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A Review on Mechanical Properties of Aluminum Silicon (LM series) Based Metal Matrix Composites

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Abstract:

Aluminium Metal Matrix composites have replaced the major conventional materials because of its superior mechanical properties such as high strength, lesser weight and good wear resistance. Aluminum-silicon (LM series) metal matrix composite can fulfil the needs of emerging trends in engineering and industrial advancements. The present study attempted to review the researches undergone on the influence of various reinforcements such as ZrO_2, TiB_2, AlB_2, SiC, MoS_2, B_4C, etc., on LM based aluminium alloys on their properties like tensile and compression strength, hardness, impact strength. The methodology of various papers has been studied and the corresponding conclusion was included in this study.

Key words: *Aluminium- silicon alloys, Metal matrix composites, Stir casting, Mechanical properties.*

Introduction

Composite materials are the most favoured engineering materials due to their exquisite mechanical properties. In composite, the desirable properties of distinct materials were mixed via mechanically or metallurgically binding them together. There are numerous varieties of composite materials, product categories and each day innovative composites were being introduced. For the Metal Matrix Composite - aluminium, magnesium and their alloys are often preferred as base materials in the manufacturing MMC owing to their desirable properties [1].

Hybrid Composite are produced via reinforcing of two or more materials of differing properties with the base material to produce enhanced mechanical and tribological properties [2]. Aluminium is considered one of the most predominant matrix materials considering its properties as compared to other challenging materials like Magnesium and Titanium. Aluminium LM series alloys are well-matched for fabricating automobile components with compact weight and also play a vital role in both industrial and commercial desires [3]. Table 1 shows that the LM based composites for automotive applications

A particulate reinforced aluminium matrix composites can enhance significantly the strength and hardness of aluminium and its alloys. Yet, at the same time, the plasticity and ductility can noticeably decrease. This will affect the safety and dependability of components manufactured from Aluminium matrix composites [4]. The wide range of manufacturing techniques was available for manufacturing metal matrix composite such as liquid metallurgy route, extrusion casting, powder metallurgy etc. Among the various fabrication technique accessible in intermittent metal matrix composites, stir casting was most extensively used and acknowledged for viable and practical approaches because of its ease, flexibility and applicability to bulk production. It is also

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the most cost-effective method in making metal matrix composites. A stirring was advanced for consistent dispersion of fabricating particulate metal matrix composites in an economic [5].

Table 1. LM Based Composites for Automotive Applications [3]

Alloy	Applications	Properties
LM 4 LM 6	Marine, Automobile, Aerospace industries	corrosion resistance, casting properties Mechanical properties increased by heat treatment
LM 13	Used for piston which undergoes thermal stresses.	Good wear resistance Machinability
LM 24	Die castings components in engineering applications	Good mechanical properties High resistance to corrosion
LM 25	Used for wheels, cylinder blocks and heads, and other engine and body castings	Good corrosion resistance, Improved thermal properties and high Strength by heat treatment
LM 26	Piston and Piston rings	Good wear resistance Thermal resistance Machinability.
LM 28	Used in Piston alloy	Lower coefficient of thermal expansion.
LM 29 LM 30	Unlined die cast cylinder blocks	Low expansion Excellent wear resistance.

In this article, the several mechanical properties like Hardness, Tensile strength, compression strength and Impact strength of Aluminum-silicon (LM series) metal matrix composite with various reinforcement of by stir casting method was studied.

Literature review

Shanmugaselvam et al. [6] evaluated the tribological behaviour and hardness of Aluminium LM4 Alloy reinforced with Nano alumina and micro molybdenum fabricated by Stir casting method by changing the weight percentage of alumina and molybdenum. The weight % of alumina is 1, 1.5, 2.5 and 5% and weight % of molybdenum 0.5% to all samples. From the observation, it has been concluded that 5% alumina and 0.5% molybdenum provided improved hardness and wear resistant. The nano alumina particle forms an oxide layer on aluminium LM4 alloy along with molybdenum and acts as clogged to the movement of dislodgment of particles.

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Arivukkarasan et al. [7] investigated the macro and tribological properties of tungsten carbide (5%, 10%, 15% wt) reinforced in aluminium LM4 matrix by the liquid route casting process. The supreme enhancement in hardness (214.77 VHN), impact strength(6MPa) and tensile strength (271.11 MPa) was attained for the LM4 contains 15 wt% of Tungsten carbide.

Arun et al. [8] examined the mechanical behaviour on aluminium LM04 alloy with varying weight % Al_2O_3 nanoparticles (1%, 1.5%, 2.5% and 5% vol) fabricated by stir casting method. The composite comprises 1.5 vol % of Al_2O_3 has higher tensile strength and hardness because of reinforcement uniformly dispersed in matrix and the bonding of matrix and reinforcement phase. Stalin et al. [9] synthesized aluminium LM04 Matrix reinforced with Nano boron carbide (5%,10% and 15%) by the liquid stir casting process. The composite was tested for tensile strength and compared with the base metal. The tensile strength was maximum for 15% wt of B_4C (159.17 Mpa) obtained as of the role of B_4C tendency to restrict the movement of LM04 within its locality.

Narassima et al. [10] investigated the outcome of reinforcement (zinc) and aging time on wear behaviour and mechanical properties of Aluminium LM4. Zinc particles at the micro level were reinforced in an Aluminium matrix by the stir casting process. The weight % of Zinc are 3%, 5% and 7% respectively reinforced with remaining Al matrix. The hardness rises with an increase in aging time, a maximum value of 72.41BHN and UTM 145.9Mpa for the specimen with an aging time of 14hrs from the experimental value.

Ravichandra et al. [11] explored the mechanical behaviour of LM4 reinforced with Zirconium oxide (0%, 3%, 6%, 9% and 12% wt) for Structural applications by stir casting applications. Hardness value observed that 6% of wt has higher value comparing other wt%. Tensile and Compression value was more at 12%. Koushik et al. [12] inspected the mechanical behaviour for LM4 alloys reinforced with soda glass (wt 2% & 5%). For smaller size and higher weight % of soda glass, it increases both hardness and shear strength of aluminium LM4 alloy.

Suswagata Poria et al. [13] analysed the tribological behaviour of stir casting LM4 – TiB_2 Metal Matrix Composites. Different weight % (1%, 2.5%, 4%, 5.5%) of TiB_2 powders having average sizes of 5- 40 microns were incorporated into molten LM4 by stir casting method. Vicker microhardness shows that increase in wt% increase the hardness and wear rate. Karthikeyan et al. [14] examined on mechanical and wear behaviour of Aluminium LM6/ Zirconium oxide fabricated by stir casting method. 12% of ZrO_2 shows higher hardness value and better wear rate and efficient performance comparing other sample wt% (0%, 3%, 6%, 9%). The maximum Tensile value (209 Mpa), Compression value (218 Mpa) and impact strength was obtained at 12% of ZrO_2.

Libu George and Bharanidaran [15] evaluated the impact strength and hardness of LM6 - soda lime glass powder (1.5%, 3% and 4.5 wt%) composites. On observing the results, Ultimate Tensile strength, Hardness and Impact strength in a composite comprising 3% glass has a higher value.

Prashant Kumar Suragimath and Purohit [16] experimented the mechanical behaviour of Aluminium alloy LM6 reinforced with Silicon Carbide (5%) and Fly ash (5%, 15%). Stir casting methods had been adopted. The outcome displays that escalation of fly ash increases the Tensile strength, Impact strength and wear resistance of samples and diminution the % of elongation at 15% of fly ash.

Samson Jerold Samuel Chelladurai et al. [17] explored the macro properties of Squeeze cast LM6 alloy reinforced with Zinc coated steel wire mesh. Layer on reinforcement rises the boundary piling among reinforcement and matrix, wetting that in turn surges the mechanical properties of the composite. The hardness amplified with increasing distance from LM6 to reinforcement. Tensile strength increases with an orientation of reinforcement.

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Kirandeep Kaur Sandhu et al. [18] developed the aluminium LM6 based matrix reinforced with SiC and Al_2O_3 by liquid metallurgy process. Tensile strength, hardness and impact strength tests were taken and compared with base LM6 alloy. Result concluded that maximum tensile strength (238 N/mm2), impact strength (7.09 Nm) and hardness (131 VHN) was obtained and it was greater than the base LM6 alloy.

Anguraj et al. [19] examined the mechanical properties of Aluminium LM6 alloy with Boron Carbide (2.5%, 5%, 10% of wt) and Fly ash (5% wt) using a stir casting process. Consequence observed for composites increase in mechanical properties up to 5% fly ash and 10% B_4C and maximum hardness (124BHN) and Ultimate Tensile strength (145Mpa) obtained for 5% fly ash and 10% B_4C. David Rathnaraj and Sathish [20] investigated LM6 Metal Matrix Composites reinforced with Boron silicate glass powder (2.5%, 5%, 7.5%, 10%) for aerospace application fabricated by stir casting technique. Addition of reinforcement up to 7.5% shows a gradual rise in hardness, tensile and impact strength. Exceeding 7.5% i.e., 10%, value declines due to huddling of reinforcement which permits crack propagation.

Dhanalakshmi et al. [21] investigated the influence of processing parameters such as Melt temperature (730^0C, 800^0c, 850^0c) and stirring speed (400, 500, 600, 700) rpm for Aluminium LM09 alloy with Silicon Carbide by liquid metallurgy method. The study exposed that stir speed of 500rpm shows uniform distribution compared to others and peak tensile strength achieved at melt temperature 800^0C due to suitable wetting of reinforcement.

Vidyasagar Shetty and Vijayakumar [22] observed the outcome of Silicon oxide (9% wt) and Carbon nanotubes (2%, 4%) on mechanical properties of LM12 alloy hybrid metal matrix composites. Aluminium alloy LM 12- 9% SiO_2- CNT 4% had higher strength and hardness compared with monolithic aluminium alloy LM 12.

Suresh et al. [23] investigated the consequence of mechanical properties of LM12 with the reinforcement of Silicon Carbide (0%, 5%, 10%, 15% & 20% wt) by the stir casting process. Brinell hardness and impact strength surges by reinforcement wt% rise in hardness at 20% SiC (84.8 BHN), Mallikarjuna et al. [24] evaluated the Aluminium LM13 alloy – Silica composites by casting route. The weight % of reinforcement Silicon dioxide are 3%, 6%, 9% & 12% and remaining LM13 Matrix. Tensile strength and hardness were rises up to weight percentage of 9 of silica for micron size of 106 μm, later those declines. Result determined that 9% of silica has a higher tensile strength (209.84 MPa) and hardness (141 VHN).

Mallikarjuna et al. [25] studied the macro properties of LM13- Al_2O_3 composites by the stir casting process. Among all Al_2O_3 reinforcement weight % samples (3%, 6%, 9% & 12%), 9% has higher Tensile strength (262 MPa), Compression strength (549 MPa) and Hardness (146 VHN) respectively.

Akhil et al. [26] studied the cooling rate and impact on mechanical properties of AA LM13 matrix B_4C reinforced composites. The cooling rate was calculated via k type thermocouple. Based on the temperature measurement, cooling rate and cooling curve were measured with varying wt % (3, 6, 9) B_4C. 9% of B_4C has higher tensile strength, impact strength and hardness comparing other samples.

Raghu et al. [27] evaluated the properties of cryogenically solidified MMC LM13-Zirconium dioxide (2%, 4%, 6% & 8% wt). Hexachloroethane tablet was added to molten metal for degassing aluminium alloys LM13 and also grain refining. Flux was added to avoid non-metal inclusion, absorption of hydrogen gas and oxides. Passing the liquid nitrogen before pouring molten metal mixture to create the cryogenic effect in copper end chill block. Observing from the

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results, Tensile strength, compression strength and Hardness were amplified with a rise in wt% of reinforcement in LM13 MMC.

Ravindra Sagar et al. [28] studied on mechanical properties of AA LM13 matrix with Magnesium oxide with changing weight % (2%, 4%, 6%, 8% & 10%) fabricated by stir casting techniques. Observed from the outcomes, Hardness and Tensile value displays a gradual rise up to 6% wt of reinforcement and starts to diminish over 6% wt of reinforcement. For compression strength, the addition of reinforcement up to 10% shows a gradual increase in compression strength.

Jojith et al. [29] fabricated the LM13 Hybrid Metal Matrix Composite reinforced with Titanium oxide (12% wt) and Molybdenum disulphide (3% wt) fabricated by liquid metallurgy route and evaluated the mechanical properties. Addition of reinforcement compared to the base metal, Hardness and Tensile strength increased by 16.5% and 35% respectively.

Ranjithkumar et al. [30] studied on mechanical properties of AA LM13 reinforced with ceramic particles through stir casting techniques. Aluminium oxide and graphite added by varying weight % as 100% LM13, 90% LM13- 10% Al_2O_3, 90% LM13- 5% Al_2O_3- 5% graphite. Among 3 specimens 90% LM13- 10% Al_2O_3 has higher Hardness and Tensile strength.

Krishna Prasad Yadav et al. [31] fabricated and analysed the structure of Aluminium alloy LM16 reinforced with Graphite and granite powder. By varying weight %, 3 samples- LM 16 (100%), 91% LM 16- 4% graphite- 5% granite powder,86% LM 16- 4% graphite- 10% granite powder were considered. Hardness and Tensile strength were maximum at sample 86% LM 16- 4% graphite- 10% granite powder and has Modulus of elasticity 76.7 x 10^3N/mm^2.

Sreekanth et al. [32] evaluated the piston using Aluminium LM21 alloy reinforced with Silicon carbide (5%, 6.5% & 7.5% wt) and Graphite (5%, 3.5% & 2.5% wt). From the observation, that the tensile strength and hardness enhanced with an escalation in reinforcement percent but lessening in elongation percent. The maximum Hardness and tensile strength obtained for sample LM24- 6.5% SiC- 3.5% graphite comparing other samples.

Senthilkumar et al. [33] investigated the mechanical behaviour on AA LM24/ Si_3N_4 (10% wt)/ Graphite (7% wt) hybrid composites. The increase of silicon nitrate and graphite weight percentage in LM24 improves the hardness value and tensile strength increased than the base LM24 alloy.

Chandrasekaran et al. [34] studied the impact of Al_20_3 on AA LM24 composites in dry sliding condition. The addition of the Al_20_3 reinforcement particles in the base AA LM24 caused protruding on the wear surface. The wear rate of LM24- Al_20_3 has 15% higher wear rate of base LM24.

Senthilkumar et al. [35] explored the mechanical and wear properties of LM24/ silicate (4%, 8%, 12%, 16%, 20% & 24% wt) / Fly ash (4% wt) hybrid composites using vortex technique. Comparing the samples, 24% wt of SiO_2 and 4% of Fly ash has superior Tensile strength (212 N/mm) and Hardness (102 VHN). The figure 1 exposed that the hardness, tensile strength and density of LM24/silicate/fly ash hybrid composite.

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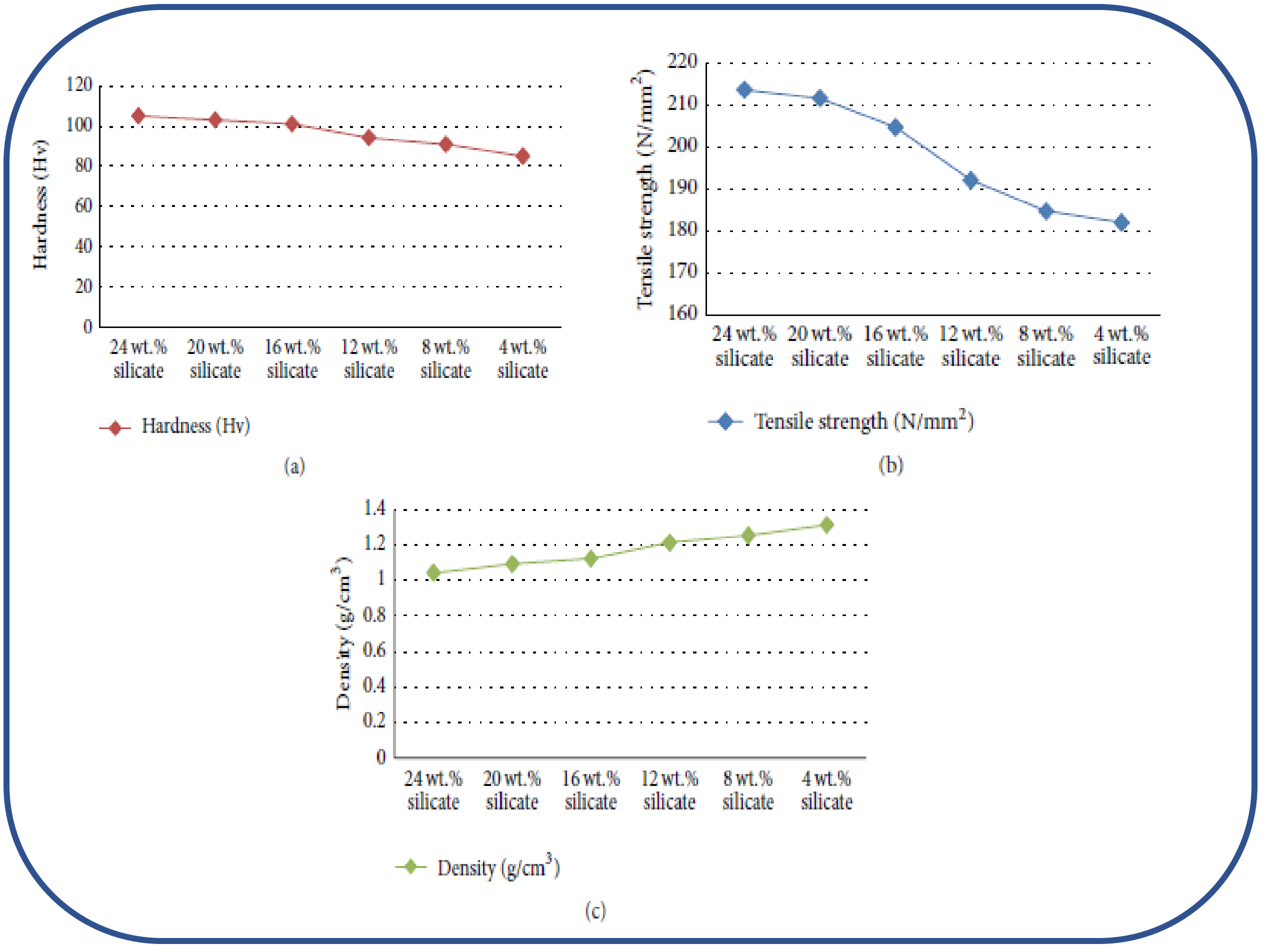

Figure 1. (a) Hardness of LM24/silicate/fly ash hybrid composite (b) Tensile strength of LM24/silicate/fly ash hybrid composite (c) Density of LM24/silicate/fly ash hybrid composite [35]

Keshav Singh et al. [36] fabricated the LM24/ B_4C (3%, 5% & 7% wt) composites and tested the mechanical properties with varying weight % of reinforcement. For 7% B_4C reinforced with remaining wt % of LM24 has improved 94% in impact strength than the base LM24 and Maximum Tensile strength and hardness were obtained.

Arunagiri et al. [37] studied the wear characterization of tempered AA LM25 with AlB_2 (10% wt) composites fabricated by the stir casting process. Aging was done at different temperature (160^{0}C, 175^{0}C, 200^{0}C, 250^{0}C) for various aged time (4, 6 and 8 hrs). The maximum hardness 82 HRB obtained for aged at 250^{0}C for 6 hrs time. Aritakula Venugopal Rao et al. [38] examined the wear resistance and mechanical properties of Aluminium Alloy LM25 with alumina (9% wt) and Graphite (3%, 4% & 5%). Tensile strength and Hardness of sample having 9% Al_2O_3 and 4% of Graphite with remaining LM25 were superior to other recast alloys. Table 2 shows that the comparison of properties between un-reinforced LM 25 Al. alloy & hybrid (LM 25/9% Al_2O_3/4%graphite) composite

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Table 2. Comparison of Properties between un-reinforced LM 25 Al. alloy & Hybrid (LM25/9% Al_2O_3/4%Graphite) composite [38]

Mechanical properties	Sample-1 (LM25 Al Alloy)	Sample-3(LM25 Al. Alloy with 9 wt.% of Al_2O_3/4 wt.% Gr)
Hardness (Hv)	105	108
Tensile Strength (MPa)	115	180
Compressive Strength (MPa)	273	243
Impact Strength (J)	4	3
Wear (Weight) loss (g)	0.0184	0.0142

Shanawaz Patil et al. [39] explored the mechanical properties of AA LM25 with SiC and Activated Carbon by stir casting. By varying weight % if reinforcement samples were fabricated as 100% LM25, 96% LM25- 2% SiC- 2% AC, 94% LM25- 4% SiC- 2% AC and 92% LM25- 6% SiC- 2% AC. Among other samples 92% LM25- 6% SiC- 2% AC has higher Hardness (68.12BHN) and Maximum tensile strength (154 MPa). Karthikeyan Govindan et al. [40] inspected the mechanical and metallurgical behaviour of LM25/ Zirconium oxide (3%, 6%, 9% & 12%) composites fabricated by liquid route methods. The hardness (75.36 BHN), Tensile strength (200.11 Mpa), Compression strength (230 MPa), Ductility (4.4%) and Impact strength (13%) were maximum for a sample with 12% of ZrO2 reinforcement.

Balamurugan et al. [41] examined the mechanical properties of AA LM25 with Fly ash (0.5%, 1%, 1.5% wt) and Activated Carbon (0.5%, 1%, 1.5% wt) using Stir casting method. The maximum hardness (283 N/mm^2) and tensile strength (324 Mpa) obtained for sample 98% LM25- 1% Fly ash- 1% Activated Carbon composites.

Thirumalvalavan et al. [42] investigated the mechanical properties of AA LM25 with Silica (0, 4, 8 & 12 wt%) Composites by the stir casting process. Comparing the samples based on wt %, 8% of silica reinforced with LM25 has higher hardness and Ultimate Tensile strength.

Rakesh Kumar et al. [43] studied the mechanical properties of Basalt fibre (1%, 2%, 3%, 4% & 5% wt) reinforced with Aluminium LM25 composites by stir casting methods. 30% rise in tensile strength and 15% growth in ductility contrast to base LM25 alloy for 5 wt % of Basalt fibre reinforcement.

Suresh et al. [44] inspected the mechanical and wear behaviour of LM25 AMMC reinforced with Boron Carbide, Graphite and Iron oxide. By varying weight % of composites the samples were prepared as sample 1= 100% LM25, sample 2= 97% LM25- 3% B_4C, sample 3= 94% LM25- 3% B_4C- 3% Gr, sample 4=91% LM25- 3% B_4C- 3% Gr- 3% Fe_2O_3. From the test results, sample 4 has higher hardness and tensile strength than the other 3 samples.

Radhika et al. [45] studied the mechanical properties and tribological behaviour of LM25 with Silicon Carbide and Alumina hybrid composites. The samples were prepared by varying weight % of reinforcement as 1= 100% LM25, 2= 90% LM25- 5% SiC- 5% Al_2O_3, 3= 80% LM25- 10% SiC- 10% Al_2O_3 and 4= 70% LM25- 15% SiC- 15% Al_2O_3. Sample 4 has the maximum hardness (106 VHN) and tensile strength (158.4 Mpa) and low wear rate compared to other samples.

Sannidev et al. [46] studied the mechanical properties of ceramics reinforced AA LM26 for piston material. The porcelain ceramics were used as reinforced material. The composition of samples was 1=100% LM26, 2=98% LM26 - 2%porcelain ceramics, 3=96% LM26-4%porcelain ceramics, 4=94% LM26-6%porcelain ceramics, 5=92% LM26 - 8%porcelain ceramics. The void

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fraction declines from 0.58 to 0.36% by adding weight percentage from 0 to 6% weight of porcelain ceramics and then void fraction increases for 8%. The maximum microhardness (112HV) increased 10% by adding 8% weight of porcelain ceramics. The maximum tensile strength increased (181.03Mpa) 20% by addition of 6% of porcelain ceramics.

Navneet Kumar et al. [47] development and morphological study of the stir Al/B_4C composites. The size of B4C particles in the range of 20 to 100µm. The weight percentage of samples were 1=100% LM27, 2=95% LM27 - 5% B_4C, 3=90% LM27 - 10% B_4C, 4=85% LM27 - 15% B_4C. The hardness rises with the addition of boron carbide from 0 to 15%wt and decreases with an increase in the size of reinforcement particles from 20-100 µm. The maximum hardness was 67HRB obtained in sample 4.

Pratiksha A. Patil et al. [48] analysis of Mechanical behaviour of LM28 Aluminium Matrix Composite reinforced with TiC for Cylinder Head of Commercial vehicles. The weight percentage of TiC were 0,5,10,15 & 20%. The tensile strength and hardness (125 BHN) rise by rises in wt% of reinforcement. The elongation percentage declines by addition of weight % of TiC. Pathalinga prasad et al. [49] processing and Mechanical Characterization of LM29 Alloy & B_4C particulate reinforced composite. The weight percentage of B_4C were 0, 3 and 6%. The maximum hardness (80.4 BHN), compression strength (681.5 Mpa) and tensile strength (197.2 Mpa) were obtained at 6% wt of B_4C particle. The ductility declines with an increase in weight percentage of B_4C particle.

Shivtej Chandrakant Jadhav et al. [50] mechanical behaviour and Analysis of LM30 Aluminium MMC reinforced with TiB_2 for piston at elevated temperature. The weight percentage of TiB_2 were 5,10,15& 20%. LM30 is tested at 100°C, 150°C & 200°C. Same procedure repeated for different reinforcement. LM30 with 20% TiB_2 had maximum tensile strength (235.1Mpa), maximum hardness (137BHN) and lowest elongation percentage (1.2%).

Conclusion

From the detailed literature, it has been clearly understood that most of the research paper focused on the studies of different mechanical properties like tensile strength, compression strength hardness and yield strength of the reinforced LM based aluminium alloys matrix composites were enhanced significantly. This review paper describes the merits of various reinforcement particles reinforced with LM alloys. The overall literature review concluded that the effect of various reinforcement and reinforcement weight percentage on their mechanical properties of LM based aluminium alloys.

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