Production of Brake Pad from Epoxy Resin: From Polymerization Concept to the Experiment with Analysis of Mechanical Properties

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Abstract

The purpose of this study was to determine the production of brake pad from epoxy resin. This study also evaluate the effect of variations in the use of catalysts on the performance of brake pads. Additional polymerization concept was also added. The performance testing was done using compressive strength and puncture strength. The brake pads were formed from a mixture of Bisphenol A-epichlorohydrin and cycloaliphatic amine as the raw resin and the catalyst, respectively. The ratios of raw resin and catalyst were varied: 1:1, 1:2, and 1:3. The mixed resin was then put into the template and dried naturally. Based on the results of the study, it was found that brake pads with samples B and C had better performance. The hardness values of samples A, B, and C are 307.4; 331.1; and 334.3 N, respectively. The ratio of resin and catalyst mixture affects the performance of the brake pad. The more catalysts added, the faster the hardening process; indeed, it affects to the polymerization process. It is hoped that this research can be the basis for developing brake pads.

Kata Kunci: *Binder, brake pad, epoxy, hardness, resin*

1. Introduction

The advancement of automotive technology in the field of aerodynamics is very rapid; for example, current engine performance is increasing. In various fields, technology must evolve in response to the needs and demands of life, which continue to grow from year to year. Similarly, the vehicle's braking system continues to develop as a system that is considered very important in its existence in vehicles from year to year [1]. Then, as previously stated, as engine performance improves, a good and effective braking system is required to support the engine's power and extinguishing speed. The brake pad is the most important component of the braking system because it acts as a medium to slow or stop the movement of the vehicle's wheels. Brake pads are important in high-speed vehicles because they support the driver's soul, and the performance of the brake pads is determined by their quality of the brake pads [2, 3].

In general, brake pad friction materials are made up of three components: binders, fibers, and fillers. Phenolic, formaldehyde, epoxy, polyester silicone, and rubber are among the resins used in the binder. In friction, the resin acts as a constituent. At a relatively stable temperature, the binder can form a matrix. The thermal stability of these binders is critical for ensuring that the brake pads perform consistently and reliably even when temperatures rise under harsh service conditions. During braking, the surface of the pad can reach temperatures of between 600 and 800°C, and even higher in places of local friction. Meanwhile, fibers and/or fillers serve to increase the material's coefficient of friction and mechanical strength.

The use of a binder for Friction Composites (FCs) with high thermal stability at elevated temperatures is unavoidable to control the fade phenomenon. The type and amount of binder used in the formulation of brake pad material are critical in managing fade resistance. The ideal amount of binder provides structural integrity to the brake pad without sacrificing other important properties. The resin was modified to improve the friction and wear resistance of the brake pad material in these studies. In terms of friction stability and wear resistance, there are studies that the modified resin outperformed nonmodified resin [4].

Individually, the phenolic resin was modified with Si and Boron phosphorous and tested for fade and wear resistance. It was discovered that boron phosphorous-modified phenolic resin outperformed pure phenolic resin. Then, according to another study, the performance of brake pad materials does not change uniformly as the binder content increases [3, 5]. In this work, we demonstrate the production of brake pad using epoxy resin. Epoxy resin was chosen because of its good thermomechanical properties. The aim of this was to investigate the effect of catalyst composition on brake pads. Three sets of brake pads, with fixed resin formulations and different catalyst formulations, were prepared to evaluate their performance such as a hardness test compression test, and puncture test.

2. Concept

Based on our earlier work [2], the idea behind making resin-based brake pads is now presented. In short, the preparation binds and compacts reinforcement components by utilizing the concept of polymerization. Detailed information as well as material formation is explained elsewhere [2].

The polymerization involves the reaction of epoxy resin formation at room temperature (from combination of raw resin and catalyst). Through co-reactants, epoxy resins can be reacted (cross-linked) with one another to create polyepoxy.

The brake pad matrix substance was from monomer, namely bisphenol A-epichlorohydrin, also referred to as raw resin or phenoxy resin. The phenomena in the polymerization involve a two-step response process.

In the first step, bisphenol A and epichlorohydrin react to form bisepoxides (see Fig. 1). Then, stoichiometric amounts of hydroxide ion and bisepoxides were combined to create bisphenol A diglycidyl ether (DGEBA), water, and sodium chloride. The epoxy matrix's strength, elongation, and ductility were all increased by bisphenol A.

After that in the second step, the liquid epoxy resin (DGEBA) underwent a chain extension process by interacting with additional molecules of bisphenol A (see Fig. 2). This exothermic oligomerization process advances quickly to near complextion and produces a higher molecular weight epoxy (as a long-chain polymer).

The long-chain polymer of phenoxy resin, which has a high molecular weight, was converted into an insoluble solid with three-dimensional thermoset networks by crosslinker curing. Cycloaliphatic amine was employed in this investigation as a curing agent (see Fig. 3).

By cracking open the oxirane ring during the curing process, longer C-O linkages were created. As a consequence of the curing agent molecules cross-linking the long polymer in its body, the reaction creates a three-dimensional structure in the product (see Fig. 4).

The shrinkage and dimensional stability of cured epoxides were connected to this procedure. Since cycloaliphatic amines can cure resin at low temperatures or room temperature with good color and a long pot life, they were used as a curing agent for the resin-based brake pad. Additionally, the electrical, mechanical, and thermal properties were improved by cycloaliphatic amine.

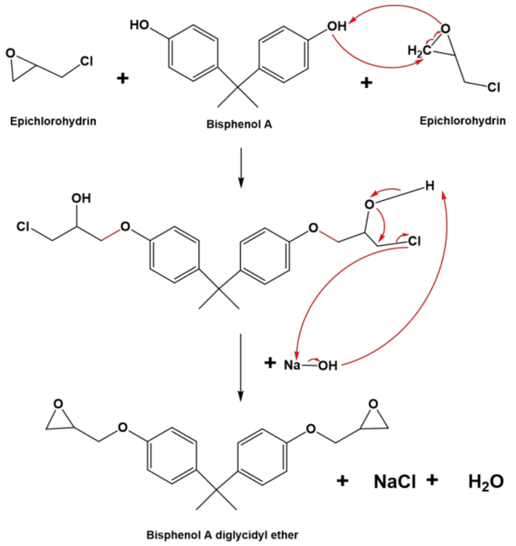

Figure 1. Synthesis of bisphenol A diglycidyl ether (DGEBA). Figure was adopted from Reference [1]

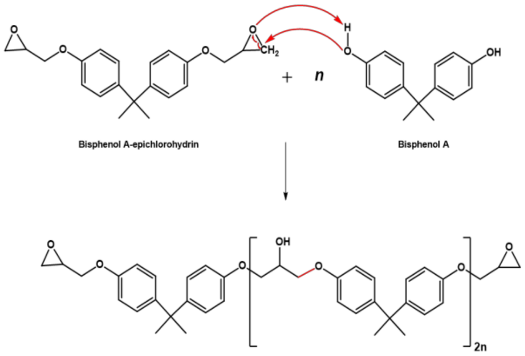

Figure 2. Polymerization process between DGEBA and other bisphenol A molecules. Figure was adopted from Reference [1]

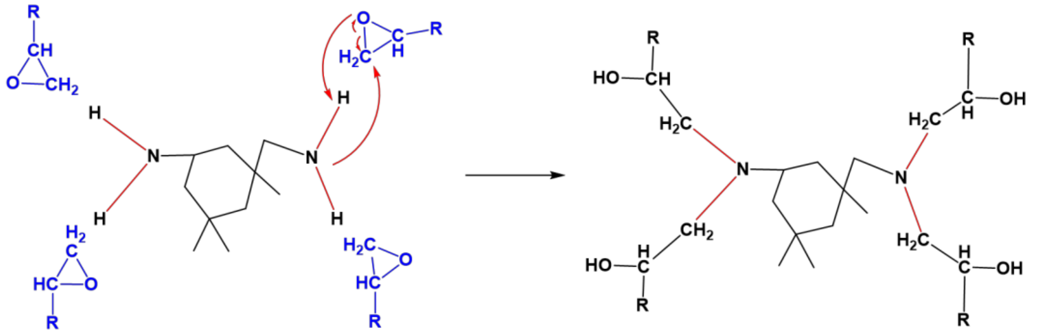

Figure 3. Curing process of bisphenol A derived epoxy resin by cycloaliphatic amine. Figure was adopted from Reference [1]

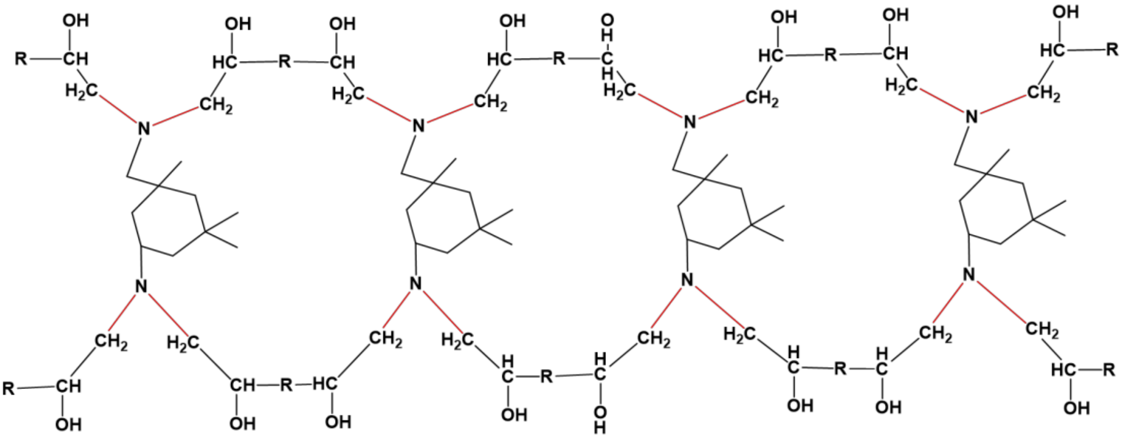

Figure 4. Bisphenol A derived resin with cycloaliphatic amine. Figure was adopted from Reference [1]

3. Method

3.1. Brake Pad Production

The resin material was made from a mixture of Bisphenol A-epichlorohydrin (as a raw resin) and cycloaliphatic (as a catalyst). Prepare brake pad, it was done by mixing Bisphenol A-epichlorohydrin and cycloaliphatic in a certain ratio. The two ingredients were then combined in the following proportions: 1:1, 1:2, and 1:3, respectively, for resin and catalyst. Samples with resin and catalyst compositions of 1:1, 1:2, and 1:3 were labeled as specimens A, B, and C, respectively. After that, the mixture of resin/catalyst was stirred until evenly ± 5 minutes. After that, the prepared mixture was put into a silicone mold with a size of 1 x 1 cm and dried at room temperature and pressure for 1 x 24 hours. In the process of recommendations to avoid direct sunlight. For characterization, brake pads are prepared and cut to specific sizes.

3.2. Mechanical Characterization

To test the properties of the brake pads, compressive and puncture strength tests were carried out. The compression test was performed on a Screw Mount Test Instrument (Model I ALX-J, China, ASTM D-2240) equipped with a digital force measuring instrument (Model HP-500, Serial No H5001909262, ASTM D-4713). The brake pad was subjected to a constant rate of 2.6 mm/min during testing. Simultaneously, the compressive force was measured, yielding a curve that depicted the texture profile. The maximum point of the compressive stress-strain curve was then used to calculate compressive strength. Furthermore, during the test, the maximum applied force (in Newtons/square millimeter (N/mm^2) is used to determine the hardness of the sample.

Next, the maximum applied force (in Newton Units (N) was used to assess the hardness of the sample during testing. A Shore Durometer Instrument (Shore A Hardness, in size, China) was used to perform the puncture strength test. During the test, a probe was used to puncture the brakes. Measured on a scale from 0 to 100.

4. Results and Discussion

Figure 5 depicts the results of the digital microscope analysis. Figs. 5(a-c) depicts the physical image of a brake pad sample, Figs. 5(d-f) depicts the outer surface of a brake pad sample, and Figs. 5(g-i) depicts the inner surface of an inner sample.

The physical appearance of the specimen showed that the brake pad specimen with the lowest and medium catalyst composition had a white appearance (see Figs. 5(a and b). Meanwhile, the specimen with the highest catalyst composition had a clearer physical appearance (see Fig. 5(c)) In addition, holes were also seen in the brake pad specimen. Therefore, all brake pad specimen contains holes. The results of surface analysis (both on the outer and inner) show that the brake pad surface is not heterogeneous (see Figs. 5(d-i)). Then, the holes observed on the micrograph indicate the absence of chemical bonds between the components of the mixture [6].

Figure 6 shows the results of the compression test. From this figure, the greater compressive resistance of the material is indicated by the higher compressive stress obtained from the compression test. Fig. 2 shows the highest peak for the brake pad C specimen. The detail values for the brake pad specimens A, B, and C are 307.4; 331.1; and 334.3 N, respectively (see Fig. 6). Thus, based on the compression test, the toughest specimen is brake pad specimen C. However, specimen B is also not less hard than specimen C because the hardness of specimens B and C can be said to be relatively the same.

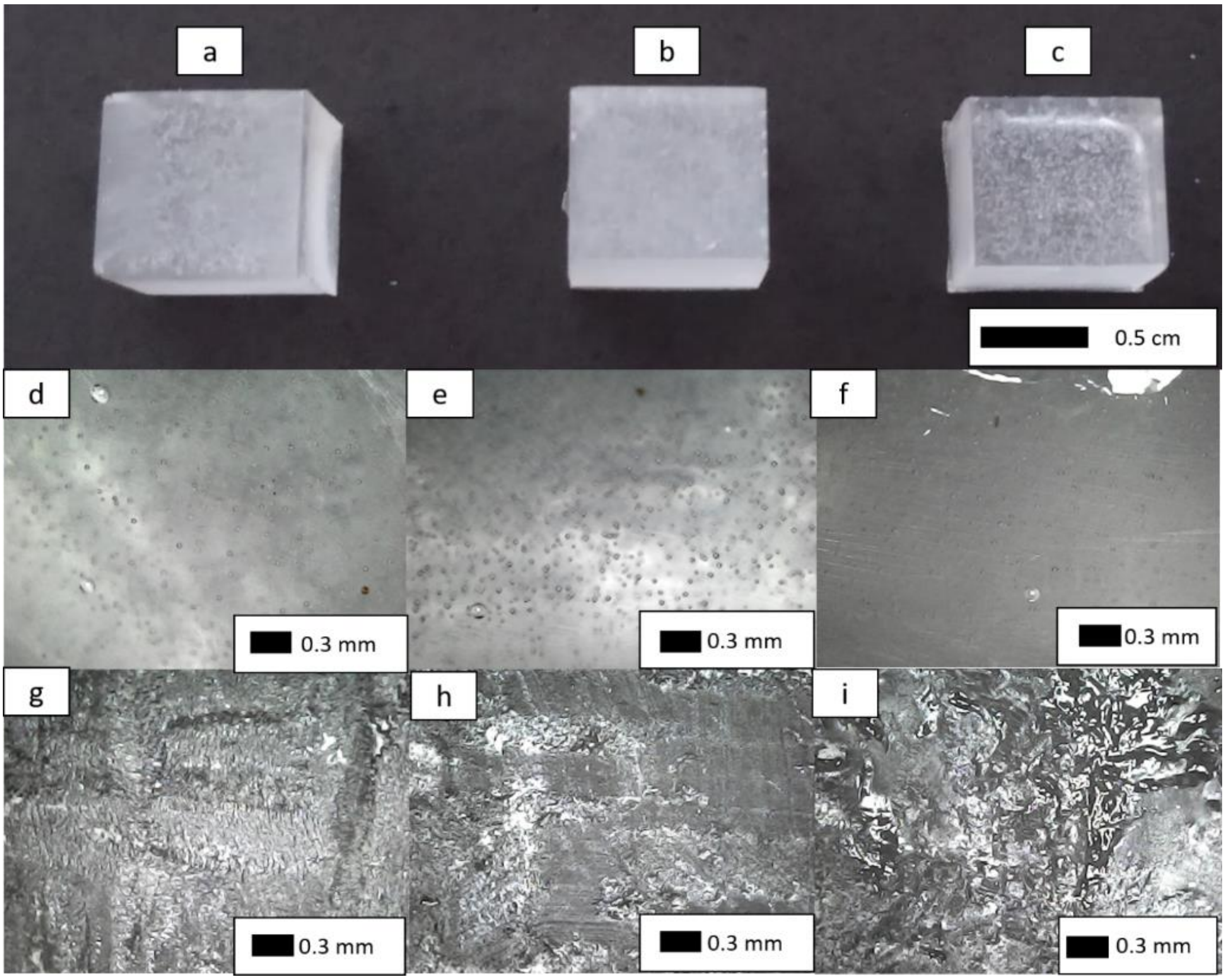

Figure 5. Photograph images of the brake pad with composition of resin-to-catalyst: (a) 1:1, (b) 1:2, and (c) 1:3. The inner and outer surfaces of the brake pad samples with a resin-catalyst composition of 1:1 (d and g), 1:2 (e and h), and 1:3 (f and i)

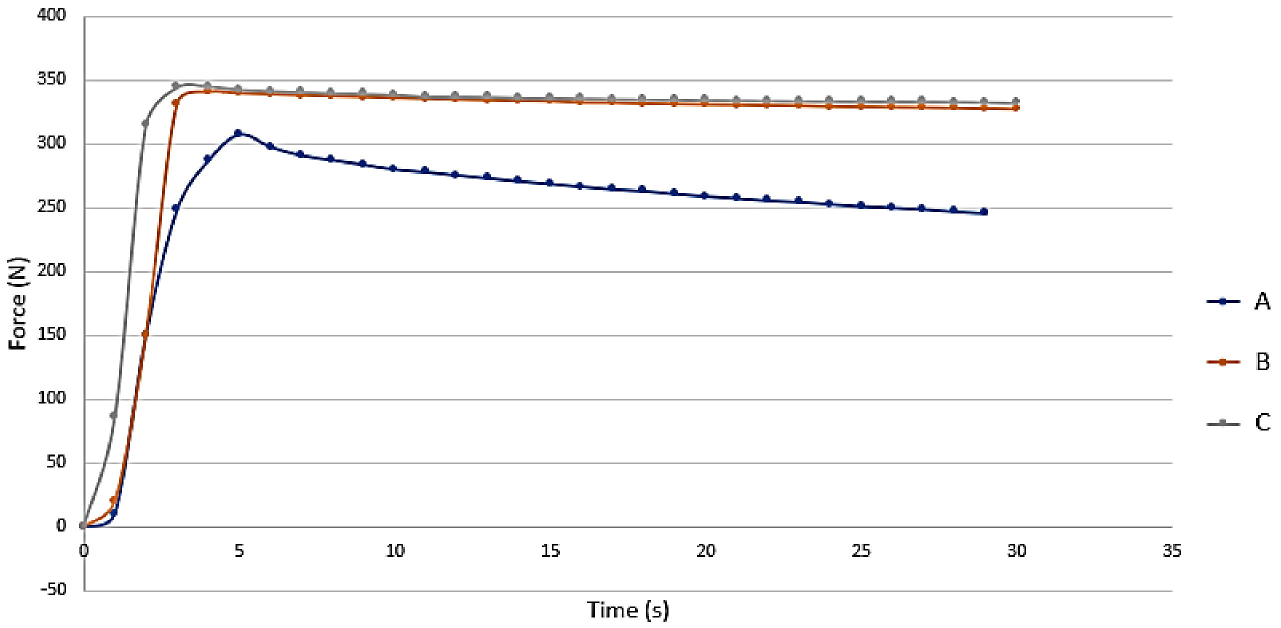

Figure 6. The compressive stress-strain curves

A puncture test was carried out to confirm the compression test results. Table 1 displays the results of the puncture test. The puncture test results show that when the hardness level is low, a higher value is obtained. The depth of the needle inserted into the specimen is represented by the specimen hardness value. A deeper puncture indicates that the specimen is more brittle [7]. The results of this puncture test are consistent with the results of the compression test (Fig. 6), which revealed that the brake pads with the highest hardness were obtained sequentially by specimens C and B (see Table 1).

Table 1. The puncture strength result

Brake Pad Specimen	Puncture strength result
A	96.41
B	92.14
C	91.14

This catalyst is used to aid in the drying of resin. The amount of catalyst mixed determines how long it takes for the resin to turn into plastic. In this study, the more catalysts added, the faster the hardening process, but if the catalyst is added too much, the brittle material or resin can burn. A good amount of catalyst to add is one percent of the resin volume. Higher catalyst increases cross-linking so that the sample becomes stronger [8]. Based on this research, the ideal compositions to make a strong brake pad are when using 1:2 and 1:3 composition.

Although the material was supported by the puncture strength results, further analyses are needed. For example, the analyses of additional microstructure mechanical properties are required as we did in our previous studies [9–13]. The additional friction analysis is also needed for ensuring and comparing the present materials with commercial brake pad, informing whether the prepared materials fit with standard [2, 3]. Further, comparison with bibliometric [14] and the techno-economic analysis [3, 15] for understanding the feasibility of the production of the prepared material in industry is crucial. All analyses will be done in our future work.

5. Conclusion

This study demonstrates the production of brake pad from epoxy resin. Overall, the results of the analysis showed that increasing the amount of catalyst composition gave good mechanical results in the fabrication of brake pads without reinforcing materials. Brake pads B and C with an ideal amount of catalyst composition have the best mechanical properties than sample A. This is based on the results of the hardness test, pressure test, and friction test has been carried out. The greater the amount of catalyst composition in the brake pads accelerate the hardening process because a higher amount of catalyst increases cross-linking. Thus, the sample becomes stronger. It is hoped that this research can be basis for a study on the development of brake pads.

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