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Influence of Heat Treatment and Extrusion Process on Mechanical Properties of LM13-nano ZrO_2 MMC's

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Abstract

In the present investigation, aluminum alloy (LM 13)-nano-ZrO_2 metal matrix composites were manufactured by stir casting technique followed by the hot extrusion process. The nano ZrO_2 particulates addiction varies from 2 to 10wt% in steps of 2% in the composite. The metallographic and SEM tests were conducted for confirmation of the presence of ZrO_2 particulates in the LM 13 alloy and to know the distribution of the ZrO_2 particulates in the Lm 13 alloy. The micro hardness, tensile test, and compression test were conducted on the nano metal matrix composites. The result reveals that the mechanical properties were improved in the nano metal matrix compared to the alloy. The heat treatment and the extrusion process have very good influence on improvement of the mechanical properties in the nano metal matrix compared to the alloy.

Keywords:

LM13;
Extrusion Process;
Nano Composites;
Nano-ZrO_2;
Heat Treatment.

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1. Introduction

The metal matrix nano-composites have encountered a massive development in the recent days due to their enhanced belongings. Particulate-reinforced nano-composites have been extensively employed in the automotive industry for their capability to withstand high temperature and pressure conditions. Nano-composite metal-matrix materials have emerged as a viable alternative to overcome the limitations of metal matrix composites; however nano-composites are challenging to produce as structural components due to difficulties in attaining a homogeneous distribution of the nano-phased particles. Nano-particles have progressively replaced other discontinuous reinforcement structures such as nano-fibers, nano-wires or nano-platelets. Nano-composite materials offer improved performance when compared to monolithic alloys and micro-composites. The possible applications of these materials are numerous and involve several market fields. Multi-functional materials with novel properties have been engineered. Although, the size reduction to the nano-meter scale poses new technologic challenge that will have to be overcome, such as particle agglomeration and de-bonding from the matrix. Zebarjad et al. [1] compared the effect of 25 µm, 5 µm, and 70 nm SiC particles on dimensional stability in an aluminum alloy. The temperature sensitivity of aluminum decreases in the presence of both micro and nano-sized silicon carbide, though the effect of nano-sized silicon carbide on dimensional stability is much higher than that of micro-sized ones. Ren and Chan [2] added SiC nano-particles (50 nm) to 7075 aluminum alloy. They pointed out increased wear resistance and high temperature creep resistance when comparing to the same alloy reinforced with 13 µm SiC particles. Hashim *et al.*, [3] have identified the important process variables that affect the mechanical properties of MMC. The holding temperature, stirring speed, size of the impeller and the position of the impeller in the melt are to be considered in the production of cast metal matrix composites. Sahin [4] has developed a setup

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for manufacturing MMCs. The setup has a bottom tapping facility. Hardness of the aluminium alloy improved significantly by addition of SiC particles into it, while density of the composite also increased almost linearly with the weight fraction of particles. Kok [5] produced Al_2O_3 particle-reinforced 2024 aluminium alloy composites by stir casting followed by application of pressure. The tensile strength and hardness of MMCs increased but the elongation decreased, with decreasing size and increasing weight percentage of the particles. Mazahery *et al*., [6] developed a new method based on stir casting to fabricate nano- Al_2O_3 particulate reinforced aluminum composites in order to avoid agglomeration and segregation of particles. Experimental results revealed that the presence of nano-Al_2O_3 reinforcement led to significant improvement in hardness, 0.2% yield strength, UTS and ductility.

S.A. Sajjadi et al [8] investigated the physical and mechanical properties of Aluminium matrix composites reinforced with micro and nano-sized Al2O3 particles. Authors also analysed the influence of various processing parameters such as heat treatment of particles, stirring speed, reinforcement particle size, and weight percentage of reinforcement particle size on microstructure and mechanical properties of the AMCs. Al2O3 particles with two different sizes of 20 μm and 50 nm were chosen as the reinforcement particles. M. Karbalaei Akbari et.al [9] Fabricated nano-metric alumina particle – reinforced A356 composites. The hardness and tensile properties were improved by addition of Nano-alumina particles. The maximum hardness was achieved at 4 min of stirring time. By means of increasing the stirring time, there will be a reduction in the tensile performance of composite. A. Ansary Yar et.al [10] fabricated Aluminium alloy matrix composite reinforced with nano-particle Mgo through stir casting method. Aluminium alloy (A356.1) matrix composites reinforced with 1.5, 2.5, and 5 vol% nano particles of Mgo. Composite was fabricated at 800, 850 and 9500C. Mechanical properties like hardness and compressive strength increased at 1.5 vol% Mgo fabricated at 850^{o}C. L.

Rasidhar et.al [11] fabricated ilmenite (FeTio3) based Aluminium based nano composite. The tensile and hardness values increased with increase in reinforcement. The tensile and hardness values were maximum at 5 wt % of illmenite reinforcement. Hossein Abdizadeh et.al [12] fabricated and investigated the mechanical properties of nano-Mgo reinforced Al composites by stir casting and powder metallurgy methods. Better mechanical properties were observed at 625 and 8500c for powder metallurgy and stir casting respectively. Karbalaei Akbari et.al [13] have evaluated hardness, wear resistance and compressive strength of nano-sized Al2O3 reinforced A356 alloy matrix. Addition of nano-particles also increased hardness, compressive strength and wear resistance.

Hamid Reza Ezatpour et.al [14] have investigated the microstructure and mechanical properties of Al6061-nanocomposite fabricated by stir casting. Nano sized Al2O3 particles are used as the reinforcement material. After fabrication by stir casting, the nano-composites were extruded at 550^{o}C. Extrusion is used as secondary processing so as to eliminate agglomeration of particles and reduction or elimination of porosity and improves bonding. Fabrication and study on mechanical properties and fracture behavior of nano-metric Al2O3 particle-reinforced A356 composites focusing on the parameters of vortex method was reported by Karbalaei Akbari et al.,[15] and characterized the 7075 Al alloy reinforced with SiC particulates by Rajesh Kumar Bhushanet al., [16].

In the present study the LM13-nano ZrO_2 MMCs were prepared by dispersed nano ZrO_2 in the amount of addiction varies from 2 to 10wt% in steps of 2%. The metallographic and SEM tests were conducted for confirmation of the presence of ZrO_2 particulates in the LM 13 alloy and to know the distribution of the ZrO_2 particulates in the Lm 13 alloy. The micro hardness, tensile test, and compression test were conducted on the nano metal matrix composites.

2. Material Selection

The matrix material selected for the development of the composite material is aluminum (LM13) alloy. Aluminum (LM13) alloy is desirable because of low density, cost, corrosion resistant, good mechanical properties, easy to cast and easy to machine as a base material in the development of nano metal matrix composites. Table 1 illustrates the chemical composition of aluminum (LM13) Matrix alloy. The reinforcement material used was nano-ZrO_2 particulates of size is 50 nm. The properties of reinforcement (ZrO_2) are shown in table 2 and ZrO_2 reinforcement material is provided by Nano Structured and Amorphous Materials, Inc., USA.

Table 1: Chemical composition of aluminum (LM13) alloy

Elements	**Zn**	**Mg**	**Si**	**Ni**	**Fe**	**Mn**	**Al**
Wt.%	0.5	1.4	12	1.5	1.0	0.5	Bal

Table 2: Properties of the synthesized nano-ZrO_2 particulates

Property	Value
Density	8.2 gm/cm^3
Melting Point	1860˚c
UTS	428 MPa
VHN	151
Young's modulus	97 GPa

3. Fabrication of Aluminium Nano MMCs

The aluminum (LM13)- nano ZrO_2 metal matrix composite materials were fabricated by stir casting method by varying the reinforcement from 0 wt.% to 10 wt.% in steps of 2 wt.%. The aluminum (LM13) alloy in melted in the electrical resistance furnace with a temperature controlling device. The known quantity of aluminum (LM13) alloy was melted to a temperature of 735^0C in the alumina crucible of electrical resistance furnace. After melting, the required amount of reinforcement particulates were preheated to around 350^0C then added into the molten metal slowly and stirred continuously by using mechanical stirrer which is attached to the electrical resistance furnace. The vortex is produced to get a homogeneous distribution of nano ZrO_2 particulates in the aluminum (LM13) alloy matrix. The melt blend was transferred into the mould at a pouring temperature of 780^oC and was allowed to cool at atmospheric conditions. The castings were taken out from the mould and the castings were tested to know the common casting defects using an ultrasonic flaw detector. Then the castings were cut to required shape and size as per ASTM standard for conducting one set of experiments on the test specimens of as-cast nano composite. Figure 1 shows the castings obtained by stir casting technique.

LM13 alloy LM13+2 Wt.% nano ZrO_2

Figure 1: As-cast LM 13 alloy and its nano composite

4. Extrusion of LM13+Nano ZrO_2 MMCs

After the as-cast aluminium (LM13) alloy and the aluminium (LM13) + nano ZrO_2 MMCs were developed by stir casting method, castings were machined to 17 mm diameter for extrusion. The extrusion process was conducted on as-cast aluminium (LM13) alloy and the aluminium (LM13) + nano ZrO_2 MMCs by diminishing in 25% of the area. During extrusion process the as-cast aluminium (LM13) alloy and the aluminium (LM13) + nano ZrO_2 MMCs were heated to 500 ^{o}C temperature for 30 minutes prior to extrusion process. The specimens were prepared from the extruded aluminium (LM13) alloy and aluminium (LM13) + nano ZrO_2 MMCs. Ultimate surface finish was obtained by mechanically buffing the sample by excellent grid size emery paper.

5. Heat Treatment of LM13 Alloy and LM13+Nano ZrO_2 MMCs

The test samples were prepared from the both as-cast and extruded aluminium (LM13) alloy and the developed aluminium (LM13) + nano ZrO_2 MMCs. The hardness, tensile, compression and fracture stiffness test specimens were subjected to artificial ageing at a temperature of $175\underline{+}5$ ^{o}C in a muffle furnace for 2hrs, 4hrs, 6hrs, 8 hrs and 10 hrs.

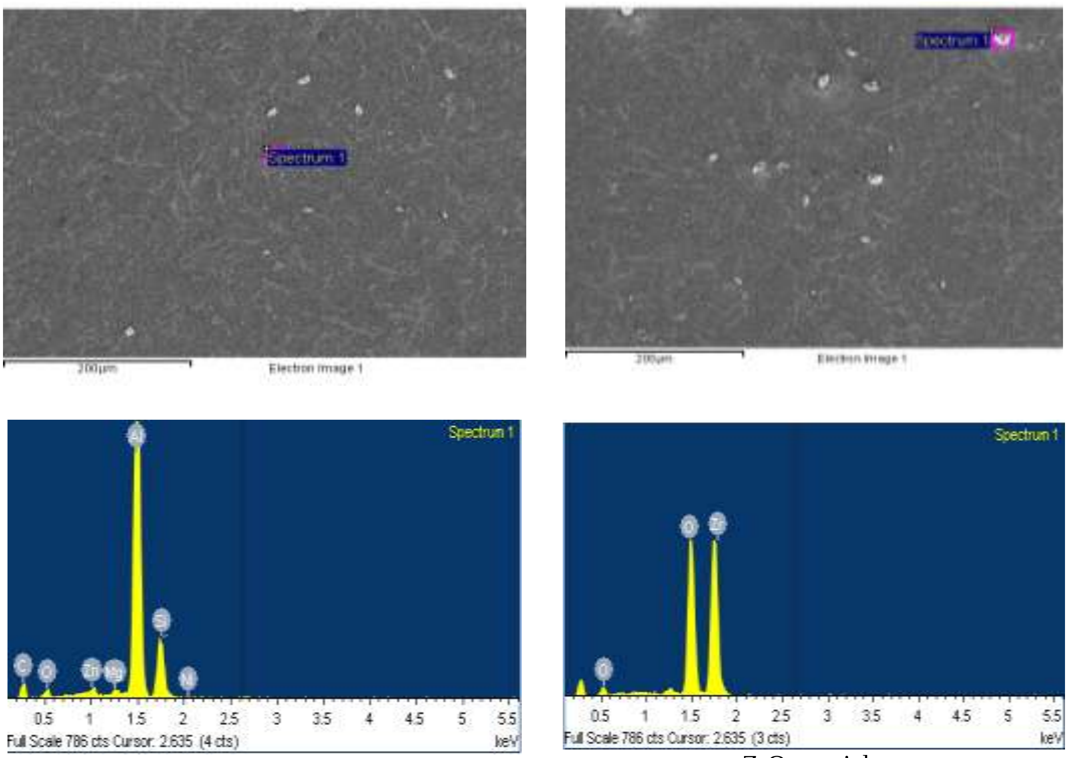
6. Testing of Nano MMC's

The test samples of 20 mm diameter and 15 mm height were machined. The specimens were fine polished and etched by etching agent for 20 seconds. The etching was cleaned by cotton and water. Then the specimens were dried for few seconds. The microstructures of aluminium (LM13) alloy and the developed aluminium (LM13) + nano ZrO_2 MMCs were observed under optical microscope. The tensile test was conducted on aluminium (LM13) alloy and aluminium (LM13) + nano ZrO_2 MMCs in accordance with ASTM E8-95 standard using TUE-C-400 computerized universal testing machine. The tensile test specimens of actual 12.5 mm diameter and gauge length of 62.5 mm were prepared. Ultimate surface finish was obtained by mechanically buffing the sample by excellent grid size emery paper. The test sample was fixed between two manually modifiable grips of computerized universal testing machine attached with an electronic extensometer and the surrounding temperature is 35°C. Due to the application of load, the elongation and maximum load of the specimen are recorded. The compression test was conducted on aluminium (LM13) alloy and aluminium (LM13) + nano ZrO_2 MMCs specimens prepared according to ASTM E9-95 standard using TUE-C-400 computerized universal testing machine. The compression test samples of 13 mm actual diameter and gauge length of 25 mm were prepared. Ultimate surface finish was obtained by mechanically buffing the sample by excellent grid size emery paper.The test sample was fixed between two jaws of computerized universal testing machine attached with an electronic extensometer and the surrounding temperature is 35°C.

7. Results and Discussions

7.1 Optical Micrographs and SEM Studies

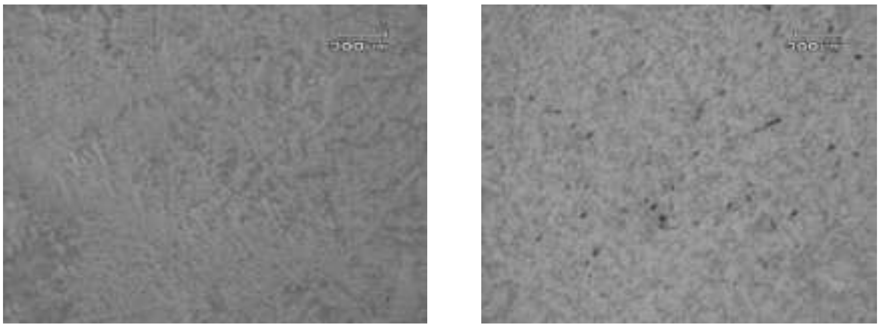
Figure 2 shows the SEM photographs of aluminium (LM13) alloy and EDAX pattern of aluminium (LM13) alloy used for the development of the aluminum (LM13)-nano ZrO_2 metal matrix composites. The EDAX pattern shows the presence of the aluminium alloy elements in the aluminium (LM13) alloy. The EDAX pattern confirms presence of the ZrO_2 particles in the aluminum (LM13)-nano ZrO_2 metal matrix composites.



Aluminium (LM13) alloy ZrO_2 particle

Figure 2: SEM photographs and EDAX pattern of Aluminium (LM13) alloy and ZrO_2 particle in MMC

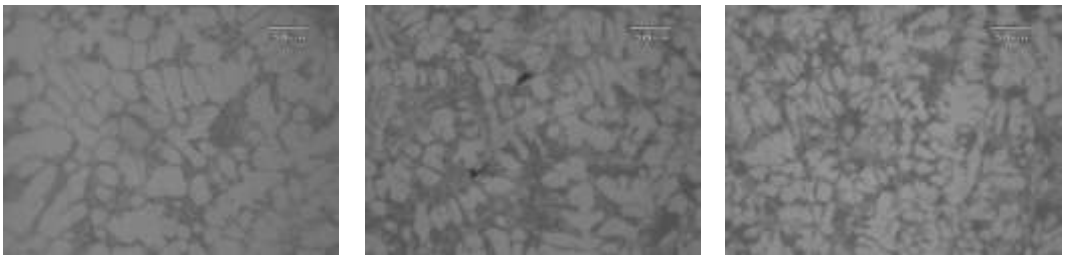
Figure 3 shows the optical micrographs of as-cast aluminium alloy and aluminum (LM13)-nano ZrO_2 MMCs. The micrograph indicates that the MMNCs exhibit uniform distribution of reinforcements in the matrix material. The nano ZrO_2 reinforcement particles are uniformly allocated in the aluminium (LM13) matrix which directly influences to enhance the belongings of the aluminum (LM13)- 4 wt.% of nano ZrO_2 MMCs.



LM 13 alloy LM 13 + 4 wt.% of ZrO_2

Figure 3: Optical micrographs of as-cast aluminium alloy and aluminum (LM13)-nano ZrO_2 MMCs

The micro structural characteristics of as- cast, extruded and 6hrs heat treated aluminum (LM13)-2 wt. % nano ZrO_2 MMCs are shown in the figure 4 and indicates the reinforcement and matrix interfacial reliability. Micro structural studies performed on the as-cast, extruded and 6hrs heat treated aluminum (LM13)-2 wt. % nano ZrO_2 MMC shows good interfacial reliability and considerable grain improvement. These are achieved because of the sensible choice of stirring constraints and good wetting is accomplished by the preheated reinforcement.



As-cast **Extruded** **6 hr Heat treated**

Figure 4: Optical micrographs of as-cast, extruded and heat treated LM13-2 wt.% nano ZrO_2 MMC

7.2 Micro hardness of nano composites

Figure 5 explains the outcome of heat treatment on the micro hardness of the extruded aluminium (LM13) alloy and extruded aluminum (LM13)-nano ZrO_2 MMCs. The micro hardness of extruded aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs increases after heat treatment process. This increase in the micro hardness in the heat treated aluminium (LM13) alloy and heat treated aluminum (LM13)-nano ZrO_2 MMCs is due to enhanced excellent union among the nano ZrO_2 particles and the matrix alloy. The heat treatment process also helps in the formation of precipitation in alloying elements which leads to boost in the micro hardness in the aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs. The micro hardness increases as ageing (heat treatment) duration increases from 2 hrs to 6 hrs and further increase in the ageing duration micro hardness declines. The 6 hrs heat treated aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs shows maximum micro hardness as compared to supplementary heat treated aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs. The maximum micro hardness indicated at the 6 hrs heat treatment by aluminium (LM13) +8 wt.% nano ZrO_2 MMC. The micro hardness of 6 hrs aged aluminium (LM13) alloy increases by 24.44% and micro hardness boosted by 0.063% in the 2 hrs aged aluminium (LM13) alloy with that of extruded aluminium (LM13) alloy. The micro hardness of 10 hrs aged aluminium (LM13) alloy decreases by 0.045% as compared to 6 hrs aged aluminium (LM13) alloy. Finally, the figure indicates that the 6 hrs aged aluminum (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs shows the maximum micro hardness therefore the specimens of tensile, compression, fracture toughness, sliding wear, thermal conductivity and coefficient thermal expansion tests were subjected to heat treatment 6 hrs at 175 $\pm$ 5 ^{o}C for conducting the experimentations.

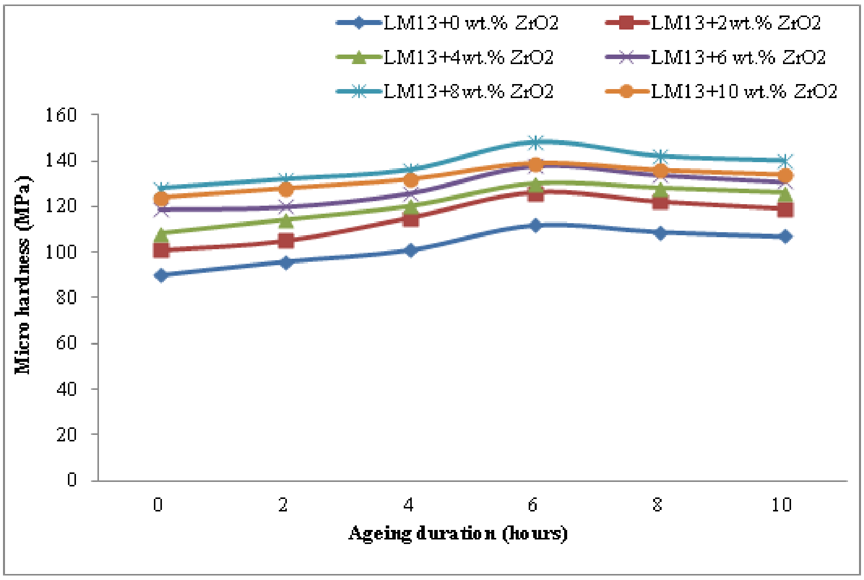


Figure 5: Influence of heat treatment on micro hardness of the extruded LM13-nano ZrO_2 MMCs

Figure 6 shows the effect of heat treatment and extrusion on micro hardness of the aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs as compared to as-cast aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs. The heat treatment and extrusion process increases the micro hardness of aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs. This increase in the micro hardness in the extruded aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs is due to uniform allocation of particles and achieving good bonding between the nano ZrO_2 particles in the matrix alloy. The micro hardness of 6 hrs heat treated aluminium (LM13) alloy increases by 64.62% and increase 38.46% in the micro hardness of extruded aluminium (LM13) alloy with that of as-cast aluminium (LM13) alloy. The micro hardness increases by 34.74% due to extrusion of aluminium (LM13) +8 wt.% nano ZrO_2 MMC and increases by 55.8% due to 6 hrs heat treatment of aluminium (LM13) +8 wt.% nano ZrO_2 MMC with that of as-cast aluminium (LM13)+8 wt.% nano ZrO_2 MMC. The micro hardness of 6 hrs heat treated aluminium (LM13) +10 wt.% nano ZrO_2 MMC decreases by 0.06% with that 6 hrs heat treated aluminium (LM13) +8 wt.% nano ZrO_2 MMC. The micro hardness of extruded aluminium (LM13) +10 wt.% nano ZrO_2 MMC decreases by 0.031% with that extruded aluminium (LM13) +8 wt.% nano ZrO_2 MMC.

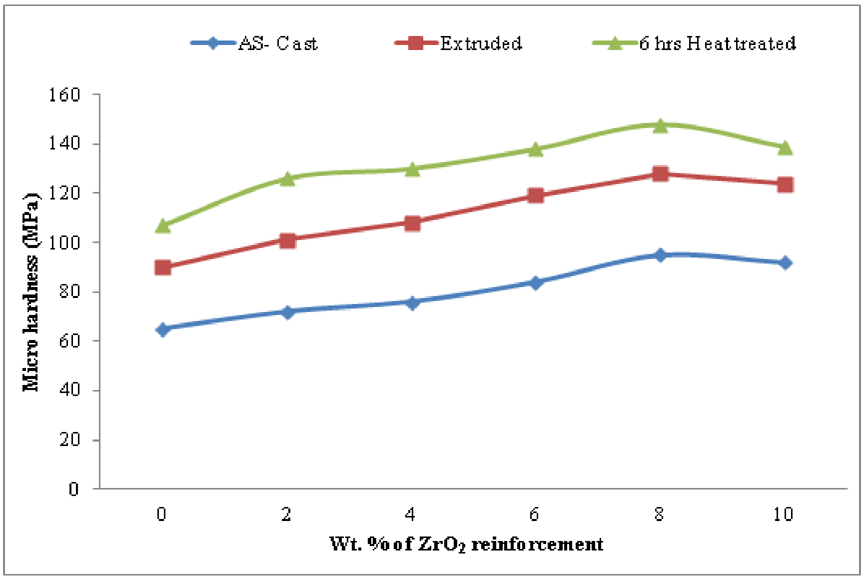


Figure 6: Influence of extrusion and heat treatment on micro hardness of the LM13-nano ZrO_2 MMCs

7.3 Tensile Strength

Figure 7 reveals the consequence of heat treatment and extrusion on UTS of the aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs as compared to as-cast aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs. The heat treatment and extrusion process increases the UTS of aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs. This increase in the UTS in the extruded aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs is due to uniform allocation of particles and achieving fine union among the nano ZrO_2 particles in the matrix alloy. The UTS of 6 hrs heat treated aluminium (LM13) alloy increases by 26.47% and increase 10.59% in the UTS of extruded aluminium (LM13) alloy with that of as-cast aluminium (LM13) alloy. The UTS increases by 12.12% due to extrusion of aluminium (LM13) +4 wt.% nano ZrO_2 MMC and increases by 26.40% due to 6 hrs heat treatment of aluminium (LM13) +4 wt.% nano ZrO_2 MMC with that of as-cast aluminium (LM13)+4 wt.% nano ZrO_2 MMC. The UTS increases by 9.16% due to extrusion of aluminium (LM13) +8 wt.% nano ZrO_2 MMC and increases by 24% due to 6 hrs heat treatment of aluminium (LM13) +8 wt.% nano ZrO_2 MMC with that of as-cast aluminium (LM13)+8 wt.% nano ZrO_2 MMC. The UTS of 6 hrs heat treated aluminium (LM13) +10 wt.% nano ZrO_2 MMC decreases by 0.01% with that 6 hrs heat treated aluminium (LM13) +8 wt.% nano ZrO_2 MMC. The UTS of extruded aluminium (LM13) +10 wt.% nano ZrO_2 MMC decreases by 0.024% with that extruded aluminium (LM13) +8 wt.% nano ZrO_2 MMC.

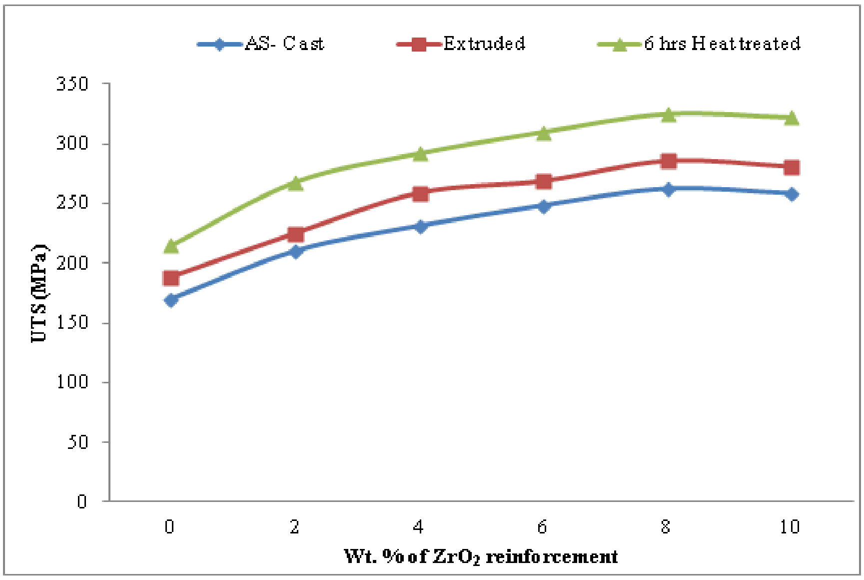


Figure 7: Influence of extrusion and heat treatment on UTS of the LM13-nano ZrO_2 MMCs

7.4 Yield strength

Figure 8 exposes the consequence of heat treatment and extrusion on yield strength of the aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs as compared to as-cast aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs. The heat treatment and extrusion process increases the yield strength of aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs. The increase in the yield strength in the aluminum (LM13)-nano ZrO_2 MMCs may be due to nano scale ZrO_2 particulates reinforcement in the aluminium (LM13) matrix alloy. The yield strength of 6 hrs heat treated aluminium (LM13) alloy increases by 35% and increase 11.67% in the yield strength of extruded aluminium (LM13) alloy with that of as-cast aluminium (LM13) alloy. The yield strength increases by 28.23% due to extrusion of aluminium (LM13) +2 wt.% nano ZrO_2 MMC and increases by 49.19% due to 6 hrs heat treatment of aluminium (LM13) +2 wt.% nano ZrO_2 MMC with that of as-cast aluminium (LM13)+2 wt.% nano ZrO_2 MMC. The yield strength increases by 23.49% due to extrusion of aluminium (LM13) +8 wt.% nano ZrO_2 MMC and increases by 44.26% due to 6 hrs heat treatment of aluminium (LM13) +8 wt.% nano ZrO_2 MMC with that of as-cast aluminium (LM13)+8 wt.% nano ZrO_2 MMC. The yield strength of extruded aluminium (LM13) +8 wt.% nano ZrO_2 MMC enhances by 88.33% and 6 hrs heat treated aluminium (LM13) +8 wt.% nano ZrO_2 MMC shows 120% increase in the yield strength as compared to yield strength of as-cast aluminum (LM13) alloy and 75% increase in the yield strength of extruded aluminium (LM13) +10 wt.% nano ZrO_2 MMC and 108.33% increase in the yield strength of 6 hrs heat treated aluminium (LM13) +10 wt.% nano ZrO_2 MMC with that of as-cast aluminium (LM13) alloy.

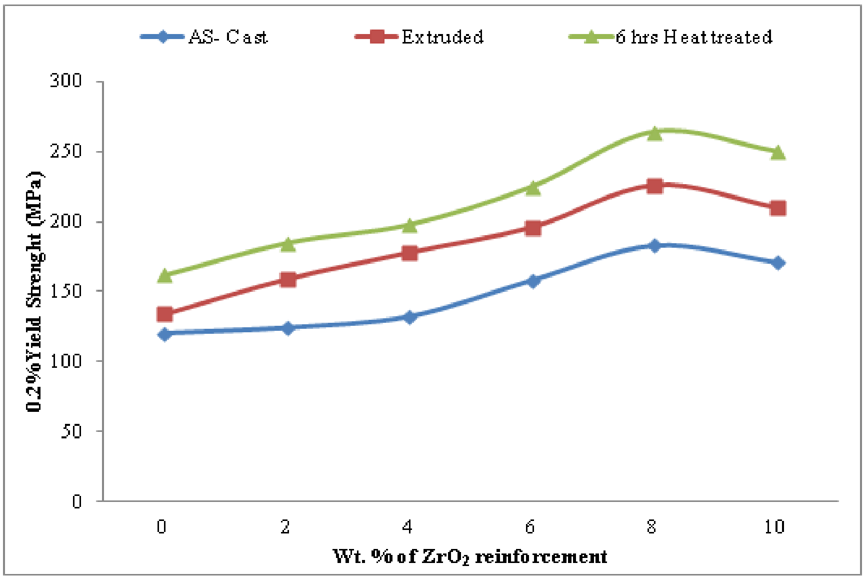


Figure 8: Influence of extrusion and heat treatment on yield strength of the LM13-nano ZrO_2 MMCs

7.5 Ductility

Figure 9 reveals the consequence of heat treatment and extrusion on ductility of the aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs as compared to as-cast aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs. The heat treatment and extrusion process decreases the ductility of aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs. The ductility of 6 hrs heat treated aluminium (LM13) alloy decreases by 45.45% and decrease 18.18% in the ductility of extruded aluminium (LM13) alloy with that of as-cast aluminium (LM13) alloy. The ductility decreases by 15.12% due to extrusion of aluminium (LM13) +4 wt.% nano ZrO_2 MMC and decreases by 34.48% due to 6 hrs heat treatment of aluminium (LM13) +4 wt.% nano ZrO_2 MMC with that of as-cast aluminium (LM13)+4 wt.% nano ZrO_2 MMC. The ductility decreases by 26.19% due to extrusion of aluminium (LM13) +8 wt.% nano ZrO_2 MMC and decreases by 38.1% due to 6 hrs heat treatment of aluminium (LM13) +8 wt.% nano ZrO_2 MMC with that of as-cast aluminium (LM13)+8 wt.% nano ZrO_2 MMC.

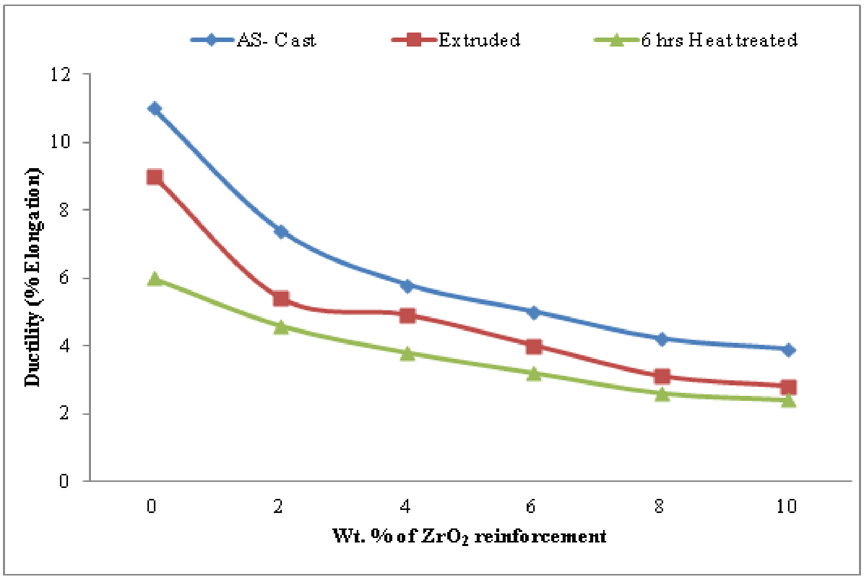


Figure 9: Influence of extrusion and heat treatment on ductility of the LM13-nano ZrO_2 MMCs

7.6 Compression strength

Figure 10 reveals the consequence of heat treatment and extrusion on compression strength of the aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs as compared to as-cast aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs. The heat treatment and extrusion process increases the compression strength of aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs. This increase in the compression strength in the extruded aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs is due to even allocation of particles and achieving good union among the nano ZrO_2 particles in the matrix alloy. The compression strength of 6 hrs heat treated aluminium (LM13) alloy increases by 37.41% and increase 18.71% in the compression strength of extruded aluminium (LM13) alloy with that of as-cast aluminium (LM13) alloy. The compression strength increases by 11.72% due to extrusion of aluminium (LM13) +8 wt.% nano ZrO_2 MMC and increases by 25.52% due to 6 hrs heat treatment of aluminium (LM13) +8 wt.% nano ZrO_2 MMC with that of as-cast aluminium (LM13)+8 wt.% nano ZrO_2 MMC.

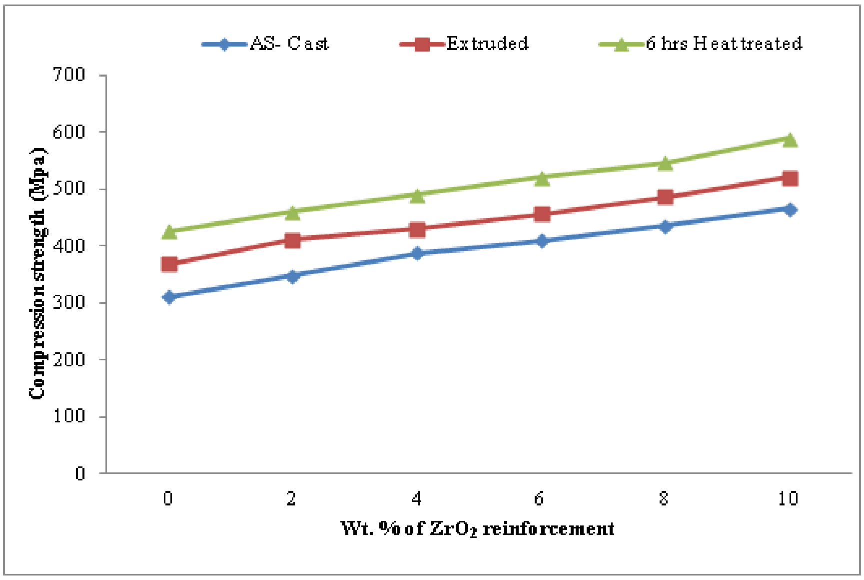


Figure 10: Influence of extrusion and heat treatment on compression strength of the LM13-nano ZrO_2 MMCs

7.7 Fracture toughness

Figure 11 illustrates the consequence of heat treatment and extrusion on fracture toughness of the aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs as compared to as-cast aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs. The heat treatment and extrusion process increases the fracture toughness of aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs. This boost in the fracture toughness in the extruded aluminium (LM13) alloy and aluminum (LM13)-nano ZrO_2 MMCs is due to uniform allocation of particles and achieving good union among the nano ZrO_2 particles in the matrix alloy. The fracture toughness of 6 hrs heat treated aluminium (LM13) alloy increases by 50.77% and increase 23.1% in the fracture toughness of extruded aluminium (LM13) alloy with that of as-cast aluminium (LM13) alloy. The fracture toughness increases by 16.13% due to extrusion of aluminium (LM13) +8 wt.% nano ZrO_2 MMC and increases by 35.48% due to 6 hrs heat treatment of aluminium (LM13) +8 wt.% nano ZrO_2 MMC with that of as-cast aluminium (LM13)+8 wt.% nano ZrO_2 MMC.

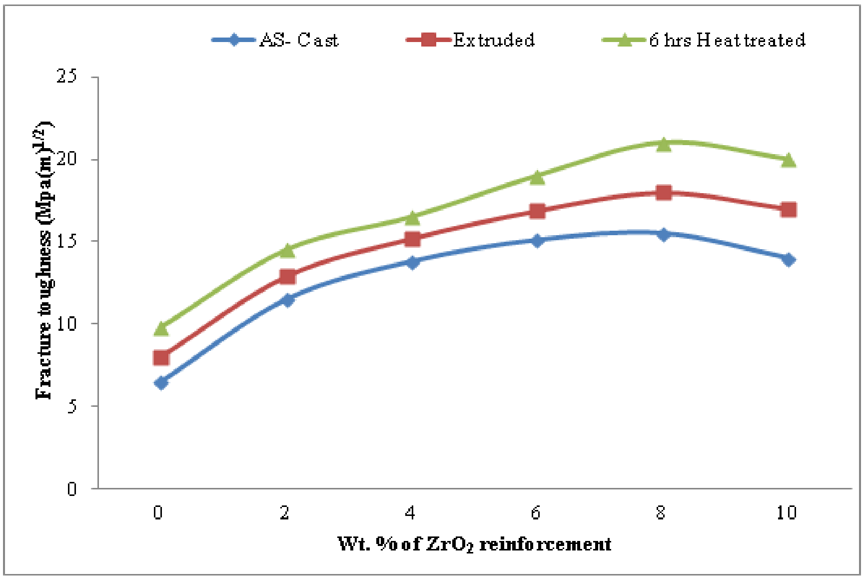


Figure 11: Influence of extrusion and heat treatment on fracture toughness of LM13-nano ZrO_2 MMCs

8. Conclusions

The following conclusions were drawn from the above study. The LM13-ZrO_2 nano metal matrix composite materials have been fabricated by stir casting method followed by extrusion process. The nano ZrO_2 particulates are evenly dispersed in the matrix alloy. The micro hardness of LM13-ZrO_2 nano metal matrix composite material is superior than the matrix material. The micro hardness increases by 12.2% by the addition of 2 wt.% of ZrO_2 nano particulates in aluminum (LM13) matrix alloy. The inclusion of ZrO_2 nano particulates in LM13 matrix alloy significantly enhanced the ultimate tensile strength and yield strength of the LM13-ZrO_2 nano metal matrix composite materials. The 8 wt.% of ZrO_2 reinforced aluminum (LM13)-ZrO_2 nano composite shows 54.11% increase in the ultimate tensile strength as compared to ultimate tensile strength of LM 13 alloy. The ductility of LM13-ZrO_2 nano MMC decreases with that of LM 13 alloy. The ductility decreases by 32.72% with the inducing of 2 wt. % of ZrO_2 nano particulates in aluminum (LM13) matrix alloy. The compression strength increases as the fraction of reinforcement enhances in the matrix material. The 8 wt.% of ZrO_2 reinforced as-cast aluminum (LM13)-ZrO_2 nano composite shows 40.32% increase in the compression strength as compared to compression strength of aluminum (LM13) alloy. Fracture toughness increases as the reinforcement substance amplifies in the matrix material. The fracture toughness increases by 130% by the addition of 2 wt. % of ZrO_2 nano particulates in LM13 matrix alloy.

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