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Reinforcing of Composite Material for Disk Brake: Review

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Abstract

The disc brake system is one important system to look at since it is not only used in automotive industries but also in locomotives and in jumbo jets as well and hence elaborating more on disc brake system. In most vehicles these brake discs (disc ring) are made of cast iron, which has good anti-wear properties and it is cheap as well. But in certain other cases such as high performance vehicles, these brake discs are not up to their standards of high performance because the cast iron brake discs are heavy in weight and so reduces the vehicle's performance to a particular extent. The critical issues identified in this review were used as a basis for addressing the study objectives and important research gaps have been identified on the basis of literature review.

Introduction

This presents the detailed account of the literature review. The literature review was carried out to identify the previous research efforts and directions related to our focal area. The objective of this literature review was to identify the research gaps and highlight research motivations. The discussion pertaining to the review is presented in chronological order, so that it also indicates the underlying pattern of evolution of thoughts and ideas in that domain. Similarly, to the extent possible, care was taken to reproduce the original terminology used by the authors, to preserve the originality of the views. The critical issues identified in this review were thermal problem of friction during braking, to understand the behavior of abrasive particles, method for stability analysis of a closed-loop flexible mechanism etc. The review is presented hereunder

Zhou and Davies[45] (1995) investigated thick glass/polyester woven roving laminated plates subject to low-velocity impact using a guided drop-weight test rig in ascending energy order up to 1500 J. The impact response and energy-absorbing characteristics have been determined by impact-force and absorbed-energy histories, and by force-displacement relationships. Impact damage is examined by visual inspection, ultrasonic C-scan and an optical microscope so that a three-staged sequential damage model is proposed to characterize damage growth. Static tests are also conducted to examine strain rate effect. It is demonstrated that the maximum impact forces are increased by 36% for the thin plates and by 22% for the thick plates, although the initial threshold forces are less strain-rate sensitive. Two thicknesses of laminated plates are used to study the thickness effect, and the scaling rules are developed for the delaminated plates. It is shown that both the maximum static and impact forces, and the incident kinetic energy can be scaled by the thickness ratio if these laminates have the same diameter and their behavior is dominated by shear. The finite element modelling is carried out for relatively low energy cases; the impact structural response is well captured by linear elastic solution.

Yevtushenko[40] et al., (1995) proposed a model which enables the surface friction temperature of disk brakes and the value of normal temperature displacements in braking to be found. The change of the heat flow generated by friction forces with time and with respect to coordinate is taking into account. The model predicts fairly well the literature experimental data. It is shown that the change in magnitude of a contact area due to a thermal distortion of an originally plane disk surface may be neglected.

Kakemi[13] et al., (1995) developed a mathematical model for the tensile behavior of cement composites reinforced with two types of continuous and unidirectional aligned fibers. The model is based on the theory for single fiber composites proposed by Aveston, Cooper and Kelly I. Theoretical curves have been obtained for the tensile properties of the polypropylene/glass fiber-reinforced cement composites by means of substituting parameters into the developed equations, and these curves were compared with experimental

results for a limited range of fiber combinations. It is shown that to attain optimum hybrid effects for toughness and the first maximum point of the stress-strain curve, the correct fiber volume combinations should be included.

El-Tayeb[6] (1996) presented results of an experimental study of friction and wear properties of a unidirectional oriented E-glass fiber reinforced epoxy (EGFRE) composite. Friction and wear experiments were conducted in the normal direction of the fiber orientation against a cylindrical counter face using a pin-on-ring technique for different sliding surface conditions. Friction coefficient and wear rate at various normal loads and sliding velocities were determined. Improvement in friction coefficient and wear rate were observed when sliding took place against either clean or wet counter face. In addition, microscopic observations of the worn surfaces allowed identifying the involved different wear mechanisms.

Sharma[29] et al., (1997) evaluated the corrosion characteristics of short-glass-fiber-reinforced ZA-27 alloy composites. The unreinforced matrix, as well as the composites containing 1, 3 and 5% by weight of glass fibres, was tested. The composites were fabricated by the compocasting technique. The specimens were tested in both as cast and heat-treated conditions. The corrodent used was 1 N hydrochloric acid. As the glass fiber content was increased, the composite was seen to become more resistant to corrosion. Heat treatment at 320°C for a few hours also enhanced the corrosion resistance of the composites as well as of the unreinforced matrix material. An attempt is made to explain these phenomena.

Skrifvars[31] et al., (1998) described the use of experimental design in the development of unsaturated polyester resins. The process conditions, which are critical in order to achieve unsaturated polyester with good delamination strength, have been identified and optimized. Qualitative data was obtained by using response surface modeling, and the delamination strength was estimated using a wedge test and the double cantilever beam method. According to the authors, the most optimal process conditions can be identified from the response surfaces.

Yang and Park[18] (1998) presented a method for stability analysis of a closed-loop flexible mechanism by using modal coordinates.The experimentally-determined bending strains and critical speeds are compared with numerical results obtained from the proposed method. The experimental and analytical results show fairly good agreement.

Optimal design of today's brake systems is found by Hohmann[10] et al., (1999) using additional calculations based on finite element methods. For both types of brake systems, drum brakes and disk brakes, the different parts of brakes, i.e. the brake pad with the friction material, the counter body and calliper, can be modelled. Two examples are given in this study: a drum brake of a trailer and a typical disk brake used in passenger cars. The main problem to be solved is the calculation of the distribution of contact forces between brake pad and counter body (drum or disk). The contact problem includes friction and is solved using the ADINA 7.1 sparse solver. After the brake pressure is applied, the turning moment on the axle rises constantly until the drum or disk respectively changes from sticking to sliding condition. It is shown that the sparse solver is highly efficient for this sophisticated nonlinear problem.

Sampathkumaran[28] et al., (2001) recorded the scanning electron microscope (SEM) features of glass fiber–epoxy composites subjected to sliding wear for distances ranging from 500m to 6 km . The results have shown that there is an existence of noticeable features on the worn surfaces. Thus for the longer run case interface separation is noticed, while for shorter runs matrix debris formation and occasional glass fiber fragmentation are seen. The work also highlights the effect of load and sliding velocity on the wear loss pattern.

Hong-Sen[11] et al., (2001) presented novel method for four-bar linkages that satisfies kinematic design requirements and also attains trade-off of dynamic balance. By properly designing the speed trajectory of the input link, the disk counterweight of moving links, and link dimensions of the given or desired mechanisms, the expected output motion characteristics and dynamic balancing performance are obtained. The input motion characteristics are designed with Bezier curves. Optimization is applied to find out optimal design parameters for reaching the trade-off of dynamic balance. The input speed trajectory of the input link could be generated by a

servomotor. Examples are given to demonstrate the design procedure of this approach.

Kinkaid[17] et al., (2005) examined the dynamics of a simple model for a braking process. The 4 d of model is designed to capture some of the dynamics of a set of brake pads halting a rotor. The authors find from our model that the motion of the system transverse to the direction of braking experiences a sharp change in excitation when the slip velocity in the braking direction is low. This change results in a complicated vibration which occurs at low slip speeds. In addition, there is often no correlation between the frequencies of the resulting vibration and the natural frequencies of system in the absence of friction. Based on the results from our numerical investigations authors are able to propose a new mechanism for disc brake squeal. This mechanism is similar to previously proposed mechanisms in that the writers view squeal as a friction-induced phenomenon. However, in contrast to the majority of these mechanisms, authors are able to encompass the transient, dissipative nature of a braking process.

Boniardi[3] et al., (2006) analysed the disc brakes investigating both the main causes and the evolution of its deterioration in order to find out possible solutions. The short lifespan of such discs has to be ascribed to the rapid decay of the mechanical properties of the manufacturing material. Material decay is liable for starting cracks. Several actions could be chosen to face this problem. The choice of a particular chemical composition, which will be demonstrated to be unfit for the purpose, produced an extreme tempering of the steel as a direct result of its protracted exposure to high temperatures (a situation which can be considered usual referring to disc brakes). In this work, authors present the effect of choosing a different kind of steel, characterized by a greater resistance to the tempering processes.

Larena[20] et al., (2006) employed polypropylene matrix composites, with different degrees of reinforcement with long glass fibres, in different fields of the industry, such as aeronautics or automotive. Samples of the material were exposed to artificial accelerated photo-ageing in UV chamber (Heraeus Xenotest 150S). Their high content of glass fibres causes a surface degradation that can seriously affect mechanical properties. Therefore, dynamic mechanical and tensile tests were carried out in order to compare the changes of the properties with exposure time. These modifications are accompanied with microscopic changes in the crystallinity as can be seen in the thermal analysis experiments.

Mader[23] et al., (2007) systematically analyzed the fiber surface sizing effects on composites' mechanical performance using the quasi static single fiber pull-out test and a cyclic loading (micro-fatigue) test, dynamic mechanical thermal analysis, fatigue and other mechanical tests. Our experiments show that the polymer sizing provides the glass fiber with significantly improved both static and fatigue properties. Together, these results demonstrate a correlation between the fatigue behavior and the interfacial adhesion, with the higher interfacial adhesion performing better in fatigue, where the interface should dominate in determining fatigue life. A cooperatively analysis of dynamic mechanical thermal analysis data reflects constriction effects on molecular mobility of matrix and is consistent with the results of interfacial adhesion and the tendency of fatigue resistance.

Thomason[36] et al., (2007) investigated the mechanical performance of injection moulded long glass fibre reinforced polypropylene with a glass fibre content in the range 0– 73% by weight . The composite modulus exhibited a linear dependence on fibre content over the full range of the study. Composite strength and impact resistance exhibited a maximum in performance in the 40–50% by weight reinforcement content range. The residual fibre length, average fibre orientation, interfacial shear strength, and fibre strain at composite failure in the samples have been characterized. These parameters were also found to be fibre concentration dependent. The interfacial shear strength was found to be influenced by both physical and chemical contributions.

Pihtili[26] et al., (2009) examined the effects of resin content on the wear of woven roving glass fibre–epoxy resin and glass fibre–polyester resin composite materials. Furthermore, composite materials are experimentally investigated under different loads and speeds by using a block-on-shaft wear tester. The influences of two thermosetting resins epoxy and polyester on the wear of glass-woven roving reinforced composites under has been investigated dry conditions. The glass fibre–epoxy

resin and the glass fibre–polyester resin composite materials specimens have been tested under different experiment conditions. Tests were conducted for 0.39 and 0.557 m/s speeds, at two different loads of 5 and 10 N. The weight losses were measured after measuring different sliding distances. Wear in the experiments was determined as weight loss. The amount of wear was measured before the experiment and after the experiment with the apparatus of balance scales with the accuracy of 10. 3 g. Glass fibre–epoxy resin composites generally showed higher strength and minimum wear when compared with glass fibre–polyester resin composites materials. In addition, Scanning electron microscopy is used to study the worn surface to verify the results.

Thevenet[34] et al., (2010) developed a fiber optic two-color pyrometer for brake disc surface temperature and emissivity measurements. The two-color pyrometer consists of a fluoride glass optical fiber, two HgCdTe detectors equipped with bandwidth filters and a data conditioning and acquisition device. The two-color pyrometer measures the brake disc temperature in the 200–800 _C range with a time resolution of 8 ls. The calibration formula for the signals obtained using a blackbody of known temperature is used to compute the true temperature. The uncertainty estimation for temperature and emissivity was obtained from the calibration results. Tests were carried out on known temperature target and a good correlation was found between results obtained with our two-color pyrometer and those obtained with a commercial two-color pyrometer. Hold braking and deceleration braking tests performed on a braking test bench enabled us to reach the brake disc surface temperature and emissivity during braking. Experimental results show a significant variation of emissivity during braking. Direct measurement of emissivity was carried out on the brake disc after braking and shows the emissivity dependence with the surface quality.

Xiao[39] et al., (2010) investigated a group of non- asbestos organic based friction materials containing 16 ingredients in this work using the techniques of design of experiment (2k DOE), response surface methodology (RSM), and artificial neural network(ANN).The ingredients effects on three friction characteristics including 1st fading rate, 2nd fadingrate,and speed sensitivity were studied by 2k DOE. Five ingredients of phenolicres in, synthetic graphite, potassium titanate, mineral fiber, and calcium silicate were found to be statistically significant for these responses and should be studied further. In the mean time, an artificial neural network with Elman recurrent configuration was trained and tested using the data generatedfromdynamometertestsin2k DOE experiments. Concerning the confounding of two-ingredient interaction effects and main effects, response surface methodology was employed to optimize the friction material formulation. The well trained and tested Elman artificial neural network was then used to predict the friction characteristics of the trials generated by RSM.

Yevtushenko[41] et al., (2011) obtained the solution to a thermal problem of friction during braking for a three-element tribosystem disc/pad/ caliper with time-dependent specific power of friction and heat transfer through a contact surface.The influence of duration of increase in pressure (from zero at the initial moment of time to nominal value at the moment of a stop) and the Biot number on the temperature for such materials as cast iron isc/metaleceramic pad/steel caliper has been studied.

Kim[16] et al., (2011) investigated the automotive brake friction materials with four different abrasive particles. The abrasives used in this study were commercial grade silicon carbide, zircon, quartz and magnesia. For microscopic understanding of friction and wear by abrasive particles in the brake friction material, single-particle scratch tests followed by scratch tests with multiple particles were performed first to understand the behavior of abrasive particles at the sliding interface during brake applications. The results showed that the fracture toughness of the abrasives played a crucial role in determining the friction level, wear debris formation and stick–slip. The friction material with silicon carbide exhibited a micro cutting mode with considerable stick–slip behavior, indicating a possible high propensity of noise occurrence during brake applications. On the other hand, the quartz and magnesia particles with low fracture toughness showed relatively small stick–slip amplitudes, suggesting that the fracture toughness of the abrasives can play important roles on the noise and vibration occurred during brake applications.

Conclusion

The literature indicated that the quality of mechanical product such as disc brakes largely depends on the quality of material of which it is made. Though many studies have been carried out in order to improve the performance of the disc brakes, the lack of standardized material poses innumerable challenges for the automobile industry. Moreover, it has been observed there is a strong possibility that the currently used disc brakes can be replaced by the composite material discs, which has numerous advantages over it. These advantages include but are not limited to crack propagation due to heat, load caring capacity, stiffness and weight savings etc. A composite disc made up of glass fiber reinforced polymer seems to be the future of brake system, however, there appears to the variation in the types of composition combinations suggested by the researchers. Hence, it is evident from the literature review that there is a need to undertake a systematic study for evaluating the performance of Disc Brakes made up of different types of composite material.

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