Investigation of Friction Materials of Brake Pad in Automobile Disk Brake

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Abstract— Nowadays, a composite material is used as replacement of the conventional materials in Automobile industries because of high strength to light weight properties, which reduces the overall vehicle weight without compromising the strength and reliability. Composite materials with higher specific stiffness, low weight, and high damping capacity have greater torque capacity than conventional drive shaft. The advanced composite materials such as carbon and glass with epoxy resin are widely used because of their high specific strength and high specific modulus. The aim of this work is to replace the conventional asbestos brake pad of automobiles with an appropriate carbon/glass composite brake pad. Study also includes the preparation of composite brake pad for overall weight reduction, whereas the conventional asbestos brake pad has lots of issue related to environment. In this approach, optimum designed brake pad finite element model will be prepared in finite element commercial software ABAQUS. The noise, vibration and buckling analysis will be done which are very much essential for friction materials like brake pad Experiment also conducted on instrument to measure the vibration and mechanical properties of composite shaft.

Keywords: Composite Materials, Brake Pad, ABAQUS, Noise

I. Introduction

Automotive brakes are designed to slow and stop a vehicle by transforming kinetic (motion) energy into heat energy. As the brake linings contact the drums/rotors they create friction which produces the heat energy. The intensity of the heat is proportional to the vehicle speed, the weight of the vehicle, and the quickness of the stop. Faster speeds, heavier vehicles, and quicker stops equal more heat. The geometric space available for the brakes in a car is however rather limited and constrained by the dimensions of the wheel, so that new forms of brake design had to be developed and some of these new designs were more susceptible to generate unwanted noises. A typical modern floating caliper disk brake in shown in figure 1.2 in an artist's view. The brake consists of a brake disk, housing, piston, yoke and brake pads [7].

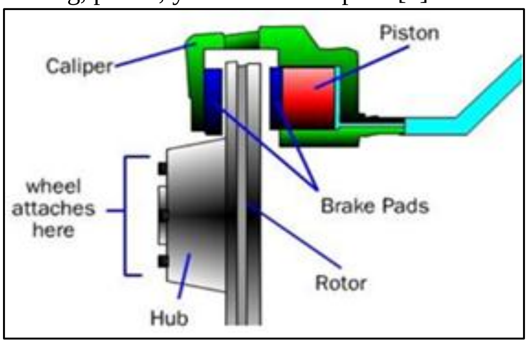


Fig. 1: A typical floating calliper disk brake

A. Brake Pad

A brake pad consists of a friction material which is attached to a stiff back plate. Figure 1.3 shows a brake pad attached to a back plate. Sometimes the friction material and back plate together are called a brake pad. A brake pad usually incorporates slots on its face and chamfers at the ends. Figure 1.4 shows different configurations of pads. A pad can have more than one slot and it could be arranged in different orientations.

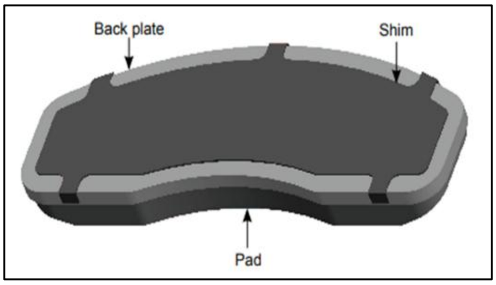


Fig. 2: An assembly of pad, back plate and shim

In the present study, an investigation of disc brake squeal is performed by using the new complex eigenvalue capability of the finite element (FE) software ABAQUS version 6.4. This FE method uses nonlinear static analysis to calculate the friction coupling prior to the complex eigenvalue extraction, as opposed to the direct matrix input approach that requires the user to tailor the friction coupling to stiffness matrix, Thus, the effect of non-uniform contact and other nonlinear effects are incorporated. A systematic analysis is done to investigate the effects of system parameters, such as the hydraulic pressure, the rotational velocity of the disc, the friction coefficient of the contact interactions between the pads and the disc, the stiffness of the disc, and the stiffness of the back plates of the pads, on the disc squeal. The simulations performed in this work present a guideline to reduce the squeal noise of the disc brake system.

II. Literature review

Friction-induced vibrations in automotive disc brakes are of substantial interest for academic research as wells for industry. The numerous customer complaints due to brake noise cause high warranty costs in the automotive industry. To enable silent brakes to be developed, noise, vibration and harshness (NVH) engineers analyze these phenomena using computational and experimental simulations as well as vehicle tests. In the automotive industry, computational simulations have become increasingly important because of shorter product development processes as well as cost reduction necessities.

Conventional materials are replaced by composite materials in so many fields due to their lightweight and easy processing. Nowadays hybrid composite drive shafts are also used in replacement of the steel and aluminum for the preparation of these composites automotive parts. Synthetic fibers mainly carbon, glass, Kevlar have satisfactory strength properties coupled with relatively low cost, recyclability and biodegradability and are being used in automotive industries, construction as well as in packaging industries with few drawbacks. The low density of fibers allows fabrication of composites that gives good mechanical properties with a low specific mass. The increased interest in the use of fiber among researchers and technologist's has been well known. In automotive industry brake squeal has become an important cost factor because of customer dissatisfaction. In North America up to one billion dollars p.a. were spent on noise, vibration and harness (NVH) issues. From the literature it is observed that many researcher and automobile industries are working on reduction of noise and vibration.

S. Oberst and J. C.S. Lai studied the influence of geometrical parameters (namely, the number and location of slots) of brake pads on brake squeal noise. Four different brakes lining geometry were prepared (i) basic configuration without any slot (ii) basic configuration modified with a vertical slot in the mid-surfaces (iii) basic configuration with two slots and (iv) basic configuration with diagonals slot. This study reveals for the first time that severe nonlinearity is directly correlated with brake squeal and could be the reason for bad noise performance.

T. Jearsiripongkul and D. Hochlenert studied the mathematical-mechanical models for studying the brakes dynamics of modern passenger's cars. A simplified model for the dynamics of a floating calliper disk brake is presented. The model includes the brake disk, modelled as a flexible rotating plate, calliper and brake pads. In the model all the prominent features of squeal are reproduced, such as e.g. independence of the frequency on the speed, etc. For a moderately wide frequency range (1-5 kHz) the transverse vibration of the disk plays a significant role in squeal. The pad stiffness and damping coefficient are modelled by distributed nonlinear springs and linear dampers, respectively. The development and laboratory implementation of the active squeal control goes along with a more profound understanding of brake squeal and a better modelling of the phenomena, ultimately leading improvements in the design of disk brakes.

M. Nouby and K. Srinivasan investigated the influence of brake design parameters on brakes squeal. They studied by modifying the various structure of brake pad to reduce the squeal. The finite element method (FEM) is used to simulate and predict the disc brake squeal using a complex eigenvalue analysis. An approach to examine the disc brake squeal based on the complex eigenvalue analysis is proposed in which a positive real part indicates that the corresponding Eigen mode is unstable and in turn squeal may occur. From the several simulations done by complex eigenvalues analysis, it is observed that higher coefficient of friction increases the likelihood of squeal. The squeal can be reduced by decreasing the stiffness of the back plates of the pads. The chamfer provided significant squeal reduction. To explain the effect of slot configurations on squeal, the understanding of the pressure contact distribution between the pad and rotor are required.

L. Rudolf examined the study of fade in conventional disc brakes results from two basic causes. (1) The brake pads overheat, reducing their coefficient of friction which decreases braking ability, and (2) Excessive heat in the brake pads is transferred via the hydraulic pistons to the brake fluid, which boils and produces bubbles in the brake lines. The full circle disc Brake resists these fade inducing causes by: (1) Distributing in-pad heat over a greater area and conducting heat both away from and through the brake pads into the brake body structure to enable more efficient heat dissipation, and (2) isolating the hydraulic cylinder from the brake pads so that direct heat is not transferred to the brake fluid.

III. DESIGN AND ANALYSIS OF BRAKE PAD

Grey cast iron is used for maruti Suzuki ecco passenger vehicle in disk brake rotor applications. The material properties of the grey cast iron is given by the supplier.

A. *Complex Eigenvalue Analysis*

During braking operation, the friction between the brake pad and the disc can induce a dynamic instability in the system. This instability can create noise, commonly known as squeal. In order to study the squeal propensity of the disc brake, a stability analysis is performed on the model, and the unstable modes are equated to a possible squealing occurrence. The governing equation of the system is

$$M\{\ddot{u}\} + C\{\dot{u}\} + K\{u\} = 0$$

Where M, C, and, K are respectively the mass, damping and stiffness matrices. u is the displacement Vector. For friction induced vibration, it's assumed that the forcing function is mainly contributed by the friction force fluctuation between the rotor and friction material, the force vector is linearized as

$$\{F\} = [K_f]\{u\}$$

Where, Kf is the friction stiffness matrix. The governing equation is the obtained by combining

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K - K]\{u\} = \{0\}$$

A complex eigenvalue algorithm is then used to solve this eigenvalue problem in order to obtain eigenvalues and eigenvectors in complex values.

B. *Dynamic, Temperature Displacement Explicit Analysis*

A static analysis is used to determine the displacements, stresses, strains and forces in structures or components caused by loads that do not induce significant inertia and damping effects. A static analysis can however include steady inertia loads such as gravity, spinning and time varying loads.

Disk brake rotor is developed using Creo parametric 4.0 software using exiting dimension of Eecco disk brake rotor as given in table 4.4. All the dimension presented in table 4.4 is measured using vernier calliper. Figure 4.1 and 4.2 shows the 3D model of disk brake rotor and 2D drawing of rotor respectively.

Parameter name	Dimension
Outer diameter of the rotor disc	232 mm
Inner diameter of rotor dics	125 mm
Hole diameter	60 mm
Thickness of rotor disc	17 mm
Calliper piston diameter	44 mm

Mass of disc	4.42 kg

Table 4.4: Dimension of grey cast iron disk brake rotor

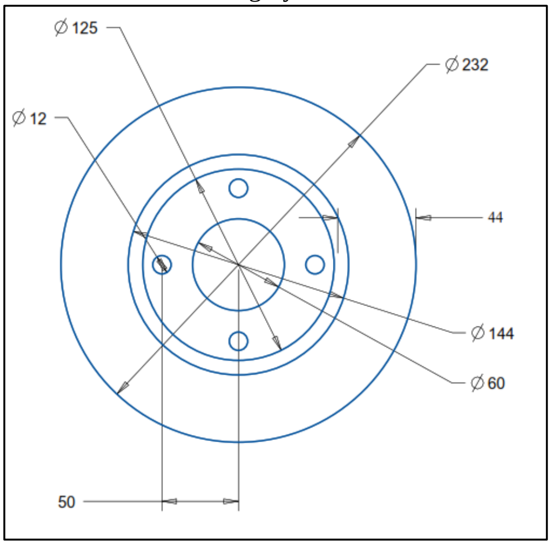


Fig. 3: 2D drawing of disk brake rotor in Creo 4.0

A finite element model of the disc brake is generated using the finite element (FE) software ABAQUS version 6.14. The brake model used in this study consists of the two main components contributing to squeal: the disc and the pad as shown in figure 4.2. The disc has a diameter of 232 mm and a thickness with typical value of 17 mm and is made of grey cast iron. The pair of brake pads, which consist of friction plates and back plates, are pressed against the disc in order to generate a friction torque to slow the disc rotation. The friction materials are made of a kevlar-carbon organic composite friction material and the back plates are made of steel. The Dynamic, temperature displacement explicit analysis has been done on ABAQUS 6.14 software by explicit module as depicted in figure 4.3.

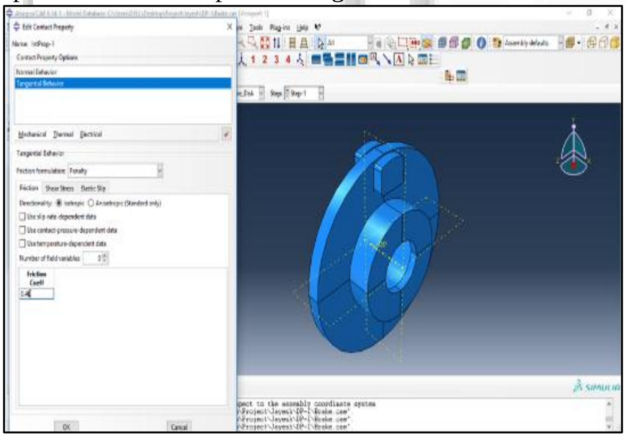


Fig. 4.8: Specifying Material Properties in ANSYS 18.1 Software

In this static step a rotational velocity is imposed on the disc as a predefined field variable. This provides for the modeling of steady-state frictional sliding between two bodies that are moving with different velocities. The imposed velocity of 123.65 rad/s corresponds to braking at low velocity. Figure 4.9 shows the pressure is applied on the pistons and housing in astatic analysis.

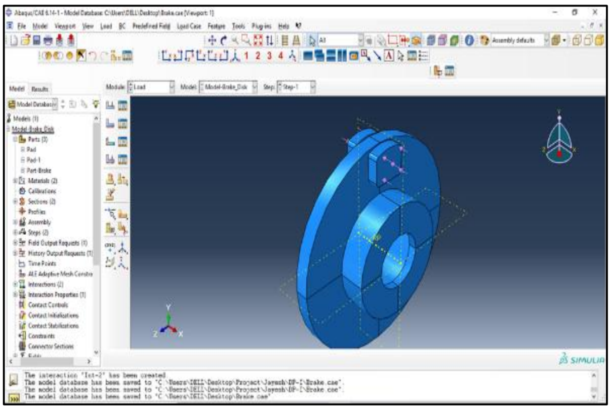


Fig. 4.9: Applying Pressure on Both Side of Brake Pad

In present study following mesh type and size has been selected as demonstrated in figure 4.10. Meshing size is refined at the hole where the disc brake rotor is fixed with wheel. Figure 4.11 shows the load applied on disk and pad respectively.

Type of meshing: - C3D8T

Type of elements: - Hex

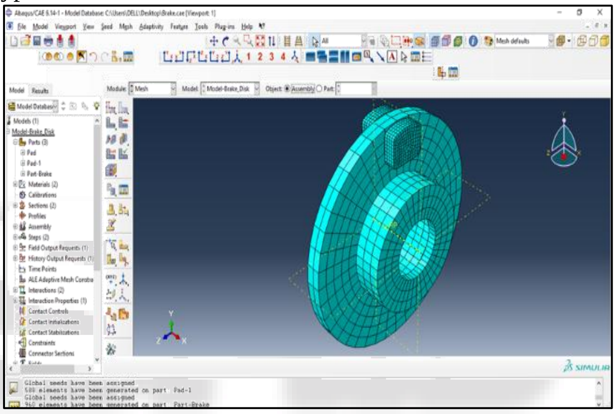
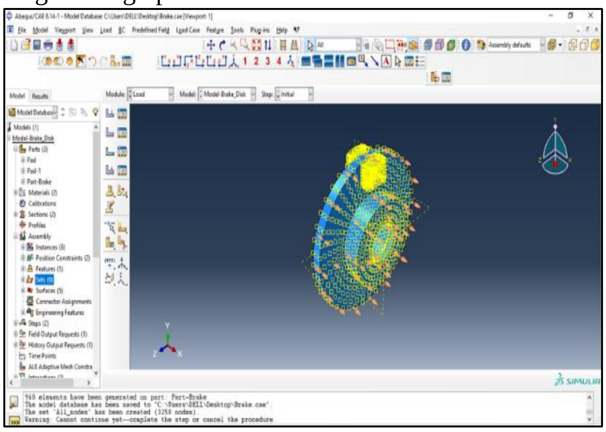


Fig. 4.10: Disc mesh, showing refinement under pad contact area

Maximum load condition for disc brake rotor occurs during applying brake to de acceleration the moving vehicle. The disc brake rotor is connected with wheel by bolts behaves as a fixed body offering zero displacement and withstand during braking operation.



IV. RESULTS AND DISCUSSION

In the present FEA study total temperature distribution, friction dissipation and kinetic energy is considered for evaluating the results. The temperature distribution of the grey cast iron rotor and brake pad is calculated and the values obtained are the maximum temperature is 345 °C m and the minimum temperature is 20 °C as shown in figure 4.12.

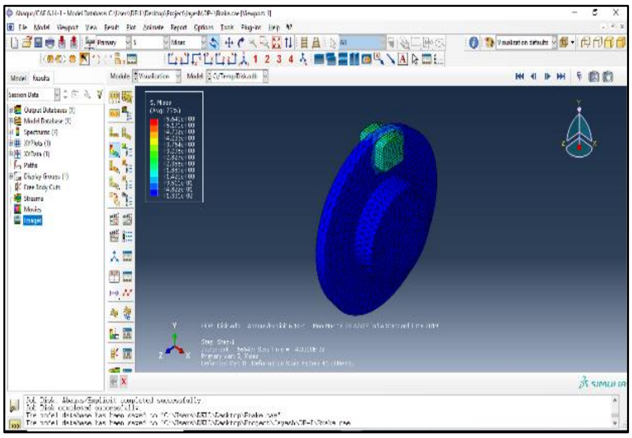


Fig. 4.12: Temperature distribution of grey cast iron rotor disc and pad

The brake is applied for 4.24 second by brake pad with help of hydraulic cylinder pressure on the grey cast iron rotor and vehicle will stop at distance of 141.55 m. The obtained temperature distribution as shown in figure 4.13 due high friction between brake rotor and pad.

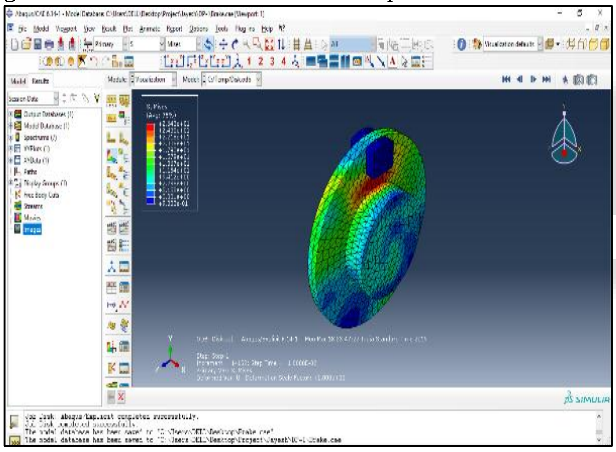


Fig. 4.13: Temperature distribution of grey cast iron rotor disc

As show in figure 4.14, when brake is applied high amount of heat is generated between rotor and brake pad for 4.24 seconds. The generated heat is absorbed by rotor and gradually dissipated in environment.

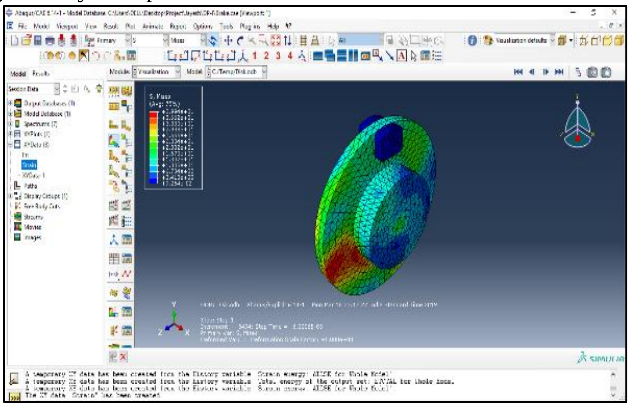


Fig. 4.14: Equivalent elastic stress of grey cast iron rotor disc

The surface pressure distribution on the brake linings after the application of pressure in is shown in figure 4.15 and figure 4.16 The accuracy of the complex mode calculation depends strongly on the accuracy of the surface pressure distribution between the pad and the disc.

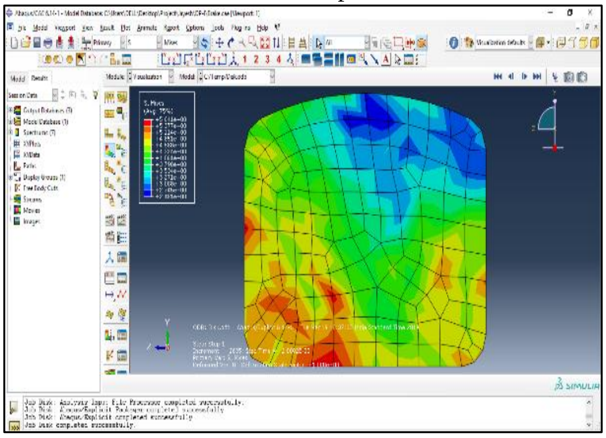


Fig. 4.15: Contact pressure distribution on the inboard lining

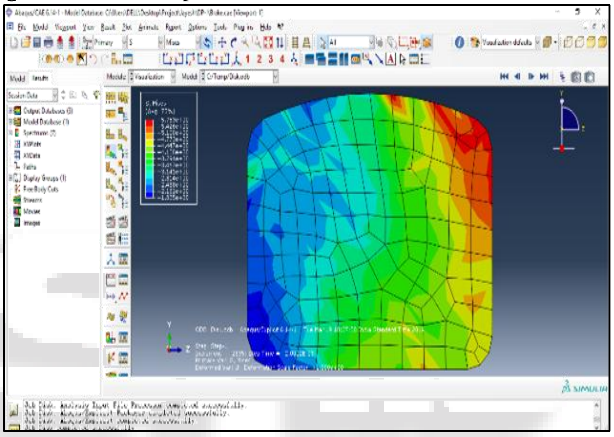


Fig. 4.16: Contact pressure distribution on the inboard lining

V. CONCLUSION

Disk brake squeal based on Friction-induced is investigated using the new function of ABAQUS version 6.4, which combines a nonlinear static analysis and a complex eigenvalue extraction method. The nonlinear effects can be taken into account in the preloading steps in order to more accurately model a deformed configuration at which a complex eigenvalue analysis is performed. The systematic analysis here shows that significant pad bending vibration may be responsible for causing the disc brake squeal and the major squeal frequency is approximately 12 kHz for the present disc brake system. The effects of the friction between the pads and the disc, the stiffness of the disc, and the stiffness of the back plates of the pads, on disc squeal, are significant, but the effects of the hydraulic pressure and the angular velocity of the disc on disc squeal are not obvious. The squeal can be reduced by decreasing the friction coefficient, increasing the stiffness of the disc, using damping material on the back of the pads, and modifying the shape of the brake pads.

References

[1] Chogdu C and Sooick A, “Thermo-Elastic Analysis for Chattering Phenomenon of automotive disk brake”, KSME Inter. J., 2001, 15, 569-579.
[2] Thira J.and Daniel H, “Disk Brake Squeal: Modelling and Active Control”, Diploma Thesis, TU Darmstadt, Institute f¨ur Mecha, 2003.
[3] Introduction to Brake Systems – Study Guide, Melior General Motors Corporation, Service Operations License Agreement, 2004.
[4] Pandya NA, “Computer Aided Design and Analysis of Disc Brake Rotors Advances in Automobile Engineering,” BITS Pilani, Dubai Campus, Dubai International Academic City (DIAC), Dubai, UAE Amrish, Adv Automob Eng, 2016, 5:2.
[5] Swapnil R. Abhang, Bhaskar DP, “Design and Analysis of Disc Brake”, Inter. J. of Engin. Trends and Techn. (IJETT) –4- Feb 2014
[6] Ameer S. and Lakshmi S,“Structural and Thermal Analysis of Disc Brake Without Cross-drilled Rotor Of Race Car”, Inter. J. of Advan. Engg. Rese. and Studies, 2012 , 2249-8974, 39-43
[7] Phillip H. and Nick w. “Materials of brake pads”, https://auto.howstuffworks.com/auto-parts/brakes/brake-types/disc-brake.htm
[8] Ibrahim RA, “Friction-Induced Vibration”, Chatter, Squeal and Chaos Part II, ASME Applied Mechanics Reviews, 47, 1994, 227-259.
[9] Chakraborty G, Jearsiripongkul T, Wagner UV and Hagedorn P,”A New Model for Floating Calliper Disk Brake”, VDI-Tagung Reibung and Schwingungen in Fahrzeugen und Anlagen, Hannover, November 26-27, 2002.
[10] Chowdhary HV, Bajaj AK and Krousgrill CM, “An Analytical Approach to Model Disc Brake System for Squeal Prediction”, Proceedings of ASME DETC 2001, Pittsburgh, September 9-12, 2001.
[11] Ouyang H and Mottershead JE, “Friction-Induced Parametric Resonances in Disc: Effect of A Negative Friction-Velocity Relationship”, J. of Sound and Vibration, 209(2), 1998, 251-264.
[12] Lin SC, Guan CC, Bakar ARA, Jamaluddin MR, M.M.W. Harujan W, and Ghani BA, Disc brake squeal suppression through chamfered and slotted pad. Intern. J. of Vehicle Struc. and Syst., 3(1), 2011, 28–35.
[13] Dai Y and Lim TC, “Suppression of brake squeal noise applying finite element brake and pad model enhanced by spectral-based assurance criteria”, Applied Acoustics, 69(3), 2008,196 – 214.
[14] Ghazaly NM and Faris WF, “Optimal design of a brake pad for squeal noise reduction using response surface methodology”, Inter. J. of Vehicle Noise and Vibration, 8(2), 125–135, 2012.
[15] Eriksson M, Bergman F, and Jacobson S, “On the nature of tribological contact in automotive brakes”, Wear, 252(1-2), 2002, 26–36.
[16] Lee K and Barber JR, “An experimental investigation of frictionally excited thermo elastic instability in automotive disk brakes under a drag brake application”, J. of Tribology, 116(3), 1994, 409–414.
[17] Hiller MB, “Correlation between parameters of the tribosystem and automotive disc brake squeal”, PhD thesis, University of Paderborn, 2006
[18] Matozo L, Menetrier A, and Tamagna A. Analysis of high damping underlayer materials for brake pads and its effects on NVH performance. SAE Technical Paper, pages 01–3223, 2006.
[19] Automotive Disc Brake Manual: The Complete Guide to the Theory and Practice of Automotive Disc Braking Systems. Techbook Series. Haynes, Somerset, 1998.
[20] Matozo L, Menetrier A, and Tamagna A, “Analysis of high damping underlay materials for brake pads and its effects on NVH performance”, SAE Technical Paper, 01–3223, 2006.
[21] Automotive Disc Brake Manual: “The Complete Guide to the Theory and Practice of Automotive Disc Braking Systems”, Tech book Series. Haynes, Somerset, 1998.
[22] Balvedi AM and Gerges SNY, “Squeal noise in disc brakes and the influence of damping on the system dynamic stability”, Acta Acustica united with Acustica, 94(2), 2008, 254–264.
[23] Kinkaid OM, Reilly O and Papadopoulos P, “Automotive disc brake squeal”, J. of Sound and Vibration, 267(1), 2003, 105–166.
[24] Chan D and. Stachowiak GW, “Review of automotive brake friction materials”, Proc. of Inst. of mech. Engin., Part D: J. of Automobile Engin. 218(9), 2004, 953-966.
[25] Hong US, Jung SL, Cho KH, Cho MH, Kim SJ, and Jang H, “Wear mechanism of multiphase friction materials with different phenolic resin matrices wear”, 266 (7-8), 2009, 739- 744.
[26] Fu Z, Suo B, Yun R, Lu Y, Wang H, Qi S, Jang S, Lu Y, and Matejka V, “Development of eco-friendly brake friction composites contains flax fibres”, J. of Reinf. Plastics and Composites, 32(10), 2012, 681-689.
[27] Jang H, Ko K, Kim SJ, Basch RH, and Fash JW, “The effect of metal fibres on the friction performance of automotive brake friction materials”, Wear, 256(3- 4), 2004, 406 – 414.
[28] Blau PJ, “Compositions, functions, and testing of friction brake materials and their additives”, Tech. Report No. ORNL/TM-2001/64, Oak Ridge National Lab., TN (US), 2001.
[29] Oberst S, Lai JCS, “Statistical analysis of brake squeal noise”, J. of Sound and Vibration 330(2011), 2978–2994.
[30] Jearsiripongkul T, Hochlenert D, “Disk brake sequel: Modelling and active control”, RAM 2006, IEEE.