ABSTRACT

Replacement of Phenolic Resin by Novel Eco-Friendly Resins in Copper-free Brake Pads

Friction materials (FMs) in brake pads/brake shoes, clutch facings, etc., play a crucial role in meeting the vehicles' desirable and reliable braking performance. Their formulations make up a well-balanced combination of resin/binder and other ingredients, such as fibers, friction modifiers, and space fillers. Phenolic resins (a family of thermosetting polymers) are invariably used as binders. They provide structural integrity by holding the multiple ingredients together firmly and efficiently to perform their intended tasks. However, phenolics have serious problems, including those related to environmental pollution.

- Short shelf life renders them useless during transportation and storage unless extra care (preserving in cold and humid - free storage) is taken to extend the life to a small extent. It adds to the cost. This is the most challenging problem in the friction industry.
- During product molding, noxious volatiles (ammonia, formaldehyde, etc.) evolve, causing pollution and cracks, cavities, and fissures in the molded product.
- During curing, condensation products are evolved, leading to shrinkage and dimensional changes in the molded product
- During its synthesis, harsh chemicals such as NaOH are required as catalysts.

As a result, one of the most pressing problems in the friction industry is the successful replacement of phenolic resins with a new resin that would not have the same problems with equal or better performance.

This thesis has attempted to address these issues to the extent possible. New resins, such as high-performance epoxy, thermosetting poly aryl ether ketone (PAEK), Polybenzoxazines (PBZs), and cardanol-based PBZs were explored for developing eco-friendly (Cu-free) brake pads with eco-friendly resins and compared with the pads with identical composition but containing straight phenolic resin (benchmark samples).

Another challenge was to improve the performance of existing phenolic-based brake-pads by surface treatments (siloxane and plasma) of a selected novel functional filler (Diatomite) and to assess the comparative potential of both treatments.

Additionally, two functional fillers with porous structures (hollow inside) viz. particulate Diatomite and Promaxon-D(PD) were selected to compare the potential to improve the

performance of brake-pads. Promaxon pads performed better; as a result, the proportion of Promaxon-D in the formulation was optimized for tribo and noise vibration performance.

With these considerations, the following themes were selected for the research studies. The work was organized into nine chapters. The first was the introduction, and the second was experimental. The chapters 3rd to 8th were based on working on the following themes.

- Optimization of the amount of a functional filler, Promaxon-D, to enhance the performance of Cu-free brake-pads – (Chapter 3)
- Performance enhancement of brake pads by surface treatments of Diatomite- a functional filler- and to evaluate the comparative potential of Promaxon D and Diatomite particles as tribo and NV fillers – (Chapter 4)
- Novel high-performance epoxy resin as a replacement for phenolic resin in Cu-free brake-pads – (Chapter 5)
- PAEK, a high-performance thermoset polymer as a replacement for phenolic resin in Cu-free brake-pads – (Chapter 6)
- Petro-based Polybenzoxazine resins as a replacement for phenolic resin in Cu-free brake pads – (Chapter 7)
- Cardanol based Polybenzoxazine resins as a replacement for phenolic resin in Cu-free brake pads – (Chapter 8)

The thesis ends with the last chapter, conclusions, and scope for future work.

The first chapter addresses issues related to phenolic resins and the need to replace them. It then focuses on relevant literature pertaining to the selected themes, followed by research gaps, motivation to work, problem definition, objectives, and implementation strategy.

The second chapter details materials selected in parent formulations. The theme ingredients are discussed in individual chapters. The chapter discusses the experimental techniques for formulating and fabricating brake pads, their characterization, performance evaluation and analysis.

In each chapter (3rd to 8th), several series of brake-pads were developed, keeping parent ingredients fixed and changing the theme ingredients, either type or amount. Each chapter starts with an introduction related to the theme, brake pad formulation characterization, analysis of results, etc. It ends with salient conclusions.

A series of five types of brake-pads was developed by varying Promaxon-D content from 0-20 wt.% in step 5. The PD content of 15 wt.% in the brake-pads proved best for overall performance. In another theme, three types of brake pads were developed by adding 10 wt.% untreated Diatomite particles, treated Diatomite particles, and plasma-treated Diatomite particles, and one more series uses 10 wt.% Diatomite and Promaxon-D. The results showed that pads with siloxane-treated particles excelled in all performance properties and Promaxon-D performed better than Diatomite in all performance properties in other series.

To identify an alternative for phenolic resin, high-performance epoxy resin is used as a binder with varying amounts (15, 20, and 25 vol.%) to develop brake-pads and compared with phenolic pads (20 vol.%). Overall, brake-pads with 15 vol.% epoxy resin performed the best.

In another study, the thermosetting PAEK is used as a binder in brake-pads by altering the percentage from 4-12 wt.% in step 2 and finally, compared with 8 wt.% phenolic resin. The results showed the best overall performance is achieved with 6-8 wt.% PAEK binder.

The five types of BZ monomers were employed to fabricate brake pads and compare all performance with phenolic pads. The PBZ-dma pads excelled in almost all tribological performance and NV performance. In addition, BZ monomer has an infinite shelf life and no harmful gases throughout the manufacturing process, making it a safer choice.

Finally, cardanol was used for resin synthesis, and three distinct monomers were used to fabricate brake pads and compared with the phenolic pads. In terms of tribology and noise-vibration characteristics, PBZ-trisapm pads surpassed all other pads. Additionally, it is derived from biosources and has an infinite shelf life.

In the last chapters of the conclusion and scape for future work, salient conclusions of individual chapters were compiled, and scope was highlighted.

The cardanol-based PBZs proved to be the most successful alternative for phenolics, followed by Petro-based PBZs, and PAEK -thermoset. All three resins have full potential to replace phenolics with a little compromise on minor properties. Epoxy resin, however, did not prove that successful. Plasma treatment to functional filler Diatomite proved to be very promising.