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Design and Analysis of Fixed Brake Caliper using Additive Manufacturing

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Abstract: ***The brake caliper's function is to channel the mechanical force generated by the driver's mechanical action on the brake master cylinder—pressurized fluid—into an outward force that may be directed to the car's brake rotors. The effectiveness of the brakes plays a significant role in a vehicle's performance, and the design of the caliper may be improved by taking into account elements like the bleeding port, the brake pads, and the fluid flow path.***
As two-wheeler calipers are often used in automobiles, the entire system must be dismantled, bled, and then reassembled involved halves.
Custom calipers have been employed by commercial automakers to cut back on the extra work involved in developing and producing RH and LH calipers. This project aims of this project are to create, evaluate, and maybe construct a front brake caliper prototype for the Formula Student cars.
The desired outcome would be for the brake caliper to outperform all of the "firms" and set us apart from the other competing teams. Additive manufacturing is a new and rapidly developing manufacturing method. The current manufacturing processes for brake calipers separate components assembler.
But the major issue with this method is increased failure points. Additive manufacturing allows manufacturing these complex components in a single structure without compromising structural integrity.
Keywords: Automobile, Brake Caliper, 3D Printing, Solid Modelling, Finite Element Analysis, Internal Routing

I. INTRODUCTION

Project design may be roughly classified into two areas. Analysis and design of the fixed brake caliper. Review of the Brake Disc Rotor By applying pressure to a brake disc with a pair of calipers to force brake pads against it, the disc brake is a form of wheel brake that employs friction to limit wheel rotation. A disc that is connected to the wheel hub and a stationary housing called a caliper together make up a disc brake.

Repair centers may replace the discs in response to any disc issue. This is typically done when the price of a new disc is cheaper than the expense of hiring people to resurface the previous disc.

This is mechanically superfluous, rendering the discs dangerous to use, unless the vane has corroded, or the discs have reached the minimum acceptable thickness specified by the manufacturer. Determining the right design and analysis of the brake disc rotor by us is therefore crucial.

The axle casing or stub axle, or another permanent component of the car, is where the caliper is fastened. Between each piston is a friction pad, and other mechanisms such as retention pins, spring plates, and other devices hold the disc in place. The caliper has passageways that allow fluid to enter and exit each housing.

To prevent bleeding, the channels are also connected. Each cylinder has a rubber sealing ring between it and the piston. The piston diameter must be large enough for the calipers' force to outweigh the necessary braking force in order the best braking performance. Furthermore, as we are modifying the caliper to meet our requirements and include new, sophisticated functions, good compatibility with the caliper is necessary.

General fixed brake calipers available in the market have external routing in between the pistons on both sides of the caliper. This method increases the risk of leakages. We have designed a method where we keep internal, through the body of the caliper, without compromising the structural integrity of the caliper. This reduces the complexity of the components and also the performance remains up to the mark.

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II. METHODOLOGY/EXPERIMENTAL

A. *Synthesis/Algorithm/Design/Method*

As this is a fixed caliper with two pistons are 3 main aspects taken into consideration while deciding the design parameters.

1) *Appropriate Pressure is Generated in the Caliper*

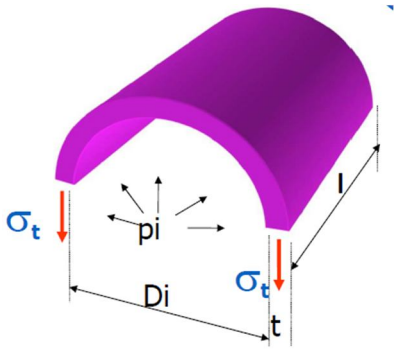
A hydraulic braking system becomes effective after a certain force is being been applied to the disc by the brake pads. The brake caliper produces this force by generating enough pressure in the hydraulic system.

When the driver presses the brake pedal, pressure is developed in the master cylinder. As the entire hydraulic circuit is filled with hydraulic fluid, the pressure is the circuit same throughout. This means for a fixed force from the driver we can amplify the force by adjusting the diameter of the ports in the master cylinder and brake caliper as pressure is directly proportional to force and inversely to the area it is acting on.

2) *Wall Thickness*

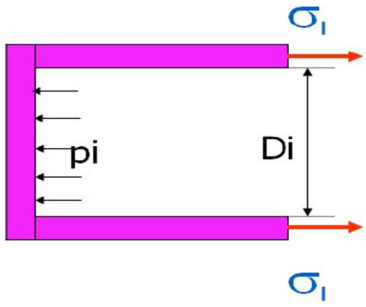
The pressure developed in the caliper pistons is considerably high, as the force required is also high. This means that the wall of the pistons should be strong so that the walls do not deform, which will make the seals fail or even the structural strength might be affected resulting in the fracturing of components. The wall thickness is calculated using 'Hoop Stress' and 'Longitudinal Stress'. The thickness was kept according to design and then validate according to the ultimate tensile strength of the material.

$\sigma_t = \frac{pi*Di}{2*t}$



a. Hoop Stress

$\sigma_l = \frac{pi*Di}{4*t}$



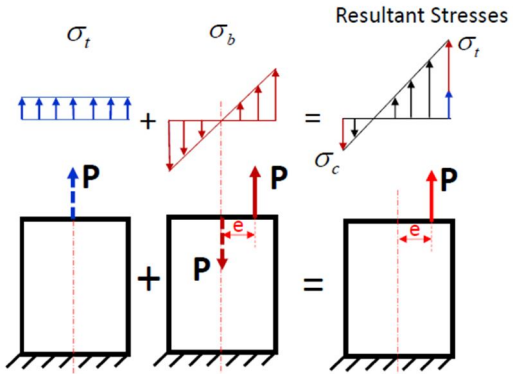
b. Longitudinal Stress

3) *Thickness of Connecting body Between both Sides*

The pads are applying force to the discs and apply equal and opposite normal force to the pads and in turn on the caliper. The disc and caliper don't have any freedom of movement in the direction of the force. This means that force develops stress in the body of the caliper. The connecting body on both sides of the caliper restricts the motion of the caliper body in the direction of force; hence, stress is developed there. While deciding design parameters this stress has to be taken into taken consideration. The calculation is done using the concept of stress developed due to eccentric loading. The thickness was decided according to design and then validated according to the material's ultimate tensile strength.

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$$\sigma_t = \frac{P}{A}$$
$$\sigma_b = \frac{(P*e)*y}{I}$$

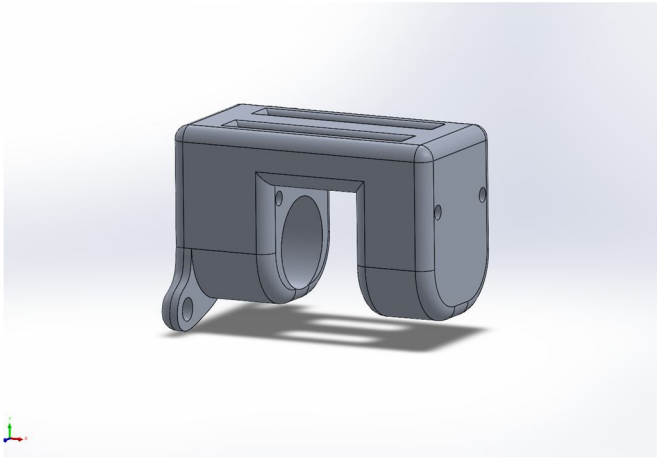


c. Stress due to Eccentric Loading

III. RESULT AND DISCUSSION

A. Lightweight Parts

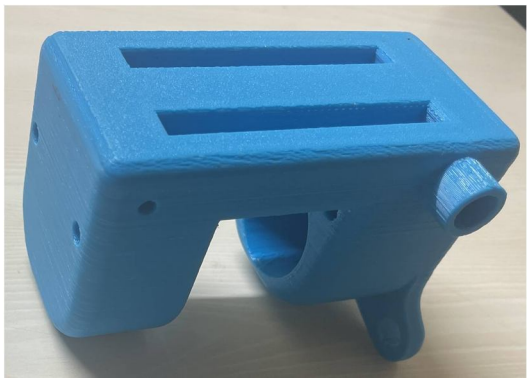
Weight plays a crucial role in whether a race is won or lost. To perform well, sports cars must be relatively light. As a result, the majority of their components are made of aluminum, which is light but relatively strong. Motorsport vehicles can greatly benefit from this aspect of 3D printing. Parts for motorsports can be easily made with 3D printing, and the materials used will keep them light. Lattices, which can be used inside the parts to keep their structure strong while reducing weight, material use, and costs, are an additional solution to that problem. Also, 3D printing allows us to add material wherever necessary only reducing weight due to excess material. The brake caliper design has very little excess material for safety purposes.



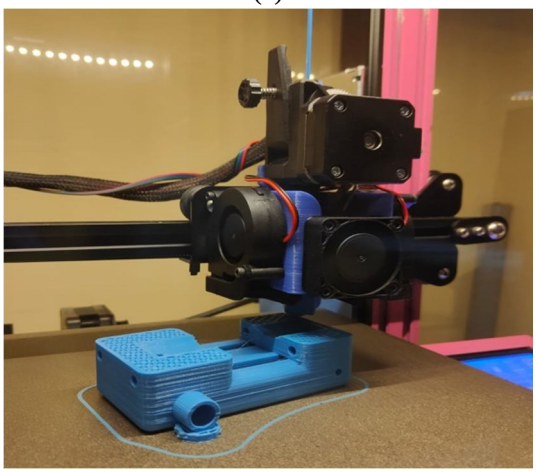
d. Model of the brake caliper. The model has very less excess material.

B. Rapid Prototyping

Vehicles are built out of many parts, which need to be secure and fully functional. To achieve the ultimate form, weight, strength, and resistance, the parts must be tested, and many prototypes are needed to cover all the requirements. Additive Manufacturing is the answer to that. It is cost-effective, rapid, and highly accurate. The prototypes can perform and behave very similarly to the final part allowing tests to provide accurate data and analysis. We designed a brake caliper according to calculations made for Aluminium as the material. But before metal 3D printing a caliper, we printed the brake caliper using ABS in an FDM 3D printer. This model helps verify the feasibility of the model and validate its assembly with other parts of the vehicle so that the final component will have minimum to no errors.



(a)

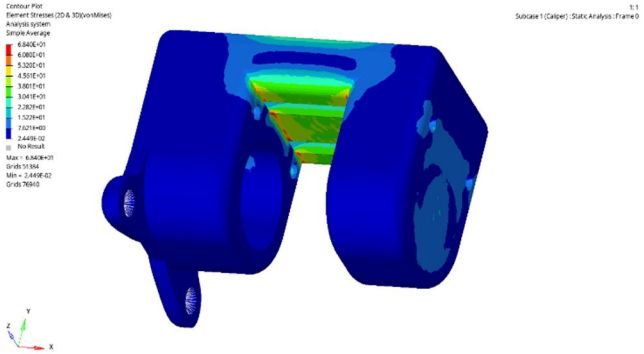


(b)

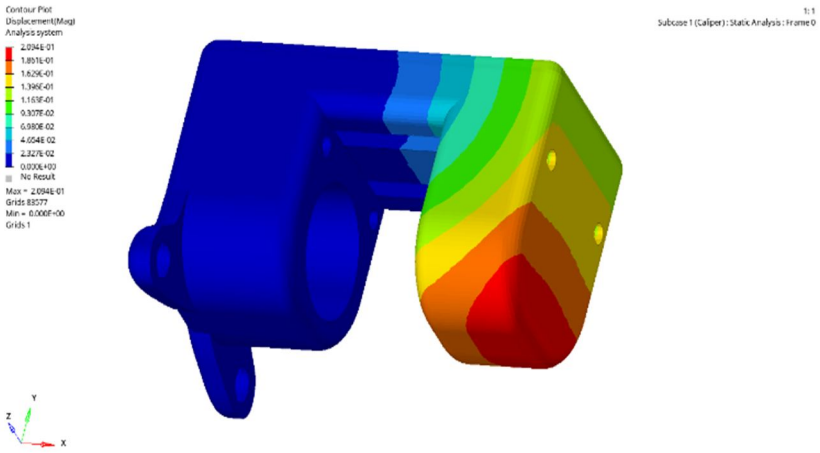
e. Rapid Prototyping of Brake Caliper

C. New Design Freedom

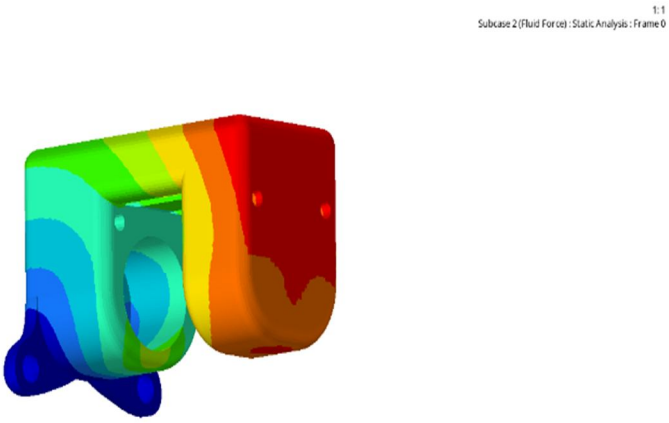
In addition to being cost-effective and quick, 3D printing offers completely novel design options. It makes it possible to quickly modify car parts and create prototypes and gives you a lot of leeways when creating and evaluating brand-new concepts. The speed with which adaptations can be made along with rapid prototyping. In our brake caliper, we included internal routing for the brake fluid from the inlet to the pistons. Then we used Finite Element Analysis (FEA) to validate that the stresses developed can be sustained without affecting the internal routing of the caliper. The material considered for FEA was Aluminium 7075 with a yield strength of 480 MPa. The results show that the maximum stress on the body connecting both sides of the caliper, which has the internal routing going through it, is 68 MPa which is a little different from the physical calculations which were affected due to the approximation of values for making calculations easier. Also, FEA results show only 0.2 mm displacement. These results show that the Factor Of Safety of the component is '7'.



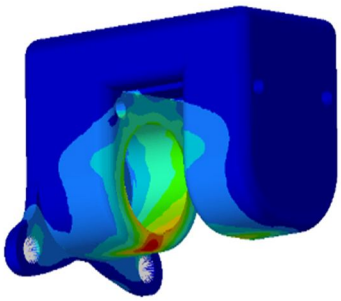
f. Stress Analysis Results



g. Displacement Analysis Results



h. Displacement Analysis of Piston



i. Stress Analysis of Piston

IV. MATH

A. Inputs

Name of quantity	Symbol	Value	Unit
mass	m	170	kg
deceleration in g	a	1.2	
height in C.G	h	0.265	m
wheelbase	b	1.54	m
coefficient of friction(tyre & road)		1.3	
coefficient of friction(pad & disc)		0.45	
radius of tyre(mean)	Rt	0.2286	m
radius of front disc	Rf	0.078	m
radius of rear disc	Rr	0.073	m
pedal ratio	pr	5.89	
initial mass on front	m/2	85	kg
initial mass on rear	m/2	85	kg
acceleration due to gravity	g	9.81	m/s^2
area of M.C piston	aream	0.000191	m^2
area of calliper piston	areac	0.000774	m^2
diameter of caliper piston	dia1	0.0314	m
thickness of wall	t	0.0053	m
area of supporting structure	areaS	554.43	mm^2
I for eccentric loading	I	15309	
distance of force from neutral axis	e	32	mm
distance of neutral axis	Y	9	mm

B. Outputs

Quantity	Value	Unit
normal on 1 tyre	589.1096	N
braking force	2244.508	N
normal on pad	2493.897	N
pressure in fluid	3222179	Pa
force on mc piston	613.9799	N
force on pedal	104.2411	N
force in kg	10.626	kg
Stress(longitudinal)	134.0587	Mpa
Hoop Stress	268.1175	MPa
stress(Ecc.-tensile)	4.498128	MPa
stress(ECC.-bend)	46.91635	MPa

V. FUTURE SCOPE

The brake caliper also has to be able to sustain high temperatures. But the reason for the caliper heating up is due to heat transfer from the brake disc to the caliper through the atmosphere. We can make the design to ensure that the caliper doesn't heat up too much to start deforming by taking some cooling measures in the design. The next goal is to print the caliper using a metal 3D printer.

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VI. CONCLUSION

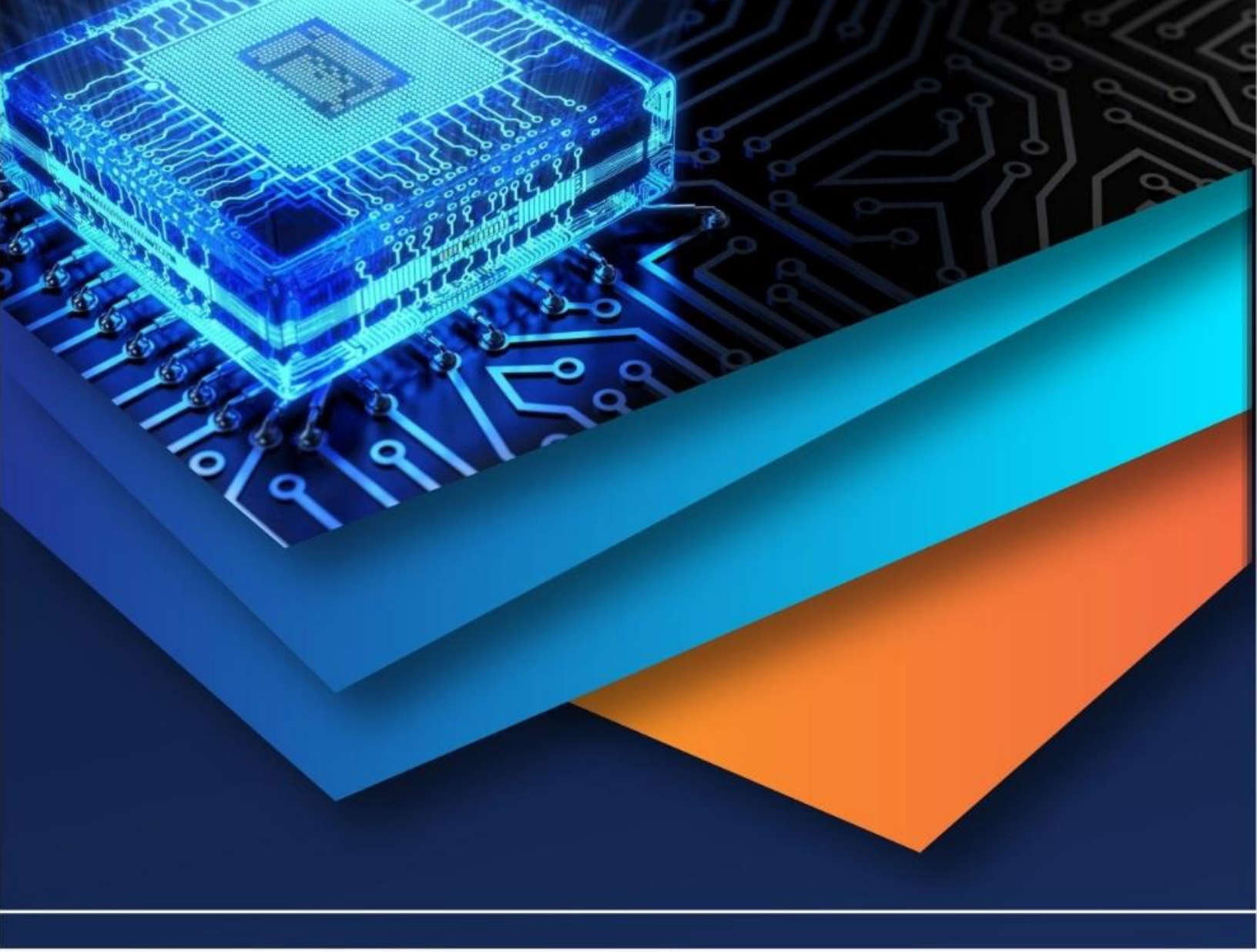
This project aimed to develop a lightweight brake caliper for the motorbike that is not currently commercially accessible by utilizing contemporary additive manufacturing technology. We have encountered several challenges throughout the course of this project, which have necessitated finding alternate solutions to keep moving forward. To do this, we used Solidworks and finite element analysis. Even though everyone involved in this project had a learning curve, we were able to create a brake caliper that satisfied all the specifications. All of the calculations and specifications used to create the design were based on data acquired from motorcycles using well-known characteristics. Overall, we believe that the objective was achieved, and we have created strong foundations for further growth. These results together show that the design is safe, feasible, easy assembly, lightweight, accurate, and easy to manufacture complicated components.

VII. ACKNOWLEDGMENT

We would like to thank 'Peeps Of Blefuscu' for their assistance in rapid prototyping.

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