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Design and Analysis 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 E-glass with Epoxy 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. The paper will investigate possible designs of conveyor structure using composite material. These designs will be analyzed using Ansys & Ansys Composite Preppost (analysis software) to recommend the lightest and cheapest design. To conclude, the preliminary design selected will be analyzed with accordance to the structure's total stresses and deflection. The paper also contains factor such as material composition and suitability, cost, weight as well as ease of manufacture and assembly necessary to develop a model of a composite conveyor support structure. The paper will also investigate the potential for composite materials to be used in underground conveyor support structures in the mining industry to reduce the accident percentage. The paper aims to identify need and use of composites in this field.

Keywords- **Underground conveyor, Composite material, Weight reduction, Ansys Preppost**

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I. 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. 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. As mentioned earlier, the conveyor designed must be made up of separate components that can be dismantled apart.

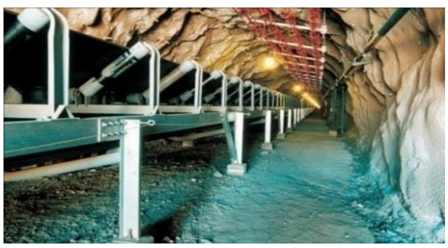

Fig.1 Traditional underground conveyors

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.

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.

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 I
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 Labour and 'Fatal Accident Register and Annual Performance Report of Coal India Limited'. [1]

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.

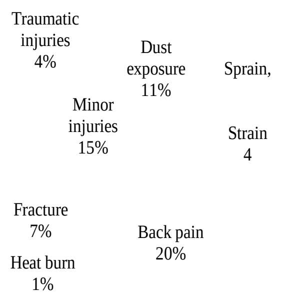

Fig.2 Types of injuries coal workers suffers

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. [2]

I. MATERIAL SELECTION

A. Glass Fiber

The aim of fiber reinforced plastics is to combine the stiffness and strength of fibrous material. This material has corrosion resistance, low density and mould ability. The majority of reinforced plastics produced today are glass reinforced epoxy or polyester resins, both of which are thermosetting. Glass fibers have also been used with phenolics, silicones, polystyrene and polyvinyl chloride. Glass fibers are the obvious choice as reinforcing agents, principally because of the relative ease with which high strengths can be obtained fiber a few microns in diameters. It is possible to produce composites with a range of strength according to glass content and nature of the reinforcement. The epoxy resins have lower shrinkage than the other resins.

Glass is the most common fiber used in polymer matrix composites. The most commonly used glass fibers are E-glass, S-glass, R-glass, C-glass and D-glass fibers. The E in the E-glass stands for electrical as it was designed for electrical applications. E-glass fiber is a high quality glass fiber used as a standard reinforcement for all the resin systems and as a well complying with mechanical property requirements. Thus E-glass fiber was found appropriate for our applications. In S-glass S stands for higher content of silica. It retains its strength at high temperature and has higher fatigue strength. It is used mainly in aerospace applications. In C-glass C stand for corrosion, it is designed to give improved surface finish. It is available usually in the form of a surface tissue for the reinforcement of corrosive barriers in chemical plant. In D-glass D stands for dielectric used for applications requiring low electric constants.

Glass fiber is most widely used as are reinforcement of all composites due to the following advantages:

- Molten glass easily drawn into high-strength fibers
- Readily available/easy to fabricate
- Relatively strong fibers produce very high strength in composite form
- Chemically insert in plastics.

These materials are limited to low temperature applications where strength is important without the need for high rigidity. Typical uses for this material are boat hulls, flooring materials and automobile bodies. The main type of glass used is E-glass. However, it is used for many other purposes now such as decorations and structural applications.[3]

B. Epoxy Resin

Epoxy resins are the most commonly used resins. They are low molecular weight organic liquids containing epoxide groups. Epoxide has three members in its ring 1 Oxygen and 2 Carbon atoms. The reactions of Epichlorohydrin with phenols or aromatic amines make most epoxies. Hardeners, plasticizers and fillers are also added to produce epoxies with a wide range of properties of viscosity, impact, degradation, etc. Although epoxy is costlier than other polymer matrices, it is the most popular PMC matrix. More than two thirds of the polymer matrices used in aerospace applications is epoxy based. The main reasons for epoxy being the most used polymer matrix materials are

- Good compatibility with Glass fiber
- High strength
- Low viscosity and low flow rates, which allow good wetting of fibers and misalignment of fibers during processing
- Low shrink rates which reduce the tendency of gaining large shear stresses of the bond between epoxy and its reinforcement.
- Available in more than 20 grades to meet specific property and processing requirements. [3]

II. METHODOLOGY

A. *CAD Modelling*

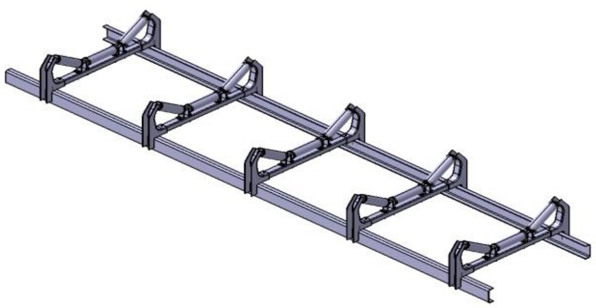

Fig.3 Conveyor model generated using CATIAV5

CAD modeling was done using CATIA V5 R16. CATIA has advanced modeling and surfacing tools to create complicated shapes. Conveyor structure was modeled in Part design & surfacing modules and assembled in Assembly design module. Fig.3 shows conveyor structure.

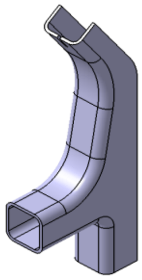

Fig.4 Bracket of conveyor

Bracket is the most critical part of conveyor structure so we have taken the bracket for finite element analysis. Fig.4 shows Bracket modeled using CATIA.

B. Finite element analysis

1) Meshing: Meshing is the process in which the object is discredited into very small parts known as elements. It is also known as piecewise approximation. Here the model of leaf spring is meshed with an element size of 5mm brick mesh.

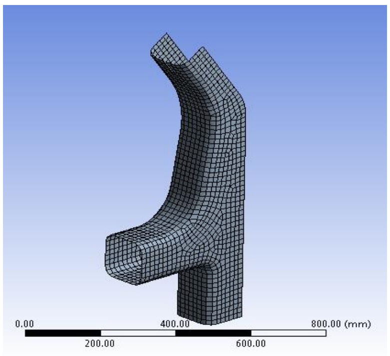

Fig.5. Meshing of Bracket

Engineering layered composites involves complex definitions that include numerous layers, materials, thicknesses and orientations. Simulation is ideal for this when considering stresses and deformations as well as a range of failure criteria. ANSYS Composite Preppost software provides all necessary functionalities for FEA (finite element) analysis of layered composites structures. This will help us to predict how well the finished composite product will perform under real-world working conditions.

The composite layered solid element model appears in Workbench Mechanical as a meshed body. The user can define loads, boundary conditions and connections to other parts in the usual Workbench Mechanical fashion. An example of such a solid model workflow is shown below.

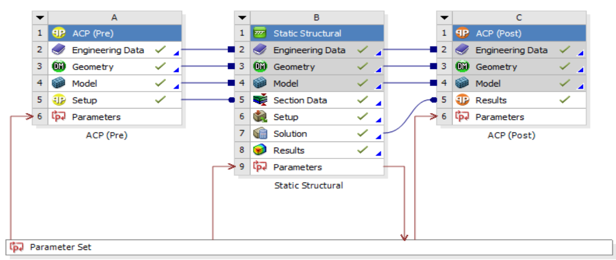

Fig.6 Workbench workflow for composite solid modeling

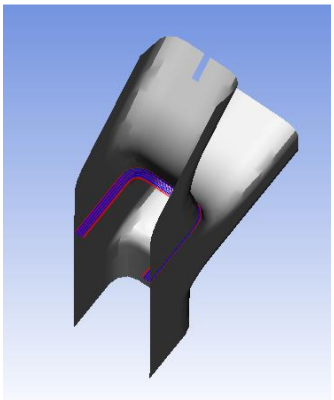

Fig.7 Layered model of bracket in Ansys Preppost

Fig.7 shows the bracket having layered structured prepared in ACP preppost. Thickness of bracket is 5mm. Configuration of composite layers are as below.

E-glass layer thickness = 0.5mm
Epoxy resin thickness is = 0.2mm
Number of E-glass layers = 7
Number of Epoxy resin layers = 8
Fiber orientation = 0 to 90^{o}

By using this layered composite model of bracket is prepared in Ansys ACP.

B. Boundary Condition

Loads are taken accordingly existing conveyor data available in the company. Load acting on the bracket is 2200N.

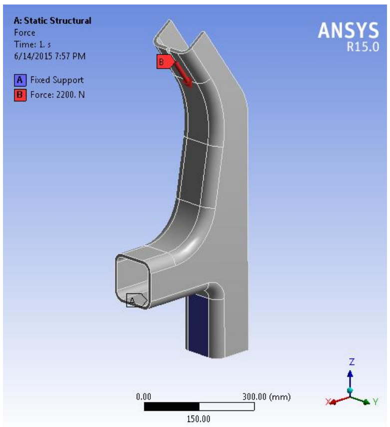

Fig.8 Loading and Boundary conditions

Fig.8 shows loading conditions of bracket in Ansys. Loads are applied on the bracket at location where roller transfers the load to the bracket. Fixed support is given at the base where bracket rests on the railing.

C. Stress analysis

ACP (Post) is used to get the results of Composite bracket. Static structural domain in Ansys is used to get the results of Steel bracket

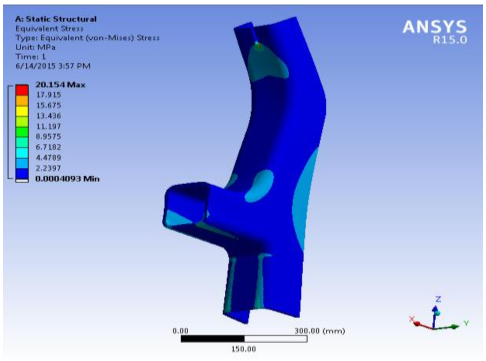

Fig.9 Stresses in Steel Bracket

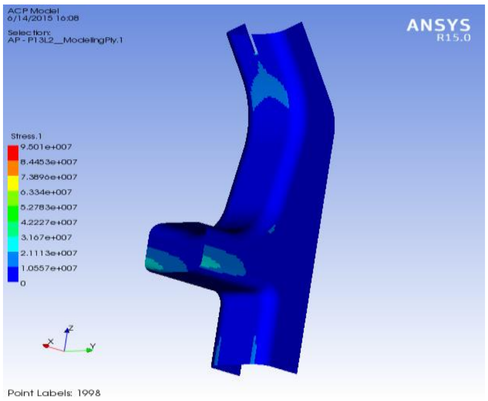

Fig.10 Stresses in Composite bracket

D. Deformation analysis

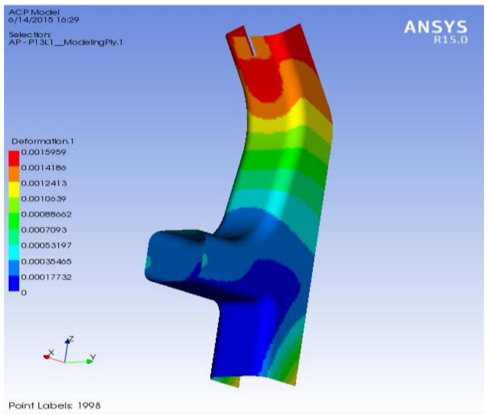

Fig.11 Deformation in Steel bracket

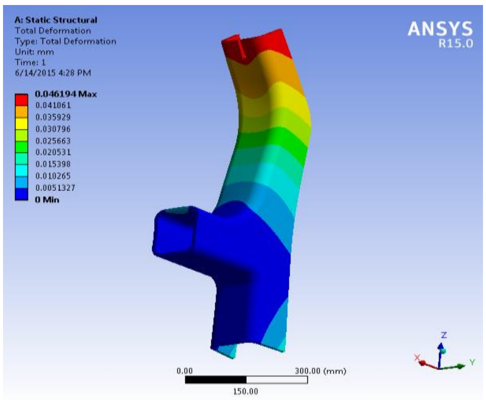

Fig.12 Deformation in Composite bracket

E. Strain energy analysis

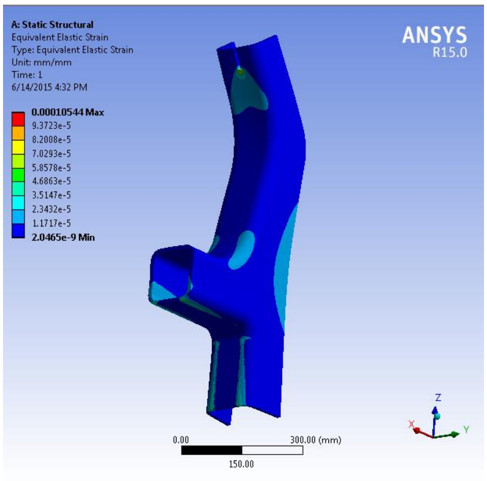

Fig.13 Strain in Steel Bracket

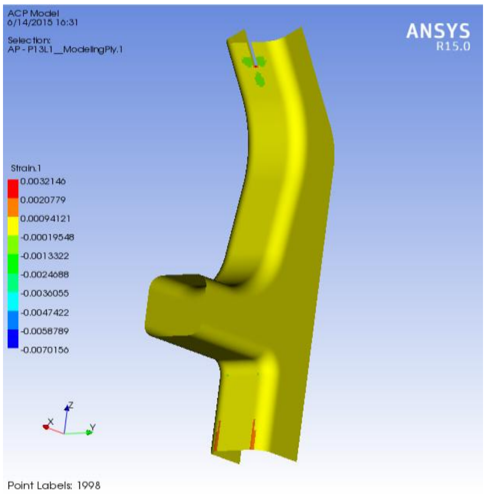

Fig.14 Strain in Composite bracket

III. Results

Below table shows result obtained from FEA analysis

TABLE III
COMPARISON OF STEEL AND COMPOSITE BRACKET

Description	Steel Bracket	Composite Bracket
Density (Kg/m^3)	7860	1520
Weight (Kg)	17.2	3.5
Cost (Rs)	5000	1400
Max. stress (N/mm^2)	20.15	31.67
Max. strain	0.0001	0.002
Maximum Deformation (mm)	0.046	1.6

Conclusion

The Design and Analysis of composite bumper is done. By the comparison of results between steel & composite bracket, it is found that weight of bracket reduced drastically. Steel bumper weighs about 17.2 Kg where the weight of composite bumper is 3.5 kg which is 79.6% lesser than steel bumper. Cost of composite bracket is 1400 Rs. which is 72% less than the steel bracket. Maximum stress induced in steel bracket is 20.15 Mpa where as in E-glass/Epoxy composite is 31.67 Mpa which is below allowable limit. As far as strength concern Composite material sustained at given loading conditions. So we can conclude that the Steel can be successfully replaced by E-glass/Epoxy composite in underground conveyors. Composite is having layered structure so to get accurate results Ansys Preppost add in is used to define layered structure successfully & results are obtained precisely. Hence we can conclude that the using composite material can be an option to reduce weight of underground conveyor which will help to reduce the accident percentage in mines.

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