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BEHAVIOUR OF FLEXIBLE/ELASTIC MATERIALS UNDER QUASI-STATIC FORCE

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ABSTRACT

Elasticity and stress absorption are present in many different materials in our daily life. Understanding how materials behave under pressure (whether that is constant or dynamic), and how and when they deform can be fundamental in terms of their success or longevity. Elastic behaviour is present in many different forms in different materials, e.g.: meats or other food. Interestingly, elasticity is also a major issue in the oral cavity, when talking about healthy dental tissues, such as dentin or even special dental restorative materials. The article focuses on the general mechanical behaviour of elastic and viscoelastic materials and measurements performed on them.

Keywords: viscoelastic materials, elasticity, stress absorption, meat, dentin

1. INTRODUCTION

Rheology is the study of the deformation and creep of materials under force, taking into account the effects of time. Measurements are made to study the time-dependent stress-strain relationships, permanent flow, stress-relaxation and viscosity [1].
The concepts and definitions necessary for the discussion of rheology due to the specific structure of biological materials are presented below. Fig. 1 shows a general force-displacement curve.

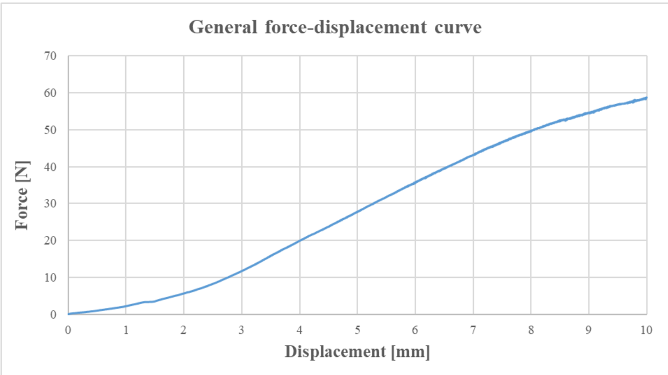

Figure 1. General force and displacement curve

The biological yield point is the point on the stress-deformation curve from which the stress decreases or remains constant as the deformation increases. This point indicates that an initial rupture occurs in the small volume of the cellular system. The biological yield point plays an important role in determining the vulnerability of materials. The breaking point is the point on the stress-deformation curve where the stress decreases steeply and significantly as the deformation increases. The point indicates that a significant volume

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of the material is fractured. For soft, tough materials, fracture occurs after significant plastic deformation. The stiffness of materials is characterised by the directional tangent of the initial, more or less straight section of the stress-strain curve. This is the modulus of elasticity. If the initial section of the curve is linear, it can be used to determine the initial tangent modulus, the secant modulus and the tangent modulus at a given point. Degree of flexibility: The ratio of elastic deformation to total deformation when the material is loaded to a certain value and then unloaded. Toughness is characterised by the work invested up to the breaking point [Nmm], which is equal to the area under the curve. Hardness: The resistance of a material to penetration by a given pressure head. Deformation work: The ability of a material to store deformation energy in its elastic range. If the material is more or less elastic, the deformation work [Nmm] is given by the area under the stress-strain curve. If the material is not elastic, it can be determined by taking the load cycle. Mechanical hysteresis is the energy absorbed by the material in the load-unload cycle. The energy absorbed is equal to the area between the curves. The mechanical hysteresis also characterises the damping capacity of the material. Energy recovery is the ratio of the energy recovered during unloading to the energy invested during loading [2].

When testing flexible materials (foodstuffs, dental materials, etc.), the relationship between force and deformation is most often investigated. Loading can be done with a cylindrical compression head, spherical head or a flat plate. It is assumed that steel loading heads are considered rigid to the material under test and therefore do not deform [3]. The force-deformation relationship can also be used to determine the elastic modulus E, the biological yield point, the breaking point and the Poisson's ratio. During the measurements, the condition indicators of the material (moisture content, temperature, ripeness, storage time after harvesting or threshing, etc.) must be accurately recorded.

A striking property of materials is that the force-deformation relationship also depends on the rate of deformation. This means that the relationship is not between two factors (stress and deformation) but between three factors. Materials where the time effect has to be taken into account are called viscoelastic materials. These materials are partly solids and partly liquids [4].

For some materials and at relatively low loads, the stress and deformation are a function of time alone but do not depend on the magnitude of the stress. Such materials are known as linear viscoelastic materials [5]. For many materials, where much of the load-induced deformation cannot be recovered during load release, the stress-strain relationship depends on the magnitude of the stress as well as on time. In such cases we speak of non-linear viscoelasticity.

Solid but at the same time elastic materials can be found among dental restorative materials in the form of short fiber-reinforced composites (SFRC). These materials due to their mechanical properties and elasticity are suitable and ideal to substitute missing dentin when restoring decayed teeth either with direct or indirect restorations [6]. In case of healthy natural teeth dentin acts a stress-absorbing base not allowing cracks originating from the enamel to penetrate into dentin. This is due to the unique elasticity, fracture toughness and anisotrophicity of dentin. When SFRC is used for dentin-substitution in the form of an anatomical build-up, not only restorations become more resistant ([7], [8], [9]), but also cracks can be redirected as the reach the SFRC core (Fig. 2) [10]. Furthermore, SFRC is able to shift the fracture pattern from a non-restorable direction into a restorable direction ([11], [12], [13]).

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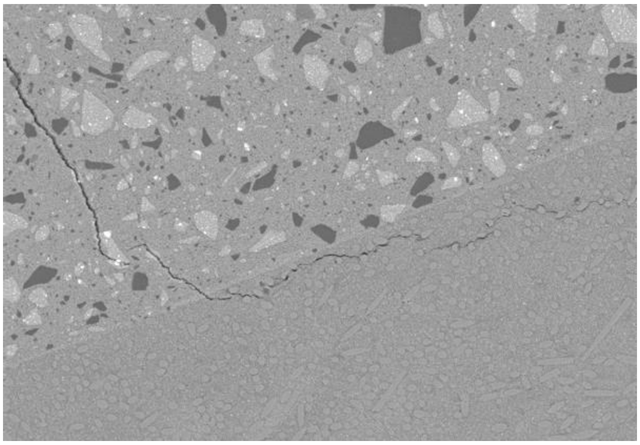

Figure 2. Picture showing the redirection of cracks when invading the SFRC core from [10]

2. MATERIALS AND METHODS

The LLOYD 1000R is specifically designed to determine the hardness, elasticity and tensile strength of various materials, and can determine the hardness, elasticity and tensile strength of any food or other object, as it can measure both compression and tension depending on its setting [14]. The instrument operates on the basis of uniaxial pressure (load mode).

Figure 3. Lloyd 1000R machine

The graph shows 0 N and max. N and their associated path length, the maximum force required to break the material (hereafter referred to as the breaking force), and the breaking work associated with the breaking force, given by the area under the curve, can be determined. The deformation modulus, modulus of elasticity can also be determined from the force displacement curve.

Measurement device settings:

- for the measurement a gauge head of 100N was used for foodstuffs, 5000 N for teeth,

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- the speed of the pressure head when measuring the sample is 2 mm/min,
- the height variation (x-axis length) of the probe during the measurement is 3 mm – teeth, 4-10 mm – foods,
- y-axis height was adjusted based on the hardness of the sample and the position of the specimen.

Food samples were selected from different meat materials, buffalo meat, bison meat, cattle meat (Fig. 4), which show elastic deformation under load. The same behaviour was observed for different salami preparations, where the samples were mangalica salami, pork salami, turkey salami and grey cattle salami. The stock measurement was performed with LLOYD 1000 Texture Machine type metering device with three repeats.

Figure 4. Cattle, bison, buffalo meat

In our work the hardness of the salami was measured and calculated the spring constant. The spring constant is the physical quantity that shows the force required to stretch a spring over a unit length. From our data obtained from the force-displacement curve, the 2 values of penetration depth were observed between which the sample hardness values increase steeply. Based on the force-displacement curves of each sample, the spring constant value was calculated between 2 mm and 4 mm. We then looked at the hardness values associated with the 2 penetration depth values and used these to calculate the spring constant value using the formula below:

$$D = \frac{F_2 - F_1}{x_2 - x_1} \quad (1)$$

where:

- D: spring constant value [N/mm],
- F_2: value of the applied force to the penetration depth x_2 [N],
- F_1: value of the applied force to the penetration depth x_1 [N],
- x_2: value of the second penetration depth used for the measurement [mm],
- x_1: value of the first penetration depth used for the measurement [mm],

3. RESULTS AND DISCUSSION

The results obtained from averaging the measured data were plotted on a force-displacement curve (Fig. 5). From the curve, the grey cattle salami proved to be the hardest (100.3 N was the hardness corresponding to the maximum penetration value). This was followed by pork/pig salami (83.7 N hardness) and turkey salami (44.62 N hardness). Mangalica salami was the softest (13.63 N).

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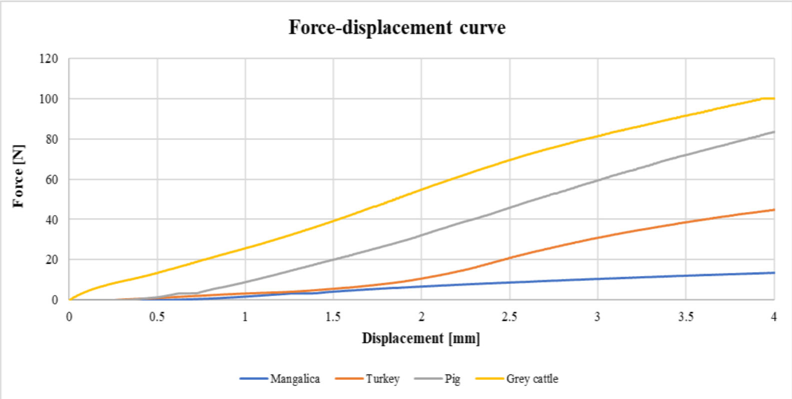

Figure 5. Force-displacement curve (Mangalica salami, turkey salami, pork/pig salami, grey cattle salami)

The value of the spring constant also was calculated. Based on the force-displacement curves of each specimen, the spring constant was calculated between 2 mm and 4 mm using Equation (1) and plotted in a bar graph (Fig. 6).

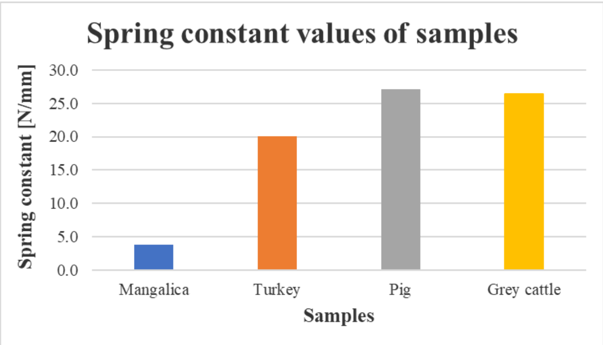

Figure 6. Values obtained for the spring constant (Mangalica salami, turkey salami, pork/pig salami, grey cattle salami)

The figure shows that the pig salami has the highest spring constant (27.07 N/mm), followed by the grey cattle salami (26.43 N/mm) and the turkey salami (20.02 N/mm), with the smallest value for the mangalica salami (3.8 N/mm).
The following force-displacement curve (Fig. 7) shows that bison meat proved to be the hardest (15.84 N for the maximum penetration value), followed by buffalo meat (8.11 N). The softest meat was cattle meat (3.97 N).

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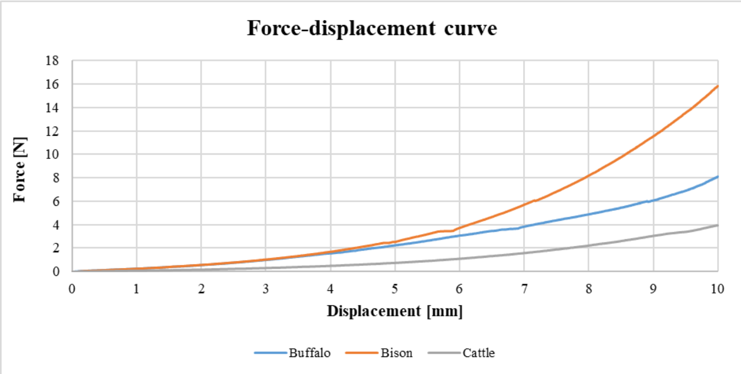

Figure 7. Force-displacement curve (buffalo, bison, cattle meat)

The value of the spring constant also was calculated. Based on the force-displacement curves of each specimen, the spring constant was calculated between 2 mm and 4 mm using Equation (1) and plotted in a bar graph (Fig. 8).

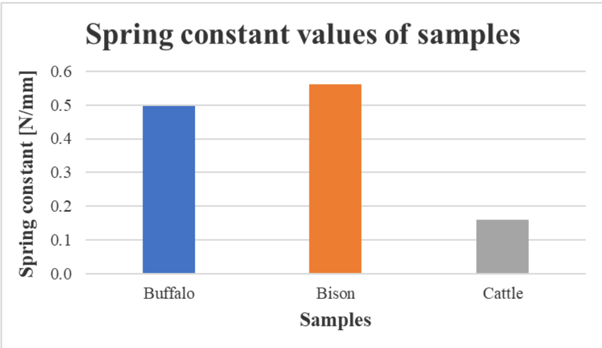

Figure 8. Values obtained for the spring constant (buffalo, bison, cattle meat)

The figure shows that bison meat has the highest spring constant (0.56 N/mm), followed by buffalo meat (0.50 N/mm), with cattle meat having the lowest value (0.16 N/mm).

4. CONCLUSIONS

In conclusion, both raw meat and meat products undergo flexible deformation under compressive forces. When two groups of samples are compared, salami shows a more flexible behaviour.
Looking at the results obtained during the instrumental stock measurement of the meats, it can be stated that bison meat proved to be the hardest, approximately five times harder than cattle, which turned out to be the softest, and twice as hard as buffalo meat. A similar trend was observed based on the spring constant values. Based on the values obtained during the stock measurement of the salamis (hardness, spring constant), it can be concluded that the grey cattle salami proved to be the hardest, it was almost ten times harder compared to the Mangalica salami, which was the softest, and twice as hard as the turkey salami. The closest hardness value was pig salami, whose spring constant value was higher (not significantly) than grey cattle salami.

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However, it should be noted that, compared to meat, the stock of a meat product – its hardness and spring constant value – is not only influenced by the raw material and quantity of the meat, but also by the added fat and stock-improving additives.

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REFERENCES

[1] N. Mohsenin, Physical Properties of Plant and Animal Materials, Gordon and Breach, 1968
[2] Gy. Sitkei, Mezőgazdasági anyagok mechanikája, Akadémiai Kiadó, Budapest, 1981
[3] A. J. Rosenthal, Food Texture: Perception and Measurement, Aspen Publishers, Gaithersburg, 1999
[4] M. Peleg, E. B. Bagley, Physical Properties of Food. AVI Publishing, Westport, 1982
[5] J. D. Ferry, Viscoelastic Properties of Polymers, Wiley, New York, 1980
[6] S. Garoushi, A. Gargoum, P. K. Vallittu, L. Lassila, Short fiber-reinforced composite restorations: A review of the current literature, Journal of Investigative and Clinical Dentistry, 9 (3) (2018), p. e12330. https://doi.org/10.1111/jicd.12330
[7] E. Battancs, T. Sáry, J. Molnár, G. Braunitzer, M. Skolnikovics, Á. Schindler, B. P. Szabó, S. Garoushi, M. Fráter, Fracture Resistance and Microleakage around Direct Restorations in High C-Factor Cavities, Polymers (Basel). 14 (17) (2022), p. 3463. https://doi.org/10.3390/polym14173463
[8] M. Fráter, T. Sáry, B. Jókai, G. Braunitzer, E. Säilynoja, P. K. Vallittu, L. Lassila, S. Garoushi, Fatigue behavior of endodontically treated premolars restored with different fiber-reinforced designs, Dental Materials, 37 (3) (2021), pp. 391-402. https://doi.org/10.1016/j.dental.2020.11.026
[9] M. Fráter, T. Sáry, J. Molnár, G. Braunitzer, L. Lassila, P. K. Vallittu, S. Garoushi, Fatigue performance of endodontically treated premolars restored with direct and indirect cuspal coverage restorations utilizing fiber-reinforced cores, Clinical Oral Investigations, 26 (4) (2022), pp. 3501-3513. https://doi.org/10.1007/s00784-021-04319-3
[10] J. Molnár, M. Fráter, T. Sáry, G. Braunitzer, P. K. Vallittu, L. Lassila, S. Garoushi, Fatigue performance of endodontically treated molars restored with different dentin replacement materials. Dental Materials, 38 (4) (2022), pp. e83-e93. https://doi.org/10.1016/j.dental.2022.02.007
[11] M. Fráter, T. Sáry, E. Vincze-Bandi, A. Volom, G. Braunitzer, B. P. Szabó, S. Garoushi, A. Forster, Fracture Behavior of Short Fiber-Reinforced Direct Restorations in Large MOD Cavities, Polymers (Basel), 13 (13) (2021), p. 2040. https://doi.org/10.3390/polym13132040
[12] T. Sáry, S. Garoushi, G. Braunitzer, D. Alleman, A. Volom, M. Fráter, Fracture behaviour of MOD restorations reinforced by various fibre-reinforced techniques - An in vitro study. Journal of the Mechanical Behavior of Biomedical Materials, 98 (2019), pp. 348-356. https://doi.org/10.1016/j.jmbbm.2019.07.006. Epub 2019 Jul 9. Erratum in: Journal of the Mechanical Behavior of Biomedical Materials, 2020 Feb, 102:103505.
[13] M. Fráter, A. Forster, M. Keresztúri, G. Braunitzer, K. Nagy, In vitro fracture resistance of molar teeth restored with a short fibre-reinforced composite material, Journal of Dentistry, 42 (9) (2014), pp. 1143-50. https://doi.org/10.1016/j.jdent.2014.05.004
[14] Lloyd Instruments, Materials testing machines, Operating instructions, Copyright: Lloyd Instruments Limited, 1991