COMPARATIVE STUDY ON THE EFFECT OF FIBRE SUBSTITUTION ON THE PROPERTIES OF COMPOSITE RAILWAY BRAKE SHOE

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Abstract: During the design process, railway friction materials are subject to extensive testing which allows for a thorough assessment of their compliance with versatile requirements and expected characteristics. These tests include, among other, laboratory tests of mechanical, physicochemical, thermophysical and tribological properties. For a designer it is crucial to understand how formulation modification influences characteristics of the friction material. One of the key ingredients in the formulation of friction materials is reinforcing fibre. In this study, two composite, organic railway brake shoes with equal amount of two different reinforcing fibres, namely steel wool and glass fibre, were tested according to the procedures of a railway friction materials manufacturer. Test results were analysed and compared. The substitution of reinforcing fibre had a noticeable effect on each of the properties of the composites considered in this study.

Keywords: friction material formulation, coefficient of friction, dynamometer test, composite brake shoe.

1. INTRODUCTION

Composite materials are defined as multiphase materials obtained by artificial combination of different materials, so as to attain properties that the individual components by themselves cannot attain [1]. The properties of interest in the course of the design process of composite friction materials are: i) frictional characteristics, such as coefficient of friction and its dependency on the operation conditions as well as wear of the friction material and counterface material, ii) mechanical and physical properties, iii) environmental aspects and iv) price. Thermophysical properties of the friction material such as thermal conductivity and heat capacity are also important to characterise the material because of their influence on the heat flow during contact of the friction pair which in turn has crucial effect on frictional behaviour. It is of high importance to predict how changing of the formulation, i.e. contents of the constituents, may influence certain properties of the composite. However, as these relations are of very complex nature, this knowledge is often empirical and mostly qualitative rather than quantitative [2, 3].

Friction materials are subject to high shear and compressive forces while phenolic resin – a typical binder – is brittle. To reinforce the composite, fibres were introduced to the composition of the friction material almost from the beginning of development of composite friction materials based on phenolic resin [4]. In recent 20 years, one of the challenges for the manufacturers of the friction materials was to find a suitable raw material to substitute asbestos which is a known carcinogen [4]. Possible ways to substitute asbestos and additionally improve other properties of the composite were thoroughly investigated. The range of the fibres used for this purpose includes, among other: glass, metallic (steel, brass, aluminium), aramid, thermoplastic, acrylic, potassium titanate, sepiolite, ceramic, mineral, carbon and cellulosic fibres [4–6]. Apart from mechanical strength, fibres can influence tribological properties, e.g. reduce wear or increase value of the coefficient of friction. It is common to use more than one type of reinforcing fibre in order to attain all of the desired characteristics [4].

Binder used commonly in composite friction materials, namely phenolic resin is characterised by poor thermal conductivity. To improve it, allowing for better heat dispersion, fibres which have high

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thermal conductivity may be introduced to the formulation. The effective thermal conductivity depends not only on intrinsic thermophysical properties of the ingredients and their concentration, but also on their morphology and geometry. Thermal conductivity is improved when the thermally-conductive particles touch one another and form a continuous heat conduction path [7].

Although there are many papers investigating the relationship between formulation of the friction material and its properties, not many concern materials used in railway braking. In this study the effect of substitution of glass fibre with steel wool on properties of railway brake shoe was investigated.

2. EXPERIMENTAL

Two mixtures and two associated sets of prototype brake shoes were manufactured. Both mixtures contained reinforcing fibre in the same weight concentration. They are denoted Material A and Material B. Material A contained glass fibre, while Material B contained steel wool. The remaining constituents in the formulation, their weight concentration as well as manufacturing process were kept identical for both materials (Table 1).

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Material A</th>
<th>Material B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass fibre</td>
<td>25–35%</td>
<td>0%</td>
</tr>
<tr>
<td>Steel wool</td>
<td>0%</td>
<td>25–35%</td>
</tr>
<tr>
<td>Balance</td>
<td>65–75%</td>
<td>65–75%</td>
</tr>
</tbody>
</table>

The experimental part of this study covered characterisation of i) mechanical properties, ii) chemical and physical properties, iii) coefficient of friction on the reduced-scale dynamometer and iv) heat capacity.

Methods used to determine HB and HRX hardness, modulus of elasticity, density and acetone soluble content as well as the apparatus used in the reduced-scale friction test are described elsewhere [8].

Flexural strength was measured on a universal testing machine in a three-point bending setup on a specimen rectangular in shape under an increasing load at a crosshead speed of 50 mm/min. The dimensions of the specimen were 50×10×5 mm (length, width and thickness respectively). The specimen was placed symmetrically on the support span and the load was exerted centrally between supports. The load increased until fracture of the specimen. The test method was based on a standard method used to test plastics [9].

Shear strength was measured on a universal testing machine according to the method described in [10]. The standard requires samples to have dimensions of 20×20×5 mm (length, width and thickness respectively), however as the maximum load of the testing machine is 10 kN, the dimensions of the specimens used in the test were reduced (15×10×5 mm). Crosshead speed was 50 mm/min. The force was exerted in the direction perpendicular to the moulding direction.

Compressive strength was measured on a universal testing machine by compressing the test specimen at a constant speed in the direction along which normal (contact) force during brake application acts (the direction also parallel to this of moulding) until it fractured. The dimensions of the specimen were 10×4×10 mm (length, width and thickness respectively). The test method was based on a standard method used to test plastics [11].

Impact strength was measured by Charpy impact test [12]. The method consists in measuring energy needed to fracture a beam-like specimen. The energy of a pendulum is released in an impact to the central part of the beam. The specimen was unnotched and had dimensions of 50×10×5 mm (length, width and thickness respectively).

Heat capacity was measured on a differential scanning calorimeter at Warsaw University of Technology. Before the measurement, the samples were conditioned at 200 °C to ensure that no chemical process (eg. curing of remnant resin) will interfere with the results. The samples were in powder form (drilled from the prototypes). 20 mg of each material was used for this test. The measurement was taken in the temperature range between 20 °C and 200 °C.
The reduced-scale dynamometer test was performed according to the internal procedure of the manufacturer of friction materials for railway. The test is divided into two phases: bedding-in and assessment. Bedding-in phase comprises 6 cycles, each one including 5 brake applications, whereas assessment phase consists of 7 cycles of 10 brake applications. The total number of brake applications in the test programme is 100. Each brake application lasts 5 s, followed by 10 s pause with the brake released and the disc still rotating. During the brake application, the tested friction material samples (having the apparent contact surface of about 22 cm²) are pressed by the hydraulic actuator to the brake disc (having the diameter of 238 mm) rotating at the predetermined velocity. The braking torque is compensated by the torque generated by the electric motor. In this way constant velocity brake applications are performed. The decrease in the friction pair temperature during pause is slight, therefore the initial temperature of brake application rises as the cycle proceeds. Before subsequent cycle in the phase commences, the friction pair cools down to 100 °C. 7th cycle in the assessment phase is executed with additional cooling of the friction pair ensured by forced air convection – by means of a suction fan.

3. RESULTS AND DISCUSSION

The results of laboratory measurements of mechanical, chemical and physical properties are collated in Table 2. Material B has in general higher mechanical strength (with comparable value of compressive strength) and lower hardness. Density of Material B is higher due to the higher density of steel wool in comparison to glass fibre which is used in Material A. Acetone soluble content indicates that Material A has higher content of uncured resin. It may be explained by the fact that Material A, which contains glass fibre, has presumably lower thermal conductivity – it may have led to different heat distribution in the brake shoes during curing process, which had equal parameters for both materials, and consequently difference in the course of the chemical reaction.

Table 2. Mechanical properties of the tested materials.

<table>
<thead>
<tr>
<th>Property</th>
<th>Material A</th>
<th>Material B</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRX hardness</td>
<td>87</td>
<td>76</td>
</tr>
<tr>
<td>HB hardness</td>
<td>74.3 N/mm²</td>
<td>61.6 N/mm²</td>
</tr>
<tr>
<td>Modulus of elasticity</td>
<td>1673 N/mm²</td>
<td>870 N/mm²</td>
</tr>
<tr>
<td>Flexural strength</td>
<td>17.9 N/mm²</td>
<td>19.5 N/mm²</td>
</tr>
<tr>
<td>Shear strength</td>
<td>13.5 N/mm²</td>
<td>16.2 N/mm²</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>39.0 N/mm²</td>
<td>41.0 N/mm²</td>
</tr>
<tr>
<td>Impact strength</td>
<td>3.4 kJ/m²</td>
<td>5.9 kJ/m²</td>
</tr>
<tr>
<td>Density</td>
<td>1.93 g/cm³</td>
<td>2.35 g/cm³</td>
</tr>
<tr>
<td>Acetone soluble content</td>
<td>0.4%</td>
<td>0.27%</td>
</tr>
</tbody>
</table>

Table 3 presents the data which characterise thermal capacity of the tested composites. Material B has lower thermal capacity in comparison to Material A – its value is approximately 16% lower at 30 °C and 17% lower at 100 °C. Thermal capacity of both materials increases with temperature. Thermal capacity of Material A at 100 °C is about 20% higher than at 30 °C, while thermal capacity of Material B at 100 °C is about 18% higher than at 30 °C.

Table 3. Thermal capacity of the tested materials.

<table>
<thead>
<tr>
<th>Property</th>
<th>Material A</th>
<th>Material B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal capacity at 30 °C</td>
<td>0.87 J/(g·°C)</td>
<td>0.73 J/(g·°C)</td>
</tr>
<tr>
<td>Thermal capacity at 100 °C</td>
<td>1.04 J/(g·°C)</td>
<td>0.86 J/(g·°C)</td>
</tr>
</tbody>
</table>

Frictional characteristics tested on a reduced-scale dynamometer are presented in Figs. 1 and 2. In Fig. 1, values of mean coefficient of friction for each brake application in the test programme are plotted. Bar chart in Fig. 1 demonstrates temperature increase caused by the frictional heating. Material A exhibits more stable and repeatable frictional characteristics than Material B. The temperature-induced change in friction coefficient constitutes a repeatable pattern for Material A (see results for brake applications no. 51–90 in Fig. 1), whereas in the case of Material B, values of mean coefficient of friction in each subsequent cycle are higher than respective values in previous cycles (measured for brake applications in similar conditions).
Comparison of the reduced-scale dynamometer test results for both materials is shown in Fig. 2. Variation of the coefficient of friction in the first two cycles of the assessment phase (brake applications no. 31–50) for both tested materials may have been caused by not yet fully-developed contact surface. Starting from brake application no. 51, Material B exhibits in general higher coefficient of friction than Material A, (with the exception of brake application no. 60). For both tested materials the lowest value of mean coefficient of friction in each cycle correlates with the highest value of initial temperature. The difference between the highest and the lowest value of the mean coefficient of friction in each of the cycles is distinctly higher for Material B, which leads to the conclusion that Material B is less resistant to temperature-induced decrease in friction coefficient, i.e. fading phenomenon [13].

Fig. 3 presents exemplary relation between the mean coefficient of friction and the initial temperature of the friction pair (the data shown on the chart concern brake applications no. 72–80). In the entire range of initial temperature, Material B exhibits higher coefficient of friction, but the decrease in its value is much more pronounced than in the case of Material A. Moreover, value of the mean coefficient of friction of Material A is relatively stable up to about 175 °C, while the coefficient of friction of Material B decreases just as the initial temperature of the friction pair increases.
CONCLUSIONS

Two friction materials were thoroughly tested according to the procedures typical for brake shoes intended for use in railway vehicles. The difference in their formulation was strictly defined which allowed for analysis of the influence of two constituents, namely glass fibre and steel wool on mechanical, thermophysical and tribological properties of the friction materials. The modification in formulation investigated in this study had a noticeable effect on mechanical, chemical, physical, thermophysical and frictional characteristics of the tested composites. Substitution of glass fibre with steel wool had generally beneficial effect on mechanical strength. On the other hand its effect on the coefficient of friction was unfavourable – its value became more dependent on the temperature of the friction pair and led to high variability of the friction coefficient in the course of the test. The more general conclusion is that while designing friction materials, it is crucial not to dismiss potential influence of the changes in formulation on any of the properties significant from the functional perspective.

In future, it is planned to determine thermal diffusivity of both materials using the method described by Kochanowski et al. [14]. Thermal conductivity may be then calculated as a product of three measured values: thermal diffusivity, density and thermal capacity.

ACKNOWLEDGEMENTS

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