Design and Optimization of Piston for Two Wheeler Disc Brake Master Cylinder using Plastic Material

Sourabh M. Dhole, Prof. V. V. Saidpatil, Dr. S. Y. Gajjal

Abstract— **Most of the two wheeler vehicles have disc brakes on front wheel for effective braking of vehicle. The piston compresses the brake fluid and passes it into oil hose under pressure, is an important part of brake assembly. The existing AL 6026 piston is heavier and costlier. To reduce weight and cost, it is necessary to manufacture the piston in Polyphenylene sulfide and Stanyl® materials. In previous work, it was manufactured in PTFE as parts or subparts and then it assembled into a single part. In this dissertation work, the attempt is made to manufacture the piston in cost effective Polyphenylene sulfide and Stanyl® material. The CAE and Experimental methods are used to validate the results. The models of existing AL 6026 piston and Polyphenylene sulfide and Stanyl® pistons are developed in CAD software and the analysis is done in finite element tool to find the compressive stresses. To reduce these compressive stresses, the ribs are added on piston. Experimental testing was carried out on Universal Testing Machine to find the compressive stresses. From Software results and Experimental investigations, it is found that compressive stresses reduced by 31% to 34% and weight reduced by 34.63% to 45.65%.**

Keywords— **Master Cylinder Piston, Material Change, Plastic Material, Design and Optimization, FEA Stress Calculation, Experimental Testing.**

I. INTRODUCTION

Most of the two wheeler vehicles have disc brakes on front wheel for effective braking of vehicle. The piston compresses the brake fluid and passes it into oil hose under pressure, is an important part of brake assembly. The existing aluminium piston has limitations of weight and cost. There is a possibility of scarcity of aluminium material makes it costly and hence it is necessary to find the more easily and abundant available material. To overcome these limitations, it is important to manufacture the piston in plastic material. The focus of this project work is to find the stress and strain so that to design and optimize the piston to reduce the stress and weight by changing the material of the piston from aluminum to plastic. In this dissertation work, the attempt is made to manufacture the piston in cost effective plastic material to reduce the weight. The advantages of the piston with changed material are the low weight, low cost and superior material properties.

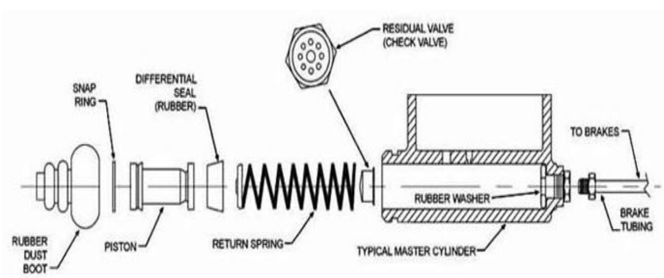

Fig. 1 Schematic of Master Cylinder

II. LITERATURE REVIEW

Schuller W., Eckstein U., [1] invented and manufactured a piston by using plastic material such as polytetrafluorethylene. The one end of the piston is called strike surface on which cam element exerts the linear forces. The wear resistant material such as metal like hardened steel or sintered ceramic is used as cam strike piece. This material is used as cam strike piece in disk shaped in between piston and strike surface to bear the stresses due to friction. The disk shaped cam strike piece is used as insert in the injection molding tool and plastic is injected around the insert except on the strike face. The piston is manufactured in one operation by using injection molding procedure which is simple, quick and cheap method. As the piston is manufactured by using plastic, it has the advantage of positive sliding property while sliding linearly in cylinder housing.

Hauser M., Alaze N., et al. [2] to manufacture a master cylinder piston easily and at low price rate, inventors proposes a methodology that the piston includes a sleeve shaped part and a valve seat part made of plastic material and the valve seat part is press fitted into shaped part. This methodology allows a small and compact design of master cylinder. The other advantage of methodology that, it has minimum components that are manufactured from simple and low rate

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Sourabh M. Dhole, M.E. Mechanical (Design) Student, NBN Sinhgad School of Engineering, Ambegaon Bk, Pune-411041 (e-mail: sourabh.dhole@gmail.com)

Prof. V. V. Saidpatil, NBN Sinhgad School of Engineering, Ambegaon Bk, Pune-411041 (e-mail: vishal.saidpatil@sinhgad.edu)

Dr. S. Y. Gajjal, PG Head, Mechanical (Design), NBN Sinhgad School of Engineering, Ambegaon Bk, Pune-411041 (e-mail: shekhar.gajjal@sinhgad.edu)

parts. They optimized the piston for its manufacturability while maintaining its functionality.

Nakamura K., [3] manufactured a piston and master cylinder body from fiber glass nylon material as strengthened resinous material by molding operation which produces as single component as a result reduces weight and cost. The other objective of the invention is to produce a new and improved piston for a master cylinder which eliminates the previous disadvantages of piston. They found that, as the plug rests on the center of the concave surface of the piston, while manufacturing the piston by molding process, the flow of resinous material will improve and hence the dimensional accuracy of piston will be improved.

Schard M. M., [4] manufactured the master cylinder piston as a composite assembly. This piston has an insert made of metallic, ceramic or high glass filled nylon plastic. The glass filled nylon plastic is molded around this insert to form a complete finished piston. The material of insert should be rigid enough and strong to transmit the longitudinal forces to which the piston is experienced without change in shape and wear through its lifetime.

Genz O. F., Park E., [5] has following claims,

1) The piston assembly having two body members which have diameter less than the inside diameter of the cylinder. The body members formed a piston which reciprocates inside the cylinder. This movement of piston assembly increases the temperature of oil and piston assembly as well. To compensate the expansion of piston assembly, the materials used for piston body assembly have higher degree of thermal expansion than the cylinder material.
2) These body members have axial grooves on their surface to compensate an “O” ring.
3) Overall, the piston assembly comprises of the packing rings on piston assembly body, compression washer and a threaded nut on piston rod for varying the body members’ diameter and also the axial grooves on the surface. These body members are so formed that they can expand if temperature of oil or piston assembly increases.

III. OBJECTIVE

Objective of the dissertation work is,

1. To find out the stresses in aluminium piston and plastic piston in FEA Software so to design and optimize the plastic piston to reduce the stresses occurred in it.
2. To reduce the weight of piston.

IV. METHODOLOGY

Methodology adopted for design and optimization of piston is as follows,

1. The locally manufactured existing aluminium piston was used for this work.
2. Aluminium piston was laser scanned and raw CAD model converted into a repaired, clean CAD model using Creo 2.0 software.
3. The repaired, clean CAD model was meshed using Hypermesh and to find the stresses in piston, the analysis was done in Abaqus using Aluminium and plastic material properties, the obtained results treated as primary observations.
4. After studying these results, to reduce the stresses, ribs are added on piston and the piston was once again analyzed using plastic material.
5. Polyphenylene Sulfide and Stanyl® materials are used to manufacture the piston.
6. Experimental testing was carried out on Universal Testing Machine to calculate compressive stresses.

V. FORCE REQUIRED TO STOP VEHICLE

[7] To calculate the force required to stop the vehicle, the two wheeler of 150cc capacity is considered of mass 144kg is travelling at 60kmph. To determine 1) kinematic energy it possess. 2) The average braking force to bring it to rest in 30 meters.

where, KE = kinetic energy of vehicle
M = mass of vehicle, kg
U = speed of vehicle, m/s

The work done in bringing the vehicle to rest is given by

$W_D = FS$,

where, W_D = work done, J
F = average braking force, N
S = distance travelled, m

1) Speed of vehicle U = 16.67 m/ sec.

2) $Kinematic\ energy = \frac{1}{2} MU^2$

$\therefore$ Kinematic energy = 20008 J

3) while braking a moving vehicle to a standstill, the work done by the brake drums must equal the initial kinetic energy possessed by the vehicle so that

Work done to stop vehicle = change in vehicle kinetic energy

$\therefore K.E. = W_D$

$\therefore FS = \frac{1}{2} MU^2$

$\therefore$ F = 666.933N

After rounding off the figure to its nearest value, considered it as 670 N.

This value of force was used for applying the stress in CAE.

VI. FINITE ELEMENT ANALYSIS

A. *CAD Model Generation*

The locally manufactured existing aluminium piston was used for this work. The piston was laser scanned on Faro Laser Scanner V4 machine which has least count of 0.040mm and the raw cad model data was saved in “.stl” file format. The raw cad model then imported in Creo CAD software to remove rough edges or repair broken model.

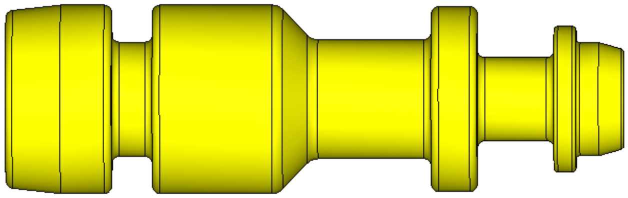


Fig. 2 Repaired CAD model of Aluminium Piston

B. Preprocessing: Meshing

The repaired cad model was saved in ".igs" file format and imported to Hypermesh software for preprocessing. The repaired cad model was cleaned up for unnecessary lines and saved in ".hm" file format and then meshed, shown as below.

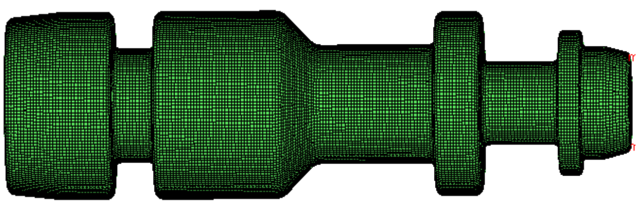
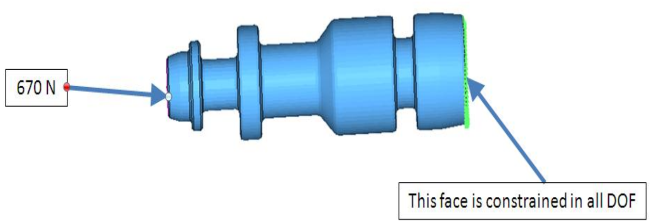


Fig. 3 Meshed Model of Aluminium Piston

C. Boundary Conditions for Stress Calculation

The face of piston where brake lever is rests is called lever face and the other face where spring is rests is called spring face. The meshed model was analyzed in Abaqus. The loading of 670 N was applied on spring face and the lever face was constrained for all Degree of Freedom.



Sr. No	Material	Density (tonnes /mm³)	Tensile Modulus (MPa)	Poisson's Ratio	Tensile Stress at Break (MPa)	Strain at Break (%)
1	Aluminium 6026	2.72E-09	69000	0.33	360	4

Fig. 4 Load Application on Piston

D. Processing and Post Processing

As shown in above Fig. 4, the lever face was constrained for all Degree of Freedom and load of 670N was applied on the spring face. As the piston is made in aluminium, for analysis purpose, the material properties of Aluminium alloy 6026 grade was considered.

Table No. I Aluminium 6026 Material Properties [8]

The FE analysis gives the following results for Stress-Strain in Aluminium 6026,

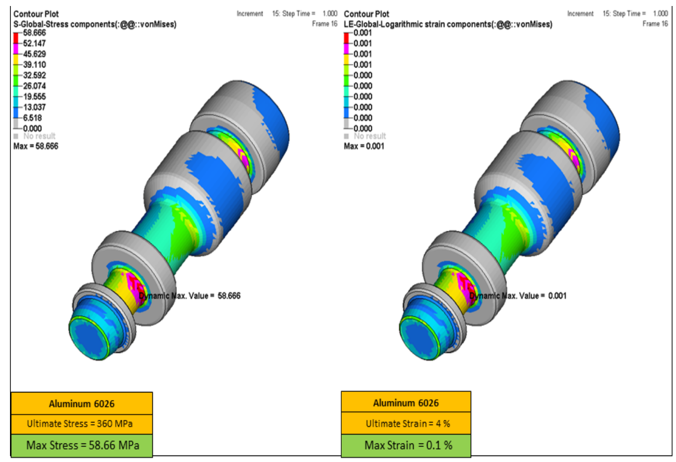


Fig. 5 Stress-Strain in Aluminium 6026

From above Fig. 5, the maximum stress occurred was 58.66 MPa. The plastic material should also bear the stress equal to Aluminium material i.e. 58.66 MPa. To sustain this much stress, the plastic material was selected considering following main criteria's such as,

1) It should chemically inert
2) It should high temperature resistant
3) Hence it should maintain mechanical properties
4) It should wear resistant

Based on above criteria's and after studying various plastic family materials, FORTRON® Polyphenylene Sulfide 1140L4 40% Glass Filled material was selected.

Table No. II Polyphenylene Sulfide 40% Glass Filled Material Properties [9]

Sr. No	Material	Density (tonnes /mm³)	Tensile Modulus (MPa)	Poisson's Ratio	Tensile Stress at Break (MPa)	Strain at Break (%)
1	FORTRON® PPS 1140L4	1.65E-09	14700	0.38	195	1.9

To check the stresses occurred in the piston for comparison purpose and stress reduction, the FE analysis was carried out using plastic material properties as mentioned in above Table No. II. The cad model of Aluminium was used for FE analysis of piston using plastic materials. For piston using Fortron® Polyphenylene Sulfide 1140L4 40% Glass Filled, the Stress-Strain plot is as shown below,

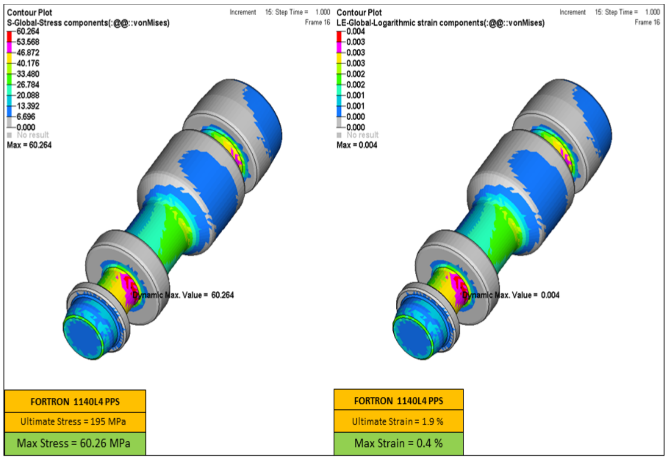


Fig. 6 Stress-Strain in Fortron® PPS 40% GF

As a second material, the DSM Engineering Plastic's patented product called Stanyl® TW241F6 30% Glass Filled was made available by company officials for study purpose. The corresponding properties are as follows,

Table No. III Stanyl® TW241F6 30% Glass Filled Material Properties [10]

Sr. No	Material	Density (tonnes /mm³)	Tensile Modulus (MPa)	Poisson's Ratio	Tensile Stress at Break (MPa)	Strain at Break (%)
1	Stanyl® TW241 F6	1.41E-09	10000	0.37	210	7.5

For piston using Stanyl® TW241F6 30% GF, the Stress-Strain plot is as shown below,

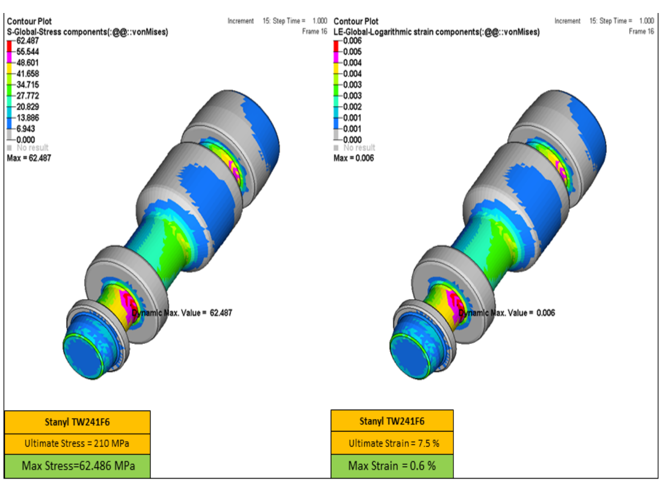


Fig. 7 Stress-Strain in Stanyl® TW241F6 30% GF

E. Comparison of FE Analysis Results for Aluminium, Polyphenylene Sulphide 40% Glass Filled and Stanyl® TW241F6 30% Glass Filled

Table No. IV Comparison of FE Analysis Results for Aluminium 6026 and Polyphenylene Sulphide 40% GF and Stanyl® TW214F6 30% GF

Description	Aluminium 6026	Polyphenylene Sulphide	Stanyl® TW241F6
Force Applied (N)	670	670	670
Overall Displacements (mm)	0.036	0.182	0.285
Ultimate Stress (MPa)	360	195	210
Maximum Stress observed (MPa)	58.666	60.26	62.486
Ultimate Strain (%)	4	1.9	7.5
Maximum Strain observed (%)	0.1	0.4	0.6

From Table No. IV, it is seen that, though Aluminium piston CAD model was used for analysis of piston using plastic properties, the analysis results obtained are 2MPa to 4 MPa higher than aluminium piston results. Though these results are minimum, to increase the strength and hence to reduce the stress in piston, addition of ribs from 3 to 5 numbers are proposed on the diameter of the piston between two slots of "O" rings.

VII. ANALYSIS OF PLASTIC PISTON AFTER ADDITION OF RIBS

A. Fortron® Polyphenylene Sulfide + 40% Glass Filled + 3 Ribs Stress Results

After addition of ribs, the FE analysis was carried out on plastic piston using Fortron® Polyphenylene Sulfide 1140L4 + 40% Glass Filled material in Abaqus. The Stress-Strain results are as follows,

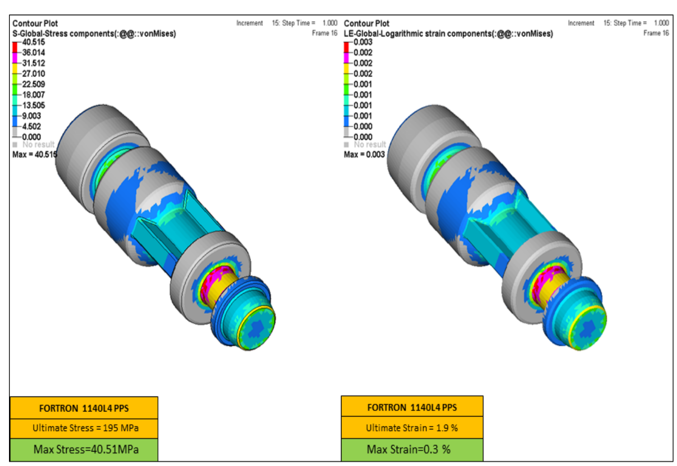


Fig. 8 Stress-Strain in Fortron® PPS 40% GF with 3 Ribs

B. Fortron® Polyphenylene Sulfide + 40% Glass Filled + 5 Ribs Stress Results

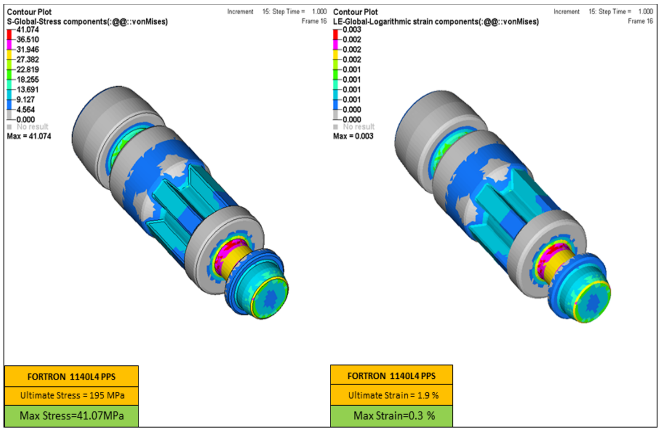


Fig. 9 Stress-Strain in Fortron® PPS 40% GF with 5 Ribs

C. Stanyl® TW241F6 30% Glass Filled+3 Ribs Stress Result

After addition of ribs on piston, the FE analysis was carried out on plastic piston using Stanyl® TW241F6 + 30% Glass Filled material in Abaqus, results are as follows,

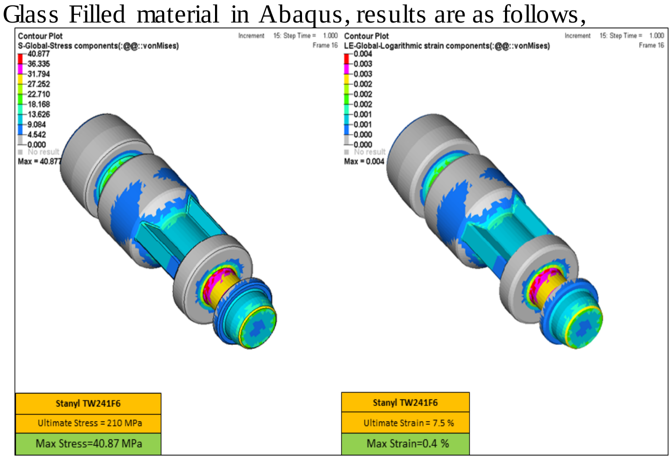


Fig. 10 Stress-Strain in Stanyl® TW241F6 30% GF with 3 Ribs

D. Stanyl® TW241F6 30% Glass Filled+5 Ribs Stress Result

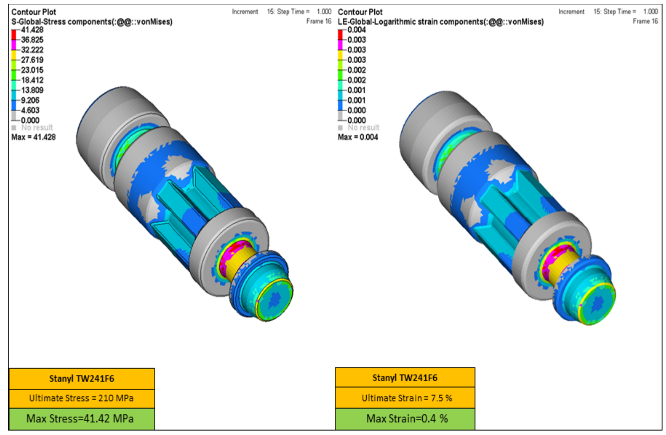


Fig. 11 Stress-Strain in Stanyl® TW241F6 30% GF with 5 Ribs

E. Comparison of FE Analysis Results for Aluminium 6026, Polyphenylene Sulphide 40% Glass Filled and Stanyl® TW241F6 30% Glass Filled with Ribs

Table No. V Comparison of FE Analysis Results for Aluminium 6026 and Polyphenylene Sulphide 40% GF and Stanyl® TW214F6 30% GF

DESCRIPTION	ALUMINIUM 6026	PPS 40% GF WITHOUT RIBS	PPS 40% GF WITH 3 RIBS	PPS 40% GF WITH 5 RIBS	STANYL® TW241F6 30% GF WITHOUT RIBS	STANYL® TW241F6 30% GF WITH 3 RIBS	STANYL® TW241F6 30% GF WITH 5 RIBS
FORCE APPLIED (N)	670	670	670	670	670	670	670
ULTIMATE STRESS (MPa)	360	195	195	195	210	210	210
MAX. STRESS OBSERVED (MPa)	58.667	60.26	40.51	41.07	62.486	40.87	41.42
ULTIMATE STRAIN (%)	4	1.9	1.9	1.9	7.5	7.5	7.5
MAX. STRAIN OBSERVED (%)	0.1	0.4	0.3	0.3	0.6	0.4	0.4

VIII. MANUFACTURING OF PISTON

The manufacturing of piston was carried out through machining route. The two materials was available for manufacturing, the Polyphenylene Sulfide 40% Glass Filled comes in granules and it was melted and moulded in a solid bar of dimension Ø16mm x L70mm. The second material was Stanyl® TW241F6 30% Glass Filled was in disc shape and cuts into round bar and both materials were machined in rod shape to manufacture through machining route. The first profile was machined on Computerized Numerical Control machine and then proposed ribs are cuts on Vertical Milling Center. The last machining operation for remaining part was done on Computerized Numerical Control machine.

During manufacturing process, it was found that both plastic materials have air trapped inside the rods, this occurs during molding process of plastic. Due to these air pockets, material becomes porous and reduces strength of material. Also, due to these air pockets, the continuity of material breaks and stress concentration increases and overall strength of the material reduces.

Fig. 12 Manufactured Pistons

IX. EXPERIMENTAL VALIDATIONS

Experimental testing is carried out on Universal Testing Machine to find compressive stresses. The compressive load applied on piston till the piston gets cracked. The loads applied are in Newton (N) unit. The results obtained are as follows,

Table No. VI UTM Compressive Load Results for Pistons

Sr. No.	Sample Identification	Compressive Load (N)	Stress (MPa)
1	PPS + 40% GF 5 RIBS	4067.00	35.96
2	PPS + 40% GF 5 RIBS	4517.80	39.94
3	PPS + 40% GF 3 RIBS	3929.80	34.75
4	PPS + 40% GF 3 RIBS	3322.20	29.37
5	STANYL® + 30% GF 5 RIBS	4047.40	35.78
6	STANYL® + 30% GF 5 RIBS	4459.00	39.42
7	STANYL® + 30% GF 3 RIBS	2557.80	22.61
8	STANYL® + 30% GF 3 RIBS	3381.00	29.90

The Table VI tabulates the compressive load (N) applied and calculated stress (MPa)

Fig. 13 PPS Pistons checked on UTM for Compressive Load till cracking

Fig. 14 Stanyl® Pistons checked on UTM for Compressive Load till cracking

From above images it is seen that pistons get cracked in compressive load exactly as indicated in Abaqus software analysis results.

X. RESULTS & DISCUSSIONS

On Universal Testing Machine, the loads applied on pistons are in Newton (N) unit. To calculate the compressive stresses occurred in pistons these loads require to divide by the cross sectional area of piston. The specimen calculation shown as below,

As per formula for stress,

$$Stress\ (\sigma) = \frac{Load}{Area} \ldots.\ (1)$$

$$Cross\ sectional\ area\ of\ Piston\ = \frac{\pi}{4} \times \left(D^2\right)\ \ldots.\ (2)$$

Table No. VII Comparison of Software results and Experimental results

DESCRIPTION	ULTIMATE STRESS (MPa)	SOFTWARE RESULTS		EXPERIMENTAL RESULTS		DIFFERENCE (SOFTWARE-EXPERIMENTAL) (MPa)	DIFFERENCE PERCENTAGE (%)
		FORCE APPLIED (N)	MAX STRESS OBSERVED (MPa)	FORCE APPLIED (N)	MAX. STRESS OBSERVED (MPa)		
POLYPHENYLENE SULFIDE 40% GF WITH 3 RIBS	195	670	40.51	3929.8	34.747	5.763	14.22
POLYPHENYLENE SULFIDE 40% GF WITH 5 RIBS	195	670	41.07	4067	35.96	5.11	12.44
STANYL TW241F6 30% GF WITH 3 RIBS	210	670	40.87	3381	29.894	10.976	26.85
STANYL TW241F6 30% GF WITH 5 RIBS	210	670	41.42	4459	39.426	1.994	4.81

To find the area of piston, the overall diameter of piston was considered as 12 mm.

$$\therefore Cross\ sectional\ area\ of\ piston\ = \frac{\pi}{4} \times (12^2)$$

$$= 113.097\ \text{mm}^2$$

By using equation number (1) and (2), the values for stresses was derived and tabulated as below,

A. *Comparison of Software result and Experimental result*

The below results show that the difference between software results & experimental results are from 5% to 27%.

B. *Weight Comparison and Reduction*

The weight of aluminium piston and plastic pistons have taken on weighing machine, as follows,

Table No. VIII Weight Comparison of Aluminium, Polyphenylene Sulfide 40% GF and Stanyl® TW241F6 30% GF Pistons

Piston	Weight (gm)	Weight Reduction (%)
Aluminium	6.900	-
PPS with 3 Ribs	4.510	34.637
PPS with 5 Ribs	4.550	34.057
Stanyl® with 3 Ribs	3.750	45.652
Stanyl® with 5 Ribs	3.820	44.637

From above table, it is seen that the weight of plastic pistons are reduced by 34.057% to 45.652%.

XI. CONCLUSIONS

In this dissertation work the analysis of pistons for stresses, design and optimization of plastic piston is presented. During this work following conclusions are made,

1. After addition of ribs on piston the FE analysis result shows the reductions in stresses by 31% to 34%. The experimental result for stresses deviates from software results by 5% to 27% which can be controlled.
2. The weight of plastic piston is reduced by 34.63% to 45.65% as compared to Aluminium piston.

XII. FUTURE SCOPE

3. As these pistons are manufactured through machining route, it has inherent characteristics of machining operations. To achieve high accuracy in producing piston the precision mould can be used, which is suitable for mass production and for commercial purpose.
4. The durability testing of these pistons can be done on test rig or on vehicle in actual condition. The fatigue, wear and tear, performance can be studied using these pistons.

ACKNOWLEDGMENT

It gives me great pleasure to present a paper on 'Design and Optimization of Piston for Two Wheeler Disc Brake Master Cylinder using Plastic Material'. In presenting this paper, number of hands helped me directly and indirectly. Therefore it becomes my duty to express my gratitude towards them.

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