Von misses Stress Analysis of Mine Hoisting Equipment of CS Gear

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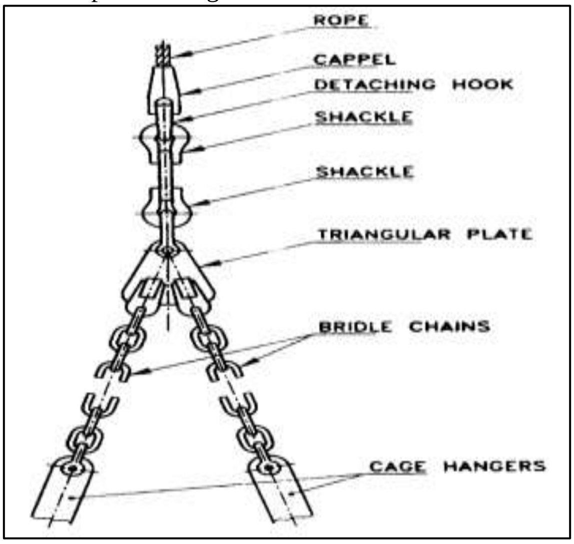
Abstract — Haulage rope Capple and triangular plate is commonly used as a coupling device, in various applications such as mining etc. Haulage rope Capple are used for connecting winding rope to interlink cage or skip to the mine cage suspension gear (CSG) through links/ropes for transportation of materials, man, and machineries. and This paper deals with the cracks developed and deformation of components under different static load conditions found during quality assessment followed by VON –Misses stress analysis. All the HRC nad triangular plate of different materials are observed under same load and von miss's analysis is done. When different materials under same load analyzed in software, they showed different curves which are very helpful in analyzing and predicting the strength and life of the component. This paper also deals with the health monitoring of the HRC.

Keywords: HRC; DGMS Circular; CSG; Crack Size; Triangular Plate, Von-Misses Stress, FEA Analysis, Mine Transportation

I. Introduction

GENERAL-Mine cage suspension gear (CSG) is an arrangement of mine hoisting system between cage and winding rope which is used to raising and lowering of conveyances safely within the mine shaft. CSG is used for suspension of cage/ skip for winding in underground mines. It has different components which are safety hook rope cappel, safety hook, distribution plate, bridle chase box and/ or chains and link plates as shown in Figure 1. There are two types of assembly of cage suspension gear (CSG): Single point and Bridle chain type. In bridle chain type CSG different types of shackles are used to connect different parts, where cage shackle is used to connect cage/skip with distribution plate through chain.



For safety purposes in mining operations, it is mandatory to maintain FOS 10 for CSG components in mining .The CSG components must be subjected for quality assessment before putting in service.. Basically two types of defects are found in the material which are: subsurface or surface internal flaws and imperfection. There are many NDT methods to assess the quality of material. CSIR has adopted magnetic particle crack detection for surface/subsurface imperfection, whereas, ultrasonic flaw detection for internal flaws. Maximum number of CSG materials were rejected in magnetic particle crack detection, due to subsurface or surface imperfection, cracks formed due to faults in manufacturing. To reduce the rate of rejection of material of surface imperfections are allowed. These acceptance /rejection norms are defined in national/international norms, which are NCB norms, DGMS Cir. Tech. 1/2001.and IS 7587 part 1:2004.

Among CSG components, haulage rope cappel is the most critical component. It is also found that haulage rope cappel are more prone to surface and subsurface imperfections and many number of haulage rope cappel are rejected after magnetic particle test. Figure 1.3 shows a systematic diagram of critical zones of haulage rope cappel. There are two zones in haulage rope cappel which are considered to be critical that are upper one and bottom part. Haulage rope cappel also divides in two regions: shaded and unshaded. The stress concentration value is variable and depends upon the configuration and geometry of HRC. The stress concentration factor is maximum in the shaded region, therefore their permissible limit for the lengths of the cracks are not same throughout. The flaws can be either longitudinal or transverse or longitudinal. Maintaining the Integrity of the Specifications

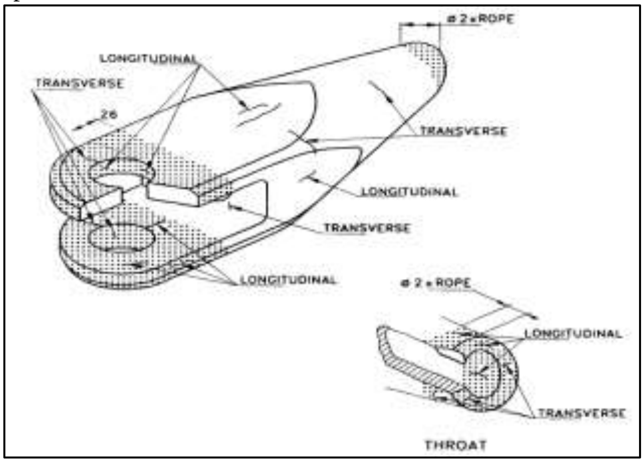


Table 1.1 shows the permissible limit of total cracks length, both longitudinal as well as transverse for a haulage rope Capple as per different Norms (NCB norms DGMS Cir. Tech. 1/2001.and IS 7587 part 1:2004. It is observed that it is necessary to abate the rate of rejection of haulage rope Cappel by increasing the permissible limit of cracks in the haulage rope Cappel. This paper will draw attention towards lessening rejection of not only haulage rope Cappel, but also other CSG components by modifying the

acceptance/rejection norms and analyzing the effects of different deformations developed due to change in load.

Part	Types of Imperfections Shaded area	Permissible deformation
Throat and surfaces	Transverse	. None
	Longitudinal	None>10mm
edges and holes	Transverse	None
	Longitudinal Unshaded	None>16mm
edges and body	Transverse	None
	Longitudinal	None>32mm

Table 1.1 Permissible Imperfections of Haulage rope Capel

II. Objectives

The main objective of this project is to learn and estimate different types of cracks generated at different static load. By doing these tests we may get idea about the rate of deformation at different loads and estimate the rejection rate.

Another main objective is to see the stress developed for the components due to deformation of the components from its original geometry under different static load- FEA approach.

The following objectives are given below: -

1) Important of Visual inspection
2) Use of Ultrasonic testing
3) Characteristics of magnetic particle testing
4) Stress developed under different static loads- FEA.
5) Deformation of material under different static load FEA

1) Purpose of material testing

Materials are tested for the following reasons:

- To formulate the mechanical and thermal properties of the materials numerically assess numerically.
- To determine the best material for different applications.
- To estimate force deformation or stress value to draw upsets of specifications upon which the engineer can base the design.

2) Classification of Tests

Test on material may be classified as:

- Proof load test,
- Destructive test and
- Non-Destructive test
  - In proof load test, the material is subjected to three times of safe working load.
  - In destructive test, the components or specimens are subjected to break load test.
  - In non-destructive tests, the components do not break even after being tested, it can be used for the purpose for which it can be made.

A. Material testing Facilities.

The following facilities are available related to material testing.

Proof load test/Break load test in Material Testing Section:

- 750 kg universal testing machine
- 5 Tones universal tensile testing machine
- 10 Tones computerized tensile testing machine.
- 10 Tones universal tensile testing machine
- 50 Tones universal tensile testing machine
- 60 Tones horizontal tensile testing machine
- 500 Tones horizontal tensile testing machine
- Reserve bend testing machine for wire (dia 5 to 4mm)
- Torsion testing machine (dia 5 to 4mm)
- Wrap testing machine.
- Rope cutting machine.
- Human dummy (100+5kg)

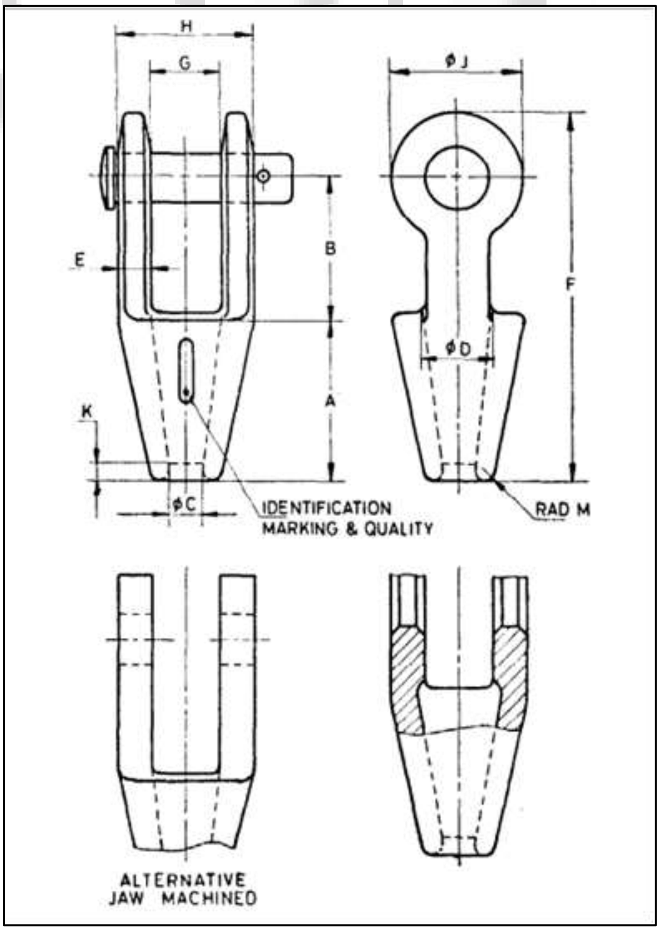
B. Designing Of Haulage Rope Cappel-

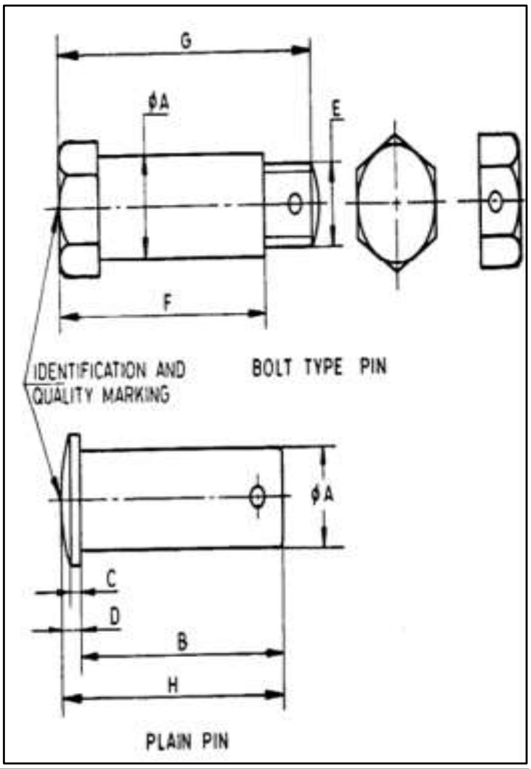
Under provision of Reg. 89(1) (c) of CMR 1957 and Reg. 97(1) (c) of MMR 1961, attachment of the following description between haulage rope and a tub or set or train of tubs or any means of conveyance is hereby approved by this general order. Existing types of attachment not in conformity with the following and not specially approved separately should be replaced as early as possible as but not later than 31.12.1977.

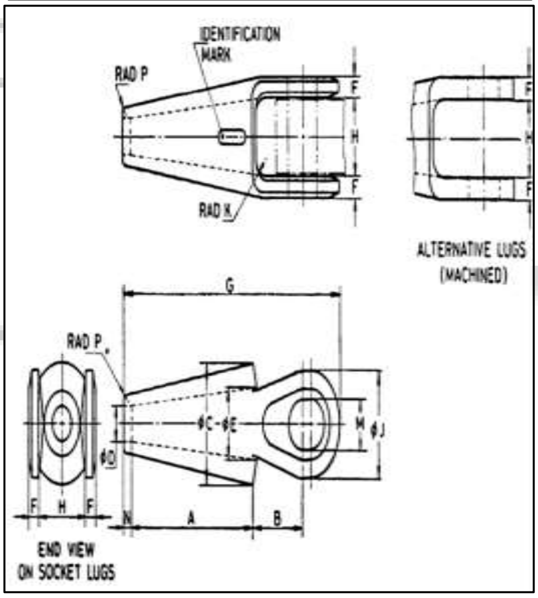
As per DGMS guidelines we have designed the mine hoisting Component Design and also making 3-D modelling & simulation.

In Different mines have different operating condition for operation. but all have maintained standard design as per DGMS Rule & regulation. As per Mines thickness its component design.

According to the standard of design for mine transportation we have taking average one. For Different Model of cage Suspension gear have different dimension & technical specification. It depends on the load capacity & structure of mine.

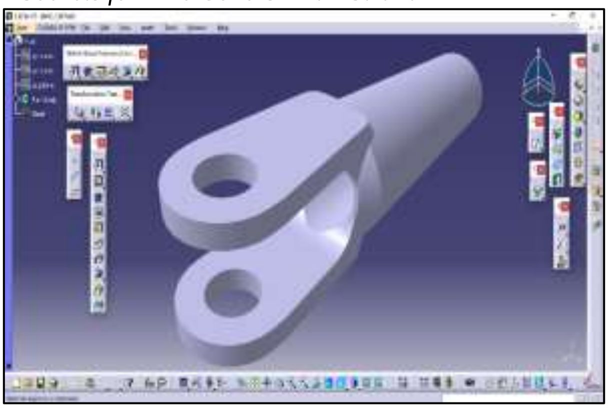




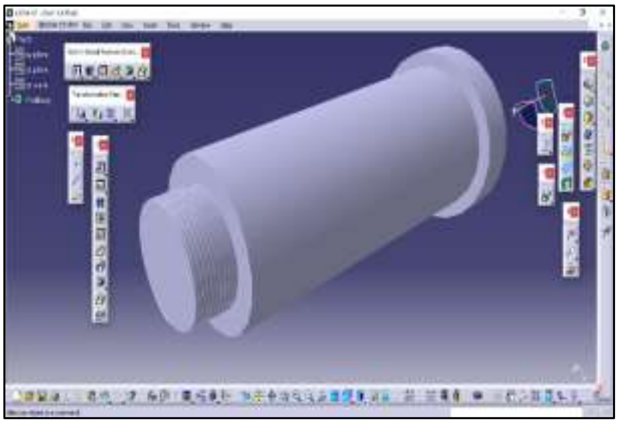


C. Parts of Haulage Rope CAPPLE

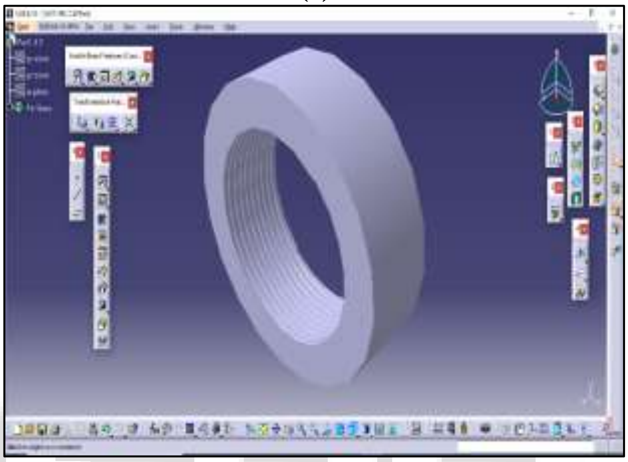
1) Sockets for Zinc Cone & Trail Strand



(a)

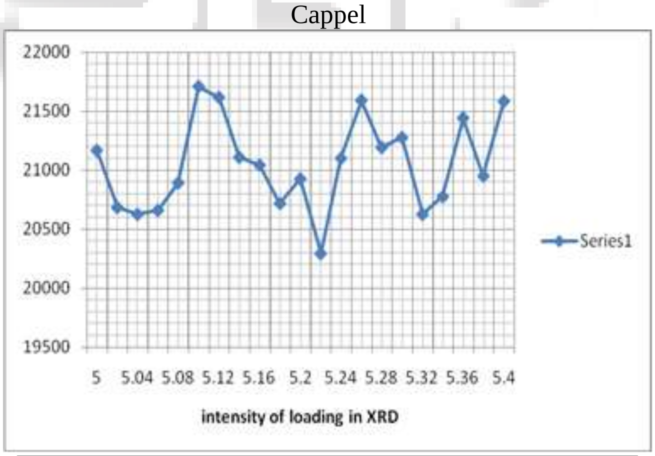


(b)



(c)

Fig. 3.1: (a),(b),(c): CAD File of Nut of Haulage Rope Cappel



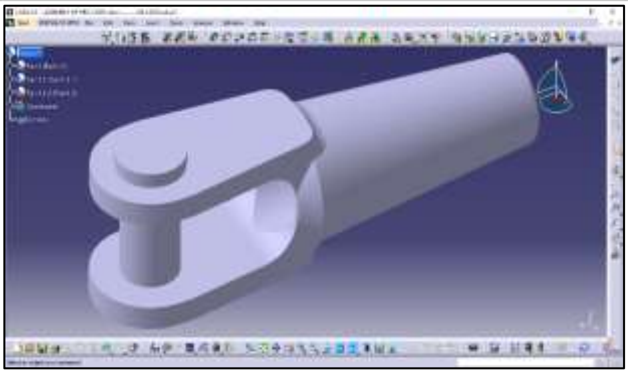


Fig. 3.2 CAD File of Assembled Body of Haulage Rope Cappel

III. FINITE ELEMENT ANALYSIS

Artificially generated deformation on haulage rope cappel was performed for finite element analysis in CAD environment. The solid model of haulage rope cappel is generated in CATIA Part Design Workbench as per discussed in earlier chapter. Then the solid model was imported in Analysis & Simulation Workbench. Mechanical properties of material for further analysis are listed in table 3.1.

Materials(specified)	Steel
Young's Modulus (σ)	2.048e+012N_m2
Poisson's Ratio,(μ)	.3
Density(ρ)	7860kg_m3
Coefficient of Thermal Expansion	1.27e-015_Kdeg
(Yield Strength)	4.42e+008N_m2

IV. LITERATURE REVIEWS

Xiang-dong Chang et.al in the year 2018, in this paper "Breaking failure analysis and finite element simulation of wear-out winding hoist wire rope"[2]. They have worked on to study about hoist ropes with different wear scars which is examine be breaking tensile test to show the failure characteristics. They have used the finite element method for the purpose to simulate the various mechanical properties for the wear out strands subjected to tensile load.

Debashish Ghosh et.al in the year 2015 presented a paper "Failure Investigation of a Cage Suspension Gear Chain used in Coal Mines"[3]. They studied about assessment the expected causes of in-service failure of CSG chain used for the purpose of mining. In this paper they have also evaluated the stress generated along the chain periphery and detailed analysis of stress. Finally, it has been seen that because of improper welding parameters or procedure presence of serious welding defects caused the failure of the end links of the investigated chain link.

Mayank Verma et.al in the year 2014 made this paper "Simulation of crack propagation of shackle used in suspension gear"[4]. This paper deals with the crack propagation of preoccupied cracks under different static load conditions found during quality assessment followed by FEA.

V. THEORY VON MISES STRESS: –

It is very important quantity of design of ductile material, it can seen in presence failure theory, classically plasticity, fatigue model or failure criteria of material etc.

$$\begin{bmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{bmatrix}$$

σ = σ hydrostatic + σ deviatric.

or

$$\begin{bmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{bmatrix} = \begin{bmatrix} \sigma_{11} & 0 & 0 \\ 0 & \sigma_{22} & 0 \\ 0 & 0 & \sigma_{33} \end{bmatrix} + \begin{bmatrix} \sigma_{11}-\sigma m & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22}-\sigma m & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33}-\sigma m \end{bmatrix}$$

Or $\sigma m = \dfrac{\sigma_{11}+\sigma_{22}+\sigma_{33}}{z}$

U= ∪ volumetric + ∪ disteration

Stress in variation -> value does not vary with the choice of the co-ordinate system.

For specimen test of tensile testing, which is used to test fatigue failure, stress-strain behaviour etc. Which is uni-axial test but reads world scenario there multi axises state of stress? In order to design decision, we have compared multi axis state of stress to experimental data which cannot be done.

$$\frac{(1+v)}{3E}\sigma vm^2 = \left(\frac{1+v}{3E}\right)_{1/2}$$

$$\sigma vm = \sqrt{1/2\{(\sigma_{11}-\sigma_{12})^2+(\sigma_{22}-\sigma_{33})^2+(\sigma_{31}-\sigma_{11})^2\}}$$

A. Von miss Yield Criteria

For initial yielding criteria Condition-It assumes that yielding can occur in a 3D state of stress, when root mean Square of the difference between principal stress reaches the same value which It has when yielding in the tensile test

Let y be the stress at which yielding is begins in simple tensile test.

For Root Mean Square of Principal

$$\sqrt{1/3(\sigma1-\sigma2)^2+(\sigma2-\sigma3)^2+(\sigma3-\sigma1)^2}$$

$$\sqrt{1/3(Y-0)^2+(0-0)^2+(0-y)^2}$$

$$\sqrt{1/3(\sigma1-\sigma2)^2+(\sigma2-\sigma3)^2+(\sigma3-\sigma1)^2} = \sqrt{2/3}\ Y$$

$$1/\sqrt{3}\sqrt{(\sigma1-\sigma2)^2+(\sigma2-\sigma3)^2+(\sigma3-\sigma1)^2} = \sqrt{2}/\sqrt{3}$$

$$Y = \sqrt{1/2(\sigma1-\sigma2)^2+(\sigma2-\sigma3)^2+(\sigma3-\sigma1)^2}$$

$$Y = 1/\sqrt{2}\sqrt{(\sigma1-\sigma2)^2+(\sigma2-\sigma3)^2+(\sigma3-\sigma1)^2}$$

Von misses yield criterion Von misses equation misses principal Complete Equation of Elasticity The following equation must be satisfied at each point of a non-accelerating, isotropic, linear-elastic body subjected to small strain.

$$\frac{\partial\sigma_x}{\partial x}+\frac{\partial\tau_{xy}}{\partial y}+\frac{\partial\tau_{xz}}{\partial z}+X=0$$

$$\frac{\partial\tau_{xy}}{\partial x}+\frac{\partial\sigma_Y}{\partial y}+\frac{\partial\tau_{xz}}{\partial z}+Y=0$$

$$\frac{\partial\tau_{xZ}}{\partial x}+\frac{\partial\tau_{yZ}}{\partial y}+\frac{\partial\sigma_Z}{\partial z}+z=0$$

Where x,y,z are the body force per unit volume in x,y,z, direction respectively

For geometry compatibility

$$\epsilon_{X}=\partial u/\partial x,\quad \Upsilon_{xy}=\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}$$

Analysis no	Type of element	No of node	Maximum von misses stress analysis (Gpa)
1	24 bilinear, quadrilateral	42	0.0138
2	96 bilinear, quadrilateral	128	0.0182
3	144 bilinear, quadrilateral	184	0.0195

4	24 quadratic, quadrilateral	103	0.0192

$$\epsilon_Y = \frac{\partial v}{\partial y}\ ,\ ,\quad \Upsilon_{yz} = \frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}$$

$$\epsilon_Z = \frac{\partial w}{\partial z}\ ,\ ,\quad \Upsilon_{yz} = \frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}$$

Where u, v, w are velocity (time dependent) displacement (independent upon time)

Component on x, y, z direction. For Stress- Strain Temperature relation

$$\epsilon_X = 1/E\ [\ \sigma_x - \Upsilon\ (\sigma_y + \sigma_z)] + \alpha(T-T_0)$$
$$\epsilon_y = 1/E\ [\ \sigma_y - \Upsilon\ (\sigma_x + \sigma_z)] + \alpha(T-T_0)$$
$$\epsilon_z = 1/E\ [\ \sigma_z - \Upsilon\ (\sigma_x - \sigma_y)] + \alpha(T-T_0)$$
$$\vartheta_{xy} = \tau_{xy}/\ G$$
$$\vartheta_{yz} = \tau_{xy}/\ G$$
$$\vartheta_{zx} = \tau_{zx}/$$

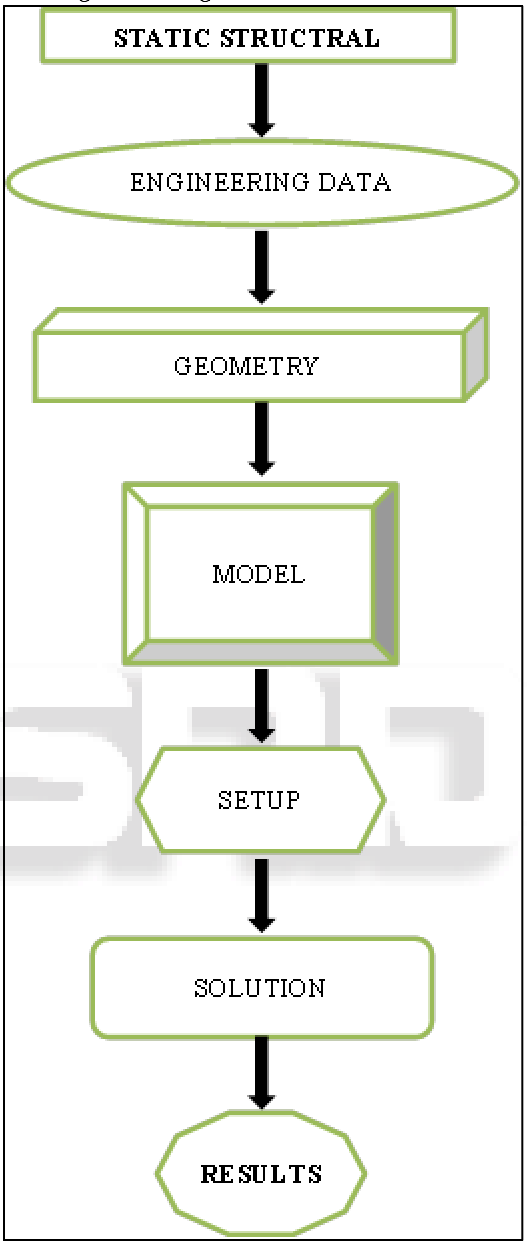
From the results obtained, it can be noted that analysis 1, which uses 24 bilinear elements, does not seem as accurate as the other three. the maximum Von Mises stress for the five analyses. It can be seen that the maximum Von Mises stress using just 24 bilinear, quadrilateral elements (41 nodes) is just about 0.0139GPa, which is a bit low when compared with the other analyses. The other analyses, especially from analyses 2 to 4 using quadrilateral elements, obtained results that are quite close to one another when we compare the maximum Von Mises stress. We can conclude that using just 24 bilinear, quadrilateral elements is definitely not sufficient in this case. The comparison also shows that using quadratic elements (eight-nodal) with a total of 105 nodes, yielded results that are close to analysis 3 with the bilinear elements and 185 nodes. In this case, the quadratic elements also have curved edges, instead of straight edges, and this would better define the curved geometry. Looking at the maximum Von Mises stress obtained using triangular elements in analysis 5, we can see that, despite having the same number of nodes as in analysis 2, the results obtained showed some deviation. This clearly shows that quadrilateral elements in general provide better accuracy than triangular elements. However, it is still convenient to use triangular elements to mesh complex geometry containing sharp corners. From the stress distribution, it can generally be seen that there is stress concentration at the corners of the rotor structure, as expected. Therefore, if structural failure is to occur, it would be at these areas of stress concentration.

Von Mises stress distribution obtained with 24 bilinear quadrilateral elements. It should be noted here that 24 elements (41 nodes) for such a problem may not be sufficient for accurate results. Analyses with a denser mesh (129 nodes and 185 nodes) using the same element type are also carried out. Their input files will be similar to that shown, but with more nodes and elements maximum von misses stress analysis

VI. Finite Element Analysis

In Finite Element Analysis steps may vary based on problems and the method we use for solution. In FEM general steps are remain more or less the same during analysis. In the solution first step is that we have to consider the problem to define the problem in detail swith available information or data. Mathematical model will be developed based on the available data or the information given to us and define the geometry of the model, material properties and governing equations, boundary and initial conditions.

The general steps for the solution of the given problem using FEM are given here



A. *Creating the Geometry*

The Top Shackle part was designed in CATIA V5R21 using the blueprint provided and saved in CATIA model file. The model was then imported to ANALYSIS workbench, the model units were changed from inches from to millimeter before importing.

B. *Meshing*

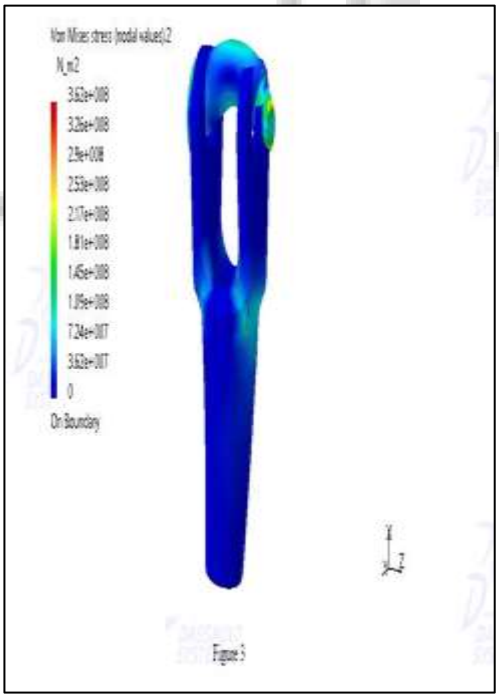
The geometry was meshed using ANALYSIS workbench. The meshing is shown in the fig

Figure 5.7 Meshed HRC
(Sample Collection for XRD analysis)

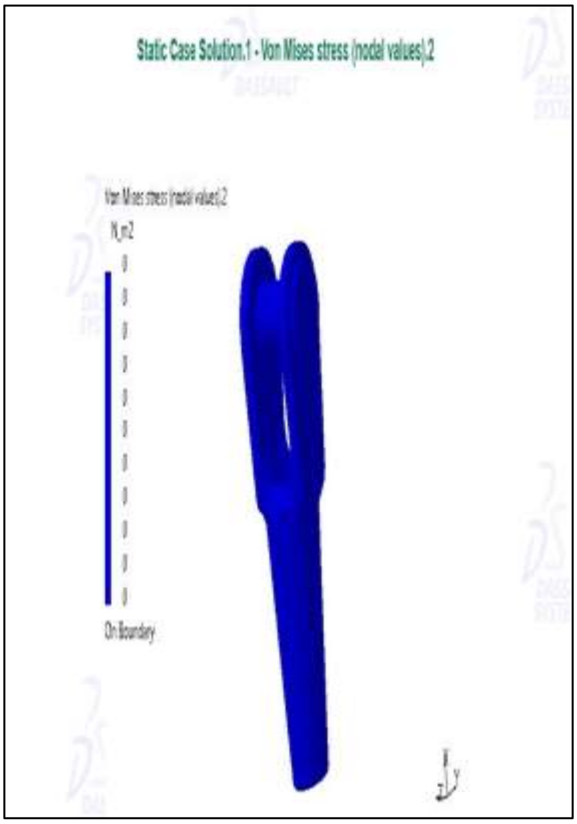
C. *Loading*

- According to the modelling considerations the load is applied on the HRC.
- A fixed proof load is applied to all the materials of 6.25 Tonnes.
- Proof load is three times the safe working load.

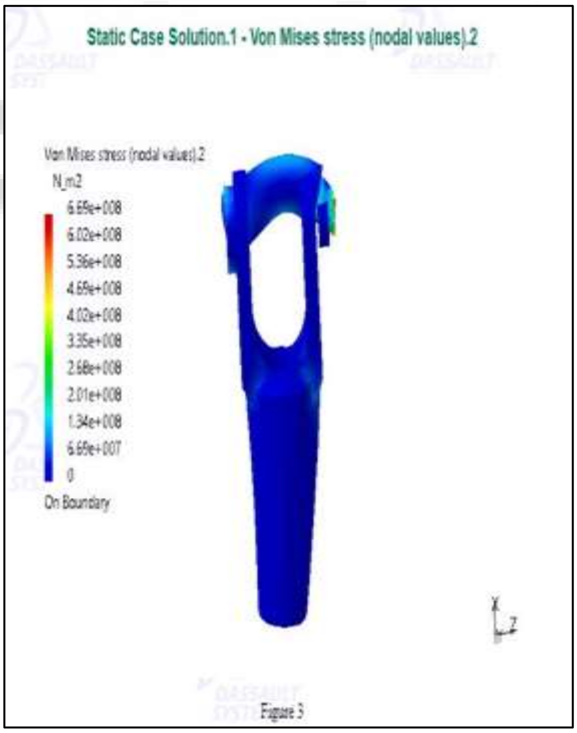
VII. Analysis Result



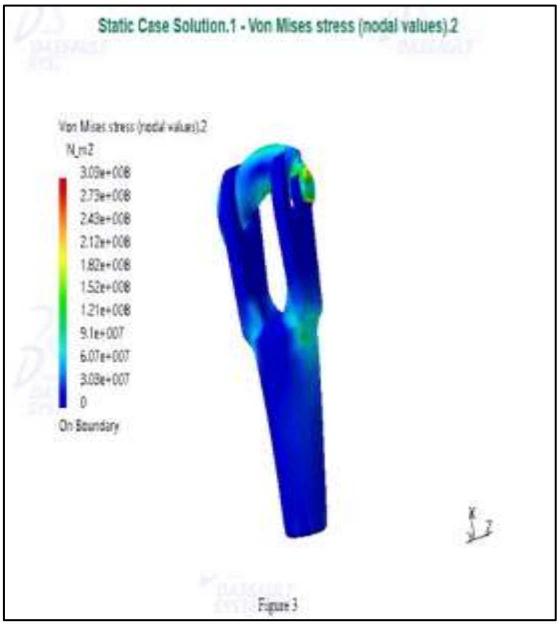
von Mises stress criteria for Mild Steel at 6.25 tonnes



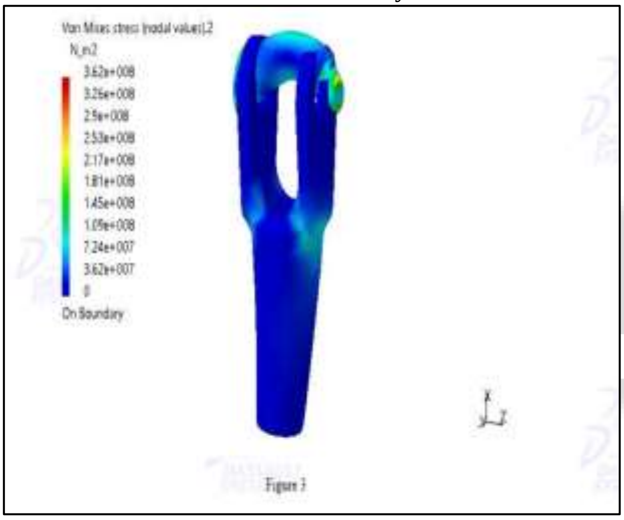
von Mises stress criteria for 20Mn2 at 6.25 tonnes



von Mises stress criteria for Stainless Steel at 6.25 tonnes



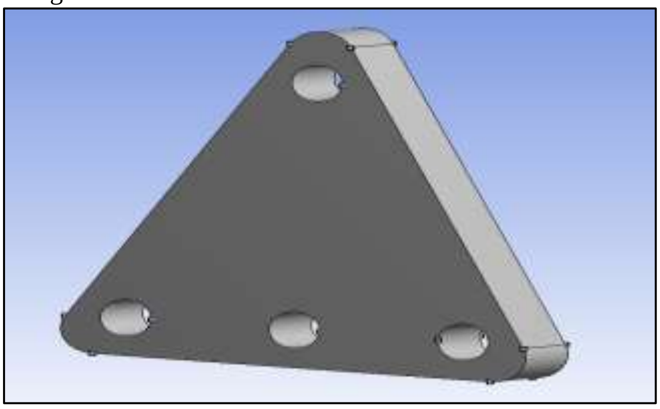
von Mises stress criteria for low alloy steel at 6.25 tonnes



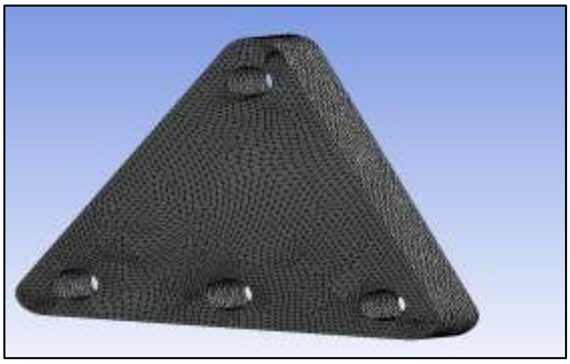
von Mises stress criteria for low carbon steel at 6.25 tonnes

A. *Major Component of CS gear analysis Result:*

Design & Simulation result of Distribution Plate:

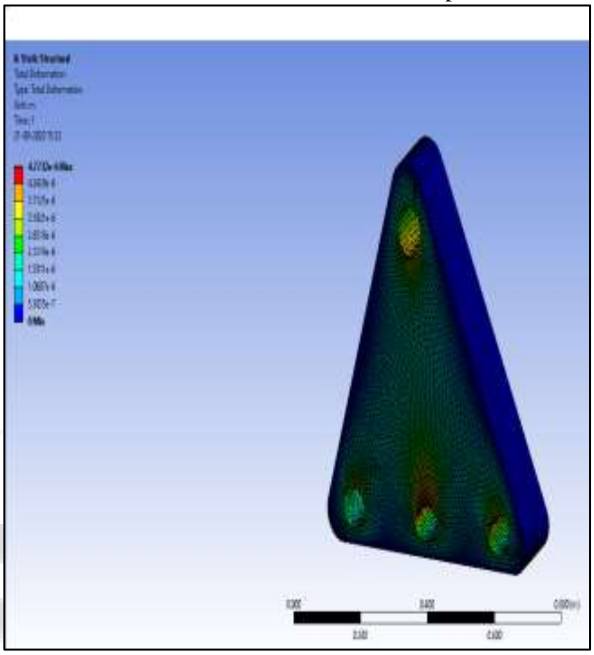


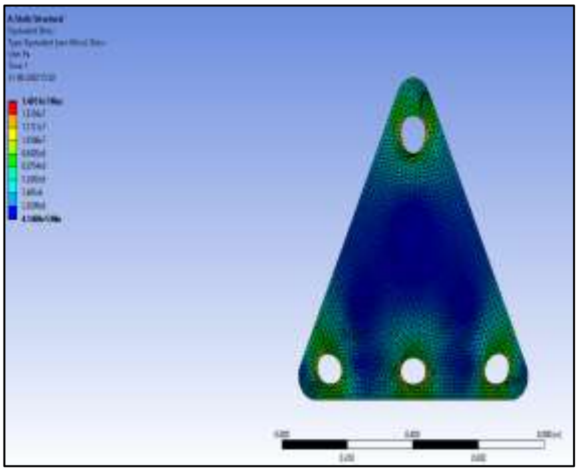
(Distribution Plate 3-D model)

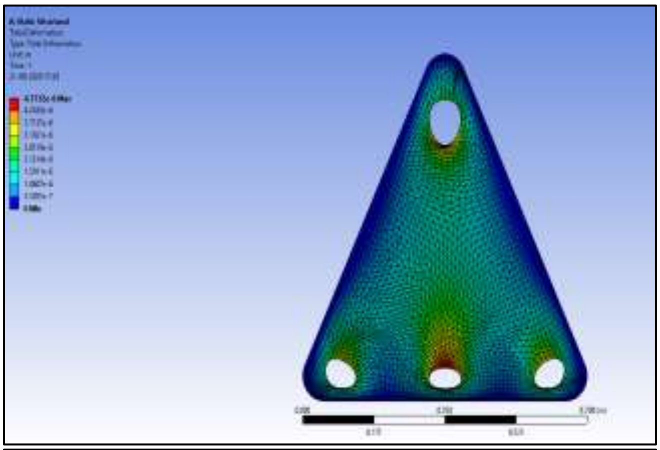


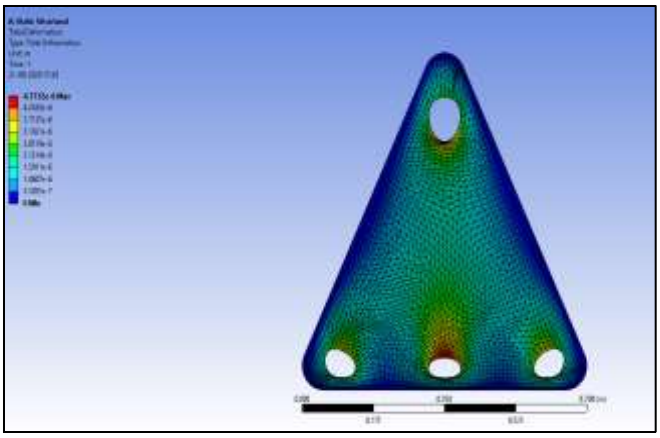
(Distribution Plate Mesing)

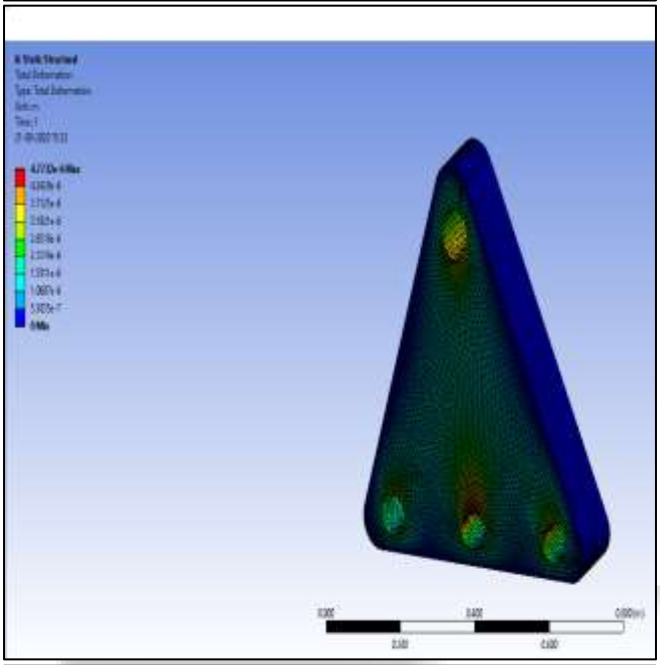
Simulation Result of Distribution plate :

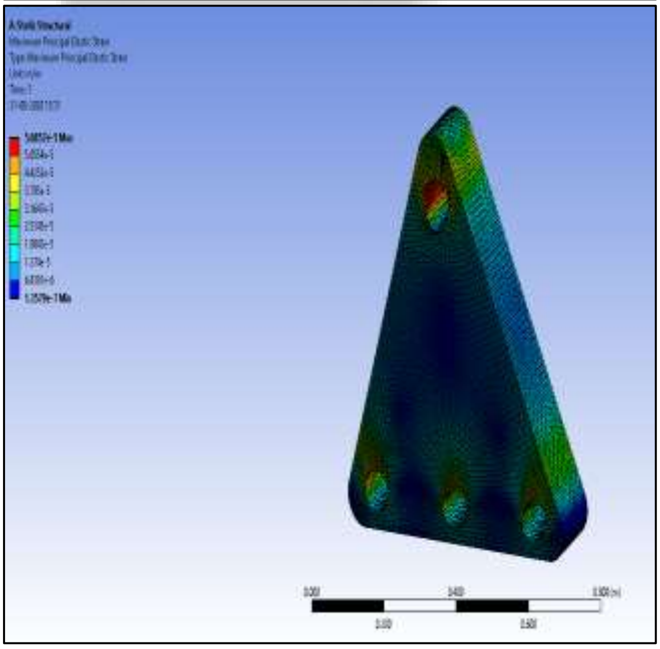












VIII. Conclusion and Future Scope of Work

- This project deals with the behavior of von Misses (equivalent) stress, von Misses (equivalent) strain, Safety Factor and Damages (Cracks) developed of HRC under proof load.
- Non-destructive evaluation must be conducted on HRC before placing it in service in mine so the failure of equipment within prescribed life can be prevented.
- As per Indian Standards & Discard Norms, the permissible length of cracks in regions of higher stress concentration are less compared to those in regions of higher stress concentration factor.
- Different materials under same load had different stress ‘
- It can also be concluded that among all the materials 20Mn2 i.e., the material prescribed in DGMS circular was best for Haulage Rope Cappel.
- Design and Analysis will be carried out for HRC of Cage Suspension Gear. Through this analysis we came to know that we can apply more load on the HRC of material 20Mn2 based on the requirements and applications.
- We can find the load where the deformation starts and study the propagation of cracks at higher loads.
- We can remove the material where there is minimum stress developed.
- We can do a study on the increase in length of preoccupied cracks.
- We have done a study of FEM analysis of distribution plate of cage suspension gear.
- In Distribution plate carries major load distribution of cage suspension gear.
- FEM analysis of Distribution plate of CS Gear give accurate result of Failure analysis.
- Failure analysis of CS gear Completely depends on distribution plate.

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