Analysis of Bronze Hybrid Composite for Spark Ignition Engine Piston

Dhanesh. C
Associate Professor
Department of Mechanical Engineering
S.A.Engineering College
Chennai
India

Anand. T
Professor
Department of Mechanical& Automation Engineering
Agni College of Technology
Chennai
India

Venkatesan. J
Professor
Department of Mechanical Engineering
Sri Venkateswara College of Engineering
Sriperumbudur,Chennai
India

The development in automotive industry leads to economy and comfort of the vehicles and thus forces the designers to develop new materials for the improved performance. In this work, Bronze hybrid composite with Alumimum and Silicon reinforcementfor spark ignition engine piston was fabricated through vacuum stir casting process. Conventional machining techniques such as turning, drilling and boring etc., were used to manufacture the piston. Thermal analysis on the composite piston was carried out using Finite Element Software ANSYS. The mechanical properties tensile and impact strength and hardness of the composite were measured. Wear analysis on the composite material was carried out and wear rate was calculated. The results were compared with the existing material and found enhanced with bronze hybrid composites. Emission test was also carried out and found improved. Microstructure examination was carried out to study the structure of the composites..

***Keywords -** Bronze, Aluminium hybrid composite, Thermal analysis, ANSYS, Wear rate, Emission..*

1. INTRODUCTION

In automobiles, engine is the main part which will be used to determine the performance. Piston is the most inevitable part of the engine. The piston used in automobiles engine should have good strength and heat resistance. The piston should have rigid construction in order to avoid the mechanical and thermal distortions. The inertia force is also considered for the design of piston. Normally the inertia force should be minimum for which the weight of the piston to be reduced. Shaping of the combustion chamber, sealing, kinetic arrangement and gas force transmission are some of the functions of engine piston [1].

Generally, 700 K is the temperature observed in the crown of the piston at high rotational speed and loads. Frictional force, gas and mass forces are the sources of mechanical loads in piston [2]. Composite materials are used to manufacture the piston in order to increase the mechanical strength, reduce wear and to enhance the thermal properties.

The trend in modern automtive and aircraft structures is the replacement of metallic materials with different types of composite materials [3]. In this work composite piston was made with bronze as the matrix material and aluminium and silicon were the reinforcements. Vacuum stir casting method was used to fabricate the composite piston

Generally metals like steel and cast iron are used to manufacture engines. Since the engines made of metals are heavy, it consumes more amount of fuel. The torque, compressive forces and harmonic vibrations produced in conventional engines need to be dampened using dampeners, flywheels and counterbalancing pistons. The centrifugal, internal and reciprocating forces, loads and momentum were generated by the moving parts of the engine made of steel and cast iron. The power, performance and efficiency of the engine are affected by the engine's increasing weight, Engine parts made of light weight composite materials are employed in diesel and gasoline powered automobile engines, aircrafts, truck, marine, single and two cylinder engines, portable generators, lawn movers and other internal combustion engines. The fuel and gasoline consumption of such engines made of light weight composite material reduces to a greater extent. This is also helped in other ways such as quieter performance due to attenuate noise reduction and permitting the engine to operate in higher speeds. Higher horse power is produced by light weight composite parts used engines when compared to conventional engines, along with dimensional stability, maintaining its shape, structural integrity and operating conditions of the engine. The composite material parts used engines diminishes the momentum, internal force, centrifugal and reciprocating force and load on the engine. Piston design is changed. New materials graphite and carbide is added,overall to minimize pollutants and increase efficiency [4].

This work dealt with the manufacturing of engine valve guide using Aluminium – Silicon Carbide composite material and other alternative materials to improve the engine's reliability. Aluminium metal matrix composites have identified as the best suitable material for making components used in automotive and aviation industries. It gives greater scope in the development of such engineering fields. Finite element analyses of Titanium alloy (Ti-834), copper nickel silicon alloy were compared with Aluminium – SiC through ANSYS 13.0 software. The stress produced in engine valve guide due to various pressure and temperature were taken for the analysis. The range of pressure and temperature used in the analysis were 10 MPa and

Received: February 2020, Accepted: July 2020
Correspondence to: Dhanesh. C, Associate Professor
Department of Mechanical Engineering
S.A.Engineering College, Chennai, India
E-mail: dhaneshc@saec.ac.in
doi:10.5937/fme2004962D

600^0C and 650^0C. The principal stress and strain, temperature distribution of the valve guide's entire surface were calculated. The analysis results obtained were compared with allowable values and found low in Al-SiC composites and concluded that it was suitable for the use [5].

The piston of a spark ignition engine made of bronze hybrid composite is mainly used in automotive and power generation and aircraft industries. It reduces the shortcomings of S.I Engines made with conventional material piston. It increases the durability of the engine. It has more strength compared to conventional piston. Thermal expansion of the composite material piston is also very low [6].

Engine piston and cylinder are the prime components employed in the conversion of chemical energy produced during the combustion process into torque. The modern I.C. Engines are generally converting 30% of generated energy into useful work. 70% of the energy is lost due to friction between the moving parts of engine, Waste heat and pumping air out and into the engine. Fuel consumption and emissions produced increase due to friction [7, 8]. This work concentrates on the enhancement of the performance of S.I. engine with Composite material piston by reducing friction and emission characteristics, which was less explored in earlier studies.

2. EXPERIMENTAL WORK

2.1 Material Selection

In this research work a new metal matrix composite was used to fabricate the piston. Table 1 Shows the composition of the existing material. The material has aluminium in major prportion and silicon in considerable %.

Table 1. Composition of piston material - Existing

Material	Composition %	Material	Composition %
Aluminium	80.54	Magnesium	1.181
Silicon	12.362	Zinc	0.075
Iron	0.456	Chromium	0.002
Copper	4.361	Nickel	0.946
Manganese	0.011	Titanium	0.011

In order to improve the mechanical strength, wear resistance and thermal properties a new metal matrix composite was developed. Table 2 shows the composition of proposed piston material. It has 70% of bronze, 18% of aluminium and 12% of silicon.

Table 2. Composition of proposed piston material

Material	Composition %
Aluminium	18
Bronze	70
Silicon	12

2.2 Fabrication of Composite Piston

The composite material made with the composition mentioned above was manufactured using vacuum stir casting method. Figure 1 shows the bootom pouring type vacuum stir casting equipment.

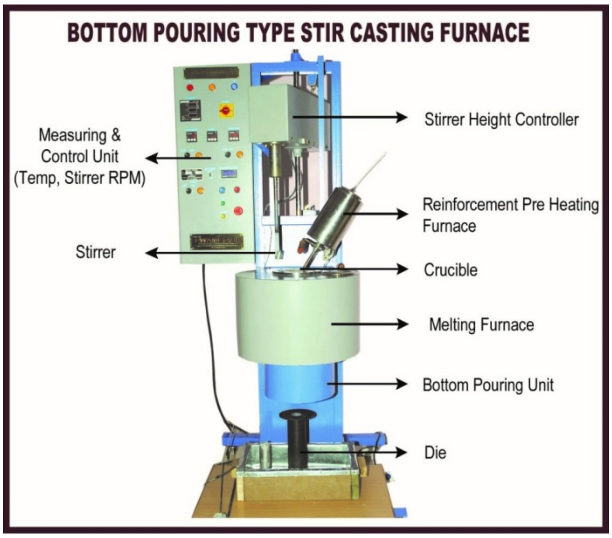

Figure 1. Bottom pouring type Vacuum Stir Casting Equipment

In vacuum type stir casting the mould was kept at vacuum with 10 mbar in order to remove the gases formed in the melt. There are many types in vacuum stir casting. Stir casting machine with bottom pouring type was used in this work. Double stage vacuum pump was used. Vacuum chamber and tank made up of stainless steel. Vacuum was maintained inside the chamber with the help of dial type gauge. Split type die mould was used to obtain a casting of outer diameter 50 mm and length 300 mm [9].

The composite material melt was poured into the die and the required shape piston was obtained. Conentional machining techniques like turning, drilling boring and grinding was used to fabricate the piston as the required dimension.

Figure 2 shows the nomenclature of the piston. It contains piston head, top land, ring section, ribs, piston boss, circlip, piston pin, grooves for compression ring and oil control ring, skirt and piston barrel.

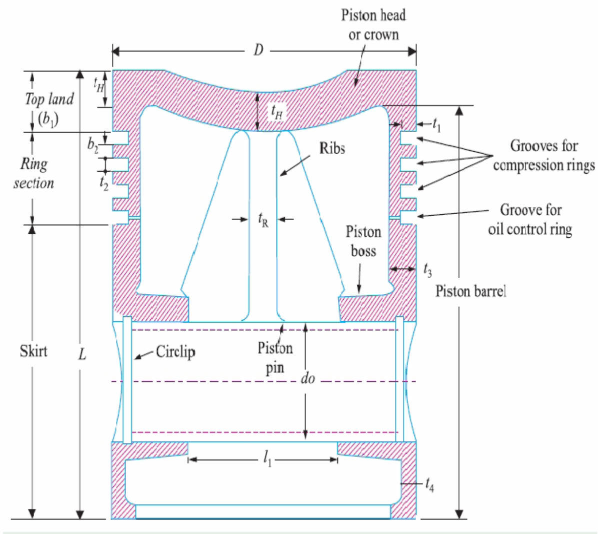

Figure 2. Nomenclature of Piston

Table 3 shows the technical specifications of the piston. Air cooled four stroke single cylinder engine was used with a ddisplacement of 97.2 cc and maximum power of 5.66 kW

Table 3. Technical specification of the piston

Engine Type	Air – Cooled, 4 Stroke single cylinder OHC
Displacement	97.2 cc
Max.Power	5.66 kW @ 5000 rpm
Max. Torque	7.130 N-m @2500 rpm
Compression Ratio	9.9 : 1
Starting	Kick / Self Start
Ignition	DC – Digital CDI
Bore	50 mm
Stroke	49 mm

The bronze, aluminium and silicon hybrid composite piston was made as per the technical specification given. The bore of the cylinder is 50 mm. An air cooled, four stroke single cylinder engine with overhead camshaft was used in this work. The Figure 3 shows the composite piston fabricated through vacuum stir casting.

2.3 Finite Element Analysis of composite piston

Finite Element Analysis was carried out in this work to analyze the thermal behavior of the composite piston. Temperature distribution and heat flux were the two parameters analyzed in this work. ANSYS R 15.0 software was used to perform the analysis.

Figure 3. Piston made of composite material in vacuum stir casting.

2.4 Mechanical Properties of the composite piston

The mechanical properties tensile strength, impact strength and hardness were calculated through experiments. The specimens made as per ASTM standards D 638 and d 256 for conducting tensile and impact test. Five specimens were taken for the analyses and the average value was recorded [10].

2.5 Wear Analysis on composite piston

Wear is one of the unavoidable phenomena in piston. Therefore analysis of wear in composite piston is essential one. Pin disc apparatus was used to conduct the wear experiment. The parameters for wear analysis were load 10 N, sliding velocity 1 m/s and sliding distance 500 m. Figure 4 shows the schematic arrangement of pin and disc. The pin was made with 8 mm diameter and 32 mm long. The pin was kept stationary and the disc was roating. Fig. 5 shows the experimental setup of pin on disc.

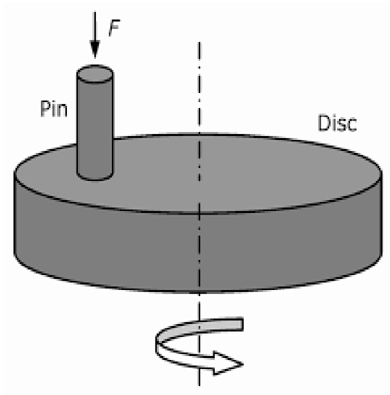

Figure 4. Schematic arrangement of Pin on disc

Figure 5. experimental setup of Pin on Disc

2.6 Emission Test

Emission test was conducted with the composite piston developed. The test was conducted in a two wheeler with petrol as the fuel and emission level of all the gasses were measured.

3. RESULTS AND DISCUSSION

Research studies have been carried out to investigate the reason for fracture in the crankshaft and piston of the transport aircraft engine, and concluded that due to excesive contact pressure and cyclic loading the fatigue crack occurred [11,12]

The thermal behaviour with transient analysis of the composite engine piston was analyzed in ANSYS R15.0. Figure 6 shows the three dimensional model of the piston developed in CATIA software. The three dimension model of the spark ignition engine piston was developed as per the specification. Meshing was done with the developed model using following parameters. Three dimensional solid elements were chosen with an element edge length of 1 mm. Fine meshing was performed. The image of the composite piston after meshing was shown in Figure 7. Thermal analysis was carried out on the meshed model of the piston using standard thermal analysis procedure.

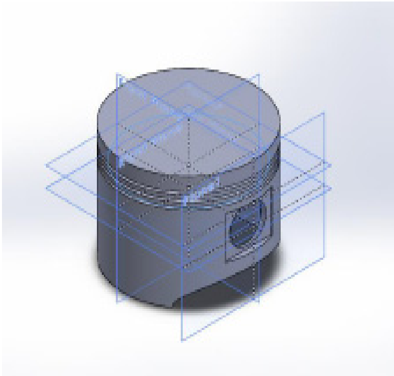

Figure 6. 3-D model of the piston

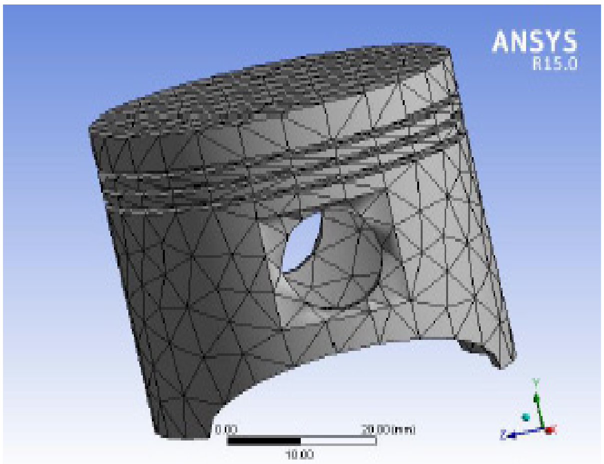

Figure 7. Meshing model of the piston

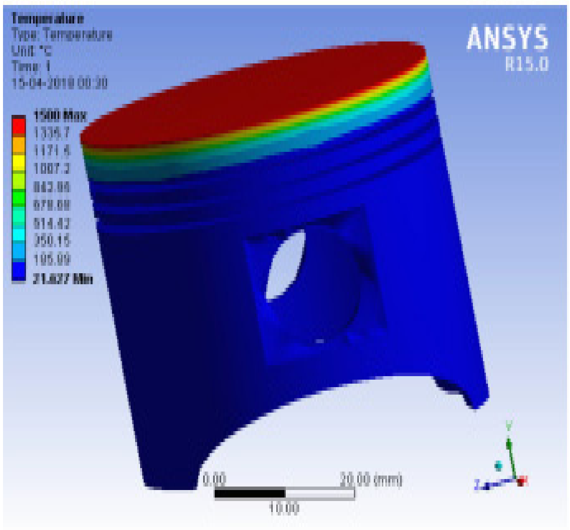

Figure 8. ANSYS Result of Temperature Distribution of Composite Piston

The temperature distribution and heat flux of piston made of bronze hybrid composite with aluminium and silicon reinforcement were shown in Figures 8 and 9. The maximum temperature observed was 1500 ^{0}C and heat flux was 10.251 W/m^2 where as for the existing material it was observed as 1275^{0}C and 1.851W/m^2. Therefore the bronze hybrid composite piston can be operated in higher temperature. The heat flux was also increased. This was due to the matrix material and reinforcement [13].

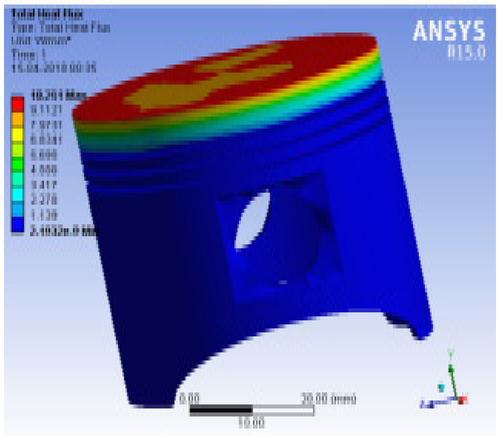

Figure 9. ANSYS Result of heat flux of composite piston

Table 4. Mechanical properties of composite piston

Sl.no	Material Description	Tensile strength (MPa)	Impact Strength (J/m^2)	Hardness (BHN)
1	Bronze reinforced with Aluminium and Silicon	684	28.6	159
2	Existing Material - Aluminium alloy	420	18.2	137

The mechanical properties of bronze hybrid composites were measured [14]. The tensile strength was observed as 684 MPa and for the existing material it was 420 MPa. Similarly the impact strength was calculated as 28.6 J/m^2 and for the existing material it was 18.2 J/m^2. The brinell hardness also calculated as 159 BHN. The mechanical properties of the composite piston were shown in Table 4.

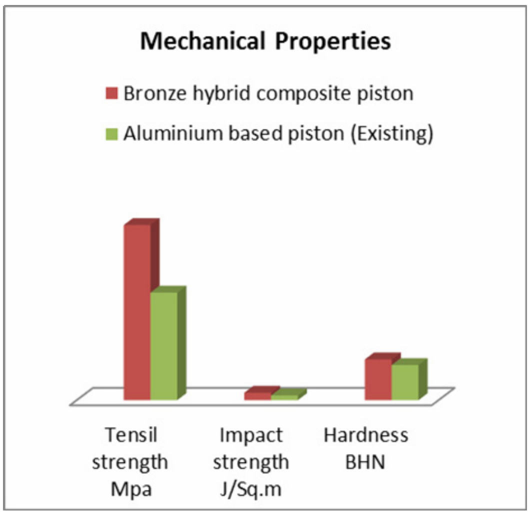

Figure 10. Mechanical properties Comparison

Figure 10 shows the comparison between the bronze hybrid composite piston and the existing material. The enhancement in tensile strength was 38.59%, impact strength was 36.36% and hardness was 13.83%.

Wear rate of the composite piston was also calculated in this work. The pin specimen was loaded against a flat rotating disc based on the circular path described by the machine. The Table 5 shows the parametersfor wear rate calculation in pin on disc apparatus [15].

Table 5. Parameters for wear rate calculation in pin on disc Apparatus

Applied load (N)	10
Sliding Velocity (m/s)	1
Sliding Distance (m)	500
Sliding Dia (mm)	44
RPM	50
Initial Weight (gm)	27.893
Final Weight (gm)	27.892

The wear rate calculated was 0.00357 mm^3/m, whereas the wear rate for existing piston material is 0.01436 mm^3/m. The wear rate of the piston made of Bronze hybrid composite was reduced [16].

The emission test was also performed with the piston made of new material i.e., bronze reinforced with aluminium and silicon. Table 6 shows the emission level of vehicle using bronze hybrid composite piston and the existing piston. Figure 11 Shows the comparison of emission levels vehicles using of new and existing piston [17].

The pollutants which are emitted from the exhaust pipe of the automobilesare known as exhaust pollutants [12]. They are formed as a result of combustion of the fuel in the engine. These pollutants are harmful to the atmosphere and living thingsin particular. The major types of exhaust pollutants are discussed in the following sections [18].

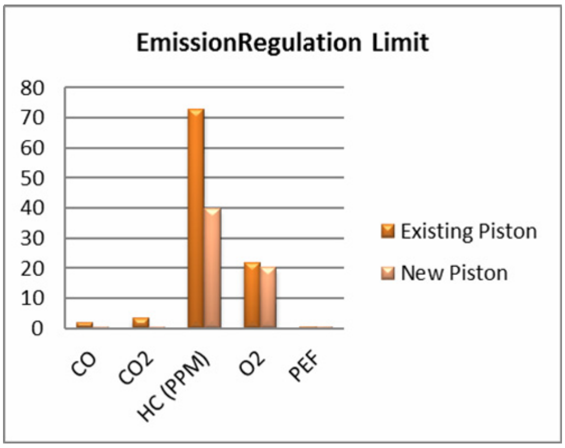

Figure 11. Comparison of Emission levels of New and Existing Piston Mechanical properties Comparison

The emission testing carried out in non- dispersive infrared measuringmethod .The measuring pollutants are CO, CO_2, HC, O_2. The emission level is reduced with the piston made of bronze hybrid composite material when compared to existing material [19].

Table 6. Emission level with new (Bronze hybrid composite) and existing piston

parameter	Regulation Limit	
	New Piston	Existing Piston
CO	0.15	1.81
CO_2	0.40	3.30
HC (PPM)	40.0	73.0
O_2	20.13	21.72
PEF	0.53	0.53

4. CONCLUSION

In this work a new material bronze hybrid composite reinforced with aluminium and silicon was proposed and tested. The following results were observed and it is concluded as follows.

- The mechanical properties of the bronze hybrid composite for piston were enhanced for tensile strength by 38.59%, impact strength by 36.3% and hardness by 13.83 %.
- The temperature distribution is better and it can withstand higher temperature than the existing material. Heat flux was also higher.
- The wear rate of bronze hybrid composite was lower than in the existing material.
- The emission level of new material proposed was lower than in the existing material.

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АНАЛИЗА ХИБРИДНОГ КОМПОЗИТА НА БАЗИ БРОНЗЕ КОД КЛИПА БЕНЗИНСКОГ МОТОРА

Данеш Ц., Ананд Т., Венкатесан Ј.

Аутомобилска индустрија се развија у правцу достизања економичности и комфора возила, што подстиче дизајнере да раде на стварању нових материјала у циљу остварења бољих перформанси возила. Клип бензинског мотора је израђен од хибридног композита на бази бронзе са ојачањем од алуминијума и силицијума методом STIR ливења у вакууму. Термичка анализа клипа је изведена применом софтвера ANSYS. Извршена су мерења следећих механичких својстава композита: јачина на кидање и удар и тврдоћа. Анализирана је отпорност на хабање и израчуната је брзина хабања материјала. Добијени резлтати показују да хибридни композит има боља својства у поређењу са постојећим материјалима. Такође је утврђено побољшање резултата теста емисије. Анализа структуре композита је обављена испитивањем микроструктуре.