Simulation Modelling Practice and Theory 84 (2018) 106–123

Contents lists available at ScienceDirect

Simulation Modelling Practice and Theory

journal homepage: www.elsevier.com/locate/simpat

Simulation and sensitivity analysis of wear on the automotive brake pad

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ARTICLE INFO

Article history:
Received 28 March 2017
Revised 22 January 2018
Accepted 26 January 2018

Keywords:
Wear simulation
Automotive brake pad
Pin on disc experiment
Finite elements method
Taguchi optimization
ANOVA

ABSTRACT

In this paper, an algorithm is proposed for finite element simulation of wear employing the Archard's wear equation. To evaluate the accuracy of a FE model, an experimental test is performed on a standard-sized pin, made of a known brake pad. Comparison of worn masses, obtained by experimental and numerical approaches shows good accuracy of the developed algorithm. As the next step, passenger car single-piston and double-piston brake pad wear cases are simulated using the proposed algorithm. The rotor/pad contact area and worn mass are compared between the two cases. It is shown that usage of a double-piston brake pad over a single-piston one, can improve brake performance. The Taguchi Method with an orthogonal array L9 is then applied to optimize the design parameters, meaning maximization of the "contact area" and minimization of the "worn mass". The ANOVA method is also used for evaluating the impact of each design parameter on desired outputs. It is shown that the contact area is most likely to be affected by back plate thickness, while the worn mass is more sensitive to the diameter of the piston, closer to the leading edge of the pad.

1. Introduction

Hydraulic disc brake system with fixed and floating calipers shown in Fig. 1, is commonly used in modern cars. Brake pads are an important part of a disc brake system through which the braking force is transferred to the rotor and the tires to decelerate and/or stop the car. The contact between disc and pad, when the disc is rotating, leads to a sliding motion which is related to wear. Surely, the softer part which is the braking material of the pad will experience more wear.

Wear is a devastating phenomenon that occurs in some parts of machines which experience friction force. This phenomenon has different types and it is possible that in some systems the wear is negligible and has no significant effect on system performance [1]. Although the friction is a major source of energy loss in dynamic systems but it is an essential factor in car control. It is an indispensable phenomenon for controlling the velocity and stopping the car in normal and emergency conditions. The wear is a consequence of sliding friction between the brake pad and rotor. The brake pad is gradually worn and is sacrificed during its limited lifetime to keep the rotor in a safe condition. However, the worn material of the brake pad is a contaminating factor which may increase the human health risk [2]. The material properties and working conditions of the brake pad have been a major concern of researchers to decrease the environmental risk. The nature of particles as well as their amount must be controlled in such a way that the braking efficiency assures the passenger

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https://doi.org/10.1016/j.simpat.2018.01.009
1569-190X/

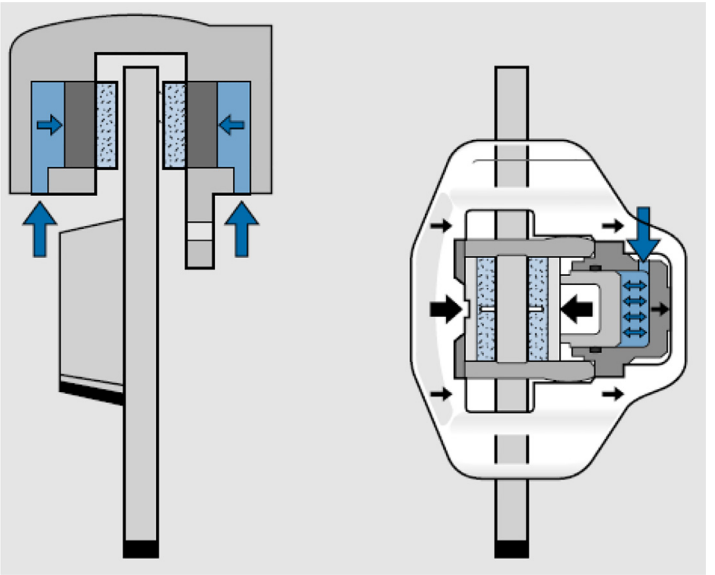

Fig. 1. Disc brake with fixed caliper (left) and floating caliper (right) [18].

safety at the same time. Combining these facts confronts the scientists with a challenging and complicating task of finding an optimized design of the braking system, especially the brake pads.

Wear analysis can be performed in two different viewpoints, namely, microscopic and macroscopic view [3]. The microscopic view is mostly used to justify worn simulation at the molecular scale and to demonstrate the effect of different substances on friction parameters and wear between surfaces. On the other hand, in practical terms, the macroscopic view to the friction phenomenon and wear is more useful in designing of a brake system, especially for wear analysis. Wear process is analyzed in previous research works, applying different numerical and experimental methods. For experimental investigation of wear, various setups of standard tests are proposed in the literature. The standard test of wear of a pin in contact with a rotary disc is a common experiment for tribological and wear study of brake pads [4].

In recent years, different researchers tried to numerically simulate the wear and some of its related characteristics. Kim et al. simulated oscillatory sliding wear between two metals with FEM and used the technique of remeshing, matched with the experimental model [5]. Oqvist also takes the effect of different wear steps into account to analyze the wear of two bodies using finite element simulation [6]. Wear phenomenon is also simulated using FEM in other studies [7,8]. Soderberg et al. simulated the pad wear using finite elements analysis [9]. Sliding contact between pad and rotor may lead to squeal as well as wear. The squeal phenomenon is generally affected by the wear and the instantaneous roughness of the contact surfaces. Abubakar et al. used the numerical and experimental methods to study the squeal phenomenon [10].

The study of different parameters related to the brake pad and their effects on wear behavior and the contact area between pad and rotor is also challenging for researchers. Abubakar et al. studied some physical pad characteristics and their effect on the amount of contact area between pad and rotor [11]. For a more precise study of different parameters and their effects on desired values and braking performance, a sensitivity analysis can be used. In this regard, different approaches such as Taguchi and analysis of variance (ANOVA) are available. Using these techniques, one may observe the effect of design parameters on the desired or required outputs. Optimization of wear characteristics of different materials by Taguchi method using different experiments are performed in previous works [12–14]. Taguchi method can be also used to obtain the optimum levels of design [15,16].

In this paper, an algorithm is presented to simulate the wear based on FE analysis combining with Archard equation using python scripting. A pin on disc wear test is carried out to find the wear and friction coefficients. The results of the pin on disc test are also compared with those obtained from developed algorithm. The validated algorithm is then used for simulating the wear of the single-piston pad. At the next part, all steps will be repeated for a double-piston brake pad and the results are compared with the single piston brake pad. Taguchi and ANOVA methods for analyzing the effect of each parameter of double-piston brake pads on outputs and finding the optimum levels are used. Finally, FE re-evaluation analysis will be carried out for the optimum levels obtained by Taguchi and the results will be used for evaluating the predicted values.

2. Experimental procedure

Pin on disc wear test is a known method for measuring friction and wear coefficients. This paper attempts to define this test for obtaining the coefficients of friction and wear between steel disc and metallic brake pad. Moreover, the worn mass