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.

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 $\sigma$ is estimated from the elastic theory (Frocht, 1948):
where:

\[ P = \text{the loading force} \]
\[ D = 2R = \text{the specimen diameter} \]
\[ L = \text{its length} \]

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:

\[ \sigma_{tx} = \frac{2P}{\pi LD} \left( \frac{D^2 - 4x^2}{D^2 + 4x^2} \right)^2 \]  

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.

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.

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).
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 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.

**Acknowledgement**

The authors acknowledge the support of the Institute of Thermomechanics AS CR, v. v. i. of the Czech Academy of Sciences through institutional support No. RVO: 61388998.

**References**


Contact address:
doc. Ing. Šárka Nedomová, PhD., Mendelova univerzita v Brně, Zemědělská 1, 613 00 Brno, Czech Republic, e-mail: snedomov@mendelu.cz