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

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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.

Basic structure of roller conveyor chain Chains are used in a variety of applications in engineering practice. Conveyors chains are used when materials are to be moved frequently between specific points. Following are the main parameters of the roller conveyor system selection.

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

1.1 TYPES OF CONVEYORS:

Roller and Gravity Conveyors
Powered Conveyors
Belt Conveyors
Pallet Conveyors
Chain Conveyor

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. However, among all he types of conveyors the most common type is chain conveyor systems. 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. The function and uses of chain are similar to a belt. They have clear advantages over belt in performance and efficiency. Automation and standardization are the two major factors combined to make the roller chain industry to become more selected and preferred in industrial applications. Roller chains have a long history as mechanical elements for transmission. 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. Chain is the most important element of the industrial processes required for transmitting power and conveying of materials. As these chains operate under various forces, failure of chain assembly is the major problem.

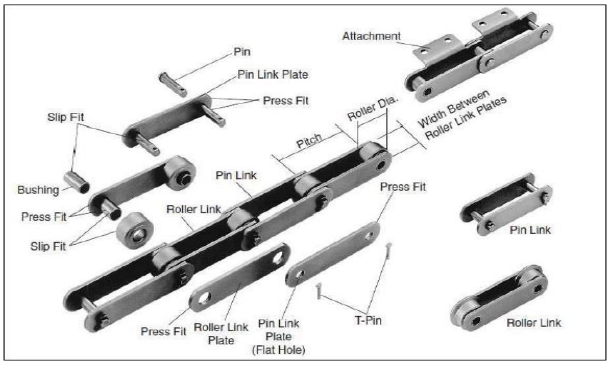

Fig. 1 Typical Roller chain Link Terminology

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 at a macroscopic level and are not soluble in each other to create a superior and unique material. This is an extremely broad definition that holds true for all composites, however, more recently the term "composite" describes reinforced plastics.

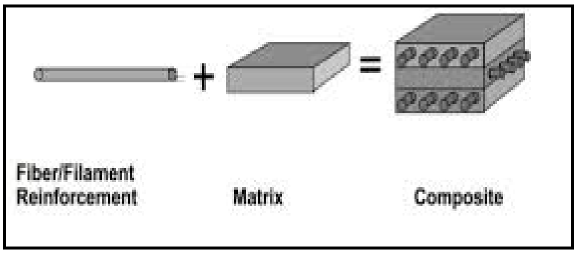

Fig. 2 Composite Material

GLASS FIBER

"Fiberglass reinforced plastics" or FRPs (commonly referred to simply as fiberglass) use textile grade glass fibres. These textile fibres 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 fiber 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.

Roving is a process where filaments are spun into larger diameter threads. These threads are then commonly used for woven reinforcing glass fabrics and mats, and in spray applications.

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 fiber 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 molding processes. Glass fiber short strands are short 0.2–0.3 mm strands of glass fibres that are used to reinforce thermoplastics most commonly for injection molding.

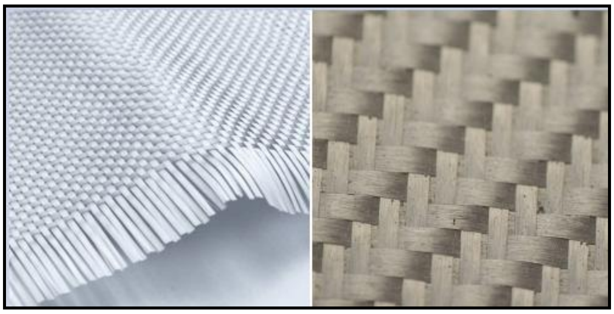

Fig. 3 Glass fiber in two different building formations

II. PROBLEM STATEMENT AND 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. METHDOLOGY

- 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.

IV. THEORETICAL ANALYSIS

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

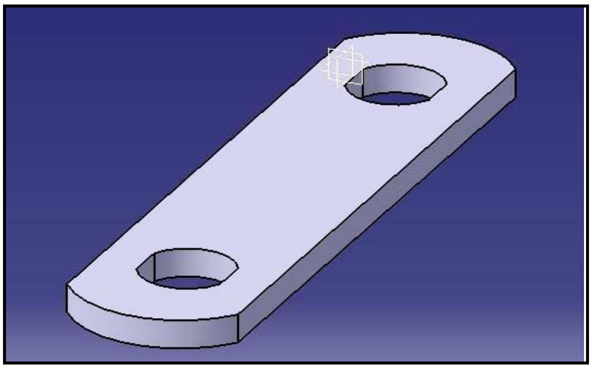

Fig. 4 Straight type chain link plate

Effective Area = (H X t) – (d X t)

= 5H – (11 X 5)

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

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

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

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

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

$$\therefore H = 27.09\ mm$$

$$\therefore H \cong 28\ mm$$

Therefore

Pitch = 76.2 mm

Height = 28 mm

Thickness = 5 mm

Density of material EN19 $\rho = 7800\ kg/m^3$

Volume obtain of link

$$EffectiveSurfaceArea = \left((P \times H) + \pi R^2\right) - (2\pi r^2)$$

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

$$EffectiveSurfaceArea = 2749.04 - 189.9$$

$$EffectiveSurfaceArea = 2559.07\ mm^2$$

Volume of link Plate is

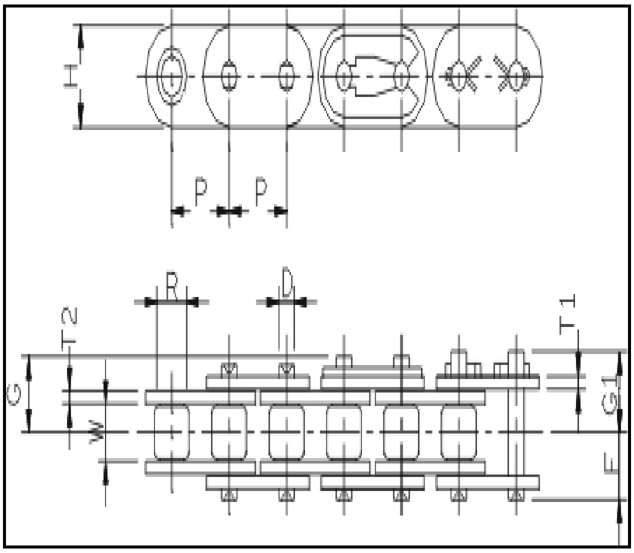

Fig. 5 Chain link plate nomenclature

$V = EffectiveSurfaceArea \times t$

$V = A_{eff} \times t$

$V = 2559.07 \times 5$

$V = 12795.35\ mm^3$

$Weightofplate = Volume \times density$

$Weightofplate = 12795.35 \times 7.8 \times 10^{-6}$

$Weightofplate = 99.8\ gm$

$WeightofplateW = 0.0998\ Kg$

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.

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

$$\therefore \sigma_{all} = \frac{P}{A} = \frac{29430}{(H-d)t_c} = \frac{29430}{(28-11)t_c} = \frac{29430}{(28-11)t_c} = \frac{29430}{17t_c}$$

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

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

$V = EffectiveArea \times t_c$

$V = 2559.07 \times 15$

$V = 38386.05\ mm^3$

Therefore Weight of GFRP plate

$W_c = V \times \rho$

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

$W_c = 0.06909 Kg$ = 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%

V. 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. Out of many options available for the CAD modelling of the product SOLIDWORKS is chosen for its ease of use in simple solid modelling operations and ease of assembly in the software. In this section procedure for the CAD modelling of the parts is explained in the complete details part by part.

VI. FINITE ELEMENT ANALYSIS

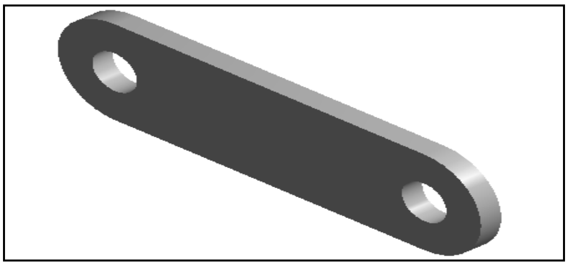

Fig.6 Steel Chain link

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

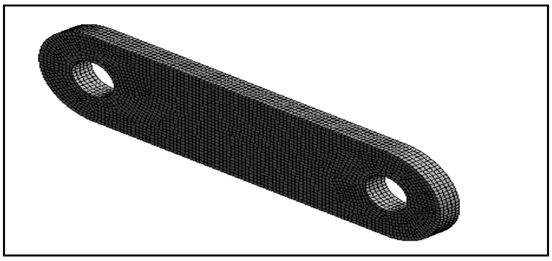

Fig.7 Meshed model chain link

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.

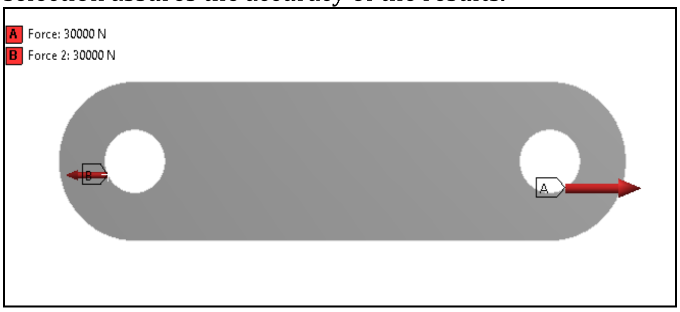

Fig.8 Boundary Condition and loading

Load of 30000 N is applied to chain link opposite holes. Figure above shows the boundary condition for the chain's static analysis.

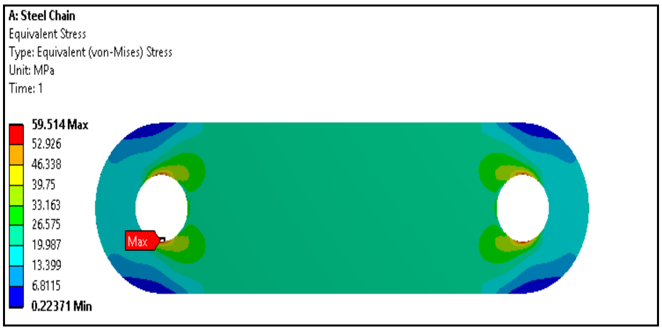

Fig.9 Von Mises Stress plot for Steel chain link

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

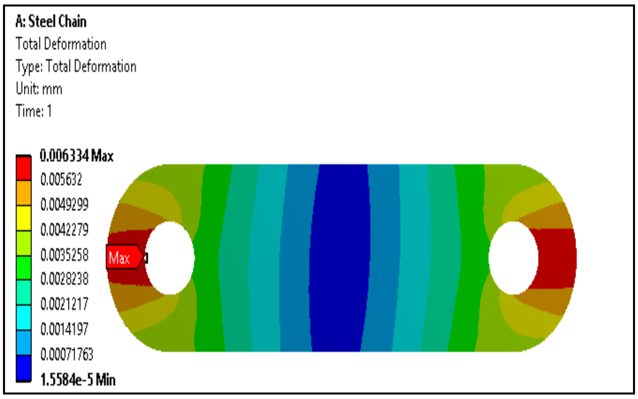

Fig.10 Total deformation plot for Steel chain link

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

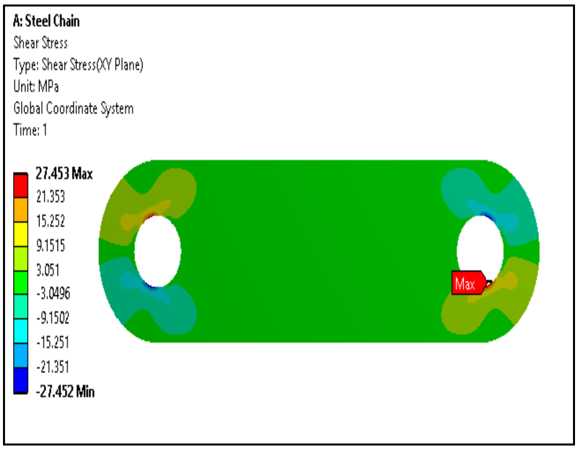

Fig.11 shear stress plot for chain link steel

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.

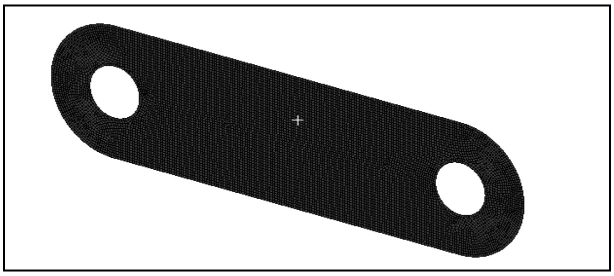

Fig.12 meshing glass fiber leaf spring shell 181

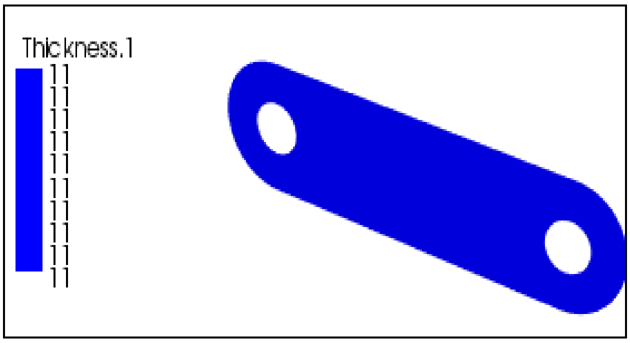

Fig.13 Thickness plot ACP ANSYS

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.

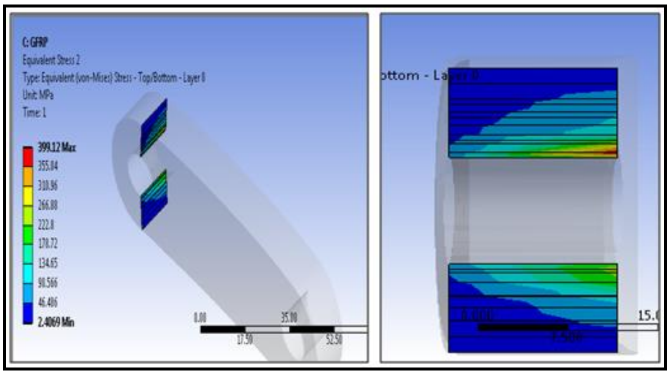

Fig.14 Average stress at the cross section

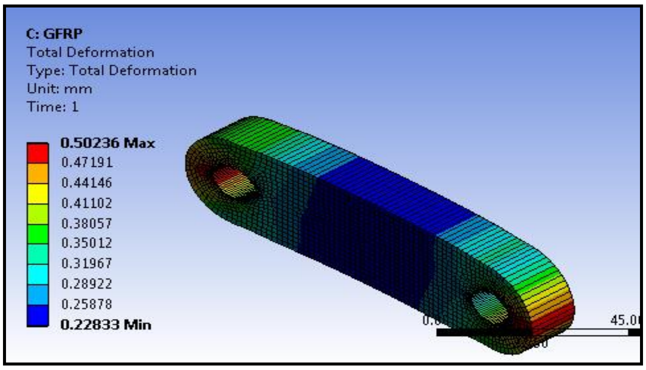

Fig.15 Total Deformation plot at GFRP chain link

Maximum deformation of 0.50236 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.

Modal Analysis

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

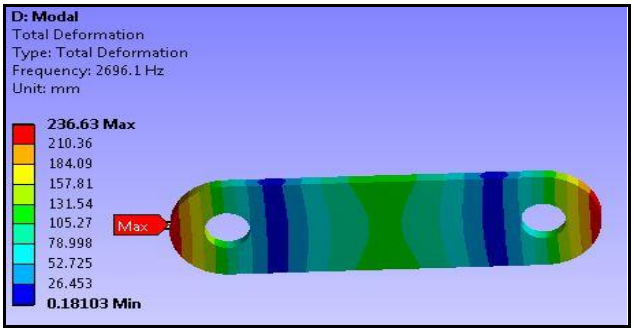

Fig.16 Natural frequency for the steel chain is 2696 Hz

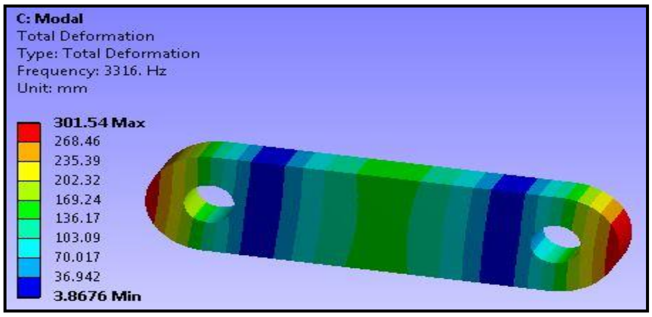

Fig.17 Natural frequency for the GFRP is 3316 Hz

VII. MANUFACTURING OF COMPOSITE CHAINLINK

GFRP material chain link is to be manufactured for 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 mould 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.

VII. EXPERIMENTAL TESTING

Experimental testing of the Glass fibre chain link can be carried out to study the effect of weight reduction in terms of alternate material for this testing Universal Testing Machine of 10tonne capacity can be utilised.

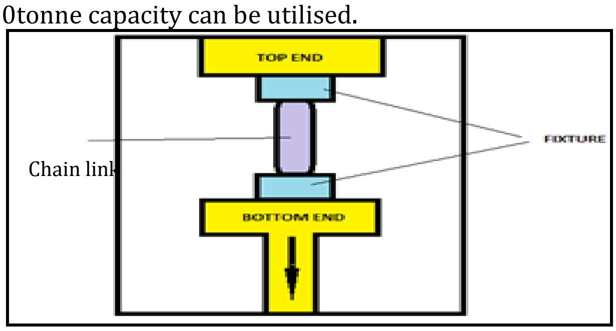

Fig.18 Testing GFRP Chain link on Universal Testing Machine

As shown in the above Schematic diagram, the chain will be put for tension testing to check and verify the load carrying capacity in tension. The testing will be conducted on a universal testing machine. The top end of UTM is fixed and bottom end is moving. The tension will be applied by moving the bottom end downwards. Results obtained from the experimental testing will be cross verified, confirmed and validated with the FEA results.

VII. RESULTS AND 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%

Table1.1 Result summary table FEA

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. Stresses in the conventional as well as in composite material chain link are within the design limit. First natural frequency of the component depends upon stiffness and mass. It is directly proportional to stiffness and inversely proportional to mass. As composite have higher strength to weight ratio when compare to steel first natural frequency of the composite is observed to be higher than the steel component. In free free modal analysis condition first natural frequency of steel chain link is 2696 Hzs while for glass fiber chain link it is 3316 Hz. Almost 30.77 % weight reduction is observed.

IX.CONCLUSIONS

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.

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