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A STUDY OF MECHANICAL AND WEAR BEHAVIOR OF SiC-CeO_2 REINFORCED Al7075 HOT ROLLED HYBRID COMPOSITES

Fabrication of aluminium (Al) composites by stir casting process is an effective method for fabrication of better quality of Metal Matrix Composites (MMCs). Stir casting technique is one of the most commonly accepted techniques. In this research work, Al7075 / SiC+CeO_2 hybrid MMCs have been fabricated with varying wt.% of SiC (2%, 4%, 6% and 8%) particulates and constant 5% of CeO_2 particulates. The ascast alloy and hybrid composite were hot rolled at a temperature of 500°C. Whereas, both the ascast and hot rolled hybrid composite was subjected to micro-structural, mechanical and wear tests. Optical microscope analysis revealed uniform dispersal of hard particles with in the base matrix in case of both of ascast and hot rolled composites. Hot rolled MMCs showed enhancement of 22.64% of hardness when compared with ascast alloy with increasing reinforcement of 0-6 wt.% of SiC content. Tensile strength increases by 28.24% for hot rolled composites when compared to the as cast and other hybrid composites. Reduction of wear loss by 54.38% for hot rolled composites when compared to the as cast and other hybrid composites. A tensile and wear fractography result shows the internal fractured structure which was analysed using a SEM analysis.

Keywords: Hybrid MMCs; Microstructure; Mechanical; Wear; Fracture behavior

1. Introduction

Aluminum Matrix Composites (AMC) are used worldwide in variety of mechanical and wear applications due to their superior properties like better strength-to-weight-ratio, hardness, low density, excellent wear resistance & stable properties at higher temperature [1-4]. Due to ease to recycling nature and non-toxic of aluminum alloys, they are finding extensive commercial applications in various areas such as automobile, space craft and structural industries where component weight reduction is the main objective [5-7]. Many research works have been done in developing Aluminum composites with different combinations of reinforcements. Sridhar Raja et al. [8] evaluated the effect of TiB_2 on micro-structural and mechanical characteristics of Al Composite. The outcomes reveal that, enhancement of tensile and hardness strength of the MMCs was observed with the increase in the reinforcement content. S. Gopalakrishnan et al. [9] revealed that wear rate increased by increasing in applied load. But, the wear rate reduced by increasing the TiC content. R. Balachandar et al. [2] evaluated the mechanical characteristics of Al reinforced with magnesium and rock dust using different weight % produced by Stir Casting technique. From the outcomes it was observed that, addition of AZ31 led to increase in tensile Strength and rock dust content led to decrease the density of developed composites. Chao Liu et al. [10] evaluated the effects of CeO_2 on the mechanical behavior. The outcomes showed that the presence of CeO_2 led to enhancement in the mechanical behavior of the Al alloys. By increasing wt.% of CeO_2, all the composites samples showed the trend of increasing, the mechanical properties of Al with porosities attained the maximum value. Reddappa et al. [11] observed that the specific wear loss has decreased with increasing wt.% of beryl content. Xuedan Dong et al. [12] studied the effect of CeO_2 particulates on micro-structure and mechanical behavior of Al composites. The outcomes showed that the presence of the suitable wt.% of CeO_2 increased the tensile strength of the MMCs. A. Anilkumar et al. [13] analyzed that the specific wear rate reduced by increase in Beryl/CeO_2 content. SEM was used to study the uniform dispersal of Beryl-CeO_2 particulates in Al6061. R. Saravanan [14] the research work is focused on the studies of wear and mechanical properties of Al reinforced with CeO_2 and TiB_2. MMC's were prepared using stir casting technique. Here, cast parts were subjected to hot rolling at the

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temperature of 515°C to reduce the thickness of developed composites from 12mm to 6mm. From the outcomes it was found that, the developed composite properties were enhanced by addition of reinforcement content. Amra et al. [15] evaluated the mechanical properties of CeO_2-SiC reinforced Al Composites. This study was aimed to manufacture Al composites with improved mechanical properties by the addition of CeO_2-SiC reinforcement particulates into the Al. Ravikumar et al. [6] studied the wear behaviour of Al7075/SiC/Al_2O_3 MMCs Using statistical method. Wear behaviour of composites was studied using pin on disc wear test equipment under dry sliding conditions. Experimental trials were carried out based on the Taguchi method. L27 OA (Orthogonal array) was used for investigation of the data. Effect of the wear parameters on the wear and coefficient of friction were studied using ANOVA technique. ANOVA results revealed that the wt.% of reinforcement has a substantial influence on wear loss and COF. Paulraj et al. [3] evaluated the influence of nano TiO_2/Micro (SiC/B_4C) reinforcement on the mechanical, wear and corrosion behaviour of A356 metal matrix composite. The wear resistance is enriched by 38.88% with the maximum reinforcement of 1% TiO_2 + 10% SiC + 10% B_4C compared to A356. According to the particles appropriate addition, the introduction of the nano TiO_2 particles enhances the resistance towards abrasion and gradual increment in the friction coefficient properties. Though, from the literature survey it is found that sufficient data on hot rolled hybrid composites is not available on the mechanical properties of Al7075 MMCs. So, the current research work aims at study micro-structure, hardness, tensile strength and wear characteristics of the hot rolled hybrid AMMCs (Al7075 + SiC + CeO_2) having different wt.% of reinforcement. The fractography of the fractured surface of tensile and wear test specimens were analyzed through SEM study.

2. Raw materials

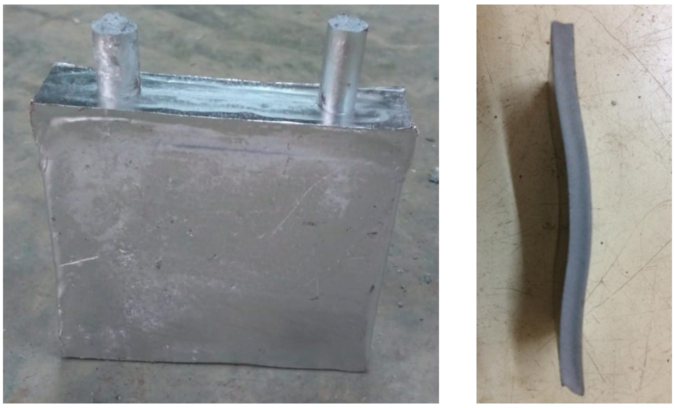
2.1. Matrix and reinforcements

Aluminium 7075 is a precipitation-hardened alloy whose major alloying element is zinc (Zn) and magnesium (Mg). Alloy 7075 sets the standard from the other alloys on account for its lightweight, medium-to-high strength and it provides an excellent corrosion resistance when exposed to atmosphere and sea water [16,17]. **Silicon carbide (SiC)** is one of the candidate material for use in the first wall and blanket components of fusion reactors, and also used in nuclear fuel particle coatings for high temperature gas cooled reactors. SiC is a hard covalently bonding material. SiC compound contains of a silicon (Si) atom and carbon (C) atoms which are covalently bonded among two of them [4,6]. **Cerium oxide (CeO_2)** is an oxide from the family of rare-earth metal called cerium. Its crystal structure is that of cubic packing. The appearance of cerium oxide is that of a pale yellow-white colour powder and plays a vital role in purification of ores by performing as an intermediate content. The stand out point of this material is in its ability to undergo reversible conversion to a nonstoichiometric oxide [18]. The chemical composition of Al7075 in wt.% is as in TABLE 1.

3. Methodology

3.1. Preparation of composites

For the fabrication of hybrid composites, the liquid metallurgy technique was selected [19]. The required content of raw materials for the fabrication of our composites was obtained in the form of ingots for Al7075 and powder in the case of SiC and CeO_2. Al7075 alloy was first melted at 800°C using an coke furnace. Graphite crucible was used to melt the matrix material. Generally, this graphite crucible helps to withstand the high temperature, and good resistance to thermal shock and chemical erosion [20,21]. The pre-heated reinforcements such as SiC (2%, 4%, 6% and 8%) and CeO_2 (5%) were added to the molten metal. While adding of required quantity of preheated reinforcements, stirring action was maintained continuously for 3 minutes at the speed of 300 rpm [22]. The continuous stirring action generally leds to attain the uniform dispersal of reinforced particulates within the base matrix. Finally, ready molten metal was poured continuously in to metallic die. After solidification, the castings were removed from the metallic die. Then, cast parts (as shown in Fig. 1(a)) were undergone to hot rolling at the temperature of 500°C to reduce the thickness of developed composites from 12mm to 6mm (as shown in the Fig. 1(b)). TABLE 2 shows the percentage of reinforcements of developed composite.



(a) (b)

Fig. 1. (a) Cast part, (b) Hot rolled composite sample

TABLE 1

Composition of Al7075 alloy with wt.%

Content	Al	Mg	Cu	Si	Fe	Ni	Sn	Mn	Pb	Sn	Ti	Zn	Cr
Wt.%	Rem	2.316	1.482	0.053	0.261	0.056	0.015	0.054	0.020	0.015	0.045	5.418	0.275

TABLE 2

Percentage of reinforcements in MMCs

Sl. No.	Al7075 alloy (%)	SiC (wt.%)	CeO_2 (wt.%)
1.	100	—	—
2.	93	2	5
3.	91	4	5
4.	89	6	5
5.	87	8	5

The developed composite samples were pre-machined by using wire EDM. Hardness, tensile and wear test samples (specimens) were prepared based on the standards (ASTM). These test specimens were subjected to study the micro-structure, mechanical, wear and fracture behavior.

4. Results and discussions

4.1. Micro-structural analysis

Hot rolling of Al7075 alloy and hybrid composites (Al7075 + SiC + CeO_2) was carried out successfully at 500°C. Uniform dispersal of SiC and CeO_2 particulates was studied by microscopic examination. Uniform dispersion of reinforcing particulates showed better impact on the mechanical properties of MMCs [23-25]. An optical microscopic image of Al7075 and Al7075 / SiC + CeO_2 hybrid composites prior to the rolling process is shown in Fig. 2(a-c).

From the Fig. 2, it is seen that reinforcement particulates have been found along with the grain boundaries [26]. It is also revealed that hard ceramic SiC particulates are uniformly dispersed in the Al7075 alloy. Results reveals that, after hot rolling, most of the reinforcement particulates have been aligned within the direction of metal flow [27,28]. When compared to the Al7075 alloy, the hybrid MMCs show a smaller size of grains due to presence of hard particles generally, which contribute to the better grain refining [29,30]. The presence of SiC, a grain refiner, will plays a vital role in grain refining of hybrid MMCs. Fig. 2(a) depicts the micro-structure images of Al7075 alloy, Fig. 2(b) depicts the micro-structure images of hybrid composites before hot rolling and Fig. 2(c) depicts the micro-structure images of hybrid composites after hot rolling. From the outcomes, it is observed that, the micro structural changes have occurred during hot rolling. The grain morphology has changed in the direction of rolling to the elongated grain structure. The nucleation of the new grains within the grain boundaries of grains; the microscopic image clearly reveals less porosity in both matrix material and in hybrid MMCs after hot rolling. In addition to this, the hybrid composites show a better bond between the base matrix and SiC particulates which may be attributed to the better wettability of particulates, refinement of reinforcement and uniform dispersion of reinforcements within the base matrix alloy leading to the enhancement in strength of the developed hybrid composites.

4.2. Hardness

The microhardness of developed composites was tested based on the E92-ASTM standards by using Vickers Micro Hardness testing apparatus. Diamond shape indenter was used under the constant load of 5 kg for a time period of 30 seconds. Hardness tests trials were carried out at 27°C (room temperature) and the hardness of each samples was evaluated at 3 different zones on the test specimens to find the average hardness value. The microhardness of as-cast, hybrid composites and hot rolled hybrid composites are depicted in Fig. 3. It is found that the presence of SiC and CeO_2 particulates has enhanced the hardness of hybrid composite when compared with base matrix. During the solidification process in cast composites, SiC elements cause increase in the dislocation of density [31-34]. From Fig. 3, it is observed that, the increase in hardness (22.64%) of hybrid composites with increasing of 0-6 wt.% of reinforcement content. Further addition of reinforcement leads to reduction of hardness due to high wt.% of agglomeration.

Xuedan Dong et al. [12] observed that, when the CeO_2 content was increased, the mechanical properties of the composites were enhanced. Since, Stir casting technique is adopted for the

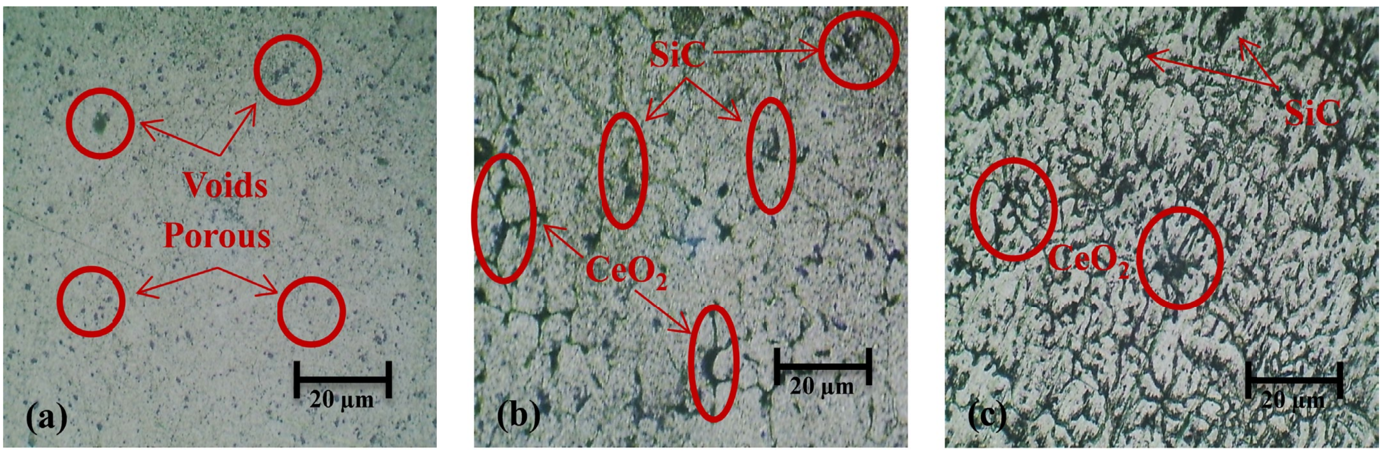


Fig. 2. Optical Micrograph of (a) Pure Al alloy (b) Al7075 reinforced with 6% SiC and 5% CeO_2 (c) Hot rolled hybrid composite with 6% SiC and 5% CeO_2

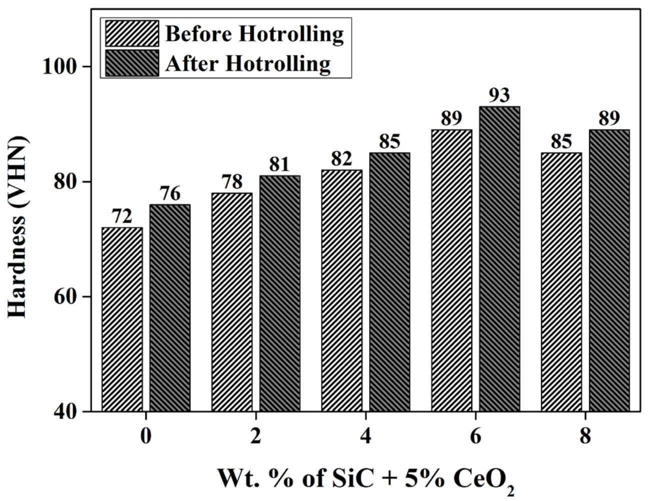


Fig. 3. Hardness results of ascast, hybrid MMCs and hot rolled hybrid MMCs

purpose of fabrication of composites, this leads to obtain uniform bonding among reinforcement and matrix. This is helpful in improving the material properties of developed hybrid MMCs. Generally, the reinforcing of ceramic particles with in the soft matrix will carry the load and also offers the better resistance [35]. In present research work, hard ceramic particulate SiC particulates acts like load bearing elements and also takes the maximum applied load for the plastic deformation and leads to increase the hardness in developed hybrid composites. SiC being a hard particulates allow the material to flow with-out undergoing the deformation. And when it exceeds the critical values it will cause fracture without any further deformations. Based on the concept of Hall-Petch equation, the hardness will be enhanced by decrease in size of grain [36]. The grain refinements can also be an effective reason for improving the hardness in SiC and CeO_2 reinforced hybrid composite. Finally, the hard ceramic particulates such as SiC and CeO_2 content had a better influence in increasing the strength of developed hybrid MMCs [37]. When the wt.% of reinforcements exceeds, the agglomeration of hard particulates was increased. The internal structure of the agglomerated particulates was loose and which usually could not efficiently bear the stresses. The capacity to transfer the stress will also reduce. The agglomerated particulates will be irregular/uneven in shape which leads to crack initiation in the development of plastic deformation. It is also found that, agglomeration leads to reduce the hardness of hybrid composites at higher wt.% of reinforcements [38]. Whereas, in the hot rolled MMCs, the bonding between matrix and reinforcements is very good when compared to the as-cast composites. Due to better bonding between matrix and reinforcements, the stir casted hot rolled MMCs exhibited enhanced microhardness. One more reason for enhancement in hardness is restraint to dislocations of movement by SiC & CeO_2 particulates. The hard particulates such as SiC & CeO_2 in the base matrix act like a barrier to the movements of dislocation and also increase the stresses essential for the purpose of movement of dislocation. Uniformly distributed SiC & CeO_2 particulates in the base alloy will enhance in overall stress which leads to increasing in microhardness. In addition, it is observed from the micro-structure study, the amount of defects is less in the hot rolled MMCs which leads in enhancement of microhardness. This is generally due to the existence of minor flaws and be restored during the hot rolling process [36,39].

4.3. Tensile strength

The test samples were machined according ASTM-E8 standards [40,41] and tension tests were conducted on UTM which was having maximum load is 400 KN. Fig. 4 depicts ultimate tensile strength of ascast and hot rolled hybrid MMCs.

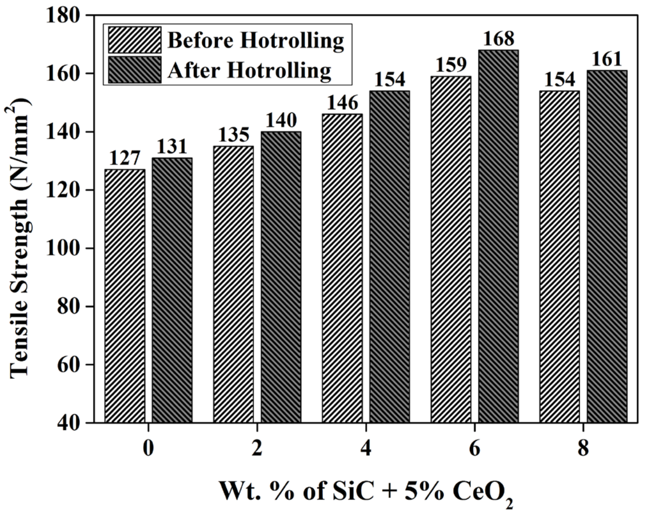


Fig. 4. Tensile strength of Al7075, hybrid MMCs and hot rolled hybrid MMCs

The presence of SiC and CeO_2 particulates enhanced the overall mechanical strength of developed composites in both ascast and hot rolled conditions. Better enhancement in tensile strength after hot rolling shows the effective forming method in densifying the ascast and MMCs. Tensile strength increases by 28.24% for hot rolled composites when compared to the as cast and other hybrid composites. Similar results were found in elsever [28,29]. Improved ultimate tensile strength may be due to the existence of elongated grains within the direction of hot roll [39]. There are several factors which lead to improve the mechanical behavior of hybrid MMCs which includes dispersion of particles, grain size and interfacial bonding among matrix and reinforcements. Generally, the hot rolling does not only leads to decrease the grain size by the strain-hardening, but also increases the dispersal of reinforcement/s more uniformly with in the base matrix. The fresh interface formed at the time of casting, the bonding among SiC and CeO_2 particulates and matrix alloy increase further due to hot rolling process. Enhancement in the tensile strength can also be ascribed to strengthening of mechanisms such as grain refinements, dislocation, load transfer and “Orowan” strengthening. It is identified that there must be stability among the matrix material and hard reinforcement particulates during load on a bulk material for the load transfer. Interface with better bonding among the matrix and reinforcement particulates confirm that the load transferred is more effectively from the matrix alloy to hard particulates (SiC and CeO_2) [26]. The strengthening mechanism which can take place by the recrystallization at the time of thermo-mechanical processing. The hard particulates do not deform at the time of hot rolling and strain with in the base material forms the deformation region around the particulates. Particulates deformation region is formed nearby hard particulates because of mismatching among them and base material. Thus, the recrystallization will takes place easily in these deformation regions due to the particulates stimulated nucleation. And resultant grains are formed because of recrystallization with in hot rolled hybrid MMCs compared to ascast Al7075 and hybrid MMCs. The grain refinements by particulates stimulated nucleation leads to increase in material strength of hot rolled hybrid MMCs according to the Hall-Petch concepts. The existence of higher dislocations density with in hot rolled hybrid MMCs results in significant improved strength. It revealed that, "Orowan-Strengthening" mechanism also leads to improvement in tension strength (tensile) of hybrid MMCs from preventing movement of dislocation by finely distributed hard particulates like SiC and CeO_2 [36]. The formed hard particulates are uniformly dispersed within the base matrix and act like obstacle for dislocations. This is mainly because the particulates are very hard and also non-deformable because it is very difficult for the dislocations and also to cut them. Fig. 5 depicts the ductility of Al7075 alloy, hybrid composites and hot rolled hybrid MMCs. From the graph, it is observed that, the increasing SiC and CeO_2 particulates content in Al-7075, marginally reduces the ductility in ascast and hot rolled composites [42,43]. When compared to ascast, it is found that the hot rolled matrix and its MMCs show improved ductility. This is generally due to the existence of defects in casting like solidification shrinkages and porosities acts like a crack nucleation due to the load which aids in propagation of cracks and nucleation.

Whereas, in the case of hot rolled hybrid MMCs the defects are reduced because of the plastic deformation at a higher temperature. The grain refinement due to the hard particulates also leads to better ductility in hybrid composites. Reduction of ductility by increased wt.% of SiC and CeO_2 particulates due to existence of cracks nucleating sites mainly at interface among reinforcement and base alloy in large number and also due to the existence of micro-porosities. Hard particulates of SiC and CeO_2 will changes the directions of cracks propagation and it results in bridging of cracks, branching and deflection in the direction along with the direction of tension load. This needs high amount of the energy. And also it leads to high resistance to the cracks propagation causing in the higher ductility and fracture toughness [44]. High wt.% of cluster (agglomeration) in SiC and CeO_2 particles leads to high debonding of reinforced particulates from interface of matrix and reinforcements during tensile loading, and this leads to decreased ductility [39]. The tensile stress-strain curves of the hot rolled hybrid composite samples fabricated by the stir casting method are shown in Fig. 6. Stress-strain diagram is plotted for as-received and hot rolled hybrid composite samples and all the points are indicated. Out

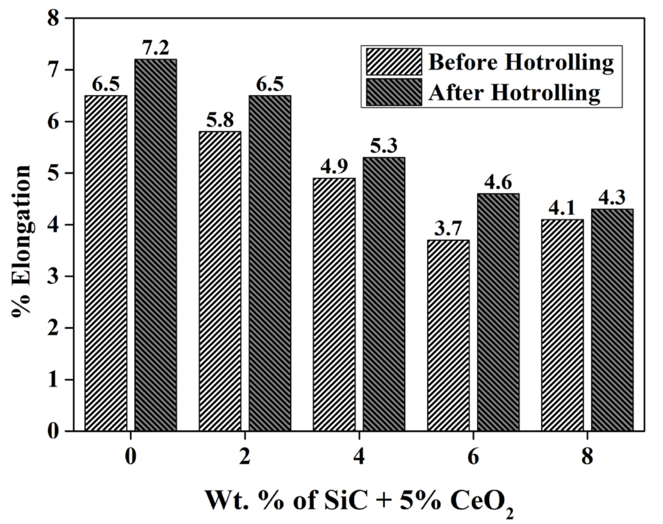


Fig. 5. Ductility of ascast, hybrid composites and hot rolled hybrid MMCs

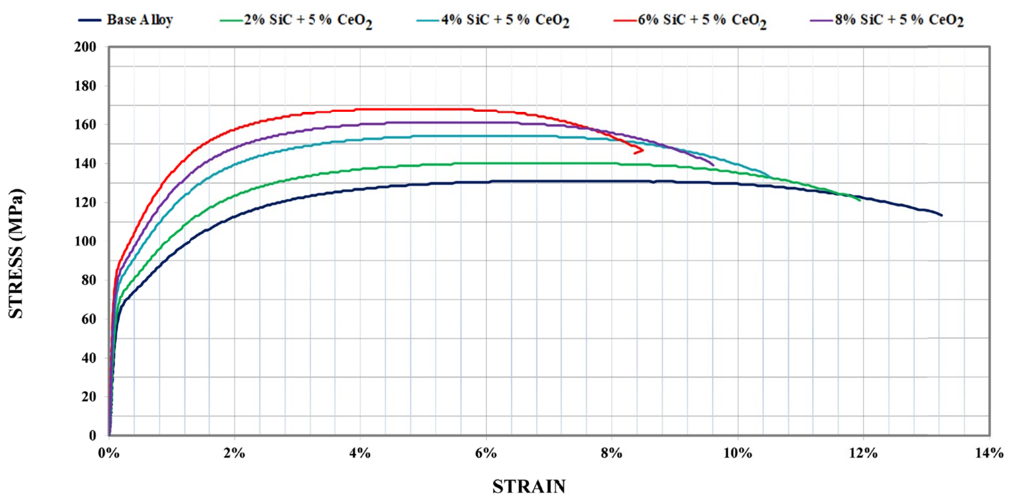


Fig. 6. Stress-strain curve for as-received and hot rolled hybrid composite samples

of all these composite specimens, the tensile strength is higher for specimen (composite) reinforced with 6% SiC – 5% CeO_2. The stress-strain curve indicates the improved toughness apart from high tensile strength. This is significant. Meanwhile, most strength improvement methods cause decreasing ductility [30].

Tensile fractography images of hybrid composites and hot rolled hybrid composites with 7.5% SiC and 5% CeO_2 are shown in Fig. 7. In the hybrid composites sample shown in Fig. 7(a), fractured surface reveals the existence of dimples showing ductile nature of fracture. But, the size of micro voids formed after the fracture show debonding of Al grains, which are placed adjacent to micro-porosities and agglomeration of hard particulates [30]. The existence of hard particulates such as SiC and CeO_2 on the fractured surface shows better bonding with the base alloy due to the clean interface.

Whereas, in hot rolled hybrid composites depicted in Fig. 7(b), micro voids and dimples in small size are formed over the fracture surface. Fracture begins with development of coalescence and micro-voids occur by increasing in applied load. When the load reaches the high ultimate value, then the micro-voids become bigger size to nucleate the cracks which leads to the fracture [45]. Close investigation of fracture surface exhibited the fracturing of hard particulates rather than the de-bonding. The de-bonding of reinforced particulates usually occurs in MMCs where it is very hard to achieve better bonding among base material and the reinforced particulates [29]. So, the application of applied load led to development of cracks near the interface as well as removal of the whole reinforcement/s in that region. But in current research work, because of better bonding attained via stir casting of SiC and CeO_2 particulates and hot rolling results in good interface. The results of better interface are revealed due to the witness of particulates fracturing.

4.4. Wear Loss

The wear test was conducted as per the standards (ASTM). In the present research the tests were executed at the sliding-speed of 2 m/s and constant load of 30 N against steel disc (Grade: EN-32). The test samples of 5 mm thickness and 8 mm of diameter were prepared by wire EDM process. The wear loss of ascast, hybrid and hot rolled hybrid composites were studied by weight loss method. Fig. 8 depicts the wear behavior of SiC and CeO_2 reinforced Al hybrid composite. The addition hard particulates increase the van-der-wall forces inside the matrix material. Generally, this will leads to reduce the dislocations and results in high wear resistance [34]. The decrease in wear loss may leads to capacity of higher load bearing of hard particulates. It can be observed that the hybrid composites exibhits lower weight loss indicating the effect of addition of SiC and CeO_2 particles. It reveals that hot rolled hybrid composites show lesser wear loss when it is compared to ascast and un-rolled hybrid composites. This is due to increase in hardness of the developed MMCs with the extent of hot rolling and also the due to the abrasive nature of SiC and CeO_2 particulates. The finer

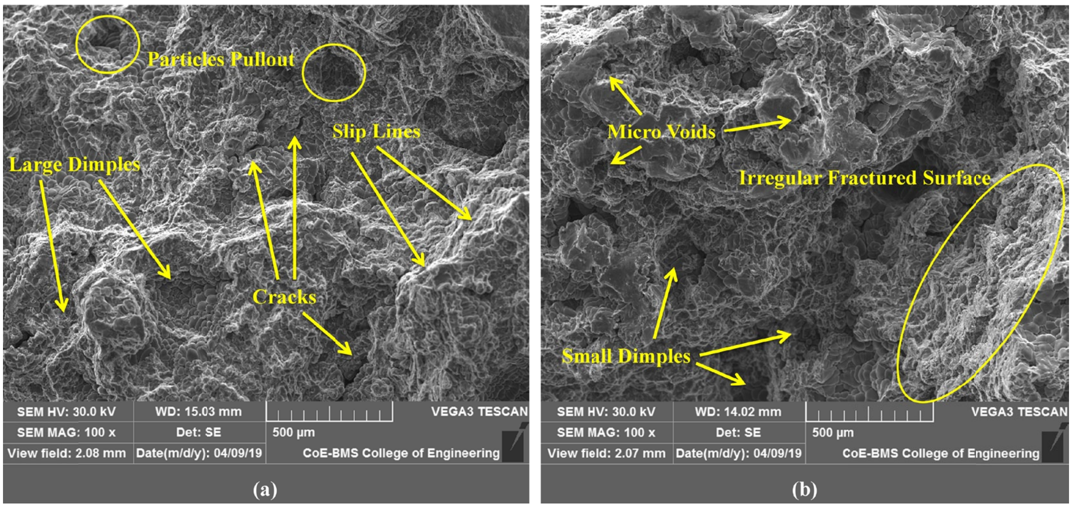


Fig. 7. SEM images of fractured surface of tensile test samples (a) Hybrid composites (b) Hot rolled hybrid composites

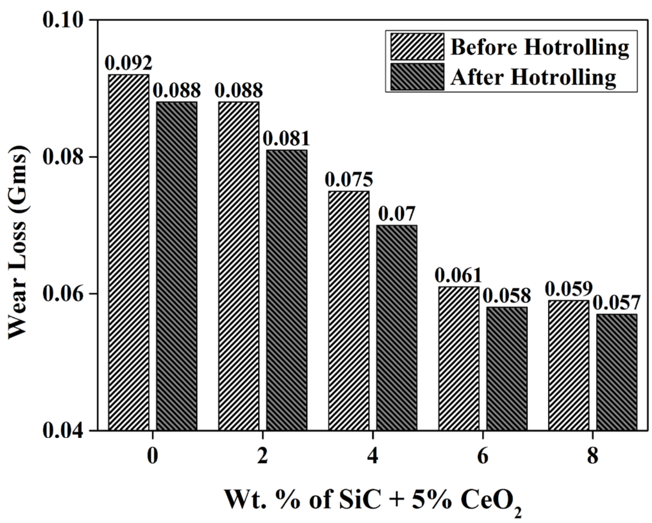


Fig. 8. Wear loss of ascast, hybrid composites and hot rolled hybrid MMCs

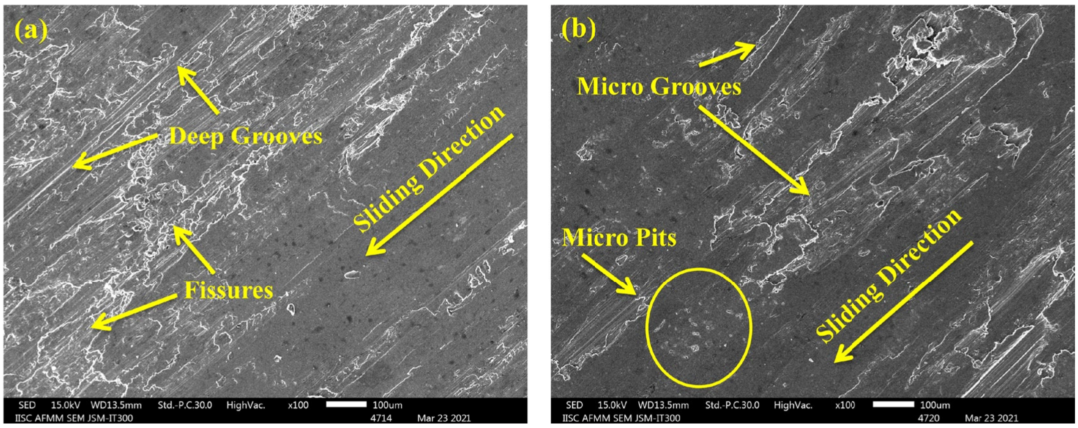


Fig. 9. SEM fractography of worn-out surface of (a) hybrid composites (b) hot rolled hybrid composites

dispersal of the hard fragmented particles generally strengthens the hybrid composite [46].

The sliding wear tracks on the test samples were examined by SEM analysis. The SEM analyses of the wornout surfaces were examined to study the effect of the hard particulates on the wear characteristics of the developed MMCs and hot rolled hybrid composites. The wornout surfaces of the SEM images of test samples (8% SiC and 5% of CeO_2) of both hybrid and hot rolled hybrid composites is depicted in Fig. 9.

It is observed in Fig. 9(a,b) that, the existence of grooves of different sizes was seen on the SEM images wornout surface. The worn-debris particulates are likely to act like a third body abrasion particulates. The SiC and CeO_2 particulates trapped among the test samples and counter face caused micro ploughing on contact surface of the developed hybrid MMCs. The wear surfaces were characterized by the significant transfer of the material among the sliding surfaces. SiC and CeO_2 could be spread inside the matrix material with good bonding results in higher wear resistance. The high debris can be observed in the tracks of hybrid composite Fig. 9(a) while in Fig. 9(b) shows uniform sliding wear track with the reasonable lower debris. The lower wear loss of hot rolled hybrid composites may be due to the fact of material is high denser, good interfacial bond among the particulates and the base matrix than in the un-rolled hybrid composites samples [46]. Also it is found that the hot rolled hybrid composite reinforced up to 8 wt.% SiC and 5 wt.% CeO_2 with a constant load and sliding speed, there is less fracture initiation at the matrix and particulates interfaces.

5. Conclusions

The research works represents an investigation of microstructure, mechanical and wear characteristics of ascast, ascast and hot rolled hybrid MMCs. The outputs from the present work are as follows:

Al7075 + SiC + CeO_2 hybrid MMCs have been manufactured by stir casting method and also effectively hot rolled under the temperature of 500°C. Microstructure study reveals the uniform dispersal of SiC + CeO_2 particulates with better bonding among reinforcement and matrix under both ascast and hot rolled conditions. MMCs and hot rolled MMCs showed maximum enhancement of hardness when compared with ascast alloy. Tensile strength of the MMCs found to be increased in both MMCs and hot rolled MMCs as compared to ascast alloy. Hot rolled MMCs showed enhancement of 22.64% of hardness when compared with ascast alloy with increasing reinforcement of 0-6 wt.% of SiC content. Tensile strength increases by 28.24% for hot rolled composites when compared to the as cast and other hybrid composites. The hot rolled hybrid MMCs show better enhancement in the ductility as compared to ascast alloy. High wear resistance was found in both MMCs and hot rolled MMCs as compared to ascast alloy. Fractography outcome shows the internal fractured structure of a tensile and wear specimen which was analysed using a SEM analysis.

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