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DESIGN AND STRESS ANALYSIS OF A SIMPLIFIED CREEP TESTING MACHINE

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Abstract— *This paper presents a design of a simplified creep testing machine. During creep testing operation the parts of the creep testing machine may undergo heavy loads. It is necessary to ensure that the machine parts do not fail during the operation. The deformation of the parts should be very low otherwise it will lead to errors in the results of the creep test. In this study a creep testing machine was designed and stress analysis of its important components was done. The study presents a practical application methodology in FEM analysis for the mechanical parts design. The CATIA Analysis software is used for FEM analysis.*

Keywords— *Creep testing machine, Lever arm, CATIA software, FEM, von Mises stress*

I. INTRODUCTION

The testing of materials enables engineers and designers to choose the best material for a particular use. For cost effective design, the designers have to study the strength characteristics of a material under various environmental conditions. At high temperatures, stresses imposed on metal components produce a continuously increasing strain even if they are below the yield point and result in a phenomenon known as creep. In order to measure creep, an apparatus is required that can maintain a sample at a constant temperature, apply a constant load to that sample and measure its elongation over time. The apparatus for this purpose is called the creep testing machine. The creep curve can be drawn for a particular material using the information from the creep testing machine. From this curve the safe life period of a specimen at a particular load can be find out. A constant tensile load lever arm type creep testing machine is discussed in this work.

During creep testing operation the parts of the creep testing machine may undergo heavy loads. It is necessary to ensure that the machine parts should not fail during the operation. The deformation of the parts should be very low otherwise it will lead to errors in the results of the creep test. Creep testing machines mainly consists of a lever arm which is hinged to a frame. One end of the lever arm dead weight pan is given and in the opposite side, near to hinge the connection to specimen is attached. Since the creep testing machine undergoes heavy loads during operation, stress analysis of the components should be done. Due to loads the lever arm may undergo deflection or even failure. For obtaining correct results from creep testing, the stability of the lever arm is very important. ie, the lever arm should be maintained in its straight position during the testing operation. So we have to do the deflection analysis of lever arm along with stress analysis and ensure that the deflection is within the limits. For the lever arm used in this work the maximum deflection should be less than 2 mm. The stability of the frame should be ensured and that the frame should not buckle during the testing operation. Stress analysis of other components which carries mechanical loads also should be carried out.

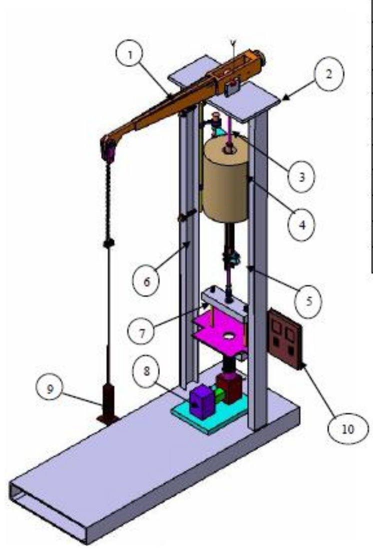
This paper discussed about the design of a 20KN constant load lever arm type creep testing machine. A 20KN constant load creep testing machine means a creep testing machine which can apply a 20KN constant load on the specimen throughout operation. During this operation the different components of the creep testing machine will undergo heavy loads. So stress analysis of these components has to be done for ensuring whether the design is safe or not.

II. LITERATURE REVIEW

ASTM (American Society for Testing and Materials) [1] gives standard test methods for conducting creep, creep rupture, and stress rupture tests metallic materials. A.K. Ogunkoya et.al.[2], designed and developed of constant stress creep testing equipment. The overall constant stress creep testing equipment was modelled using parametric 3-D design software- Pro/ Engineer. S.M.A. Hosseini et.al. [3] developed a creep testing equipment to obtain long-term deformation parameters of salt rocks. The study describes the main ideas of the design and manufacturing of a new creep testing machine that is set up at Shahrood University of Technology (SUT). John J et.al. [4] made a modification and performance evaluation of a low cost electro-mechanically operated creep testing machine. Existing mechanically operated tensile and creep testing machine was modified to a low cost, electro-mechanically operated creep testing machine capable of determining the creep properties of aluminum, lead and thermoplastic materials as a function of applied stress, time and temperature. T. H. Hyde, C. J. Hyde and W. Sun [5] made a study on basis for selecting the most appropriate small specimen creep test type. M. Ciesla, F. Binczyk and M. Manka [8] made a study on Impact of Surface and Volume Modification of Nickel Superalloys IN-713C and MAR-247 on High Temperature Creep Resistance. Ghionea Ionut [9] made conference paper on the practical approach in the finite element method study of a mechanical part. The paper presents a practical application methodology in FEM analysis for the mechanical parts design.

III. PROPOSED DESIGN

The proposed design of the simplified lever arm type tensile creep testing machine is shown in the figure.



No:	Part Name
1	Lever Assembly
2	Support Plate
3	Specimen Train Assembly
4	Furnace Assembly
5	Extensometer Assembly
6	Frame
7	Draw Head Assembly
8	Draw Head drive Mechanism
9	Weights
10	Control Panel

Fig. 1 Proposed Design of Creep Testing Machine

The design mainly consists of a lever arm which is connected to a support plate with a fulcrum knife edge. This support plate is welded to the frame. At one end of the lever arm there is a weight pan on which the dead weights are added and the other side of the fulcrum knife edge the specimen is attached through a load coupling. The lever arm ratio about this fulcrum knife edge is 1:20. In order to keep the centroid of the lever arm at the fulcrum knife edge point, a counter weight system is attached at the reared end of the lever arm. The assembly made by coupling the specimen with pull rods is called the specimen train. The upper end of the specimen train is attached to the lever arm through a load coupling and the lower end of the specimen train is connected to a draw head assembly with a universal coupling. When the specimen elongates during the operation, the lever arm will deviate from horizontality. This change affects the lever arm ratio and the load applied at the specimen. For avoiding this problem, the horizontality of the lever arm should be maintained by pulling down the load train till the lever arm becomes again in horizontal position. This function is done by the draw head assembly. The draw head assembly is a part of this creep testing machine where the lower end of the specimen train is attached. The draw head assembly consists of draw head drive mechanism which is attached to the base of the creep testing machine. The specimen train is attached to the draw head using a universal coupling. The moving nut is pinned to the draw head drive mechanism and consists of a threaded shaft which can be operated manually and by electrical motor. During the creep test, if the lever arm deflection exceeds a pre set value, the electrical motor operates and the draw head assembly pulls down the specimen train till the horizontality is achieved. There is an extensometer to measure the extension of the specimen. This may be either a dial gauge or any sensors like LVDT (Linear variable differential transformer). The furnace assembly is attached to the frame. Split type furnace is suitable for this creep testing machine. A furnace which is capable of developing a temperature up to 1000 degree Celsius is selected. The specimen train is passes through the furnace in such a way that the specimen will locate of the middle of the furnace where the high temperature is maintained. The temperature inside the furnace is controlled by the control unit.

IV. WORKING PROCEDURE

Initially, there were no weights on the weight pan. The lever arm was in equilibrium position by the effect of counter weight. The specimen was attached to the lever arm through the load coupling and pull rods. The specimen was kept at the centre of the furnace. The bottom end of the specimen train was attached to a draw head assembly. The draw head was connected to the draw head drive mechanism. The extensometer was attached to the specimen in proper way. The thermocouple thermometers were used to measure the temperature in the furnace. After that the split furnace closed. A small fraction of test force may be applied before the heating of the specimen to improve the axiality of loading. After all the initial set ups, switch on the furnace to attain the required temperature. Once the test temperature is reached, the weights were gradually added to the weight pan till the required load is set up at the specimen. The temperature inside the furnace was measured and controlled by the thermocouples. Now the specimen is under a constant load and temperature and creep deformation will occur in the specimen. The deformation is measured by the extensometer.

V. MODELLING AND ANALYSIS OF DIFFERENT COMPONENTS

The creep testing machine and its components are modelled in CATIA V4 R16. The analysis of the components are also done in CATIA to predict whether the components of the creep testing machine is safe or not under the heavy loads developed during the creep testing operation.

5.1. STRESS ANALYSIS OF LEVER ARM

Only rotation about x axis is allowable. All other motions are constrained at fulcrum point. Loads of 1000N and 20000N are applied at the dead weight point and load coupling point respectively. The material used for making lever arm is mild steel (Yield strength $=2.5\times10^8$ N/m^2).

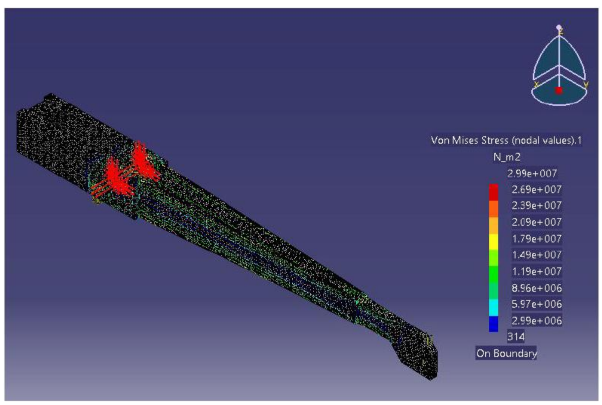


Fig. 2 Stress Analysis of Lever Arm

Element type – Linear tetrahedron
Size of the element – 5mm
Number of nodes – 45328
Number of elements - 184649
Maximum von Mises stress developed = $2.99 \times 10^7 N/m^2$

The maximum value of the von Mises stress is less than yield strength of the mild steel. Therefore the design is safe.

5.2. STRESS ANALYSIS OF FRAME

The material used for making frame is mild steel. Frame carries all loads from the components. The load from lever arm itself is 21000N and the weights of lever arm, furnace, control unit etc. also need to be considered. Considering all the above we applied a load of 23000N is applied on the frame. Base of the frame is fully constrained.

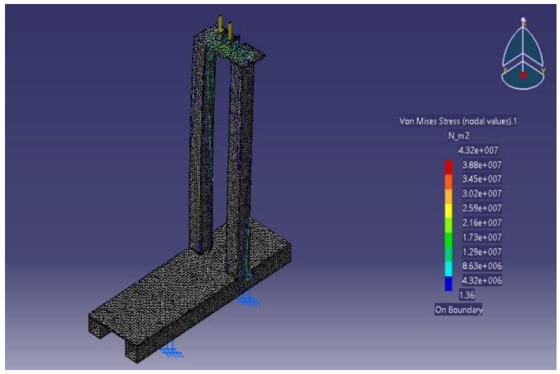


Fig. 3 Stress Analysis of Frame

Element type – Linear tetrahedron
Size of the element – 10mm
Number of nodes – 22140
Number of elements – 68779

Maximum von Mises stress developed = 4.32 x 10^7 N/m^2
The maximum value of the von Mises stress is less than yield strength of the mild steel. Therefore the design is safe.

5.3. STRESS ANALYSIS OF FULCRUM KNIFE EDGE

The material used for making fulcrum knife edge pin is mild steel. The lever arm was hinged to the frame by this fulcrum knife edge pin. The calculated value of force at fulcrum knife edge 21000 N was transmitted to fulcrum through the lever arm. In addition, considering the weight of lever arm assembly, the total force is 21500 N. The force is vertically downwards and this fulcrum knife edge pin was sitting on the fulcrum v block, so the pin was vertically constrained at knife edge part. Other two mutually perpendicular constrains are given to end faces.

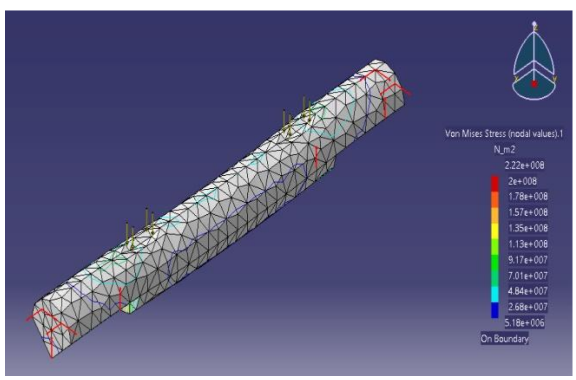


Fig. 4 Stress Analysis of Fulcrum Knife Edge

Element type – Linear tetrahedron
Size of the element – 5 mm
Number of nodes – 702
Number of elements – 2661
Maximum von Mises stress developed = 2.22 x 10^8 N/m^2

The maximum value of the von Mises stress is less than yield strength of the mild steel. Therefore the design is safe.

5.4. STRESS ANALYSIS OF LOAD COUPLING

The material used is mild steel. A load of 20000 N is applied to the tail end. The flat surface of the hole is the seat for v-block and so this surface is constrained.

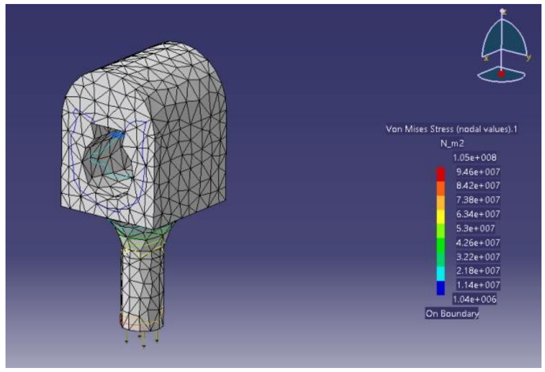


Fig. 5 Stress Analysis of Load Coupling

Element type – Linear tetrahedron
Size of the element – 5 mm
Number of nodes – 919
Number of elements – 3392
Maximum von Mises stress developed = 1.05×10^8 N/m^2

The maximum value of the von Mises stress is less than yield strength of the mild steel. Therefore the design is safe.

5.5. STRESS ANALYSIS OF LOAD COUPLING KNIFE EDGE

Material used for making load coupling knife edge pin is mild steel. The load coupling is attached to this pin with v-block sitting. A of load of 20000N is applied linearly through knife edge part. The vertical constrains are given through the bottom part of cylindrical portion where the lever arm attachment is come. Other constrain are given to the end faces.

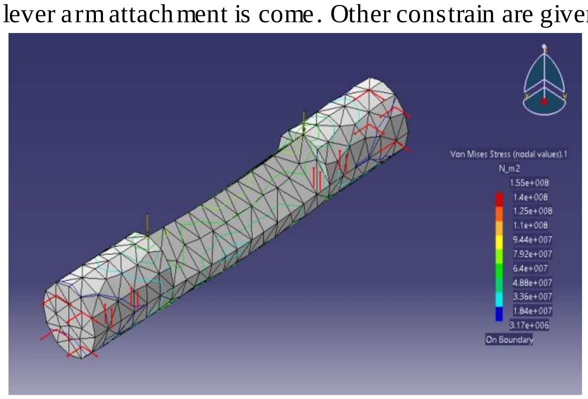


Fig. 6 Stress Analysis of Load Coupling Knife Edge

Element type – Linear tetrahedron
Size of the element – 5 mm
Number of nodes – 509
Number of elements – 1889
Maximum von Mises stress developed = 1.55×10^8 N/m^2

The maximum value of the von Mises stress is less than yield strength of the mild steel. Therefore the design is safe.

5.6. STRESS ANALYSIS OF HOT PULL ROD

Hot pull is used for connecting specimen to cold pull rod. The tensile force is given to the specimen through this pull rod. There are two hot pull rods one is attached at upper end of the specimen then connected to the upper cold pull rod and the other is attached at lower end of the specimen then connected to the lower cold pull rod. Material used for making this hot pull is IN-713C, which is a creep resistant material. A load of 20000N is applied at one of end face and the other end face is fully constrained. At 800^0 C the yield strength of IN-713C is 763MPa.

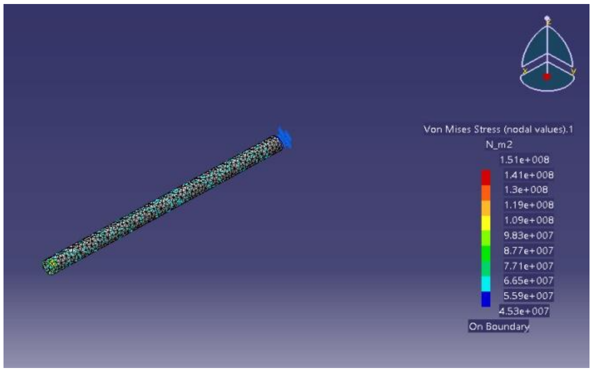


Fig. 7 Stress Analysis of Hot Pull Rod

Element type – Linear tetrahedron
Size of the element – 5 mm
Number of nodes – 1476
Number of elements – 5849
Maximum von Mises stress developed = 1.51×10^8 N/m^2
The maximum value of the von Mises stress is less than yield strength of the IN-713C. Therefore the design is safe.

5.7. STRESS ANALYSIS OF COLD PULL ROD

There are two cold pull rods. One is attached to the upper pull rod and then connected to the load coupling. The other is attached to lower hot pull rod and then connected to the draw head assembly. The material used for making this cold rods are IN-713C, a creep resistant material which has a yield strength of 763MPa and Young's modulus 1.58×10^5 MPa at 800^0c temperature. A load of 20000N is applied at one of end face and the other end face is fully constrained.

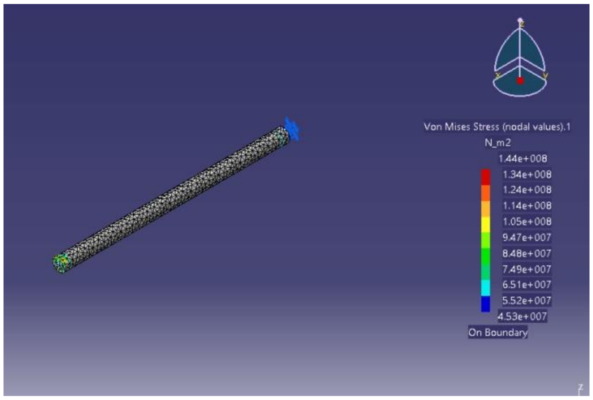


Fig. 8 Stress Analysis of Cold Pull Rod

Element type – Linear tetrahedron
Size of the element – 5 mm
Number of nodes – 1392
Number of elements – 5513
Maximum von Mises stress developed = 1.44 x 10^8 N/m^2

The maximum value of the von Mises stress is less than yield strength of the IN-713C. Therefore the design is safe.

VI. RESULTS

The analyzed components and the results obtained are

TABLE I
The analysed components and results

Component	Material	Yield Strength in MPa	Von Mises stress obtained in MPa	Result
Lever Arm	Mild Steel	250	29.9	Safe
Frame	Mild Steel	250	43.2	Safe
Fulcrum Knife Edge	Mild Steel	250	222	Safe
Load Coupling	Mild Steel	250	105	Safe
Load Coupling Knife Edge	Mild Steel	250	155	Safe
Hot Pull Rod	IN-713C	763	151	Safe
Cold Pull Rod	IN-713C	763	144	Safe

Since the von Mises stress developed in each component is less its yield strength, the designed components are safe during the testing operation.

VII. SUMMARY

A 20KN constant tensile load lever arm type creep testing machine was designed. That means a creep testing machine which can apply a 20 KN constant tensile force on the specimen which is placed inside a furnace of the apparatus. Because of this, the components of the creep testing machine will experience heavy loads. Stress analysis of these components was done in order to ensure that the components are safe under this load. The distortion energy (von Mises) failure criterion is used here. Using analysis software (CATIA) the von Mises stress of different components were calculated and found that the maximum von Mises stress of each component is less than its yield strengths. So the designed components of the creep testing machine are safe during testing operation.

VIII. CONCLUSION

The design and stress analysis of various components of a constant load creep testing machine has been undertaken in this work. The stress analysis results of various components ensured that, the designed components are capable to use in the proposed 20 KN constant load creep testing machine.

The materials used for making the creep testing machine are locally available and therefore expected to be easily assessable and affordable. The design is simple and cheap, and hence it provides a low cost solution for Mechanics of Materials laboratories interested in creep testing experiment.

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