

Technical Report 1

Compression tests on grape pomace vitreous biomaterial

Eugenio Hamm
Department of Physics,
Universidad de Santiago de Chile
luis.hamm@usach.cl

(Dated: January 19, 2023)

Abstract

The results of compression tests on vitreous biomaterial, obtained through Powder House's Vitreous Transformation Process of grape pomace, are reported. The objective is to determine some mechanical properties of this vitreous biomaterial, such as tensile strength (quantitative) and brittleness (qualitative). These properties, together with others of physical and chemical character, may be important to determine the grindability of this biomaterial.

I. INTRODUCTION

The results of diametral compression tests (side crushing strength test, SCS [1]) of vitreous biomaterial obtained through Powder House's Vitreous Transformation Process of grape pomace, are reported. A compression test allows us to overcome the difficulty of applying a tensile test to this kind of specimen, especially due to the almost null possibility of holding it by its ends with the grips of a mechanical testing machine. The SCS test, also called the Brazilian test, consists of subjecting a cylindrical specimen to compression along one of its diameters at a constant velocity.

In the first case, the height h of the specimen is less than or similar to its diameter D ($h \leq D$), and it is customary to report the compressive strength and the resistance of the specimen (maximum force at the moment of breaking). In the case of a vitreous biomaterial, its height is slightly greater than its diameter ($h \geq D$), and it seems more useful to determine the specific force per unit length, since the force in that case is an extensive quantity (proportional to the length of the specimen). The aim is to establish the degree of brittleness of the vitreous biomaterial and determine its tensile strength.

II. METHODOLOGY

A. Test Tubes

Each specimen was chosen to be as cylindrical as possible. Specifically, vitreous biomaterial that did not have a straight axis of symmetry or that were visibly inhomogeneous were discarded. Since the vitreous biomaterial are narrow or irregular at their ends, they were either trimmed with a razor or hand-abraded to obtain the flattest possible shape. Often, the vitreous biomaterial did not withstand this process and was discarded. Approximately 1 out of 5 units of vitreous biomaterial remained in an acceptable shape for testing. Even so, the vitreous biomaterial is very irregular in shape.

The dimensions of the vitreous biomaterial used for the specimens were $D = 4.8$ mm and 6.3 mm $< h < 12.5$ mm. The unit of vitreous biomaterial diameter is relatively constant since it is determined by the process, and therefore was not measured for all specimens. Although this is a compressive test, it is possible to infer the tensile strength if it is assumed that the fracture of the vitreous biomaterial occurs along the line joining the points where it is compressed.

The fracture behavior—whether brittle or ductile—of the vitreous biomaterial is determined from the force curve, based on analysis as presented in Smith et al. [2].

B. Compression Tests

For the tests, an Instron 3365 tensile/compression machine was used, equipped with a 2.5 kN load cell and two compression platens of 56 mm diameter each (Fig. 1). Initially, the upper platen is located about 5.5 mm away from the lower platen. The specimen is placed in the center of the lower stage. The test proceeds at a crosshead lowering speed of 1 mm/min. The machine records the crosshead position (d) and the compressive force (F), at a rate of 100 samples per second. Twenty identical tests were performed with 20 specimens of varying length.

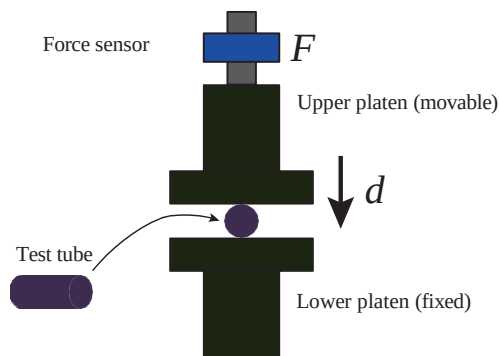


Figure 1. Illustration of the diametral compression test, SCS.

III. RESULTS

Figure 2 shows the graphs of F vs. d for the 20 tests. In all of them, the compression was performed at a constant speed of 1 mm/min and stopped automatically when the force reached 200 N. A large variability in the force is observed, even though the height h of the vitreous biomaterial is similar among all of them.

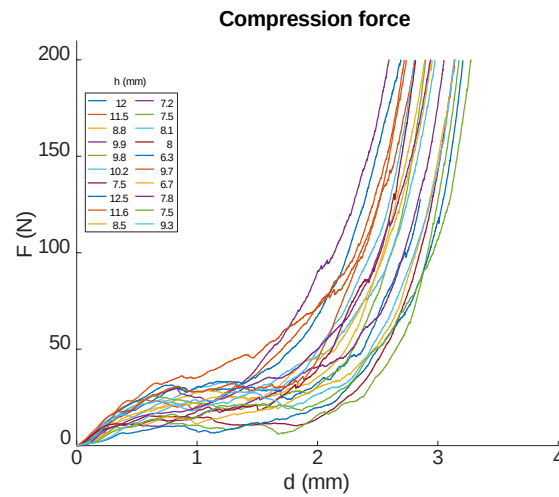


Figure 2. Compressive force vs. displacement for 20 units of vitreous biomaterial. Each test stops when the force reaches 200 N.

IV. ANALYSIS AND DISCUSSION

In Figure 3, three of the 20 tests were selected to illustrate the typical response of a vitreous biomaterial under compression. First, there is a steady increase in force with displacement up to just under 1 mm. Then, a variable number of events occur where the force drops and rises again. Finally, from a displacement of slightly less than 2 mm, the force increases steadily once more.

We can interpret the sequence of behaviors as follows: A response resulting from the resistance of the vitreous biomaterial to deformation (elastic, plastic, or viscous). The appearance of fractures or localized defects that reduce compressive strength. A “granular”

regime where the vitreous biomaterial, once fragmented, behaves like a “pancake” that flattens and spreads—explaining the substantial increase in force for displacements over 2 mm. In regime (i), additional tests would be needed to determine the nature of the deformation: Elastic (reversible, independent of compression rate), Plastic (irreversible, independent), or Viscous (irreversible, rate-dependent).

Another important observation is the different behaviors in regime (ii). For instance: Specimen 4 (blue curve) shows a drop around $d \approx 0.8$ mm, indicating a fracture event.

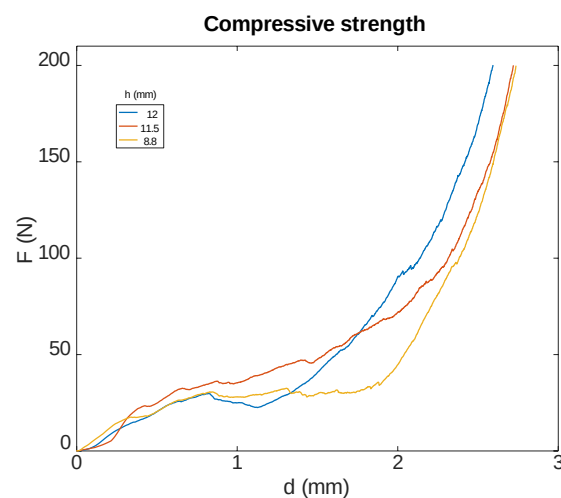


Figure 3. Compressive strength vs. displacement for specimens 4, 9, and 16.

Specimen 16 (yellow curve) has a plateau with small fluctuations, suggesting successive fracture events. Specimen 9 (red curve) exhibits a monotonic increase despite similar fluctuations, indicating continued resistance with no clear fracture.

In none of the 20 tests was a sudden drop in strength observed, which rules out a brittle behavior. Instead, the gradual drops indicate an intermediate behavior between brittle and ductile.

To rule out the effects of variable vitreous biomaterial length, it is convenient to analyze the longitudinal force

$$f = F/h'$$

which represents the compressive force per unit length. The longitudinal forces for the 20 tests are shown in Fig. 4. A comparison between Figs. 2 and 4 immediately establishes that the dispersion of the curves observed in Fig. 2 is attributable, at least in part, to the varying size of the specimens. Plotting the specific strength shows that the curves tend to come together in the range $0 < d \leq 1.5$ mm.

To estimate the vitreous biomaterial strength, the average longitudinal force of the longitudinal forces of the 20 specimens was calculated. In Fig. 5 we have plotted $f = \langle F/h \rangle$

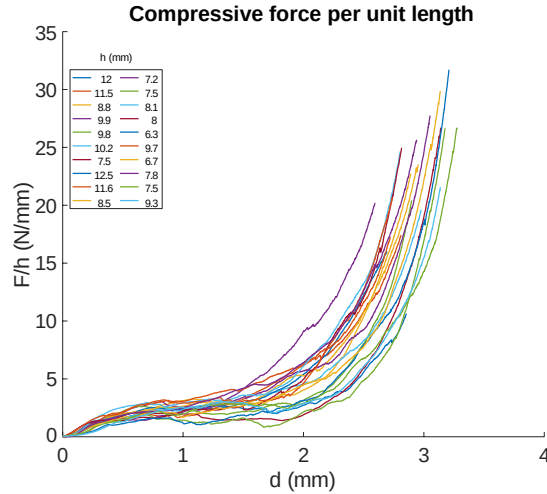


FIG. 4. Longitudinal compressive strength (per unit length) vs. displacement corresponding to the same 20 specimens of Fig. 2.

together with the envelope of the longitudinal force curves in Fig. 4. The resulting curve indicates a more ductile behavior, albeit with a small drop in force at $d = 0.9$ mm. The drop is

so small that it could just as well be stated that the longitudinal force exhibits plateau-like behavior in regime (ii). An operational value of resistance can be defined as the maximum value that the force reaches before starting to fall, in regime (ii), i.e., $f_{\max} = 2.3 \text{ N/mm}$, although this same value could also represent the plateau value.

A drawback of this strength value is that it does not have the units of force per unit area, typical of the so-called ultimate tensile strength (in traction on), σ_f , of a material. In the literature we find a value of ultimate tensile strength that can be extracted from a diametral compression test [3],

$$\sigma_f = \frac{2F_f}{\pi D h}, \quad (2)$$

where F_f is the maximum force at fracture failure. Since no clear force drop was observed in the tests (in some yes), the application of equation (2) to the results obtained is not evident.

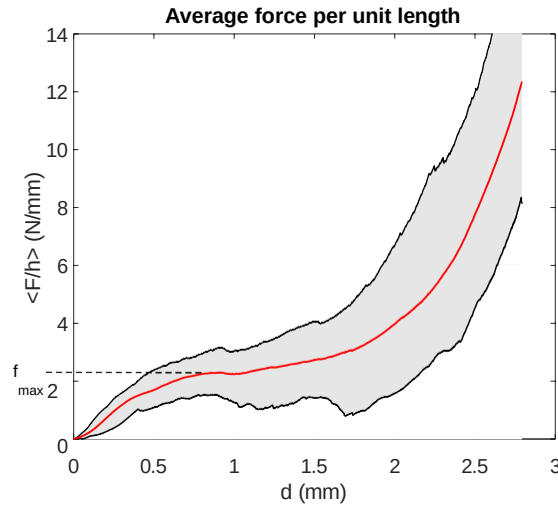


FIG. 5. Average longitudinal force calculated based on the 20 longitudinal force curves in Fig. 5. The gray area is the envelope of all curves.

V. CONCLUSIONS

The mechanical behavior of the vitreous biomaterial, as inferred from a diametral compression (SCS) test, indicates that the material exhibits semi-fragile behavior, as described by Smith et al. [2], or plastic with gradual fracture, according to Procopio et al. [1]. This contrasts with the abrupt breakage seen in truly brittle materials, where the specimen splits cleanly in two. In the tests performed, the force–displacement curves show several successive drops, likely associated with small-scale fracture events. The average curve shown in Figure 5 smooths out these drops, resulting in a monotonic increase of force with a plateau region—this plateau can be used to define an operational longitudinal strength for the vitreous biomaterial.

[1] A.T. Procopio, A. Zavaliangos, and J.C. Cunningham. Analysis of the diametrical compression test and the applicability to plastically deforming materials. *Journal of Materials Science*, 38(17):3629–3639, 2003.

[2] Rachel M. Smith and James D. Litster. Examining the failure modes of wet granular materials using dynamic diametrical compression. *Powder Technology*, 224:189–195, 2012.

[3] L.G. Tabil Jr. and S.S. Sokhansanj. Compression and compaction behavior of alfalfa grinds Part 2: Compaction behavior. *Powder Handling and Processing*, 8(2):117–122, 1996.

[4] M.A.F.B. Thomas and A.F.B. Van der Poel. Physical quality of pelleted animal feed 1. Criteria for pellet quality. *Animal Feed Science and Technology*, 61(1–4):89–112, 1996.