Development and Sliding Wear Response of Epoxy Composites Filled with Coal Mine Overburden Material

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Abstract: The paper reports on development and characterization of epoxy based composites filled with micro-sized mine overburden material. Coal mine overburden material is typically highly heterogeneous and is considered as waste material. For excavating each ton of coal, roughly 5 tons of overburden materials are removed and is dumped nearby occupying large space. Gainful utilization of this waste is a major challenge. In the present work, this material is used as filler materials in making a new class of epoxy matrix composites. Composites with different weight proportions of fillers (0, 10, 20, 30 and 40) wt. % are prepared by hand layup technique. Compression tests are performed as per corresponding ASTM standards to assess the compressive strength of these composites. Further, dry sliding tests are performed following ASTM G99 standards using a pin on disk machine. A design of experiment approach based on Taguchi’s L16 orthogonal arrays is adopted. Tests are performed at different sliding velocities for multiple sliding distances under varying normal loads. Specific wear rates of the composites under different test conditions are obtained. The analysis of the test results revealed that the filler content and the sliding velocity are the most predominant control factors affecting the wear rate. This work thus, opens up a new avenue for the value added utilization of coal mine overburden material.

Keywords: Epoxy, taguchi method, coal mine overburden, polymer composites

1. Introduction

India produces ample amount of coal every year. Maximum number of thermal plants as well as household activities depends upon coal. So, through opencast mining process, coal is extracted from the environment. For excavating each ton of coal, near about five to six tons of overburden material are excavated. After digging the coal, these mine overburden materials are left over lands. These soils are occupying useful lands and destroying its fertility. Overburden materials are combined with both coarse and fine grains with equal amounts. Since, it is having fine grains and is typically loose, so due to wind they are highly prone to flow and damages the surrounding which leads to health issues. So, utilization, recycle and reuse of mine overburden material are necessary. Earlier some trials had been made to discover reuse techniques for a huge range of waste substances along with blast furnace and steel slag, construction waste, fly ash, red mud and so forth.

Polymers are found in numerous applications including aerospace, vehicles, household appliances, constructing materials and many others. Due to weight sensitiveness, polymers are used, but their high cost is a drawback. Therefore, to reduce the cost, industrial wastes are used. Proper mixing of matrix and reinforcement will provide a better composite material. The addition of filler material to polymer matrix increases its resistance to moisture and improves its mechanical characteristics.
Although many works have been focused on polymer composites filled with particulates in the past, reports on the use of industrial solid wastes as particulate fillers have been rare. Only a few studies on use of industrial wastes like red mud, fly ash, copper slag etc. in polymer composites have been reported so far. Mechanical properties of epoxy and fly ash composites are studied by Chaowasakoo and Sombatsompop [1]. Compressive strength of fly ash epoxy composites are reported by Srivastava and Pawar [2]. Patnaik et al. [3, 4] explained the fabrication of the glass-fibre reinforced fly ash filled polyester composites and showed the erosion wear using Taguchi’s orthogonal array. Incorporation of solid waste and E-glass fiber with polyester has been showed by Mahapatra [5]. Gangilet al. [6] produced homogenous and functionally graded vinyl ester composites by mixing the particulate-filled CBPD and short Kevlar fibre. The physio-mechanical polypropylene composites filled with red mud studied by Zhang et al. [7].

Similarly, from copper extraction industries copper slag are generated during matter smelting and refining of copper [8]. Biswas and Satapathy [9] reported the use copper slag in polymers. Reports are also available on characterization and sliding wear behaviour of epoxy composites filled with steel industry wastes like blast furnace slag [10] and LD sludge [11].

Although a number of studies have been reported on the use of various solid wastes as fillers in polymer composites, till date there has not been any work reported on composites using overburden material produced from coal mines as filler. This work explores the possibility of developing such a composite and studies the effect of mine overburden material on the sliding wear behaviour.

2. Materials and methods

2.1 Material used

The overburden material is collected from the Bharatpur Mines, Talcher, Odisha. This coal belongs to Gondwana Series. Freshly dumped overburden materials in the dumping yard were collected in the gunny bag, then; the mouth is sealed and was packed into another poly bag and sealed. Couples of overburden material in multiple gunny bags are approximately transported to the laboratory. The sealing was to preserve the original moisture content. At the time of experimentation, gunny bags were opened and material was taken out. It was crushed and sieved to 0-2 microns grain sizes.

2.2 Composite fabrication

These overburden materials are collected and crushed properly. Then, these particles are sieved to get a size of range 70-100 micrometer. The epoxy (LY 556) and hardener (HY 951) is blended within the ratio of 10:1 by using weight. The overburden material and epoxy are then mixed together in numerous proportions to prepare the composites. The combination is very well combined until uniform dough is formed. Before pouring the dough inside the test tube, it is coated with wax. After that, dough is poured inside the test tube and then kept at room temperature for 24 hours for curing. When the composites are prepared, the test tubes are broken and the composites came out in easy manner. Likewise four samples are made with different compositions (0, 10, 20, 30, 40 wt. %) of overburden material.

2.3 Compressive test

The cylindrical shaped composite samples of required dimension of length 3 cm and diameter 1.2 cm are used for compressive test as per ASTM D695, ISO 604 so as to get the aspect ratio from 2-2.5. The specimen is kept in between two platens of the compression testing machine. A compressive load is applied to the sample slowly till the failure takes place.

2.4 Sliding wear test

In dry sliding test, by using the pin on disc machine, the wear test was done by ASTM G99 standard. The disc which is made up of hardened steel was rotating while the sample was kept constant. Samples are fitted to the holder and sliding rpm is set, track radius and normal load are set before starting the test. In a pin-on disc test, the sample is stationary and the disc is rotating with a certain
speed and a lever mechanism is used to apply load. A series of tests using Taguchi’s L$_{16}$ orthogonal array are conducted with four sliding velocities of 32, 63, 94 and 126 cm/sec under four different normal loadings of 20, 30, 40 and 50 N, respectively. After each trial, both the specimen and the disc are cleaned with acetone so as to get perfect readings. The sample is tested before and after wearing every time.

$$W_s = \frac{\Delta m}{\rho \times t \times V_s \times f_n}$$

Where, $\Delta m$ the mass loss in the test (g), $\rho$ is the density (g/mm$^3$), $t$ is the test duration (s), $V_s$ is the sliding velocity (m/s), $f_n$ is the normal load (N) and $W_s$ is the specific wear rate (mm$^3$/Nm).

2.5 Taguchi experimental design

Design of Experiment (DOE) is an effective device used for interpreting and modeling the influence of control factors on overall performance output. In design of experiment, selection of control factors is very much essential. Numerous parameters like sliding velocity, normal load, sliding distance and filler content are there to study the L$_{16}$ orthogonal array. The use of Taguchi L$_{16}$ reduced the number of experiments from $4^4$=256 conventional runs to simply 16 runs. It saves the cost as well as time. The Signal to Noise (S/N) ratio for minimum wear rate can be expressed as “smaller is better” and can be calculated in logarithmic transformation as shown below.

$$\frac{S}{N} = -10 \log \frac{1}{n} \sum y^2$$

Where, y is the observed data and n is the number of observations.

| Control Factors | 1   | 2   | 3   | 4   | Units   |
|-----------------|-----|-----|-----|-----|---------|
| Sliding Velocity| 32  | 63  | 94  | 126 | cm/sec  |
| Normal Load     | 20  | 30  | 40  | 50  | N       |
| Sliding Distance| 500 | 1000| 1500| 2000| m       |
| Filler Content  | 10  | 20  | 30  | 40  | wt. (%) |

3. Results and Discussion

3.1 Compressive strength

For applications like automobile, designing of hauled roads and ceramic parts, the unconfined compression test is generally used. It is often used as an index to measure the strength enhancement of materials due to treatment. After performing the compression test, the tested sample is shown in figure 1. Similarly in figure 2, the stress-strain diagram of 30 wt. % and 40 wt. % of epoxy-overburden material composites are shown. Table 2 and table 3 as shows the test results for composites filled with epoxy and overburden material of 30 wt. % and 40 wt. %, respectively. These tables also present the values of Young’s modulus, Poisson’s ratio, Modulus of rigidity and Bulk modulus of the composites. It is observed that the compressive strength of the epoxy-overburden material composite increases with increase in overburden material is mixed with epoxy resin. All the samples in unconfined compressive loading situations exhibited shear type failure. Except some samples, all samples failed by means of shear which reflects the mixed impact of sample and system traits.
### Table 2: Mechanical properties of epoxy composites filled with 30 wt. % OB

| P(N) | A(mm²) | dL(mm) | L(mm) | dD(mm) | D(mm) | σ (MPa) | dL/L (strain) | dD/D | E | μ | G | K |
|------|--------|--------|-------|--------|-------|---------|-------------|------|----|----|---|---|
| 2000 | 113.04 | 0.81   | 30    | 0.11   | 12    | 17.69285| 0.027       | 0.009167| 655.2908| 0.339506| 244.6016| 680.4943|
| 5000 | 113.04 | 1.21   | 30    | 0.17   | 12    | 44.23213| 0.040333  | 0.014167| 1096.664 | 0.35124 | 405.7994| 1228.67  |
| 6000 | 113.04 | 1.67   | 30    | 0.25   | 12    | 53.07856| 0.055667  | 0.025833| 953.507  | 0.374251| 346.9187| 1263.775 |
| 7000 | 113.04 | 1.88   | 30    | 0.33   | 12    | 61.92498| 0.062667  | 0.0275  | 988.1646| 0.43883 | 343.3918| 2692.391 |
| 9000 | 113.04 | 2.55   | 30    | 0.36   | 12    | 79.61783| 0.085     | 0.03    | 936.6804| 0.352941| 346.1645| 1061.571 |
| 10000| 113.04 | 2.9    | 30    | 0.42   | 12    | 88.46426| 0.096667  | 0.035   | 915.1475| 0.362069| 335.9402| 1105.803 |
| 13000| 113.04 | 3.49   | 30    | 0.48   | 12    | 115.0035| 0.116333  | 0.04    | 988.5691| 0.34384 | 367.8152| 1055.078 |
| 15000| 113.04 | 3.88   | 30    | 0.57   | 12    | 132.6964| 0.129333  | 0.0475  | 1026.003| 0.36768 | 375.2019| 1288.314 |
| 18000| 113.04 | 4.32   | 30    | 0.66   | 12    | 159.2357| 0.144     | 0.055   | 1105.803| 0.381944| 408.0896| 1561.134 |
| 19000| 113.04 | 4.86   | 30    | 0.73   | 12    | 168.0821| 0.162     | 0.068833| 1037.544| 0.375514| 377.1476| 1389.108 |
| 21000| 113.04 | 5.23   | 30    | 0.84   | 12    | 185.749 | 0.174333  | 0.07    | 1065.631| 0.40153 | 380.167 | 1803.64  |
| 17000| 113.04 | 6.01   | 30    | 0.9    | 12    | 150.3892| 0.200333  | 0.075   | 750.6951| 0.374767| 273.104 | 995.9552|

### Table 3: Mechanical properties of epoxy composites filled with 40 wt. % OB

| P(N) | A(mm²) | dL(mm) | L(mm) | dD(mm) | D(mm) | σ (MPa) | dL/L (strain) | dD/D | E | μ | G | K |
|------|--------|--------|-------|--------|-------|---------|-------------|------|----|----|---|---|
| 3000 | 113.04 | 0.77   | 30    | 0.14   | 12    | 26.53928| 0.025667  | 0.011661| 1033.998| 0.454545| 355.4368| 3791.325 |
| 6000 | 113.04 | 1.03   | 30    | 0.18   | 12    | 53.07856| 0.034333  | 0.015   | 1545.977| 0.436893| 537.9583| 4082.966 |
| 9000 | 113.04 | 1.49   | 30    | 0.29   | 12    | 61.92498| 0.049667  | 0.024167| 1246.812| 0.486577| 419.3565| 15481.25 |
| 12000| 113.04 | 1.82   | 30    | 0.35   | 12    | 79.61783| 0.060667  | 0.029167| 1312.382| 0.480769| 441.1419| 11313.98 |
| 11000| 113.04 | 2.36   | 30    | 0.39   | 12    | 97.31069| 0.078667  | 0.0325  | 1237   | 0.413136| 437.6792| 2373.431 |
| 12000| 113.04 | 2.7    | 30    | 0.45   | 12    | 106.1571| 0.09     | 0.0375 | 1179.523| 0.416067| 416.0294| 2389.047 |
| 13000| 113.04 | 3.12   | 30    | 0.52   | 12    | 132.6964| 0.104    | 0.043333| 1275.927| 0.416667| 450.3271| 2551.834 |
| 17000| 113.04 | 3.77   | 30    | 0.59   | 12    | 150.3892| 0.125667  | 0.049167| 1196.731| 0.391247| 430.0932| 1834.015 |
| 18000| 113.04 | 4.08   | 30    | 0.68   | 12    | 159.2357| 0.136    | 0.056667| 1170.851| 0.416667| 413.2144| 2341.701 |
| 21000| 113.04 | 4.79   | 30    | 0.72   | 12    | 185.7749| 0.159667  | 0.06    | 1163.517| 0.375783| 422.8565| 1561.134 |
3.2 Sliding wear results

The specific wear rates are determined on the basis of test results and the corresponding S/N ratios for all the 16 test runs are presented in table 4. By using the MINITAB 14 software, the graphs are drawn in figure 3 and from there, the lowest specific wear is observed. From this experiment, it is discovered that the specific wear rate is influenced more due to filler content as compared to all other 3 factors like sliding velocity, sliding distance and normal load.

Table 4: Taguchi experimental design for sliding wear test

| Test Run | Sliding Velocity (cm/sec) | Load (N) | Sliding Distance (m) | Filler Content (wt %) | Specific Wear Rate (mm$^3$/Nm) | S/N Ratio |
|----------|--------------------------|----------|---------------------|---------------------|-------------------------------|-----------|
| 1        | 32                       | 20       | 500                 | 10                  | 9.739                         | -19.7703  |
| 2        | 32                       | 30       | 1000                | 20                  | 7.807                         | -17.8497  |
| 3        | 32                       | 40       | 1500                | 30                  | 5.761                         | -15.2100  |
| 4        | 32                       | 50       | 2000                | 40                  | 4.576                         | -13.2097  |
| 5        | 63                       | 20       | 1000                | 30                  | 7.023                         | -16.9305  |
| 6        | 63                       | 30       | 500                 | 40                  | 5.424                         | -14.6864  |
| 7        | 63                       | 40       | 2000                | 10                  | 10.304                        | -20.2601  |
| 8        | 63                       | 50       | 1500                | 20                  | 6.661                         | -16.4708  |
| 9        | 94                       | 20       | 1500                | 40                  | 4.674                         | -13.3938  |
| 10       | 94                       | 30       | 2000                | 30                  | 6.276                         | -15.9337  |
| 11       | 94                       | 40       | 500                 | 20                  | 8.753                         | -18.8431  |
| 12       | 94                       | 50       | 1000                | 10                  | 13.736                        | -22.7572  |
| 13       | 126                      | 20       | 2000                | 20                  | 10.130                        | -20.1122  |
| 14       | 126                      | 30       | 1500                | 10                  | 14.158                        | -23.0200  |
| 15       | 126                      | 40       | 1000                | 40                  | 5.521                         | -14.8404  |
| 16       | 126                      | 50       | 500                 | 30                  | 6.509                         | -16.2703  |

Figure 3: Effects of control factors on sliding wear rate of epoxy-OB composites
4. Conclusions

- The work establishes the use of overburden material, a solid waste in the coal mining sites as a potential filler material in the making of polymer composites.
- It shows that with the enhancement of filler content of coal mine overburden material compressive strength also increases.
- Using of overburden material has resulted in substantial improvement in the wear resistance of epoxy resin.
- Through Taguchi experimental design, dry sliding wear can be measured successfully.
- The analysis reveals that overburden material content and the sliding velocity are the most predominant control factors affecting the wear rates of the composites.
- In future, this study can be extended by mixing this waste with other industrial waste to produce better strength and to fabricate new composites.

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