Design of reinforced composite material to overcome wear occurrence in transportation pipes

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Abstract. The wear of carbon steel piping systems has been one of the major problems for various industries that involve the high-speed transportation of their raw materials and/or products. Transportation of cement in construction materials manufacturing factories through carbon steel pipes was studied to suggest a resistible material of unsaturated polyester reinforced with glass fiber and the aluminum honeycomb to be used instead of these pipes. A laboratory-scale apparatus was built to examine the wearing in pipes for the carbon steel and composites specimens. The electrical and mechanical prosperities of the composites were studied by using the ASTM standards to find the best conditions for the newly constructed pipes. It was found that, by increasing the concentration of aluminum powder up to 50 wt% of the composite mixture, the electrical conductivity was increased to be within the range of semi-conductance but the mechanical properties decreased. The best concentration of aluminum powder was found to be 30 wt% of the composite mixture, which represents the most suitable electrical and mechanical properties. Also, it was found that the samples of aluminum honeycomb were gained very good electrical conductivity with special mechanical properties that are suitable for many practical applications.

1. Introduction
The wear is an important factor to be considered for storing and conveying bulk materials, as it takes place on the walls and bottoms of bins and inside the pipes of conveying chute caused by the movement of the material during charging or discharging. This wear depends mainly on the hardness, size of the stored materials, kind of pipes of conveying and on the hopper wall material itself [1]. Sudden change in the bore diameter or direction of the pipe, badly fitting gasket or joint, which introduces a discontinuity in the otherwise smooth metal surface, cracks that allow solid flow outside the main body of the pipe and the presence of deposits that may disturb the flow, are the main causes of wear in pipes [2]. Wear in bulk materials handling plants may result from impact or abrasion or, as is often the case, a combination of both. Erosive wear due to impact occurs when streams of bulk solid particles impinge, usually at medium to high velocity, on inclined surfaces. Typical examples include the intake end of chutes, bin and hopper walls subject to impact loading during filling. In the case of the pneumatic conveyor systems, erosive bend wear can be quite substantial due to the high velocity of particles in the airstream [3]. Abrasive or rubbing wear occurs when the bulk solid flows along the walls of bins and chute. Wear in this case is a combination of pressure and rubbing velocity [4]. Despite the considerable amount of research and investigation into the subject of abrasive wear, there is limited information pertaining directly to the wear in bins and chutes. Johanson and Royal [5] have
developed a special abrasive wear apparatus to permit quantitative wear tests to be performed on a hopper and chute lining materials. Zandi [6] studied the flow of particulate solids through open-ended pipes of different lengths at various angles and determined the rate of flow of particulate iron oxide through open-ended slopping pipes and through slopping pipes connecting fluidized beds. In general, the particle size, bulk density, and the pipe material were kept constant and the effects of diameter, length angle and back-pressure were studied. He found that the length of the pipe does not influence the flow rate of the solids in pipes. Wall friction has a particularly significant influence on the performance and wears the life of bulk handling plant. Wall friction depends on the interaction between the bulk solid properties with those of the wall material and the relevant properties may be summarized as bulk solid properties and the wall material properties: these include surface hardness, surface roughness, chemical composition, and wall vibrations [7,8]. Wear resistance is one of the properties that can be improved by forming composite material in addition to strength, fatigue life, stiffness, temperature-dependent behavior, corrosion resistance and thermal conductivity [9]. Garzón and Palza [10] proved that electrically conductive particles can be added to a polymer that is considered as a poor conductor to produce a composite of enhanced electrical, heat and magnetic conductivity and conductivity. Dilhan et.al. [11] studied the effect of the mixing process variables of graphite, carbon, Al, Au, Ag, Cu and stainless steel powders (electrically conductive filler) when distributed into an insulating polymer. They found that when the time of mixing increases, the electrical conductivity decreases due to the better coating and hence the insulation of the conductive particles from each other.

This paper aims to examine the consumption in cement transportation pipes (carbon steel pipes) within cement manufacturing complex to suggest suitable substitutes for composite material pipes that grant the required mechanical and electrical properties to avoid many of the disadvantages made by using the common pipes.

2. Experimental setup

An experimental apparatus was constructed to test the degree of erosion made by cement flowing through the carbon steel pipes with several angles made to show the effect of these angles on the degree of wear and the cement flow rate. Figure 1 shows the 3D-schematic diagram of the experimental apparatus. The cylindrical Aluminium (diameter of 56cm and height of 70cm), that ends with a semi-cylindrical part (height of 50cm and 28cm final), would serve as the cement container. Low carbon-steel pipes with an inside diameter of 3.6cm were welded to each other in different angles (35, 45 and 90°) to test the wear effect of cement that would circulate by type Eopk 80c-2 air blower (HP=0.5, power= 0.5kW, speed= 2880rpm). The materials that would be composed to fabricate the new piping system are listed in table 1.

![Figure 1. 3D-schematic diagram of the experimental apparatus.](image-url)
Table 1. The materials used for the preparation of composite materials pipes.

| Material                        | Specific gravity | Concentration % |
|---------------------------------|------------------|-----------------|
| Unsaturated polyester (UPE)     | 1.102            | 66.67           |
| Methyl-ethyl ketone peroxide    | 0.985            | 1.0             |
| Cobalt Octoate                  | 1.07             | 10              |
| Glass fiber SiO₂ (65%), Al₂O₃ (15%), CaO (15%), MgO (5%) |                  |                 |
| Aluminum powder                 |                  |                 |
| Aluminum honeycomb              |                  |                 |

3. Experimental procedure
The experimental procedure was divided into two consecutive parts. The first is concerned with the wear behavior of the cement flowing through the piping system, and the other one was to produce and test the proper conductive composites to replace the commercial carbon-steel in the production of the piping system. The wear behavior of carbon-steel pipes was carried out using the weight loss technique under controlled conditions of cement flow rate, various flow angles, constant pipe diameter, and pneumatic conveyance, for twelve hours operation time. The composite specimens were investigated under the same conditions, but for twenty-four hours to verify the enhancement efficiency. Weight loss tests were achieved via a 4 digits electronic digital balance type BP211D-OCE Sartorius. The mechanical and electrical properties of both carbon steel and the composite material were tested according to the standards that are tabulated in table 2.

Table 2. The standard testing procedures for the mechanical properties under study.

| Type                  | Test                       | Standard                  |
|-----------------------|----------------------------|---------------------------|
| Mechanical properties | Bending test               | ASTM D-790 [12]           |
|                       | Flexural strength          |                           |
| Electrical properties | D-C volume and surface resistivity | ASTM D-257 [13]       |

4. Results and discussions
Several tests were made on the carbon-steel pipes to involve all the angles of inclination to determine the degree of wear due to the flowing cement by measuring the weight loss. The curves in figure 2 represent the weight loss of the pipes as a result of the flow of cement for each of the tested angles of inclination; 35°, 45°, and 90°.

![Figure 2. The weight loss of carbon-steel pipes vs. the cement flow rate.](image-url)
The weight loss increases as the flow rate increases for all the tested angles of inclination and this is attributed to the increase of the chaotic movement of the solid globules that would increase the friction with the walls. This means that the decrease of the inclination angle would reduce the amount of wear for high solid flow rates and the wear might be reduced for a certain angle by reducing the solids flow rate. On the contrary, the replacement of carbon steel pipes with the conductive composite material proved no significant weight loss for the piping system, in remarkable evidence for the success of this replacement against the effect of wear even with doubling the operational time from 12 to 24 hours.

The Hookean behavior of the carbon-steel and composite material with various Aluminium content is demonstrated in figures 3(a) and (b), that show the obedience of all tested specimens to the Hook’s law. The remarkable note here was the great enhancement of this behavior with the 40-50% aluminum powder content in the unsaturated polyester with a fiberglass composite material that made about 4-10 times deflection under the same load as compared to the carbon-steel.

![Figure 3. The bending test results of carbon steel and various aluminum content composite materials: (a) 0-30 wt% aluminum powder; (b) 40-50 wt% aluminum powder.](image)

Flexural strength test that determines the highest twisting stress the specimens can tolerate. Figures 4 and 5 show the effect of the addition of aluminum powder, on the flexural strength and shear stress of the test specimen. It was clear that the increase of the aluminum powder decreased the flexural strength and shear stress, and this might be attributed to the reduction of the cross-link density of the polymer with the glass fiber as a result of the intrusion of the aluminum particles.

![Figure 4. Effect of Aluminium powder concentration on the flexural strength.](image)  
![Figure 5. Effect of Aluminium powder concentration on the shear strength.](image)
The electrical conducting test was made to examine the electrical conductivity of the composites samples, and the results of which are shown in figure 6 for various aluminum powder weight percentages. These results proved that the 0, 10 and 20 wt% samples were in the insulation region of the electrical conductivity, while the 30, 40 and 50 wt% of the aluminum powder samples were in the semi-conduction region, and the carbon-steel and the aluminum honeycomb samples were in the region of the metal. Also, it was proved that the addition of conducting aluminum powder decreases the electrical resistivity as shown in figure 7, but the aluminum honeycomb made the composite sample fully conducting (like metals).

5. Conclusions
The wear problem of the carbon steel pipes in industrial projects that involve the transfer of particulate materials was examined in a laboratory model for the transfer of cement under various operational and design variables. As it was determined that the weight loss (wear) increase as a direct impact of the increase of the pipes inclination angle and the cement flow rate, and this may negatively affect the working capacity of such industries, the unsaturated polyester resin reinforced with glass fiber was examined as a replacement for the carbon steel pipes. This replacement proved a good resistance against the wear process. The conversion of electrically insulating unsaturated polyester to a conducting material by the addition of aluminum powder was determined to make it a semiconductor composite that is suitable to be used as an antistatic material but with the drawback of the decrease in the required mechanical properties especially with the increase of aluminum powder. The best combination of electrical and mechanical properties was found with the addition of 30 wt% aluminum powder, as it resulted in electrical conductivity in the semi-conductor range, and mechanical properties that were close to the mechanical properties of carbon steel. Also, the utilization of aluminum honeycomb tests resulted in electrical conductivity in the metal range with specific mechanical properties that were proved to be suitable for the required applications.

6. References
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