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Determination of Stress Relaxation of Three Varieties of Benue State Grown Yam Tubers

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ABSTRACT

The determination of stress relaxation of three varieties of Benue state grown yams was carried out using the universal testing machine to study the behaviour of the named varieties; bitter yam, water yam and white yam tubers under loading. The yam tubers were cut into cubes of 2700mm^3 and the stress relaxation was observed under the application of constant stress and constant strain. It was observed that the stress relaxation across the three varieties of yams ranged from 0.0370460-0.0983780 (Mpa) with water yam (Dioscoreaalata) having the highest value of 0.0983780Mpa while bitter yam (Dioscoreadumetorum) have the least value of 0.0370460Mpa. ANOVA revealed a significant difference in the compressive stress at total relaxation (Mpa), compressive load at total relaxation (n), load at total relaxation (n), maximum compressive stress (Mpa), compressive load at maximum compressive stress (n) and load at maximum compressive stress (n) of the three varieties of yam tubers while there's no significant difference in the compressive strain at total relaxation (mm/mm), compressive extension at total relaxation (mm), extension at total relaxation (mm), compressive strain at maximum compressive stress (mm/mm), compressive extension at maximum compressive stress (mm), and extension at maximum compressive stress (mm) of the three varieties of yam tubers. These results are important for maximum efficiency in designing equipment for further processing of yam and the reduction of its mechanical damage during postharvest operations such as transportation, packaging and storage of yam tubers.

Key words: Stress Relaxation, Yam Varieties, Benue State

INTRODUCTION

Yams (*Dioscorea Species*) are starchy staples in the form of large tubers produced by annual and perennial vines grown in Africa, the Americas, the Caribbean, South Pacific and Asia [1]. There is over six hundreds of wild and domesticated Dioscorea Species across the globe. White yam (*D. Rotundata*) is the most important species in the dominant yam production zone in West and Central Africa. It is indigenous to West Africa compared to the Bitter yam (*D. Dumetorum*). Water yam (*D. Alata*) is the second most cultivated species originated from Asia and the most widely distributed in the world [2].

Nigeria produces yam in high quantity and accounts for about 70% of the world's total yam production, and because of this, it is termed the largest producer of yams globally followed by Ghana and Côte d'Ivoire with their respective quantity in metric tons of 40,500,000, 6,074,574 and 4,731, 719 [1].

Yam is highly grown in Benue State of Nigeria which is the Food Basket of the Nation and other States such as Taraba, Niger, Enugu, Cross River, Adamawa, Delta, Ekiti, Imo, Edo, Kaduna, Ogun, Kwara, Ondo, Osun, Plateau and Oyo are also producers of different varieties of yam even though it grows better in some States, which is attributed mostly to the soil type.

Yams are grown for direct human consumption and are marketed raw or processed by boiling, baking or frying. Boiled and baked yam can be eaten with vegetable sauce or palm oil. Boiled yam can also be pounded or mashed in mortar and eaten as "fufu". It is one of the common foods served during traditional marriages and occasions in Benue State. It is also processed into several food products such as the yam flour, which are enjoyed in many parts of the tropics. Industrial processing and utilization of yam includes starch, poultry and livestock feed and flour productions among others [3].

Transportation of yam tubers in Nigeria is done by some of the farmers on their heads using materials like baskets and sacks; and sometimes tied together and transported by Bicycles and wheelbarrows. Transportation could be done using improved transportation system like motorcycle, pick-up vans, Lorries and trucks in conveying yam tubers from farms to homes or markets [4]. When yam tubers are harvested, they are still living organisms, and during postharvest operations, yams should be handled with care to reduce bruising and breaking of the skin which is relatively soft textured, compared to cereal [5]. Yams with irregular shape are difficult to pack conveniently or effectively during handling. The large size and awkward shape of the tubers always renders them very liable to mechanical damage during transportation, especially when transported by road (without proper handling methods) and the damage inflicted can enhanced decay.

Viscoelasticity of Yam

Yam just like any other biomaterial, when subjected to applied load respond in a characteristic manner which is dependent on the properties of the material and can be used to describe the material under test.

Elasticity is the characteristic of a material which allows the material to return to its original dimensions upon the release of a deforming stress. In an ideal elastic material, the strain is proportional to the applied stress and these two factors are related through the "Modulus of Elasticity" or "Young's Modulus". This relationship is expressed in the form: $\sigma = E\varepsilon$

Where, *E=Young's modulus,*

σ = stress, in pounds per square inch and

ε =strain, in inches per inch

A viscous material will show no tendency to return to its original, dimensions or internal arrangement after it has been strained. Viscosity is commonly considered in relation to fluids and is regarded as the internal resistance of the material to the application of a shearing force. A material which exhibits both elastic and viscous properties is defined as being "Viscoelastic". Viscosity may arise in a solid due to a flow of the particles of the material in respect to each other without exhibiting a strain hardening. Viscosity in a solid is characterized by two factors; stress relaxation and creep deformation [6].

Stress Relaxation

Stress relaxation in a material is characterized by the gradual dissipation of an applied stress when the material is held under a constant strain. The form of the stress relaxation curve is the characteristic of the material under test and is used to define the relaxation time constants of the material. Many viscoelastic materials have several relaxation constants to take into consideration the shape of the relaxation curve [6].

This study aimed at determining the stress relaxation of three varieties of Benue State grown yam namely; white yam, bitter yam and water yam which will provide data for the development of better means of transportation, packaging and storage of yam tubers.

MATERIAL AND METHODS

The three varieties of Benue grown yam; Bitter yam, Water yam and White yam (Plate 1, 2 and 3) used for this work were gotten directly from a farm in Zakibiam, Benue State and transported in perforated cartoons to the Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Nigeria for experimentation.



Plate 1: Water Yam **Plate 2:** White Yam **Plate 3:** Bitter Yam

Each sample was cut into cubes of five replications with dimension of approximately $2700mm^3$. The specimen was fixed up to the jigs of the Universal Testing Machine and the load balanced on the specimen by clicking on the load cell soft key which displayed zero. The extension was set to ZERO and the extensometer was allowed to balance for the test to begin. The crosshead moved at the specified rate until the test was stopped. As the end of test conditions were met, the screen returned to the beginning of test screen. The extensometer was balanced on the specimen by pulling the spring clips back. After the specimen was stretched, the readings were computed automatically by the computer and this procedure was repeated for all samples.

RESULTS AND DISCUSSION

RESULTS

Table 1 shows the mean results gotten from the compression test experiment of three varieties of Benue State grown yam (bitter yam, water yam and white yam) and the stress-time relationship between the three varieties of yam is shown in Fig. 1, 2, 3 and 4.

Table -1 Compressive Stress and Compressive Strain of Three Varieties of Yams with Time

Samples	Time (sec)	Compressive Strain (mm/mm)	Compressive Stress (Mpa)	Compressive Extension (mm)	Compressive Load (N)
	00	0.000000	-0.000340	0.000000	-0.21296
	10	0.027778	0.027698	0.833630	34.34925
	20	0.055552	0.075918	1.666940	59.26691
Bitter Yam	30	0.060000	0.066294	1.799940	59.54347
	40	0.060000	0.060994	1.799940	56.15685
	50	0.060000	0.058016	1.799940	54.37037
	60	0.060000	0.055714	1.799940	53.04504
	00	0.000000	-0.004050	0.000000	-0.29931
	10	0.027780	0.100550	0.833500	71.1708
	20	0.055554	0.205092	1.666810	174.9375
Water Yam	30	0.060000	0.180494	1.800000	164.3689
	40	0.060000	0.165180	1.800000	153.69859
	50	0.060000	0.155954	1.800000	147.2729
	60	0.060000	0.148722	1.800000	142.63978
	00	0.000000	-0.000556	0.000000	-0.39718
	10	0.027780	0.066752	0.833310	16.20479
	20	0.055550	0.150598	1.666500	85.59156
White Yam	30	0.060000	0.132692	1.799940	80.90162
	40	0.060000	0.122850	1.799940	75.47055
	50	0.060000	0.116986	1.800000	72.33867
	60	0.060000	0.112602	1.800000	70.06866

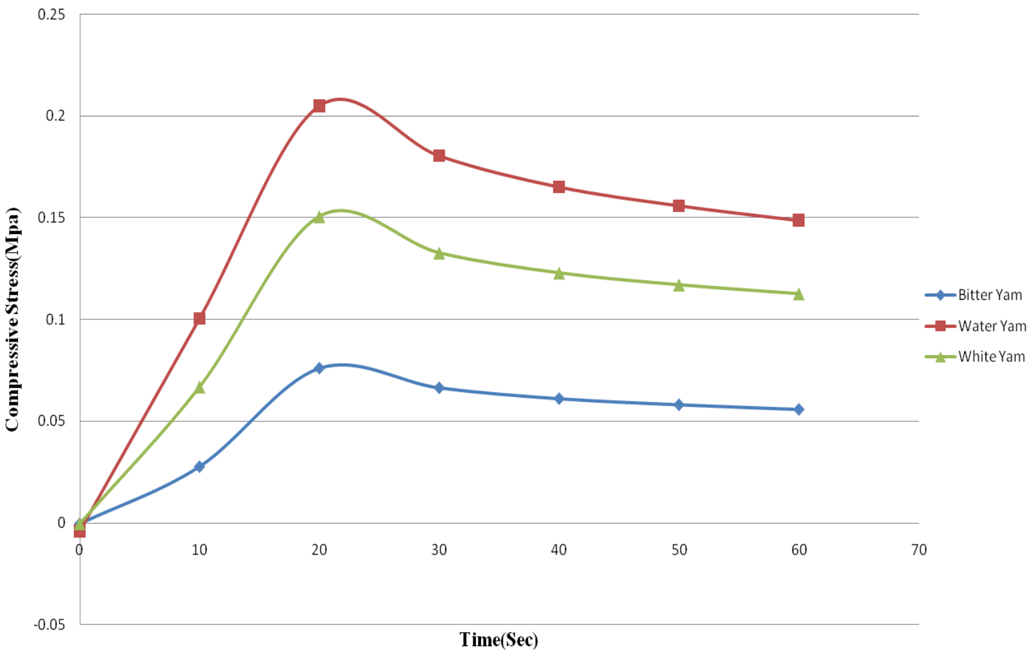

Fig. 1 Stress-Time Curve of Three Varieties of Yams

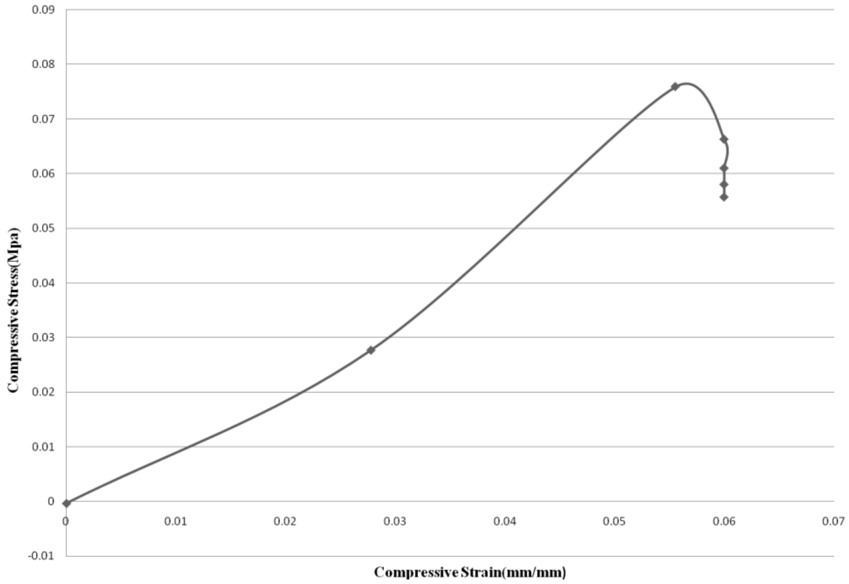

Fig. 2 Compressive Stress-Strain Curve for Bitter Yam

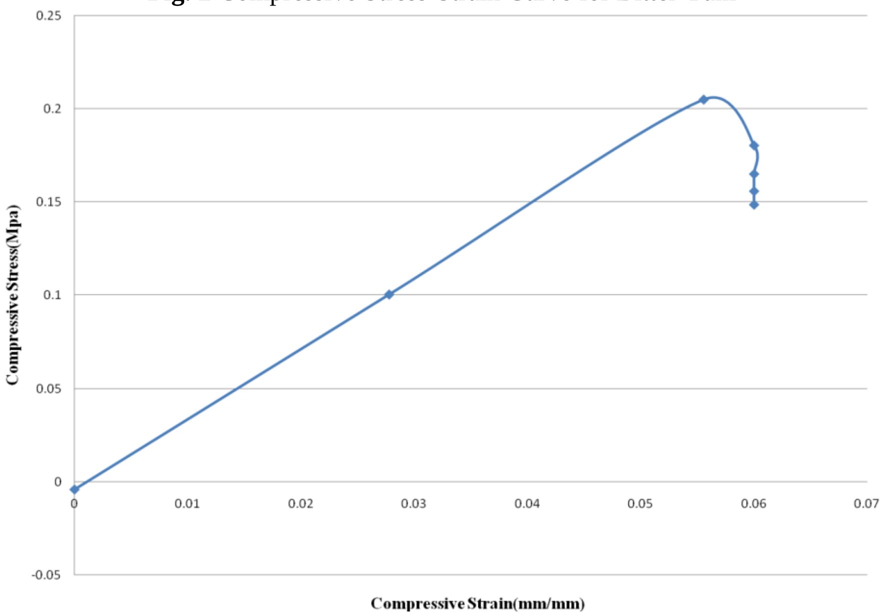

Fig. 3 Compressive Stress—Strain Curve for Water Yam

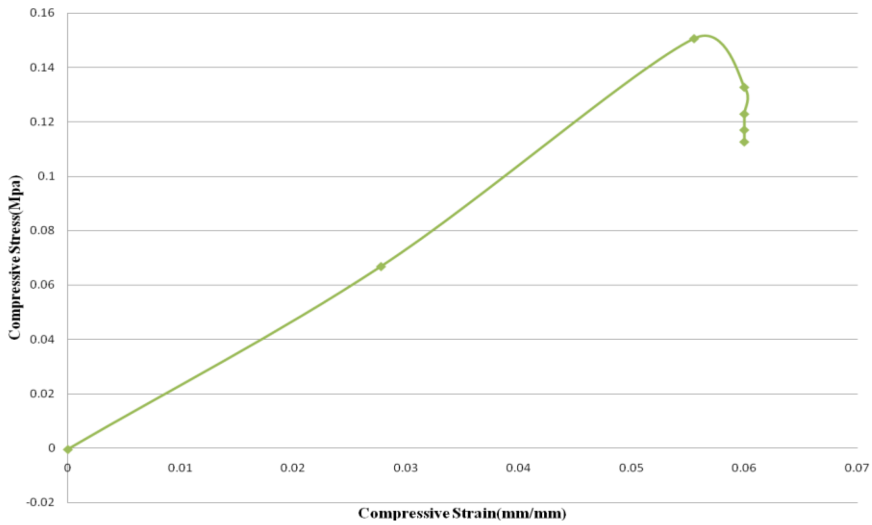

Fig. 4 Compressive Stress—Strain Curve for White Yam

Table -2 Mean Values of the Mechanical Properties of the Three Varieties of Yam Samples Used

Properties	Varieties	NRep.	Mean	Std. Deviation
Compressive Stress at Total Relaxation (Mpa)	White Yam	5 5	00.0673860[ab]	00.02806223
	Water Yam	5 5	00.0983780[b]	00.04888041
	Bitter Yam	5 5	00.0370460[a]	00.01347017
	Total	15	00.0676033	00.04038856
Compressive Strain at Total relaxation (mm/mm)	White Yam	5	00.0000640[a]	00.00001342
	Water Yam	5	00.0000660[a]	00.00000894
	Bitter Yam	5	00.0000720[a]	00.00001095
	Total	15	00.0000673	00.00001100
Compressive Load at Total Relaxation (N)	White Yam	5	60.6495880[ab]	25.25706324
	Water Yam	5	88.5414920[b]	43.99264575
	Bitter Yam	5	33.3413640[a]	12.12087323
	Total	15	60.8441480	36.35015228
Compressive Extension at Total Relaxation (mm)	White Yam	5	00.0019520[a]	00.00044707
	Water Yam	5	00.0020000[a]	00.00032657
	Bitter Yam	5	00.0021760[a]	00.00041753
	Total	15	00.0020427	00.00038382
Load at Total Relaxation (N)	White Yam	5	60.6495880[ab]	25.25706324
	Water Yam	5	88.5414920[b]	43.99264575
	Bitter Yam	5	33.3413640[a]	12.12087323
	Total	15	60.8441480	36.35015228
Extension at Total Relaxation (mm)	White Yam	5	00.0019520[a]	00.00044707
	Water Yam	5	00.0020000[a]	00.00032657
	Bitter Yam	5	00.0021760[a]	00.00041753
	Total	15	00.0020427	00.00038382
Maximum Compressive Stress (Mpa)	White Yam	5	00.1651140[b]	00.05279674
	Water Yam	5	00.2223960[b]	00.04800867
	Bitter Yam	5	00.0856780[a]	00.02467652
	Total	15	00.1577293	00.07068217
Compressive Strain at Maximum Compressive Stress (mm/mm)	White Yam	5	00.0600640[a]	00.00001342
	Water Yam	5	00.0600660[a]	00.00000894
	Bitter Yam	5	00.0600700[a]	00.00001414
	Total	15	00.0600667	00.00001175
Compressive Load at Maximum Compressive Stress (N)	White Yam	5	148.6015280[b]	47.51403699
	Water Yam	5	200.1551480[b]	43.20562258
	Bitter Yam	5	77.1105860[a]	22.20803731
	Total	15	141.9557540	63.61220893
Compressive Extension at Maximum Compressive Stress (mm)	White Yam	5	01.8019400[a]	00.00044424
	Water Yam	5	01.8019880[a]	00.00032213
	Bitter Yam	5	01.8021520[a]	00.00045030
	Total	15	01.8020267	00.00039089
Load at Maximum Compressive Stress (N)	White Yam	5	148.6015280[b]	47.51403699
	Water Yam	5	200.1551480[b]	43.20562258
	Bitter Yam	5	77.1105860[a]	22.20803731
	Total	15	141.9557540	63.61220893
Extension at Maximum Compressive Stress (mm)	White Yam	5	01.8019400[a]	00.00044424
	Water Yam	5	01.8019880[a]	00.00032213
	Bitter Yam	5	01.8021520[a]	00.00045030
	Total	15	01.8020267	00.00039089

Note: Means with the same superscripts are not significantly different while means with different superscripts are significantly different.

DISCUSSION

The research on the three varieties of Benue State grown yams was successfully done and at the end; it was observed that the compressive stress at total relaxation for the three varieties of yam ranged from 0.0370460Mpa to 0.0983780Mpa with Bitter yam having the least value and Water yam having the highest value; and ANOVA test revealed there is significant difference across the three varieties of yam at $P \leq 0.05$ as shown in Table 2.

The compressive strain at total relaxation for the three yam varieties ranged from 0.0000640 to 0.0000720 and ANOVA revealed there is no significant difference across the three varieties of yam at $P \leq 0.05$ as shown in Table 2, though white yam was found to be a little lower than the rest varieties of yam and bitter yam a little higher.
The compressive load at total relaxation for the three varieties of yam ranged from 33.3413640N to 88.5414920 with Bitter yam having the least value and Water yam having the highest value; and ANOVA test revealed there is significant difference across the three varieties of yam at $P \leq 0.05$ as shown in Table 2.
The compressive extension at total relaxation for the three yam varieties ranged from 0.0019520mm to 0.0021760mm. ANOVA revealed there is no significant difference across the three varieties of yam at $P \leq 0.05$ as shown in Table 2 even though white yam was found to be a little lower than the rest varieties of yam and bitter yam a little higher.
The load at total relaxation for the three varieties of yam ranged from 33.3413640N to 88.5414920 with Bitter yam having the least value and Water yam having the highest value; and ANOVA test revealed there is significant difference across the three varieties of yam at $P \leq 0.05$ as shown in Table 2.
The extension at total relaxation for the three yam varieties ranged from 0.0019520mm to 0.0021760mm. Though white yam was found to be a little lower than the rest varieties of yam and bitter yam a little higher; the ANOVA revealed there is no significant difference across the three varieties of yam at $P \leq 0.05$ as shown in Table 2.
The maximum compressive stress for the three varieties of yam ranged from 0.0856780Mpa to 0.2223960Mpa with Bitter yam having the least value and Water yam having the highest value; and ANOVA test revealed there is significant difference across the three varieties of yam at $P \leq 0.05$ as shown in Table 2.
The compressive strain at total maximum compressive stress for the three yam varieties ranged from 0.0600640 to 0.0600700. Though white yam was found to be a little lower than the rest varieties of yam and bitter yam a little higher; the ANOVA revealed there is no significant difference across the three varieties of yam at $P \leq 0.05$ as shown in Table 2.
The compressive load at maximum compressive stress for the three varieties of yam ranged from 77.1105860N to 200.1551480N with Bitter yam having the least value and Water yam having the highest value; and ANOVA test revealed there is significant difference across the three varieties of yam at $P \leq 0.05$ as shown in Table 2.
The compressive strain at total maximum compressive stress for the three yam varieties ranged from 1.8019400mm to 1.8021520mm. Though white yam was found to be a little lower than the rest varieties of yam and bitter yam a little higher; ANOVA revealed there is no significant difference across the three varieties of yam at $P \leq 0.05$ as shown in Table 2.
That the load at maximum compressive stress for the three varieties of yam ranged from 77.1105860N to 200.1551480N with Bitter yam having the least value and Water yam having the highest value; and ANOVA test revealed there is significant difference across the three varieties of yam at $P \leq 0.05$.
The compressive strain at total maximum compressive stress for the three yam varieties ranged from 1.8019400 to 1.8021520. Though white yam was found to be a little lower than the rest varieties of yam and bitter yam a little higher; the ANOVA revealed there is no significant difference across the three varieties of yam at $P \leq 0.05$.
It was observed from the mean results that, compressive stress and compressive strain of bitter yam, white yam and water yam behaved in the same manner.

CONCLUSION

The compression test of the three varieties of Benue State grown yam using the universal testing machine was carried out and it was discovered that the compressive stress relaxation of bitter yam is lower compared with water yam and white yam. Water yam has the highest compressive stress relaxation followed by white yam. This means that, the effect of compressive stress is higher on water yam than white yam, and higher on white yam than bitter yam.
From analysis of variance, it is concluded that compressive stress at total relaxation of bitter yam, white yam and water yam are significantly different. The analysis revealed that bitter yam has the highest stress relaxation while water yam has the lowest stress relaxation; and the stress relaxation of white yam is in between bitter yam and water yam. It was then established that the determined stress relaxation is vital for the design of postharvest handling and processing of the three varieties of Benue State grown yam (bitter yam, white yam and water yam).

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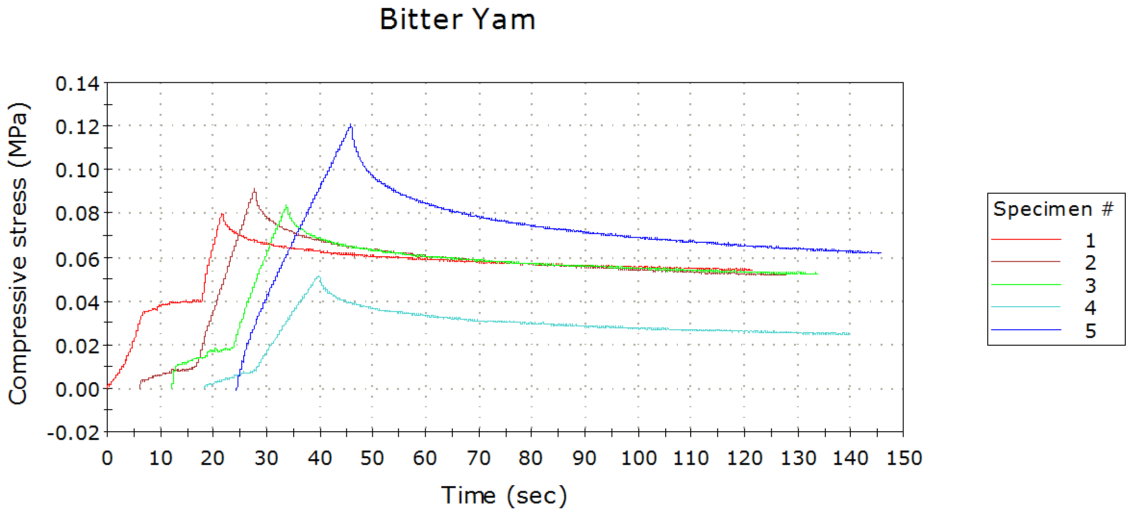
APPENDIX

Appendix i: Compression Relaxation Test / Creep Test on Agricultural Produces



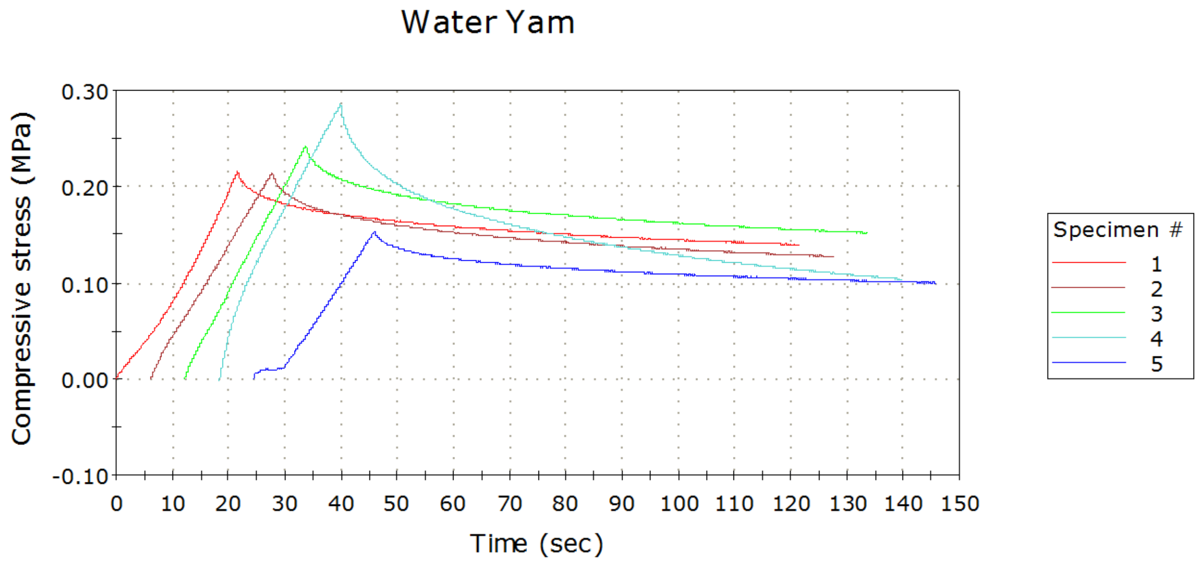
	Anvil height (mm)	Thickness (mm)	Width (mm)	Compressive stress at Total Relaxation (MPa)
1	30.00000	30.00000	30.00000	0.02695
2	30.00000	30.00000	30.00000	0.03967
3	30.00000	30.00000	30.00000	0.03181
4	30.00000	30.00000	30.00000	0.02745
5	30.00000	30.00000	30.00000	0.05935
Mean	30.00000	30.00000	30.00000	0.03705
Standard Deviation	0.00000	0.00000	0.00000	0.01347

	Compressive strain at Total Relaxation (mm/mm)	Compressive load at Total Relaxation (N)	Compressive extension at Total Relaxation (mm)	Load at Total Relaxation (N)
1	0.00006	24.25773	0.00175	-24.25773
2	0.00008	35.70051	0.00244	-35.70051
3	0.00008	28.62850	0.00250	-28.62850
4	0.00006	24.70792	0.00169	-24.70792
5	0.00008	53.41216	0.00250	-53.41216
Mean	0.00007	33.34137	0.00217	-33.34137
Standard Deviation	0.00001	12.12087	0.00042	12.12087

	Extension at Total Relaxation (mm)	Maximum Compressive stress (MPa)	Compressive strain at Maximum Compressive stress (mm/mm)	Compressive load at Maximum Compressive stress (N)
1	-0.00175	0.08055	0.06006	72.49129
2	-0.00244	0.09111	0.06008	82.00288
3	-0.00250	0.08390	0.06008	75.50723
4	-0.00169	0.05195	0.06005	46.75916
5	-0.00250	0.12088	0.06008	108.79237
Mean	-0.00217	0.08568	0.06007	77.11058
Standard Deviation	0.00042	0.02468	0.00002	22.20804

	Compressive extension at Maximum Compressive stress (mm)	Load at Maximum Compressive stress (N)	Extension at Maximum Compressive stress (mm)
1	1.80169	-72.49129	-1.80169
2	1.80244	-82.00288	-1.80244
3	1.80250	-75.50723	-1.80250
4	1.80163	-46.75916	-1.80163
5	1.80250	-108.79237	-1.80250
Mean	1.80215	-77.11058	-1.80215
Standard Deviation	0.00045	22.20804	0.00045

Appendix ii: Compression Relaxation Test / Creep Test on Agricultural Produces



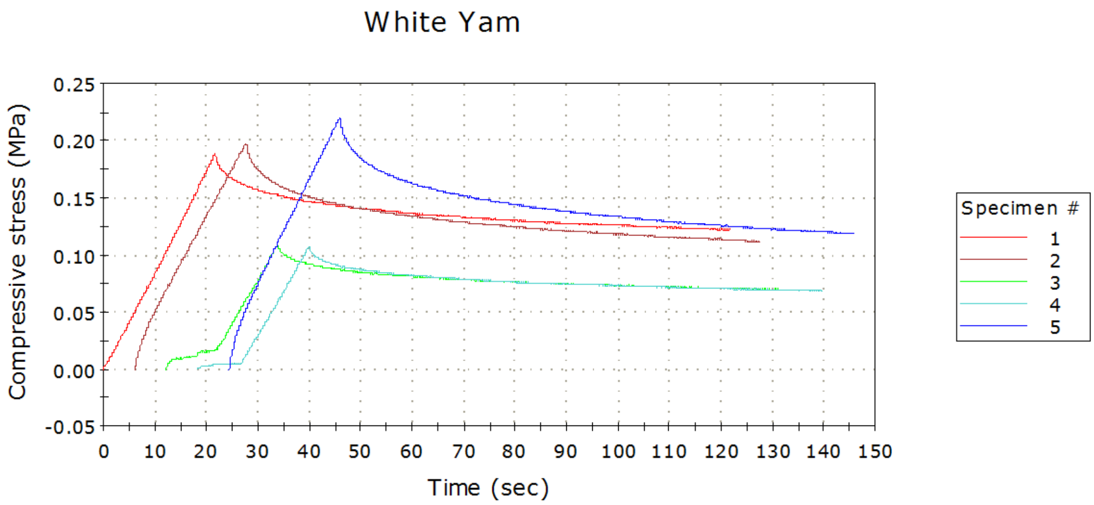
	Anvil height (mm)	Thickness (mm)	Width (mm)	Compressive stress at Total Relaxation (MPa)
1	30.00000	30.00000	30.00000	0.07678
2	30.00000	30.00000	30.00000	0.08842
3	30.00000	30.00000	30.00000	0.09112
4	30.00000	30.00000	30.00000	0.18176
5	30.00000	30.00000	30.00000	0.05381
Mean	30.00000	30.00000	30.00000	0.09838
Standard Deviation	0.00000	0.00000	0.00000	0.04888

	Compressive strain at Total Relaxation (mm/mm)	Compressive load at Total Relaxation (N)	Compressive extension at Total Relaxation (mm)	Load at Total Relaxation (N)
1	0.00006	69.09751	0.00194	-69.09751
2	0.00006	79.58248	0.00169	-79.58248
3	0.00008	82.01203	0.00250	-82.01203
4	0.00006	163.58509	0.00175	-163.58509
5	0.00007	48.43035	0.00212	-48.43035
Mean	0.00007	88.54149	0.00200	-88.54149
Standard Deviation	0.00001	43.99265	0.00033	43.99265

	Extension at Total Relaxation (mm)	Maximum Compressive stress (MPa)	Compressive strain at Maximum Compressive stress (mm/mm)	Compressive load at Maximum Compressive stress (N)
1	-0.00194	0.21566	0.06006	194.09002
2	-0.00169	0.21522	0.06006	193.70074
3	-0.00250	0.24262	0.06008	218.35496
4	-0.00175	0.28517	0.06006	256.64920
5	-0.00212	0.15331	0.06007	137.98082
Mean	-0.00200	0.22239	0.06007	200.15515
Standard Deviation	0.00033	0.04801	0.00001	43.20562

	Compressive extension at Maximum Compressive stress (mm)	Load at Maximum Compressive stress (N)	Extension at Maximum Compressive stress (mm)
1	1.80194	-194.09002	-1.80194
2	1.80169	-193.70074	-1.80169
3	1.80250	-218.35496	-1.80250
4	1.80175	-256.64920	-1.80175
5	1.80206	-137.98082	-1.80206
Mean	1.80199	-200.15515	-1.80199
Standard Deviation	0.00032	43.20562	0.00032

Appendix iii: Compression Relaxation Test / Creep Test on Agricultural Produces



	Anvil height (mm)	Thickness (mm)	Width (mm)	Compressive stress at Total Relaxation (MPa)
1	30.00000	30.00000	30.00000	0.06687
2	30.00000	30.00000	30.00000	0.08735
3	30.00000	30.00000	30.00000	0.04102
4	30.00000	30.00000	30.00000	0.03897
5	30.00000	30.00000	30.00000	0.10272
Mean	30.00000	30.00000	30.00000	0.06739
Standard Deviation	0.00000	0.00000	0.00000	0.02806

	Compressive strain at Total Relaxation (mm/mm)	Compressive load at Total Relaxation (N)	Compressive extension at Total Relaxation (mm)	Load at Total Relaxation (N)
1	0.00005	60.18485	0.00163	-60.18485
2	0.00008	78.61940	0.00250	-78.61940
3	0.00007	36.92060	0.00219	-36.92060
4	0.00007	35.07258	0.00206	-35.07258
5	0.00005	92.45051	0.00138	-92.45051
Mean	0.00006	60.64959	0.00195	-60.64959
Standard Deviation	0.00001	25.25706	0.00045	25.25706

	Extension at Total Relaxation (mm)	Maximum Compressive stress (MPa)	Compressive strain at Maximum Compressive stress (mm/mm)	Compressive load at Maximum Compressive stress (N)
1	-0.00163	0.18881	0.06005	169.92475
2	-0.00250	0.19850	0.06008	178.64638
3	-0.00219	0.11001	0.06007	99.01111
4	-0.00206	0.10740	0.06007	96.66286
5	-0.00138	0.22085	0.06005	198.76254
Mean	-0.00195	0.16511	0.06006	148.60153
Standard Deviation	0.00045	0.05279	0.00001	47.51403

	Compressive extension at Maximum Compressive stress (mm)	Load at Maximum Compressive stress (N)	Extension at Maximum Compressive stress (mm)
1	1.80163	-169.92475	-1.80163
2	1.80250	-178.64638	-1.80250
3	1.80219	-99.01111	-1.80219
4	1.80200	-96.66286	-1.80200
5	1.80138	-198.76254	-1.80138
Mean	1.80194	-148.60153	-1.80194
Standard Deviation	0.00045	47.51403	0.00045