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A Study of Erosion Rate of Homogenized Structural AL7175 Alloy for Aircraft Application

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Abstract

Structural alloys (Al7175) are widely used in aviation, marine, automobile and aerospace application due to their special characteristics such as high strength to weight ratio, high ductility, light weight, good corrosion resistance, low density, good thermal and electrical conductivity.

Improvement in the microstructural, mechanical properties of this alloy can be achieved by homogenization process. Aluminum alloys were subjected to heat treatment to obtain a fine grain structure. Heat treated and as-cast aluminium alloy processed material were characterized using scanning electron microscope, x-ray diffraction, hardness test and erosion test. Material loss in structural materials is aggravated by erosive action and create a massive problem in industrial application such as turbine, agriculture equipment, pumps etc. Study of erosion behaviour on the structural aluminum alloy composite, erosion test of structural aluminum alloy composites was performed at different impingement angle (30º and 90º) and at specified velocity of erodent using erosion test machine (Air Jet Erosion Tester TR-471-800). Investigation was carried out as-cast aluminium alloy Al7175 and homogenized alloys, then set of reading were recorded at 50 m/s velocity of erodent by keeping other parameters like erodent discharge, impingement angle and temperature are variables parameters to obtain the erosion rate.

Keywords: *Structural Alloys, Aircraft, light weight, Aviation, fine grain structure, heat-treated, erodent discharge.*

1.0 Introduction

Because of its strong corrosion resistance, high electrical and thermal conductivity, superb reflectivity, and excellent recycling qualities, aluminium is a particularly important metal. With a melting point of 660°C, aluminium atoms are organised in a face-centered cubic (FCC) configuration. There are nine distinct series of aluminium, four of which are known as heat-treatable aluminium alloys because of the possibility of increasing mechanical properties by heat treatment process. The qualities of heat treatable Al-alloys can be improved even more by adding a reinforcing phase that improves the entire composite's mechanical properties. Aluminum is a nonferrous metal with a high strength-to-weight ratio as well as a low manufacturing cost. Aluminium alloys and composites are particularly attractive and competitive structural materials in a variety of sectors due to their characteristics. Aluminum is alloyed with metals including copper, zinc, magnesium, and

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manganese for applications to require higher mechanical strength. The aluminium alloy's series is determined by the alloying components. 1xxx to 9xxx are the possible series categories. The method for achieving more uniformity is referred to as "homogenization." The portion is heated to near-melting temperatures from 480ºC to 540°C and then progressively cooled, causing the precipitating elements to become more uniformly dispersed all over the material. Homogenizing is a kind of annealing known as diffusion annealing or uniform annealing. To create more appropriate for machining is the goal of annealing, but it may also be used to minimize internal tensions, deformation less probable and making cracking. It should be noted that pure aluminium does not react to heat treatment. There are two steps in the homogenization process which are (1) heating process (2) cooling process. In the heating process, the temperature needed to cause homogeneity is extremely close to the melting point of aluminium alloy and this varies depend upon the other metals in material, but it is usually not greater than 680ºC and this implies that the metal will typically be heated to temperatures close to 537ºC. The component may burn, causing it to become deformed and prone to degradation, if the temperature is too high. The heat preservation time for aluminium homogenising is quite lengthy, often ranging 10 to 15 hrs that depends on the item thickness. And in the cooling process, the cooling phase starts after the heating is finished. This is frequently preceded by a soak in the quench media and then by a period of cooldown. The cooling rate might vary based on the constituents in the alloy. It's also worth noting that quenching aluminium alloys must be done practically soon after material is withdrawn from furnace to keep the shape acquired during the heating process.

When alloys are first cast, the method results in an uneven distribution of aluminium and other alloying elements. Following the heating stage of the homogenization process, the atoms of the material are permitted to rearrange themselves more uniformly throughout the alloy. This procedure is conducted while the material is slowly cooling.

1.1 Structural Aluminium Alloys

The 2000 series alloys give strength and damage tolerance, the 6000 series alloys provide strong corrosion resistance and enhanced machinability, the 7000 series alloys provide increased strength potential, and the 8000 series alloys provide high temperature performance[2]. Applications of aluminium alloys in aircraft components are shown in Table 1[2], and Figure 1 shows the critical parts of the aircraft[3].

Table 1: Applications of Al alloys in aircraft components [2]

Components	Materials	Alloys series	Alloying elements	Properties
Front legs of sea	Al 2017 Al2024	Al 2xxx	Cu\Mg	High fatigue strength, corrosion resistance with cladding, good machining, high strength alloy,
Wing leading edge	Al 2024			
Seat ejectors	Al2004			
Floor sections of the aircraft	Al 2090-T86 Al 2090-T62			
Seat structure	Al 2090-T86			
Supporting members of fuselage structure	Al 2090-T651			
Backrests and armrests	Al 6xxx	Al 6xxx	Mg\Si	High strength, corrosion resistance, good formability and weldability.
Fuselage skins, stringers and bulkheads	Al 6013 Al 6050 Al7050			
Wings skins, panels and covers	Al7079	Al7xxx	Zn/Mn/Cu	Highest strength aluminium alloy, high toughness, good machinability
Rear legs of seat and seat spreaders	Al7075			
Wing spars, ribs	Al 7075			
Wheels and landing gear links	Al 7055-T77			
Horizontal and vertical stabilizers				
Upper and lower wing skins				

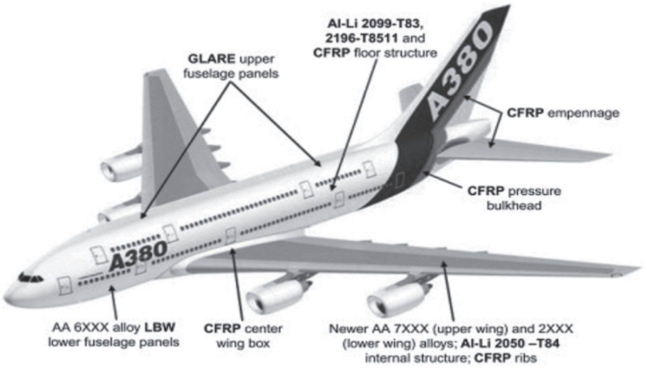


Figure 1: Advanced material used for structural areas of the airbus A380[3]

1.2 Erosion Problem in Aircraft

The effects of erosion on aircraft produced by rain, sand, volcanic ash, and other erodents have been observed since the start of aviation. Attack of solid particles and liquid droplets, in particular, can change the properties of aircraft outer cover material during flight. A variety of vehicle parameters determine this influence, including the erodent's exposure time, variety of erodent, and lastly the erodent's impact speed[4]. Liquid, solid and a combination of solid and liquid impingement erosion are the three main categories to consider when discussing erosion on the aero vehicles of high-speed. The exposure of the structure to a bombardment of small liquid droplets that all contact the structure at the same time from liquid impact erosion. When an aeroplane passes through a cloud or is exposed to precipitation, such an encounter is possible.

SPE is caused by many particles' types, such as ice or hail striking an aircraft's fuselage or sand particles impacting the frame of aeroplane while landing and take-off in a desert environment. Most constructions, despite their appearance, are prone to both solid and liquid erosion for a short period of time.

Different particles or flying species may collide with an aircraft's engines and forward-facing surfaces as it flies through the atmosphere. sand, dust, ice, hailstorm, and rain are examples of particles. The aircraft's numerous surfaces may also be subject to foreign object damage caused by insect and bird collide[6-7]. Rain and sand, in particular, can have a severe influence on the body of the aircraft and significantly decrease the components lifecycle, as this attack can occur in a variety of conditions.

Certain areas of an aircraft are more vulnerable to damage from strikes during flight. In general, the front areas of the aircraft that face the approaching air stream suffer from a higher rate of damage since the impact speed is significantly higher there. As a result, the downstream sites only experience low-speed effects. Figure 2 depicts the impact rate distribution on the commercial aeroplane[8]. Items that move at a medium speed are represent by bigger dots. The smaller dots represent impact locations for slower moving items, whereas the hatched zone depicts the impact on high-speed collisions, which are common.

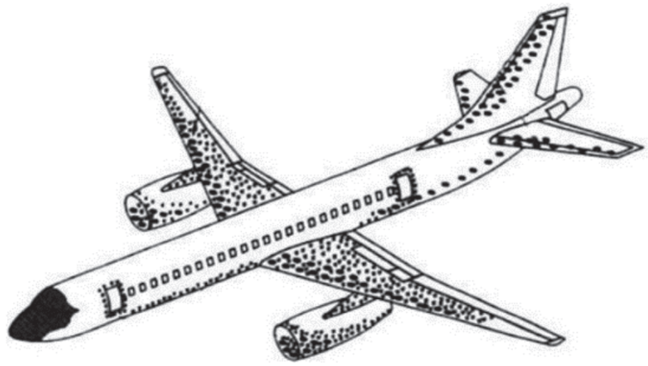


Figure 2: Impact distribution on aeroplane.
Source: Adapted from[8].

2.0 Experimental details

2.1 Material Preparation

Al 7175 alloy was used in the work, with addition of nickel as 2, 5 and 10% wt, the homogenization process was carried on the Al 7175 base alloy and its composite at 490°C for 15 hours. The chemical composition was determined by using energy dispersive spectroscopy (EDS), and to determine the microstructural properties scanning electron microscope (SEM) is used. For all the test the specimen dimension was cut into 25×20×5mm using machining process.

2.2 Microstructural analysis

To study the microstructural analysis of prepared samples of Al 7175 aluminium alloys, the samples of size 25×20×5 mm were considered for erosion test and the same samples were taken for microstructural studies. Mirror finished surface sample were taken for the test. samples were then subject to SEM analysis using Tescan Vega-3 SEM (BMSCE Bengaluru), before the testing the samples were etched using Keller Reagent. SEM analysis was performed on before and after homogenization of Al 7175 base alloy and its composites in order to investigate the microstructural changes that occurred in the given alloys.

The Energy Dispersive X-ray Analysis (EDX) and X-ray Diffraction analysis (XRD) scan that was performed on the Al 7175 base alloy and its composites to reveal the chemical composition and intermetallic phase.

2.3 Mechanical properties

Vickers hardness is used. Mitutoyo hardness tester (RIT, Bengaluru) was used. The testing condition for hardness test about 100gf (0.1N) for 15 sec dwell time. Indentation is performed on several locations of the specimen, and an average value is determined[10].

The hardness test was conducted on Al 7175 (1) non-heat-treated (2) Homogenised. Hardness test was carried out according to ASTM E8 M standard.

2.4 Erosion test

Erosion test was carried on the Air Jet Erosion Tester TR-471-800 (RIT, Bengaluru) according to condition given in Table 2[9].

Table 2: Erosion Test Conditions

	Parameters	Description
1.	Sample size (mm)	25×25×5 and 25×20×5
2.	Angle (º)	30, 90.
3.	Erodent	Alumina – Al_2O_3
4.	Erodent feed rate	3g/min.
5.	Particle velocity	50 m/s
6.	Test time	Cycle of 5 min
7.	Temperature	Temperature
8.	Nozzle size	ID: 1.5mm, OD: 15mm × 50mm

In this experimental study, the formula used for the erosion rate analysis is given below.

$$E = \frac{\Delta Ms}{\Delta Me} \quad \text{... (1)}$$

Where E is the erosion rate (mg/g), ΔMs and ΔMe is the weight loss of the specimens (mg) and the weight of the erodent particles (g) used during erosion test (i.e., testing time *x* particles feed rate)[9].

The test was carried out on Al 7175 alloys for non-homogenised and homogenised condition. And the graphs are plotted between the erosion rate (g/g) v/s cumulative mass loss (g) for all the alloys.

3.0 Result and Discussion

3.1 Mechanical Properties

The hardness of the composites and base alloy before heat treatment and after heat treatment is shown in Figure 3. The results of the experiment indicate that the hardness of the base alloy in its as-cast state is about 209.66 HV. When the percentage of nickel in the alloy was increased by 2%, the micro hardness dropped to 174.667 HV. When the percentage of nickel in the alloy was increased by 5%, the micro hardness increased to 184.33 HV. Finally, when the percentage of nickel in the alloy was increased by 10%, the hardness values was again increased to 192 HV.

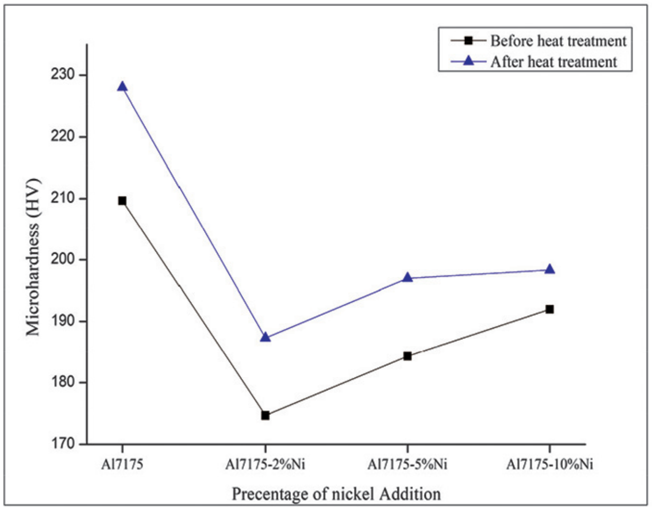


Figure 3: Variation in the values of hardness with increase in percentage of nickel

After heat-treatment the hardness of the Al 7175 base alloy was increased up to 228HV, when the nickel composition was increased by 2%, hardness was deteriorated to 187.33 HV, with the increase in 5% composition of nickel, 197HV was the hardness enhanced, then by increasing the nickel content by 10%, the hardness values was improved to 198.33HV. After heat treatment the hardness values increase, base alloys and composites can be made harder by heat treatment.

SEM and XRD analysis of the samples reveals the presence of coarsened intermetallic phases (i.e., aluminium nickel, aluminium magnesium zinc, magnesium zinc etc.) as compared to AA7175 base alloy. S.R. Yamanglu et al.[11] studied the production and the characterization of Al sxNi composites using hot pressing, through these trials. They noticed that when the nickel and intermetallic contents increased, so did the composites' hardness ratings.

3.2 Erosion Test

Figures 4(a) and (b) show the erosion rate Al 7175 for non-heat-treated condition for impact angle for 30º and 90º. it shows the erosion rate of the Al 7175 at 90º impact angle is higher than 30º, which is due to characteristic behaviour of the ductile material, where the material removal takes place predominantly by plastic deformation. It was discovered that weight loss rises with exposure duration until it reaches maximum values, following which it decreases continually to lower levels for a longer time

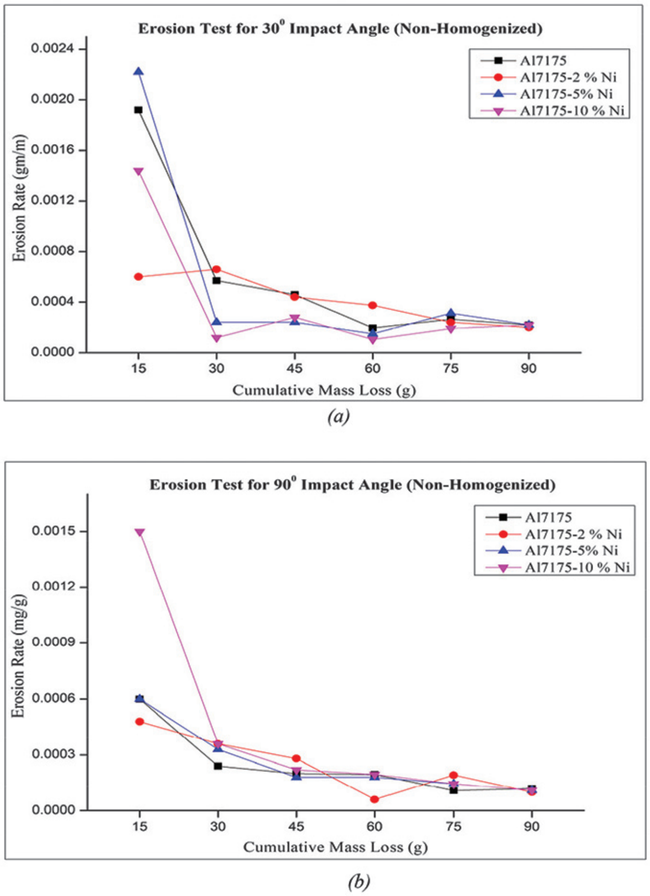


Figure 4: Erosion rate of Al 7175(Non-heat-treated) at (a) Impact Angle 30^o (b) Impact Angle 90^o

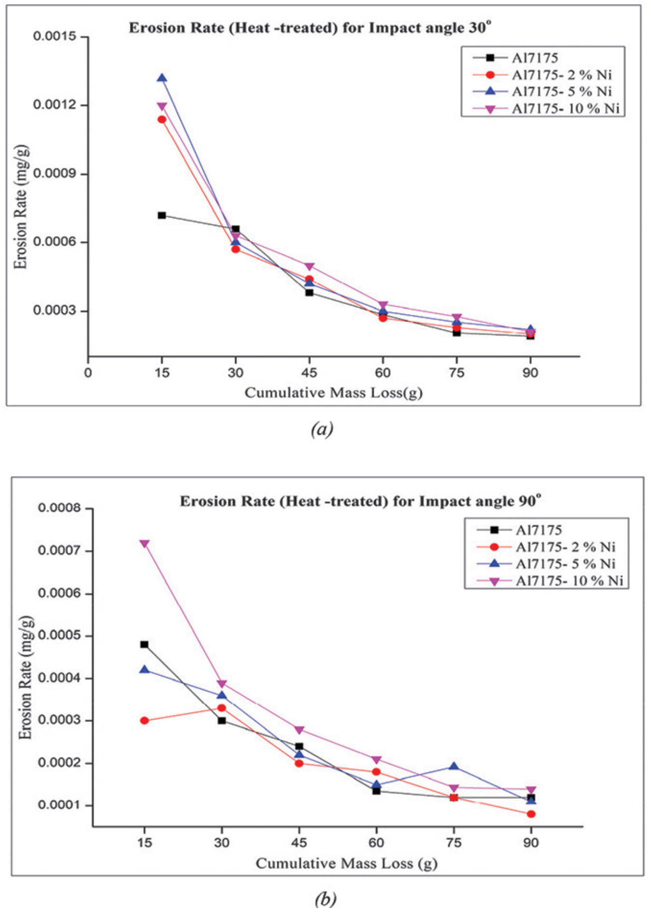


Figure 5: Erosion rate of Al 7175 (heat-treated) at (a) Impact angle 30^o (b) Impact angle 90^o

period. It is due to the alumina erodent which erode the soft metal surface layer.

It can be explained that the erosion phenomena in the air produces the weight loss rate which occurs from the mechanical action from the high velocity of air with erodent that produces the cavitation, impingement and erosion.

Figure 5 (a) and (b) shows the erosion rate Al 7175 for homogenized condition for impact angle for 30^o and 90^o. it shows the erosion rate of the Al 7175 at 30^o impact angle is higher than 90^o. Because of the heat treatment process for aluminium alloy, solution heat treatment commences at high temperatures to accommodate the elements in solid solution. When this alloy is stored at a temperature greater than room temperature, its strength improves but its ductility decreases. As it remains highly saturated, precipitation production commences. Alloy offers better strength, lower density, greater toughness, and lighter weight, as well as corrosion resistance.

Here the erosion rate of heat treated when compared to the non-heat-treated- condition both the condition shows the decrease in the erosion rate in the impact angle of 90^o in Figure 5(b), due to the improved fluidity, grain refinement, decreased dendrite arm size of the heat-treated alloy.

3.3 X-ray Diffraction Analysis

Figure 6 depcits X-Ray diffraction (XRD) analysis of Al 7075 after the heat treatment (490ºC for 15hr) and results that presence of nickel (Ni) in elemental form, aluminium magnesium zinc, aluminium magnesium, aluminium iron nickel, iron nickel, magnesium zinc and aluminium nickel are metal-metal interactions. Nickel (solubility is less than 0.04%) is less soluble in aluminium and forms an intermetallic phase called Al-Ni in the matrix of aluminium[12]. It is found in excess of this proportion as an insoluble intermetallic, frequently in combination with iron. Nickel (up to 2% concentration) improves the strength of high-purity aluminium while decreasing its ductility[12]. Although binary aluminum-nickel alloys are no longer used, nickel is added to aluminum-copper and aluminum-silicon alloys to increase hardness and strength at high temperatures and to decrease the coefficient of expansion.

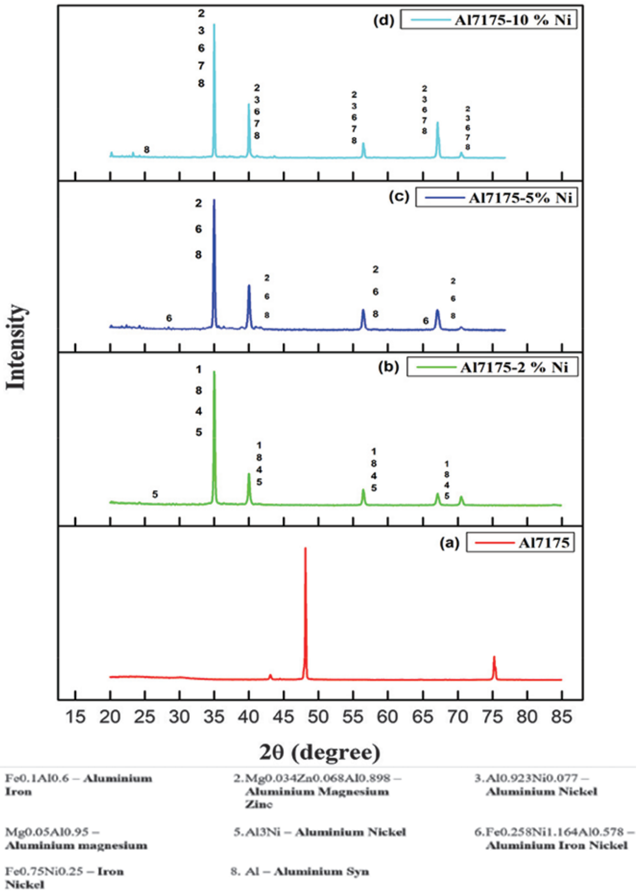


Figure 6: X-Ray diffraction (XRD) analysis of heat-treated aluminium alloy (a) 0% Ni (b) 2% Ni (C) 5% Ni (d) 10%Ni

The ferocity of the phase aluminium nickel diffraction peaks besides Al0.923Ni0.0077, and Al0.578 Ni1.164 Fe0.258 and there are various peaks of magnesium-zinc are enhanced due to the effects of the methods in the heat treatment process. Adeyemi Dayo Isadare et al. investigated the impact of heat treatment on some mechanical properties of Al 7075 and looked at the production of fine $MgZn_2$ precipitates as a result of age hardening. The Al-Ni phase diagram is used by Liming Ke et al.[13] to describe how Al-Ni intermetallic composites are formed. The binary system is shown to consist of consists of five stable intermetallic complexes, two solid solutions, namely, $AlNi_3$, AlNi, Al_3Ni, Al_3Ni_2 and Al_3Ni_5. According to research, when nickel and aluminium are combined, the reaction does not immediately produce the Al_3Ni phase. However, the reaction happens gradually, starting from the nickel powder's outside and moving within[14]. In this investigation, the aluminium alloy 7175 was utilised with varied weight percentages of nickel, that is inserted to matrix is around 2%, 5%, 10%, and Al_3Ni phases are created.

3.1 Scanning Electron Microscope Analysis (SEM)

SEM analysis was performed on before and after homogenization of Al 7175 base alloy and its composites in order to investigate the microstructural changes that occurred in the given alloys.

Figure 7 illustrates the SEM image of the non-heat-treated AA7175 base alloy and its composites at magnification of 300X and size 20µm, it reveals the microstructure of non-heat-treated alloy. It consists of aluminium-rich solid primary dendrites and the formation of intermetallic compounds around the primary grains. After the XRD analysis of these samples their intermetallic phases were obtained. These intermetallic phases are MgZn, AlNi, AlMnZn etc.

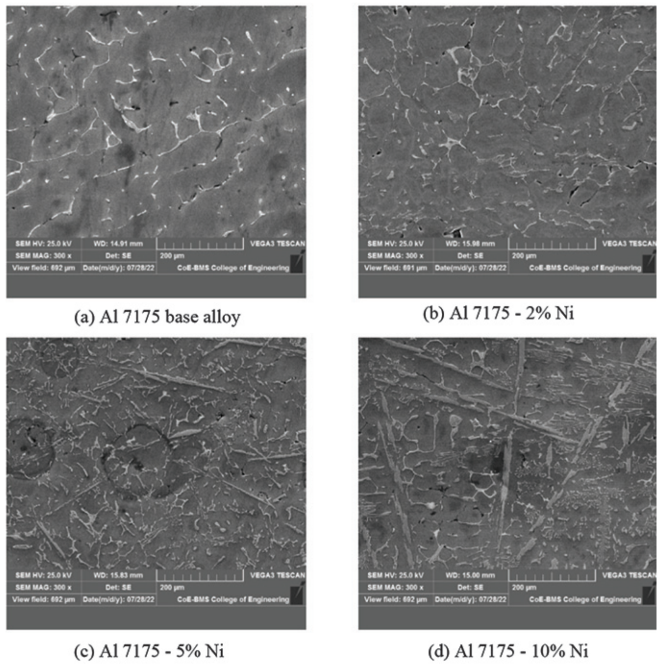


Figure 7: SEM analysis of non- heat-treated alloy at 300X -200µm

In Figures 7(b) (c) (f) elongated inclusions in the alloy with 2% Ni and globular inclusions in the alloy in 5% and 10%. By comparing the Figures 7 (b) (c) (d), as the concentration of nickel increases more intermetallic phase are formed which are AlNi, AlMgZn etc, and confirmed by XRD analysis. This is because addition of nickel into the aluminium melt acts as nucleation sites for the grains. The nickel blocks the columnar growth which often starts from the mold wall and form appropriate sites for the nucleation of the first aluminium phases during solidification process.

Al 7175 base alloy with its composite's microstructure study shows improved fluidity, grain refinement, decreased dendrite arm size, different aluminum and eutectic boundary

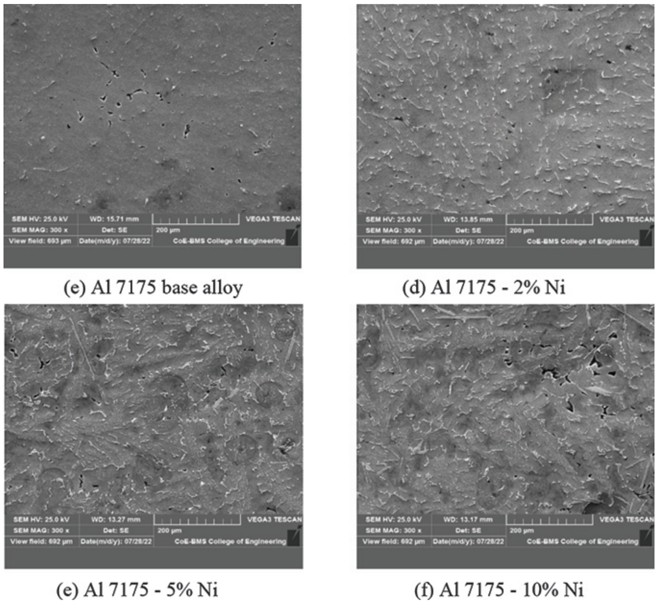
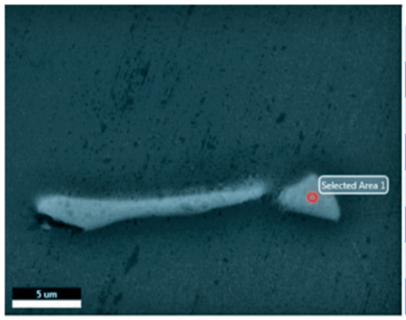
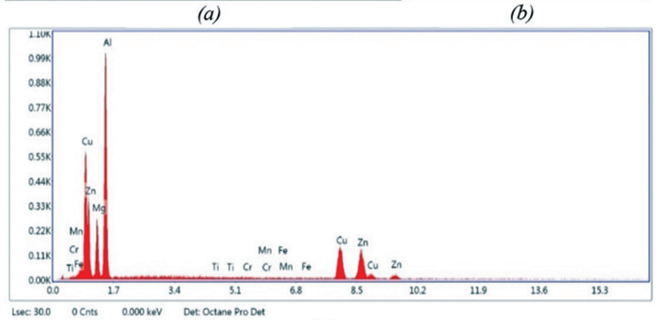


Figure 8: SEM analysis of heat-treated alloy at 300X-200µm



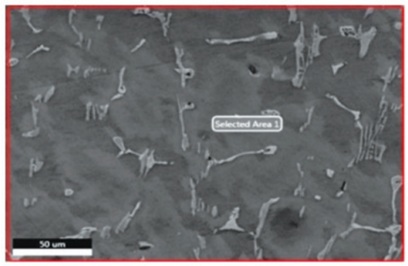
Element	Weight %	Atomic %
MgK	13.96	19.88
AlK	45.27	58.12
TiK	0.17	0.13
CrK	0.33	0.22
MnK	0.08	0.05
FeK	0.15	0.09
CuK	19.32	10.53
ZnK	20.72	10.98

(a) *(b)*



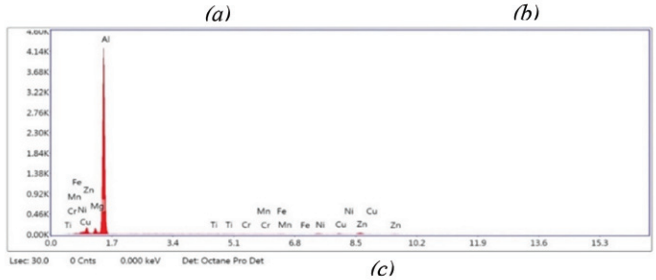
(c)

Figure 9: Edx analysis of Al 7175 base alloy



Element	Weight %	Atomic %
MgK	2.78	3.23
AlK	88.53	92.79
TiK	0.32	0.19
CrK	0.29	0.16
MnK	0.25	0.13
FeK	0.41	0.21
NiK	1.41	0.68
CuK	1.50	0.67
ZnK	4.52	1.96

(a) *(b)*



(c)

Figure 10: Edx analysis of Al 7175 2 % Ni

phases. Different Al 7175 composition microstructure is study and shown in Figure 8. The effects on the microstructure of heat treatment greatly improve the trans granular fracture ratio. It results in uniform strain within grains and improved grain boundaries bonding. Increased mechanical properties due to enhancing homogeneity of precipitated particles and adequate crystallographic texture distribution.

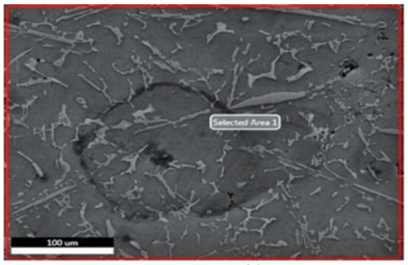
Figure 8(a) the microstructure of homogenised aluminium 7175 base alloy shows that the dendrites formation of Mg Zn compounds and there are few porosity observed in the castings. Figure 8(b) shows the microstructure of homogenised aluminium 7175 with 2.0% of Ni additions, it can be seen that fibrous formation of AlMg, AlZn and $Al_2Mg_3Zn_3$ compounds along with nickel intermetallic compound i.e Al_3Ni spread across the Al matrix. Figure 8(c) and Figure 9(f) show the microstructure of homogenised aluminium 7175 with 5.0% and 10.0% of Ni additions, It can be seen that fibrous formation and few flakes of AlMg, AlZn compounds along with nickel intermetallic compound i.e. Al_3Ni spread across the Al matrix.

3.2 Energy Dispresive X-Ray Spectroscopy (EDS)

Energy dispresive x-ray spectroscopy (Edx) was carried out on the Al 7175 base and as well as Al 7175 with diffrerent percentage of nickel addition (i.e., 2%, 5%, 10%) to reveal the chemical composition of the encricle region for the given sample.

The Edx analysis reveals the elemental anaylsis at the encircled region to check the weight precentage of the elements on the selected area. Figure 9(a) shows the selected region (red encircled) and the size is 5µm, which gives the Edx analysis of the AA7175, here the Figure 9(c) the shows the high peak of the Al, Cu, Mg, Zn. Figure 9(b) gives the weight % of elements present in the Al 7175 base alloy, here we can observe that the major element is Al which is about 45.57% based on the selected region and there is no presence of Ni in Al 7175 base alloy. Which can be claified by the Edx analysis.

The Figure 10, 11, 12 give the Edx analysis the Al 7175 with nickel varying i.e., 2%Ni, 5%Ni, 10%Ni. Here we can obseve that the presnece of the nickel in the alloys, which



(a)

Element	Weight %	Atomic %
MgK	2.67	3.14
AlK	87.27	92.21
TiK	0.17	0.10
CrK	0.24	0.13
MnK	0.14	0.07
FeK	0.32	0.16
NiK	3.29	1.60
CuK	1.52	0.68
ZnK	4.39	1.91

(b)

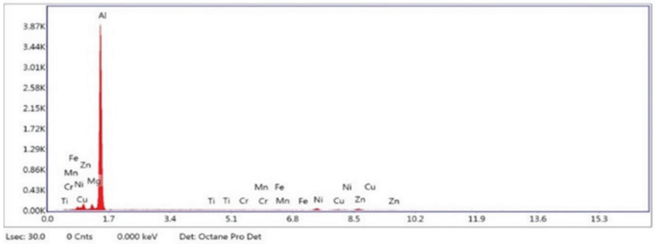


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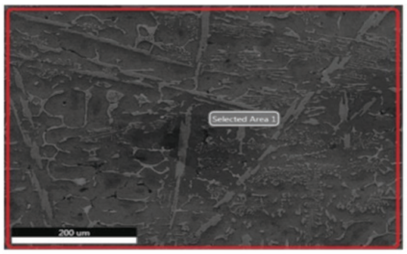
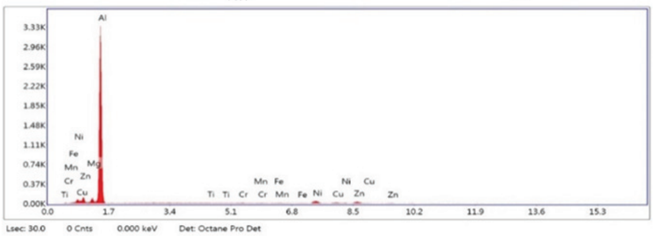
Figure 11: Edx analysis of Al 7175 5 % Ni



(a)

Element	Weight %	Atomic %
MgK	2.66	3.16
AlK	84.75	90.86
TiK	0.25	0.15
CrK	0.44	0.25
MnK	0.21	0.11
FeK	0.24	0.13
NiK	5.09	2.51
CuK	1.68	0.77
ZnK	4.67	2.06

(b)



(c)

Figure 12: Edx analysis of Al 7175 10 % Ni

are varying with the Nickel concentration. In the Figures 6.11(c) 6.12(c) 6.13(c) we can observe that the aluminium is the higest peak, along with magnesium and copper. SEM and XRD Analysis gives intermetallic phases which AlNi, AlMgZn, AlFe etc, here from the Edx we can clarify the presence of the Elements like Al, Zn, Cu, Ni.

4.0 Conclusions

In the current study, nickel particles were used as reinforcement to change the mechanical characteristics of the aluminium alloy Al 7175 and create an intermetallic composite of nickel and Aluminium. With more nickel added, the matrix material's micro hardness characteristics improved., after heat treatment, the measured maximum microhardness was found in the range of 185 to 220 HVN.

SEM analysis for non-homogenized, it consists of Aluminium-rich solid primary dendrites and the formation of intermetallic compounds around the primary grains. After the XRD analysis of these samples their intermetallic phases were obtained. These intermetallic phases are MgZn, AlNi, AlMnZn etc. and for Heat-treated alloy it was observed that improved fluidity, grain refinement, decreased dendrite arm size and formation of intermetallic phases.

XRD results shows that Al-Ni intermetallic phases were formed along with AlMgZn and FE-Ni compounds in 2%Ni, 5%Ni and 10%Ni addition samples. However, it can be observed in Energy dispersive X ray spectroscopy results that there is few percentages of nickel dispersed along the matrix of aluminium.

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