Experimental Analysis of Aluminium Alloys for Aerospace Applications

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Abstract - *Manufacturing of any object in the aerospace components that to particularly through forming process is to achieve the product superiority characteristics and mechanical properties with process cost and time, Aluminium alloys with light weight and high performance characteristics are important materials for aerospace applications. The mechanical properties of different Aluminium alloys such as AA6061, AA7075 were evaluated and tensile test was performed under annealed condition and these alloys have excellent corrosion resistance and machining properties. In this project we have done that the hardness test, Microstructure study and mechanical properties such as Ultimate tensile strength, Yield strength, and % of elongation as well as % of reduction at fracture are performed by experimentally and then these results were compared with theoretical as well as COSMOS works analysis tool. From the results of AA6061, AA7075 it is observed that the magnesium content in AA7075 is slightly high as compared to other two alloys hence the AA7075 has more strength as well as high tensile strength and yield strength than the other two alloys.*

Key Words: **Maximum Tensile strength, Maximum Yield strength, % of Elongation, % of Reduction in Area**

1. INTRODUCTION

The mechanical properties of metals and its alloys can be improved by a combination of metallurgical, manufacturing and design measures, which increase the reliability and service life of the component manufactured. Due to good physical and mechanical properties of aluminum and its chemical composition imparts this widely used metal after the steel. Aluminum and its alloys have high strength-to-weight ratio and other desirable properties like non-toxic, non-magnetic, high thermal and electrical conductivities, high corrosion resistance and easy to fabricate. By addition of alloys like silicon, magnesium, iron and manganese improve its mechanical properties and its strength-to-weight ratio and widely used for aircraft and space vehicles, construction and building materials, and electrical transmission lines and the alloys which are used for aerospace applications are 6061, 7075 aluminium alloys and the main objective of this research is to investigate the influence of alloying elements on the tensile properties and hardness of aluminum alloys and its significance on the microstructure of the aluminum alloy. This study also focuses the impact of dimensions of the specimen on the strength and ductility of the alloy.

2. Experimental materials and methods

This research has considered aluminum alloys to study the effects of added alloys on mechanical properties of the material. Pure aluminum is a weak and ductile material, but by adding small % of impurities in aluminum its tensile strength as well as hardness increased considerably and many researchers are focusing on Al alloys of 6000, 7000 series due to its application in aerospace, automobile and construction industry. The chemical compositions of two Aluminium alloys considered for this research have been shown in below tables

The specimens are manufactured as per the ASTM standards by sectioning, mounting, grinding and polishing. Once the specimen are prepared then the chemical composition of the specimens was determined by spectrographic analyzer and then hardness test was done by using Brinell hardness test machine and then tensile test was performed by using universal testing machine.

The tensile test is used to determine the tensile strength for a material and also measure the percentage of elongation at the fracture. During the test a single axis stress state has generated by applying an external load to the specimen in a longitudinal direction. This results in a uniform normal distribution of stress across the test cross-section of the specimen. The load on the specimen is increased slowly and continuously by turning the hand wheel until it breaks. The resulting maximum test force is a measure of the material's strength called ultimate tensile strength in N/mm2 is calculated from the maximum test force in N, determined from the force-elongation diagram and the initial cross-section A0 of the specimen in mm2. The elongation at fracture is the ratio of the change in length of the specimen to its original length Lo and is calculated by measuring the length Lu of the specimen after fracture. After fracture, the two ends of the specimen are placed together cleanly at the fracture point and the distance between the two measuring marks has been measured. The result of tensile test has been represented in a stress-elongation diagram. From the graph, the ultimate tensile strength, the yielding point and the fracture strength, percentage of elongation as well as percentage of reduction can be calculated and noted in the Table. Specimens of each material have been tested at room temperature on Universal Testing Machine (UTM) with constant crosshead movement of 2 mm/min for tensile strength of the material. An extensometer has been used to calibrate and measure the sample strain upon loading. Tensile tests were performed at room temperature on 12 mm diameter cylindrical specimen with a gauge length of 60 mm for AA 6061 alloy specimen and the dimensions are reduced that is gauge diameter 8 mm and length 70 mm for 6061 alloy and for 7071 Aluminium alloy the initial gauge length is 60 mm and diameter is 12 mm and after the tensile test the dimensions are reduced to final gauge length of 66 mm and diameter is 11.1mm

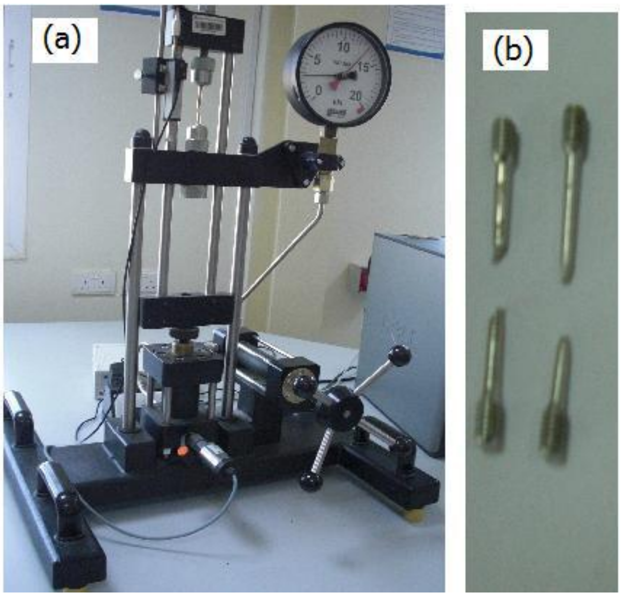


Fig. 1 – (a) Universal Testing Machine and (b) specimen after fracture

3. 6061 Aluminium Alloys

3.1 Spectrographic analysis

Lab spectrometer or spectrographic analyzer which uses thermo pressure software is used to determine the chemical composition of the specimen. During the test a sparks was induced on the surface of the specimen by using an electrode by this the software record the chemical composition, this procedure was repeated 2 or 3 times and then average values was recorded and the chemical composition of Aluminium was shown in given in below table 3.1

3.2 Hardness test

The hardness test was done by using Brinell hardness testing machine in which a precision Ball Indenter of 10 mm is impressed on a material with a load of 500 kg for 15 sec and 2 or 3 indentations were done at different locations of the material and the Brinell hardness number was recorded and the hardness value of 6061 Aluminium alloy is 92.6

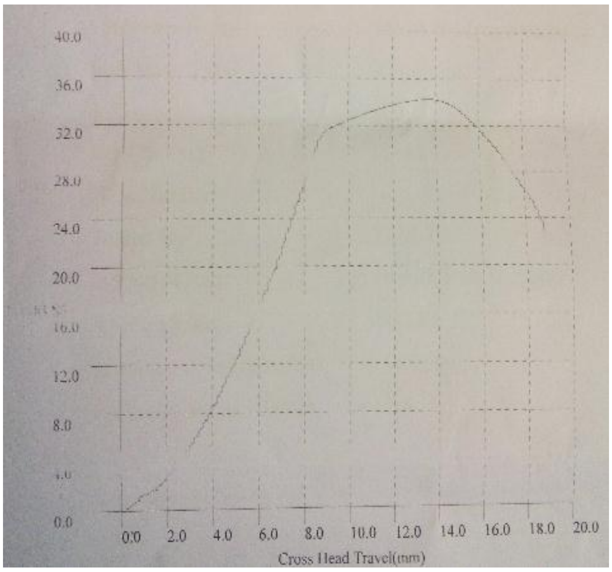
3.3 Tensile test

The standard specimens of Aluminium alloy materials have been used to find tensile strength of the materials. Two test specimens one specimen is 6061 Aluminium alloy and other is 7071 Aluminium alloy have been used for determining the tensile strength of the materials on Universal Testing Machine (UTM) of 20 KN capacity at across head speed of 2 mm/min, from which the load deflection curve obtained for each specimen. The mechanical behavior of each specimen has been determined from tensile test and data were generated during the test like applied load, elongation, stress and % elongation in table and the graphs and curves have been plotted for each specimen by continuous application of load until fracture.

3.4 Tensile test results of 6061 Aluminium alloy

Initial gauge length (L_0)	60 mm
Final gauge length (L_1)	70 mm
Outer diameter (D_0)	12 mm
Inner diameter (Initial)	0 mm
Outer diameter (D_1)	8 mm
Peak load	34.28 KN
Maximum elongation travel	13.9 mm
Tensile strength	303.06 N/mm^2
Load at yield	25.76 KN
Elongation at yield	7.8 mm
Yield stress	227.74 N/mm^2
Load at break	22.84 KN
Elongation at break	18.80 mm
% of Elongation	16.67 %
% of Reduction area	55.56 %

The load versus displacement graph is shown below



3.5 Calculation results

- Initial area (A_0) = $\frac{\pi}{4} \times (D_0)^2 = \frac{\pi}{4} \times (12)^2$

  = 113.04 mm²
- Final area (A_1) = $\frac{\pi}{4} \times (D_1)^2 = \frac{\pi}{4} \times (8)^2$

  = 50.26 mm²
- Tensile stress = $\frac{Peak\ load}{Initial\ area} = \frac{34.28 \times 10^3}{113.04}$

  = 303.25 N/mm²
- Yield stress = $\frac{Load\ at\ yield}{Initial\ area} = \frac{25.76 \times 10^3}{113.04}$

  = 227.88 N/mm²

% of Elongation = $\frac{Final\ length\ (L_1) - Initial\ length\ (L_0)}{Initial\ length\ (L_0)} \times 100$

$= \frac{70-60}{60} \times 100$

= 16.67 %

% of Reduction area = $\frac{Initial\ area\ (A_0) - Final\ area\ (A_1)}{Initial\ area\ (A_0)} \times 100$

$= \frac{113.04-50.26}{113.04} \times 100$

= 55.56 %

Similarly the calculation was done for other loads and the results are listed in below table

Load (P)	Elongation (e) mm	Diameter (D_0) mm	Initial area mm²	Stress $\frac{P}{A}$ N/mm²	%Elongation $\frac{e}{L_0} \times 100$
4	3.0	12	113.04	35.38	5.000
8	3.9	12	113.04	70.77	6.500
12	5.0	12	113.04	106.15	8.333
16	5.9	12	113.04	141.54	9.833
20	6.3	12	113.04	176.92	10.500
24	7.4	12	113.04	212.31	12.333
28	8.1	12	113.04	247.6	13.500
32	9.2	12	113.04	283.08	15.333
35	13.9	12	113.04	309.62	23.166

4. 7075 Aluminium alloy

4.1 Spectrographic analysis

The chemical composition of 7075 Aluminium alloy is shown in below Table 4.1

4.2 Hardness test

The hardness test for this alloy is same as done on above material and the hardness value for 7075 Aluminium alloy is found as 142.7

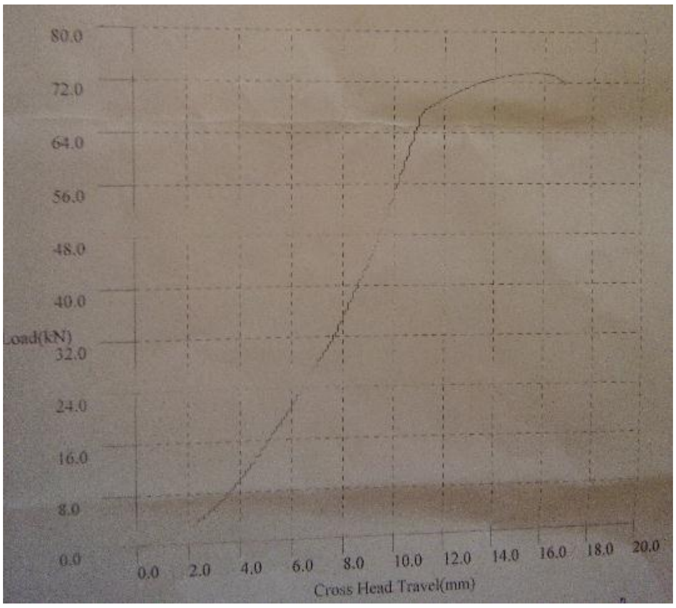
4.3 Tensile test

The procedure is same as done for the 6061 Aluminium alloy and results were noted down as shown below

4.4 Tensile test results of 7075 Aluminium alloy

Initial gauge length (L_0)	60 mm
Final gauge length (L_1)	66 mm
Outer diameter (D_0)	12 mm
Inner diameter (Initial)	0 mm
Outer diameter (D_1)	11.1 mm
Peak load	73.48 KN
Maximum elongation travel	15.8 mm
Tensile strength	649.62 N/mm^2
Load at yield	55.20 KN
Elongation at yield	10.0 mm
Yield stress	488.01 N/mm^2
Load at break	71.68 KN
Elongation at break	16.80 mm
% of Elongation	10.0 %
% of Reduction area	14.45 %

Load versus deformation graph of 7075 Aluminium alloy is shown below



4.5 Calculation Results

a) Initial area (A_0) = $\frac{\pi}{4} \times (D_0)^2 = \frac{\pi}{4} \times (12)^2$

= 113.04 mm^2

b) Final area (A_1) = $\frac{\pi}{4} \times (D_1)^2 = \frac{\pi}{4} \times (11.1)^2$

= 96.76 mm^2

c) Tensile stress = $\frac{Peak\ load}{Initial\ area} = \frac{73.48 \times 10^3}{113.04}$

= 650.03 N/mm^2

d) Yield stress = $\frac{Load\ at\ yield}{Initial\ area} = \frac{55.20 \times 10^3}{113.04}$

= 488.32 N/mm^2

% of Elongation = $\frac{Final\ length\ (L_1) - Initial\ length\ (L_0)}{Initial\ length\ (L_0)} \times 100$

$= \frac{66-60}{60} \times 100$

= 10 %

% of Reduction area = $\frac{Initial\ area\ (A_0) - Final\ area\ (A_1)}{Initial\ area\ (A_0)} \times 100$

$= \frac{113.04-96.76}{113.04} \times 100$

= 14.40 %

Similarly the other values are calculated in same manner and the results are listed in below table

Load (P) KN	**Elongation (e) mm**	**Diameter (D_0) mm**	**Initial area mm^2**	**Stress $\frac{P}{A}$ N/mm^2**	**%Elongation $\frac{e}{L_0} \times 100$**
8	3.6	12	113.4	70.77	6.0
16	5.0	12	113.4	141.54	8.333
24	6.2	12	113.4	212.31	10.333
32	7.6	12	113.4	283.08	12.666
40	8.4	12	113.4	353.85	14.000
48	9.2	12	113.4	424.62	15.333
56	10.1	12	113.4	495.39	16.833
64	10.4	12	113.4	566.17	17.333
73	14.0	12	113.4	645.78	23.333

Table 3.1 Chemical composition of 6061 Aluminium alloy

Elements	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn
Composition (%)	0.57505	0.08184	0.23276	0.00629	0.97169	0.09990	0.00113	0.00362

Elements	Na	P	Pb	Sb	Sn	Sr	V	Al
Composition (%)	0.00063	0.00075	0.00138	0.00001	0.00328	0.00001	0.00315	98.00261

Table 4.1 Chemical composition of 7075 Aluminium alloy

Elements	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn
Composition (%)	0.06160	0.16564	1.42042	0.02821	2.18282	0.16037	0.00523	5.93301

Elements	Na	P	Pb	Sb	Sn	Sr	V	Al
Composition (%)	0.00001	0.00116	0.00114	0.00173	0.00147	0.00001	0.00772	89.96287

5. COSMOS Work

In COSMOS Work analysis tool a hydraulic cylinder which is used in landing gears of airplanes was designed and the hydraulic cylinder was designed by using 7075 Aluminium alloy and the dimensions are used according to the aerospace standards

d = 100 mm

Force (F) = 20 T = 20000 $\times$ 9.81

= 196200 N

Area (A) = $\frac{\pi}{4}(d)^2 = \frac{\pi}{4}(100)^2$ = 7850 mm²

- Pressure (P) = $\frac{Force}{Area} = \frac{196200}{7850}$ = 25 N/mm²

If the diameter to thickness of the cylinder is more than 10 known as thin cylinders and if the diameter to thickness ratio is less than 10 known as thick cylinders.

Therefore, $\frac{d}{t} = \frac{100}{5} = 20$ which is more than 10 hence it is a thin cylinder

- Hoop stress = Circumferential stress

$$= \frac{P \times d}{2 \times t} = \frac{25 \times 100}{2 \times 5} = 250\ N/mm^2$$

- Longitudinal stress = $\frac{P \times d}{4 \times t} = \frac{25 \times 100}{4 \times 5}$

$$= 125\ N/mm^2$$

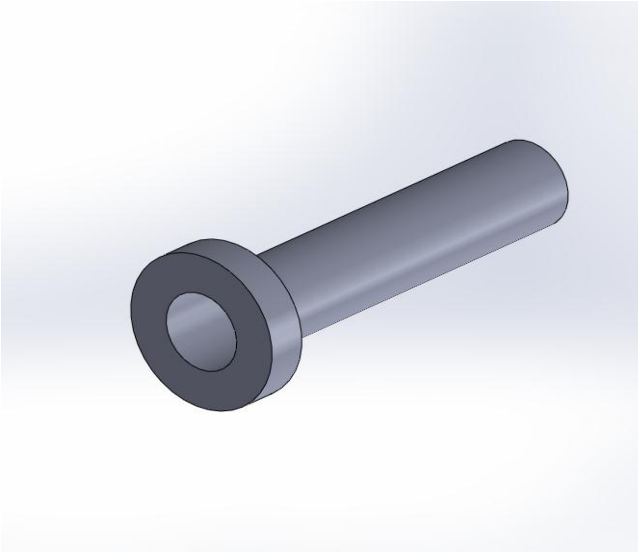


Fig 2 Geometry of the Hydraulic cylinder

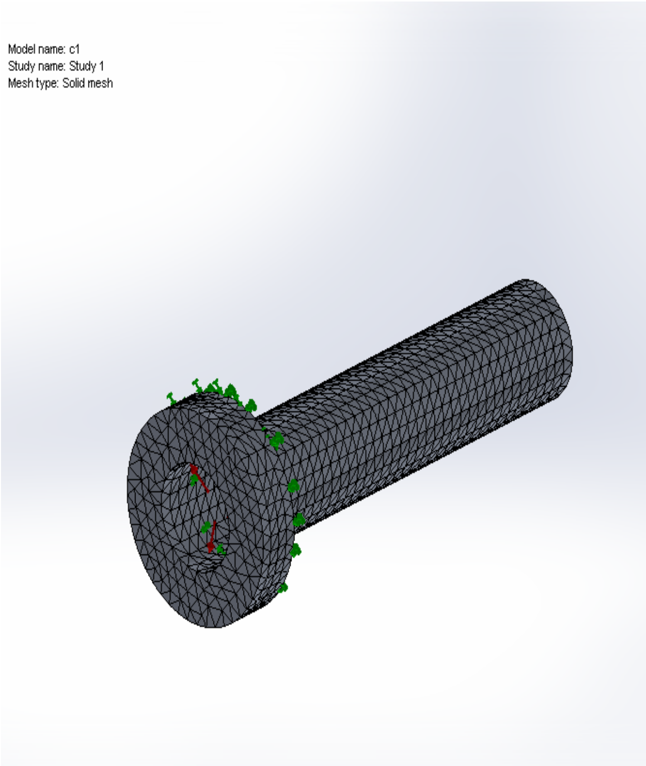


Fig 3 Meshed model

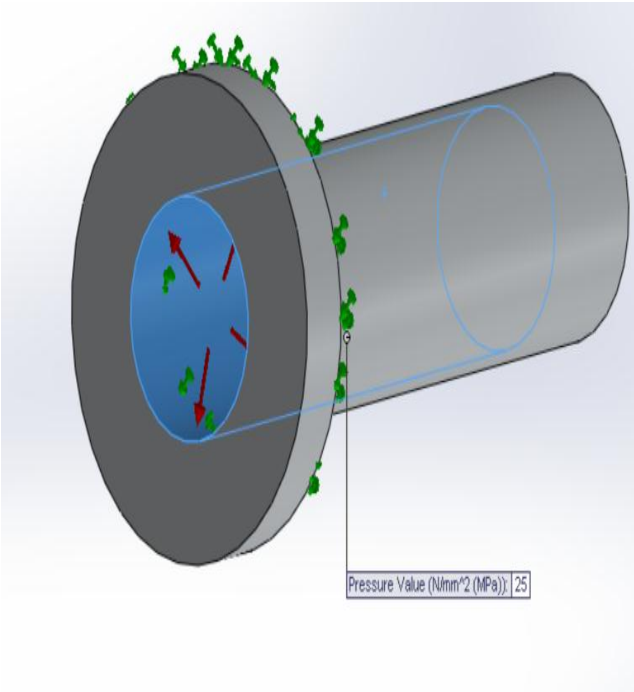


Fig 4 Load and Constaints on model

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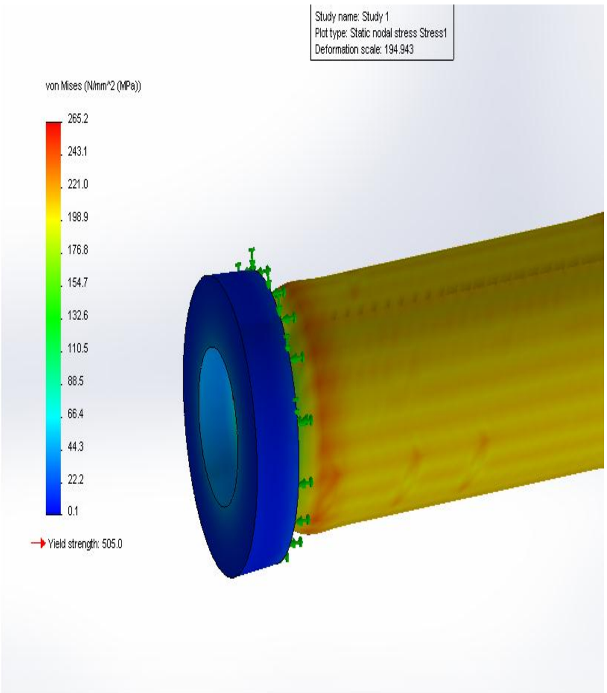

Fig 5 Results

5 Conclusion

Aluminium hydraulic cylinder is an important component of the aircraft system, it plays important role in the hydraulic system of aircraft for actuating various components. We have done Experimental analysis and FE analysis on 6061 and 7075 Aluminium alloys.

Aluminium Hydraulic cylinder is designed suspiciously and checked properly to achieve the requirements. As experimental analysis is carried out on above material the yield stresses and Factor of safety were found as the yield strength of 6061 Aluminium alloy is 227.74 N/mm^2 and FOS is 0.9 and yield strength of 7075 Aluminium alloy is 488.01 N/mm^2 FOS is 1.952. After comparing the above experimental results 7075 Aluminium alloy has higher yield and Tensile strength than the 6061Aluminium alloy hence the same material is used in order to manufacture Aluminium hydraulic cylinder in the aerospace and the results are found satisfactorily.

Also the experimental results are compared with the COSMOS work analysis tool and the yield strength of 7075 Aluminium alloy experimentally found as 488.09 N/mm2 and by

COSMOS work analysis tool the yield strength is of 505.09 N/mm2 and the percentage of error is 17% because of the type of meshing is selected for analysis purpose.

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BIOGRAPHIES

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