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EXPERIMENTAL AND NUMERICAL INVESTIGATION OF EPOXY HYBRID POLYMER COMPOSITE REINFORCED WITH ZrB_2 AND PTFE PARTICLES USING A PIN-ON-DISC TRIBOMETER

TRIBOLOŠKE EKSPERIMENTALNE IN NUMERIČNE RAZISKAVE HIBRIDNEGA POLIMERNO EPOKSIDNEGA KOMPOZITA OJAČANEGA Z ZrB_2 IN PTFE DELCI

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Thermal and mechanical performance evaluations of sliding systems are required to avoid the failure of surfaces due to high temperature and a stress focus on a small contact area. This work investigates the thermal and tribological performance of an epoxy composite reinforced with zirconium diboride (ZrB_2) and polytetrafluoroethylene (PTFE) particles. Three-dimensional thermal and mechanical finite-element models are used to study the heat generated (heat flux), the temperature field, the stresses, and the deformation of a pin-on-disc system during sliding. These finite-element (FE) results help to study the effect of the coefficient of friction, load, and sliding speed on the contact temperature and stress distribution, which in turn affect the wear. The contact temperature for the epoxy hybrid composite is decreased by 38.9 % due to the addition of fillers. When the load is incremented by 10 N, the contact temperature and stress increase by 25 % and 92 %, respectively. Accurate calculations of the heat generation and stress distribution are considered the key to predicting the sliding system's performance, the wear characteristics, and the stability of the contacting surfaces.

Keywords: finite-element method, zirconium diboride, polytetrafluoroethylene

Ovrednotenje termičnih in mehanskih lastnosti drsnih sistemov je potrebno zato, da bi se izognili poškodbam površine zaradi visokih temperatur in napetosti, ki nastanejo med drsenjem na majhnih kontaktnih površinah. V tem članku avtorja opisujeta raziskavo termičnih in triboloških lastnosti epoksidnega kompozita ojačanega s cirkon-diboridnimi (ZrB_2) in politetra-fluoroetilenskimi (PTFE) delci. Za analizo in študij tvorbe toplotnega toka in polja napetosti in deformacij na sistemu drsenja čep (trn) na vrtečem se disku (angl.: pin-on-disc) so uporabili tridimenzionalni mehanski in termični model na osnovi metode končnih elementov (3D MKE). Rezultati MKE modela so avtorjem pomagali pri študiju vpliva koeficienta trenja, obremenitve in hitrosti drsenja na rezultirajočo kontaktno temperaturo in porazdelitev napetosti, ki povratno vpliva na obrabo. Kontaktna temperatura epoksidnega kompozita se je zmanjšala za 38,9 % zaradi dodatka polnil. S postopnim povečevanjem obremenitve za 10 N je kontaktna temperatura narasla za 25 % in napetost za 92 %. Avtorji v članku ocenjujejo, da je natančen izračun generirane toplote in napetosti ključen za napoved lastnosti drsnega sistema, obrabe materiala in stabilnosti kontaktnih površin.

Ključne besede: metoda na osnovi končnih elementov, cirkonijev diborid, politetrafluoroetilen

1 INTRODUCTION

Hybrid PTFE/epoxy composites are suitable candidates for bearings and tribological parts that are used at elevated temperatures. The pin-on-disc tribological test is commonly applied for the characterization of materials in brake and bearings systems to investigate the wear behaviour of materials in contact during sliding motion. The engagement of sliding surfaces can cause an increase in the temperature due to frictional heat generation. A premature failure of the contacting friction surfaces can occur as the high temperature and stress focus on a small area. An investigation of the thermal and mechanical performance of the sliding system is required to avoid such failures.[1] During sliding, the frictional heat and the resulting contact temperature determine the tribological performance of polymer composites. A low thermal conductivity usually leads to the accumulation of frictional heat, which can affect the functional capability of the composite. Hence, a low friction coefficient and relatively high thermal conductivity with improved heat transfer are required to achieve good performance.[2] A performance evaluation of the newly developed composites for tribological applications requires a measurement of the temperature and stress distribution in the contact zone. As gathering these measurements at contact zones is a difficult task, the finite-element (FE) method can be used as an effective tool to find a solution to the thermal and mechanical problems of sliding systems. Researchers have proposed several analytical models to estimate the contact temperature in sliding contact problems.[3] Kennedy et al. studied moving heat sources and used the heat-partition method to calculate contact temperatures.[4] Mu et al. used the FE model to predict the

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contact temperature on a ring-on-block system using two-dimensional thermal analysis.[5] Straffelini et al. developed a three-dimensional thermal model for the pin-on-disc apparatus to study the contact temperature and its effects on tribotesting.[6]

The present work uses thermal and mechanical boundary conditions consistent with the real sliding phenomena of the pin-on-disc configuration. The thermal and mechanical models can be used to predict the wear rate and can be applied to investigate the stability or failure situation in the sliding system by considering surface temperature and the von Mises stress criteria. In this work, the epoxy polymer is reinforced with micro-sized ZrB_2 and PTFE particles to enhance the thermal and tribological properties by reducing frictional heat accumulation for tribological applications. The optimum composition of the composite can reduce the wear rate and high local temperature due to friction, thereby enhancing the service life of tribological parts. ZrB_2 is one of the ultra-high-temperature ceramics with improved thermal and tribological performance due to its lamellar crystal structure.[7] PTFE molecular chains can be drawn out on the surface to form an extended chain type of crystal structure that is conducive to low shear and thus low friction.[8] The present work aims to derive a material with a low friction coefficient and a high thermal conductivity capable of reducing frictional heat accumulation for tribological applications such as bearings, gears, shaft parts, etc. Thermal and mechanical models with improved boundary conditions are developed to investigate the contact temperature, stress distribution, wear characteristics, and mechanical stability of sliding systems using the FE method. These models present a promising tool to investigate the effect of materials type, boundary conditions, and material properties in sliding systems.

2 EXPERIMENTAL PART

Bisphenol-A-based epoxy resin (Lapox L12), a medium-viscous semi-solid polymer with a density of 1100 kg/m^3, was used as the matrix and K-6 aliphatic polyamine as the curing agent. The reinforcement materials used are zirconium diboride (ZrB_2) and polytetrafluoroethylene (PTFE). The properties of the reinforcements are given in **Table 1**. Initially, the reinforcements, ZrB_2 and PTFE were preheated to 120 °C in a muffle furnace and mixed with bare epoxy using an ultrasonic mixer for 30 min. One mL of curing agent was added and hand-stirred gently to avoid trapping bubbles and the mixture was then poured into molds. The specimens were allowed to cure in the molds for 24 h at room temperature.

Table 1: Properties of reinforcements

Material	Size (μm)	Density (kg/m^3)
ZrB_2	1–3	6080
PTFE	10–12	2200

A tensile and compressive test of the composites was conducted using a computerized universal testing machine with a crosshead speed of 1 mm/min. Test samples were prepared as per the ASTM E4 Standard. For each composition, five tests were conducted, and the average value was taken. The hardness of the composites and the matrix polymer was measured using a Rockwell hardness tester on cubes of 20 mm in size. Indentation was made using a steel ball indenter of 6.35 mm in diameter with a pre-load of 10 kg and an applied load of 60 kg for 5 s (the dwell time). A tribological characterization of the epoxy hybrid composites and the matrix polymer was conducted using a pin-on-disc tribometer (DUCOM TR-20-CH 600). The cast composites were machined to a size of 7.5 mm in diameter and 30 mm in length (ASTM G99 standard) with a flat end. The pin-on-disc tribometer, with EN 31 hardened to a 60-HRC disc with a diameter of 150 mm and surface roughness R_a = (0.45 ± 0.02) μm, was used for the wear testing. The test parameters, namely the sliding speed, load, contact pressure, and sliding distance, were kept constant at 1.25 m/s, 40 N, 0.91 MPa, and 750 m, respectively. The test included 3000 revolutions at 299 min^{-1} and a track diameter of 80 mm. The study employed a Hot Disk TPS 500 thermal constants analyzer to evaluate the thermal conductivity of the composite. The contact temperature on the wear track was measured using a FLUKE thermal infrared imager. All the tests were performed at 22 °C.

3 FEM MODEL AND BOUNDARY CONDITIONS

For the development of the finite-element model, the following assumptions are made:

- Composites and counterparts are homogeneous and their thermal properties are invariant with temperature.
- Plastic deformation and the wear of the composites are assumed to be independent of the heat-flow behaviours.
- The friction coefficient of the composites is temperature independent during the tribological tests.
- All the friction energy is dissipated between the pin and the disk with negligible irradiation.

Table 2: Material properties used in the FE model.

Material	Thermal conductivity (W/(m·K))	Density (kg/m^3)	Specific heat capacity (J/(kg K))	Young's modulus (GPa)	Poisson ratio
EN 31 Steel disk	46.6	7810	475	215	0.29
Composite pin	0.3	1414	1474	23.4	0.3

Material properties used in the FE model are given in **Table 2**. Thermal properties of the composite measured

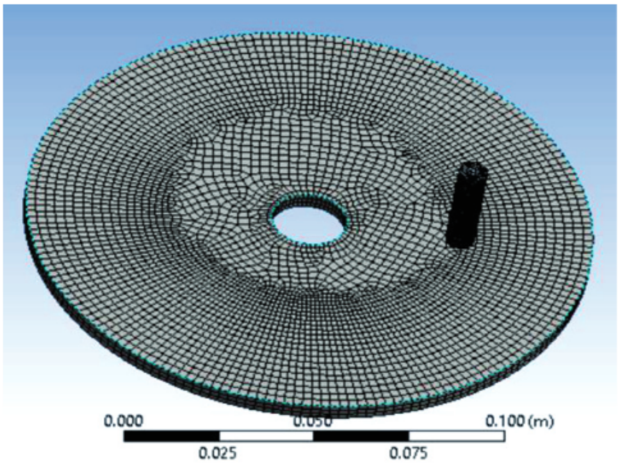

Figure 1: Geometry and mesh of the model

using the Hot Disk TPS 500 thermal constants analyzer and Young's modulus of composite is found by the rule of mixtures. The simulation is based on the perfect contact approach at the pin–disc interface, assuming that the surface temperatures of the contact bodies are the same.

The three-dimensional model of the pin on the disc tribometer was modelled using the Design Modeler of the ANSYS workbench. The mesh was refined successfully to reach an optimum element number considering the convergence of the solution. The geometry and mesh of the model are shown in **Figure 1**. An element size of 2.5 mm is selected for the analysis.

For frictional contact analysis, an augmented Lagrange formulation was used for the convergence of the solution. After defining the body and the counter-body geometry, and material properties, the following boundary conditions were applied to the thermal model, which is consistent with the experimental tests.

- During sliding, the friction heat source at the interface is treated as a thermal load for the pin on disk. Thus, the heat flux $q(t)$ applied at the contact is calculated using Equation (1).

$$q(t) = \mu(t)Fv \quad (1)$$

  where $\mu(t)$ is the friction coefficient of the composite taken from the experiments, F is the load (N), and v is the sliding velocity (m/s).
- In the dry-sliding process, some of the frictional heat goes out into the air by convection. Convection is applied on the upper surface of the disk and pin surfaces other than the contact surface. Equation (2) gives the average heat-convection coefficient from the surface of a solid disk rotating with angular velocity ω at room temperature, assuming laminar flow.

$$h_c = 2.25\sqrt{\omega} \quad (2)$$

The following boundary conditions and loads were applied to the mechanical model:

- A force of 40 N is applied at the top face of the pin facing a downward direction.
- Movement along radial and circumferential directions (r and θ) of the pin are constrained.
- An EN 31steel disc material is set to rotate about its axis with an angular velocity of 31.3 rad/s.
- Movement along the radial and axial directions (r and z) of the disc is constrained.
- To provide only the circular motion of the pin along the θ-axis of the fixed disc, a restriction was imposed on the displacement in the z-direction of the disc.

4 RESULTS AND DISCUSSION

4.1 Pin-on-disc tribotesting

The response surface methodology (RSM) approach was employed to study the impact of two independent variables on the hardness, wear rate, and coefficient of friction (COF) of the epoxy hybrid composites.[9] The independent variables that were chosen were ZrB_2 1 φ/% ZrB_2 (volume %) and 1 φ/% PTFE, while the responses were the hardness, wear rate, and COF. A large number of initial trial runs were carried out to achieve the required range and span of variables for the DOE. The trials were performed by varying one variable at a time and keeping the other variables constant. The samples produced in this way were visually inspected, and the lowest and highest values of the variable under study, which produced externally defect-free samples, were identified and set as the range for that variable. Typical defect-free samples include 3–7 of 1 φ/% ZrB_2 and 3–9 of 1 φ/% PTFE. Response-surface regression was used to construct a complete quadratic mathematical equation for the hardness, wear rate, and COF of the epoxy hybrid composites. Each model was subjected to an analysis of variance (ANOVA). Design–Expert 13, a statistical software from Stat-Ease, Inc., specifically dedicated to performing the design of experiments (DOE) for developing mathematical models and optimization processes, was used to generate the response-surface plots and contour plots. The optimization of multi-response characteristics was achieved using the desirability function approach, which is one of the widely used methods in industries. The experimental and the optimization results using design expert software show that a maximum hardness of 78.8 HRB, minimum wear rate, and COF of 3.3×10^{-4} mm^3/(N·m) and 0.18, respectively, were observed, corresponding to optimized values of 5.05 of 1 φ/% ZrB_2 and 5.95 of 1 φ/% PTFE. The hard ceramic ZrB_2 particles act as protuberances over the surface. These protuberances tend to protect the matrix from the uniform contact with the counter-facing steel disc, thereby reducing the contact area between the test surface and the rotating disc, resulting in reduced wear. PTFE acts as a lubricant, thereby reducing the friction and the resultant wear. The incorporation of hard ceramic ZrB_2 particles, which is one of the most important ultra-high-temperature ceramics with high elastic modulus, high strength, excellent wear resistance, and high thermal conductivity, improves the hardness of the composites. In the case of PTFE reinforcement particles, the addition of reinforcements decreases the hardness. PTFE, being a softer material compared to hard ceramic particle ZrB_2, acts as a solid lubricant in the composite.

Table 3: Comparison of composite with bare epoxy

Composite	Hardness (HRB)	Wear rate ($mm^3/(N·m)$)	COF
Bare epoxy	53.7	35×10^{-4}	0.39
Epoxy/PTFE/ZrB_2	78.5	3.4×10^{-4}	0.18

Table 3 shows a comparison of the bare epoxy with a composite having the optimum composition. A comparison of the response variables of the epoxy hybrid composite with bare epoxy shows that hardness increases by 46.7 %, wear and COF decrease by 90.6 % and 52.2 %, respectively. This can aid in improving the tribological performance of the composite.

4.1.1 Effect of load

To study the influence of load on the wear and the coefficient of friction at the optimum composition, the load is varied from 10 N to 60 N. The sliding speed and the sliding distance were kept constant at 1.25 m/s and 750 m, respectively, throughout the testing. An increase in the wear and the coefficient of friction is observed as the load increased from 10 N to 60 N, as shown in **Figure 2**. At low loads, a light contact pressure exists between the two mating surfaces, which leads to less material removal, resulting in a reduced wear and coefficient of friction. On increasing the load, the contact pressure is increased, which in turn increases the actual contact area between the mating surfaces.

This eventually produces higher deformation and debris formation, which leads to an increased wear and coefficient of friction. Further, the debris formed in the wear track starts cramming between the surfaces and results in more wear. Up to 30 N, the protuberances (particles) in the mating surface of the pin created a small contact area, resulting in a smaller wear and coefficient of friction. When the load increases, the particles become worn out and the soft matrix part is exposed. Hence, the contact area between the mating surfaces increases, resulting in a higher wear and coefficient of friction.

4.1.2 Effect of sliding speed

To study the influence of sliding speed on wear and coefficient of friction at the optimum composition, the sliding speed is varied from 0.75 m/s to 2 m/s. The load and the sliding distance are kept constant at 40 N and 750 m, respectively, throughout the testing. As is commonly observed in polymer composites, the temperature rise due to higher sliding speed causes an increase in the wear and the coefficient of friction. This phenomenon is observed in this case as shown in **Figure 3.** The wear increases as the sliding speed increases from 0.75 to 2 m/s due to the frictional heat generation and causes the softening of material, which in turn increases the coefficient of friction. Up to 1.5 m/s, the increase in wear and the coefficient of friction is marginal due to the presence of ZrB_2. ZrB_2 is an ultra-high-temperature ceramic material that inhibits the rise in temperature at higher sliding speeds. PTFE is a self-lubricating material and helps to reduce heat accumulation. This will help the composite to withstand relatively higher temperatures induced due to higher sliding speeds. Beyond 2 m/s, the wear rate and coefficient of friction increase rapidly due to the significant temperature rise.

4.2 Results of finite-element study

The epoxy/PTFE/ZrB_2 composite at optimum composition is used for the finite-element study. The finite-element study of the distribution of the contact temperature at the pin-on-disc surface at the end of the test is depicted in **Figure 4**. As the surface temperature during the time of experimentation could not be measured accurately, the surface temperature in the wear track was measured as soon as the experiment was stopped. It was 52.5 °C. The experimental values show a close agreement with the contact temperature obtained from FE analysis with a 3.5 % error. For the base epoxy, the contact temperature developed on the surface is 82.93 °C. The contact temperature corresponding to the epoxy hybrid composite at optimum composition at 40 N load and 1.25 m/s sliding speed developed is 50.65 °C, decreased by 38.9 %. This is due to the presence of the ultra-high-temperature ceramic ZrB_2 and the frictional modifier PTFE particles.

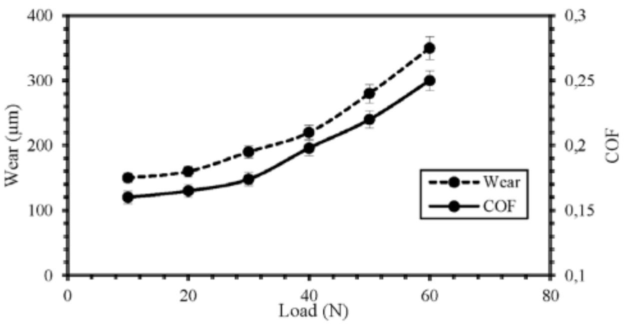

Figure 2: Wear and COF of PMC's versus load (N) at 1.25 m/s sliding

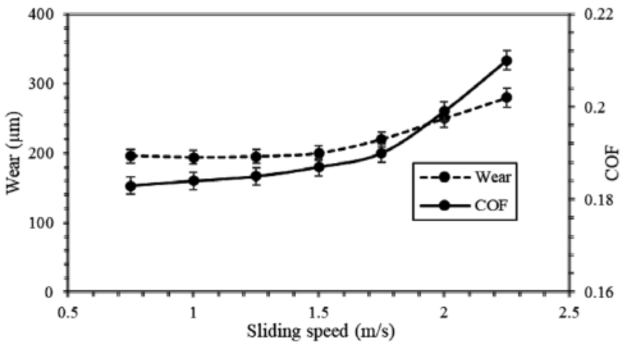

Figure 3: Wear and COF of PMC's versus sliding speed at 40 N

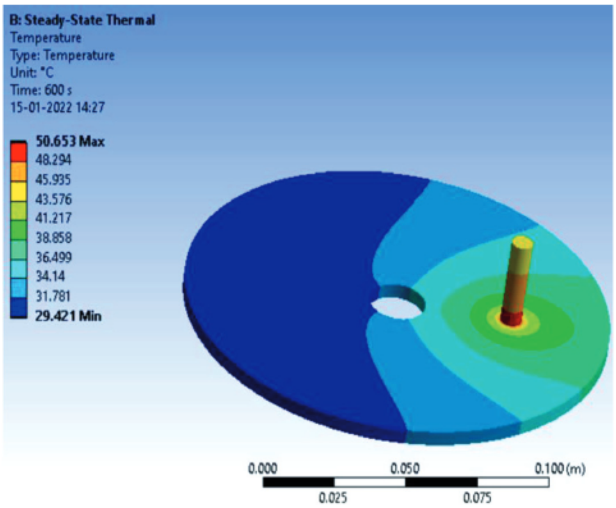

Figure 4: Contact temperature and heat flux at the pin-on-disc surface

For the base matrix, the epoxy value of the thermal conductivity obtained experimentally is 0.2 Wm/K. At optimum composition, the value of the thermal conductivity is 0.3 Wm/K, increased by 50 %. The improved thermal conductivity can provide better heat transfer and reduce the contact temperature on the surface of the material, resulting in a reduction of the wear. The glass-transition temperature for bare epoxy is 160 °C, which is the temperature where the epoxy transitions from hard, glassy material to a soft, rubbery material. As epoxies are thermosetting materials and chemically cross-link during the curing process, the final cured epoxy material does not melt or reflow when heated (unlike thermoplastic materials), but undergoes a slight softening at elevated temperatures. At 80 mm/s sliding speed, the maximum load that the material can handle safely is 4000 N. Beyond 4000 N, the temperature rise occurs due to the high load, which is sufficient to cause failure of the material. Similarly, at 40 N load, the material can handle sliding velocity and revolution per minute without failure is 8 m/s and 2000 min^{-1}, respectively.

Figure 5 presents the equivalent von Mises stress in the contact zone. The maximum von Mises in the contact zone is 0.756 MPa. A material is said to start yielding when the von Mises stress reaches the yield strength ($\sigma_v \geq \sigma_y$). The von Mises stress is used to predict the failure of materials under loading from the results of uniaxial tensile tests. At 40 N load and 1.25 m/s sliding speed the von Mises stress obtained is one-hundredth of that yield point of cthe omposite (74 MPa), which indicates the higher strength of the material. In the 1-D stress state, the von Mises stress can be written as:

$$\sigma_{vm} = \sqrt{\frac{2}{3}\sigma} \qquad (3)$$

where σ is the uniaxial stress that is equal to 0.9 MPa. The von Mises stress obtained from Equation (3) is 0.735 MPa. The FE result of the von Mises stress shows a –2.8 % error with the value obtained using Equation

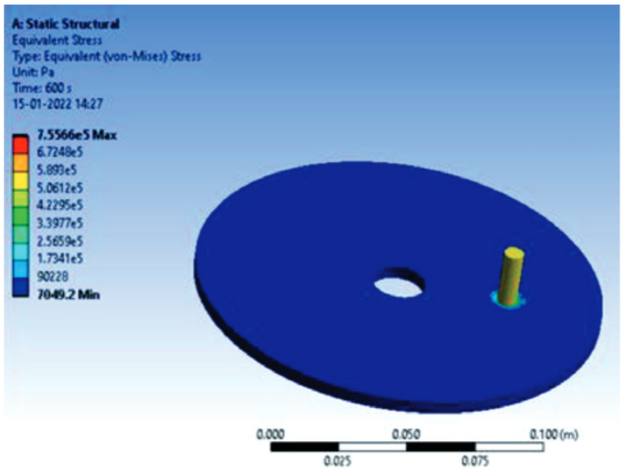

Figure 5: Equivalent von Mises stress in the contact zone

(3). Up to 4000 N the material can provide safe working conditions. Beyond 4000 N, the von Mises stress reaches the yield strength of composite and results in failure. Similar variants of PTFE-based self-lubricating composites for bearing material can handle loads of 2000–3000 N.[10] When compared to other polymer-based particle-filled bearing materials, the newly developed composite can provide improved load capacity.

4.2.1 Effect of load and sliding velocity

To study the influence of load on the contact temperature using a finite-element model, the load is varied from 10 N to 60 N. The sliding speed was kept constant at 1.25 m/s. A higher load leads to increased frictional heat and contact temperature, resulting in increased wear rate. The FE results of the variation of contact temperature with the load are shown in **Figure 6**. As the load increases by 10 N, the contact temperature increases by 25 %.

To study the influence of the sliding speed on the contact temperature of the epoxy hybrid composite for the optimum composition, the sliding speed was varied

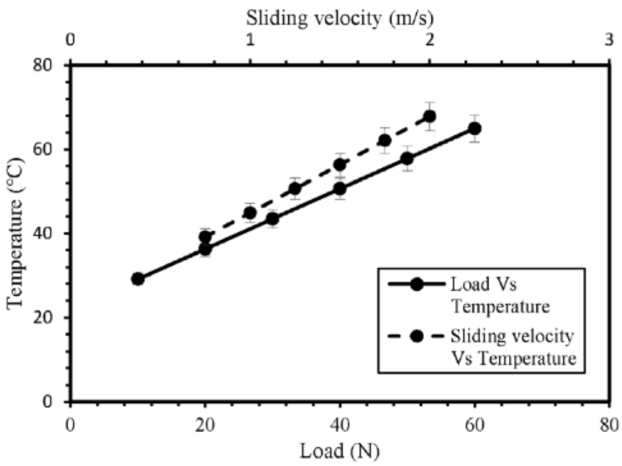

Figure 6: Effect of load and sliding velocity on the contact temperature

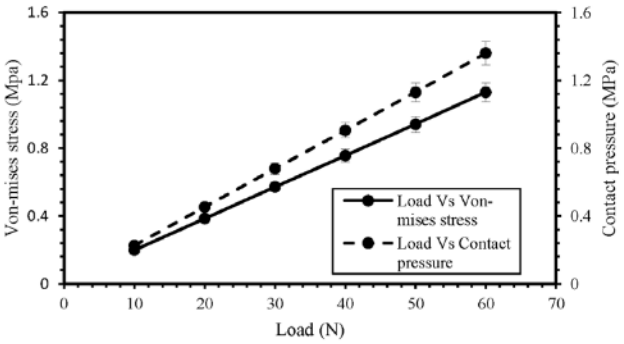

Figure 7: Effect of load on contact pressure and von Mises stress

from 0.75 m/s to 2 m/s. The load was kept constant at 40 N. When the sliding speed increases, the frictional stress is thermally activated. Eventually, the temperature rise at the contact spot will be significantly higher. A higher sliding speed can cause a high temperature between the sliding pair. As the sliding speed increased by 0.25 m/s, the contact temperature increased by 15 %, as shown in **Figure 6**. The experimental values are found to be very close to the values predicted by the FE analysis.

4.2.2 Effect of load on the stress and pressure

To study the influence of load on the von Mises stress and the contact pressure of the epoxy hybrid composite using the finite-element model, the load is varied from 10 N to 60 N. The sliding velocity was kept constant at 1.25 m/s. When the load is incremented by 10 N, the von Mises stress and the contact pressure increase by 92 % and 100 %, respectively, as shown in **Figure 7**. On increasing the load, the contact pressure gets increased, which in turn increases the actual contact area between the mating surfaces, and also leads to an increase of the von Mises stress.

4.2.3 Effect of rotational velocity on stress

To study the influence of rotational velocity on the von Mises stress of the epoxy hybrid composite, the sliding speed is varied from 0.75 m/s to 2 m/s. For each sliding velocity, the rotational velocity is calculated by keeping the load constant at 40 N. When the rotational velocity increases by 33.3 %, the von Mises stress is

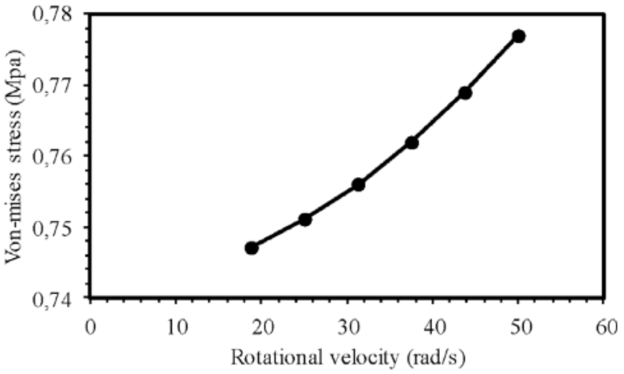

Figure 8: Effect of rotational velocity on the von Mises stress

only a 0.5 % increase, as shown in **Figure 8**. The result shows that the load has more effect on the stress and the contact pressure than the sliding velocity and the rotational velocity.

5 NUMERICAL PREDICTION OF WEAR RATE USING THE FEM MODEL

The contact temperature and the contact pressure obtained from the FEM model can be used to predict the wear in the sliding system. This method provides a simple and effective technique to quantitatively characterize the wear behaviour of a dry-sliding system. The temperature rises and the contact pressure at the interface of the contacting bodies are important in characterizing the behavior of the tribosystem. The wear rate is calculated with Equation (4) and the wear coefficient with Equation (5).

$$w = \frac{hA}{PL} \tag{4}$$

$$W_1 = \frac{w}{h} \tag{5}$$

where h is the wear height loss, A is pin cross-sectional area P is the load and L is the sliding distance (750 m).

The 40 N load is applied at contact area 44.17×10^{-6} m^2. The load is the product of the contact pressure and the area.

The steady-state heat generation due to friction can be expressed as Equation (6):

$$Q = \mu UP \tag{6}$$

where μ is the coefficient of friction and U is the sliding velocity.

The increase in the temperature is given by Equation (7).[11]

$$\Delta T = \varphi Q \tag{7}$$

ΔT increase in the temperature is $T_0 - T_1$, where T_0 is room temperature (22 °C) and T_1 is the contact temperature from the FEM model (50.65 °C).

There is a linear relationship between the temperature rise at the interface and the heat transferred to the body. The results of the temperature rise plotted against the heat dissipation are shown in **Figure 9**, where $\varphi = 3.18$ is the slope of the line.

Normal load P, using Equation (6) and Equation (7) results in:

$$P = \frac{\Delta T}{\varphi \mu U} \tag{8}$$

The substitution of P from Equation (8) into Equation (5) gives a relation for the wear coefficient as follows:

$$W^1 = \frac{A\varphi\mu U}{\Delta TL} = 1.51 \times 10^{-9} \text{ m/N} \tag{9}$$

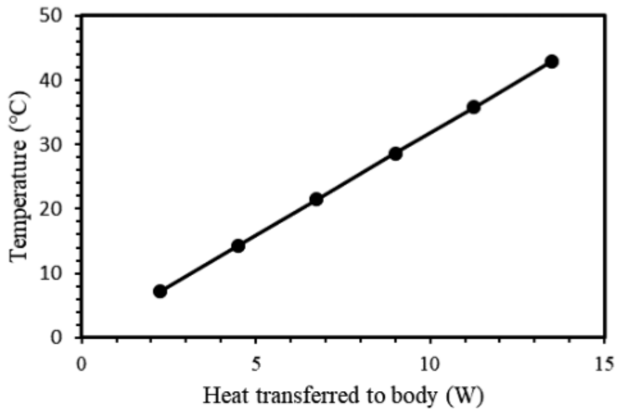

Figure 9: Temperature rise ΔT, against the heat entering body Q

The experimental result of 1.48×10^{-9} m/N agrees with the value obtained from Equation (9) with a –2.1 % error. This method provides a simple and effective technique to quantitatively characterize the wear behaviour of a dry-sliding system. This method is particularly useful because of the availability of the analytical and experimental results for predicting the contact temperature under various operating conditions and configurations.

6 CONCLUSIONS

The tribological and thermal properties of an epoxy hybrid polymer composite reinforced with ZrB_2 and PTFE particles were studied in this work. The experimental and the optimization results show that a maximum hardness of 78.8 HRB, a minimum wear rate, and a COF of 3.3×10^{-4} mm³/(N·m) and 0.18, respectively, were observed, corresponding to optimized values of 5.05 % of ZrB_2 and 5.95 % of PTFE. Ultra-high-temperature ceramic ZrB_2 particles act as protuberances over the surface. These protuberances tend to protect the matrix from uniform contact. The self-lubricating property of PTFE provides a reduced wear rate and coefficient of friction. The thermal conductivity of the composites is also enhanced by 50 % with the addition of fillers. This reduces the heat accumulation by improving the heat transfer and the temperature developed in the contact zone.

The finite-element study helped to investigate the performance of the sliding system by varying the load and the sliding speed on the contact temperature and the stress. The contact temperature corresponding to the epoxy hybrid composite at the optimum composition for a 40 N load and 1.25 m/s sliding speed developed is decreased by 38.9 %. The contact temperature and the stress obtained from the FEM models provide a simple and effective technique to quantitatively characterize the wear behaviour of a dry-sliding system. When the load is incremented by 10 N, the contact temperature and stress increase by 25 % and 92 %, respectively. The load has more effect on the contact temperature and the equivalent von Mises stress than the sliding speed and the rotational velocity. It also can be applied to investigate the stability or failure situation in the sliding system by considering the surface temperature and the von Mises stress criteria. The von Mises stress obtained is one-hundredth of that yield point of the composite, which shows the mechanical stability of the material. At an 80 mm/s sliding speed, the maximum load that the material can handle safely is 4000 N. Similarly, at 40 N the load material can handle sliding velocity and the revolution per minute without failure is 8 m/s and 2000 min^{-1}, respectively. By comparing other polymer-based particle-filled bearing materials, the newly developed composite can provide improved load capacity. Due to these effects, this composite can ensure an increased service life for tribological parts.

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