Journal of Materials and Engineering Structures

Research Paper

Evaluation of Tribological aspects of Al-Si 12 alloy and their Metal Matrix hybrid Composites produced by Liquid-metal Forging Method

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ARTICLE INFO

Article history :

Received : 5 June 2021

Revised : 23 December 2021

Accepted : 25 December 2021

Keywords:

Wear resistance;

Friction

Squeeze pressure

Die Preheating temperature and Pouring temperature

ABSTRACT

Particulate Aluminium Metal Matrix Composites (Al-MMC) have emerged as advanced engineering materials in view of their improved properties. Ceramic reinforced Al-MMC were more suitable because of being economical and exhibiting isotropic properties. Al-MMCs manufacturing methods are expensive, demand skilled and complex operations and vortex liquid metallurgy results into higher porosity. The liquid-metal forging/squeezed casting of stirred molten slurry can eliminate porosity as molten metal is pressurized during solidification forming near net shapes. During many instances, influence of process parameter (PP)s on mechanical part properties is being studied. In the present study, composites were produced using Al-Si12 alloy as base material, aluminium oxide and silicon carbide particles as reinforcements by varying the PPs. Tribological tests were conducted under dry sliding condition at room temperature showed hard reinforcements in Al alloy reduced the wear rate (WR) and increased the coefficient of friction (*f*) for all PPs. For PPs, increasing the squeeze pressure and decreasing the pouring and die preheating temperature resulted in a reduction of WR and *f* with an increase in normal load and sliding velocity. Initially *f* falls and then raised with an increase in normal load, but only raised with growing sliding velocity compared to Aluminium base material.

1 Introduction

The intensified challenge for light weighing substances with higher strength in the automotive, aerospace industries, electronic packaging, and recreational product markets has rocketed the progress and application of metal matrix composites (MMC). MMCs are one of the advanced engineering substances consisting of two principal quantities (1. metal and 2. a different metal or a ceramic or an organic compound). MMCs can be custom-made to give excellent electrical, mechanical, and even chemical properties [1]. The metal matrix (MM) being a continuous phase formed by light metal alloys like aluminium (Al), magnesium (Mg), titanium (Ti), and copper (Cu) and the reinforcing part has to be hard, strong, and stiff compared to MM. Reinforcing elements like carbides (SiC, B_4C), nitrides ($Si3N_4$, AlN), oxides (e.g., Al_2O_3, SiO_2) and

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e-ISSN: 2170-127X,

RESEARCH REVIEW of Sciences and Technologies

fundamental materials (e.g., C, Si). MMC's properties greatly reliant on their component material properties, dispersion of particles/ fibers, and accomplished link. Fiber and Particulate reinforced MMC types are available. The particulate reinforcements improve the composite's stiffness to a certain extent but are not very effective in improving fracture resistance. Ceramic particles are widely used to improve the mechanical and tribological properties of matrix materials. Currently, production of discontinuous reinforced MMC attracting huge consideration as any available recognized reinforcing types, regulated metalworking processes, and very economical. Many MMC producing processes are economical but result in ideal separation, porosity, and widespread interface reactions. Squeeze casting/liquid metal forging process integrates the benefits of conventional permanent mold casting and standard forging technology [2]. It involves a single-phase metal founding process utilizing the pressurized solidification principles as the pressure will be acting throughout the procedure where melted substance flow into the shrinkable cavities. Therefore, hydrogen gas dissolves and staying in the solution eliminates defects like porosity and shrinkage. The process of Liquid metal forging is schematically shown in Figure 1. The direct application of pressure on the melted substance during solidification without gating arrangement provides full dense parts and speedy heat transfer, which yields fine grain structure.

Wear Resistance (WR) of Al 6061 alloy/fibers of Alumina (Al_2O_3)/ whiskers of SiC composites showed very high compared to that of Al6061/SiC composites. Around 5 to 10% volume fraction of SiC whisker to Al6061/ Al_2O_3 composites improved WR remarkably. Reinforcement like short fibers of Al_2O_3 and whiskers of SiC mixed in the Al alloy matrix using a direct squeeze infiltration method resulted in high WR as whiskers block against the slip of short fibers Al_2O_3 [3]. WR of Al-MMC is made with aluminosilicate fiber under dry conditions from room temperature to 400°C decreased with an increase in the volume content, and f is found lowest at 4.5% fiber in MMC [4]. By incorporating carbon fibers into Al/ Al_2O_3MMCs, the influence of volume % of carbon and Al_2O_3 fibers in Al-based hybrid composites was substantially increased. The carbon fibers formed solid lubrication film improved the WR of Al/carbon/ Al_2O_3 hybrid composites [5]. Abrasive WR of Al/ Al_2O_3 was decreased with an increase of volume fraction and size of Al_2O_3 particle, but porosity increased. WR was slightly affected even with an increase of porosity [6].

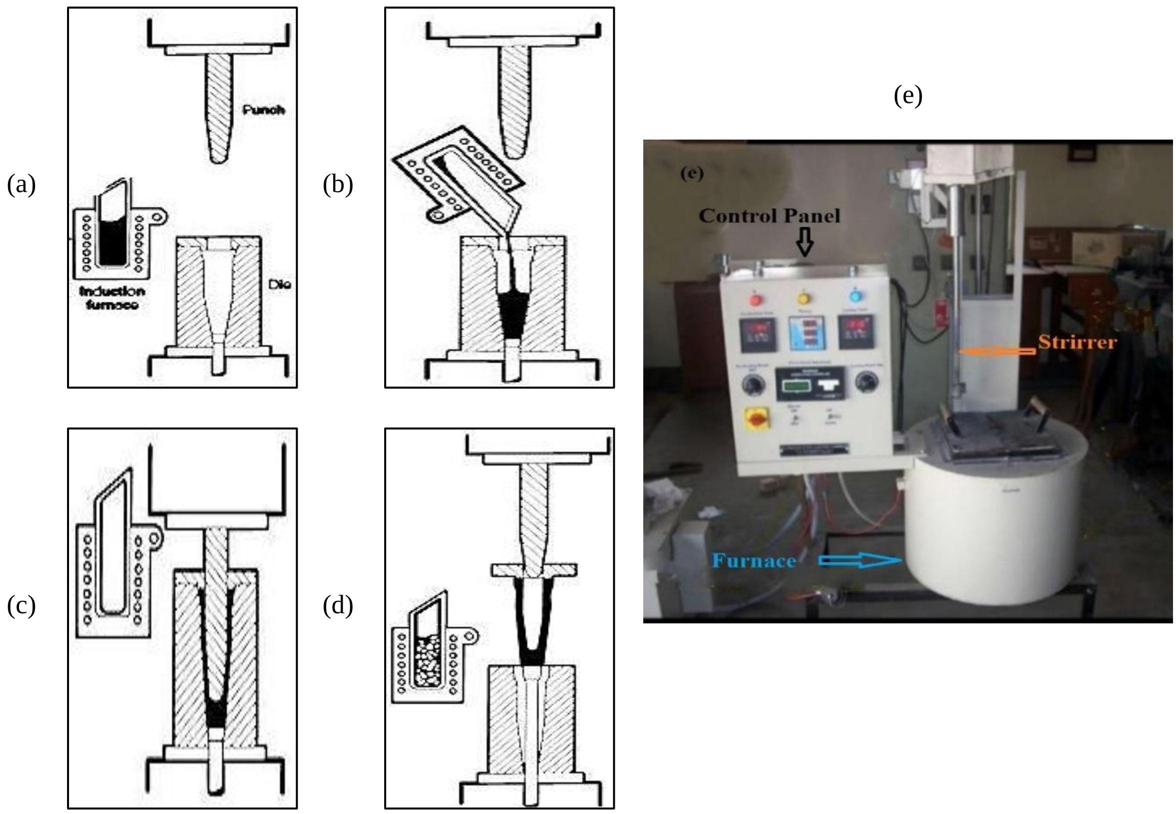

Fig. 1 – A diagram depicting the activities of the stir casting process. (a) Melt charge, preheat, and lubricate tooling (b) Transfer melts into die cavity (c) Close tooling solidify melt under pressure (d) Eject casting, clean dies, charge melt stock (e) Fabrication setup.

The increase of volume fraction and particle size of the reinforcement improved the WR in squeeze cast technique Al/SiC_p composites at room and elevated temperatures than the vortex cast fabrication technique [7]. Al with Al_2O_3 and SiC particulates hybrid composites fabricated by pressure infiltration technique introduce Magnesium up to 8 wt.% in their mixtures. The WR of such composites in terms of metal to metal and metal to abrasive wear increases as the Mg concentration rises [8]. The abrasive WR of both Al MMC reinforced with Al_2O_3 and zircon sand particles was improved with the decrease in particle size. While comparing two composites, low WR was observed for Al_2O_3 particle reinforced composite. Adding copper of 5% wt. in Al+4% wt. Al_2O_3 MMC has increased both hardness and WR with a modest increase of *f*. Whereas copper in Al+4 wt.% MMC reinforced with SiC particles resulted in a significant improvement both in WR and *f* [9]. In dry sliding wear behavior of non-hybrid (Al6061/SiC_p) and hybrid (Al6061/SiC/graphite) composites, WR discovered that it decreased as SiC particle size was increased. Moreover, the hybrid composites showed lower *f* and high WR compared to non-hybrid composites. The hybrid composites were practically worn away by abrasion and delamination, as the wear mechanism shifted from adhesive to abrasive [10].

B_4C coated on TiB_2 particles in Al and copper alloys formed composites showing WR was very high than Al alloys and increased with increasing B_4C size and wt.%. It was increasing plastic deformation by micro-cutting and micro-plowing at the worn-out surfaces [11]. Due to the soft Graphite phase, the addition of Graphite or Al_2O_3 along with SiC particles in Al 6061-T6 hybrid composites revealed that Al/SiC/Gr hybrid composites had lower hardness values. Even so, with better WR and f. The Al/SiC/Al_2O_3 system, on the other hand, had a greater hardness value due to both harder phase particles, but Gr particles had a more solid lubricant [12]. WR of squeeze cast MMCs under both dry and lubricated conditions for Al/Saffil and Al/Saffil/SiC at high temperature and high load found to be similar in both cases and higher. The wear mechanism was changed from abrasive to adhesive wear as a direct function of load or temperature but finally transformed into a high temperature molten wear [13]. The WR of Al 2024/ Al_2O_3 composites increased with increasing Al_2O_3 particle content and size and reduced with increasing sliding distance, wear load, and abrasive grit size [14]. SiC_p and Graphite MMCs with Al has exhibited good WR at all sliding speeds. Due to subsurface deformation compared to the graphite free composite [15]. The aging period of abrasive WR has increased in Al6061/SiC_p/E-glass fibers composites due to reinforcements. WR, on the other hand, decreased as the sliding distance was increased (for as-cast and heat-treated composites) [16].

Al/SiC squeeze cast composites at high loads showed excellent WR and low *f* in the water than air [17]. Dry sliding WR decreased in the (Al-4.5Cu-3Mg/15%vol. SiC) MMC with increasing sliding speed and applied load, but f decreased [18]. WR of Al/ Al_2O_3 fibers /SiC particulates MMCs improved at 150°C due to the precipitation strengthening, but f was low at 150°C than at 100°C [19]. Optimization of dry sliding wear parameters of liquid metal cast Al/ Al_2O_3 short fibers/ GNF hybrid composites using the Taguchi approach resulted in increasing load and sliding distance as significant factors while increasing WR, decreasing *f* [20]. Squeeze cast Al/B_4C composites reported that *f* and WR decreased as the volume %, applied load, and sliding distance increased, but WR increased as the velocity is increased. It was observed that the wear mechanism was a combination of adhesive, abrasive, and delamination wear [21]. The increasing squeeze pressure has increased the hardness, but abrasive WR of the Al-Si12/fly ash composite has decreased and then increased [22]. Al-Cu/SiC MMC showed a homogeneous distribution of SiC particles in the matrix alloy at stirring speed of 400rpm and higher pouring temperature, but WR decreased [23].

Under low loads and speeds, Al and its alloys showed mild wear with oxidation, however at higher loads, severe metallic wear resulted in significant surface damage and the development of metallic pieces in the wear debris stuck to the counter face. Nanocomposites, on the other hand, have been proven to withstand substantially higher loads before exhibiting serious wear. At low loads, they display abrasion wear, but at higher loads, they transition to severe wear, with material loss via the delamination process; nevertheless, this happens at far higher loads than non - reinforced alloys, prolonging the oxidational wear state. A characteristic dark lubricative and thermally shielded tribolayer forms at the contact, which is reported to decrease wear greatly. Nano reinforcements, when compared to micro elements, are shown to refine microstructure, considerably increasing strength and hardness while shows the lowest impact on ductility. Nanoparticles have a priority with the matrix, and they can operate as third new abrasives after being dragged out under intense wear conditions until being removed from the interface at a quick rate. After pull-out, microparticles of a larger size form larger void, which provide sites for subsurface fracture propagation, resulting in huge detritus particulates and higher volume loss under extreme wear. The tribological characteristics of hybrid MM nanocomposites with many forms of reinforcement are shown to be better to unified nanocomposites and far superior to micro composites. Manufacturers can learn how to identify the optimal composite for application-specific tribological pairings by comparing the tribological behavior about the same matrix reinforced with different reinforcement types under identical circumstances [24].

A limited study on the fabrication of Al alloy hybrid composites comprising rigid ceramic particulate reinforcements by liquid metal forging method has been carried out. The role of liquid-metal forging process parameters on particle reinforced Al-MMC's tribological characteristics has not been attempted. Based on the research gaps identified, it was decided to study the tribological wear behavior of Al-Si alloy hybrid composites containing Al_2O_3 and SiC particles using a melt stirred squeeze casting technique. Further, the researchers planned to fabricate composites samples by varying the weight percent of reinforcing particles in the matrix alloy. It was also decided to vary the liquid -metal forging process parameters such as squeezing pressure, pouring, and die preheating temperature to produce high-quality MMCs.

2 Methods and Materials

In this research work, a melt stirred liquid-metal forging Method is used to fabricate Al-MMCs. Al_2O_3 and SiC particulates were stirred mixed into the molten Al matrix using a mechanical stirrer, and the composite mixture was forged by applying pressure using a hydraulic press. Commercially available Al-Si 12 alloy is used as the matrix material whose chemical composition (CC) as per British Standards and the actual CC of the alloy used are provided in Table 1. Al-Si12 alloy possesses various properties like good flowability, excellent pressure withstanding, excellent forgeability, good machinability, etc. Particulates are the most frequent and least expensive reinforcing materials used in MMCs to give them their exceptional isotropic properties. Alumina (Al_2O_3) and silicon carbide (SiC) have obtained higher consideration as reinforcing segments as they consistently increase the strength and WR of Al-MMCs. In this research work, Al_2O_3 of average size 35 µm and silicon carbide of average 45 µm particles were chosen as reinforcements. More specifically, high Si content can prevent the formation of extensive use in numerous specific applications such as engine cylinders, pistons, manifolds, and motor casings. The reinforcing elements were preheated to 1075K for about an hour or two hours to take out all moisture and surface impurities.

Table 1 – Chemical composition of LM6 Al alloy

Elements	Cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Sn	Ti	Al
BS (wt.%) max.	0.1	0.1	10 -13	0.6	0.5	0.1	0.1	0.1	0.05	0.2	Remainder
Ingot analysis (wt.%)	0.1	0.1	11.81	0.56	0.5	0.1	0.1	0.1	0.05	0.1	Remainder

The hybrid Al- MMCs were developed by stirring the molten metal of Al-Si 12 alloy (at 1073 K) in a liquid- metal forging process where reinforcing elements added forged with an external pressure applied. The MMCs were fabricated by varying the % weight of reinforcing like 5, 10, and 15 in 1 Al_2O_3:1SiC particles ratio. The MMCs were fabricated by varying the forging parameters squeezing pressure, pouring temperature, and die preheating temperature. For producing quality, Al forged and their MMCs various range of liquid metal forging method variables were selected recommended by various experts, as provided in Table 2. Also, Al-Si 12 alloys samples were produced using the same methodology of MMCs produced for comparison studies.

Table 2 – Details of process parameters

Sl. No	Process Parameters	Fixed factors	Adjustable Factors
1	Squeezing pressure in MPa, SP	PT = 993K DPT =525K	SP = 50, 75, 100, 130
2	Pouring temperature in K, PT	SP = 90 MPa DPT= 525K	PT = 933, 963, 993, 1023K
3	Die preheating temperature in K, DPT	SP = 90 MPa PT = 993K	DPT = 310, 425, 475, 525K

2.1 Experimental Procedure

The forged samples were tested for tribological qualities using a pin on disc device (see Figure 2) in a dry sliding state at room temperature, according to ASTM G99-03 Standard. The pin samples of cylindrical shape (Φ10 mm x length 30 mm) were developed from the Al-Si 12 alloy and their MMCs, but the disc (EN32 steel with a hardness of 65 HRC) was rotated at the speed range of 0-2000 rev/min using a D.C. motor attaining track diameter of 50-180 mm such that if offers sliding velocity upto10 m/s. A deadweight was used to provide a load to the pin (specimen) using a pulley rope arrangement. The system could handle a maximum load of 200 N. The pin and disc surfaces were burnished with emery sheets before the test to verify that the contact was smooth and consistent. The pin specimen was first washed and carefully weighed using a digital electronic weighing balance with a precision of 0.0001 g. In the present study, the wear test was conducted based on different parameters like normal load (10,20 and 30N) at a sliding velocity of 1.5, 2.25, and 3 m/s with a sliding period of 15 minutes. The weight difference between the pin specimens before and after the test was used to compute the weight loss (m) during the sliding wear test. The volumetric wear rate (Wv) of the MMCs was calculated using the standard expression.

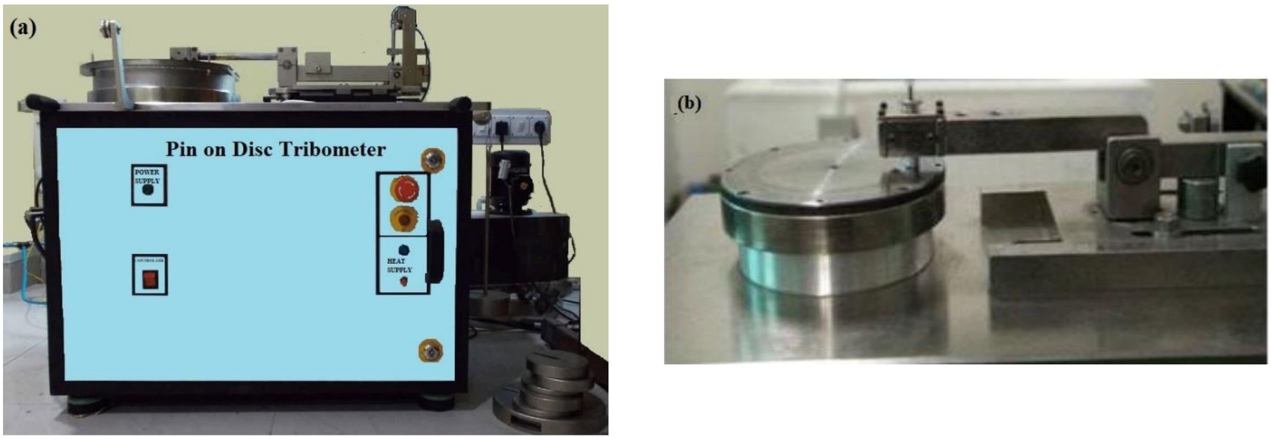

Fig. 2 – Pin- on-Disc Tribometer and Enlarged view of Disc with pin

3 Results and Discussions

Al-MMC specimens were produced at various squeezing pressures (SP) of (50, 75, 100, and 130 MPa) for studying the impact of it on Tribological properties. The pouring temperature of 995°K and die preheating temperature of 525°K were maintained constant during the production of Al alloy and Al-MMC composite mold casting.

3.1 Wear Rate Percentage

3.1.1 Influence of Squeezing Pressure

The % Wear rate (PWR) of Al alloy and their composites as a basis of squeezing pressure and normal load (NL) for varying sliding velocities (SV) (produced at 993ºK pouring temperature) are depicted in Figures 3-5. Figure 3 shows the PWR against varying squeezing pressure at a sliding velocity of 1.5 m/s. The plot revealed that the PWR of MMCs and Al-Si 12 alloy increased with increasing applied normal load. The PWR of Al alloy was more significant than the composites at all the loads and increased with the increasing normal load [24]. The PWR of Al- alloy was 32% greater than 5% wt. Al_2O_3 and SiC particles reinforced composite at 10 N load. Though the increment in the content of Al_2O_3 and SiC particles decreased the wear rate, the noted variations of wear rate were low. The reduction in wear rate was 20, 30, and 45% for composites containing 5, 10, and 15% wt. reinforcements compared to that of Al alloy. However, the least PWR almost 45% lower than Al alloy was found for a composite having reinforcements of 15 wt.% of Al_2O_3 and SiC particles at an NL of 10 N. The PWR of the above MMC was increased by 18% on varying the load from 10 to 30 N.

Low PWR is found at low load because the surface contact maintains flat terrain, and the temperature developed was low. Conversely, at higher normal loads, the surface contact loses flat terrain shape, and a rise in temperature increases higher PWR [18]. This can also be accredited to the large plastic deformation and ensuing delamination at higher loads for all combinations of composites. A similar results trend was seen in Figures 4 and 5 for sliding velocities 2.26 and 3.02 m/s. The PWR increased with an increase in sliding velocity by 5-7% and 22-33% from 1.51 to 2.25 and 2.25 to 3 m/s. Low PWR was seen at lower sliding velocity as the sliding surfaces mechanical layer due to mixing formed would resist, but at higher velocities, Al alloy's thermal softening breaks down the mechanical layer letting better direct metallic contact results in high PWR [24]. It maintains a similar results trend for variable normal loads 20 and 30 N.

Figures 3 to 5 show that the Al-Si 12 alloy wears out rapidly than the MMCs because it is much softer than the hard steel disc. Additionally, the roughness of the steel disc might penetrate deeply into the Al alloy surface, creating considerable plastic deformation on the surface and a greater quantity of material loss. The hard-ceramic particles in the Al-Si 12 alloy limited the plastic deformation. They resisted the counter surface asperities' penetration, ensuring the low amount of material loss in composites. So, the PWR of the composites reduced by increasing the content of reinforcement particles.

The effect of squeezing pressure on the PWR of 5 wt. percent Al_2O_3 and SiC particles reinforced MMCs with squeeze pressure at a sliding rate of 1.51 m/s was investigated. It was discovered from the graph that the wear rate reduced as the squeeze pressure was increased. The composite's wear rate at 120 MPa pressure was 21% lower than that of at 30 MPa pressure for an NL of 10 N. This drop was 20 and 18% for the normal loads 20 and 30 N, respectively. It was clear from the graph that the wear rate of composites increased almost linearly with increasing NL, but the wear rate was the same in magnitude for 30 and 60 MPa squeeze pressure at a NL of 30 N. The same trend of results (Table 5.2) was observed for sliding velocities 2.26 and 3.02 m/s.

The effect of increasing squeezing pressure on the PWR of 5% wt. Al_2O_3 and SiC reinforced MMCs for NL of 10 N (refer Figure 3 to 5) shown that the PWR was reduced by 22% at 1.50 m/s. A high amount of PWR is seen at 50 MPa pressure at 3 m/s due to a gradual increase of PWR (between 1.50 to 2.25 m/s), and subsequently, a drastic improvement was found for every pressure level considered.

3.1.2 Influence of Pouring Temperature

The influence of various pouring temperatures of 933, 963, 993 and 1023°K on wear properties of Al-Si 12 alloy and their MMCs by maintaining the squeezing pressure of 90 MPa and die preheating temperature of 525°K during the production of specimens. Figures 6-8 show PWR varying as a function of pouring temperature (PT), Normal load and % weight of reinforcing elements in composites a SV of 1.5, 2.25 and 3 m/s respectively. It was clear from the graph that the wear rate of composite increased linearly on increasing the normal load. On increasing the pouring temperature from 933 to 963°K, PWR increased around 8%, and larger boost in PWR of approx. 21% was seen for the temperature (963-993°K) and for 10 and 20 N loads. Further, the variation in PWR for PT (993 to1023°K) was 7 and 12% for NL of 10 and 20 N respectively. There was a steady rise in PWR with the PT for the NL of 30 N. Similar tendency of results were noticed for SV of 2.25 and 3 m/s.

The outcome of PT on the PWR of MMCs (5 wt.% of Al_2O_3+SiC) at a NL of 10 N is found that the PWR increased on rising SV. The PWR increased gradually when the SV was increased from 1.5 to 2.25 m/s and the increment was around 8% for all the PT considered and bigger boost of PWR about 20-28% was noticed when the SV was raised above 2.26 m/s when PT was increased from 933 to 1023°K. Similar trend of results were noticed for normal loads 20 and 30 N. the PWR increased with an increase in PT in spite of MMCs had higher hardness and strength compared to Al alloy, the PWR of MMC (5 wt.% of Al_2O_3+SiC particles) was low at all the PT. However, an increase in PT decreased the hardness and strength of MMCs which resulted in higher PWR. The model of PWR of Al-Si 12 alloy, Al-MMCs (10 and 15 wt.% of Al_2O_3+SiC) were found similar to that of MMC (5 wt.% of Al_2O_3+SiC). It was also noticed that PWR decreased with increasing weight % of reinforcing particles and increased when the PT, NL and SV were increased.

3.1.3 Influence of Preheating temperature of Dies

The consequence of die preheating temperature (DPT) on PWR of MMC (5% wt. Al_2O_3 + SiC_p) with the NL and SV are plotted in Figures 9-11. It was noticed from the plots that the PWR of MMCs was increased on increasing the NL. The increase of DPT (310 to 425°K) has increased the PWR by 9, 10, and 9% for the NLs of 10, 20, and 30 N, respectively. Besides increasing the DPT from 425 to 475°K, the PWR drastically increased by 24, 22.5, and 13%. The variation in PWR was low in the DPT range 475 to 525°K compared to that of the DPT range 425 to 475°K for all the NLs considered. The variation in PWR was low on increasing the NL for a DPT of 475°K compared to other DPT studied.

A similar distribution of results was noticed for SV of 2.25 and 3 m/s. The effect of DPT on PWR of MMC (5% wt. Al_2O_3 + SiC) at an NL of 10 N showed that the PWR increased on increasing SV. The increase in PWR was low when the SV was increased from 1.5 to 2.25 m/s, and it increased by 7.5, 8, 6, and 5% for all the DPT studied.

But it was very high when the sliding velocity was increased above 2.26 m/s and increased by 42, 38, 32, and 34%. More significant PWR variation was noted in the DPT range 425 to 475K compared to other DPT ranges. The same trend of results (Table 5.18) was observed for NL 20 and 30 N.

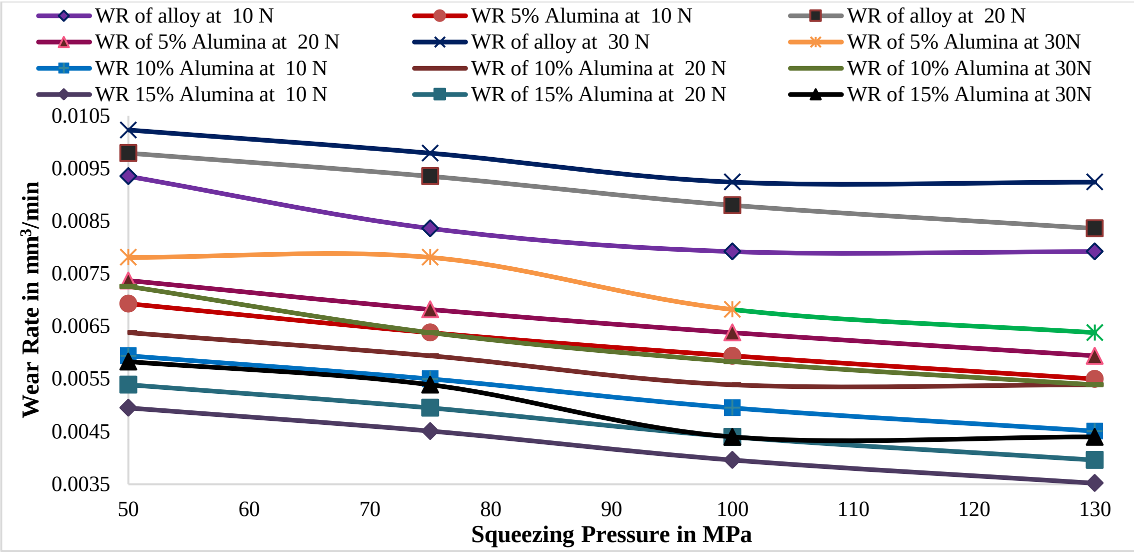

Fig. 3 – % Wear rate of Al alloy and Al-MMC vs. Squeezing Pressure and normal load at SV=1.5 m/s

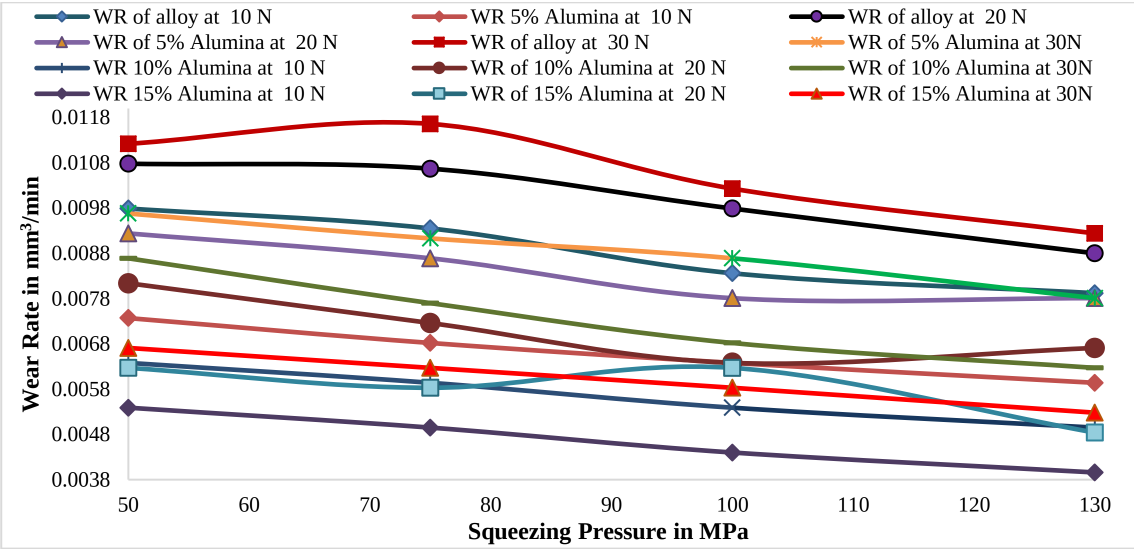

Fig. 4 – % Wear rate of Al alloy and Al-MMC vs. Squeezing Pressure and normal load at SV=2.25 m/s

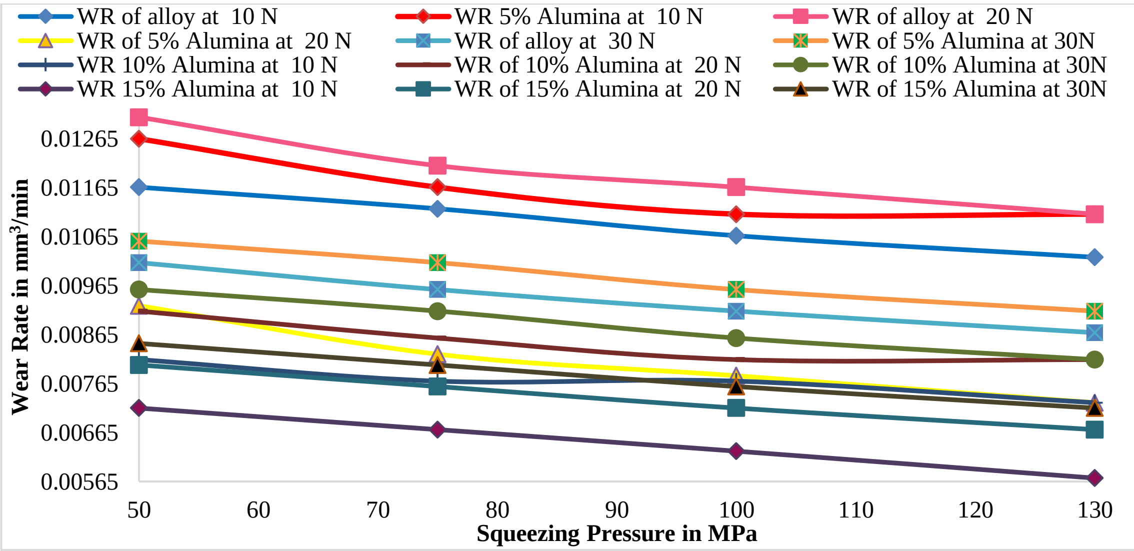

Fig. 5 – % Wear rate of Al alloy and Al-MMC vs. Squeezing Pressure and normal load at SV=3 m/s

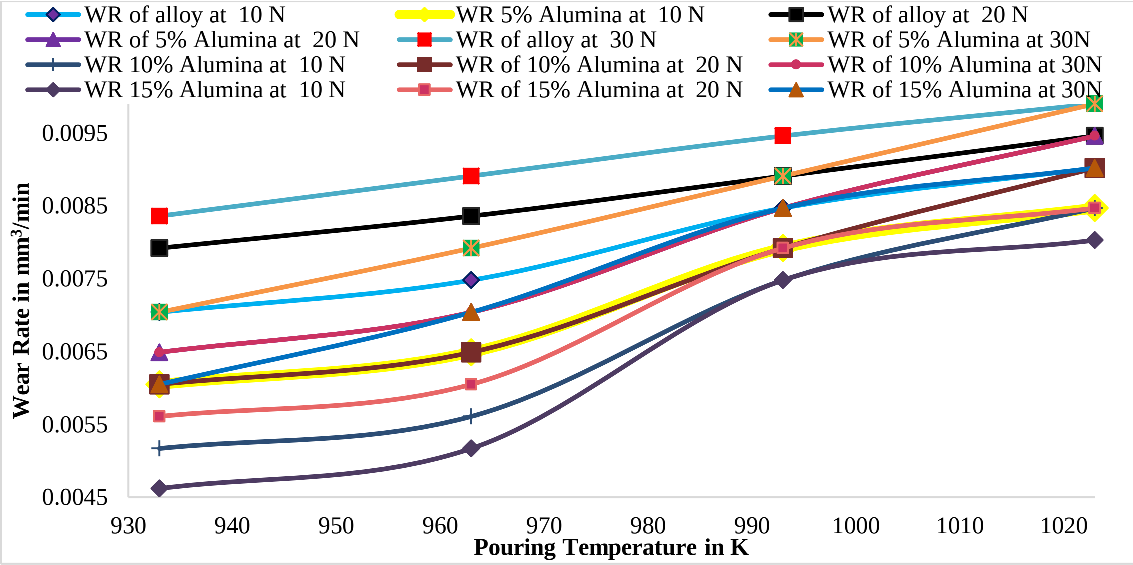

Fig. 6 – % Wear rate of Al alloy and Al-MMC vs. Pouring temperature normal load at SV=1.5 m/s

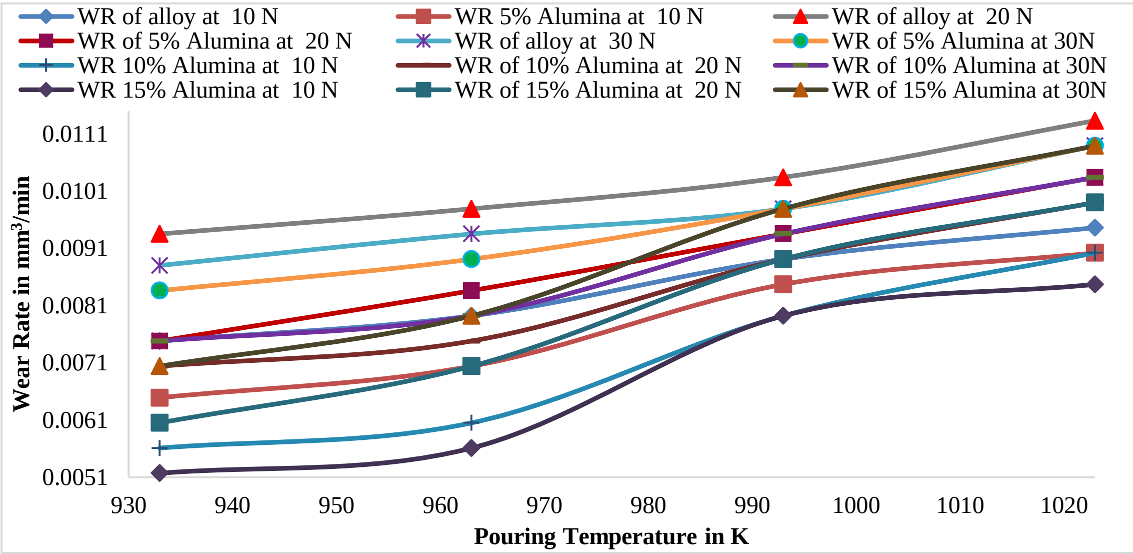

Fig. 7 – % Wear rate of Al alloy and Al-MMC vs. Pouring temperature normal load at SV=2.25 m/s

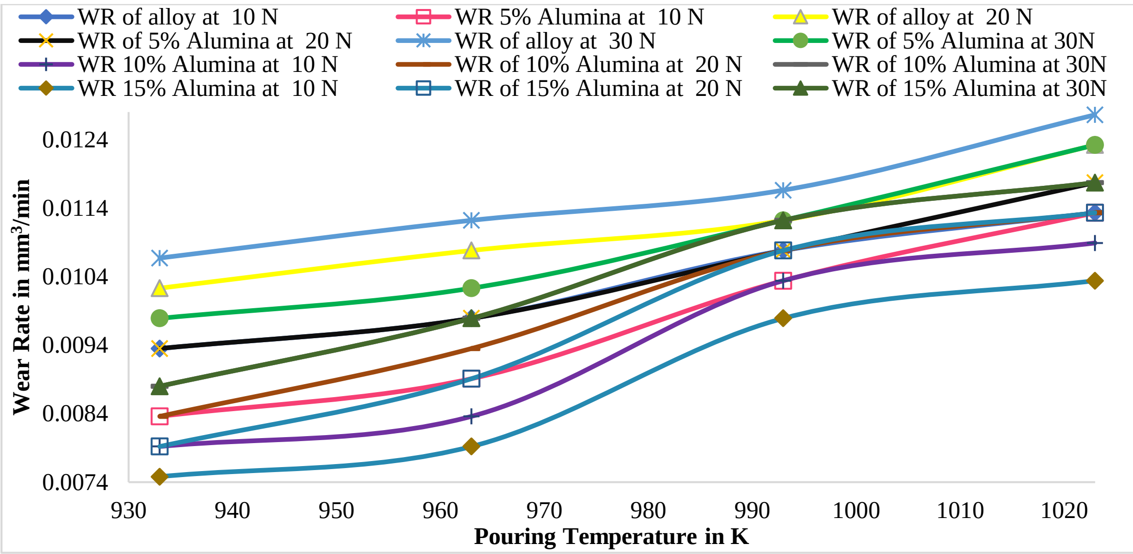

Fig. 8 – % Wear rate of Al alloy and Al-MMC vs. Pouring temperature normal load at SV=3 m/ s

It was observed from the Figure 9-11 that the PWR increased with an increase in DPT. On increasing the DPT, the hardness and strength of composites decreased, which increased the wear rate. The pattern of PWR of LM6 Al alloy, 10, and 15% wt. Al_2O_3 and SiC reinforced composites were similar to that of MMC (5% wt. Al_2O_3+SiC). The PWR decreased with the weight fraction of reinforcing particles and increased with the DPT, NL, and SV.

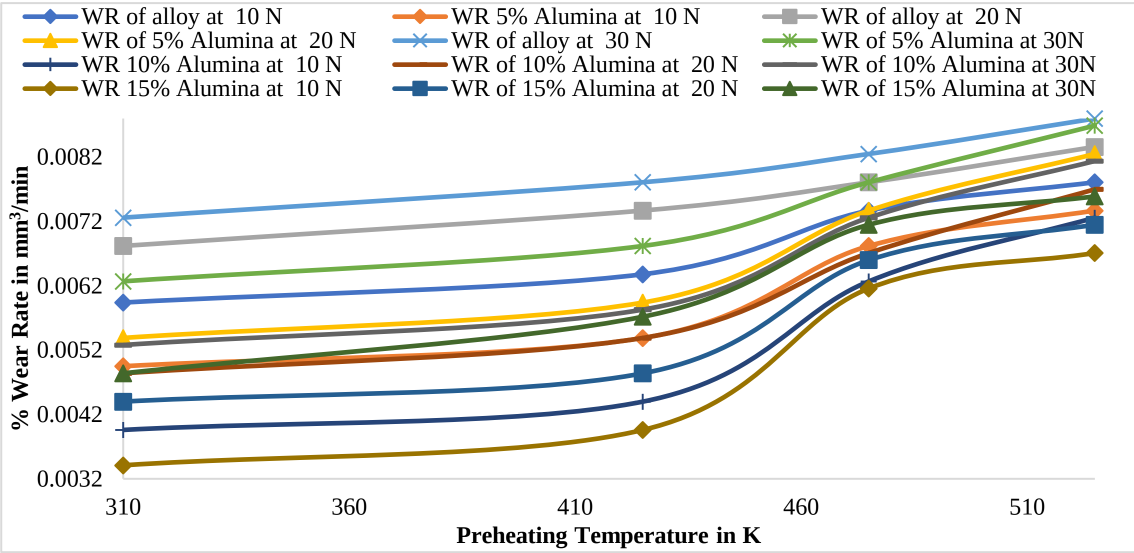

Fig. 9 – % Wear rate of Al alloy and Al-MMC vs. Preheating temperature of dies and normal load at SV=1.5 m/s

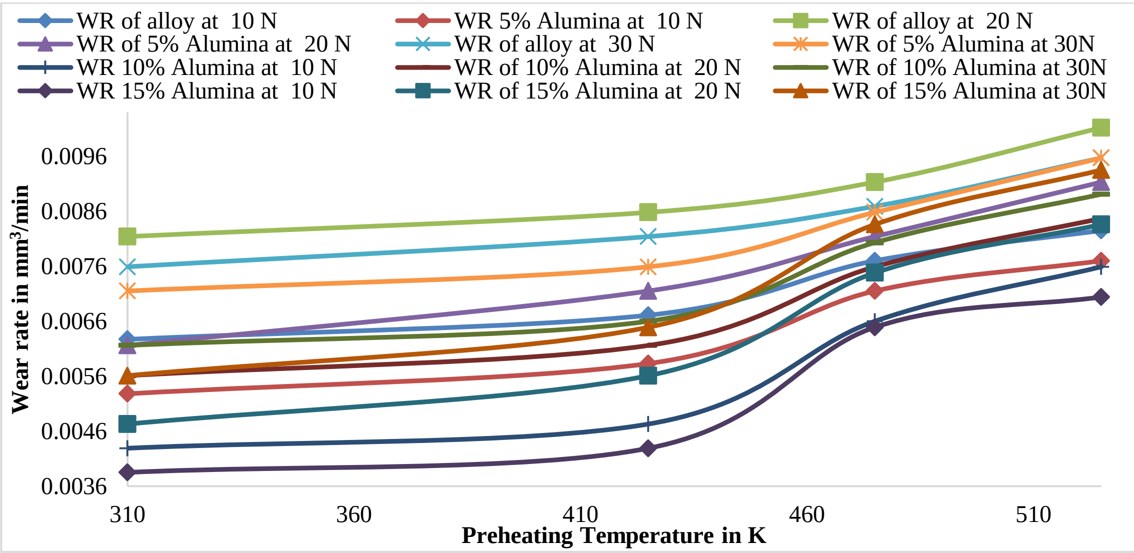

Fig. 10 – % Wear rate of Al alloy and Al-MMC vs. Preheating temperature of dies and normal load at SV=2.25 m/s

3.2 Coefficient of Friction, f

3.2.1 Influence of Squeezing Pressure

Figures 6-8 represent the variation of *f* as a function of SPs, weight fraction of reinforcements, and NLs in MMCs (produced at 933K) at different SV of 1.5 to 3 m/s. Figure 6 shows the f of Al-Si 12 alloy and MMCs at a sliding velocity of 1.5 m/s. The graph shows that *f* decreased up to 20 N, and then it increased drastically with loads for all the materials studied. The *f* of Al-Si 12 alloy and Al-MMCs are containing 15% wt. (SiC+ Al_2O_3) decreased by 7 and 5% and 17 and 13% on the NL varying from 10 to 20 N and 20 to 30N, respectively. Factors NL and SV influenced the growth and splitting, and the stability of the mechanical layer formed at the contacting surfaces. At low NL, the *f* remains low because of the reduced contacting region.

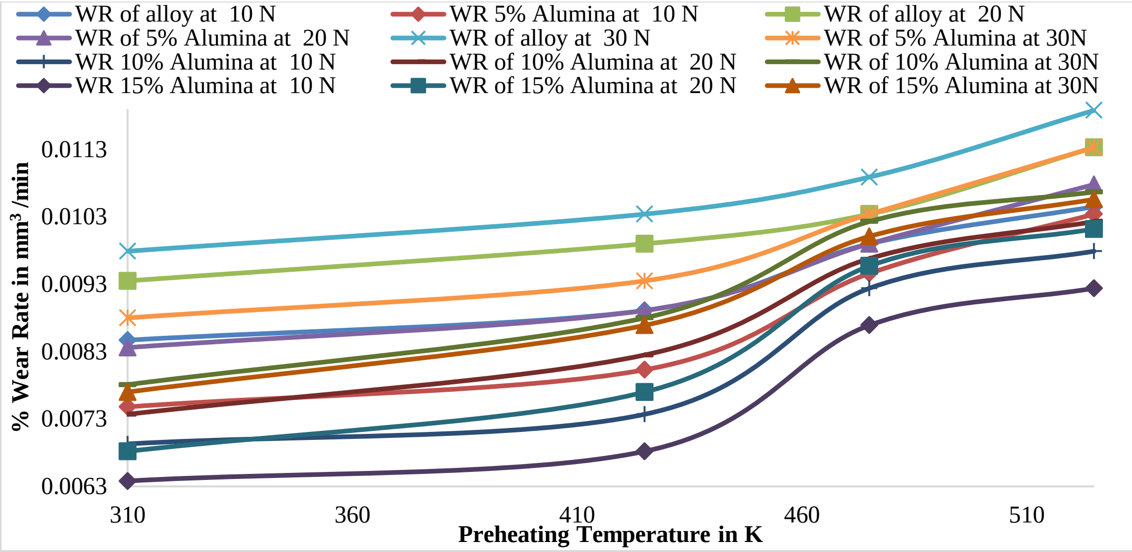

Fig. 11 – % Wear rate of Al alloy and Al-MMC vs. Preheating temperature of dies and normal load at SV=3 m/s

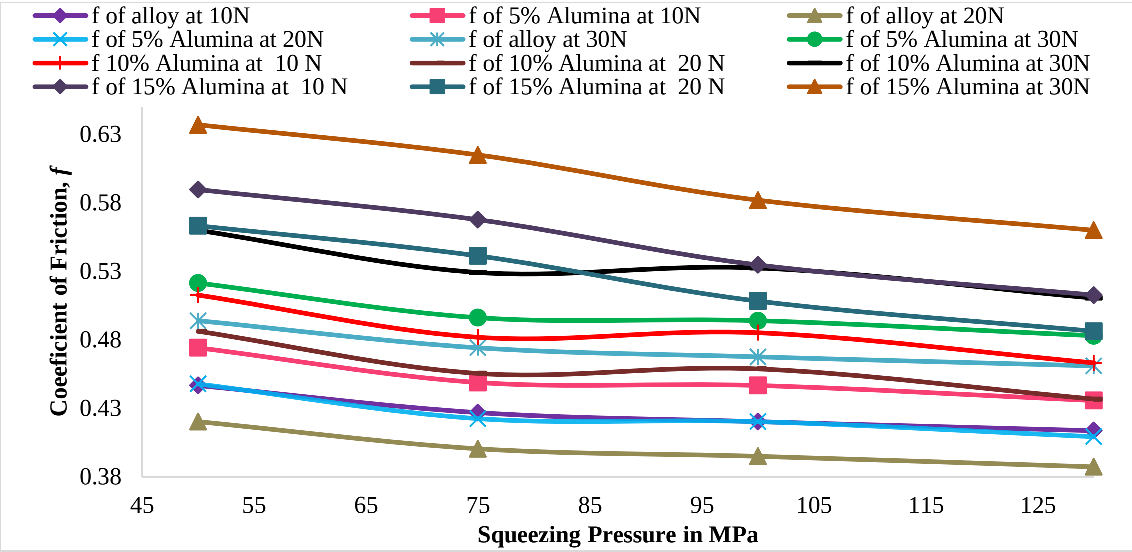

Fig. 12 – Coefficient of Friction of Al alloy and Al-MMC vs. Squeezing pressure and normal load at SV=1.5 m/s.

At medium NL, primarily f increases due to sizeable contacting region. Afterward, it was gradually decreasing because of mechanically mixed film formation by worn-out particles. But the overall *f* was less compared to lower NL. At high NL, the thickness of the mechanical film was containing a large quantity of reinforcing particles results in the breaking of the mechanical film; hence the *f* was increased. Similar results were observed for SV of 2.25 and 3 m/s. *f* for Al-Si 12 alloy and its MMCs varied linearly with SV and SV increasing from 1.5 to 2.25 m/s has increased *f* by 10% (Al alloy), 10, 9 and 7.5% (MMC with 5, 10 and 15% wt. Al_2O_3+SiC) respectively. Besides, a 5% increase in f was found for every material formed, and SV had beyond 2.25 m/s due to reinforced particles of the composites spread onto the contacting surfaces to form Mechanical film retained only for a short time to rising SV. The mechanical film would be removed or forced out at the contacting region resulting in a higher *f* at larger SV. Similar kinds of results were seen for NL of 20 and 30 N.

As reinforcing contents (Al_2O_3 + SiC) increased in Al-Si 12 alloy, *f* was increased with more excellent value at 15% wt. (Al_2O_3 +SiC) (Jiang et al. 1994; Abdel Azim et al. 1995). After a certain period, these reinforcing particles were pulled out from the contacting areas and increased the *f* due to jam-packed at the contacting surfaces leading to the higher *f*. The *f* of Al-MMC (5% wt. Al_2O_3 +SiC particles) at an SV of 1.5 m/s found decreasing for increasing squeezing pressure (50 to 130 MPa) by 5.5 to 6% for the NLs (10-30 N). The hardness and strength of composite were increased by raising the squeezing pressure, resulting in a low *f*. From the graph, the *f* of MMCs decreased on increasing the NL from 10 to 20 N and then kept increasing the NL beyond 20 N. Similar results were noticed for SV of 2.25 and 3m/s. At lower squeeze pressure, the MMCs had low hardness and strength due to some porosity and forging defects, leading to higher *f*. The trend of the *f* of Al-Si12 alloy and MMCs (10% &and 15% wt. Al_2O_3 +SiC) was similar to that of MMC (5% wt. Al_2O_3+SiC).

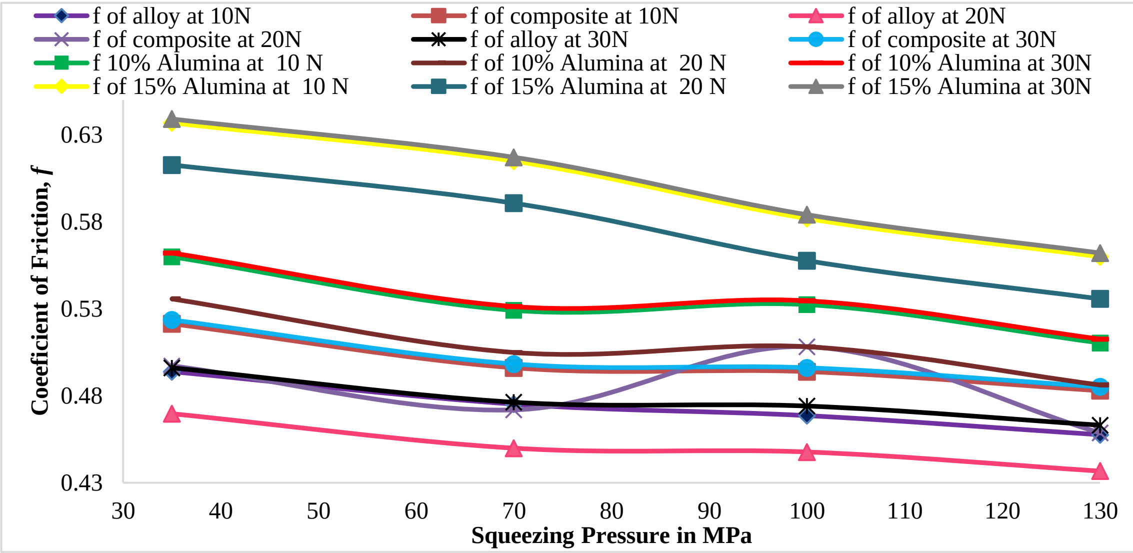

Fig. 13 – Coefficient of friction of Al alloy and Al-MMC vs. Squeezing pressure and normal load at SV=2.25 m/s.

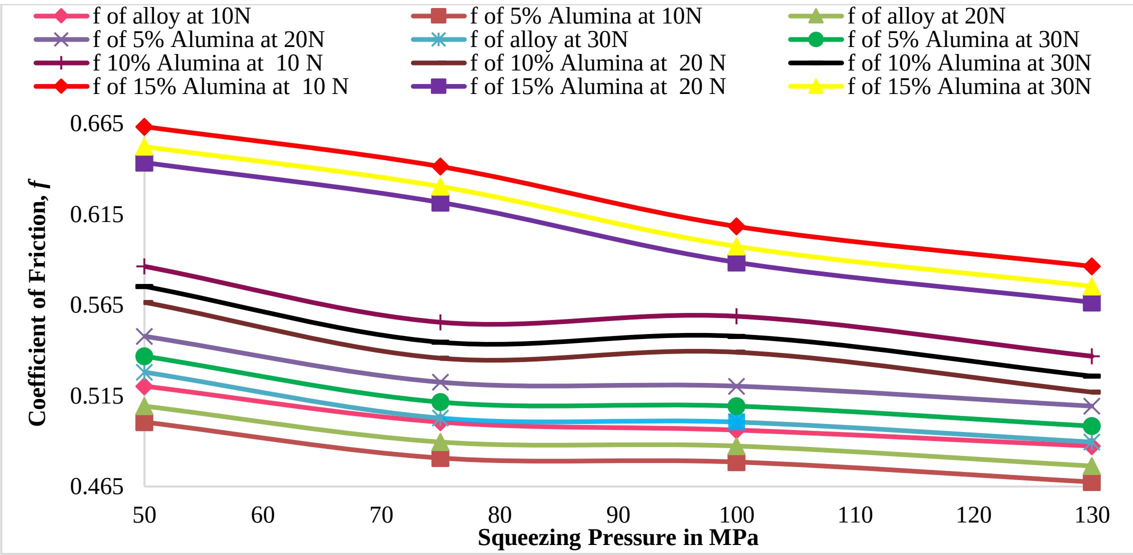

Fig. 14 – Coefficient of friction of Al alloy and Al-MMC vs. Squeezing pressure and normal load at SV=3 m/s.

3.2.2 Effect of Pouring temperature

The impact of PT on the f of MMC (5% wt. Al_2O_3+SiC particles) based on various NL, and SV are presented as a part of plots in Figures 15-17. The *f* of MMCs with PT (933 K) at an SV of 1.51 m/s was initially 0.2937 increased by 10% when the PT maintained at 963K and NL of 20 N. Furthermore, a small boost approximately 2.5 and 3% when the PT was increased from 963-993K, and 993-1023 K. Similar pattern results of *f* were seen for other set NL and SV. Plot show that the *f* of MMCs decreased and then increased with a rising NL and SV of 2.25 and 3 m/s. The same thing holds for the *f* of Al-Si 12 alloy and MMCs (10 & 15% wt. Al_2O_3+SiC) variation, similar to that of MMC (5 wt. % of Al_2O_3+SiC) as seen in Figures 15-17. Raising *f* in MMCs due to hard ceramic particles possess higher hardness, and strength got reduced on increasing the PT. The coefficient of friction rose as the quantity of reinforcing particles and the pouring temperature increased. Further, it firstly decreased and then increased on increasing the NLs, and SVs.

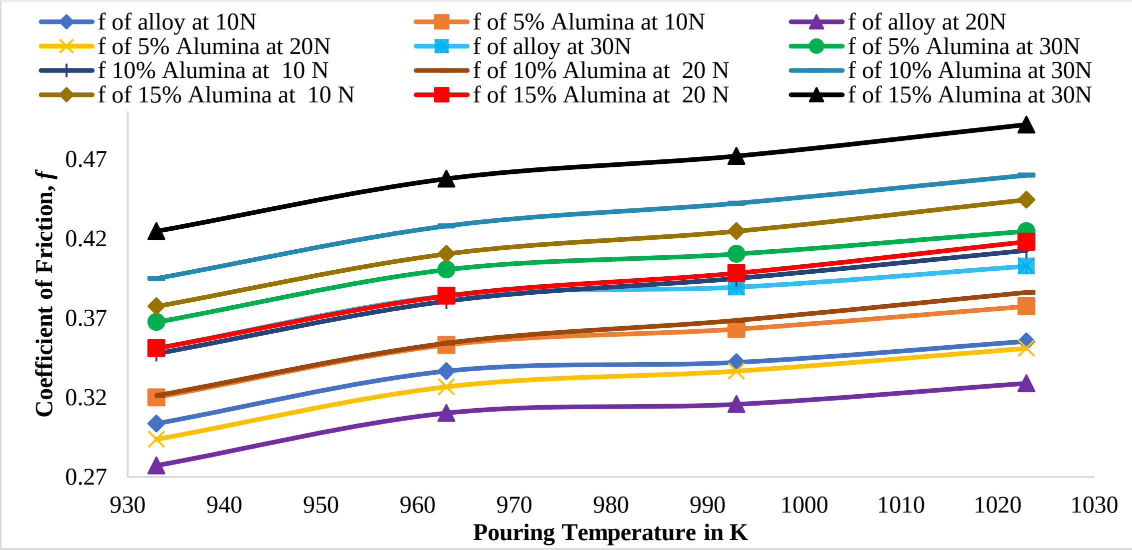

Fig. 15 – Coefficient of friction of Al alloy and Al-MMC vs. Pouring temperature and normal load at SV=1.5 m/s.

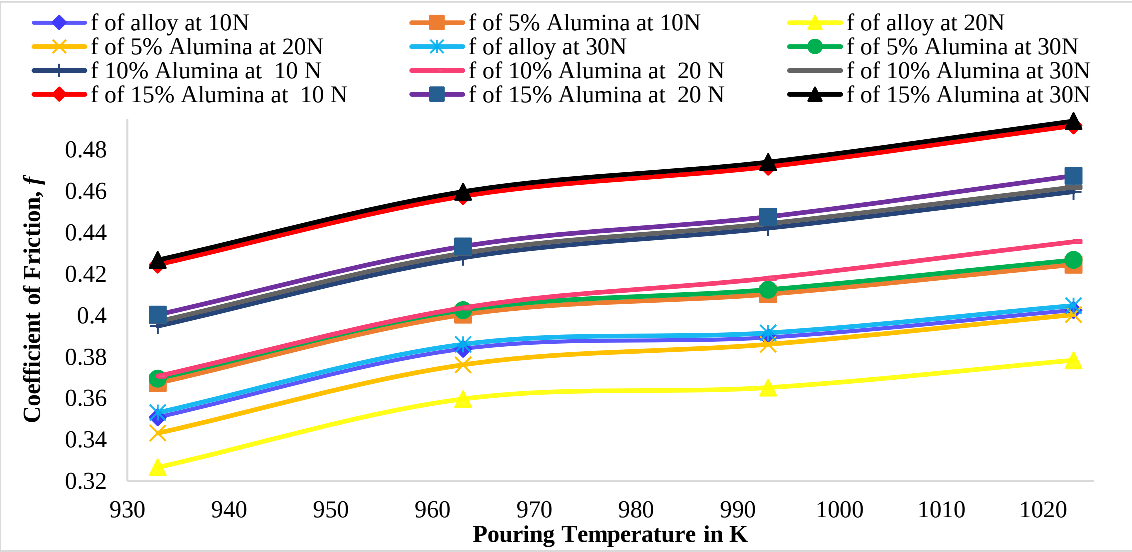

Fig. 16 – Coefficient of friction of Al alloy & Al-MMC vs. Pouring temperature and normal load at SV=2.25 m/s.

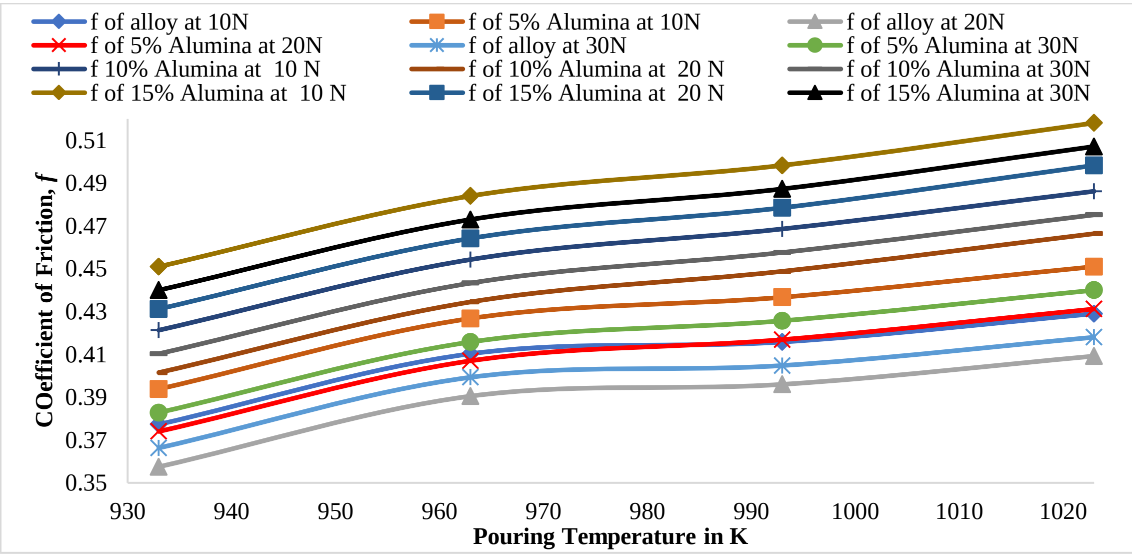

Fig. 17 – Coefficient of friction of Al alloy & Al-MMC vs. Pouring temperature and normal load at SV=3 m/s.

3.2.3 Effect of Die Preheating Temperature

The Al-Si 12 alloy and Al-MMC samples were fabricated at different DPT of 310, 425, 475 and 725K maintaining SP of 90 MPa and PT of 993K to study the consequences of DPT on Tribological properties. Firstly, MMC (5 wt.% of Al_2O_3 and SiC particles) as a function of NLs and SVs are taken partly from Figures 18-20 for varying DPT. At a SV of 1.51 m/s, the *f* was increased by 9, 10 and 8 % when the DPT was increased from 310 to 425K and NL of 10, 20 and 30 N respectively. Similarly, the *f* was increased by 3, 2.5 and 2% and 4, 3.8 and 3.4% for DPT from 425 to 473K and above 473K and at NL of 10, 20 and 30 N respectively. Similar result pattern was noticed for SV of 2.26 and 3.02 m/s. Figures 18-20 revealed that the *f* was increased with an increase in DPT for all NL and SV considered. The reason for this is decreasing hardness and strength of MMCs with increasing DPT. Above pattern of results of the *f* of MMC (5 wt.% of Al_2O_3+SiC) are followed by Al-Si 12 alloy and MMCs (10 and 15 wt.% of Al_2O_3+SiC) and were varied in the similar fashion.

It is inferred that *f* was increased when % weight of reinforcing particles and DPT were increased as well as firstly decreases and then increases as the NLs and SVs are increased.

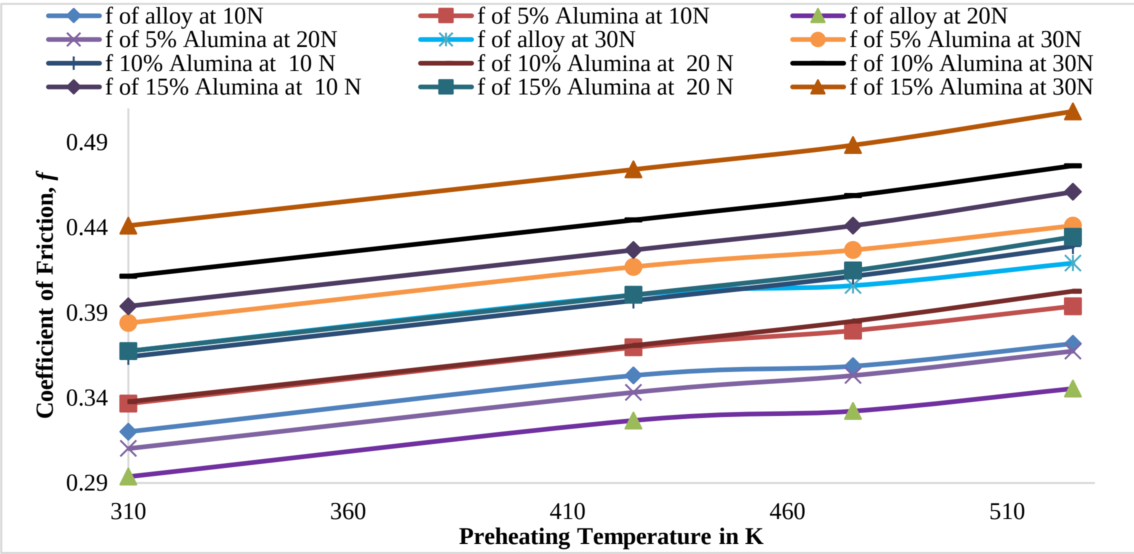

Fig. 18 – Coefficient of friction of Al alloy & Al-MMC vs. Preheating temperature of die and NL at SV=1.5 m/s.

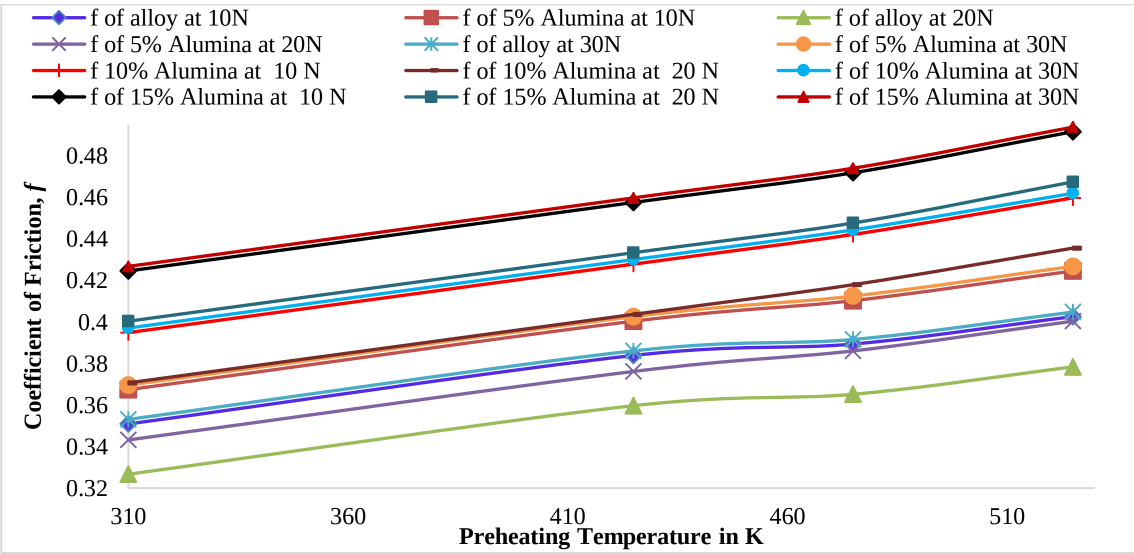

Fig. 19 – Coefficient of Friction of Al alloy & Al-MMC vs. Preheating temperature of die and NL at SV=2.25 m/s.

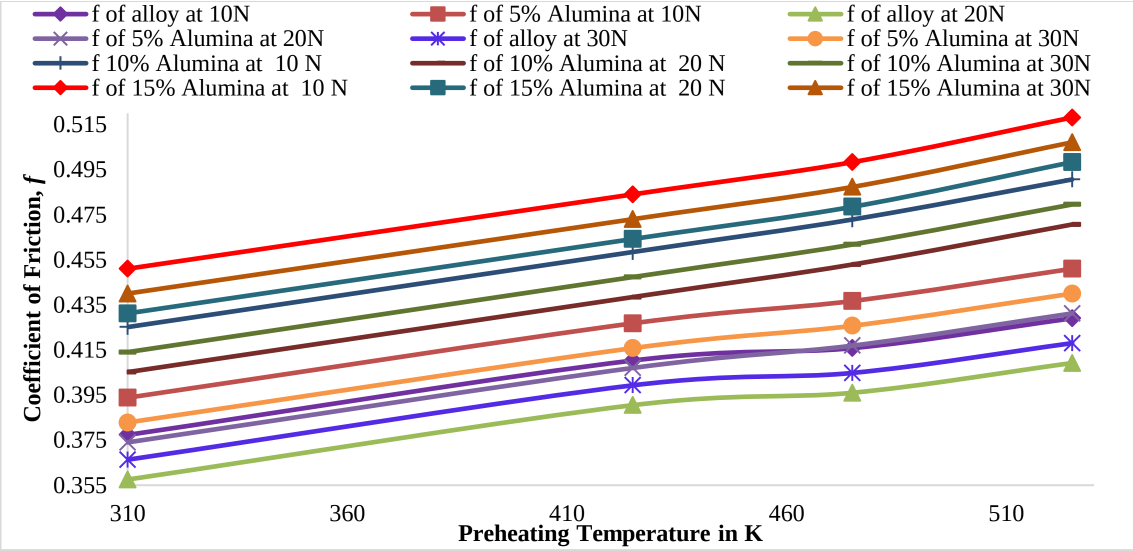

Fig. 20 – Coefficient of friction of Al alloy & Al-MMC vs. Preheating temperature of die and NL at SV=3 m/s.

The work can be extended to other properties like machining characteristics, mechanical and fracture properties. Mathematical modeling of tribological properties can be developed in forecasting the future data remotely without experimentation.

4 Conclusions

The consequences of input factors of liquid metal forging or squeeze casting on tribological properties of Al-Si 12 alloy and MMCs were studied to understand the role of such factors in obtaining quality products. The reinforcing elements (Al_2O_3 and SiC) are more rigid particles in Al alloy reduced the PWR and increased the *f*, coefficient of friction at every level of liquid metal forging parameter considered in this study. An increase in the squeezing pressure intensity resulted in a dropping of PWR, and *f*. similar trend of results were seen with decreasing PT and DPT on the PWR and coefficient of friction. The PWR of MMCs was increased with an increase in NL and SV at considered factors of the forging process. Conversely, *f* of MMCs initially declined and then raised with an increase in NL and SV. Reinforcing elements % weight has also contributed to PWR and *f* in a similar trend.

CONFLICTS OF INTEREST

The authors have no conflicts of interest.

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