

## **Evaluation of Strength of Novel Polymeric Resinous Matrix for Industry**

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### **INTRODUCTION:**

The function of clutch is to transmit power from one point to another and the brakes has to decelerate the speeding counter-surface. In both the cases, the interface between clutch/brake surface and the counter-surface undergoes intense frictional action that results in higher instant flash temperature that in turns causes loss of frictional response hence affects the performance. Therefore, material designing of such parts needs paramount attention for the best running performance.

Continuous emphasis on the development of durable and efficient friction materials for the braking applications conforming to the stringent norms, such as, higher friction coefficient, negligible fading, faster recovery, better wear resistance, low-sensitivity towards load-speed alterations, least noise and vibration propensity for safe and reliable operation over a wider range of braking application has been the theme of automotive braking industries.

Friction and wear behaviour of automotive brake lining is complex and depends on uniform distribution of heterogeneous composition, operating parameters like temperature, rubbing/sliding speed, contact pressure and the surface characteristics of the counter face. These must have adequate strength/ compressibility in order to withstand high contact pressure. These must have adequate shear strength in order to transfer the friction forces to the structure. These should have good thermal properties like high heat capacity, good thermal conductivity and oxidation stability. This enables the composite lining to withstand high interfacial frictional heat or the temperature rise without degrading itself. Good thermal resilience enables high resistance to thermal cracking and thermal fatigue.

To perform various characterization in order to justify commercial viability of the product and to co-relate various thermo-physical-mechanical characteristics and their possible influence on the braking tribology and wear performance. The braking performance or frictional response and wear behaviour of these composites are evaluated using standard test protocol on Krauss friction tester.

### **LITERATURE REVIEW:**

Dante et al. proposed a relation: Specific wear rate ( $w$ ) =  $v/p$ , where  $w$  has unit of volume energy<sup>-1</sup>,  $v$  is wear rate expressed as depth lost per unit time,  $p$  is dissipated powder density (during normal braking instances the  $p \sim 2-5 \text{ kWcm}^{-2}$ ) and given by  $P/A=T\omega/A$  where  $P$  is dissipated power,  $A$  is apparent area of friction material,  $T$  is the torque and  $\omega$  is the angular velocity. At lower  $p \sim 2 \text{ kWcm}^{-2}$  the specific wear rate is nearly constant thereafter it increases linearly ( $\sim 750 \text{ s}$ ) and becomes constant after prolonged rubbing.

Serverin et al. studied complex friction system in industrial brakes. According to them the effective friction mechanism probably results from the interaction between the local friction surface temperature, the local friction intensity, the heat depended thermal contact resistance and in large brake systems the deformation of the metal friction partner.

Myshkin studied transfer film formation in boundary lubrication condition. According to them failure mode, debris formation and transfer of matter were based on two main mechanical concepts: (1) adhesion and formation of interface junction that further subjected to shear; (2) accumulation of subsurface damage (fatigue) and separation of failure fragments results in crack development and propagation. The boundary lubrication affects the friction transfer process by localizing shear stresses in thinner layers and changing the size, number and chemical composition of the debris.

Liu et al. studied transfer film characteristics of organic pad; they observed that by doubling load and speed, drum wear rate increased by 70% whereas pad wear rate increased by 250%.

Satapathy et al. studied frictional performance of friction materials based on 3% variation in nature of organic fibres Aramid pulp (A), PAN (A), Carbon(C), cellulose (S). They reported that the fade and recovery characteristics of the investigated composites are within the permissible ranges of 0–30% and 90–140%.

The literature study reveals that resinous (a thermosetting phenolic resin and its variants) constituents contributes significantly in providing physical integrity to the brake friction composite materials by holding the ingredients together firmly at all the times, under the mechanical and thermal stresses during the braking operation so that friction composite can adequately and reliably contribute to the performance.

### **RESEARCH GAPS**

The review of literatures presented above and reveals the following research gaps that need to be paid attention:

There are fewer research reports regarding influence of phenolic resin and its variants or modifications. It is interesting to explore/extent the research based on different modified form of phenolic resins or other grades of binderresin. A comparative analysis of the performance data, then clearly reveals the applicability/significance of resin to a particular brake lining for commercial application.

### **DESIGN OF FORMULATION**

The present investigation aims to explore the optimisation the quantity of straight phenolic resin, possible modification and combination of straight phenolic and modified versions to enhance the performance properties of brake composite. The main focus of the work is to establish a possible correlation between the composition variables and performance- attributes specifically with regards to enhanced frictional-response, fade-resistance and faster recovery performance with promising wear reduction for the automotive braking application.

**Table 1 Design of the formulation for optimising of amount of straight phenolic resin on NVH properties of a friction material composite (N-series):**

| <i>S.No</i> | <i>Ingredients Name (%wt.)</i> | <i>Composite Nomenclatures</i> |           |           |           |
|-------------|--------------------------------|--------------------------------|-----------|-----------|-----------|
|             |                                | <i>N1</i>                      | <i>N2</i> | <i>N3</i> | <i>N4</i> |
| 1           | Pan fiber                      | 10                             | 10        | 10        | 10        |
| 2           | Barium sulphate                | 27                             | 25        | 23        | 21        |
| 3           | Rockwool fiber                 | 25                             | 25        | 25        | 25        |
| 4           | Natural graphite               | 10                             | 10        | 10        | 10        |
| 5           | Copper powder                  | 10                             | 10        | 10        | 10        |
| 6           | Fused Alumina                  | 5                              | 5         | 5         | 5         |
| 7           | NBR powder                     | 5                              | 5         | 5         | 5         |
| 8           | Phenolic resin                 | 8                              | 10        | 12        | 14        |

**Table 2: Design of the formulation to analyse influence of modification of phenolicresin on life of railway brake block (M- series):**

| <i>S.No</i> | <i>Ingredients Name (%wt.)</i> | <i>Composite Nomenclatures</i> |           |           |
|-------------|--------------------------------|--------------------------------|-----------|-----------|
|             |                                | <i>M1</i>                      | <i>M2</i> | <i>M3</i> |
| 1           | Kevlar                         | 5                              | 5         | 5         |
| 2           | Barium sulphate                | 20                             | 20        | 20        |
| 3           | Rockwool fiber                 | 20                             | 20        | 20        |
| 4           | Synthetic graphite             | 15                             | 15        | 15        |
| 5           | Copper powder                  | 15                             | 15        | 15        |
| 6           | Alumina                        | 5                              | 5         | 5         |
| 7           | SBR powder                     | 8                              | 8         | 8         |
| 8           | CNSL Modified resin            | 12                             | --        | --        |
| 9           | Linseed oil Mod. resin         | --                             | 12        | --        |
| 10          | Alkyl Benzene Mod. resin       | --                             | --        | 12        |

**Table 3 Details of the fabrication conditions of the composites:**

| Procedure | Conditions |
|-----------|------------|
|-----------|------------|

|                       |  |
|-----------------------|--|
| Mixing of ingredients | Plough shear mixer with plough at 150 rpm and chopper at 3000 rpm. First Aramid pulp and barium are mixed for 30 minutes; all other ingredients are mixed with previously opened mixture of aramid and barium for 5 min. Thus total mixer run up time is 35 minutes. |
| Compression moulding  | Hot moulding is done by compression moulding machine under pressure of 250 kg/cm <sup>2</sup> for 4-8 min at 150-160°C.  |
| Post curing           | Post curing is done in electric oven at 160-180°C for 5 -8 hours.  |
| Finishing             | Light polishing or upper surface grinding by grinding wheel to attain desired thickness and to remove glazed surface   |

**RESULTS AND DISCUSSION:**

**A Chemical, Physical and mechanical characterization of N-series friction composites**

The physical and mechanical characteristics of friction composites of N-series are illustrated in Table 4. The following salient observation could be marked:

The variations in the ash content (~34.3-40.2%) magnitude observed to be consistently influenced by the presence straight phenolic resin which shows better thermal stability. When roasting at high temperature for several hours the organic matter present in the friction composites finishes and leaving only thermally stable materials i.e. copper powder, barium sulphate, rock wool fibre and fused alumina. Thus, in general magnitude of ash content follows increasing trend with composition variables, except N4.

**Table 4: Physical and mechanical properties of the N-series composites to evaluate the effect of straight phenolic resin on performance properties of composite:**

| <i>Properties</i>  | <i>Unit/ scale</i>  | <i>N1</i> | <i>N2</i> | <i>N3</i> | <i>N4</i> |
|--------------------|---------------------|-----------|-----------|-----------|-----------|
| Rockwell Hardness  | HRL                 | 80        | 83        | 87        | 91        |
| Ash content        | % Wt.               | 34.3      | 35.5      | 40.2      | 39.7      |
| Cold shear         | Kgf/cm <sup>2</sup> | 31.4      | 35.4      | 35.1      | 42.1      |
| Hot shear          | Kgf/cm <sup>2</sup> | 25.7      | 28.6      | 30.3      | 29.6      |
| Cold Adhesion area | %                   | 70        | 72        | 75        | 71        |
| Hot Adhesion area  | %                   | 65        | 70        | 74        | 69        |
| Porosity           | %                   | 15.7      | 14.8      | 14.7      | 14.2      |
| Heat swell         | mm                  | 0.19      | 0.18      | 0.12      | 0.15      |
| Water swell        | mm                  | 0.07      | 0.06      | 0.05      | 0.06      |
| Compressibility    | %                   | 2.1       | 1.95      | 1.88      | 1.96      |

The increase in the mechanical properties may attributed to the fact that increase in the resin proportion increases the micro-packing of the fibres in the cured and cross-linked network, that cause mechanical compaction of the fibrous ingredients thereby shows effective synergism, as has already been reported in. The role of fibre combinations to be influencing the strength of the composites is well reported in literatures. The lower strength magnitude may attribute to improper/poor interfacial adhesion between matrix and other ingredients probably because of insufficient resin to adhere other ingredients that lowers the effectiveness of stress transfer.

**A Physical and mechanical characterization of M-series friction composites**

The physical and mechanical characteristics of friction composites of M-series are illustrated in Table 5. The following salient observation could be observed; the void fraction (~18.26-17.27%) which shows that linseed oil modification and Alkyl benzene modification decreases the void content or porosity of the composite, hardness (~85-83HR-L) decreases, Ash content is highest in composite made with linseed oil modified resin as it has highest loss during LOI. Adhesion area is most important property for a brake pad and it is highest in composite made with Alkyl benzene modified resin which

shows a better bonding property of composite with back plate. Heat swell and water swell are directly related to field performance and these are also lowest in M3 composite having alkyl modified resin.

**Table 5: Physical and mechanical properties of the M-series composites to evaluate the effect of different modifications phenolic resin on performance of composite:**

| <i>Properties</i>  | <i>Unit/ scale</i>  | <i>M1</i> | <i>M2</i> | <i>M3</i> |
|--------------------|---------------------|-----------|-----------|-----------|
| Rockwell Hardness  | HRL                 | 85        | 82        | 83        |
| Ash content        | %Wt.                | 38.20     | 38.08     | 37.82     |
| Cold shear         | Kgf/cm <sup>2</sup> | 32.26     | 33.89     | 37.48     |
| Hot shear          | Kgf/cm <sup>2</sup> | 26.12     | 25.49     | 31.89     |
| Cold Adhesion area | %                   | 90        | 85        | 95        |
| Hot Adhesion area  | %                   | 70        | 70        | 82        |
| Porosity           | %                   | 18.26     | 16.28     | 17.27     |
| Heat swell         | mm                  | 0.21      | 0.20      | 0.08      |
| Water swell        | mm                  | 0.06      | 0.07      | 0.03      |
| Compressibility    | %                   | 2.50      | 2.35      | 1.99      |

Results of selected resins reveals that all properties of resin meet the industrial specifications and suitable for use in friction composite, as shown in table 5. Hexamine content which is responsible for fast curing to bind the all ingredients of the composite is 11.03 in linseed oil modified resin. IPF (3.3-4.7 cm) and highest in linseed oil modified resin, Gel time (87-96 sec) highest in Linseed oil modified Melting point and ashcontent are (78-96 °C) and (0.27-0.53 %) respectively. Melting point gives an idea of maintain and set moulding temperature.

**Based on final optimization by TOPSIS method, ranking of friction composites was:**

Ranking of type-1 friction materials: N3>N1>N4>N2

Ranking of type-2 friction materials: M3>M2>M1

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