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A Novel Design of Constant Load Creep Test Machine

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Abstract

Polymer materials have been used in a wide area from our homes to industry today. For this reason, creep curves from the mechanical properties of polymer materials are an important factor for the correct use of polymers. This article presents a new constant load creep test machine design which is a mechatronic system to perform creep testing of polymers. A low-cost creep test machine was developed by mounting clamps, pulleys, weights and steel cable on top of a main frame. With the measurement unit, the linear movement of the steel cable was detected and recorded with the data logging system together with the ambient temperature. Tests were made with a 15% calcium carbonate reinforced polypropylene specimen. It was observed that the experimental data obtained were compatible with a standard creep test curve. These findings confirm that the presented constant load creep test machine design works efficiently.

Key Words

"Creep Test Machine, Calcium Carbonate Reinforced Polypropylene, Constant Load, Mechatronic System"

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1. Introduction

Materials are generally both viscoelastic and extensible. Viscoelastic materials can be deformed by elongating under the loads they are exposed to. The temperature of the material being tested has a significant impact on a polymer's creep behaviour, which deforms at the fastest rate near the glass transition point. Depending on the rate at which its molecules are distorted, a polymer at a given temperature and molecular weight may behave as either a liquid or a solid. Viscoelastic behaviour is the broad term used to describe this phenomenon. The amount and duration of elongation of materials under a constant load can be quite interesting (Vogel & Papanicolaou, 1983). The permanent deformation of solid materials by continuous constant mechanical loads is called creep or cold flow. The material, which is exposed to loads for a long time, changes in size and shape (Asyraf et al., 2019). The amount of the load, time, temperature, and the structure and morphology of the polymer all affect how much the material deforms under creep (Hughes & Nix, 1986). Most polymers' creep behaviour can be roughly predicted using a power-law model, illustrated by Equation 1., (Osswald & Menges, 2012).

$$\varepsilon(t) = M(\sigma, T)t^n \quad (1)$$

where n is a material dependent property.

According to Hooke's law, the material behaves elastically. According to this principle, the force applied up to the yield strength causes the material to deform in the direction of the force and store elastic energy. If the applied force is removed without exceeding the yield strength, the material tends to return to its original shape. However, if the applied force exceeds the yield strength, the material exhibits a plastic behaviour and begins to tear and breaks (Sun & Frazier, 2007; Taniguchi et al., 2010).

An instantaneous deformation is a purely elastic response when a load is applied. Following this deformation is primary deformation, characterized by a rapid decrease in deformation. The next stage is secondary deformation, a steady-state linear deformation. Tertiary deformation, which occurs as the sample nears fracture, is the acceleration of deformation up to fracture (Plaseied & Fatemi, 2009). The typical stages of creep deformation are shown in Figure 1.

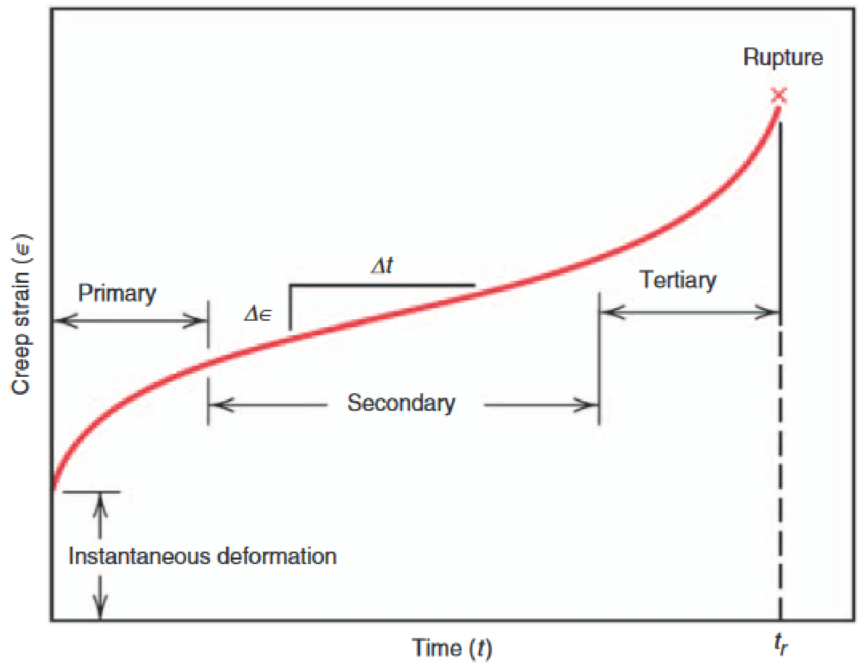

Figure 1.An example of a creep strain vs. time curve at constant tension and increasing temperature shows three separate deformation areas.

Anisotropic materials such as polymeric composites require more than ten years to rupture through creep testing. For this reason, creep tests of such materials are performed at high temperature to shorten the rupture time (Zhang et al., 2004). Therefore, creep tests are performed depending on time and temperature (Asyraf et al., 2020). Although the force applied to the specimen is constant in the creep test, the force applied to the cross-sectional area will increase because the cross-sectional area will decrease with the creep of the specimen. Machines that work with the technique of increasing the force applied to the cross-sectional area are called constant load creep machines, and the test devices in which the force applied to the cross-sectional area is constant are called constant stress creep machine. In constant load creep machines, a specimen is placed between two fixation devices such as a jaw and exposed to a load (Grishaber et al., 1997).

Typically, the temperature at which engineering components in power plants, oil refineries, and chemical industries function is around 500°C. Nuclear power plants and space rockets operate at much greater temperatures (about 1000°C), which calls for materials with high creep resistance. We can identify the condition and progression of creep at any early and non-critical stage by applying testing methodologies since creep in system components may have catastrophic effects (Khan et al., 2015). A horizontal test machine or a vertical test machine can be used to measure creep. The specimen is kept in both scenarios under constant tensile tension and at a constant temperature (Presby, 2015).

In this article, a low-cost test machine has been developed to perform creep tests under constant load of polymeric composite materials, which are widely used today. The most important feature that distinguishes the test device performed from other examples is that it is simple and low-cost to perform creep tests of polymer materials, which are used extensively today. Other reasons are that it can be accessed due to its low cost and can reduce production costs, however, it can be preferred in laboratory studies. Mechanical structure and electronic measurement circuit design has been made and applied. The mechanical structure consists of a main frame, clamps, steel cable transmitting the force and loading weights. Electronic measurement system was realized with microprocessor, rotary encoder, LCD display, temperature sensor and datalogger. A specimen was formed from calcium carbonate reinforced polypropylene composite material and uniaxial creep test was performed using the recommended test machine.

2. Background of Creep Testing Machines

Vicat was the first to examine the subject of high temperature deformation in the modern era and he carried out the experiments with a constant load. It is known that the strength of solids is time dependent, as they break at smaller loads as the time the load is applied increases. In addition, it has been determined that the strength of thermally activated solids changes (Vanel et al., 2009). Creep test machines were designed within the scope of all this information.

In general, there are two types of creep machines with uniaxial tension loading (Grishaber et al., 1997). It is a constant load creep machine using constant weights and constant stress creep machine. As shown in Figure 2, in a conventional creep test device today, specimens are loaded with constant weights by a lever arm mounted on a fixed body. In a standard creep test, specimens are tested in air at a constant temperature with constant weights. In addition, different creep test devices were developed to determine the behaviour of some materials at different temperatures, in different axes and working environments (Asyraf et al., 2020; Kelly, 1976; Ravi et al., 2014). External factors such as humidity and vibration cause uncertainty in creep test results (Buratti & Mazzotti, 2017).

The most important disadvantage of the creep test machine with a typical lever arm is the initial geometry of the sample (Grishaber et al., 1997). Depending on the mechanical structure of the specimen material and the possibility of creating different working conditions, the dimensions and costs of the test machines vary.

The test setup's precision and sensitivity must be extremely good for long-term measurements. The creep behaviour, particularly the second creep stage and the timing of failure, is strongly affected by even little changes in the load conditions. This may result in inappropriate behaviour and inaccurate failure predictions (Jorik et al., 2019). In this study, considering the mechanical properties of polymeric composite materials, a small size and low-cost creep test machine design was presented. Also, tensile creep test apparatus was done to optimize long-term measurements.

3. Design of Creep Testing System

The test machine design was built on a main carrier body. In order to simplify the machine, the lever arm was removed and the specimens were directly loaded. The most striking aspect of the design is the absence of a lever arm. The most striking aspect of the design is the absence of a lever arm. The absence of the lever arm resulted in no load gain, causing tests to be performed at lower loads. In the test machine, the load is transferred to the specimen with a steel cable. The cable span is approximately 280 mm, the overall span of approximately is 600 mm, the width is 400 mm and the height is 600 mm. The maximum test load that the machine can carry is designed as 24 kg. The CAD model and new design of the test machine is given in Figure 3.

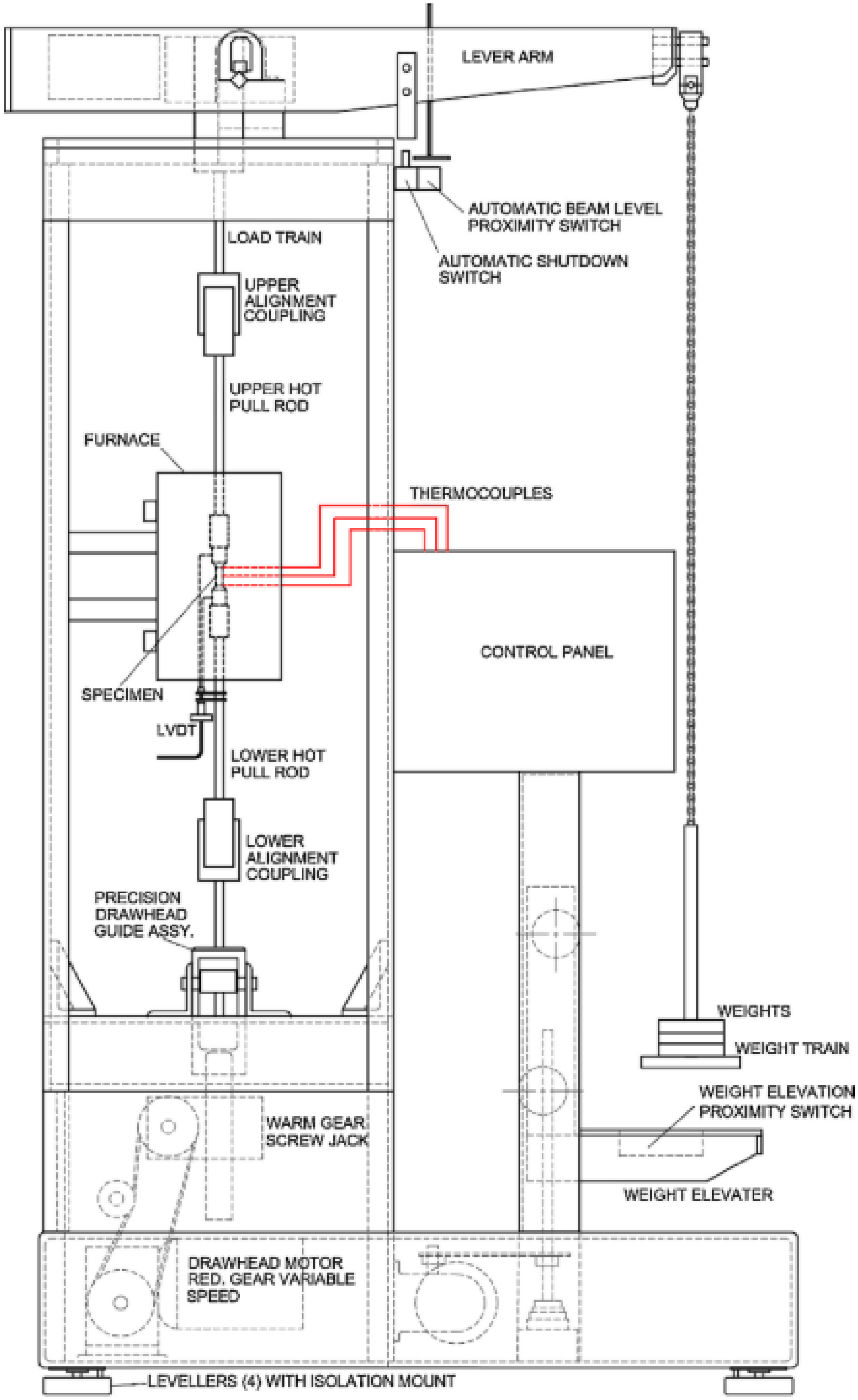

Figure 2. Conventional creep testing machine diagram (Ravi et al., 2014).

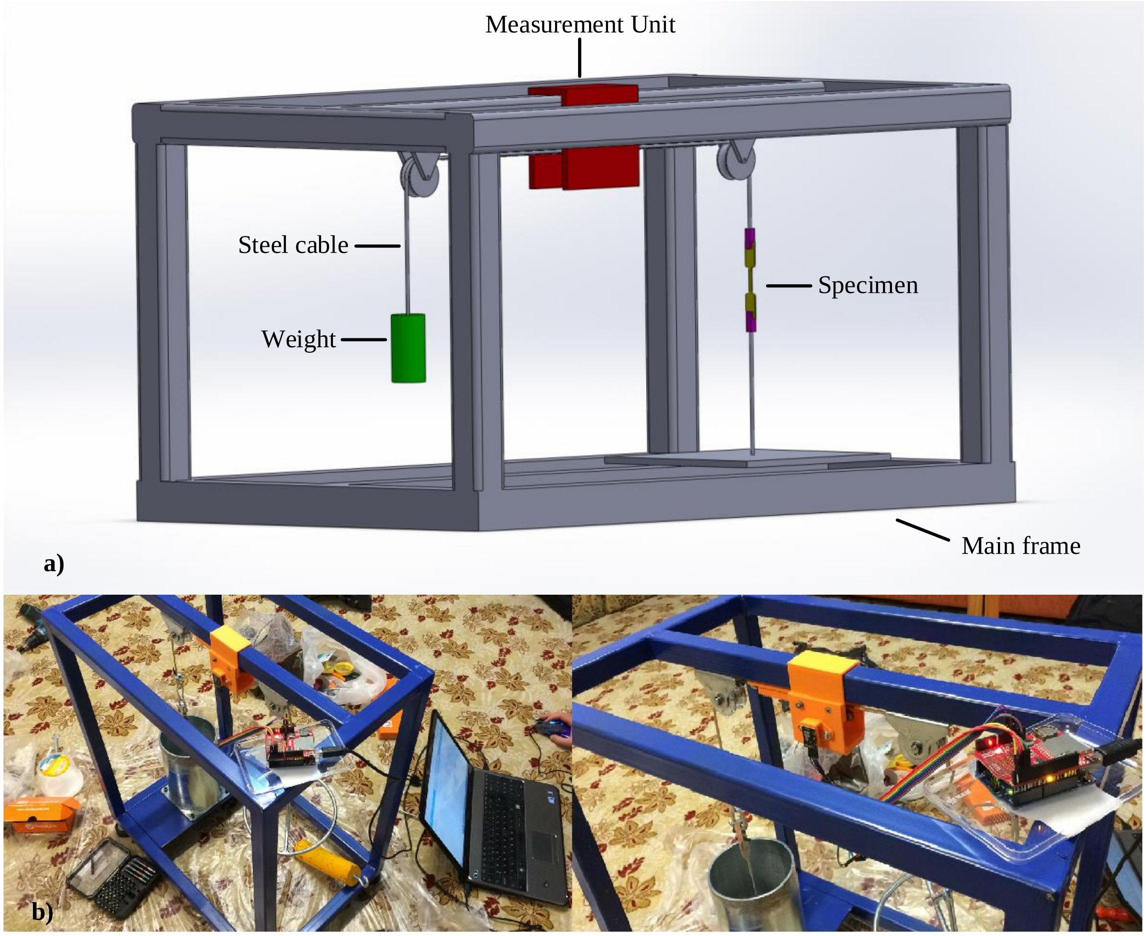

Figure 3. a) The CAD model of the designed creep testing machine; **b)** new design of creep test machine.

The measuring unit works according to the principle of sensing the displacement by the linear gear placed on the cable turning a circular gear. The circular gear rotates rotary encoder and the linear displacement is determined. Since the amount of elongation of the steel cable indicates the creep of the specimen, the data from the rotary encoder is converted to the elongation and recorded with the temperature depending on the time during the test using a data logger. The test device measurement software was created specifically for the mechanical structure of the device. The algorithm was implemented by the authors in an open source compiler without using commercial software. There is no temperature control in the test machine, so the experiments are carried out at ambient temperature and the ambient temperature is also measured and recorded in the experiments. The limits of the test machine are determined by the sensitivity of the electronic equipment and the dimensions of the mechanical structure. The position accuracy of the device is related to the encoder resolution and is 1.57 mm. Maximum creep measurement is 48 mm. A schematic of the creep testing machine is shown in Figure 4.

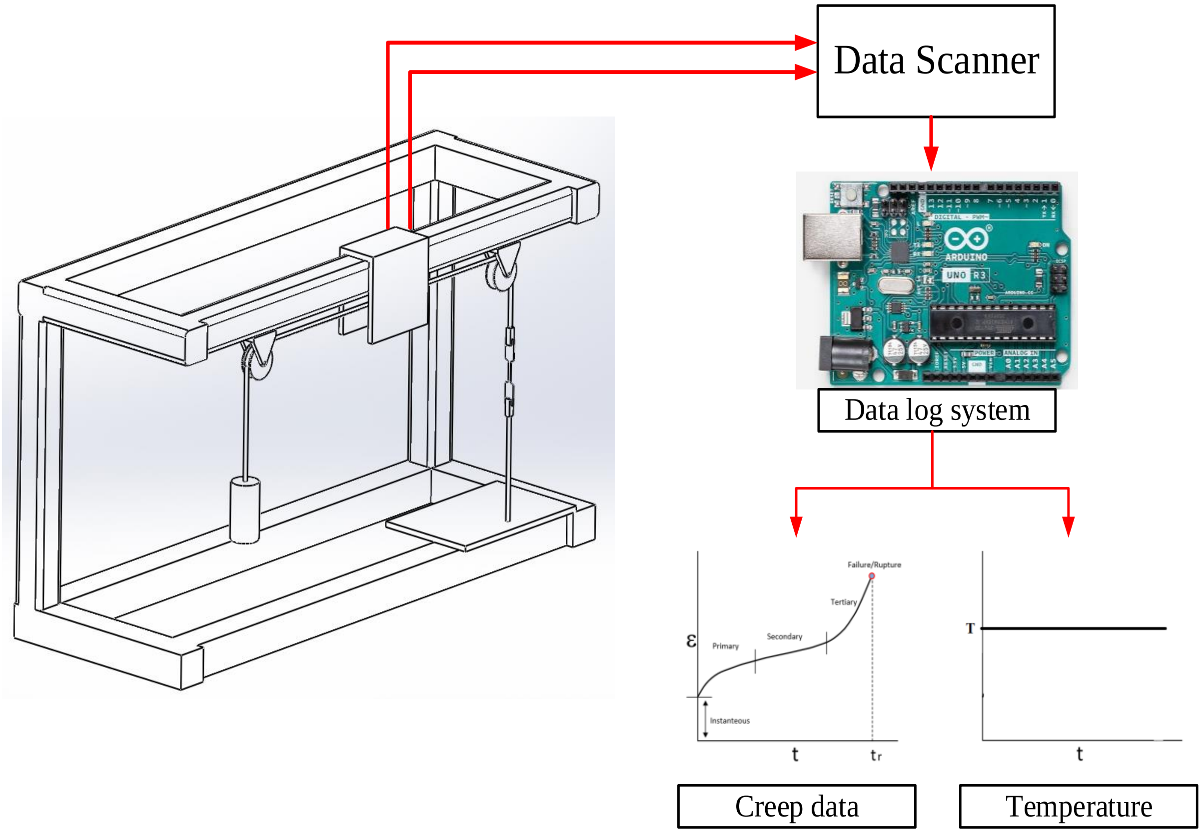

Figure 4. A schematic of the creep testing machine.

4. Testing Procedure

A very commonly used polymeric material was tested with the new test machine. Based on the dead load principle, the load is applied. By adjusting the weight or the cross-section of the specimen, the stress can be altered. A consistent plane stress state results from the specimen being clamped with sufficient accuracy. The test took 16 minutes.

4.1. Material And Specimen

High molecular weight substances formed as a result of the bonding of simple molecules by chemical bonds are called polymers. Today, polymeric materials such as PVC, nylon, teflon are widely used. Polymeric materials are used in many areas in industry, depending on their physical and mechanical properties. For this reason, the information given by the creep tests of polymer materials is important. In this study, a creep test specimen of 15% by weight calcium carbonate reinforced polypropylene (15% CaCO3_PP) composite material was produced by plastic injection molding method. The mechanical properties of the specimen are given in Table 1.

Table 1. Elongation, initial length, final length and percent elongation of specimen.

Tensile strength (MPa)	Young's modulus (MPa)	Poisson's ratio	Shear modulus (MPa)
~ 37	1347.7	0.38377	487.35

The shape and dimensions of the specimen are given in Figure 5 and the specimen was produced according to the standard ASTM D-638 protocol. The specimen is connected by clamps between the main frame and the steel cable. After loading the specimen with a constant weight of 12 kg, the measurement was started at room temperature. During the experiment, the deformation of the specimen and the ambient temperature were recorded with a data logger.

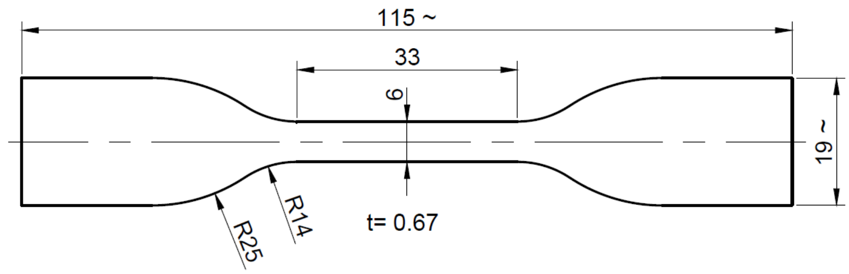

Figure 5. The specimen of %15 CaCO3_PP.

5. Results

A failure mode may or may not be present in creep, a deformation mechanism. When stress is applied, creep deformation does not happen instantly. Instead, persistent stress causes strain to build up. Creep tests at constant temperature take place in three stages. Primary creep takes place at the beginning of the test and the specimen begins to elongate with the effect of dislocation movements. Second creep is called stable creep. At this stage the creep speed is constant and is the longest stage of the testing process. In the tertiary creep, there is an increase in the creep speed and internal cracks and grain boundary separations occur in the material. With the decrease of the cross-sectional area, the deformation speed increases rapidly and the specimen breaks. In experiments, factors such as the type of materials and temperature affect the results. Creep tests of polymer materials also take place in three stages.

In this study, the tests were carried out at ambient temperature and with a 15% calcium carbonate reinforced polypropylene specimen. The elongation-time graph of the material under 28 MPa loading stress is given in Figure 6 and the temperature at which the experiment was carried out is given in Figure 7. When the creep curve is analysed, it is seen that there is a non-linear relationship between time and elongation.

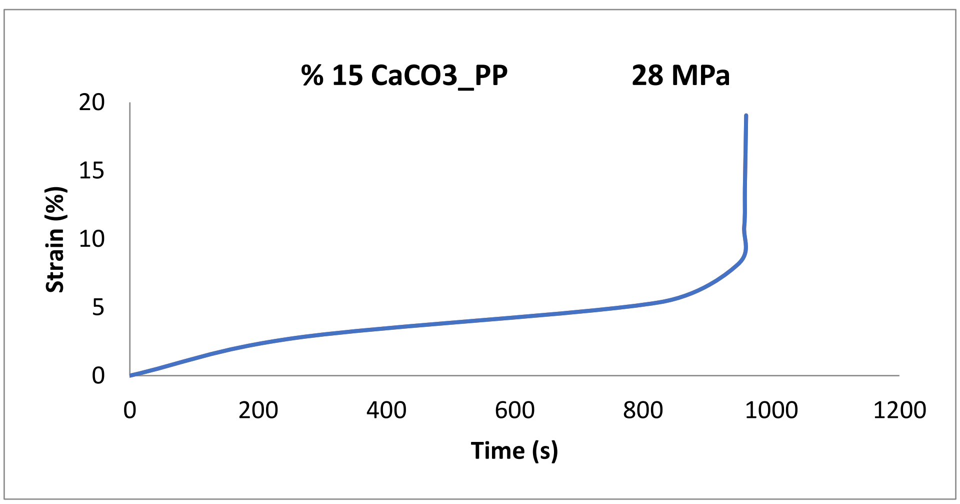

Figure 6. Creep curve of 15% CaCO3_PP.

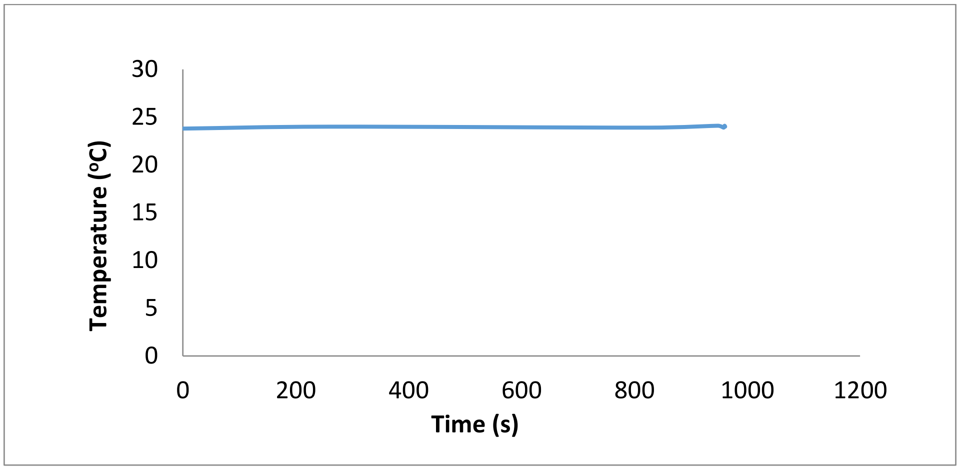

Figure 7. The temperature of the experiment.

In Table 2, time dependent elongation, initial length, final length and percent elongation obtained from the creep test were given. When the data in the table are examined, it is seen that the first stage takes place in the range of 0-260 seconds. In the second stage, the stable creep stage, the creep speed is constant and occurred in the range of 260-826 seconds. At this stage, the material has undergone more deformation because it has softened partially. The third stage started at the 826th second and lasted until the 961th second, when the sample rupture. The picture of the broken sample is given in Figure 8. In this phase, due to the increased creep speed, the sample lengthened. With the lengthening of the size, the cross-sectional area decreased and the stresses on the cross-sectional area increased. As a result of these developments, the specimen broke.

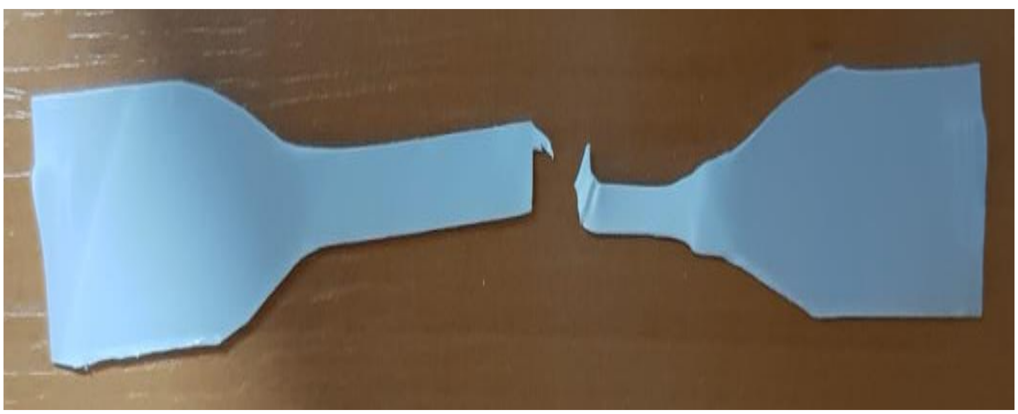

Figure 8. The ruptured specimen with elongation.

Table 2. Elongation, initial length, final length and percent elongation of specimen.

Time (s)	Elongation (%)	Elongation (mm)	The initial length (mm)	The final length (mm)
0	0	0	115.5	115.5
260	2.770563	3.2	115.5	118.7
826	5.367965	6.2	115.5	121.7
948	8.138528	9.4	115.5	124.9
958	10.90909	12.6	115.5	128.1
959	13.67965	15.8	115.5	131.3
960	16.27706	18.8	115.5	134.3
961	19.04762	22	115.5	137.5

6. Conclusion

This study presents a low-cost constant load creep test machine for performing creep testing of polymer materials. Today, polymer materials have a very common usage area and it is very important to know their mechanical properties. Therefore, a simple low-cost test system was created by adding clamps, weights, steel cable and pulleys on a main frame. The measuring unit sensed the linear displacement on the steel cable and recorded the change in sample length depending on time with the data logger system. At the same time, the ambient temperature data was recorded and the temperature information at which the experiments took place was obtained. The test was carried out for the 15% calcium carbonate reinforced polypropylene specimen. It was determined that the obtained data and the elongation graph were similar to a standard creep graph.

In summary, a low-cost test machine has been developed to examine the constant load creep properties of polymer materials. In the future, methods will be proposed for performing temperature-controlled creep tests under variable stresses.

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