Numerical modelling of sliding wear caused by pin-on-disk method over copper coated ABS plastic substrate

S Nigam¹, S S Mahapatra¹ and S K Patel¹
¹Mechanical Engineering Department, National Institute of Technology, Rourkela-769008, Odisha, India

Abstract. The coating of metal increases the face value of the plastic and inhibits other properties like conductivity, hardness and lustre. Thus the combination of plastic and metal coating results in a material that is light in weight because of the presence of plastic as the base material and; electrical and thermal conductive because of the presence of metal on the surface. The requirement of such materials is growing day by day. Copper coated plastic has various applications such as in fabrication of printed circuit boards (PCB’s) and various automobile parts and in electromagnetic interference shielding. It is important to analyse the tribological aspect of the same in order to broaden its range of application. The present work contains 3D modelling of thermally sprayed copper on ABS plastic and simulation of sliding wear test by pin-on-disc method. The Johnson cook flow stress model is selected for the coating material. Archard’s wear model has provided the best results for calculating the wear rate. The results obtained are in good agreement with the experimental values.

Keywords: ABS plastic, copper coating, metallization, sliding wear

1. Introduction
Metallization is gaining popularity in the recent years because of its application in various fields. The plastic gains additional properties like conductivity, hardness and strength. The metallized plastics find applications in manufacturing of toys, decorative items, cell phone, watches and cosmetic packing and in electromagnetic shielding [1-4]. The conventional approach to metallization has been reported to be hazardous to the job coaters and hence the other techniques of metallization are being looked out for [5-10]. Coating properties varies with the deposition technique used. Tribological aspects such as sliding wear, abrasive wear and erosion wear are important to be thoroughly analysed as they reveal the nature and strength of the coating obtained. This may broaden up the range of its application. In the last few years researches have studied the sliding wear aspect of thermally sprayed coating on various metal substrates by 2D and 3D model by numerical simulation [11-13]. Various researchers have modelled the process in order to simplify the efforts and to save the time of the engineers in taking a decision. In the last few years the 3D modelling and simulation has gained huge popularity mainly because it replaces the real time experimentation and rescues the engineers from the wastage of time and money in conducting the real time experiments [14-16].

Finite element modelling was attempted by using the Deform 3D software. It is a practical and an efficient tool to predict the material flow in industries without any monetary investment and delay due to shop trials. Deform 3D is one such software used for conducting such simulations. In past, sliding
wear by pin on disk method has been modelled by the researchers using this software and the results obtained are quite promising [17-18]. Numerical modelling consists of mainly three steps. Preprocessor step defines the work piece and tool geometry, parametric set up as well as the other aspects of the process to be modelled. Simulation step take the input for the iteration method and the solver. It is important to select a suitable method which would give the best result. Hit and trial methods have been if required. The total running time of the simulation depends on the random access memory (RAM) of the computer. In a work presented by Podra et al., it has been shown that the simulation model results can be treated as the base for analyzing wear coefficient-sliding distance change [18]. Archard’s wear model has gained popularity as the results in computing wear results either considering the sliding distance or the time interval in numerical modelling [19-20]. According to Archard’s equation the wear loss is proportional to sliding distance and the load applied whereas is inversely proportional to the hardness of the material. So far limited attempts have been made to model the sliding wear test on metal coated plastics. Thus works may predict the wear rate at different loads and at different speed of revolution.

2. Numerical Simulation
The simulation consists of three sections as categorised in the software pre-processor, simulator and post-processor. The 3D geometry was created for the pin on disk according to the prescribed ASTM standards. Disk was assumed to be of rigid in nature, whereas copper and ABS plastic were treated as elasto-plastic and plastic respectively. By considering this we assume that the disk doesn’t undergo wear whereas the pin does. After referring to various past researches, it was observed that the flow stresses for the copper metal is well defined by the Johnson-cook model. The constant for the same are shown in table 1 [21-22]. It is basically a function of strain, strain hardening coefficient, reference strain rate, work-piece temperature, room temperature, melting temperature, and strain rate sensitivity index. Meshing plays a significant role in obtaining accurate results and this has been established by past literatures. Deform has a feature of automatically generating mesh. This is popularly known as Automatic mesh generator (AGM). Tetrahedral and fine meshing type (as shown in the figure 1) was used in order to get higher accuracy in the results. During the simulation it is very important to thoroughly define the material. Elastic and thermal properties along with surface properties like surface roughness and hardness, of EN-32 steel (for disk) and copper-coated ABS plastic (for pin), were given as the input in order to define the material, as shown in the table 2 The properties define the nature of the material [23-25]. SI unit has been maintained throughout. With Newton-Raphson as the method of iteration, solution converges in lesser number of iterations. Sparse solver was used over conjugate-gradient as it gives the direct solution that uses the sparseness of the FEM. The Langrangian incremental type simulation was run. Inter-object properties such as friction, was assumed to be hybrid in nature i.e. both coulomb and shear as 0.65 and 0.36 respectively; heat transfer coefficient is taken as 45 N/sec/m/C. It was assumed that ambient temperature was 25 °C. The finite element analysis was performed on a computer with Intel Core i7 processor with 4 GB RAM. From previous researches it is found that Archard’s model, as shown by the equation (1), is suitable for studying the wear in the pin-on-disk model. The expression expressed by equation (1) is basically a function of interface pressure (P), sliding velocity (v) and hardness (H) whereas as the values of a, b, c and K are material specific. Figure 2 shows the stress distribution obtained during the material removal process. The accumulated stress is highest at the both ends. Effective-stress reached up to 70 MPa mostly but at some of the locations it crossed 100 MPa. Temperature distribution has been shown by the figure 3. It has been observed that the temperature rises to maximum at the lower end which undergoes the sliding wear by the disc. Volume loss during the process performed through simulation is shown by the figure 4. It has been observed that after for about 40-50 seconds the loss tends to almost negligible. Thus the wear rate is calculated by dividing the volume loss by the total time (t in seconds) shown by the equation (2). Volume loss is calculated by finding the difference between the initial volume (V0) and final volume (Vf). Initial volume was calculated by considering a copper coating of 200 µm on the plastic substrate.
\[
W = \int K \frac{P^a t^b}{H^c} dt
\]  
(1)

\[
\text{Wear rate } = \frac{(V_{in} - x V_j)}{t}
\]  
(2)

### Table 1. Constant for Johnson-Cook Model

| Constant | A  | B  | n   | C  | m   | Reference temperature | Reference strain rate |
|----------|----|----|-----|----|-----|-----------------------|----------------------|
| Value    | 90 | 292| 0.31| 0.025| 1.09| 298 K                 | 1/s                  |

**Figure 1.** Tetrahedral and fine meshing of (a) pin, (b) pin-on-disc

### Table 2. Properties of copper plated ABS plastic

| Properties               | Cu            | ABS plastic |
|--------------------------|---------------|-------------|
| 1 Young’s Modulus        | 130 GPa       | 1.1GPa      |
| 2 Density                | 1.1 g/cm³     | 8.95 g/cm³ |
| 3 Thermal expansion coeff| 8 X 10⁻⁵/K    | 1.7 X 10⁻⁵/K|
| 4 Emissivity             | 0.9           | 0.03        |
| 5 Surface Roughness      | 14 µm         | 26 µm       |
| 6 Poisson’s Ratio        | 0.34          | 0.4         |
| 7 Thermal Conductivity   | 0.17          | 391 Wm/K    |
| 8 Melting point          | 1357 K        | -           |
| 9 Sp. Heat capacity      | 0.386         | 0.02        |

**Figure 2.** The stress distribution
3. Experimentation

The plastic used in the current work is Acrylonitrile Butadiene Styrene, commonly called as ABS plastic. This is one of the toughest plastic available in the market. The ABS plastic substrate (as per ASTM G9904) was fabricated using RP machine (Fortus 400mc 3D production system, manufactured by Stratasys) that works on the principle of fused deposition modelling (FDM). The method involved the deposition copper metal on the ABS plastic through electric arc thermal spray method. The generated arc melts the two copper wires and the supply of air jet forces the metal droplets to fall on the ABS plastic substrate. After about 5-7 minutes of spraying a coating thickness of about 200 microns is achieved. The image of coated substrate is as shown in the figure 5. Once the coating was deposited, sliding wear test was performed using Computerized DUCOM friction and wear monitor coupled with pin-on-disk pin on disc method. Force of 10 N on the pin whereas the disk rotated at a speed of 200 rpm. Track diameter was kept as 60 mm. Disc made up of EN 32 steel was rotated against the coated samples for a time period of 5 mins. The trend of wear loss in term of change in height is shown by the figure 6. Change in height of the pin denotes the wear loss and thus is used for calculating the wear loss. Initial curve in the plot is may be due to the presence on some foreign particle. Wear rate was measured using equation (3). The equation is a function of height loss (\(H_{\text{loss}}\)), radius (\(r\)) and sliding distance (\(d\)).
Wear rate = \((2\pi r^3 \times H_{loss}) / d\)  \hspace{1cm} (3)

d = 2\pi r \times t' \hspace{1cm} (4)

Sliding distance is the total distance travelled by the pin during the stipulated time period (\(t'\) in minutes). Three consecutive experiments were conducted and the average of the three wear losses was considered. Therefore by the application of the formula represented by equation (3) and (4), wear rate is calculated. On observing under scanning electron microscopy, the images of as-coated and of worn out surfaces were obtained as shown in the figure 7 (a) and (b) respectively. Cauliflower like microstructures structures is prominently evident in all the samples.

**Figure 5.** Copper coated ABS plastic samples with the dimensions as per the ASTM standards

**Figure 6.** Graphical plot showing wear loss in terms of height (\(\mu\)m) vs time (in sec)
4. Comparison of the and Validation through the experiment
On superimposing the results obtained by numerical modelling and the actual experimentation, the obtained graph is denoted by the figure 8. It was observed that maximum wear occurred in the initial 40 seconds and then wear rate assumed a decreasing trend. Table 3 prove that the results obtained through simulation and through experimentation are comparable and are in good agreement with each other.

Table 3. Comparison between the predicted and experimental results

| Wear rate (mm$^3$/sec) |          |
|------------------------|----------|
| Numerical Simulation   | 2.81 mm$^3$/sec |
| Experimental           | 2.54 mm$^3$/sec |

Figure 8. Comparison between predicted and experimental

5. Conclusion
The numerical simulation by FEM for sliding wear test by pin on disk model was successfully modelled using Deform 3D software. It can be concluded that the Archard’s wear model gave best
result for the present case. Sparse solver along with Newton Raphson method helped in converging the solution in lesser iterations. Hence the result was obtained in lesser time. This work can be used to predict the wear loss at various applied loads and at different speed of revolution of the disk without conducting the real time experiments.

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