Research Methodology for alternating the disk Brake Material

[1]Prof.R.K.Pohane, [2]Dr. S.C.Kongare
[1]Ph-D Scholar, [2]Hod(Mech. Engg.) A.S.Polytechnic, Wardha,
[1]raj.pohane@gmail.com, [2] suhas_kongare@rediffmail.com.,

Abstract: This paper discuss the detail research methodological procedure for changing the disk brake material, which give the optimum performance of material. This paper also review on the various optimizing technique for selection of material on qualitative and quantitative approaches.

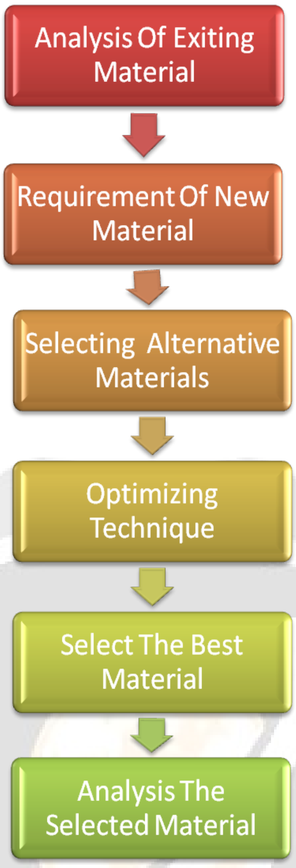
Keyword: Research Methodology, Disk Brake, Composite Material, Optimizing Technique.

Introduction:

The purpose of friction brakes is to decelerate a vehicle by transforming the kinetic energy of the vehicle to heat, via friction, and dissipating that heat to the surroundings. As a part of a commercial truck or automobile, brake materials have additional requirements, like resistance to corrosion, light weight, long life, low noise, stable friction, low wear rate, and acceptable cost versus performance. There are two common types of friction brakes – drum/shoe brakes and disk/pad brakes. The design of the brakes affects heat flow, reliability, noise characteristics, and ease of maintenance. History records the use of many kinds of materials for brakes, In order to achieve the properties required of brakes, most brake materials are not composed of single elements or compounds, but rather are composites of many materials. More than 2000 different materials and their variants are now used in commercial brake components. [Weintraub (1998) Weintraub (1998), Brake additives consultant. Private communication.].

Most common types of friction brakes operate on the principle that friction can be used to convert the mechanical energy of a moving object into heat energy, which is absorbed by the brake. The essential components of a friction brake are a rotating part, such as a wheel, axle, disk, or brake drum and a stationary part that is pressed against the rotating part to slow or stop it. The stationary part usually has a lining, called a brake lining that can generate a great amount of friction yet give long wear life. The principal types of friction brake are the block brake, the band brake, the internal-shoe brake and the disk brake. All brake lining friction materials for a brake system should be designed to maintain stable and reliable friction force/coefficient at a wide range of pedal pressure, vehicle speed, temperature, humidity and others [1] . The performance (i.e. safety, durability and comfort) of various brake situations is mainly controlled by the composition and microstructure of the brake shoe lining material [2]. A great deal of effort has been given to the development of multiphase composites for a friction material since a single material has never been successful to meet the numerous performance related demands [3]. The role of each ingredient in the multiphase friction material has been intensively studied and new ingredients are being developed to achieve better friction performance. Among many ingredients, the binder resin plays a crucial role in determining the friction characteristics. In general, thermosetting novolac type phenolic resin is widely used as a binder and fibre, filler and little amount of metallic particles are used to develop better friction properties. In this study physical and chemical characteristic of some commercially available brake shoe lining materials have been investigated in order to obtain the maximum information for better brake performance.

Research Procedure:



1. **Analysis of Exiting Material:**

Indentify which type of material is used for disk brake; what are the various properties which affect the performance of the disk brake.

2. **Fault Identification:**

Problems Associated With Overheating Brakes. If the temperatures reached in braking become too high, deterioration in braking May Result, and in extreme conditions complete failure of the braking system can occur. It can be difficult to attribute thermal brake failure to motor vehicle accidents as normal braking operation may return to the vehicle when the temperatures return to below their critical level, (Hunter et al. 1998).

One of the most common problems caused by high temperatures is brake fade; other problems that may occur are excessive component wear, rotor deterioration, and thermally excited vibration (brake judder). Heat conduction to surrounding components can also lead to damaged seals, brake fluid vaporisation, as well as wheel bearing damage, while heat radiated to the tyre can cause damage at tyre temperatures as low as 200°F (93°C), (Limpert 1975). The major problems associated with elevated brake temperatures are outlined below.

Brake Fade

Brake fade is a temporary loss of braking that occurs as a result of very high temperatures in the friction material. The high temperature reduces the coefficient of friction between the friction material and the rotor, and results in reduced braking effectiveness and ultimately failure. Generally fade is designed to occur at temperatures lower than the flame temperature of the friction material to reduce the possibility of fire at extreme temperatures. Normal braking will usually return when temperatures drop below their critical level.

Brake Fluid Vaporisation

Most braking systems are hydraulically actuated, with the exception of heavy-duty trucking. If temperatures reached during braking exceed the boiling point of the hydraulic fluid then brake fluid vaporisation will occur. A vapour lock will then form in the hydraulic circuit, and as gas is more compressible than liquid the pedal stroke is used to compress this gas without actuating the brakes. Brake fluid is hydroscopic causing it to absorb water from the atmosphere over time; this may result in a reduced boiling temperature of the fluid, (Hunter et al. 1998). Therefore it is usually recommended by vehicle manufacturers to replace brake fluid periodically.

Excessive Component Wear

High temperatures in the braking system can form thermal deformation of the rotors leading to uneven braking, accelerated wear and premature replacement. The life of the friction material is also temperature dependent, at higher temperatures chemical reactions in the friction material may cause a breakdown in its mechanical strength, which reduces braking effectiveness and causes rapid wear. The wear of frictional material is directly proportional to contact pressure, but exponentially related to temperature, (Day and Newcomb 1984); therefore more rapid wear will occur at elevated temperatures.

Thermal Judder

On application of the vehicles brakes, low frequency vibrations may occur, these

vibrations can be felt by the driver as body shake, steering shake and in some cases an audible drone, (Kao et al. 2000). This phenomenon is known as ‘judder’. Two types of judder exists; hot (or thermal judder) and cold judder. Cold judder is caused by uneven thickness of the rotor, known as disc thickness variation, this leads to deviations in contact pressure as the pads connect with the rotor. This results in uneven braking or brake torque variation. The second type, thermal judder, occurs at elevated temperatures, and is caused by thermal deformation of the rotor. When a rotor containing a cold disc thickness variation is subjected to braking, the contact pressure in the thicker parts will be much greater than the thinner parts. As a result, the thicker parts become hotter causing uneven thermal expansion of the rotor, which compounds the original disc thickness variation and creates a “self accelerating instability”, (Little et al. 1998). Thermal judder can also be aresult of ‘hotspots’ on the rotor surface. Hotspots can be caused by localised contact between the pads and rotor resulting in small areas of very high temperatures, >700 °C, which causes a thermal disc thickness variation. This thermal disc thickness variation may develop into a permanent disc thickness variation due to a phase change from pearlite to martensite, (Kao, et al. 2000), when cast iron is cooled rapidly. Martensite occupies a larger volume than pearlite, and therefore a cold disc thickness variation is formed and the problem is again compounded.

3. Requirement of New Material:

The property of disk brake material which affect the performance are Good comprehensive strength. Higher friction coefficient. Wear resistant. Light weight. Good thermal capacity. Optimum hardness. Economically viable.

4. Selecting the alternative material:

Selecting the alternative material from number of alternative material by using various criteria (requirement) which satisfied the desire requirement of the Disk brake. This can be done by the various optimizing technique specially multi criteria decision making tool and technique. The various MCDM tool and technique are:

4.1. DIGITAL LOGIC (DL) METHOD

The digital logic method can be employed for the optimum material selection using with ranking. As a first step, the property requirements for a brake rotor were determined based on previous discussion. The properties and the total number of decisions, i.e. $N (N - 1)/2 = 10$ are given in Table 1. The weighting factor for each property, which is indicative of the importance of one property as compared to others, was obtained by dividing the numbers of positive decisions given to each property by the total number of decisions. The total positive decisions for each property and corresponding weighting factor were calculated.

4.2. The WSM Method

The weighted sum model (WSM) is probably the most commonly used approach, especially in single dimensional problems. If there are m alternatives and n criteria then, the best alternative is the one that satisfies the following expression

AWSM =max ∑ ao wf

for i=1,2,3,----m, (4.1)

Where Awsm is the WSM score of the best alternative, n is the number of decision criteria, ao is the actual value of the i-th alternative in terms of the j-th criterion, and wf is the weight of importance of the j-th criterion. The assumption that governs this model is the additive utility assumption. That is the total value of each alternative is equal to the sum of the products given in the equation 4.1. In single-dimensional cases, where all the units are same, the WSM can be used without difficulty. Difficulty with this method emerges when it is applied to multi dimensional MCDM problems. Then, in combining different dimensions, and consequently different units, the additive utility assumption is violated and the result is equivalent to ‘adding apples and oranges’.

4.3. The WPM Method

The weighted product model (WPM) is very similar to the WSM. The main difference is that instead of addition in the model there is multiplication. Each alternative is compared with the others by multiplying a number of ratios, one for each criterion. Each ration is raised to the power equivalent to the relative weight of the corresponding criterion. In general, in order to compare two alternatives AK and AL, the following product has to be calculated

R (AK/ AL) =akj/aij (4.2)

Where n is the number of criteria, a is the actual value of the i-th alternative in terms of the j-th criterion, and wf is the weight of the j-th criterion. If the term R(AK/ AL) is greater than or equal to one, then it indicates that alternative AK is more desirable than alternative AL (in the maximization case). The best alternative is the one that is better than or at least equal to all other alternatives. The WPM is sometimes called dimensionless analysis because its structure eliminates any units of measure. Thus, the WPM can be used in single- and multi-dimensional MCDM. An advantage of the method is that instead of the actual values it can use relative ones

4.4. The AHP method

The Analytic Hierarchy Process (AHP) decomposes a complex MCDM problem into a system of hierarchies. The final step in the AHP deals with the structure of an m*n matrix (Where m is the number of alternatives and n is the number of criteria). The matrix is constructed by using the relative importance of the alternatives in terms of each criterion. Analytic Hierarchy Process (AHP) is an MCMD method based on priority theory. It deals with complex problems which involve the consideration of multiple criteria/alternatives simultaneously. Its ability to incorporate data and judgment of experts into the model in a logical way, to provide a scale for measuring intangibles and method of establishing priorities to deal with interdependence of elements in a system to allow revision of judgments in a short time to monitor the consistency in the decision-maker's judgments to accommodate group judgments if the groups cannot reach a natural consensus, makes this method a valuable contribution to the field of MCDM. The methodology is capable of Breaking down a complex, unstructured situation into its component parts, Arranging these parts into a hierarchic order (criteria, sub-criteria, alternatives etc.) Assigning numerical values from 1 to 9 to subjective judgments on the relative importance of each criterion based on the characteristics Synthesizing the judgments to determine the overall priorities of criteria/sub-criteria/ alternatives Eigenvector approach is used to compute the priorities/weights of the criteria/ sub-criteria/alternatives for the given pairwise comparison matrix. In order to fully specify reciprocal and square pairwise comparison matrix, N (N-1)/2 pairs of criteria/sub- criteria/alternatives are to be evaluated. The eigen vector corresponding to the maximum eigenvalue (ëMAX) is required to be computed to determine the weight vectors of the criteria/sub-criteria/alternatives. Small changes in the elements of the pairwise comparison matrix imply a small change in ëMAX and the deviation of ëMAX from N is a deviation of consistency. This is represented by Consistency Index (CI). i.e. (ëMAX – N)/(N-1). Randon Index (RI) is the consistency index for a randomly-filled matrix of size. Consistency ratio (CR) is the ration of CI to average RI for the same size matrix. A CR value of 0.1 or less is considered as acceptable. Other wise, an attempt is to be made to improve the consistency ny obtaining additional information. Prof. Thomas L. Saaty (1980) originally developed the Analytic Hierarchy Process (AHP) to enable decision making in situations characterized by multiple attributes and alternatives. AHP is one of the Multi Criteria decision making techniques. AHP has been applied successfully in many areas of decision-making. In short, it is a method to derive ratio scales from paired comparisons. Four major steps in applying the AHP technique are:

1 Develop a hierarchy of factors impacting the final decision. This is known as the AHP decision model. The last level of the hierarchy is the three candidates as an alternative.
2 Elicit pair wise comparisons between the factors using inputs from users/managers
3 Evaluate relative importance weights at each level of the hierarchy
4 Combine relative importance weights to obtain an overall ranking of the three candidates.

4.5. PROMTHE:

The PROMETHEE (Preference Ranking Organization method for Enrichment Evaluation) is a multi-criteria decision- making method developed by Brans et al. Brans and Vincke 1985; Brans et al. 1986)(). It is a quite simple ranking method in conception and application compared with other methods used for multi-criteria analysis. It is well adapted to problems where a finite number of alternatives are to be ranked according to several, sometimes conflicting criteria (Albadvi et al. 2007). The evaluation table is the starting point of the PROMETHEE(1) method. In this table, the alternatives are evaluated on the different criteria. The implementation of PROMETHEE requires two additional types of information, namely : (1) Information on the relative importance that is the weights of the criteria considered. (2) Information on the decision-makers preference function, which he/she uses when comparing the contribution of the alternatives in terms of each separate criterion.The information on the relative importance that is the weights of criteria (wj) can be determined by various methods (Nijkamp et al. 1990; Mergias et al.2007).Numerical scale method is used to determine the criteria weights in this study. After calculating the weights of the criteria, the next step is to have the information on the decision maker preference function, which he/she uses when comparing the contribution of the alternatives in terms of each separate criterion. The preference function (Pj) translates the difference between the evaluations obtained by two alternatives (a and b) in terms of a particular criterion, into a preference degree ranging from 0 to 1. Let Pj(a,b) be the preference function associated to the criterion fj(i).

$$Pj(a,b) = Gj[fj(a) - fj(b)] \quad ... (1)$$

$$0 \le Pj(a,b) \le 1 \quad ....(2)$$

Where Gj is a non-decreasing function of the observed deviation (d) between two alternatives a and b over the criterion fj. In order to facilitate the selection of a specific preference function, six basic types were proposed. These include "usual function", "linear function", "U-shape function", "V-shape function", "level function" and "Gaussian function". Preference "usual function" which is equal to the simple difference between the values of the criterion fj for alternatives 'a' and 'b' is adapted in this paper because of its simplicity. PROMETHEE permits the computation of the following quantities for each alternative a and b For each alternative a, belonging to the set A of alternatives, π (a, b) is an overall preference index of a over b. The leaving flow φ+ (a) is the measure of the outranking character of a (how a dominates all the other alternatives of A). Symmetrically, the entering flow φ− (a) gives the outranked character of a (how a is dominated by all the other alternatives of A). φ (a) represents a value function, whereby a higher value reflects a higher attractiveness of alternative a and is called net flow. PROMTHEE provides a complete ranking of the alternatives from the best to the worst one using the net flows.

4.6. ELECTRA:

The ELECTRE (for Elimination and Choice Translating Reality; method was first introduced in 1966. The basic concept of the ELECTRE method is to deal with "outranking relations" by using pairwise comparisons among alternatives under each one of the criteria separately. The outranking relationship of the two alternatives Ai and Aj describes that even when the i-th alternative does not determine the j-th alternative quantitatively, then the decision maker may still take the risk of regarding Ai as almost better than Aj. Alternatives are said to be dominated, if there is another alternative which excels them in one or more criteria and equals in the remaining criteria. The ELECTRE method begins with pairwise comparisons of alternatives under each criterion. Using physical or monetary values, denoted as gi(Ai) and gj(Aj) of the alternatives Ai and Aj respectively, and by introducing threshold levels for the different gi(Ai) and gj(Aj), the decision maker may declare that he/she is indifferent between the alternatives under consideration, that he/she has a weak or strict preference for one of the two, or that he/she is unable to express any of these preference relations. Therefore a set of binary relations of alternatives, the so-called outranking relations may be complete or incomplete. Next the decision maker is requested to assign weights or importance factors in order to express their relative importance. Through the consecutive assessments of the outranking relations of the alternatives, the ELECTRE method elicits the so-called concordance index defined as the amount of evidence to support the conclusion that
alternative Aj outranks or dominates, alternatives Ai, as well as the discordance index the counter-part of the concordance index.

Finally, the ELECTRE method yields a system of binary outranking relations between the alternatives. Because this system is not necessarily complete, the ELECTRE method is sometimes unable to identify the most preferred alternative. It only produces a core of leading alternatives. This method has a clearer view of alternatives by eliminating less favourable ones. This method is especially convenient when there are decision problems that involve a few criteria with a large number of alternaives.

4.7. The TOPSIS Method

TOPSIS (for the Technique for Order Preference by Similarly to Ideal Solution) was developed by Hwang and Yoon in 1980 as an alternative to the ELECTRE method and can be considered as one of its most widely accepted variants. The basic concept of this method is that the selected alternative should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution in some geometrical sense.

The TOPSIS method assumes that each criterion has a tendency of monotonically increasing or decreasing utility. Therefore, it is easy to define the ideal and negat ive-ideal solutions. The Euclidean distance approach was proposed to evaluate the relative closeness of the alternatives to the ideal solution. Thus, the preference order of the alternatives can be derived by a series of comparisons of these relative distances. The TOPSIS method first converts the various criteria dimensions into non-dimensional criteria as was the case with the ELECTRE method. As a remark, it should be stated that in the ELECTRE and TOPSIS methods the Euclidean distance represent some plausible assumptions. Other alternative distance measures could be used as well, in which case it is possible for one to get different answers for the same problem. However, it is reasonable to assume here that for the benefit criteria, the decision maker wants to have a maximum value among the alternatives. For the cost criteria, the decision maker wants to have a minimum value among the alternatives. Generally A+ indicates the most preferable alternative or the ideal solution. Similarly, alternative A- indicates the least preferable alternative or the negative ideal solution.

4.8. The Fuzzy AHP Method

Fuzzy AHP is Fuzzification of the AHP (analytic hierarchy process) used in conventional market surveys, etc. In AHP, several products and alternatives are evaluated, and by means of pair comparisons, the weight of each evaluation item and the evaluation values for each product and alternatives are found for each evaluation item, but the results of pair comparisons are not 0,1, but rather the degree is given by a numerical value. In fuzzy AHP, the weight is expressed by possibility measure or necessary measure, and in addition, the conventional condition that the total of various weights be 1 is relaxed.

4.9. NURAL TECHNIQUE:

Neural networks take a different approach to problem solving than that of conventional computers. Conventional computers use an algorithmic approach i.e. the computer follows a set of instructions in order to solve a problem. Unless the specific steps that the computer needs to follow are known the computer cannot solve the problem. That restricts the problem solving capability of conventional computers to problems that we already understand and know how to solve. But computers would be so much more useful if they could do things that we don't exactly know how to do. Neural networks process information in a similar way the human brain does. The network is composed of a large number of highly interconnected processing elements (neurons) working in parallel to solve a specific problem. Neural networks learn by example. They cannot be programmed to perform a specific task. The examples must be selected carefully otherwise useful time is wasted or even worse the net-work might be functioning incorrectly. The disadvantage is that because the network finds out how to solve the problem by itself, its operation can be unpredictable. On the other hand, conventional computers use a cognitive approach to problem solving; the way theproblem is to solved must be known and stated in small unambiguous instructions. These instructions are then converted to a high level language program and then into machine code that the computer can understand. These machines are totally predictable; if anything goes wrong is due to a software or hardware fault. Neural networks and conventional algorithmic computers are not in competition but complement each other. There are tasks are more suited to an algorithmic approach like arithmetic operations and tasks that are more suited to neural networks. Even more, a large number of tasks, require systems that use a combination of the two approaches (normally a conventional computer is used to supervise the neural network) in order to perform at maximum efficiency.

5. Select Best Material:

By using optimum technique select the best alternative material which satisfied the all criteria in optimal level.

6. Analysis the selected material:

For the analysis of selected material various test are carry out which give the concrete base to our selection.

6.1 STRUCTURAL ANALYSIS

Structural analysis is probably the most common application of the finite element method. The term structural (or structure) implies not only civil engineering structures such as bridges and buildings, but also naval, aeronautical, and mechanical structures such as ship hulls, aircraft bodies, and machine housings, as well as mechanical components such as pistons, machine parts, and tools. Thermal analysis to calculate the heat flux, temperature gradient & temperature variation. Two solution methods are available for solving Structural problems.

i) The h-method.
ii) The p-method.

The h-method can be used for any type of analysis, but the p-method can be used only for linear structural static analyses. Depending on the problem to be solved, the h method usually requires a finer mesh than the p-method. The p-method provides an excellent way to solve a problem to a desired level of accuracy while using a coarse mesh.

6.2 Thermal Stress Analysis

Thermal stress was predicted from the temperature distribution during single stop braking. The predicted surface compressive stresses associated with the temperature rise can cause yielding in compression of the material in the disc surface because thermal stresses are much higher than purely mechanical stresses on the friction surface. It can be seen that high initial stresses at the friction surface follow from a high thermal gradient. Brake disc surface cracking only occurs when the thermal stress exceeds the yield stress of the material. Murakami, Tsudada, and Kitamura [13] reported on a finite element analysis of automotive disk brakes to compare the calculated resonance frequencies with previous measurements of brake squeal on a chassis dynamometer and to associate them with calculated deformation of the brake components.

6.3 Finite element model

A disc brake system consists of a disc that rotates about the axis of a wheel, a calliper– piston assembly where the piston slides inside the calliper that is mounted to the vehicle suspension system, and a pair of brake pads. When hydraulic pressure is applied, the piston is pushed forward to press the inner pad against the disc and simultaneously the outer pad is pressed by the calliper against the disc. Static analysis is used to determine the displacements stresses, stains and forces in structures or components due to loads that do not induce significant inertia and damping effects. Steady loading in response conditions are assumed. The kinds of loading that can be applied in a static analysis include externally applied forces and pressures, steady state inertial forces such as gravity or rotational velocity imposed (non-zero) displacements, temperatures (for thermal strain).A static analysis can be either linear or non- linear. The procedure for static analysis consists of these main steps

1. Building the model.
2. Obtaining the solution.
3. Reviewing the results.

SOLUTION STEPS ON FINITE ELEMENT ANALYSIS. we define the analysis type and options, apply loads and initiate the finite element solution. This involves three phases:

1. Pre-processor phase
2. Solution phase
3. Post-processor phase

Pre-processor has been developed so that the same program is available on micro, mini, super-mini and mainframe computer system. This slows easy transfer of models one system to other.

Conclusion :

In this paper we discussed about the detail research methodology for disk brake material. Also the various optimizing technique which to be used in analysis the disk brake.

References:

1. [1] S.J. Kim, H. Jang, Friction and wear of friction materials containing two different phenolic resin reinforced with aramid pulp, Tribol. Int. 33 (2000) 477–484.
2. [2] W. Österle, M. Griepentrog, Th. Gross, I. Urban, Chemical and microsturctural changes induced by friction and wear of brakes, Wear 251 (2001) 1469–1476.
3. [3] S.J. Kim, M.H. Cho, D.-S. Lim, H. Jang, Synergistic effect of aramid pulp and potassium titanate whiskers in the automotive friction material, Wear 251 (2001) 1484–1491.
4. Querol X, Alastuey A, Ruiz C R, Artiñano B, Hansson H C, Harrison R M, Buringh E, Ten Brink H M, Lutz M, Bruckmann P, Straeh P, Schneider J. 2004. Speciation and origin of PM10 and PM2.5 in selected European cities. Atmospheric Environment, 38(38), 6547–6555.
5. Gehrig R, Hill M, Buchmann B. 2004. Separate determination of PM10 emission factors of road traffic for tailpipe emissions and emissions from abrasion and resuspension processes. International Journal of Environment and Pollution, 22(3), 312–325.
6. Seaton A, Cherrie J, Dennekamp M, Donaldson K, Hurley J, Tran C. 2005. The London underground: dust and hazards to health. Occupational and Environmental Medicine, 62(6), 355–362.
7. Branis M. 2006. The contributions of ambient sources to particle pollution in spaces and trains of the Prague underground transport system. Atmospheric Environment, 40(2), 348–356.
8. Abu-Allaban M, Gillies J A, Gertler A W, Clayton R, Proffitt D. 2003. Tailpipe, resuspended road dust, and brake-wear emission factors from on-road vehicles. Atmospheric Environment, 37(37), 5283–5293.
9. Weckwerth G. 2001. Verification of traffic-emitted aerosol components in the ambient air of Cologne (Germany). Atmospheric Environment, 35(32), 5525–5536.
10. Katsouyanni K, Touloumi G, Samoli E, Gryparis A, Le Tertre A, Monopolis Y, Rossi G, Zmirou D. 2001. Confounding and effect modification in the short-term effects of ambient particles on total mortality: results from 29 European cities within the APHEA2 project. Epidemiology, 12(5), 521–531.
11. Samet J M , Dominici F, Curriero F C, Coursac I, Zeger S L. 2000. Fine particulate air pollution and mortality in 20 U.S. cities, 1987–1994. New England Journal of Medicine, 343(24), 1742–1749.
12. ANDERSON, A. E. Friction and wear of automotive brakes. Materials Park, OH. ASM Handbook, v. 18, 1992.
13. E.H. Kraft, Opportunities for Low Cost Titanium in Reduced Fuel Consumption, Improved Emissions, and Enhanced Durability Heavy-Duty Vehicles, Oak Ridge National Laboratory Tech. Report ORNL/Sub/ 4000013062/1, Office of Sci. andTech. Information, Oak Ridge,Tennessee, 2002, 59 pp
14. K.G. Budinski, Tribological properties of titanium alloys,Wear 151 (1991) 203–217M.
15. Pevec, I. Potrc, G. Bombek and D. Vranesevic,"Prediction of the cooling factors of a vehicle brake Disc and its influence on the results Of a thermal numerical simulation", International Journal of Automotive Technology,Vol.13,No.5,(2012) pp.725−733
16. Pyung Hwang and Xuan Wu,"Investigation of temperature and thermal stress in ventilated disc brake based on 3D thermo-mechanical coupling model", Journal of Mechanical Science and Technology,Vol.24 (2010) pp.81-84
17. Molinari, T.B. Straffelini, T. Bacci, Dry sliding wear mechanisms of the Ti6Al4V alloy, Wear 208 (1997) 105–112.
18. 6. Ali Belhocine, Mostefa Bouchetara,"Thermal analysis of a solid brake disc", Journal of Applied Thermal Engineering, Vol.32 (2012),pp.59-67