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Failure Analysis of Hydraulic Piston in Luffing System and Comparison with Alternative Materials

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ABSTRACT

Hydraulic operated cylinder and piston(Luffing system) used for lifting the whole equipment i.e. boom, conveyors, bucket wheels and beams etc., in stacker cum reclaimer used for piling and recovering of raw material (coal) from yard, the hydraulic piston should carry and lift heavy weight with the aid of oil pressure as a result the piston should have good mechanical properties. In this project the hydraulic cylinder and piston is designed in Solid works 2019 and analysis is done using ANSYS workbench. This project is dealing with the analysis and coMParison of stress, deformation,strain, strain energy of various materials like **19MnVs6**, **20MnV6** and **46 MnVs6** which are used to manufacture piston, under the application of fluid pressure and load in different cases, to study its properties and analyse their behaviour up to failure. And also coMParing their behaviour in buckling loads.

INTRODUCTION

In a luffing system, the primary function of the hydraulic piston and cylinder assembly is to facilitate precise control of the movement and position of the boom of stacker cum reclaimer. The luffing mechanism adjusts the angle of the boom to enable vertical and horizontal reach, which is essential for various lifting operations.The hydraulic cylinder, which houses the piston, converts the hydraulic energy into linear motion i.e components that convert fluid pressure into mechanical force. This action occurs when hydraulic fluid is pumped into the cylinder chamber, forcing the piston to move, which in turn moves the connected boom.A separate power pack is available for luffing motion where the pressurized fluid required to move the piston is developed by hydraulic pump powered by an electric motor the fluid is available in tank and double pass filter to clean the hydraulic oil and heat exchanger to keep the temperature of hydraulic oil at desired temperature.The boom is luffed(raising and lowering) upwards as the height of the stockpile increases in Stacker cum Reclaimer.

The main components of Luffing system are Hydraulic Cylinder,Piston and Piston rod,Oil Tank,Air Filter,Motor pump assembly,Electric Motor,Axial Piston Pump,Bell Housing,HY- Manifold Block, Cabin Leveling Cylinder,Valves (check valve, pressure relief valve, solenoid,valve etc.,),Gauges and Couplings.

This analysis include studying the mechanical behaviour of the piston which include stress, strain, total deformation and also Safety factor by varying the input parameters in different cases.There are three possible failures of hydraulic piston under the application of load they are Static failure,Buckling failure and Fatigue failure,in this project we performed both static and buckling analysis.this project also includes comparing the results of existing materials with other alternative materials and finding the best alternative material.

Stacking Operation:
The material on the forward moving yard conveyor is raised by the tripper and discharged through a discharge guide chute onto an intermediate inclined conveyor which lift the material and ultimately discharges on to the boom conveyor by a chute.

The boom conveyor carries the material up to its end and allow it to fall from a stockpile. Thestacking operation starts at one end of the stockpile with the boom kept low. The travel motion penetrates simultaneously and at the other end of the stockpile, the motor reverse after a number of such cycle the boom is luffed up and the cycle repeated.

Luffing System

The bucket boom is luffed by hydraulic cylinders between the mast lower part and superstructure. The associated hydraulic set is located on the superstructure. The luffing mechanism enables the boom to move vertically up and down, the boom is pivoted to the reclaimer. The luffing mechanism consists of:

- ➤ Hydraulic drive unit
- ➤ Hydraulic pump
- ➤Hydraulic tank

Hydraulic elements (pressure limiting valves, shut off valves, pressure gauges, valves and filter units) Hydraulic cylinders:

Operation: A separate power pack is available for luffing motion where the pressurized fluid required to move the piston is developed by hydraulic pump powered by an electric motor the fluid is available in tank and double pass filter to clean the hydraulic oil and heat exchanger to keep the temperature of hydraulic oil at desired temperature.

Figure 3 Luffing system

LITERATURE REVIEW

Literature Review based on various Research papers.

[1] Irwin's fracture toughness method and the British Standard were used to help in the decision–making process. Using inspection, discontinuities were found at the first look in the cylinder cross–section at the region of welding of the cylinder ends. A more detailed analysis was conducted by ultrasonic mapping, crossing the cylinder transverse thickness and longitudinal to its length.

[2] The focus of this study is a double effect hydraulic cylinder installed on the excavator. Its design has been addressed using three different materials: the composite one made of carbon fibre, the classic structural steel and the aluminium alloy. The analytical sizing was verified through the FEM analysis. The results show that the hydraulic cylinder made of composite material has a very similar performance, in terms of the safety factor, to the one made of structural steel and that the weight reduction is about 87% passing from 2286 N to 314 N.

[3]A new hydraulic luffing system adopting a new type hydraulic transformer for hydraulic cylinder control has been designed in this paper. The structure and working principle of the new hydraulic luffing system was then analysed, and a mathematical model of the system was built. A control strategy, combining the switching present control angle and a fuzzy PID controller, has been proposed to improve the smoothness of the switching process.

[4]A distinct feature of this machine is its size: the 3990 mm long rod has an outside diameter of 340 mm. The rod is manufactured machining a solid cylinder of 42CrMo4 steel, along most of its length, into a hollow cylindrical rod with inside diameter 165 mm. typical maximum loads applied are of the order of 10000 kN. In one of the extremities where load is applied, the rod is solid (not hollow), and the complete fracture occurred in the transition of the solid to the hollow parts, during a test performed under maximum load of 8200 kN under *R* (load ratio) of approximately 0.

[5]In this paper, the energy consumption of the valve-controlled hydraulic luffing system (VHLS) of a Bergepanzer has been analyzed with the help of simulation and experiment, including the main reasons for low efficiency. In addition, a new hydraulic hybrid luffing system (NHLS) based on CPR, was designed. Furthermore, a hybrid control method, which combined the switching preset control angle based upon the input signal and pressure feedback and Fuzzy PID control was put forward for the NHLS.

[6] A method for the elimination of stiction in hydraulic cylinders is presented and experimentally verified. The method utilizes the rotational degree of freedom between the piston and the cylinder to add relative velocity at the contact surfaces between piston and cylinder when the main axial motion is zero. For modeling purposes an augmentation of the Stribeck friction force equation is introduced that reflects the influence of the added motion. The possible impact of stiction elimination on the performance of heave compensation equipment is discussed and examplified via time domain simulations.

[7] Piston is one of the most stressed components of an engine. The stable stress distribution and the deformation under the thermo-mechanical coupling condition were firstly calculated. Calculating results indicates that the maximum stress concentration is at the upper end of piston pin boss inner hole, and is mainly caused by the peak pressure of the fuel gas. Then the finite element dynamic analysis was conducted based on the mechanical fatigue testing method, and the mechanical fatigue life-span was calculated. All these work indicate that the design of the piston is reasonable

[8] We propose a convenient framework where both rigid body velocities and velocities caused by flexible behavior are represented as twists. Such formulation allows for using screw transformations, which leads to systematic derivations. Dynamics of a crane and mass balance of hydraulic cylinders are coupled using the bond graph method. In addition, we present a procedure for the determination of reaction forces in passive joints, which is conveniently given as an extension of the dynamic modeling procedure.

[9]As the cylinders are workings up and down direction, then the boom conveyor of machine also working up and down direction. Thus the whole working is termed as Luffing system. Due to the problem of Luffing system, it may cause stoppage of plant generation with a big financial loss of Rs. 5, 23,300/-. By knowing the root cause, we formulated the solution by using number of tools and techniques. A new modified pipe is then fabricated with the cost of just Rs. 450/-.

[10]It is desired to reduce the stress cycles in the cylinder force due to unwanted dynamics in the hydraulic driven luffing cylinder of the boom crane. To suppress the oscillations in the cylinder force due to the hydraulic eigendynamics and excited through motions of the crane's boom two different control approaches are proposed and comp ared in the paper.The control approaches are a Finite Impulse Response (FIR) filter suppressing one nominal frequency and a flatness based feedforward controller inverting the system dynamics. Both control approaches are evaluated and coMPared with simulation and measurement results obtained at a real harbor mobile crane of Liebherr.

[11] In this paper a comparatively new robust design optimization (RDO) approach for design of SRS is explored. The involved parameter of SRS e.g., material loading, incrustation, normal digging, etc., may not have well-defined probability density functions and can be expressed as uncertain but bounded (UBB) type parameters. Also, as conventional least squares method (LSM) based RSM may be a source of error, this study adopts a coMParatively new moving LSM (MLSM) based adaptive RSM in RDO. The RDO results depict that UBB type uncertainty is more critical than the probabilistic case.

DESIGNING AND MODELLING

SolidWorks is a computer-aided design (CAD) software program developed by Dassault Systèmes SolidWorks Corporation. It allows engineers, designers, and other professionals to create realistic 3D models and 2D engineering drawings.

Key Functionality:

- **3D Modeling:** SolidWorks offers a comprehensive suite of tools for creating detailed and accurate 3D models of parts and assemblies. Users can sketch 2D profiles, extrude them into 3D forms, and manipulate them using various features like revolves, sweeps, and lofts.
- **Assembly Modeling:** SolidWorks allows for the creation of complex assemblies by bringing together individual parts. Users can define relationships between components, simulate movement, and check for interferences.
- **Engineering Drawings:** SolidWorks generates industry-standard 2D engineering drawings directly from 3D models. Users can add dimensions, annotations, and views to create clear and concise documentation.
- **Photorealistic Rendering:** SolidWorks offers tools for creating photorealistic images of models. This allows for visualization of the final product, aiding in design decisions and marketing materials.
- **Simulation & Analysis:** SolidWorks integrates simulation tools for analyzing stress, strain, and other engineering factors on a design. This helps engineers optimize performance and avoid potential failures.

Designing of Piston and Cylinder in Solid WorkS
Piston and Cylinder drawing

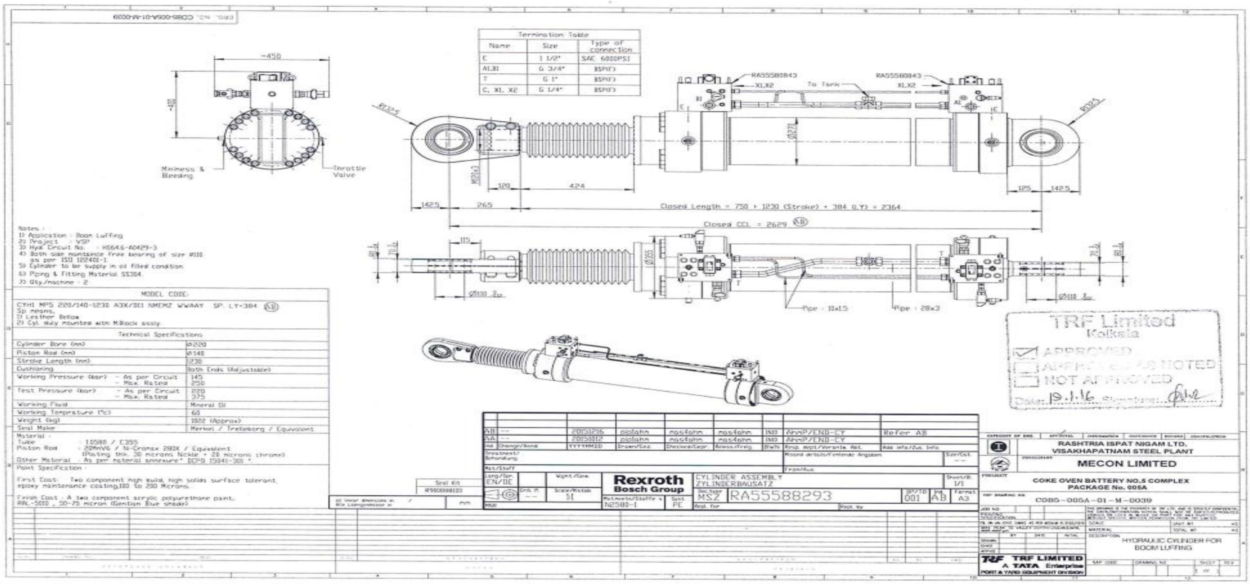

Figure 2 Assembled drawing of Piston and Cylinder

Designing of Piston in SolidWorks

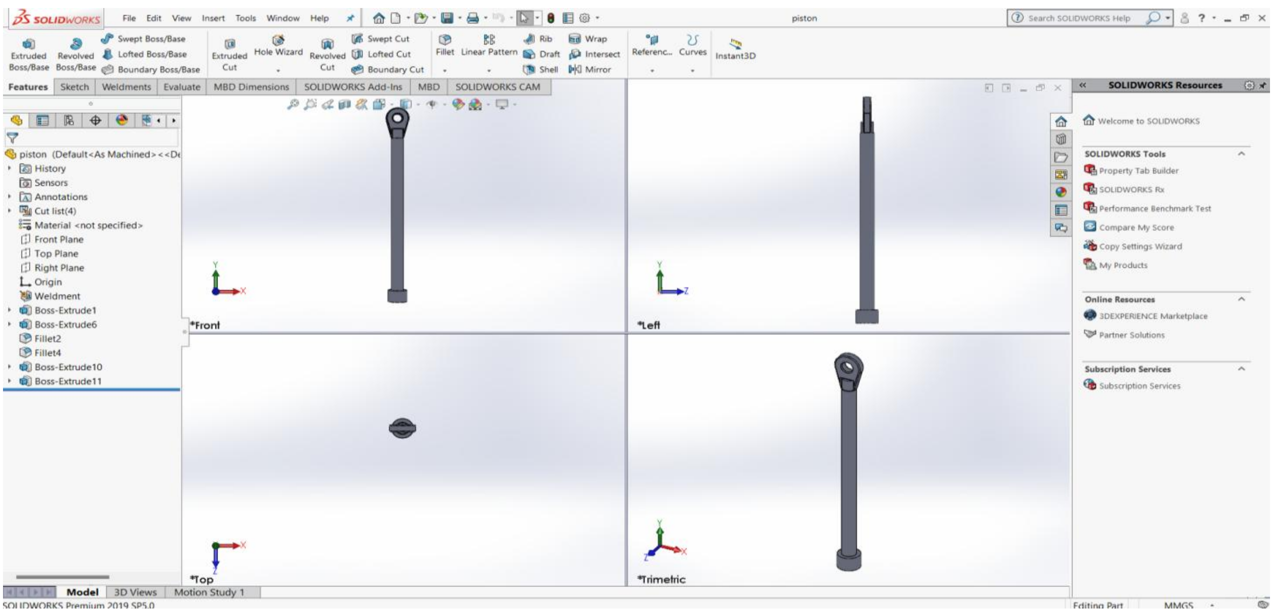

Figure 3 Orthographic views of Piston

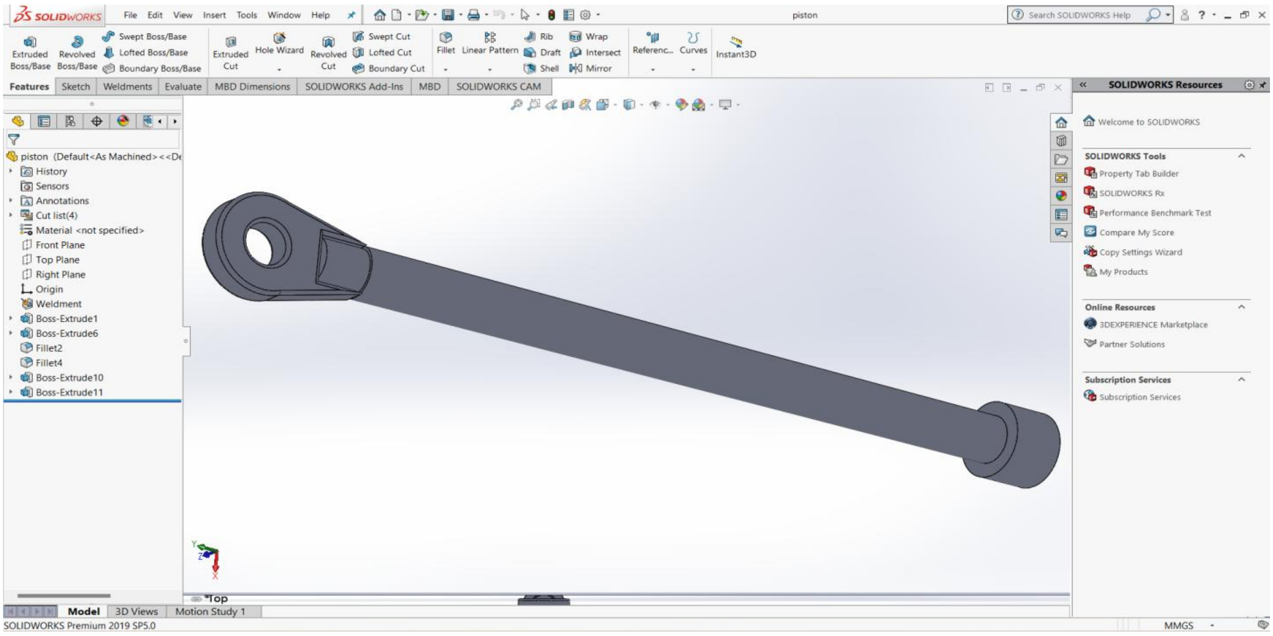

Figure 1 Isometric view of Piston

Designing of Cylinder and other parts in Solid Works

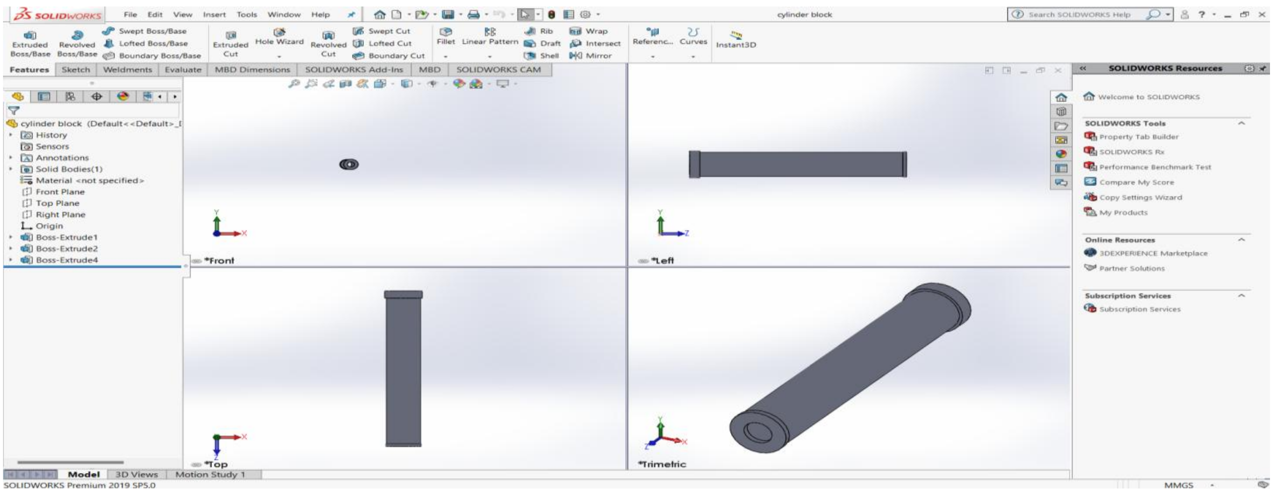

Figure 5 Orthographic view of Cylinder

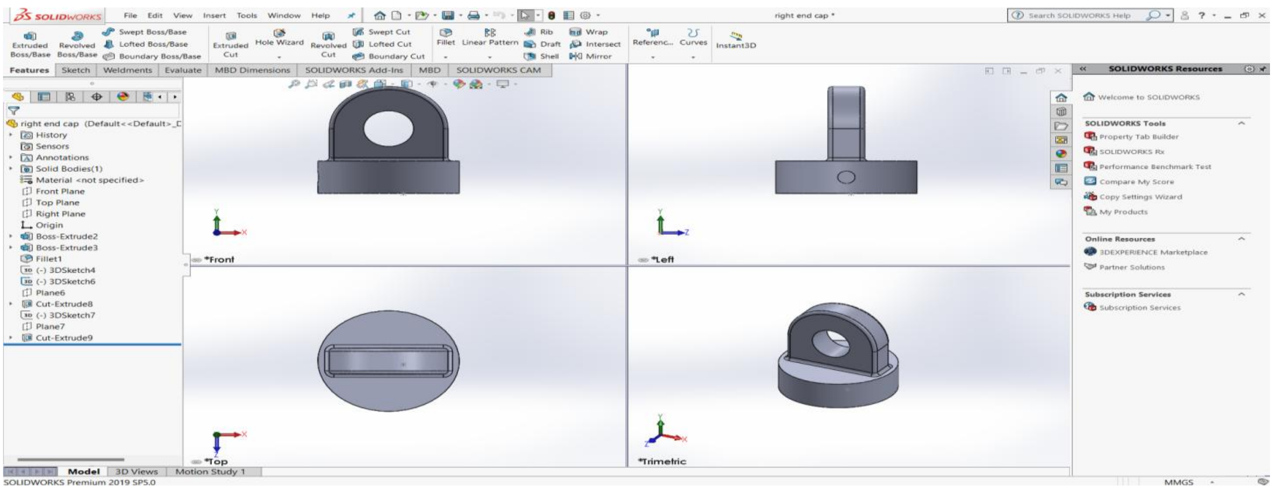

Figure 2 Orthographic views of cap

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STATIC STRUCTURAL ANALYSIS IN ANSYS WORKBENCH

Material Assignment

20MnV6

20MnV6 is a carbon-manganese steel micro alloyed with vanadium, generally supplied in the black hot rolled condition Characterized by excellent machinability due to silicon - calcium treatment and precise control of the sulphur content, excellent weld ability with high yield and tensile strengths due to the micro - alloying effect of the vanadium. The low carbon content and the vanadium addition allows surface hardening by carburising, carbonitriding or nitriding. It will also respond to high or medium frequency induction hardening and can be through hardened and tempered producing a moderate improvement in tensile and yield strength, this varying depending upon wall thickness.

20MnV6 hollow bar is used extensively by all industry sectors for a wide range of applications utilizing its considerable saving on machining time and weight over solid bar. Typical applications are: Bushes, Cylinders Various, Conveyor Rolls, Hollow Shafts, Hollow Parts and components, Nuts, Rings, etc.

Chemical Composition (Base Material)

Min. %	Max %	Min%
Carbon	0.16	0.22
Silicon	0.10	0.35
Manganese	1.30	1.60
Vanadium	0.08	0.15
Phosphorous	0	0.03
Sulphur	0.02	0.04

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	7800	kg m^-3	☐	☐
4	Isotropic Secant Coefficient of Thermal Expansion			☐	
6	Isotropic Elasticity			☐	
7	Derive from	Young's Modul...			
8	Young's Modulus	2.1E+11	Pa		☐
9	Poisson's Ratio	0.3			☐
10	Bulk Modulus	1.75E+11	Pa		☐
11	Shear Modulus	8.0769E+10	Pa		☐
12	Tensile Yield Strength	5.7E+08	Pa	☐	☐
13	Compressive Yield Strength	5.5E+08	Pa	☐	☐
14	Tensile Ultimate Strength	7.9E+08	Pa	☐	☐

Figure 3 Properties of 20MnV6

19MnVs6

19MnVS6 according to EN10267 may with its generous chemical analysis and moderate mechanical requirements host a number of grades all variants are micro alloyed with vanadium which gives a fine grain size and a good start for excellent toughness. The most frequent usage is as rolled, but all members inthe family may be heat-treated in different ways. A heat-treatment will naturally affect the mechanical properties.

46MnVs6

This high strength MN v based steel is a low alloy high grade steel with good machinability for controlled cooling from working heat, applicable for automotive

E355

E335 is a general construction steel. It is applicated for wear and strength loaded construction parts (bolts, shafts, spindles, axles, wedges). The steel is surface hardenable.

Table 1 chemical composition of E355

C	Si	Mn	P	S
max 0.22	max 0.55	max 1.6	max 0.045	max 0.045

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	7800	kg m^-3		
4	Isotropic Elasticity				
5	Derive from	Young's Modulus an...			
6	Young's Modulus	1.9E+11	Pa		
7	Poisson's Ratio	0.29			
8	Bulk Modulus	1.5079E+11	Pa		
9	Shear Modulus	7.3643E+10	Pa		
10	Tensile Yield Strength	4.5E+08	Pa		
11	Compressive Yield Strength	4E+08	Pa		
12	Tensile Ultimate Strength	6.2E+08	Pa		

Figure 4 Properties of E355

Case (1):- ACTUAL CONDITION

Meshing

We have created a mesh over our geometry by Ansys default mesh, statistically our mesh has 44846 Nodes and 17578elements. The shape and size of elements are adaptive according to the geometry.

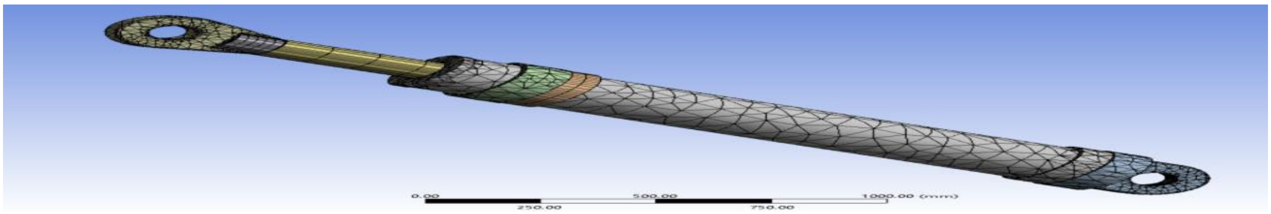


Figure 9 Meshing of cylinder and piston

Boundry Conditions and Model Setup

The top portion of the piston is subjected to **50Tonnes** load and the upper portion of the piston is subjected to fluid pressure of **25MPa**other parts like cylinder and caps are fixed.

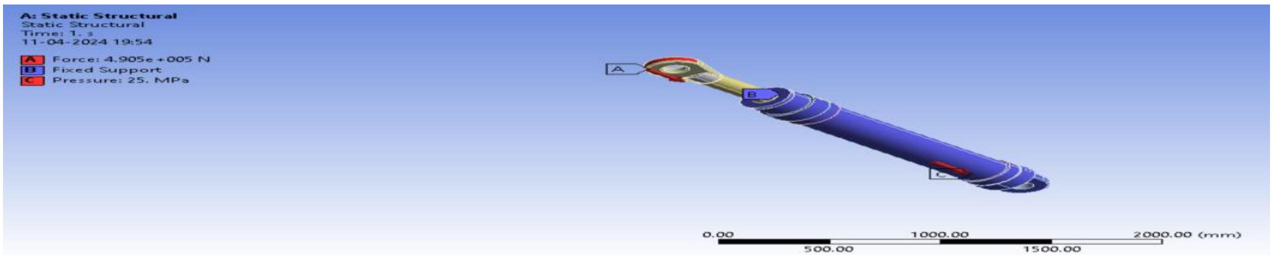


Figure10 Boundary conditions and loading

Case (2):- Both Pressure and Load increasing with fixed intervals

Meshing

We have created a mesh over our geometry by Ansys default mesh, statistically our mesh has 44846 Nodes and 17578elements. The shape and size of elements are adaptive according to the geometry.

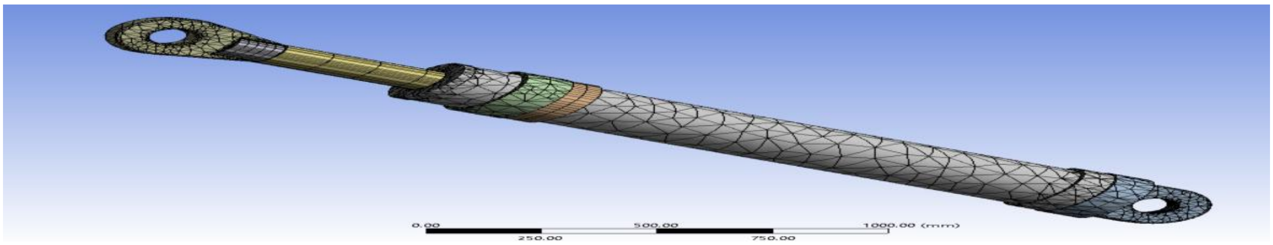


Figure 11 Meshing of cylinder and piston

Boundary conditions and model setup

In this case the top portion of the piston rod is subjected to load of **50 Tonnes** and top portion of the piston is subjected to fluid pressure of **25MPa**and we increased both parameters with an interval of 10 upto failure i.e.., upto the factor of safety is less than one (1) and other parts like cylinder and caps are fixed.

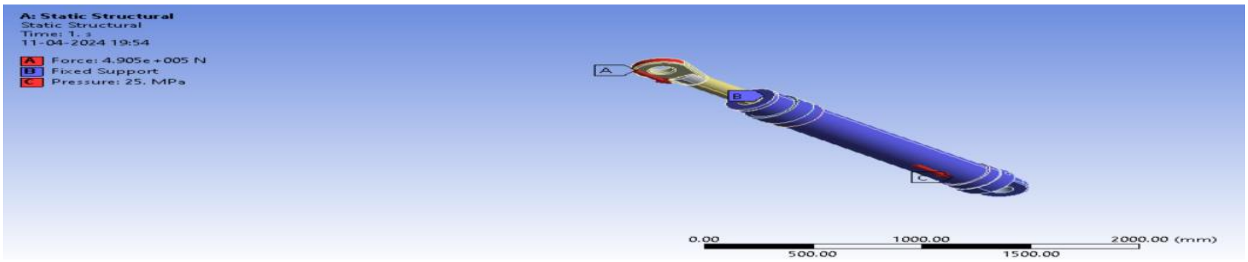


Figure 12 Boundary and loading

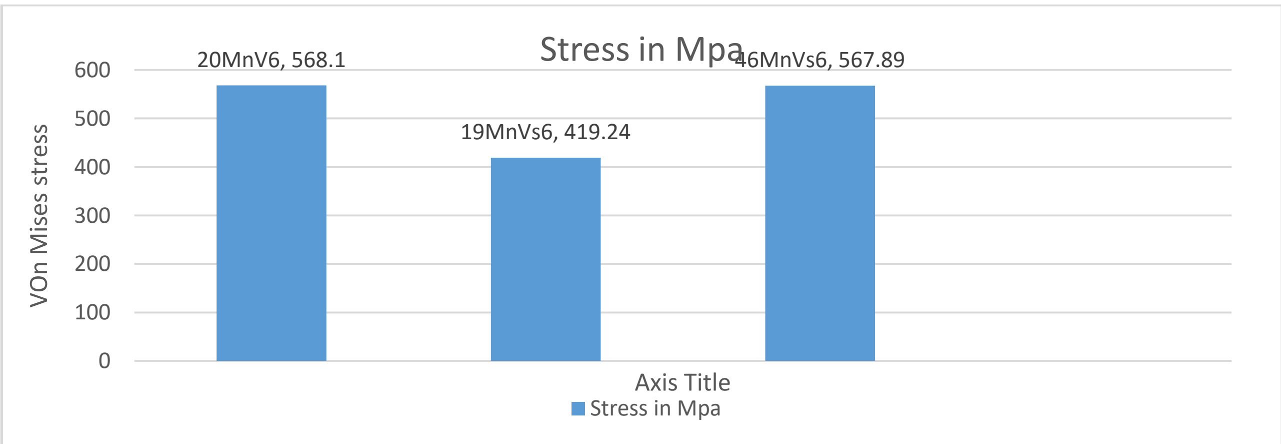
OPTIMUM CONDITION

After analysing all the results of three materials under different cases like
1) Actual case
2) Both load and pressure increasing in fixed intervals
3) Pressure constant and load increased
4) Pressure increasing and load constant

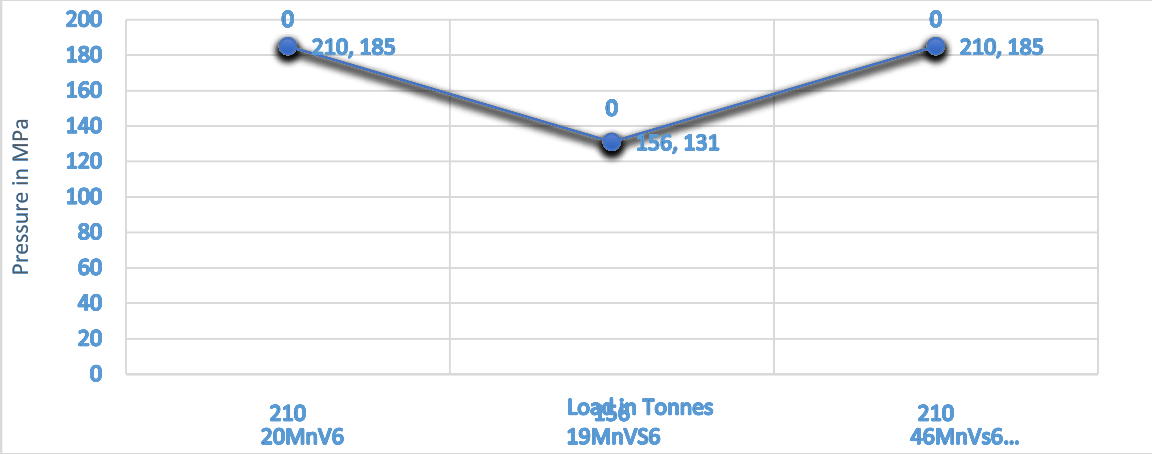
We found one best possible optimal condition for all the three materials that satisfies the above cases, upto the respective optimal conditions pressure and load the component is safe in all cases,

Table 2 optimal solution data

S.no	Material	Load in **Tonnes**	Pressure in MPa	Stress in **MPa**	Strain	Total Deformation In mm	Safety Factor
1	20MnV6	210	185	568.1	3.4529e-003	0.6208	1.0032
2	19MnVs6	156	131	419.24	2.5497e-003	0.46545	1.0018
3	46MnVs6	210	185	567.89	3.4541e-003	0.62094	1.0037



Graph 1 Showing stress for optimum conditions



Graph 2 showing Load vs pressure for optimum conditions

CONCLUSIONS

In this project we did static structural analysis of Hydraulic piston and cylinder used in luffing system of Stacker Reclaimer, with three materials in which 20MnV6 is already in use, remaining two materials are 19MnVs6 and 46MnVs6.We performed static analysis on the three materials in different case like, both pressure and load increasing, increasing pressure by keeping load constant and increasing load by keeping pressure constant upto their failure. By the results obtained from Ansys for all materials in all cases we found one best optimal solution for three materials respectively, which satisfies all the cases of loadings. After coMParing the three optimal solutions we came to a conclusion that the best alternative material for 20MnV6 is 46MnVs6 because the optimal solution is almost similar to the 20MnVs6 and parameters like stress, strain, total deformation and safety factor is also almost similar in optimal case and also all cases. 19MnVs6 optimal solution is very different from the 20MnVs6 solution and other parameters this is the reason it is not suitable for alternative material for piston. And we also performed Buckling analysis on three materials for the optimal solution these results are also in favour with static anslysis results.

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