**Effect of Nano-Sized SiO2 Particles Addition on The Surface Roughness and Micro Hardness of Copper-Based Friction Materials**

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**ABSTRACT**

An automotive brake disk pad is a tool for slowing or stopping the motion of a wheel safely while it runs at a certain speed. For the assurance of a brake to do its function in highly performance, we developed and prepared a copper-based friction material with SiO2 nanoparticles that can be used for manufacturing a brake pad. The effect of the addition of SiO2 nanoparticles with different concentrations (0, 3, 6, and 9) % wt. to the prepared friction material was investigated. Four cylindrical samples of friction material were prepared using the powder metallurgy method to examine the roughness and hardness of the produced pad materials. The results demonstrated the nano oxide silicon with 9% SiO2 was more effective in increasing hardness by 18.11% and roughness values by 5.4%. The experimental results confirm the success of the manufacturing process of the friction material with the powder metallurgy method, and the possibility to enhance the friction coefficient of the brake pad. The prepared composition materials for brake pads has beneficial effects since the values of roughness increased and hardness were enhanced with the addition of nano particles.

**KEYWORDS**

Copper-based Friction Materials, SiO2 Nanoparticles, Powder metallurgy, Hardness, Roughness

**INTRODUCTION**

The subject of frictional characteristics variation is still an area of intense research due to material composition variation to the friction pair [1,2,3]. The modern braking systems in the vehicle need a wide range of requirements such as friction stability, resistance to corrosion, lightweight, long life, low noise, low wear rate, and acceptable cost. Employing these requirements to achieve high performance. The purpose of friction brakes is to stop or slow a vehicle's motion. The kinetic energy of the moving parts should be a transfer outside to the surrounding as heat energy, via friction pads manufactured of composites of many materials. From literature, woven was the first material used in lining brake and then in the 1920s replaced with molded materials consists of chrysotile asbestos fibers and a plentiful mineral. The materials of resin-bonded metallic linings were introduced in the 1950s, and by the 1960s the materials that contain a high concentration of metal additives called ‘semi- Mets’ were developed for better performance [4,5]. Cu nanoparticles are widely studied to illustrate how they use in lubricant oils to get better its tribological properties [6,7].

The tribological behavior of a Cu-based composite frictional train brake composed of several elements material was analyzed by pad-on-disk tests without lubrication besides the wear rate to identify the effects of the sintering temperature on the base materials composition [8]. Brake pads containing different carbon fiber with copper-based content was evaluated on a scale dynamometer. The microhardness and plastic deformation resistance of the tribofilm enhanced with the introduction of the fiber [9]. However, the tribological properties of the modified SiO2 nanoparticles with polyvinyl pyrrolidone as lubricating oil additives in lubricant oil can effectively improve anti-friction and anti-wear properties [10]. The effect of ceramic nanoparticles additive on the microstructure and texture
of friction stir processed copper has been investigated with alumina Al2O3 nanoparticles [11]. Experimental work has been conducted to add nanoparticles of alumina with different concentrations starting with 2%, 4%, and up to 6% to the original alloy in which, optimization in mechanical properties such as hardness and tensile strength property in the composite alloy [12]. The addition of weight percentage ratio of chromium additive to the matrix is used for fabrication cast iron to enhance the corrosion and erosion resistance [13].

The powder metallurgy technique was used to fabricate copper-based composites with copper-coated, in which the hardness increases and enhanced the mechanical and tribological properties in comparison with the copper matrix [14]. Another research used powder metallurgy in copper-based friction materials to improve the magnitude and stability of friction coefficient. The method used graphite concentrations with a varied proportion of granular graphite designed for high-speed railway trains [15]. The toughest substance used in friction industries is silicon carbide. A small volume of silicon carbide increases frictional coefficients, stability, and wear rates [16,17,18]. A study showed how increasing hardeners influence the coefficient of friction. Findings explain low porosity with high hardness. Pores act as material insulators and decrease the interface temperature and porosity enhances the coefficient of friction [19].

Based on our knowledge from literature, no one has certainly used varying nano-silica particles concentrations (0, 3, 6, and 9) % wt. to examine the hardness and pad the roughness properties of friction material. In this paper, we attempt to do these things to enhance a brake function. The objective of the current work is to prepare a copper-based friction material for the application of a brake pad by the powder metallurgy method. Moreover, to study the effects of the additive of varying nano-silica SiO2 particles as weight percentage concentration on the resulting properties of friction material.

EXPERIMENTAL PART

This paper illustrates the steps and procedures of practical part starting from the selecting and sieving powders, determination of its required amounts, and passing on compacting and sintering of samples. In addition, the roughness and hardness test with inspections. The flowing path shows the experimental work producer.

1-Selected powder.
2- Milling the powder under 100 μm.
3- Mixing the weighted powder.
4- Sintering at 900°C for 2 h.
5- Drying at 125°C for 15 min.
6- Compact at 600MPa.
7- Tests and inspections.
8- Roughness and hardness tests.

These steps illustrated in Figure 1.

Figure 1. Flow chart of Experimental work
In this paper, four specimens of Copper-based friction material with composition listed were chosen as shown in Table 1. Nano oxide silicon SiO$_2$ was added to the composition in different concentrations (0, 3, 6, 9) % wt. to study their effects on prepared friction material.

**Table 1.** The composition prepared friction material

<table>
<thead>
<tr>
<th>No.</th>
<th>Symbol</th>
<th>Cu (%)</th>
<th>Graphite (%)</th>
<th>ZnS (%)</th>
<th>Sn (%)</th>
<th>Pb (%)</th>
<th>Cu (%)</th>
<th>Nano SiO$_2$ (%)</th>
<th>Mass / each sample (gram)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>75</td>
<td>6</td>
<td>7</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>72</td>
<td>6</td>
<td>7</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>69</td>
<td>6</td>
<td>7</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
<td>66</td>
<td>6</td>
<td>7</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Total Wt.</td>
<td>28.2</td>
<td>2.4</td>
<td>2.8</td>
<td>1.6</td>
<td>2</td>
<td>1.2</td>
<td>1.8</td>
<td>40</td>
</tr>
</tbody>
</table>

After supplying the required powders, the powders milling by ball mill as shown in Figure 2 and sieving to ≤ 100 μm by sieves vibrating device in Figure 3a, then the specified weight of each powder was determined by using a four-digit electronic balance in Figure 3b. Nanoparticles of SiO$_2$ with varying content of weight percent (0, 3, 6, % wt.) were used in making samples. The powder metallurgy process was used to prepare the samples in this project. For the preparation of the samples, the required amounts of powders and Nano SiO$_2$ with adding the (Polyvinyl alcohol) PVA as a binder were mixed mechanically for 10 min to ensure suitably and even distribution of powder particles. Afterward, the mixed powder was drying in an oven in Figure 4a at a temperature of 125°C for 15 min to avoid moisture problems. The final mixture was pressed at 600 MPa for 30 sec by a hydraulic press (Figure 5a). Finally, the compacted sample was sintered at 900 for 2 h at an electric furnace (Figure 4b) and the sample was left to cool to lab temperature in the furnace itself. Figure 5(b) illustrates the sintered sample.

**Figure 2.** Ball mill
Effect of Nano-Sized SiO2 Particles Addition on The Surface Roughness and Micro Hardness of Copper-Based Friction Materials

TESTS AND INSPECTION

Roughness test

The obtained sample is prepared for the test is a cylindrical shape with a 10mm diameter and 20mm height as shown in Figure 5(b). The roughness measurement was done by using a surface finish measuring instrument type stylus in Figure 6. The work of this instrument depends on the vertical movement of the stylus on the surface of the specimen.
Effect of Nano-Sized SiO2 Particles Addition on The Surface Roughness and Micro Hardness of Copper-Based Friction Materials

Arithmetic mean surface roughness value ($R_a$) can be taken and recorded directly on a strip paper from the instrument supplier.

![Roughness measurement instrument](image)

**Figure 6.** Roughness measurement instrument

Micro hardness test

Vickers micro-hard meter instrument is used to conduct the hardness test as depicted in Figure 7. A load of 500 g at 15 s was applied in the device to do the experiment of the test. To get accurate results, investigation focuses were divided to dispose of the effect of neighboring indentations, and the hardness was estimated by taking two indentations on each sample and then take the average of these two readings.

![Vickers micro-hardometer instrument](image)

**Figure 7.** Vickers micro-hardometer instrument

RESULTS AND DISCUSSION

The discussion of the results begins with the experimental work for four prepared friction material samples in this work. The effects of concentration of nano SiO$_2$ on properties of prepared friction material samples are discussed.
Effect of Nano-Sized SiO2 Particles Addition on The Surface Roughness and Micro Hardness of Copper-Based Friction Materials

Figure 8. The surface roughness values for samples

Figure 8 shows the values for surface roughness obtained by surface finish measuring instrument expressed as arithmetic roughness (Ra). The result demonstrates that there was a significant increase in roughness reading with an increase in the nano SiO2 particles added to the composition of the prepared friction material. Where the higher roughness reading obtained with 9 % nano SiO2 by 5.4% compare to the first sample. This will be a benefit for brake pads. As a result, the friction coefficient increases. The increase in surface roughness with the addition of nano SiO2 may be attributed to the abrasive nature of SiO2 particles.

Figure 9. The hardness values for samples

How much resistance to indentation by an external force can be expressed as hardness characterization? Figure 9 presents the relation between the sample designation and the hardness values. The hardness of friction material is closely related to the properties of its components, and it can be controlled by tailoring the chemical composition, weight fraction of each element, and particle size. The figure reveals the effects of the addition of nano SiO2 on the hardness values of prepared friction material. The nano SiO2 addition increases the hardness value in the different samples starting from sample A up to sample D by 18.11%. This improvement in the hardness of the materials due to incorporating a greater percentage of a hard component (SiO2) into the composition of friction material. The
n nanoparticles act as a barrier against the external forces and restricted the mobility of the other particles to pass each other and the orientation which consequently resulted in an increase in hardness.

CONCLUSION AND RECOMMENDATION

Based on the results and the discussion of this paper, the following conclusions can be drawn as listed below.

1. The prepared composition is excellent to produce the friction materials for brake pads.
2. The addition of nano SiO\textsubscript{2} has beneficial effects on the prepared friction material since the values of roughness and hardness were enhanced with the addition of nano SiO\textsubscript{2}.

The paper can be expanded for future work to include:

1. Study the influences of changing the concentration of another element in the composition of the friction materials.
2. Investigate the effects of using other nanoparticles like Al\textsubscript{2}O\textsubscript{3} mixing with the composition of friction materials on the resultant properties.
3. Perform more testing like wear on prepared friction materials.

REFERENCES


