Coated and uncoated reinforcements metal matrix composites characteristics and applications – A critical review

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Coated and uncoated reinforcements metal matrix composites characteristics and applications – A critical review

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Abstract: Nowadays, metal matrix composites are being comprehensively used in aero and automotive applications. The usage of composites increased because of their impressive properties viz., improved strength, impact resistance, and tailored features. Compared to uncoated, coated reinforcements in the matrix improves wettability with thinner grain boundary, grain fineness, and the ability for secondary hardening. Improvement in thermal expansion and conductivity makes the composite suitable for moderate temperature shock resistance is the new openings in the field. Conventional liquid stir casting, Rheo-process, and Diffusion roll bonding are some of the methods employed for the processing of composites. Hybridisation of reinforcements with at least one as coated in the matrix improves solid solution strengthening of composites, hence responsible for improved strength and bulk hardness. Generally, a critical literature survey points to copper and nickel coatings. Copper coating rises microhardness, shows poor EMI shielding effectiveness compared to nickel-coated, whereas, nickel-coated reinforcement composites show excellent corrosion resistance compared to that of copper-coated reinforcement.

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PUBLIC INTEREST STATEMENT

The paper explains the different reinforcement additions in the coated or bare form on aluminium alloy matrices. Other processing techniques of metal matrix composites are also looked upon with relative merits and demerits. The silicon, boron and tungsten carbide powders are compared for general properties and relative abilities in composites. The various authors work on different aluminium matrices, improvement in mechanical properties, morphological variations and allowable limit of reinforcements in the case of lighter and heavier types, benefits over other reinforcements and application of relative composites are covered. The possibilities of hybridisation of reinforcements with oxides of aluminium and titanium are also attempted. The effect of reinforcement on wear and fatigue resistance is also covered. Coatings used on carbide reinforcements like copper, nickel, cobalt, etc., are dealt with relative benefits. Even the effect of coating thickness on refractoriness and bond strength of composites are covered as per the present need.
Cobalt-coated nanoparticles reinforced composites upsurges compressive strength and tribological properties compared to nickel-coated ones. However, the extensive review work undertaken collects the possibilities of using different reinforcements in bare state and coated state with or without hybridisation. A comparison of data with property analysis will open the way for further research activities with hybridisation of both or single-coated reinforcements in the matrix and may help to prepare the standard guidelines to advance with a statistical approach. The objective of the present work is to collect the data on the aluminium matrix composites with different reinforcements in coated as well as bare forms and dig on the possibilities for property enhancement.

Subjects: Composites; Materials Processing; Metals & Alloys

Keywords: Metal matrix composite (MMCs); aluminum alloy; composites; coating; reinforcements

1. Introduction

The composite material is a macro-fusion of different materials leading to improved properties compared to the individual material. The applications of composite materials are increasing day to day in the modern world due to the higher strength to weight ratio (Bowman et al., 1995; Busquets-Mataix et al., 2004; Corbin & Wilkinson, 1996; Doel & Bowen, 1996; Gupta et al., 1996; Schröder & Kainer, 1991; Seshappa et al., 2018; Veeresh Kumar et al., 2010). Particle reinforced composites are stronger than the whisker or fiber-reinforced composites. Hence, particle reinforced composites are preferable over other composites because of their cost-benefit, excellent heat, and wear-resistant properties (Chawla & Chawla, 2006; Das, 2004; Jagadish, 2015; Kumar & Balasubramonian, 2010; Lloyd, 1994; Reddy et al., 2017; Rohatgi, 1994). The coated reinforcement in aluminium matrix gains more significance due to lower cost and isotropic properties for the production of the aero and automotive parts (Chou & Liu, 2005; M.C. Gowri Shankar et al., 2013; Navinšek et al., 1999; Rao et al., 2016; Sánchez et al., 2010).

Recently there has been a change in pattern to the evolvement of aluminum metal matrix composites (AMMCs) based on the usage of aluminium alloy (Amanov et al., 2013; Aruri et al., 2013; Gowri Shankar, Kini, Sharma et al., 2016; S. S. Sharma et al., 2016). The reinforcements are placed into an alloy matrix to enhance the mechanical and material properties. The reinforcement not only performs a structural element but also changes the physical properties viz., coefficient of friction, thermal conductivity, or resistance to wear (Gowri Shankar et al., 2017).

Reinforcement surfaces can be coated with non-metallic or metallic compounds, to improve adhesion (wettability), mechanical properties and to evade any unpleasant chemical reaction within the matrix and reinforcement at elevated temperatures. There are different methods of coatings like Electroless Nickel Plating (EN), Chemical Vapour Deposition (CVD), Physical Vapour Deposition (PVD), etc. PVD is a technique where the condensed phase material enters to a material phase of vapour as thin film. Sputtering and evaporation are the most common PVD processes (Navinšek et al., 1999; Sathyashankarasharma et al., 2019; Shankar et al., 2018; S. Sharma et al., 2018). PVD is used for high melting point and low vapour pressure materials. CVD is a deposition method to chemically produce pure, high-performance solid materials. In the general CVD process, the desired output is produced when the substrate reacts and decomposes when exposed to several volatile precursors (Chou & Liu, 2005; Sathyashankarasharma et al., 2019). In Electroless Nickel plating (EN) technique, plating of nickel phosphorous alloy by the process of chemical reduction on the catalytic metal surface. The deposits from EN processes have high corrosion resistance, lower wear surface. They have a noticeable lower amount of porosity, which results in
outstanding wearing off and the abrasion resistance of the thickness quotient (S. S. Sharma et al., 2016; Sánchez et al., 2010).

Coating the reinforcement offers advantages viz., protection from the reaction with the matrix inter as a diffusion obstacle; increases the bonding and wetting amongst matrix and reinforcement; augments the properties of the MMCs. Generally, reinforcements are coated with copper, cobalt, magnesium, nickel, borax, etc. In the current review, works from various researchers are collectively studied related to the effects of coated and uncoated reinforcements on characteristics and applications of AMMCs.

2. Matrix and reinforcement material
The Al alloys are expressed as 1XXX, 2XXX up to 8XXX. Alloys that belong to 1, 3, and 5XXX series are non-heat-treatable, strengthened by work hardening, or adding some of the alloying elements (e.g., having an increase in Mg content). Strengthening mechanism of 2, 6, and 7XXX mainly depends on precipitation of coherent intermetallics during heat treatment and finds major application in construction, aerospace, marine, automotive, and other similar areas. Researchers have undergone a comprehensive study based on technological significance due to exceptional improvement in strength gained by precipitation hardening (Gowri Shankar, Kini, Sharma et al., 2016; Jenix Rino et al., 2012; Shorowordi et al., 2003). Gowrishankar et al. (Gowri Shankar, Kini, Sharma et al., 2016) work on Al6061 with SiC and B$_4$C reinforcement composites concluded that by the addition of optimum quantity of hybrid reinforcements, upto 30% and 40% increase in hardness and tensile strength respectively when compared with the composite with same quantity of single reinforcement. The results of the several investigations associated to the importance of various reinforcements such as Silicon carbide (SiC), Boron carbide (B$_4$C) and Tungsten carbide (WC) on different types of Al alloys can be summarized as follows:

2.1. Silicon carbide
The presence of SiC reinforcement in MMCs shows higher hardness, specific strength, stiffness, and thermal properties. These MMCs are progressively used to produce brake motors, cylinder heads, pistons, and liners (Allison & Cole, 1993). The low thermal expansion with high thermal conductivity supported by enhanced toughness makes SiC reinforced MMC as ideal for thermal shock resistance applications (S. Sharma et al., 2018). Sohni et al. (Sohini, 2003) studied the consequences of reinforcing various particulate sizes of SiC in alloy Al2024 by the cost-effective method of mixing molten metal. The increasing weight (wt.) fraction of the particle causes a linear escalation in the composite density. In contrast, increasing particulate volume fraction in the alloy matrix causes an almost linear increase in aluminium matrix composite’s hardness and toughness at elevated temperatures. Further, Miyajima et al. (Miyajima & Iwai, 2003) stated that for similar volume fraction, compared to Al2024-SiC whisker reinforced composites, Al2024-SiC particle composite’s density is higher whereas Al2024-B$_4$C composite has excellent specific hardness at all temperatures compared to SiC reinforcement in the same aluminium MMCs. From the statement, it is worth to conclude that the improvement in density is owed to the ceramic particle’s higher density and toughness. Chawla et al. (Chawla & Shen, 2001) observed that higher wt. fraction of SiC particles in Al2080 matrix shows substantial improvement in Young’s modulus, rate of work hardening, and ultimate tensile strength. Boopathi et al. (Boopathi et al., 2013) observed that increasing reinforcement’s surface area fraction in the alloy enhances mechanical properties. By adding fly ash and SiC into Al2024 alloy, the percentage elongation rate of the hybrid MMCs is greatly reduced. Dong et al. (Xiao-dong et al., 2007) observed the impact of SiC reinforcements on Al5210 MMCs with particle sizes of 10, 28, 40 & 63 μm on stiffness & wear resistance with finer grit size contributing toughness and coarser one on wear resistance. A decrease in size of reinforcement results in an augmentation in bending strength of SiC/Al5210; also, with a 50% volume fraction, finer grit combination provides excellent fracture toughness. Mahadevan et al. (Basavarajappa et al., 2007) carried out rotating bending fatigue studies on Al6061-SiC MMCs with distinct solutionizing and aging treatments. Composite fatigue strength mainly depends on solutionizing temperature as compared to different aging temperature and time intervals. Veeresh et al. (Kumar et al., 2011)
observed that with the inclusion of the ceramic reinforcement, a decrease in the Al6061-SiC composite's high-temperature thermal expansion is noticed. Roebuck et al. (Roebuck, 1987) studied non-reinforced matrix alloy systems, with SiC particles in Al6061 MMCs, found a maximum 20% increase in yield strength, lower wear rate and a lower coefficient of thermal expansion (CTE). Veeresh et al. (Veeresh Kumar et al., 2014) observed the properties of Al7075-Al2O3 and Al6061-SiC MMCs with different reinforcement particle sizes. The Al7075-Al2O3 composites have higher density and hardness than Al6061-SiC and can be accounted for the high values of density of Al2O3. According to Zaklina et al. (Gnjidić et al., 2001) SiC particles boost the modulus of elasticity and yield strength but decrease the Al7XXX base alloy's ultimate compressive strength and ductility. Mohanavel et al. (Mohanavel et al., 2018) studied that the existence of SiC on AA6351 results in improved tensile properties, composite's density, and hardness. It is also concluded that 20–25% increase in tensile property is possible with SiC reinforcement on Al6XXX matrix composites produced by stir casting technique. Srivatsan et al. (Srivatsan et al., 2005) led to research on fatigue cycle and observed the fractography of 7034/SiC/15p-PA and 7034/SiC/15p-UA MMCs. Both ductility, and strength of the composite microstructure reduced with an increase in temperature. With the under-age microstructure the deterioration in cyclic fatigue life was more pronounced than for the peak-age microstructure. Increasing the load ratio often resulted in increased severity of fatigue for a given ageing condition. Murthy et al. (Murty et al., 2003) worked on hot-working characterization of the SiC and Al2O3 reinforced Al6061 MMC's. From the productivity point of view, work suggested that a higher region of strain rate with high efficiency and mass values must be chosen for processes in bulk and the regions of lower strain rate for secondary metal processes. Rahman et al. (Rahman & Rashed, 2014) studied the effect of SiC reinforcements on the AMMCs and noted that improvement in ultimate tensile strength (UTS), hardness and wear resistance with increase in reinforcement particles, and uniform distribution of reinforcements was found for 20 wt.%. SiC reinforcement of as shown in Figure 1.

Ozben et al. (Ozben et al., 2008) in the research work with 0–15 wt.% SiC particle reinforced AMMCs machinability and mechanical properties. Results revealed that an increase in hardness, UTS, and density during the increase in reinforcement ratio and found maximum at 15 wt.% of SiC, but decreased impact toughness. (Ozden et al., 2007) observed weak matrix-reinforcement bonding, particle cracking, and clustering which influence on the impact behavior of AMC composites in Al alloy SiC reinforced composites. On the impact behavior, the temperature effect is negligible. (Thünenmann et al., 2007) observed AMMC's properties based on preceramic-polymer-bonded silicon carbide preforms with a binder Polymethysiloxane (PMS). 1.25 wt.% polymer content provided the preforms with sufficient stability to allow composite processing. It is therefore demonstrated that the binder derived from PMS provides silicon carbide with the sufficient

![Figure 1. Microstructure of 20 wt. % SiC reinforced AMC (Rahman & Rashed, 2014).](image-url)
strength without affecting the properties of Al-SiC composites. (Sujan et al., 2012) worked on stir cast with 5, 10 and 15 wt.% SiC reinforced AMMC and found an improvement of low thermal expansion coefficient, higher hardness, tensile strength, and impact strength for 15 wt.% SiC reinforcement. In the automobile industry, these composite materials can be used to reduce the weight of the assembly. It is observed that in comparison to the Al-Al₂O₃ composites, the Al-SiC reinforced particle composite showed better mechanical properties. Peng et al. (Peng & Fuguo, 2010) observed the particle clustering effects on silicon carbide reinforced aluminum MMC's flow behavior. The results showed that the clustering of particles during the tensile deformation has less effect on the elastic response of the matrix than the mechanical response, and also greatly affects the plastic deformation. Prabhu et al. (Prabhu et al., 2006) examined the dispersivity of particles in Al alloy-SiC metal matrix casting based on the stirring time, stirrer speed and also discovered that increasing stirring time and speed helps in achieving good distribution homogeneity of SiC in the matrix. Tzamtzis et al. (Tzamtzis et al., 2009) suggested the processing by Rheo-process of aluminum/silicon carbide particulate MMCs under intense shear. Often clustered particles are created in the ductile matrix with the present processing techniques like the traditional stir casting method and also result in extremely low ductility of these composites. Rheo-process drastically improves the distribution of the matrix reinforcement by using adequate shear stress (s) to agglomerated particles rooted in liquid metal to resolve the cluster's average tensile strength or cohesive force. Garcia et al. (Garcia et al., 2010) proposed an alternative SiC compo forging method that strengthened Al-Si MMC to increase the mechanical elongation resistance. This technique is more cost-effective since it eliminates the fabrication stages and also the energy and time consumption. (Gomes et al., 2005) examined that, due to a supportive combination of cost-efficiency, hardness, and density, SiC and Al₂O₃ are widely used among many ceramic materials Al-MMCs reinforced with these reinforcements, shows a substantial improvement in its strength, hardness, wear-resistance, and elastic modulus. (Ravichandran et al., 1992) discovered that the reason for alumina and other oxide particles like TiO₂ etc. is gaining attention as aluminium alloy reinforcements by gifted blessings of improved wear resistance, tensile strength, and hardness.

2.2. Tungsten carbide
Tungsten Carbide (WC) is one of the strongest materials often used for abrasives and cutting operations. It is mainly known for its high impact strength and hardness. Kishore et al. (Kishore et al., 2019) investigated the tribological behavior of Al5052 reinforced with 1–5 wt.% of WC particles. The 5 wt.% of WC reinforced composite resulted in better resistance to wear and a minimum coefficient of friction. WC is usually used for making protective coatings, cutting tools, and wear-resistant tools due to excellent wear resistance properties. Due to greater strength, high hardness, a better resistance at high temperatures, low density, high rigidity, and strong chemical stability, it is one of the most favorable ceramic materials. WC is used in the fabrication of radiation shielding materials due to the high atomic number. Huang et al. (Huang et al., 2018) worked on the development of equiaxial finer microstructure on aluminium alloy matrix composites reinforced with tungsten carbide and concluded that increase in tensile strength is directly proportional to fineness of grains. Lekatou et al. (Lekatou et al., 2015) fabricated AMCs by submicron-sized TiC and WC reinforcement particles in Al1050 matrix. Wear resistance of tungsten carbide reinforced composites are better than composites with TiC reinforcements. 9 wt.% of WC reinforced composites show higher hardness, UTS, and wear resistance due to the formation of Al₃Ti and Al₂W intermetallics as shown in Figure 2. Navya et al. (Hegde et al., 2019) focused on improvement in the properties of LM25 Al alloy composites. The addition of tungsten carbide will hold back the composite solid solution strengthening, hence increases strength.

Jerry et al. (Fabian & Selvam, 2014) found that the addition of 2.5, 5, 7.5, and 10 wt.% of WC to Al composite increases density. Madhukumar et al. (Madhukumar et al., 2017) investigated that the addition of 6 wt.% of WC to Al7075 improved the composite strength with a reduction in ductility. Ravikumar et al. (Ravikumar et al., 2017) examined the mechanical properties of
Al6082-2, 4, 6, 8 and 10 wt.% WC composites and found that best results for the addition of 10 wt.% WC reinforcements which decreased density, and improved UTS and hardness of composites. Veeresh et al. (Kumar et al., 2018) work on WC to Al6061 show that wear resistance, tensile strength, and hardness were excellent for 3 wt.% of WC, but the ductility of the composites decreased. Bhaskar et al. (Bhaskar Raju et al., 2019) examined mechanical properties of 2, 4, 6, 8, 10, and 12 wt.% of WC particulates manufactured by powder metallurgy technique reinforced in Al6061 showing better modulus of rigidity, tensile strength, and hardness for 12 wt.% WC. Avirukkarasan et al. (Avirukkarasan et al., 2018) studied the effect of wear behavior of WC reinforced aluminium LM4 matrix. It was observed that presence of WC particles shows substantial improvement in impact strength, tensile strength, hardness, and reduced wear rate. Abhijith et al. (Abhijith & Harish, 2016) found that for 9 wt.% WC to Al2024 showed better microhardness and reduced wear rate. Swamy et al. (Swamy et al., 2011) in the experimental work on aluminium 6061 hybrid composites in the tungsten carbide and graphite reinforcements revealed that impact resistance increase is directly proportional to the decrease in particle size of tungsten carbide particles. Also, noted that the existence of WC particle in Al6061 composites results in major improvements in hardness, tensile properties at the expense of reduction in ductility. Compared to the Al6061-WC composite, the use of graphite as a reinforcement indicates a significant improvement in Young’s modulus, total tensile strength within the Al6061 matrix.

2.3. Boron carbide
The lower density Boron carbide (B4C) particles compared to other common reinforcements like SiC and Al2O3 resulting in greater specific composite rigidity; the Al-based alloy/B4C system is of particular interest (Gowrishankar et al., 2020; Hu et al., 2001). B4C has a high melting point, higher wear resistance, low density, remarkable chemical resistance, and exceptional thermal stability, which in practice makes it perfect for material shielding (K. B. Lee et al., 2001; Thevenot, 1990). B4C is mainly used in brake discs of automotive or railway transport industries because of its higher dynamic friction coefficient and low wear rate (Gomez et al., 2009). Gopal Krishna et al. (Gopal Krishna et al., 2013) found that for 12 wt.% addition of B4C to Al6061 matrix showed the greatest improvement in the hardness of composites. Shirvanimoghaddam et al. (Shirvanimoghaddam et al., 2016) studied the mechanical properties of Al356-B4C MMCs found that 15 wt.% of B4C composite prepared by stirring the melt at 1000°C showed better hardness and tensile strength. Increasing the process temperature improves wettability and results in better mixing. Previtali et al. (Previtali et al., 2008) researched the impact of the conventional investment casting process in aluminium MMCs. 20 wt.% SiC reinforced composites show lower wear rate as compared to B4C reinforced MMCs. Akhil et al. (Akhil et al., 2017) revealed that increasing thewt.% of B4C in aluminium MMCs resulted in decreased cooling rate or increased solidification time. Due to homogeneous distribution of reinforcements shown in Figure 3, the 9 wt.% of B4C reinforced MMCs showed better hardness, tensile strength, and impact strength. B4C particle has got more surface area as well as lower density.
For the given wt.% of reinforcements, there is an increase in the volume fraction of particles in lower density B$_4$C in the matrix compared to SiC and WC, giving rise to more nucleation sites to trigger the rate of nucleation with reduction in the grain size of precipitating intermetallics during heat treatment, leads to improvement in hardness and strength. It was discovered that B$_4$C has the highest compressive strength and modulus of rigidity compared to SiC and WC (Fabian & Selvam, 2014). Aluminium alloy with alumina-boron carbide MMCs was fabricated, and mechanical properties were studied. The result showed that a high percentage of reinforcement improves AMMC’s mechanical strength (Ramnath et al., 2014).

Kalaiselvan et al. (Kalaiselvan et al., 2011) found that, with the addition of B$_4$C particles to AA6061 alloy, 60% improvement in the micro-hardness and 75% improvement in the macro-hardness were observed as compared to matrix alloy. Upon the inclusion of reinforcements in the matrix, an increase in the surface area of the reinforcement and a decrease of the matrix grain sizes is observed. High resistance to plastic deformation and an improvement in the hardness of composites is resulted due to the presence of such hard, more surface area particles.

Onoro et al. (Onoro et al., 2009) found that the improvement in hardness and tensile strength due to the presence of composites reinforced with B$_4$C particles compared to Al6061 and Al7015 alloy matrix. Yongpeng et al. (Tang et al., 2020) described related role in achieving optimized ductility-strength balance by the precipitation of ultrafine-grains for aluminium alloy during the combined processing of accumulative roll bonding (ARB) and aging at 100°C. Pazhuhanfar et al. (Pazhuhanfar & Eghbali, 2019) in his work studied the behavior of stir cast Al6061–B$_4$C MMCs. Post-ARB processing and aging treatment stated, homogeneous distribution of reinforced particles in microstructure is found with post-ARB. With roll bonding accumulative cycles, the particle-free zones and agglomerates decreased and disappeared at higher strains. With the increase in accumulative roll bonding cycles resulting from the elimination of particle clusters, the porosity content of composites decreased. There is a provision to use coat reinforcement for better interface bonding and enhance hardness related properties. Zhang et al. (Zhang et al., 2004) stated that the retort of the 6092/B$_4$C composite aluminum strain rate escalates with an increase in the reinforcement volume fraction. Yücel et al. (Yücel & Tekin, 1997) revealed that in the Al7075 MMCs containing B$_4$C powder reinforcement, substantial improvement in the hardness and inferior fracture toughness were found as compared to matrix Al7075 alloy.

Uvaraj et al. (Uvaraja et al., 2013) observed in his work that the introduction of B$_4$C and SiC particulates to aluminum alloy shows an improvement in mechanical properties as compared...
AI6061 alloy, as these additives act as hindrances to the dislocation movement. Hybrid composites with AI6061-SiC+B_{4}C demonstrate optimal combination to achieve high strength and hardness. (Gowri Shankar, Kini, Sharma et al., 2016) showed that up to 40% increase in wear resistance is observed as the weight % of B_{4}C increases from 1 to 3 in peak aged condition by the formation of mechanical mixed layer during sliding wear churning effect. Sharma et al. (S. Sharma et al., 2018) in the experimental work concluded that increase in B_{4}C in the aluminium 6061 matrix composite increases the number of ultra fine dimples with minimum river pattern appearances in SEM fractography. Different properties of reinforcement particles are summarized by different authors and shown in Table 1.

3. Coating
Reinforcement surfaces can be coated with non-metallic or metallic compounds, to improve adhesion (wettability), mechanical properties and to evade any undesirable matrix and reinforcement reaction at elevated temperatures. In general, a coating on the reinforcement offers some advantages such as protection of the fiber from the reaction with the matrix acting as a diffusion barrier, increases the bonding and wetting between fiber and matrix, and also increases the mechanical properties of the MMCs. Generally, reinforcements are coated with copper (Cu), cobalt (Co), nickel (Ni), etc. The results of the many investigated inquiries concerning the importance of different types of reinforcements coating can be summarized as follows:

3.1. Copper
Copper has properties like excellent thermal and electrical conductivities with a higher melting point. (Antil et al., 2019; Pourhosseini et al., 2018); these features make copper more desirable when used in electronic packaging. Particle reinforced copper composites have excellent ductility & toughness; also, copper is corrosion resistant (Davidson & Regener, 2000; Deepa et al., 2015; Y. F. Lee et al., 1999). Copper coatings on particles before dispersion enhanced the excellent bonding of the reinforcements with the matrix. It also reduced the frequency of the potential interfacial reaction between molten metals and the Cu coated particles. (Abraham et al., 1992; Kulkarni et al., 1979; Mandal et al., 2007; Mousavian et al., 2005; Pourhosseini et al., 2018; Singh & Balasubramonian, 2009). Mandal et al. (Mandal et al., 2007) experimented on copper coating on steel fibres reinforcements in aluminium base composites to observe 30% increase in corrosion resistance and durability of the component. Copper coated particles show a better distribution in the melts, abrasion & wear resistance (Deepa et al., 2015; Mousavian et al., 2005; Pai & Rohatgi, 1979). It is anticipated that the presence of Cu on the reinforcement surface will improve the sinterability between the matrix and reinforcement interface (Davidson & Regener, 2000). The microhardness of composites will increase when Cu coated reinforcements are reinforced. When reinforcement is coated with Cu, yield, and ultimate tensile strength increased significantly compared to uncoated (Deshmukh et al., 2015; Maqbool et al., 2013; Mousavian et al., 2005; Pourhosseini et al., 2018). Copper coating provides low efficacy EMI shielding relative to nickel coating (Tzeng & Chang, 2001). The composites containing Cu coated reinforcement is observed to have high hardness. (Mithun et al., 2017; Pourhosseini et al., 2018).

| Properties                  | WC   | B_{4}C | SiC |
|-----------------------------|------|--------|-----|
| Density (g/cc)              | 15.63| 2.51   | 3.30|
| Coefficient of Thermal Expansion (10−6/°C⁻¹) | 4.4  | 3.2    | 4.6 |
| Tensile Strength (Mpa)      | 344  | 261    | 588 |
| Modulus of Elasticity (GPa) | 550  | 445    | 345 |
| Poisson's ratio             | 0.31 | 0.20   | 0.18|
| Hardness (kg/mm²)           | 2242 | 3000   | 2800|
3.2. Cobalt
Cobalt (Co) is an extremely ferromagnetic element that exhibits strong induction when mixed with iron and produced using hydrotreating (HDT) processes low excitation field strengths (Bas et al., 2003). When the coating is used in the air, the oxidation of Co metal at 200 °C can cause decomposition (Vitt, 1989). The wear resistance of the cobalt coatings is higher and the coefficient of friction is nearly twice that of nickel coatings of roughly equal grain size under the similar tribological conditions (Wang et al., 2006). It is found that there will be substantial improvement in the stiffness of nanocrystalline cobalt coatings with declining grain length from micrometer to nanometer (Wang et al., 2006). Pure cobalt coatings show higher interfacial stress. The coatings of over 10% of Co have high tensile strength. Microhardness, abrasion resistance, and electrical resistance increase with more Co amount in the coating (Nineva et al., 2006). Bike et al. (Baik, 2013) observed the improvement in fracture resistance when alumina is coated with cobalt in aluminium alloy matrix composites by suppressing the formation of interfacial reaction product Al2C. Cobalt-coated fibers have higher tensile strengths, and moduli also improve wettability (Baik, 2013; Kulkarni et al., 1979; Pourhosseini et al., 2018). There is an improvement in adhesion, and the creation of an intense interfacial reinforcement-matrix bonding of cobalt-coated nanoparticles into the molten matrix is noticed. It is observed that when Co coated nanoparticles are used in reinforcement, there is an advancement in the compressive strengths of the composites. According to Shi et al. (Shi et al., 2006), electrodeposited hybrid Ni-Co coating has higher intensity and stiffness, different magnetic properties, and greater tolerance to wear and corrosion resistance at high temperature.

In the analysis done by Chivavibul et al. (Chivavibul et al., 2007) and Upadhyaya et al. (Upadhyaya, 1998), the properties of WC–Co coating decreased with increasing cobalt content. Higher impact strength, and lower wear rate are observed; these enhanced properties stem from the importance of cobalt in microstructure refining and decreasing the need for organic grain refiners. Microstructure refinement by the solid solution of cobalt excludes fragility and reducing of the ultimate tensile strength (UTS) (Fenineche et al., 1990; Li et al., 2008; Zamani et al., 2016). Sahoo et al. (Sahoo & Das, 2011) in the review work concluded that coating of reinforcement may improve up to 50% in tribological properties of aluminium alloy composites. Higher Co monohydroxide adsorption potential increases the level of coating in the alloys (Chung & Chang, 2009; Kakuno et al., 1997; Lin & Selman, 1993; Qiao et al., 2005; Sahoo & Das, 2011; Vaes et al., 2000; Zamani et al., 2016). According to analysis done by Zamani et al. (Zamani et al., 2016), the quantity of cobalt up to 45% caused a decrease in grain deposit size, and also the stiffness, YS, and UTS improved. In contrast, at 55% of Co content, these mechanical parameters decreased & also maximal ductility was measured for 25% Co coating (Zamani et al., 2016). Co rich alloy coating has great wear and friction tolerance because of the hexagonal close-packed (HCP) crystal structure (Goldnitsky et al., 1998; Lokhande & Bagi, 2014; Wang et al., 2005). According to Ocelik et al. (Ocelik et al., 2007), Co-based coating on cast iron is a good way to enhance local wear and corrosion tolerance of typical factory pieces conventionally made from cast iron.

3.3. Nickel
Sanchez et al. (Sanchez et al., 2010) performed a method of centrifugal infiltration of carbon fiber reinforced aluminum composites. During the process of manufacturing, the technique called lost-wax-casting was implemented. Nickel coating was done on a few samples in order to enhance wetting between reinforcement and molten aluminium alloy. Results revealed that the addition of nickel coatings boosts the preform’s wetting, allowing them to infiltrate at lower temperatures. The hardness value of the desired composites manufactured with nickel-coated carbon fibers has a higher value than that of composites with uncoated fiber. Mandal et al. (Mandal et al., 2007) observed electroless deposition techniques to coat copper (2 μm) and nickel (1.64 μm) on the plain steel fiber. It has been found that coating is significantly responsible for the surface stiffness and corrosion behavior of steel and aluminium fiber-reinforced composites. Nickel coated fiber composites showed the least corrosion compared to copper coatings, in spite of both having excellent wear resistance. Sudagar et al. (Sudagar et al., 2010) studied fine nickel-phosphorous coating on Al7075 artificially peak aged and step heated at 200 and 400°C/h. This coating on Al7075 substrate improved hardness, wear-
resistance, and frictional characteristics by altering the process parameters as well as pretreatments. These properties were further improved by age hardening. Mohandas et al. (Mohandas & Radhika, 2017) performed a centrifugal casting method to fabricate aluminium (AlSi6Cu)/nickel-coated SiC metal matrix composite. The microstructure and hardness were analysed from the outer periphery towards the core taken in the radial direction. Hardness and tensile properties were improved in the outer region compared to inner regions. Jerin et al. (Pancrecious et al., 2015) studied electroless Cu and Ni-B coated B4C particle reinforced powder metallurgy processed aluminum composites and concentrated on the phase structure and electrochemical properties. It was found that metallic coating improves compatibility, wettability, and curtails the interfacial reaction between the matrix and the reinforcement. It was found that the coating had better hardness and reduced porosity as compared to the uncoated particles. Jerin et al. (Pancrecious et al., 2015), determined the differences in structural and mechanical features of coatings on aluminium alloy substrate by the combined action of magnetic stirring and ultrasonication techniques. Al356 aluminium strip was coated with Ni-B alloy and Ni-B-CeO2 by electroless coating. Ultrasonication had better efficiency of coating with 99% of Ni and an insignificant quantity of aluminium on the surface in Ni-B coating. Electroless composite and alloy coatings created by ultrasonication shows a decrease in surface roughness and wear property. The influence of reinforcement coating on the mechanical properties of Al2O3 nanocomposites was examined by Shirin et al. (Pourhosseini et al., 2018). Al356 alloy was reinforced by coated aluminium oxide nanoparticles by a stir casting method. Alumina nanoparticles were coated with Co, No and Cu by means of an electroless deposition method. There was an extensive improvement in the mechanical characteristics of the nanocomposites when coated nanocomposites were used as reinforcements. Ni-coating on Al2O3 nanocomposites had better hardness and tensile properties compared to Cu and Co coated and uncoated nano-composites. Taherzadeh et al. (Mousavian et al., 2005) observed the mechanical behavior of metallic coatings on SiC reinforced in a pure aluminium matrix. The particles of SiC (80 μm) were coated with nickel (1.02 μm) and cobalt (1.83 μm) metallic layers using an electroless deposition process. The stiffness, yield strength, and UTS of samples were better in nickel-coated SiC particles as compared to cobalt coated SiC particles. Kim et al. (Kim et al., 2009) examined the thermal and mechanical characteristics of Ni-coated (0.3 μm thickness) single-walled carbon nanotube (SWNT) embedded with Cu composites. The Ni-coated SWNT reinforced Cu- MMCs notably have better properties when compared with pure copper and copper-nickel samples. Ashassi et al. (Ashassi-Sorkhabi & Rafizadeh, 2004) investigated the impact of coating duration and thermal treatment on mechanical characteristics of electroless Ni-P alloy coated mild steel. As the coating duration increased, the percentage of phosphorous content decreases with increasing coating thickness. The hardness of electroless nickel plating, in as-deposit condition, seems to improve with a decrease in phosphorous content. There was a 32% increase in hardness of coated samples heated at 400°C for 1 h as compared with untreated specimens. Kulkarni et al. (Kulkarni et al., 1979), studies and investigates mechanical properties of different metallic coatings on carbon fibers. The different grades of carbon fibers (Polyacrylonitrile (PAN) supplied by USA, PAN, Courtaulds Grafil “A” type, and Morganite Modmor) were coated with Ni and Cu by the cementation process. The tensile properties of nickel-coated samples were higher compared to uncoated and copper coated samples. Zheng et al. (Zheng et al., 2008) studied the metallography of Ti6Al4V composites, which was laser-deposited using nickel-coated powder. Gas atomised Ti6Al4V powder was reinforced with different quantities (10 & 20 wt. %) of nickel-coated TiC carbide particles using the LENS (Laser Engineered Net Shaping) method. The compressive yield strength of Ti6Al4V + TiC/Ni was later compared with the unreinforced composite. The substantial upswing in the strength is due to the presence of a titanium-nickel intermetallic compound, having higher strength. Kim et al. (Kim et al., 2009) in the experimental work noticed matrix strengthening is possible by the formation of Ni-Cu based intermetallics with suitable pretreatments.
4. Conclusion
The paper discusses on the possibilities of single/hybrid reinforcements as bare or coated form in aluminium alloy matrix. The lighter reinforcements like WC, B₄C improves wear resistance, but difficult to disperse. On the other hand, the reinforcements like SiC, copper, nickel are heavier, easy to disperse with larger weight percentage compared to lighter reinforcements. Coated reinforcements with copper or magnesium improve bond strength between the reinforcements and matrix by improving wettability. The specific conclusions are as follows:

1. Extensive literature review display Aluminium MMCs have superior mechanical properties and establish prime importance in the applications in aircraft fittings, couplings, brake pistons, camera lens mounts, hinge pins, magneto parts, hydraulic pistons, bike frames, marine fittings, and hardware.

2. Addition of 20 wt.% of SiC in aluminium matrix shows better mechanical properties, high thermal response, and low thermal expansion; hence it can be used in thermal shocks resistant applications such as cylinder heads, pistons, liners, and brake motors.

3. WC reinforcements produce intermetallics, which improves the mechanical characteristics of composites, and it is mainly used in the fabrication of radiation shielding materials due to its high atomic number.

4. B₄C is mainly used in brake discs of automotive or railway transport industries because of its higher dynamic coefficient friction and lower wear rate.

5. Compared to SiC and B₄C, it was found that WC has the highest compressive strength and modulus of rigidity.

6. Copper coating rises microhardness, shows poor EMI shielding effectiveness compared to nickel-coated composites.

7. Cobalt coated nanoparticle reinforced composites increases compressive strength and tribological properties compared to nickel-coated one.

8. Ni coating has greater mechanical and tribological properties than coatings produced from copper and cobalt.

Finally, in spite of good mechanical properties of MMCs with single or hybrid reinforcements, there is a provision to go for hybridization of composites by using reinforcements both coated or one among uncoated to take the benefit of cost and property enhancement. There is a provision to improve refractoriness, bond strength at elevated temperature, thermal conductivity, and electrochemical property of the composites with high-temperature dimensional stability by rolling over to coated reinforcements in the composite.

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