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A Study on Material Selection of IC Engine Piston under Static Loads

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***Abstract*- The present work deals with redesigning IC Engine piston of 2 stroke bike RX 100, YAMAHA. Many efforts for the redesign of the engine parts are carried out by numerous researchers so far. Especially, weight reduction and cost of material reduction researches are playing vital role in Engineering Industries. These efforts are taken to get the desired performance of the engine under different load conditions. Present work is devoted to redesign of piston pertaining to various materials such as Cast Aluminum, Nickel Chromium Alloy, Cast steel, Carbon steel and four kinds of Aluminium Alloy Compositions. Through this work validation can be done for any Engineering concerns that the redesign of piston is worthy. First of all the geometric model of the RX100 piston is created using Pro-E package and then the piston is analyzed in popular FEA package ANSYS to know the stresses and deformations produced for the various materials mentioned above. Then the selected material is analyzed for different load cases. The scope of this paper is to suggest an alternate material for the piston which can produce lower values of stress, deformations for which structural analysis is carried out.**

***Index Terms* – ANSYS, piston, material selection and structural analysis.**

I. INTRODUCTION

The globalization and economic reforms have changed the face and pace of world economy in the last two decades. To sustain in the competitive market, industries have to update their knowledge, acquire new skills to offer world-class products. Design and analysis of complex components has reached new heights with the application of Finite Element Method. Automobile Industry has benefited a lot with the development of CAD/CAM technologies, from engine performance to aesthetic appeal. The lead time to manufacture automobiles has drastically reduced in the recent times, because of advancements in Geometric modeling and Computer Integrated Manufacturing (CIM).Design of Internal Combustion (IC) Engine parts plays a crucial role in improving the functioning of an automobile. Design and modifications of all the important components are carried out to increase the performance and thereby efficiency. Many redesign concepts have been emerged for cylinder head, connecting rod, crankshaft, piston, carburetor, Fuel injection pump and other engine components. Especially redesign of Piston is carried out to get enough strength to sustain the gas pressure and to have the better thermal stability. Also new researches are going on to select an alternate material to cope up with the existing load cases, to get higher compression ratio, to reduce the inertia forces to increase the speed of the vehicle (by reducing the weight of the reciprocating masses).

II. LITERATURE SURVEY

Jason Swanson, Dan sehok, Allen Kelley, David callow (1) have made meaningful improvements to the Hamilton Beach 730 CT Drink Master Classic Chrome drink and Milkshake mixer. During the reverse engineering and redesign processes they have dissected, analyzed and redesigned each part of the milkshake mixer in order to come up its final design. VL.Markine, AP Benan, C Esveld (2) discussed the procedure for design of Railway track. The mechanical behavior of a track is analyzed using 2D and 3D finite element models wherein the track and moving train has been incorporate. The 2D numerical model has been implemented in the rail program. The analysis of the 3D model can be performed using the general purpose finite element analysis package ANSYS. Finally the optimum track parameters are determined.

YaserDeger (3) performed a study focused on possible local redesign of the platform of machine tool mounting device in order to ensure a resonance free operation. In a first step the significant eigen frequencies with corresponding mode shapes were obtained by means of an experimental modal analysis.JW Rings berg, BL Josephson (4) described the finite element analysis of rolling contact fatigue crack initiation in railheads. A strategy proposed for fatigue analysis comprises a critical plane approach used together with a multi-axial fatigue model.

Kettil P and Wiberg N.E (5) presented the work on the integrated use of computational methods (geometric modeling, simulation, visualization) for structural analysis and design. The focus in this paper is on 3D solid modeling and dynamic simulation. Their work shows that 3D modeling and simulation are versatile tools for design of structures. Razmi and N. Choupani (6) presented a work on 2D Fracture Analysis of the First Compression Piston Ring. In this the incidence of mechanical fracture of automobile piston rings prompted development of fracture analysis method on this case. The three rings (two compression rings and one oil ring) were smashed into several parts during the power-test (after manufacturing the engine) causing piston and liner to be damaged.

Junwei Andrzej Niewczas, CezarySarnowski (7) worked on the Analysis of deformation in Composite Pistons of a Diesel Engine, the paper presented some results of simulational research of composite pistons used in a direct injection diesel engine. Pistons were locally reinforced with Al_2O_3 in the area of piston crown and an optimization attempt applied to piston shape and dimensions of preforms sealed in pistons are also presented.

III. PROBLEM IDENTIFICATION

Even though Aluminum Alloy is lighter in weight, it is so soft. Hence, lubricating oil is embedded in it causes a sort of grinding or abrasion of cylinder walls. Thus life is less. It has low strength. For this thicker sections must be used thereby weight is increased. To overcome these difficulties faced by using the available Aluminum Alloy piston, the new compositions in the same Aluminium Alloy and other materials like cast steel, Nickel chromium alloy, carbon steel and cast iron are tested.

A. Square Engine

When the stroke length of the engine is equal to the bore diameter of the cylinder then it is called square engine. Generally, the engines have more stroke length than bore diameter. But for the same revolution of the crankshaft, a square engine has lower piston sliding speed than the similar engine of the large stroke. Therefore, it develops more power with less consumption of fuel as compared to an engine of larger stroke. It needs less lubricant also. It has more life for both piston and cylinder. The velox and Vauxhall engines are the good examples of the square engine.

B. Piston Selected for Analysis

Vehicle	:	Yamaha
Model	:	RX 100
Model code No.	:	1L1
Frame serial No.	:	YYM1L1000001
Engine serial No.	:	YYM1L1000001

C. Engine

Type	:	Air cooled, two stroke, Gasoline, & port Torque Induction
Displacement	:	98 cc, Bore x Stroke : 50mm x 50mm (Square Engine)

D. Load Calculations

On account of the considerable variation in the maximum gas pressure subjected to the piston head, the mean effective gas pressure is calculated from the design principle.
The design data for the considered Yamaha piston is given below:
Brake horse power , P = 11 BHP = 11 x 735.5 = 8090.5 Watts
Stroke length L = 50mm,Diameter of bore D = 50mm, Speed N = 3750 rpm
Area of cross section of piston A = 1964.2858 mm^2

E. Brake Mean Effective Pressure Calculation

We know that, Brake mean effective pressure

Pmb = BP /(n x Vs) N/mm^2 , Here n = No.of working strokes/second ,
Vs = Swept volume in mm^3, BP = Brake power

Vs = A x L mm^3
= 1964.2858 x 50
= 98214.29 mm^3

Pmb = (8090.5 x 1000 x 60)/ (3750 x 98214.29)
Pmb = 1.32 N/mm^2

F. Solid Modeling of Piston

Due to the complex geometry of the selected piston, it is first modeled using the software Pro-E. The basic structure of the piston is first created on sketcher and later the solid is obtained by shafting in part design. The grooves for various piston rings are created by grooving. The gudgeon pin holes are pocketed with inside hubs with smooth filleting and draft. The embossing like provision is created using solid freeform option. The rectangular pockets with fillets and various other recesses, inside piston head ribs with proper fillets are recreated with utmost care in such a way that the model is idealized as it is. The varying thickness of the barrel is maintained as per the dimensions. The solid model of the piston depicting various key features is presented in Fig.3.1 and the imported model, meshed model are depicted in Fig.3.2 and Fig.3.3.

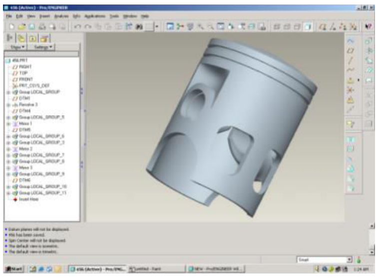

Fig. 3.1 Full model created using Pro –E

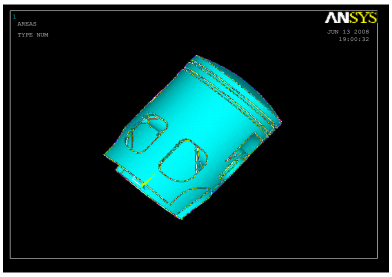

Fig3.2 Imported Solid Model in ANSYS

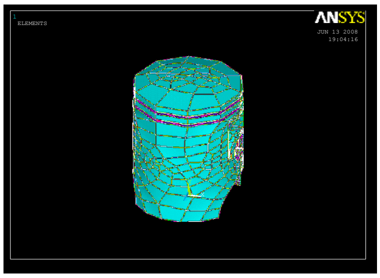

Fig. 3.3 Meshed Model

G. Existing Selection

Used material: Al. Alloy, Young's modulus = $0.8 \times 10^5 N/mm^2$,Poisson ratio = 0.34, Density=2.8×10^{-6} kg/mm^3

TABLE-I MATERIAL COMPOSITIONS

Sl. No	Material	Compositios in Weight (%)															
		Cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Sn	Al	C	P	S	Cr	Ca	Ti
1	Carbon steel	-	-	0.6	97.9	0.7	-	-	-	-	-	0.7	0.05	0.05	-	-	-
2	Cast Iron	-	-	2.5	93.3	1	-	-	-	-	-	3	0.15	0.1	-	-	-
3	Ni.Cr. Alloy	-	-	1.5	-	-	78.4	-	-	-	-	-	-	-	20	0.1	-
4	Cast Al	1	1.5	12	0.8	0.5	2.5	0.1	0.1	0.1	81.4	-	-	-	-	-	-
5	Al. Alloy 1	4.6	0.3	0.1	0.15	0.4	-	-	-	-	94.33	-	-	-	-	-	0.22
6	Al. Alloy 2	-	0.9	-	-	-	-	7	-	-	91.82	-	-	-	0.13	-	0.15
7	Al. Alloy 3	-	0.6	7	-	-	-	-	-	-	92.25	-	-	-	-	-	0.15
8	Al. Alloy 4	4.5	0.6	17	-	-	-	1.3	-	-	76.6	-	-	-	-	-	-

TABLE-II MATERIAL PROPERTIES

Sl. No	Material	Young's Modulus (N/mm^2)	Poisson ratio (1/m)	Density (Kg/mm^3)	Permissible stress (fos2)N/mm^2	Yield Stress (N/mm^2)
1.	Carbon steel	2×10^5	0.28	7.8×10^{-6}	210	420
2.	Cast Iron	1.034×10^5	0.28	7.2×10^{-6}	175	350
3	Nickel Chromium alloy	0.448×10^5	0.33	1.8×10^{-6}	170	340
4	Cast Al	0.75×10^5	0.33	2.7×10^{-6}	190	380

5	Al.Alloy 1	0.8×10^5	0.34	2.8×10^{-6}	172.5	345
6	Al.Alloy 2	0.78×10^5	0.34	2.8×10^{-6}	185	370
7	Al.Alloy 3	0.77×10^5	0.33	2.75×10^{-6}	205	410
8	Al.Alloy 4	0.7×10^5	0.33	2.6×10^{-6}	210	420

IV. Analysis of Piston

The analysis of piston is carried out in ANSYS FEA Package. The model which is created by Pro-E is imported to ANSYS in IGES format which was stored in Shell. The 3D shell element of plastic 4node 143 is selected for meshing. Shell element is so selected because it is well suited for model non-linear, flat or wrapped, thin to moderately thick shell structures. The element has 6 degrees of freedom at each node. They are translation in x, y and z directions and rotation about modal x, y and z axis. The deformation shapes are linear in in-plane direction. For out-of-plane motion, it uses a mixed interpolation of tensorial components.After meshing of the piston, the surface load (pressure) is applied uniformly on the top surface of the piston head. The inner surfaces of the gudgeon pin bosses are totally constrained. The Analysis is performed with considered materials such as Carbon steel, cast iron, Nickel chromium Alloy, Cast Aluminium and Four kinds of Aluminum Alloy compositions. This process is carried out for all the materials selected for analysis. Then the deformations and induced stresses for all the materials are presented.

A. Static Analysis Results

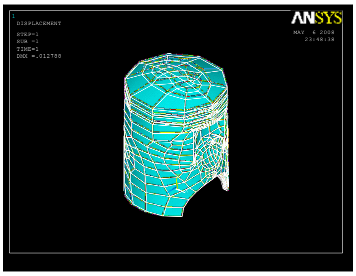

Fig. 4.1 Carbon steel Deformation

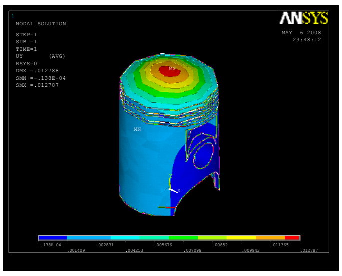

Fig. 4.2 Carbon steel deformation in y-Direction

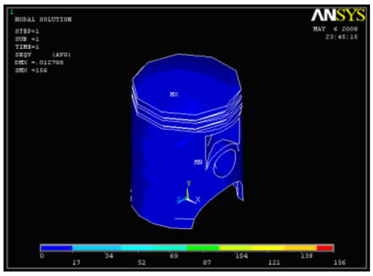

Fig. 4.3 Carbon steel Von-mises stress

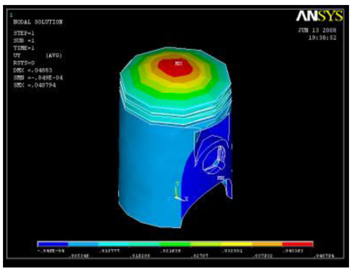

Fig. 4.4 Aluminium Alloy -4 Deformation

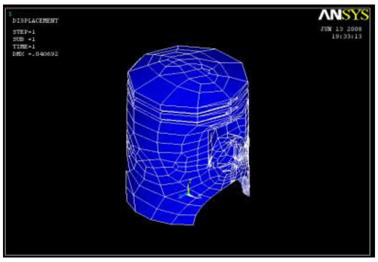

Fig.4.5 Aluminium Alloy- 4 Deformation y-direction

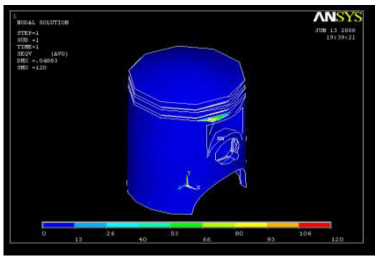

Fig .4.6 Aluminium Alloy- 4 Von-mises stress

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TABLE-III COMPARISON OF ANSYS RESULTS WITH MATERIAL PROPERTIES

Sl. No	Material	ANSYS Results		Material properties	
		Maximum Deformation mm	Maximum Induced Stress N/mm^2	Permissible Stress (fos=2) N/mm^2	Yield Stress N/mm^2
1.	Carbon Steel	0.012788	156	210	420
2.	Cast Iron	0.024735	156	175	350
3.	Ni.Cr Alloy	0.056724	158	170	340
4.	Cast Aluminium	0.033759	248	190	380
5.	Al.Alloy 1	0.035386	159	172.5	345
6.	Al.Alloy 2	0.034684	159	185	370
7.	Al.Alloy 3	0.032049	248	205	410
8.	Al.Alloy 4	0.048830	120	210	420

V. RESULTS AND DISCUSSION

The factor of safety for automotive applications is usually 1.3 to 1.8, but in exceptional cases it can be upto 5 also. The maximum deformation and Von-mises stress values obtained for the materials analysed are compared in Table III with the respective permissible stresses (Factor of safety =2) for the calculated design load of 1.32 N/mm2. It can be observed from the Table III that Cast Aluminium and Aluminium Alloy-3 have the induced stresses beyond the permissible value. Hence, these two materials are neglected from considerations.And among the remaining materials (Carbon steel, Cast iron,Nickel Chromium Alloy, Aluminium Alloy-1, Aluminium Alloy-2 and Aluminium Alloy 4) Aluminium Alloy 4 shows the least value of induced stress for the applied load. Hence, it can be the suitable material for the piston among the materials considered for the discussion.This material is then analysed for different load cases of the existing design load (1.32 N/mm2) to identify the maximum load carrying capacity of the piston. The deformations and induced stresses for Aluminium Alloy-4 for different load cases are presented in Table IV. By the observation the RX 100 Two wheeler piston is within safe stress up to a load of 2.64 N/mm2, or twice the designed load (200% of the loading). This comparision is plotted in the Fig. 5.13.

A. Static Analysis Results for Aluminium Alloy-4 under Different Load Conditions

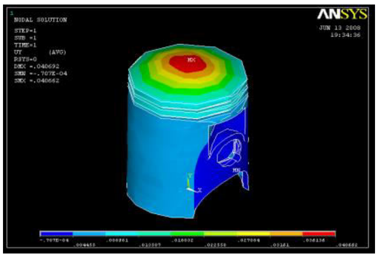

Fig.5.1 Deformation in Y-Direction (Load 75%)

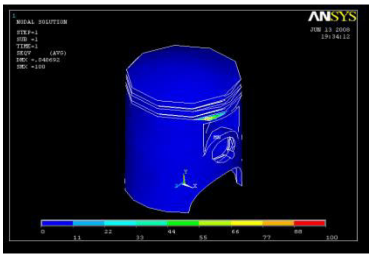

Fig.5.2 Von-mises Stress (Load 75%)

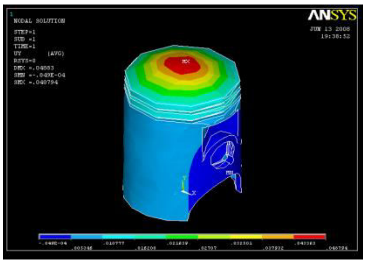

Fig.5.3 Deformation in Y-Direction (Load 100%)

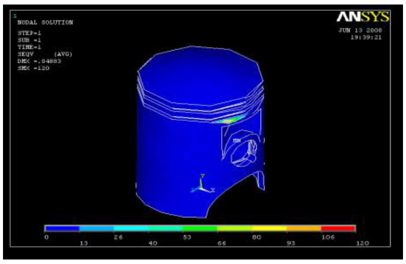

Fig.5.4. Von-mises Stress in Y-Direction (Load 100%)

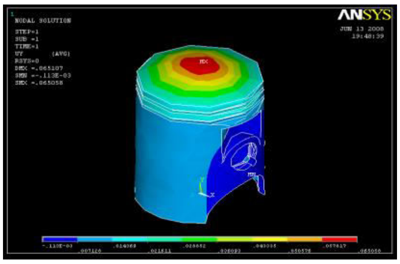

Fig.5.5 Deformation in Y-Direction (Load 150%)

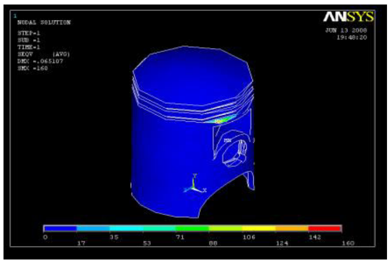

Fig.5.6 Von-mises Stress (Load 150%)

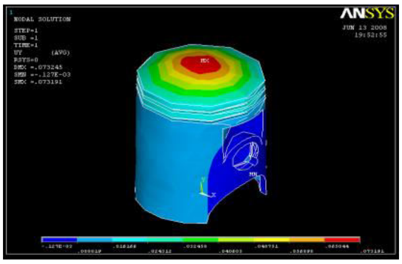

Fig.5.7 Deformation in Y-Direction (Load 175%)

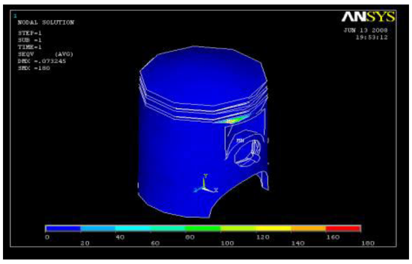

Fig.5.8 Von-mises Stress (Load 175%)

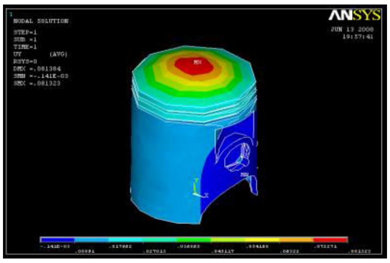

Fig.5.9 Deformation in Y-Direction (Load 200%)

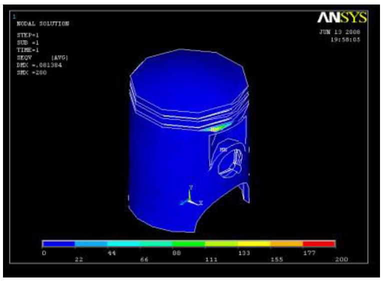

Fig.5.10 Von-mises Stress (Load 200%)

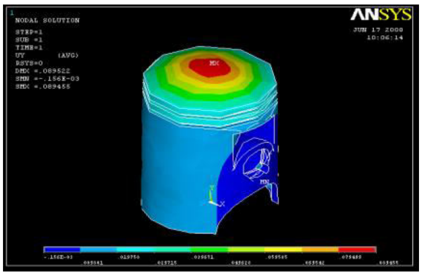

Fig.5.11 Deformation in Y-Direction (Load 225%)

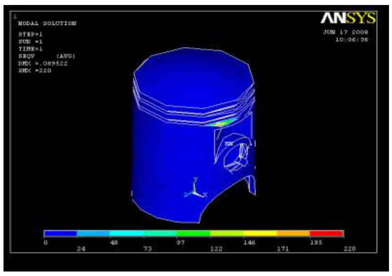

Fig.5.12 Von-mises Stress (Load 225%)

TABLE-IV STATIC ANALYSIS RESULTS FOR AL ALLOY-4 UNDER DIFFERENT LOAD CASES

S.No	Type of loading	Pressure value (N/mm^2)	Deformation (mm)	Induced stress (N/mm^2)
1	50%	0.66	0.032553	80
2	75%	0.99	0.040692	100
3	100%	1.32	0.048830	120
4	125%	1.65	0.056969	140
5	150%	1.98	0.065107	160
6	175%	2.31	0.073191	180
7	**200%**	**2.64**	**0.081323**	**200**
8	225%	2.97	0.089455	220
9	250%	3.3	0.097588	240

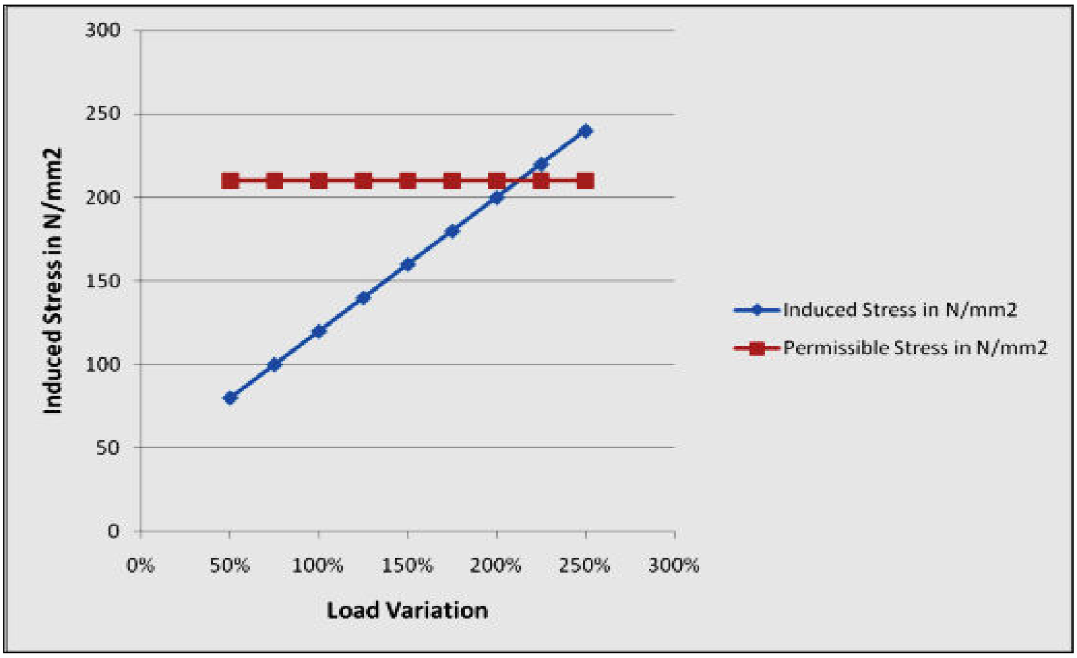

Fig. 5.13 Comparison of Stress Analysis result under different load cases with permissible stress.

VI. Conclusion

The piston selected for analysis is made up of Aluminium Alloy with one composition (Aluminium Alloy-1) and the suggested material is with another composition (Aluminium Alloy-4). By comparing Induced Stress and Deformation values, Aluminium Alloy-1 is somewhat inferior in strength and shows more sress in ANSYS result. But Aluminium Alloy-4 has higher strength and shows lower stress value than Aluminium Alloy-1. Also due to the lesser density value, weight of the piston is reduced considerably thereby rpm of the vehicle is increased slightly (Inertia force is less due to lesser weight).Yamaha, RX 100 vehicle is of square engine type which has more power with lesser fuel consumption for same crankshaft speed compared with the larger stroke piston used in other vehicles. Because of the more strength with less mass, Aluminium Alloy-4 piston can produce more power, more speed and consume less fuel and lubricant for the same design load of 1.32 N/mm^2.

By the analysis performed on Aluminium Alloy-4 with different load cases, it is seen that the piston is within safe stress up to a load of 2.64 N/mm2, or twice the design load (200% of the loading). Due to the higher strength and considerable deformations for different types of loading, Aluminium Alloy- 4 can be used as the alternate and suitable piston material for Yamaha, RX 100 vehicle.

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