Chapter 5

Conclusions

Brake materials made of phenolic matrix composites reinforced with flax and basalt fibers were taken up for this investigation. Thermal behavior of the composites has been analyzed by Differential Scanning Calorimetry and Thermo Gravimetry Analysis. Wear tests have been conducted for different compositions of phenolic composites under different sliding conditions using pin on disc tester. SEM is employed to examine the worn out specimens and the images of different wear mechanisms were observed. Hardness test was employed to study the hardness behavior of the composites. Based on the study the following conclusions are arrived.

1. Compression moulding of phenolic composites was found to be a successful production technique for the manufacturing of polymer composites.

2. The samples obtained are found to be a defect free and a smooth surface finish was achieved.

3. Differential Scanning Calorimetry analysis of Flax Fiber Reinforced Composites has revealed that the degradation of samples was observed beyond a temperature of 300°C. The reason behind significant loss of mass in the lignocelluloses flax fibers is due to thermal degradation of cellulose and hemicellulose.

4. The optimum percentage of flax fiber in the phenolic composites is found to be 6%\(V_f\), beyond which there appears to be reduction in the degradation
temperature of phenolic composites that reinforced with 8 and 10% $V_f$ of flax fibers.

5. BFRC-6 exhibited the maximum value of glass transition temperature. This may be due to the optimal volume percentage of basalt fiber, which was able to offer better mechanical interlocking with the matrix material when compared with other samples of our present study. Hence we believe that the better proportion of BFRC-6 may be due to the optimum percentage of basalt fiber of 6 % could be responsible for improvement in thermal stability.

6. A maximum glass transition temperature of 249.7°C was observed in the case of BFRC-6. The BFRC composites are highly interconnected by hydrogen bonding leads to higher glass transition temperature (Tg). The presence of other friction modifiers, solid lubricants and fillers may support this bonding and enhance the glass transition temperature.

7. The thermal behaviour of HFRC composites was found to be inconsistent with respect to glass transition temperature. For example a maximum glass transition temperature was exhibited by HFRC-4 while a minimum glass transition temperature has exhibited by HFRC-10, whereas the other composites HFRC-2, HFRC-6 and HFRC-8 exhibited the values of Tg in between those two extremes.

8. The optimization of HFRC fiber loading into phenolic composites could not be realized in this case as they exhibited a complex behaviour towards glass transition temperature followed by wear mechanism. As a consequence no correlation between glass transition temperature and wear in HFRC composites
was made. This behaviour may be due to inherent incompatibility that existed between the organic flax fiber and inorganic basalt fiber.

9. TGA analyses of FFRC have revealed that FFRC-6 sample alone showed a single degradation pattern unlike the other composites indicating its unique thermal stability. The FFRC-6 exhibits the best thermal stability among all the composites. For example it undergoes a final degradation at temperatures 673.31°C with the weight loss of only 2.14%.

10. When it was compared to the TGA analysis for FFRC-10, FFRC-6 and BFRC-6, the BFRC-6 is the optimum volume % to obtained the better thermal stability which could have improved the bonding with the phenolic resin matrix.

11. TGA analyses of BFRC samples have inferred that the BFRC-6 exhibits the best thermal stability among all the composites. For example it undergoes a final degradation at temperature 802.08 °C with the weight loss of only about 13.44%. On the other hand, the BFRC-10 appears to exhibit the least thermal stability along with weight loss of 14.55% at the temperature 727.19°C.

12. BFRC-6 is thermally stable up to temperature of 802.08 °C with minimum weight loss, whereas remaining BFRC samples underwent more weight loss at lower temperature. During this high temperature range, the thermal degradation of BFRC only occurs in the weakest heat resistant ingredients of the brake materials. Degradation of molybdenum disulphide at 540°C, graphite degradation at 700°C followed by rapid oxidation that released carbon
monoxide (CO) and carbon dioxide (CO$_2$) gases are the main reason behind reduction in weight loss.

13. TGA analyses of HFRC proved that the HFRC-2 exhibits the best thermal stability among all the composites. For example it undergoes a final degradation at temperature 722.14°C with the weight loss of only assert 9.95%. On the other hand, the HFRC-6 appears to exhibit the least thermal stability along with weight loss of 26.61% at the temperature 661.25°C. That is HFRC-2 is thermally stable up to temperature of 722.14°C with minimum weight loss, whereas remaining HFRC samples have more weight loss.

14. It was interesting to observe that the hybridization of fiber namely flax, basalt fibers does not seem to have offered any synergistic property to enhance the thermal stability of HFRC. This may be due to the inadequate compatibility between organic flax fiber and inorganic basalt fiber and apparently the HFRC samples showed inferior thermal stability than FFRC and BFRC samples. Among all the composites, BFRC-6 appears to have exception thermal stability when studied using TGA analysis.

15. The wear behavior of flax and basalt fiber reinforced phenolic composites with different volume fractions are analyzed with the help of wear mechanism maps.

16. The centroids of each wear regime were found out by Fuzzy C Means clustering method. Then the boundaries between the wear regimes were drawn by removing the intermediate contours of the wear map.
17. For all the materials used in this study, ironing is the dominant mechanism that prevailed during the mild wear regime, whereas the severe wear regime is dominated by the occurrence of matrix fracture and ploughing. Finally the ultra severe regime is dominated by fiber matrix debonding and fiber fracture.

18. From the wear studies of FFRC, it can be concluded that FFRC-6 is found to be better wear resistant material when compared to FFRC-2, FFRC-4, FFRC-8 and FFRC-10 samples.

19. The wear studies of BFRC have proved that the BFRC-6 is found to have better wear resistance than BFRC-2, BFRC-4, BFRC-8 and BFRC-10 samples.

20. The wear studies of HFRC inferred that the optimum volume percentage for incorporation of hybrid fibers in HFRC is found to be 10 %\(V_f\).

21. The inorganic basalt fiber presents in BFRC material shows the high hardness value than FFRC and HFRC samples. Also BFRC-6 exhibits maximum hardness compared to other samples that proved to be a better material for brake applications. The hardness study on brake material concluded that due to the complexity of polymer matrix nature, the hardness property is not even in all regions. Also it can be concluded that there is no correlation between wear and hardness properties for FFRC and HFRC samples. But there is correlation of hardness and wear properties for BFRC samples.

22. Finally it can be concluded that BFRC-6 sample can be recommended for automobile brake applications after subjected to professional in vivo experiments.
**Scope for Future Work**

- In the future, incorporation of organic nano powders in the phenolic composites is suggested.

- Conducting invivo experiments on the brake materials will give the clear results than invitro experiments.

- Since a high coefficient of friction is needed for braking applications, natural fibers with high hardness may be selected to replace the present fibers.

- Finding an alternate thermoplastic polymer to replace phenolic resin is a great challenge, which will provide opportunities to adopt different manufacturing techniques like injection moulding and twin screw extrusion.
Publication Based on this Research Work


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