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Performance Evaluation of a Low Cost Creep Testing Machine

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Abstract Mechanical systems and components like steam generators or boilers, nuclear reactors, turbine rotors are operated at very high temperature under significant stress. For this reason, the components and structures need to be designed so that excessive creep distortion must not occur within the expected operating life of the system. Creep is defined as a time-dependent deformation that happens when metals are subjected to constant load at high temperature over a period of time. Knowledge of the creep behavior of metals is therefore important and for this reason Creep testing machines are predominantly used to measure how a given material will perform under constant load, at elevated temperature. This paper aims to study creep properties of various materials being used in high temperature applications through locally made creep testing machine. The basic design of a creep testing machine is the support structure, the loading device, the fixture device (grips and pull rods), and the furnace. The specimen being tested is held in place by the grips and a furnace surrounds the test section and maintains a constant temperature. Maximum applied load on the specimen can be 15 kg and tests could be carried out at maximum temperature of 500°C. Creep curves of strain versus time of aluminum alloy were plotted at a different stress level and temperature. The data are plotted in a simple manner, but analysis easily shows the effect of increased stress due the reduction in specimen cross-section as strain increases. The creep testing machine developed in this work has proven to be satisfactory, cost effective and good alternative to imported creep testing machine.

Keywords: *creep, lattice structure, plastic deformation*

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1. Introduction

Creep has been acknowledged to be the most active failure mechanism of engineering materials under stress at elevated temperature conditions [1]. Engineering components in many industries such as metallurgical processing, power generation, petrochemical, spacecraft, and nuclear plants are normally operated at very high temperature and creep failure of different components/parts has been well reported [2]. So as Creep in system components has catastrophic consequences; therefore, by using testing methods, we are capable of determining the condition and development of creep at any early and non-critical stage [3].

Researchers are testing various samples with a creep machine to understand the process of metallurgy and the physical mechanical properties of a metal and determine whether a sample or material is within the boundary of what they are testing [4].

Creep is dependent on time so the curve that the machine generates is a time vs. strain graph. The slope of a creep curve is the creep rate dε/dt [5] .The trend of the curve is an upward slope. The graphs are important to learn the trends of the alloys or materials used and by the production of the creep-time graph; it is easier to determine the better material for a specific application. A Creep strain curve is shown in the Figure 1.

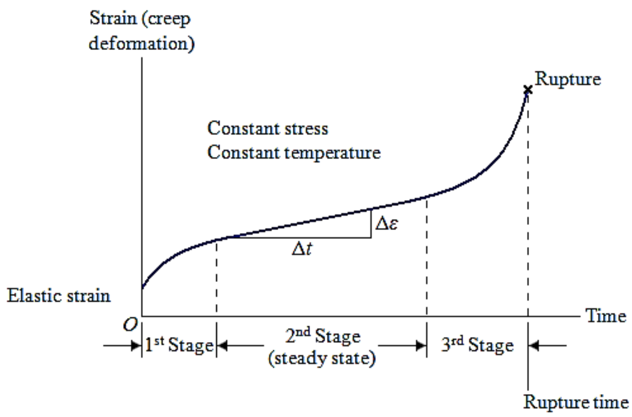

Figure 1. Creep Curve showing the strain-time relationship until stress fracture

There are three stages of creep:

- **Primary Creep**: the initial creep stage where the slope is rising rapidly at first in a short amount of time. After a certain amount of time has elapsed, the slope will begin to slowly decrease from its initial rise.

- **Steady State Creep**: the creep rate has a relatively uniform rate and the curve shows a straight line.
- **Tertiary Creep**: This is a period of accelerating creep rate that leads to fracture. It is associated with necking and consequent stress increase, cracking, metallurgical instability and over-aging. The material is thus less resistant to creep at this stage. The slope of this stage is very steep for most materials.

By examining the three stages above, scientists are able to determine the temperature and interval in which an object will be disturbed once exposed to the load. Some materials have a very small secondary creep state and may go straight from the primary creep to the tertiary creep state. This is dependent on the properties of the material that is being tested. This is important to note because going straight to the tertiary state causes the material to break faster from its form [6].

A linear graph denotes that the material under stress is gradually deforming and this would be harder to track at what level of stress an object can handle. This would also mean that the material would not have distinct stages, which would make object's breaking point would be less predictable. This is a disadvantage to scientists and engineers when trying to determine the level of creep the object can handle [6].

Ritu et al. [7], Alaneme et al. [8], Khan et al. [9] designed and fabricated cost effective, technically efficient, and easily operated creep testing facility for creep behavior analysis of different materials. This paper also aims to study creep properties of various materials being used in high temperature applications through locally made creep testing machine.

2. Design and Construction of Creep Testing Machine

The basic design of a creep machine is the furnace, loading device and support structure. The main type of creep testing machine that is most commonly used is a constant load creep testing machine. The constant load creep machine consists of a loading platform, foundation, fixture devices and furnace.

The casing for the heating chamber was made with 5mm thick metallic sheet. It is first positioned and lined with Glass wool and then plastered using a mixture of kaolin, clay, and water. The top of the furnace is covered with moveable metallic door. Four heating coil is mounted inside the heating chamber and is powered through an industrial switch linked to an AC power source. The progression in heating measured by temperature is monitored with the help of the LED light indicator and temperature controller display. The assembly of the electro-technical devices in its housing required the connection of the thermocouple through the thermocouple lead to the temperature controller. The gripping devices for the mounting of the specimens for testing were positioned within the chamber with the help of hinge both at bottom and the top portion of the heating chamber. The bottom portion of the gripping system connected to the load hanger system with the help of a hinge. On completion of the assembly of the various components of the machine, it was cleaned using emery papers to obtain a smooth finish and then sprayed to improve the finishing. The interior view of the heating chamber and the external view of the fabricated machine are presented in Figure 2.

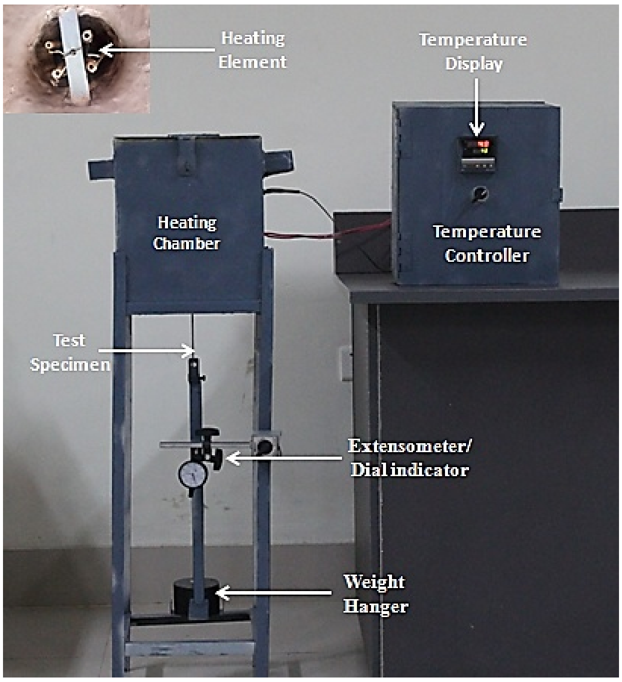

Figure 2. Complete assembled model of creep testing machine

3. Creep Test Procedure

First, fine pieces of aluminum solder wire (3mm diameter) were cut to a length of 50 cm. If there is any bends and kinks in wire it should be removed and properly straightened. Then the initial diameter of the test specimen should be measured and recorded. Then the specimen is to be placed between the lower and upper grips in the heating chamber and carefully tightened by screw so that the specimen could not move up and down. The dial gauge was set to zero while making contact with the loading pan. The desired load was then placed on the pan attached to the loading system holding the specimen. The initial extension was noted. The heating system was switched on and desired temperature was set using the control knob. Extensions were measured against time and consequently, strains were obtained. The process repeated for different temperature with load pan having 8 kg and 10 kg of mass.

4. Results and Discussions

In order to benchmark the new creep testing machine, several standard measurements and calibrations were made. Creep curves of strain versus time were plotted at a stress level of 8.72 MPa and 10.9 MPa with temperature of 300°C, 350°C and 400° C respectively.

Figure 3 and Figure 4 show the effect of temperature on the creep curves of aluminum sample at a constant stress of 8.72 MPa 10.9MPa respectively. From the figure, it is observed that as the temperature increases the steady-state creep rate increases and the rupture time decreases. High temperature also leads to reduced primary, secondary and tertiary creep lives.

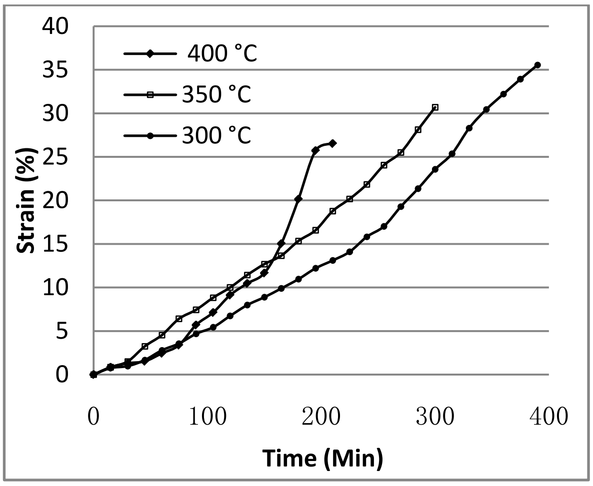

Figure 3. Creep curves of Aluminum sample at 8.72 MPa

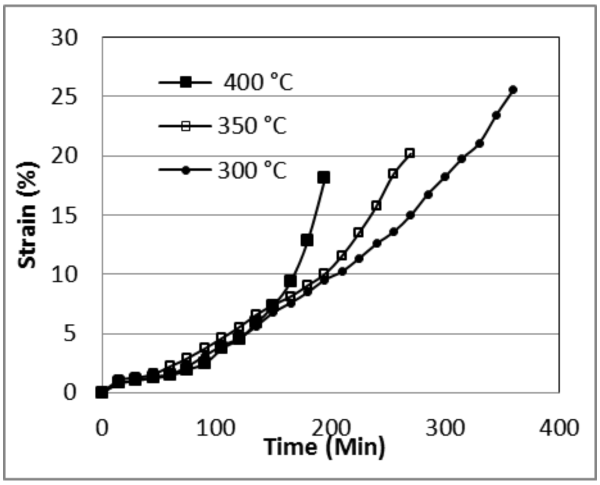

Figure 4. Creep curves of Aluminum sample at 10.9 MPa

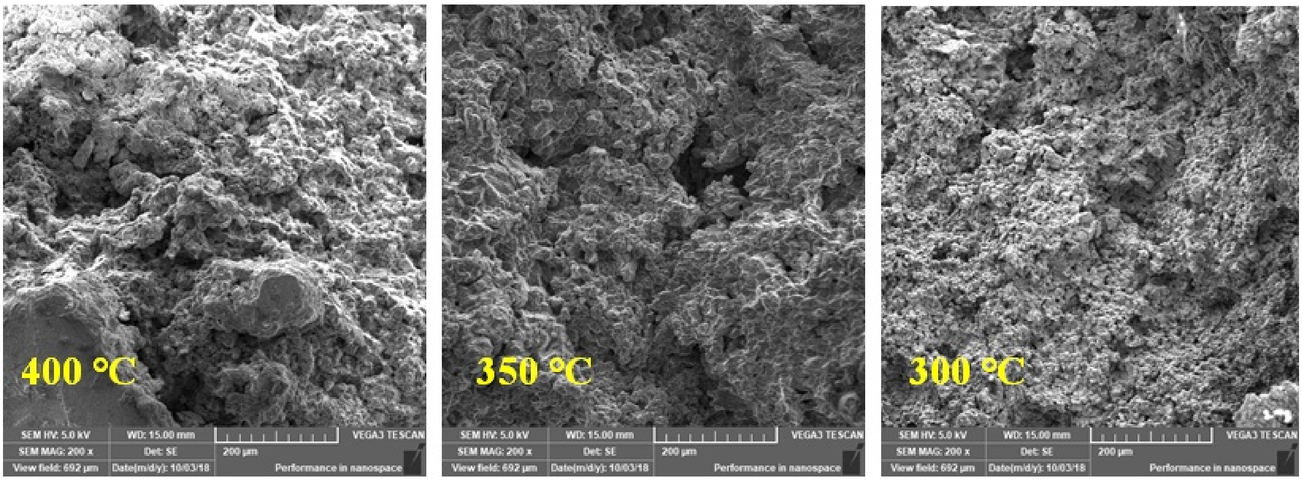

Figure 5. SEM image of fractured surface at 10 kg Load

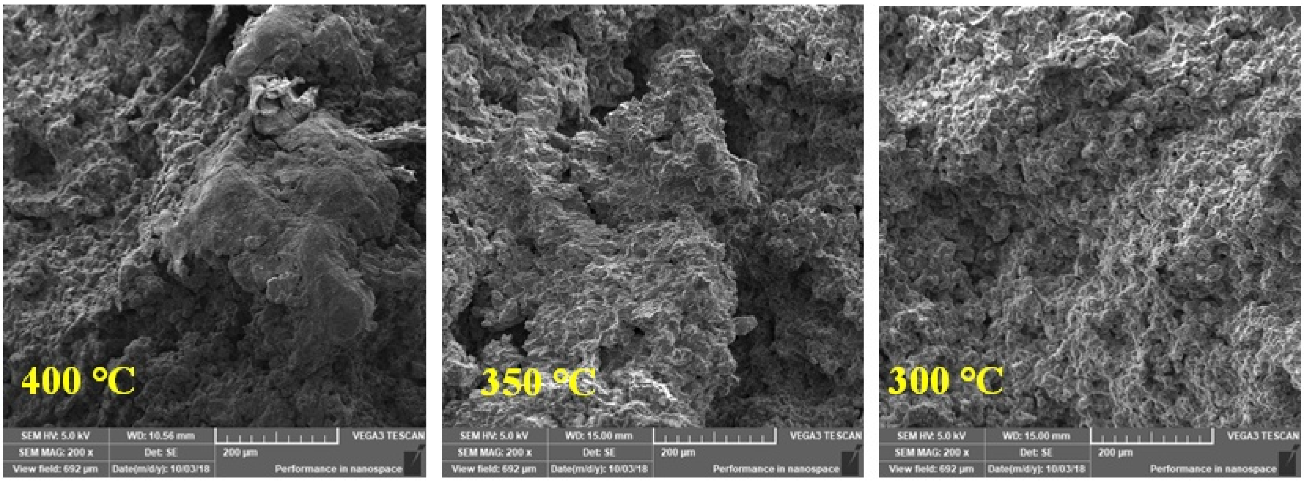

Figure 6. SEM image of fractured surface at 8 kg Load

Table 1. Reduction of diameter with load and Temperature

Sample		Elongation (mm)	Diameter	Reduction of Diameter (mm)
10 kg Load	300 °C	25.59	2.2	0.8
	350 °C	20.18	2.26	0.74
	400 °C	18.8	2.32	0.68
8 kg Load	300 °C	35.56	2.34	0.53
	350 °C	30.68	2.39	0.61
	400 °C	26.52	2.47	0.66

From the data of Table 1, it is also observed that with the increase of temperature and load the elongation of the material is increased and diameter is reduced. Figure 5 and Figure 6 shows the Scanning Electron Microscope images of the fractured surfaces at 10kg and 8 kg load respectively and it is observed that with the increase of temperature the deformation of the fractured surface is increased.

5. Conclusion

The creep test can be done by varying the temperature and loads for the different specimens for the different materials. The machine function was optimized by careful application of some operational strategies especially with the heating unit which is the automated part of the machine. The thermocouple tip is positioned close to the position of the gripping system where the specimens are mounted to ensure that the temperature of the specimen is at the set point temperature value and not just the temperature of the furnace environment that is sensed.

Regular calibration of the temperature controller using an external probe is performed to ensure reliability of the temperature readings obtained from the furnace. When testing is to be performed thorough care is taken to ensure that the specimens are tightly clamped in the chuck to safeguard against removal of specimen when the machine is in operation. It was also ensured that the whole machine set up was securely fasted to the machine frame to ensure safety of operator and machine during testing. The mode of operation of the machine can be easily comprehended and does not require complicated basis for data recording. In the case of machine malfunction, the design was made such that all parts can be easily detached and repaired. The replacement of any of the machine parts and fabrication materials when required can be done easily as all parts used in the design of the machine are relatively cheap and can be sourced locally.

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