Weight Optimization of Chain Link using Glass Fiber Composite as Alternative Material

Mr. Shivanand Bhosale[1] Prof. A. R. Patil[2]
[1,2]Department of Mechanical Engineering
[1,2]Sahyadri Valley College of Engineering, Savitribai Phule Pune University Maharashtra, India

Abstract— Chain is the most important element of the industrial processes required for transmitting power and conveying of materials. Roller conveyor chain performs efficient and economical in wide range of applications in manufacturing and agricultural industries. In chain conveyor system motor capacity of conveyor depends on the weight of chain and weight of chain conveyor is covered by outer link and inner link. So, weight is the main problem with metal chain and power consumption is more due to bulky stacker chain. So, to reduce power consumption we have to reduce weight of chain link plate. In this project we performed, theoretical analysis of the stresses in chain link, pin and estimation of required breaking load as per given capacity of roller conveyor chain, finite element analysis of stresses in chain link and pin for traditional material and composite material (Glass Fiber) using ANSYS. Then Experimental analysis of chain link and pin of suggested alternative composite material (Glass Fiber) will be done and comparison of theoretical, FEA and experimental results for Chain Link Plate made of Glass Fiber will lead to the conclusion of the study and final results.

Key words: Chain link, shape optimization, von Mises stress

I. Introduction

"Material handling is a field which involves the transport, storage, and control of goods and products throughout the processes of manufacturing, distribution, consumption and disposal of all related materials. The focus of the material handling industry is on the methods, mechanical equipment, systems and related controls used to achieve necessary functions". "The conveyor systems" is a much easier term to grasp the above explanation very correctly and in the true sense.

A conveyor is a mechanical material-handling machine that helps in moving goods from one place to another in a prearranged trail. The use of conveyors in material handling has been since the early 20th century and can be known as the back bone of material handling. With their long history, conveyors are easier known as a piece of equipment that moves material from one place to another and are especially useful when applications call for the transportation of heavy or bulky material at all shapes and size.

Conveyor systems are commonly used in many industries, including the automotive, agricultural, computer, electronic, food processing, aerospace, pharmaceutical, chemical, bottling and canning, print finishing and packaging. Though a wide variety of materials can be conveyed, some of the most common include food items such as beans and nuts, bottles and cans, automotive components, scrap metal, pills and powders, wood and furniture and grain and animal feed. Many factors are important in the appropriate selection of a conveyor system. Some individual areas those are helpful to consider are the required conveyor operations, like transportation, accumulation and sorting, the material sizes, weights and shapes and where the loading and pickup points need to be.

Following are the main parameters of the roller conveyor system selection.

- Product dimensions
- Product weight
- Product variability
- Surrounding environment
- Power requirements

A. Types of Conveyors:

1) Roller and Gravity Conveyors

Fig. 1.1: Roller and Gravity Conveyor

These conveyors make transportation of goods around a warehouse to be an easy task. They use rollers which allow goods to be pushed around from one place to another. They can also use the force of gravity to move the goods.

2) Powered Conveyors

These types are controlled. These transport goods around from one part of a warehouse to another and even from one floor to another. The controller can manipulate the starting point, stopping point and direction they are supposed to take.

Fig. 1.2: Powered Conveyors

3) Belt Conveyors

These are mainly used for a perpendicular change in a system. They allow a warehouse to use multiple floors on different levels. Vertical or spiral lifts also allow goods to be taken in an up or down movement to other levels. It is typically used in package handling, raw material handling, and small part handling.

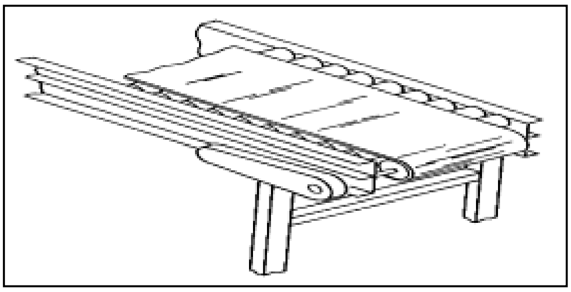


Fig. 1.3: Belt Conveyor

4) Chain Conveyor

A chain conveyor is a type of conveyor system for moving material through automatic production lines, material feeding lines. There are various types of conveyors that are available as explained in detail above. Each can be installed to serve specific needs and specifications particularly this conveyor system can be used to serve varied production implementations and much versatile and modular. Chains are reliable machine component, which transmits power by means of tensile forces, and is used primarily for power transmission and conveyance systems. From a theoretical viewpoint chain is a continuous flexible rack engaging the teeth on a pair of gears. Certainly a sprocket being a toothed wheel, whose teeth are shaped to mesh with a chain, is a form of gear. When a load is put on the chain, the chain begins to move forward due to friction. It pulls the load simultaneously in the forward direction by using the same method. Based on its history and development, chain is a mechanical belt running over sprockets that can be used to transmit power or convey materials. Most of the time chain is under tension which causes elastic and plastic stresses which results into elongation of chain. As these chains operate under various forces, failure of chain assembly is the major problem.

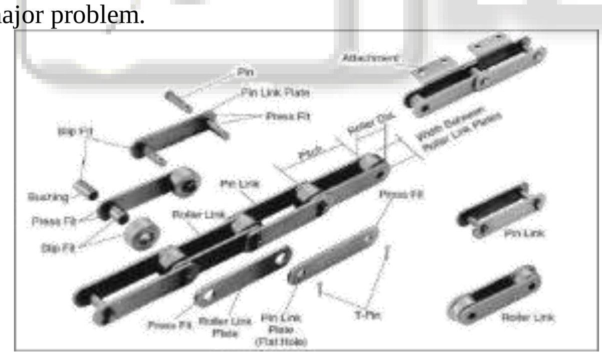


Fig. 1.4: Typical Roller chain Link Terminology

5) Composite Material

A composite material also called a composition material or shortened to composite which is the common name, is when two or more different materials are combined together at a macroscopic level and are not soluble in each other to create a superior and unique material.

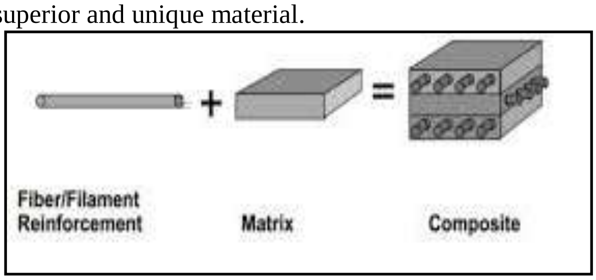


Fig. 1.5: Composite Material

B. Glass Fiber

"Fibreglass reinforced plastics" or FRPs (commonly referred to simply as fibreglass) use textile grade glass fibres. These textile fibers are different from other forms of glass fibres used to deliberately trap air, for insulating applications (see glass wool). Textile glass fibres begin as varying combinations of SiO_2, Al_2O_3, B_2O_3, CaO, or MgO in powder form. These mixtures are then heated through direct melting to temperatures around 1300 degrees Celsius, after which dies are used to extrude filaments of glass fibre in diameter ranging from 9 to 17 µm. These filaments are then wound into larger threads and spun onto bobbins for transportation and further processing. Glass fibre is by far the most popular means to reinforce plastic and thus enjoys a wealth of production processes, some of which are applicable to aramid and carbon fibres as well owing to their shared fibrous qualities.

Fibre fabrics are web-form fabric reinforcing material that has both warp and weft directions. Fibre mats are web-form non-woven mats of glass fibres. Mats are manufactured in cut dimensions with chopped fibres, or in continuous mats using continuous fibres. Chopped fibre glass is used in processes where lengths of glass threads are cut between 3 and 26 mm, threads are then used in plastics most commonly intended for moulding processes. Glass fibre short strands are short 0.2–0.3 mm strands of glass fibres that are used to reinforce thermoplastics most commonly for injection moulding.

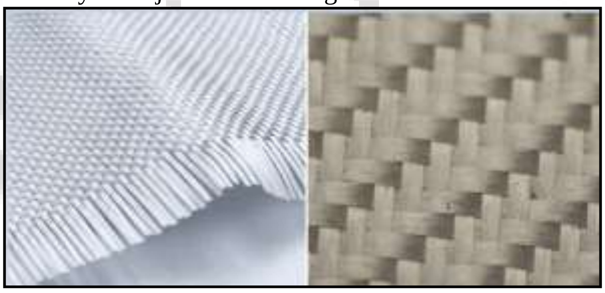


Fig. 1.6: Glass fiber in two different building formations

II. PROBLEM STATEMENT & OBJECTIVE

Chains are machine elements that are subjected to extreme service conditions, such as high tensile loads, compressive loads, friction, and sometimes aggressive operating environment. This causes wear and tear of components of chains and hence unexpected failure and costly production. In chain conveyor system motor capacity of conveyor depends on the weight of chain. It was determined that maximum amount of weight of chain conveyor is covered by chain link plates. In case of long distance transmission with metal chain, large driving force is required to cover the huge mass of chain that means power requirement is also high according to the weight of chain. So, weight is the main problem with metal chain and power consumption is more due to bulky stacker chain.

Our focus will be on reducing the weight of the Chain link plate of roller chain conveyor by using alternative light weight composite material (Glass Fiber) for it which will contribute in reduction of weight of the whole assembly.

III. LITERATURE REVIEW

Mayur S. Kamble, Vinod D. Yelpale & Dr. R. N. Panchal (July 2006) presented a paper on "Weight Optimization Using Topological Approach and Strength Evaluation of Chain Link Plate". In this paper work done to reduce weight of chain link plate by using topological approach, In application like sugar factories where chain conveyors are used for many applications power consumption is more due to bulky stacker chain. So to reduce this power consumption topology optimization is done using ANSYS software. EN19 material is used for chain link plate for better strength. Area where stresses are low for applied loading and environment are reduced by using software topology optimization. Shape optimization gives proper shape of a chain link plate. Weight of link plate before optimization is 0.504 kg, after optimization weight reduced to 0.431 kg, so 15% weight reduction is achieved for modified design of link plate. Structural analysis is done of final design by using ANSYS to find out maximum stresses in chain link plate. Experimentation is carried out on redesigned chain link plate by using computerized universal testing machine to find out breaking load of chain link plate. As breaking load found in the range of +/- 10 % of initial working load and hence new design declared as safe. [1]

Tushar S. Shahane, Professor Ameeth. M. Umbrajkaar (Feb. 2015) presented a paper on "Design and Analysis of Chain Outer Link by Using Composite Material". The scope of this paper is to review the applications in the industry and explore the design considerations that go into the design of the assembly. The paper delves into various application aspects and manufacturing aspects to formulate an idea of the system. Finite Element Analysis (FEA) has been used to conduct shape optimization. Since lot of work has already been done in other components, in this paper the focus has been narrowed down to specific component of outer link. Composite material is used for chain out link to minimize the weight of link. Weight of link plate before optimization is 0.3135 kg, after optimization weight reduced to 0.2407 kg. By using glass fiber link, there is reduction in weight of the outer link material. With increase in glass fiber link thickness, the stress is reduced to a great extent. The reduction in weight and maximum stress is obtained by using glass fiber as compared to original outer chain link. [2]

Barge P.R, Gaikwad M.U (Feb. 2015) Presented paper on "Design Optimization of Roller Chain Link Plate used in Sugar Industry". In this paper Finite Element Analysis (FEA) has used to conduct shape optimization and weight optimization of roller chain outer link plate. Paper work is concentrated on outer link plate and weight reduction of link plate by changing the shape of outer link plate. The aim of this paper is design optimization of roller chain link plate. In this paper the analytical and numerical methods are used for optimization of roller chain link plate. Also the experimentation has done to check validation of the work. The advantage of this paper is that it saves 72gm of weight per link plate and 1.2 kg per meter length of chain. The weight saving thus achieved (Typical chain link 504 gm and optimized chain link 432 gm) 72 gm per link plate and 1.5 Kg per meter of roller chain have a major impact on cost of the chain, and more importantly with a light weight chain, the cost savings during operation is also significant achievement. The weight saving achieved have a significant impact on reducing wear of sprocket and roller chain link plate itself it also impact on reduction in power consumption of motor as chain weight reduced, it also effects on reducing the centrifugal force and unnecessary movement because of it. [3]

IV. METHODOLOGY

- Find out the major reasons of failure of Roller conveyor chain.
- Design of required breaking load as per capacity of roller conveyor chain for traditional material.
- Theoretical analysis of the stresses in chain link and pin.
- Modeling of chain link plate, pin and chain assembly in Solid works.
- Finite element analysis of chain link plate made of traditional material using ANSYS.
- Finite element analysis of chain link plate made of composite material (Glass Fiber) using ANSYS and suggestion of modified design with lesser weight.
- Comparison of stress and deformation results of traditional chain link plate and chain link plate made of Glass fiber as an alternate material.
- Experimental testing of chain link plate made of Glass fiber, pin and chain assembly using Computerized Universal Testing Machine.
- Comparison of theoretical, FEA and experimental results.

V. THEORETICAL ANALYSIS

A. *Problem Statement:*

Pitch Given – 76.2mm
Load on chain :- 29430 N
Material for chain link plate :- EN 19
Syt_{MAX}:- 1230 N/mm^2
Syt_{MIN}:-1097 N/mm^2
Factor of safety:- 3
Modulus of elasticity :- 2.05 X 10^5 N/mm^2
Design calculation are based on min yield strength for safer design.
d = dia. Of pin calculated
d = 11 mm

Stress will be maximum at minimum area hence considering cross-section of plate at hole section A-A

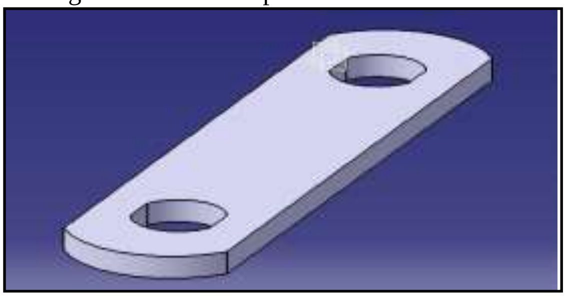


Fig. 1.7: Straight type chain link plate

Effective Area = (H X t) – (d X t)
= 5H – (11 X 5)

$$\sigma_{all} = \frac{\sigma_{min}}{FOS}$$

$$\sigma_{all} = \frac{1097}{3}$$

$$\sigma_{all} = 365.67\ N/mm^2$$

$$\sigma_{all} = \frac{p(Load)}{A(effective\ area)}$$

$$365.67 = \frac{29430}{5H - 55}$$

$\therefore$ H = 27.09 mm
$\therefore$ H $\cong$ 28 mm
Therefore
Pitch = 76.2 mm
Height = 28 mm
Thickness = 5 mm
Density of material EN19 $\rho = 7800\ kg/m^3$
Volume obtain of link

$$\text{Effective Surface Area} = \left((P \times H) + \pi R^2\right) - (2\pi r^2)$$

Effective Surface Area

$$= \left((76.2 \times 28) + (\pi 14^2)\right) - (2\pi \times 55^2)$$

$$\text{Effective Surface Area} = 2749.04 - 189.9$$

$$\text{Effective Surface Area} = 2559.07\ mm^2$$

Volume of link Plate is

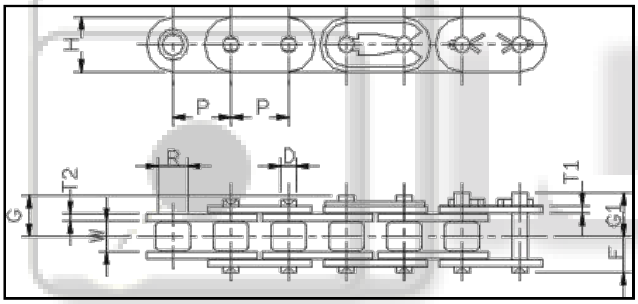


Fig. 1.8: Chain link plate nomenclature

$$V = \text{Effective Surface Area} \times t$$

$$V = A_{eff} \times t$$

$$V = 2559.07 \times 5$$

$$V = 12795.35\ mm^3$$

$$\text{Weight of plate} = \text{Volume} \times \text{density}$$

$$\text{Weight of plate} = 12795.35 \times 7.8 \times 10^{-6}$$

$$\text{Weight of plate} = 99.8\ gm$$

$$\text{Weight of plate } W = 0.0998\ Kg$$

B. Design of Glass fiber Chain:-

Ultimate Tensile Strength = 593 Mpa
As material is non-linear,

$$\sigma_{all} = \frac{\sigma_{ut}}{FOS} = \frac{593}{5}$$

Factor of Safety 5 consider for Impact Loading.

$$\sigma_{all} = 118\ N/mm^2$$

$$\therefore \sigma_{all} = \frac{P}{A} = \frac{29430}{(H-d)t_c} = \frac{29430}{(18-11)t_c} = \frac{29430}{(28-11)t_c}$$

$$= \frac{29430}{17t_c}$$

$$t_c = \frac{29430}{118 \times 17} = 14.67 \cong 15mm$$

Therefore t_c = 15 mm For GFRP

Weight Calculation for GFRP
Density $\rho = 1800\ kg/m^3$
Density $\rho = 1.800 \times 10^{-6} kg/mm^3$
Volume of GFRP plate

$$V = \text{Effective Area} \times t_c$$

$$V = 2559.07 \times 15$$

$$V = 38386.05\ mm^3$$

Therefore Weight of GFRP plate

$$W_c = V \times \rho$$

$$W_c = 38386.05 \times 1.80 \times 10^{-6}$$

$$W_c = 0.06909Kg = 69.09\ gm$$

Therefore Weight Reduce = 0.0307 Kg
Percentage Weight Reduction

$$= \frac{W_{EN19} - W_c}{W_{EN19}} \times 100$$

$$= \frac{0.0998 - 0.06909}{0.0998} \times 100$$

Weight Reduction = 30.77%

VI. CAD MODELING

Once all the dimensions of the different components of the chain link assembly are finalized the detailed Computer Aided Design models are created for the given assembly using SOLIDWORKS 2015 CAD Package. In this section procedure for the CAD modelling of the parts is explained in the complete details part by part.

VII. FINITE ELEMENT ANALYSIS

The finite element analysis (FEA) is a computational technique used to obtain approximate solution of boundary value problems in engineering. The static structural analysis of steel chain link is done by finite element analysis using ANSYS 16.2 software.

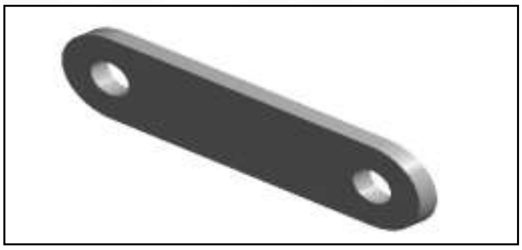


Fig. 1.9: Steel Chain link

Simply stated, a boundary value problem is mathematical problem in which one or more dependent variables must satisfy a differential equation everywhere within a known domain of independent variables and satisfy specific conditions on the boundary of the domain.

Fig. 1.10: Meshed model chain link

While building FEA model chain link has been modeled using solid with Element type 185 is used for meshing them. Figure below shows the meshed model for the assembly. Standard element size of 1 mm is used for the good results in the analysis. Total of 70055 nodes and 16006 elements are used for the meshing of the model. This small element size selection assures the accuracy of the results.

Fig. 1.11: Boundary Condition and loading

Load of 3000 N is applied to chain link opposite holes. Figure above shows the boundary condition for the chain's static analysis.

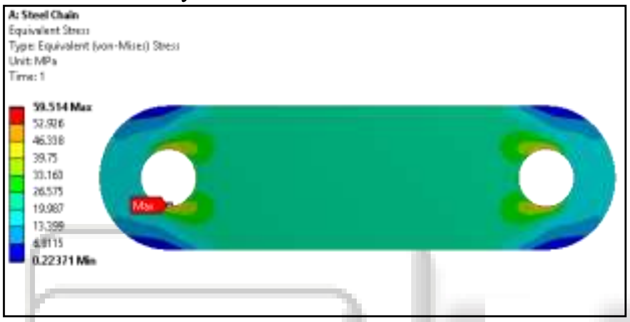


Fig. 1.12: Von Mises Stress plot for Steel chain link

1) *Interpretation: The maximum stress is 59.51 MPa at the loading surface of the Steel chain link.*

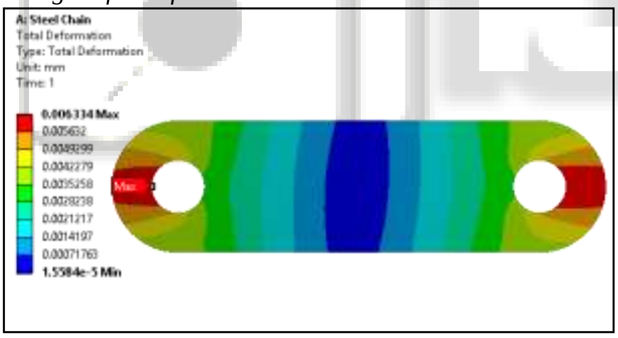


Fig. 1.13: Total deformation plot for Steel chain link

2) *Interpretation: The maximum deformation of the chain link is 0.006334 mm.*

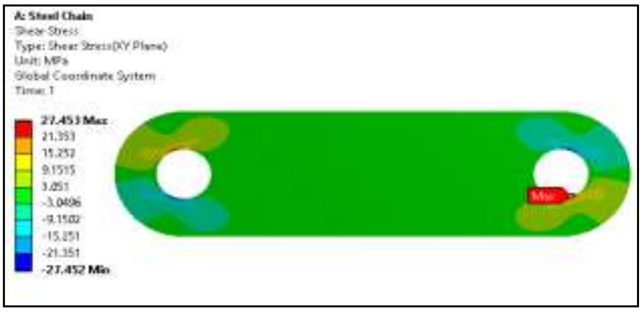


Fig. 1.14: shear stress plot for chain link steel

Similar analysis is performed on the Glass fiber chain link and analysis is performed to find out maximum stress and maximum deformation plot and shear stress. Shell 181 element types are used to model glass fiber chain link model. Image below shows the glass fiber link plate with 0.5 mm meshing size.

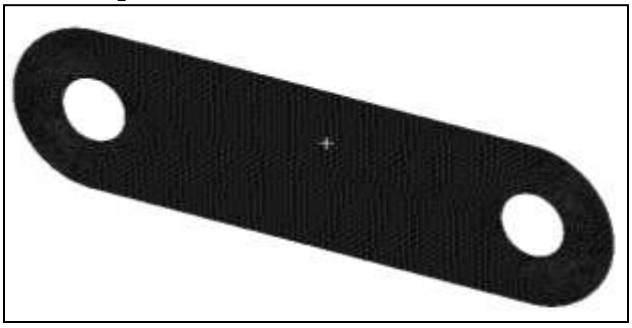


Fig. 1.15: Meshing glass fiber leaf spring shell 181

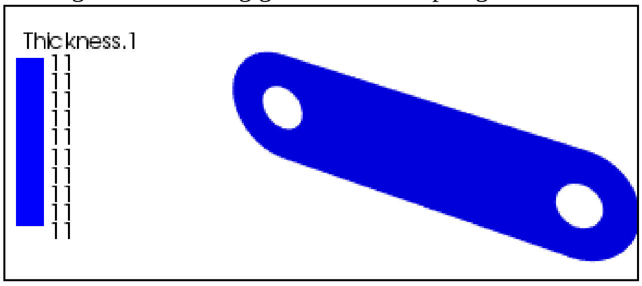


Fig. 1.16: Thickness plot ACP ANSYS

Ansys Composite Processing used for setting up the cloth of epoxy E-Glass and epoxy resin and create the intended stack up of 15 mm. 30 layers of epoxy E-Glass of 0.25 mm of and 30 layers of 0.25 mm epoxy resin is used for preparation of the link plate.

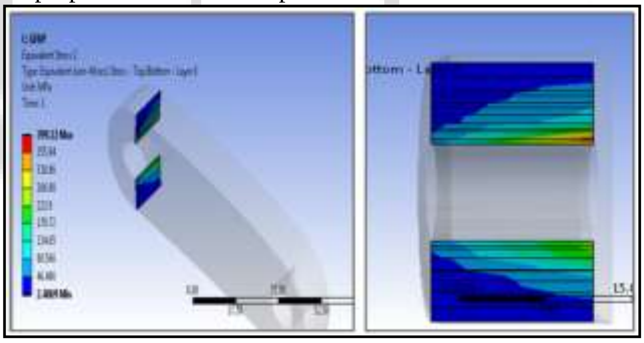


Fig. 1.17: Average stress at the cross section

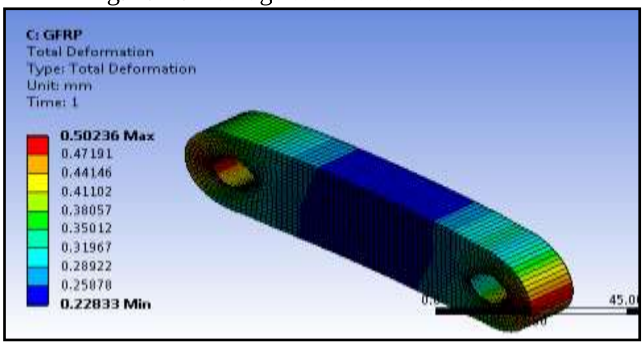


Fig. 1.18: Total Deformation plot at GFRP chain link

Maximum deformation of 0.25 mm is observed at the chain link made using GFRP. Results above prove that chain link is safe in both shear and tensions in case of GFRP chain link design.

B. *Modal Analysis*

Free-Free modal analysis is performed on the both the components to find the natural frequency of the system.

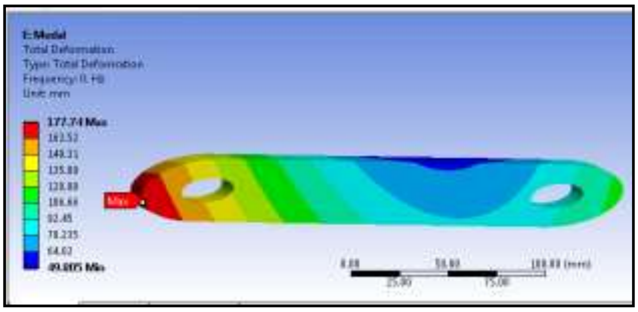


Fig. 1.19: Natural frequency for the steel chain is 2696 Hz

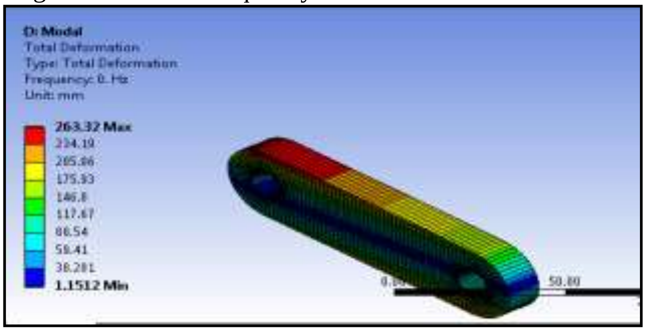


Fig. 1.20: Natural frequency for the GFRP is 3316 Hz

VIII. MANUFACTURING OF COMPOSITE CHAIN LINK

A. *Mold Manufacturing*

Mold is prepared from wooden ply of dimensions 130mm* 60mm*11mm as specimen size is small and the mold is used to manufacture the rectangular plate of thickness 11mm. We took two wooden plies. On one ply the wooden plate of thickness 11mm is nailed. We cut that wooden handle with the particular measurement and give 60 mm radius in light of the fact that our chamber tallness is 60 mm.

Fig. 1.21: Mold creation using ply wood

Before the lay-up the layers of GFRP and epoxy sharp corner and all edges of mold get filled with the wax to remove the gap between ply and lapping wooden plate.

Fig. 1.22: Filling of wax at corner and edges to avoid leakage

After filling wax, the excess wax is removed by the blade to avoid the wax mix in component then GFRP cloth is cut as per required dimension and lay-ups.

Fiber Cutting

We take bidirectional carbon fiber sheet and cut that in pieces measurement 150 mm X 60 mm lengths.

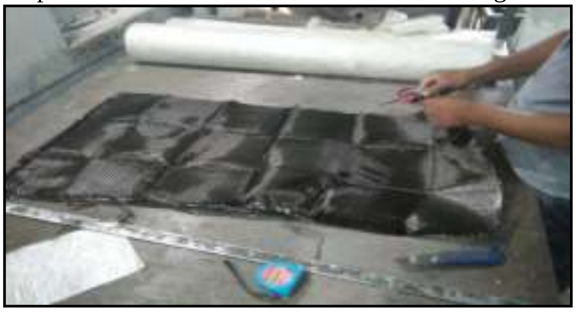


Fig. 1.23: GFRP material marking

Fig. 1.24: GFRP material cutting

Fig. 1.25: Application of Epoxy

Fig. 1.26: Lay-up of GFRP cloth after epoxy

Fig. 1.27: Clamping of mold

Fig. 1.28: Component after curing

Fig. 1.29: Water jet cutting for actual dimensions

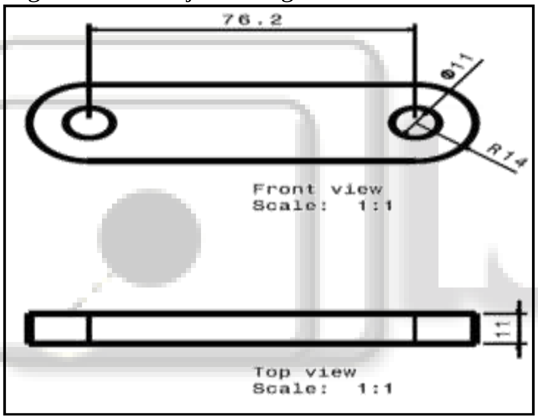


Fig. 1.30: Drawing for water jet cutting

Fig. 1.31: Component after cutting

1) Experimentation

The composite chain link is tested on Universal Testing Machine table test rig by mounting on fixture with loading condition, over the operational loading range. The glass fiber chain link was mounted on the fixture and the load for deformation was set based on the analysis data (simulation). Deformation can be predicted before the component is produced through the use of software which relies on FEA principles. The prediction at the component design stage ensures that the chosen geometry is compatible with the conditions of use.

The parameters influencing the performance

- Type of material
- Mechanical properties of the material
- Thickness of the component at a given section
- Method of assembly and type of joint mating parts
- Type and magnitude of force exerted

2) Requirements for Physical Experimentation

- Mounting fixture and fixing of composite chain link with fixture on base frame to clamp on machine.
- Universal Testing Machine.
- Trials/ Physical Experimentation.

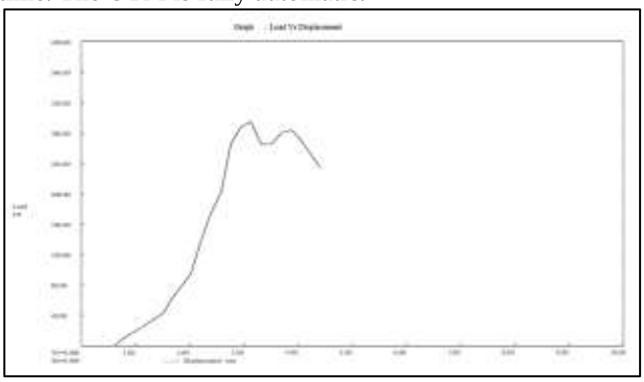
3) Testing of chain link on UTM

Experimental testing of chain link is carried out to study the effect of composite material on the load bearing capacity of the chain link. For this testing we are using a Universal Testing Machine of 40 tonne capacity.

Fig. 1.32: Testing of chain link

As shown in figure the chain link is clamped on the Universal Testing Machine fixed jaw with the help of fixture. By checking all the connections, the test is started by gradually opening the valve to give hydraulic pressure. In this way fiber chain link tested and the Force- Displacement plots for were drawn.

Computer is used for operating the UTM and for recording the load v/s displacement data with respect to time. The UTM is fully automatic.



Graph 1: Load vs. Displacement Plot

For experimental validation GFRP material chain link is to be manufactured the design dimensions. Manufacturing technique used for the GFRP chain link fabrication is hand layup technique. Mold will be prepared from wooden ply of dimensions 130mm* 60mm*15mm as specimen size is small and the mold is used to manufacture the rectangular plate of thickness 15mm. We took two wooden plies. On one ply the wooden plate of thickness 15mm is nailed. We cut that wooden handle with the particular measurement and give 60 mm radius in light of the fact that our chamber tallness is 60 mm.

IX. RESULTS & DISCUSSION

Material	EQV Stress	Max Delta	F (Hz)	M (grams)	Reduction
Steel	59.5	0.0063	2696.6	99.8	0
Glass Fiber	68.06	0.502	3316	69.09	30.77%

Table 1.1: Result summary table FEA

Table shows that results for FEA iterations which says steel chain link has stress of 59.5 MPa while glass fiber reinforced polymer (GFRP) chain link has 68.06 MPa stress maximum across the cross section. Natural frequency of the component in free free modal analysis condition is 2696 Hz for steel chain link while for glass fiber chain link it is 3316 Hz.

X. CONCLUSION

In this present work stress analysis and modal analysis is performed on the steel link of roller conveyor for both steel and glass fiber material. We have found out that approximately 30.77 % weight can be saved if we use GFRP material for the conveyor chain link instead of conventional steel material. We have observed that frequency can be improved up to 1.2 times by replacing the current steel design with the GFRP design. Load taking capacity of the current GFRP chain link will be tested by performing UTM test on the manufactured component of newly designed chain link.

XI. FUTURE SCOPE

We can try and find better suitable materials for the chain link. We can use combinations of composites like carbon fibers and glass fiber reinforcements alternatively in combinations. We can try and optimize the ply angles for the design of glass fiber layup design for manufacturing.

ACKNOWLEDGMENT

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