Fabrication of a Glass Fibre Reinforced Composite Rotor Disc for a bicycle Disc brake

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Abstract. As we move towards more sustainable livelihood there has been a certain increment in the usage of eco-friendly transport medium. Even corporate and non-corporate organisations have started adopting non-pollutant vehicles such as bicycles, solar-powered vehicles etc. As there have been many technological advancements in the recent past even bicycles have been considered a fast and easy medium of transport thereby requiring efficient and effective safety parameters concerning structural and integral stability. As it is known that there has been a constant growth in the study of materials being used for braking applications, depending upon the economic and performance factors many investigations are ongoing in this field. Brakes play a vital role in controlling the speeding vehicles as in today’s bicycles. In order to provide a better efficient and economical braking system for bicycles, a rotor disc made of Glass Fibre Reinforced Composite (GFRC) was studied along with the conventional rotor discs. Upon testing and analysis factors affecting the performance of vehicles such as weight ratio, braking efficiency, durability, impact strength and few other material characteristics were studied for use and fabrication. GFRC was found to be a promising material to be used for the fabrication of rotor disc which is durable, efficient and economical.

Keywords: Glass Fibre Reinforced Composite, Rotor Disc, Disc Brake, Bicycle

1. Introduction

Braking systems are one of the crucial components designed in controlling vehicles momentum. These are extensively required to decelerate and stop the vehicle in a minimum stopping sight distance. These are not just used for decreasing the speed or stopping the vehicle but also provided to keep the vehicle at rest without moving. The braking systems work on the principle of kinetic energy which is converted into heat energy wherein, the heat generated due to the friction is dissipated into the surrounding environment. These brakes are usually categorized into two types based upon their performance and functionality. The first category is considered as the primary or service brakes in the main braking system provided for decelerating and stopping the vehicle which is in motion. The second category consists of secondary or parking brakes which are predominantly used to keep the vehicle intact in a rest position over any inclined or plane surface. The primary brakes further classified into various types based on its working principle as drum type, disc type, hydraulic and air-compressor type. Among all primary brake types, disc type brakes are considered to be one of the most efficient, effective and economical in terms of performance and safety criteria. For light weight vehicles, these type of brakes
is widely adopted. A disc brake usually consists of a circular metal disc which is bolted to a stationary housing over wheel hub called calliper [1]. This calliper is further connected to the vehicle which is rigid and stationary like the axle casing which is cast in two parts each containing a piston. A friction pad is provided between the piston and a circular disc, which retains its position using pins and spring plates. The calliper is drilled with the perforations such that a passage is created for the fluid to enter and leave each housing. These passages are interconnected to allow bleeding. To provide better sealing a rubber ring between each piston and cylinder is provided. The brakes work on the principle of hydraulic forces acted mechanically using pistons such that when brakes are applied due to hydraulic application of pistons, the friction pads make contact with the surface of circular disc applying equal and opposite forces resulting in braking. Similarly, when the braking is released, the rubber sealing rings provided to act as a return spring, which thereby retracts the pistons along with the friction pad away from the circular disc providing free motion. As there is friction generated which is directly proportional to the speed of the vehicle and intensity of braking, a variable amount of heat is generated thereby increasing the temperature across the brakes [2]. This heat generated results in wear and tear and compromises the durability of the braking system. In order to dissipate the excess amount of heat generated investigations were made on various materials, which could absorb and dissipate heat so that the efficiency, durability and performance of disc brakes would enhance. Though the disc brakes provide greater efficiency over its predecessor drum brakes, which are under a closed casing, yet, there is the need of using an effective and economical material in the disc braking system providing optimum outputs. To analyse various materials, many attributes of disc brakes were studied such as geometry, working principle and attrition loading characteristics. Materials were also being analysed for their thermal capacity and heat resistance to provide better heat dissipation. The problem of heat dissipation generally occurred over racing circumstances or fast-moving vehicles which needs sudden braking application. After many investigations, Glass fibre reinforced composite was tested and examined.

Conventionally rotor disc of the disc brakes is made up of cast iron which is very cheap and also carries good resistance towards wear and tear. To overcome corrosion effects even cast steels have been put to use have significant wear and tear resistance. Many more materials like carbon fibres, ceramics, polymers and few others have made a significant impact in the recent advancements in the application of braking systems in the automotive industry. Apart from material characteristics, many investigations over geometrical and structural characteristics have been led. Originally two types of discs were made based upon its structural performance as solid and ventilated type. In order to accompany better heat dissipation and provide a better cooling system by almost 30%, a perforated or ventilated disc was put to often use when compared with a solid disc. As the structural integrity seemed to be reduced due to perforations made, to increase the structural integrity these ventilated discs were made slightly thicker compared to solid discs. Undoubtedly the few ventilated disc showed higher durability with longer pad life yet resulted in few disadvantages like increase in weight.

2. Literature Survey
As per the published literature, several investigations were conducted to evaluate the effect of various materials in manufacturing rotor disc in a disc braking system. V.M.M. Thilak [3] has studied the structural and transient thermal analysis for the rotor disc of disc brake with the usage of various materials which are lighter than cast iron with good yield strength, young’s modulus and better density properties. Prof. Mit Patel [4] has studied the thermo-mechanical behaviour of the rotor disc during the braking phase by determining the deformation and von-misses stress which help in performance enhancement of the rotor disc through FEA. Borse [5] has provided a detailed study of various materials for structural and thermal analysis of a vented disc with cross-drilled holes disc for efficient heat dissipation during faster braking mechanism. S.A.M Da Silva [6] has observed the stress versus load results for both grooved disc brake rotor along with drilled and grooved disc brake rotor which is based on the design parameters of a Brembo brake rotor for a Renault type vehicle and found that grooved disc brake rotor experiences greater stress concentration and displacement. Deepak Kumar Sahu [7] has identified the thermal behaviour of the existing disc brake rotor and modelled a rotor disc configuration which is passionately secure about thermal stress circulation using solid works. Yousef Ali Al Mulla [8]
has presented a study on the effect of rotor disc break condition on the integrity of braking system on GMC Scadia 2008 model, which showed that good condition brake disc rotors has a 10% force difference between right and left brakes, whereas the modified rotor disc mounted rear axles has a force difference of 27% which above the critical values of force, this difference in brake forces leads to the spinning and out of control vehicle may cause a fatal accident. P Shiva Shanker [9] has reviewed on the various braking methods and procedures used in braking systems by analysing various materials in the form of MMC’s and their physical, mechanical and tribological properties compared to conventional materials which are in use for the past few decades. Balaji R [10] has investigated the friction, wear and tribo-characteristics of aluminium matrix composites with Al2O3 as reinforcements, Kevlar-119, carbon-ceramics composites and Ni-Cr-Mo-V steel as the braking materials. And identified the influence on the mechanical properties and tribological behaviour of these materials. Pandya Nakul Amrish [11] has analysed different types of disc brake rotors which are in common usage in the automobile industry and a proposed a new design of brake rotor. A comparative study of existing brake rotors and proposed new design for structural analysis and steady-state thermal analysis using ANSYS software was observed. N.K. Kharate [12] has investigated the disc brake squeal with various materials for disc brake components by developing a finite element model (FEM) to understand the impact on properties of disc brake [13] squeal and validate with experimental modal analysis (EMA), which resulted that braking components has a sustainable role to play in generating the brake squeal.

3. Materials and Methods
A glass fibre reinforced composite is a material which mainly comprises of composites of glass and polymer. A polymer material is reinforced using fine glass particles which are arranged in a complex manner or woven like a mat. Various types of the plastic matrix may be used such as thermosetting plastic, polyester epoxy, vinyl ester or a thermoplastic [14]. Various types of glass fibres with different compositions are available depending upon the mechanical characteristics. The common composites of glass contain silica with varying amounts of magnesium, oxides of calcium and sometimes barium too as shown in Table 1. In the production of glass fibres, a very high rate of a factor of safety is used leaving a marginal and minimal defect.

3.1 Methodology
In order to evaluate a good structural glass fibre and individual glass fibre is tested for tension, durability and resistance against wear and tear which is usually stiff and strong. Generally, the glass fibre is considered to be highly strong in tension and weak in compression. This is due to its ratio of length and width. Due to larger length often the fibre tends to buckle their by leading towards a lower compressive strength. Glass fibres are also considered to be weak in shear across its axis. To increase the compressive strength and shear strength of the glass fibre, they are placed in all orientations at the centroid axis of the glass fibre strands. By providing the glass fibres in different directions the compressive strength can be increased. To prepare a sample for the purpose of testing two strands of glass fibre were taken and were weaved in a mat shape. These Mat structured glass fibres were cut into a circular disk shape, which was used further along with the epoxy resin for casting [15]. Almost seven layers of these glass fibre mats were used in casting. These layers were multiaxial thereby increasing the tensile, compressive and shear strength in the glass fibre along with the epoxy resin. The sample prepared was more a resemblance of lamination as in each glass fibre mat was layered using a thin film of epoxy resin. The glass fibre along with the resin provided a reinforced composite structure which was investigated for enhanced strength and durability. The general properties of E-glass fibre are shown in Table 2.

3.2 Advantages and Disadvantages
A glass fibre reinforced composite acquires rather more advantages with disadvantages.

- Glass fibre is such an element which would instil a higher mechanical strength almost to any product.
Glass fibre is such a material which can be easily moulded into any shape and shall provide higher strength characteristics compared to its geometry and weight. It surpasses many products when compared its ease and ability to transform and perform.

Glass fibre is such an element which will last for a longer time when compared to any other product.

These fibres can also be of any colour providing ease of aesthetics. Apart from these a glass fibre is also an anti-magnetic, insulating, fire resistance, low maintaining and a complete weatherproof element, which could be used in most scenarios.

The primary disadvantage of the glass fibre reinforced Composites is that it needs to be recoated with epoxy if used continuously over five years such that the fibre strands exposed shall not become airborne and cause asthmatic problems.

Glass fibres are not the only components which are strong and stiff. Carbon fibres are considered to be of higher strength and lesser brittle but expensive when compared to the glass fibres.

E-glass is one of the most common types of glass fibres used which comprises of least amount of alkali oxides less than 1% w/w and is made of alumina-borosilicate used for glass-reinforced plastics. It is quite common to use E-glass as the primary reinforcing agent in the plastic matrix. In order to gain optimum strength, the fibres should be laid in a uni-direction which are aligned parallel, straight and are continuous. As such arrangement would not provide strength in other direction, the same phenomena of alignment of fibres in other directions are simultaneously laminated over each other. The properties of fibre can be partially controlled by the process variables such as temperature and drawing/spinning rate. The temperature window that can be used to produce a melt of suitable viscosity is quite larger, making this composition suitable.

E-glass fibre roll was made using fibreglass strands of length not more than 50mm and was bonded together using high compression or an emulsion. Usually, these strands are pressed into definitive alignments to create an E-glass fibre mat. A filament binding technique is most prudently for binding these fibre strands. An E-glass fibre showed many effective characteristics like high mechanical strength, dirt resistance, water resistance, lower water absorption, uniform geometry, lower impurity, low fuss, higher interlocking and capsulation with many more structural benefits. The E-glass fibre mat unit weight ranges between EMC 250- EMC 600 and its width ranging between 600-2540 mm. The mats weight is usually approximately up to 30kgs.

![Industrial E-glass fibre roll](image)

**Figure 1.** Industrial E-glass fibre roll

**Table 1. Component Elements properties**

| Elements | Al₂O₃ | BaO | CaO | MgO | NaO₂ | SiO₂ |
|----------|-------|-----|-----|-----|------|------|
| Metric (%) | 15.2  | 8.0 | 17.2| 4.7 | 0.6  | 54.3 |
Table 2. Properties of E-glass fibre

| Properties                  | Metric                          |
|-----------------------------|---------------------------------|
| Density                     | 2.54 – 2.60 g/cc                |
| Ultimate Tensile strength   | 521 MPa                         |
| Elongation at break         | 4.8%                            |
| Modulus of Elasticity       | 72.4 GPa                        |
| Poisson’s ratio             | 0.2                             |
| Shear modulus               | 30 GPa                          |
| Specific Heat               | 0.810 J/g.-°C                   |
| Thermal Conductivity        | 1.30 W/m-K                      |
| Melting Point               | <= 1725 °C                      |
| Softening Point             | 840.6 °C                        |

*Polyester resin* or GP resin is a thermoset resin. Here an un-accelerated resin is used. A Polyester resin shows promising mechanical properties such as resistance to water, wear and impact load. This un-accelerated resin is known as GP-PA and grade is *espol 15.00*. This resin performs better when laminated and when completely post-cured. The curing time depends upon the quantity of accelerator and catalyst.

![Figure 2. Polyester resin](image-url)
3.3 Fabrication method

A design for rotor disc is modelled in CREO parametric 3D-design software as shown in Figure 5, using reverse engineering technique acquired the required dimensions as follows

| Dimensions               | Metric in mm |
|--------------------------|--------------|
| Outer diameter           | 150          |
| Inner diameter           | 30           |
| Thickness of disc        | 3            |
| Ventilated hole diameter | 5            |
| Number of holes          | 54           |

Fabrication mould is made with the help of cardboard, tress paper as shown in Figure 6 and the fibres are placed in the mould in a layer by layer formation and resin mixture is added in between each layer, such seven layers are formed and then a weight of 100kg is subjected nominally and the whole setup remains unaltered for a time period of 36 hours in order to allow the fibre glass and resin to be hardened. After the hardening process, the prototype is subjected to the machining of ventilated holes and surface finish as shown in Figure 7.
4. Results and Discussions
The fabricated final rotor disc is tested for impact strength on a universal testing machine (UTM) and observations for stress versus strain curve, load versus displacement curve under the loading of 100N are obtained as shown in Figure 8 and Figure 9.
Table 4. Results acquired from the graph

|                          |          |
|--------------------------|----------|
| Maximum force (Fm)       | 6.750 kN |
| Disp. At Fm              | 12.900 mm|
| Max. Disp.               | 13.400 mm|
| c/s Area                 | 201.143 mm$^2$ |
| Tensile strength         | 0.034 kN/mm$^2$ |
| Elongation               | 12.500%  |
| Reduction in Area        | 12.109%  |

Figure 8. Stress versus Strain curve

Figure 9. Load versus Displacement curve

4.1 Practical Application
The GFRC Disc Brake was tested on a Mountain bicycle with 21 gears. It was tested to wear and Tear along with impact. About 1000 Cycles were run to test wear and Tear, which showed optimum Outputs. There was also a greater Heat dissipation observed compared to conventional Discs. The Prototype was firmly attached on the front wheel of the mountain bicycle as shown in Figure 10 and 11.
Figure 10. GFRC Rotor Disc Front View

Figure 10. GFRC Rotor Disc Rear View

5. Conclusions
Fibreglass as the metal matrix composite acquires an immense effect than conventional metals used in the manufacturing process of rotor disc because,

- These are readily available materials with less weight and high durability.
- The fibreglass rotor disc compared to the cast iron metal disc has shown a weight reduction in 75% in wt. manufacturing of fibreglass disc is a much easier process than that of the cast-iron discs.
- Economically it has also shown the cost reduction by 85% to that of cast-iron discs in the market.
- High strength glass fibre composites have also shown promising friction and wear behaviour.
- There has been significantly a better thermal efficiency obtained rather than metallic composites.
- To bring in aesthetic appeal, desired pigments can be used to personalize.
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