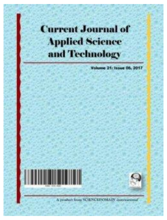

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Development of a Set-up for Creep Test of Biological/Viscoelastic Materials Subjected to Uniaxial Compressive Loading

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Authors' contributions

This work was carried out in collaboration between all authors. Authors AP and AK designed the study, performed the statistical analysis, wrote the protocol and first draft of the manuscript. Author MS guided the analyses of the study. Author MS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

A set-up was developed for testing of creep test of viscoelastic materials like vegetables, fruits etc. creep test was provided under in uniaxial compressive loading. If a constant load is applied to biological materials and if stresses are relatively large, the material will continue to deform with time, this slow deformation with time is known as creep. Green pea kernels were taken in the set-up for testing of creep. Set-up is consisted of a PVC cylinder, two SS plates, a rectangular wooden box, A stand is provided to facilitate mounting of scale for measurement of downward movement of cover plate inside the cylinder. seven different compressive stresses 88.55, 177.11, 265.66, 354.22, 442.77, 531.33 and 708.44 N/m^2 were used and deformation was observed at different time intervals 0, 0^+,5, 10, 15, 20, 45, 60, 90, 120 and 150 minutes. Creep

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curves were plotted to show the variation in volumetric strain for different time intervals. The volumetric strain with respect to variation of loading is maximum in case of maximum stress that was 708.44 N/m^2.

Keywords: Creep test; viscoelastic materials; compressive stresses; volumetric strain; creep curves.

1. INTRODUCTION

Viscoelasticity is the property of materials that exhibit both viscous and elastic characteristics when undergoing deformation [1]. Food show both viscous and elastic properties which are known as viscoelastic materials. Immediate deformation under load in a biological materials is due to their elastic nature where as the deformation that continuous with time is due to the viscous flow of inter cellular fluids under pressure with time [2].

Static uniaxial normal creep is a condition in which the constant shear or dynamic forces involved are all parallel to the longitudinal axis of the specimen [4]. This imposed stress must not be so great as to yield large deformation to the point where elastic limit of the material is exceeded and it no longer behaves as a linearly viscoelastic material [3]. In the creep experiment, when the load (force) is applied to the sample instantaneously the sample is rapidly deformed, imposing a strain on the material which continues to increase at a decreasing rate as a function of time [5]. Regardless of sample dimensions, when the specimen is deformed in compression the strain generated will decrease height of the sample, and result in a increase in the sample diameter or width to a value dependent on the bulk modulus of the material or its poisons ratio [10]. In many cases the transverse strain may be neglected because of the partly compressible nature of the most agricultural materials which cause the resultant lateral strain to be negligible when compared to the uniaxial/longitudinal strain [8]. A plot of uniaxial strain or deformation as a functions of time results in a curve know as creep curve [6]. To prepare the creep curve for freshly harvested green peas seven deformation are measured in the form of volumetric strain [11].

The creep test can be used to predict the deformation of agricultural products such as fruits, vegetables, silage etc. under dead load as a function of time [9]. This is particularly important for transportation and storage of perishable agricultural products [7]. Static uniaxial normal creep is the condition in which a constant dead load (stress) parallel to longitudinal axis of the specimen is suddenly applied and held constant, and the deformation is measured as a function of time [18].

2. MATERIALS USED FOR CREEP TEST

1. Experimental set-up
2. Green pea kernels
3. Load (50, 100, 150, 200, 250, 300,400 gms)

2.1 Experimental Set-Up

Creep in biomaterials is a representative of deformation in biomaterial with respect to time when subjected to compressive load [12].

Following conceptual drawing was prepared to provide guideline for fabricating equipment for creep test of green pea kernels.

Keeping in mind the above conceptual drawing experimental set-up (Plate 1.) was fabricated, for determination of creep behavior as well as volumetric strain of biological materials.

The equipment consisted of a PVC cylinder (Plate 2) 16.6 cm internal diameter and 38 cm in depth and 7 mm thickness of wall was used. This cylinder is used to facilitate placing the grain for uniaxial compressive loading [14].

A rectangular wooden box provided (Plate 3) with a cylinder cavity to firmly hold the PVC cylinder at the bottom [13]. There were four adjustable screws (plate 3) attached to the lower part of rectangular wooden box so as to facility alignment with the horizontal on any platform such that the compressive load applied is perfectly vertical during experimentation [16].

A stand was provided to facilitate mounting of scale for measurement of downward movement of cover plate inside the cylinder. The load applied to the green pea kernels through cover plate placed inside the cylinder was attached to a pointer through a string (plate 4) passing over the four pullies fitted on the stand [15].

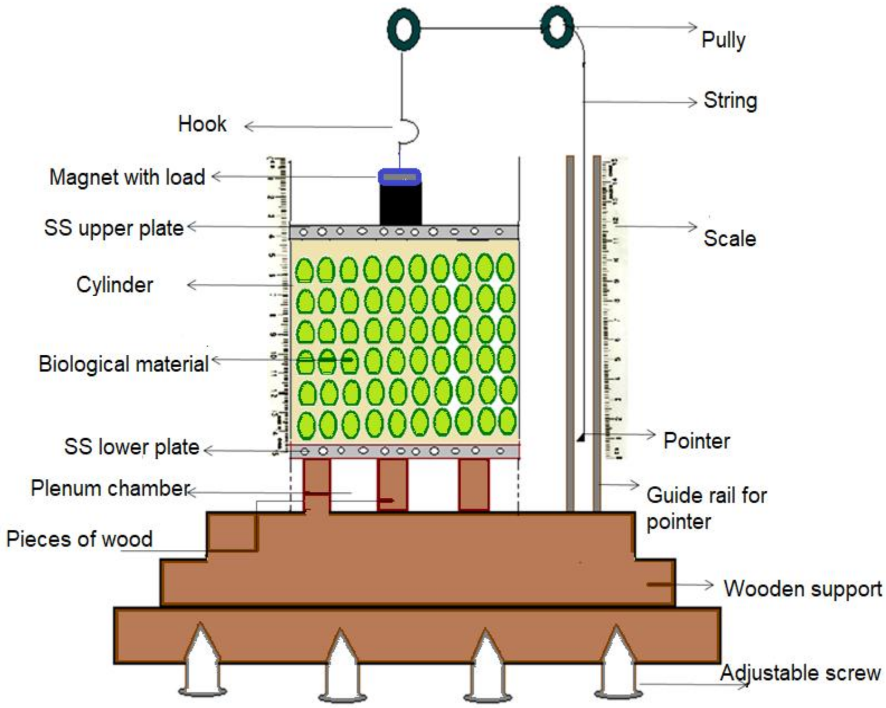

Fig. 1. Conceptual drawing of creep test set-up for viscoelastic materials

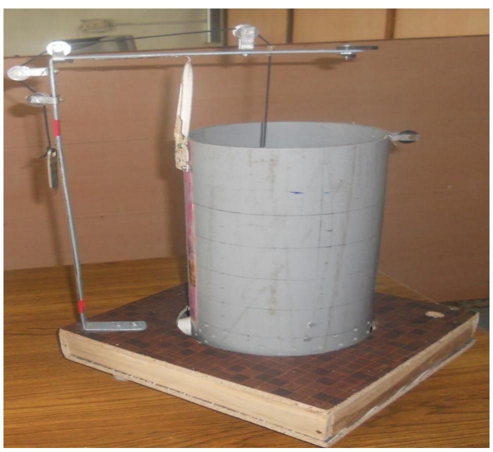

Plate 1. Experimental set-up

To ensure upward movement of pointer on scale along with the downward movement of load inside the cylinder, the string was attached to a magnet force-fitted through a cap and a hook (Plate 5) to the string attached with the pointer [23]. The magnet was attached to the iron load to ensure that the string moves downward inside the cylinder along with the load placed on cover plate [20].

The compression in the green pea kernels resulting in upward movement of pointer attached to the stand [19]. The distance travelled by load inside the cylinder can be directly noted by noting the position of pointer on scale for any given time interval [17].

The PVC cylinder was perforated at the bottom and just above the perforation a perforated SS plate (plate 6) having 16 cm diameter this was fitted with the help of four screws threaded at four diametrically opposite position on a horizontal plane just above the perforation [20]. The purpose of lower circular plate is to provide a firm base to hold the green pea kernels inside the cylinder. The bottom plate was provided (Plate 7) with perforation so that the respiration of green pea kernels Is not obstructed [22]. A similar circular perforated cover plate was provided to cover the green pea kernels on the top and to facilitate placing the desired load on the top surface as well as to transmit the load uniformly over the entire cross section of green pea kernels placed inside the cylinder [21].

The top cover plate was also perforated to permit the respiration of green pea kernels subjected to compressive loading inside the cylinder [25]. The size of perforation was kept smaller than the smallest green pea kernels used in experimentation [24].

Plate 2. PVC cylinder

Plate 3. Rectangular wooden box with four adjustable screws

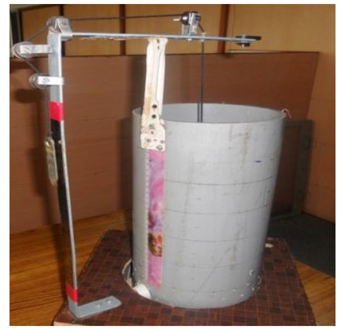

Plate 4. Vertical supporter with four pullies

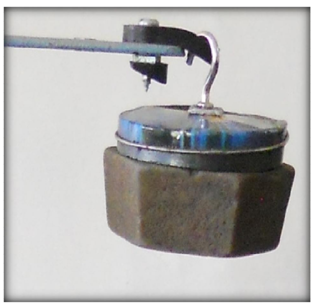

Plate 5. Magnet attached with iron load

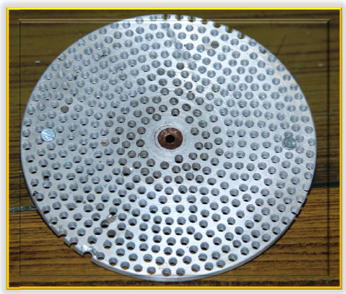

Plate 6. Perforated SS plate

Plate 7. SS lower plate

2.2 Green Pea Kernels

In this experiment it was decided to use green pea kernels for uniaxial compressive loading [26]. The green pea kernels are usually spherical in shape not so firm yet strong enough to bear large compression without any failure due to surface rupture because the green pea kernels are very flexible in nature therefore elastic component denoted by spring in Kelvin model is comparatively high as compare to any other biomaterial [30]. Also looking to the short season of green pea kernels are depodded stored, processed and again store in small containers. Thus providing a opportunity to investigate the depth of container for long term storage of green pea kernels [29].

In this experiment green pea (irrespective of variety) was purchase from local market. Green pea pod was manually depodded and used for the experiment .

2.3 Loads

In this experiment seven loads mainly 50, 100, 150, 200, 250, 300 and 400 gms were used. Loads were taken from the commercial weight box. The load applied was noted in terms of stress applied in N/m^2 over a cross sectional area (0.022m^2). The loads used was converted to stress applied resulting in following seven different stresses 88.55, 177.11, 265.66, 354.22, 442.77, 531.33 and 708.44 N/m^2.

In this experiment, green pea kernels are used inside the PVC cylinder and covered with perforated SS plate. On the cover plate applied the different stresses (88.55, 177.11, 265.66, 354.22, 442.77, 531.33 and 708.44 N/m^2) at different time intervals (0, 0^+, 5, 10, 15, 30, 45, 60, 90, 120, and 150 minutes). Then measured the height of compressed kernels with the help of pointer and also measured the volumetric strain with respect to time.

The deformation is initially high later it is reduced to almost a constant value. The initial high rate of deformation in biomaterials is represented by a spring element where-as slowly creeping increase in deformation with time is represented by a dashpot in a Kelvin model [27]. The Kelvin model is a combination of spring effect as well as viscous effect which is

Plate 8. Placing the SS plate on the sample

Plate 9. Placing the load on the SS plate

represented by a parallel arrangement of a spring and a dashpot. Measurement of creep in biomaterials provides an information regarding behaviour of the biomaterials stored up to different depth in a container. The creep behaviour in biomaterial is represented by Kelvin model [28].

The sample having volume approximating 1190 m^3 was taken in the cylinder; it was then shaken in ordered to let the seeds settle. The seeds were then covered with a perforated cover plate. The depth of top of the cover plate was measured with the help of pointer attached to the cover plate. This depth plus thickness of cover plate when subtracted from the height of the cylinder, gave the height of compress seeds inside the cylinder. The change in volume of seeds sample at any instant with respect to initial volume was calculated, knowing the change in volume the corresponding volumetric strain was calculated. The volumetric strain of all the samples at different time intervals was calculated similarly. A graph was then plotted to show the nature of variation of volumetric strain with respect to time.

3. METHODOLOGY

A sample of green pea kernels weighted in a balance to determine the mass were placed in the cylinder which was shaken to let the kernels settle. Then these kernels were covered with the cover plate. The depth of the cover plate was measured from the top of the cylinder just before and after the application of load at the four previously marked (diametrically opposite) point on the cylinder. The average of these four readings was used to represent the depth of the cover plate. This depth plus the thickness of the cover plate, when subtracted from the total depth of the cylinder will give the height of the sample present in the cylinder. In this experiment used PVC cylinder which had area 0.006 m^2. The volume of the sample was calculated for each time interval (0, 0^+, 5, 10, 15, 30, 45, 60, 90, 120,150, 180 minutes, 0^+ is time just after applying the load). The change in volume (ΔV) of the cylinder, at all time interval (0, 0^+, 5, 10, 15, 30, 45, 60, 90, 120,150, 180 minutes) with respect to its original volume (V_0) was also calculated. Knowing the change in volume (ΔV) the corresponding volumetric strain may be calculated.

The volume of cylinder was calculated by using the following relationship:

Volume of cylinder,

$$V_0 = \pi r^2 l \tag{3.1}$$

Where,

V_0 = original volume of the cylinder,
r = radius of the cylinder,
l = depth of grain inside the cylinder.

The change in volume (ΔV) of the cylinder was calculated by using the following relation:

$$\Delta V = V_0 - V_t \tag{3.2}$$

Where,

ΔV = Change in volume of the cylinder,
V_0 = original volume of the cylinder
V_t = volume at time t

Then volumetric strain for all seven samples for every time interval was calculated by using the relationship:

$$V_\delta = \frac{\Delta V}{V_0} \quad (3.3)$$

Where,

V_δ = volumetric strain
ΔV = change in volume
V_0 = original volume of the cylinder

Creep curves were plotted to show the variation in volumetric strain for different time intervals.

4. RESULT AND DISCUSSION

The creep in biomaterials is a phenomenon the virtue of which a biomaterial subjected to stress goes on deforming with time in the direction of application of stress. The deformation is initially high later it is reduced to almost a constant value. The initial high rate of deformation in biomaterials is represented by a spring element where as slowly creeping increase in deformation with time is represented by a dashpot in a Kelvin model. The Kelvin model is a combination of spring effect as well as viscous effect which is represented by a parallel arrangement of a spring and a dashpot. Measurement of creep in biomaterials provides an information regarding behaviour of the biomaterials stored up to different depth in a container.

In preliminary testing it was found that the deformation of seeds was significant and hence,

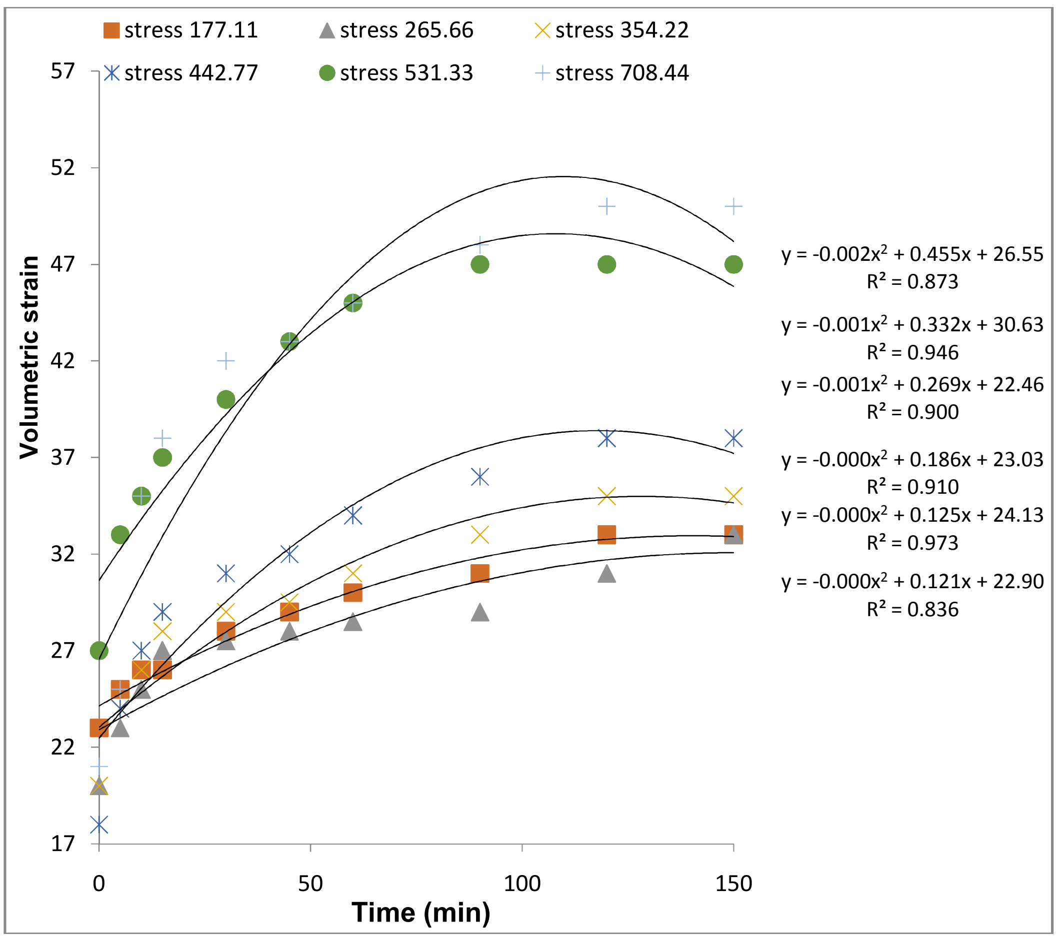

Fig. 2. Curve between volumetric strain and time

it could be measured at the time interval of 0, 0^+, 5, 10, 15, 30, 45, 60, 90, 120 and 150 minutes after application of load. The observations were thus recorded at these time intervals.

The sample having volume approximating 1190 m^3. was taken in the cylinder; it was then shaken in ordered to let the seeds settle. The seeds were then covered with a perforated cover plate. The depth of top of the cover plate was measured with the help of pointer attached to the cover plate. This depth plus thickness of cover plate when subtracted from the height of the cylinder, gave the height of Compress seeds inside the cylinder. The change in volume of seeds sample at any instant with respect to initial volume was calculated, knowing the change in volume the corresponding volumetric strain was calculated. The volumetric strain of all the samples at different time intervals was calculated similarly.

From the curve it is evident that the slope of curve is steep at the beginning and then with the increase in duration of loading the slope of curve flattened down which shows that the rate of change of volumetric strain for a given sample at a given stress is large at the beginning and as the time passes, the rate of change becomes less and less. Also as it is noted from the high value of coefficient of deformation (R^2 =0.972) the relationship between two variables i. e. change in volumetric strain with respect to time is strongly correlated with each other. The reason for slope of curve being steep initially may be as the load is applied, the seeds get rearrange and the air voids are minimized also the elastic deformation take place only initially. During later part of stress application the slope of curve flattened down, the reason for the slope to flatten down with time may be due to reduction of air voids and because viscoelastic deformation becomes smaller with increase in time.

Also it can be noted that the volumetric strain with respect to variation of loading is maximum in case of maximum stress that is 708.44 N/m^2, the pattern of change of the volumetric strain the same and conforms for all the seven compressive stresses. In the creep experiment, when the load (force) is applied to the sample instantaneously the sample is rapidly deformed, imposing a strain on the material which continues to increase at a decreasing rate as a function of time. Regardless of sample dimensions, when the specimen is deformed in compression the strain generated will decrease height of the sample, and result in a increase in the sample diameter or width to a value dependent on the bulk modulus of the material or its poisons ratio.

5. CONCLUSION

A set up was developed for creep test of biological materials. The developed set up has a facility for application of different stresses, measurement of volumetric deformation, housing the desired sample in required quantity and for horizontally levelling of set up. This set up is used for measurement of variation in volumetric strain with time for seven different stresses namely 88.55, 177.11, 265.66, 354.22, 442.77, 531.33 and 708.44 N/m^2.

In creep test of biomaterials, it is comparatively mechanical and apparent to apply a compressive stress and go on observing the variation and deformation with time. All the biomaterials are affected environmental condition therefore long term studies to documents the effect of environmental variation need to be conducted. During maturity, the form of kernels varies therefore in appropriate study should be conducted to find out the effect of stage of maturity in the creep behavior of biological materials. Duration of stress application is a very important component in the study. In the present experiment the maximum duration observed was 150 min however experiment should be designed to observed for longer durations for more number of biomaterials.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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