

Development of a set-up for creep test of biological / viscoelastic materials subjected to uniaxial compressive loading

Aaradhana Patel^{1*}, Dr. Mohan Singh², Avinash kumar³

¹Department of Post Harvest Process and Food Engineering, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh 482004, India

²H.O.D. of Department of Post Harvest Process and Food Engineering, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh 482004, India

³Department of Farm Machinery and Power Engineering, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh 482004, India

Author's contributions:

This work was carried out in collaboration between all authors. Author AP and Author AK designed the study, performed the statistical analysis, wrote the protocol, and wrote the 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.

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/m² 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/m².

34 **KEYWORDS:**

35 *creep test, viscoelastic materials, compressive stresses, volumetric strain, creep*
36 *curves.*

37 **INTRODUCTION**

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

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

61 The creep test can be used to predict the deformation of agricultural products
62 such as fruits, vegetables, silage etc. under dead load as a function of time [9]. This
63 is particularly important for transportation and storage of perishable agricultural
64 products [7]. Static uniaxial normal creep is the condition in which a constant dead

65 load (stress) parallel to longitudinal axis of the specimen is suddenly applied and
66 held constant, and the deformation is measured as a function of time [18].

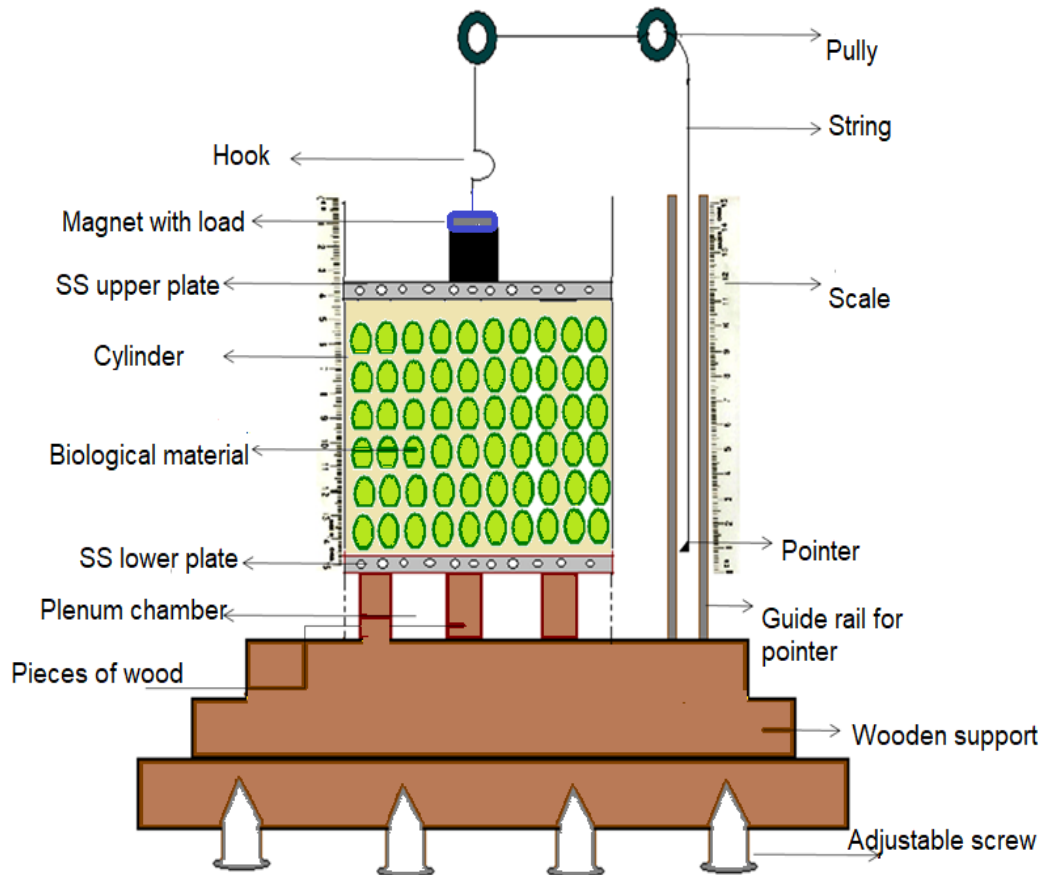
67 MATERIALS USED FOR CREEP TEST

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

71 1- EXPERIMENTAL SET-UP

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

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



76

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

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

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

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

89



90

91

Plate 1. Experimental set-up

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

96 To ensure upward movement of pointer on scale along with the downward
97 movement of load inside the cylinder, the string was attached to a magnet force-
98 fitted through a cap and a hook (plate 5) to the string attached with the pointer [23].

99 The magnet was attached to the iron load to ensure that the string moves downward
100 inside the cylinder along with the load placed on cover plate [20].

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

105 The PVC cylinder was perforated at the bottom and just above the perforation
106 a perforated SS plate (plate 6) having 16 cm diameter this was fitted with the help of
107 four screws threaded at four diametrically opposite position on a horizontal plane just
108 above the perforation [20]. The purpose of lower circular plate is to provide a firm
109 base to hold the green pea kernels inside the cylinder. The bottom plate was
110 provided (plate 7) with perforation so that the respiration of green pea kernels is not
111 obstructed [22]. A similar circular perforated cover plate was provided to cover the
112 green pea kernels on the top and to facilitate placing the desired load on the top
113 surface as well as to



Plate 2- PVC cylinder



Plate 3- Rectangular wooden box
with four adjustable screws



Plate 4- Vertical supporter with
four pullies

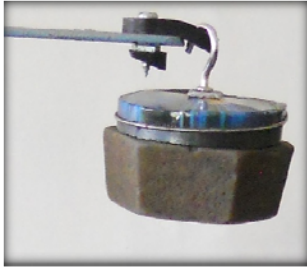


Plate 5- Magnet
attached with iron load



Plate 6- Perforated SS plate



Plate 7- SS lower plate

114 transmit the load uniformly over the entire cross section of green pea kernels placed
115 inside the cylinder [21].

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

120 **2- GREEN PEA KERNELS**

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

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

132 **3- LOADS**

133 In this experiment seven loads mainly 50, 100, 150, 200, 250, 300 and 400
134 gms were used. Loads were taken from the commercial weight box. The load applied
135 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/m².

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/m²) 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 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 cu.m. 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.



Plate a- Placing the SS plate on the sample



Plate b- Placing the load on the SS plate

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,

$$V_0 = \pi r^2 l \text{ ----- (3.1)}$$

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:

$$\Delta V = V_0 - V_t \quad \text{-----} \quad (3.2)$$

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:

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

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.

RESULT AND DISCUSSION

The creep in biomaterials is a phenomenon by 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.

212 In preliminary testing it was found that the deformation of seeds was
213 significant and hence, it could be measured at the time interval of 0, 0⁺, 5, 10, 15, 30,
214 45, 60, 90, 120 and 150 minutes after application of load. The observations were
215 thus recorded at these time intervals.

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

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

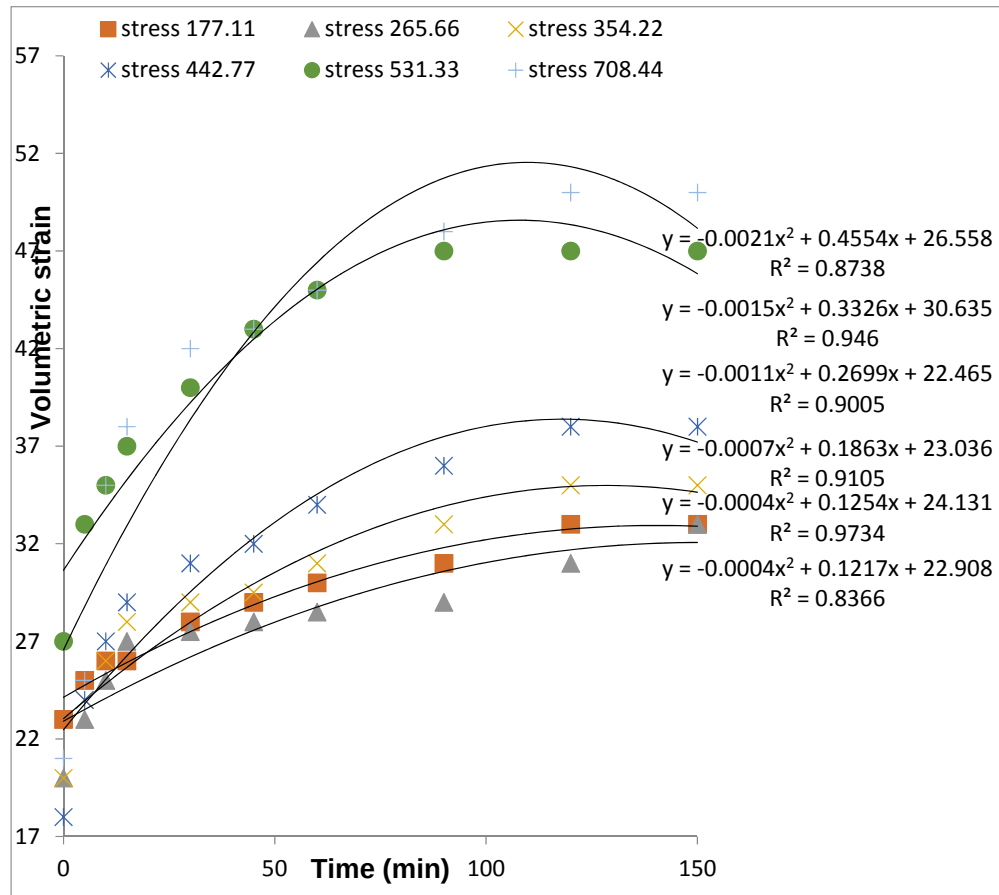


Fig. 2 Curve between volumetric strain and time

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/m², 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.

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/m².

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.

REFERENCES

- [1] Abd El-Maksoud MA, Gamea,GR and Abd El-Gawad, AM. 2009. Rheological Constants of four Elements Burgers Model for Potato Tubers Affected by Various Fixed Loads Under Different Storage conditions. *Misr J. Ag. Eng.* 26(1): 359-384.
- [2] Albaloushi NS. 2013. Rheological Behavior of Tomato Fruits Affected by Various Loads Under Storage Conditions. *American Journal of Engineering Research* 2(3): 36-43.
- [3] Alvarez MD, Canet W, Cuesta F and Lamua M. 1998. Viscoelastic characterization of solid foods from creep compliance data: Application to potato tissue. *Zlebensm Unters Forsch, A*, 207: 356–362.
- [4] Ayman H, Amer Eissa, Abdul Rahman O, Alghannam and Mostafa M Azam. 2012. Mathematical Evaluation Changes in Rheological and Mechanical Properties of Pears during Storage under Variable Conditions. *Journal of Food Science and Engineering* (2): 564-575.
- [5] Banks HT, Hu S and Kenz ZR. 2010. A brief Review of Elasticity and Viscoelasticity for Solids *Advances in Applied Mathematics and Mechanics* 3(1): 1-51
- [6] Berg JD. 2010. Mechanical Testing Device for Vicoelastic Biomaterials. *Mechanical (and Materials) Engineering - Dissertations, Thesis, and Student Research*. Paper 13.<http://digitalcommons.unl.edu/mechengdiss/13>.
- [7] Brodt M, Cook LS and Lakes RS. 1995. Apparatus for measuring viscoelastic properties over ten decades: refinements. *Review of Scientific Instruments* 66(11): 5292-5297.

- 287 [8] Chen CP and Lakes RS. 1989. Apparatus for determining the viscoelastic properties of
288 materials over ten decades of frequency and time. *Journal of Rheology* 33:
289 1231-1249.
- 290 [9] Davis DC, McMahan PF and Leung KH. 1983. Rheological modeling of cooked potatoes.
291 *Transactions of American Society of Agricultural Engineers* 26: 630–634.
- 292 [10] Fafard M, Boudjelal MT, Bissonnette B and Cloutier A. 2001. Three - Dimension
293 Viscoelastic Model with Nonconstant Coefficients. *Journal of Engineering*
294 *Mechanics* 127(8): 808-815.
- 295 [11] Finney, FE and Hall CW. 1967. Elastic properties of potatoes. *Transactions of ASAE*
296 10(1): 4-8.
- 297 [12] Jafarzadeh T, Erfan M, Watts DC. 2004. Creep and Viscoelastic Behaviour of Human
298 Dentin *Journal of Dentistry*, Tehran University of Medical Sciences, Tehran, Iran
299 1(1): 5-14.
- 300 [13] Janssen AM, Van Vliet T and Vereijken JM. 1996. Rheological Behavior of Wheat
301 Glutens at Small and large Deformation. Comparison of Two Glutens Differing in
302 bread Making Potential. *Journal of cereal Science* 23: 19-31.
- 303 [14] Kakar R. 2013. rheological responses of viscoelastic models under dynamical loading.
304 *European Scientific Journal* 9(12): 287-308.
- 305 [15] Kopac M. 1999. Evaluation of a Modified Jefeys Type Model for Viscoelastic Fluids. *Tr. J.*
306 *of Engineering and Environmental Science* 23: 49-57.
- 307 [16] Kucharova M, Doubal S, Klemra P, Rejchrt P, Navratil M. 2007. Viscoelasticity of
308 Biological Materials – Measurement and Practical Impact on Biomedicine.
309 *Physiol. Res.* 56 (1): 33-37.
- 310 [17] Kuo M-I, Wang Y-C, and Gunasekaran S. 2000. A Viscoelasticity Index for Cheese
311 Meltability Evaluation. *Journal of Dairy Science* 83(3): 412-417.
- 312 [18] Levental I, Georges PC and Janmey PA. 2006. Soft biological materials and their
313 impact on cell function. *Journal of the royal society of chemistry* 3: 299-306.
- 314 [19] Linn J, Lang H and Tuganov A. 2013. Derivation of a viscoelastic constitutive model of
315 Kelvin{Voigt type for Cosserat rods. *Berichte des Fraunhofer ITWM*, Nr. p225.
- 316 [20] Maestro A, Gonzalez C, and Gutierrez JM. 2001. Rheological behavior of
317 hydrophobically modified hydroxyethyl cellulose solutions: a linear viscoelastic
318 model. *The Society of Rheology, Inc. J. Rheol* 46(1): 127-143.

319 [21] Mainardi F and Spada G. 2011. Creep, Relaxation and Viscosity Properties for Basic
320 Fractional Models in Rheology. The European Physical Journal 193: 133–160.

321 [22] Mencik J. 2007. Determination of Parameter of Viscoelastic Materials by Instrumented
322 Indentation. Chem. Listy 105: 115-119.

323 [23] Mohsenin NN. 1996. Physical properties of plant and animal materials. Gordon and
324 Breach science publishers, New York p498.

325 [24] Monsia MD (2011a). A Hyperlogistic-type Model for the Prediction of Time-dependent
326 Nonlinear Behavior of Viscoelastic Materials. International Journal of Mechanical
327 Engineering 4: 1-4.

328 [25] Monsia MD (2011b). A Nonlinear Generalized Standard Solid Model for Viscoelastic
329 Materials. International Journal of Mechanical Engineering 4: 11-15.

330 [26] Monsia MD (2011c). A Modified Voigt Model for Nonlinear Viscoelastic Materials.
331 International Journal of Mechanical Engineering 4: 17-20.

332 [27] Monsia MD (2011d). Lambert and Hyperlogistic Equations Models for Viscoelastic
333 Materials: Time-dependent Analysis. International Journal of Mechanical
334 Engineering 4: 5-10.

335 [28] Monsia MD (2011e). A Simplified Nonlinear Generalized Maxwell Model for Predicting
336 the Time Dependent Behavior of Viscoelastic Materials. World Journal of
337 Mechanics 1: 158-167.

338 [29] Moravec F and Letzelter N. 2007. On the modeling of the linear viscoelastic behavior of
339 biological materials using Comsol Multiphysics. Applied and Computational
340 Mechanics 1: 75 –184.

341 [30] Mow VC, Kuei SC, Lai WM and Armstrong CG. 1980. Biphasic Creep and Stress
342 Relaxation of Articular Cartilage in Compression. Theory and Experiments, JBME
343 102(1): 73-84.

344