JJMIE

Volume 18, Number 1, March. 2024
ISSN 1995-6665
Pages 145- 157
https://doi.org/10.59038/jjmie/180111
Editor-in-Chief: Prof. Ali M. Jawarneh

Jordan Journal of Mechanical and Industrial Engineering

Study on Strontium and Sodium Modification Elements on Microstructure, Mechanical, Wear and Fracture Behavior of Al7075 Alloy by Taguchi Technique

Ravikumar M[1*], Hanumanthe Gowda[2], Vijay Kumar S[3], Reddappa H N[4], Suresh R[5]

[1]*Department of Mechanical Engineering, B M S College ofEngineering, Visvesvaraya Technological University, Bengaluru, Karnataka*
[2] *Department of Mechanical Engineering, R L Jalappa Institute of Technology, Visvesvaraya Technological University, Doddaballapur, Karnataka*
[3]*Centre for Robotics Research & Department of Mechanical Engineering, Nitte Meenakshi Institute of Technology, Bangalore, Karnataka, India- 560064*
[4]*Department of Mechanical Engineering, Bangalore Institute of Technology, Visvesvaraya Technological University, Bengaluru, Karnataka*
[5]*Department of Mechanical and Manufacturing Engineering, M.S. Ramaiah University of Applied Sciences, Bangalore, Karnataka*

Received 10 Sep 2023 *Accepted 4 Feb 2024*

Abstract

Several industrial applications make substantial use of the aluminium alloy. The impact of Sr/Na on the microstructure, mechanical properties, and wear mechanics of Al7075 alloy was examined in the current experiment. The findings showed that the microstructure improved by the inclusion of elements (Sr/Na). Uniform dispersion of particles (Sr/Na) and changed structure of silicon (Si) in the Al7075 alloy were noted. Hardness of the developed alloys was checked with micro hardness tester and micrographs were taken using metallurgical microscope. Pin-and-Disc wear test equipment was used to measure the wear rate of the modified alloys. The wear test trials were carried out using the Taguchi technique in order to increase the accuracy of the results. The L27 array was used to evaluate the data. Applying ANOVA (Analysis of Variance) approach, the impact of changing parameters (factors) on wear loss and COF was examined. The obtained result indicates that, hardness and tensile strength increases by 37.78% and 14.57% respectively when compared to the base alloy. It is due to the increase of wt. % Sr modifier. The ANOVA analysis results indicate that, wt. % of Sr is most significant (69.70 %) parameter followed by Na (wt. %), Load (N) & Speed (rpm).The Sr/Na content has a more substantial impact on the wear behaviour and COF of the modified alloy, according to the results of the ANOVA. A worn-out surface's internal fracture structure can be seen in a wear fractography report after SEM analysis.

Keywords: Al7075; Sr/Na modification elements; Stir casting; Tensile strength; Hardness; Wear behavior; Taguchi technique; Fracture behavior.

1. Introduction

Aluminum alloys have received significant attention in recent years due to their superior mechanical qualities and generally strong corrosion resistance. Due to their high strength, lightweight construction, high wear resistance, better thermal and electrical conductivity, excellent castability, and strengthening using precipitation hardening, aluminium (Al) alloy composites are primarily used for a variety of functional applications, including agricultural mechanization, soil anchoring, and building structures [1]. Chemical modifiers, which provide superior microstructure during the solidification process, can often be added to materials to increase their mechanical strength. In addition to changing the eutectic "Si" morphology from a coarse structure to a fine fibrous structure, adding Ba, Sr, Ca, Na, and Eu has a positive impact on the ductility and material strength. Although the effects of chemical modification were well established ten decades ago, no consensus existed regarding the process by which the microstructure may alter with the addition of a little amount of additional metal ingredient(s) [2]. The best technique to increase the ductility and toughness of an Al-Si alloy is by modification. By using modification treatment, eutectic silicon's morphology can be changed from flake-like to fibrous structure. The inclusion of specific modifier elements, such as Na, Sr, Sb, Eu, Ca, and Yb, among which Sr and Na are most frequently utilized in the aluminum industry, can be used to modify the structure of eutectic silicon. The first modifying element that underwent substantial research was sodium. Typically, it is infused into the molten aluminium in the form of a salt solution that contains Sodium fluoride (NaF). To fully modify eutectic silicon, a very small amount of sodium is required. It is frequently employed in industries because of

* Corresponding author e-mail: ravikumarm.mech@bmsce.ac.in.

its low cost and great modification performance. Due to the benefits of zero emissions and good re-melting qualities, Sr has currently begun to replace Na as a modifier for cast Al-Si alloys. Because strontium's potential for modification lasts much longer than that of sodium, it is the most common modifying agent employed in aluminium foundries today. Hence, adding Sr to Al alloys has become a common method adopted to enhance their mechanical properties. b-Al5FeSi intermetallic particles have been found to be modified by strontium, which results in high stress concentrations and a degradation of the mechanical properties. Not all of the adverse effects caused by increasing Sr, meanwhile, are positive. Al alloys were said to have more porosity as a result of Sr additions. It has been noted that the addition of Sr improves the efficiency of oxide inclusions in the melt of aluminium as pore nucleation sites. Hence, the variation in Sr oxide content in the solidified structure determines the porosity parameters. Low-quality castings are frequently produced as a result of porosity, which reduces the mechanical properties [3]. Aluminum alloys containing silicon can be effectively modified structurally using strontium. Many studies have been conducted on the effects of strontium on the microstructure and mechanical characteristics of commercial binary and multicomponent aluminum-silicon alloys. Both hypoeutectic and almost eutectic compositions have been used to study the mechanical characteristics of strontium modified alloy. Also, it was discovered that a eutectic composition had the highest values of the ultimate tensile strength of an unaltered alloy. By steadily and simultaneously increasing the silicon content and the rate of alloy solidification in accordance with the eutectic composition versus solidification rate curve, the ultimate strength can be raised. When solidification rates exceed 480 m/s, this allows for the independent coupled rise of alloy component content, which is associated to increasing super cooling. Intermetallic particle modification that results in high stress concentrations has also been described by Sr. However, not all of the adverse effects created by Sr increase are beneficial. Sr addition resulted in improved porosity in the Al-Si alloy. It has been suggested that adding Sr increases the effectiveness of oxide inclusions acting as pore nucleation sites inside the Al melt. Hence, the amount of Sr present in the solidified structures affects the change in porosity properties. Porosity lowers the mechanical strength of cast items and lowers their quality. Sr increases also were related to Al foundry alloy grain refinements [4, 5]. In [6] the researcher investigated the effect of adjusting the Sr in the Al matrix alloy on the mechanical behaviour and discovered that, following the modification of the Sr element, there was an increase in the influence released energies with a reduction in grain size. Investigational data proved that the number and quality of Sr particles make Sr modification successful. Low "Sr" amounts are needed for improved mechanical quality. Strontium-based modifier alloys are commonly adopted to modify the eutectic silicon in aluminum-silicon casting alloys by changing the silicon shape from an acicular to a spherical form. Usually, the modifier alloy necessary to properly change the silicon shape depends on the silicon content, but the alloying elements' content may have an influence [7]. The Sr content has an obvious influence on the microstructure and properties of the A356 Al alloy. The grains of eutectic silicon are fine or vermicular and diffusely distributed in the alloy with 0.012 w/% Sr. The mechanical properties are excellent including a tensile strength of 208.5 MPa and elongation of 17.5 %. The performance of the alloy does not improve with the increased Sr content [8]. It was discovered that the addition of sodium elements transformed the rough acicular morphology of silicon into fibrous form. The eutectic Si morphology was promoted and strengthened as a result of additions from these modifiers in the range of a few hundred ppm [9]. One of the frequent impurities in aluminium and magnesium alloys is sodium. In the industrial setting, cryolite (Al_2O_3+Na3AlF6), which is added to lower the melting point, and molten alumina are electrolyzed to create primary aluminium using the Hall-Héroult method. As a result, aluminium that has not been treated further will inevitably contain some sodium (>0.002%), and the electrolysis's thermodynamics and kinetics will have an impact on this content [10]. Calcium and sodium alteration have similar effects. It has been established that sodium is a better modulator than calcium. This component works well with others so that modifications and additions can be combined without having a negative impact. However, eutectic alteration is only permanent when these components are added artificially. The most efficient kind of modification is adding traces of specific elements, such Na, Sr, and Sb, to aluminum alloys. However, when a thermal modification technique is combined with a chemical or mechanical procedure, the degree of modification is maximized [11]. The effect of Na is more ephemeral, but Sr is more permanent, according to the explanation above. When Sr and Na are added together, the incubation period seems to be shorter than when Sr is added alone. Na and Sr do not react negatively, but rather, their combination is advantageous for offering lasting modification (less fading). As a result, long-term alteration with sodium and strontium can result in a well-modified microstructure [12]. In order to change the eutectic silicon from faceted acicular flakes to a fine fibrous structure, strontium or sodium is added to the Al alloy. This improves the mechanical properties, particularly fracture toughness and elongation. According to reports, adding sodium to Al alloys has some disadvantages, including a clear effect on porosity and sodium fading. On the other hand, adding Sr causes the hydrogen content to increase and the incubation time to lengthen [13]. Three cast components were, therefore, evaluated in the current work. The samples (cast components) were evaluated in both the unaltered and altered states. To determine the relationship between the alterations, alloys were produced using the stir casting method, and test samples had their mechanical and wear properties assessed. After the Sr and Ca alteration, fractrograph as well as worn-out surfaces were studied. Highlighting the mechanical and wear behaviour of Al7075 after Sr and Na alteration is the aim of the current study endeavor. Evaluation of many parameters, as well as the contributing effects between these process parameters, which were disregarded in previous study, are required for better, more thorough studies on wear characteristics. When the Taguchi method is contrasted with conventional design techniques, it is chosen as a powerful design. The

Taguchi method demonstrates that it is an efficient and ideal way for reducing the time and expense required to conduct experimental trials in order to optimize the variable parameters. The Taguchi technique primarily utilizes crucial instruments like the S/N (Signal-to-Noise) ratio, which typically exhibits the superior characteristic variance due to process parameter uncontrollability. Just choosing the criteria for the Design of Experiments (DOE) concept constitutes a significant measure. The test trials remarkably play a significant role in Taguchi approach. The experimental trials will be conducted in accordance with the 27 trials to ensure more accuracy of the results (L27 OA). Weight percentage of reinforcing substance, load, and sliding distance were chosen as the process parameters in the current experiment. According to a literature review, it was discovered that variable parameter optimization is one of the key elements needed to assess the mechanical band wear behaviour of generated hybrid composites. Investigation of the impact of strontium (Sr) and sodium (Na) content on the microstructure, hardness, wear behaviour, and tensile strength of the Al7075 modified alloy is the innovative aspect of the research effort. Design of Experiments (DOE) is a major and an efficient method applied for assessing the impact of multiple process parameters at once. The evaluation of the influence of each individual process parameter at a relatively low number of test trials was a key component of the Design of Experiments. In general, several researchers have employed these methods to assess the material properties of AMMCs with success. Due to the Design of Experiments, Taguchi method typically minimizes the overall number of experimental trials. Table 1 shows the effect of modifiers on the mechanical properties in Al based alloys. However, it can be inferred from the literature review that sufficient information on mechanical properties, and wear behavior of Strontium (Sr) and Sodium (Na) modified Al7075 alloy is lacking. The novelty of the present work was to examine the study on microstructure, mechanical, wear and fracture behavior of Al7075 Alloy modified by Sr and Na elements. In this present research work, modified alloy were developed by stircasting method. Wear behavior were studied and analyzed by using statistical (Taguchi) technique. Finally, experimental outcomes were correlated with regression-analysis.

2. Fabrication of cast parts

Strontium (Sr) and Sodium (Na) were employed as two distinct modifying elements to create modified cast parts using A7075 as the base alloy. Three distinct cast pieces (Al7075, A7075+Sr, and A7075+Na) were produced in the current work using the Stir casting technique. Here, the weight percentage of two modifying parts was changed in steps of 3% from 3-12%. A7075 material was melted in a coke furnace. The melt was continuously stirred as Sr/Na granular was added after keeping the temperature at 600°C. After adding the Sr/Na particles, stirring was done continuously for about a minute to ensure even distribution throughout the molten liquid. The melting temperature was then held at 700 °C for 15 minutes, allowing Sr and Na particles to dissolve in the liquid melt. Three distinct cast components, including one without a modifier (Al7075), one with a modifier (Al7075+Sr), and one with a modifier (Al7075+Na), were fabricated by pouring ready-molten melt into a hot mould box. The cast components were removed from the mould box, and then the test specimens were machined in accordance with. Above casting parameters are selected based on the preliminary test and literature review. The samples of base alloy Al7075 and other modified alloys are removed from the hot mould box and pre-machined using CNC machining process. The development of modified alloy and process parameters for the fabrication are tabulated in the Table 2.

Table 1. Effect of modefier on the mechanical properties in Al based alloys.

Ref. No.	Author/s	Matrix &Modifiers	Properties	Outcome Measures
[1]	W. Khraisat and W. Abu Jadayil	Aluminum / 1-5 % of Fe3Al-based aluminide	Mechanical and Metallurgical Characteristics	Studies have shown that the ductility of the Fe3Al-based aluminide can be substantially improved by increasing aluminum content from 25 to 28%. Thus by increasing the amount of iron in the alloys studied the amount of aluminum in the intermetallic phase decreases leading to a decrease in ductility.
[2]	Kheder et al.	Aluminum /5-20 % SiC, Al_2O_3 and MgO	Mechanical and Metallurgical Characteristics	The addition of SiC, MgO& Al_2O_3 particulates into the matrix alloy increased the yield strength, the ultimate tensile strength & the hardness, & decreased elongation (ductility) of the composites in comparison with those of the matrix.
[5]	Xiaodong et al.	Aluminum / 2-6 % Sr	Microstructure and Mechanical Properties	The refinement of the eutectic Si phase by Sr modification can improve the mechanical properties slightly to castings with thin wall, but the improvement of mechanical propertied by Sr modification is obvious to thick wall castings.
[13]	Saravana Kumar et al.	Al6063 / 0.5 – 1.5 % Mg + 0.2 – 0.7 % Sr	Mechanical Properties	Alloying aluminium with certain metals like strontium, manganese, cobalt enhances the aluminium strength.
[31]	Sivaraos et al.	AA7178 / 5-15 % Si3N4	Optimization of Mechanical Properties	The samples of trials are employed to estimate the tensile behaviour of the composite material. The optimized results indicated that, filler content is highly influenced on mechanical properties.

Table 2. Details of modified alloy and process parameters for the fabrication.

Sl. No	Modified Alloys	Casting Temp (°C)	Stirring Speed (rpm)	Stirring Time (Min.)	Degasifier
1	Al7075 (Ascast)	700	150	15	Aluflux 08 Degassing Tablet
2	Al7075 + 3 - 12% Sr				
3	Al7075 + 3 - 12% Na				

3. Material characterization

3.1. Microstructure

The microstructure samples were polished using 500, 800 and 1200 grit size emery papers. Further, samples were polished with velvet cloth. For the microstructure study, keller's reagent (mixture of anhydrous (glacial) acetic acid) was applied on the samples and wiped with sterilized cotton. The standard specification ASTM B483 was used for the study of microstructural analysis. Subsequently, both ascast and modified alloys etched samples were dried in air and subject to microscopic examination by using Metallurgical Microscope equipment. The equipment used for this study is NIKON EPIHOT 200 and supported by Clemex Vision Image Analysis P.E. 5.0.

3.2. Hardness

The microhardness of the manufactured modified alloy was measured using Vickers microhardness testing equipment in line with E92-ASTM standards. A diamond-shaped indenter was used for 15 seconds with a 5 kg load. Three unique zones on wear test specimens were employed to analyse each hardness test trial at 27°C room temperature in order to obtain the average hardness values.

3.3. Tensile behavior

Tensile tests were conducted in accordance with ASTM standard E8. Tensile tests were carried out by applying an axial or longitudinal load to the test specimen at a specific rate of load extension until the specimen failed. Using UTM with a maximum load capacity of 390-400 KN, test experiments were conducted.

3.4. Wear test

The ASTM standard norms for wear testing were followed. Testing against steel discs was done in the current study with different parameter levels (Grade: EN-32). Test specimens were prepared for machining and finished using traditional and Wire Electrical Discharge Machining (WEDM) techniques, respectively. According to ASTM G99-05 standards, wear test samples measuring 6 mm in diameter and 30 mm in length were prepared. By using the weight loss method, the wear loss of hot-rolled hybrid composites was investigated. The hot-rolled hybrid Al composite samples were rigidly held against a rotating hard steel disc during the wear tests (EN-32 grade). After each and every test trial, 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).

4. Result and discussion

4.1. Microstructural analysis

The mechanical and wear characteristics of cast items were improved by uniform dispersion of modifying particles. Figure 1 shows the eutectic microstructure of a non-modified, Sr-modified, and Na-modified alloy. The intermetallic phases and, in general, the alloying element determines the microstructure of an unaltered alloy. As was already mentioned, Mg, Fe, and Mn content of the Al alloys examined in this research effort varies. Particles act as a nucleation site and offers barrier for grain growth; it results in grain refinement and increment in dislocation density. More grain boundaries and high dislocation density obstruct the deformation/dislocation movement and finally strengthen the composite [5]. By examining the microstructure, some intermetallic phases can be seen. In general, the composition of Al alloys affects the number of inter-metallic phases present and how they affect the alloy's mechanical properties. Several of these inter-metallic phases, such as -Al5FeSi, results in decreased elongation as iron (Fe) content rises, i.e. reduction in elongation. In alloys, Fe-intermetallic phases were found. Strength of developed cast pieces is substantially influenced by Sr/Na [14]. According to Figure 1(a), the Al alloy has a coarse microstructure and a main -phase distribution that was disorganised throughout the cast component. The microstructure is altered by the addition of Sr, as shown in Figure 1(b). It was found that grain refinement induced a sharp increase in the hardness of composites with various compositions [18]. 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, Al alloy becomes hypo-eutectic rather than hyper-eutectic at this composition. Thus, these alloys' microstructure is altered and their characteristics may be greatly enhanced by the addition of a little quantity of Sr [15]. The Sr content has an obvious influence on the microstructure and properties of the Al alloy. The grains of eutectic silicon are fine or vermicular and diffusely distributed in the alloy with Sr element [8]. The morphology of the eutectic silicon phase can alter with the addition of a little quantity of Sr, changing the Al alloy's coarse structure to a fine fibrous one. Structure formed when "Na" was changed in the Al alloys is as shown in Figure 1(c), and it is seen that the primary -phase dendrites are minimized. The Al alloy's microstructure underwent the best refining when Na was introduced. The primary -phase with the smallest dendritic size was also seen, and it routinely settled within the base alloy. The microstructure of the Al alloys began to erode with the addition of Na. A primary -phase's primary dendrite gets coarse. Hence, the primary-phase dendritic was very small in size and distributed uniformly. In general, the importance of adding Na to A7075 during casting conditions aids in improving the mechanical characteristics and lowering the rate of corrosion. The reduction of dendritic structure formation caused by the addition of Na to the A7075 alloy in the current research effort improved the mechanical and wear properties [16]. As a result, long-term modification with sodium and strontium can result in a well-modified microstructure.

4.2. Hardness

The Figure 2 shows how Sr and Na modifications affect the hardness of an alloy made of aluminium. The sample's hardness was determined at five distinct sites, and the average mean value was taken into account. It was discovered that simultaneously modified Sr/Na cast pieces had harder surfaces than unaffected parts. Such developed cast components made by stir casting showed a similar fluctuation in hardness. The changed components that improve the particles wettability in the alloy may be responsible for the rise in hardness of the produced cast parts. Chemical alterations could cause the phenomenon of fragmentation, which produces tiny, rounded Si crystals. Small, rounded Si particles lower the alloy's stress concentration, which boosts the material's strength [17, 18]. The microstructural modifications brought about by the addition of Sr resulted in improvement in the alloy's hardness when it was cast in metal moulds. The platelet Fe-rich phases were converted to an AlFeSi by the addition of Sr particles. The creation of a-AlFeSi was aided by the addition of Sr, which also increased the material's strength. Also, it was found that Sr was added to Al alloys to increase their material qualities. Al7075 contains Fe as one of its alloying constituents. Fe-rich intermetallic phases feature morphologies that are far more complex and appear brittle and fragile. The strength, ductility, and fatigue characteristics of Al alloys typically suffer when Fe is present. When compared to the hardness of the unmodified cast component, the produced cast part's hardness was increased when the Na concentration was changed. The change seen was attributed to an increase in grain fineness that corresponded with it. When compared to the hardness of Al7075+Sr cast parts, the hardness of Al7075+Na cast parts is lower. Due of agglomeration effects, the hardness decreased at higher weight percent Sr and Na content [19]. Moreover, as the Sr and Na element content in the base material rises above 10%, the percentage porosity rises as well. Conclusion: Decreases in the hardness of the Al7075 alloy lead to changes in the porosity of the underlying components. Irina Brodova et al [18] stated that, grain refinement induced a sharp increase in the hardness of composites with various compositions.

4.3. Tensile strength

The Figure 3 depicts the influence of modification on the tensile strength of Al alloys and concurrently modified Sr and Na cast components. It is discovered that the simultaneously modified Sr/Na cast pieces have higher tensile strength than the unmodified parts. Such developed cast components produced by stir casting showed a similar fluctuation in UTS [20]. The changed components, which increase the particles wettability in the alloy, may be responsible for the improvement in tensile strength of the resulting cast parts. It was, therefore, expected that the modifiers would exhibit notable variations in the percentage of elongation. Because chemical alterations could cause the phenomenon of fragmentation, which produces tiny, rounded Si crystals. Small Si particles lower the alloy's stress concentration, which boosts the alloy's ductility during plastic deformations [21]. The microstructural modifications brought about by the addition of Sr result in an improvement in the tensile strength of the alloy when it is cast in sand or metal moulds. The platelet Fe-rich phases were converted to an AlFeSi by the addition of Sr particles. Sr was added to help a-AlFeSi evolve, and it also significantly improved extrusion properties, particularly tensile strength. Also, it was found that Sr was added to Al alloys to increase their physical characteristics. Al7075 contains Fe as one of its alloying constituents. Fe-rich intermetallic phases feature morphologies that are far more complex and appear brittle and fragile. The strength, ductility, and fatigue characteristics of Al alloys are typically affected when Fe is present. When compared to the tensile strength of the produced cast component and the unmodified cast part, the tensile strength of the developed cast part increased after adjusting Na content. The increase in grain refinement that went along with it was responsible for the observed development [22]. Al7075+Na cast parts have a lower tensile strength than Al7075+Sr cast parts, which have a higher tensile strength. Other researchers also had seen similar results [5, 7 & 8]. However, at a Sr and Na level of 12 weight percent, the tensile strength dropped as a result of agglomeration effects.

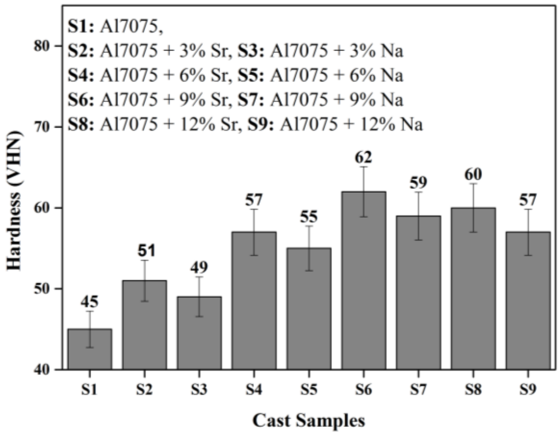

Figure 2. Hardness of Al7075 and varying wt. % of Sr and Na

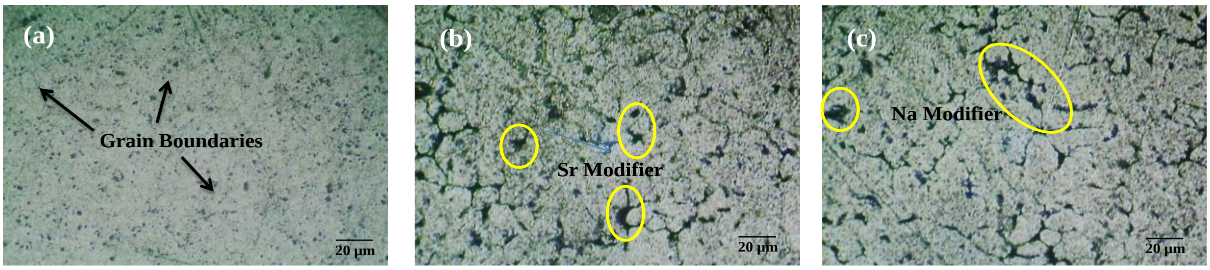

Figure 1. Microstructure of (a) Al7075 (b) Al7075+Sr (c) Al7075+Na

The Figure 4 shows stress-strain curves for Al7075 alloys. It is observed that, the concurrently changes in Sr/Ca cast components. The stress-strain curves primarily demonstrate thefracture strain decreases with increase in tensile strength, it is due to the adding of more modifying elements in the developed alloys. When compared to cast parts made of Al7075+Sr and Al7075+Na, it is discovered that the unaltered alloy exhibits the lowest resistance to plastic deformation and has the highest plastic strain rate. When compared to untreated alloys, it can be noted that the changed cast pieces show improved strength. This is typically brought on by improved grain refinement as well as particle strength. The mismatch strengthening and also the high load bearing capacity created by the Sr/Na particles in the element changed cast component often effect the material strength improvement. As the base alloy cools from solidification temperature due to the thermal-mismatch stress, there is a tendency for the dislocation of density to increase. At the interface between the particles and the base alloy, the dislocation causes stress. The temperature at which the cast parts were cooled when they were formed typically affects this stress. Increased stress at the interface is a result of high temperature. This results in extremely rigid plastic deformation and increases the strength of cast pieces. The presence of hard particles (Sr/Na) that limit the migration of dislocations inside the alloy accounts for the improvement in material strength of modified cast components as compared to the base alloy. Dislocation strengthening is the process of increasing dislocation density inside an alloy of aluminium and sodium by increasing the weight percentage of Sr/Na particles. In comparison to Na modified cast parts, the created cast parts possess improved tensile strength due to the dislocations which are trapped by the Sr particles.

A fractured surface of the tensile test specimen was examined to study the failure mechanisms of the developed cast parts. Figure 5(a) depicts the fractured surface of unmodified alloy. Figure 5(b) depicts the fractured surface of Al7075+Sr modified cast part. Figure 5(c) depicts the fractured surface of Al7075+Na modified cast part. The extent of cracking is high in the test samples modified by the Sr/Na. This indicates strong bonding at the interface. In-fact, when the interface is very strong with an alloy, the Sr/Na gets loaded to their fracture crack. Relatively a large number of cracked surfaces are seen in the case of addition of Sr/Na, and this number is less in unmodified test samples, as shown in Figure 5(a), and similar results were observed in [20]. The fractured surfaces show that the unmodified alloys are brittle in nature of fracture, which follows the eutectic Si modules and are further improved by contribution due to iron-rich phase. Whereas, the modified alloys have a nature of ductile fracture. Generally, this follows largely through the plastic deformation of Al alloy [23].

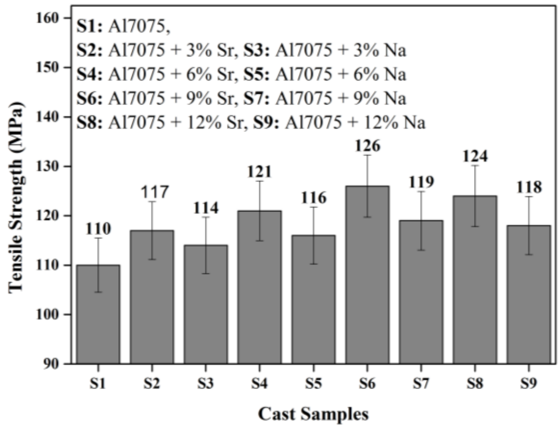

Figure 3. Tensile strength of Al7075 and varying wt. % of Sr and Na

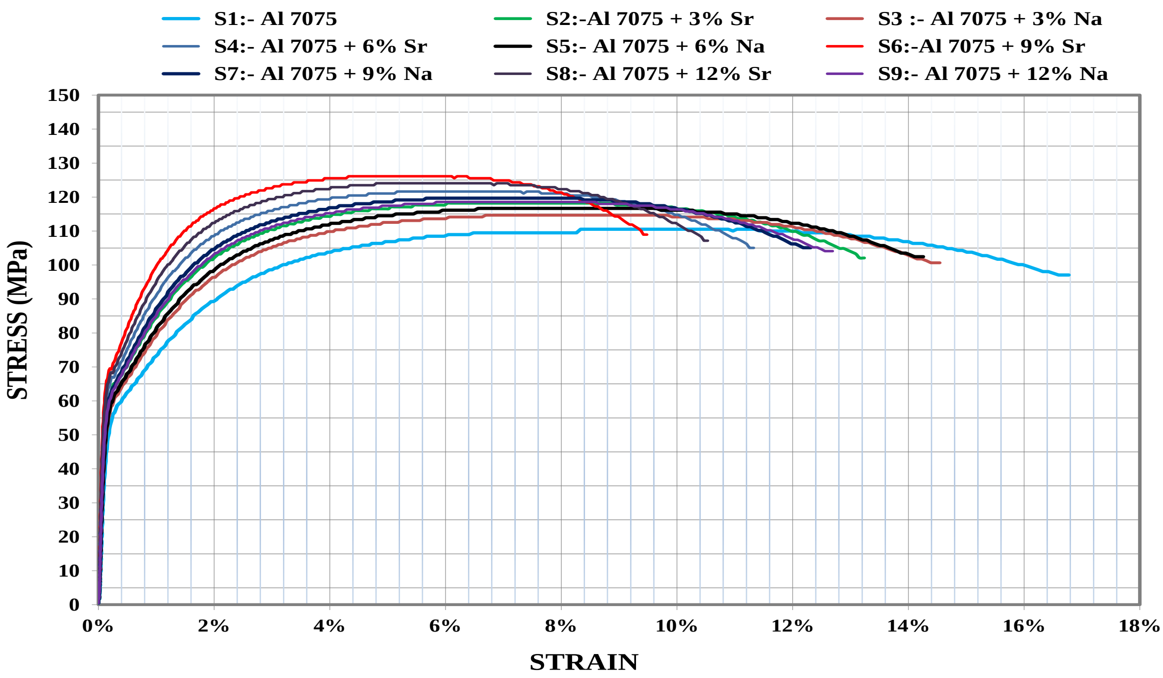

Figure 4. Stress strain curve of Al7075 and varying wt. % of Sr and Na cast parts

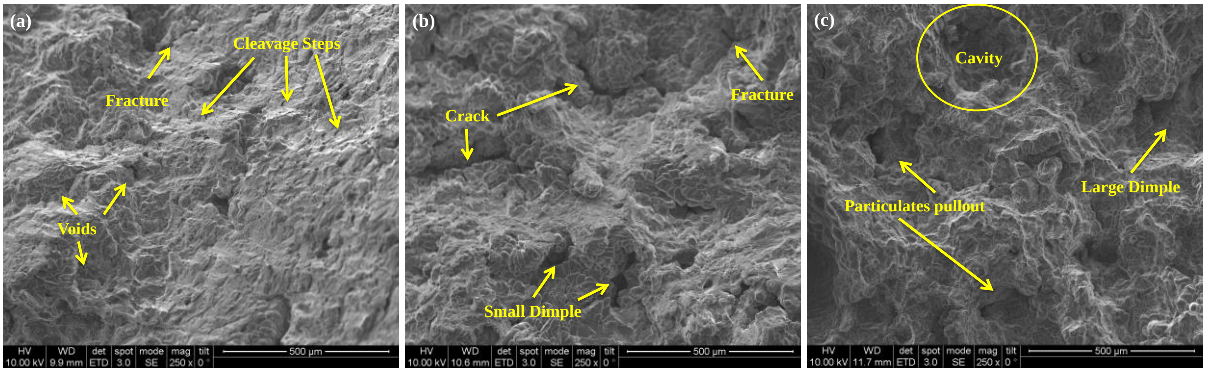

Figure 5. Fracture surface of (a) Al7075, (b) Al7075+Sr and (c) Al7075+Na

4.4. Wear loss

Wear behavior was evaluated as per ASTM standards at a constant speed (sliding speed) of 2 m/s and 10 N of load against a steel disc (grade: EN-32). Test samples of 30 mm length and 6 mm dia were prepared by CNC machining as per the ASTM standards. The amount of wear loss of the developed cast parts were calculated by weight loss method. Figure 6 depicts the wear loss of all the developed cast parts. From the Figure 6, it can be seen that, the wear loss of Al7075 alloy is high when it is compared to the cast parts of Al7075+Sr. But whereas, the wear loss of Al7075+Na cast parts was again high when it is compared to cast parts of AL7075+Sr. By adding Sr content, the granular eutectic silicon phases are uniformly dispersed in aluminium dendrite boundaries. Fe-rich phase is entirely refined and also distributed within the centre of the silicon phase. So, the stress concentration among the secondary phase substrate is also lessened and the adhesion between the secondary phase & substrate can be significantly enhanced and this has led to better wear resistance. Al7075 with appropriate wt. % of Sr effected improvement of wear resistance when compared to the cast parts without Sr modification. Though, higher hardness and brittleness can also lead to deterioration of the wear resistance. Figure 6 shows that as the Sr concentration increases, wear loss first significantly decreases and then increases further. This is mostly related to shifts in the average sizes of the base alloys' principal Mg2Si phases. When compared to unmodified cast components, Na-modified cast parts exhibit greater wear resistance. Additionally, Al7075+Na's wear resistance is lower than Al7075+Sr's. Other researchers have shown similar results [13] and that the agglomeration effect is typically responsible for the increase in wear loss at greater weight percentages of modifying materials [24].

4.5. COF (μ)

The coefficient of friction (COF) of the alloy and modified cast parts are shown in the Figure 7. The average value of COF of Al7075 without Sr / Na is found to be highest. By increasing in Sr content, the average value of COF of the Al7075 alloys is less. On addition of Sr content, the average COF of alloy reaches minimum value. Friction arises as due to bonding of surfaces, the molecules on both the surfaces bond with each other, and after resistance when the surfaces try to move away and break the bonding. As stated, when the content of Sr content is increased, the wear loss is minimum. Consequently, the amount of wear debris accrued among asperities is also significantly reduced. At constant applied load, reduced COF would generally lead to the lower friction factor. Na modified cast parts show improved COF compared to unmodified cast parts. But whereas, compared to Na modified cast parts, Al7075+Sr cast parts exhibit improved COF.

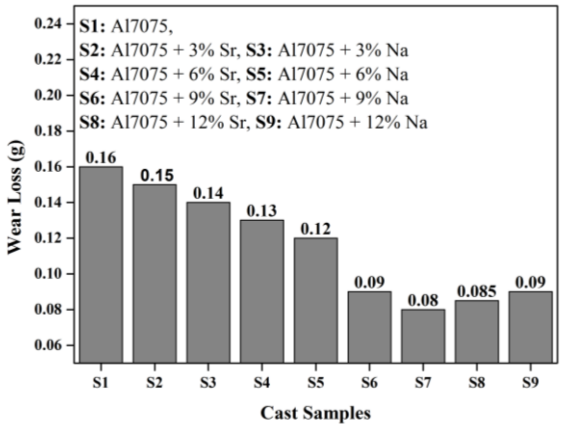

Figure 6. Wear loss of A7075 and varying wt. % of Sr and Na

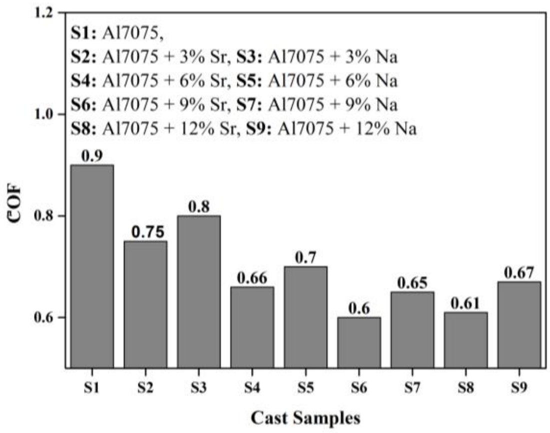

Figure 7. COF of A7075 and varying wt. % of Sr and Na

4.6. Experimenting with wear behaviour using the Taguchi Method

This method is a potent design concept that is frequently used in many different industries. It is frequently developed to provide superior goods at a lesser price. It is typically used to analyse the effects of varying the parameters. Testing was carried out on the test samples utilizing Taguchi evaluation of the L27 orthogonal array at room temperature (27°C) (OA). Wear test specimens were produced using the ASTMG99 size of 6 mm in diameter and 30 mm in length. During the wear tests, the test specimens were firmly pressed against the hard rotating steel disc. After every trial, the disc and test samples were carefully cleaned with an organic chemical (acetone) to ensure the correctness of the results. Current experiment evaluated the wear behaviour as a loss of weight (g) of a test material. The specimens were frequently cleaned with acetone solution before being weighed on a digital scale to ensure an accuracy of 0.0001 g throughout the studies. The test specimens were cleaned, and the final weight was accurately measured. Wear loss was evaluated by considering the difference between initial and final weight of the test samples. Test trials were conducted on the basis of factors that were selected and respective levels, which are shown in Table 1. Using samples of Al7075, Al7075+Sr, and Al7075+Na, 27 orthogonal array (OA) tests were performed. The findings are given in Table 2.

Experimental results of wear loss for modified alloy under the varying process parameters are depicted in Table 2. ANOVA was implemented to evaluate the significance level of each process parameter. By implementing ANOVA technique, it is possible to determine which factor has control over other factor. Also, significance level of each process parameter which are used in this research can be evaluated. Means its shown in ANOVA table indicate the percentage of contribution of each parameter and significant effects on the wear rate Also, table indicates whether the parameters are statistically significant or not. Investigational studies were carried out at a level of significance with 0.05 [25]. The factors with a P-value of < 0.05 were been considered to contribute to the significance of the performances. ANOVA results for wear loss of the modified alloy are depicted in Table 3. It is seen that, the wt. % of Sr is an extremely significant factor with a maximum of 69.70 % contribution between the other parameters followed by other parameters.

Table 1. Process parameters and levels

Sl. No.	Parameters	Levels	Levels	Levels
1	Sr (Wt. %)	3	6	9
2	Na (Wt. %)	3	6	9
3	Load (N)	15	20	25
4	Sliding Speed, rpm	100	200	300

Table 2. Taguchi L27 Orthogonal Array and their outcomes

Trial No.	Sr (Wt. %)	Na (Wt. %)	Load (N)	Sliding Speed (rpm)	Wear Loss (g)
1	3	3	15	100	0.070
2	3	3	20	200	0.088
3	3	3	25	300	0.096
4	3	6	15	200	0.080
5	3	6	20	300	0.090
6	3	6	25	100	0.080
7	3	9	15	300	0.075
8	3	9	20	100	0.050
9	3	9	25	200	0.085
10	6	3	15	100	0.060
11	6	3	20	200	0.065
12	6	3	25	300	0.090
13	6	6	15	200	0.045
14	6	6	20	300	0.055
15	6	6	25	100	0.045
16	6	9	15	300	0.055
17	6	9	20	100	0.050
18	6	9	25	200	0.080
19	9	3	15	100	0.035
20	9	3	20	200	0.040
21	9	3	25	300	0.045
22	9	6	15	200	0.030
23	9	6	20	300	0.045
24	9	6	25	100	0.030
25	9	9	15	300	0.026
26	9	9	20	100	0.025
27	9	9	25	200	0.035

Table 3. ANOVA outcomes of wear loss

Parameters	DoF	Seq. S S	Adj. S S	Adj. M S	F-Values	P-Values	Contribution (%)	Observation
Sr (Wt. %)	1	0.0090227	0.0090227	0.0090227	121.595	0.00000	69.70	Significant
Na (Wt. %)	1	0.0006480	0.0006480	0.0006480	8.733	0.00731	5.00	
Load (N)	1	0.0006722	0.0006722	0.0006722	9.059	0.00644	5.19	Significant
Sliding Speed (rpm)	1	0.0009680	0.0009680	0.0009680	13.045	0.00154	7.47	Significant
Error	22	0.0016325	0.0016325	0.0000742			12.61	
Total	26	0.0129434					100	

R-Sq = 87.39 %

Main Effects Plots of varying factors of wear loss of modified alloy are depictedin Figure 8. Figure 8 shows that, increasing the Sr and Na 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 improved adhesion between the two, there is better wear resistance. Al7075 with appropriate wt. % of Sr effected improvement of wear resistance when compared to the cast parts without Sr modification. Though, high hardness and brittleness also led to deterioration of the wear resistance. From Figure 8, it is evidenced that the wear loss considerably decreases initially and further increases due to increase in Sr content. This mainly confirms with changing the trends in average size of the primary Mg2Si phases of the base alloys [26]. Na modified cast parts have higher wear resistance compared to unmodified cast parts. In Figure 8, it is depicted that, Sr and Na elements of 9%, load of 15 N and sliding speed of 100 rpm are the optimal levels for achieving minimum wear loss of modified alloy. It is also seen that, increasing the applied load from 15 N to 25 N, there is an increase in the wear loss of modified alloy. When a load pressed the modified alloy samples intensely towards the hard disc and sharper particulates will be subjected to high stress. Generally, this produces high rubbing action which leads to plastic deformation. Also itreduces the bonding between modifying element and the alloy. Due to this, the modified Sr and Na particulates broke and moved towards to the base alloy and high material was removed from modified alloy samples. It is also seen that, increase in wear rate is observed for the process parameters such as sliding speed between 100 m - 300 rpm. The Sr and Na particles protruding on Al alloy surface generally cause sharp asperity and leads to non-uniform interactions among the test samples and counter interface which cause high wear loss in modified alloy [27]. Also Wear rate increased due to increase in the sliding speed. Generally, this leads to increase in the temperature of the surfaces due to high sliding speed, generally causes a high softening effect on modified alloy. And, also, it is observed that, the development of high surface damages result in high wear rate.

Interaction graph indicates the influence of parameters used to evaluate the wear loss and the COF of the modified alloy. Other researchers [28, 29] came to the conclusion that a process parameter with a high angle of slope exhibits a higher significance rate. Additionally, it is seen that the plotted lines in the interaction plots are not parallel, indicating that the interaction between the process parameters is stronger. Figure 9 shows interaction maps for wear rate of changed alloy. It can be concluded that the plotted lines intersect(crossing) each other significantly.

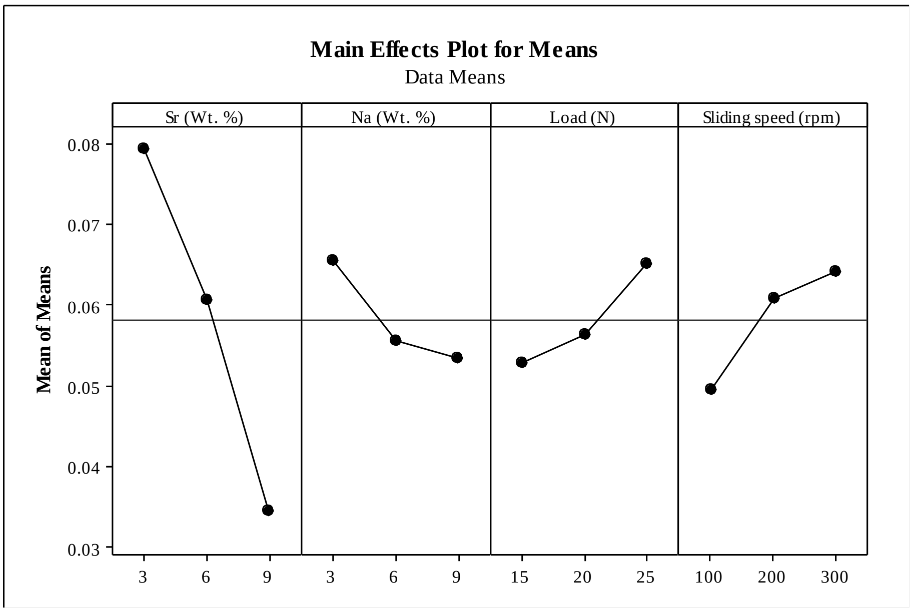

Figure 8. Effect of varying parameters on wear loss

Table 4. The response data for monolithic material

Levels	Sr (Wt. %)	Na (Wt. %)	Load (N)	Sliding speed (rpm)
1	0.07933	0.06544	0.05289	0.04944
2	0.06056	0.05556	0.05644	0.06089
3	0.03456	0.05344	0.06511	0.06411
Delta	0.04478	0.01200	0.01222	0.01467
Rank	1	4	3	2

The model adequacy was also evaluated by analysis of residuals [30]. Generally, it 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. fit plots. The residual histogram plots generally aid in determining if the obtained data are skewed [31]. Figure 10 shows the wear rate residual plots for the modified alloy.

Regression analysis uses a linear regression equation to illustrate the correlation between two or more predictor variables [32]. The relationship between the wear factors and their interactions is established via a regression equation. Eqs. (1) represent the regression analysis equations for the modified alloy.

Wear Loss (g) = 0.0758148 - 0.00746296 Sr (Wt. %) - 0.002 Na (Wt. %) + 0.00122222 Load (N) + 7.33333e-005 Sliding speed (rpm) (1)

To check the accuracy of predicted values, the comparison between the predicted and experimental values is shown in graphical representations. Outcomes of the experimental and predicted values of wear loss of the modified alloy are depicted in Figure 11. From the plots, it is observed that there is a better correlation between the experimental and predicted values.

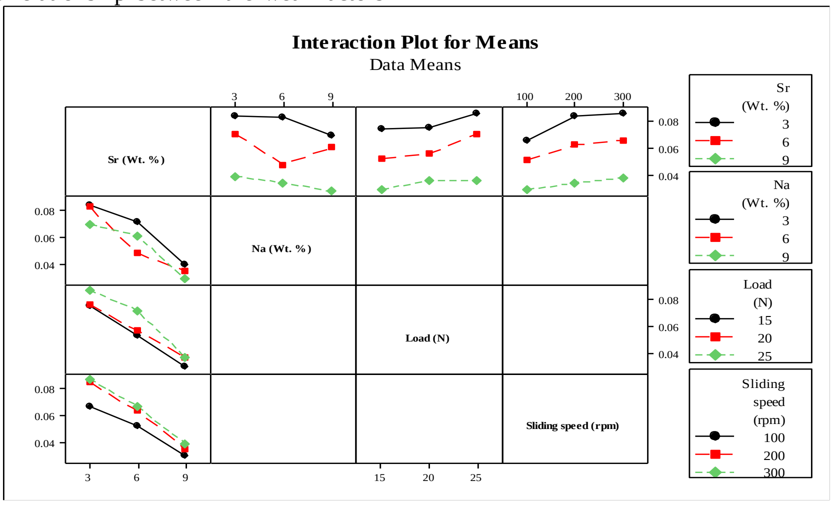

Figure 9. Interaction plots for wear loss

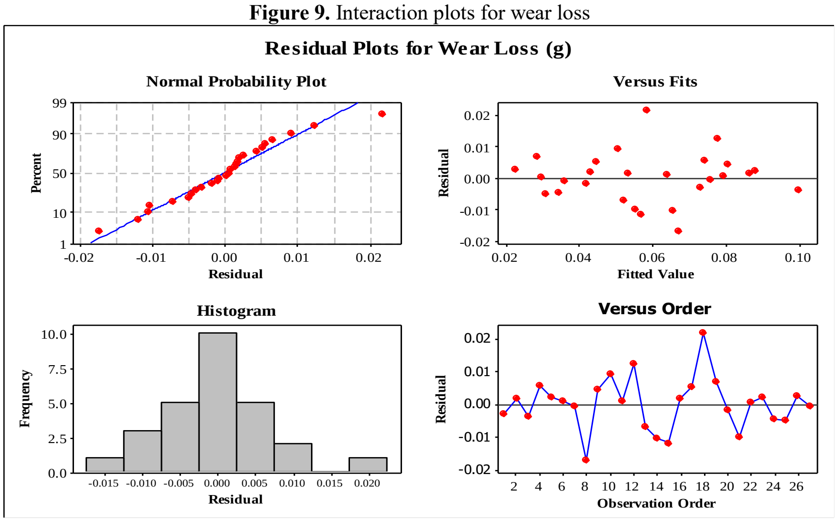

Figure 10. The residual graphs for wear loss

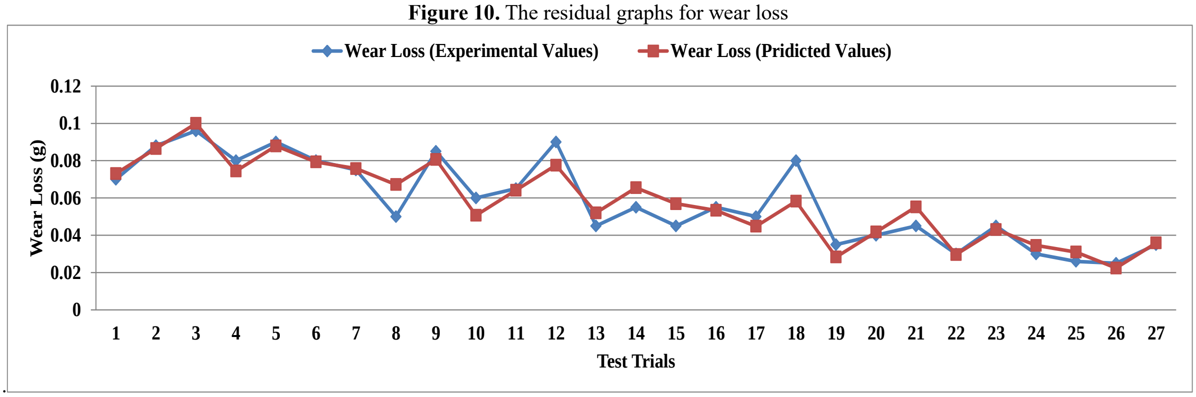

Figure 11. Experimental vs. predicted values of wear loss

The regression model's contour plots, are drawn and utilized to display the combined impact of the parameters used in the current inquiry. These graphs are typically used to show how the two parameters interact with one another. The optimal values of each parameter could be anticipated by analyzing these plots [29]. Figure 12 displays the contour graphs for the wear loss based on the independent factors for all the developed materials.

The worn-out surfaces of Al7075 alloy and other cast parts of varying wt. % of Sr / Na content are depicted in Figure 13. The main factors that contribute to the production of oxidized coatings on the grinding surface of Al alloy are released heat and surface roughness when subjected to greater loads. The oxide film's direct interaction with the base alloy and hard disc is prevented by the lubricants. Therefore, oxide films increase wear resistance while simultaneously lowering the COF. Nevertheless, at sufficient normal force, the base alloy's surfaces bend plastically, which typically causes the oxide film layer to split.

It can be seen in Figure 13 (a), that a plastic deformation ensued and parallel scratch marks developed due to rubbing action between hard spots of friction pairs. In Figure 13 (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 limit 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 [33]. Compared with one in Figure 13 (b), the peeling pit in Figure 13 (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 Al7075+Sr in Figure 13 (b) are finer when compared to the A7075 without Sr addition in Figure 13 (a). As depicted in Figure 13 (b), almost no peeling pit or plastic deformation is found on the worn-out surface of A7075 alloy modified with Sr content. Figure 13 (c) depicts the wear debris produced from the wear tests of A7075 alloy modified with Na content. According to the worn-out surface images, it is seen that, the size of debris belonging to A7075 + Na is very much smaller as compared to that of unmodified A7075 alloy. The modified alloy surfaces are less damaged than the un-modified alloy surfaces. Figure 14 displays the results of an EDS analysis of Al7075, Al7075+Sr and Al7075+Na alloy. An EDS analysis of Al7075 is depicted in Figure 14(a). An EDS analysis of the Sr modified alloy surface depicted in Figure 14(b) indicates the existence of Strontium ("Sr" peak), suggesting that the alloy contains Strontium (Sr). An EDS analysis of the Na modified alloy surface depicted in Figure 14(c) indicates the existence of Sodium ("Na" peak), suggesting that the alloy contains Sodium (Na).

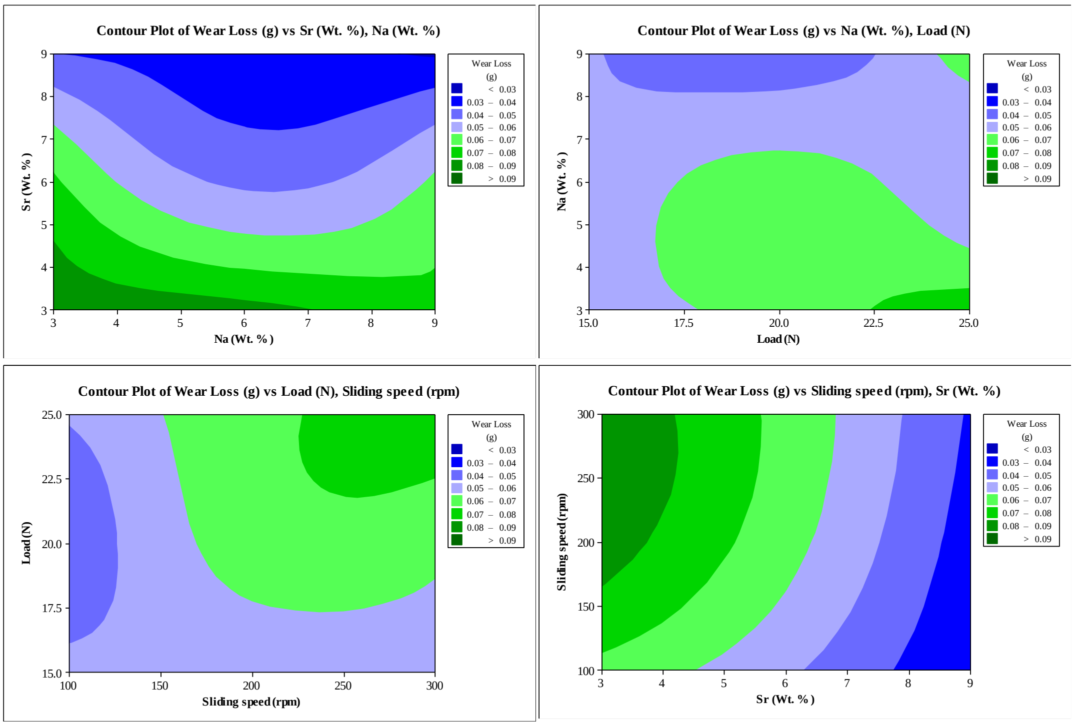

Figure 12. Contour Plot for wear loss of modified alloy

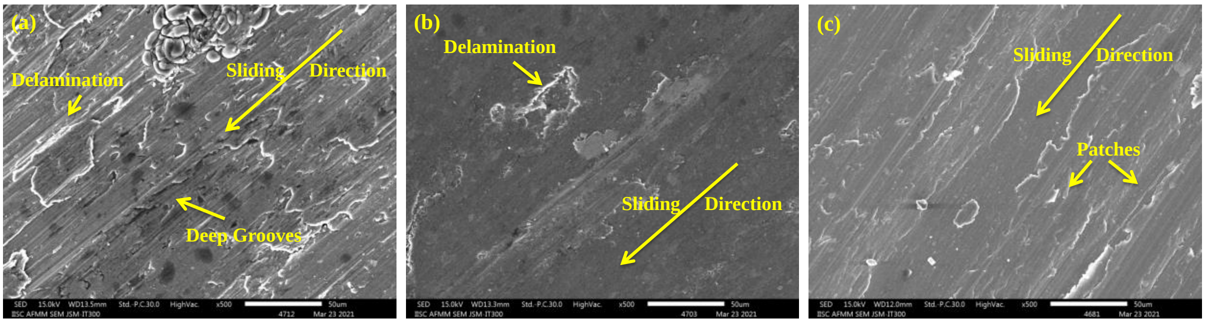

Figure 13. Wornout surface of (a) Al7075, (b) Al7075+Sr and (c) Al7075+Na

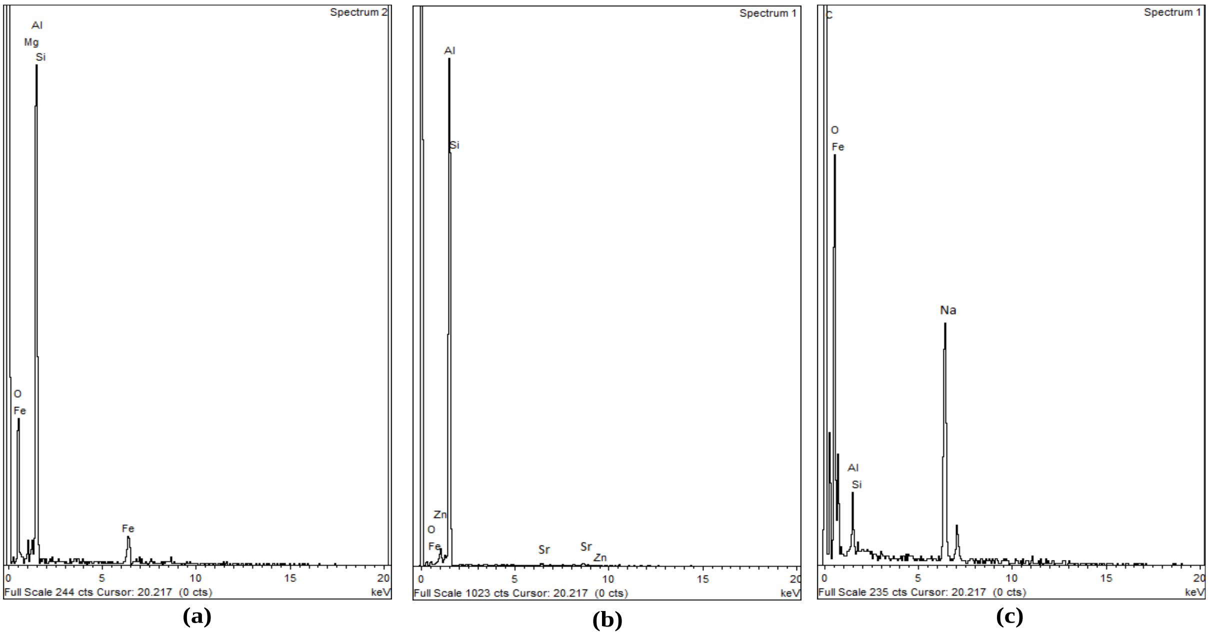

Figure 14. EDS analysis of (a) Al7075, (b) Al7075 + Sr and (c) Al7075 + Na

5. Conclusions

The outcomes of the present research work are summarized as follows:

- Al7075-Sr/Na cast parts were produced by Stir Casting method. Different wt. % of Sr and Na (3, 6, 9 and 12%) were added (modified) to Al7075 alloy to achieve optimum levels of Sr and Na on the microstructural amendment. Further study was undertaken to examine the mechanical and wear behaviour of developed materials by modifying with Sr and Na.
- The outcomes revealed that addition of elements (Sr / Na) enhance the microstructural features. Uniform dispersal of particulates (Sr / Na) in Al7075 alloy and also the modified structure of silicon (Si) were observed. Additions of Sr / Na content showed that the hardness of Al7075-Sr / Na cast parts increased to some extent. But, at higher wt. % of Sr / Na 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 and Na (3%, 6% & 9%), load (15 N, 20 N & 25 N) and sliding speed (100, 200 & 300 rpm) were selected.
- ANOVA outcomes have shown that, the Sr content has a better significant impact on wear behaviour of the modified alloy. From the SEM images of fractured surfaces, the fracture like brittleness is observed in Al7075 (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.

References

[1] Khraisat, Abu Jadayil, (2010) "Strengthening Aluminum Scrap by Alloying with Iron", Jordan Journal of Mechanical and Industrial Engineering, Vol. 4, No. 3, pp. 372-377.

[2] Kheder, Marahleh, Al-Jamea, (2011) "Strengthening of Aluminum by SiC, Al_2O_3 and MgO", Jordan Journal of Mechanical and Industrial Engineering, Vol. 5, No. 6, pp. 533-541.

[3] EzhilVannan, Paul Vizhian, (2015) "Corrosion Characteristics of Basalt Short Fiber Reinforced with Al-7075 Metal Matrix Composites", Jordan Journal of

Mechanical and Industrial Engineering, Vol. 9, No. 2, pp. 121-128.

[4] Abdul Kalam Azad1, Mohamed FayasSaffiudeen, Abdullah Syed, Fasil T. Mohammed, (2023) "Fabrication of Al-6061/SiC Nano Composite Material Through Ultrasonic Cavitation Technique and Its Analysis", Jordan Journal of Mechanical and Industrial Engineering, Vol. 17, No. 3, pp. 121-128.

[5] Ranjeet Kumar Arya, Rajan Kumar, Amit Telang, Anil Singh Yadav, (2023) "Effect of Microstructure on Mechanical Behaviors of Al6061 Metal Matrix Composite Reinforced with Silicon Nitride (Si3N4) and Silicon Carbide (SiC) Micro Particles", Silicon, Vol. 15, pp. 5911.5923, https://doi.org/10.1007/s12633-023-02468-6.

[6] Samuel, Doty, Valtierra, Samuel, (2014) "Effect of Grain Refining and Sr-Modification Interactions on the Impact Toughness of Al-Si-Mg Cast Alloys", Mater. Des. Vol. 56, pp. 264-273.

[7] Elisa Fracchia, Federico Simone Gobber, Mario Rosso (2021) "Effect of Alloying Elements on the Sr Modification of Al-Si Cast Alloys", Metals, Vol. 11, https://doi.org/10.3390/met11020342.

[8] Wenduan Yan, Gaosheng Fu, Yanhua Xu, Wanqing Lai, Hongling Chen, (2021) "Effect Of Sr Addition On The Microstructure And Properties of The A356 Al Alloy", Materials and technology, Vol. 55, pp. 443-448.

[9] Omran, Mohamed M Ali, Moatasem M K H, Mohammed Ezzeldien, (2018) "Effect of Strontium Content on the Mechanical Properties of Hypo and Hyper Al-Si Cast Alloys", Journal of Al Azhar University Engineering Sector, Vol. 13, pp. 1322-1331.

[10] Zi-Kui Liu, Shengjun Zhang, Qingyou Han, Vinod Sikka, (2006) "The Effect of Impurities on the Processing of Aluminum Alloys", Industrial Materials for the Future, pp. 1-75.

[11] Williams S, Ebhota, Tien-Chien Jen, (2017) "Effects of Modification Techniques on Mechanical Properties of Al-Si Cast Alloys, Alluminium Alloys", https://doi.org/10.5772/intechopen.70391.

[12] Zhu, N J Gu, B J Zhou, (2017) "Effects of Combining Na and Sr additions on Eutectic Modification in Al-Si alloy", IOP Conf. Series: Materials Science and Engineering, Vol. 230, https://doi.org/10.1088/1757-899X/230/1/012015.

[13] Saravana Kumar, Pramodh, Prasanna Kumar, Pradeep, (2018) "Comparative Study of Addition of Strontium in Aluminium (AA6063)", International Journal of Research in Engineering. Science and Management, Vol. 1, pp. 383-388.

[14] Sarada, Srinivasamurthy, (2013) "Microstructural Characteristics of Sr and Na Modified Al-Mg-Si Alloy", IJIRSET, Vol. 2, pp. 3975-3983.

[15] Hu Seyin S Evik, S Can Kurnaz S, (2014) "The Effect of strontium on the microstructure and mechanical properties of Mg-6Al-0.3Mn-0.3Ti-1Sn", Journal of Magnesium and Alloys, Vol. 2, pp. 214-219.

[16] Jafer T. Al-Haidary, MahdieMutier Hanon, YasirMuhiAbdulsahib, (2015) "Effect of Sodium Chloride on Microstructure and Mechanical Properties of Al-Si alloy". Engg. & Tech. Journal, Vol. 33, pp. 2187-2197.

[17] Jun Qi Gan, Yu Jian Huang, Cheng Wen, Jun Du, (2020) "Effect of Sr modification on microstructure and thermal conductivity of hypoeutectic Al-Si alloys", Transactions of Nonferrous Metals Society of China, Vol. 30, pp. 2879-2890.

[18] Irina Brodova, (2022) "Effect of Grain Size on the Properties of Aluminum Matrix Composites with Graphene", Metals, Vol. 12, https://doi.org/10.3390/met12061054.

[19] Jianbin Zhu, Zhongmin Luo, Shuo Wu, Hong Yan. (2018) "The Effect of Sr on the microstructure and wear properties of AlSi5Cu1Mg alloy", Advances in Mechanical Engineering, Vol. 10, pp. 1-10.

[20] Najimi, Emamy, Lashgari, (2011) "The effect of simultaneous addition of Ca and Sr on the microstructure and tensile properties of A357-20% Al_2O_3 composite", Mechanics of Advanced Materials and Structures, Vol. 18, pp. 201-209, https://doi.org/10.1080/15376494.2010.516883.

[21] Wang, C H Caceres, J R Griffiths, (2003) "Damage by eutectic particle cracking in aluminum casting alloys A356/357", Metall. Mater. Trans. A, Vol. 34(A), pp. 2901-2912.

[22] Peng Tang, Wenfang Li, Kang Wang, Jun Du, Xiyong Chen, Yanjun Zhao, Weizhou Li, (2017) "Effect of Al-Ti-C master alloy addition on microstructures and mechanical properties of cast eutectic Al-Si-Fe-Cu alloy", Mater. Des. Vol. 115.

[23] Sreenivasa Iyengar, Sethuramu, Ravikumar, (2023) "Mechanical, Wear, and Fracture Behavior of Titanium Diboride (TiB_2) - Cerium Oxide (CeO_2) Reinforced Al-6061 Hot-rolled Hybrid Composites", FratturaedIntegritaStrutturale, Vol. 63, pp. 289-300.

[24] Razaghian, Emamy, Najimi, SeyedEbrahimi, (2009) "Sr effect on the microstructure and tensile properties of A357 aluminum alloy and Al_2O_3/SiC-A357 cast composites", Materials Characterization, Vol. 60, pp. 1361-1369.

[25] Abbas Al-Refaie, Tai-Hsi Wu, Ming-Hsien Li, (2010) "An Effective Approach for Solving The Multi-Response Problem in Taguchi Method". Jordan Journal of Mechanical and Industrial Engineering, Vol. 4, No. 2, pp. 314-323.

[26] Mengqi Cong, Ziquan Li, Jinsong Liu, Shaohua Li, (2014) "Effect of Sr on microstructure, tensile properties and wear behavior of as-cast Mg–6Zn–4Si alloy, Materials and Design, Vol. 53, pp. 430-434.

[27] Nagesh, S Raghavendra, Nm Sivaram, S Suresh, B Manjunatha, S Sanketh, (2021) "Tribological characteristics of Al6061, boron, and graphite hybrid metal matrix composites", Advances in Materials and Processing Technologies, https://doi.org/10.1080/2374068X.2021.1946323.

[28] Mohanavel, Ravichandran, (2022) "Optimization of Parameters to Improve the Properties of AA7178/Si3N4 Composites Employing Taguchi Approach", Silicon, Vol. 14, pp. 1381-1394.

[29] MorahemAshengroph, IrajNahvi, JahanshirAmini, (2013) "Application of Taguchi Design and Response Surface Methodology for Improving Conversion of Isoeugenol into Vanillin by Resting Cells of Psychrobacter sp. CSW4", Iranian Journal of Pharmaceutical Research, Vol. 12, pp. 411-421.

[30] Emad Al-Momani, Ibrahim Rawabdeh, (2008) "An Application of Finite Element Method and Design of Experiments in the Optimization of Sheet Metal Blanking Process", Jordan Journal of Mechanical and Industrial Engineering, Vol. 2, No. 1, pp. 53-63.

[31] Sivaraos, Milkey, Samsudin, Dubey, Kidd, (2014) " Comparison between Taguchi Method and Response Surface Methodology (RSM) in Modelling CO_2 Laser Machining", Jordan Journal of Mechanical and Industrial Engineering, Vol. 8, No. 1, pp. 35-42.

[32] Kadirgama, Noor, Zuki, Rahman, Rejab, Daud, Abou-El-Hossein, (2008) "Optimization of Surface Roughness in End Milling on Mould Aluminium Alloys (AA6061-T6) Using Response Surface Method and Radian Basis Function Network", Jordan Journal of Mechanical and Industrial Engineering, Vol. 2, No. 4, pp. 209-214.

[33] Ravikumar, Reddappa, Suresh, Ram Mohan, Nagaraja C Reddy, Babu E Reddy, (2021) "Investigations on tensile fractography and wear characteristics of Al7075-Al_2O_3-SiC Hybrid Metal Matrix Composites routed through liquid metallurgical techniques", Frattura ed Integrità Strutturale, Vol. 56, pp. 160-170.