Investigation of Tensile and wear properties of aluminium metal matrix composite

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Abstract. The recent development of piston materials in internal combustion engines has contributed to the overall improvement in terms of durability and operation reliability. R&D and scientific centers both at home and abroad are conducting studies aimed at increasing the net power, torque and reducing the fuel consumption. The main function of piston is to convert thermal energy into mechanical work. Therefore selection of best material for piston plays a vital role in terms of extending its life, engine efficiency and low fuel consumption. Recent research has come up with a concept of composite materials, which shows that it has good mechanical properties compared to existing materials.

Keywords: automobiles, heavy transport, light transport, medium transport.

1. INTRODUCTION:

Materials that are most commonly used for manufacturing pistons include cast iron, alloy steel and Aluminium alloys, Aluminium-silicon (Al- Si) alloys and Aluminium-copper Aluminium alloys are distinguished by good formability during casting and good machinability (machine cutting). (1) The major drawbacks of these alloys include: a large thermal expansion coefficient, low hardness and low strength indices at elevated temperatures. (2) Cast-iron pistons are less and less often used. They can be found in low-speed self-ignition engines. They are characterized by the slide properties, retaining good mechanical properties at the elevated temperatures, and a small thermal expansion coefficient. The main disadvantage is that limit the use of cast-iron piston in contemporary high-speed engines a low thermal conductivity coefficient and high density. It results in a large piston mass and considerable inertia forces. (3) Due to high strength and low thermal expansion, pistons are increased oftenly and made of alloy steels. In spite of high density of steel, to take advantage of good mechanical properties of the material, designers give pistons appropriate shapes with small overall dimensions, which reduces the piston mass and make it compare to the mass of Aluminium alloy pistons. (4). The main objective of the study is to understand the suitability of Aluminium alloy (8090). The properties of Al alloy (8090) shows that it has better resistive properties to withstand the thermal stress in combustion chamber.

2. PISTON FAILURES

The most frequently occurring engine breakdowns are the failure of the engine pistons. The Engine piston occur at various mileage and due to different cause. This failure is caused by the material defect and engineering operational error. The common causes of piston failures include: their insufficient cooling, insufficient lubrication of the piston guiding part, thermal fatigue of the piston head surface, failures due to an incorrect combustion process, and mechanical damage. During the engine operation, piston attain higher temperature than the cylinder, which will result in different thermal expansion of piston and cylinder. The thermal expansion of piston is much larger than the cylinder. In addition, the thermal expansion coefficient of Aluminium alloys is two times greater than the grey cast iron.
2.1 TYPES OF FAILURES

**Cracked piston**: Detonation is most likely caused of a cracked or broken piston. The hammer-like blow of detonation is literally beat a piston to death. It causes similar to those that can burn a piston: the lean fuel mixture, the over-advanced spark timing, bad knock sensor, a low octane fuel that cause the engine to run hotter.

**Scuffed piston**: Scuffed pistons is caused by too much heat in the combustion chamber, the engine overheat or inadequate lubrication. The piston-to-cylinder clearance is late-model engines which is much less and they are used to reduce piston rock and noise. If the piston or cylinder get too hot, the clearance will go away and get metal-to-metal contact.

**Destroyed piston**: If the piston is shattered and self-destructed, it will hit a valve. On interference engines, there is not enough clearance between piston and valves to avoid direct contact, the timing belt breaks. In most instance, the piston will survive a timing belt failure but bend it valves. But, some instance, the impact of a valve against a piston is more than casting can handle the piston to shatter like hand grenade. The debris goes into crankcase and it cause additional damage to bearings or piston.

2.2 WEAR PROPERTY OF A MATERIAL

Wear is progressive loss of material from operating surface of solid occurring as a result of relative motion between two surfaces. It appears as it occurs due to the relative motion between two bodies which are solid. There can be different mode or form of wear such as abrasion, adhesion, erosion and fatigue. When the two surface appears smooth macroscopically are brought together then the contact occurs at the isolated asperities on the surface. In general, wear can be classified into following types and it is explained in the following sections.

Abrasive wear, Fretting wear, Corrosive wear, Adhesive wear, Fatigue wear

3. PROPOSED METHOD

The in-depth study is carried out to understand the performance of Al alloy (8090) reinforced with the fly ash and zirconia under various test (tensile and wear). The comparative analysis of study between Al alloys (8090) reinforced with different compositions of zirconium and fly ash has been carried in this project work.

3.1 MATERIAL SELECTIONS

A composite material is the material made from two or more constituent material with significantly different physical or chemical properties, when combined, produce the material with characteristics different from individual components. The individual components remains separate and distinct with the finished structure. The new material is preferred for many reasons: common examples include materials which are stronger, lighter, or less expensive when compared to traditional material. Composites is made up of individual material referred to as constituent materials. There are two main categories of the constituent materials: matrix and reinforcement. At least one portion of type is required. The matrix material surrounds and support the reinforcement materials by maintaining the relative position. The reinforcements impart their special mechanical and physical property to enhance the matrix properties. A synergism produces the material properties unavailable from the individual constituent materials, the wide variety of matrix and strengthening materials allow the designer of product or structure to choose an optimum combination.
3.2 METAL MATRIX COMPOSITES (MMCs)

Metal matrix composites (MMCs) are consist of a metal or an alloy as continuous matrix and a reinforcement that can be a particle, short fiber or whisker, or continuous fiber. There are three kind of MMCs such as particle reinforced MMCs, short fiber or whisker reinforced MMCs, continuous fiber or sheet reinforced MMCs. Important metallic matrices are aluminium alloys, titanium alloys, magnesium alloys, copper etc. Many process for fabricating the metal matrix composites are available. For most of the part, these processes involve processing in the liquid and solid state.

3.2.1 MATRIX

The matrix is the material in which the reinforcement is embedded, and is completely continuous. This means that it is a path through the matrix to any point in the material, unlike two materials sandwiched together. In structural application, the matrix is usually lighter metal such as aluminium magnesium and it provides a compliant support for reinforcement. In high-temperature application, cobalt and cobalt–nickel alloy matrices both are common.

3.2.2 REINFORCEMENT

The reinforcement material is embedded with a matrix. It does not always serve purely structural task (reinforcing the compound), but is also used to change the physical properties such as coefficient, or. The reinforcement. It can be either continuous, or discontinuous. Discontinuous MMCs can be worked with the standard metalworking techniques, such as extrusion, forging, or rolling. In addition, it may be machined using conventional techniques, but commonly need the use of polycrystalline diamond tooling (PCD).

3.2.3 ALUMINIUM ALLOY 8090 (MATRIX)

Aluminium 8090 alloy is a lithium-based wrought alloy. Addition of lithium to aluminum will helps to reduce the density and increase stiffness. When it is properly alloyed, aluminum–lithium alloys can have an excellent combination of strength and toughness. The alloy has an excellent mechanical properties and is designed to promote the less density with increased stiffness. It is used for an advanced material in the design of high technology parts for the aerospace sector. It is used in the defense and weaponry systems.

| Property                  | Value          |
|---------------------------|----------------|
| Density                   | 2540 kg/m³    |
| Melting Point             | 600-655 °C    |
| Elastic Modulus           | 77 GPa        |
| Tensile Strength          | 450 MPa       |
| Yield Strength             | 370 MPa       |
| Percent Elongation        | 7%            |
| Thermal Expansion Coefficient | $21.4 \times 10^6$/K |

Table 3.1 Properties of Aluminium Alloy 8090
| CONSTITUENT       | PERCENTAGE       |
|-------------------|------------------|
| Aluminum, Al      | 93 - 96.2        |
| Lithium, Li       | 2.2 - 2.7        |
| Copper, Cu        | 1 - 1.6          |
| Magnesium, Mg     | 0.60 - 1.3       |
| Iron, Fe          | ≤ 0.30           |
| Zinc, Zn          | ≤ 0.25           |
| Silicon, Si       | ≤ 0.20           |
| Titanium, Ti      | ≤ 0.10           |
| Chromium, Cr      | ≤ 0.10           |
| Manganese, Mn     | ≤ 0.10           |
| Zirconium, Zr     | 0.040 - 0.16     |

Table 3.2 Compositions of Aluminium Alloy 8090

3.2.4 ZIRCONIA (REINFORCEMENT)

Zirconia has an excellent resistance to the chemicals and corrosion without typical brittleness common in technical ceramics. When compared to the other advanced ceramic materials, zirconia has exceptional strength at room temperature. The principal properties of the material include high fracture toughness, high density, high hardness and wear resistance, good frictional behavior, high temperature capability up to 2400ºC, non-magnetic, low thermal conductivity, electrical insulation, coefficient of the thermal expansion is similar to iron, and modulus of elasticity which is similar to steel.

3.2.5 FLY ASH (REINFORCEMENT)

The preference is to use fly ash as a filler or reinforcement in metal and polymer matrices is Fly ash which is a byproduct of coal combustion, available in very large quantities (80 million tons per year) at very low cost since much of it is currently land filled. Currently, the use of the manufactured glass microspheres has limited applications due to their high cost of production. Therefore, the material costs of composites can be reduced significantly by the incorporating fly ash into matrices of polymers and metallic alloys. However, very little information is available on aid in the design of the composite materials, even though the attempt is made to incorporate the fly ash in both polymer and metal matrices. Cenosphere fly ash has a lower density than the talc and calcium carbonate, but it slightly higher than hollow glass. The cost of the cenosphere is likely to be much lower than the hollow glass.
Cenosphere may be turn out to be one of the lowest cost fillers in terms of cost per volume. The high electrical resistivity, the low thermal conductivity and low density of fly-ash may be helpful for making the light weight insulating composites. Fly ash is a filler in Al casting which reduces cost, decreases density and increase hardness, stiffness, wear and abrasion resistance. It also improve the Mach inability, damping capacity, coefficient of friction etc. which are needed in the various industries like automotive etc. As the production of Al is reduced by utilization of fly ash. It reduces the generation of greenhouse gases as they are produced during the bauxite processing and the alumina reduction.

| COMPOSITION | BITUMINOUS | SUB BITUMINOUS | LIGNITE |
|-------------|------------|----------------|--------|
| SiO2%       | 20-60      | 40-60          | 15-45  |
| Al2O3%      | 5-35       | 20-30          | 20-25  |
| Fe2O3%      | 10-40      | 4-10           | 4-15   |
| CaO%        | 1-12       | 5-30           | 15-40  |
| LOI%        | 0-15       | 0-3            | 0-5    |

Table 3.3 Chemical Composition of Fly Ash

4. METHODOLOGY

4.1 COMPOSITE MATERIAL PREPARATION

Recent trends in the fabricating metal matrix composite is stir casting. Stir casting is a liquid state method of the composite material fabrication, in which a dispersed phase (ceramic particles, short fibers) mixed with the molten matrix metal by means of the mechanical stirring. Stir casting is simple and the most cost effective method of the liquid state fabrication. The liquid composite material is cast by the conventional casting methods and it may also be processed by the conventional Metal forming technologies.

4.1.1 STIR CASTING PROCESS

- Pre- heating time of die- 500°C for 90 minutes.
- Pre- heating time of reinforcement- 600°C for 90 minutes.
- Temperature of the furnace- 800°C.
- Stirring speed- 700 rpm to 1200 rpm for 10 minutes.
- Weight of the matrix material- 650 grams per sample.
4.1.2 DIFFERENT COMPOSITIONS OF SPECIMENS

- Specimen 1: Al+3% fly ash
  650 grams of Al +19.5 grams fly ash

- Specimen 2: Al+5% fly ash
  650 grams Al+32.5 grams fly ash

- Specimen 3: Al+ 5% zirconia
  650 grams Al+32.5 grams zirconia

- Specimen 4: Al+3% fly ash +3% Zirconia
  650 grams Al+19.5 grams fly ash+19.5 grams zirconia

- Specimen 5: Al+ 5% fly ash+5% zirconia
  650 grams Al+ 32.5 grams fly ash+ 32.5 grams zirconia

Experimental setup

Muffle furnace is used to heat the material to the desired temperatures by conduction, convection, or black body radiation from the electrical resistance of heating elements. A muffle furnace is a furnace in which the subject material is isolated from fuel and all the products of combustion are including gases and flying ash. This furnace has a capacity to achieve the maximum temperature of 1000°C, which is shown in the Figure.4.1
4.2 STIRRING PROCES

The stirrer is used in the process is made of stainless steel. Because of the high temperature the crucible, the stirrer should be capable of withstanding the temperature. Hence the stainless steel is used for making the stirrer in Figure 4.2. A crucible container that can be withstand at very high temperatures and is used for the metal, glass, and pigment production as well as number of modern laboratory processes is used. The crucible is used here and is made up of graphite.

4.3 SPECIMEN PREPARATION

Pure Al 8090 of 650 grams placed in the graphite of crucible and is kept in an electric Resistance furnace. The furnace is set to the maximum temperature of 800°C. The melting point of Aluminum starts at 750°C after an elapsed time of 90 minutes. The furnace is kept at untouched for more than one hour at 800°C. 3% Fly Ash is taken and preheated to temperature of 600°C in order to ensure the moisture of free surface. The die is also placed in the separate furnace at a temperature Of 500°C for pouring the molten metal. Then Fly Ash is added to the molten metal and the mixture is stirred for 10 to 15 minutes at 700 rpm using stirrer. Then the slurry is poured to the die and allowed to solidify. After solidification, the die is opened and the casted piece is also taken out. The above said procedure is repeated for the casting and for remaining specimens. The casted piece is 180mm in length and 20 mm in diameter. The fabricated specimens are shown in the Figure 4.3 below.

Figure 4.2. Stirring Process

Figure 4.3. Casted Specimens
4.4 MATERIAL TESTINGPROCEDURE

Tensile Testing
The specimen for tensile testing is prepared from casted specimen. This specimen has a length of 180 mm and diameter 20mm. The Tensile testing specimen should have gauge length of 5*D of the casted specimen. So the length of 100 mm is taken as gauge length where the elongation takes place. Knurling is done on remaining portion of the specimen on both sides to hold the specimen in Universal Testing Machine (UTM), which is shown in the Figure.4.4.

![Figure.4.4 Specimen for Tensile Test](image)

Four specimens are casted in stir casting is subjected to tensile test one by one. The specimen should be mounted on machine carefully by rotating the wheels placed here. After the confirmation of the correct placement of specimen, the machine is switched ON. The UTM setup is shown in the Figure.4.5

![Figure.4.5 Specimen Mounted in Universal Testing Machine](image)

4.4.1.UTM SETUP

The initial load in the machine is kept as the tare load. From the tare load it starts to increase as the load is applied in the specimen gets increased. At a certain point the load slightly decreases and increases which will represent the breaking point of the specimen. The specimen gets destructed at the point and the damaged pieces are collected which is shown below Figure.4.6. The change in the length after the tensile testing is measured for percentage elongation of specimen.
4.5. WEAR TESTING

For testing the wear in the specimen, a pin from the specimen and a disc of suitable material is required. In this work, the composite material is proposed for the piston application. So it is important to select the disc material for application. The piston is in the cylinder reciprocates from TDC to BDC during the Combustion process. Due to the movement, wear occurs between the piston and cylinder walls. Most of the cylinders in the Internal Combustion engines are made of the cast iron. Hence in this work the composite material is used for making Pin while the cast iron is used to make the disc to perform wear test. The pin is made with dimensions of length 50mm and diameter 7mm. The disc is made with dimensions of diameter 30 mm which is shown above in Figure.4.7.
For the piston application, the high temperature wear test was carried in the project work using pin on the disc apparatus shown in the Figure 4.8. Three specimens are used here for performing wear test. With the help of the diameter of disc and distance to be covered by pin, the time for the test is calculated. The distance is to be covered by the pin is estimated as 1000 meters. The load is applied for each specimen is 25 kN. With the help of the function, the time in the apparatus is set to 22 minutes for covering the distance.

By brief survey of literature on the wear testing, it is noted that the friction rate starts to increase at the temperature of 300°C. With the help of this, the temperature for the wear test is set to 300°C. It is difficult to predict the temperature inside combustion chamber of an I.C engine. From the literature survey, many of the authors had conducted wear and analysis the starting temperature of 250°C. The speed of the disc is set to 300 rpm for all the three specimens. Hence this temperature is kept at constant for all three specimens which are subjected to wear test. The friction rate will be different for each specimen. After comparing the reduction of weight in the specimens, graphs for the different parameters is to be plotted.

5 RESULTS AND DISCUSSION

5.1 BREAKING LOAD OF SPECIMENS

The tensile strength is determine the load bearing capacity of the material. In this work, the fabricated composite material is allowed to tensile stress until there is destruction in the specimen. The above test is performed at room temperature. Two graphs are drawn using the parameters such as load vs displacement and stress vs strain. The displacement of the particular specimen is given load shown below in Figure 5.1

![Figure 5.1 Load vs Displacement Graph](image)

The reinforcement addition is the metal matrix contributes to the various results in the tensile stress of material. From the above graph it is noted that to increase in the reinforcement decreases the chance of material to be ductile. Only small increment in the deformation is seen when the material is subjected to the loading. 5% fly ash in the matrix shows least breaking load on other specimens. This is because of agglomeration in the composite material due to addition of fly ash. While 5% zirconia addition tends to the withstand some loads more than other specimens. The maximum displacement for specimen reinforced with 5% zirconia is at 25.5 mm, the percentage of the elongation is about 3% with 25.580 KN breaking load.
For 3% fly ash + 3% zirconia in the matrix, the maximum displacement is to 21.1 mm. The percentage of the elongation is about 3%. The breaking load is at 17.660 kN. The addition of the fly ash with zirconia shows disadvantages over tensile strength of specimen. When zirconia and fly ash added separately it show good responses in properties individually. The maximum displacement among all the specimens is exhibited by 3% fly ash. 27.9 mm is the displacement of the specimen when breaking with 9% elongation. 5% fly ash addition holds average breaking load of 17.26 KN with a maximum displacement of 18.6mm. Fly ash is individually does not hold the property of stiffness and hardness seen from the results above.

5.2 TENSILE STRENGTH OF SPECIMENS

The stress vs strain curve describes the maximum tensile strength of specimen that can hold before breaking. The 5% zirconia shows major tensile strength of about 0.081 kN/mm² with the total strain of 24 mm at breaking. 5% addition of Zirconia holds the maximum stress during the testing the other specimens are failed to reach maximum value. The stress vs strain curve is shown in Figure.5.2

![Stress vs Strain Curve](image)

**Figure 5.2 Stress vs Strain Curve**

5.3 WEAR RATE OF THE SPECIMENS

The Friction force and co-efficient of friction are two important parameters which will influence the wear rate in specimen. When the friction between pin and the disc is less, the resistance to wear is also enhanced. The co-efficient friction is also contribute in the wear behavior of the material. The pin weight of 5% zirconia reinforcement is reduced to the 5.34 gm from 5.39 gm. The reduction in weight after testing is 0.05 gm. For 3% fly ash + 3% zirconia addition, the weight will reduced to 5.23 gm from 5.30 gm. The difference in the weight before and after testing is 0.07 gm. This specimen shows less contribution to wear resistance. Even though fly ash is added for wear resistance property, the reaction between the fly ash and zirconia when added together shows adverse effect on material. 5% fly ash + 5% zirconia shows greater wear resistance among all specimens. The weight of the specimen is reduced to 5.22 gm from 5.25 gm. This is because the addition of more amount of the fly ash and the previous specimen. 2% fly ash + 2% zirconia addition shows positive effect on wear resistance. Due to the hardness of zirconia, the first specimen holds average wear resistance than second specimen. The friction force vs time graph is shown in the Figure.5.3.
The red curve in above graph represent the least frictional force which depends on the wear property of fly ash. 5% fly ash specimen holds the properties- efficient of friction. There is difference on the co-efficient for 5% zirconia specimen. After 12 minutes, the friction co-efficient start in the increasing rapidly than other specimens. There is a delay in frictional force increase the same specimen in the above graph. This is because of sliding velocity of pin in the disc which increases the coefficient at certain points. Even though this velocity influence the friction rate, the 5% fly ash specimen shows the steady wear track. For 3% fly ash addition, there is a sudden increase in friction coefficient at the time of interval of 9 to 18 minutes ending to a normal wear track near 5% fly ash + 5% zirconia specimen. Addition of fly ash in matrix that clearly exhibits wear resistance and wear track which is constant throughout the testing.

6. CONCLUSION

Addition of the fly ash in matrix material shows poor response in the case of tensile strength. Where as in case of wear, fly ash contributes the great influence in the resistance to wear rate. As fly ash is easily available it can be used for the dominant property. While other properties does not suit for modern application. Zirconia addition contribute its actual property of hardness in term of tensile strength. Wear property is also a good when it is added together with fly ash. Zirconia holds a good reinforcement in the metal matrix. Sometimes the casting defects like cracks, blow holes occur during composite material preparation. These defects might show negative effects on the property of material. The casting is to be done carefully to avoid these effects. Improper reinforcement in the matrix material causes adverse effect in individual property of composite material. This is eliminated by the proper dispersion of reinforcement in the matrix material during casting. The mechanical behavior of ZrO2 reinforced composites showed the improved results when compared with double reinforcement with fly ash. Finally it is noted that separate addition of reinforcement will be improve the mechanical behavior in case of tensile properties. While wear the resistance of fly ash with ZrO2 is due to ability to restrict the deformation and preventing the hard asperities from causing abrasive wear.
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