NOVATEUR PUBLICATIONS
INTERNATIONAL JOURNAL OF INNOVATIONS IN ENGINEERING RESEARCH AND TECHNOLOGY [IJIERT]
ISSN: 2394-3696
VOLUME 3, ISSUE 8, Aug.-2016

DESIGN AND WEIGHT OPTIMIZATION OF GRAVITY ROLLER CONVEYOR

MR. SUNIL KRISHNA NALGESHI
M.E Scholar, Department of Mechanical Engineering/
VVPIET, Solapur University/Maharashtra, India

ABSTRACT

This paper is about design and analysis of gravity roller conveyor for weight optimization without hampering its structural strength. Gravity roller conveyor or non-powered roller conveyor are the most economical and common method of conveying unit loads. The conveyor is typically mounted on a slight decline angle, therefore using gravity with initial manual push to assist product movement, especially for long distances. Gravity roller conveyor consists of components like roller, shaft, bearings, c-channel for chassis and supports.

In this work each component is designed analytically and total weight of conveyor is determined by adding weight of various components of gravity roller conveyor. The study found great scope in weight reduction in roller component due to its higher factor of safety. Therefore to optimize the weight of conveyor, the material of roller is changed from mild steel to polycarbonate material. The total weight of gravity roller conveyor for mild steel roller is 196.03kg and after changing the material of roller to polycarbonate, the weight gets reduced to 100.61kg. Therefore there is a 95.42 kg weight reduction in the total weight of conveyor. The validation of the design of gravity roller conveyor for mild steel roller and polycarbonate roller is carried out by ANSYS APDL. This conveyor is used for handling pallets, drums and containers containing load weighing 280-350 kg.

KEYWORDS – Factor of safety, Structural strength, Material.

INTRODUCTION

Gravity roller conveyor is a powerful material handling tool. It offers the opportunity to boost productivity, reduce product handling and damage, and minimize labour content in a manufacturing or distribution facility. Conveyor is generally classified as unit load conveyor that is designed to handle specific uniform units such as cartons or pallets, and process conveyor that is designed to handle loose product such as sand, gravel, coffee, cookies, etc. which are fed to machinery for further operations or mixing. It is quite common for manufacturing plants to combine both process and unit load conveyors in its operations.

Many factors are important in the accurate selection of a conveyor system. It is important to know how the conveyor system will be used beforehand. Some individual areas that are helpful to consider are the required conveyor operations, such as transportation, accumulation and sorting, the material sizes, weights and shapes and where the loading and pickup points need to be.

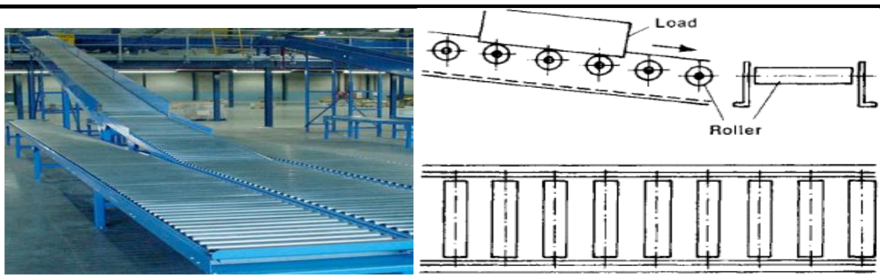

Fig. 1. Gravity roller conveyor system.

Gravity roller conveyor is not subjected to complex state of loading; still it is found that it is designed with higher factor of safety. If the critical parts of the conveyor (roller, channels) are redesigned then it is possible to minimize the overall weight of the assembly. The gravity roller conveyor assembly normally involves the use of channels, rollers and /bars that are heavy by virtue of their structure and the material used (steel).The amount of material needed (kg) is directly dependent on the thickness of the channel or pipe to be used as roller. While evaluating the design, there appears to be a scope for weight reduction of the entire assembly (through weight optimization.

PROBLEM IDENTIFICATION

It is found that gravity roller conveyor is designed with higher factor of safety, though it is not subjected to complex state of loading. Hence there is a scope for weight reduction.

OBJECTIVES OF STUDY

1. Study of the gravity roller conveyor and its design
2. Geometric modeling of gravity roller conveyor by using CATIA V5.
3. To generate FEA model using ANSYS APDL
4. To carry out static analysis of gravity roller conveyor.
5. Modification of critical conveyor parts for weight optimization.
6. To carry out analysis of optimized design for same loading condition.
7. Comparing the results of both designs

STUDY OF THE GRAVITY ROLLER CONVEYOR AND ITS DESIGN

Gravity roller conveyor has to convey 280-350 kg load, 762 mm above ground and inclined at 2- 4 degree.
Components of gravity roller conveyor are as shown below:

Sr. No.	Component	Material	Qty.
1	C-Channels for Chassis	ISMC 100	2
2	Rollers	Mild Steel	15
3	Bearing	Std.	30
4	C-Channels for Support	ISMC 75	4
5	Shaft	Mild Steel	15

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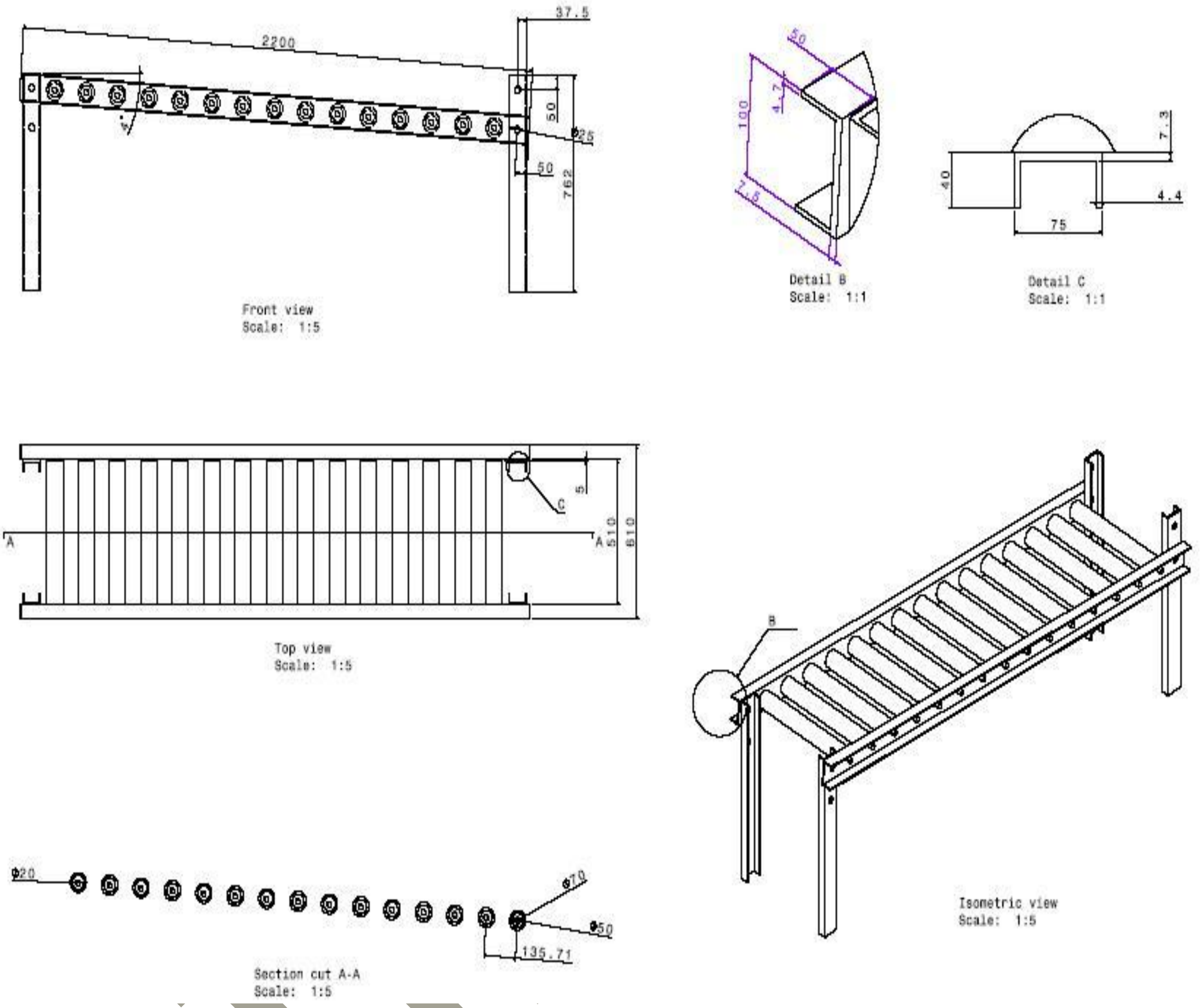


Fig. 2. Details of gravity roller conveyor

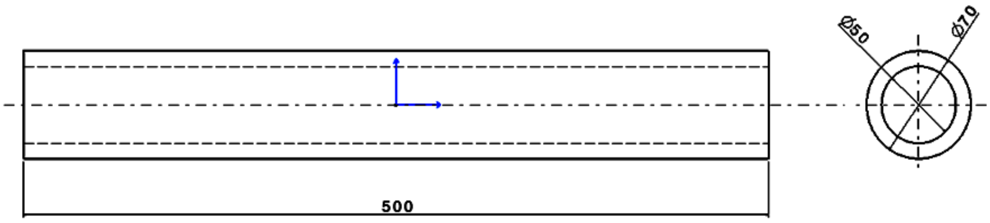
A. TOTAL WEIGHT OF GRAVITY ROLLER CONVEYOR (MILD STEEL ROLLER)

Sr. No.	Name of Component	Weight (Kg)
1	C- Channel for Chassis	40.30
2	Rollers(Mild steel)	110.97
3	Shafts	20.7156
4	Bearing	4.11
5	C- Channel for Supports	19.932
	Total Weight of assembly	196.03

As the load will act directly on the roller, there will be chances of failure of roller due to bending stress induced in it. Therefore only roller is taken into account for design.

B. DESIGN OF MILD STEEL ROLLER

Analytical method for static case:



A) PROPERTIES OF ROLLER

Material – M.S., Young's modulus of elasticity (E) = 2.10x10^5 MPa, Density (ρ) =7850 Kg/m^3, Yield stress = 260 MPa
D1=outer diameter of roller=70mm=0.07m, D2=inner diameter of roller=50mm=0.05m, W=width of roller=500mm=0.5m, y = distance of outer fiber from neutral axis =35mm =0.035m

B) MAXIMUM STRESS CALCULATION FOR GIVEN CONDITION

Consider an uniform distributed load acting on roller and assume f.s=1.5
Allowable stress = yield stress/ f.s = 260/1.5 = 173.33 MPa
Number of rollers upon which the resting surface of pallet or drum or container is placed Are four. This pallet or drum or container contains 350 kg load.

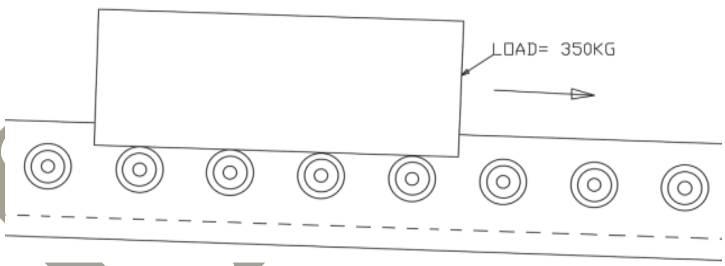
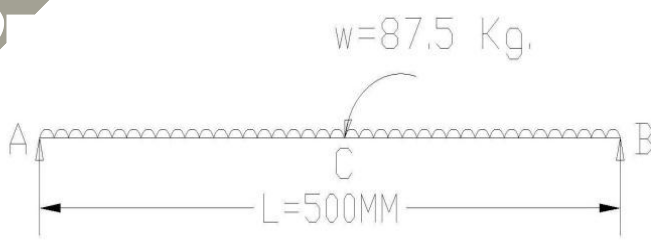


Fig 3. Gravity roller conveyor carrying load

Now, load acting on each roller at a time is
P = 350/4 = 87.5 kg.
Considering udl,



Maximum bending Moment (M_{max}) = W x L^2 / 8
= (87.5 x 9.81 x $.5^2$) / 8
M_{max} = 26.8242 N-m

Moment of inertia (I) = $\pi/64 \times (D_1^4 - D_2^{4)}$

$= \pi/64 \times (0.07^4 - 0.05^4)$

$= 8.7179 \times 10^{-7}\ m^4$

Maximum bending stress (σ_b) = (M_{max} x Y) / I

$= (26.8242 \times 0.035) / (8.7179 \times 10^{-7)}$

$\sigma_b = 1.077$ MPa

As maximum bending stress << allowable stress, the roller is safe for given loading condition.

C) CHECKING FACTOR OF SAFETY FOR DESIGN.

f.s = σ_{all} / σ_b

= 173.33/1.077

f.s = 160.9

As calculated f.s is greater than assumed f.s, selected material can be considered as safe. As f.s is very high in this component, there is a scope to reduce weight in this component.

D) MAXIMUM DEFLECTION

(y_{max}) = 5 x W x L^3 / 384EI

$= (5 \times 87.5 \times 9.81 \times .5^3) / (384 \times 2.10 \times 10^{11} \times 8.7179 \times 10^{-7})$

$y_{max} = 0.00763$ mm.

As compared to length 500 mm, deflection of 0.00763 mm is very negligible.
Hence, selected roller can be considered as safe.

C. FINITE ELEMENT METHOD

The FEA is a numerical procedure for analyzing structures of complicated shapes, which otherwise would be difficult by analytical method. Analytical solution is a mathematical expression that gives values of desired unknown quantity at any location in a body or a structure and it is valid for an infinite number of locations in body or structure. But analytical solution can be obtained only for simple engineering problems. It is extremely difficult and many a times impossible to obtain exact analytical mathematical solution for complex engineering problems. In such cases FEM is used which gives approximate solution.

Static analysis of gravity roller conveyer (mild steel roller) by finite element analysis

Static analysis determines the displacements, stresses in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time. Here, it is assumed the load of 350 kg over four rollers at a time. Therefore the load over one roller will be 87.5kg; this is because of equal load distribution over each roller. So here static analysis of only one roller-shaft assembly is sufficient to be carried. Therefore modeling of only one roller-shaft assembly as shown in fig. below is sufficient for analysis

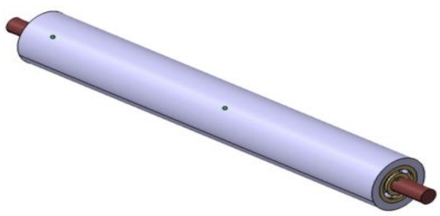


Fig.4. 3-D View of roller-shaft assembly

CAD MODEL:

CAD model resembling the actual roller-shaft assembly is modeled in CATIA and then exported as IGES. This IGES is imported in ANSYS APDL and used for further FEA analysis. Following figure shows the CAD model after importing in ANSYS

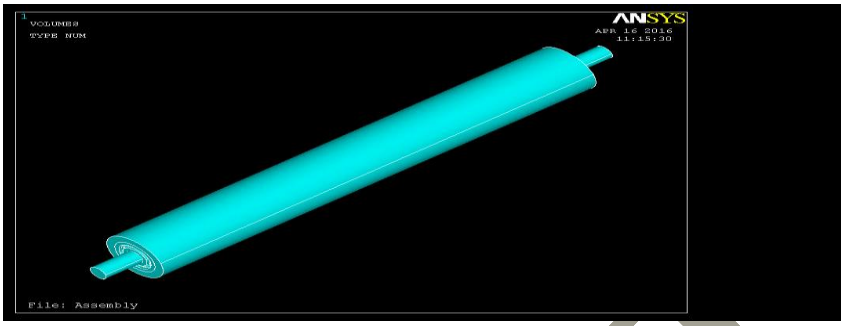


Fig 5. Model of roller-shaft assembly

MESH GENERATION:

After successful import of CAD model, elements were generated with Solid 187 element of ANSYS. Solid 187 is 3-D 10-Node Tetrahedral structural solid as shown in figure below.

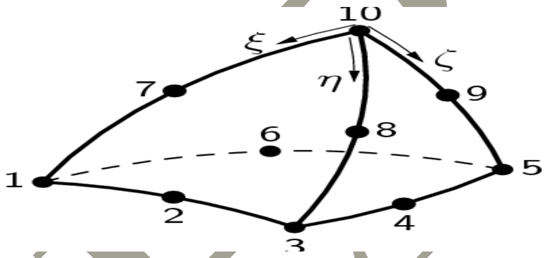


Fig.6 Tetrahedron structure

Solid 187 element is a higher order element. It has a quadratic displacement behavior and is well suited to modeling irregular meshes. The element is defined by 10 nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions.

Following figure shows meshing of roller-shaft assembly.

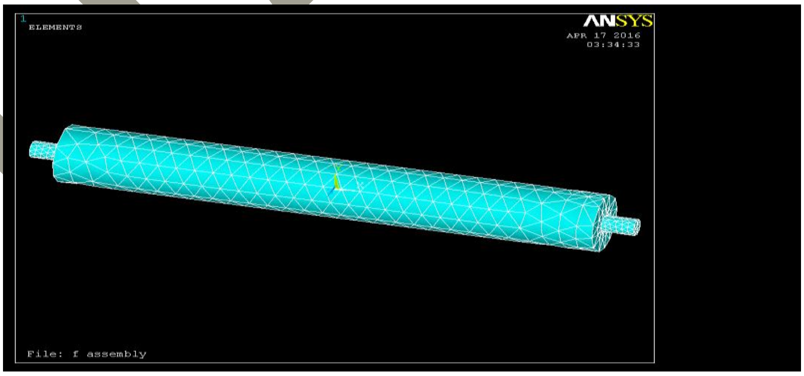


Fig 7.Meshing of roller-shaft model

MATERIAL PROPERTIES:

Material: Mild steel

Young's modulus of elasticity: 2.1×10^5 MPa

Poisson's ratio: 0.3

Density: 7850 Kg/m^3

Yield strength: 260MPa

LOADS AND BOUNDARY CONDITIONS:

Load of 87.5 kg (858.37 N) is applied on entire span of a roller. And boundary conditions were applied at the end of roller locations as shown in fig. below.

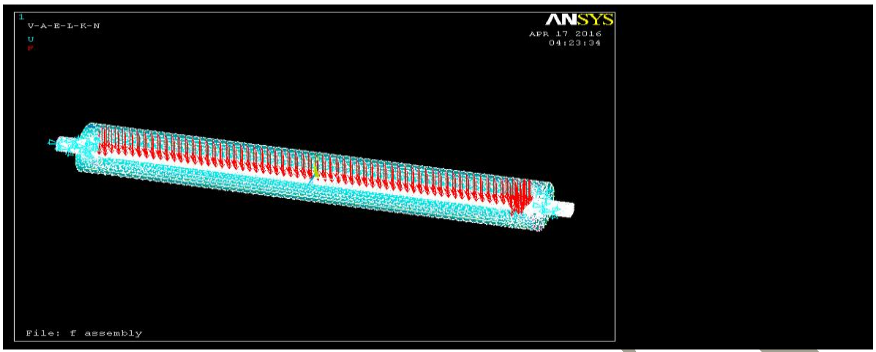


Fig 8. Load and boundary conditions

RESULTS

Induced stresses in roller-shaft assembly are as shown below:

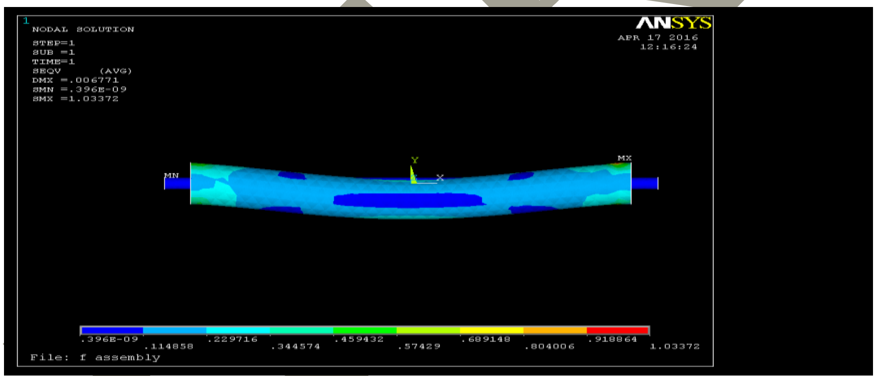


Fig 9. Stress plot

From figure it can be seen that 1.03372 MPa is maximum stress induced in the roller due to loads and boundary conditions.

Induced deflections in roller-shaft assembly are as shown below:

Fig.10 Deflection plot

From figure it can be seen that 0.006771 mm is maximum deflection induced in the roller due to loads and boundary conditions.

NEED OF OPTIMIZATION

As factor of safety of roller is very high there is a scope of weight reduction in this component. Therefore here mild steel roller is replaced by another low density material i.e. polycarbonate roller to reduce the overall weight of conveyor assembly. And then static analysis is carried out for polycarbonate roller

STUDY OF THE OPTIMIZED GRAVITY ROLLER CONVEYOR AND ITS DESIGN

A. TOTAL WEIGHT OF OPTIMIZED GRAVITY ROLLER CONVEYOR (POLYCARBONATE ROLLER)

Sr.No.	Name of Component	Weight (Kg)
1	C- Channel for Chassis	40.30
2	Rollers (Polycarbonate)	15.55
3	Shafts	20.7156
4	Bearing	4.11
5	C- Channel for Supports	19.932
	Total weight of assembly	100.61

B. DESIGN OF POLYCARBONATE ROLLER

Analytical method for static case

A) PROPERTIES OF ROLLER

Material – Polycarbonate, Young's modulus of elasticity (E) = 2.75 x10^3 MPa,
Density (ρ) =1100 Kg/m^3, yield strength=70 MPa
D1=outer diameter of roller =70mm=0.07m, D2=inner diameter of roller=50mm=0.05m,
W=width of roller=500mm=0.5m, y=distance of outer fiber from neutral axis=35mm=0.035m

B) MAXIMUM STRESS CALCULATION FOR GIVEN CONDITION

Allowable stress = yield strength / f.s = 70/1.5= 46.66 MPa
As stress is independent of material, maximum bending stress is same as mild steel roller
As maximum bending stress << allowable stress i.e.(1.077<<46.66), the roller is safe for given loading condition

C) CHECKING FACTOR OF SAFETY FOR DESIGN.

f.s = σ_{all} / σ_b
= 46.66 / 1.077
f.s = 43.32
As calculated f.s is greater than assumed f.s, selected material can be considered as safe.

D) MAXIMUM DEFLECTION

(y_{max}) = 5 x W x L^3 / 384EI

$= (5 \times 87.5 \times 9.81 \times .5^3) / (384 \times 2.75 \times 10^9 \times 8.7179 \times 10^{-7})$

$y_{max} = 0.58$ mm.

As compared to length 500 mm, deflection of 0.58 mm is very negligible.
Hence, selected roller can be considered as safe.

C. STATIC ANALYSIS OF OPTIMIZED GRAVITY ROLLER CONVEYOR (POLYCARBONATE ROLLER) BY FINITE ELEMENT ANALYSIS

CAD Model, Meshing, loads and boundary conditions are same except material properties that change are as given below.

MATERIAL PROPERTIES

Material: Polycarbonate
Young's modulus of elasticity: 2.75×10^3Mpa
Poisson's ratio: 0.38
Density: 1100 Kg/m^3
Yield strength: 70MPa

RESULTS:

Induced stresses in roller-shaft assembly are as shown below:

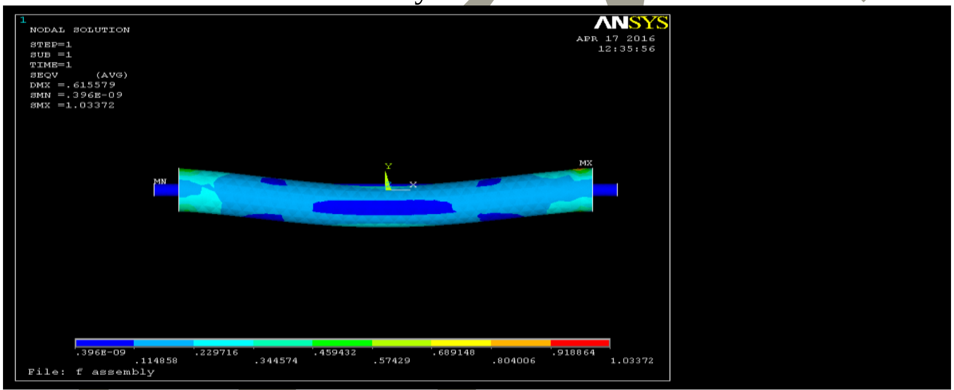


Fig 11. Stress plot

From figure it can be seen that 1.03372 MPa is maximum stress induced in the roller due to loads and boundary conditions.

Induced deflections in roller-shaft assembly are as shown below:

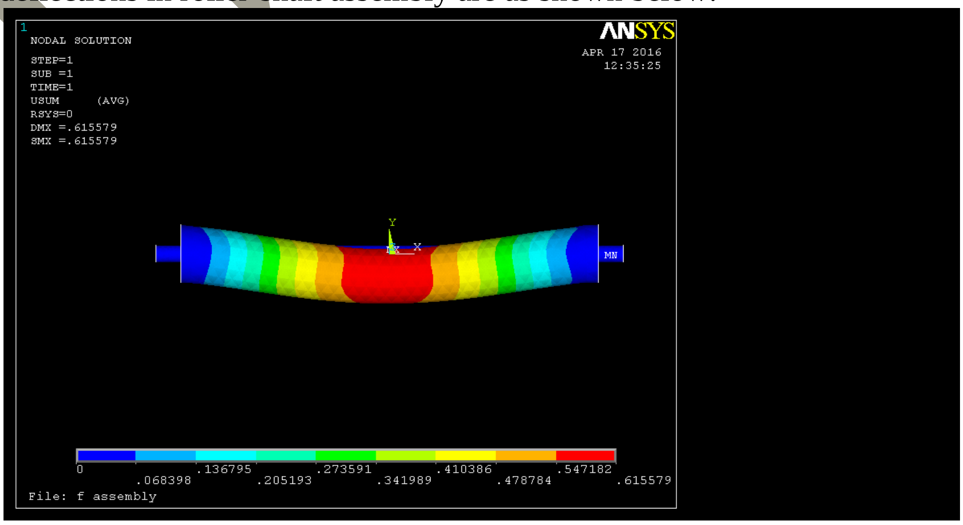


Fig.12 Deflection plot

Method	Before optimization		After optimization	
	Mild steel roller		Polycarbonate roller	
	Stress(MPa)	Deflection(mm)	Stress(MPa)	Deflection(mm)
Analytical	1.077	0.00763	1.077	0.58
FEA	1.033	0.00677	1.033	0.61
Error %	4.08	11.27	4.08	4.92

From figure it can be seen that 0.615579 mm is maximum deflection induced in the roller due to loads and boundary conditions.

Comparison between analytical and finite element analysis results

Sr. no.	Name of components	Weight (Kg) Before optimization	Weight (Kg) After optimization
01	Rollers	110.97 (Mild steel)	15.55 (Polycarbonate)
02	Shafts	20.7156	20.7156
03	Bearings	4.11	4.11
04	C-Channels for Chassis	40.30	40.30
05	C-Channels for Supports	19.932	19.932
06	Total weight of conveyor assembly	196.03	100.61

From above table, it can be seen that analytically calculated stress and deflection is in well agreement with ANSYS results for static case Total weight comparison

EFFECT OF OPTIMIZED DESIGN OF GRAVITY ROLLER CONVEYOR

From the above table of weight comparison, it can be seen that there is a great change in weight of optimized design as compared to before optimized design. (95.42 kg weight reduction for conveyor containing polycarbonate roller)

CONCLUSIONS

1) Design calculation of gravity roller conveyor shows the factor of safety is very high in roller component and therefore this is utilized as a scope for weight reduction in this component
2) Mild steel material is replaced by polycarbonate material for roller for weight optimization of gravity roller conveyor
3) Though value of deflection is more in case of optimized design, it is within allowable limit and maximum stress induced is also within allowable limit. Therefore the design of the optimized conveyor is safe
4) There is 95.42 kg of weight reduction due to use of polycarbonate roller in gravity roller conveyor
5) The gravity roller conveyor is designed on the basis of static loading. The stresses induced in the roller and deflections are validated by FEA using ANSYS software for static case.

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