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EFFECT OF HEAT TREATMENT ON MECHANICAL PROPERTIES OF ALUMINIUM 7075 ALLOY REINFORCED WITH SILICON CARBIDE AND ALUMINA

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Abstract - In the present study, prepared specimens were heat treated temperature to 470^{0}C , soaking them at this temperature for 3 hours and then furnace cooled .and another set of samples were heat treated by temperature to 465^{0}C , soaking them at this temp for 2 hours and then quenched at different medium (oil, water)in order to investigate mechanical properties. The change in mechanical behaviour as compared to untreated samples is investigated in terms of change in impact strength and hardness. Result showed that the mechanical properties of aluminium metal matrix composite by Al7075 alloy reinforced with SiC and Al_2O_3 can be improved by customized heat treatment for specific application.

Key Words: Mechanical Properties, Impact Strength, Hardness, Metal Matrix Composite, Heat Treatment, Etc.

1.INTRODUCTION *(Size 11 , cambria font)*

For the last few years, it has been discovered that the utilization of aluminium mixtures has been increased rapidly in different areas due to less weight, density, better mechanical properties. Aluminium mixtures and aluminium related matrix metal hybrid composite can be adopted in the fabrication of different vehicle parts and aerospace industries. Alloys are materials having metallic properties and are made of two or more elements, at least one of which is a metal. In the case of Aluminium alloys, most of them contain 90 to 96% Aluminium. Aluminium alloys are categorized under two headings i.e. wrought alloys and cast alloys. Aluminium casting alloys are used in a large number of applications including automobiles, trucks, transmission of electricity, development of transportation infrastructures, and in the aerospace and defence industries. The fast growth of aluminium alloys in industrial applications is related to their high strength-to-weight ratio which improves the mechanical properties and performance of the products. Among different foundry alloys, aluminium casting alloys are very popular, as they have the highest cast-ability ratings, possess good fluidity and comparably low melting points. Their light weight and high strength-to-weight ratio are the main reasons why cast iron and steel components are being increasingly replaced by aluminium alloys, particularly in the automotive industry. Choosing one casting alloy over another tends to be determined by the relative ability of the alloy to meet one or more of the characteristics required for a specific application. Heat treatment is is an important operation in the fabrication process of any engineering component. The objective of heat treatment is to make the metal better suited, structurally and physically, for some specific application. The optimum properties of aluminium of aluminium are achieved by alloying elements and heat treatments. This promotes the formation of small hard precipitates which interfere with the motion of dislocation and improve mechanical properties. One of the most commonly used aluminium alloy for structural application is Al7075 alloy due to its attractive comprehensive properties such as low density, high strength, ductility, toughness and resistance to fatigue . It has been extensively utilized in aircraft structural parts and others highly stressed structural application. The objective of the work are to investigate the effects of annealing and age hardening heat treatment of impact strength, hardness and microstructure of aluminium 7075 alloy reinforced with silicon carbide and aluminium oxide.

2. Literature Review

Sedat ozden et al.,[1] examined the impact properties of aluminium alloys reinforced with silicon carbide particles. The charpy test was conducted for the specimens with varying the temperatures from -176^{0}C to 300^{0}C for various aluminium alloys 2124, 5083 and 6063 reinforced with silicon carbide particles. Two SiC sizes of 157µm and 511µm and two extrusion ratio of 13:63:1 and 19:63:1 were selected. The effect strength decreases with presence of SiC particles. SiC reinforced Al-6063 alloy shows highest impact strength. The SEM images shows that uniform distribution of silicon carbide particles. From this research paper we conclude that, various base Aluminium alloy could be chosen for the enhancement of mechanical properties.

Dr. Jassim Mohammed [2] examine the impact of warmth treatment on mechanical properties of aluminium 2024 by influencing the various factors like aging time, solution treatment temperature and aging temperature. The solution temperature was done at 525^{0}C to 575^{0}C (25^{0}C interval). The ageing time also varied from 3hr to 21hr (at 6hr interval). The aging temperature also varied from 160^{0}C to 190^{0}C (15^{0}C interval). The hardness and impact toughness increases at solution temperature 525 to 550 and minimizes

at 575. After enhancing the aging time 3hr - 21hr at aging temperature 175^{0}C the hardness increases and impact toughness decreases. This research paper concluded that with proper solution temperature, aging temperature and aging time the mechanical properties can be improved.

O.K Abubakre et al., [3] evaluate the mechanical properties of aluminium 6061 which was fabricated and quenched in various liquids like water, palm oil and sheanut oil at elevated temperatures of 400^{0}C, 450^{0}C, 530^{0}C. Various tests like tensile, hardness and impact strength test was conducted for quenched specimens. The result shows that the specimen which is quenched in water at 530^{0}C has highest tensile strength of 109 N/mm^2, yield strength of 70.89 N/mm2 and hardness of 35.50 HRC. The specimen which is quenched in sheanut oil at 530^{0}C shows highest impact strength and least influence strength was detected in water quenched specimen at 400^{0}C. The microstructure analysis shows that water quenched specimen at 530^{0}C has fine microstructure and maximum extraction of heat. From this journal paper we came to know that, Al 6061 alloy quenched in various liquid after heat treatment enhances the mechanical properties.

Adeyemi Dayo Isadare et al.,[4] examined the properties of age hardening and annealing heat treatment on the mechanical properties and microstructural analysis of Al-7075 alloy. The specimens prepared as the cylindrical rods. Many tests like tensile, hardness and impact strength was accompanied. The specimens were as cast (steadily cooled), as cast (quickly cooled), annealing and age hardening. The result shows yield strength, hardness and tensile strength, increases in as cast (gradually cooled) specimens. Annealing specimen shows increases in impact strength. The microstructure shows $MnZn_2$ microsegregations in graduall cooling specimen. From this research paper it is reasoned that appropriate heat treatment and rapid cooling the microsegregation can be diminished.

3. Experimental Procedure

3.1 Material selection

- Aluminium-7075 base metal
- Silicon Carbide(SiC) and Alumina(Al_2O_3)

a) Base Alloy

Aluminium-7075

The aluminium alloy Al-7075 has been selected as the matrix material is more compatible with the reinforcement and has good mechanical property and castability at the alloy level itself. The application of the alloy in automobile and aircraft application itself indicated that it is the proper selection. The material is also having good response to age hardening, heat treatment process and precipitation hardening. Aluminium7075 is an aluminium alloy in which zinc is a primary alloying element.

The composition and properties of aluminium7075 is shown below.

Table 1: composition of Aluminium-7075

ELEMENT	Cu	Cr	Mn	Mg	Si	Ti	Zn	Fe	Al
PERCENTAGE (%)	1.6	0.15	0.3	2.5	0.4	0.2	5.5	0.5	Balance

Table 2: Properties of Aluminium 7075

Mechanical properties	Value
Ultimate tensile strength	220 Mpa
Tensile yield strength	95 Mpa
Hardness number	150
Shear strength	150 Mpa
Elongation	9-10%
Poisson's ratio	0.33
Density	2.81 g/cc
Young's modulus	71.7 Gpa
Melting point	483^{0}C

b) Reinforcement materials

Silicon Carbide (SiC)

Silicon carbide is the only chemical compound of carbon and silicon. It was originally produced by a high temperature electro-chemical reaction of sand and carbon. Silicon carbide is an excellent abrasive and has been produced and made into grinding wheels and other abrasive products for over one hundred years. SiC are application such as sandblasting injectors, automotive water pump seals, bearings, pump components extrusion dies that use high hardness, abrasion resistance, and corrosion resistance of carbide of siicon. Today the material has been developed into a high quality technical grade ceramic with very good mechanical properties.

Alumina(Al_2O_3)

The chemical formula of aluminium oxide is Al2O3. It is commonly referred to as alumina, or corundum in its crystalline form, as well as many other names, reflecting its widespread occurrence in nature and industry. Aluminium oxide having strong ionic inter atomic bonding gives increase in its desirable material properties. Its most significant use is in the production of aluminium metal, although it is also used as an abrasive due to its hardness and as a refractory material due to its high melting point. Application include electrical insulator, seal faces, valve seats etc.

Fig 1: Silicon Carbide

Fig 2: Alumina (Al_2O_3)

Table 4: Specimen composition for varying volume fraction

Sl no	Al-7075	SiC	Al_2O_3
1	100%	0	0
2	90%	5%	5%
3	80%	10%	10%
4	70%	15%	15%

3.2 Stir Casting Process

Base alloy Aluminium 7075 and Reinforcement particle SiC and Al2O3 was successfully fabricated by using liquid vortex method. Crucible and mould box is kept for preheating to eliminate moisture and other particles from the inner surface. The various volume fraction of reinforcement particles are 5%, 10%, 15% of SiC and Al2O3. The different weight % of (SiC and Al2O3) are taken separately in small crucibles and kept for preheat in a muffle furnace. The preheat the reinforcement temperature was held at 800˚C. 340 grams of Aluminium pieces is fed into the crucible which starts melting as the temperature of open hearth go to around 720˚C. As the temperature of furnace reaches to 700˚C, Aluminium pieces in the crucible will melt down. Hexachloroethane (C_2Cl_6) Degasifier is added to semi-solid phase Aluminium, to remove the hydrogen content from molten Aluminium. Slag formed in the crucible is removed and preheated (800˚C) SiC and Al2O3 powder is poured slowly into the crucible containing Liquid stage Aluminium. Stirring action has performed with an mechanical stirrer continuously for 5 minutes. The Cover flux (45%NaCl+45%KCl+10%NaF) is added to the liquid molten metal. forms a protective layer over the liquid metal which reduces oxidation. Then liquid Aluminium poured in to the mould box and specimen is obtained. The casted specimens are sent for machining to perform various tests as per ASTM standards.

Fig 3-Stir Casting set up

Fig 4- Casted specimen

3.3 Heat Treatment

There are five basic heat treatment process

i. 1Annealing
ii. 1Normalising
iii. 1Hardening
iv. 1Tempering
v. 1Case hardening

Annealing: Strengthening is heat treatment technique which modifies the microstructure of a material to change its mechanical or electrical properties. Heat specimen at temperature 470^{0}C. hold them at 3 hours in furnace 470^{0}C .After that Allow to cool slowly, use a dry cooling material (sand) or furnace Reduces internal residual stress.

Hardening: A strategy where one segment is exposed to two full solidifying exercises or initial, a strengthening technique joined by a solidifying strategy. Treating is a procedure of low temperature heat treatment that is typically performed after the solidifying procedure to accomplish the ideal hardness/durability proportion. Process used to increase the hardness of metal, Heat specimen at temperature 465^{0}C, Holding time 2 hours maintain temp 465^{0}C, After that rapidly quench in cold water, oil, molten salt for few minutes.

Tempering: Treating is a low temperature heat treatment process regularly performed subsequent to solidifying process so as to achieve wanted hardness/strength proportion. After hardening process again heat specimen in muffle furnace at temp 120^{0}C,Holding time 5 hours maintain temp 120^{0}c take out the specimen form furnace and cooled in air, it increases ductility.

Fig. 5: Heat treatment cycle.

Fig 6: Muffle Furnace

Fig 7: specimens placed in furnace for heating

a) Oil quenched specimens b) Water quenched specimens vvvvvvvvvvvc) Specimen cooled in atmospheric air

Fig. 8: Specimens quenched in different media.

3.4 Test to be performed

i) Impact test

Impact tests are performed to assess the shock absorbing capacity of the material under impact or sudden load. The stresses produced in the components during impact loading are many times more than gradual loading. Therefore impact strength of a material is defined as the ability of a material to withstand impact or sudden load pr unit cross sectional area. Impact test are conducted with two types of specimen

- Charpy test specimen
- Izod test specimen

For this research work charpy impact test was used. The impact load is applied to the center and behind the notch. The specimen has standerd v-notch with included angle of 45^0 size of specimen according to ASTM E23for charpy test(55*10*10).

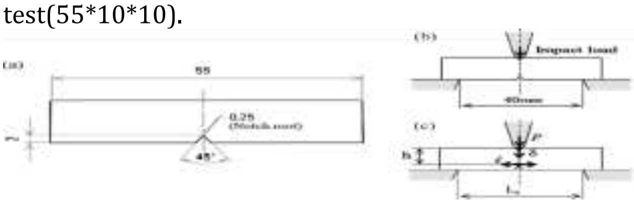


Fig 9: Impact Test Specimens after Testing

Fig 10: Impact Testing Machine Fig 11: Impact Test zzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzxxxxxxSpecimens after xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxTesting

ii) Hardness Test

Hardness is the property of a material that enables it to resist plastic deformation, penetration, indentation, and scratching. The application of hardness testing enables to evaluate material properties, such as strength, ductility and wear resistance. The heat treated specimens were subjected to the Vickers hardness test. The specimens were polished to 200, 400, 600, 800 and 1000 grit size of emery paper and mounted on the machine using dwell time of 10 sec.

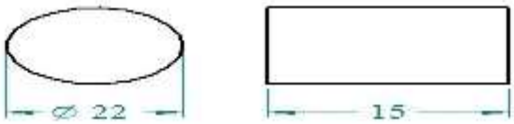


Fig 12: Hardness Test Specimens and dimension (ASTM E18)

Fig 13: Vickers Hardness Testing Machine and prepared specimens

Testing machine consists of square pyramid indenter having a 136^0 Cone angle. Hardness test specimen has to be place in anvil and fixed to the indenter by means of elevating screw using hand wheel. 30 kg of load has to be applied on the specimen at a 10 sec dwell time. Load has to withdrawn after the dwell time. Vickers Hardness Number of a material can be calculated using the formula

$$VHN = 1.854 \times \frac{P}{d^2}$$

P -Applied Load

d –Indentation Diagonal measurement

iii) Microstructure Analysis

Various mechanical properties like hardness, strength, toughness, etc strongly influence the microstructure of the materials. Microstructure analysis is widely used in the industries for quality control of the materials. Optical microscope is used to investigate the Microstructure analysis. All specimens with various weight % of Silicon carbide and alumina subjected for micro structural investigation. The specimens were made good mirror polished using 100, 220, 400, 600, 1000 grit emery paper sequentially. The specimens were kept on the moving table of computerized microscope and investigated at 10X, 40X,

60X magnification. The micro images obtained are stored in computer.


Fig 14: Computerized optical microscope and polished specimen

4. Result and Discussion

i) Impact test (Charpy v-notch test).

The Impact test has been conducted by using pendulum impact testing machine as per ASTM E23 for 4 different composition of AL7075, considering aluminium as base alloy and silicon carbide as reinforcement (SiC and Al2O3). Totally 35 composite fabricated specimen are tested and results are chosen for one of better values among 2or 3 trials and reading are tabulated below.

Table 5: comparison of Untreated, Air cooling, Furnace cooling, Water quenching and oil quenching with different composition

Sl. No.	Composition	Untreated	Furnace cooling	Air cooling	Water quenching	Oil quenching (Castrol)
1	AL7075	425	306.25	615	360	268.75
2	AL7075+5%SiC+5%Al_2O_3	456.25	312.5	625	302.5	168.75
3	AL7075+10%SiC+10%Al_2O_3	520	361.25	633.75	281.25	162.5
4	AL7075+15%SiC+15%Al_2O_3	482.5	329.25	608.75	183.75	152.5

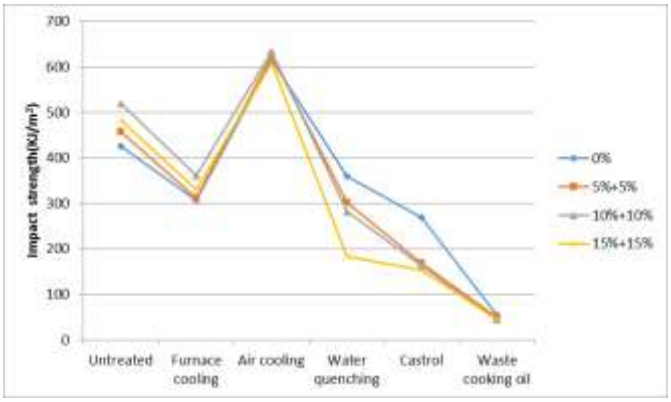


Fig. 15: comparison of Untreated, Air cooling, Furnace cooling, Water quenching and oil quenching

The fabricate specimens as per ASTM (E23) standards were tested in pendulum impact tresting machine, the obtained values of impact strength corresponding different composition are shown in line graph. The above figure shows the Impact strength value of various heat treatments such as Air cooling, furnace cooling, water quenching and oil quenching processes of aluminium 7075 alloy reinforced with silicon carbide and alumina is shown in above table. It is observed that furnace cooling has lower value of energy absorption when compared to air cooling in the case annealing and also it is observed that furnace cooling during annealing has lower value of energy absorption when compared age hardening. When compared to all heat treatment processes the air cooling has higher value of energy absorption during annealing. Hence from the above result we can say that the impact strength of the AMCs is more at 10% of reinforcement for Air cooling.

ii)Hardness Test

Vickers hardness test

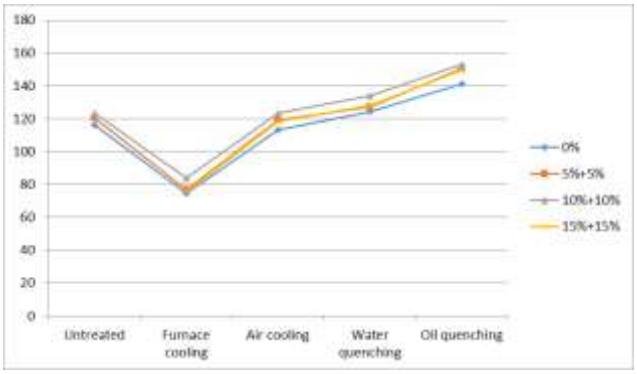
The heat treated samples were conducted Vickers hardness test. The specimens were polished to 1000 microns and mounted on the machine using dwell time 10 seconds.

$$VHN = 1.854 \times \frac{P}{d^2}$$

P -Applied Load, d–Indentation Diagonal measurement

Table 6: Comparison of hardness values for different

Sl.no.	Composition	Untreated	Furnace cooling	Air cooling	Water quenching	Oil quenching
1	0%	116.28	74.81	113.3	124.38	141.44
2	5%+5%	120.39	76.54	119.08	127.16	150.72
3	10%+10%	123.41	84.10	123.47	134.01	153.18
4	15%+15%	119.20	75.67	118.23	128.10	149.51



heat treatment process

Fig 16: Comparison of Hardness for different heat treatment process.

The fabricate specimens as per ASTM (E18) standards were tested in Vickers hardness testing machine, the obtained values of impact strength corresponding

different composition are shown in line graph. The above figure shows the hardness values of different heat treatments such as Air cooling, furnace cooling, water quenching and oil quenching processes of aluminium 7075 alloy reinforced with silicon carbide and alumina is shown in above table. It is observed that the lowest hardness values are found for furnace cooling in te case of annealing and also observed that the hardness values are higher for the case of aging. Hence from the above result we can say that the hardness of the AMCs is more at 10% of reinforcement for the case aging.

iii) Microstructure Analysis

Microstructure of the composite samples reveals the presence and homogenous distribution of reinforcements in the Al 7075 matrix. Microstructure examination was conducted by optical microscope. The microstructure of the material can strongly influence physical properties like strength, ductility, hardness, toughness, corrosion resistance and wear resistance. microstructure of a prepared surface specimen tested by inverted metallurgical microscope of 10X, 40X, 60x and 100X magnification. The formation of dendritic structure resulted by solidification process observed before heat treatment of composite Metallographic examination were carried out to see the distribution of silico carbide and alumina particulates in aluminum metal matrix and investigates the condition of grains both as cast and heat-treated composite metal matrix as shown. Silicon carbide and alumina particles melted and mixed homogenously by heat treatment and uniform distribution of reinforcements.

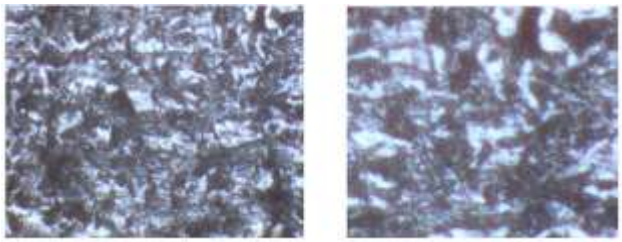


Fig. 17: Microstructure of Age hardening 7075 Al alloy reinforced with SiC and Al_2O_3.

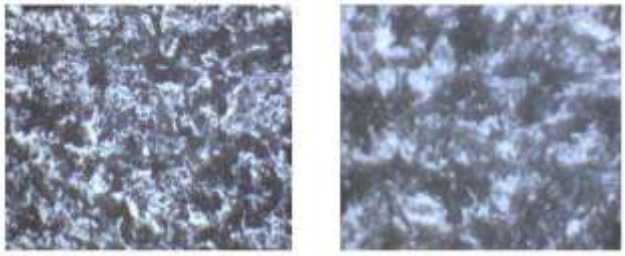


Fig. 18: Microstructure of annealed 7075 Al alloy reinforced with SiC and Al_2O_3.

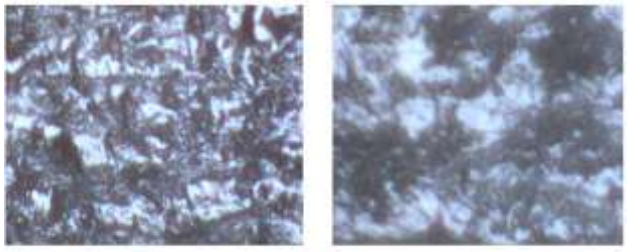


Fig.19: Microstructure of untreated 7075 Al alloy reinforced with SiC and Al_2O_3

5. Conclusions

The study on the effect of various heat treatment processes on Aluminium 7075 alloy reinforced with silicon carbide and alumina was conducted and attempt were made to relate mechanical properties such as hardness, Impact strength and also study on Microstructure after heat treatment. The following conclusion was made regarding the effect of various heat treatment processes.

1. Aluminium alloy hybrid composite has been fabricated using stir casting technique. Stir casting technique is the most economical and conventional method of casting composites.
2. It has been found that rapid solidification process and heat treatment eliminate formation of micro segregation and significantly improved some mechanical properties.
3. Annealing heat treatment operation improves impact strength but lower hardness values.
4. The hardness values are higher for the case for the case of aging in oil quenching.
5. The lowest hardness values are found for the case of furnace cooling.

Scope of Future Work

1. The research work is extended further by varying temperature of various heat treatment process
2. The other reinforcement such as boron carbide, titanium carbide, graphite etc can also be used with aluminium alloys in order to enhance its property and use it for different application.

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