Determination of mechanical properties of Aluminum Alloy (7075) reinforced with Aluminum oxide (Al2O3)

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Abstract--- Aluminium alloys are widely used in aerospace and automobile industries due to their low density and good mechanical properties, better corrosion resistance and wear, low thermal coefficient of expansion as compared to conventional metals and alloys. The excellent mechanical properties of these materials and relatively low production cost make them a very attractive candidate for a variety of applications both from scientific and technological viewpoints. The aim involved in designing metal matrix composite materials is to combine the desirable attributes of metals and Ceramics. Present work is focused on the study of behaviour of Aluminium Alloy 7075 with Al_2O_3 composite produced by the stir casting technique. Different % age of reinforcement is used. Tensile test, Hardness Test, Compression test performed on the samples obtained by the stir casting process. Optical Microscope was performed to know the presence of the phases of reinforced material. Hardness tester is employed to evaluate the interfacial bonding between the particles and the matrix by indenting the hardness with the constant load and constant time. Optical Microscopy was done to know the distribution of Alumina particles in Aluminium alloy.

Keywords--- Aluminium alloy 7075, Alumina Al_2O_3, Ceramics, Tensile test, Hardness Test, Compression test

I. Introduction

The term “Composite” broadly refers to a material system which is composed of a discrete constituent (the reinforcement) distributed in a continuous phase (the matrix), and which derives its distinguishing characteristics from the properties of its constituents, from the geometry and architecture of the constituents, and from the properties of the boundaries (interfaces) between different constituents. Composite materials are usually classified on the basis of the physical or chemical nature of the matrix phase, e.g., polymer matrix, metal-matrix and ceramic composites. In addition there are some reports to indicate the emergence of Inter metallic-matrix and carbon-matrix composites. This review is concerned with metal matrix composites and more specifically on the aluminium matrix composites (AMCs). In AMCs one of the constituent is aluminium/aluminium alloy, which forms percolating network and is termed as matrix phase. The other constituent is embedded in this aluminium/aluminium alloy matrix and serves as reinforcement, which is usually non-metallic and commonly ceramic such as SiC and Al_2O_3. Properties of AMCs can be tailored by varying the nature of constituents and their volume fraction. [1]

These advantages can be quantified for better appreciation. For example, elastic modulus of pure aluminium can be enhanced from 70GPa to 240GPa by reinforcing with 60 vol. % continuous aluminium fibre. On the other hand incorporation of 60 vol. % alumina fibre in pure aluminium leads to decrease in the coefficient of expansion from 24ppm/ ̊C to 7ppm/ ̊C.

Similarly it is possible to process Al-9% Si-20 vol. % SiC composites having wear resistance equivalent or better than that of grey cast iron. All these examples illustrate that it is possible to alter several technological properties of aluminium/aluminium alloy by more than two– three orders of magnitude by incorporating appropriate reinforcement in suitable volume fraction.

Aluminium alloy 7075

Aluminium alloys are in which aluminium is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon, tin and zinc. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. About 85% of aluminium is used for wrought products, for example rolled plate, foils and extrusions. Cast aluminium alloys yield cost-effective products due to the low melting point, although they generally have lower tensile strengths than wrought alloys. The most important cast aluminium alloy system is Al–Si, where the high levels of silicon (4.0–13%) contribute to give good casting characteristics. Alloy 7075 has a major shortcoming among other 7xxx series alloys. Its superb heat-treated mechanical properties depend on high quench rates to maximize the artificial aging (precipitation hardening) response. High quench rates, however, cause thermal Stresses to develop that can exceed the instantaneous local yield strength. In these cases, tensile plastic flow occurs at the part surface where stresses are highest. Upon full cooling, the part exhibits compressive surface stress balanced by tensile core stress. [2]

The composition, Physical Property, Mechanical Property Aluminium alloy 7075.

The composition of Aluminium alloy 7075[6] is as shown in the ***Table 1***

Table 1: Aluminium alloy 7075 composition

Chemical Composition	Weight (%)
Zn	6.1
Mg	2.9
Cu	2.0
Fe	0.5
Si	0.4
Mn	0.3
Cr	0.28
Ti	0.2
Other Each	0.5
Other Total	0.15

The Physical Property of Aluminium Alloy 7075 is as shown in the ***Table 2***

Table 2: Physical Property of Aluminium Alloy 7075

Physical Property	Value
Density	2.81 G/cc
Thermal Conductivity	130 W/m-k
Melting Point	635 ◦C
Solution Temperature	480

The Mechanical Property of Aluminium Alloy 7075 is as shown in the ***Table 3***

Table 3: Mechanical Property of Aluminium Alloy 7075

Mechanical Property	Value
Ultimate Tensile Strength	572 Mpa
Modulus Of Elasticity	71.7 Gpa
Poisson Ratio	0.33
Fatigue Stress	159 Mpa
Shear Strength	331 Mpa
Hardness, Brinell	150
Fracture Toughness	25 $pa\text{-}m^{1/2}$

Advantage of Al-alloy 7075

- Heat treatable.
- Age hardens naturally, there for will recover properties in heat affected zone after welding.
- Susceptible to stress corrosion.
- Good ballistic deterrent properties and there application.
- High strength/Density ratio.

Application of Al-alloy 7075

- 7000 series alloys such as 7075 are often used in transport applications
- It used in marine, automotive and aviation industries.
- Rock climbing equipment, bicycle components, inline skating-frames and hang glider airframes are commonly made from 7075 aluminium alloy.
- Hobby grade RC models commonly use 7075 and 6061 for chassis plates.
- In particular high quality M16 rifle lower and upper receivers as well as extension tubes are typically made from 7075-T6 alloy.

Aluminium Oxide (Al_2O_3)

Alumina is one of the most cost effective and widely used materials in the family of engineering ceramics. The raw materials from which this high performance technical grade ceramic is made are readily available and reasonably priced, resulting in good value for the cost in fabricated alumina shapes. With an excellent combination of properties and an attractive price, it is no surprise that fine grain technical grade alumina has a very wide range of applications. Aluminium oxide, commonly referred to as alumina, possesses strong ionic interatomic bonding giving rise to its desirable material characteristics.

Properties of Aluminium oxide (Al_2O_3)

The properties of aluminium oxide (Al_2O_3) [2] is as shown in the ***Table 4***

Table 4: Properties of Aluminium oxide

MECHANICAL PROPERTY	VALUE
Density	3.39 gm/cc
Elastic Modulus	375 Gpa
Poisson's Ratio	0.22
Hardness	1440 kg/m^2
Shear Modulus	152 Gpa
Bulk Modulus	228 Gpa
Max. Temperature	1718 ◦c

THERMAL PROPERTIES	VALUE
Thermal conductivity	35 W/m-k
Coefficient of thermal expansion	$8.4*10^{-6}$/◦c
Specific heat	1. kg-k

Stir Casting

Stir Casting is the simplest and the most cost effective method of liquid state fabrication. A dispersed phase (ceramic particles, short fibres) is mixed with a molten matrix metal by means of mechanical stirring. Liquid state composite material is then cast by conventional casting methods and may also be processed by conventional metal forming technologies. When CNTs are selected as a reinforcing phase, uniform distribution of CNTs in the matrix structure should be obtained since the CNT exhibits inherent deficiency of wetting for molten magnesium and magnesium alloy matrices. The Stir casting setup arrangement is as shown in figure 1

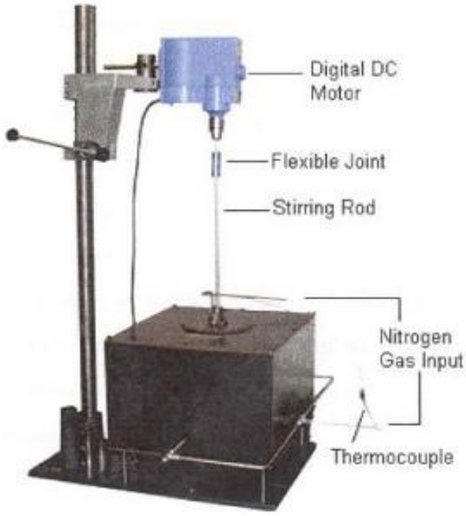

Figure 1: Stir casting setup

II. Steps followed in casting process:-

1. Initially furnace is set to the 718oC, preheating of crucible is carried out up to 100oC and the solid aluminium is placed in the crucible.

2. During the mean time of melting of the alloy, the die is cleaned and pasted with a chalk powder, chalk powder is pasted to the die in order to the easy removal of the casted product after the solidifying.

3. Then the die is placed into the pre-heating chamber which is set to the 250oC, the preheating is done in order to remove the moisture content, and to reduce the chilling effects.

4. Once the alloy is melted the degassing tablet is added into the crucible, degassing tablet is added in order to remove the gases which is removed in the form of slag.

5. Stirring setup is brought near the furnace and the stirrer is dipped into the molten metal, stirring speed is set to the 50 rpm.

6. Once stirring started (Al_2O_3) particle is slowly poured into molten metal. As the impeller rotates, it generates a vortex that draws the reinforcement particles into the melt from the surface. Stirring process is carried out up to 10mins.

7. After completing stirring process the molten metal is poured into the die, molten metal is made to solidify and the prepared casting is removed from the die. The Casting process Shown in the ***Figure 2.***

Figure 2**:** Stir Casting Process

Machining of Hardness Specimen.

Prepared casting is converted into the finished product by machining operation; machining process is carried out on lathe for Hardness specimen. The specimen required for the various tests for mechanical properties are prepare by machining the cast rods. The specimens are prepared according to ASME G91 standards. Specimens for hardness test are prepared with diameter of 11 mm and with a length of 10 mm.

Hardness Test

Brinell hardness test method is used to find the hardness of the specimen as Shown in the ***Figure 3.***

Figure 3: Hardness specimens.

Steps followed for conduction of hardness test

1. According to standard chart for aluminium alloy load of 187.5kgf and indenter ball diameter of 2.5mm is used.
2. Specimen is placed on the anvil properly and establish the contact with indenter.
3. Load is applied on specimen for the duration of 30 seconds.
4. The specimen is removed and the diameter of the indentation diameter is measured using the microscope.5. Hardness number is calculated using the relation

BHN=2F/ [π D (D-√ (D2-d2)]

Were F is the applied load,

D is the diameter of the ball in mm,

Tensile Test

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Tensile test is used to find the strength of the specimen. The Specimen is shown in ***Figure 4***

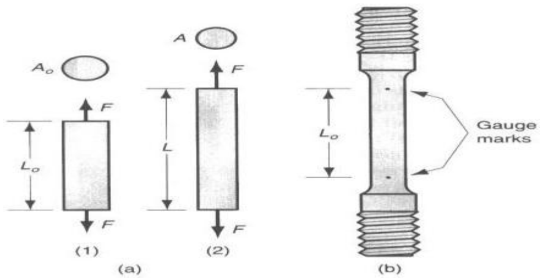

Figure 4: Tensile Test Specimen

III. Characterization, Results and Discussion

Optical Microscope with Clemex Image Analyses Results

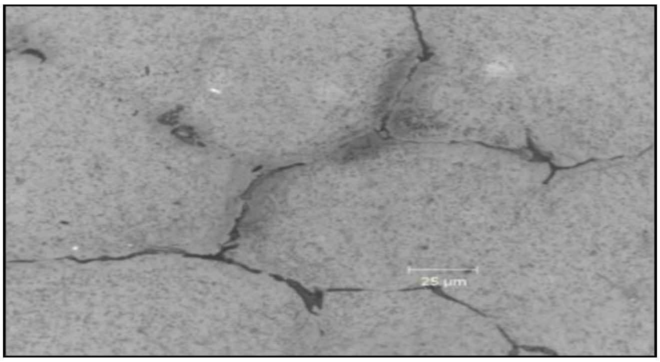

***Figure 5:* 500X With Keller's Reagent Al-Alloy 7075 Reinforced with 1% Al_2O_3**

The figure 5 shows the Microstructure with 500X Magnification with Keller's reagent (10mm=25µm), Which consists of fine Reinforced with 1% Al_2O_3 precipitates(Al_2O_3) of alloying elements dispersed along the grain boundary in the matrix of aluminium 7075 solid solution.

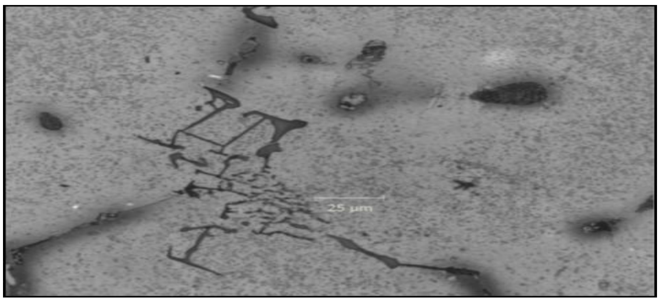

***Figure 6:* 500X With Keller's Reagent Al-Alloy 7075 Reinforced with 7% Al_2O_3**

The figure 6 shows the Microstructure with 500X Magnification with Keller's reagent (10mm=25µm), Which consists of fine Reinforced with 7% Al_2O_3 precipitates(Al_2O_3) of alloying elements dispersed along the grain boundary in the matrix of aluminium 7075 solid solution.

Hardness Test Results

Formulae and calculation for 0% Composition

Brinell hardness=2F÷ $\pi D(D - \sqrt{(D2 - d2)}$

F→Applied load (Kgf),

D→Ball diameter (mm),

d→ Indentation diameter (mm)

BHN=2× 250 ÷ π × 5(5 − √ (5^2 – 2.2^2))

BHN=62.2 Kgf/mm2

Aluminium alloy 7075 reinforced with 1 Wt. % Al_2O_3

Table 5: Hardness Test tabulation for 1% Al_2O_3

Composition (%)	Ball Diameter 'D' (mm)	Load 'F' (Kgf)	Diameter of indentation 'd' (mm)	Mean diameter of indentation 'd' (mm)	Brinell Hardness (Kgf/mm2)
1	5	250	2.274 2.274 2.273	2.273	58.2

Hardness test is made for different specimen with percentage variation of Al_2O_3 (0, 1, 3, 5, 7 Wt. % Al_2O_3)

V. Comparison of Hardness Test Results

The Comparison between the different compositions of Alumina in Al Alloy 7075 is shown in ***Table 6*** and ***Graph 1***

Table 6: Hardness test comparison

Reinforcement %	Brinell hardness (Kgf/mm2)
0	62.2
1	58.2
3	52.2
5	51.7
7	47.6

The Hardness of the specimen of different composition decreases as the composition percentage of Al_2O_3 by weight increases in the base matrix of aluminium alloy 7075, this is because we use Al_2O_3 of whisker's form not fine grain form so we don't get the appropriate result and also as we know Al-alloy 7075 is a heat treatable and self-aged hardening material, since we did not carry out any of the process so we get decreasing results.

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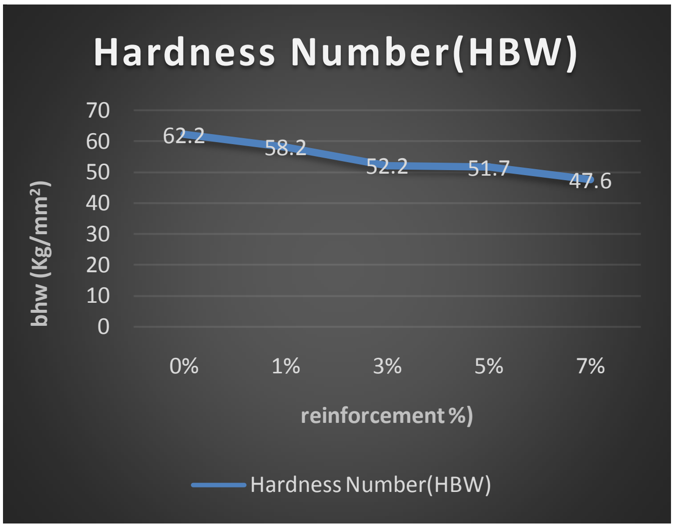
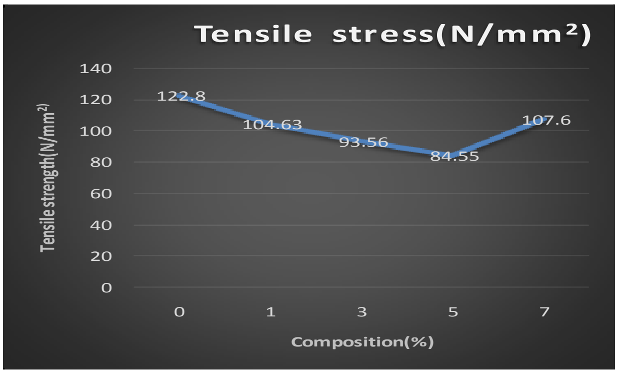


Graph 1: The BHN for Al Alloy 7075 reinforced with different wt. % of Al_2O_3 material at room temperature.

Comparison of Tensile Test Properties

Tensile test properties of different composition are compared to each other on the basis of their different properties as shown in ***Table 6*** and ***Graph 2***

Composition (%)	Modulus of Elasticity (Mpa)	Yield Stress (Mpa)	Tensile Strength (Mpa)	Elongation (%)	Peak Load (KN)
0	572.63	110.69	122.8	3.6	15
1	526.55	92.17	104.63	2.55	12.76
3	523.35	81.87	93.56	1.54	11.52
5	338.33	76.38	84.55	2.35	10.36
7	391.60	83.58	107.60	5.81	13.08



***Graph 2:* Shows the tensile strength vs composition % of Al_2O_3**

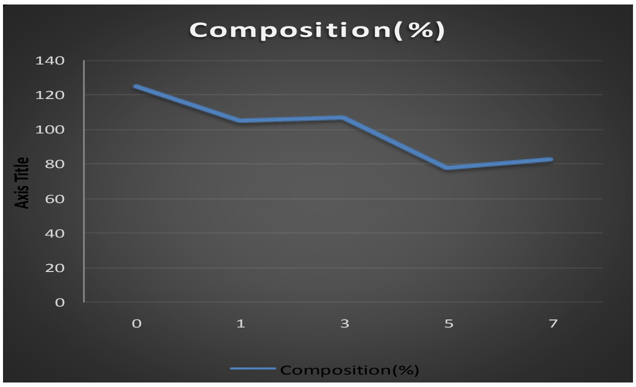
The variation in the tensile strength in the Specimens of different composition are shown in the ***graph 2***, which shows decreasing till 5% of Al_2O_3 composition then suddenly increases, so at higher composition the better results can be obtain.

Comparison of Compression Test Results

Compression test properties of different composition are compared to each other on the basis of their different properties as shown in ***Table 7*** and ***Graph 3***

Table 7: Compression test properties of Specimen of different composition

Composition (%)	Peak Load (KN)	Compression Strength (N/mm^2)	Length Compressed (mm)
0	707.04	124.96	19.2
1	593.65	104.92	18.3
3	606.55	107.20	18.2
5	441.33	78	14.6
7	468.27	82.76	16.8



***Graph 3:* Graph of Comparison b/w Composition vs Compression**

IV. Conclusion

1. Stir casting process, Stirrer Design and position, Stirring speed and time, particle preheating temperature, particle incorporation weight etc. Are the important process parameters.
2. Microstructure results showed the presence of Al_2O_3 particles in alloy matrix. The oxide phases like Al_2O_3 have dispersed uniformly throughout in the MMC, thus strengthening resulting composite.
3. The Hardness decrease after addition of Al_2O_3 in the matrix due to improper solution.[15]
4. Aluminium matrix composite have been successfully fabricated by stir casting technique with fairly uniform distribution of Al_2O_3 particles.
5. It is found that elongation tends to decrease with increasing particles weight %, which confirm that alumina in addition increase brittleness.
6. Dispersion of Al_2O_3 particles in aluminium matrix improves the tensile strength at higher %age of particles of Al_2O_3 reinforcement.
7. It appears from this study that UTS and yield strength trend starts decreases with increases in weight %age of Al_2O_3 in matrix.
8. After conducting the Brinell hardness test for various specimens having different percentages of the aluminium oxide material (0%, 1%, 3%, 5%,7%) and after calculating the Brinell hardness,

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we have come to conclusion that the maximum hardness for the specimen having 0 wt.% of aluminium oxide material.

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