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TENSILE STRENGTH OF DARK CHOCOLATE

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The effect of loading rate as well as the cocoa content on the tensile strength of dark chocolate has been studied. Tensile strength was measured using the Brazilian test. The main advantage of this test consists in the use of a specimen of simple geometry in comparison with a specimen for tensile tests. Tensile strength increases with loading rate. The cocoa content exhibits the same effect.

Keywords: chocolate, Brazilian test, tensile strength, loading rate

Chocolate is, in essence, cocoa mass and sugar suspended in a cocoa butter matrix. Cocoa butter has a distinct texture due to unique interactions of polymorphic lipid structures. In order to describe its texture, it is necessary to evaluate its mechanical properties. These properties are studied using many different experimental methods. A penetration test using a thin probe is an empirical method of assessing the mechanical properties of chocolate or confectionery products (Liang and Hartel, 2004; Do et al., 2007; Afoakwa et al., 2008, 2009). This method has been used to study the effect of composition, particle size distribution, fat crystallization behaviour and tempering on the mechanical properties in chocolate bars (Afoakwa et al., 2008, 2009). Fundamental methods, such as compression and three-point bend tests, have also been applied to investigate hardness (Beckett, 2000) as well as chocolate texture as a function of composition, fat content or storage conditions (Tscheuschner and Markov, 1986, 1989; Andrae-Nightingale et al., 2009). In both methods, a normal force is applied to the chocolate during the test.

By applying normal stress, as in the three-point bend test, the force required to break the specimen results from both pressure and tension. This requires that the material is homogeneous with good adhesion between its different components. However, chocolate is a particulate material in which solid sugar and cocoa particles are surrounded by a continuous fat phase containing both a crystal and a liquid fraction, resulting in a heterogeneous structure.

Thus, applying longitudinal forces as in a traction test provides more representative results as it is not influenced by poor adhesion between different ingredients and instead provides an adequate measure of the strength between the different chocolate components such as non-fat solids and cocoa butter. Previously, traction tests were performed on plain chocolate at different levels of freezing by anchoring rectangular sticks of chocolate between two clamps in a traction machine under uniaxial traction (Tremeac et al., 2008). However, as chocolate is brittle, it is difficult to mount between two clamps in the traction machine without inducing stresses, causing it to break or weaken preferentially at the clamp contact points prior to start of the test. To overcome these difficulties, another kind of test was developed based on the idea of using compressive loads to generate tensile stresses in the specimen. One of these methods is the splitting test of discs or cubes (Brazilian test), originally developed to characterise the tensile strength of concrete (Faihurst, 1964).

This method has been applied in this paper in order to study the influence of loading rate on the tensile strength of commercially available chocolate. The influence of the cocoa content is also studied.

Material and methods

For the experiments, commercially available LINDT chocolates Excellence 70 %, 85 % and 90 % Cocoa solid particles have been used. The specimens in the form of a cylinder (14 mm in diameter and 6 mm in thickness) have been prepared from this chocolate.

The specimens were loaded using a TIRA testing machine at different crosshead speeds: 1, 10 and 100 mm/min. The scheme of this experiment is shown in Fig. 1.

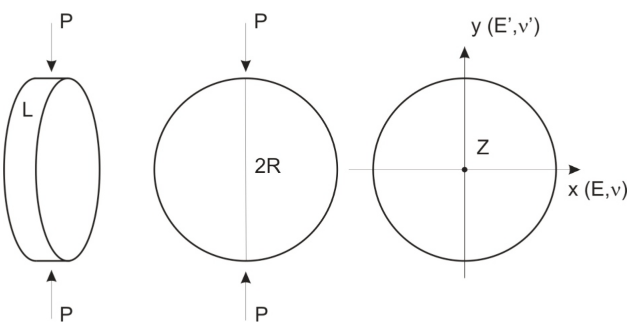

Figure 1 Scheme of the Brazilian test

In the Brazilian tension test, a circular disk placed between two platens is loaded in compression, producing a nearly uniform tensile stress distribution normal to the loaded (vertical) diametric plane, leading to the failure of the disk by splitting (Rocco et al., 1999). This tensile stress st-v is estimated from the elastic theory (Frocht, 1948):

$$\sigma_{t\text{-}v} = \frac{2P}{\pi LD} \quad (1)$$

where:
P – the loading force
$D = 2R$ – the specimen diameter
L – its length

Along the horizontal diametric plane, tensile stress (and equivalent strain) values rapidly decrease from a peak level [Eq. (1)] as a function of distance x from the centre of the disk:

$$\sigma_{t\text{-}h} = \frac{2P}{\pi LD}\left(\frac{D^2 - 4x^2}{D^2 + 4x^2}\right)^2 \quad (2)$$

All experiments have been performed at a temperature of 20 °C.

Results and discussion

The experiment shown in Fig. 1 leads to the development of tensile stress in the specimen. This tensile stress can and does lead to the cracking of the specimen. This is shown in Fig. 2.

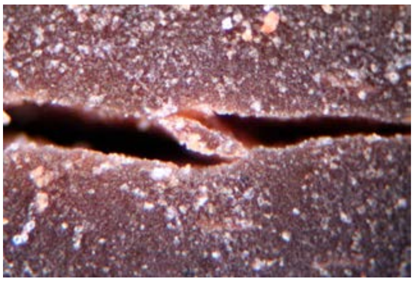

Figure 2 Crack in the specimen of the chocolate (85 % cocoa content) loaded at 10 mm/min

All the tested specimens exhibited the same feature. Examples of the experimental records of compressive force versus crosshead displacement are displayed in Fig. 3. All these records are characterised by a drop in force. The maximum of force before its sudden decrease corresponds to the moment of specimen fracture initiation. It has been verified by experiments where crosshead displacement was stopped before force drop. The corresponding tensile stress evaluated using Eq. (1) is shown in Fig. 4. This equation is valid up to specimen fracture.

The stress corresponding to the maximum before the drop represents the tensile strength of the tested material. The values of tensile strength are plotted in Fig. 5.

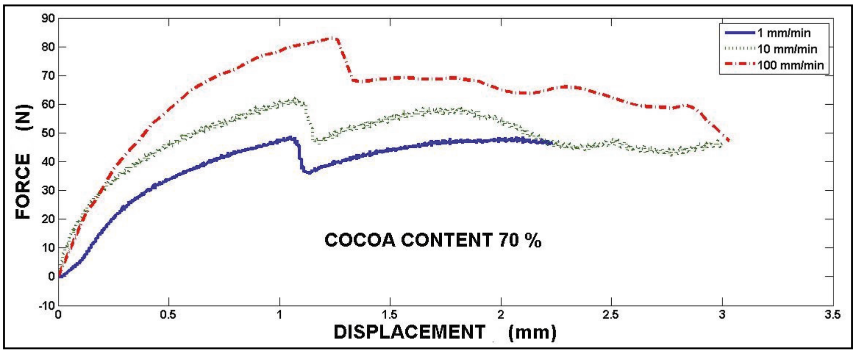

Figure 3 Effect of crosshead displacement on compressive force

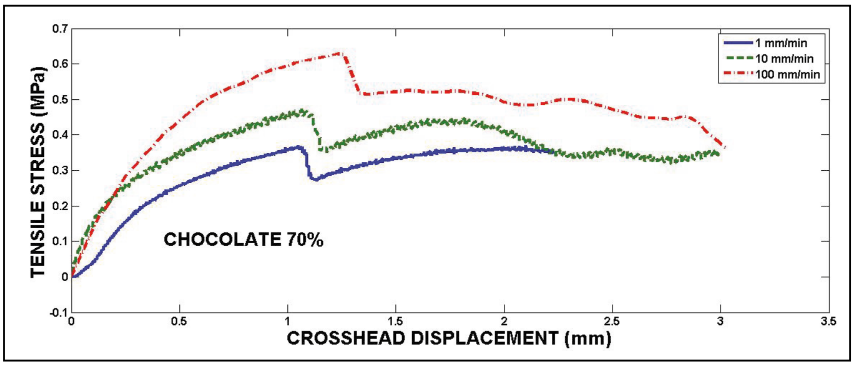

Figure 4 Tensile stress vs. crosshead displacement

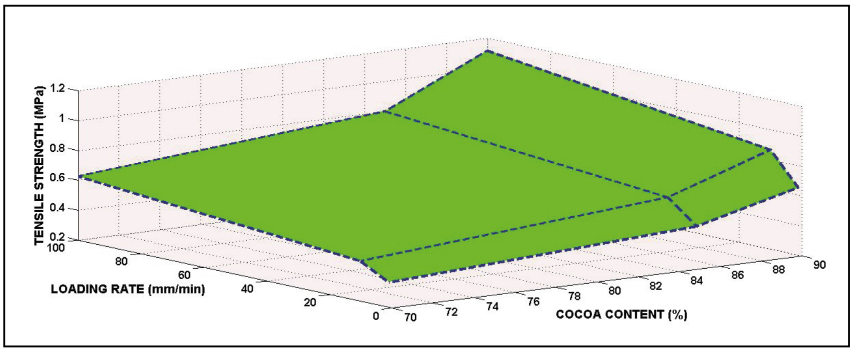

Figure 5 Tensile strength of the tested chocolates

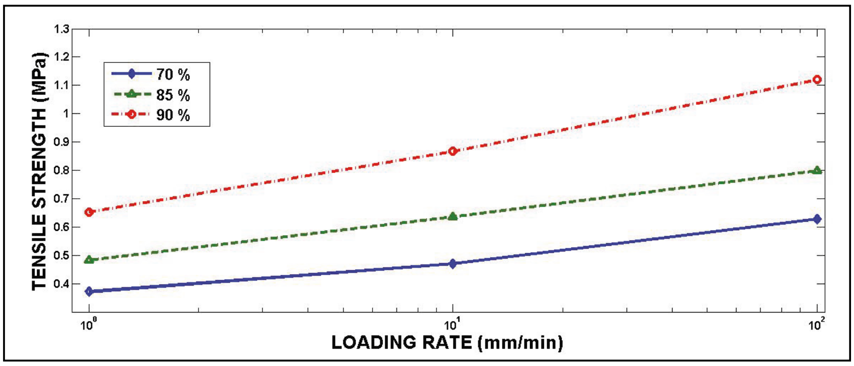

Figure 6 Effect of loading rate on the tensile strength of the chocolate

It is obvious that strength increases with loading rate as well as with cocoa content. It seems that tensile strength increases with the logarithm of loading rate as shown in Fig. 6.

This dependence has been observed for many other materials (Meyers, 1994).

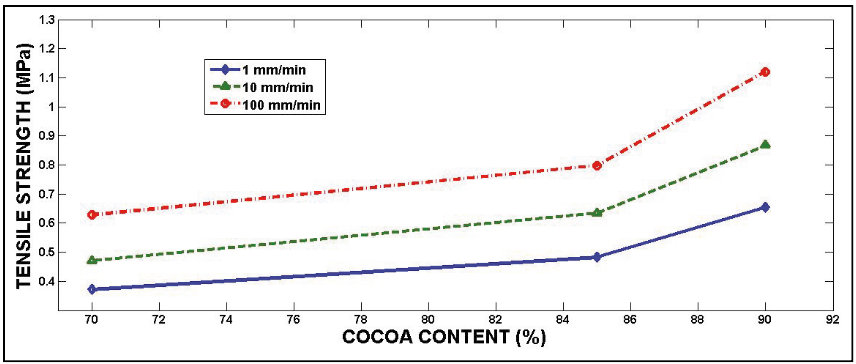

Figure 7 Effect of the cocoa solid particle content on the tensile strength of the chocolate

A detailed view of the influence of cocoa solid particles is shown in Fig. 7.

The obtained values of tensile strength are in agreement with results presented by Svanberg et al. (2012). The explanation of observed results should be based on a detailed analysis of chocolate microstructure. Dark chocolate has high concentrations of suspended solid particles comprising of sugar crystals and cocoa solids, dispersed in a continuous matrix of cocoa butter. In this way, dark chocolate represents a composite material where relatively hard particles (cocoa solids etc.) are dispersed in a plastic material (cocoa butter). This model can very easily explain the increase in tensile strength with the increase of cocoa solids. The cocoa butter exhibits a significant viscous behaviour (Afoakwa et al., 2007). It means this component is responsible for the effect of loading rate. The quantitative explanation must be based on a more detailed description of particle size distribution as well as on the measurement of viscous properties of a pure cocoa butter. This research will be the subject of forthcoming papers.

Conclusion

The performed research shows that the Brazilian test represents a very simple tool for evaluating the tensile strength of the chocolate. Preliminary results obtained in the given paper show that the tensile strength of the chocolate is significantly dependent on loading rate. It seems that tensile strength increases with the logarithm of loading rate. For all used loading rates, tensile strength increases with the content of cocoa particles. The increase due to the increase in the content of cocoa particles is probably independent on loading rate. The increase of tensile strength with loading rate is probably given by the rheological properties of cocoa butter. The verification of this hypothesis needs some other experiments mentioned in the present paper.

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References

AFOAKWA, E. O. – PATERSON, A. – FOWLER, M. 2007. Factor influencing rheological and textural qualities in chocolate – a review. In Trends in Food Science and Technology, vol. 18, 2007, pp. 290–298.

AFOAKWA, E. O. – PATERSON, A. – FOWLER, M. – VIEIRA, J. 2008. Effects of tempering and fat crystallization behaviour on microstructure, mechanical properties and appearance in dark chocolate systems. In J. Food Eng., vol. 89, 2008, pp.128–136.

AFOAKWA, E. O. – PATERSON, A. – FOWLER, M. – VIEIRA, J. 2009. Microstructure and mechanical properties related to particle size distribution and composition in dark chocolate. In Int. J. Food Sci. Technol., vol. 44, 2009, pp. 111–119.

ANDRAE-NIGHTINGALE, L. M. – LEE, S. Y. – ENGESETH, N. J. 2009. Textural changes in chocolate characterized by instrumental and sensory techniques. In J. Texture Studies, vol. 40, 2009, pp. 427–444.

BECKETT, S. T. 2000. The Science of Chocolate. Cambridge, U.K. : The Royal Society of Chemistry.

FAIRHURST, C. 1964. On the validity of the "Brazilian" test for brittle materials. In Int J Rock Mech Min Sci, vol. 1, 1964, pp. 535–46.

FROCHT, M. M. 1948. Photoelasticity. New York : John Wiley, vol. 2, 1948.

LIANG, B. – HARTEL, R. W. 2004. Effects of milk powders in milk chocolate. In J. Dairy Sci., vol. 87, 2004, pp. 20–31.

MEYERS, M. A. 1994. Dynamic Behaviour of Materials. New York : J. Wiley. ISBN 047158262X.

ROCCO, C. – GUINEA, G. V. – PLANAS, J. – ELICES, M. 1999. Mechanisms of rupture in splitting tests. In ACI Mater. J., vol. 96, 1999, pp. 52–60.

SVANBERG, L. – AHRNÉ, L. – LORÉN, N. – WINDHAB, E. 2012. A method to assess changes in mechanical properties of chocolate confectionery systems subjected to moisture and fat migration during storage. In Journal of Texture Studies, vol. 43, 2012, pp. 106–114.

TSCHEUSCHNER, H. D. – MARKOV, E. 1986. Instrumental texture studies on chocolate. I. Methods of measurement and texture characteristics. In J. Texture Studies, vol. 17, 1986, pp. 37–50.

TSCHEUSCHNER, H. D. – MARKOV, E. 1989. Instrumental texture studies on chocolate. II. Compositional factors influencing texture. In J. Texture Studies, vol. 20, 1989, pp. 335–345.

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