INFLUENCE OF GRAPHITE ON PERFORMANCE PROPERTIES OF PHENOLIC BASED FRICTION COMPOSITES

by

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Submitted

In fulfillment of the requirements of the degree of Doctor of Philosophy

to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI

AUGUST 2008

CERTIFICATE

This is to certify that the thesis entitled " **Influence of Graphite on Performance Properties of Phenolic Based Friction Composites** " being submitted by **Mr. Dilip Kumar Kolluri** to Centre for Polymer Science and Engineering (CPSE), Indian Institute of Technology, Delhi is worthy of consideration for the award of degree of **Doctor of Philosophy** and is a record of the original bonafide research work carried out by him under our guidance and supervision and has fulfilled the requirements for the submission of this thesis, which to our knowledge has reached the requisite standard.

The results contained in this thesis are original and have not been submitted, in part or full, to any other University or Institute for the award of any degree or diploma.

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Acknowledgement

First of all I would like to offer utmost thanks to my **Lord the Saviour Jesus Christ** for His benevolent shower of grace that led me throughout this arduous work.

I find words falling short in expressing the multitude of ever flowing gratitude for two special people, my supervisors, **Prof. Anup Kumar Ghosh** and **Prof. Jayashree Bijwe** because of whose impetus, sustained efforts and able and persistent guidance, the research project could be undertaken and fostered me with the strength and spirit to see to its culmination. I must not forget less, their timely catering to my otherwise tough needs posed by times past, which enabled me to garner enough strength to persuade the uphill task in the face of turmoil.

It is a pleasant aspect to express my deep sense of gratitude to all who have helped me along my way through the doctoral studies and a memorable stay at IIT Delhi. There are, of course, very few words to properly thank all of them.

My thanks are due to the members of my Ph.D committee **Prof. A. K. Gupta, Prof. S. N. Maiti** and **Prof. R. K. Pandey** for the valuable suggestions and advice. I express my sincere thanks to **Dr. Naresh Bhatnagar** for his kind cooperation, support and benevolent gestures throughout the course of this work. I am also thankful to **Prof. I. K. Varma, Prof. Veena Choudhary, Prof. A. R. Ray and Dr.Josemon Jacob,** all from CPSE for their support whenever I needed.

My sincere heartfelt thanks to **Prof. Gerard Degallaix, Dr. Yannick Desplanques** and **Dr. Xavier Boidin,** *Laboratoire de M'ecanique de Lille (UMR CNRS 8107), Ecole Centrale de Lille, France* for they have been very supportive and helpful in preparing one full chapter of this research work by providing the necessary facilities to

stay and work on the tribometer. The interaction and discussions I had with them have enlightened me a path to my research progress.

I take immense pleasure in expressing my sincere gratitude to **Prof. P. R. Bijwe**, whose affection and blessings along with his objective oriented suggestions kept me going throughout this period.

I accord my thanks to **Dr. Shashi Motilal**, for boosting up my spirits and her suggestions now and then.

I am extremely thankful to **Mr. Tulsiram** (Jr. Technical Superintendent) who has been a constant help and support throughout. **Mr. Avtar Singh** (Jr. Technical Superintendent) deserves special thanks **since** without his help in experimental work, this thesis would not have seen the day-light.

Mr. Kushwaha(Technical Superintendent), **Mr. Mukhesh(Assistant), Mr. Ashok Kapoor** (Technical Superintendent), **Mr. Shivkant** (Jr. Technical Superintendent), **Mr. Devander Singh** (Jr. Technical Superintendent), **Mr. Surender Sharma** (Technical Superintendent), **Mr. A. Kapoor** (Technical Superintendent), **Mr. Pratap** (Jr. Technical Superintendent), are needless to be mentioned along with all the other technical staff of CPSE and ITMMEC for their cordial association and timely help rendered during the tenure of this work.

I extend my very personal thanks to **Mr. B.S. Tomar** of Allied Nippon Industries for his invaluable information and **Mr. Kamal Bhola** for their unconditional and selfless cooperation and help as and when required by me.

I express my special thanks to **Dr. N. C. Mehra**, USIC, Delhi University, Delhi, for his valuable contribution in the SEM study of the samples.

No amount of gratefulness is sufficient to express my indebtedness to **Dr. Bhabani Kumar Satapathy** for his love, successful suggestions and guidence in all the aspects of research and personel life during my I I T life.

My special thanks to my colleagues and friends, **Dr. John Rajesh, Dr. Purnima, Dr Nidhi, Dr Fahim, Mr. Rama Krishna, Mr. Mohit, Mr. Koteswara Rao, Mr. Mekala Bhikshapathy, Mr. Sashidhar Ram, Mr. Hari Nag, Ms. Aditi, Dr. Kavita, Ms. Sangita, Mr. Prasath Balamurugan, Mr. Prakashan, Dr. Gurunath, Mr. Mukesh, Ms. Sukhdeep Kaur, Ms. Rekha Ratan, Ms. Himani, Mr. Parvin, Ms. Dipti, Dr. Neetu, Dr. Rashmi, , Mr. Satish, Mr. Satpal, Mr. Saikat, Mr. Manas,** and **Dr. Senthil Kumar** for their all time cooperation, fun and frolicking which nonetheless added zest and humour to life, during the entire period.

I cannot help but feel from my depths for my dear friends **Mr. Purna Chandra Kumar, Mr. Gopi, Mr. Ajay, Mr. Pradeep, Ms. Yamini, Mr. Ramana** and **Ms. Jahnavi** in whose long association and companionship and with their numerous assistance and unfailing support in my testing times made my stay in IIT a memorable one.

I cannot, at this moment fail to remember with utmost love, my parents and brother and sister who have tolerated my long absence and bore me with patience all through.

Last but not the least, the incessant love, cooperation and perseverance put forth by my Fiancee, **Ms. Haritha Rani**, has made the accomplishment of the work a spirited affair, to be remembered forever.

With this I surrender to my Almighty, **Adona**.

(Dilip Kumar Kolluri)

ABSTRACT

The friction materials are used in a variety of applications such as brakes, clutches, etc. These are sacrificial materials intended to provide necessary friction under all mild to severe service conditions. The formulation of these materials which need to satisfy number of performance properties is a multiple criteria optimization problem and hence it is still treated as an art rather than science by the Industry.

Non-asbestos Organic (NAO) resin based composites are most popular and friction materials for today's industry for automobiles and locomotives. It is basically because of the ban on asbestos and ever increasing performance requirements in friction materials for aggressive operating conditions.

NAO based composites consists of four classes of materials viz., organic resins as binders, fibers as reinforcements, abrasives and lubricants as friction modifiers and inert materials as volume fillers. In these composites, abrasives are added to boost the coefficient of friction (μ) to a desired level. These abrasives, however, impart fluctuations in μ. To accommodate this problem, solid lubricants (viz. graphite, MoS_2 etc,) are added in adequate amount. Among the solid lubricants, graphite is the most popular and widely used in friction materials, the amount being around 10-15 wt%. It smoothens the fluctuations in μ leading to stable μ during frequent brakings. Interestingly, it has a dual role. It not only moderates the μ at lower temperature performing as a solid lubricant, it also tries to boost the μ at elevated temperatures when the friction material is used in severe operating conditions and is vulnerable to temperature related problems causing fade due to organic contents such as resin Aramid pulp, CNSL powder etc. Lubricity of graphite is based on the adsorption of moisture. Elevated temperature leads to desorption of moisture and affects its lubricating efficiency. Thus as a matter of fact, it sometimes

enhances the μ in such situations, additional increase in μ at elevated temperature compensates for the fade in μ due to high temperature. Moreover, graphite being very good conductor of heat, helps heat dissipation at the interface efficiently leading to minimizing the fading in μ and deterioration of the binder. It also has added advantages of very good compatibility with phenolic resins and other general ingredients, low cost and easy availability. The literature, however, does not provide clear evidences on this aspect and is silent over graphite related issues in friction materials.

A variety of graphites varying in its origin, purity, crystallinity, thermal conductivity, size, shape etc. is available commercially and used in friction composites based on available field experience rather than scientific information or support. Though it is universally accepted fact that these variable features of graphite can affect tribological properties of any composite, hardly any literature pertaining to this fact is available in case of friction composites.

In this scenario it was extremely urgent and important to

- understand the role of graphites in controlling friction and wear performance of composites and,
- generate the data and reasoning which would help the practitioners to select the right type of graphite for their formulations.

On this background, this research work was focused to investigate the role of graphites with varying origin (natural and synthetic), particle size and crystallinity on performance properties of brake-materials in the form of brake-pads under three major testing modes viz. load-speed sensitivity of friction coefficient, fade and recovery behavior and thermal localization phenomenon on the disc.

The proposed research work was accomplished by selecting fourteen graphites with different properties (origin, size and crystallinity) and categorizing them into three major series and sub series as follows.

Series 1: Differing in particle size keeping crystallinity and origin (natural) constant

Series 2: Differing in particle size keeping crystallinity and origin (synthetic) constant

Series 3: Differing in origin (natural and synthetic) keeping crystallinity and particle size constant

To investigate and highlight the performance properties of these graphites, the formulation was designed in such a manner that all the ingredients of full scale friction composites were kept identical in the type and amount except the type of graphite (10 wt. %). In all, fourteen composites in the form of brake-pads and tensile specimens were formulated and fabricated.

The developed composites were characterized for physical, thermal, and mechanical properties. The brake-pads were evaluated on three types of testing modes. First, on reduced scale proto type rig (RSP) to evaluate sensitivity of μ towards load and speed. Second was a Krauss machine for fade and recovery behavior of the composites basically intended to investigate sensitivity of μ towards temperature. The third was specially designed pin-on-disc tribo-meter for evaluating counter face friendliness in more realistic and more severe conditions. In depth studies brought out the influences of variation of each feature of graphite keeping other two constant on tribo-performance in three major modes.

Natural graphite proved to be a better choice than the synthetic one in most of the performance properties. It was concluded that the larger sized graphite particles rendered high performance μ under mild operating conditions which showed sharp decline under

severe conditions indicating unsuitability of larger sized particles. Very fine particles also proved unsuitable since these could not lead to desired friction level for the brake-material. These graphites, however, proved the best in terms of minimal tendency to generate hot –spots on the disc. Over all, moderate sized particles (137 μm) proved best performers in terms of sensitivity of μ towards load, speed and temperature (Fade & Recovery studies). These were superior from wear point of view also but not from hot-spots generation point of view. The selection of friction material is a multi-criteria decision problem and is handled based on weight-ages of the performance parameters. Keeping this in view, natural graphite having average particle size in the range of 137 μm and crystallinity in the range of 80% can be recommended for developing brake- material of required performance.

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