Visual Abstract

Investigation on microstructure, hardness, wear behavior and fracture surface analysis of Strontium (Sr) and Calcium (Ca) content A357 modified alloy by statistical technique

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ABSTRACT. The aluminum alloy are extensively used in several industrial applications. Stir casting is one of the most frequently accepted methods. In the present investigation, how the microstructure, mechanical and wear mechanics of A357 alloy were impacted by the presence of Sr/Ca was investigated. The outcomes revealed that addition of elements (Sr/Ca) enhance the microstructural features. Uniform dispersal of particulates (Sr/Ca) in Al357 alloy and also the modified structure of silicon (Si) were observed. Hardness of modified alloy was evaluated by using hardness tester. A result reveals that hardness of modified alloy was improved by increasing in the Sr/Ca content. The wear rate of modified alloy was evaluated by using Pin and Disc wear test rig. Test trials were conducted according to Taguchi technique. L27 array was implemented for evaluation of data. The effect of varying parameters (factors) on wear loss and COF were analyzed using ANOVA (Analysis of Variance) method. ANOVA outcomes shown that, the Sr/Ca content has a better significant impact on wear behavior and COF of the modified alloy. A wear fractography result shows the internal fracture structure of a wornout surface which was studied by SEM analysis.

KEYWORDS. A357 Alloy, Strontium (Sr), Calcium (Ca), Stir casting, Hardness,

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Wear behavior, Fracture surface, Statistical technique.

INTRODUCTION

Aluminum alloy is the major alloy used for light weight metal parts because of good castability, low cost, low weight, and also exhibits better mechanical characteristics [1]. Aluminum alloy is extensity used in various engineering applications like, aircraft/aerospace, automobile and industrial products. Subsequent solidification of casting effects mechanical and wear properties of cast parts due to microstructural changes [2, 3]. Mechanical strength can be enhanced by the addition of chemical modifiers generally, which cause better microstructure during solidification process. Adding of Ba, Sr, Ca, Na, and Eu, causes modification of the eutectic "Si" morphology from the coarse structure into fine fibrous structure and also a positive effect on ductility and material strength [4]. Though the effects of chemical modifications were known from 10 decades back but there was no universally recognized understanding of the mechanism that which allows the micro-structure to change upon addition of little extra metal ingredient/s was available [5,6]. In the past 55-65 years, several mechanisms of eutectic modifications were written about in literature survey, some of them focused on the eutectic growth [7], and others on the eutectic nucleation [8]. Alloying elements like Cu and Mg, Al-silicon alloy in heat-treatment enable to attain improved mechanical and wear behavior [9, 10]. In most cases, heat treatment involves a first stage when solubilization occurs. The second stage of artificial ageing occurs as the alloying element(s) solubilize in the -Al matrix, while intermetallic phases nucleate in the Al matrix, improving the mechanical characteristics. Some chemical elements (Sr, K, Na, Rb, Ca, La, Ce, Yb and Ba) lead to promote the modifications of eutectic Si instead of heat-treatment [11, 12]. Introduction of "strontium" (Sr) leads to further refinement of the structure and enhances the ultimate tensile strength. These characteristics of the directionally crystallized alloys are greater than the eutectic alloy achieved by casting in a mold [13-15]. Sr has also been reported about modification of the inter-metallic particles which lead to high stress concentrations. Though, not all the side effects formed by addition of Sr are good. Addition of Sr was effected improved porosity with in Al-Si alloy. Sr addition has been stated to improve the efficiency of oxide inclusions within the Al melt as pore nucleation's site. The change in porosity features thus is influenced by the amount of Sr existing in the solidified structures. Porosity causes reduction in mechanical strength and leads to lower-quality of cast parts. Sr additions will also relate with grain refinements of Al foundry alloy [16-18]. In [19], the researcher studied the influence of modifying Sr in A357 matrix alloy on the mechanical behavior and it was found that, there was an increase in the influence released energies with reduction in the grain size after the modifying of Sr element. Investigational evidence confirmed that Sr modification leads to effective due to the both quantity and quality of Sr particulates. Improved quality in mechanical properties requires a low "Sr" amount [20]. In [21], addition of Sr was examined in the alloy, and concluded that "Sr" causes a considerable enhancement in tensile strength compared to properties of unmodified cast part. Beneficial application of calcium (Ca) contain modifier in Al-Si alloy, iron neutraliser in the recycled Al alloys with more iron content, scavenger of P, Bi and Sb from secondary alloy, stiffening agent in the fabrication of Al foams and also wetting promoter within the synthesis of the Al MMCs; as an alloying elements, and calcium will impart the superplasticity [22]. The use of Ca like a modifier is presently under technical discussion as the existence of Ca in the Al alloy may lead to negative impact. In small quantity, Ca may positively impact the subsequent alloys structure and consequently, its ensuing properties. In larger amount, Ca has an effect on undesired gasification of alloys, which leads to a rise in the porosity of a resultant structure [23]. In [24], it was concluded that, Ca can be used as significant alloying element content in Mg alloy to increase their high strength and cause better creep resistance. Al alloys with added calcium become low-cost Mg alloys which can be used as enhanced heat resistant component in automobile applications [25, 26]. The researcher [27], stated that, Ca offers a thermally stabled second phase (Mg_2Ca) and thus considerably enhanced the creep property and elevated high temperature strength. It was stated that, the adding small quantity of Ca into Al alloy can lead to refinement of the grain-structures and also enhances the mechanical properties. It is observed that, the Ca can be used like grain refiner in Al alloy material [28]. Drits et al. [29] concluded that, addition of Ca content in Mg based alloys not only refines the micro-structure but also it improves the creep resistance and resists high temperature oxidation. For better comprehensive studies on wear characteristics, evaluation of various parameters is needed and the contribution effects between these process parameters which are been ignored in the previous research were necessary to be evaluated. The Taguchi method is selected as strong design when it is compared to the traditional design methods. Taguchi method shows that, it is an effective and optimal technique to minimizing the time and cost for carrying out the experimental trials to optimize the varying parameters. Taguchi method basically pays with important tools like S/N (Signal-to-Noise) ratio generally which shows the better characteristic variance due to un-controllable of process parameters. Significant measure is just the choice of parameters for the concept of DOE. In Taguchi technique, the test trials remarkably play an important role. For more accuracy of the outcomes, the experimental trials will be achieved according to the 27 trials (L27 OA). Process parameters for the present investigation are weight percentage of reinforcement content, load (N) and sliding distance (m). From literature survey, it was found that the optimization of varying parameters is important factors which required in evaluating the mechanical band wear behavior of the developed hybrid composites. The novelty of the research work is to investigate the effect of the Strontium (Sr) and Calcium (Ca) content on microstructure, hardness, wear behavior and tensile strength of A357 modified alloy. Design of Experiments (DOE) is an effective and a significant technique to evaluate the effect of process parameters simultaneously. Significant feature of the Design of Experiments was to evaluate the influence of individual process parameter at very less number of test trials. Generally, these techniques have been successfully used by many researchers to evaluate the material characteristics of AMMCs. Taguchi method usually reduces the total number of experimental trials due to the Design of Experiments.

FABRICATION OF CAST PARTS

A357 was used as a base alloy and two dissimilar modifying elements Strontium (Sr) and Calcium (Ca) were used for the fabrication of modified cast parts. In the present work, three different cast parts (A357, A357+Sr and A357+Ca) were fabricated by stircasting method. Here, the wt. % of two modifying elements was varied like 4-10% in steps of 2%. Electrical furnace was used to melt A357 material. After maintaining the temperature between 700-750°C, Sr / Ca granular were added in to the melt with continuous stirring action. Stirring was maintained continuously for about 2-3 min after the addition of Sr / Ca particulates for uniform dispersal in the molten melt. Then, the melting temperature was maintained upto 800°C for a period of 30 min, so that Sr and Ca particulates got dissolved into the molten melt. Three different cast parts such as without modifier (A357), with modifier i.e., A357+Sr and A357+Ca cast parts were fabricated by pouring of ready molten melt into the preheated mould box. The cast components were removed from the mold box, and the test samples were then machined in accordance with ASTM requirements.

MATERIAL CHARACTERIZATION

Hardness

Using Vickers Microhardness testing equipment, the microhardness of produced composites was evaluated in accordance with E92-ASTM criteria. For 15 seconds, a diamond-shaped indenter was utilised with a load of 5 kg. In order to get the average hardness values, three distinct zones on wear test specimens were used to analyse each hardness test trial at room temperature of 27˚C.

Wear test

Wear testing was done in accordance with the ASTM standard norms. In the current study, testing against steel discs were conducted with varied parameter levels (Grade: EN-32). Test specimens were pre-machined and finishing using conventional machining process and WEDM machining process respectively. Wear test samples with size of 8 mm in diameter and 50 mm in length were developed according to ASTM G99-05 standards. The wear loss of hot rolled hybrid composites were studied by weight loss method. During wear tests, the hot rolled hybrid Al composite samples were held rigidly towards rotating hard steel disc (EN-32 grade). After each and every test trails, the samples were measured. In the present research, the wear rate was determined based on the weight loss method (weight difference between initial and final of the test specimens).

RESULT AND DISCUSSION

Microstructure study

An eutectic microstructure of unmodified, Sr-modified and Ca-modified alloy is depicted in Fig. 1. Microstructures of unmodified alloy depend on the inter-metallic phases and which generally depends on the alloying element. The amount of inter-metallic phases in the Al alloy and their effect on mechanical characteristics generally depends on the compositions of Al alloys. Some of these inter-metallic phases have proved to be detrimental, such as β-

Al5FeSi, increasing in iron (Fe) content, causes reduction in elongation. Fe-β inter-metallic phases were observed in alloys. Sr / Ca significantly influence strength in developed cast parts. Fig. 1 (a) shows the microstructure of A357 alloy without modification of Sr / Ca and also primary α-phase was distributed in a disorderly manner. The addition of "Sr" causes modification of the micro-structure as depicted in Fig. 1 (b). The eutectic point is effectively changed by Sr addition to have a larger silicon (Si) concentration at low temperature. When the eutectic points are displaced far enough, the Al alloy becomes hypo-eutectic rather than hyper-eutectic at this composition. As a result, these alloys' microstructure is altered and their characteristics may be significantly improved by a small amount of Sr. [30-32]. Small amount of Sr can bring about a change in the morphology of eutectic silicon phase which causes change in Al alloy from the coarse structure to a fine fibrous structure. When "Ca" was modified in the Al alloys as depicted in Fig. 1 (c), it is observed that, the primary α-phase dendrites was reduced. When Ca was added the best refinement in the microstructure in Al alloy was observed. And also the primary α-phase with smallest dendrite size, which was settled regularly within the base alloy, was seen. By Ca addition, the micro-structure of the Al alloys started to deteriorate. The primary dendrite of a primary α-phase becomes coarse. So, the size of the primary α-phase dendritic was very small and also it is in uniform distribution [33].

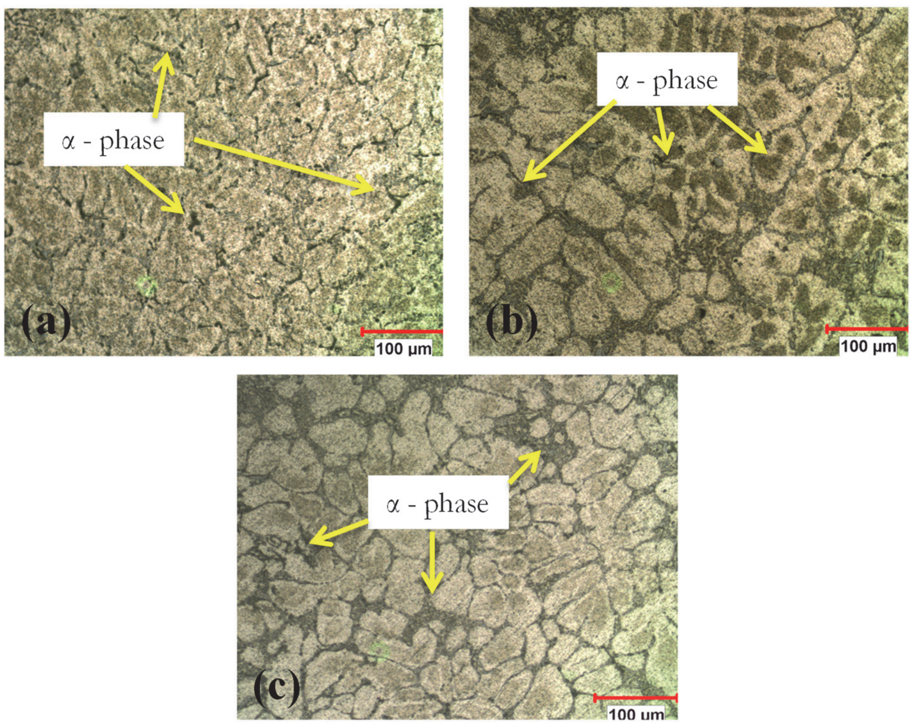

Figure 1. Microstructure images of (a) A357 (b) A357+Sr (c) A357+Ca

Hardness

The influence of Sr and Ca modification on hardness of Al alloy is as shown in Fig. 2. Hardness was measured at five different locations on the sample and average mean value of the hardness is considered. The variation of the hardness values were found with ±2 HVN in each sample. It is found that the hardness of unmodified is lower than that of simultaneously modified Sr / Ca cast parts. Similar variation in hardness of such developed cast parts fabricated by stir casting was observed. Enhancement in the hardness of the developed cast parts maybe related to the modified elements which increase particulates wettability in alloy [34]. Since, chemical modifications could form tiny and round Si crystal due to the phenomena of fragmentation. The existence of tiny and round Si particulates reduces the stress concentration in alloy and consequently increases strength in material [35-37]. The changes in micro-structure due to Sr modification produce an enhancement in the hardness of the alloy cast in metal moulds. Sr particulates were also applied to transform the platelet Fe-rich phases to an AlFeSi. The addition of Sr promoted the development of a-AlFeSi and also improved the strength in material. It was also observed that, the material properties were improved by the addition of Sr into Al alloys. Fe is one of the alloying elements in A357. Fe-rich intermetallic phases have much more multifaceted morphologies, with brittle and fragile appearance. The existence of Fe is usually reported to have a detrimental effect on strength, ductility, and fatigue properties of Al alloys. After modifying Ca content, the hardness of the developed cast part was enhanced when compared with the hardness of unmodified cast part. The development observed was attributed to the corresponding enhancement in grain refinement [38]. Whereas the hardness of A357+Ca cast parts is lower when it is compared to the hardness of A357+Sr cast parts. Similar outcomes were also observed from other researcher [34]. But at high wt. % of Sr and Ca content, led to reduction in the hardness due to agglomeration effects [39, 40]. Also, the percentage porosity increases as the Ca and Sr elements content increases beyond 10% in the base material (A357). It can be concluded that the changes in porosity of the base materials that occurs as a result of decreases in hardness of the A357 alloy.

Wear Behavior and COF

Objective of the present research is to study the importance of process parameters which were used in the current investigation to achieve the improved wear resistance and enhanced COF. In the present study, 'Minitab-v16' software was used for the statistical analysis. The parameters and their varying levels used in this current research are depicted in Tab. 1. Based on several trials and also referred the research papers and finally selected process parameters with their levels for the wear loss and COF studies. According to Taguchi design of experiments, L27-orthogonal array selected for the statistical analysis. All the 27 trials were conducted and measured the responses like, wear loss and COF are tabulated. Samples were undergone to test trials according to the Taguchi study with L27-orthogonal array (OA). Design of test trails along with the outcomes of COF and wear rate are depicted in Tab. 2.

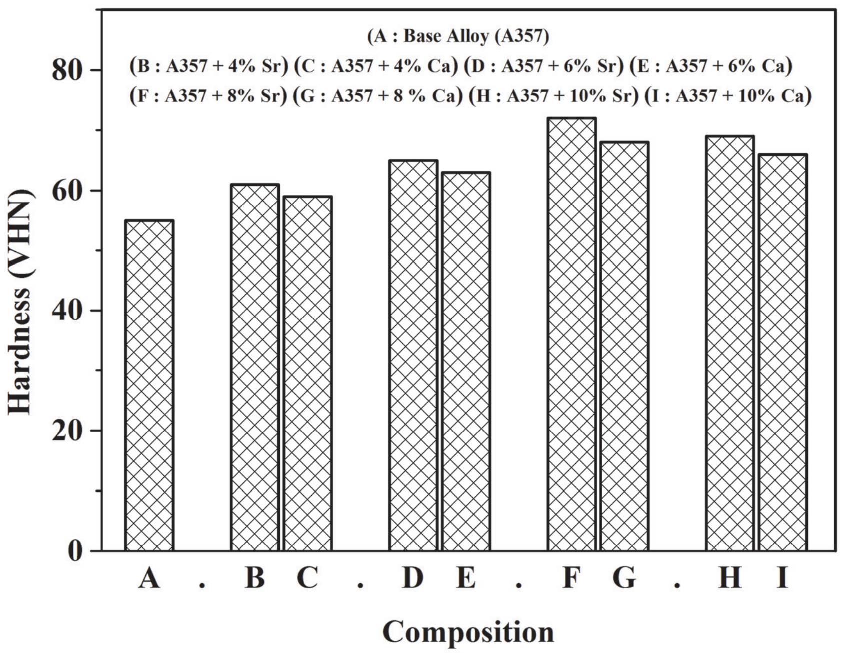

Figure 2: Hardness of A357 and varying wt. % of Sr and Ca

Sl. No.	Parameters	Varying Levels		
		Level 1	Level 2	Level 3
1	Sr (Wt. %)	4	6	8
2	Ca (Wt. %)	4	6	8
3	Load (N)	10	20	30
4	Sliding Distance (m)	750	1000	1250

Table 1: Selected process parameters with their levels.

Experimental results of wear loss and the COF for modified alloy under the varying process parameters are depicted in Tab. 2. The ANOVA was implemented to evaluate the significance level of the each process parameter. By implementing ANOVA technique, it is likely to define which factor is controlled over the other factor. Also, significance level of each process parameter which are been used in this research could be evaluated. Means that ANOVA tables indicates the percentage of contribution of each parameters and their effects on the wear arte and COF and also tables indicates the parameters are statistically significances or not. Investigational studies were carried out at a level of significance with 0.05. The factors with a P-value of < 0.05 were been considered to contribute the significance of the performances [24, 27]. ANOVA results for wear loss of the modified alloy are depicted in Tab. 3. It reveals that, the wt. % of Sr is extremely significant factor with a maximum % (70.59) of contribution between the other parameters followed by the wt. % of Ca, load and sliding distance was the least significant parameter.

The ANOVA results for COF of the modified alloy were depicted in Tab. 4. It is reveals that, the wt. % of Sr is extremely significant factor with 38.31 % of impact between the other parameters, followed by the sliding distance, load and wt. % of Ca was the minimum significant parameter.

Sl. No.	Sr (wt. %)	Ca (wt. %)	Load (N)	Sliding distance (m)	Wear loss, g	COF (μ)
1	4	4	10	750	0.080	0.35
2	4	4	20	1000	0.090	0.25
3	4	4	30	1250	0.095	0.18
4	4	6	10	1000	0.089	0.20
5	4	6	20	1250	0.095	0.30
6	4	6	30	750	0.084	0.20
7	4	8	10	1250	0.072	0.15
8	4	8	20	750	0.055	0.50
9	4	8	30	1000	0.075	0.30
10	6	4	10	750	0.050	0.65
11	6	4	20	1000	0.055	0.25
12	6	4	30	1250	0.095	0.10
13	6	6	10	1000	0.035	0.55
14	6	6	20	1250	0.051	0.40
15	6	6	30	750	0.049	0.55
16	6	8	10	1250	0.052	0.50
17	6	8	20	750	0.044	0.70
18	6	8	30	1000	0.080	0.41
19	8	4	10	750	0.039	0.70
20	8	4	20	1000	0.047	0.50
21	8	4	30	1250	0.040	0.40
22	8	6	10	1000	0.021	0.70
23	8	6	20	1250	0.029	0.30
24	8	6	30	750	0.028	0.50
25	8	8	10	1250	0.025	0.65
26	8	8	20	750	0.021	0.70
27	8	8	30	1000	0.030	0.50

Table 2: L27-OA Taguchi and the responses.

Sources	DOF	Seq-SS	Adj-SS	Adj-MS	F-Value	P-Value	% of Cont.	Observations
Sr (wt. %)	1	0.0115015	0.0115014	0.112014	103.771	0.0000000	70.59	Significant
Ca (wt. %)	1	0.0010427	0.0010427	0.0010427	9.408	0.0056404	6.39	Significant
Load (N)	1	0.0007094	0.0007094	0.0007094	6.400	0.0190765	4.35	Significant
Sliding distance (m)	1	0.0006009	0.0006009	0.0006009	5.422	0.0294788	3.68	Significant
Error	22	0.0024384	0.0024384	0.0001108			14.96	
Total	26	0.0162927					100	

Table 3. The ANOVA outcomes for Wear loss.

Sources	DOF	Seq-SS	Adj-SS	Adj-MS	F-Value	P-Value	% of Cont.	Observations
Sr (wt. %)	1	0.352800	0.352800	0.352800	35.3577	0.0000055	38.31	Significant
Ca (wt. %)	1	0.058939	0.058939	0.058939	5.9069	0.0236914	6.40	Significant
Load (N)	1	0.095339	0.095339	0.095339	9.5549	0.0053350	10.35	Significant
Sliding distance (m)	1	0.194272	0.194272	0.194272	19.4700	0.0002203	21.09	Significant
Error	22	0.219517	0.219517	0.009978			23.83	
Total	26	0.920867					100	

Table 4. The ANOVA outcomes for COF (μ).

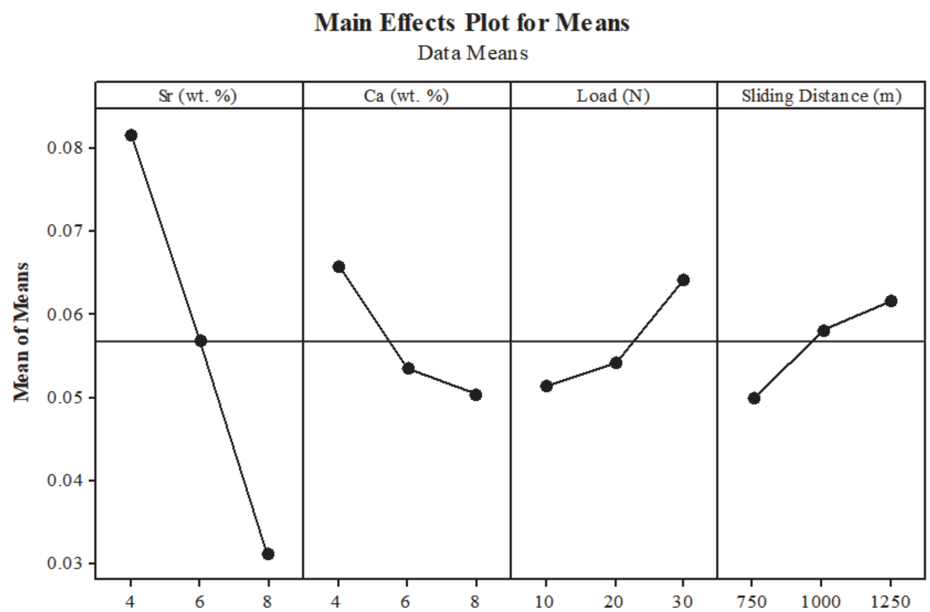

Figure 3: Effect of varying factor on wear loss.

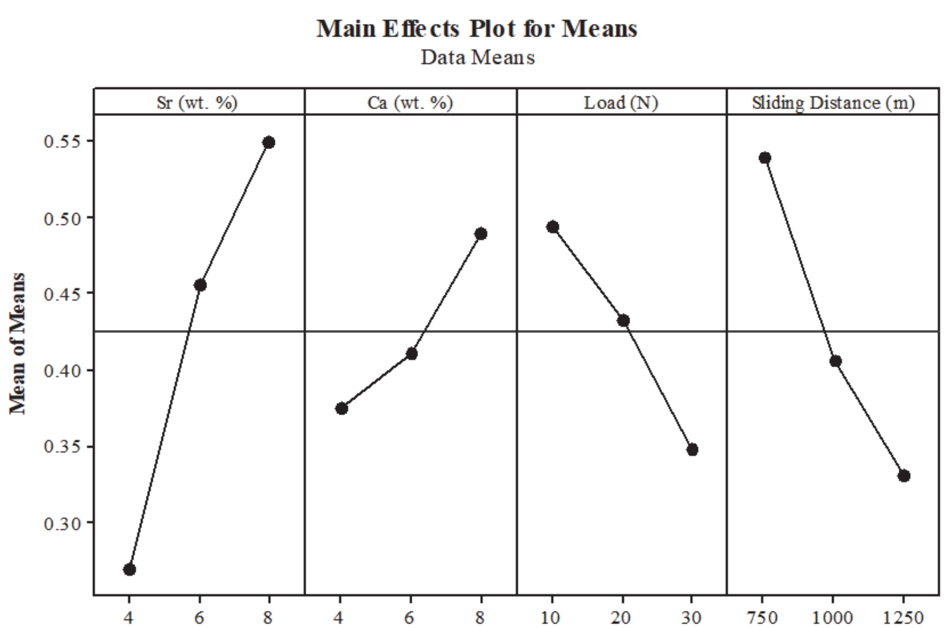

Figure 4: Effect of varying factor on COF.

Main Effects Plots of varying factors of wear loss and the COF of modified alloy are revealed in Fig. 3 and 4 respectively. Fig. 3 shows that, by increasing the Sr and Ca content, improved the wear resistance of the modified alloy. Granular eutectic "Si" phases are equally disseminated in Al dendrite boundaries by the addition of Sr content. The silicon phase is completely purified and spread throughout the Fe-rich phase. Because of the reduced stress concentration between the secondary phase and substrate and the greatly improved adhesion between the two, there is better wear resistance. A357 with appropriate wt. % of Sr effected improvement of wear resistance when compared to the cast parts without Sr modification. Though, too hard and brittleness can also led to deterioration of the wear resistance [41]. From Fig. 3, it is evidenced that the wear loss considerably decreases at initially and further increases due to increase in Sr content. This is mainly coincident with changing the trends in average size of the primary Mg2Si phases of the base alloys [42]. Ca modified cast parts have higher wear resistance compared to unmodified cast parts. Similar outcomes have been found in [43]. From the Fig. 3, it is revealed that, Sr and Ca elements of 8%, load of 10 N and sliding distance of 750 m are the optimal levels in achieving minimum wear loss of modified alloy. It is also reveals that, increasing in applied load from 10 N to 30 N, the wear loss of modified alloy increased. When a load pushed the modified alloy samples intensely towards the hard disc and high rate of stress will acts on sharper particulates. Generally, this produces high rubbing actions which leds to plastic deformation. Also reduces the strength between modifying element and the alloy. As a significance of this, the modified Sr and Ca particulates were broke and moved towards to the base alloy and high material has been removed from modified alloy samples [44, 45]. It is also seen that, the increasing in wear rate is observed for the process parameters such as sliding distance between 750 m - 1250 m. The Sr and Ca particles protruding on Al alloy surface generally causes sharpen asperity and leds to non-uniform interactions among the test samples and counter interface which cause to high wear loss in modified alloy [46]. Wear rate has been increased due to increase in the sliding distance. Generally, this leds to increase temperature of the surfaces at high sliding speed, generally which makes a high softening effect on modified alloy. And also it is observed that, the development of high surface damages results in high wear rate [45]. The Fig. 4 shows that, when the load is increased, it is seen that, reduction in COF in modified alloy. The main reason for this may be a development of MML, which generally led to reduce COF of modified alloy. Fig. 4 shows that, COF increased with increasing in wt. % of Sr and Ca content. In the case of modified alloy with high wt. % Sr and Ca content, COF was pointed to be high when it is compared with modified alloy with lower wt. % of Sr and Ca content. Fig. 4 depicts that COF reduced with increasing in the sliding distance. It was revealed that, COF of modified alloy was low due to presence of Sr and Ca content. The increasing in Sr and Ca content in the modified alloy led to the creation of MML which results in reduction of COF. The main effect graph shows the optimal conditions which leds to achieve the better wear rate and COF. The ranking of each parameter found for varying levels are shown in Tab. 5 and 6. Process parameters are been important and also it is observed that, wt. % of Sr and Ca content is a major foremost factor followed by the other factors which are been considered in the present investigation.

Levels	Sr (wt. %)	Ca (wt. %)	Load (N)	Sliding distance (m)
1	0.08167	0.06567	0.05144	0.05000
2	0.05678	0.05344	0.05411	0.05800
3	0.03111	0.05044	0.06400	0.06156
Delta	0.05056	0.01522	0.01256	0.01156
Rank	1	2	3	4

Table 5: Response table of means for wear loss.

Levels	Sr (wt. %)	Ca (wt. %)	Load (N)	Sliding Distance (m)
1	0.2700	0.3756	0.4944	0.5389
2	0.4567	0.4111	0.4333	0.4067
3	0.5500	0.4900	0.3489	0.3311
Delta	0.2800	0.1144	0.1456	0.2078
Rank	1	4	3	2

Table 6: Response table of means for COF.

Interaction graph indicates the influence of parameters used to evaluate the wear loss and the COF of the modified alloy. Other researchers [47, 48] concluded that a process parameter with a high angle of slope exhibits a higher significance rate. Additionally, it is said that the plotted lines in the interaction plots are not parallel, indicating that the interaction between the process parameters is stronger. Figs. 5 and 6 show interaction maps for wear rate and Friction coefficient of changed alloy. It can be concludes that the plotted lines are highly intersecting (crossing) between each other.

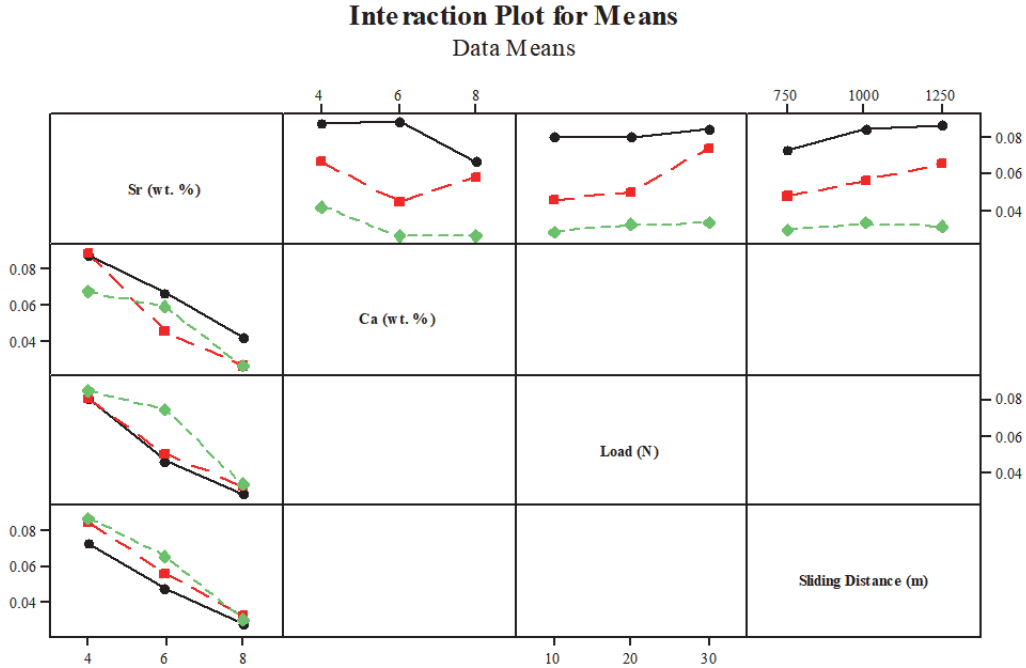

Figure 5: Interaction plots for wear loss.

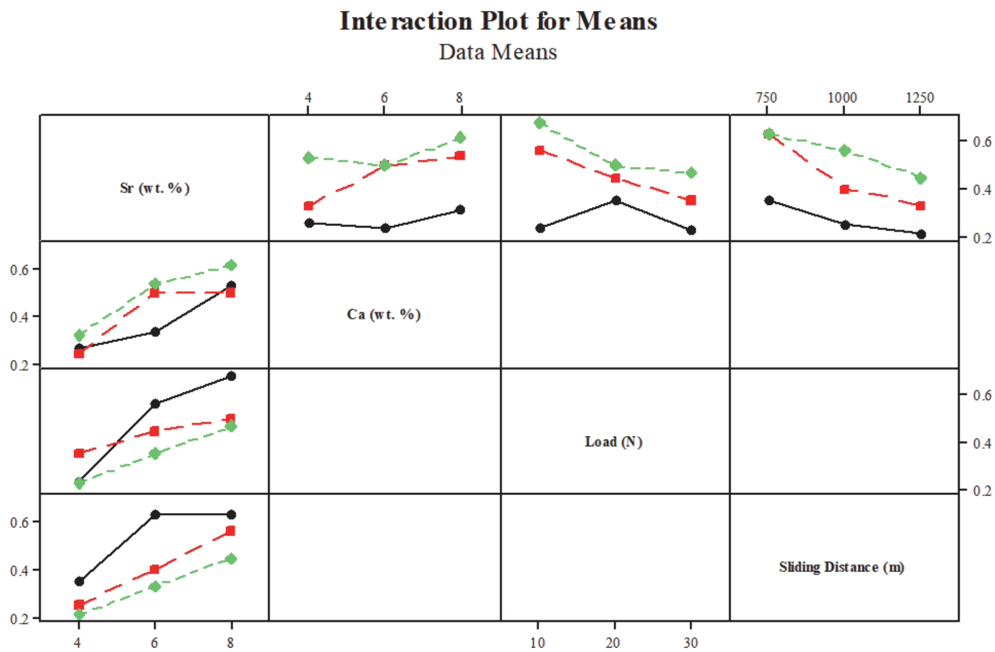

Figure 6: Interaction plots for COF.

The model adequacy was also evaluated by analysis of residuals. Generally, it is helps to study the model fit. When the model fits the data very well, there are fewer residuals and non-normality structures seen on the normal probability plots. The time evolution in residuals was observed using the residual v/s. order graphs. The results of residuals and abscissa on ordinate were used to plot the residual v/s. fits plots. The residual histogram plots generally aid in determining if the obtained data are skewed. Figs. 7 and 8 show the wear rate and COF residual plots for the improved composites.

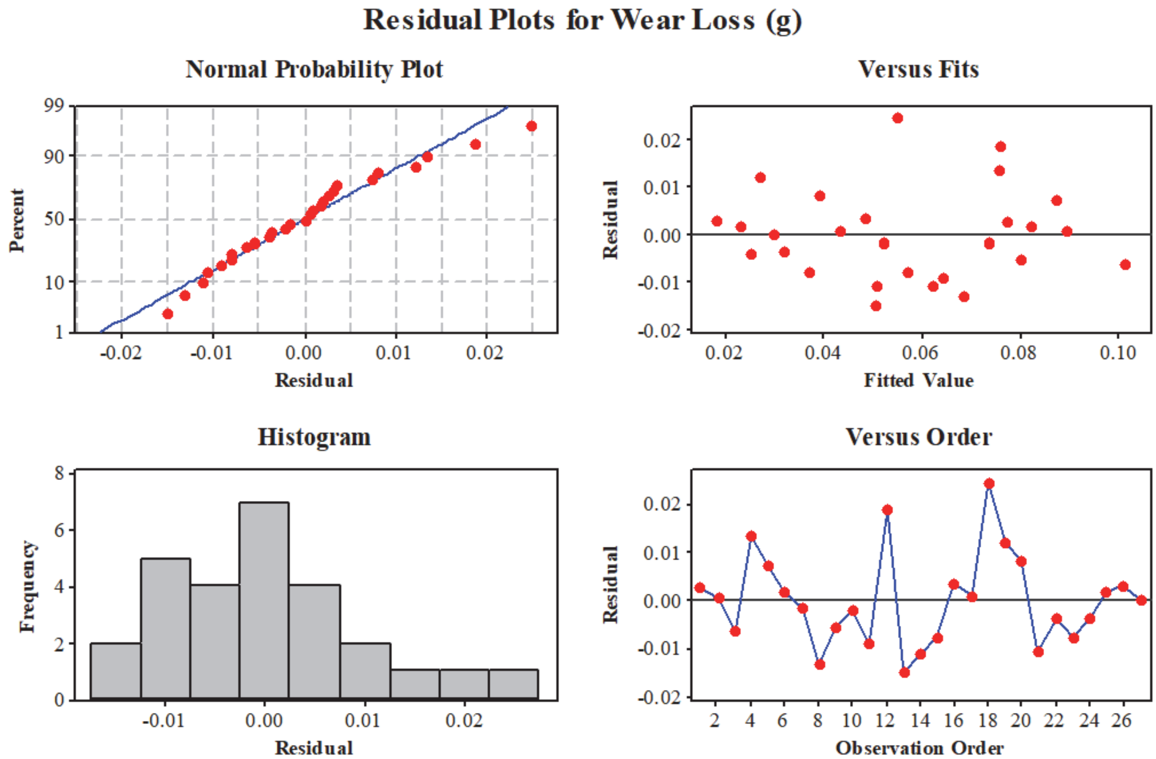

Figure 7: The residual graphs for wear loss.

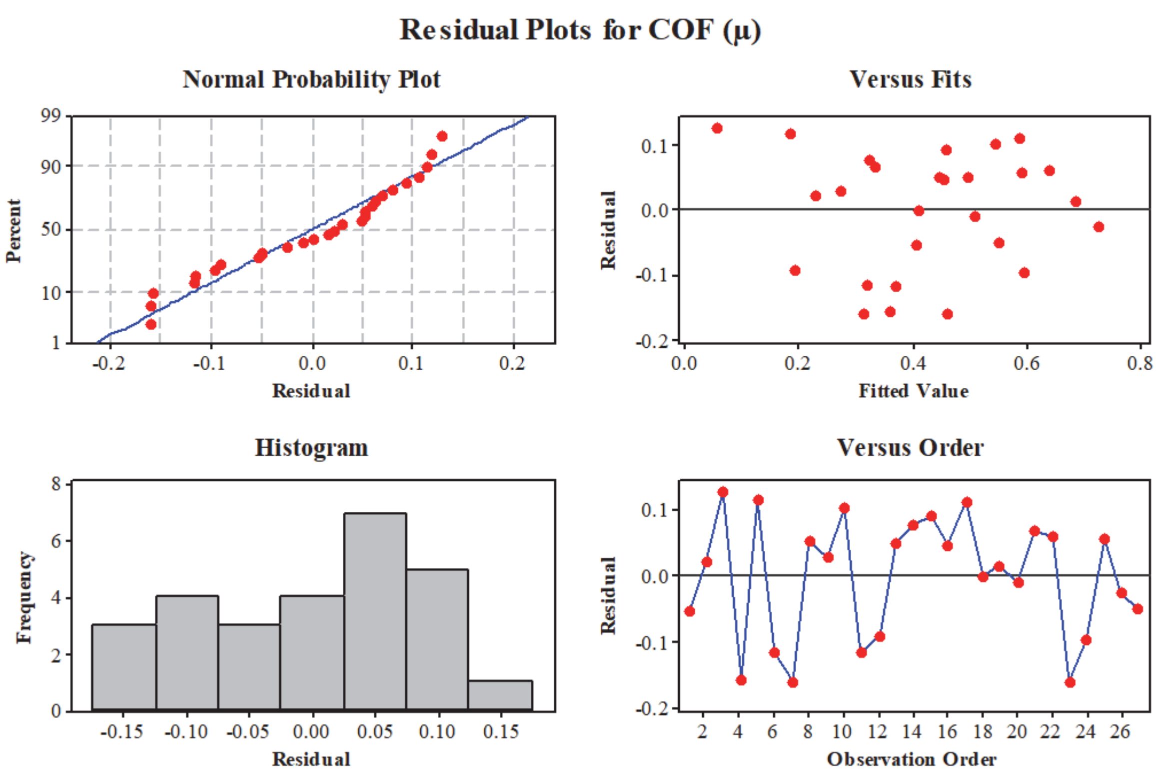

Figure 8: The residual graphs for COF.

The regression analysis / equations are used to forecast the outcomes within the process parameters used in the present investigation. Relation found by the regression study of the wear rate and COF are presented in the Eqn. 1 and Eqn. 2.

$$\text{Wear Loss (gms)} = 0.119519 - 0.0126389\ \text{Sr (wt. \%)} - 0.00380556\ \text{Ca (wt. \%)} + 0.000627778\ \text{Load (N)} + 2.31111\text{e-}005\ \text{Sliding Distance (m)} \quad (1)$$

$$\text{COF } (\mu) = 0.395 + 0.07\ \text{Sr (wt. \%)} + 0.0286111\ \text{Ca (wt. \%)} - 0.00727778\ \text{Load (N)} - 0.000415556\ \text{Sliding Distance (m)} \quad (2)$$

To check the accurateness of predicted values, the comparison between the predicted and experimentation values are shown in graphical representations. Outcomes of the experimental and predicted values of wear loss and COF of the modified alloy are depicted in Fig. 9 and 10. From the plots, it is observed that a better correlation among the experimental and predicted values [43]. The optimized parameters for the lower wear loss and COF are tabulated in the Tab. 7.

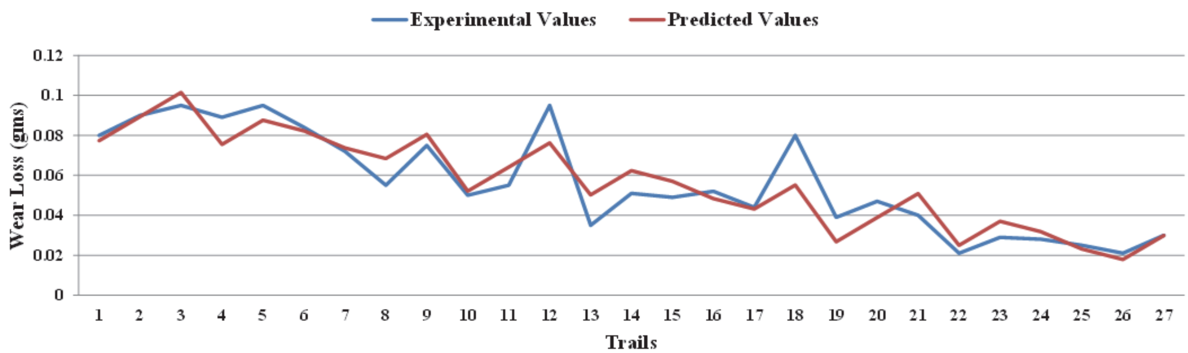

Figure 9: Comparison between experimental v/s. predicted values for wear loss.

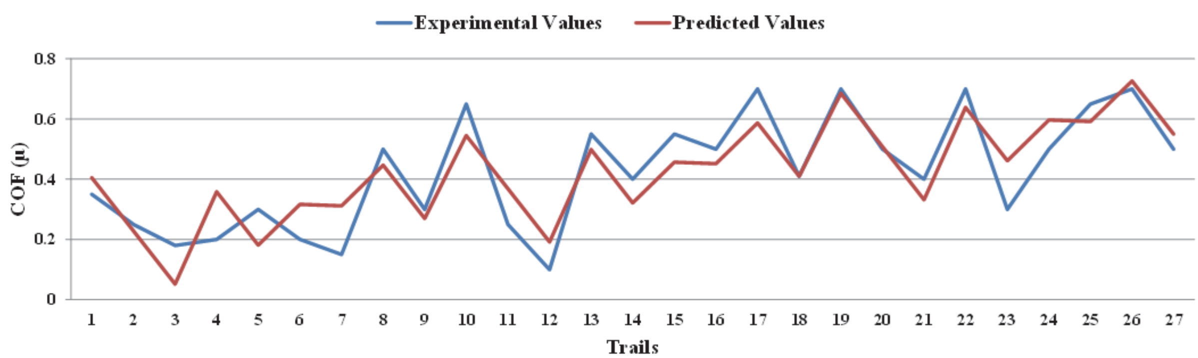

Figure 10: Comparison between experimental v/s. predicted values for COF.

Sl. No	Sr (wt. %)	Ca (wt. %)	Load (N)	Sliding distance (m)
1. Optimized parameters for the lower wear loss				
	8	8	10	750
2. Optimized parameters for the COF				
	4	4	30	1250

Table 7: Main effects plot results for wear loss and COF

The worn-out surfaces of A357 alloy and other cast parts of varying wt. % of Sr / Ca content are depicted in Fig. 11. A thick oxidation film is placed on surface of Al alloy under room temperature (27°C). The main factors that contribute to the production of oxidised coatings on the grinding surface of Al alloy are the released heat and surface roughness when subjected to greater loads. The oxide film's direct interaction with the base alloy and hard disc is stopped by the lubricant's presence. Therefore, oxide films increase wear resistance while simultaneously lowering the COF. Nevertheless, at sufficient normal force, the base alloy's surfaces will bend plastically, which typically causes the oxide film layer to split. It can be seen in Fig. 11 (a), that a plastic deformation ensued and parallel scratch marks are created due to rubbing action between hard spots of friction pairs. In Fig. 11 (a), larger pits are seen at sliding surfaces. It shows that delamination wear occurred during wear testing. Delamination wear is a form of fatigue wear brought on by the base alloy's continual sliding wear. Additionally, flake cracks are shown to grow in the subsurface as well as the surface layer. Material peeling is caused by many cracks that spread to the worn surface. Due to its brittle nature, when an alloy of aluminium exceeds its load limits under external forces, the oxide film typically breaks. Thus, the higher wear loss is caused by direct contact between the friction pair and the softer Al alloy. [49, 50]. Compared with one in Fig. 11 (b), the peeling pit in Fig. 11 (c) has wider and deeper scratches. With additional Sr content, eutectic silicon and also Fe-rich phases have granular shape, which generally causes tight adhesion between the alloy and secondary phase. It lessens the development, growth, and extension of the crack and prevents the sliding of the grain boundary as well as the shear effect between both the soft aluminum matrix and hard asperity. Addition of Sr content can modify the alloy microstructure to improve the material strength. So, the scratches on the wear surface of A357+Sr in Fig. 11 (b) are finer when compared to the A357 without Sr addition in Fig. 11 (a). As depicted in Fig. 11 (b), almost no peeling pit or plastic deformation is found on the worn-out surface of A357 alloy modified with Sr content. Fig. 11 (c) depicts the wear debris produced from the wear tests of A357 alloy modified with Ca content. According to the worn-out surface images, it is seen that, the size of debris belonging to A357 + Ca is very much smaller as compared to that of unmodified A357 alloy [50]. The ground surfaces are less damaged than the un-modified test samples.

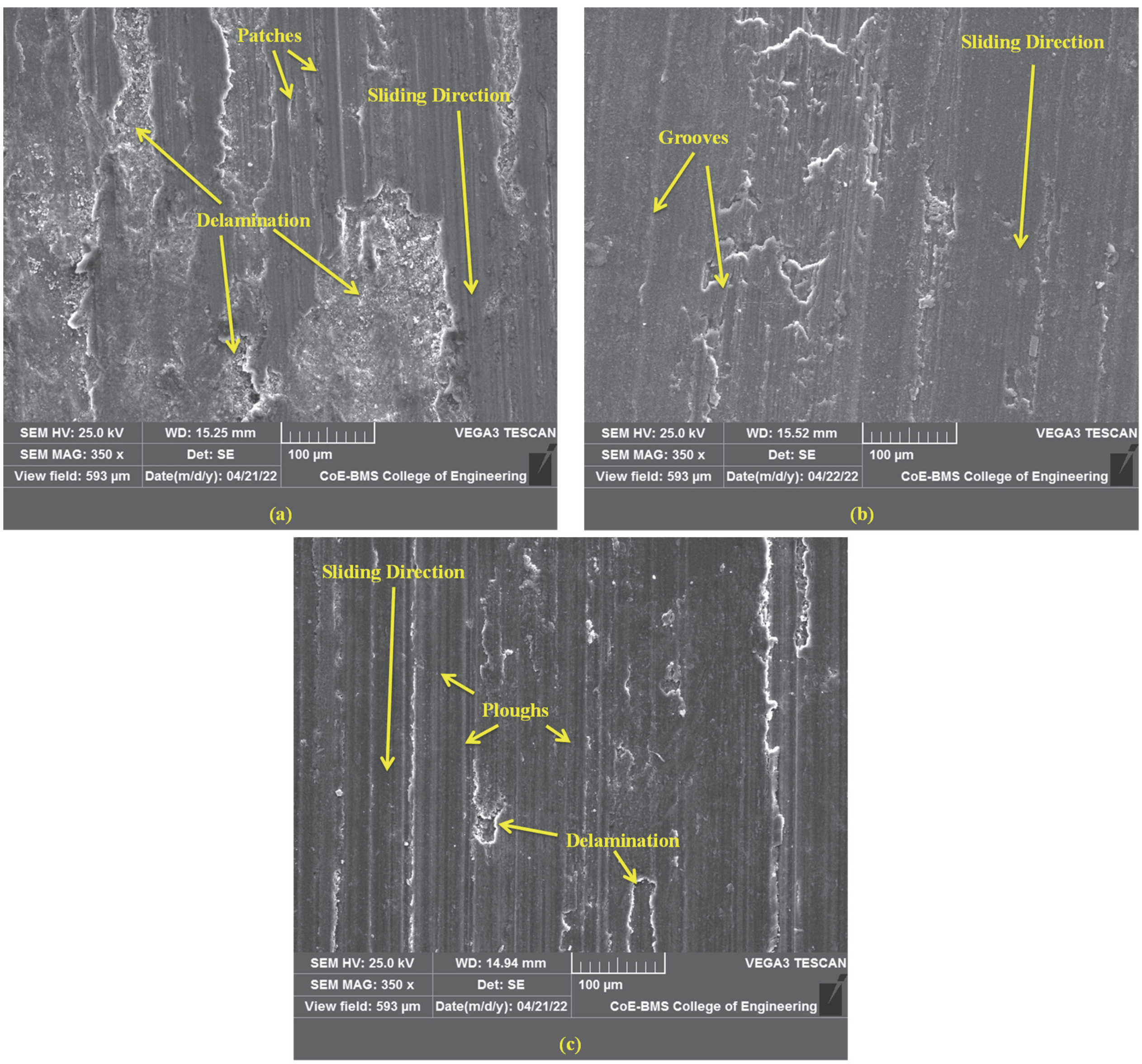

Figure 11: Worn-out surface morphology of (a) A357, (b) A357+Sr, and (c) A357+Ca.

CONCLUSIONS

- In the present study, A357-Sr / Ca cast parts was produced by stircasting method. Different wt. % of Sr and Ca (4, 6, 8 and 10%) were added (modified) to A357 alloy to achieve optimum levels of Sr and Ca on the microstructural, mechanical and wear amendment.
- The outcomes revealed that addition of elements (Sr / Ca) enhance the microstructural features. Uniform dispersal of particulates (Sr / Ca) in Al357 alloy and also the modified structure of silicon (Si) were observed.
- Additions of Sr / Ca content enhance the hardness of A357-Sa / Ca cast parts to some extent. But at higher wt. % of Sr / Ca it led to reduction in the material strength due to the agglomeration effect.
- Wear behaviour of modified alloy were evaluated through Taguchi technique. Based on the hardness results, the levels of parameters were selected to evaluate the wear behaviour.
- To study the wear behaviour the parameters such as Sr (4%, 6% & 8%), Ca (4%, 6% & 8%), load (10 N, 20 N & 30 N) and sliding distance (750 m, 1000 m & 1250 m) were selected. Optimum process parameter to achieve the minimum wear loss is 8% Sr, 8% Ca, 10 N of load and 750 m of sliding distance. Optimum process parameter to achieve the minimum COF is 4% Sr, 4% Ca, 30 N of load and 1250 m of sliding distance.
- ANOVA outcomes shown that, the Sr / Ca content has a better significant impact on wear behaviour and COF of the modified alloy.
- From the SEM images of fractured surfaces, the fracture like brittleness is observed in A357 (unmodified) cast part samples. The wear mechanism of examined alloys is a mild abrasive oxidative wear with the little adhesion. The interior cracked structure of a wear sample that was examined using a SEM is also displayed in the results of wear fractography.

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