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INVESTIGATIONS ON THE INFLUENCE OF LASER SURFACE TREATMENT ON HARDNESS AND WEAR BEHAVIOUR OF AL-MMC PREPARED THROUGH POWDER METALLURGY ROUTE

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Abstract. *Aluminium metal matrix composites (Al-MMCs) are extensively used in various industrial sectors, including aerospace, automotive, construction, and electronics, owing to higher hardness, low density, higher fatigue and specific strength. Powder metallurgy is an effective method for manufacturing composite materials. Compared to pure metals and alloys, the mechanical characteristics of the SiC-reinforced MMCs are enhanced. The Al-MMC surface can undergo metallurgical changes due to the laser treatment, which can also strengthen the binding between the matrix material and the reinforcement particles. Therefore, the current work investigates the impact of SiC particle addition and laser surface treatment on the hardness and wear characteristics of aluminium metal matrix composite (Al-MMC). The Al-MMC is initially fabricated using a powder metallurgy process, and then the MMC is treated with a laser. Compared to the untreated MMC, the laser surface treatment increased the hardness by almost 12%. Additionally, the addition of SiC content by 10%, 15%, 20%, and 25% in laser-treated Al-MMC resulted in increased hardness by 12%, 14%, 15%, and 16%, respectively, compared to untreated Al-MMC. Furthermore, the wear resistance improved as the reinforcement particles increased. The laser-treated samples exhibited lower wear than untreated ones due to the formation of a new layer on the treated surface, preventing the release of SiC particles. The surface treatment of MMC through the laser is a novel approach to fabricating wear-resistant Al-MMCs.*

Key words: *Al-MMC, Laser treatment, Powder metallurgy, Hardness, Wear*

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1. INTRODUCTION

Laser (light amplification by stimulated emission of radiation) is helpful in all manufacturing sectors like machining, forming, and fabrication [1-3]. Composites are specialized materials to fulfil many high-end engineering application requirements. The aluminium-based provide an alternative to iron and copper-based composites due to its improved properties, such as high specific strength, light weight, low density, enhanced tribological properties, etc. [4]. The development of composites can also be complimented by a laser. It is also possible to use laser in many ways to fabricate metal matrix composites (MMC) through an additive manufacturing approach or surface treatment. Moreover, surface alloying can also be done. Laser sintering is one of the most popular techniques for creating materials like MMC [5]. Laser sintering is a name given to one of the rapid prototyping techniques to fabricate MMC and the application of laser for processing MMCs in different ways, such as surface treatment, fabricating porous MMCs by melting layers of powder on one another, or surface alloying. It provides much versatility when working with complicated shapes. Dealing with the components of metal matrix composites with higher melting temperatures and harder materials requires laser sintering as well [6]. Surfaces of Aluminium metal matrix composites (Al-MMC) can be treated with the laser by varying laser power and scanning speed. Kumar and Kruth [7] presented the study of various rapid prototyping processes for composite materials. According to their work, apart from fusion deposition modelling (FDM) for polymers and polymer-based materials, the FDM approach can be extended to metal-based composite, i.e., MMCs, selective laser sintering/melting (SLS/SLM), laser-engineered net shaping (LENS), and ultrasonic consolidation, which are new emerging rapid prototyping techniques [8]. For example, Cu-Fe-based MMC can be fabricated using laser-based technology, where the purpose of copper is not to enhance the properties of iron. Instead, copper can help effectively consolidate the iron powder without causing any hindrance [9]. Laser-based methods can also process various reinforcements in the polymer matrix. Hence, various types of composite material can be fabricated using laser, e.g., al-filled polyamide powders, which are developed to reduce agglomeration effectively. Such powder can be further processed by laser just like in FDM techniques, or this powder can be used in other processes like powder metallurgy or hot isostatic pressing (HIP). Gill and Hon [10] utilized a laser in the form of SLS to fabricate SiC-based polyamide composites. They fabricated the composite using 50W of laser power. They experimentally found that the power of the laser beam and scan speed are the most critical parameters that can be optimized for developing target MMC with the required properties. The laser-based methods are also used to fabricate tungsten carbide and cobalt-based MMC with the addition of copper, as surface tension in the melt is affected by the presence of copper [11].

In past studies, various composite materials were processed by laser technology, and it can be seen that laser can process a wide variety of materials to fabricate MMC, hybrid MMC and Ceramic-based composites [12-14]. The laser energy is also used to control chemical reactions. Since the laser melts the material, this phenomenon is known as a laser-induced chemical reaction. The laser beam energy is used to overcome the activation energy needed to form compounds and to trigger the production of sufficient thermal energy to propagate chemical reactions. According to Kruth et al. [15], the in-situ formation of MMC involves both types of phenomena. MMC is better than those MMC in which reinforcement material is added conventionally [16], such as stir casting [17]. Copper-based MMC uses the activation energy-based phenomenon, and TiC-Al_2O_3-based MMC uses the second phenomenon, i.e., the release of thermal energy to form compound-based MMC from TiO_2, Al, and C.

Gaard et al. [18] fabricated TiC-based MMC in the matrix of invar 36 through the direct metal laser sintering (DMLS) approach. Furthermore, liquid-phased sintering was the prime mechanism for forming a Tic-based dendritic structure along with a thin shell-like structure. Thermal cracking was also observed when the proportion of Tic was increased by 20% in the matrix. However, thermal cracking was not observed for the lower proportion of TiC, which signifies that laser can affect the bond formation to a maximum extent by thermally affecting hard compounds like TiC. The formation of spherical particles confirms the melting and quick recasting of constituents in the compound form. They investigated the wetting properties of the liquid phase of constituents, which are responsible for forming a dense layer in the structure, affecting the strength of the MMC. Nofar et al. [19] reported increased wear resistance of Al-AlTi3-based metal matrix composites when processed by hot pressed technique. Mishra et al. [20] reported that due to DMLS, the bonding of SiC particles in the matrix of Ti6Al4V improved, and TiAl was formed due to exothermic chemical reactions. They reported that the hardness of MMC improves due to laser treatment, and the laser power was the critical factor for hardness. This resulted in the increased wear resistance of MMC much higher than that of pure Ti6Al4V alloy. Sateesh et al. [21] fabricated coated SiC-based Inconel MMC through Direct Metal Laser Sintering (DMLS). They applied a 240W laser to fabricate the MMC at four different scan speeds. They found that the density of MMC increased due to lower scan speed. At lower scan speed, more laser interaction with matrix and reinforcement material occurs. Hence, due to favourable metallurgical changes, density improves. They reported that the hardness of laser-processed MMC increased by 13 to 33 %, as due to laser processing, the dislocation density increased, and MMC became more resistant to plastic deformation. They also proposed that the difference between the CTE of Inconel-625 and SiC is also one of the reasons for improving the density and hardness of laser-processed MMC.

Muvvala et al. [22] conducted an experimental investigation on TiC - Inconel 718 MMC processed through laser and reported that increasing the exposure time of TiC to high temperature can result in the decomposition of TiC, which further results in a change in the solidification behaviour of MMC and TiC particles can form dendritic structure. Chang and Gu [23] worked on carbon nanotubes (CNT) reinforced Ti–MMC through DMLS. They reported that micropores were generated at the interfacial regions due to the distribution characteristics of CNTs and the balling effect, which affected the density of the resultant MMC. By increasing the laser power, such issues could be resolved, agglomerations could be converted into homo-disperse, and the wear rate of MMC could be reduced significantly. Promakhov [24] found that there is a scope for self-propagating high-temperature synthesis during Inconel 625–TiB2 MMC fabrication by laser application. Due to this, the wettability of the matrix material and reinforcement material improved. As a result, the bonding and distribution of reinforcement particles were improved to a large extent. The microhardness of Inconel 625–TiB_2 MMC was 1.5 times more than that of the parent material, and tensile strength was improved by 15% compared to pure Inconel. Venkatesh et al. [25] synthesized Al-MMC using stir casting by reinforcing 0.5 wt%SiC, 1.0 wt%SiC, 1.5 wt%SiC and 2.0 wt%SiC nanoparticles. It was found that the maximum hardness of 431 MPa and ultimate tensile strength of 163 BHN resulted with

1.5 wt% SiC reinforced composite. However, 2 wt% SiC reduced the mechanical properties due to brittle agglomeration. Similar findings were reported, concluding that adding 2 wt% SiC in the aluminium develops the secondary phases due to chemical reactions with neighbouring particles. Which further reduced the strength of Al-MMc [26]. Adding uniform SiC nanoparticles to aluminium matrix dispersion improves the bonding strength between the nearby particles, prevents dislocations, and improves mechanical strength. Adding more than 2 wt% SiC results in slip planes and initiates plastic deformation compared to 1.2 wt% SiC [27]. Chong et al. [28] found that surface treatment through laser on Mo-WC-based MMC showed excellent wear resistance, especially crack-free s laser sintered MMCs were excellent against abrasive wear compared to base metal or conventional alloy. Hussain et al. [29] investigated the effect of laser power on the density of TiN-SS316 MMC, and they found that with the increase of laser power, density improves for all the compositions of MMC, i.e., TiN was used as reinforcement by 10%,15%, and 20%. The intense energy of the laser caused massive consolidation. Therefore, density improved and porosity was reduced. Hence, the laser treatment can also be considered as an alternative secondary process to reduce the porosity when MMCs are fabricated through the powder metallurgy route [30].

It is understood from the available literature that the fused deposition of powder is one of the techniques by which metal matrix composites can be fabricated. In many cases, the laser can be utilized to fuse the powder on a layer basis to fabricate metal matrix composites. Many works are reported with laser processing to fabricate metal matrix composites (MMCs). However, limited research attempts have been reported towards analyzing laser-treated MMCs fabricated through the powder metallurgy route. Considering these facts, the current work attempts to conduct an experimental investigation on aluminium metal matrix composite (Al-MMC) fabricated through powder metallurgy. The objective of the work is to investigate the impact of SiC particle addition and laser surface treatment on the hardness and wear characteristics of aluminium metal matrix composite (Al-MMC). The work also aims to investigate the effect of SiC particle addition and laser treatment on the coefficient of friction compared to untreated Al-MMC. A laser is used to treat the Al-MMC surface. It was discovered that applying a laser to MMC's surface increased its hardness compared to untreated MMC, and the wear resistance is improved with the increase in the percentage of reinforcing particles. Therefore, with this approach, Al-MMCs with target properties can be fabricated. Hence, the surface treatment of MMC through the laser is a novel approach to fabricating wear-resistant Al-MMCs. Further, the enhanced hardness after laser treatment can reduce the requirement of hard reinforcement particles, which is also a significant factor in the optimum usage of reinforcement material.

2. MATERIALS AND METHODS

The preparation of the metal matrix composite material included using pure aluminium and silicon carbide (SiC) powders. The aluminium powder was obtained from Central Drug House (P) Ltd., New Delhi, India. The purity of aluminium powder was 99%, and the average size of aluminium and SiC particles was 50-75 microns. The Al-MMC samples were fabricated through the powder metallurgy route. The methodology followed for conducting the experiments and analysis is shown in Fig. 1.

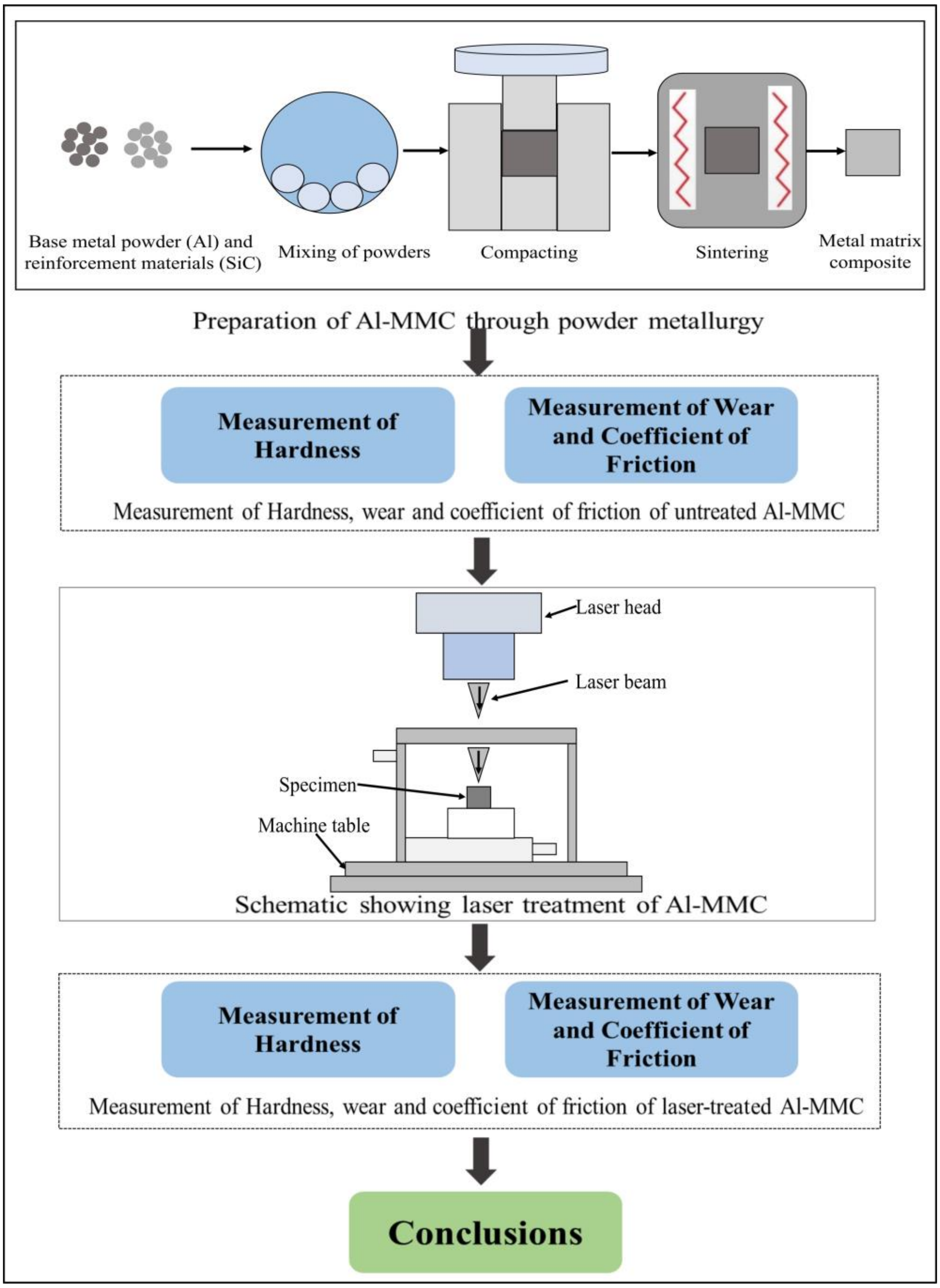

Fig. 1 Procedure followed in the present research work

In powder metallurgy, a 40 KN UTM machine was employed. Green compacts were fabricated by compacting powders at a pressure of 150 MPa. After carefully moving to a muffle furnace, the green compacts were sintered for an hour at 595°C. A muffle furnace operating in an inert argon gas environment was used to complete the sintering process. The inert atmosphere of argon gas helps prevent oxide formations of aluminium and achieve adequate bonding of particles. Following the sintering process, the specimens underwent water cooling and surface cleaning. Hardness and wear testing was carried out before and after laser treatment.

The hardness of Al-MMC specimens was measured on Rockwell B Scale at 100 kgf of major load. Before the hardness measurement, Al-MMC's surface was cleaned using fine-grit emery paper. Around 5 to 8 measurements for hardness were carried out at each face. The laser treatment of specimens was carried out using a pulse laser with a maximum peak power of 1500W, a pulse width of 0.05-50 ms, and max pulse energy of 15 J. The modulation frequency of the laser machine was 0~5000 Hz. The samples were subjected to laser treatment for 27 seconds at 400W of power, the distance between the laser head and specimen surface was 5 mm, the tool path was a concentric circle with a spacing of 0.2 mm, and the scanning speed was 300 mm/s (Fig. 2). Subsequently, the hardness of the laser-treated samples was measured again. Pin-on-disk wear tests were performed on MMC samples before and after laser processing to determine the effect of laser surface treatment.

Fig. 2 Laser processing of prepared samples

Fig. 3 shows the Al-MMC samples before and after the laser treatment. A depression on the surface is created after applying the laser, which shows that the laser affects the surface of Al-MMC in real time. The intense energy of the laser causes the aluminum matrix's melting since it has a low melting point compared to SiC. Due to the quick melting and recasting of the upper layer, porosity at the surface level is eliminated. Hence a shallow depression is seen on the surface of Al-MMC samples. The depression level at the surface depends on the laser's power. All the Al-MMC samples are laser-treated with different laser powers and scanning speeds, and al-MMC's hardness and wear behavior are evaluated.

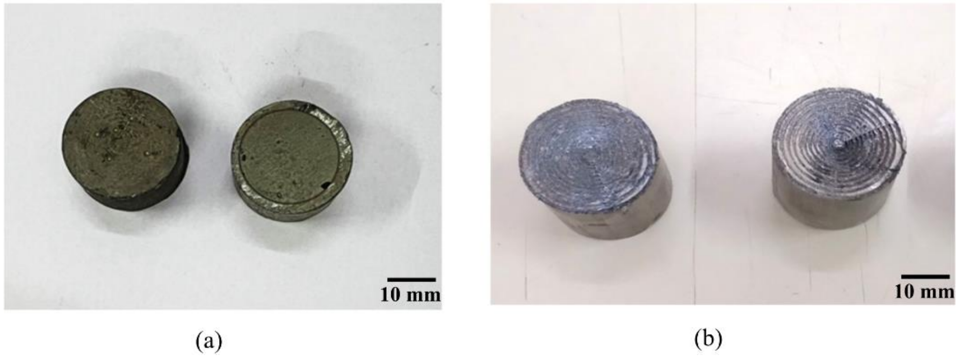

Fig. 3 Al-MMC samples (a) before (b) after the laser treatment

Pin-on Disc apparatus was used to investigate the wear behaviour of the Al-MMC. The samples were machined to the diameter of 10-12 mm to mount them in the sample holder of the pin-on-disc apparatus, as shown in Fig. 4. The wear tests were conducted on a 'Ducom' make computerized pin-on-disk apparatus. The apparatus can apply a maximum 200 N load on specimen during testing and run the disc from 20 rpm to 2000 rpm. A hardened steel disc is mounted for wear testing. The steel disc is 165 mm in diameter and 8 mm thick and hardened to 62 HRC. For wear testing, a pin of 3 mm to 12 mm in diameter is mounted on the specimen holder. An initial mass of samples was noted, and wear tests were performed. The mass of samples is recorded by utilizing a precision digital weighing machine. This procedure is followed for both types of Al-MMCs, i.e., laser-treated and untreated ones.

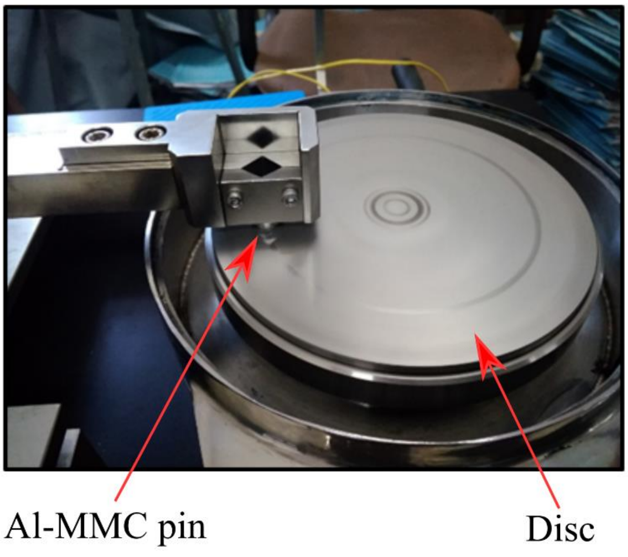

Fig. 4 Wear testing of Al-MMC on Pin-on-Disc setup

3. Results and Discussion

Laser treatment of Al-MMC for the different compositions, i.e., 10%, 15%, 18%, 20%, and 25% of SiC reinforcement, was carried out, and the surface hardness was measured. A surface micrograph is obtained through an image analyzer, wear testing is done, and results are presented and discussed below. Re-melting and recasting of matrix material, i.e., aluminum, was observed, and thus bonding of matrix material with SiC particles was further improved.

3.1 Change in Hardness of Al-MMC through Laser Treatment

The hardness of Al-MMC was measured before and after the laser treatment. With the increase in the proportion of SiC in the aluminuim matrix, as the hard SiC particles take the significant load, bonding is improved due to the fusion of the aluminium matrix under the action of the laser beam. The SiC particles are held more rigidly. Hence, the hardness of MMC increases after the laser treatment [31]. The intense energy of the laser can re-melt the soft matrix easily. Simultaneously, because of the high temperature, there is an improvement in the bonding between the hard SiC particles and the soft matrix, which is aluminium, as the matrix material melts and is recast. The temperature of the laser beam impacts the surface energy of SiC particles, which lowers the total surface tension at the edges of SiC particles. This improves the affinity of SiC particles with aluminum and results in better bonding. As a result, the hardness of Al-MMC improves after laser treatment.

Fig. 5 illustrates a micrograph of Al-MMC's surface following laser treatment, whereas Fig. 6 displays an SEM image of the same material. In many regions, as presented in Fig. 5, small nodular type or tiny spherical-shaped particles can be seen. These are the nodules resulting from the melting and recasting of aluminium, a matrix material with a low melting point compared to SiC. Since SiC particles have sharp edges, i.e., angular grains like structure, bonding between matrix and reinforcement further increases during melting and recasting of matrix material, which completely engulfs the SiC particles. An interlocking action is also possible to improve the bonding of particles. Hence, the hardness of Al-MMC can be further improved by laser treatment.

Due to the intense action of the laser beam, dislocation generations happen due to a thermal mismatch between the matrix material and SiC particles [32]. Moreover, the quick recasting of matrix material while engulfing the SiC particles cause a reduction in the average particle size resulting in a smaller grain size. The smaller grain size can offer resistance to dislocation mobility. Hence, hardness increases [33]. Strong interfacial bonds are on the top layer of Al-MMC after laser treatment. Therefore, load transfer from soft matrix to hard reinforcement particle improves, causing hardness enhancement. The improvement in bond in the matrix material is partially improved due to super-solidus liquid phase sintering. It promotes the in-situ transformation of reinforcement particles into the matrix, which has a comparatively lower melting point than reinforcement material [34].

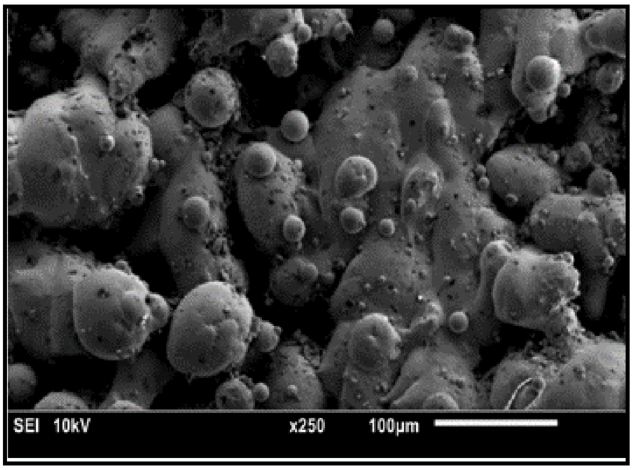

Fig. 5 Traces of recast nodules of matrix material

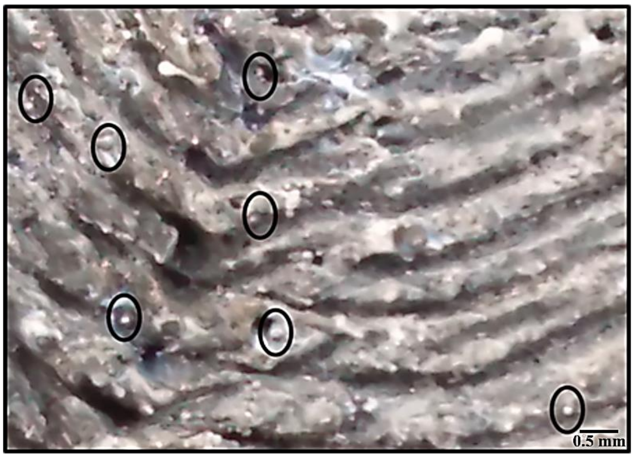

Fig. 6 SEM image of laser-treated Al-MMC, showing fine spheroids

The action of the laser is very intense and develops much thermal energy due to the concentration at a minimal area. Fig. 7 shows the intense effect of the laser. Even after removing the top layer from the laser-treated Al-MMC sample, traces of the laser path were visible at the macro level, i.e., through the naked eye, the laser traces can be seen very clearly. This serves as evidence that a laser can impact the properties of Al-MMC through its thermal energy. It can be viewed that the surface treatment of Al-MMC can be considered secondary sintering, by which properties at the surface level can be altered easily, and it is also possible that more than one reinforcement can be introduced in the matrix material through the surface alloying approach. By doing this, hybrid MMCs can be produced.

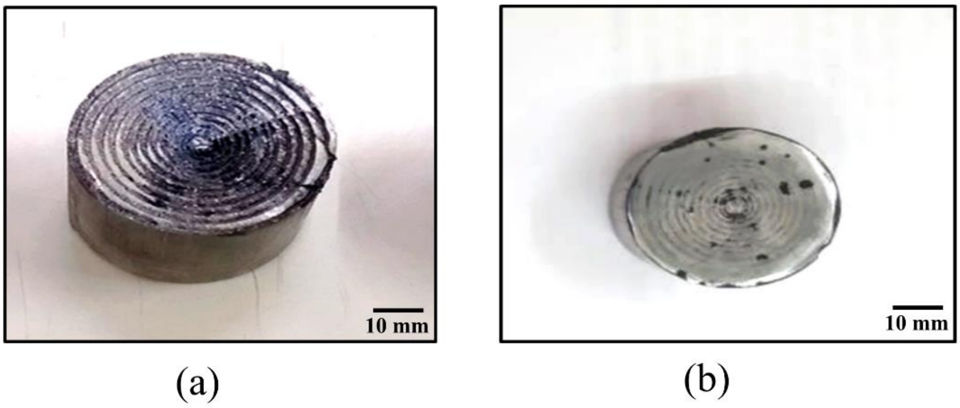

Fig. 7 Traces of Laser tracks, showing the effect of the laser beam (a) on the surface (b) laser tracks at 3 mm depth

An improvement in hardness by more than 12% is seen through laser treatment. The hardness of Al-MMC increases with the increase of reinforcement, which follows the rule of mixture. However, the hardness of Al-MMC further improves with laser treatment, and this enhancement is more pronounced when Al-MMC contains a higher amount of reinforcement particles. The results show that hardness increases by 12% for the 10% SiC content, while the hardness increases by an average of 15% for the 20% SiC and 16% for the 25% SiC content in Al-MMC. The Comparison of hardness achieved is graphically shown in Fig. 8.

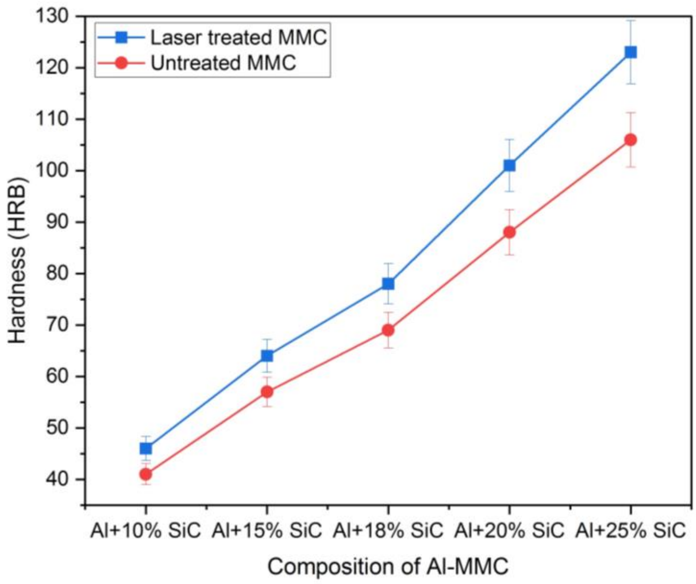

Fig. 8 Comparisons of the hardness of laser treated and untreated MMC

With a higher amount of reinforcement, saturation in the increase in hardness can be observed due to limitations of the sintering of MMC through conventional furnaces. This issue can also be addressed through the use of laser. Kundu et al. [35] also concluded through their experimental work that the hardness of MMC does increase with the increase in laser power apart from the reinforcement. When the scanning speed is maintained while the laser power increases, a portion of the molten pool fills the microscopic spaces, resulting in more significant densification. Hardness increases as a result of stronger bonds created by more fusion. The laser scan speed may also affect Al-MMC's hardness. With faster scan speeds, thermal action lasts a shorter time. Therefore, the impact of thermal energy on the modification of surface properties may be another area of research [36]. The energy absorption of the laser beam will be influenced by optical interaction or the laser beam scattering on the Al-MMC surface. This will determine the temperature that is produced in the surface area that is being laser-treated. According to Gosh et al. [37], higher scan speeds may cause some MMC to remain untreated. Therefore, using laser treatment, optimization techniques can be used to optimize the scan speed for the specified range of hardness in the Al-MMC.

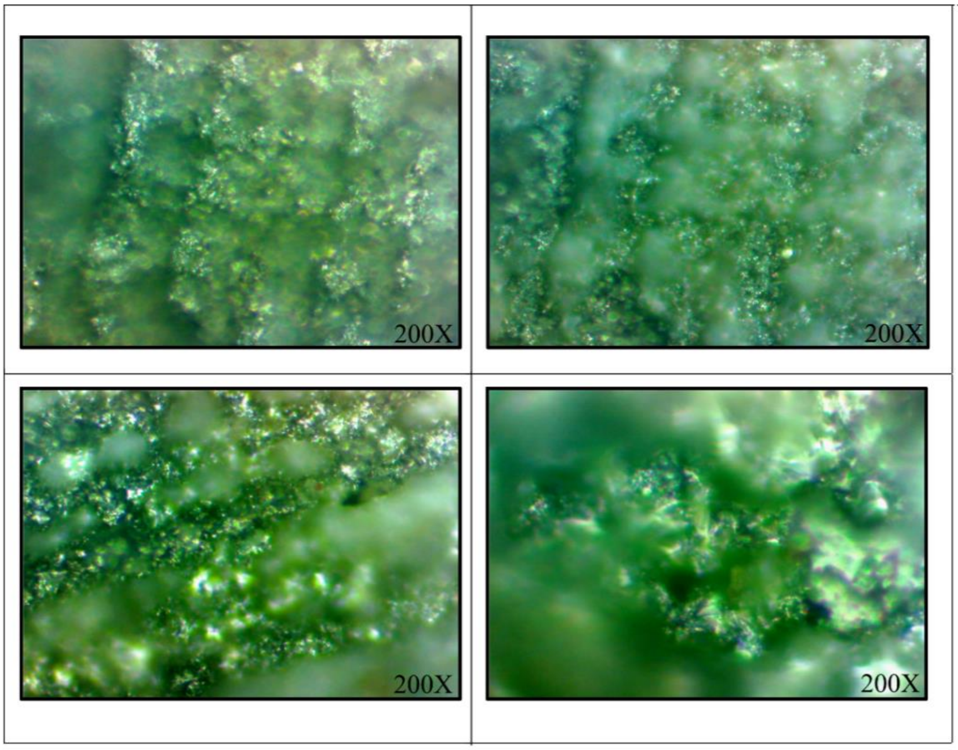

Fig. 9 Micrographs of the laser-treated surface of Al-MMC, showing the distinct alternate region

The micrographs of Al-MMC surfaces treated with laser are shown in Fig. 9. This was done using an image analyzer. Additional findings from the laser-treated materials show evidence of thermal action due to the laser beam's high energy. Furthermore, the fact that the aluminium matrix of Al-MMC has melted throughout is confirmed by nodular formations on its top layer. The micrograph, which demonstrates that the laser does affect the surface topography, demonstrates that melting and recasting are the causes of the surface appearance and the creation of sphere formations. After MMC has been laser-treated, the high heat action can also reduce the surface tension at the aluminum/silicon interface, enhancing bonding.

3.2 Change in Wear Resistance of Al-MMC through Laser Treatment

Fig. 10 shows the specimen before and after the wear tests. It is to be noted from the appearance of the face of the Al-MMC sample that even after too much rubbing, hard particles are retained and offer resistance to wear. The steel grey colour appearance can be seen. As discussed in the previous section, the retainment of SiC particles and lower mass loss signifies that bonding between the matrix material and reinforcement particles increases due to laser treatment.

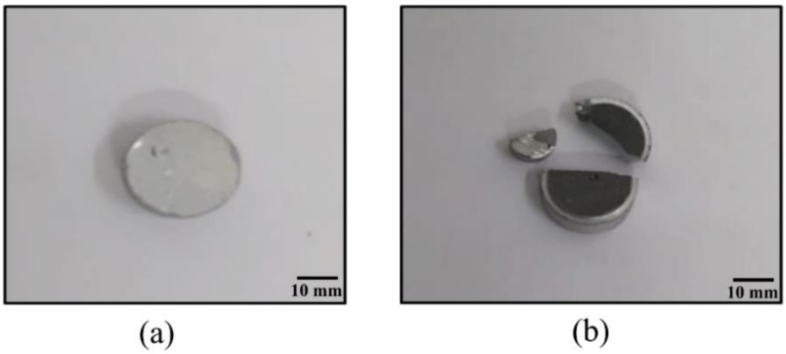

Fig. 10 Al-MMC sample before, and after wear testing, the dark color shows the rubbing of SiC particles still embedded in the matrix.

The results of wear testing are shown in Fig. 11 for all four compositions of Al-MMC. A load of 40 N is applied during testing. The mass of each sample was measured before and after testing, and it was done for both treated lasers and untreated samples. It was found that laser-treated samples had better resistance to wear than untreated samples, i.e., there was less mass loss with laser-treated Al-MMC samples. At higher sliding distances, the wear loss is less, i.e., laser-treated Al-MMC shows higher wear resistance. The new layer formed on the top surface of MMC due to laser treatment does not allow SiC particles to get released. Instead, they are held firmly, with a greater exposure. As a result, the wear resistance increases [38]. In the initial region of wear testing, only the sharp edges of hard SiC particles are chopped off. After that, no sign of loss of SiC particles was observed. Hence, increased wear resistance is mainly due to the thermal action of the laser, which has improved the bonding of Al-matrix with SiC particles and, at the same time, prevented the detachment of the SiC particles.

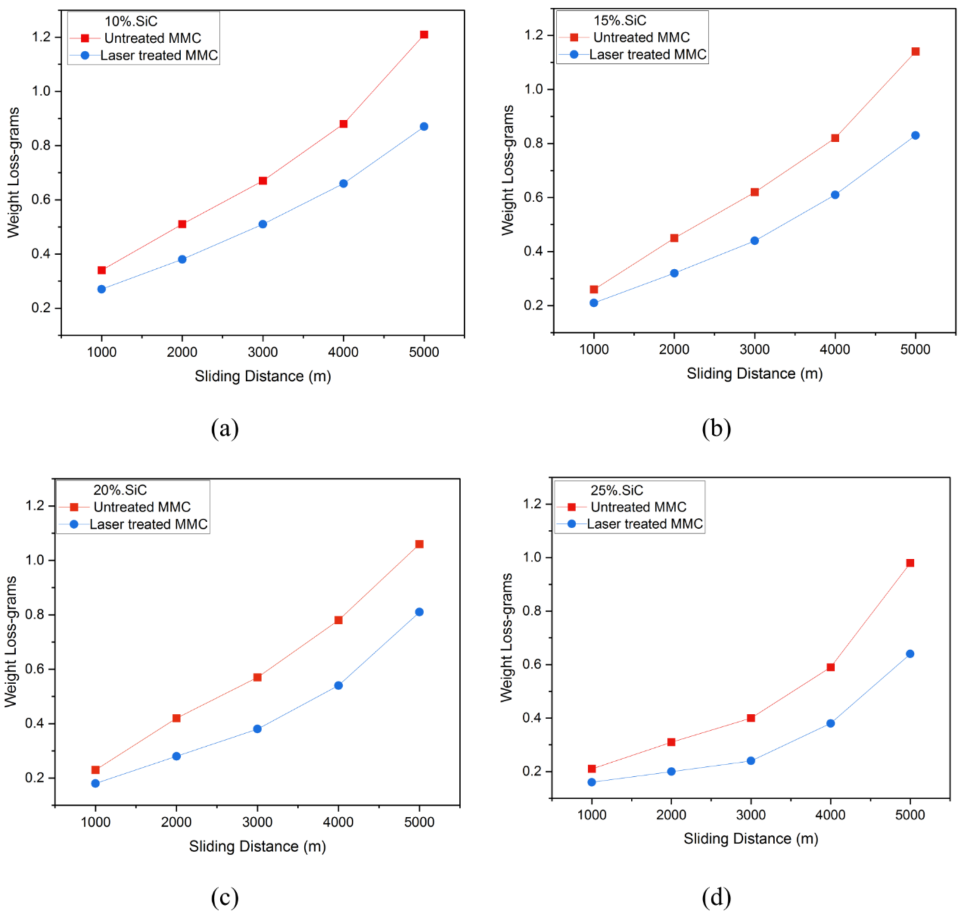

Fig. 11 Wear of laser-treated and untreated Al-MMC with (a) 10% SiC (b) 15% SiC (c) 20% SiC (d) 25% SiC at 40 N load

As discussed in the previous section, Al-MMC that has been laser-treated has a harder surface than untreated Al-MMC. This harder surface also contributes significantly to increased wear resistance. Forming a stable tribo-layer also helps reduce mass loss during the dry sliding wear test. The dark appearance of the Al-MMC once formed does not change during the entire wear test, which is evidence of a stable tribo-layer. The SEM images of Al-MMC after the wear test have been obtained, and one of the images is shown in Fig. 12 (a). It can be observed that SiC particles are found firmly held in the matrix and projected on the surface. This confirms that the thermal action of laser bonding has been improved. It may be concluded that along with improved bonding, the hardness of Al-MMC also improves as firmly bonded SiC particles offer resistance to deformation under loading, which indicates that hardness has increased.

The sub-surfaces of laser-treated Al-MMC were examined for microstructural changes. It can be seen from Fig. 12 (b) that, after laser treatment, a small grain structure is formed. It shows that the energy liberated from the laser beam could settle the large grain into smaller grains due to melting and recasting. Except for a few sites, micro-porosity also diminishes significantly, indicating an improvement in bond strength [39]. Fig. 12 (c) shows an SEM image of overlapping layers seen with the presence of sharp-edged SiC particles. These overlapping layers in the microstructure can be referred to as clad layers. The clad layers are not showing any significant separation. Instead, they are attached well to each other, which is another sign of confirmation that bonding is improved after the laser treatment and reinforcement particles, i.e., SiC, are held and exposed, causing increased exposure to wear resistance. It may be noted that an increased number of projected particles can affect the coefficient of friction also. Hence such Al-MMC can be considered a replacement for conventional brake lining materials.

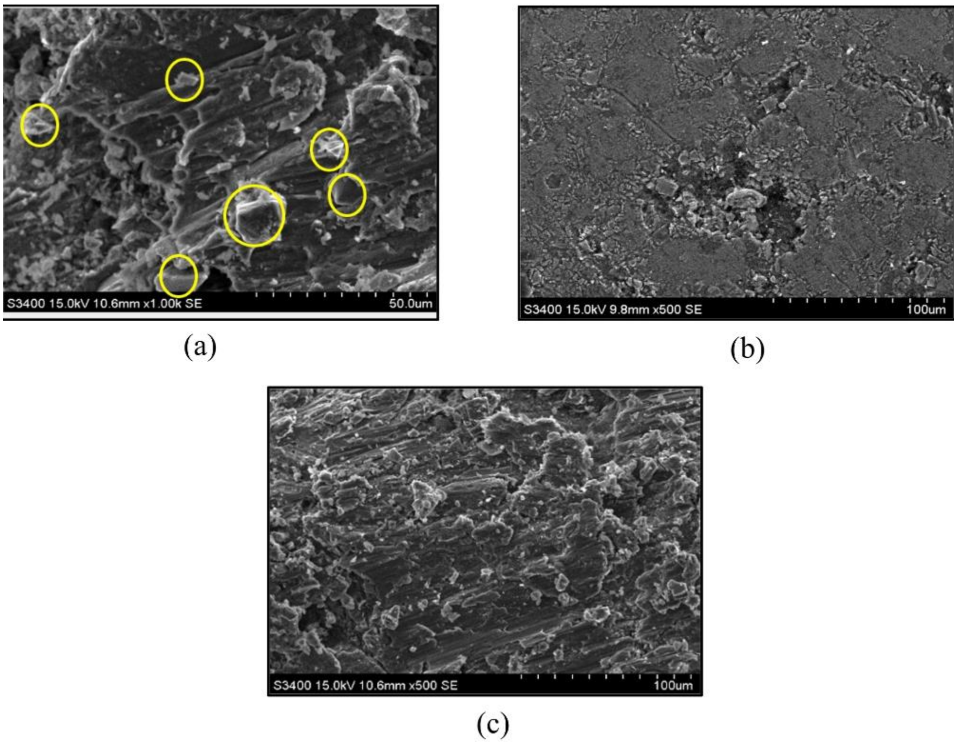

Fig. 12 SEM images of (a) Al-MMC after wear test with SiC particles in the matrix (b) microstructure of subsurface of laser-treated Al-MMC (c) microstructure of laser-treated Al-MMC with clad layers

A similar effect was reported by Lorusso et al. [40] when they investigated the tribological behaviour of AlSi10Mg-TiB_2 MMC. The MMCs were fabricated through direct metal laser sintering (DMLS), and their performance was compared with cast MMCs to see the effect of laser processing. The microstructure of laser-processed Al-MMC showed a very fine grain structure against the dendritic structure of cast Al-MMC. The total dissolution of reinforcement particles makes the Al-MMC strong and harder than the cast Al-MMC. The same was observed through the measurement of hardness, i.e., the hardness of laser sintering-based Al-MMC was superior to that of cast MMC. In the light of improved hardness, laser or DMLS-based Al-MMC was proved to be a better wear-resistant material, and the micrograph of cast MMC and laser-processed Al-MMC revealed that except for plough marks, no other wear tracks were observed. Also, there was no evidence of subsurface cracking during the wear test. Hence it can be concluded that the laser can help produce wear-resistant Al-MMCs, and the results are in line with the work of other researchers.

However, there is a limit to which Al-MMC can be wear-resistant, and the applied load and pressure intensity can decide this limit. If severe plastic deformation starts under the applied load, then Al-MMC can wear out. Increased size of wear debris due to predominant sub-surface cracking can cause higher wear rates. Hence if laser treatment prevents this, then even at higher loads, Al-MMC can be transformed into more wear-resistant MMCs.This approach makes it possible to fabricate a wear-resistant material, even with less reinforcement (for target application). Also, surface alloying can make the Al-MMC, a hybrid MMC, with enhanced properties compared to conventional materials.

The coefficient of friction has also been evaluated using a computerized pin-on-disc setup, and the results are shown in Fig. 13. The coefficient of friction increases with SiC content in Al-MMC, while it is even higher in the case of laser-treated Al-MMC for the same composition. Due to laser treatment, rearrangement of SiC particles happens, and more particles are exposed. As a result, the coefficient of friction increases with the laser treatment of Al-MMC, and the high content of SiC also contributes to the same. The increased number of exposed SiC particles does not lower the asperity of the junction, and no traces of any oxide layers were found. Hence, the coefficient of friction increases. Hard SiC particles do not form a passive layer compared to carbon nanotubes (CNT), where CNTs form a carbonaceous layer, reducing the friction coefficient. Gupta et al. [41] also reported similar results of increased friction coefficients of the laser-processed Al-MMCs. In their study, the coefficient of friction is obtained in the range of 0.193 to 0. 339. The laser power of 400W was found to be sufficient to cause engulfing of B4C and CBN particles in the matrix, and these particles got exposed very well during the wear test. Hence, the same hypothesis mentioned above, i.e., when more particles are exposed and firmly held in the matrix, the coefficient of friction is increased [42]. Kumar et al. [43] utilized MoS_2 particles as reinforcement in Al-4% Mg and observed increased density and microhardness. The wear test revealed a reduction in wear loss by 16.03% for the composite with 4% Mg and 6% MoS_2. The study found that using the powder metallurgy approach to create Al-Mg-MoS_2 composites can increase wear resistance. In the case of powder metallurgy, micro-porosity is an inherent issue. In the case of metal matrix composite, it can be a severe issue when significant grain angle boundaries are formed, and poor matric-reinforcement interfacial interaction happens during sintering. This issue can be addressed very well on the surface by applying high-density energy provided by laser.

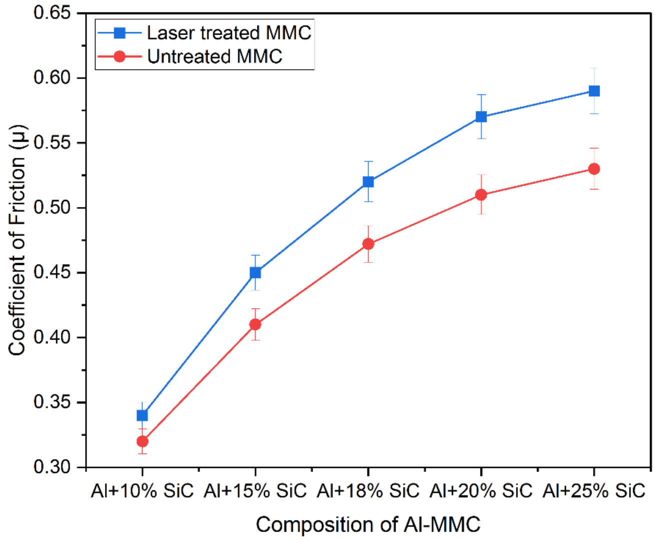

Fig. 13 Variation of coefficient of friction for laser-treated and untreated Al-MMC

4. Conclusion

This work presents the application of laser to alter the mechanical properties of the Al-MMC at the surface level. Based on the findings, the following important conclusions are summarized:

1. In laser-treated Al-MMC, an average of 12% improvement in the hardness is achieved at the surface level. Laser-treated Al-MMC could become more wear-resistant due to the improved bonding, i.e., during the dry sliding wear test, laser-treated Al-MMC is subject to less wear loss. Hence it is possible to develop target service life-based Al-MMC for wear applications.
2. The hardness comparison showed that the hardness of prepared samples increased by 12% for the 10% SiC content, while the hardness increased by an average of 15% for the 20% SiC and 16% for the 25% SiC content in Al-MMC.
3. The SEM analysis revealed that SiC particles are firmly held in the matrix after a dry sliding wear test. Hence, along with improved bonding, the hardness of Al-MMC also improves as firmly bonded SiC particles offer resistance to deformation under loading, which indicates that hardness is increased.
4. The laser-treated Al-MMC resulted in a higher coefficient of friction due to laser treatment, rearrangement of SiC particles happens, and more particles are exposed. As a result, the coefficient of friction increases with the laser treatment of Al-MMC, and the high content of SiC also contributes to the same.

In future work, the effect of laser treatment on the surface quality of the workpiece can be evaluated. Furthermore, the effect of the different laser power and scanning speeds of the laser on the mechanical properties of Al-MMCs can be explored. Besides, the wear behaviour of laser-treated Al-MMCs under different lubricating environments can be analyzed for their practical use in industries.

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