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A Review on Mechanical and Tribological Behaviors of Stir Cast Aluminum Matrix Composites.

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Abstract

In the past few years the global need for low cost, high performance and good quality materials has caused a shift in research from monolithic to composite materials. In case of MMC's, aluminum matrix composite due their high strength to weight ratio, low cost and high wear resistance are widely manufactured and used in structural applications along with aerospace and automobile industry. Also a simple and cost effective method for manufacturing of the composites is very essential for expanding their application. Reinforcements like particulate alumina, silicon carbide, graphite, fly ash etc can easily be incorporated in the melt using cheap and widely available stir casting method. This paper presents a review on the mechanical and tribological properties of stir cast aluminum matrix composites containing single and multiple reinforcement. Addition of alumina to aluminum has shown an increase in its mechanical and tribological properties. Organic reinforcement like fly ash, coconut ash also improved the tensile and yield strength. Self-lubricating property of graphite improved the machinability of aluminum. Many authors have also reported about modified stir casting route.

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Keywords: aluminium metal composites; reinforcement; silicon carbide; alumina, graphite.

1. Introduction

A composite material is a material system composed of a suitably arranged mixture or combination of two or more nano, micro, or macro constituents with an interface separating them that differ in form and chemical composition and are essentially insoluble in each other. Smith and Hashemi (2008).

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The discrete constituent is called the reinforcement and the continuous phase is called the matrix. According to the chemical nature of the matrix phase, composite are classified as metal matrix (MMC), polymer matrix (PMC) and ceramic matrix composites (CMC). MMC's recently are drawing interests of the researchers because of the ability to alter their physical properties like density, thermal expansion, thermal diffusivity and mechanical properties like tensile and compressive behaviour, creep, tribological behaviour etc. by varying the filler phase. Also the growing requirement for advanced materials in the areas of aerospace and automotive industries had led to a rapid development of MMC's. Allison et al. (1993); Narula et al. (1996). In AMC the matrix phase is of pure aluminium or an alloy of it and the reinforcement used is a non-metallic ceramic such as SiC, Al_2O_3, SiO_2, B_4C, Al-N. Aluminium alloys are more and more used due to good corrosion resistance, high damping capacity, low density and good electrical and thermal conductivities. AMC's have been tested and proved useful in different engineering sectors including functional and structural applications because of variation in mechanical properties depending upon the proportion of reinforcement and chemical composition of Al matrix.

The disadvantage of producing AMC's usually lies in the relatively high cost of fabrication and of the reinforcement materials. The cost effective method for manufacturing composites is very important for expanding their application. Particulate-reinforced aluminum-metal matrix composites (AMCs) because of their isotropic properties and relatively low cost are attracting researchers. With the evolution of new processing techniques stir casting process has proved to be relatively economical and easy to use method. This paper presents a detailed review of stir cast aluminum matrix composite regarding their improved mechanical and tribological properties.

2. Stir casting

In a stir casting process, usually the particulate reinforcement is distributed into the aluminum melt by mechanical stirring. In 1968, S. Ray incorporated alumina particles into aluminum melt by stirring molten aluminum alloys containing the ceramic particles. Ray (1969). Mechanical stirring is a key element of this process. Composites with up to 30% volume fractions can be suitably manufactured using this method. Luo (1995); Saravanan et al. (2000). A problem associated with the stir casting process is the segregation of reinforcing particles due to settling of particles during solidification. The distribution of the particles in the final solid depends on strength of mixing, wetting condition of the particles with the melt, rate of solidification and relative density. Geometry of the mechanical stirrer, position of stirrer in the melt, melt temperature, and the properties of the particles added determines the distribution of particles in molten matrix. Harnby et al. (1985); Girot et al.(1987).

A recent development in stir casting process is a double stir casting or two-step mixing process. In this process, first the matrix material is heated to above its liquidus temperature. The melt is then cooled down to a temperature between the liquidus and solidus points to a semi-solid state. At this point the preheated reinforcement particles are added and mixed. Again the slurry is heated to a fully liquid state and mixed thoroughly. In double stir casting the resulting microstructure has been found to be more uniform as compared with conventional stirring. The potency of this two-step mixing method is mainly due to its ability to break the gas layer around the particle surface which otherwise impedes wetting between the particles and molten metal. Thus the mixing of the particles in the semi-solid state helps to break the gas layer because of the abrasive action due to the high melt viscosity. Su et al. (2012) designed a new three step stir casting method for fabrication of nano particle reinforced composite. First the reinforcement and Al particles are mixed using ball mills to break the initial clustering of nano particles. The composite powder is then incorporated into the melt with along with mechanical stirring. After adequate stirring the composite slurry is sonicated using an ultrasonic probe or transducer in order to improve the distribution of reinforced particles. Kumar et al. (2013) used a 3 phase induction motor for electromagnetically stirring the aluminum melt and showed improvement in particle matrix interface bonding with a small grain size structure.

The major advantage of stir casting process is its applicability to mass production. Compared to other fabrication methods, stir casting process costs as low as $1/3^{rd}$ to $1/10^{th}$ for mass production of metal matrix composites. Maruyama (1998); Surappa et al. (1981). Because of the above reasons, stir casting is the most widely used commercial method of producing aluminum based composites.

3. Mechanical properties

The mechanical properties of a composite depend on many factors such type of reinforcement, quantity of reinforcement, shape, size etc. The proper understanding of the mechanical behaviour is thus essential as they are employed in different areas. Kamat et al. (1989) evaluated the mechanical properties of Al2024/ Al_2O_3 composite and observed that yield and ultimate tensile strength of the composite increased with increase in volume fraction of Al_2O_3 particles. Azim et al. (1995) fabricated Al2024/ Al_2O_{3p} composite and investigated its mechanical properties. The authors observed that yield strength of the composite increased while ultimate tensile strength and ductility decreased with increase in volume percentage of ceramic material. Tee et al. (1999) developed in situ Al-TiB_2 composite by stir casting. They observed that the tensile and the yield strength of the composite was twice that that of unreinforced matrix but the ductility showed a lower value. Alaneme et al. (2013) investigated the mechanical and corrosion behaviour of SiC bamboo ash reinforced Al-Mg-Si alloy hybrid composite. The author reported that the ultimate tensile strength, hardness and yield strength values of the composite decreased with increase in percentage weight of bamboo leaf ash while the fracture toughness of the hybrid composite was superior. Corrosion resistance of the hybrid composite was superior in basic solution as compared to acidic solution. Azim et al. (2002) studied the mechanical and wear properties of the stir cast AlSi18CuNi/ Al_2O_{3p} composite. They observed that the composite with 2% by weight Al_2O_3 possessed a tensile strength and hardness values of 505 MPa and 123Hv over that of unreinforced matrix alloy. And wear resistance also increased in case of the composite. Kok (2005) fabricated Al2024/ Al_2O_{3p} composite and studied its mechanical properties. The author has revealed that the hardness and tensile strength of the composite with increasing the weight percentage of the reinforcement.

Yar et al. (2009) produced Al (A356.1) matrix composite reinforced with nano particle of MgO. The authors observed that the hardness and compressive strength of the composite was higher compared to the matrix alloy. Amirkhanlou et al. (2010) evaluated the hardness and impact energy of the Al(A356)/SiC_p composite and observed that the hardness and the impact energy of the composite was higher compared to the pure alloy. Sajjadi et al. (2011) studied the mechanical properties of the stir cast Al (A356)/ Al_2O_{3p} composite. The author has revealed that the hardness and compressive strength of the composite increased with increasing the weight percentage of Al_2O_3 and also by decreasing the particle size. Su et al. (2012) studied the tensile strength of nano particle Al_2O_3 reinforced Al (2024) matrix composite using 3 step casting method and observed that yield strength and tensile strength of the composite was superior to pure matrix alloy.

Kakaiselvan et al. (2011) produced Al (6061-T6)/B_4C composite and investigated its mechanical properties. They observed that the hardness (fig 1 a) and the tensile strength (fig 1 b) of the composite are linearly increasing with increasing weight percentage of the B_4C particulate.

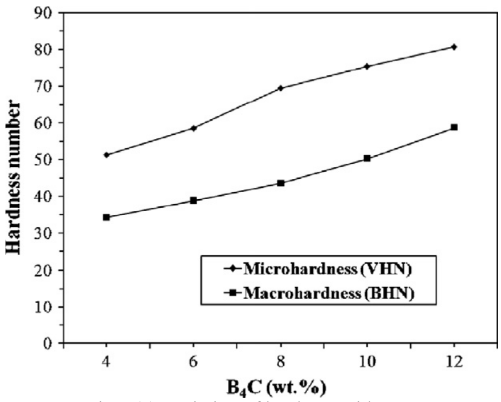

Fig 1 (a) Variation of hardness with B_4C content (Kakaiselvan et al.(2011))

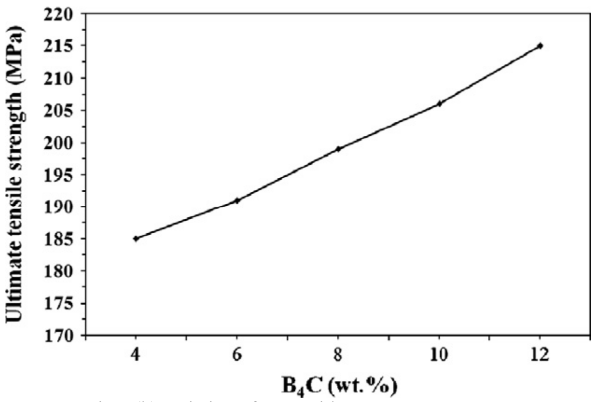

Fig 1 (b)Variation of UTS with B_4C content (Kakaiselvan et al.(2011))

Mazaheri et al (2013) conducted a comparative study of mechanical properties of Al-TiC, Al-B_4C and Al-

TiC-B_4C hybrid composite. The author has revealed that Al/TiC/ B_4C composite possessed highest hardness. Highest yield strength and tensile strength was shown by Al- B_4C composite and Al-TiC showed maximum elongation. Kumar et al. (2013) fabricated A359/ Al_2O_3 composite via electromagnetic stir casting method. The author revealed that the hardness values increased to 72.8 HRC compared to pure alloy (46HRC). Also the tensile strength of the composite increased to 148.7N/mm^2 as compared to pure alloy (103.7N/mm^2). Akbari et al. (2013) fabricated samples of Al (A356) alloy matrix composite reinforced with mixture of milled nano Al_2O_3 and Al particles and with nano Al_2O_3 and Cu particles. The authors observed that ultimate tensile strength and compressive strength of the composite is higher than that of pure alloy. The increase in mechanical properties is higher in case of Al (A356)/ Al_2O_3/Cu composite. Jinfeng et al. (2008) investigated the machinability of SiC/Gr/Al composite and observed that tensile strength and elastic modulus of the composite was higher compared to pure matrix and it increased with increase in volume fraction of graphite.

Baradeswarn et al. (2013) studied the mechanical behaviour of B_4C reinforced AL-7075 matrix composite. The author has revealed that the ultimate tensile strength (fig 2 a), the compressive strength (fig 2 c) and the hardness (fig 2 b) of the composite increased linearly with increase in volume percentage of B_4C.

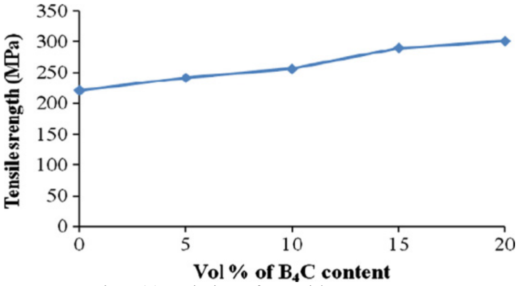

Fig 2 (a)Variation of TS with B4c content
(Baradeswarn et al.(2013))

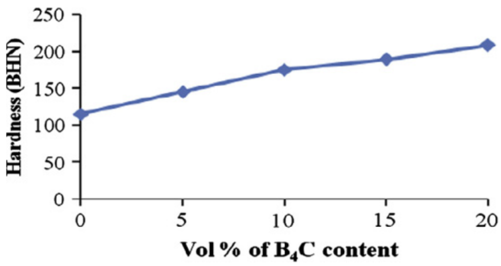

Fig 2 (b)Variation of hardness with B4c content
(Baradeswarn et al.(2013))

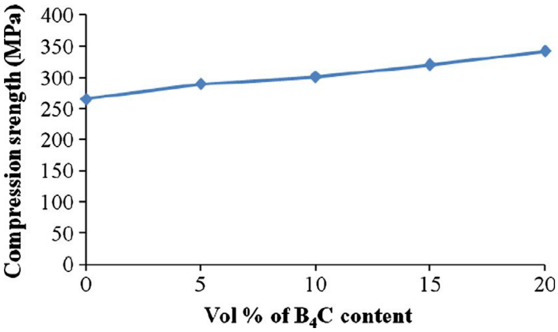

Fig 2 (c)Variation of compressive strength with B4c content
(Baradeswarn et al.(2013))

Kumar et al. (2008) fabricated Al-7Si alloy composite reinforced with in situ TiB_2 and investigated it's mechanical and wear behaviour. The authors observed that the increase in values of the hardness, ultimate tensile strength, the yield strength and the young modulus were observed with increase in weight percentage of TiB_2. Also the coefficient of friction and war rate decreased with addition of TiB_2 compared to pure alloy. Mazahery et al. (2009) produced stir cast A356 alloy matrix composite reinforced with nano- Al_2O_3 particles. The author has revealed that the values of the yield strength, the ultimate tensile strength and ductility of the composite increased with the increase in volume percentage of the nano particles. Also the hardness of the composite improved compared to pure alloy.

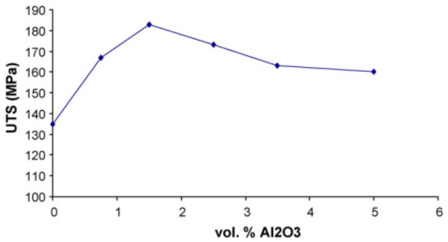

Fig 3 (a)Variation of UTS with Al_2O_3 content (Mazahery et al.(2009))

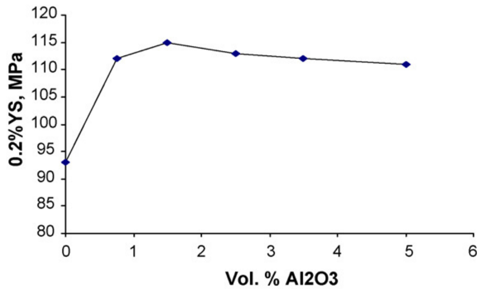

Fig 3 (b)Variation of yield strength with Al_2O_3 content (Mazahery et al.(2009))

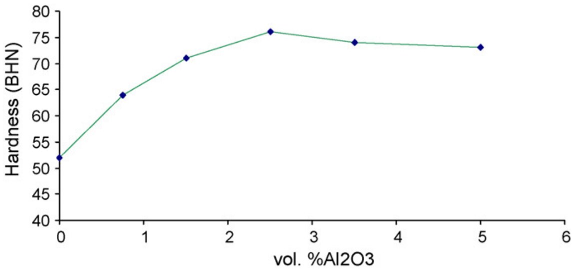

Fig 3 (c)Variation of hardness with Al_2O_3 content (Mazahery et al.(2009))

Ling et al (2010) fabricated Aluminium matrix composite reinforced with Al9 (Co, Ni)$_2$ particles. They observed that the ultimate tensile strength and the yield strength of the composite increased with increase in volume fraction of reinforcement. While the elongation fracture first increased and then decreased with increase in reinforcement. Prasad et al. (2011) fabricated A356.2 Al/Rice hush ash (RHA) metal matrix composites (MMCs) by stir casting method. The author observed that the hardness and ultimate tensile strength of the composite was higher compared to pure alloy. Kumar et al. (2012) investigated the mechanical behaviour of stir cast Al (6061) matrix composite reinforced with Al-N particles and concluded that ultimate tensile strength and yield strength of the composite was better than pure alloy. The author revealed that micro hardness and macro hardness of the composite increased with increase in percentage of Al-N into the alloy matrix. Atuanya et al. (2012) fabricated breadfruit seed hull ash reinforced Al-Si-Fe alloy matrix composite using stir casting technique. The author reported an increase in tensile strength and hardness values for the composite while the impact strength decreased compared to matrix alloy.

Selvam. J et al. (2013) studied the mechanical properties of stir cast (SiC + Fly Ash) reinforced aluminium (6061) hybrid composite. The author has revealed that the macro hardness and tensile strength of the composite increased with increase in wt. percent of the SiC particles. Boopathi et al. (2013) fabricated hybrid metal matrix composites from Aluminium 2024 and silicon carbide and fly ash as reinforcement. The authors observed an increase in values of the mechanical properties like the tensile strength, the yield strength and the hardness of the composite compared to unreinforced alloy. Alaneme et al. (2013) studied the mechanical behaviour of double stir cast Rice husk ash (RHA)-Alumina reinforced Aluminium alloy hybrid composite. The author has revealed that the hardness, tensile strength and specific strength of the hybrid composite was slightly lower compared to single reinforced Al- Al_2O_3 composite while the fracture toughness increased within percentage wt. of RHA up to 3% by weight.

4. Tribilogical properties

Aluminum–matrix composites have attracted much attention and wide acceptance due to their high specific strength and superior wear resistance. Tribological behavior of Aluminum metal matrix composites has been investigated by several researchers due to their application as bearing material, brushes, contact strips etc. Wilson et al. (1996) investigated the high temperature dry sliding wear behaviour of Al(A356)/SiC, Al(A356)/(SiC+ Graphite) and Al(6061)/Al_2O_3 composite. The authors observed that addition of ceramic particles improves the seizure resistance of the composite at higher temperature compared to pure alloy, SiC being more effective than Al_2O_3. The hybrid composite possessed better resistance to severe wear compared to other two composites at higher temperature regimes. Shipway et al. (1998) studied the influence of load and TiC content on the dry sliding wear behaviour of Al-4Cu/TiC, Al (A356)/TiC, and Al (pure)/TiC composite. The authors concluded that the composite had reduced wear rates compared to pure alloys, Al (A356)-10%TiC showing the highest resistance of all. Tee et al. (2000) investigated the dry sliding wear behaviour of in situ Al-Tib and Al-4.5% Cu-Tib_2 composites developed by stir casting method. The author has revealed that wear losses of the both composite reduced with increase in volume fraction of Tib_2. Fig 4 c below shows that as the sliding distance increases wear loss also increases but at much less rate compared to pure alloy. Also the wear resistance of the Al-Tib_2 composite was higher than Al-4.5% Cu-Tib_2 composite.

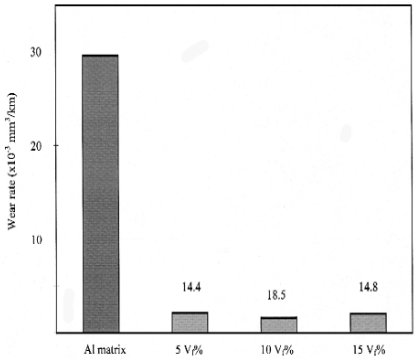

Fig 4 (a)Variation of wear rate (Tee et al.(2000))

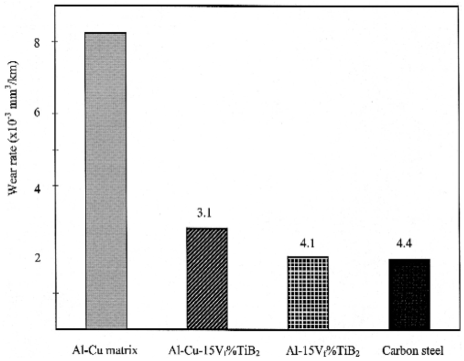

Fig 4 (b)Variation of wear rate (Tee et al.(2000))

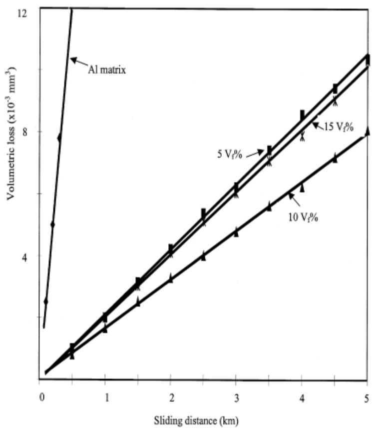

Fig 4 (c)Variation of volume loss(Tee et al.(2000))

Sahin et al. (2003) investigated the abrasive wear behaviour of SiC_p reinforced aluminium matrix composite. The authors observed that wear rate increased with increasing applied load, sliding distance and abrasive size for SiC emery paper while it decreased with sliding distance for Al_2O_3 paper. Kok (2006) investigated the wear behavior of Al (2024)/ Al_2O_{3p} composite and evaluated the influence of sliding distance, Al_2O_{3p} content, size of reinforcement and abrasive grit size, on the abrasive wear properties. The authors revealed that the volume loss of pure alloy is much higher compared to composite material. The wear losses increased with increase in grit size and sliding distance. Also the volumetric wear losses lowered with the increase in particle size and weight fraction of

Al_2O_3 particles. Hosking et al. (1982) studied the wear behavior of 2024 Al/ Al_2O_3 composite and observed a decrease in wear rate of the composites with the increase in the volume fraction of Al_2O_3 particles at constant particle size. Also with the increase in particle size wear rate lowered at constant volume fraction.

Suresha et al. (2012) investigated statistically the dry sliding friction behaviour of hybrid aluminium matrix composite reinforced with combined SiC and Graphite particles. The authors concluded that load in the most important factor affecting the friction coefficient of the hybrid composite followed by sliding speed. The coefficient of friction increased with increase in load and sliding distance. The author also revealed that the average friction coefficient of the hybrid composite is quite low compared to pure alloy. Pramila Bai et al. (1992) studied the dry sliding wear behaviour of A356-Al-SiCp composite and have revealed that the wear resistance of the composite increases with increasing weight percentage of SiC particle from 15 to 25. Das et al. (2007) conducted a comparative study on the abrasive wear behaviour of aluminium alloy based composite reinforced with alumina and zircon sand. The authors observed a increase in wear resistance for both the composites with decrease in particle size of the reinforcement. The author also revealed that wear resistance of zircon sand reinforced composite was better than Al_2O_3 reinforced composite. Fig 5 shows that wear rate is constant with increase in sliding distance.

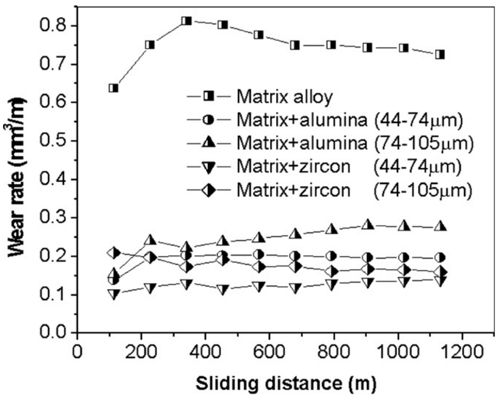

Fig 5 Variation of wear rate (Das et al.(2007))

Sivaprasad et al. (2008) analysed the wear characteristics of the as-cast Al (6063)/Tib_2 in-situ composite. The authors observed that the abrasive wear rate of the composite decreased with increase in weight percent of Tib2 particles and wear resistance decreases with increase in load. The author also revealed that as weight percent of Tib_2 particles increases the volume losses decreases and with increase in distance traversed the volume losses increases. Hassan et al. (2009) studied the friction and wear behaviour of Al-Mg-Cu alloy based composite reinforced with Sic particles. The authors concluded that the wear resistance of the composite increased compared to pure aluminium alloy. The wear losses increased linearly with the sliding distance for both composite and pure alloy but composite showed a lower rate of volume loss than that of matrix. Alaneme et al. (2013) incorporated rice husk ash (RHA) and alumina particles into Al-Mg-Si alloy matrix and studied its corrosion and wear behaviour. The authors concluded that corrosion resistance and wear rate of the hybrid composite increased with increase in wt% of RHA in alloy matrix.

Ramachandra et al. (2007) investigated the wear and friction characteristics of Al (12% sic) matrix composite reinforced with fly ash particles. The authors observed that wear resistance of the composite increased with increase in weight percent of fly ash while it decreased with increase in normal load and sliding velocity. With increase in fly ash content the slurry erosive wear resistance of the composite increased and the corrosion resistance decreased. Kumar et al. (2013) investigated the tribological behaviour of dual reinforced aluminium based metal matrix composite incorporated with zircon sand and silicon carbide. The author observed that wear resistance of the dual reinforced composite was higher than both single reinforced composite and pure alloy at low and high loads. Dwivedi et al. (2010) statistically studied the dry reciprocating wear behaviour of Al-Si-SiC_p composite and observed that composite with high silicon content shoed lower wear looses compared to that of low silicon content composite. Sliding distance is the main factor which affects the wear behaviour of the composite followed by load, reciprocating velocity and weight percentage of silicon. The interaction between load and sliding distance also had a pronounced effect on wear behaviour. In case of friction behaviour load is the controlling factor followed by weight percentage of silicon. Apasi et al. (2012) investigated the dry sliding wear behaviour of Al-Si-Fe alloy matrix composite reinforced with different weight fractions of coconut shell ash particles. The author observed that the wear rate of the composite decreased with increase in wt. percentage of coconut shell ash and decrease in applied load. Prasad el al. (2012) developed Al (A356.2) alloy composite reinforced with rice husk ash (RHA) and investigated its tribological properties. The author has revealed that the wear rate and friction coefficient of the composite decreases with the increase in weight percentage of the RHA particles in the alloy matrix. Venkat prasad et al. (2011) studied the dry sliding wear behaviour of Al/fly ash/graphite hybrid composite and has revealed that the hybrid composite showed a improved tribological characteristic and reduced wear losses.

5. Conclusion

The above review for the stir cast aluminum based metal matrix composite leads to the following conclusions:

- Stir casting method can be successfully used to manufacture metal matrix composite with desired properties.
- Reinforcing Aluminum and its alloys with ceramics particles has shown an appreciable increase in its mechanical properties.
- Addition of alumina, SiC, B_4C etc. particles in aluminum improves the hardness, yield strength, tensile strength while ductility is decreased.
- Addition of graphite in aluminum increases the tensile strength and elastic modulus but hardness is decreased. Also it shows a decrease in friction coefficient in case of tribological behavior.
- Organic reinforcements like coconut ash, rice husk ash also improved the mechanical properties of the aluminum along with the tribological behavior of the composite.
- For Al MMCs with organic reinforcements, very limited work has been reported. Organic reinforcement additions to aluminum matrix systems have shown significant increase in the mechanical properties of resulting composites. However, substantial improvement in the tribological properties has not been achieved in the limited reported literature in this area. This provides scope for further investigations in the field.
- A few authors have reported about modified stir casting methods for improving the distribution of the reinforcement in the matrix. However, there is a lack of work regarding availability of efficient techniques for nano level reinforcements.
- Hybrid ceramic reinforcement has increased the mechanical properties much but literature on tribological properties in case of hybrid reinforcement is limited.

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