



Mechanical Properties and Wear Behaviour of Stir Cast Aluminum Metal Matrix Composite: A Review

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ABSTRACT

In this 21st century, various materials like metals, alloys, and composites are available for different industrial applications. Composite materials are gaining popularity due to their enhanced mechanical properties over other materials. However, for continuous improvement in the properties of these materials, different research groups are constantly involved in it. In this research paper, the focus is to review the mechanical properties like hardness, tensile strength, flexural strength, impact strength along with surface characteristics like wear resistance of AMMC's. As per the available literature, liquid state processing is more popular than solid-state processing due to the better dispersion of the reinforcement particles in the matrix materials. Stir casting is mostly used liquid state processing method because of its ease and the overall low cost of production. It has been noticed that the mechanical and surface characteristics of AMMC's can be improved by adding different reinforcement particles in small percentages (usually 0.5-20%). It has been observed that hardness, tensile strength, and flexural strength for mostly used AMMC's ranges from 38-99.6 HV, 100-478 MPa, and 199.52-430 MPa respectively. This research paper also included the influence of various working parameters on the wear rate of AMMC's. It is noticed that wear loss for AMMC's generally varies from 0.0050-0.004 g. The impact resistance is a crucial parameter in the study of AMMC's used for aerospace and automotive applications and it has been noticed that its value for popular AMMC's varies from 3.6-38 J.

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NOMENCLATURE

Wt. %	Weight Percentage
MPa	Mega Pascal
B ₄ C	Boron Carbide

ZrO ₂	Zirconium Oxide
GNP	Graphene nanoplates
Al ₂ O ₃	Alumina
CNT	Carbon Nano Tubes

1. INTRODUCTION

The historical backdrop of the advanced composites began in the 1930s. In 1960, polymer-based composites' performance triggered numerous areas in research. The materials research leads to the development of intelligent materials such as alloys, ceramics and composites [1]. Due to matrix cracking, breakage, delamination and de-bonding of matrix [2], in 1970 aluminum-based metal matrix composites (AMMC's) using silicon carbide (SiC) whisker particles came into the picture as an alternative material for aerospace and automotive applications [3-7]. MMCs are the combination of two or more constituent materials

(where the matrix material consists of metal and reinforcement can be metal or non-metal) [8]. The addition of ceramic reinforcement to the matrix metal emerges a new version of the materials [9], which enhances the density, hardness, strength, wear-resistance and capability to endure environmental effects [6]. Stir casting method is found to be superior to other casting methods in terms of technical and economical aspects. The easiness, flexibility, bulk production and manufacturing of intricate components are the main advantages of the stir casting method for the production of AMMC's [7]. The composites are classified as mentioned in Figure 1.

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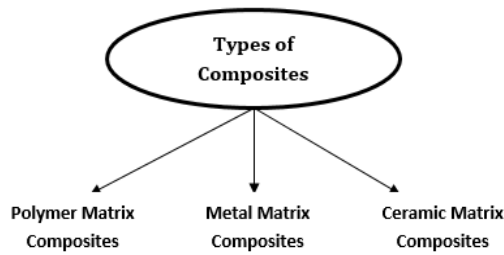


Figure 1. Classification of composites according to matrix metal

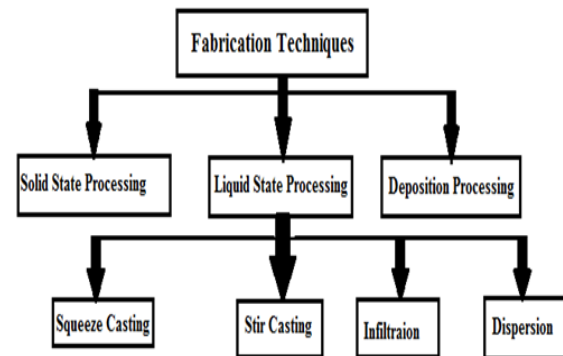


Figure 2. Classification of fabrication techniques

1. 1. Materials Used in MMCs

1. 1. 1. Matrix Material

The major portion of MMC's is the matrix material, as it gives shape to the composite and binds the reinforcement particles along with it. Aluminum, magnesium, copper, iron, and titanium are commonly used matrix for the fabrication of MMCs [10-14].

1. 1. 2. Reinforcement Materials

The reinforcement materials play important role in the fabrication of MMC's. These can be added in different percentages in the matrix materials to change their characteristics [15]. There are two types of reinforcements: organic and inorganic [16], which are further classified as shown in Table 1.

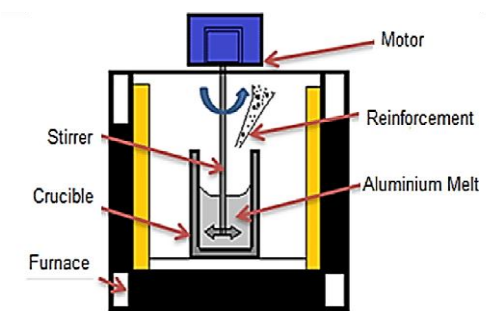


Figure 3. Setup for Stir Casting [38]

2. METHOD OF FABRICATION OF MMC

The literature review describes that there are various fabrication techniques which can be used to prepare MMC's. Figure 2 represents the types of fabrication techniques for MMC's. The main focus of the current study is on the stir casting method for MMC's fabrication and is also used for the formation of irregular and complex shapes [37].

TABLE 1. Types of Reinforcement

S. No.	Reinforcement Type	Reinforcement Name	Ref.	
1	Organic	Redmud	[5]	
		Flyash	[17]	
	Oxide	Al ₂ O ₃ , TiO ₂ , SiO ₂	[18-21]	
		Nitride	TiN, BN, Si ₃ N ₄	[22-24]
2	Inorganic	Carbide	TiC, SiC, CNT, B ₄ C	[25-29]
		Boride	TiB ₂ , ZrB ₂	[30-33]
		Others	Diamond	[34-36]

In this process, metal in powder, plate or ingot form is heated in the barometrical controlled heater and afterward permitted to arrive at the liquid state. When the base matrix metal is converted into a liquid state then the reinforcement such as ceramic metal or supplementary metals can be added either without preheating or in preheated form. The stirrer is used to mix the amalgamation formed due to addition of reinforcement in molten metal. The stirrer material should have melting characteristics like titanium carbide (TiC), silicon carbide (SiC), and graphite (Gr). After heating in the crucible, the molten metal is poured into the mould and allowed to solidify [39]. After solidification, the MMC's can be removed from the mould and processed further as per requirement. The setup for stir casting is shown in Figure 3.

3. REINFORCEMENTS EFFECTS ON MECHANICAL PROPERTIES

3. 1. Hardness

The hardness is an important property for MMC's as it is a measure of how much a material resists changes in its shape. Various researches show a comparative study of between the fabricated MMC's and their base metals. Bhubnaeswar [40] concluded that the 5, 10, 15, and 20 wt% SiC_p, when reinforced in the matrix of Al6061 using stir casting, the hardness of the fabricated composite increased. The 18%

increase in the hardness of fabricated composite has been recorded as compared to aluminum alloy. Reddy et al. [25] fabricated the Al6063-xTiC MMC using the stir casting fabrication technique. The MMC was fabricated as 5 /10 / 15 wt.% TiC along with Al6063 (see Figure 4). The 99.6 hardness value (HV) has been reported in the fabricated composite as compared to Al 6063 alloy, which has 59.6 HV [25].

The hardness value for the Al5083 matrix, when reinforced using SiC particles via stir casting method, increased to 85 BHN from 52 BHN, which principally increased the loads bearing capability due to SiC particles present in the composite. The hardness increment of 85% in developed material provides longer life and also enhances the wear resistance in fabricated material as reported by Chaubey et al. [28]. Yashpal et al. [41] performed hardness test on MMC produced by the combination of Al alloy and SiC reinforcement. It has been found that the mechanical properties such as yield strength, Young's modulus, and hardness are improved magnificently due to the homogeneous scattering of SiC particles in the matrix material. From the literature review, it has been noticed that hardness can be improved by using refined reinforced particles and by controlling the size of particulates present in the AMMC's.

3. 2. Tensile Strength

From the industry point of view, tensile testing has great importance before going to mass production stage of actual components that has to work under tensile loading. The testing also leads to cost reduction without compromising to the quality during production. The tensile testing concludes the functionality of the manufactured products [42].

Baradeswaran and Elaya Perumal [43] produced a MMC using Al7075, 5wt. % Gr and Al₂O₃ (2, 4, 6, and 8 Wt. %) via stir casting method. The tensile strength of 238 MPa had been achieved, which was 11% higher than pure Al alloy as shown in the Figure 5. Lata et al. [44] also opted stir casting route for the fabrication of Al7075-TiC (5, 10 and 15 wt. %) MMC and determined its tensile strength which had increased due to the uniform dispersion of TiC particles. A uniform trend was observed up to 10 wt. % of

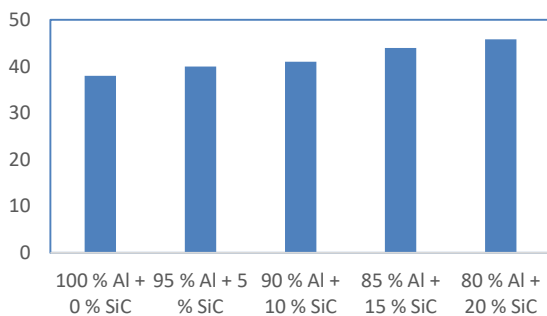


Figure 4. Hardness of various MMC's [40]

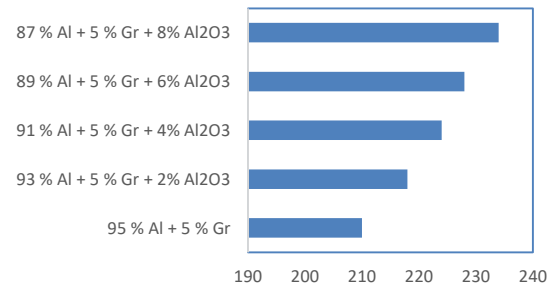


Figure 5. Tensile strength representation of AMMC's

TiC and beyond 10 wt. % of TiC the tensile strength has been increased [44]. Saravanan et al. [45] fabricated Al6061-5% Gr composite using stir casting route. An increment of 157 % in tensile strength as compared to Al6061 alloy (97 MPa to 249 MPa) has been observed.

Khanna et al. [46] fabricate Al6061-GO/CNT (0.5-2 Wt. % of GO/CNT) composite using stir casting method and concluded that the improvement in strength was due to constant dispersion and good cohesion characteristics of GO/CNT. It has been observed from the literature that the stirring operation is helpful in breaking agglomeration of different segregated reinforcement particles during fabrication of AMMC's. It has been also observed that the tensile strength can be improved via uniform mixing of reinforcements in the matrix material [43-47].

3. 3. Impact Testing

Impact testing has a crucial role in selecting the material for the particular application. The energy is required to cause the specimen to fail, relying on the material's application. Podder et al. [48] fabricated Al6063 and ZrO₂/TiO₂ (3:7, 1:1 and 7:3 Vol. %) composites by stir casting technique. The Charpy impact test machine (Aimil Co India Ltd.) has been utilized to measure impact energy. The higher impact energy has been found in the case of AMMC containing 7 Vol. % ZrO₂ and 3 Vol. % TiO₂ [48]. Al alloy LM25 was used as the matrix and boron carbide and alumina as reinforcement by Vijaya Ramnath et al. [49] for the production of MMC using stir casting technique. IS:1757 has been used to perform impact test. The highest impact energy of 2.42 J was observed for MMC with 95% LM25, 2% Al₂O₃, and 3% B₄C [49]. Kumar and Singh [50] tested Al4032-SiC (3-9 wt. %) composites for their impact strength. The MMC was prepared by stir casting technique. The uniform dispersion of reinforced particles enhances the impact energy of the fabricated material. The maximum impact energy of 42 J has been found for 6% SiC reinforced composite. It has been also observed that with increase of reinforcement percentage in MMC, its ductility decreases [50]. Ramnath et al. [51] reviewed the stir cast composite of Al6061/B₄C/Al₂O₃ and concluded that an increment of 21% in impact energy can be achieved by addition of 2 wt.

% Al₂O₃ and B₄C 3 wt. % reinforcement in the hybrid composite. Vijay Kashimatt and Hemanth Kymar [52] found that due to 3 wt. % particle addition of SiC in the Al alloy increases its impact energy from 0.075 J (pure Al alloy) to 0.0875 J (MMC). Gireesh et al. [53] developed a composite of Al6061/SiC/Al₂O₃ through stir casting process. The 17% increase in impact energy was achieved by addition of reinforcement in the hybrid composite [53]. Stir casting process was used to prepare composite of Al/SiC (0, 5, 10 and 20 wt. %) by Shukla et al. [54]. It has been observed that impact energy increases significantly up to 36% with increase in SiC reinforcement percentage. From the literature studied it has been found that resistance to dislocation of reinforced particles can be improved by increasing the reinforcement wt.% up to optimization level. By increasing the wt.% of reinforcement, interspacing in-between reinforced particles decreased, which results in the improvement of impact strength [52-55].

3. 4. Flexural Strength

The flexural test notifies about the maximum flexibility and bending of the material. The Volume/weight percentage of reinforcements has significant effect on the flexural strength of AMMC's. Other factors like the proportion of mixtures and grain size of reinforced particles also have crucial effects on the flexural behaviour of AMMC's. Vijaya Ramnath et al. [49] has fabricated the composite of aluminum alloy LM25 as base metal, boron carbide and alumina as reinforcement using stir casting method. ASTM: A-370 has been used to cut the specimen and tested on a three-point flexural test machine. The author has concluded that the flexural strength of fabricated AMMC decreases due to uneven dispersion and poor stirring of the reinforcement in AMMC. The maximum flexural strength (226.84 MPa) has been achieved in unreinforced Al alloy [49].

ASTM: B925-08 has been used to fabricate the specimen of AMMC reinforced with nano-alumina (1, 3, 5, and 7 Vol%). and tested on a three-point flexural test machine by Panda et al. [55]. The author has concluded that due to fine grain size and accurate dispersion of added reinforcement increases the flexural strength. The maximum flexural strength has been achieved with reinforcement of 7 Vol.% [56]. Surya and Prasanthi [57] reported that increment in the flexural strength has been observed in MMC of Al7075/SiC (5,10, and 15 Wt. %). The composite with 15 wt. % SiC particles contribute higher flexural strength of 320 N/mm² as compared to aluminum alloy 7075 (175 N/mm²). Baradeswaran and Elaya Perumal [43] concluded that the increment in the weight percentage of the reinforcement increases the mechanical, physical, and metallurgical properties of the composite. The authors concluded that the flexural strength of Al 7075 with reinforcements of alumina 8wt.% and graphene 5wt.% was increased from 185 N/mm² to 430 N/mm² as shown in Figure 6 [43]. The literature also reported that the homogenous mixing and binding action

of reinforcements enhances the flexural strength of the AMMC's [43, 56, 57].

4. EFFECT OF PROCESS PARAMETERS ON WEAR

In this era, the advancement of tribological properties is the key development for the materials and the enhancement of wear resistance is also the main concern in the existing metals. This material phenomenon gives us an idea about the deformation of the metal and loss in functionality of the material. Table 2 shows the wear of different MMC's.

Stir casting method was adopted by Thiraviam et al. [24] to fabricate MMC with steel and alumina chips (5, 7.5, and 10 wt. %) reinforcement. The wear rate has been improved due to presence of the steel chips in fabricated AMMC [24]. Patil et al. has fabricated Al7075-TiC/Gr (4, 8, and 12 Vol. % of TiC and Gr) MMC. It has been observed that the interfacial bonding of Al alloy and reinforcement particles to be essential factor for improving wear resistance [10]. Figure 7 shows the wear comparison under different loads [61].

The liquid state processing was used to fabricate Al6061-SiC (2, 4, 6 wt.% of SiC) composite by Veeresh Kumar et al. [58]. The wear resistance has been significantly increased with increase in wt.% of SiC

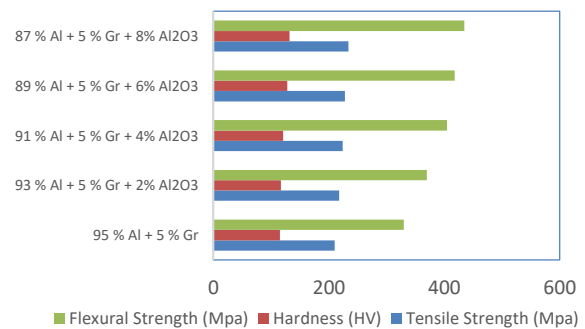


Figure 6. Effect of composition on mechanical properties

TABLE 2. Wear data for various AMMC

S No	Reinforcement	Wear		Ref.
		Al Alloy	AMMC	
1	6% SiC	130 x 10 ⁻³ mg/m	88 x 10 ⁻³ mg/m	[58]
2	1% Al ₂ O ₃ + 8% SiC	0.0050 g	0.0015 g	[21]
3	0.5% CNT + 2% TiC	0.0039g	0.0020 g	[59]
4	8% Al ₂ O ₃ + 5% Gr	0.0029 mm ³ /m	0.0015 mm ³ /m	[43]
5	1% Al ₂ O ₃ + 8% SiC	0.485 g	0.150 g	[60]
6	4% Al ₂ O ₃	0.017 g	0.004 g	[24]

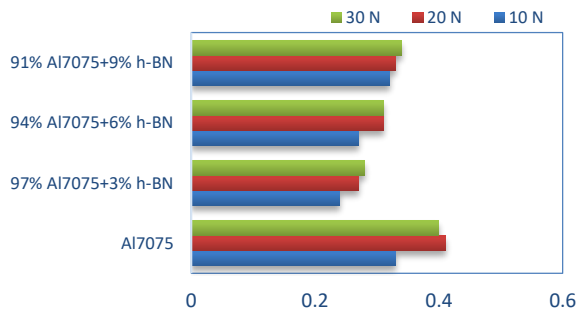


Figure 7. Wear rate under different loads

particles. So, It was concluded that superior wear resistance has been achieved with 6wt.% of SiC along with Al6061 alloy. Kuldeep et al. [62] fabricated stir cast MMC of Al7075 and hexagonal-boron nitride (h-BN) with 3, 6, and 9 wt. %. The study described that reinforcement with 3 wt. % h-BN produced the best result for wear rate. The decrement of 24.5% in wear loss was found in AMMC as compared to base alloy.

4. 1. Wear Affected By Average Load Wear predominantly dependent on average load during testing of MMC's. The outcomes indicate that wear rate increases as the average load was increased during analysis on pin and disc apparatus. This can be the resultant of abrasion and delamination on MMC surface due to the increment of load [63-65].

4. 2. Wear Affected By Slid Velocity The wear behaviour is also affected by slid velocity in composite material. The literature outcomes indicates that decrement in the wear rate was observed for slid velocity up to 5 m/s. After 5 m/s of slid velocity, the oxidation, abrasion and melting of the MMC surface starts which increases the material loss [66-68].

4. 3. Wear Affected By Slid Distance Slid distance is another important factor in wear analysis of metal matrix composite. From the literature studied, it has been concluded that during wear test, the wear largely depends on slid distance as well as on slid time, which are proportional to each other. Wear rate increases with the enhancement of both the parameters. This is because of melting and formation of hardened layer on the contact surfaces of AMMC's and wear testing tool [69-71].

4. 4. Wear Affected by Weight Percent of Reinforcement The percentage of reinforcement weight affects the physical and mechanical characteristics of the composite. However, the reinforcement's weight proportion also influences the surface properties. The decrement in the wear rate has been observed as percentage of reinforcement increases in the fabricated composite. The

coarse particles and excessive addition of reinforcement proportions leads to porosity which causes increment in material loss [71-73].

5. CONCLUSIONS

This review paper discusses about Aluminum based metal matrix composites with diverse reinforcements. The tribo-mechanical properties are discussed and based on the current review following conclusions can be drawn:

- 1) The Aluminum metal matrix composites has wide applications in aerospace, automotive and defence industries.
- 2) The stir casting is the most reliable technique to fabricate aluminum metal matrix composites due to its technical and economic aspects.
- 3) The working parameters like stirring speed, stirring time, melting temperature and impeller size have significant effect on the composite quality. The reinforcement weight / Volume percentage, shape and size have crucial relation to the performance of fabricated composite.
- 4) The hardness, tensile strength and flexural strength for mostly used AMMC's ranges from 38-99.6 HV, 100-478 MPa and 199.52-430 MPa respectively. Also, the impact energy for AMMC's varies from 3.6-38 J. The enhancement in these mechanical properties largely depends upon grain refinement, uniform dispersion, and interspacing of reinforcement particles in the fabricated composite material.
- 5) The wear behaviour of the fabricated composite significantly affected by the average load, slid distance, slid velocity, and reinforcement weight percentage during the wear test. The material loss generally observed in the range of 0.0050-0.004 g. The abrasion, oxidation, melting and delamination of the surface are the main reason observed as wear loss.

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Persian Abstract

چکیده

در قرن بیست و یکم، مواد مختلفی مانند فلزات، آلیاژها و کامپوزیت ها برای کاربردهای مختلف صنعتی در دسترس هستند. مواد کامپوزیت به دلیل خواص مکانیکی افزایش یافته نسبت به مواد دیگر محبوبیت پیدا می کنند. با این حال، برای بهبود مستمر در خواص این مواد، گروه های مختلف تحقیقاتی به طور مداوم درگیر آن هستند. در این مقاله تحقیقاتی، تمرکز بر بررسی خواص مکانیکی مانند سختی، استحکام کششی، مقاومت خمشی، مقاومت ضربه ای به همراه ویژگی های سطحی مانند مقاومت به سایش AMMC است. طبق ادبیات موجود، پردازش حالت مایع به دلیل پراکندگی بهتر ذرات تقویت کننده در مواد ماتریس، محبوب تر از پردازش حالت جامد است. ریخته گری همزن به دلیل سهولت و هزینه کم تولید بیشتر از روش پردازش حالت مایع استفاده می شود. مشخص شده است که ویژگی های مکانیکی و سطحی AMMC ها را می توان با افزودن ذرات تقویت کننده مختلف در درصد های کوچک (معمولاً ۰.۵-۲٪) بهبود بخشید. مشاهده شده است که سختی، استحکام کششی و استحکام خمشی برای AMMC های بیشتر مورد استفاده به ترتیب بین HV ۳۸-۹۹/۶، ۱۰۰-۴۷۸ MPa و ۱۹۹/۵۲-۴۳۰ MPa است. مقاله تحقیقاتی همچنین شامل تأثیر پارامترهای مختلف کاری بر نرخ سایش AMMC می شود. توجه شده است که کاهش سایش برای AMMC به طور کلی از ۰/۰۰۴-۰/۰۰۵ گرم متغیر است. مقاومت در برابر ضربه یک پارامتر حیاتی در مطالعه AMMC های مورد استفاده برای کاربردهای هوا فضا و خودرو است و توجه شده است که مقدار آن برای AMMC های محبوب بین ۳،۶-۳۸ J متفاوت است.
