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Full Length Article

Effects of process parameters on the properties of brake pad developed from seashell as reinforcement material using grey relational analysis

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ABSTRACT

Over the years, asbestos was used as reinforcement material in brake pads production. However, due to its carcinogenic nature, it has lost its favor and there is need to find an alternative material. In this study, brake pads were produced from locally sourced non-hazardous raw materials using grey relational analysis. The materials used for production include seashell, epoxy resin (binder), graphite (friction modifier) and aluminum oxide (abrasive). Twenty- seven different samples were produced using seashell as reinforcement material by varying the process parameters. Rule of mixture was used for formulation and a weight percent of 52% reinforcement, 35% binder, 8% abrasive and 5% friction modifier were used for production. Grey relational analysis was conducted in order to scale the multi-response performance to a single response. The results indicate that optimum performance can be achieved with 14 MPa molding pressure, 160 °C molding temperature, 12 min curing time and 1 h heat treatment time. Analysis of variance shows that curing time has the least significant effect on the mechanical properties, while curing time of 24.26% and 55.23% has the most significant effect on coefficient of friction and wear rate respectively on the brake pad developed.

1. Introduction

Braking system is one of the basic organs which control an automobile [9]. Brake pads serve to reduce heat and wear caused as a result of the contact between mating surfaces. Frictional materials applied in automotive brake pads were formulated many years ago. Herbert Frood in the 1870s invented the earliest frictional material composed of cotton material and bitumen solution. This invention led to the establishment of Ferodo Company which still produce and supply friction materials up till date [6]. In a common brake or clutch repair work, these accumulated dusts are always wiped off before the old pads or shoes are replaced and as such, automobile mechanics are exposed to asbestos dust. Any of this method can cause particles of asbestos to become airborne. If these old brake pads are still hard enough to be applied, mechanics working on them often utilize bench grinder to normalize the surface, or dissolve the oil and dirt of the pad. Also, when replacing brake pads or shoes, the mechanic often grinds the face of the pad in order to increase the engagement process, bevel the grinding wheel edges to reduce the noise when in use, and then drill holes for riveting. These processes often lead to the release of asbestos particles which could be inhaled thereby putting the mechanic at risk of contacting diseases such as pleural, peritoneal or pericardial mesothelioma, asbestos related cancer and asbestosis [3,28]. Therefore, significant efforts have been made towards replacing fibres of asbestos in brake pads. This was reported in the work of Nakagawa et al. [26], where fibres of metals were utilized for inclusion in the production of brake pads so as to counter environmental pollution. Ibhadode and Dagwa [19], Deepika et al. [16] developed a non-asbestos-containing brake pad material using an agro-waste material base, palm kernel shell (PKS) as filler material. The authors reported that palm kernel shell was selected because it exhibited more favourable properties than the other agro-waste they investigated. Aigbodion et al. [2], Bashar et al. [6], Lawal et al. [24], Ikpambese et al. [21] and Ruzaidi et al., [29], also developed a non-asbestos brake pad by utilizing bagasse, coconut shell, palm kernel fibers and palm ash respectively as reinforcement materials. The result of their studies showed that the selected reinforcement materials were comparable with other commercially available brake pad materials. Choe-Yung et al. [14] modeled a drum brake squeal as friction excited vibration using modal assurance criterion (MAC). The study concluded that design alterations of mode

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separation led to increase in system damping and the reduction of contact stiffness eliminate squeal in the friction coefficient range of $0.1 \leq \mu \leq 0.5$. Also, Ishak et al. [22] developed a one-dimensional model of leading trailing drum-type parking brake model. The results show that the torque generated by the parking brake in the downhill direction exceeds that in the uphill direction which may be due to the type of leading-trailing shoe used in the drum brake mechanism. Similarly, Khaled et al. [23] conducted series of experiments with the aim of investigating the effect of sliding speed and normal force on the coefficient of friction between brake pad and disc. The results indicated that coefficient of friction has considerable effect on disc brakes dynamics and this effect was more noticeable with wedge disc brake mechanism compared to conventional disc brake system. Belhocine and Nouby [7] developed a finite element model of the disc brake assembly with the aim of improving the understanding of the influence of Young's modulus on squeal generation. The simulation result showed that instability of the disc brake made it sensitive to Young's modulus variations of the disc brake components. Bin et al. [10] reported a modeling and control system design for the integrated electric parking brake system (IEPBs). The experiment and simulation results show that the force sensor strategy, though could reach the desired force, but could also leads to high cost and installation problems.

Grey relational analysis (GRA) is a grey system theory proposed by Deng [17] and is suitable for solving problems with complex interrelationships between multiple responses and factors, thereby reducing a research problem to a single-objective decision-making problem. [25]. Yiyo et al. [30] reported that GRA optimization procedure involves combining all performance characteristics into a particular value which can be utilized as the single characteristic in optimization problems. Therefore, in this work, seashell reinforcement materials combined with other frictional ingredients were used to develop brake pad using powder metallurgy technique. Norazlina et al. [27] reported that seashell consist primarily of calcium carbonate ($CaCO_3$), been naturally above 80% $CaCO_3$ by weight with only about 2% protein content. However, what is not known or reported in the literature is the performance of seashell as an alternative material for brake pad development, with respect to the extent to which the mechanical and tribological properties are enhanced compared to other reinforcement materials. In this paper, mechanical properties (tensile strength, compressive strength, hardness, impact strength and flexural strength) and tribological properties (coefficient of friction and wear rate) of the brake pad developed using seashell as non-hazardous reinforcement materials were evaluated. The results are discussed in a later section.

2. Materials and methods

2.1. Materials

(i) *Reinforcement materials:* the seashells shown in Fig. 1 were used as reinforcement material. Seashells (the shells of sea snails) were collected from a seafood vendor situated in Lagos bar beach, Lagos – Nigeria, while coconut shells were obtained from a coconut trader in a Sabon Tasha market in Kaduna – Nigeria.

Fig. 1. Seashells obtained from Bar Beach.

(ii) *Binder:* Epoxy resin (Epoblock, FIP Chemicals) was used together with a co-reactant known as hardener (Sikadur 42 T, Sika Corporation U.S) to form a cross-linking reaction. These materials were obtained from a chemical store located in Onitsha, Anambra State, Nigeria.

(iii) *Friction Modifier and Abrasive Material:* Reagent grade aluminum oxide with the following specification: (Cat. No. 34143; Lot. No. 44100) was purchased from a commercial chemical shop situated in Onitsha, Anambra State, Nigeria, which served as an abrasive. Graphite powder was used as a friction modifier and was obtained from used 1.5 V TIGER head dry cell batteries.

2.2. Method

The development of brake pads involved the preparation of filler materials, formulation using rule of mixture theorem, design of experiment, compression molding process, heat treatment, mechanical and tribological examination as well as optimisation using grey relational analysis (GRA).

2.2.1. Materials preparation

Prior to the preparation of the seashell and graphite powder, the seashells were washed with soap and detergent, cleaned using dried cloth and were dried in a hot air oven at a temperature of 150 °C. This was followed by crushing with the seashells with pestle and mortar. They were then grinded and sieved using a sieve size of 125 μm.

2.2.2. Formulation of brake pad

Samples formulation was done using rule of mixture. To use this theorem, the volume fraction and density of the individual brake pad constituents were calculated using a specified weight percent. The volume fraction for individual constituent for the seashell and coconut shell reinforced composite was calculated using Equ. 1;[4].

$$\textit{Volume Fraction of Constituent}\,(V_i) = \frac{W_i}{\rho_i} \div \sum \frac{W_j}{\rho_j} \tag{1}$$

where, W_i and W_j are the weight percent of the individual and total constituent respectively, V_i is the volume fraction of the individual constituent. ρ_i and ρ_j are the densities of the individual and total constituents respectively.

The theoretical densities of the seashell and coconut shell reinforced composite can be determined by Eq. (2). [4].

$$\rho_{composite\,(seashell-based)} = \rho_s V_s + \rho_a V_a + \rho_g V_g + \rho_b V_b \tag{2}$$

where, ρ_s, ρ_a and ρ_b are the densities of the seashell, aluminum oxide, graphite and epoxy resin respectively. The density of seashell, and graphite were determined using Archimedes principle, while the densities of reagent grade aluminum oxide and epoxy resin were specified by the manufacturers.

V_s, V_a, V_g and V_b are the volume fraction of the seashell, aluminum oxide, graphite and epoxy resin respectively.

2.2.3. Design of experiment using response surface methodology (RSM)

In this study, response surface methodology (RSM) via central composite RSM design (CCD) was used. This design method was selected in preference to Box-behnken RSM design (BBD) due to its ability to combine two-level full factorial design with additional two points (axial and centre points). It also contains the combination where all factors are at their lower and higher levels. This experimental design was built in accordance to standard RSM's