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*Review Article*

# Review of an Underground Conveyor using Composite Materials

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***Abstract***

*Aim of this paper is to analyze feasibility of adopting composite material in underground conveyors used in coal mines. Steel is the conventional material generally used in the underground conveyors which is to be replaced by composite material such as fiberglass with vinyl ester resin. A design using composite material is required because of heavy structure of conventional conveyors. One main reason of accidents in coal mines is physical strain in the workers due to transportation of heavy conveyor structure. Analysis of various designs with composite material will help to find out lightest and cheapest design. The report will investigate the potential for composite materials to be used in underground conveyor support structures in the mining industry to reduce the accident percentage. The report aims to identify need and use of composites in this field.*

***Keywords:*** *Underground conveyor, composite material, Weight reduction, fiberglass, vinyl ester resin*

## 1. Introduction

Underground conveyor is used in coal mines for the transportation of coal (Fig.1). Conveyor line should have to assemble and disassemble every time when carrying it from one site to another site underground. This leads to some small injuries as well as major physical injuries to the workers in the mine. Company has to pay the compensation to the workers. As well as time wasted in changeover of conveyor reduces the production rate. As workers are supposed to carry the conveyor components underground for long distances, therefore weight is a decisive matter to be considered in the design. Accordingly the company's are targeted the design to be structured using advanced materials such as composites.

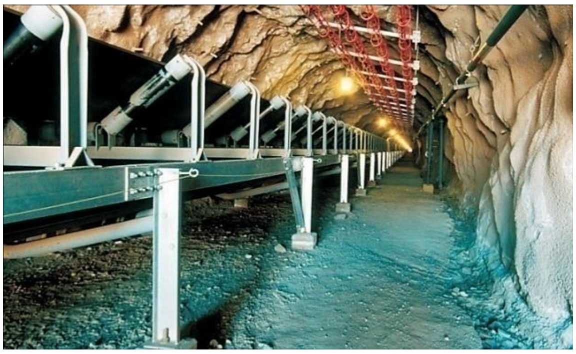

**Fig.1** Traditional underground conveyors

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Composites are known for decades for its high strength/weight ratio, low cost and better strength properties. However, there are some limitations to be considered during the design phase, such as fatigue resistance which limits their direct application in a conveyor structure. In addition to their traditional manufacturing requirements, this leads to permanent bonds between the components. As mentioned earlier, the conveyor designed must be made up of separate components that can be dismantled apart. The environment where the conveyor is operating is harsh conditions where miners use limited basic tools and carry manually the components to another place. Therefore the components must not be bonded permanently, so structured and manufactured accordingly. The legislations, Indian standards, materials used, manufacturing processes should be considered during design phase.

A composite material is combination of two or more materials to achieve better properties than those of the individual material used alone. In contrast to metallic alloys, each material retains its separate chemical, physical, and mechanical properties. The two constituents are reinforcement and a matrix. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part.

## 2. Literature survey

Many researchers studied the issues and problems related to coal mines. Some of them focused on worker heaths and accident. Recently researchers are working on safe design to avoid accident in coal mines. Composites materials found suitable for underground conveyor.

QoS (A. Mandal, *et al*, 1999) did the analysis of fatal accidents of Indian coal mines from April 1989 to March1998. It is found that Indian mines have considerably higher accident and fatality rates compared to those in USA and South Africa, respectively. While open cast mines are generally known to be safer than underground mines, the Indian open cast mines are shown to be at least as hazardous to the workers. Analysis of the accident rates is made via a few regression models involving the effects of working shifts, the various companies, the types of mine, man shift and production. The accident-prone combinations of mine type and company are identified for follow-up action. The break-up of the accidents by cause is also studied.

**Table 1** Fatal accident rates in US and India, 1989-97

| Year | Accidents per million tons of production per year | | Accidents per million man hours per year | |
|---|---|---|---|---|
| | India | USA | India | USA |
| 1989 | 0.722 | 0.077 | 0.112 | 0.05 |
| 1990 | 0.638 | 0.071 | 0.105 | 0.04 |
| 1991 | 0.587 | 0.068 | 0.103 | 0.04 |
| 1992 | 0.644 | 0.060 | 0.118 | 0.04 |
| 1993 | 0.541 | 0.055 | 0.103 | 0.04 |
| 1994 | 0.484 | 0.049 | 0.099 | 0.04 |
| 1995 | 0.468 | 0.050 | 0.103 | 0.04 |
| 1996 | 0.383 | 0.040 | 0.089 | 0.04 |
| 1997 | 0.380 | 0.030 | 0.091 | 0.03 |

Coal is an important mineral in India, besides being the main source of fuel in power plants, companies. The coal industry has over 600,000 miners and other workers. Safety in the Indian coal mines is therefore a very important issue. However, there has been no significant statistical analysis of the safety records of Indian coal mines. The fatal accident rates in India and US during the period 1989-97 are shown in Table 1. The data for this research was taken from 'US Department of Labor' and 'Fatal Accident Register and Annual Performance Report of Coal India Limited'.

Qos (Salahuddin azad, *et al*, 2013) made study on health of coal miners in Baluchistan. They observed that no health related record of coal miners was maintained at any level like coal mine owners, Hospitals etc. The Survey of medical facilities where the coal workers used to get treatment says that coal workers mostly suffer the diseases as shown in Fig. 2. It is the data collected during year 2012-2013. It's quite evident that most frequently occurring injuries are due to strain/stress, and back problems due to working position in the coal mine. 41.7% injuries are due sprain/strain in the workers. The main reasons are inadequate working facilities, non-availability of modern mining techniques and allied facilities at site.

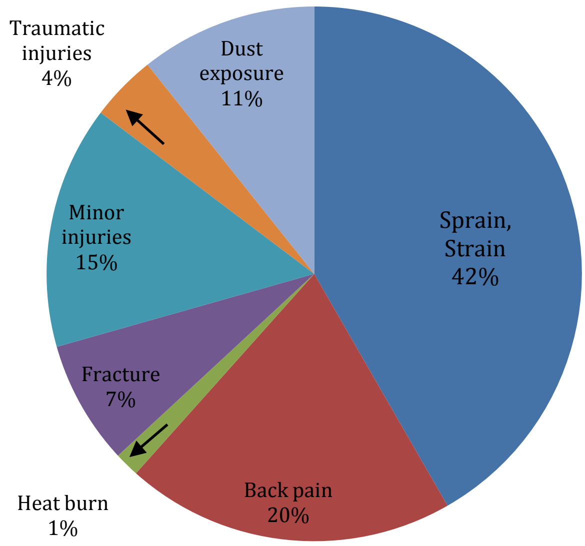


**Fig.2** Types of injuries coal workers suffers

Coal handling system plays an important role in production rate of coal mines. Supply chain of coal is mainly depends on the coal handling equipments. So workforce related to coal conveyor is more. Space available to undertake job is very small and the workers have to carry heavy structure, this lead to the high percentage in strain. According to this paper weight and easy assembly is one of the main issues to be solved for future benefits.

QoS (S. Prabhakaran, *et al*, 2012) tested the feasibility of using composite material in automobile cars. The fuel efficiency and emission gas regulation of passenger cars are two important issues in these days. The best way to increase the fuel efficiency without sacrificing safety is to employ fiber reinforced composite materials in the cars. Bumper is the one of the part having more weight. In this paper the existing steel bumper is replaced with composite bumper. They have designed and fabricated composite bumper made up of glass fiber reinforced polymer by which weight of bumper can be reduced. Fabrication of composite bumper is carried out by hand layup process by using E- Glass/ Epoxy bidirectional laminates. Composite bumper is analyzed and tested using Charpy impact test. They have achieved following results as shown in Table 2.

**Table 2** Comparison between steel and composite bumper

| **Description** | **Steel Bumper** | **Composite bumper** | **% of reduction** |
|---|---|---|---|
| Weight (Kg) | 5.15 | 2.38 | 53.78 |
| Cost (Rs) | 3600 | 820 | 77.22 |
| Impact strength (J/mm$^2$) | 3.25 | 7.35 | - |
| Max. stress (N/mm$^2$) | 369.168 | 142.471 | - |
| F.O.S | 1.2 | 3.4 | - |

Design, fabrication and testing of steel and composite bumper (using glass fiber material) are completed and also composite bumper is analyzed and compared with steel bumper.

Design, fabrication and testing of steel and composite bumper (using glass fiber material) are completed and also composite bumper is analyzed and compared with steel bumper. The steel bumper weighs about 5.15 Kg where the weight of composite bumper is 2.38 kg. Which is 53.8% lesser than steel bumper. It is proved that fuel economy of the vehicle is improved as the composite bumper weighs less when compared with steel bumper. Cost of composite bumper is Rs. 820/- which is 80% less than steel bumper. Impact strength of composite bumper is 7.35 J/mm$^2$ where steel bumper is 3.25 J/mm$^2$. The existing and composite bumper is analyzed in ANSYS 10.0 and the Maximum stress induced in the composite bumper is 159.4 N/mm$^2$ where steel is 292.6 N/mm$^2$. Factor of safety for composite bumper is increased by 64%. From the study, it is concluded that fiber reinforced plastic material is a suitable material for manufacturing the bumper.

QoS (John R. Etherton, *et al*, 2014) tested composite material for design of structure over steel. The aim of project was o develop Rollover protective structure for farm tractors using pultruded FRP composite material. Deaths have been increasing due to tractors accidents. Accordingly a design is required to reduce the deaths and increase the workers safety. A composite ROPS will guarantee that these requirements plus lower shipping weight and low fabrication cost, will easily be applicable on the tractors.

The three steps undertaken to achieve the right material selection and last the structure design, where the lay of the fiber, matrix strain, fiber strain and last the geometry of the structure. The lay of the fibers should be in the axial strength to attain progressive crushing and hoop strength so it will lead to micro failure instead of global. Moreover, the matrix or resin strain should have higher strain than that of the fiber to allow higher strength to the composite material. But for the advice of the geometry, where circular tubes have better energy absorption than rectangular and square, it was not used for the conveyor structure that was designed. Pultrusion was the manufacturing process used in this project. It is a continuous process for composites manufacture, with constant cross sectional shape. In this process fiber tows are pulled from the creel and then placed in a resin bath impregnator. By using pre-forming guides the fibers tows are guided, then it is pultruded through curing dies. Then at the last stage the pultruded sections are cut to shape. The project targeted on applying load to the structure that is 1.75 times the tractor's mass and greater than 1341 J of energy transfer on the structure. By comparing steel to the composite materials, steel has limitations in energy absorption within plastic range, as ultimate failure propagates soon. On the other hand composites have higher energy absorption, where the damage zone (not plastic as in steel) is where it experience the deformation.

QoS (Steven J. Smith, *et al, 2000*) done analysis and testing of a prototype pultruded composite causeway structure. The preliminary design of a floating causeway system made from pultruded composite materials is described. As part of the design effort a 24-ft long×15-ft wide×5-ft high (7.3 m×4.6 m×1.5 m) pultruded GFRP scaled prototype was fabricated. Testing revealed that the prototype composite structure was capable of supporting the expected service sustained loads, as well as, the lifting loads. Strain and deflection data indicated that minimal stress levels existed in the structure during testing. For predictive and comparative purposes, two finite element models were developed that corresponded to the sustained load and lifting load tests. These were relatively simple two-dimensional models; however, they effectively captured global and localized structural behavior.

QoS (A. Mohamed Ansar, *et al*, 2013) studied the fatigue life of GFRP composites based on an extensive experimental study. Then the loss of stiffness was used as a damage parameter and related to raise the temperature.

They have used bidirectional (0°/90°) glass fiber reinforced epoxy laminate for the study of project. Here the composite laminate is made up of seven layers of glass fibers with epoxy resin were fabricated. The plain weave fabric of E glass E420 fibers and LY 556 Epoxy Resin with XY 951 Hardener were used. The constant thickness of 3.4mm will be maintained throughout the experiment. Fiber-volume fraction of the composites was 65%. Vacuum bagging technique was used for the manufacturing of composite laminate. Resin and hardener were mixed in the ratio of 10:1. Alternate layer of resin-hardener mixture and carbon fibers were applied at room temperature. Curing at room temperature was done for 24 hours and post-curing at 100°C was done for 2 hours. The objective of this project is to analyze the damage and ageing effects in composites and find the change in physical and mechanical properties. They have done fatigue analysis of glass fiber reinforced composites with varying loads and number of cycles with stand. The fatigue test for GFRP shows that it can withstand the fatigue load efficiently compare to aluminum. In the future this work can be extended with different loading conditions to prove who the stress variation can be improved, by knowing the stress variation this can be used in airframe of the aircrafts.

QoS (Christopher Wonderly, *et al,* 2005) presented the paper showing comparisons of mechanical properties of glass fiber/vinyl ester and carbon fiber/vinyl ester composites. Different experiments were undertaken for both composites to analyze their performance in different fields. Most of the choices of the materials depend on the cost and performance. But weight is the first preference in the material choice, as carbon fiber has been used widely in aerospace structures, where its performance and cost side is superior from the fiber glass. On the other hand the ships manufacturing has been using mainly fiber glass, as its structure does require different characteristics in the material from the aerospace requirements. The ships are not as sensitive to excess weight, as aerospace specifications, to be scrupulous in choosing the expensive material. According to the researchers, the mechanical properties have been tested through tensile strength, compression strength, open hole tensile (OHT) strength, open hole compression (OHC) strength and transverse tensile strength. All these settings were demonstrated in Table 3 below their results.

The study of the mechanical properties between carbon fiber and glass fiber, under different loads applied to them were compared after their evaluations. The evaluations showed that the reinforcements were similar to each other. Although during the testing the carbon plies were thinner than the glass fiber as normally in the ships manufacturing, the thickness used for the fiber is much thicker than what aerospace structure uses for the carbon thickness. Table 3. illustrates the results achieved by all the different testing.

**Table 3** Strength of carbon fiber and glass fiber

| | Tension | Compre-ssion | OHT | OHC | Trans-tense |
|---|---|---|---|---|---|
| Carbon | 958 | 328 | 621 | 235 | 18 |
| Glass | 544 | 396 | 367 | 239 | 24 |
| Ratio | 1.76 | 0.83 | 1.69 | 1 | 0.8 |

As a conclusion to these results, the specific properties (i.e. property divided by density or mass), fiber glass was performing better than carbon fiber in transverse tensile strength. While for the other properties carbon outperformed the glass fiber in the other properties. But in general, both materials perform really well in high strength and light structures.

QoS (S. Feih, *et al*, 2007) studied the performance of glass fiber composite in fire. A thermal-mechanical model is presented to calculate the tensile strength and time-to-failure of glass fiber reinforced polymer composites in fire. The thermal component of the model considers the effects of heat conduction, matrix decomposition and volatile out gassing on the temperature-time response of composites. The mechanical component of the model considers the tensile softening of the polymer matrix and glass fibers in fire, with softening of the fibers analyzed as a function of temperature and heating time. Experimental fire tests are performed on dry fiberglass fabric and fiberglass/vinyl ester composite specimens to validate the model. It is shown that the model gives an approximate estimate of the tensile strength and time-to-failure of the materials when exposed to one-sided heating at a constant heat flux.

It is concluded from the test that, thermal softening of the polymer matrix reduces slightly the tensile strength of fiberglass composites when initially exposed to fire, but eventually has no significant affect once the matrix is fully softened and decomposed. The model also considers thermal softening of the glass reinforcement, which is dependent on both the temperature and heating time. The model shows that tensile failure of fiberglass composites is controlled mostly by fiber softening. The model can accurately predict the tensile strength and failure time of fiberglass fabric laminates, although it gives an approximation of the tensile strength of fiberglass-vinyl ester composites, particularly under low load and low heat flux conditions. While this study has shown that the model gives a good estimate of the tensile strength and failure time for vinyl ester composites.

## Conclusion

This research work has discussed the necessity and feasibility of composite material in coal mines. Some conclusions can be made from the present research work. New technologies should be introduced in Indian coal mines to reduce accident percentage in coal mines. The weight of conveyor should be reduced to avoid the accidents occurring due to strain on workers. The composite material can be used instead of steel material for conveyor structure successfully. The composite material gives good strength to weight ratio than the traditional material steel. The composite material has the better energy absorption than steel. Fire resistance of property can be increased by adding additives in the composite. Vinyl ester resin has good fire resistance property. From researches we can conclude that vinyl ester resin is the suitable material for coal mine conveyors as it has good strength, low weight, low cost & fire resistance properties.

## Future scope

To check the practical feasibility we can design conveyor structure using composite material. Analysis of structure can be done using ANSYS software for optimization of structure. Experimental testing should have to be done to validate the ANSYS results. We can test the composite structure by varying the volume fraction of Matrix and reinforcement.

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