KAUNAS UNIVERSITY OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING AND DESIGN

Swati Ramesh Jadhav

FAILURE ANALYSIS OF CONVEYOR CHAIN LINKS

Final project for Master Degree

Supervisor
Assoc. Prof. Dr. Evaldas Narvydas

KAUNAS, 2015

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Reviewer
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Project made by
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(Title and code of study programme)

FAILURE ANALYSIS OF CONVEYOR CHAIN LINKS
DECLARATION OF ACADEMIC HONESTY

4 June 2015
Kaunas

I confirm that a final project by me, Swati Ramesh Jadhav, on the subject "*FAILURE ANALYSIS OF CONVEYOR CHAIN LINKS*" is written completely by myself; all provided data and research results are correct and obtained honestly. None of the parts of this thesis have been plagiarized from any printed or Internet sources, all direct and indirect quotations from other resources are indicated in literature references. No monetary amounts not provided for by law have been paid to anyone for this thesis.

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Approved:

Head of Mechanical Engineering Department ______________________
(Signature, date)

Vytautas Grigas
(Name, Surname)

MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme MECHANICAL ENGINERING

The final project of Master studies to gain the master qualification degree is research or applied type project, for completion and defence of which 30 credits are assigned. The final project of the student must demonstrate the deepened and enlarged knowledge acquired in the main studies, also gained skills to formulate and solve an actual problem having limited and (or) contradictory information, independently conduct scientific or applied analysis and properly interpret data. By completing and defending the final project Master studies student must demonstrate the creativity, ability to apply fundamental knowledge, understanding of social and commercial environment, Legal Acts and financial possibilities, show the information search skills, ability to carry out the qualified analysis, use numerical methods, applied software, common information technologies and correct language, ability to formulate proper conclusions.

1.Title of the Project

Failure analysis of conveyor chain links

Approved by the Dean 2015 y. May m. 11 d. Order No. ST17-F-11-2

2. Aim of the project

To investigate the causes of failure of chain systems and to propose improvements for the chain system design

3. Structure of the project

The final project consists of: summary in Lithuanian and English; introduction with emphasized aim and topicality of the project; literature survey; presentation of the research methods; research results; conclusions and list of references.

4. Requirements and conditions

Analysis object – conveyor chain loaded by 20.8 kN, initial design – horizontal slat conveyor; initial material – carbon steel.

5. This task assignment is an integral part of the final project
6. Project submission deadline: 2015 June 1st.

Given to the student

____

Task Assignment received Jadhav Swati Ramesh ______________________
(*Name, Surname of the Student*) (*Signature, date*)

Supervisor assoc. prof. Evaldas Narvydas ______________________
(*Position, Name, Surname*) (*Signature, date*)

Jadhav.S.R. *FAILURE ANALYSIS OF CONVEYOR CHAIN LINKS.*

Final Master's Degree Project / supervisor Assoc. Prof. Dr. Evaldas Narvydas; Kaunas University of Technology, Faculty of Mechanical Engineering and Design, Department of Mechanical engineering.

Kaunas, 2015. 47 p.

SUMMARY

Roller chains have a long history as mechanical elements for transmission. Although they have clear advantages over belts in terms of performance and efficiency, their larger weight has always been a disadvantage. In this research, finite element method (FEM) analysis of the stress and deformation in a link plate of a roller chain performed with the material composite. In this research the focus has been narrowed down to specific component of outer link because it is having more stress as compared to other components such as roller, bush, inner link etc. In a case of long-distance transmission using a metal chain, a large driving force is required owing to the enlarged mass of the chain. To solve such a problem, weight saving for the chain is desired. So, to reduce weight and failure modes material composite have used instead of steel and stress and deformation analysis, optimization has performed to achieve the aim.

Jadhav S. R. Konvejerių grandinių gedimų tyrimas. *Magistro* baigiamasis projektas / vadovas doc. dr. Evaldas Narvydas; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas, Mechanikos inžinerijos katedra.

Kaunas, 2015. 47 psl.

SANTRAUKA

Grandininiai ritininiai konvejeriai nuo seno naudojami krovinių transportavimui. Daugeliu parametrų jie yra pranašesni už diržinius transporterius, tačiau turi ir aiškų trūkumą – sąlyginai didelį savąjį svorį. Šiame projekte, taikant baigtinių elementų metodą (BEM) atlikta ritininio konvejerio grandinės jungiamųjų plokštelių įtempių ir deformacijų analizė panaudojant ne tik įprastą konstrukcinį plieną, bet ir kompozicines medžiagas. Tyrimams pasirinkta išorinė grandinės plokštelė, nes ji patiria didesnius įtempius eksploatacijos metu, lyginant su įvore, vidine plokštele, pleištu ir kt. Didėjant grandinės, pagamintos iš plieno detalių, ilgiui, labai išauga jos masė ir jėga reikalinga transporterio veikimui. Norint išspręsti šią problemą, labai svarbu sumažinti grandinės detalių masę. Taigi, detalių iš daug lengvesnių kompozitinių medžiagų panaudojimas, patikrinus jų stiprumą bei detalių formos optimizavimas išsprendžia šią problemą.

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INTRODUCTION

A roller chain is known and used as a mechanical element for drive train or material handling systems. Fundamentally, its mechanism is a type of engaging between a chain and a sprocket wheel. Compared with that in belts, Roller conveyor chain gives clear advantages in terms of its performance and efficiency. In this research the focus has been narrowed down to specific component of outer link because maximum stresses will be produced on outer link as compare to other components. In a case of long-distance transmission using a conventional chain, a large driving force is required to grab the huge mass of chain. To solve such a problem, weight saving for the chain is important. Till now material steel and polymer has been used for the conveyor chain link but, with steel the design is so big, with steel its weight is high so, in this paper Analysis of the chain has been done with composite material to minimize weight of the link and failure modes. Its design is small as compared to steel and with this material failure modes also can be reduced in chain link plate. To reduce weight shape optimization has been done by two ways. First is by reducing the thickness of the chain link and second way by changing the design of the link accordingly its stress area.

Aim of the work

The aim of this research work is to design, analysis and optimization of the chains outer link by using composite material to reduce weight and failure modes.

Objective

The objective of the research work is to design, analyse and propose a method of fabrication of composite roller link for conveyor chain system. This is done to achieve the following-

i. This design helps in the replacement of conventional steel roller link with composite link plate with better ride quality.

ii. To achieve substantial weight reduction in the conveyor chain system by replacing steel link plate with mono composite link plate.

Scope of the work

i. The investigation of the failure component and the chain system design will be based on component and materials. i.e steel and composite.

ii. To identify the types of failure that exist at conveyor chain links either designing-in defects, manufacturing-in defects, operating-in defects and environment-in defects [13]

Tasks

- Study of failure cases of chain system
- Take practical input from industry
- Design of chain links by using hand calculation(Analytical Method)
- Analysis same model by using FEMAP
- Redesign of link with new composite material.
- Analysis using FEMAP
- Experimental verification.
- Conclusion.

Methods and means of the research work

This topic describes the methodology used to achieve the project objectives. Analysis has performed for this research by FEM with the help of software FEMAP. And second is analytical method used for the stress calculation and to compare with FEM results. Analysis has done by using both the materials steel and composite and by comparing both results select material with good results to reduce failure modes.

Practical applicability

- Mining/power generation.
- Iron and steel works.
- Tunnel construction.
- Quarrying.
- Chemical industry.
- Recycling.
- Cement industry.

1. LITERATURE SURVEY

The literature review has been conducted on failure analysis of conveyor chain link. This topic reviews the relevant literature of failure analysis of chain conveyor and link can be divided into two categories. The first category includes FEA of chain conveyor link for weight reduction and shape optimization. The second category includes types of defects that have been found in conveyor chain link.

1.1 FEA of chain link

The failure analysis process relies on collecting failed components for subsequent examination of the cause or causes of failure by many types of array methods.

Meanwhile Bhoite [1] described that "FEA based study of effect of radial variation of outer link in a typical roller chain link assembly Chain Link assembly" is extensively used in the industry; the scope of his paper was to review the applications in the industry and investigate the design considerations that go into the design of the assembly. His research delves with various application aspects and manufacturing aspects to find an idea of the system. Finally he found Finite Element Analysis (FEA) has been used to conduct shape optimization. According to him lot of work has already been done in other components so, in his paper the focused down to specific component of outer link. For outer link, most dimensions in the industry are parametrically defined, however one dimension, the radius that is in between the inter connecting holes is left to manufacturer convenience. In this paper he had assesses the impact of this radius on the stress in the system and sees if material saving and consequently efficiency increment is possible.

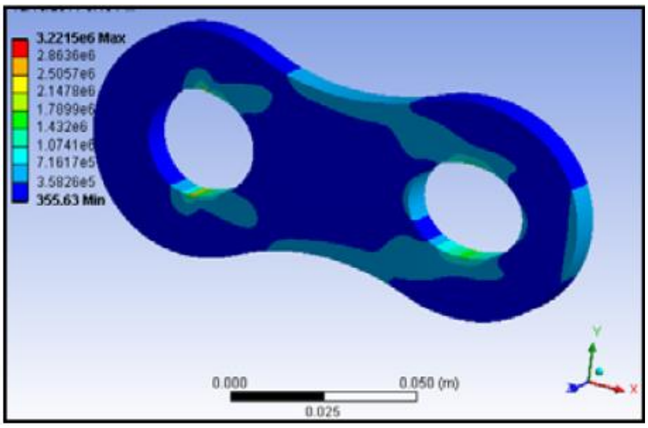


Fig.1.1. Stress analysis [1]

After this weight reduction, Suhas and RB patil. [4] described that "over years a lot of work has been done and still continuing with great effort to save weight and cost of the chain link. According to him the trend is to provide weight/cost effective products which can fulfill the requirements. The aim of his paper was to study existing conveyor system and optimize the critical parts like shafts, roller, to minimize the overall weight of assembly and material saving, C-channels for chassis and support. Existing design calculation shows the factor of safety is very greater than need and there is chance for weight reduction. Critical parameter which reduces the weight is roller outer diameter and roller thickness, C channels.

Most recently in last year, M.D Jagtap [2] studied the “roller conveyor chain link under tensile loading” he described in his paper that conveyor chain drives are one of the major systems used in industry to transmit power and material handling. Conveyor chain that suffers from premature elongation due to wear and needs to be replaced on a frequent basis will negatively impact productivity and increase the cost of the operation M.D Jagtap [2] Roller conveyor chains are the critical component in coal mine, paper mill, cement industry, fertilizer industry, pharmaceutical industry, food processing, foundry industry, sugar mills, heat treatment units, etc. According to him the importance of this paper is to study the behavior of chain strip under tensile loading. For now, very few literatures on the wear of conveyor chain are available. In this paper he studied the analytical, experimental and numerical behavior of strip under tensile loading. At the end he found the analytical, experimental and numerical behavior of strip under tensile loading. The fatigue initially nucleated at the external cracks of the link, and later propagated to the inside of the links until sudden fracture occurred.

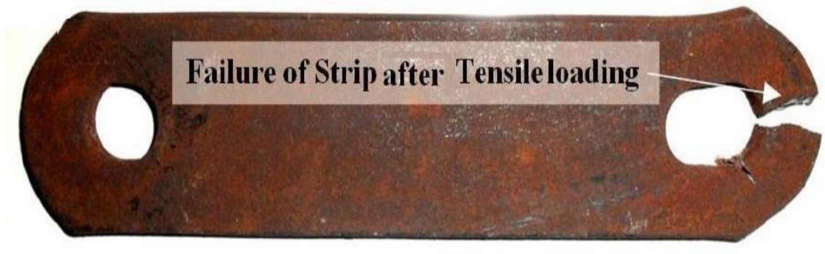


Fig.1.2.Failure under tensile loading [2]

Kerremans [30] described that “Wear of conveyor chains with polymer rollers, sustainable construction and design”. Roller conveyor chains are very common which is used to transport goods in production lines or assembly lines, such as cars or steel coils, pallets. Sometimes they are used in severe environments, foreign particles, soiled with water, chemicals or other contaminants. It can be result in wear of the components of the chain and of course which can lead to unexpected failure and costly production downtime. In this research he had done there are different components of conveyor chains and the loading conditions are described. Moreover, the applications and disadvantages of chains with polymer rollers are discussed. Abrasive and adhesive wear between the chain components are discussed. From the contact mechanics of the chain and pressure-velocity limit of the roller materials, the design constraints for the laboratory test-rig were derived [30]. The capabilities and working principles of the developed test-rig are discussed in this paper. Conveyor chains with polymer rollers are widely used in industries. Because they are capable to work without any lubrication and they have very good corrosion resistance. For conveyor chains with polymer rollers, the expected wear mechanisms are adhesive wear, abrasive wear, impact with sprocket and softening of the polymer due to heat generation. [30] Existing test-apparatuses were found not suitable to look at the wear of transport chains with polymer rollers. Along these new test-apparatus was designed. The outline limitations for the ordinary load and passing on speed were acquired from the weight speed breaking point of regularly utilized polymers. Load of the chain was used to determine the tensile force in chain. Tests performed on this test-apparatus will give better correspondence with the wear instruments happening in genuine transport chain applications. Toward the end in results he has found that, transport chains with polymer rollers are broadly utilized.

Moreover, umesh,MK and mohan singh, [3] They both discovered that failure analysis of brittle chain which used for hoisting in mines chain is one of familiar for mine hoist plus one of the most useful of mechanical device. It is made up of a series of links attached through each other. As a rule, a chain is subjected to heavy loads and must transmit large forces, and upon its ability to withstand the stresses to which it is subjected by its loading may depend on the success of a great mechanical operation, or even the safety of lives Chains usually stretch under excessive loading so that the individual links bend slightly. umesh,MK and mohan singh, [3]. Those bent links are warning that the chain has been overloaded and might fail anytime under a load. If a chain is attached with the proper hook, the hook should start to fail first, showing that the chain is overloaded. By seeing these facts, it is visible that the chain has received large attention from investigators in the field of elasticity and strength of materials. Then some Experiments have been made, that is true, but all those experiments were for the find out the ultimate strength of the chain, not for the testing a theory. Recipes for the stacking of chains have been based upon a definitive quality of the affix when tried to obliteration and are in this way simply observational. It might be encouraged that the present experimental tenets are tasteful, while they prompt palatable results.

Bun [16] in his investigation of chain conveyor at dewatering system used four tools and technique of failure analysis to find out the causes of the conveyor chain failure. He had use visual examination, hardness testing, chemical analysis by using Scanning Electron Microscopy Energy Dispersive Analysis by X-Ray (EDAX) and microstructure examination. These four techniques normally being used by the researchers to collect and analyze the data in the failure field [5].

Bun [16] In his analysis, done by metallographic examination reveals the shrinkage cavities, high density of gas porosity and cracks in the junction of the cast chain link. [5] The presence of the large cavities and high porosity was formed during solidification in casting. The spherical area that exists is due to bubbles of gas that are ejected as the metal freezes and then trapped before they can leave the liquid.

Fig.1.3. Crack plate [22]

Based on his investigation, Bun [16] concluded these manufacturing defects are the dominant source that responsible on the failure. He accepted that a thorough quality control framework in the assembling procedure can diminish the reason for material imperfections.

At the end the literature reviews that have been discussed above were divided into two categories. First category is a discussion about the FEA with shape optimization for weight reduction. Most of the previous study used Scanning tensile testing and hardness testing. Bošnjak S. et. al. [15] diversifies the investigation with finite element method to prove the most stresses zone have been identified around the chain link. There are several factors that contribute to the failures that can be categorized into four; manufacturing-in defects, designing-in defects, operating-in defects and environment-in defects. These types of defects can be inherited defects of generated defects.

2. TERMINOLOGY OF CHAIN CONVEYOR AND PROBLEM STATEMENT

2.1 conveyor system

Conveyor chain system define and mainly known for the material handling. Such as solids or free-flowing bulk materials over a horizontal, inclined, declined, or vertical path of travel with continuous motion [5] In last days conveyor system is the only mechanical thing which used for material handling from one point to another or from one place to another place. Today, there are many types of conveying system. Such as belt conveyors, roller conveyors, wheel conveyors and chain conveyors, suit different type of applications such as is shown below. They can convey horizontally, vertically, around corners, incline and decline [18]

Table.2.1. Different kind of applications for chain, belt and roller [9]

Conveyor type	Chain	Belt	Roller
Bulk handling	❖	❖	▪
Unit handling	❖	○	❖
Dust in conveying bulky goods	❖	○	
Space required	Small	Large	Large

❖ **:** Excellent,

○ : Good ,

▪ : Poor

2.2 chain conveyor

A chain is a machine component consist of various connected links. It can be used to transmit power or material. There are various types of steel materials are used for chain like a structural steel, carbon steel ,mild steel and except steel its polymer which is widely used for roller because they are capable to work without lubrication.

Referring to above table, chain conveyor has clear advantages over belt conveyor [5]

i. Able to handle bulk material

ii. Easy for production.

iii. It takes small place as compared to belt conveyor.

Because of these advantages, conveyor chain had been applied widely in coal mining, food processing, sewage treatment, timber harvesting, agricultural, bakery, harvesting, and textile machines; car, cement, and chemical plants; and sorting, handling, and material conveyors[5]

Fig.2.1.Floor type conveyor [36]

Fig.2.2.Overhead conveyor [35]

2.3 Roller chain conveyor

Nowadays, one of the largest share of chain that being produced is steel chain or commonly called roller chain as shown in Figure 2.1, So, for the most part in this research, we will refer roller chain simply as chain. Chains can be sort according to their uses which can be broadly divided into six types [9] [5]

i. Power transmission

ii. Small pitch conveyor

iii. Precision conveyor

iv. Top Chain

v. Free Flow Chain

vi. Large pitch conveyor chain

Conveyor chain consist of main four parts that is plate (link), bush, roller and pin

Table.2.2.Function and criteria of chain conveyor

Part	Function
Plate	It Carries the tension placed on the chain
Pin	It transmits the shearing and bending forces to the plate
Bushing	It takes shock load while chain engages with sprocket plus transmits shearing and bending forces by plate and roller to pin.

Typical conveyor chain is constructed with two different types of links that are the inner link and the outer link as shown in Figure 2.3 and Figure 2.4 [30] outer link plate and inner link plate are the component that takes the tension placed on the chain [5], Repeated loading and sometimes it goes by shock also and it can causes the failure of plate. So, link is one of the important parts that must have great static tensile strength and must hold up the dynamic forces of load [5]. Furthermore, the plate must meet environmental resistance like a corrosion and abrasion [5]

From last research on roller conveyor chain many papers are focusing on link performance and improvement of its efficiency. But, very few journals are available which focuses on improving life of the chain and minimization of its failure. Very few researchers have studied and described the fatigue life estimation and stress analysis for the chain assembly.

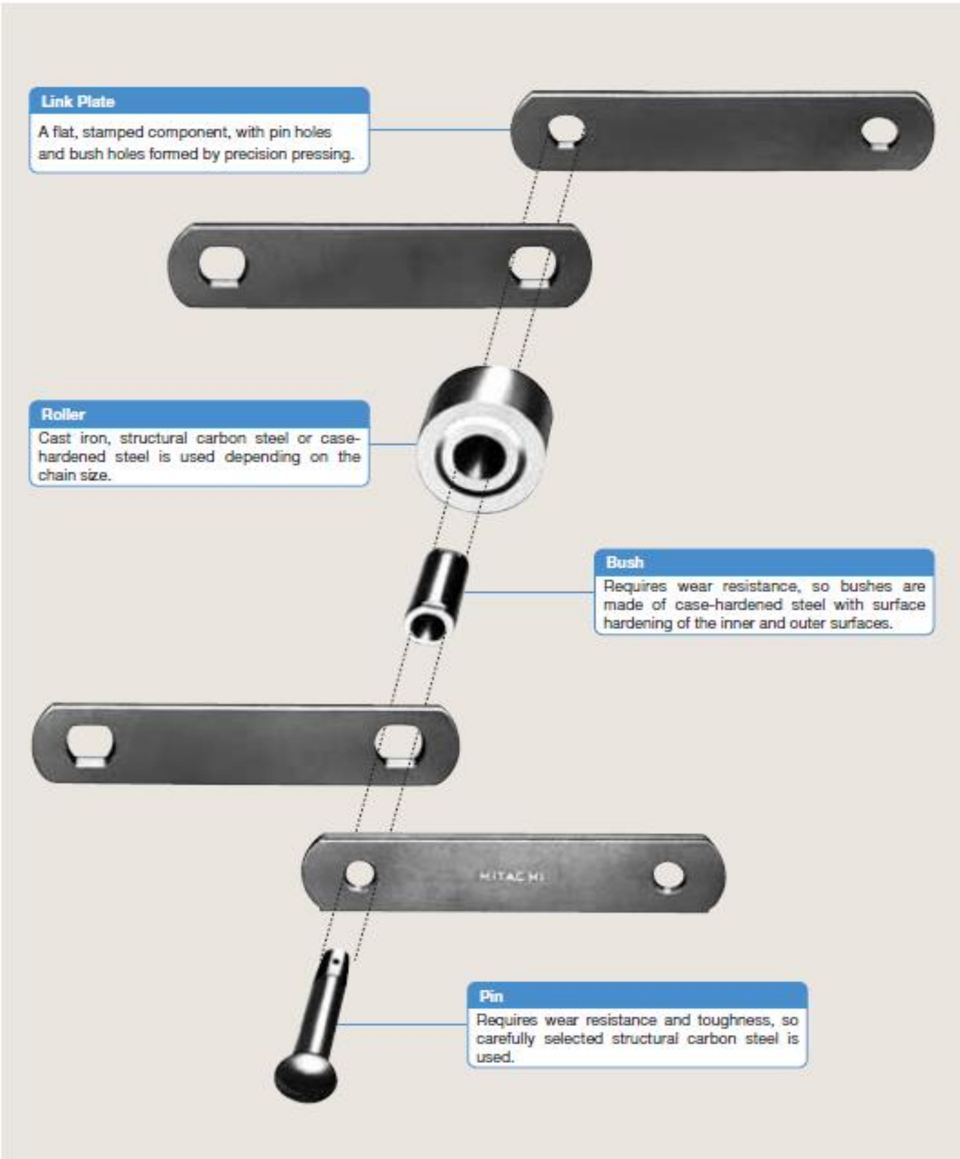


Fig.2.3.Basic structure of a conveyor chain [10]

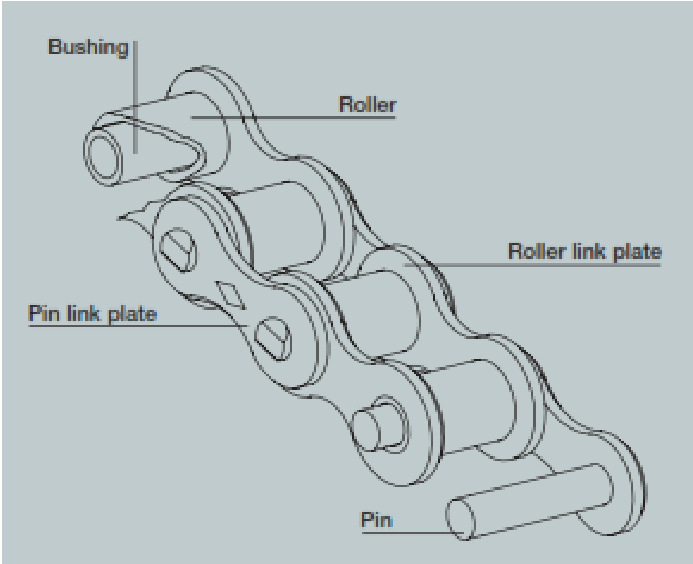


Fig.2.4.Five components of chain conveyor [5]

A typical roller conveyor chain is constructed with two different types of links: the inner link and the pin link that is outer link see Fig.2.4. The roller connection comprises of two steel bushings that are fitted inside the roller connection links, while the pin connection comprises out of two steel pins fitted inside the pin connection plates to avoid withdrawing of plates and pins, bolted pins are utilized [5] Transport chains can be settle in two ways: the power can be connected as an afterthought links by utilization of connections which are associated with the side plates, see Fig.2.4.Then of course the force can be applied on the pins. Therefore hollow pins and axles used instead of solid pins. The rollers transfer the normal force, due to the weight of the conveyed objects, to the track. The driving sprocket put a force on the chain to pull the load, these results in a tensile force inside the chain which must be large enough to overcome the sliding friction between roller/bushing and the rolling friction between roller/track.

2.4 Study of conveyor chain

2.4.1 Overview of forces acting in conveyor roller chain

This section is study the types of forces that acting in roller chains. According to Kerremans et. al. [30]: "When chain that transport pallets on a moving track, the weight of the pallets that applied on the chain and pin will resulting a normal force N02 on each pin. A tensile force Ft is acts on the chain by the sprocket. Then, this tensile force will be transferred from inner to the outer link by bushing and pin acting together as a bearing. The normal force is passed from pin to bushing and then from bushing to track through roller. The pin and bushing have a small clearance which called eccentricity e23. And other side, bushing and roller have a small eccentricity e34". Here it's Assume that the chain moving on a track from left to right and small eccentricity e34 exaggerated on drawing as shown in Fig.2.5.

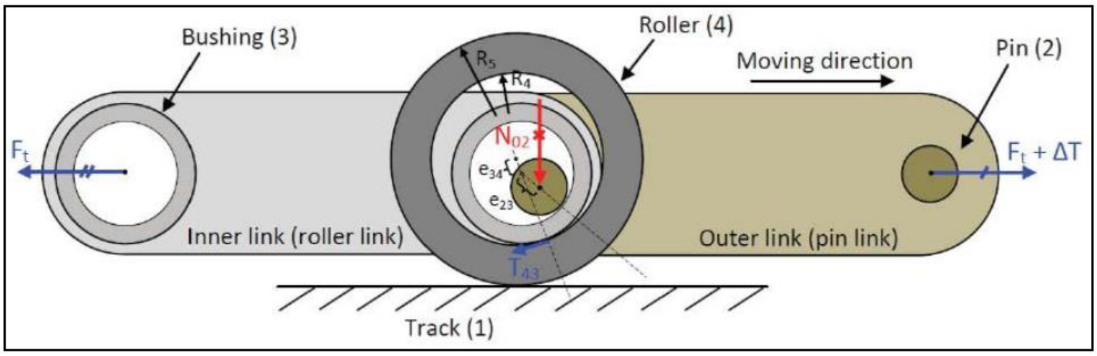


Fig.2.5.Section view of a roller chain with exaggerated clearances [30]

3. FAILURE CASES OF CHAIN SYSTEM

In this topic, we will describe the general description of failure cases in chain system including all parts of the chain as our focus is on outer link of chain.

3.1 Failure of conveyor

Failure mean is not meeting a desirable objective. There are five general failure categories that are fracture, cracking, distortion, corrosion (pitting, through wall perforation) and wear (material wastage). Gagg, [23] and Bošnjak S. et. al. [15] pointed out in his study that failures can be cause by: [5]

i. Designing –in defects

ii. Manufacturing-in defects

iii. Operating-in defects

iv. Environment-in defects

Reddy [12] described in his investigation that there are two types of defects that are generally observed in materials:

i. Inherited defects where the origin is in the ingot

ii. Generated defects that are introduced in the material during various metal working operations and thermal treatments

Meanwhile, failure analysis is the process of collecting and analyzing data to determine the cause of a failure. [14] Failure analysis is a process that is performed in order to determine the causes or factors that have led to undesired loss or functionality.

3.2 Failure cases in chain system

Roller conveyor chains are commonly used to transport goods in production or assembly lines, such as pallets, cars or steel coils. They are in some cases utilized as a part of serious situations, ruined with water, outside particles, chemicals or different contaminants [30]. Typical utilization will bring about wear of the segments of the fasten which can prompt surprising disappointment and expensive creation downtime. In this research the different components of conveyor chains and the loading conditions are described. Abrasive and adhesive wear between pin, bushing, rollers tracks are discussed in this. As some researchers investigated that till now steel and polymer have been used for the link and in this materials mostly three types of failure have been found is Tribological failure such as surface cracking, impact, fatigue, sticking etc. Second one is plastic deformation and fracture like, fatigue, overload, wrong heat treatment, hydrogen embrittlement etc. and the last type is corrosion such as oxidation and chemical degradation. Those are the major failures have been determined in conveyor chain.

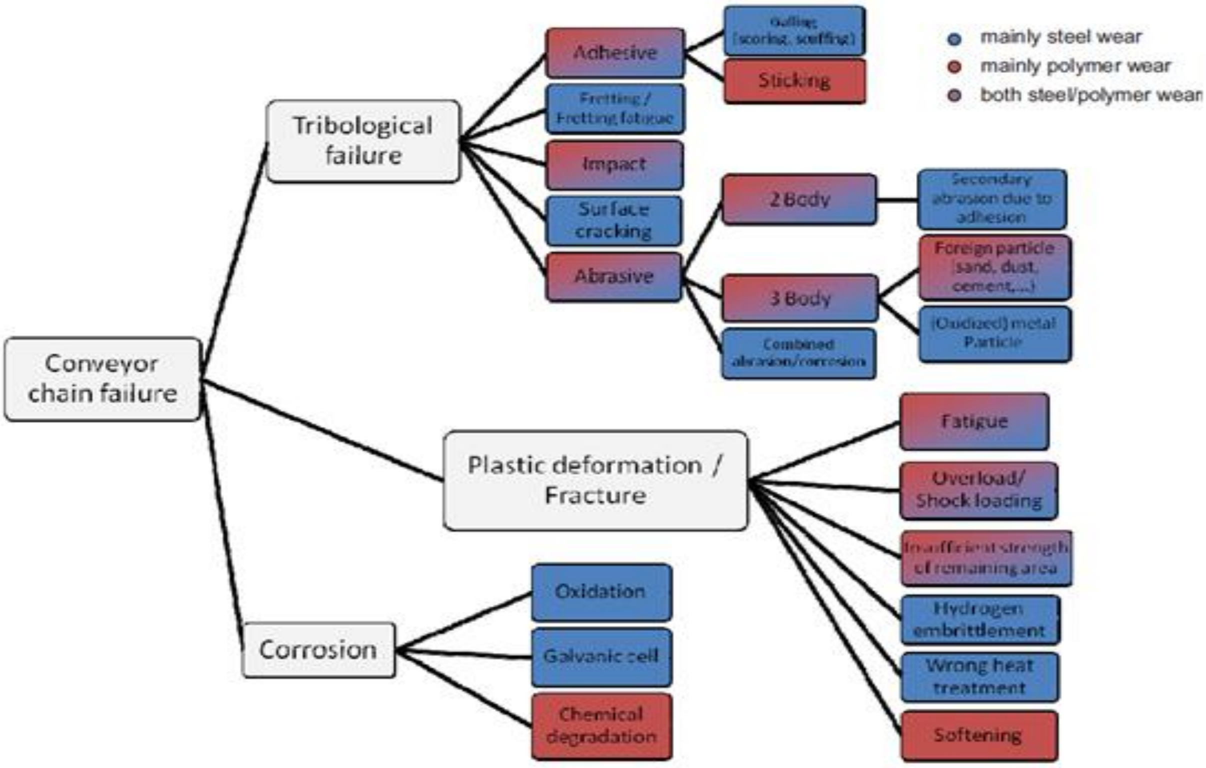
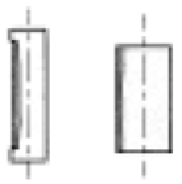
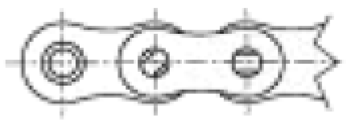
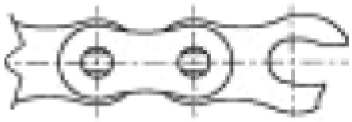
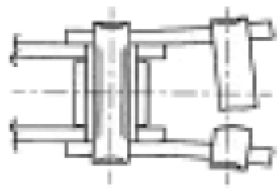
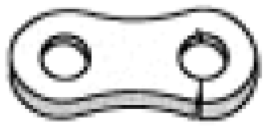
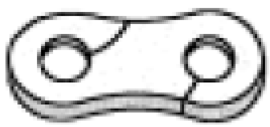


Fig.3.1.Failure cases in chain system [30]

Most common chain link failures and their possible causes of failure [17]

Table.3.1 Most common chain failures and causes [17]

No	Problem	Possible causes of problem
1.	pin or bushing galling 	• Overload • Inadequate lubrication
2.	Turned pins 	• Overload • Inadequate lubrication
3.	Excessive noise	• Too little or too much slack • Chain obstruction

		• Loose chain guard or bearing
4.	Chain vibration	• Excessive chain slack • Center distance too long • Stiff links
5.	Fractured plate 	• extreme overload
6.	Broken pins 	• Extreme overload
7.	Broken offset link pins 	• overload
8.	Fatigue failure 	• Loading is greater than chains dynamic capacity
9.	Cracking 	• Stress corrosion cracking • Hydrogen embrittlement

3.3 Problem statement

Conveyor chain is the major mechanical material handling system which is used in today's industry so, it is very important to study about its failure and try to save it from failures. In case of long distance transmission with metal chain, large driving force is required to cover the huge mass of chain that means of course here power requirement is also high according to the weight of chain. So, weight is the main problem with metal chain. Moreover, most of the time chain is under tension while moving on track with heavy pallets and this tension which causes failure of chain assembly which is the major problem for industrial sector such as, wear, fatigue failure, noise, vibration, pin bushing galling etc. Causes of this failure are improper design mainly. For instant now material steel have been using for link .With steel it's design is quite big, moreover, it's factor of safety is approximately 10 and weight of the link is quite high. All these parameters can be considered simultaneously and chain link design optimally.

Fig.3.2 Fatigue fracture in link [37]

So, as solution for this problem that is huge weight of the link and because of its large weight some serious failures are happening which is necessary to minimize and for this In this research a shape optimization has performed with the material composite instead of steel. Optimization is used for the design of roller chain link, for weight reduction and to save the material. Optimization is the process of obtaining the best result under given circumstances in design of system. In optimization process we can find the conditions that give the maximum and minimum value of function.

Disadvantages with steel: [40] [41]

- They have less specific modulus and strength
- Increased weight
- Corrosion resistance is less compared to composite material
- Steel link have less damping capacity

Advantages of glass fibre composite material: [31], [40]

1. Low cost , Reduced weight
2. Due to weight reduction power requirement would be reduced.
3. They have high damping capacity hence, produce less vibration and noise.
4. High modulus and strength, longer fatigue life.

5. High strength, High stiffness.
6. Relatively low density, they have good corrosion resistance.

So, let's see something more about composite in next topic.

3.4 Material

Composite material:

Composite material consisting of two or more physically and chemically distinct phase, suitably distributed. A composite material usually has characteristics that are not portrayed by any of its components in isolation [38] Using this definition, it can be determined that a huge range of engineering materials fall into this category. For example, concrete is a composite material with a mixture of Portland cement and aggregate. Fiberglass sheet is a composite since it is made of glass fibres imbedded in a polymer [39] Components of composite materials are two types. One is matrix phase and another is reinforcement. Matrix consist of the materials such as metals, ceramic and polymers while reinforcement consist of fibres and particulates such as glass, silica, ceramic, metallic, carbon, boron and aggregate. Normally in basic composites the material have phase, which is continuous called matrix and dispersed, non-continuous phase called reinforcement. Composite has higher stiffness to weight and strength to weight ratio than steel and other metal. The fundamental design concept of composites is that the matrix accepts the load over a large surface area, and transfers it to the reinforcement material, which can carry a large amount load. The significance here lies in that there are numerous matrix materials and as many fiber types, which can be combined in many ways to produce just the desired properties [25] The behavior of the composite can be made more isotropic by making several layers with this orthogonal fiber structure, and then laminating them with different fabric angles in adjacent layers. For the best thermal and mechanical behavior, the layup design should be symmetrical about a center lamina [28].

Classification of composite materials: [25]

1. Fibre reinforced: In this type fibre is primary load bearing component.
2. Dispersion strengthens: In this type matrix is the major load bearing component.
3. Particle reinforced: In this type load is shared by the matrix and particles.

Fibre reinforced:

The composite material chooses for conveyor chain link is glass fibre which classified in the fibre reinforced in which the fibre is the primary load bearing component. In this, fibre can be long continuous fibre; they can be discontinuous fibres, particles or even weaved sheets. Fibres usually combined with ductile matrix material such as metals and polymers.

Glass fibre:

Ancient egyptians and Phoenicians are among the many civilizations who produced small amount of coarse glass fibres for decoration. In 1942 Owens corning were already producing fiberglass and polyester airplane parts [33] Glass is the most common and low cost fibre. It is commonly use for the reinforcement of polymer matrices. Glass fiber does not have any fix orientation. Its nature and orientation depends on its manufacturing and the shape of the component. There are several ways to manufacturing of the glass fiber. Now days it widely used for many applications such as, car bodies, boats, insulation in homes, Water Park slides, furniture and many other. Here the kind of fiber we are talking about is made from mixture of silica and other material such as recycle glass. Normally this mixture is heated and extruded in fine strands. The strands and then collected into roving. Fiber glass roving skin either is used to directly create a product. Work can be woven into fabrics to suit the other applications. This fabric includes chopped matt, unidirectional as well as woven. Many techniques are used for production of glass fiber in that most common four techniques are: Pultrusion, gun roving, filament winding and molding. Glass has high tensile strength and fairly low density (2.5g/cc) [20]

Table.3.2. Mechanical properties of glass fibre [E-Glass/epoxy] [40] [42]

Property	Value
Young' modulus, EX, MPa EY, MPa EZ, MPa	43000 6500 6500
Poisson's ratio, PRX PRY PRZ	0.27 0.6 0.6
Elasticity , GX, MPa GY, MPa GZ, MPa	4500 2500 2500
Density, Kg/mm3	0.00002

Glass fibre does not have any significant orientation, because the composition and processing of glass results in an amorphous structure (non-crystalline). This is why it can be said that glass fibres are isotropic.Whereas; Carbon fibers have a graphitic crystal structure and molecular orientation than is aligned with the fiber axis. There is no fixed thing about glass fibre

It depends on the process of manufacturing, shape of component etc. it is sometimes found that glass fibers are orthographic as well.

Types of glass fiber: [26]

E, electrical –Low electrical conductivity

S, strength – High strength

C, chemical - High chemical durability

M, modulus - High stiffness

A, alkali- High alkali/soda lime glass

Dielectric- low dielectric constant

So, from the study of glass fiber/epoxy composite material has chosen for conveyor chain link with considering its advantages over steel. This same glass fiber material has used before for leaf spring in automobile for weight reduction in vehicles.

4. METHODOLOGY

4.1 Finite Element Analysis (FEA)

Finite Element Method is used for obtaining the approximate solution of engineering problem. In FEA, the complex region is discredited into simple geometric shapes called element. The properties are assumed over these elements and shown numerically in terms some x, y, z values on specific points called nodes. When the effect of force and conditions considering boundary are considered, a set of linear or nonlinear algebraic equations are usually obtained. Solution of these algebraic equations gives approximate behaviour of the component. The component has infinite number of degree of freedom. While model discredited with elements has finite number of degree of freedom. In, this research FEA is used to formulate the analysis and optimization of the conveyor chain link in software FEMAP (Finite Element Modelling And Post processing) FEMAP is utilized by designing associations and experts to model complex items, frameworks and procedures including satellites, flying machine, safeguard hardware, overwhelming development gear, lift cranes, marine vessels and procedure hardware.

4.2 Analytical method

Analytical method which is used in this research to calculate the tension on chain link and stresses induced with the material steel. For some standard parameters input has taken from the industry Hitachi.

Input from industry (HITACHI)

Horizontal conveyor chain

Conveyor summary:

Quantity conveyed Q 100(t/h)
Conveyor length C 30(m)

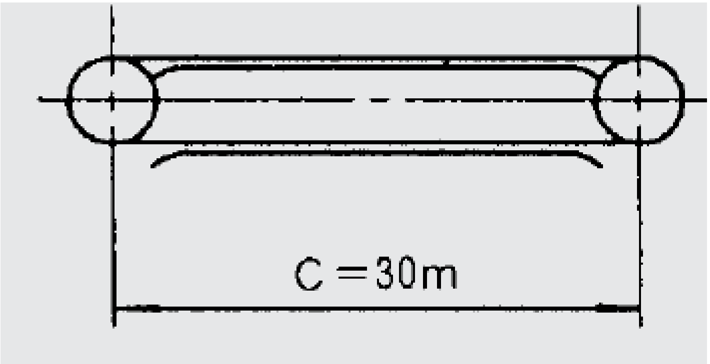


Fig.4.1.Horizontal conveyors [10]

Chain speed S 5(m/min)

No. of chains n 2(strands)

Chain used

Chain pitch p 200(mm)

Roller type F type

Attachment A-2 attachment on each link.

Slat mass W 25kg/slat

Teeth per sprocket N 12

Operating time 24(h/day)

Lubrication condition oil-less

Selection procedure.

1. No. of chain links L

$$L = \left\{\frac{2\,(\text{conveyor length } C)}{\text{Chain pitch } P} + \text{sprocket teeth } N\right\} * \text{no .of chains } n$$

$$= \left\{\frac{2(3000)}{200} + 12\right\} * 2 = 624 \text{ links}$$

2. Chain tension calculation:

❖ Calculate the force F1 required to move the load only.

- Mass of load on the conveyor W1

$$W\,1 = \frac{16.7 * \text{conveyor quantity } Q}{\text{Chain speed } S} * \text{conveyor length } C$$

$$= 16.7*100/5*30 = 10020 \text{ (kg)}$$

- Rolling coefficient of friction μ1 between chain and guide rail

  Chain is oil-less, so according to the table 1

  μ1=0.2 (provisional)

- Calculate F1

  F1= W1* μ1*g/1000

  =10020*0.2*9.80665/1000

  = 19.6 (kN)

❖ Calculate the force F2 required to move the moving parts only.
Chain mass is unknown, so calculate from the mass of slats.

- Slat mass W2 per meter
  W2= slat mass W*1000/chain pitch p
  = 25*1000/200
  =125 (kg/m)
- Calculate F2
  F2=2.1*W2*conveyor length c*coefficient of friction μ1*g/1000
  =2.1*125*30*0.2*9.80665/1000
  =15.4(kN)

❖ Calculate the force F required to move the conveyor
F=F1+F2= 19.6+15.4=35.0(kN)

3. Provisionally select a chain with average ultimate tensile strength at least ten times as high as the F calculated in step 2

   - F*10=350(kN)

     Average ultimate tensile strength of chain no.HR20019-F is

     245(kN) * 2 chains = 490(kN)

     Therefore provisionally set HR20019-F with A2 attachment on each link.

4. Formally calculate chain tensile strength

❖ Calculate chain tension T2 for 2 chains

From the following formula

$$T2 = \left(\frac{16.7 * \text{conveyed quantity } Q}{\text{Chain speed } S} + 2.1 * \dot{\varphi}\right) * \text{conveyor length } C * \text{coefficient of friction } \mu 1$$

Where $\dot{\varphi}$ is the mass of moving parts per meter.

$\dot{\varphi}$= (W3+W4)*2+W2

= (20.0+3.25)*2+125

= 171.5(kg)

W3: chain mass (kg/m)

From page p23, W3 =20.0(kg/m)

W4: Added mass of attachment A-2(kg/m)

From page23, the added mass per A-2 attachment is 0.65kg, so

W4=0.65*1000/200 = 3.25(kg/m)

W2: slat mass (kg/m)

From (2) W2= 125(kg/m)

μ1: coefficient of friction

From table on p143

μ1=0.17

T2= (16.7*100/5+2.1*171.5)*30*0.17*9.80665/1000

=34.7

- Calculate chain tension T1 for one chain

From the chain tension calculated for 2 chains in (1), allowing for eccentric loading,

T1=T2/2*1.2 =34.7/2*1.2 = 20.8 (kN)

5. Calculate the safety factor to check whether the provisionally selected chain is suitable.

$$\text{Safety factor} = \frac{\text{average ultimate tensile strength}}{\text{T1}} = 245/20.8 = 11.8 > 10$$

The above indicates that the provisionally selected HR20019-F with A-2 on each length can be used.

6. Calculate required power in kW.

$$\text{Kw} = \frac{\text{maximum tension T acting on the chain*chain speed S} \quad * 1/\eta}{60}$$

Using T2 for the chain tension in two chains, as calculated in (4),

T=T2=34.7 (kN)

From the table, mechanical transmission efficiency of the drive train

η= 0.75

Kw= (34.7*5/60) * (1/0.75)

=3.9 (kw)

7. Calculate drive sprocket speed r.

$$r = \frac{\text{1000*chain speed S}}{\text{Sprocket teeth N*chain pitch p}}$$

= 1000*5/12*200

= 2.08 (rpm)

Analytical Stress calculation:

Given-

Diameter (d) =18.9mm, Breadth (B) =50.9mm, Pitch (P) =200mm, Thickness (t) =9.5mm≈

Ultimate Strength= 1110Mpa, FOS= 10, Total load (F) = 10400N

Calculation:

CS Area= (breadth-diameter)* thickness

= (50.9-18.9)*9.5

=303.5mm2

Stress concentration factor (Kt) = 3-3.13(d/B) +3.66(d/B) ^2-1.53(d/B) ^2

Ref [24]

= 2.263314

Nominal shear stress = $\frac{10400}{303.05}$

= 35 Mpa

Maximum stress (6max) = Kt*6nom

= 2.263314*35

= 79.21 apprx **80 Mpa.** …………maximum stresses in link.

For these calculations some standard values are referred from the following tables.

Table.4.1.Coefficient of friction [10]

2. Coefficient of friction μ_1 between chain and guide rail
(1) Rolling coefficient of friction μ_1 between chain and guide rail

Roller Outer Diameter (mm)	Oiled	Oil-less
50 or less	0.15	0.20
50~65	0.14	0.19
65~75	0.13	0.18
75~100	0.12	0.17
100 or more	0.11	0.16
Roller with Bearing	0.03~0.05	
Bushed Chain (sliding)	0.30	0.43

Table.4.2.Efficiency of the drive train [10]

1. Motor efficiency η (Mechanical transmission efficiency of the drive train)

Chain Speed (m/min)	Efficiency η
Up to 10	0.75
10~20	0.80
20~30	0.85
30 or more	0.90

Table.4.3.Standard chain (HR20019-F) specifications [10]

Chain No.	Pitch P (mm)	Roller				Inner Width W (mm)	Pin				Link Plate		Average Tensile Strength		Mass (kg/m)
		Outer Dia. R (mm)	Face Width E (mm)	Flange Diameter K (mm)	Offset Z (mm)		Dia. D (mm)	Length L (mm)	Length L_1 (mm)	Length L_2 (mm)	Height H (mm)	Thickness T (mm)	(kN)	(kgf)	
HRS03075-F	75	30.0	10.6	38	3.6	16.1	7.9	36.4	17.1	19.3	22.0	3.2	29.4	3000	2.8
HRS03100-F	100														2.3
HRS03150-F	150														2.1
HRS05100-F	100	40.0	14.0	50	4.5	22.2	11.1	51.0	24.0	27.0	32.0	4.5	68.6	7000	5.2
HRS05150-F	150														4.3
HR10108-F	101.6	44.5	18.0	55	6.5	27.0	11.1	63.0	30.0	33.0	28.6	6.3	78.5	8000	6.9
HR15208-F	152.4	50.8	20.0	65	7.0	30.0		66.0	31.5	34.5	38.0				8.1
HR10011-F	100	50.8	20.0	65	6.5	30.0	14.3	68.0	32.0	36.0	38.0	6.3	112.8	11500	10.2
HR15011-F	150														7.7
HR10113-F	101.6	44.5	20.0	60	7.0	31.6	15.8	81.3	37.3	44.0	38.1	7.9	132.4	13500	10.7
HR15215-F	152.4	57.2	25.0	75	9.0	37.1	15.8	87.5	40.0	47.5	44.5	7.9	186.3	19000	12.4
HR20015-F	200	65.0	24.0	85	8.0										11.5
HR25015-F	250														10.4
HR20019-F	200	80.0	34.0	105	12.0	51.4	18.9	111.3	51.5	59.8	50.8	9.5	245.2	25000	20.0
HR25019-F	250														17.3
HR30019-F	300														15.7
HR25026-F	250	100.0	38.0	130	13.0	57.2	22.1	119.6	55.4	64.2	63.5	9.5	313.8	32000	26.7
HR30026-F	300														24.0
HR45026-F	450														19.1
HR30048-F	300	125.0	42.0	160	14.0	66.7	25.3	143.7	67.6	76.1	76.2	12.7	475.6	48500	41.9
HR45048-F	450														32.9
HR60048-F	600														28.5
HR30054-F	300	140.0	49.0	180	16.5	77.0	31.6	169.3	81.6	87.7	76.2	16.0	529.6	54000	55.2
HR45054-F	450														43.2
HR60054-F	600														37.0

Table.4.4.For average ultimate tensile strength [10]

Specification Code / Chain No.	DH, GH, CH		AH, BH, YH		PH		SH	
	kN	kgf	kN	kgf	kN	kgf	kN	kgf
HRS03075 03100 03150	29.4	3000	69.6	7100	53.9	5500	33.3	3400
HRS05075 05100 05150	68.6	7000	142.2	14500	107.9	11000	68.6	7000
HR10105	53.9	5500	98.1	10000	83.4	8500	48.1	4900
HR10108	78.5	8000	142.2	14500	122.6	12500	68.6	7000
HR15208	78.5	8000	142.2	14500	142.2	14500	68.6	7000
HR10011 15011	112.8	11500	225.6	23000	176.5	18000	107.9	11000
HR7813 10113	132.4	13500	240.3	24500	186.3	19000	122.6	12500
HR15215 20015 25015	186.3	19000	279.5	28500	264.8	27000	132.4	13500
HR15219 20019 25019 30019	245.2	25000	387.4	39500	357.9	36500	186.3	19000
HR25026 30026 45026	313.8	32000	519.8	53000	460.9	47000	250.1	25500
HR30048 45048 60048	475.6	48500	681.6	69500	—	—	—	—
HR30054 45054 60054	529.2	54000	1029.7	105000	—	—	—	—

Table.4.5.Formula for tensions [10]

Type of Conveying			Calculation Formula	
			Chain Tension	Required Power
Horizontal Conveying	Load is placed on conveyor and moved (Slat conveyor, apron conveyor, etc.)	Movement of individual items	$T=(W+2.1\times w\times C)\times\mu_1\times\frac{g}{1000}$	$kW=\frac{T\times S}{60}\times\frac{1}{\eta}$
		Movement of loose items	$T=(16.7\times\frac{Q}{S}+2.1\times w)\times C\times\mu_1\times\frac{g}{1000}$	
	Load is scraped up and carried (Flight conveyor etc.)	—	$T=(16.7\times\frac{Q}{S}\times\mu_2+2.1\times w\times\mu_1)\times C\times\frac{g}{1000}$	

Standard conveyor chain F type roller:

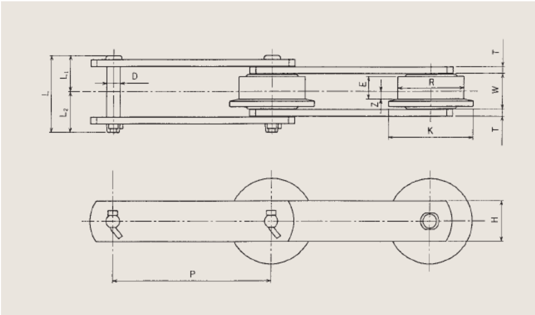


Fig.4.2.Standard conveyor chain F type roller [10]

Solid work model of F-Type roller conveyor chain:

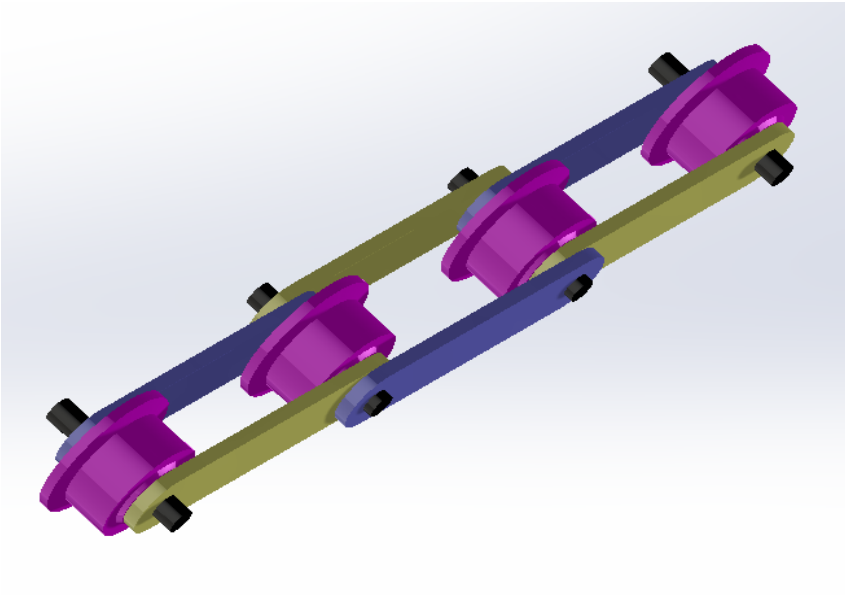


Fig.4.3.Standard conveyor chain F type rollers solid work model.

Figure shown above is complete assembly of the conveyor chain. In this research the focus has been on outer link of the conveyor chain as I mentioned in introduction that outer link has maximum stress and much failure chances as compared to inner links.so, whole analysis focused on outer link only. There are three types of roller this Hitachi industry produced from this the chosen type roller is F which shows flange has attached to the roller and its height exceeds link plate. Attachment used is A2 which is one side attachment with two holes for bolt.

Properties for analysis-

Steel [42]

AISI 1045 Steel, Medium carbon steel

Density-	7.87 g/cc
Yield and tensile strength-	310 MPa
Poisson’s ratio-	0.29
Young’s modulus-	200 GPa
Bulk modulus	140 GPa

Composite material [40][42]

Glass fiber/epoxy

Young’ modulus, EX, MPa	43000
EY, MPa	6500
EZ, MPa	6500
Poisson’s ratio, PRX	0.27
PRY	0.6
PRZ	0.6
Density, Kg/mm3	0.00002

5. RESULT AND DISCUSSION

In this topic we are going to see results of original link and composite material link on the basis of analytical and FEA methods. Analysis has been done in software FEMAP. First plot is for original conveyor chain link analysis results and then analysis with composite material chain link. In FEMAP in order to calculate the maximum stress and deformation for both the original outer link selected and the glass fiber link, statistical structural analysis is done and from the analytical, the maximum force of 20800 N is applied at both the flat hole in outward direction. For analysis I have considered only one forth part of the link and with the help of symmetry option it has been done for the complete link. Solid model of the One forth part of the link is shown below:

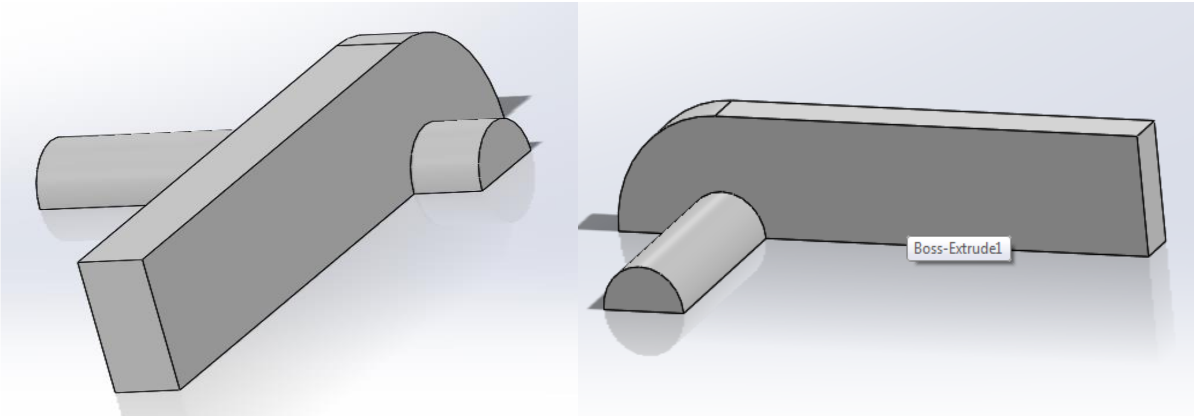


Fig.5.1.One forth part of the conveyor chain link.

Constraint:

Below figure shows the symmetric condition of one forth part of the link to x, y and z directions. Thickness is considered by z- axis direction. To perform the analysis for complete one link symmetry has to choose at direction x and y and link was settled according to its movement while chain working on the track.

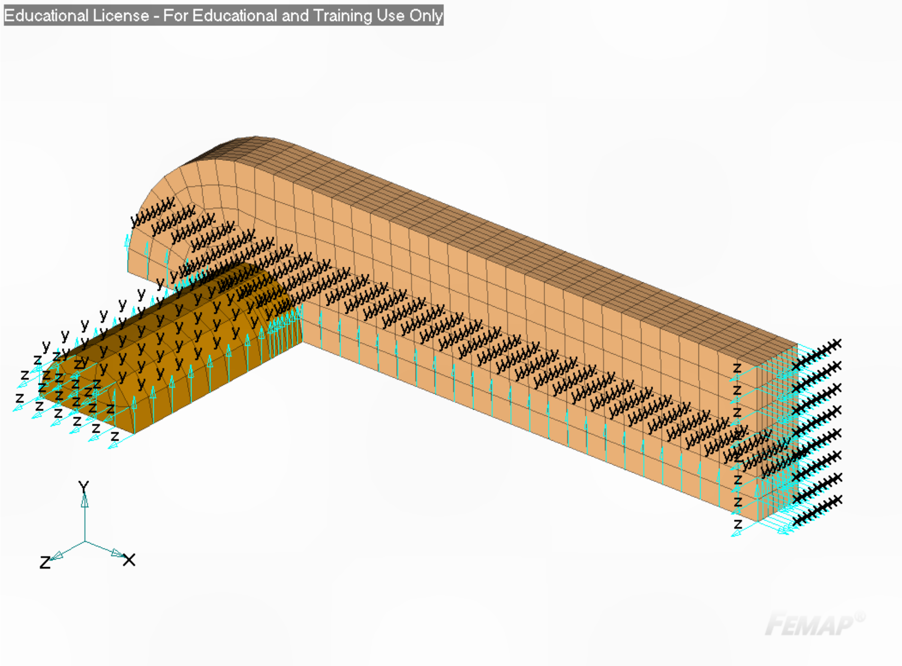


Fig.5.2.Symmetry constraint of the link

Force:

Total tension on link as per analytical calculation is 20800N. If we think about chain assembly we can observe two inner links are attached to the both sides of outer link which create tensions on both sides. The tension acts on both sides of the link on half of the pin and holes on link. So, here tension is not applied on link but on neighboring pin by x- direction. As considering one fourth part tension 5200N has applied on pin by x-direction. We can see in below figure.

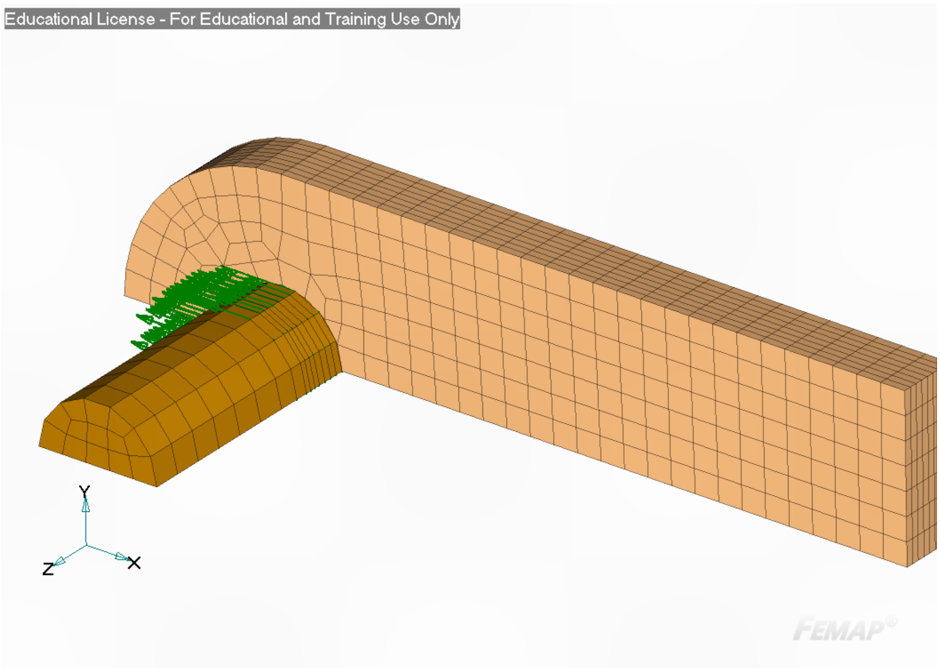


Fig.5.3.Force applied on the pin.

5.1 Analysis

5.1.1 Original link

Material

For original link-pin assembly material used is structural steel which is same for the both parts link and pin.

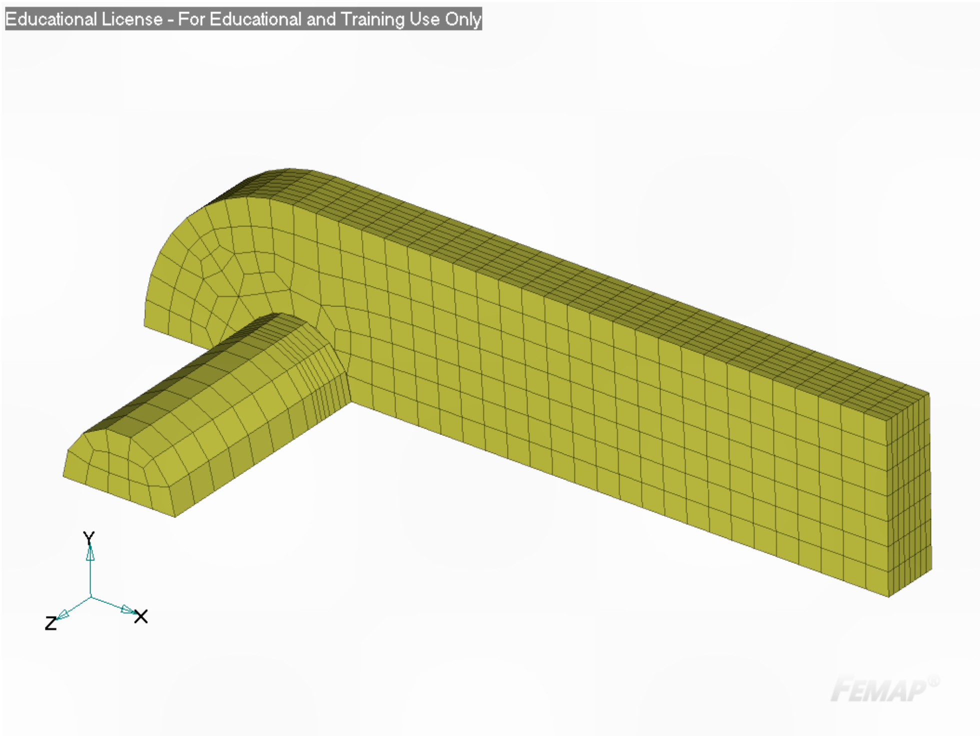


Fig.5.4.Link-Pin with the same material

Stress in pin-link assembly:

The stress and deformation analyses were performed by applying a static tensile load in the chain direction (X-direction). The load is not applied to the link plate directly but to neighbouring pins (or bushes). The deformations in the nodal points on the symmetry plane were restrained in a plane perpendicular to the symmetry plane. These results show that stress concentrates around a pin or bush. Moreover, the stress at the constricted part of the link plate is large. Although studies on the analytical results for stress occurring in the chain are few and a quantitative comparison with other research studies is difficult owing to the different analytical conditions used, it can be verified that The state of stress is similar for analytically as well. In a recorded case of a damaged link plate, cracks arise from the bottom point of contact hole of a pin or bush therefore; we can say that their analytical results are qualitatively accurate.

Stress in link-pin assembly

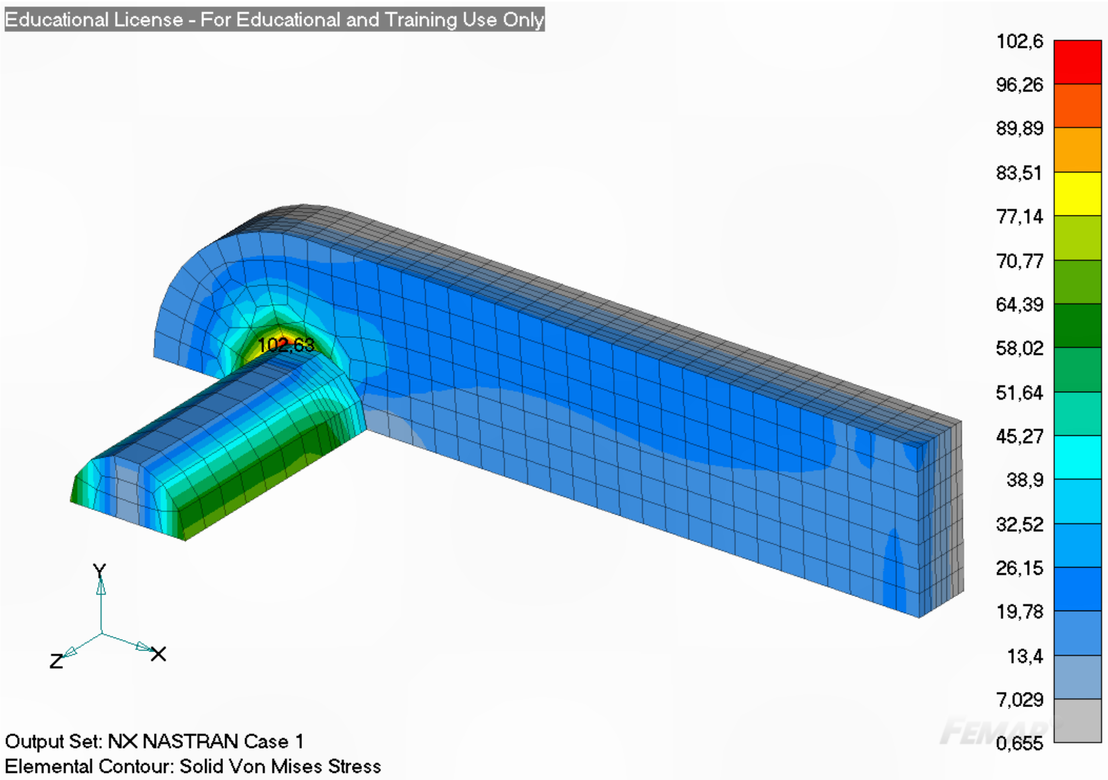


Fig.5.5.Stress in pin-link assembly

Stress in pin:

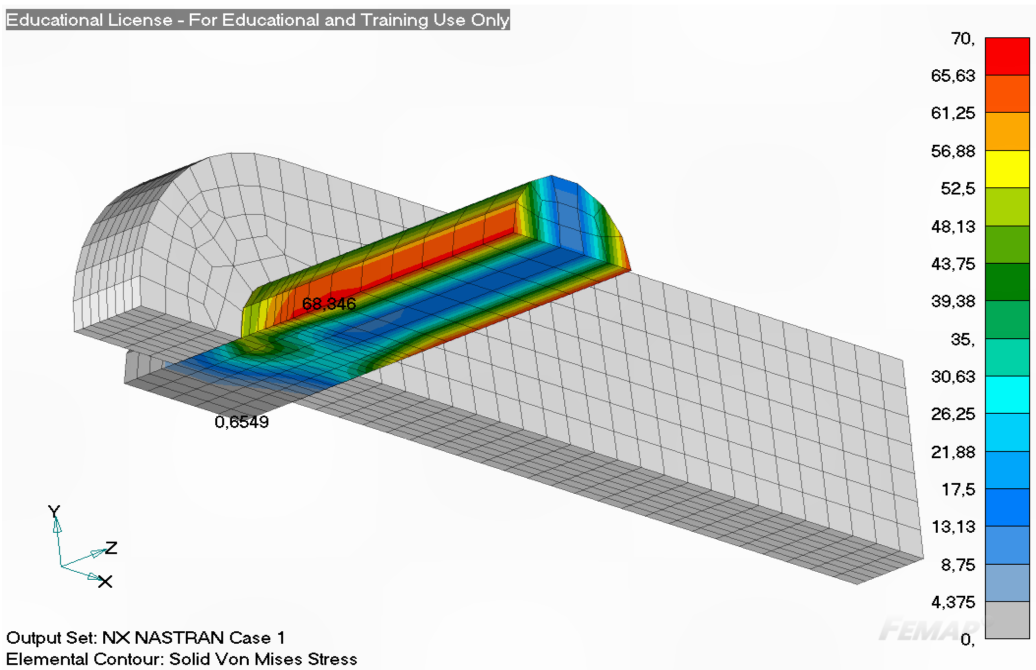


Fig.5.6.Stress in pin

Stress in link:

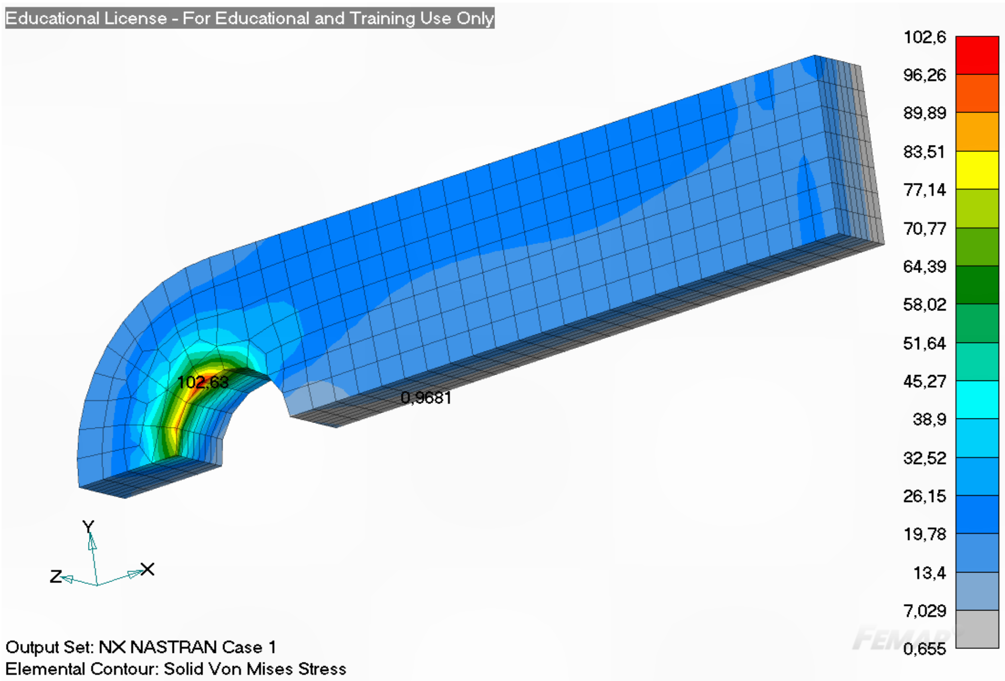


Fig.5.7.Stress in link

Deformation in pin link assembly:

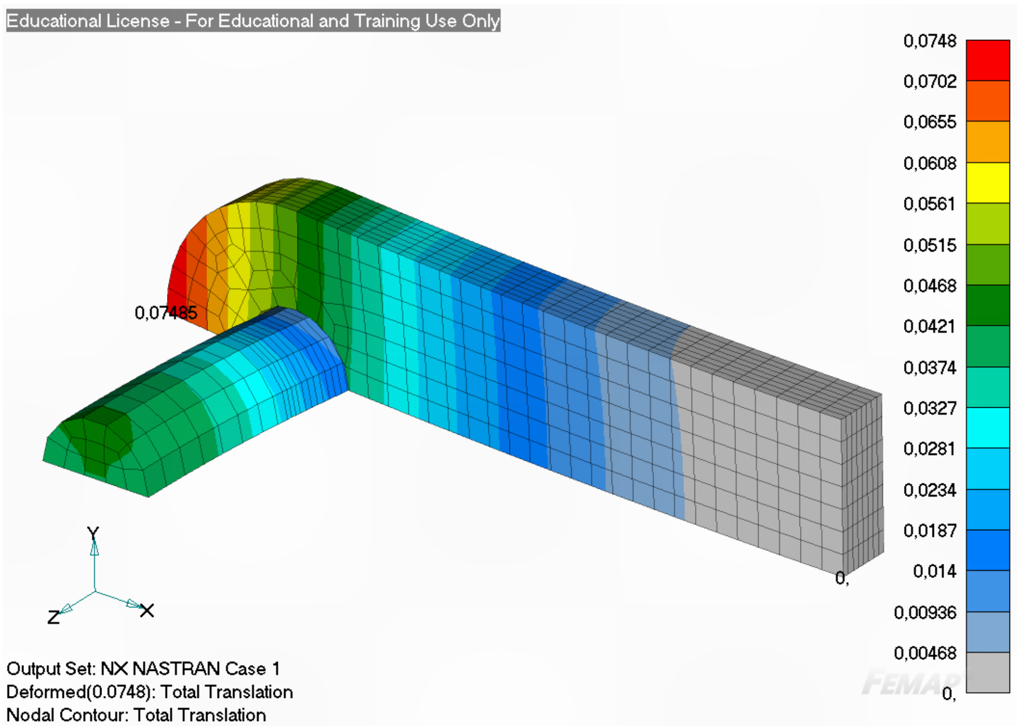


Fig.5.8.Deformation in pin link assembly

Contact pressure between pin and link:

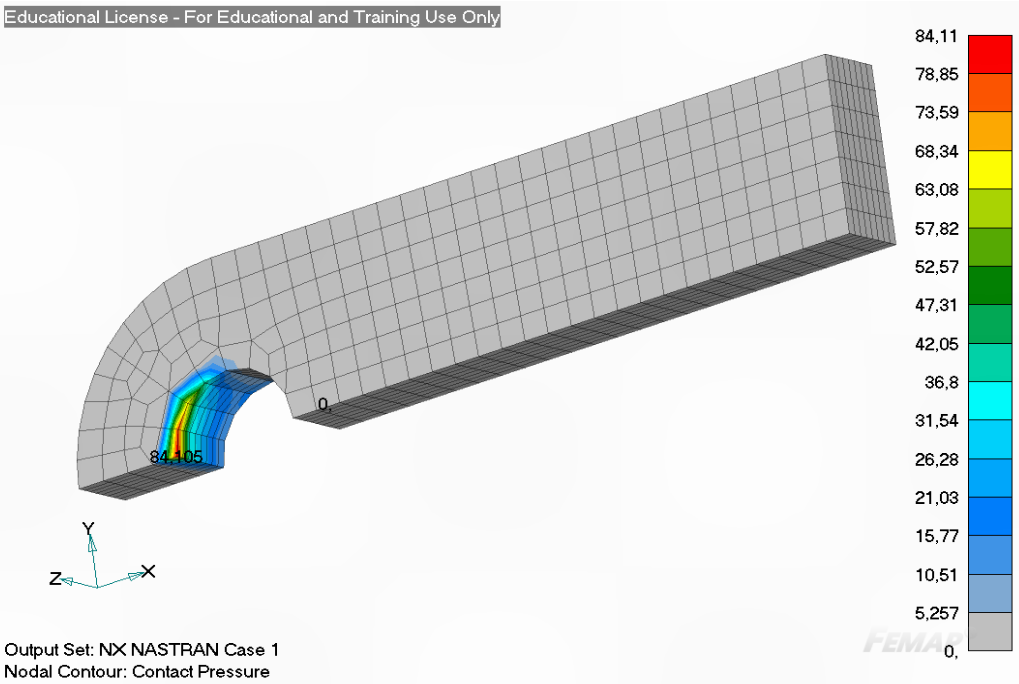


Fig.5.9.Contact pressure between pin and link

5.5.2 Redesign of link with new composite material (glass fiber)

Material

For new link-pin assembly material used for link is GLASS FIBER and for pin same as original link.

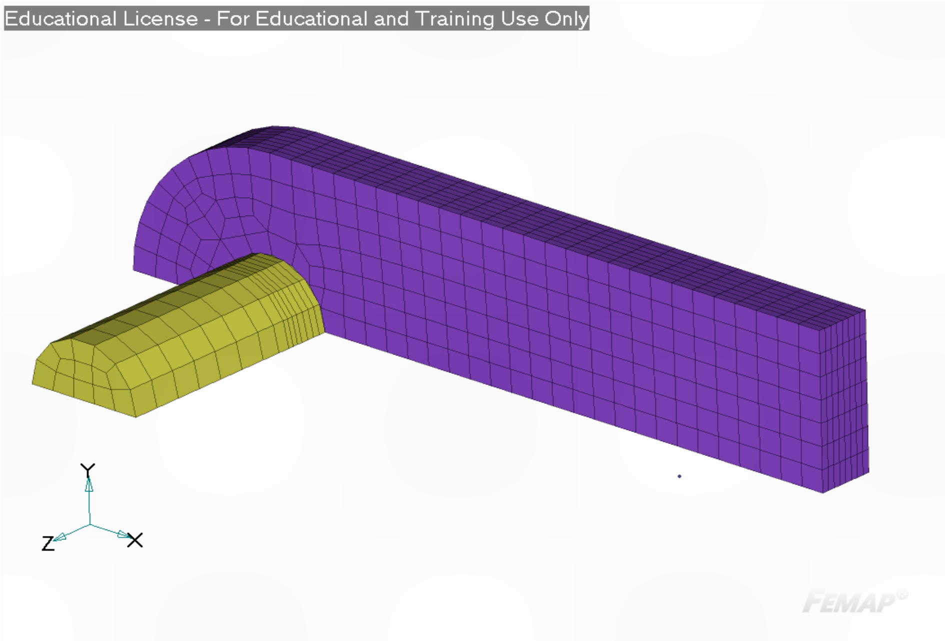


Fig.5.10.Link-pin assembly (composite-steel)

Stress in pin-link assembly

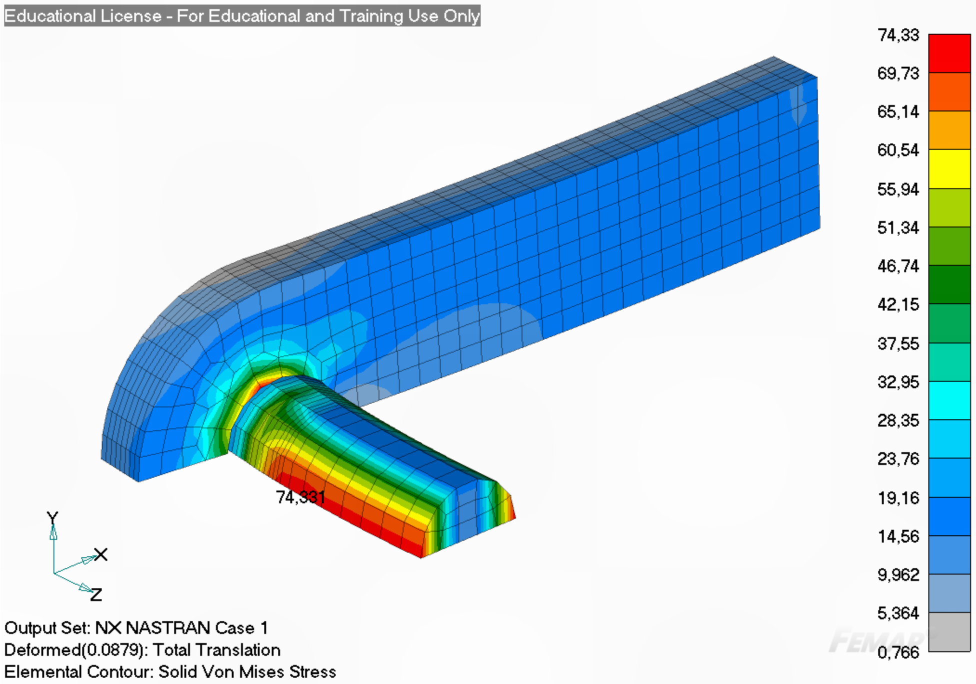


Fig.5.11.Stress in pin-link assembly

Stress in link

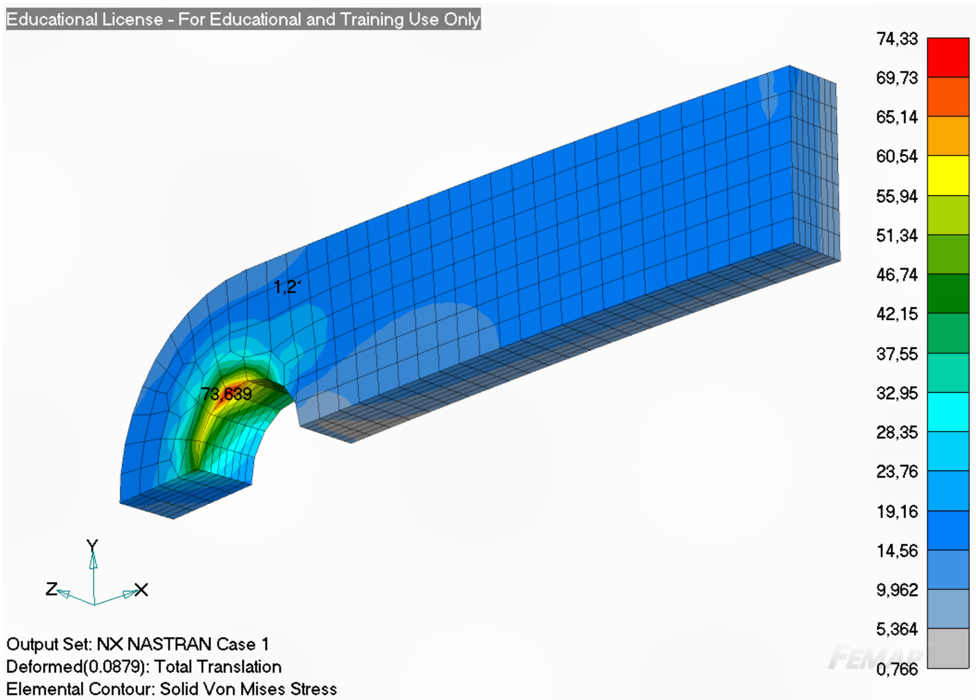


Fig.5.12.Stress in link

Stress in pin

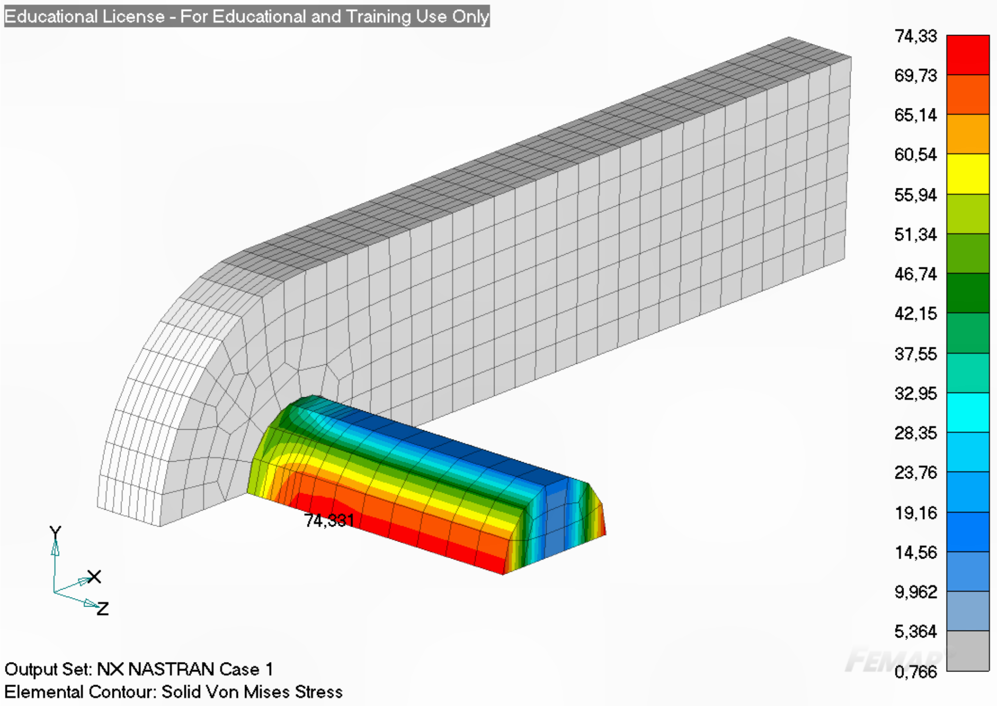


Fig.5.13.Stress in pin

Deformation in link

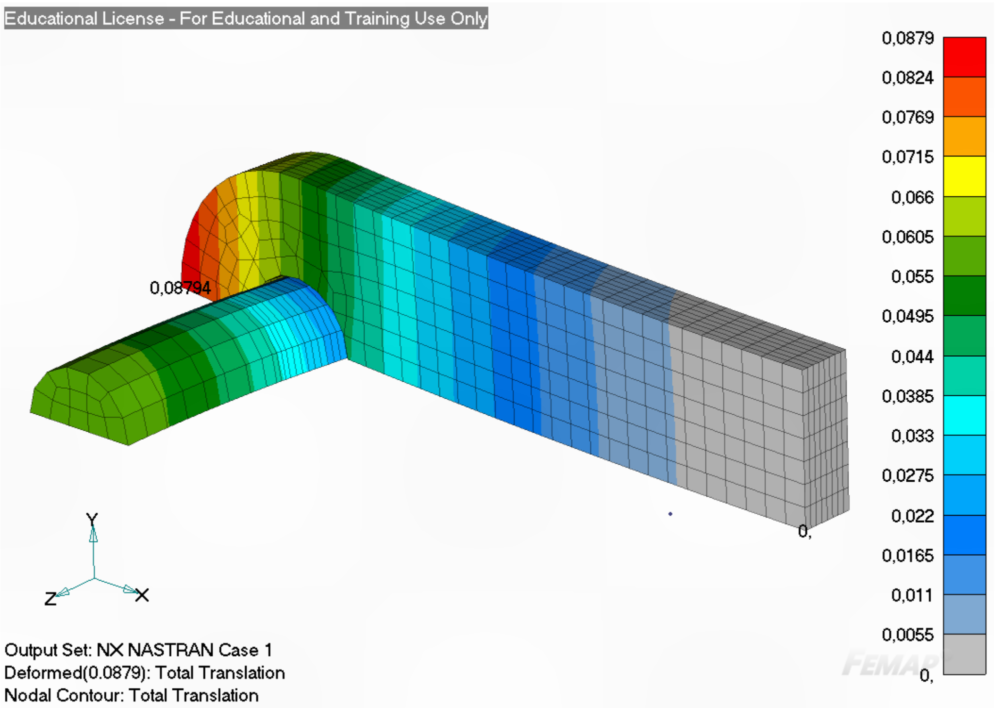


Fig.5.14.Deformations in link

Contact pressure

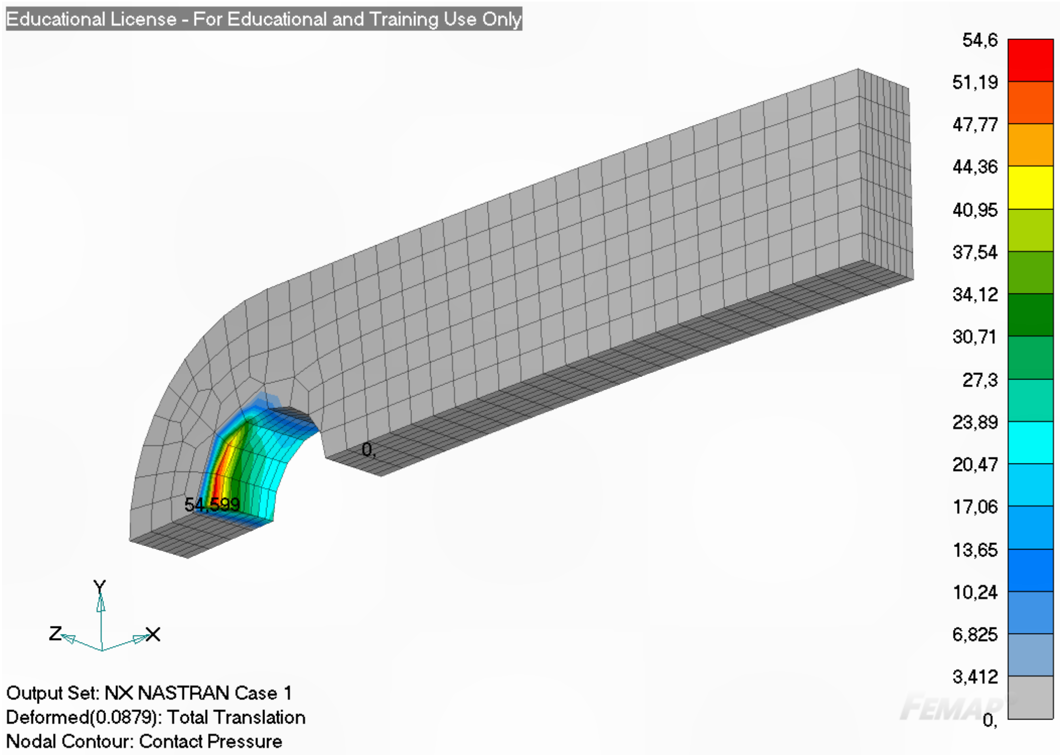


Fig.5.15.Contact pressure

After performing Stress and deformation analysis by using both materials steel and composite we can see that stresses are much higher in original link as compared to the new link with composite material.

Table.5.1.Analysis result table with material steel and composite

Material	Stress in link, MPa	Stress in pin, MPa	Deformation, mm	Contact pressure, N/mm2
Steel	102.6	70	0.0748	84.105
Composite	73.3	74.331	0.08794	54.599

5.2 Shape optimization for weight reduction

As we know shape optimization has been conducted to reduce the weight of the component and save the material of the component so here for outer link we have tested by two methods. This methods are first is by reducing the thickness of the link and second one by changing the design.

1. By reducing the thickness of the link.
2. By changing the link design.

5.2.1 By reducing the thickness of the link

If the thickness were changed, the other dimensions would remain constant. Therefore effective weight saving would be realized. Thus, the stress was analyzed with a change in the thickness of the outer link plate for the standard roller chain. Although the thickness of the link plate of the standard chain was 9.5mm and changed 3 thicknesses namely 7.13mm, 4.75mm and 2.38mm.

Stress with the changed thickness 7.13mm:

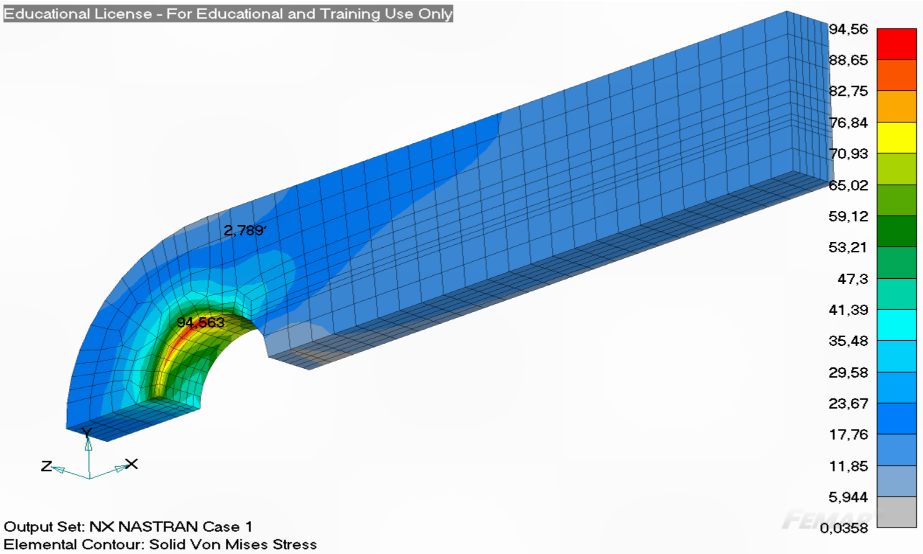


Fig.5.16.Stress with changed thickness 7.13mm

Stress with the changed thickness 4.75mm:

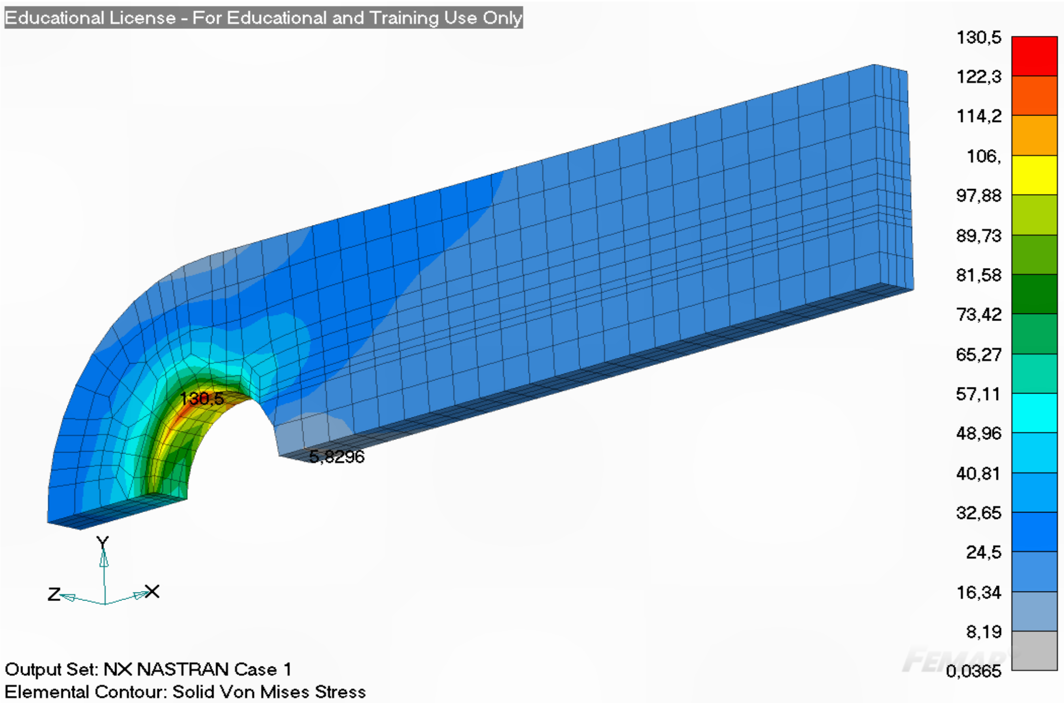


Fig.5.17.Stress with changed thickness 4.75mm

Stress with changed thickness 2.38 mm

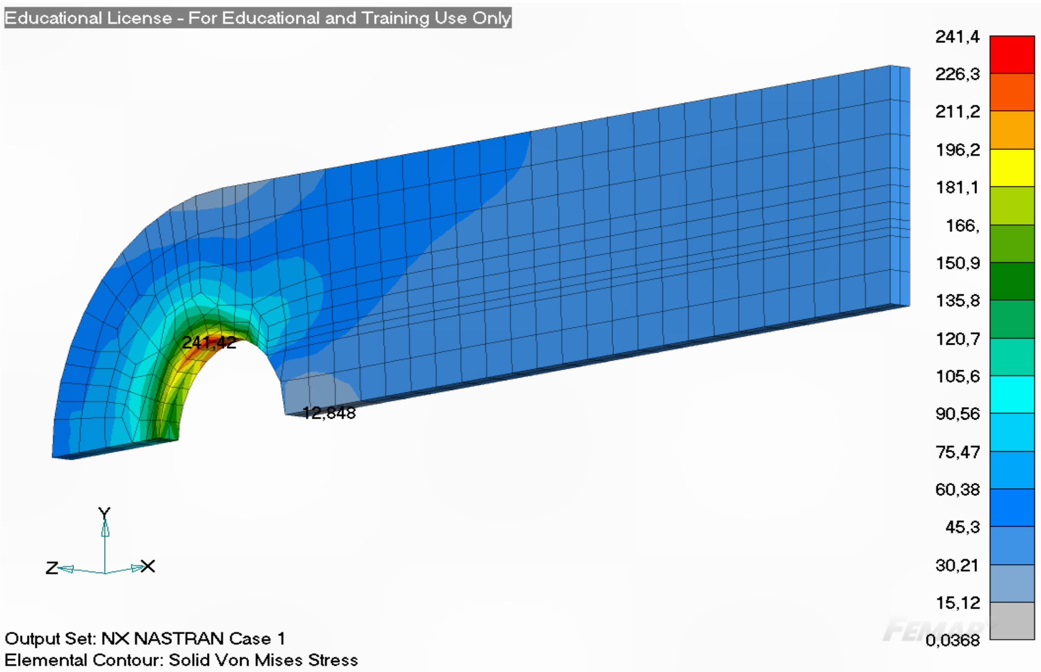


Fig.5.18.Stress with changed thickness 2.38mm

5.2.2 Optimization with the new design

As we can see in all above analysis there is very less stress in the center part of the link so if we change the design of link little we can even save the material because there is no stress on this part. In below model the design has changed from normal to slot I shape from both side of the outer link. Analysis has been done to this changed design and compared with steel analysis below.

New design of the link

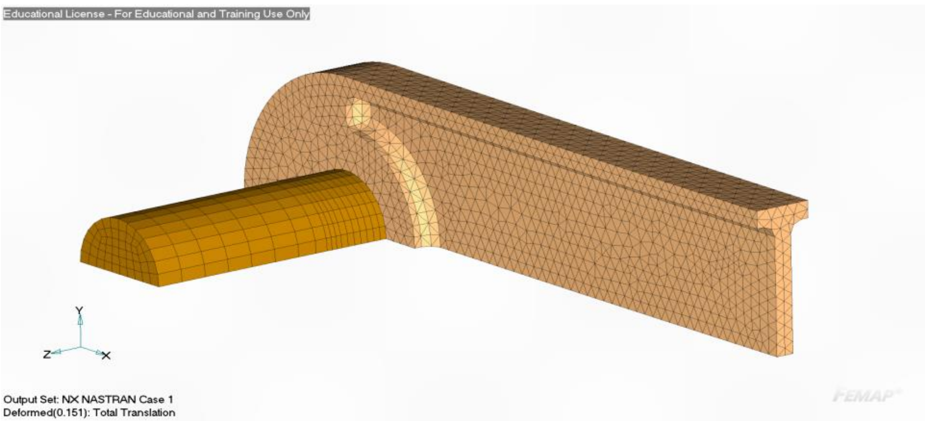


Fig.5.19.New design of the link

Stress in new link design: (composite material)

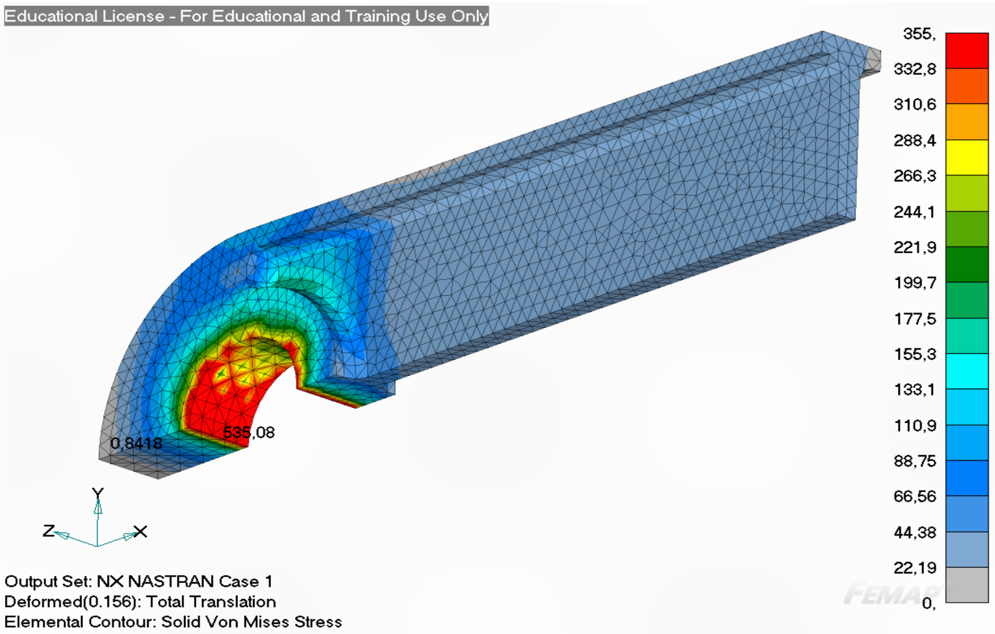


Fig.5.20.Stress in new link design

Stress in new link design: (steel)

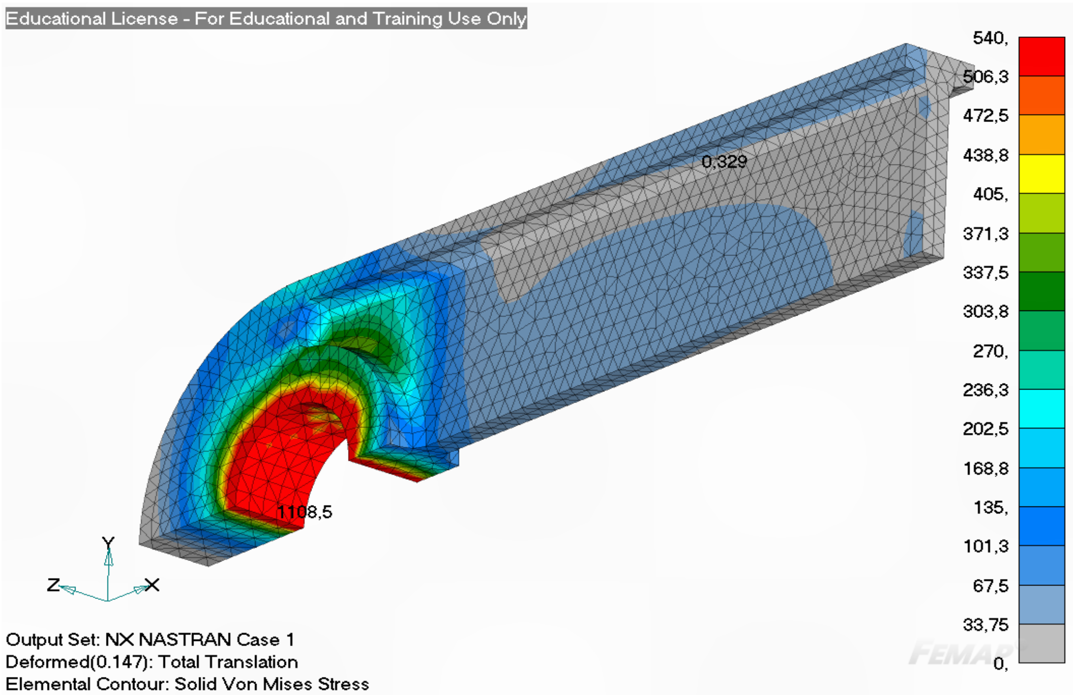


Fig.5.21.Stress in new link design

Optimization results

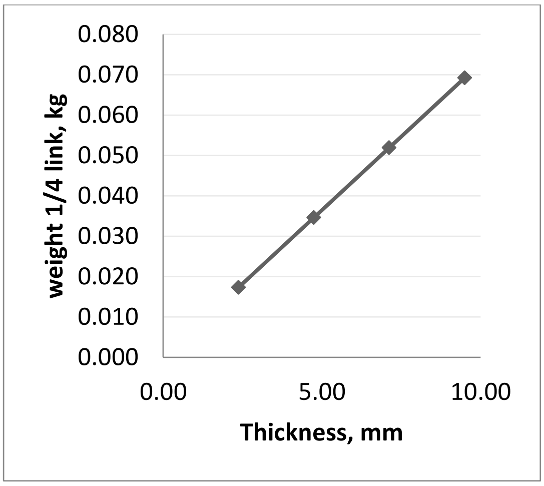
Table.5.2.Optimization table for weight reduction

Material	**Density Kg/m3**	**Thickness mm**	**Volume M3**	**Weight ¼ kg**	**Weight 1 kg**	**Stress Mpa**
Glass F	2500	9.50	2.77E-05	0.069	0.277	74.08
Opt1	2500	7.13	2.08E-05	0.052	0.208	94.563
Opt2	2500	4.75	1.38E-05	0.035	0.138	130.5
Opt3	2500	2.38	6.92E-05	0.017	0.069	241.42
Opt (new design)	2500		1.47E-05	0.037	0.147	535.08
Steel	7850	9.50	2.77E-05	0.217	0.869	102.5
Opt (new design)	7850		1.47E-05	0.115	0.462	1108.5

Graphical presentation

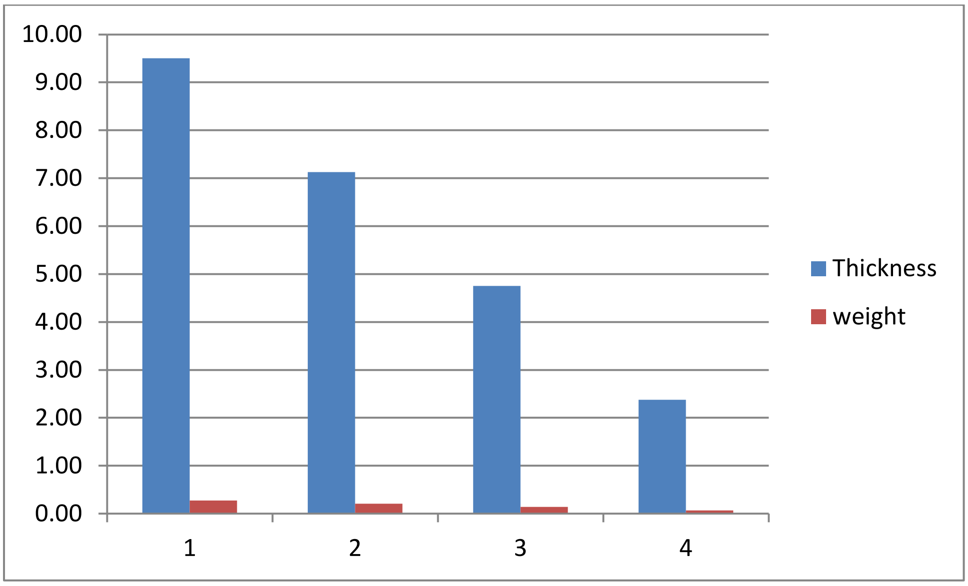
We can see in graph the nature of the link changes as we change thickness. Here we conclude that the thickness is directly proportional to the weight. As thickness Increases the weight of the link also increases. In shape optimization weight reduce by two ways one by changing the thickness and another is by changing the link design. Below graph shows as thickness reduces, weight reduces with it and by this way we can save the material and we can make it light in weight. Composite material is already light weight as compared to steel and by optimization the weight has reduced even more.

Graph shows weight reduction in ¼ links with reducing thickness.



Graph.5.1.Thickness Vs Weight of the link(1/4)

Below graph shows weight reduction in complete one link with reducing thickness.



Graph.5.2.Thickness Vs Weight of the link (1)

CONCLUSION

Reducing weight and increasing strength of the products research are high in demand in the market. And composites materials are getting up to satisfying those demands. This research deals with the analysis for link plate of roller chain with new material that is glass fiber composite material.

In this research reducing weight of conveyor chain and increasing the strength of their connected links are considered. As conveyor chain links contributes considerable amount of weight to the conveyor chain and needs to be strong enough, a single composite chain link is designed and it is shown that the resulting design and simulation stresses are much below the strength properties of the material satisfying the maximum stress failure criterion.

Static analysis was performed to achieve the first objective and in results it is found that there is a maximum displacement of 0.0748mm in the steel link and the Corresponding displacements in E-glass / epoxy, is 0.08794mm. From the static analysis results, we see that the von-misses stress in the steel is 102.6 MPa. And the von-misses stress in E-glass/Epoxy is 73MPa. E-glass/epoxy composite link plate can be suggested for replacing the steel link plate from stress and stiffness point of view. A comparative study has been made between steel and composite link with respect to strength and weight.

It must be noted that in typical industrial application thousands of such link will be needed. Thus, the weight and material saving will have significant impact on cost of the chain. So, to achieve second objective Weight reduction was achieved with composite material 59.2%. As glass fiber composite is expensive than steel so, to save cost and material. Optimization was performed by two ways:

- By changing the thickness, with this way the optimization performed by changing the thickness from 9.50 to 7.13, 4.75 and 2.38. And weight reduced 20% by thickness optimization.
- By changing the design, by this way of link plate design, weight reduction achieved 13%.

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