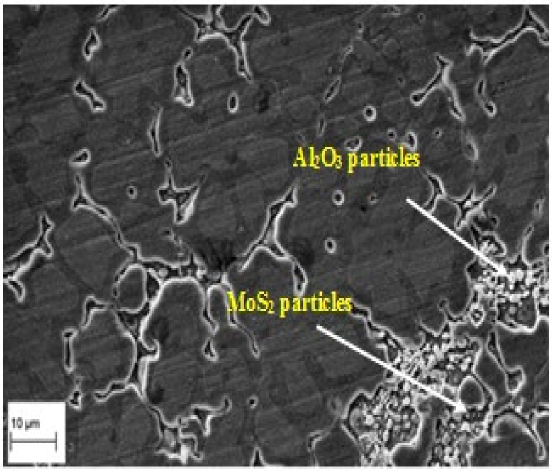
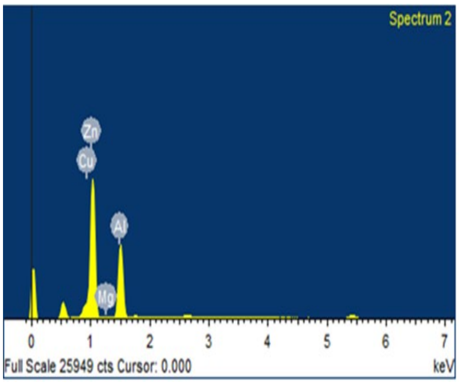


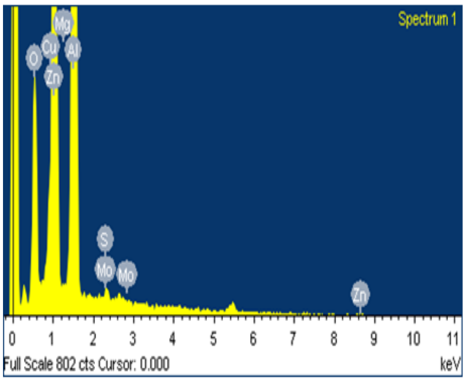
Fig. 3 (c). Hybrid nanocomposite (ZA-27+1.5wt% Al_2O_3 (nm) + 0.5 wt. % MoS_2 (nm))

EDS have been used to analyze the chemical composition of base alloy reinforced with 1.5 wt % $A_{12}O_3$ and 0.5 wt % MoS2 nanoparticles was showed in the figure 4 (a) and 4(b).



Element	Weight %
Mg	0.60
Al	33.01
Cu	1.60
Zn	64.79
Totals	100.00

Fig. 4(a) Base Material



Element	Weight%
O K	13.85
Mg K	0.18
Al K	44.60
S K	1.11
Cu L	1.21
Zn L	39.05
Mo L	1.13
Totals	100.00

Fig. 4 (b) EDS of hybrid nanocomposite (ZA-27+1.5wt% Al_2O_3 (nm) + 0.5 wt % MoS_2 (nm))

It can be seen that the EDS pattern shows no MoS_2 peak and that all of the base alloy's components are present in accordance with standards. EDS analysis of 1.5 wt % Al_2O_3 and 0.5 wt % MoS_2 nanoparticles reinforced in base alloy is shown in figure 3 (b). EDS examination confirms that Al_2O_3 and MoS_2 nanoparticles are present within ZA-27 hybrid nanocomposites. Due to the more weight percentage of alumina compare to MoS_2 nanoparticles shows the peak with the 13.82% present in the base because of low concentration of MoS_2 nanoparticles reinforced in matrix material. The elemental mapping of Mo portion verifies particle's existence in the nanocomposites as 1.13% in hybrid nanocomposite.

Mechanical Behavior of Hybrid Nanocomposites

Hardness:

Table 2 shows the micro hardness value and standard deviation for ZA-27 alloy hybrid micro and nano composites. Since the Al_2O_3 nanoparticles are hard dispersoids that will increase the hybrid nanocomposite's hardness, the hybrid nanocomposite's Vickers hardness is higher than that of the micro composite and base alloy.

Table 2. Microhardness of ZA-27 alloy Hybrid micro and nano composites

S.No	Composition	Hardness (HV)
1	Base alloy (ZA-27)	118.5
2	ZA-27 + 1.5% Al_2O_3 (20 µm) + 0.5% MoS_2 (5 µm)	128.3
3	ZA-27 + 1.5% Al_2O_3 (50 nm) + 0.5% MoS_2 (80 nm)	142.1

The improvement in the hybrid nanocomposite was due to the major content of alumina hard ceramic nanoparticles than fewer content of MoS_2, which acts as a barrier to movement of dislocations in matrix material. ZA-27 hybrid nanocomposite reinforced with 1.5 wt % alumina and 0.5 wt % of MoS_2 nanoparticles shows an increase in the microhardness by about 16.5 % when compare to ZA-27 alloy as shown in Figure 5.

Tensile Properties:

The tensile test of the hybrid micro and nanocomposites ZA-27 was carried out on the flat specimens. Electro-mechanical tensile testing equipment was used to test tensile strength of ZA-27 alloy hybrid micro and nanocomposites at room temperature and 0.679 x 10^{-4} s^{-1} strain rate. For every ZA-27 alloy hybrid micro and nanocomposites, the tests were run five times, and average UTS and YS values were computed and shown in table 3.

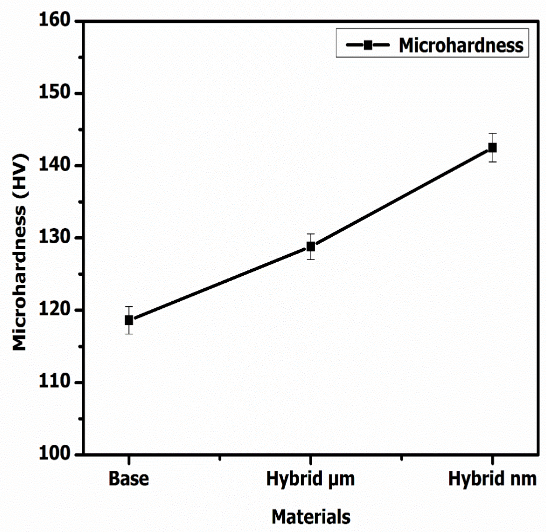


Fig 5. Microhardness of ZA-27 hybrid nanocomposites

Table 3. UTS and YS of ZA-27 alloy Hybrid micro and nano composites

S.No	Composition	UTS(MPa)	YS(MPa)
1	Base alloy (ZA-27)	366	256
2	ZA-27 + 1.5% Al_2O_3 (20 µm) + 0.5% MoS_2 (5 µm)	392	279
3	ZA-27 + 1.5% Al_2O_3 (50 nm) + 0.5% MoS_2 (80 nm)	437	312

Effect of Nanoparticles on UTS and YS:

The UTS and YS of the hybrid micro and nanocomposite increase as compared to hybrid micro composite and base alloy when reinforced with 0.5 weight percentage of molybdenum disulphide and 1.5 weight percentage of alumina nanoparticles as shown in Figure 6. The improvement in the hybrid nanocomposite was due to the major content of alumina hard ceramic nanoparticles which performance as obstacles to movement of dislocations in base alloy. The dispersion-strengthening influence in the hybrid nanocomposite was estimated to be retained even at higher temperatures and for long time periods because Al_2O_3 and MoS_2 nanoparticles were not reactive with alloy phase. These hard reinforcing particles will improve the strength of matrix material and impart additional resistance to hybrid nanocomposites against applied tensile stresses. The enhancement in the mechanical behavior can be attributed to result of numerous strengthening mechanism contributions such as elastic modulus (EM), coefficient of thermal expansion (CTE), Orowan strengthening and Hall-petch strengthening effects (A. Sanaty-Zadeh et al., 2012; P. Luo et al., 2012; D. Dzunic et al., 2015; Z. Zhang et al., 2008). The uniform distribution of the Al_2O_3 and MoS_2 nanoparticles was increase the UTS and YS of ZA-27 hybrid nanocomposite about 10.5 % when compare to the hybrid micro composite.

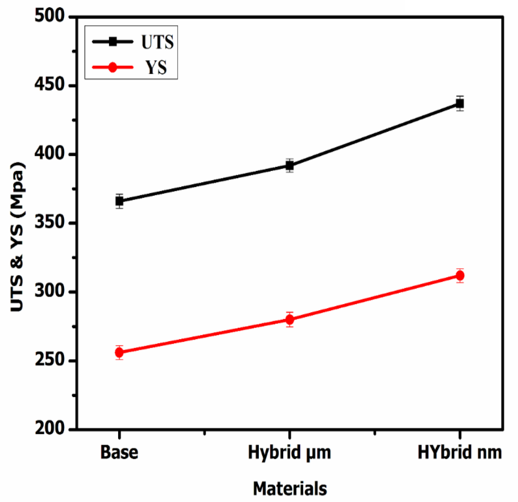


Fig 6. UTS and YS of ZA-27 hybrid micro and nanocomposites

CONCLUSIONS

The alumina and molybdenum disulphide micro and nano particles were reinforced in ZA-27 alloy with varying weight percentage were fabricated with help of stir casting method by using ultrasonification method. Due to the ultrasonic assisted process the homogenous distribution of micro and nano particles was observed in microstructures of ZA-27/ Al_2O_3/ MoS_2 hybrid micro and nanocomposite. The hardness of the hybrid composites has increases compare to the base alloy due to the addition of the hard ceramic particles of alumina. The ZA-27 hybrid nanocomposite reinforced with 0.5 wt. % of MoS_2 and 1.5 wt. % alumina nanoparticles shows an increase in the microhardness by about 20 % when compare to base alloy. The increase in the microhardness due to adding the nano particles which lead the composite materials refine the grain size to certain extent to form an intergranular structure which will improve the grain boundary. The nanoparticles contribute to improved mechanical properties through their unique effects on grain size, bonding, and matrix modification. The uniform distribution of the Al_2O_3 and MoS_2 nanoparticles was increase the UTS and YS of ZA-27 hybrid nanocomposite about 10.5 % when compare to the hybrid micro composite and 19.4 % when compared to ZA-27 alloy.

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