Journal of Army Engineering University of PLA
陆军工程大学学报

A REVIEW ON BRAKE DISC MADE OF COMPOSITE MATERIAL FOR A MOTORCYCLE

Mr. Sagar B. Porlekar[a], Dr. Ajit B. Kolekar[b], Mr. Satish B. Kale[c], Mr. Ganesh R. *Shinde*[d]

[a] *Research Scholar, Department of Technology, Shivaji University, Kolhapur, 416012, India.*

[b] *Prof and Coordinator, Mechanical Engineering, Department of Technology, Shivaji University, Kolhapur, 416012, India.*

[c] *Assistant Professor, Department of Technology, Shivaji University, Kolhapur, 416012, India.*

[d] *Assistant Professor, Department of Technology, Shivaji University, Kolhapur, 416012, India.*

Received: 10th August 2023 **Revised: 30th August 2023** **Accepted:20th September 2023**

Abstract

The researchers have done work on disc brakes. This paper contains a survey of academic works that have been written about disc brakes. In order to further reduce weight and improve cooling, an examination of the current disc is carried out, and changes or a new design can be chosen. This includes a review of the literature on alternative materials, the AMC production method, experimental studies of temperature distribution on braking discs, and thermal analysis of discs. Composite materials represent the synthesis of a useful material by combining two or more ingredients on a small scale. In automotive field sizeable numbers of studies are carried out on brake discs of conventional materials. It is found that, Aluminium based metal matrix composite (MMC) is a promising alternative material for improving the performance of brake disc.

***Keywords**: Brake disc, Thermal analysis,* Composite, *motor cycle*

1. Introduction

A set of callipers is used to force brake pads against a brake disc, slowing the rotation of the wheel as a result of the friction that results. Typically composed of cast iron, the brake disc (or rotor in American English) is used to stop a vehicle. The wheel or axle and this are related. By applying mechanical, hydraulic, pneumatic, or electromagnetic force to both sides of the disc, friction material in the form of brake pads placed on a brake calliper is pressed against the disc to stop the wheel. The disc and its connected wheel slow down or come to a stop due to friction. Brake fade [1] is a phenomena where the effectiveness of the brakes decreases as a result of overheating. Brakes work by converting motion to heat.

In the 1890s, England was the birthplace of disc-style brake invention and use. In his Birmingham, United Kingdom, business, Frederick William Lanchester invented the first calliper-type automotive disc brake, which was successfully used to Lanchester vehicles. Disc brakes provide higher stopping performance than drum brakes since the disc can be cooled more easily. A cast iron disc that is connected to the wheel hub and a calliper—a stationary housing—combine to form a disc brake. The calliper is attached to a piece of the vehicle that is permanently fixed, such as the axle casing or the stub axle, which is made up of two separate sections, each of which has a piston. The calliper has openings drilled for the fluid to enter or exit each housing between each piston and the disc. The friction pads between each piston and the disc are maintained in place by holding pins, spring plates, etc. The bleeding channels are also linked to another one. Between the cylinder and piston in each cylinder, there is a rubber-sealing ring [1]. The fig 1.1 shows a schematic diagram of brake disc operation.

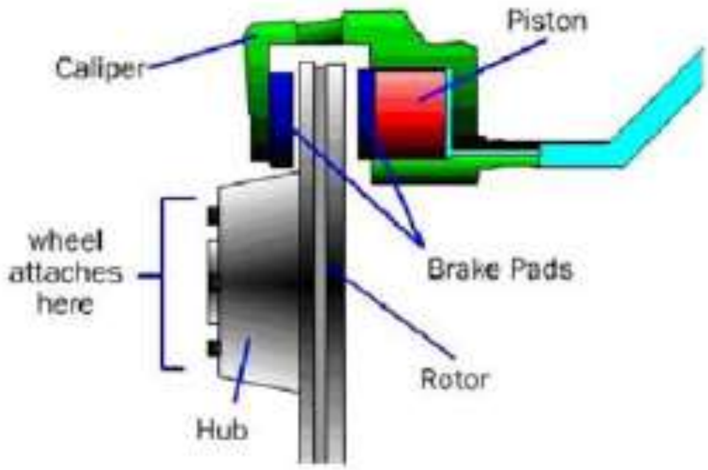

Fig.1.1: Brake Disc Operation [2]

2. Literature Reviewed:-

A detailed literature review is carried out to study work done in the area of brake disc by different researchers to identify the research issues and the findings.

Sachin Thakre et al. [3] provided a thorough analysis of the thermal response of the disc braking system. The literature study highlights the significance of disc brake thermomechanical analysis and the need to minimize the weight of the disc brake rotor in order to optimize disc brake performance. For the majority of their analyses of the thermal, mechanical, and structural behavior of disc brakes, researchers have used finite element analysis.

T.Basava Roopesh and Dr.P.K.Palani [4] found that gray cast iron and cast iron with graphite nodules rotors are often weak, and that most commercial cars on the road favor these disc rotors. Due to less stress, strain, total deformation, and thermal stability, they found that SiC disc rotors with carbon fiber reinforcement performed better than grey cast iron and cast iron with graphite nodules rotors.

Milind K Wasekar & Mohan P Khond [5] reported that composite material, which has several advantages over the current disc brakes, is likely to replace them in the near future, for example, high heat conductivity, strong compressive strength, stiffness, light weight, etc.

Sasikumar C. et al. [6] reported that a disc brake's desired criterion is to have higher thermal conductivity due to the composition ratio of aluminum nitride and boron carbide, reasonable density, an efficient heat transfer rate, and reduced abrasive wear along with acceptable other mechanical features.

Matheus Henrique Pires Miranda et al. [7] found that the temperature has a significant impact on the braking interaction because it directly affects the coefficient of friction between the disc and the pads. Given that the coefficient of friction is inversely related to both velocity and pressure, a reduction in either one makes the device more susceptible to squeaking.

Malyala Sathya Sai Dattu and Shaik Nayeem [8] studied thermo-mechanical analysis that employing grey cast iron in the production of the disk led to a FOS of 1.95. The MOS is 0.95, a measure of requirement verification, which indicates that it may fail with a sudden increase in loads even though the factor of safety is larger than 1, which shows the disk supports the design load. The results of the thermo-mechanical analysis on the Ti-Fe MMC discs, however, indicate that the composite disc with 20% Ti-Fe MMC resulted in FOS of 2.82 and MOS of 1.82, indicating that the design can withstand even a 1.82 times sudden rise in both thermal and mechanical loads compared to the designed loads.

Karthikeyan K et al. [9] suggested that using aluminum metal matrix composite as a substitute for cast iron in automotive applications such as disk brake rotors, brake pads, piston rods, and aircraft materials. AMMC offers a better wear profile and a 22-27% higher friction coefficient than cast iron. In comparison to an equal cast iron component, an AMMC disc may be 55% lighter.

M.Vijaya and K.Srinivas [10] stated that the AA6351/SiC/Gr hybrid composite and AA6351/SiC metal matrix material were successfully manufactured using the liquid metallurgy process with different weight percents of reinforcements. After measuring the density of reinforced Al/SiC and Al/SiC/Gr hybrid composites with various weight fractions, it was discovered that the density rises with SiC and falls with SiC/Gr hybrid particles, making this Al/SiC/Gr hybrid composite an ideal lightweight material for all applications. Additionally, AA6351 reinforced with graphite and 6 weight percent SiC were found to be the best evaluated materials for an experiment, according to the results of numerous specimens.

Ajay Kumar P. and Pradeep Rohatgi [11] researched the development of cast metal matrix composites (MMCs) over a period of 50 years. They demonstrate the property-motivated employment of MMC components today in automobiles, trains, spacecraft, computer hardware, and outdoor leisure gear. Data on the MMC market is provided, including a list of the largest cast MMC producers and their overall production volumes.

Samuel A Awe [12] believes that various factors will influence the future development of automotive brake discs as electric vehicles become more common in society and a number of regulations pertaining to vehicle safety, performance, and particulate matter emissions reduction become increasingly strict. This brief study examines some of the key elements that will influence the design and development of the next brake discs as well as how these parameters will influence the material selection for brake discs in the years to come.

Soundararajan Ranganathan et al. [13] studied that the disc brake was subjected to structural and thermal examination, as well as analysis using a variety of grooves, including square and circular grooves. The square groove disc brake has a lower stress value than the other two versions. Therefore, it is advised that formula vehicles use square-grooved.

K. Vinoth Babu et al. [14] said that the centrifugal casting technology had been effectively used to create the functionally graded Al-SiC composite braking rotor disc. The large volume percentage of SiC particles in the braking zone of the FGM disc results in enhanced hardness and compressive strength.

Ivan Romanov et al. [15] studied MCM of the Al-Si alloying system, which provides superior wear resistance thanks to silicon contents of roughly 7–10% and Al_2O_3 of 20–25%. MCM of the Al-Si alloying system with an Al_2O_3 composition of around 20–25% and a silicon content of 7–10%. More wear resistance is guaranteed by this alloy.

Pankaj Pathak and K.K. Jain [16] investigated several disc rotor profile shapes and discovered that the three-star form produces superior outcomes in comparison to the others. It also indicates that for the two materials, gray cast iron and steel, 3-Star shapes result in the least amount of stress on the disc rotor. Thermal research of several profile shapes on a disc rotor reveals that the optimum heat dissipation occurs when all three profiles are provided and arranged diagonally.

Jiguang Chen and Fei Gao [17] used FEM to study the homogenous distribution of thermal loads and the distribution of temperature gradients in the brake disc. In this work, thermo-mechanical behavior, nonlinear deceleration rate, and theoretically predefined train deceleration rate are disclosed by applying moment of inertia to replicate the actual braking process. By comparing grouped brake applications that adhere to the UIC regulation, parametric analysis for disc brakes has been done. The primary reason of the high temperature gradient and thermal stress.

R. S. Kajabe et al. [18] investigated heat analysis using a real-world Bajaj Pulsar 150 motorcycle disc brake rotor replica as well as disc brake rotors with various slot shapes from various other vehicles. Because of this, it provides optimal stress, deformation, and weight of the redesigned disc brake rotor as well as effective heat dissipation. New disc brake rotors are put into place based on the weight criteria.

Swapnil R. Abhang and D. P. Bhaskar [19] studied the disc brake rotor from a Bajaj Pulsar 150 motorbike and disc brake rotors with varying slot shapes from other cars were used to do heat analysis. As a result, the revised disc brake rotor experiences the least amount of stress, deformation, and weight possible while still effectively dissipating heat. Based on the weight criterion, new disc brake rotors are installed.

A.K.Matta et al. [20] have investigated how heat stresses affect brake rotors. A motor, a non-contact infrared thermometer, brake pads, and an internally ventilated cross-drilled disc are all detailed under the primary equipment. The brake rotor's thermal loads and static strength are analyzed using the finite element method (FEM). It is shown that static strength and thermal stresses are reliable. Three design concepts are shown for the disc with a 120 mm outer diameter and an interior diameter of 80 mm. The disc with internal ventilation and cross drilling is chosen after comparison. The FEM is useful for intersecting thermal stresses, static strength, and deformation. The findings demonstrate that the disc's deformation, which results in ineffective braking, is mostly caused by the disc's temperature. Despite the fact that the actual experimental readings were 0.0 mm and 82.60 0C, the estimated deformation is less than 0.0005 mm, and the maximum temperature is 82.94 0C. The cross-drilled disc with internal ventilation perfectly satisfies the design specifications.

Manjunath T V et al. [21] have studied how the dry brake disc contact behaves thermomechanically when the brakes are applied. In order to improve the functionality of the rotor disc, the coupled thermal-structural analysis is performed to calculate the Von Mises stress and deformation established in the disc for both solid and ventilated discs made of two distinct materials. All values derived from the analysis are smaller than their permitted values when analytical and FEM findings are compared. As a result, the best possible design, material, and rotor disc are recommended based on the performance, strength, and stiffness parameters.

Prem Shankar Sahu et al. [22] have reviewed the available literature on the fundamental fabrication methods for aluminum-based MMCs and recommended the least expensive approach for scientific and technological purposes.

Kashish Goyal et al. [23] have researched the different manufacturing methods for AMCs and their uses. The summary of the study includes a description of the microstructure, a change in the material's characteristics, as well as intrinsic and extrinsic impacts.

C.Saravanan et al. [24] have examined the general methods for producing reinforced composites, as well as the most recent methods used in the fabrication process. They have also discussed the impact of process variables on the characteristics of aluminum-based MMC.

A.A.Adebisi et al. [25] have provided background information on the historical development and use of metal matrix composite for brake rotors in automobiles. As a case study for the discussion, stir casting is used to analyze the product life cycle. As a consequence of a better knowledge of the mechanics of metal matrix composite, the historical review study showed that progressive advancements in material and processing methods have resulted in less weight, cheaper cost, and greater performance brake rotors. According to the report, stir casting is the most alluring production method in the sector since it is simple to use, environmentally friendly, and most importantly, incredibly cost-effective when compared to other processes. These results can be utilized to develop and produce an effective aluminum matrix composite brake rotor in the future for use in automobiles and other applications.

P. K. Zaware et al. [26] have investigated how an infrared sensor, a non-contact form of sensor, can monitor the temperature of a disc. The Bajaj Pulsar 150's Gray cast iron disc brake rotor undergone heat investigation using ANSYS as the finite element program. The experimental set-up for figuring out the rotor's temperature distribution is offered. To determine the changed form of the rotor, experimental and software findings are compared with one another.

Borchate Sourabh Shivaji et al. [27] have studied how the disc's ability to operate at high temperatures reduces thermal strains. To improve the functionality of the disk brake, it is suggested that weight be reduced and the cooling effect of the disc rotor increased. It includes an experiment designed to ascertain the "Thermal Distribution" of the disk break application. Brake disc surface temperature may be measured using a thermocouple.

D. Murali Mohan Rao et al. [28] studied to measure the heat produced on the revolving disc, using an infrared thermometer. The gray cast iron brake disc's structural and thermal analyses are performed using an experimental setup and the ANSYS program.

Karthik Ravi et al. [29] looked into the creation of an experimental test setup for disk brake temperature analysis. Heat transmission from a revolving disc is crucial for test bench dimensioning, which is calculated using theoretical braking torque evaluation. It describes the creation of brake rotors that may be used to check for hot areas. Temperature was measured using a non-contact temperature measuring equipment, and theoretically possible disc torques were calculated for the test. Hot spots and temperature dispersion in serial testing are given particular attention. Graphs are used to check the test methodology. The goal of this work is to quantify the thermal performance of various brake discs under a variety of operating conditions, such as constant load braking, varied operating speeds, and the establishment of an empirical relation that broadly characterizes the temperature distribution in brake discs. In addition, this study discusses numerous approaches to heat dissipation and problem-solving that involve new materials, altered designs, and heat dissipation.

Yathish K.O. et al. [30] investigated the disc brake's effectiveness for various materials (including cast iron and an aluminum-silic-red mud composite made of 6061 aluminum). Also software tools like ANSYS (14.5) and hypermesh are used to derive the material influence on displacement, stress, contact pressure, contact status, and contact sliding distance of the disc and pad assembly. The pressure employed in the finite element analysis is 2.5 MPa. With the aid of ANSYS software, the analysis is completed. In order to conduct the analysis, the pressure is delivered to the inner surface of the brake pad while maintaining the position of the bolt holes in all directions of rotation.

Telang A. K. et al. [31] have researched a wide range of materials to provide an increased combination of characteristics. The features that the MMCs can have are also influenced by the matrix microstructure and the reinforcing phase. High modules short fibers, whiskers, or other particles that are used to strengthen matrices result in isotropic materials that are stronger and more rigid. Production costs for this type of composite are lower. In the case of continuous fibers or whiskers with a high aspect ratio [length/diameter], the matrix functions to hold the fibers together while aligning them in the proper stress direction and transferring the applied load to the fibers. The effectiveness of the matrix in transmitting the load to the reinforcing fibers determines the mechanical characteristics of the composites, which is why the interfacial bonding between the fiber and matrix is important. Stronger and stiffer than other composite materials, these ones. However, they cost a lot of money and are not isotropic by nature. The most extensively researched MMC matrix is made up of aluminum and its alloys. Numerous studies have been done on the characteristics of AMCs, and they seem to have a lot to offer.

Suraj S. Rana et at. [32] have studied the combined dry contact thermomechanical behavior of the brake disc and pad under braking. The optimal material is established using transient thermal structural analysis carried out in ABAQUS/CAE 6.12 while taking into account five different brake disc materials, associated temperatures, shear and von-mises stresses, and contact pressure values. When compared to specialist literature, the simulation results were adequate.

G. Shaikshavali et al. [33] have studied the use of ceramic materials as SiC, Al_2O_3, B_4C, and TiB_2 as reinforcement for MMCs. The primary matrix material is Al6061. In this work, stir casting technology is employed to manufacture metal matrix composites utilizing various ceramic reinforcements and Al6061 material. It is possible to create four distinct MMCs with 10% SiC, 10% Al_2O_3, 10% B_4C, and 10% TiB_2. By performing hardness tests, tensile tests, and impact tests, the mechanical characteristics of the produced cast composites of Al6061-10% SiC, 10% Al2O3, 10% B_4C, and 10% TiB_2 are investigated. To describe the various composite materials, the acquired data were contrasted and visually displayed.

Rajeshkumar Gangaram Bhandare et al. [34] have studied the production of composite materials using SiC, Al_2O_3, and graphite particles to strengthen aluminum alloy. This procedure of stir casting ensures the wetability of all of these materials. For its mechanical, metallurgical, and tribological qualities, the constructed composite material is put to the test. Compared to the basic matrix Al alloy, the characteristics of the material after fabrication are significantly better.

Lemi Abebe et al. [35] have studied the brake disc's temperature and the distribution of thermal stress using analytical and finite element analysis. For this, cast iron, maraging steel, aluminum metal matrix composites, and e-glass were chosen among four other materials. Calculations of characteristics including braking torque, heat flux, and single stop temperature were made using the vehicle specs. Using an analytical approach and finite element analysis, the maximum temperatures for all the materials were computed. With the use of analytical and finite element analysis, maximum primary stresses were also estimated. Comparing the data, it was discovered that ALMMC experiences less stress and lower temperatures. They concluded that, among the four materials chosen for the brake disc, ALMMC is the most suitable.

3. Conclusion:-

From the literature review following research findings are observed,

3.1 Findings:

i. It is found that AMC (Aluminum Matrix composite) is better than cast iron with respect to coefficient of friction, thermal conductivity, specific gravity and heat dissipation rate.

ii. It is demonstrated that, performance of two different materials of brake disc can be compared for displacement, stress, temperature distribution, contact pressure, contact status by simulation using FEA method.

iii. It has been observed that the brake's effectiveness is influenced by the disc's capacity to dissipate heat. Therefore, the brake disc's rate of cooling affects braking effectiveness. Additionally, it is shown that shorter recovery times from high temperatures are associated with higher cooling rates.

iv. Structural and Thermal analyses are studied with cast iron as brake disc material by using analysis software and experimentally.

From the literature review, following research issues are identified which can be summarized as follows.

3.2 Issues:

i. The brake discs and brake pads that are often used in automobile braking systems are made of grey cast iron, however these kinds of components are only appropriate for braking systems that are subjected to moderate stresses.

ii. In spite of having good mechanical properties, metal matrix composite is not tested and analyzed as a potential brake disc material.
iii. The impact of thermomechanical stress concentration and displacement on the disc brake rotor has to be thoroughly investigated.
iv. Less attention has been paid to the brake fade issue of disc brake
v. An elaborate investigation about the various geometric variations of disc brake is required.

4. References:-

[1] Swapnil R. Abhang, D.P.Bhaskar. Design and Analysis of Disc Brake. 2014, 165-167.
[2] Sagar Khivsara, Rucha Bapat, Nikhil Lele, Ameya Choudhari, Mahesh Chopade. Thermal analysis and optimisation of a ventilated disk brake rotor using CFD techniques. 2015, 59-64.
[3] Sachin Thakre, Dr. Achal Shahare and Dr. G. K. Awari. Investigation of Thermal Response of Disc Brake System: A Review. IOP Conference Series: Materials Science and Engineering, 2021, 1-11.
[4] T.Basava Roopesh and Dr.P.K.Palani. Design Analysis and Optimisation of Brake Disc Made of Carbon Fiber Composite. ISSN: 2395-0072, Volume: 08 Issue: 06, 1149-1155, 2021
[5] Milind K Wasekar and Mohan P Khond. A Composite Material an alternative for manufacturing of Automotive Disc Brake: A Review. IOP Conference Series: Materials Science and Engineering, 2021, 1-8
[6] Sasikumar C. , Prakash Kanna G. , Sundaresan R. , Ramakrishnan A. Experimental analysis of Al-AlN-B4C hybrid composite material for automobile disk brake. Materials Today: Proceedings 45, 2021, 3674–3677
[7] Matheus Henrique Pires Miranda, Rômulo do Nascimento Rodrigues, Roberto de Araújo Bezerra, Pierre Maurice Christophe Lamary, Raimundo Arrais de Oliveira Neto. Numerical investigation of material properties and operating parameters effects in generating motorcycle break squeal using the finite element method. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 2020, 1-16
[8] Malyala Sathya Sai Dattu and Shaik Nayeem. Composite Disc Brake Design and Analysis. Mukt Shabd Journal**,** ISSN NO: 2347-3150, 2020, 1292-1303.
[9] Karthikeyan K, Naga Chandrika K K, Deepan Raj kumar A, Thiagarajan S, Vishnukumar V. Research on Mechanical Behavior of AMMC (Al-SiC) Composite in Disc Brake. ISSN: 2249 – 8958, Volume-8, Issue-6S3, September 2019
[10] M. Vijayaa, K. Srinivasb and N.B. Prakash Tiruveedulac. Study of Tribological Behaviour of AA6351/SiC/Gr Hybrid Metal Matrix Composite using Taguchi Technique. Int. J. Vehicle Structures & Systems, ISSN: 0975-3060, 2019

[11] Ajay Kumar P. and Pradeep Rohatgi. 50 Years of Foundry-Produced Metal Matrix Composites and Future Opportunities. International Journal of Metal casting, ISSN 1939-5981, 1-24, 2019
[12] Samuel A Awe, Developing Material Requirements for Automotive Brake Disc. Modern Concepts in Material Science, ISSN: 2692-5397, Vol-2,1-4, 2019
[13] Soundararajan Ranganathan, Sathishkumar Kuppuraj, and Shanthosh Gopal. A New Appraisal of the Thermomechanical Behaviour of a Hybrid Composite Brake Disc in a Formula Vehicle. SAE Technical Paper, 2019, 2-8
[14] K. Vinoth Babu , S. Marichamy , P. Ganesan , D. Madan , M. Uthayakumar , T.P.D. Rajan. Processing of functionally graded aluminum composite brake disc and machining parameters optimization. Materials Today: Proceedings. 21, 2019.
[15] Ivan Romanov , Evgeny Chernyshov, Alexey Romanov. Assessment of the possibility for substituting cast iron in vehicle brake disc with Aluminum-Based Metal-matrix composite material produced by internal oxidation. Materials Today: Proceedings, VL-19, 2019
[16] Pankaj Pathak , Asst. Prof Anshul Choudhary, Prof. K.K. Jain. Structure & Thermal Analysis of Disk Plate For Two Wheeler Automotive Front Disk Brake. ISSN: 2277-9655, 315-327,2017
[17] Jiguang Chen, Fei Gao. Thermo-Mechanical Simulation of Brake Disc Frictional Character by Moment of Inertia. 2013, 227-232
[18] R. S. Kajabe, R.R.Navthar. Optimization of Disc Brake Rotor with Modified Shape. International journal of research in aeronautical and mechanical engineering, 2015,52-60.
[19] Swapnil R. Abhang, D.P.Bhaskar. Design and Analysis of Disc Brake. 2014, 165-167.
[20] A.K.Matta, V.Purushottam. Analysis of the novel brake rotor using FEM. 2014, 869-1 to 869-4.
[21] Manjunath T V, Dr Suresh P M. Structural and thermal analysis of rotor disc of disc brake. 2013, 7741-7749.
[22] Prem Shankar Sahu, R. Banchhor. Fabrication methods used to prepare Al metal matrix composites- A review. 2016,123-132.
[23] Kashish Goyal and Karthikeyan Marwaha. Processing and properties of aluminium matrix composites: a short review. 2016,54-59.
[24] C.Saravanan, K Subramanian, D B Sivakumar, M. Sathyanandhan, R Sankara Narayanan. Fabrication of aluminium metal matrix composite –a review. 2015,82-87.
[25] A.A. Adebisi, M.A. Maleque, M.M. Rahman. Metal matrix composite brake rotor: historical development and product life cycle analysis. 2011,471-480.
[26] P.K.Zaware, R.J.Patil, P.R.Sonawane. Design Modification and Optimisation of Disc Brake Rotor. 2014, 1-6
[27] Borchate Sourabh Shivaji, N.S. Hanamapure, Swapnil S. Kulkarni. Design, Analysis And Performance Optimization of Disc Brake. 2014, 25-27
[28] D. Murali Mohan Rao, Dr. C. L. V. R. S. V. Prasad,T. Ramakrishna. Experimental and Simulated Studies on Temperature Distribution for Various Disc Brakes. 2013, 34-40

[29] Karthik Ravi K.M, Qaiser Bashir, Rizwan Ahmad Dar, Yasir Muid Rather. Experimental test rig for surface temperature measurements in disc brakes. 2014,191-195.

[30] Yathish K.O, Arun L.R, Kuldeep B3, Muthanna K.P. Performance Analysis And Material Optimization of Disc Brake Using MMC. 2013, 4101-4108

[31] Telang A K, Rehman A, Dixit G ,Das S. Alternate Materials In Automobile Brake Disc Applications With Emphasis On Al Composites- A Technical Review. 2010, 35-46

[32] Suraj S. Rana, Dr. W.S. Rathod. Coupled thermo-mechanical analysis of an automobile disc brake. 2016,7073-7077.

[33] G.Shaikshavali, Dr. E.Venugopal goud , M.Murali mohan, "Mechanical properties of AL6061 based metal matrix composites reinforced with ceramic particulates and effect of age hardening on its tensile characteristics ",2016,726-731.

[34] Rajeshkumar Gangaram Bhandare, Parshuram M. Sonawane. Preparation of aluminium matrix composite by using stir casting method and its characterization. 2014, 148-155.

[35] Lemi Abebe, Ramesh Babu Nallamothu, K.H.S Subrahmanyam, Seshu Kishan Nallamothu, Anantha Kamal Nallamothu. Thermal analysis of disc brake made of different materials. 2016, 5-9