

# Erosion wear response of epoxy composites filled with steel industry slag and sludge particles: A comparative study

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**Abstract:** In the field of composite research, use of industrial wastes such as slag and sludge particles as filler in wear resistant polymer composites has not been very common. Owing to the very high cost of conventional filler materials in polymer composites, exploring the possibility of using low cost minerals and industrial wastes for this purpose has become the need of the hour. In this context this work explores the possibility of such polymer composites filled with low cost industrial wastes and presents a comparison of mechanical characteristics among three types of epoxy based composites filled with Linz - Donawitz sludge (LD sludge), blast furnace slag (BF slag) and Linz - Donawitz slag (LD slag) respectively. A comparative study in regard to their solid particle erosion wear characteristics under similar test conditions is also included. Composites with different weight proportions (0, 5, 10, 15 and 20 wt. %) of LD sludge are fabricated by solution casting technique. Mechanical properties such as micro-hardness, tensile strength and flexural strength of three types of composites have been evaluated as per ASTM test standards and solid particle erosion wear test is performed following a design of experiment approach based on Taguchi's orthogonal array. Five control factors (impact velocity, erodent size, filler content, impingement angle and erodent temperature) each at five levels are considered to conduct erosion wear tests. The test results for epoxy-LD sludge composites are compared with those of epoxy-BF slag and epoxy-LD slag composites reported by previous investigators. The comparison reveals that epoxy filled with LD sludge exhibits superior mechanical and erosion wear characteristics among the three types of composites considered in this study. This work also opens up a new avenue for value added utilization of an abundant industrial waste in the making of epoxy based functional composites.

## 1. Introduction

The iron and steel industry is one of the most populated industries in India due to availability of raw materials in huge quantities. Every day enormous quantities of waste materials in the form of sludge and slag are produced from these industries. During the production of unit tonne of iron and steel, two to four tones of sludge and slag are being produced. The solid wastes that are generated during the production of iron and steel are Linz-Donawitz sludge (LDS), Linz-Donawitz slag (LD slag) and blast furnace slag (BF slag). The chemical compositions of these wastes differ widely but they have various recyclable elements such as iron, phosphorous, carbon, calcium, etc. BF slag is produced during the production of pig iron from iron ore in blast furnace. The main chemical components present in BF slag are  $\text{SiO}_2$ ,  $\text{CaO}$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{MgO}$ ,  $\text{Al}_2\text{O}_3$  etc. Similarly, LD slag is generated from LD converter during the production of steel from pig iron and mainly contains silicon oxide, calcium oxide and iron oxide. LD sludge is generated after processing of the flue dust emerging from basic oxygen furnace. It mainly contains magnetite, hematite, wüstite or  $\text{FeO}$ , calcite and silica.

Nowadays researchers are giving more attention towards the polymer matrix composites due to their superior mechanical and physical characteristics. They can also be used as wear resistance material in



several low load applications. The wear resistance and mechanical properties of neat polymer can be improved by adding a reinforcing phase into the polymer matrix [1–5]. Many reports are available on utilization of polymers and their composites in erosive wear conditions [6-7]. Although a large number of filler materials are used as reinforcing phase in polymer composites for wear resistance application [8], employment of steel industry solid wastes in this context is very rare. The slag and sludge generated from iron and steel industry can be utilized as reinforcing phase in matrix to improve the mechanical and wear characteristics of the composite samples due to presence of hard phases like magnetite, hematite, wüstite, calcite and silica [9-11]. In view of this, this work reports on the comparative study of erosion wear response of steel industry wastes filled epoxy composites.

## 2. Materials and methods

### 2.1. Fabrication of composite

The fabrications of composite samples are done by solution casting technique. The hardener HY-951 and the epoxy resin LY-556 are mixed in a ratio of 1:10 by weight. Then the LD sludge particles are added in different proportions and properly mixed with the epoxy-hardener combination. The dough is then discharged into moulds of dissimilar shapes. The moulds are kept to cure for few hours at room temperature, after which the samples are collected by breaking the moulds. Finally, the composites are cut to the required dimensions as per the prescribed standards for the evaluation of mechanical and tribological properties.

### 2.2. Characterization

The mechanical characterization such as micro-hardness tests of the fabricated composite samples are conducted with the help of a Vaiseshika micro-hardness tester. For each composition of composite samples five experiments are carried out and the mean value is noted as the micro-hardness value for that particular composite. Three point bend and tensile tests of the composite samples are conducted in the UTM Instron 1195 as per ASTM D-2344 and D-638 respectively. Tensile tests are carried out on dog bone shaped specimen whereas; flexural tests are conducted on flat specimen with dimensions 150 mm × 20 mm × 5 mm. The flexural and tensile tests are repeated three times for each sample and the mean value is noted as the flexural and tensile strength of that specimen respectively.

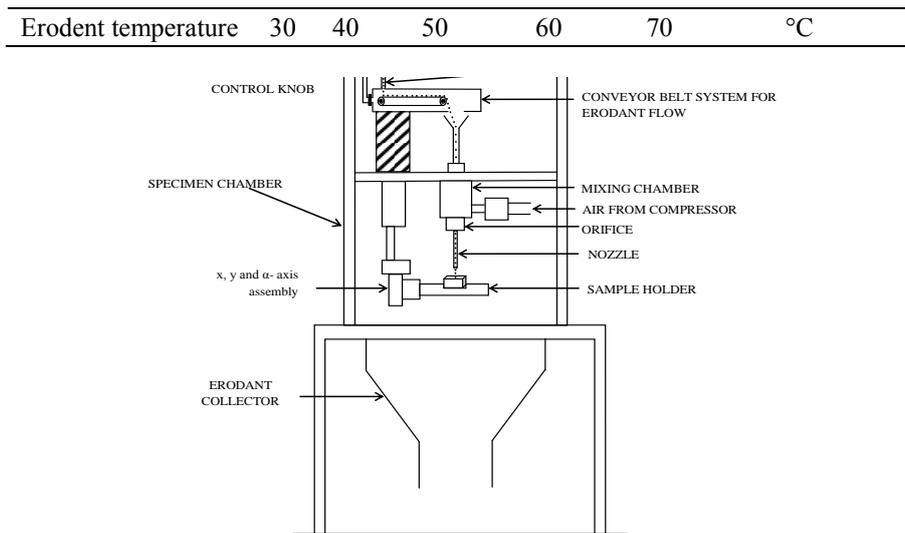
### 2.3. Erosion wear test

The erosion tests are conducted using an erosion wear equipment shown in Figure 1 as per ASTM G76. It is composed of an erodent flow control knob, an air compressor, an erodent feeder, a nozzle, an erodent collector and a specimen holder. Angle of impingement can be changed by fixing the specimen holder at a prescribed angle. Eroder particles used in the erosion tests are dry silica sand (SiO<sub>2</sub>) with average particle size ranging from 50 to 250 μm and are dried in an oven just before the tests.

The specimens of the composites for erosion tests are prepared with the thickness 5 mm and the wear faces being 20 mm × 20 mm. To conduct erosion tests, five major factors have been considered, they are filler content, impingement angle, impact velocity, erodent temperature and erodent size each at five levels as shown in Table 1. Taguchi's L<sub>25</sub> experimental design is chosen to conduct the erosion wear tests. An electronic balance is used to measure the weight loss from the composite specimen after each test. Each test is repeated for three times and mean value is reported as the erosion rate of that specimen.

**Table 1.** Process parameters and levels for solid particle erosion tests

Process parameters	Levels					Units
	I	II	III	IV	V	
Impact velocity	32	40	48	56	64	m/s
Impingement angle	30	45	60	75	90	degree
Filler content	0	5	10	15	20	wt. %
Eroder size	50	100	150	200	250	μm



**Figure 1.** Schematic diagram of the erosion test apparatus

**3. Results and Discussion**

**3.1. Micro-Hardness, Tensile and Flexural Test Results**

In the present work, the micro-hardness, tensile and flexural strength values of BF slag, LD sludge (LDS) and LD slag filled epoxy composites have been obtained and are given in Table 2. It is observed that the micro-hardness of the composites increases with increase in filler loading and this improvement is attributed to the hard phases present in the reinforcing fillers. The micro-hardness value of neat epoxy increases to 68.86% with addition of 20 wt. % LD sludge. Further, for same filler loading LD sludge filled epoxy composites show higher micro-hardness values than BF slag and LD slag filled epoxy composites. A marginal drop in tensile and flexural strength values is observed with increase in filler loading for all the three classes of composite samples reinforced with BF slag, LD sludge and LD slag. It is also examined that tensile and flexural strength of the LDS filled epoxy composites exhibit superior outcome than LD slag and BF slag reinforced composites.

**Table 2.** Comparison of Micro-hardness, flexural and tensile strength of three classes of composites

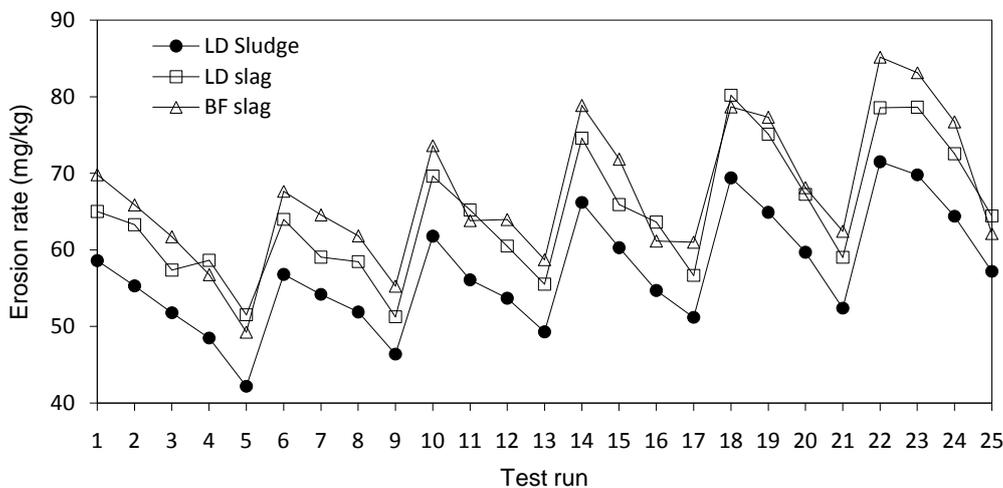
Filler Content (wt. %)	Micro-hardness (GPa)			Tensile Strength (MPa)			Flexural Strength (MPa)		
	EP-LD Slag	EP-BF Slag	EP-LD Sludge	EP-LD Slag	EP-BF Slag	EP-LD Sludge	EP-LD Slag	EP-BF Slag	EP-LD Sludge
0	0.085	0.085	0.085	48	48	48	22.5	22.5	22.5
5	0.096	0.098	0.12	43.81	45.24	45.71	19.12	20.75	20.9
10	0.108	0.112	0.181	41.23	43.98	44.37	16.38	19.81	20.1
15	0.162	0.174	0.232	39.17	42.47	42.84	14.72	18.54	19.3
20	0.182	0.196	0.273	38.51	41.05	41.62	13.23	17.53	18.8

**3.2. Erosion Wear Test Results**

Table 3 shows the erosion rates for three different industrial wastes filled epoxy composites. Each row of the table corresponds to a experiment. Total 25 experiments are carried out as per Taguchi's L<sub>25</sub> orthogonal array. From the erosion rate data given in Table 3 it has been observed that wear resistance of all the three classes of composites increases with increase in filler loading. Further, LD sludge filled composite shows superior wear resistance property than that of other two classes of composites. Figure 2 shows variation in erosion rate for all the three classes of composites.

**Table 3.** The erosion wear test results for three classes of composites

Test Run	Impact Velocity (m/s)	Impingement Angle (degree)	Filler Content (wt. %)	Erodent Size ( $\mu\text{m}$ )	Erodent Temperature ( $^{\circ}\text{C}$ )	Erosion Rate ( mg/kg)		
						EP-LD sludge	EP-LD slag	EP-BF slag
1	32	30	0	50	30	58.594	65.012	69.808
2	32	45	5	100	40	55.294	63.295	65.877
3	32	60	10	150	50	51.794	57.352	61.707
4	32	75	15	200	60	48.495	58.635	56.776
5	32	90	20	250	70	42.195	51.538	49.271
6	40	30	5	150	60	56.794	63.985	67.664
7	40	45	10	200	70	54.194	59.056	64.567
8	40	60	15	250	30	51.894	58.465	61.827
9	40	75	20	50	40	46.395	51.269	55.275
10	40	90	0	100	50	61.793	69.617	73.621
11	48	30	10	250	40	56.094	65.196	63.834
12	48	45	15	50	50	53.694	60.493	63.971
13	48	60	20	100	60	49.295	55.536	58.729
14	48	75	0	150	70	66.193	74.574	78.862
15	48	90	5	200	30	60.293	65.927	71.835
16	56	30	15	100	70	54.694	63.619	61.162
17	56	45	20	150	30	51.194	56.676	60.993
18	56	60	0	200	40	69.393	80.179	78.674
19	56	75	5	250	50	64.893	75.109	77.313
20	56	90	10	50	60	59.694	67.252	68.119
21	64	30	20	200	50	52.394	59.028	62.422
22	64	45	0	250	60	71.492	78.544	85.176
23	64	60	5	50	70	69.793	78.629	83.151
24	64	75	10	100	30	64.393	72.546	76.718
25	64	90	15	150	40	57.194	64.435	62.142



**Figure 2.** Comparative plot for erosion rates of three classes composites for 25 experiments

**4. Conclusions**

- i. Fabrication of epoxy based composites reinforced with LD sludge is feasible through solution casting route.
- ii. Superior mechanical properties are observed in case of LD sludge filler epoxy composites as compared to epoxy-LD slag and epoxy-BF slag composites.
- iii. Solid particle erosion wear analysis reveals that wear resistance of neat epoxy improves with the addition of filler and epoxy-LD sludge composite confirmed better erosive wear characteristic than other two classes of composites.

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