Research Article

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Experimental Evaluation of Al-Zn-Al_2O_3 Composite on Piston Analysis by CAE Tools

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Abstract: Today's automotive designers and material specialists regard lighter vehicles for less fuel consumption (economy and ecology) and higher safety to passengers. Metal matrix composites have been a large area of interest. Aluminium composite is potentially applied in automotive and aerospace industries, because it has a superior strength to weight ratio and is a light weight metal with high temperature resistance. Composites containing hard oxides and ceramics (such as alumina) are preferred for high wear resistance along with increased hardness. In this work, alumina and zinc are reinforced in Al-LM25 alloy through stir casting process, where alumina is varied 6% and 12% in Al-5%Zn. Various mechanical analyses were conducted and the effect of wear with different percentage of alumina reinforcement was studied. The resulting properties are imported in a piston, modelled using solid works, and analysed in ANSYS work bench. Imparting this new material for pistons could introduce deep design and improvements in engine operation of a vehicle.

Keywords: LM25 alloy, Zinc and alumina, Stir casting, Mechanical and wear behaviour, analysis in ANSYS

1 Introduction

Engine piston is the most complex part compared to other components in an automobile sector. Many research works have been conducted on piston with regard to material composition, geometry and manufacturing technique. The function of the internal combustion engine piston is to receive the energy from expanding gases during combustion and transmit it to the crankshaft by means of connecting rod. The piston expands appreciably when it gets heated during the operation; so actual clearances need to be given, otherwise it will lead to engine seize. This report is of replacing conventional piston material LM28 with a new composite [Al-LM25 +Al_2O_3 + zinc]. Zinc is added 5% throughout all three samples, and alumina is varied 6% and 12%, respectively. The addition of zinc and alumina reinforcement particles to the aluminium matrix improves the tensile strength, compressive strength and hardness behaviour. The reinforcement material has more factor of safety compared to un-reinforced alloy material because of more yield strength due to the presence of reinforcements in the matrix alloy. As per rule of mixture, the strength of the composite drops similarly, with decrease in matrix strength at increasing temperature. Composites produced at an industrial scale are used for manufacturing of pistons, cylindrical sleeves, disc sand brake drums. Specimens casting is done through stir casting technique.

To find the mechanical properties, specimens are subjected to various tests such as wear, hardness, tensile, radiography and impact tests, and interpretation of CAD/CAM/CAE is very helpful to design, analyse, optimize and interpret the data. Compared to traditional aluminium alloys, there can be better stiffness, wear resistance and creep resistance when the aluminium alloy matrix composites are reinforced with ceramic particles. Because of the properties of aluminium such as low melting point, low density, thermal conductivity and high specific strength, a wide range of reinforcement particulates such as SiC, Al_2O_3, B_4C, TiC and TiB_2. The objective of the present work was to evaluate alumina's influence on the densification, strength and hardness in Al–Zn composite. Krishnan (2013, IJMERR) fabricated composite plates subjected to mechanical properties like flexural strength, impact strength test of the various specimens are calculated by using computer-assisted universal testing machine and Charpy impact testing machine. From the results, it is found that pure basalt fibre combination maintains higher values in both flexural and tensile tests, but for impact test basalt fibre is slightly lower than jute fibre reinforced composite [17].

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2 Methodology

In this work, stir casting, a conventional metal-forming technology, is used. In this, the fabrication of composite materials is done at liquid state: the dispersed phase (short fibres, ceramic particles) is mixed in molten matrix metal by means of mechanical stirring. This liquid composite material is casted into products by conventional casting methods. The project objective involves the evaluation of wear rate, strength and hardness of Al-Zn-Al_2O_3 composite, where Al acts as the base metal matrix and zinc and aluminium oxide act as the reinforcement metals. Silicon is used to increase some of the wear and hardness property.

2.1 Numbering

The project involves three cases. Zinc is kept constant at 5%. Aluminium oxide percentage is varied as 6% and 12%. In sample A, the base material LM25 is added with 5% zinc. In sample B, the composition of sample A is considered and 6% aluminium oxide is added. In sample C, the composition of sample B is considered and another 6% aluminium oxide is added (totally 12%). The dimensions are selected based on the ASTM standards.

2.2 Stir casting process

The materials were taken in required composition and Al-LM25 alone was taken 20% higher because of slag formation in stir casting process (total weight of three samples). This alloy is heated in a furnace and it will get melted at 750°C. Care has to be taken to achieve better melting. Scum powder is used for removing the slag and to avoid defects of casting. The measured reinforcement of Zn (3 samples) is preheated to 500°C and maintained at uniform temperature for 25 minutes to remove the moisture content. The preheated zinc reinforcement is added to the molten Al-LM25 alloy and stirred at 400 to 500 rpm. When the molten metal has reached 800°C, 5% of solid dry hexachloroethane tablets are used for degassing process. The stirring molten metal creates a vortex and is kept for 10 minutes. The molten mixture of Al alloy and Zn is taken and poured into a preheated mould and cooled to obtain the sample A. Then 6% alumina is added into the remaining molten metal, stirred again, poured into mould and cooled to obtain sample B. Then 6% alumina is added and sample C is obtained.

2.3 Testing

In order to investigate the mechanical properties that need to be given as an input in the CAE analysis, the hardness test, wear, tensile and impact tests were carried out. Vickers hardness was measured and the values were compared with all samples. The samples were tested in an UTM to study their behaviour under tensile load.

3 Results and discussion

3.1 Vickers hardness test

The Vickers pyramid hardness number is determined based on an optical measurement system. It consists of indenting the test material with a diamond indenter, in the form of a right pyramid.

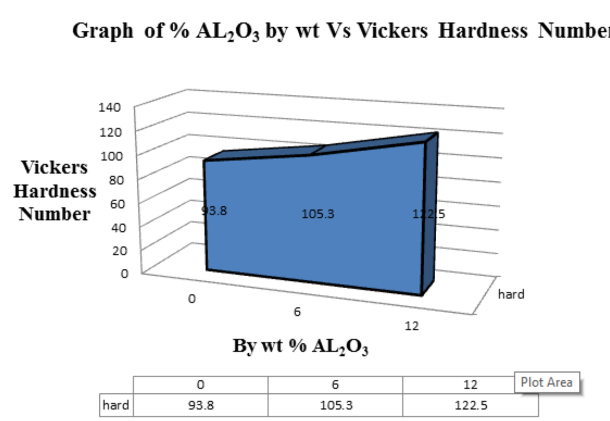

Figure 1: Vickers hardness number for samples.

The sample taken for Vickers hardness test is ⌀25 mm × 8 mm. Ten readings of hardness are taken at various points of the specimens and the average is shown in Figure 1.

3.2 Pin-on-disc wear test

The standard samples (pins – cylindrical shape) having different weight percentage of alumina were prepared (⌀10 mm × 25 mm). At normal load 20 N, the wear tests were conducted. Every wear test has been worked out for different sliding distance of 1 km at a speed of 600 rpm and the tangential force was observed simultaneously. Frictional force and wear are measured by digital display of pin-on-disc machine. Sliding occurs between the rotating disc and the stationary pin. Rotational speed, normal load and wear track diameter can be varied to suit the test conditions.

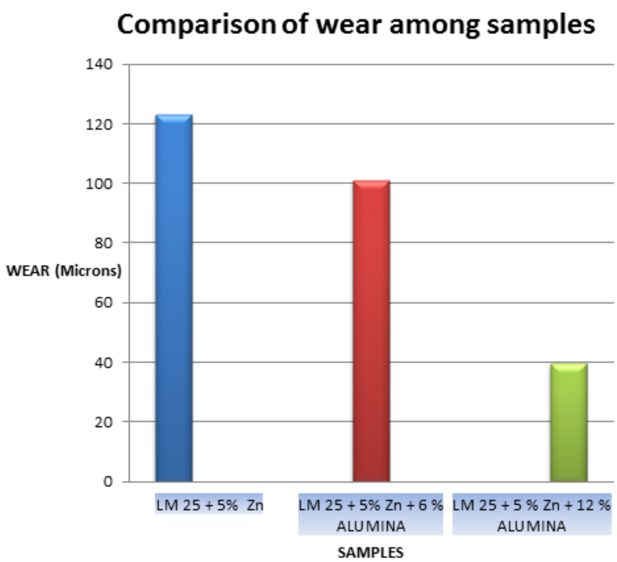

Figure 2: Wear comparison for samples.

The parameters which are available as functions of speed and load are wear and tangential force that are monitored through electronic sensors and recorded on a PC. Figure 2 shows the result of wear which gets reduced because of the alumina reinforcement in different samples. The friction and wear rate have been studied.

3.3 Impact strength between samples

The Charpy impact test is a standardized high strain rate, which is used to determine the amount of energy absorbed during fracture by a material. It is also known as the Charpy V-notch test. This absorbed energy is a measure of a given material notch toughness and acts as a tool to study temperature-dependent ductile–brittle transition. The value in Table 1 shows the ceramic material alumina which brings the strength and improves the impact strength percentage.

The test specimen shows 12.3% change in impact strength at 6% increment of Al_2O_3 with 5% zinc constant and 3.13% change in impact strength at 6% to 12% increase in Al_2O_3 in the third specimen (Figure 3).

Table 1: Percentage of Change in Impact Strength.

Sample No.	Composites	Impact Strength (nm)	% Change in Impact Strength
1	LM25 + 5% Zn	6	–
2	LM25 + 5% Zn + 6% Al_2O_3	6.5	8.33
3	LM25 + 5% Zn + 12% Al_2O Al_2O_3	7.2	10.8

Figure 3: Wear comparison for samples.

3.4 Tensile strength in UTM

The tension test is conducted at a velocity of 0.05 mm/min in the universal tensile test machine of capacity 10 kN. The ultimate tensile strength of a material is calculated by dividing the amount of the load at its failure point by the original area, which is expressed in MPa. The addition of reinforcements (zinc and alumina) to Al-LM25 increases the tensile strength of the specimen (Table 2).

These reinforcement particles in the metal matrix Al-LM25 act as barrier to the deformation of a microstructure by importing strength to the metal matrix. Hence the specimen with 6% of Al_2O_3 and 5% of zinc shows better tensile strength behaviour than the other composition.

Table 2: Tensile Strength Result Obtained in UTM.

S.No	Material	Applied Load (N)	Ultimate tensile Strength (Mpa)	STRESS (MPa)	% Change UTS
1	LM 25 + 5% Zn	80	300	240	-
2	LM 25 + 5% Zn + 6% AL_2O_3	80	349	279.2	16.33
3	LM 25 + 5% Zn + 12% AL_2O_3	80	415	332	18.9

3.5 Tensile strength in UTM

For solving numerical problems using computer as an interface and obtaining the thermo-mechanical behaviour of components, finite element analysis is one method. It has been applied to a number of physical problems. The reduction of error has been done by piece-wise continuous function to obtain a solution. The complexity of problem needs speed, efficient and optimal design. Kirloskar Rex Engine specifications have been taken into consideration. The piston model is designed in modelling software and uploaded in ANSYS. In general, the piston will be designed for high fatigue life cycles, usually > 108 life cycles (Table 3).

Table 3: Results Used for Analysis in ANSYS.

Samples	A	B	C
Tensile (MPa)	303	365	406
Ultimate tensile strength (N/mm^2)	367	426	442
Poisson's ratio	0.33	0.33	0.33
Young's modulus (GPa)	72	76	79
Density (g/cm^3)	2.785	2.84	2.9
Shear modulus	26	29	31

In this work, we have considered the effect of pressure force and inertia force and it is assumed that side thrust force is negligible, but in reality this may have some influence on stress and deformation of piston. Also the temperature effect is neglected, as and the temperature is assumed to be uniform. The pressure force and inertia force are applied on the crown (*i.e.* top face) of the piston.

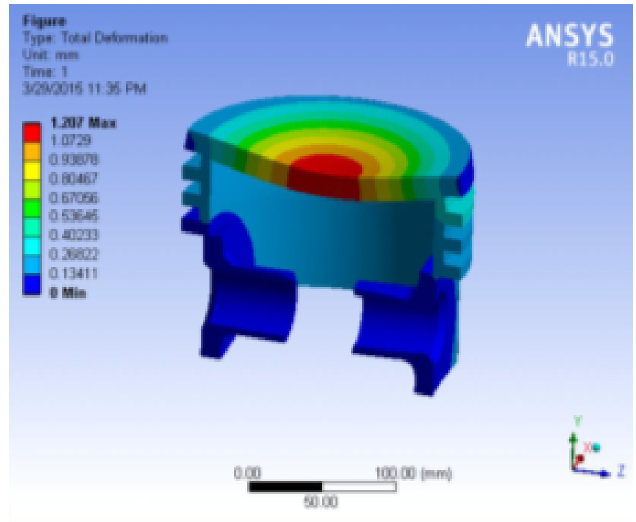

Figure 4: Sample A deformation analysis.

The maximum von Mises stress induced in the piston is 506 MPa, at the inner boss fillet area, which is due to stress concentration effect and pressure application on the top face of the piston. The stress at piston ring grooves is approximately 240 MPa. The maximum displacement is 1.206 mm observed at the centre of the piston as shown in Figure 4. The maximum elastic strain induced in the material is 0.00702. The strain energy stored in the material is 40 MPa. From Figure 5, the maximum von Mises stress induced in the piston is 506 MPa, at the inner boss fillet area, which is due to stress concentration effect and pressure application on the top face of the piston.

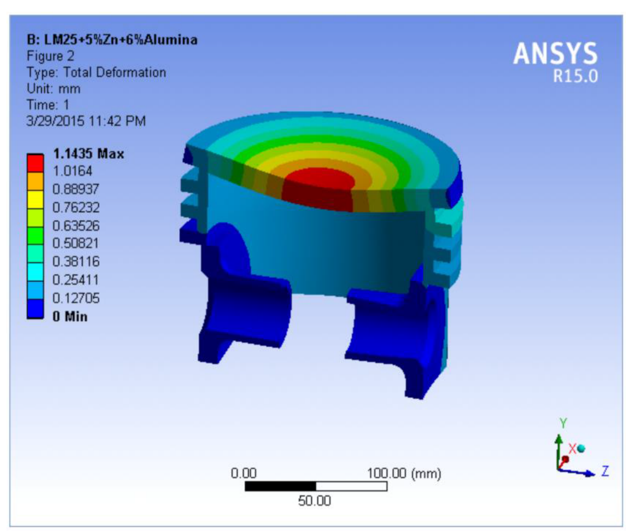

Figure 5: Sample B deformation analysis.

The stress at piston ring grooves is approximately 220 MPa. The maximum displacement is 1.013 mm observed at the centre of the piston. The maximum elastic strain induced in the material is 0.00743. The strain energy stored in the material is 35 MPa. From Figure 6, the maximum von Mises stress induced in the piston is 506 MPa, at the inner boss fillet area, which is due to stress concentration effect and pressure application on the top face of the piston. The stress at piston ring grooves is approximately 240 MPa. The maximum displacement is 1.101 mm observed at the centre of the piston. The maximum elastic strain induced in the material is 0.00729. The strain energy stored in the material is 38 MPa.

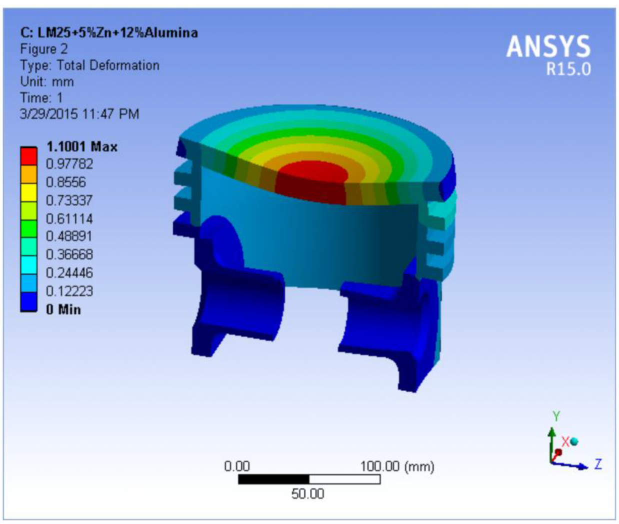

Figure 6: Sample C deformation analysis.

4 Conclusion

The conclusions drawn from the present investigation are as follows:

(a) The results confirmed that stir-formed Al alloy LM25 with Zn and Al_2O_3 reinforced composites is clearly superior to base Al alloy LM25 in the comparison of wear rate and hardness test.
(b) Dispersion of Zn and Al_2O_3 particles in aluminium matrix improves the hardness of the matrix material.
(c) Aluminium matrix composites have been successfully fabricated by stir casting technique with fairly uniform distribution of Zn and Al_2O_3 particles.
(d) The hardness increases after addition of Zn and Al_2O_3 particles in the matrix.
(e) The wear rate of the first sample is less than the other two samples. It shows Zn has good wear resistance properties.
(f) Stir casting process, stirrer design and position, stirring speed and time, particle preheating temperature, particle incorporation rate and so on are the important process parameters.

References

[1] Pawar, P.B., Abhay, A. Utpat: Development of Aluminium Based Silicon Carbide Particulate Metal Matrix Composite for Spur Gear, ELSEVIER, ICMPC, 2014.
[2] Ahemad, J., Bhaskar, S.V., Kapgate, R.A.: Development Of Al/Sic5%, Al/Sic10%, Al/Sic15%, Metal Matrix Composite And Its Comparison With Aluminium Alloy – Lm25 On Tribological Parameters, IJETAE, 3(9), 2013.
[3] Singla, M., Lakhvir, S., Vikas, C.: Study of Wear Properties of Al-Sic Composites, JMMCE, 8(10), 813-819, 2009.
[4] Singla, D., Mediratta, S.R.: Effect of Load And Speed on Wear Properties Of Al 7075-Fly Ash Composite Material, IJIRSET, 2(5), 2013.
[5] Gadade, P., Arun, L.R.: Characterisation of Aluminium-Flyash-Alumina Composite For Piston Analysis, IJIRSET, 2(12), 2013.
[6] Hashim, J. et al.: Metal matrix composites: production by the stir casting method, Journal of Materials Processing Technology, 92-93(1), 1999.
[7] Prasad, S.V.: Aluminum metal–matrix composites for automotive applications: tribological considerations, Tribology Letters, 17(3), 2004.
[8] Singla, M.: Development of Aluminium Based Silicon Carbide Particulate Metal Matrix Composite, JMMCE, 8(6), 455-467, 2009.
[9] Andersson, P.: Piston Ring Tribology A Literature Survey Vtt Industrial Systems Jaana Tamminen & Carl-Erik Sandström Helsinki University Of Technology, Internal Combustion Engine Laboratory.
[10] Silva, F.S.: Fatigue On Engine Pistons – A Compendium Of Case Studies Department Of Mechanical Engineering, University Of Minho, Azure´M, 4800-058 Guimara~ Es, Portugal 2005.
[11] Prashant, S.N., Madeva, N. and Auradi, V.: Preparation And Evaluation Of Mechanical And Wear Properties Of 6061al Reinforced With Graphite Particulate Metal Matrix Composite, 2009.
[12] Mahendra Boopathi, M., Arulshri, K.P. and Iyandurai, N.: Evaluation Of Mechanical Properties Of Aluminium Alloy 2024 Reinforced With Silicon Carbide And Fly Ash Hybrid Metal Matrix Composites, 2012.
[13] Sieminska, B. and Jankowski, A.: Composite Alloy With Very Low Dimensional Hysteresis During Heating And Cooling For Combustion Engine Piston Institute Of Aeronautics, Warszawa, Poland.
[14] Varuzan Kevorkija Zrvk. Maribor, Slovenija Development Of Aluminum MMC Composites For Automotive Industry, Yugoslav Association For Mechanical Engineers Yame. Udc669.715/419.7:629.11.
[15] Carvalheira, P. and Gonçalves, P.: FEA Of Two Engine Pistons Made Of Aluminium Cast Alloy A390 And Ductile Iron 65-45-12 Under Service Conditions, Ref: A0319.0006, 24-26 July 2006.

[16] Zhang, H., Ma, X., Ge, S.: Modeling And Transient Dynamics Analysis To a new Type Of Engine Piston, 2013.

[17] Radha Krishnan, B.Arun Prasath, K.: Mechanical Properties of Woven Fabric Basalt/Jute Fibre Reinforced Polymer Hybrid Composites, IJMERR, 2013.