CREEP TEST AND DEVELOPMENT OF KELVIN'S MODEL FOR GREEN PEA KERNELS SUBJECTED TO UNIAXIAL COMPRESSIVE LOADING

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ABSTRACT

If a constant load is applied to biological materials and if stresses are relatively large, the material will continue to deform with time, this deformation is known as creep. The objective of this study was to develop a device to facilitate the study of creep behavior of biological materials and to validate the Kelvin model for green pea kernels.

A rectangular wooden box provided with a cylinder cavity to firmly hold the PVC cylinder at the bottom. A stand was provided to facilitate mounting of scale for measurement of downward movement of cover plate inside the cylinder. Two perforated SS plates were used in this experiment. Seven different compressive stresses 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 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. The graphical method was used to develop Kelvin model.

Keywords: *rheological behavior, Green Pea Kernels, Compressive loads, Kelvin model.*

INTRODUCTION

Static uniaxial normal creep (13) is a condition in which the constant shear or dynamic forces involved are all parallel to the longitudinal axis of the specimen. 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 (12). 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 (14). 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 (16). A plot of uniaxial strain or deformation as a functions of time results in a curve know as creep curve (13). 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. This is particularly important for transportation and storage of perishable agricultural products.

Viscoelasticity is the property (1, 10, 13) of materials by the virtue of which it exhibit both viscous (8) and elastic (6) characteristics when undergoing deformation. 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, 4, 9).

Creep

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 and progressive deformation with time under a constant stress (15) is known as creep. Creep compliance function is a measure of deformation in a given viscoelastic / biological materials with time (12). It explains how the viscous flow will take place in the viscoelastic materials over the time. In this context the present study is undertaken with following objective:

- To develop a device to facilitate the study of creep behavior of biological materials.
- To validate the Kelvin model for green pea kernels.

MATERIAL AND METHODS

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

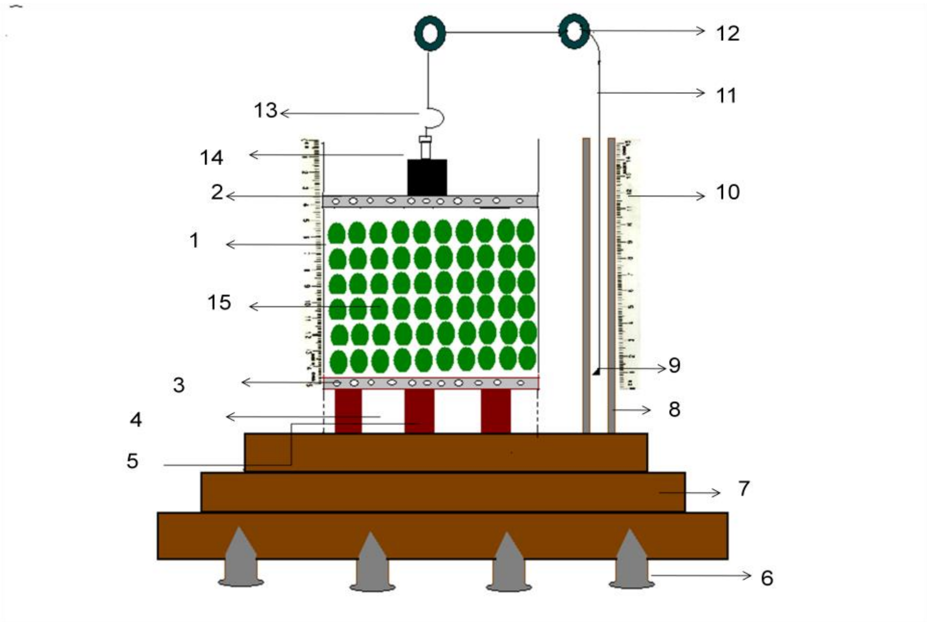

Plate 1 Conceptual drawing of creep test set-up

S. No.	Component	S. No.	Component
1.	cylinder	9.	Pointer
2.	SS upper plate	10.	Scale
3.	SS lower plate	11.	String
4.	Plenum chamber	12.	Pully
5.	Pieces of wood	13.	Hook
6.	Adjustable screw	14.	Weight
7.	Wooden support	15.	Biological material
8.	Guide rail for pointer		

Keeping in mind the above conceptual drawing experimental set-up (plate 2) was fabricated, for determination of creep behavior (5) as well as volumetric strain of biological materials. The equipment consisted of a PVC cylinder 16.6 cm internal diameter and 28 cm in depth and 7 mm thickness of wall was used. This cylinder is used to facilitate placing the grain for uniaxial compressive loading. A rectangular wooden box provided with a cylinder cavity to firmly hold the PVC cylinder at the bottom. There were four adjustable screws 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. 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 (17) through cover plate placed inside the cylinder was attached to a pointer through a string passing over the four pulleys fitted on the stand.

Plate 2 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 to the string attached with the pointer. 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. The compression in the green pea kernels resulted in upward movement of pointer attached to the stand. 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. The PVC cylinder was perforated at the bottom and just above the perforation a perforated SS plate having 16 cm diameter was fitted with the help of four screws threaded at four diametrically opposite position on a horizontal plane just above the perforation. 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 with perforation so that the respiration of green pea kernels is not obstructed. 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.

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

Green pea kernels:

In this experiment it was decided to use green pea kernels for uniaxial compressive loading. 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 (3) therefore elastic component denoted by spring in Kelvin model is comparatively high as compare to any other biomaterial. Also looking to the short season the 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. In this experiment green pea (irrespective of variety) was purchase from local market. Green pea pod was manually de-podded and used for the experiment.

Methodology

In this experiment seven stresses applied were 177.11, 265.66, 354.22, 442.77, 531.33 and 708.44 N/m^2. A sample of green pea kernels weighed in a balance to determine the mass were placed in the cylinder which was shaken to let the kernels settle. 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 gave the height of the sample present in the cylinder. PVC cylinder had cross sectional area 0.006 m^2. The volume of the sample was calculated for each time interval 0^+, 5, 10, 15, 20, 45, 60, 90, 120,150 minutes, (0^+ is time just after applying the load). The change in volume (ΔV) of the cylinder, at all time interval (0^+, 5, 10, 15, 20, 45, 60, 90, 120,150 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.

RESULT AND DISSICUTION

The relationship between volumetric strain and duration of loading for the compressive stress of 177.11, 265.66, 354.22, 442.77, 531.33 and 708.44N/m^2 is shown in Fig. 1.

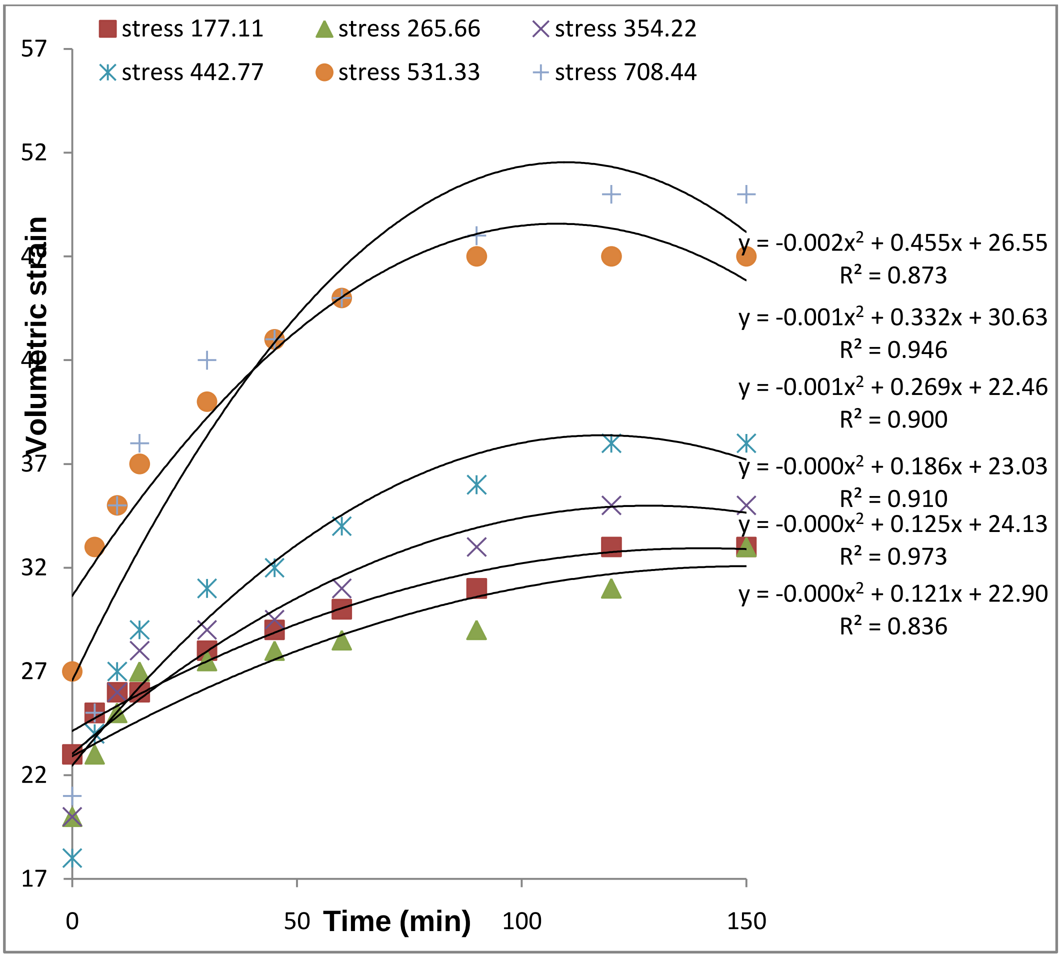

Fig. 1 Curve between volumetric strain and time

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. The equation for the Kelvin model (11) for bio materials subjected to compressive load is given by **:-**

$$\varepsilon = \frac{\sigma_0}{E} + \left(\varepsilon_0 - \frac{\sigma_0}{E}\right).e^{\frac{-t}{\tau_{ret}}}$$

Where,

ε= strain at time t, ε_0 = initial strain, σ_0 = constant stress,

E = young modulus, t= time, τ_{ret} = retardation time.

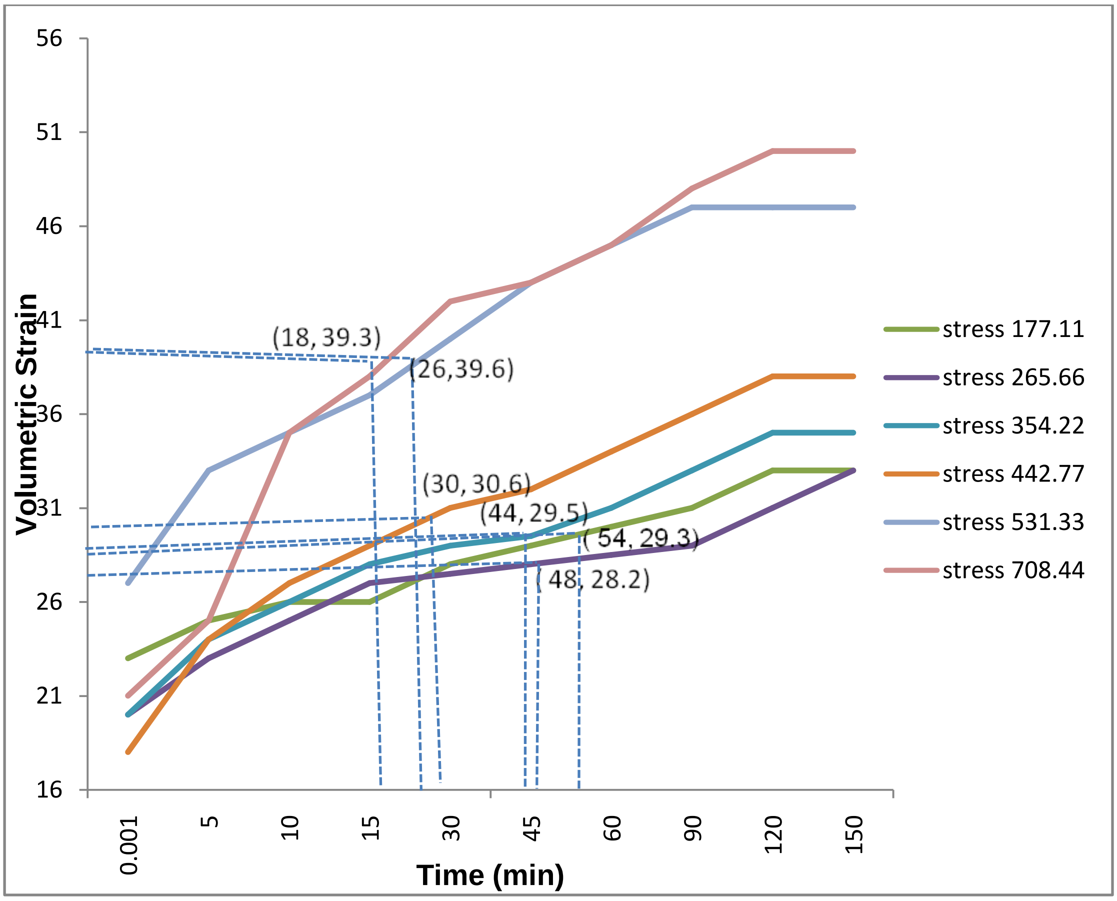

Fig 2 curve between volumetric strain and time

Now as seen from (Fig. 2) the volumetric strain increases with time of application of compressive stress. A tangent to the creep curve drawn from the constant volumetric strain on Y axis gives the value of $\frac{\sigma_0}{E}$ as ‘‘33’’. Also as seen from initial strain at time 0^+ that is just after the application of load the volumetric strain is 23. According to the definition the retardation time corresponds to the volumetric strain equal to sum of initial volumetric strain and 63% of difference of ε_0 and $\frac{\sigma_0}{E}$ which is ‘‘10 minute’’. Therefore the retardation time will converted (7) to the volumetric strain value of 23+63% of 10 =29.3. As noted from graph the retardation time corresponding to volumetric strain of 29.3 is 54 Putting all the values in equation the Kelvin model obtained for compressive loading of green pea kernels for stress of 177.11 N/m^2 is

$$\varepsilon_{(177.11)} = 33 - 10. e^{\frac{-t}{54}}$$

From the above equation it is noted that for compressive stress of 177.11 N/m^2 the retarded deformation starts 54 minute after the application of the stress. During retarded deformation due to spring component becomes insignificant as compared to the retardation due to viscous flow in biomaterials.

Similarly proceeding with the graphical method the Kelvin model was developed for all the remaining five stresses namely 265.66, 354.22, 442.77, 531.33 and 708.44 N/m^2, The Kelvin model derived for all the six compressive stresses is tabulated in table 1.

Table 1 Kelvin model with respect to different stresses.

S. No.	**Stress N/m2**	**Kelvin model**	**Retardation Time**
1	177.11	$\varepsilon_{(177.11)} = 33 - 10 . e^{\frac{-t}{54}}$	54
2	265.66	$\varepsilon_{(265.66)} = 33 - 13 . e^{\frac{-t}{48}}$	48
3	354.22	$\varepsilon_{(354.22)} = 35 - 15 . e^{\frac{-t}{44}}$	44

4	442.77	$\varepsilon_{(442.77)} = 38 - 20 \,.\, e^{\frac{-t}{30}}$	30
5	531.33	$\varepsilon_{(531.33)} = 47 - 20 \,.\, e^{\frac{-t}{26}}$	26
6	708.44	$\varepsilon_{(708.44)} = 50 - 29 \,.\, e^{\frac{-t}{18}}$	18

As seen from column no. 4 of table 1 the retardation time decreases with increase in compressive stress. It is noted that the maximum retardation time of 54 seconds corresponds to minimum compressive stress of 177.11 N/m^2, whereas the minimum retardation time of 18 seconds corresponds to the maximum compressive stress of 708.44 N/m^2. Also as seen from fig. 3 the decrease in retardation time follows a straight line relationship with negative correlated coefficient with decreasing compressive stress. The straight line relationship is given by:

$$Y = -0.0719x + 66.4$$

The negative correlated coefficient value of (R^2 = 0.957) shows a strong association between retardation time and compressive stress.

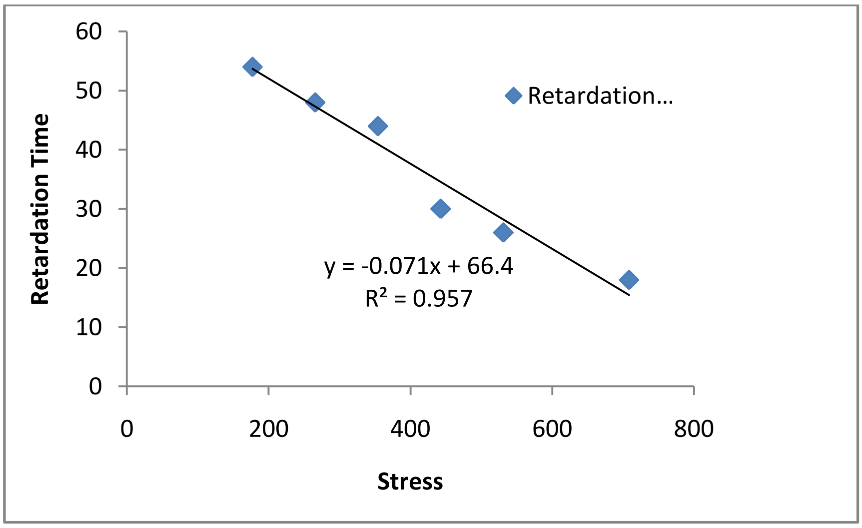

Fig. 3 Variation in time of retardation with different compressive stresses

The decrease in retardation time with increase in compressive stress may be because for higher value of compressive stresses, the elastic phase of deformation in green pea kernels reduces faster as compared to that for smaller value of compressive stress which means for higher compressive stresses the viscous phase in deformation of green pea kernels starts earlier.

CONCLUSION

1. A device as shown in plate no. (1) and (2) was developed for creep test of biological materials. The developed device has a facility for application of different stresses, measurement of volumetric deformation, housing the desired sample in required quantity and for horizontally leveling of device.
2. The developed device is used for measurement of variation in volumetric strain with time for six different stresses namely 177.11, 265.66, 354.22, 442.77, 531.33 and 708.44 N/m^2.

   The Kelvin model developed for different stresses is tabulated in table (1). It was noted from the Kelvin models the retardation time decreased from 54 minutes for 177.11 N/m^2 to 18 minutes for 708.44 N/m^2 and decrease in retardation time is found to have a straight line relationship with a strong but negative correlation coefficient.

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