A Study of Technological Innovation of Production of Automotive Piston Casting by 3D Printing

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Abstract:A study is carried out about technological innovations inpiston manufacturing process, materials and shape to meet the current demand of automotive pistons.Al-Si alloy, because of its low thermal expansion coefficient, minimal weight, strong hardness and good wear resistance qualities, is employed frequently in the piston production.Additive manufacturing is thetransformative approach to industrial production to produce higher and stronger part. A prototype of two wheeler piston is fabricated by using poly lactic acid and investigated other traditional manufacturing method which can be applied to metallic and bimetallic pistons.

Keywords: Additive manufacturing, Poly Lactic Acid, 3D printing, Bimetallic piston.

1. Introduction:

India is the second largest casting producer, after the China, in the world.India produces around 11.4 million tons of the world's 109 million tons casting production.India is world'sfourth largest producer of vehicle including vehicles [1].To maximize fuel efficiency, vehicles must be light-weighted. To decrease body weight, a variety of manufacturing technologies and materials have been developed. However, the mass of reciprocating engine components such as the piston, connecting rod, crankshaft, and engine block must be reduced. To meet the demand different materials are introduced.

The automobile piston in a vehicle must be extremely strong, durable and also heat resistance to withstand gas pressure and inertia compulsions. Also it should have less weight to minimize the inertia forces and rigid construction to endure thermal, mechanical distortion and sufficient area to avoid undue wear. The performance of a piston (shape, combustion area and displacement) has a significant impact on the engine power. In terms of the thermal efficiency of the engine the piston area and displacement are crucial, and the design of the piston can also have an influence. The combustion engine component needs to be carefully planned, particularly when the design of the engine is changed or changed. Manufacturing techniques are one of the aspects to be examined. Hence in the present work aimed to obtain innovativeness in business aspect by giving brief discussion about various manufacturing techniques, shapes of piston crownas well as different materials of the piston.

2. Literature survey:

One of the most difficult components of all automotive components in the manufacturing is the engine piston. For propulsion of vehicle engine components such as pistons, new vehicle designs, newer materials, and production procedures are proposed in several research publications and this development has been steadily improving over the previous few decades. It is the moving component, which is rendered gas-tight by piston rings by a cylinder. The aim of the engine is to transfer force through a piston rod from the compressed gas in the cylinder to the crankshaft and then to wheels. In the engine, heat is transferred from higher temperatures to lower temperatures owing to the temperature differences.

Many researchers studied and analyzed about manufacturing methods for piston production [2]. In general, the piston material must possess good wear, mechanical, thermal strength and the minimum thermal co-efficient. Piston manufacturing techniques areto be selected suitably.The Al-Si alloys have been subject of several scientific studies in the past few years and its popularity resulted in a continuing increase in their demand for components with higher and consistent mechanical properties [3].A piston has also been produced locally from aluminium piston scraps and to ensure that they conform to specifications required[4]. Taguchi method is used to examine the process parameters of aluminium alloy piston casting [5]. Researchers are always trying out the new techniques to make the piston having adequate strength coupled with light weight. Piston head or crown is also designed and fabricated with different shapes [6].

3. Automotive piston

Piston, which operates at high temperature, high pressure, corrosive and wear conditions whilst operating at high speed, is the most significant portion of the motor. The pistons are located at the centre of the internal combustion engine and the reciprocating movement of the piston crown, sidewall,

and top rings will create significant pressure. The piston top ground has to be very thin to decrease HC emissions [7]. To meet demand, piston materials and production procedures must meet rigorous standards in order to stay on track. They must be extremely strong, robust, and light in weight.

The pistons are at the heart of the internal combustion engine, and their reciprocating action puts a lot of stress on the crown, sidewall, and top rings of the piston. The piston top land must be very thin to reduce HC emission.When the engine is under load, the piston head is subjected to a huge amount of pressure. The piston head is subjected to forces from the expanding combustion gases. At the same moment, the flame front crosses the piston head, exerting more powerful forces.The forces exerted on the piston head by the expanding combustion gases and the flame front crossing can be two to three times this force. Thermal cycle loading refers to the reciprocating movement of the piston from Top Dead Centre (TDC) to Bottom Dead Centre (BDC) and the substantial temperature changes that occur during operation [8]. It is shown in Fig.1

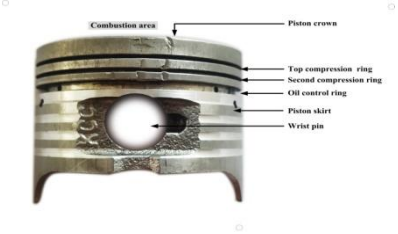

Fig 1. Schematic diagram of piston and its subsystems

Piston head is exposed to high-frequency cyclic impact loading at relatively high temperatures when the engine is operating under load. Figure 2 shows different parts of piston.

Table 1.Production data of automobiles and estimation of piston requirement during FY 2015-20.

Type of vehicle	**FY 2015**	**FY 2016**	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**
Passenger Vehicles	3,465,045	3,801,670	4,020,267	4,028,471	3,424,564	3,062,221
Commercial Vehicles	786,692	810,253	895,448	1,112,405	756,725	624,939
Total **four wheeler**	4,251,737	4,611,923	4,915,715	5,140,876	4,181,289	3,687,160
Piston production	17,006,948	18,447,692	19,662,860	20,563,504	16,725,156	14,748,640
Piston required (10%) for spare	1,700,695	1,844,769	1,966,286	2,056,350	1,672,516	1,474,864
Total piston requirement	18,707,643	20,292,461	21,629,146	22,619,854	18,397,672	16,223,504
Two Wheelers	18,830,227	19,933,739	23,154,838	24,499,777	21,032,927	18,349,941
Piston production	18,830,227	19,933,739	23,154,838	24,499,777	21,032,927	18,349,941
Piston required (10%) for spare	1,883,023	1,993,374	231,5484	2,449,978	2,103,293	1,834,994
Total piston requirement	20,713,250	21,927,113	25,470,322	26,949,755	23,136,220	20,184,935

The annual requirement of piston for two-wheeler is more when compared to the requirement of four-wheeler. The trend-line for annual production of two-wheeler and four wheelers are plotted and equations have been obtained in Fig. 2(a) &2(b).

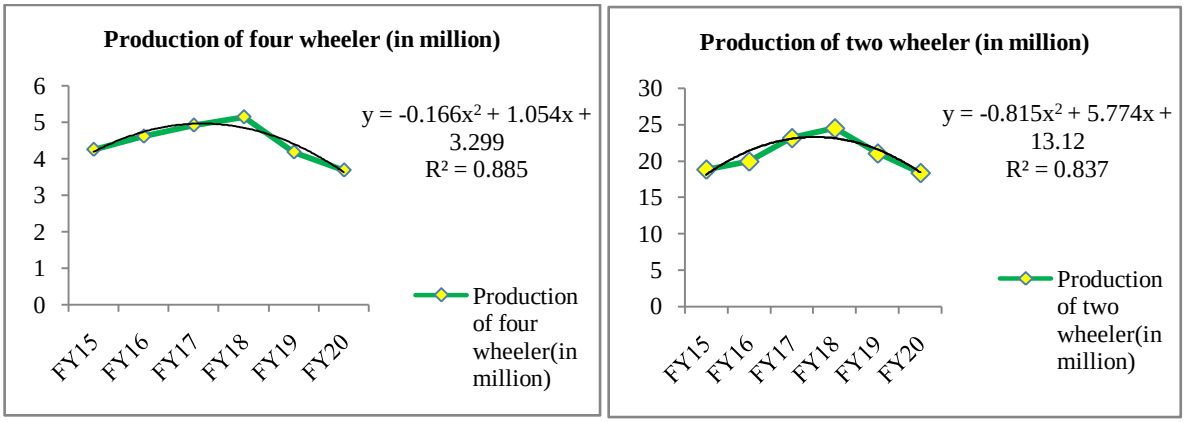

Fig 2. Forecast for production (a) Four-wheeler (b) Two-wheeler for FY15-20

Annual piston production data's in million have been shown in Table 1 during 2015-2020. Forecasting of piston production per annum is also estimated and shown in Table 2 for the year 2022. The trend line depicts a declining trajectory. The present epidemic crisis can be attributed for this scenario. In this stage, the automotive industry's outlook is bleak. With this in mind, the forecast is just for the next two years.

Table 2. Forecasting of Piston Production in 2022 FY

Annual production of piston	Forecasting equations	R (sq.)	Estimated future production (in million)	
			FY 2021	FY2022
Two-wheeler	$y = -0.815x^2 + 5.774x + 13.12$	83.75%	13.6030	7.1520
Four-wheeler	$y = -0.166x^2 + 1.054x + 3.299$	88.59%	2.5226	1.0796

4. Innovations in piston technology

4.1 Materials for piston casting

For the production of automobile pistons, a number of casting processes are developed; each casting process has its own influence on the microstructure, physical and mechanical properties, and other fundamental attributes required for vehicle pistons. Aluminium alloys offer better castability, low weight, thermal conductivity, high strength at elevated temperatures, and corrosion resistance.

Nowadays aluminum alloy is used as the replacement of steel and cast iron in automotive components like pistons. With lightweight aluminum alloy casting received a significant interest to improve their performance and efficiency. Low expansion aluminum–silicon alloys referred by Haque and Young [9].In aluminium silicon alloy, presence of silicon not only improves the high temperature strength but also reduces the coefficient of thermal expansion. Because of this, pistons are manufactured and installed with minimum clearance. Due to different thermal and mechanical load on different part of the piston, service requirement dictate the need for better material. Light weight metal reinforced strong base metal to improve the performance. Different techniques can be used to produce these bimetallic pistons.The centrifugal casting process can be used as a new and effective method in piston manufacturing compared with the permanent casting process[10].

Metal powders are used as a raw material in additive manufacturing (AM). It must consist of good flow, sintering and packing properties. In order to accommodate different materials different AM techniques evolved. Fused deposition method is widely used prototyping technology which uses PLA as a material. 3D printing is capable to print the whole part in one structure layer by layer. It gives advantage indesign flexibility for low volume customized parts. In the present work three dimensional (3D) printing method developed for piston casting (Figs. 3 and 4).

4.2 Shape of piston crown

The internal combustion process is greatly influenced by the geometry of a piston. The way heat and the air/fuel combination are handled is largely determined by the geometry of a piston. The air-fuel

combination is heavily influenced by in-cylinder fluid motion, which has a significant impact on combustion and emission characteristics. The importance of in-cylinder flow in archiving higher performance cannot be overstated.

As the piston rises for the compression stroke, the geometry of the piston bowl influences the flow of air and fuel (before the mix is ignited and the piston is pushed downward.) Before combustion (or compression), air and fuel swirl form a vortex inside the piston bowl, resulting in a better mixture. The basics shapes of the piston crown are flat top, bowl shape and dome shape. Dome pistons have a dome shape and are distinguished from flat-top pistons by the absence of a flat top. When compared to flat-top pistons, these results in more volume at the top; this extra volume results in a higher compression ratio, which improves performance [11].

Because of simplicity in basic design and ease of manufacturing,flat-top pistons are employed in mass production. The cost of manufacturing a flat-top piston is very minimal, resulting in lower costs. Because of their shape, which adds to the total combustion volume, bowl pistons are mostly employed in engines to lessen the compression ratio. These pistons are ideal for supercharged and turbocharged engines due to their purpose of lowering the compression ratio.

Bowl type pistons have the advantage of being able to be employed in a supercharged engine to avoid spark knock under specified conditions, but due to the hotter running piston, hazardous gases such as nitrogen oxides are produced more frequently. Bowl pistons produced the highest level of turbulent kinetic energy. Bowl shaped piston crown is beneficial due to preservation of tumble for longer duration than flat piston, which may reduce cyclic variations as the turbulence generation is delayed[12].

4.3 Manufacturing methods of pistons

Pistons are manufactured by sand casting, gravity die, pressure die, squeeze casting or powder metallurgy techniques. These variety of manufacturing techniques employed for the fabrication of automobile piston, each technique has its own impact on the microstructure, physical and mechanical properties.Squeeze casting and gravity die casting are both considered conventional production technologies. New production processes, on the other hand, have emerged. pressure die casting (PDC) is a automated industrial process. In a conventional die casting process, molten metal is poured into the shot sleeve by a ladle after the die is closed. The metal is driven into the die by a plunger (piston) movement, forcing the mobile part to align with the fixed part. On some die casting machines, this plunger motion can be done in four stages.However, typically it is done in two stages only. The plunger starts initially with a low velocity, then the velocity increases during the piston's motion at a change over position, the length of travel of the piston in the low velocity up to the changeover point is known as first phase length and the injection pressure is decreases at the end when nearly all the liquid metal is injected into the die and solidifies.

Due to the extensive use of digital technology in a number of applications, Additive Manufacturing (AM) or 3 Dimensional Printing (3DP) has increased in popularity across the world. It is a process of constructing real items from digital information piece by piece, line by line, surface by surface, or layer by layer, utilising 3D digital modelling tools and programmes. 3D printing is a type of printing that can construct or recreate freestanding complex structures in a single piece. The size of a 3D printer, as well as the materials utilised for printing, can have an influence on component quality. 3D printers have the potential to manufacture quality work-pieces with precision, ease of use, convenience, rapid design and printing, cheap cost, and the capacity to adapt to a variety of applications [13].

Since 1984, when the first 3D printer was designed and realized by Charles W. Hull from 3D Systems Corp., the technology has evolved and these machines have become more and more useful, while their price points lowered, thus becoming more affordable [14].

A piston is being fabricated by Fused Deposition Methods (FDM) method using Poly Lactic Acid (PLA). PLA is a biodegradable thermoplastic that is commonly used to create prototypes. It is vegetable based plastic material commonly uses cornstarch as raw material.Figure 3 shows the dimension considered for fabrication. First the design was made in AutoCAD and converted into .stl file.

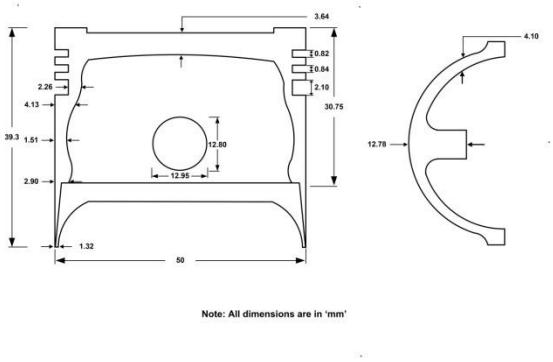

Fig 3.Dimensions of the fabricated piston

Fig 4. Fabricated piston

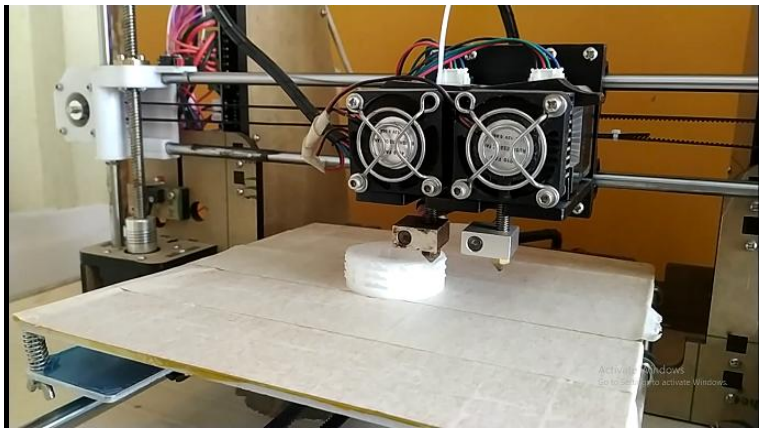

Fig.5 Setup of FDM (3D printer)

Simplify 3D is slicing software used to control every aspect and convert the design into the instructions that printer understood. Base is preheated before printing and used the nozzle diameter 0.4mm. The nozzle is heated to melt the plastic and has a mechanism which allows the flow of the melted plastic to be turned on and off. As the nozzle is moved over the table in the required geometry, it deposits a thin bead of extruded plastic to form each layer. The final printed product and the machine setup are shown in Figures 4&5 respectively.

5. Conclusions

Two-wheelers are widely utilized for personal transportation in nations such as India. Engine performance and mileage depends on piston material and crown shape and production methods. Newer lightweight materials have been found to be better.Bowl shape piston crown offers the better faster combustion rate and reduces fuel consumption. Aluminium silicon is widely used material for piston in traditional manufacturing techniques as well as new innovative techniques like additive manufacturing. Forecasted future requirements of piston castings in India and it is found that piston requirements are increasing. Proto-type piston manufacturing by PLA method was developed and manufactured which can be used for metallic and bi-metallic piston manufacturing. 3D printing provides one or more business advantages, such as better quality products, shorter processing times and higher accuracy.

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