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WEIGHT OPTIMIZATION OF OUTER LINK PLATE OF ROLLER CHAIN

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Abstract- *An objective of this paper is to optimize the weight of outer link plate of a chain by topological approach and its strength evaluation by various heat treatments. Roller chains operate under various forces resulting into failure of chain link plate and costly production downtime. Therefore productivity is highly dependent on performance of chains. As per field work study, most of time chain is under tension which causes elastic and plastic deformations and results into elongation. Main causes of these failures are improper material selection, improper design, manufacturing process errors and uncertainties in heat treatments. Since lot of work has been done in increasing the life of chain, this work focuses into reducing weight and simultaneously increasing the breaking load. For this purpose FEA has been used to weight optimization in topological approach and experimental validation has been carried out. As stress concentration near to pinholes in chain link plate is higher, breaking takes place at location of minimum cross section area. In chain link plate most dimensions are parametrically defined, however the only dimension i.e. radius between interconnecting pinholes is left to manufacturer's convenience. Thus, we access an impact of the radius on stress generated in system and to see the possibility of material saving and efficiency increment. This study will help in reducing failure modes generated during manufacturing process of chain link plate in turn help in reducing downtime and maintenance cost.*

Keywords– *EN-19, EN-24, FEA; Heating and Soaking time; tensile test; Topological approach; UTM*

I. INTRODUCTION

Maharashtra state is dominated by agricultural as well as industrial sector. Sugar factories play an important role in economy of Maharashtra state. About 60 percent processes in these factories are based on roller chain conveyors. However, failure of these chains is perennial problem in these industries which causes huge losses to these industries. Most of the time chain is under tension which causes failure of chain assembly. Causes of this failure are improper design, improper material selection, and uncertainties in manufacturing and faulty manufacturing processes.

In this study a shape optimization process is used for minimization of failure modes. This process has various design variables, such as wall thickness of link, breaking area of link, bending movement of pin, inner width of chain and shape of the link. While deciding the shape optimization of roller chain link assembly raw material plays important role, so normally medium alloy steel i.e. as per Indian Standard C45, 55C8 or as per British Standard EN8, EN9 has been used in normalized condition and after manufacturing of link it has been heat treated up to 35 to 40 HRC in order to get tensile strength up to 70 to 80 kg/mm².

This work is focused on parametric study to understand influence of these parameters on chain strength using theoretical, numerical and experimental methods. Material uncertainty plays an important role on formation of elastic and plastic stresses. Breakage of chain is also affected due to faulty manufacturing and uncertainty in heat treatment.

As most of the times failure of a chain occurs in link plates due to lower area against an action of tensile load, we emphasized more on link plate. This study will help in reducing failure modes generated during design and manufacturing process of chain link plates, ultimately in an assembly. In turn it will help in reducing down time and maintenance cost related to chain assembly in various industries.

Noguchi et al [1] proposed some methods of weight saving for roller chains. These methods are based on Finite Element Method analysis of the stress and deformation in the link plate of roller chain and also approaches for reducing stresses and weight saving in the link plate of the roller chain. Stress are 3% higher in the proposed design, but the weight is reduced by 10%. Tensile tests are performed on link plates made of resin, and the effectiveness of the proposed model is confirmed. Miyazawa and Satoh [2] developed a method of manufacturing a link plate for a roller chain which results in minimization of the link plate deformation, a bending failure generated by the interference between a warped link plate and the adjacent link plate. Moster and Ledvina [3] developed a roller chain assembly by adding material to the location on the link plate face where fatigue failure is most likely to occur. The added material increases the strength of the link plate, allowing for the use of inner links having larger bushings. After the load estimation, it was necessary to find out durability of chain under these working loads. Therefore research focus was shifted towards developing chain testing methods. Kidd M.D., Loch N.E. and Reuben R.L [4] worked on experimental examination of bicycle chain forces and experimental result have demonstrated the large variation in tension associated with bicycle chain engaged with a sprocket under pseudo static loading, Very few researchers worked on stress analysis of roller chains. Özes and Demirsoy [5] examined the effects of various loading conditions on the stress of a pin-loaded woven-glass fiber reinforced epoxy laminate conveying chain component. A numerical and experimental study was carried out to determine the stress distribution of composite conveying chain components used to convey loads.

From the previous studies, it can be noted that, even though several patents are filed on roller chains and conveyors, most of the patents are based on improvement of efficiency and performance. Hardly few patents are there on improving life of the chain and minimization of its failure. From the chain failure case studies it can be noted that the root cause of failure was faulty material processing, heat treatment and improper material selection. However, literature on uncertainty analysis due to faulty material processing, heat treatment and improper material selection is present. The failure case studies also indicate that the birth to some failure modes is given at the time of designing stage itself.

II. NUMERICAL ANALYSIS

As per the catalogue we had taken chain link plate of EN-19 material, dimensions 68.30 mm x 76.20 mm (Pitch) x 9.5 mm for outer link plate. Now by using the analytical formulae we find out the value of maximum stress i.e. ultimate tensile strength. Values from design data book

Tensile strength = 1097 N/mm^2 to 1231 N/mm^2
Modulus of elasticity = 2.05X10^5 N/mm^2
Poisson's ratio = 0.3
Maximum working stress-

$$Maximum\ Working\ stress = \frac{Maximum\ stress}{Factor\ of\ safety}$$
$$Maximum\ Working\ stress = \frac{1231}{1.5}$$
$$Maximum\ Working\ stress = 821.45\ N/mm2$$

Minimum working stress-

$$Minimum\ Working\ stress = \frac{Minimum\ stress}{Factor\ of\ safety}$$
$$Minimum\ Working\ stress = \frac{1097}{1.5}$$
$$Minimum\ Working\ stress = 731.33\ N/mm2$$

So as per the above analytical calculations we got maximum working stress of 821.45 N/mm^2 and minimum working stress of 731.33 N/mm^2. Now by using that working stress values we calculate the working load the chain link plate can carry by using the following formulae.

Outer link plate:

Maximum working load for outer chain link plate-

$$Maximum\ Working\ stress = \frac{Working\ Load}{Resisting\ Area}$$
$$821.45 = \frac{Maximum\ working\ load}{2\ (17.285\ \times 9.5)}$$
$$Maximum\ Working\ Load = 821.45 \times 328.415$$
$$Maximum\ Working\ Load = 269775\ N$$

Minimum working load for outer chain link plate-

$$Working\ stress = \frac{Minimum\ Working\ Load}{Resisting\ Area}$$
$$731.33 = \frac{Minimum\ working\ load}{2\ (9.5 \times 17.285)}$$
$$Minimum\ Working\ Load = 731.33 \times 328.415$$
$$Minimum\ Working\ Load = 240336.98\ N$$

From above calculation we got the working load range i.e. varies from 2,69,775 N to 2,40,336.98 N for chain outer link plate.

III. FINITE ELEMENT ANALYSIS

The name finite element is of recent origin, though the concept has been used for centuries. A model is divided into a mesh; two adjacent regions placed side by side will have a common edge. Once the discretization is made, the analysis follows a rather set procedure. The problem to be solved by the finite element method is done in two stages

1. The element formulation
2. The system formulation

The first stage involves the derivation of this element stiffness matrix. The next stage is the formulation of stiffness and load of the entire structure.

Steps in Finite Element Analysis:

i. FEA Pre-processor:

The pre-processor stage in the general FEA package involves the following:

a. Creating the model
b. Defining the element type
c. Applying a mesh
d. Assigning material properties
e. Apply loads
f. Applying boundary conditions

ii. Solution

The Finite Element solver can be logically divided into three mains parts, the pre-solver, the mathematical engine & the post solver. The pre-solver reads the model created by the pre-processor & formulates the mathematical representation of the problem. All parameters defined in the pre-processing stage are used to do this, so if something is left out, pre-solver will complain to form the element stiffness matrix for the problem & calls the mathematical engine which calculates the results (displacement, temperature & pressure etc.). The results are returned to the solver & the post-solver is used to calculate strains, stresses, heat fluxes, velocities etc. for each node within the component or continuum. All these results are sent to a result file which may be the post-processor.

iii. Post-processor

Here the results are read & interpreted. They can be presented in the form of table, a contour plot, deformed shape of the component or the mode shapes & frequencies if frequency analysis is involved. Most post-processors provide an animation service, which produces an animation. Slices can be made through 3-D models to facilitate the viewing of internal stress patterns.

Material properties for Link plate:

Table 1. Material properties for Link plate

Parameter	Descriptions
Material	EN19
Young's Modulus E	2.05×10^5 N/mm^2
Density ρ	$8.00 \mathrm{X} 10^{-9}$ Tons/mm^3
Poisson's ration	0.3
Tensile Strength	1231 N/mm^2

Table 2. Chemical Composition of EN-19

Properties	Limit	Value
Carbon	0.35-0.45	0.43
Manganese	0.50-0.80	0.63
Silicon	0.10-0.35	0.33
Phosphorus	0.050 Max.	0.025
Sulphur	0.050 Max.	0.036
Chromium	0.19-1.50	1.03
Molybdenum	0.20-0.40	0.23

Table 3. Micro Test Result of EN-19

Parameter	Descriptions
Material	EN-19
Hardness	35-40 HRC
Observation	Fine Tempered Martensitic Structure

Shape Optimization by topological approach

Topology optimization starts with an initial design (the original design area), which also contains any prescribed conditions (such as boundary conditions and loads). ANSYS can apply the following objectives to a topology optimization process:

- Strain energy (a measure of structural stiffness)
- Eigen frequencies

- Internal and reaction forces
- Weight and volume
- Center of gravity
- Moment of inertia

The same variables can be applied as constraints to a topology optimization process.Shape optimization use an algorithm that is similar to the algorithm used by condition-based topology optimization. It is recommended to use shape optimization at the end of the design process when the general layout of a component is fixed, and only minor changes are allowed by repositioning surface nodes in selected regions. An objective of a shape optimization is to minimize stress concentrations using the results of a stress analysis. Shape optimization tries to position the surface nodes of the selected region until the stress across the region is constant (stress homogenization).

Shape Optimization for Outer Link Plate

The chain link plate is first modeled in CATIA V-5 as shown in fig 1 and then exported to ANSYS where it is further meshed, constrained and loaded and simulated.

The major dimensions of standard roller chains are approximately proportional to the chain pitch. These proportions were derived from detailed engineering studies and much experience. These proportions give an excellent balance of properties needed for a roller chain to perform well in a wide variety of applications. The approximate proportions of standard roller chains, conforming to ASME B29.1, are listed below.

- Roller width ≈ 5/8 of the pitch.
- Chain (roller) width ≈5/8 of the pitch.
- Pin diameter ≈ 5/16 of the pitch.
- Link plate thickness ≈ 1/8 of the pitch.
- Maximum roller link plate height ≈ 0.95 × pitch.
- Maximum pin link plate height ≈ 0.82 × pitch.

Within the 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 work ANSYS Workbench is used to find the optimum shape of the link plate. As per ASME Standard baseline design model is considered as a Concept-1.

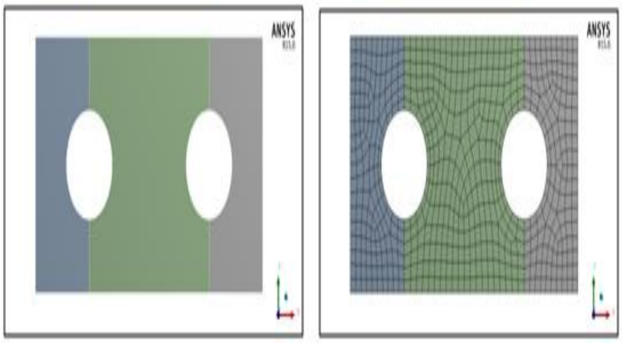

Fig 1. Geometry and Mesh model of Concept-1

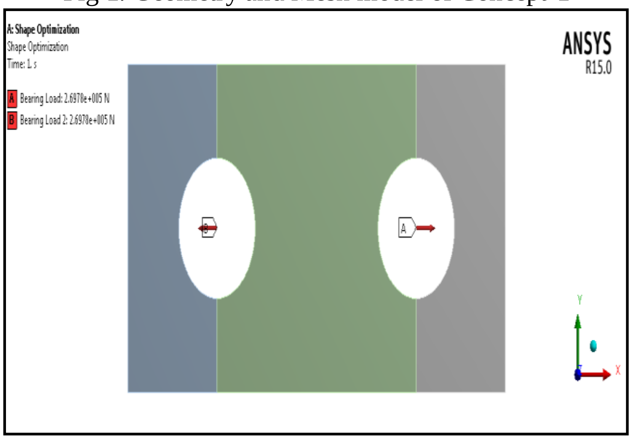

Fig 2. Boundary Conditions on Concept-1

Above Fig. 1 shows the Geometry and Mesh model of Concept-1. And Fig. 2 shows the Concept-1 with applied boundary conditions on that.

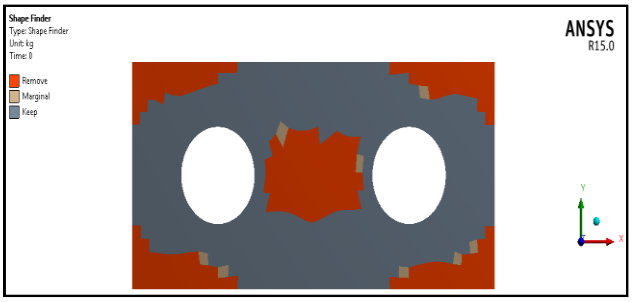

Fig 3. Shape Finder plot Concept-1

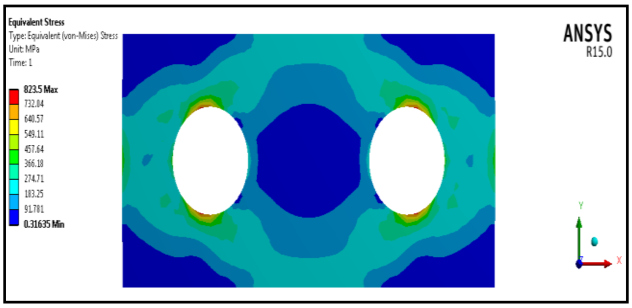

Fig 4. Von Misses Stress plot of Concept-1

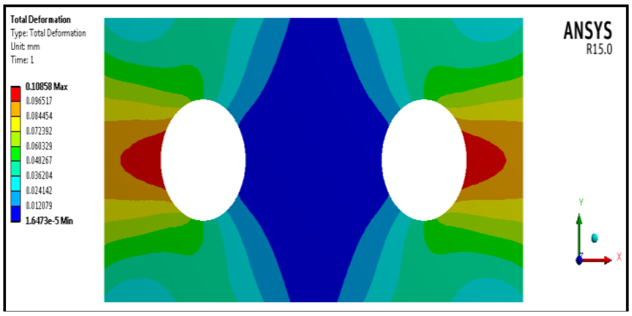

Fig 5. Displacement plot of Concept-1

Fig. 5 shows Displacement plot of Concept-1 after running the static analysis in shape optimization module in ANSYS Work Bench. From Von Misses Stress plot as shown in Fig. 4 and Shape Finder plot as shown in Fig. 3, the next iteration of out model comes. Corners of the plates are removed from link plate referring the contours of the low stress regions and shape finder plots.

As link is kinematic mechanism which must be closed and should only contain slots where coupler curve is required. Link plate used is meant to be used for load transmitter it needs to be rigid and needs additional rigidity at its peak load at which high stress concentration near hole vicinity may occur.

Thus, after seven iterations ANSYS solver gives an optimum shape as shown below.

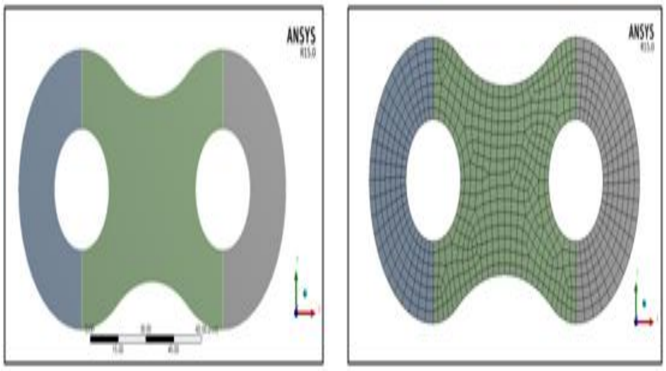

Fig 6. Geometry and Mesh model of Concept-7

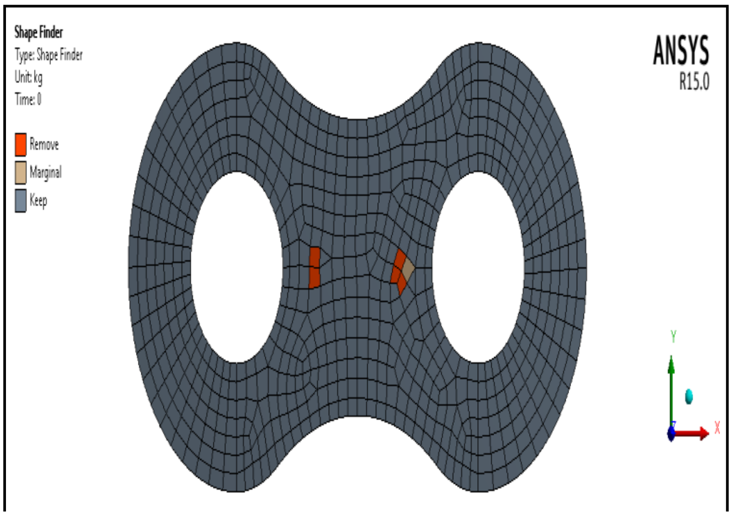

Fig 7. Shape Finder plot Concept-7

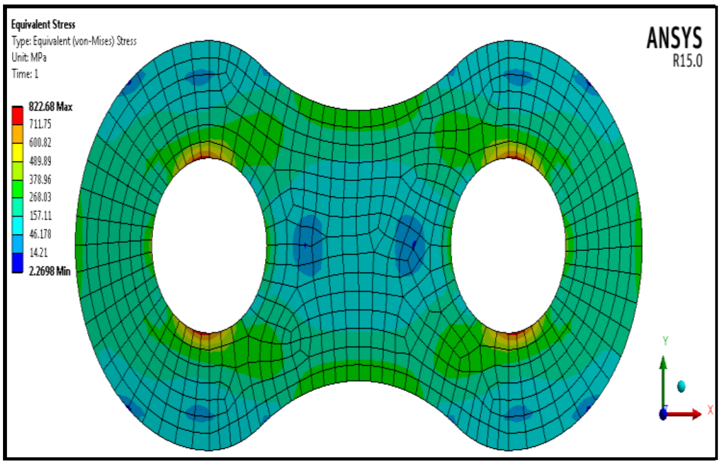

Fig 8. Von Misses stress plot of Concept-7

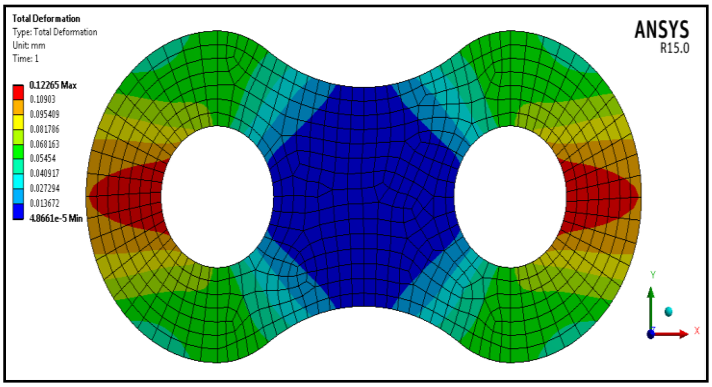

Fig 9. Displacement plot of Concept-7

IV. EXPERIMENTATION

Experimental testing of chain link plates is carried out to study the effect of material and heat treatment uncertainty on stress-strain plot. The Experimental test setup for this experiment is shown in Fig. 10 for this testing we are using a Universal Testing Machine of 100 Tons capacity.The fixtures are made of EN-24 material, hardened and tempered. A typical slot is made for insertion of link plate suitable for its thickness.

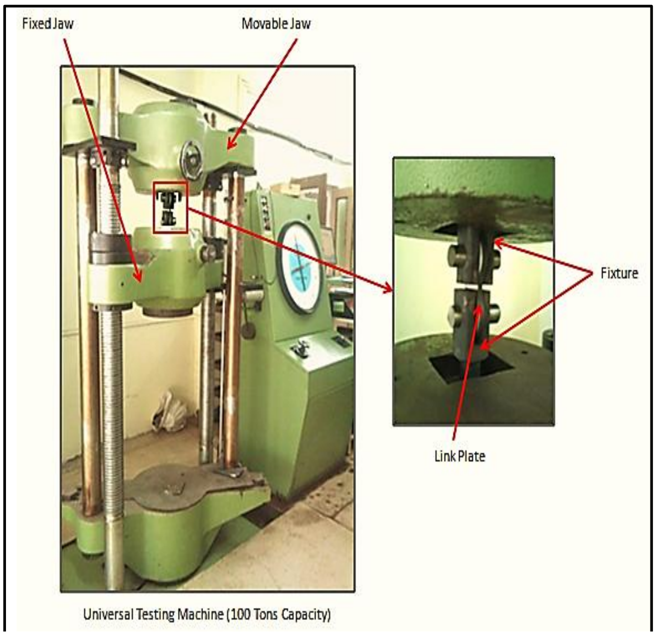

Fig 10. Testing of Chain Outer Link Plate on UTM

As shown in above Fig. 10 the outer link plate is clamped on the Universal Testing Machine with the help of two fixtures. By checking all the connections the test is started by gradually opening the valve to give hydraulic pressure. In this way chain outer link plate is tested and the Force- Displacement plot for plate is drawn.

It gives accurate values of breaking load of the link plate. The outer link plate breaks at 26.53 Tons. Outer link plate breaks same location near to hole where cross section area is minimum.

Experimental testing of chain link plate of EN-19 material has been performed on Universal Testing Machine. The dimension of optimized Outer link plate was 68.30 mm x 76.20 mm (Pitch) x 9.5 mm and middle height is 45 mm.

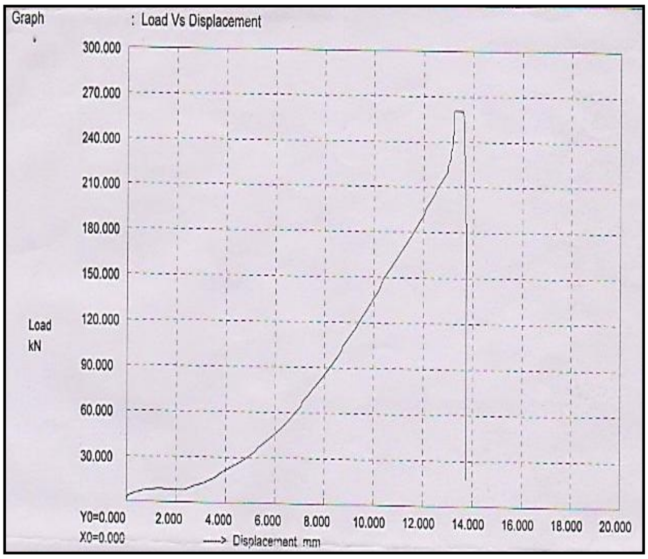

Fig 11. The graph of displacement v/s load for Outer Link Plate

The above Fig. 11 shows the graph of displacement v/s load for an outer link plate. Displacement is taken on X-axis and load in kN is taken on Y-axis. The max load of 265.30 kN is taken by the chain link plate and then it fails near hole.Maximum tensile strength of 821.45 N/mm2 was gained by the chain link plate.

V. RESULTS AND DISCUSSIONS

Theoretical calculations, finite element analysis and experimental test have been carried out on outer link plate. Following table gives the comparison of results for theoretical, numerical (Finite Element Analysis) and Experimental test for outer link plate.

Table 4: Results of Chain link plate

Sr. No.	Force (N)	Disp. (mm)	Von Misses Stress (N/mm^2)	Theoretical Stress (N/mm^2)	Experimental Breaking Load (N)
01 Outer	2,69,775	0.1226	822.68	821.45	2,65,300

The above Table 4 shows theoretical stress value for an outer link plate is 821.45 $N/mm^2$and as per numerical it is 822.68 N/mm^2. As theoretical stress value is less than allowable limit, so the chain link plate design is safe.

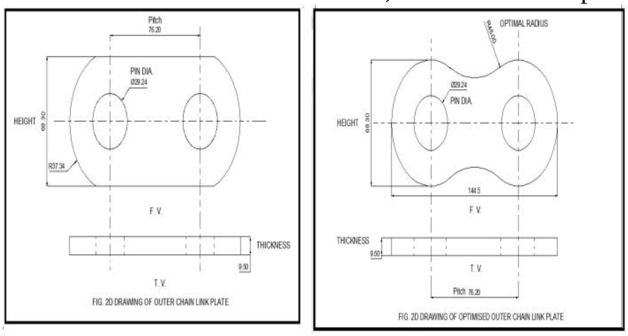

Fig12.Roller chain link plate before of link plate before optimization and after optimization

Weight optimization Results of link plates-

Based on the Theoretical, FEA and Experimental results, it is clearly shows that the optimal value of radius is 45 mm; thickness is 9.5 mmand height of the link plate 63.8 mm. Though this optimization seems insignificant on its own, it must be noted that in a typical industrial application, thousands of such links will be needed. The weight saving thus achieved (Typical chain link plate is 504 gm and optimized chain link plate is 432 gm) 72 gm per link plate.

VI. CONCLUSIONS

It is concluded from the survey of Sugar Industry, major failure modes are within roller chain link plate. Following conclusions have been drawn from the theoretical, numerical and experimental work.

As theoretical stress value is less than allowable limit, so the chain link plate design is safe. At the same time, we are succeeded in minimizing the weight of a link plate by 72 grams i.e. from 504gm to 432 gm. This is the great achievement in weight optimization.

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