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Enhancement and Performance Assessment of an Affordable Tensile Creep Testing Apparatus

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ABSTRACT

This paper describes the development and evaluation of a low-cost tensile creep testing machine designed specifically for analyzing the creep behavior of thermoplastic materials such as polypropylene and light metals like lead. The primary objective was to create a machine that could be affordably constructed and utilized within college laboratory settings to demonstrate the creep behavior curve. The conventional lever mechanism found in typical creep testing machines was substituted with a connecting mild steel metal wire, which served as a cost-effective alternative. The analysis of this modified mechanism was conducted using ANSYS 16.2, a widely used engineering simulation software package. To apply loads, a turn buckle capable of exerting up to 22500N was employed. The machine's load capacity could be adjusted by incorporating tension springs of varying strengths. Specifically, tension springs with capacities of 39.24N, 245.25N, and 392N were utilized to provide flexibility in load variation. Furthermore, a low heat treatment furnace was designed with a maximum capacity below 200°C. This furnace featured a PID temperature controller for precise temperature regulation, ensuring accurate testing conditions. In summary, this paper presents a detailed account of the design, fabrication, and analysis of a low-cost tensile creep testing machine tailored for educational purposes, specifically targeting the study of creep behavior in thermoplastic materials and light metals.

Keywords: Thermoplastic, Turnbuckle, Tension spring, Creep test, design, mild steel, furnace, ANSYS 16.2.

Objectives of Project: The objective of this work is to design and fabricate a Creep test apparatus which can be used in laboratory to demonstrate creep behaviour of engineering materials without using expensive creep testing machine.

1. INTRODUCTION

A creep-testing machine is a crucial tool used by engineers and researchers to assess how materials respond to stress, particularly at elevated temperatures, over time. It measures the material's tendency to deform or change shape under sustained loads, a phenomenon known as creep. By subjecting materials to various stress levels, such as high temperatures and pressures, the machine generates a creep curve that illustrates the material's behavior over time. These machines play a vital role in determining the suitability of materials for specific applications, as they help engineers understand the material's stability and performance under ordinary stresses. Creep testing is especially important in industries like aerospace, where materials must withstand extreme conditions such as high altitudes and temperature fluctuations. The development of creep testing machines dates back to 1948 in Britain, initially devised to assess materials for aircraft applications. Over time, they have evolved to provide insights into the steady rate of creep in materials, helping researchers and engineers optimize material selection for various purposes. Creep is more pronounced at higher temperatures and over prolonged exposure, making it essential to understand and quantify for materials intended for long-term use or high-temperature environments. By studying the creep behavior of materials, researchers can identify superior materials for specific applications, enhancing product performance and longevity. Overall, creep-testing machines are indispensable tools in material science and engineering, enabling the evaluation of material properties and the comparison of different materials' performance under stress, ultimately leading to advancements in material design and application.. A creep-testing machine measures the creep (the tendency of a material after being subjected to high levels of stress, e.g. high temperatures, to change its form in relation to time) of an object. It is a device that measures the alteration of a material after it has been put through different forms of stress. Creep machines are important to see how much strain (load) an object can handle under pressure, so engineers and researchers are able to determine what materials to use. The device generates a creep time-dependent curve by calculating the steady rate of creep in reference to the time it takes for the material to change. Creep machines are primarily used by engineers to determine the stability of a material and its behaviour when it is put through ordinary stresses.

Stages of Creep:-

- Primary Creep: - In this stage the deformation occurs and resistance to creep increases until the next stage.
- Secondary Creep: - In this stage the ratio between strain and time is constant.
- Tertiary Creep: - In this stage a reduction in cross sectional area occurs.

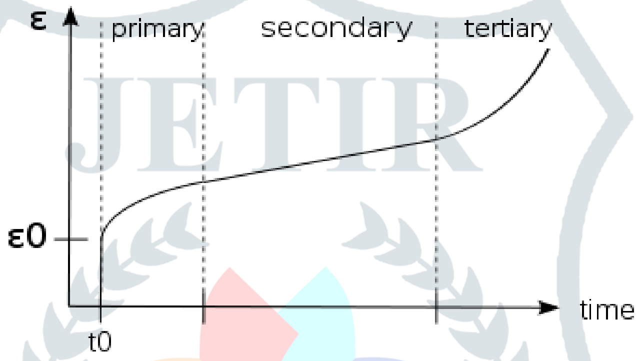


Fig.1. Stages of Creep

Existing Technology

The existing machine (Fig 2.) works on lever arm loading principle. In this, load is applied one side of a lever arm and the sample material which is to be tested is attached to the other end of the lever arm.

However, lever arm itself maintains constant tensile load to the sample material based on the lever ratio.

Fig. 2 Existing Creep Tension Machine

2. METHODOLOGY

2.1 Design of Machine Components

2.1.1 Base plate

Fig 3(a) shows, the base plate of mild steel which is designed with double "I" beam structure to sustain the whole load of machine over it. The base plate is made up of cast iron and its dimensions are 300×125×65mm.The base plate is connected with the two T-slotted columns by the application of welding and also one furnace is placed in the centre of it.

2.1.2 Column

Fig 3(b) shows, column of mild steel used are of T-shape which connects the base plate and top plate with the application of welding. The length of column is 770mm.The columns are made up of cast iron which makes the design more robust and sturdy.

2.1.3 Grips

The work of gripswhich are of hardened mild steel is to fix the specimen tightly in furnace. In this design the grips used are "Clevis Couplings" which is used for the fixation of flat rectangular specimens as shown in Fig 3(c). One grip is internally fixed at the base plate while other is adjustable to height which will be connected to the hot pull rods.

2.1.4 Pulley

The pulley of stainless steel used in this design is half round pulley as shown in Fig 3(d) whose work is to provide support and rolling motion and to support the rope which is connected to the turn buckle. In this design two pulleys are used. One is connected to the centre of the top plate and the other pulley is offset to the top plate by 135mm.

2.1.5 Top plate

Top plate is flat plate of mild steel with the dimension 300×50×5mm as illustrate in Fig 3(e). It is connected with the two columns from bottom by welding. Also a half rounded pulley is connected in the centre of it. Top plate has cut exactly in the centre for the passage of nylon wire rope to roll over pulley.

2.1.6 Furnace

As shown in Fig 3(f), furnace is the heart of this tension creep testing apparatus. It provides heating to the specimen. The furnace has a cuboid structure placed over base plate, between the two columns. The outer length, breadth and height of the furnace are 152mm, 128mm and 224mm respectively. The inner length, breadth and height of furnace are 124mm, 115mm and 200mm respectively. Bison sheet is used as refractory material having thickness of 12 mm in all sides. The furnace is attaining a maximum temperature of 200 degree Celsius. The furnace has a hole in the centre at the top of the furnace to pass the hot pull rod. Furnace is designed to load and unload specimen easily.

2.1.7 Spring

In this simplified design of tensile creep testing machine, a tension spring, SAE 6145 (oil Quenched) as shown in Fig 3(g) is used to compensate the slack generated by the nylon wire because of increment in the length of specimen. The wire diameter of spring is 1 mm and coil diameter is 10 mm with 44 numbers of active turns.

2.1.8 Digital Temperature Controller

Fig 3(h) shows digital temperature controller is an electronic operated device which is used to control the temperature of furnace for various time spans. This digital controller is placed at the left side of one column.

2.1.9 Load Cell

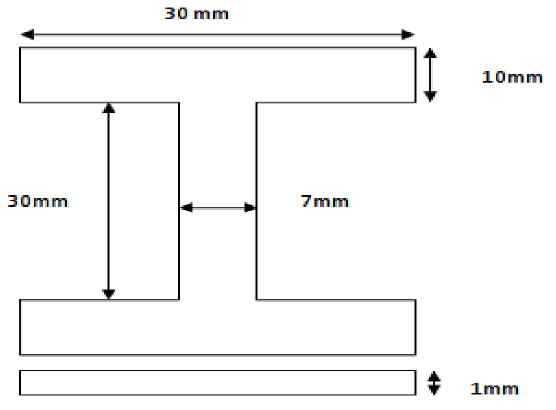
Fig 3(i) shows, load cell is an electronic device placed in the creep testing apparatus after the spring. It indicates the applied force on the specimen by a digital meter which is placed with digital temperature controller. This device is used to indicate the precise load applied on the specimen. In this apparatus the load cell can show up to 40 kg load precisely. The load cell is connected to approximately 20.5 cm above the base plate to the column.

2.1.10 Turn Buckle

Turn buckle of Stainless steel (316 grade) Fig (3j) is a device connected to a wire rope and spring in creep test apparatus to apply the desired force on the specimen at constant high temperature. Turn buckle has two ends, one end is left hand thread and the second has right hand thread. The centre part of the turn buckle is called as coupler. As the coupler rotates, the rods are either pulled together or pushed apart depending upon the direction of rotation of coupler as illustrate in Fig 3(j).

2.1.11 Test Specimens:-

Test specimens for Tensile Creep Testing Machine used are either Tin/lead or Teflon. The standard test specimen should be in the form of "I" Section



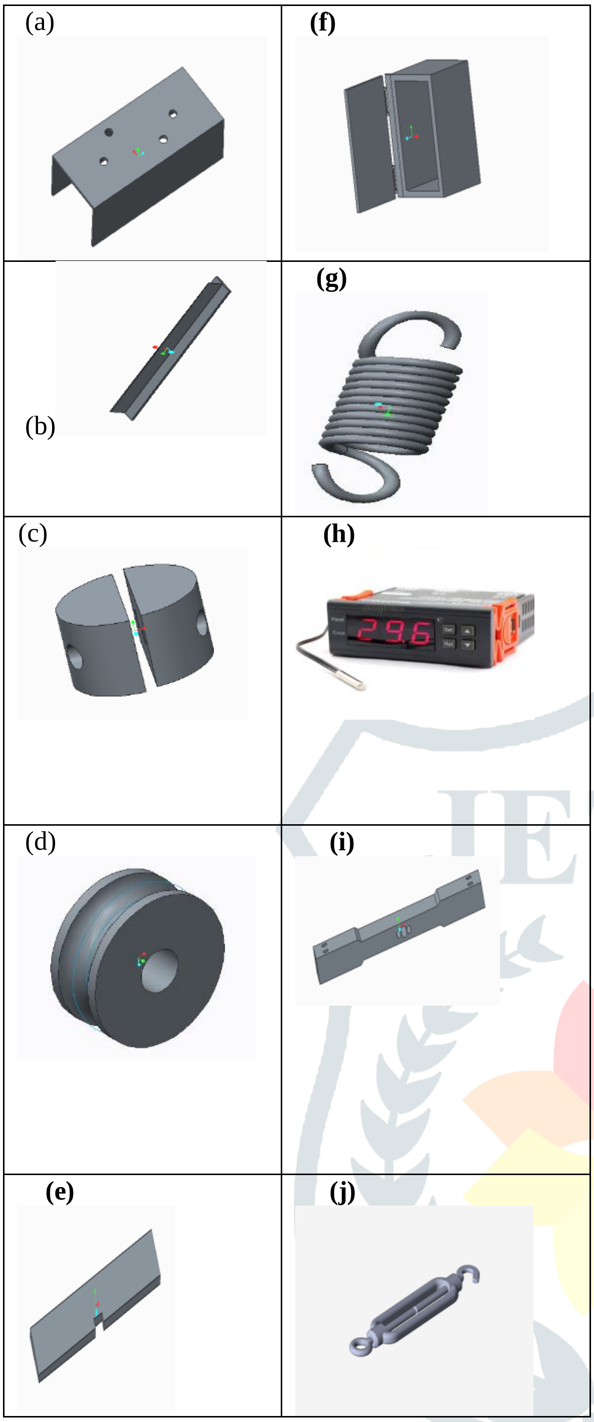


Fig3. Components of Creep Testing Machine (a) Base plate (b) Column (c) Grip for I shape specimen (d) Pulley (e) Top plate (f) Furnace (g) Spring (h) Digital temperature controller (i) Load cell (J) Turn buckle.

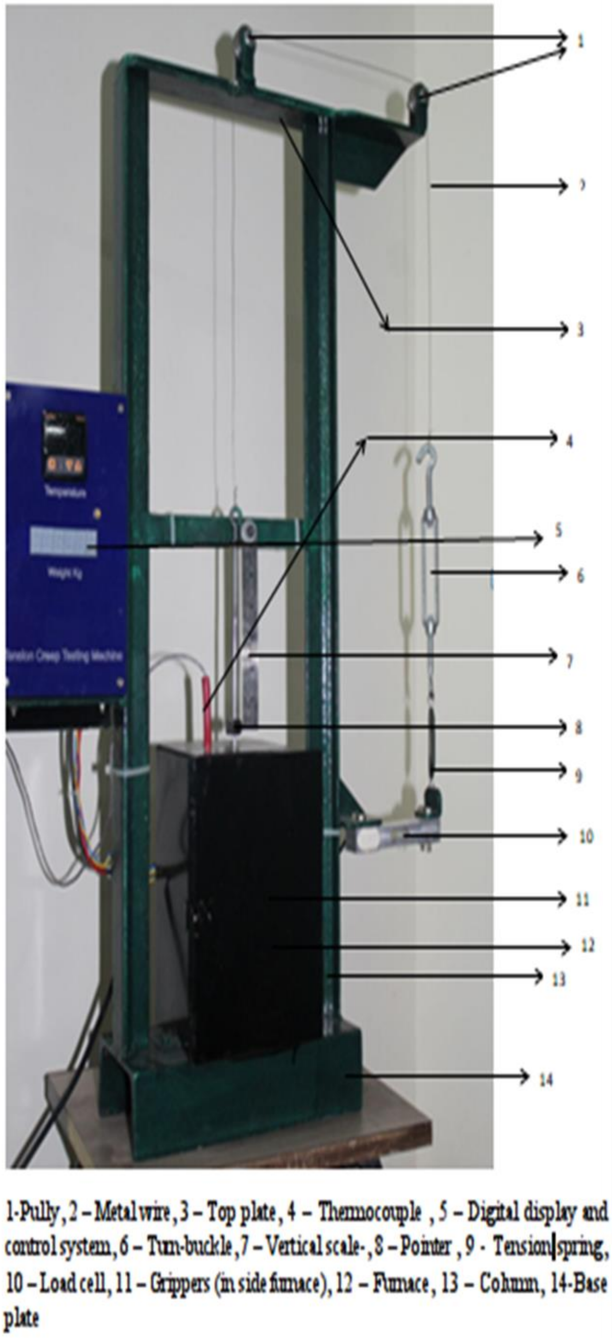


Fig4. Complete Fabricated Machine of Creep Testing machine

2.1.12 Design Calculations for Furnace

The components of the furnace are as follows:

The Heating element
Outer Casing
Insulating Materials
Grippers
Digital Temperature Indicator

The dimensions of the furnace are assumed as follows:-

Outer Length = 152mm
Outer Breadth = 128mm
Outer Height = 224 mm
Inner Length = 124 mm
Inner Breadth = 115mm
Inner Height = 200mm

The furnace is designed for maximum temperature up to 200° C and the outer surface temperature is is assumed to be 30° C. for testing the specimen is fixed in the grippers in furnace which are used to hold the specimen in testing period. The lower gripper is fixed and the upper gripper is movable. After fixing the test specimen, desired load is applied via turn buckle. When the desired load is achieved, required temperature is set inside the furnace by the help of digital temperature controller. Due to applied temperature and load after some time duration, creep phenomena is generated in the test specimen and elongation of length is produced as a result.

Taking properties at the required temperatures from data book such as density (ρ), specific heat (Cp), thermal conductivity (k), kinematic viscosity (υ), prandtl number(Pr).

At To=30°C.

Taking properties calculate Grasshoff number by using formula $Gr_x=\frac{g\beta x^3\Delta T}{\upsilon^2}$

$Gr_L=241.62x10^6$ (at x=L=224mm)

$Gr_LxPr = 169.37x10^6$

Calculating Nusselt no, $Nu=0.59x(Gr_LxPr)^{0.25}$

Nu=67.30

$Nu=\frac{hoxL}{k}$

h_o= 9.00 w/m-K

Similarly, at Ti=200° C

$Gr_L=23.17x10^6$

$Gr_L*Pr=15.76x10^6$

Nu=37.17

hi=7.30 w/m-k

Calculating heat dissipated through wall of the furnace

$Q_w = \frac{To-Ti}{\frac{1}{A1xhi}+\frac{L}{kA2}+\frac{1}{A3+h}}$

Where A_1= 0.124m^2

A_2=0.15m^2

A_3=0.164m^2

K=0.087(from data book for bison sheet)

Q_w= 60 watt

Calculating heat dissipated through grippers, selecting cast steel as a material for gripper as it can sustain the required temperature

Volume=Πxr^2xh

Where $r=35x10^{-3}m$

$h=70x10^{-3}m$

Volume=$2.69x10^{-4}m^3$

Density=7753 kg/m^3

Specific heat= 486 J/kg-K

$Q_g=mCp\Delta T$

Assuming t=15 minutes

M= $2.31x10^{-3}$

Q_g=191.45 watt

The specimen to tested is in the form of I section.

Therefore, selecting Teflon as the material for specimen as its creep temperature is 130.72°C.which is in the range.

Dimensions of I section are:-

Thickness= 2mm

Width= 30mm

length= 50mm

Flange thickness= 10mm

Web thickness= 10mm

Volume=$2x10^{-6}$ m^3

Density= 2200 kg/m^3

Specific heat= 970 J/kg-K

Q_s=mCpΔT

Q_s=0.80 watt

Adding all the heat dissipated

QT=252.25 watt

This energy is absorbed by the elements of the furnace, hence we have to consider heating coil having wattage close to the obtained result.

2.1.13 Design of turnbuckle

Step 1:- Selection of Material for turnbuckle.

Stainless steel

Sut = 465 mpa

Syt = 270 mpa

Step 2:- Selecting M8 designated Turnbuckle for Max load application.

d = 8mm, d_c = 6.466 mm ,P= 400N

Tensile Stress

$$\sigma_t = \frac{P}{\frac{\pi}{4} x d_c^2}$$

$$\sigma_t = \frac{400}{\frac{\pi}{4} x 6{,}466^2}$$

σ_t = 12.18 N/mm^2

Torsional moment

$$M_t = \frac{Pd_m}{2} x \frac{(\mu sec\theta + tan\alpha)}{(1-\mu sec\theta tan\alpha)}$$

For ISO metric screw threads

$\boldsymbol{\theta}$=30° α=2.5° d_m=0.9d

M_t = 0.098 Pd (Equation of Torque)

M_t = 0.098x400x8

M_t = 313.6N-mm

Shear stress

$$\tau = \frac{16\ Mt}{\pi d_c^3} = \frac{16x313.6}{\pi x 6.466^3}$$

τ = 5.91 N/mm^2

The principle shear stress is given by

$$\tau_{max} = \sqrt{\left(\frac{\sigma_t}{2}\right)^2 + \tau^2} = \sqrt{\left(\frac{12.18}{2}\right)^2 + 5.91^2}$$

τ_{max} = 8.486 N/mm^2

Factor of safety

$$fs = \frac{S_{sy}}{\tau_{max}} = \frac{0.5xS_{yt}}{\tau_{max}}$$

$$fs = \frac{0.5x270}{8.486}$$

fs = 15.90

The factor of safety is satisfactory. Therefore, the nominal diameter and pitch of the threaded portion of the rod should be 8mm and 1.25 mm respectively.

Equating shear resistance of the threaded to the tension in the rod,

$$\pi d_c l\tau = P$$

Now,

$$\tau = \frac{S_{ys}}{fs} = \frac{0.5xS_{yt}}{5} = \frac{0.5x270}{5}$$

τ = 27 N/mm^2

Therefore,

$$\pi d_c l\tau = P$$

π x 6.466 x *l* x *27 = 400*

l=0.73 mm......................1

l=d=8mm

l= 1.25d = 1.25x8

l = 10mm.....................2

from 1 and 2 the length of threaded portion is assumed as 9mm.

Design of coupler

P = $\frac{\pi}{4}(D^2 - d^2)\sigma_t$

$\sigma_t = \frac{S_{ut}}{fs} = \frac{465}{5}$ = 99N/mm^2

400 = $\frac{\pi}{4}(D^2 - 8^2)$x99

D = 8.468 mm

Standard portion

D = d =8 mm........................a

D = 1.5d = 1.5 x 8

D = 12 mm..........................b

From a and b, it is decided that the dimension D should be 11mm.

Check for Design

M_t = 313.6 N-mm

r = D/2=12/2

r = 6 mm

J = $\frac{\pi(D^4-d^4)}{32} = \frac{\pi(11^4-8^4)}{32}$

J = 1035.25 mm^4

τ = $\frac{M_t r}{J} = \frac{313.6\text{x}5.5}{1035.25}$

τ = 1.66 N/mm^2

$\sigma_t = \frac{P}{\frac{\pi}{4}(D^2-d^2)}$

$\sigma_t = \frac{400}{\frac{\pi}{4}(11^2-8^2)}$

σ_t = **8.935** N/mm^2

$\sigma_{max} = \frac{\sigma_t}{2} + \sqrt{\left(\frac{\sigma_t}{2}\right)^2 + \tau^2}$

σmax = 9.23 N/mm2

fs = $\frac{S_{ut}}{\sigma max}$ = *17.90*

factor of safety is satisfactory.

Now remaining dimension of turnbuckle

D_1 = d + 10 = 8 + 10

D_1 = 18mm

D_2 = 2xD_1 = 2x18

D_2 = 36mm

L = 6xd =6x8

L = 48 mm

2.1.14 Design of spring

Assume material:- SAE6145- oil quenched and drawn 425^{o}c

From data book by B.D. Shewalkar,

Sut=1570 N/mm^2

G=84x10^3 N/mm^2

Step 1:- Wire diameter of spring

Shear stress(τ) = 0.5x Sut = 0.5x1570

τ =785N/mm^2

Load(P) = 4Kg = 4x9.81 = 39.24N

Nahl factor;

K = $\frac{4C-1}{4c-4} + \frac{0.615}{C} = \frac{4\text{x}6-1}{4\text{x}6-4} + \frac{0.615}{6}$

K = 1.2525

Where, C = 6 ....(standard value)

τ = $K\frac{8PC}{\pi d^2}$

785 = 1.2525x$\frac{8\text{x}39.24\text{x}6}{\pi\text{x}d^2}$

d = 0.978 mm

So, we selected the wire diameter value as **1mm**

Step 2 :- Mean coil Diameter

D = Cxd = 6x 0.978

D = 5.868 mm

So selecting safe value as **D = 10 mm**

Step 3 :- No of active coil

Assume deflection (δ) = 150 mm for load of 4kg i.e 39.24N

δ = $\frac{8PD^3N}{Gd^4}$

150 = $\frac{8\text{x}39.24\text{x}10^3\text{x}N}{84\text{x}10^3\text{x}1^4}$

N = 40.23 turns = 41 turns

As the minimum safe number of turns occurring to be 41 turns. Hence, we are selecting **N = 44 turns**.

Step 4 :- Required spring rate

$$k = \frac{P}{\delta} = \frac{39.24}{150}$$

k = 0.261 N/mm

Step 5 :- Actual spring rate

$$k = \frac{Gd^4}{8D^3N} = \frac{84x10^3x1^4}{8x10^3x44}$$

k = 0.243 N/mm

Here we have done the spring calculation for which we got the safe design parameters and hence we selected the following design dimensions as d=1mm, D=10mm, N=44 turns.

3. RESULT AND DISCUSSION

Experimental creep test were performed on lead specimen with thickness of 1.5 mm and gauge length of 30 mm. In each experiment a constant temperature and load is maintained and creep behaviour is studied with respect to time. Deflection of Lead material at constant Load and Temperature

3.1 Exp-1Constant load and temperature on lead specimen

Material	Lead
Constant temperature	70ºC
Constant load	3kg
TIME(min)	DEFLECTION(mm)
0.00	-
60	0.5
115	1
17	1.5
197	2
205	2.5
207	2.6

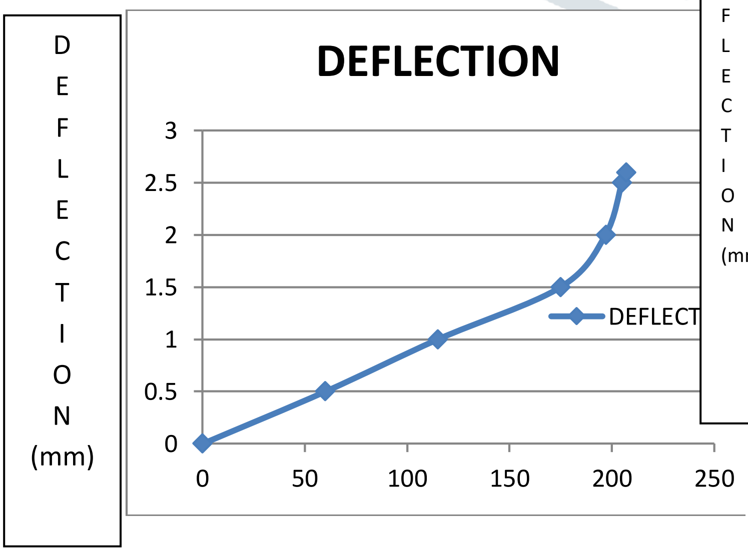


Fig 5 Deflection vs Time Graph

Result Analysis

Material	Lead
Total Deflection	2.6mm
Temperature	70ºC
Load	3Kg
Time	207 min

3.2 Exp-1Constant load and temperature on lead specimen

Material	Lead
Constant temperature	75ºC
Constant load	2.5kg
Time(min)	Deflection(mm)
O	0
19	0.3
50	0.5
80	1
90	1.5
134	1.7
144	2
147	2.1

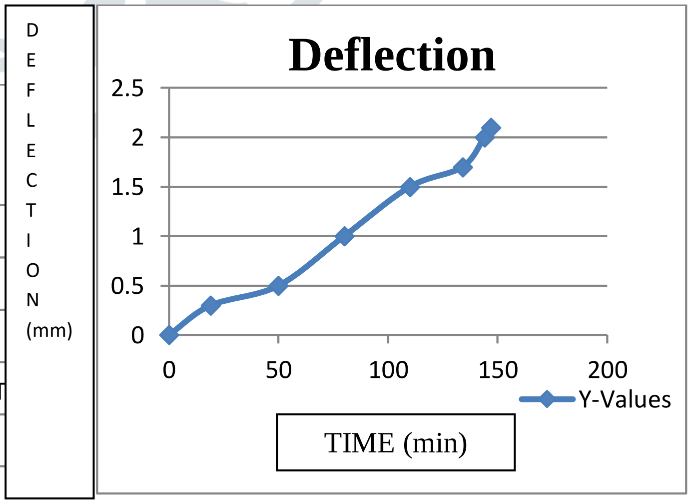


Fig No. 6 Deflection vs Time Graph

TIME (min)

Result Analysis

Material	Lead
Total Deflection	2.1mm
Temperature	75°C
Load	2.5Kg
Time	147 min

4. CONCLUSION

The purpose of this project was to design and fabricate a creep test apparatus which can be used in laboratory to demonstrate creep behaviour of engineering material without using expensive creep testing machine. Turnbuckle of stainless steel having S_{ut} = 465 Mpa and S_{yt} = 270 Mpa, M8 designated was selected according to design calculation and a tensile spring SAE6145- oil quenched drawn 425°c having S_{ut} =1570N/mm^2 and shear modulus of 84x10^3 N/mm^2 were selected according to design calculation.

management and research for providing all the required support for testing materials and fabrication work.

5. FUTURE SCOPE OF ACTION

Analysis work using different materials can be carried out by using the machine.By adding more electronic component like extensometer and data acquisition system, etc, the machine canbe made fully automatic and more accurate analysis can be done.

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