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Abstract: Metal matrix composites (MMCs) plays a major role in improving certain properties like specific strength; specific modulus, damping capacity and good wear resistance in comparison to unreinforced alloys. AMMCs are more acceptable than conventional materials in the fields of aerospace, automotive and marine applications as they posess properties like high strength to weight ratio, good wear resistance etc. The chief aim of research and the new product development in the automotive industry is aimed towards developing and implementing certain material which is light weight – high strength materials, having main objectives to improve vehicle performance, increase fuel efficiency, reduce emissions and increase vehicle safety at cheaper and competitive cost. Particle size of the reinforcement varies from micron size to nano scale sized. our paper reveals the properties of the AMMC's when they are reinforced subsequently with micron sized, nano sized and hybrid combination of particles. Each of them playing a major role in development of advanced material in the form of improved wear reduction, better strength and also reducing the weight of the material thus making them lighter than the conventional parent material or alloy.

Key Words: AMMC; Nano AMMC; Hybrid AMMC; Stir casting; Tensile Strength; Wear Resistance; Hardness.

1. Introduction: Conventional pure materials which are monolithic in nature have several limitations in attaining good combination of strength, wear resistance and density. To overcome these drawbacks and to attain the ever-increasing demand of modern-day technology of advance material, composites are most promising modern-day material and is of recent demand. Metal matrix composites (MMCs) significantly improves properties including high specific strength; specific modulus, low density, damping capacity and good wear resistance as compared to unreinforced alloys. Al-alloy is commonly used in various engineering applications including transport and construction where improved mechanical properties such as tensile, strength, hardness etc., are essential. Hard particles such as B4C, Al2O3 and SiC are commonly used as reinforcement phases in the composites.

For amenable mass production casting route is preferred as it is less expensive. Among the entire liquid state production routes, preferred simplest and cheapest route is stir casting. The only drawback with this process is the non-homogeneous distribution of the particulate due to poor wet ability and gravity regulated segregation. There are numerous reasons for accepting the MMC's. Most important reason is extra-ordinary combinations of properties which plays a vital role to meet the target as material in several major industrial applications. The combined properties usually cannot be achievable by individual alloy phase or particulate as MMC's are normally mixture of two or more than two phases among which base one is metallic alloy-based matrix phase and another one is reinforcements which are mostly particulates type or short fibre type or whisker type [1]. It is found that wear resistance properties of the composite material increased with the addition of reinforcement particulates into the matrix material [2].

Effects of Micron Sized Reinforcements

Aluminium alloys reinforced with micro particles to enhance its properties. Particles shape and size plays a major role in enhancing the properties of Aluminium (Matrix element). Several studies have demonstrated the usefulness of MMCs in different applications. Some of the important studies and the findings are described in the following section. Poria et al [1] have explained tribological performance of Al-TiB2 metal matrix composite under lubricated condition by optimizing several combination of testing parameters such as weight percentage of TiB2, speed and load together using Taguchi method coupled with grey relational analysis in order to minimize friction and wear characteristics. They observed that the friction and wear nature of Al-TiB2 metal matrix composite was highly dependent on the weight percentage of TiB2. A study of microstructure of aluminium AA-2618 alloy matrix composite reinforced with Silicon Carbide particulates using dry sliding wear tests was reported by Fadhil et al. (2016) [2]. Ghosh et.al (2013) [3] have analyzed the tribological performance of Al-7.5% SiCp metal matrix composite and it was observed that the tribological behaviour was influenced primarily by time, with a confidence level of 99%, followed by the parameters applied load) and sliding speed) respectively with a significant confidence level of 95 %. For all applied loads, both Al-Al2O3 MMC and Al-SiC MMC show a stable friction coefficient (0.30-0.60) which is essential for brake rotor applications was presented by P. R. K. Fu et.al [4]. The characteristics of four specimens, with varying compositions of aluminium and silicon carbide of Al-SiC functionally graded materials developed by powder metallurgy, have been studied using Microscope (100X Magnification) by Surya et.al (2017) [5]. The study has demonstrated that the failure of samples occurred when SiC content was raised beyond 15%. The study has also concluded that, optimal filler capacity for SiC in Pure Al was 10%. The wear behaviour of AMC reinforced with TiB2 micro particles under lubricated condition also has been studied [6]. It has been observed that the wear rate of Al-TiB2 composites was directly proportional to the load, but was inversely proportional to the weight percentage. However, it also has been observed that wear characteristics were more influenced by the effect of load in presence of lubricant as compared to the weight percentage of TiB2 and speed of roller. They have mentioned that the lubricant film present in the interacting surface region annihilated the effect of weight percentage of particulates and the film thickness also played an important role in controlling the wear behaviour. Taguchi method was used to evaluate the wear behaviour of composite. The study also found, based on ANOVA results and Taguchi analysis, that the load has 56.31% contribution in the total variance of the result followed by weight percentage of particulates. However, the rotational speed has minimal effect on controlling output. In another study, Mohapatra et.al (2016) [7] have synthesized Al-based metal matrix composites reinforced with different volume fraction of TiC particles by the hot consolidation process. Microstructural examination revealed a uniform distribution of TiC particulates in the matrix and the presence of minimal microporosity. Enhanced Young's modulus and mechanical properties with appreciable ductility have been detected in the composite samples.

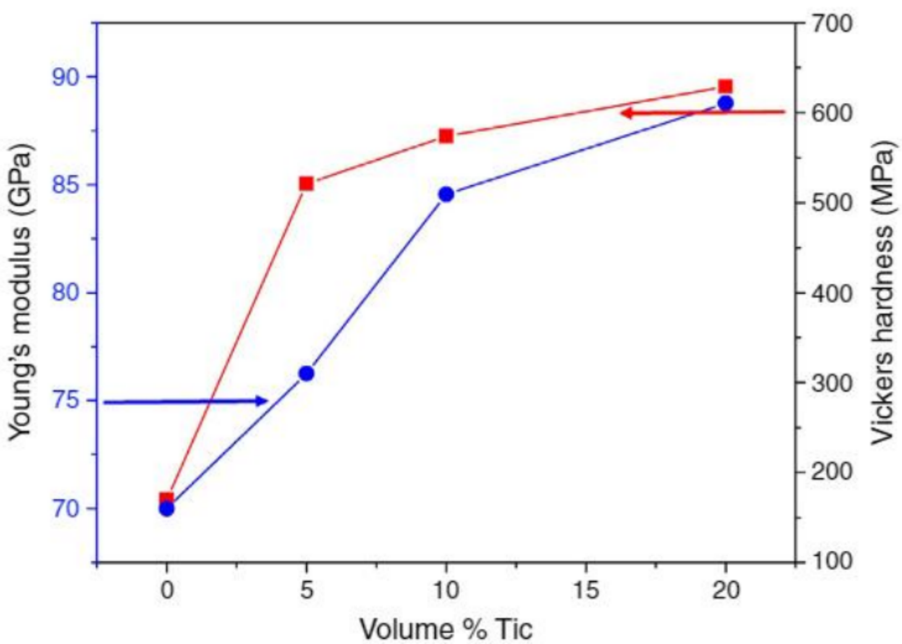

Figure 1. Young's modulus and Vickers hardness with respect to volume % of TiC in Al–TiC composites [7].

Peddavarapu et.al (2018) [8] have studied the dry sliding wear behaviour of AA6082-5%SiC and AA6082-5%TiB2 metal matrix composites fabricated by the stir casting method. Experiments have been executed at 10–50 N applied load and 200–1400 rpm rotational speed using Design of experiment software. Dry sliding wear behaviour of AA6082-5%SiC and AA6082-5%TiB2 metal matrix composites have been studied by analysing the wear mechanisms for the different sliding speeds and applied loads. For relatively moderate applied load, wear mechanism map pertaining to AA6082-5%SiC reveals maximum wear, whereas, AA6082-5%TiB2 shown to have maximum wear at relatively higher load. This study also concluded thatTiB2 reinforcements seem to be providing superior wear resistance compared to SiC reinforcements.

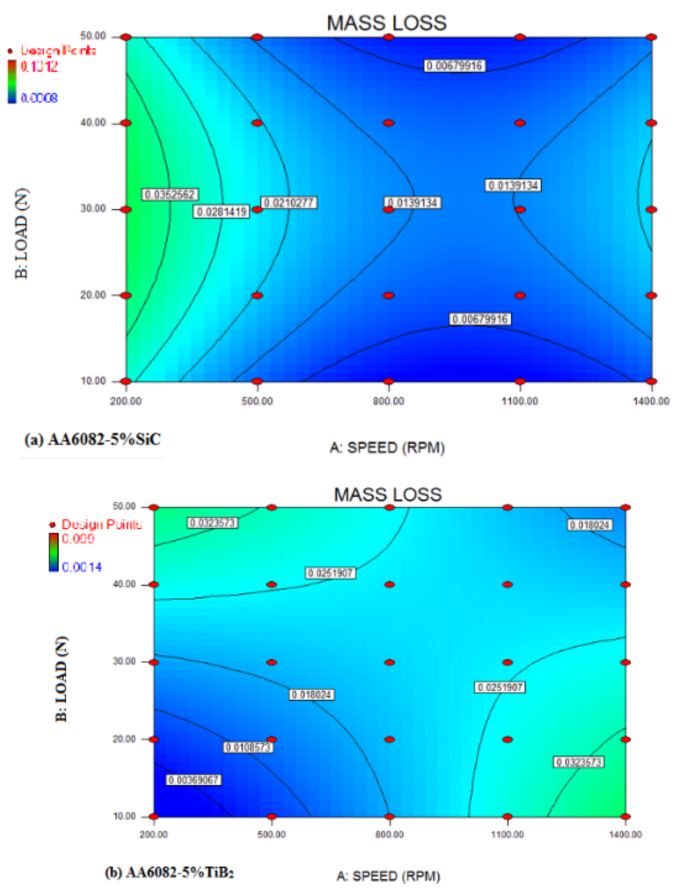

Figure 2. Wear loss maps for (a) AA6082-5%SiC; (b) AA6082-5% TiB2 [8].

Emara [2017] [9] has been investigated the mechanical properties and wear behaviour of aluminium matrix reinforced with 5, 7.5, and 10 wt. % of steel chips with an average size of 100 μm using powder metallurgy technique. The tensile, hardness and wear behaviour of pure aluminium matrix composites reinforced with steel machining chips have been investigated in comparison with that reinforced with 5 and 10 wt.% SiC particulates. The porosity level in the aluminium matrix was observed to be minimal with the addition of steel machining chips in aluminium in comparison with the porosity level of aluminium matrix reinforced with SiC. The strength and hardness values of pure Aluminium matrix was also found to be improved with increasing the steel machining chips wt.% as reinforcement with a retained ductility levels in comparison to that with the SiC reinforcements.

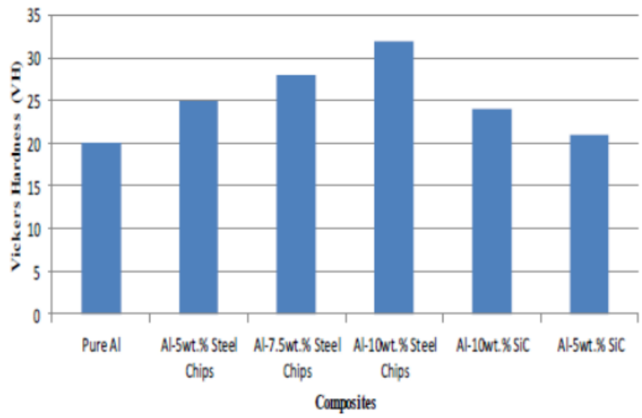

Figure 3. Vickers hardness results of the unreinforced aluminum and composites [9].

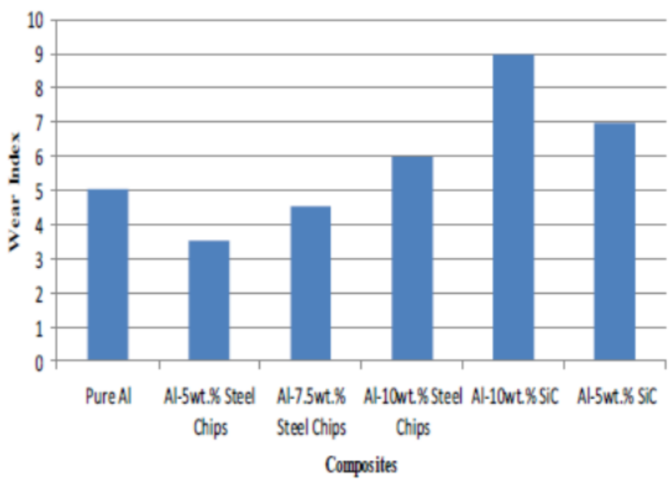

Figure 4. Wear index of the unreinforced pure aluminum and composites produced [9].

Ramnath et.al [2018] [10] also mentioned the Aluminium alloy (LM6) reinforced with a specific ratio of Zircon sand and fly ash adopting stir casting technique to fabricate MMC. Gopalakrishnan et.al (2012) [11] has been explained the fabrication process of Aluminium matrix reinforced with different volume fraction titanium carbide (Al–TiCp) in an economic way. This defect free aluminium matrix TiCp reinforced were produced in an argon atmosphere by an enhanced stir casting method. The addition of TiC could improved the specific strength of the material appreciably. Percentage elongation was also maintained at appreciable level even though specific strength was increased. Hence, this method is the most economical and effective way of producing Al–TiCp composite. Although the mathematical model showed that the wear loss increased linearly with the normal load, on the other hand, the wear rate also increased marginally with the increased of TiC addition.

Figure 5. Result of Tensile tests [10].

Manufacturing of aluminium–boron carbide composites using the stir casting method have been investigated by Shirvanimoghaddam et.al (2016) [12]. Mechanical and physical properties tests were performed after solidification of specimens, in order to obtain hardness, ultimate tensile strength (UTS) and density. Their results revealed that the hardness and tensile strength of aluminium based composite was higher than those of monolithic metal.

Suswagata et.al (2016) [13] demonstrated the tribological characterization of Al-TiB2 composites fabricated through stir cast method. A multi-tribotester was used to find out the wear and friction behaviour of as-cast composites under dry sliding conditions and ambient atmosphere for varying amount of reinforcement, applied load and sliding speed. SEM micrographs revealed that the composite was compact and TiB2 particles were almost uniformly distributed in the matrix. XRD plots also confirmed the presence of TiB2 in the composite. It was found that the friction and wear decreased with increased in percentage of TiB2 reinforcement in the composite, whereas both the friction and wear increased with the applied load and speed. N. B. Dhokey et.al 2011 [14] conducted a study on Aluminium-based TiB2 reinforced composite containing 2% by wt copper reinforced with 2.5 and 5wt% TiB2 composites were made in induction furnace by in situ synthesis process using simultaneous addition of halide fluxes (K2TiF6 and KBF4) concluding that Wear behavior gives a reasonable correlation with hardness, ultimate tensile strength, fracture strength, and strain hardening exponent of Al-MMCs. The relationship between wear rate and mechanical properties validates Archard's equation they also concluded that Wear rate decreases with increasing TiB2 content. Effect of boron carbide reinforcement on aluminium matrix composites was observed by GOPAL KRISHNA U B et.al. (2013) [16] where an effort was made to enhance the mechanical properties like tensile strength and hardness of matrix 6061Al with B4C particles and it was observed that The micro vicker's hardness of AMCs was found to be maximum for the particle size of 250µ and found maximum for 12 wt% in case of varying wt% of the reinforcement of 105µ size and The tensile strength of AMCs was found to be maximum for the particle size of 105µ and found maximum for 8 wt% in case of varying wt% of the reinforcement of 105µ size. Pradhan et.al (2016) [17] investigated the wear behaviour under corrosive environments of LM6 based MMC reinforced with 5% by weight SiC fabricated using stir casting method and compared their results with dry , deionised and sulphuric acid environments. Conclusion has been drawn from their EDX (energy dispersive X-Ray) analysis, that the wear loss could be minimized with an oxide layer, which acts as a protective layer in case of dry and deionized water environments, however, considerable wear loss occurred in sulphuric acid environment. The microstructure study by the scanning electron microscopy of the worn surfaces, revealed that both adhesive and abrasive wears are encountered. Study on Machining Parameters of TiB_2 Reinforced Al 6063 composites by K.Krishnamurthy et.al (2013) [18]. Three TiB2/Al metal matrix composites (MMCs) with 40 µm mean size were produced using a melt stirring squeeze casting route and it was noted that micro-structural examination showed that the TiB2 distributions are more or less homogeneous with lower interface porosity could be observed. Whereas hardness of the aluminum alloy improved significantly by adding up of TiB2 particles into it, while density of the composite also increased almost linearly with the weight fraction of particles. Avinash Bhat et.al (2019) [19] conducted a study on Composite materials capable of customization to provide specific mechanical and tribological properties. Wear characteristics were investigated for Al6061 and the novel composite Al6061+SiC with a Pin on disc tribometer for a load range of 5N-200N and RPM varying from 200 to 1500 and it was observed that results of the newly developed composite of Al6061 and 5% SiC has shown better wear characteristics as compared to Al6061. Poria et.al (2016) [20] also measured the wear performance using Taguchi orthogonal design with three design parameters such as, weight percentage (wt %) of TiB2, load and speed. It was observed that the Wear of Al-TiB2 composites decreased with the increased of weight percentage of TiB2 as reinforcement and also increased with the increased load as well as speed. In an experiment K. John Joshua et.al (2017) [21] tried to find the influence of mgo particles on microstructural and mechanical behaviour of AA7068 metal matrix composites and found that the Vickers microhardness number has been increased to a maximum of 68 VHN for an addition of 5% MgO and wear resistance has been improved by adding MgO particles in AA7068 matrix material. In another literature, Ghosh et.al [2015] [22] mentioned the wear behaviour of Al-SiCp metal matrix composite for varying reinforcement content, applied load, sliding speed and time. The material was synthesized by stir casting process in an electric melting furnace. L27 Taguchi orthogonal array was used to acquire the wear data in a controlled way. An analysis of variance was used to investigate the influence of four controlling parameters, such as, SiC content, normal load, sliding speed and sliding time on dry sliding wear of the composites. It was observed that the volume fraction of reinforcement was the most significant parameter which influenced the wear behaviour at the confidence level of 99% while applied load and sliding speed were also significant within the specific test range. The microstructure study of worn surfaces revealed that mostly abrasive wear mechanism has occurred on the wear tracks with some traces of adhesive wear mechanism. Tribological behaviour of Al-SiC MMCs reinforced, fabricated through the liquid stir casting method, with different weight percentages of SiC content (5.%, 7.5% and 10%) have been investigated by Pradhan et.al (2017) [23]. The result revealed that increased in applied load and sliding speed also increased the wear but on the other hand increased in applied load reduced the friction coefficient. Moreover, the wear resistance of the metal matrix increased with the addition of SiC reinforcement. The scanning electron microscope (SEM) and EDX technique were also used to analyse the wear mechanism of worn surface. The microstructure study revealed the presence of adhesive, abrasive and corrosive wear mechanisms for the removal of material from the Al-SiC MMCs. Rajaravi et.al (2018) [24] compared the properties of ex situ formed Al/SiCp and in situ formed Al/TiB2MMCs contained equal amount of reinforcements of 6% by weight of SiCp and TiB2 particles and cast in permanent and sand moulds. The values of fracture toughness, tensile and hardness were found to be higher when the composite Al/TiB2 MMCs were cast through permanent mould in comparison to the same composite when cast through sand mould. The values of fracture toughness, tensile and hardness were found to be lower when the composite Al/SiCp MMCs were cast through permanent mould in comparison to the same composite when cast through sand mould.

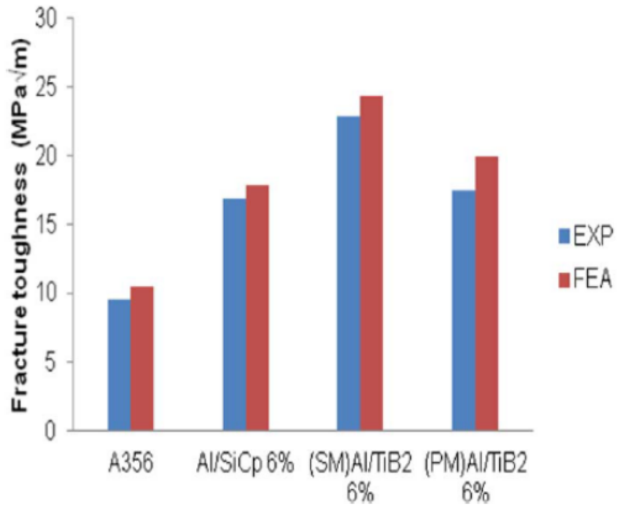

Figure 6. Effect of processing temperature on fracture toughness of composite on FEA and Experimental results [24].

M.S. Raviraj et.al (2014) [26] conducted an experimental analysis on processing and properties of Al-TiC metal matrix composites using Al6061as matrix reinforced with TiC and concluded that at higher percentage of TiC there is a decrease in mechanical properties due to strong interfacial bonding. Jayasheel I Harti et.al (2017) [27] studied, Al2219 – 2, 4 and 6 wt. % of TiC metal matrix composites were synthesized by Stir casting method. Microstructural analysis of Al2219-TiC composites was performed by using scanning electron microscopy observing that Wear in terms of wear rate was more in the case of base matrix and it was decreased as the weight percentage of reinforcement increased from 2 to 6 wt. percentages. The values predicted by Finite Element Analysis (FEA) for all the mechanical properties were found to be closer to the experimentally determined values. Kishore et.al (2015) [29] fabricated Al6061- 4% by weight of TiC metal matrix composites by in-situ process. The arrangement and presence of TiC particles were detected by performing SEM and EDX tests . Turning experiments were performed on in-situ synthesised Al6061-4wt% TiC MMC rod by using L-27 orthogonal array. Vicker's microhardness test was conducted and found that the hardness of the base material enhanced with the incorporation of TiC particles in the matrix. Bharath et.al (2012) [30] investigated the effects of different factors such as: particle size, weight percentage of the particles, processing method on the microstructure and mechanical properties of the Al6061-Al2O3 particulate metal matrix composites fabricated by liquid metallurgy route (stir casting technique). The optical micrographs revealed that the fairly uniform distribution of Al2O3 particulates in the 6061Al metal matrix. The increased in the weight percentage of Al2O3 particles also increased the hardness of composite samples. Both tensile and yield Strength of prepared composites was higher in case of composites, while ductility of composites was less when compared to as cast 6061Al. Further the tensile strength showed an increasing trend with increasing wt% of Al2O3. The sliding wear behaviour of an Al–Zn–Mg alloy (Al7009) and Al7009 25 wt% SiC particle composite was examined by D.P. Mondal et.al (2005) [31]. It was observed that the sliding wear behaviour of aluminium alloy is highly dependent on the surface conditions and the particle additions. When particles are added in the alloy the wear rate and the temperature rise reduce, but the seizure pressure and seizure temperature rises. The seizure pressure is increased by 80% and the seizure temperature is increased by 40 ◦C with the addition of Addition of 25% SiC particles. Mr. S. N. Wani et.al (2019) [32] conducted a study based on evaluation of mechanical and wear properties of aluminium /Al2o3 composite material for brake rotor using short fiber alumina as reinforcement and it was observed that Sample 10% Al2O3 and 20% Al2O3 increased tensile strength as compared sample 15% Al2O3 but yield stress of sample 10% is decreased as compare to other sample and when load is increased that wear rate is increased but adding reinforcement so decreased wear rate of composite. Due to the increase in rpm wear rate of material is reduced. Three different dynamic prediction models based on nonlinear Levenberg–Marquardt Algorithm (LMA) neural network was studied by K. Shirvanimoghaddam et.al (2016) [33]. The outcome of predictive models, experimental models and validation data are presented and the potential of the algorithm to be fitted with the ceramic reinforced aluminium composite fabrication process. Hardness and tensile strength of ceramic reinforced aluminium matrix composites were found to be higher compared to monolithic aluminium. Effect of TiC particles on the mechanical properties of aluminium alloy metal matrix composites (MMCs) was studied by Utkarsh Pandey et.al (2016) [34] and it was evident that the wear rate of the composites has been reported to decrease linearly with increasing volume fraction of titanium carbide. Average coefficient of friction also decreases linearly with increasing normal load and volume fraction of TiC. The dry sliding wear behaviour of AA6082/Gr composite (by varying Gr particles range from 0% to 12% by weight) produced in an inert atmosphere was studied by Pardeep Sharma et.al (2016) [35] using conventional stir casting method. The coefficient of friction using Taguchi orthogonal design with three design parameters viz.

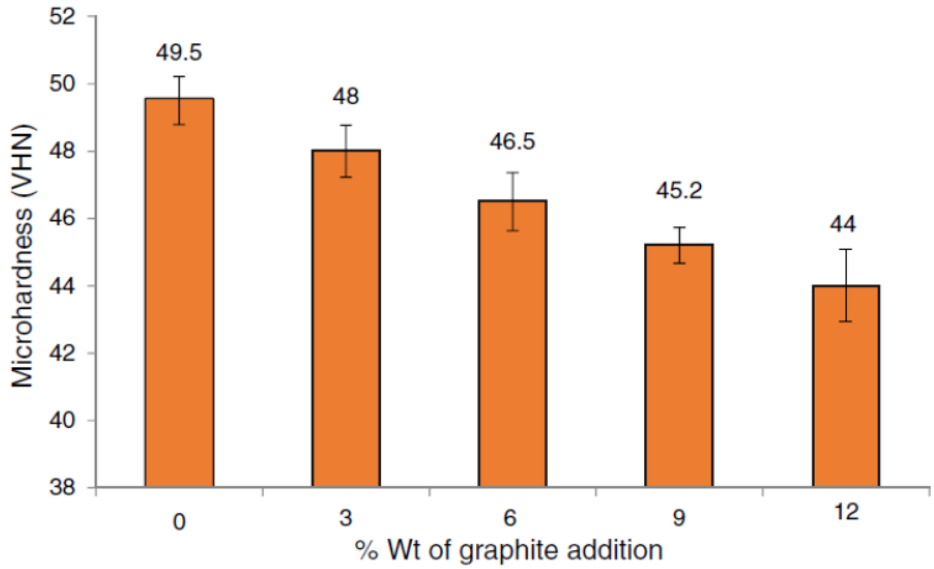

Figure 7. Variation of micro-hardness with weight percentage of Gr addition [35].

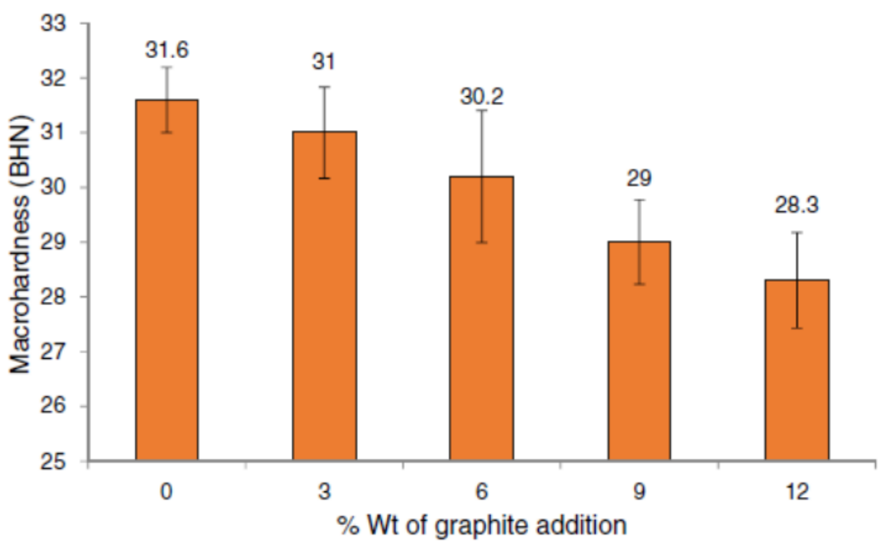

Figure 8. Variation of macro-hardness with weight percentage of Gr addition [35].

A. Pramanik [36] observed the effect of reinforcement on the wear mechanism of metal matrix composites (MMCs) by considering different parameters, such as sliding distance (6 km), pressure (0.14−1.1 MPa) and sliding speed (230−1480 r/min) and it was observed that ceramic reinforcements improve the wear resistance of a monolithic metal in all changing variables of distance, load and sliding speed and also the ceramic reinforcements enhance wear resistance of the material. Weight percentage (wt %) of TiB2, Load and Speed was studied by S.Poria et.al (2017) [37]. A multitribotester is used to find out the coefficient of friction. SEM is used for studying the worn surface morphology to observe the wear mode. The most effective parameter in controlling coefficient of friction is the Weight percentage of TiB2.

Effects of Nano Sized Reinforcements

MMC reinforced by nano particles have vast propspective application in engineering and automotive technologies due to their improved material properties. Aluminium material reinforced with nano particles show improved characteristics in terms of their wear resistance, strength, hardness and other major tribological properties due to these nano particles are finding its place in the automotive and aerospace application showing future prospect of application.

Some of the investigation with nano particles can be elaborated from the study of Zhang et.al [38] that tensile properties of nano-SiCp/Al2014 composites with an elevated temperature. They have stated that the nano-SiC particles significantly improved the σ0.2 and σUTS at 493 K of Al2014 alloy from 182 MPa and 240 MPa to 242 MPa and 314 MPa, respectively, without compromising the ductility.

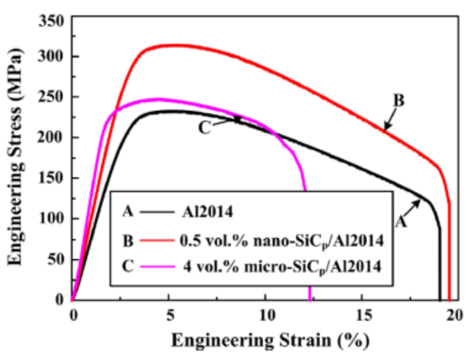

Figure 9. The tensile engineering stress–strain curves of (a) Al2014alloy, (b) 0.5 vol % nano-SiCp/Al2014 composites and (c) 4vol % micron-SiCp/Al2014 composites at 493 K.

The dry slippery metal-metal wear behaviour of Al6061 alloy, discontinuously strengthened with 2 different types of particles silicon carbide and aluminium oxide was assessed by K.Umanath et.al (2014) [39].

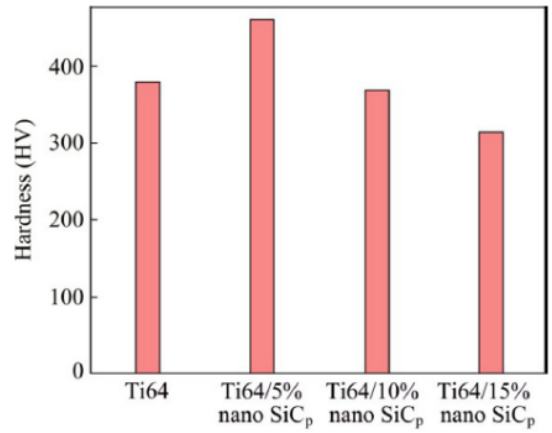

Figure 10. Vickers [hardness of Ti64 alloy and Ti64 alloy /nano SiCp composites [39].

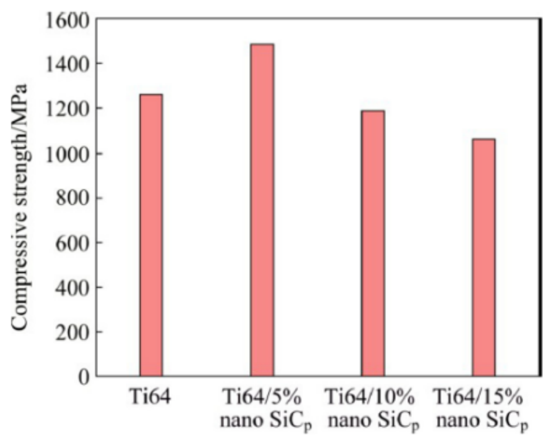

Figure 11. Compressive strength of Ti64 alloy and Ti64 alloy/nano SiCp composites [39]

The effects of WC nano-particles content on the microstructure, hardness, wear, and friction behavior of aluminium matrix composites has been studied by Pal et.al (2018) [40]. The effect of milling time on tribological properties of bulk Al6061–Al2O3 nanocomposite prepared by milling and hot press- ing was investigated by N. Hosseini et.al (2010) [41]. A comparison between tribological behavior of Al6061/Al2O3 nanocomposites with nano and microsize reinforcement particles has been carried out. Moreover, the wear rate increased with the increase in the reinforcement size because of reduction in relative density, hardness and inter-particle spacing. However, increase in mass fraction of nano SiC particles increased the porosity of the composites. Wear mechanisms were also studied through SEM images and EDAX patterns of worn surfaces. The hardness, wear and compression tests in different sections of the MMC was assessed by M. Karbalaei Akbari et.al (2013) [42]. Aluminum and copper powders were separately milled with nano-Al2O3 particles and incorporated into A356 alloy by means of vortex method. The evaluation of mechanical properties and microstructural studies showed that a rise in stirring time led to a more uniform dispersion of particles in the matrix as well as a decrease in mechanical properties due to an increase in porosity content of the composites, in comparison to those samples stirred for shorter durations. Moreover, particle distribution was affected by milling process. Nanoparticles more uniformly dispersed in the Al2O3–Cu reinforced samples in comparison to that of the samples reinforced with Al2O3–Al or pure alumina powders.

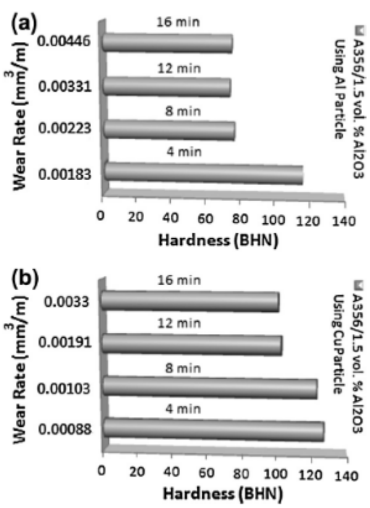

Figure 12. Variation of wear rate as a function of hardness and stirring time [42].

Two applicable methods of stir casting and conventional powder metallurgy in fabrication of Al–MgO nano-composite was investigated by Hossein Abdizadeh et.al (2014) [43] also comparing from mechanical and microstructural points of view. Al matrix nanocomposites with different MgO contents of 1.5, 2.5, and 5 vol.% were produced and their various properties were studied separately as well as together. Introduction of MgO nanoparticles to the Al matrix enhanced the hardness values which was more considerable in casting samples. The maximum hardness value for casting and sintering samples have been obtained at 850 and 625 °C respectively, in 5 vol.% of MgO. Compressive strength values of casting composites were more than sintered samples which were mainly due to the more homogeneity of Al matrix, less porosity portions, and better wettability of MgO nanoparticles in casting method. The maximum values of compressive strength for casting and sintered composites have been obtained at 850 and 625 °C, respectively. Scanning electron microscopy images revealed greatly porosity portions in sintered composites and more agglomeration and aggregation of MgO nano- particles in casting samples because of the fundamental difference of two methods. Normally, for achieving better mechanical properties in pow-der metallurgy and stir-casting, the optimum processing temperatures were 625 and 850 °C respectively.

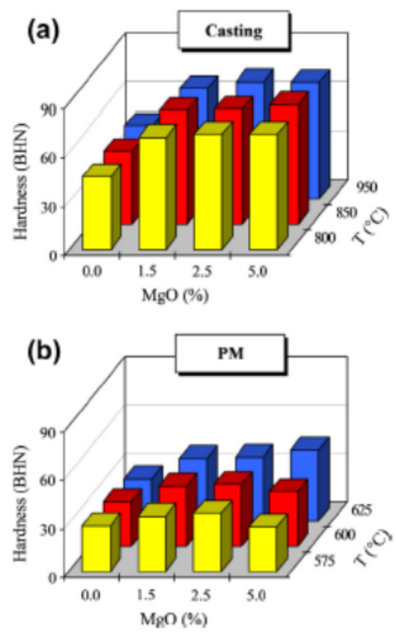

Figure 13. Hardness values of Al–MgO nanocomposites with various MgO contents of 1.5, 2.5, and 5 vol.% prepared with (a) casting method at different temperatures of 800, 850, and 950 °C and powder metallurgy method including (b) uniaxial press which sintered at various temperatures of 575, 600, and 625 °C. [43].

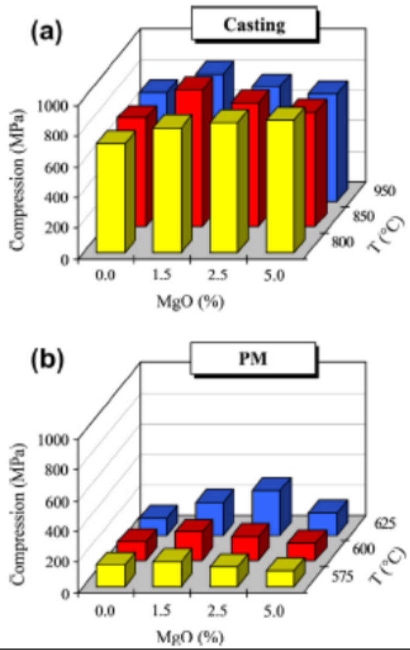

Figure 14. Compressive strength values of Al–MgO nanocomposites with various MgO contents of 1.5, 2.5, and 5 vol.% prepared with (a) casting method at different temperatures of 800, 850, and 950 °C and (b) powder metallurgy method with various sintering temperatures of 575, 600, and 625 °C. [43].

Moreover, more homogeneous data and higher values of mechanical properties was represented by the casting method in comparison to the powder metallurgy method. B4C/AA2024 composites were fabricated through casting using high-intensity ultrasonic wave technique by Dr. Govind Nandipati et.al (2013) [44]. The microstructure and micro hardness of these composites are investigated. In comparison to the base metal alloy, the mechanical properties including tensile strength and yield strength of the Nano composites were enhanced significantly, while the ductility of base metal alloy matrix castings remained unchanged. Micro structural study was carried out with an optical microscope and SEM which validates a good dispersion of nano-sized B4Cp in metal matrix. A low weight fraction of nano- sized B4C has also significantly improved the Mechanical properties of the as-cast MMNCs. The effects of TiB2 micro and nanoparticles and processing parameters (temperature, content and size of reinforcement powders) on mechanical and physical properties of Al-TiB2 compo- sites was compared by Mohammad Karbalaei Akbari et.al (2017) [45]. In order to predict the mechanical properties of Al-TiB2 composite, a multi input and multi output model has been created by using a neural network- Levenberg Marquardt Algorithm. For the introduction of appropriate material selection and processing parameters to fabricate Al-TiB2 composite, Experimental data and numerical model were used. The composites reinforced by 1.5 vol% TiB2 nanoparticles have achieved the highest tensile properties. It is reported that the NN- LMA model is highly accurate (the margin of error is less than 5%) to predict the mechanical properties of Al-TiB2 composites. The microstructure and tensile properties of as-cast nanoparticle reinforced aluminium matrix composite was studied by Hai Su et.al (2012) [46]. Fine grain microstructure, reasonable Al2O3 nanoparticles distribution in the matrix, and low porosity was found in the obtained matrix. Solid–liquid mixed casting technique was effective in inhibiting the agglomeration of nanoparticles in the matrix. The grain microstructure of the matrix was not only refined with the use of ultrasonic vibration on the composite melt during the solidification, the distribution of nano-sized reinforcement was also enhanced. The ultimate tensile strength and yield strength of 1 wt.% nano-Al2O3/2024 composite were increased by 37% and 81%, respectively in comparison to the matrix. The better tensile properties were attributed to the uniform distribution of reinforcement and grain refinement of aluminum matrix.

The impact of different volume fractions of nano and micro TiB2 particles on the tensile properties and fracture behaviour of the aluminium (A356) composites was investigated by M. Karbalaei Akbari et.al (2015) [48]. The increase in volume fraction of reinforcements resulted in decreased particle size and increased porosity. The tensile strength and toughness improved significantly with the introduction of 1.5 vol.% TiB2 nano- particles into A356 alloy; but the strength values reduced while increasing the nanoparticle content further. The ductility and toughness of Nano- composites was found to be higher in comparison to those of the microparticle reinforced counterparts. The quality of particle/matrix bonding in nanoparticle rein- forced samples was good.

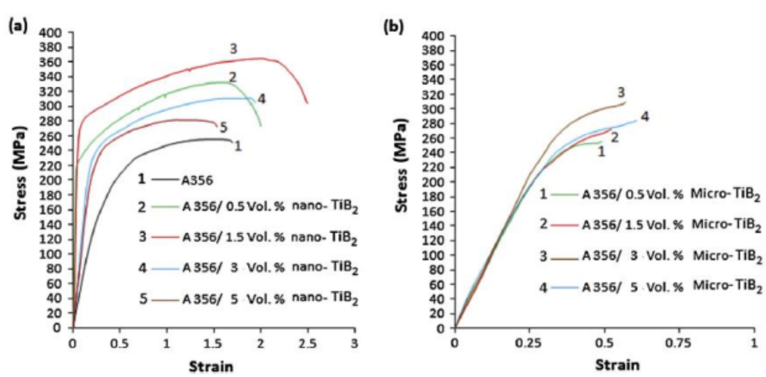

Figure 15. The tensile flow curves of (a) nano and (b) micro composites cast at 800 °C. [48].

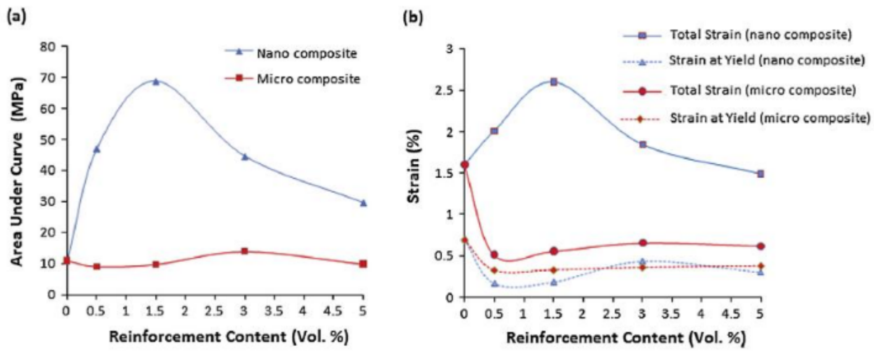

Figure 16. The effect of reinforcement content on (a) area under stress–strain curve and (b) strain at yield and total strain of composites. [48].

Agglomerated nanoparticles and individual microparticle were observed on dendrites in fracture surface of samples. Coarse, fine and ultra-fine dimples were seen in vast areas of fracture surface of composites. N. Nemati et.al (2011) [49] manufactured MMC's using a nanocrystalline alloying matrix with the composition of Al–4.5 wt.% Cu, reinforced with different concentrations of nano and micron size TiC particles in order to get the desired composite, thereby increasing the hardness and wear resistance of the composite significantly, but also decreasing the relative density, grain size and distribution homogeneity. Hardness of the composite has decreased significantly from 174 to 98 HVN, while using micron size reinforcing particulates from 5% to 10 wt.%,. Reasonably uniform distribution of TiC reinforcing particulates and presence of minimal porosity was revealed after Microstructural characterization of the as-pressed samples. The wear resistance of all specimens increase with the addition of nano and micron size TiC particles (up to 5 wt.%), as disclosed by the wear test. They observed the worn surfaces by scanning electron microscope and the dominant wear mechanism was identified as abrasive wear accompanied by some delamination wear mechanism. The effect of Al2O3 particulates on the Structural and mechanical properties of the MMCs was analysed by Chandrashekar A et.al (2018) [50]. It was observed that with the presence of 6% nano Al2O3 particles in AMMNC, tensile strength has been excellent (increased by an amount of 25.69%), and hardness has also increased by an amount of 26.31%. The AMMNC with 2 wt. % Nano Al2O3 has resulted in higher weight loss than the other; due to high corrosion rate, whereas greater corrosion resistance has been observed while using AMMNC with 6 wt. % Nano Al2O3 in comparison to the other AMMNCs combinations.

Effects of Hybrid Particles Reinforcements

Hybrid MMC is a new generation MMC having high strength and lower weight combination is of high demand in aerospace and advanced material used in automotive industry. Properties and performance of Hybrid MMC depends on combination of right reinforcement material selection.

A few combination of reinforcement particles have been investigated. The impact of effective parameters, such as type, size and weight percentage of reinforcement, on mechanical properties (tensile strength, impact strength and density) using Stir casting was also been analysed by Vamsi Krishna et.al (2015) [51]. The above-mentioned mechanical behaviour of hybrid composites was analysed by applying the design of experiments (DOE) approach using Taguchi method. Moreover, the optimal combination of influencing parameters on the mechanical behaviour was also investigated by using Fuzzy approach. They have reported that desired high strength and low density could be obtained by using the reinforcement particle size of 3μ, combined SiC/Graphite of 15 % using fuzzy logic technique.

Corrosion and lubricated sliding tribological behaviour of Al-TiB2-nano Gr hybrid composites for varying wt. % of reinforcements has been studied by Poria et.al (2018) [52]. They have observed that the wear resistance decreased with the decreased in amount of either TiB2 or nano-Gr in base alloy, whereas, wear resistance increased with the increased in load and speed. In another study, Poria et.al (2018) [53] explained the role of nano-graphite particles in determining wear and friction behaviour of Al-TiB2-nano-Gr hybrid composites. Ultrasonic cavitation assisted stir casting method has been used for fabrication of composites. Al-Si5Cu3 alloy was used as base alloy along with micro sized TiB2 hard ceramic particles (2.5 and 5.5 wt%) as reinforcement and nano-Gr particles (2 and 4 wt. %) as solid lubricant additives. SEM micrographs, EDAX spectrum and optical images were also considered to observe uniform dispersion of reinforcing phases. Vicker's microhardness tester was used to evaluate Micro-hardness. The Hardness increased with incorporation of TiB2, but the same also decreased with incorporation of graphite. Wear and friction of composites were tested for varying load (10 to 40 N) and sliding speed (0.2 to 0.4 m s−1) using a pin-on-disk tribometer. Worn surfaces were characterized using SEM and EDAX analysis. Experiment showed wear resistance of composites increased with incorporation of reinforcing phases together. Nano-Gr particles were easily sheared out from the sub- surface and provided a layer over the tribo-surface of composite which in turn enhanced friction and wear behaviour.

Wear mechanism in composites is predominantly adhesion while abrasion and ploughing was prominent in base alloy. From SEM images, smoother wear surfaces with no sign of plastic deformation were also observed in presence of nano-Gr as reinforcement.

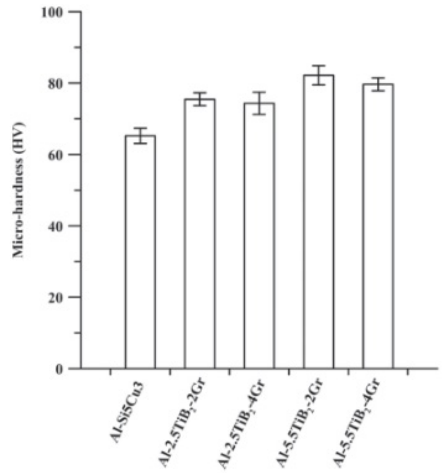

Figure 17. Hardness of base alloy and hybrid composites. [53].

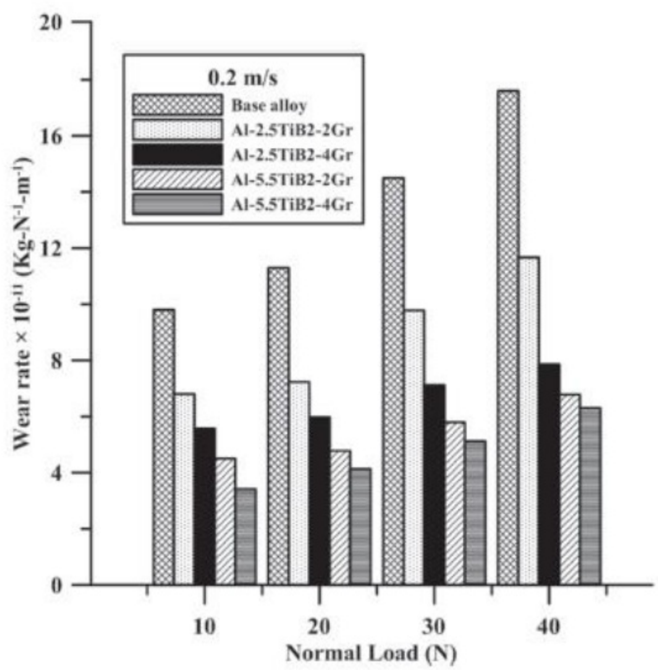

Figure 18. Wear rate of hybrid composites and base alloy for varying normal load at 0.2 m s−1 sliding speed. [53].

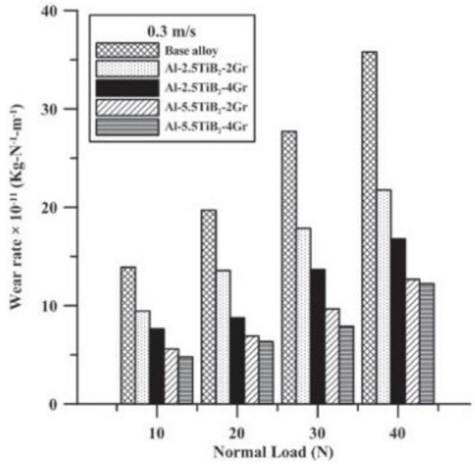

Figure 19. Wear rate of hybrid composites and base alloy for varying normal load at 0.3 m s−1 sliding speed [53].

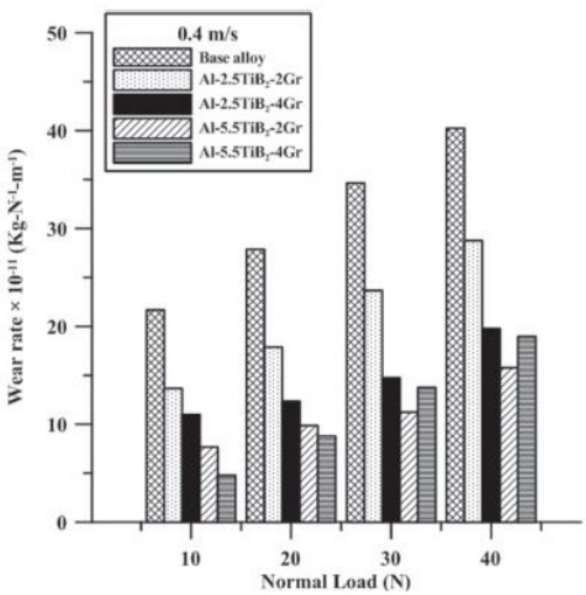

Figure 20. Wear rate of hybrid composites and base alloy for varying normal load at 0.4 m s−1 sliding speed [53].

Selvam et.al (2018) [54] also fabricated TiB2 and Al2O3 particulates reinforced AA6061 aluminium matrix composites (AMCs) using an electric stir casting furnace under a controlled environment. The formation of TiB2 and Al2O3 particulates without any other undesirable compounds was confirmed by XRD pattern.

Murugan et.al (2018) [55] studied the mechanical characteristics and the effect of reinforcements (fly ash, SiC) on the composite of Al.6061 as matrix and fly ash & SiC as the reinforcements. Taguchi technique and a Design of experiment (DOE) method was used to improve the overall performances of the cast composite by optimizing the process parameter such as stirring time, stirring speed. As evident from their results that the increased in wt. % of SiC and stirring time also increased the tensile strength value whereas decreased in stirring speed also decreased the tensile strength.

The wear behaviour of an AlSi alloy reinforced by Multi-Wall Carbon Nanotubes (MWCNT) and SiC particles was investigated by O. Carvalho et.al (2015) [56]. Determining the combined effects (the advantages) of both constituent reinforcements (CNTs and SiCp) on wear behaviour in dry reciprocating sliding conditions was the primary objective. Hardness of the all produced AlSi composites increased, and the hardness of the hybrid composite was higher as compared to unreinforced and also to the composites. The wear behaviour of the AiSi-2wt.%CNTs-5wt.%SiCp hybrid composite increased with the addition of The addition of both reinforcements (CNTs and SiCp) in AlSi matrix , in comparison to AlSi- composites.

In another study, TiB2 and TiO2 nanoparticles were used by Mohammad Karbalaei Akbari et.al (2017) [57] for the reinforcement of Al-Si alloy (A356) by using stir casting method. These nanoparticles are selected to provide a comparative case study regarding different wettability properties of TiB2 and TiO2 nanoparticles by molten aluminium. For enhancing the efficiency of design and fabrication processes and reduction of the time duration of product development, Predictive modelling as a basic tool was used to predict the mechanical and physical properties of materials. When the particle content of nanoparticles is less than 0.5 vol%, most of nanoparticle are surrounded by solidification front and distributed uniformly in matrix which is the sign of Orowan strength- ening mechanism.

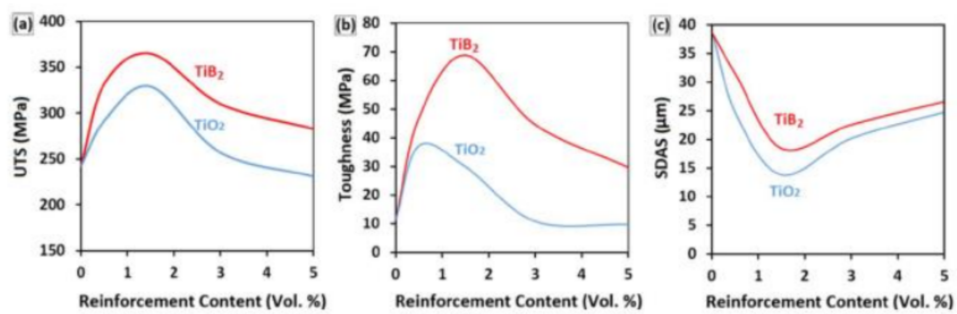

Figure 21. Variation of (a) UTS, (b) toughness and (c) SDAS of Al-TiB2 (red line) and Al-TiO2(blue line) nanocomposites versus reinforcement content. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article). [57].

Sivakumar et.al (2017) [58] also produced Ti−6Al−4V (Ti64) alloy metal matrix composites (MMCs) reinforced with different mass fractions (0, 5%, 10%, and 15%) of the synthesized nano SiC particles by the powder metallurgy method. The compressive strength and hardness of Ti64 alloy with mass fraction of 5% nano SiCp MMCs showed higher value. However, increase in mass fraction of nano SiC particles increased the porosity of the composites.

Stir casting methodology was used to fabricate this hybrid material. Pin-on-disk wear tester was used to investigate the effects of vol. fraction of the reinforcements as well as the applied load on the dry slippery metal-metal wear behavior of composites. Vickers hardness testing machine was used to check the impact of volume fraction of the reinforcement on hardness. The result confirms that, the reinforced metal matrix with Silicon Carbide and Aluminium oxide particles up to a vol. fraction of 25% decreases the wear in μm at ambient temperature. Increase in the volume fraction of the reinforcement decreases the wear in μm. The result also displays that the increase in load and sliding distance increases the wear in μm of test specimen.

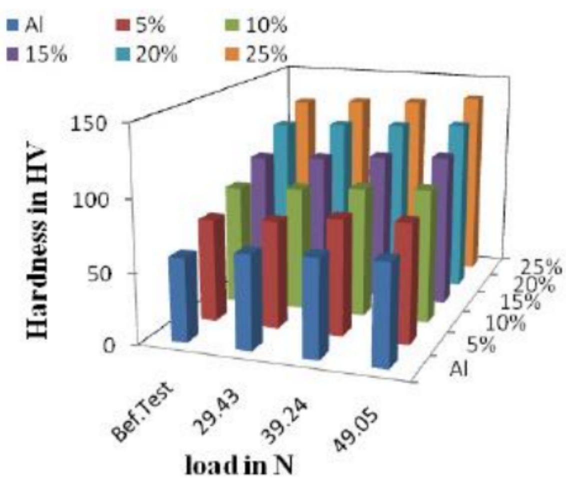

Figure 22. Microhardness of unreinforced alloy and composites before and after wear tests. [58].

4. SUMMARY

The major conclusions from the prior research works carried out can be summarised as below:

- The friction and wear behaviour of Al-TiB2 metal matrix composite was highly dependent on the weight percentage of TiB2 & the wear rate of Al-TiB2 composites was directly proportional to the load, but was inversely proportional to the weight percentage. The ductility and toughness of Nano- composites was found to be higher in comparison to those of the microparticle reinforced counterparts.

- The wear resistance decreased with the decreased in amount of either TiB2 or nano-Gr in base alloy, whereas, wear resistance increased with the increased in load and speed. The Hardness increased with incorporation of TiB2, but the same also decreased with incorporation of graphite.
- This study also concluded thatTiB2 reinforcements seem to be providing superior wear resistance compared to SiC reinforcements.
- The values of fracture toughness, tensile and hardness were found to be higher when the composite Al/TiB2 MMCs were cast through permanent mould in comparison to the same composite when cast through sand mould. The values of fracture toughness, tensile and hardness were found to be lower when the composite Al/SiCp MMCs were cast through permanent mould in comparison to the same composite when cast through sand mould.
- The porosity level in the aluminium matrix was observed to be minimal with the addition of steel machining chips in aluminium in comparison with the porosity level of aluminium matrix reinforced with SiC.
- The increased in wt. % of SiC and stirring time also increased the tensile strength value whereas decreased in stirring speed also decreased the tensile strength.
- The nano-SiC particles significantly improved the σ0.2 and σUTS at 493 K of Al2014 alloy from 182 MPa and 240 MPa to 242 MPa and 314 MPa, respectively, without compromosing the ductility. However, increase in mass fraction of nano SiC particles increased the porosity of the composites.
- The increased in the weight percentage of Al2O3 particles in the 6061Al metal matrix increased the hardness of composite samples while ductility of composites was less when compared to as cast 6061Al.
- It was observed that with the presence of 6% nano Al2O3 particles in AMMNC, tensile strength has been excellent (increased by an amount of 25.69%), and hardness has also increased by an amount of 26.31%. The AMMNC with 2 wt. % Nano Al2O3 has resulted in higher weight loss than the other; due to high corrosion rate, whereas greater corrosion resistance has been observed while using AMMNC with 6 wt. % Nano Al2O3 in comparison to the other AMMNCs combinations.

- The ultimate tensile strength and yield strength of 1 wt.% nano-Al2O3/2024 composite were increased by 37% and 81%, respectively in comparison to the matrix. Moreover, the wear rate increased with the increase in the reinforcement size because of reduction in relative density, hardness and inter-particle spacing.
- Introduction of MgO nanoparticles to the Al matrix enhanced the hardness values which was more considerable in casting samples.
- The wear resistance of all specimens increase with the addition of nano and micron size TiC particles (up to 5 wt.%), as disclosed by the wear test.
- Adding fly ash to aluminum also reduces its co-efficient of thermal expansion and increases its wear resistance along with making lighter and less expensive material.

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