# ST 38 - Colard - A new device for firmness characterization

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## A new device for firmness characterization

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## Summary

Recently, a new method has been proposed in order to characterize tobacco or filter rods hardness. This method, based on an analysis of the crushing deformation, is related to the consumers' feeling when they crush the product with their fingers.

In order to apply this method, a new apparatus has been developed. This is constituted of a proportional commanded electromagnet linked to a strength sensor allowing a step force application on the product, and a displacement sensor for the recording of the product deformation. Then, a specific algorithm allows the deformation analysis for a full mechanical characterization of the product to test.

From experimental results analysis, we demonstrate :

1 the validity of the theoretical model, confirming a linear variation of the deformation, at a given time, versus the applied load

2 the universal aspect of the method, able to forecast with a good accuracy the deformation which could be observed with an other crushing force

3. the significant decreasing of the measurement duration (divided by three) with at the same time, a more descriptive then more discriminative product characterization.

## 1. Introduction

Many methods are currently used to test the hardness of tobacco rods or filters [1,2 and 3]. Most of these methods use the same measurement principle which consists of applying a force and measuring the resulting crushing effect after a given time. The main disadvantage of these methods is that they do not give precise information on the mechanical properties of the products being tested. To get round this problem, a new firmness test has been proposed [4]. This consists of modelling the deformation of the tobacco or filter rods when a force is applied to it and to adjust the model as experience is gained so as to extract the parameters. Three parameters $p_1$, $p_2$ and $p_3$, specifications of the product's mechanical properties, are used in the theoretical expression of the deformation over the period of time d(t) :

$$d(t) = \frac{F.p_2^2.p_3}{(p_1+p_2)^2} \times \left(1 - e^{-\frac{p_1+p_2}{p_1 \cdot p_2 \cdot p_3} \times t}\right) + \frac{F}{p_1+p_2} \times t \qquad (1)$$

where
F = crushing force applied
$p_1$ = parameter specifying the dissipation of the energy on deformation (plastic deformation)
$p_2$ = parameter specifying the relaxation of the forces on crushing
$p_3$ = parameter specifying the accumulation of energy on deformation (elastic deformation)

The parameter $p_1$ relates to the resistance to crushing, $p_2$ to the resistance to relaxation and $p_3$ the extent of deformation.

The use of this new method of testing firmness requires the development of a specific experimental device providing the means to record the deformation over a period of time and, by adjusting the model with experience, analysis of the data acquired. Using this device, it is possible to optimise the measurement time and to study the scope of validity for this new method.

## 2. Device description

The device used as a basis for implementing the method is a Sodim hardness-meter. The appliance driver software was modified to allow the recording of the force and the movement of the jaws every 55 ms from the moment the moving jaw came into contact with the product being tested.

The jaws used are flat, rectangular and measure 15x30 mm. These give an average value of the firmness over a 30 mm length of product.

The use of this experimental data requires adjusting the model to the measurements. For this, our choice fell upon the Levenberg-Marquardt algorithm which has the advantage of converging quickly and of providing uncertainty on the values of the parameters obtained.

## 3. Experiment results

### 3.1. Optimising the measurement period

The recording on the deformation of a tobacco rod (Diameter: 7.9 mm, Tobacco weight: 800 mg) under a load ranging from 40g to 500g was carried out over the first 6 seconds of crushing (Figure 1).

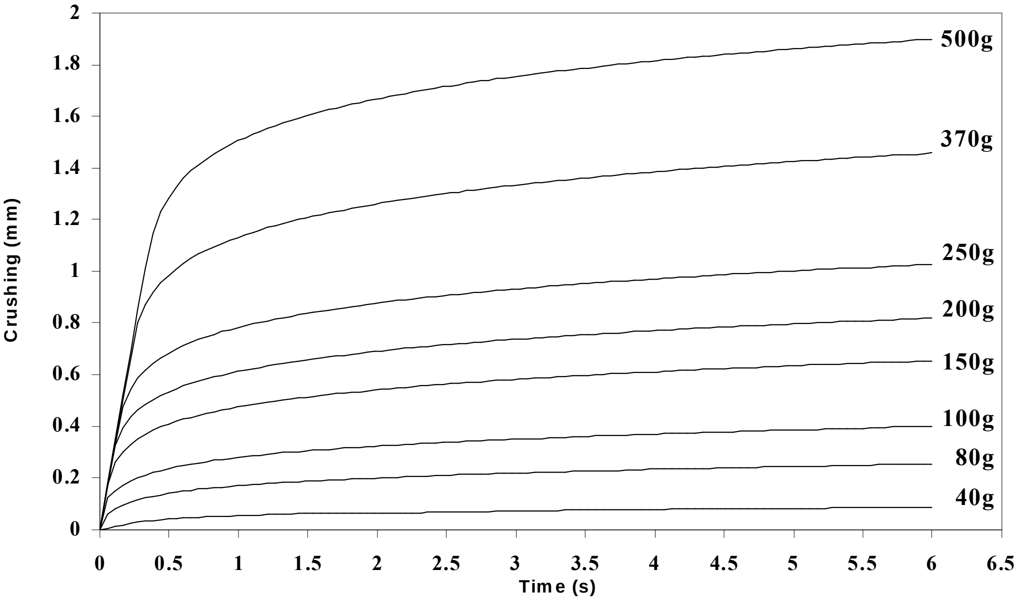

**Figure 1 - Crushing of a tobacco segment according to time and under different loads**

An analysis of the deformation means that three phases can be determined over the period of time t:

- *Phase 1, t<0.5s:* very rapid deformation
- *Phase 2, 0.5s<t<1.5s:* attenuation of the speed of deformation
- *Phase 3, t>1.5s:* slow deformation due to the relaxation phenomenon

We note that all the information on the behaviour of the product subjected to a load is contained in the first seconds of crushing. It is thus unnecessary to crush over a long period to measure the product mechanically, which is why we subsequently chose to restrict the crushing time to 3 seconds. This choice means that the measurement time can be reduced significantly compared with normal methods. This time is for example divided by three relative to a method based on the detection of a 7µm/s slope threshold.

### 3.2. Validity of the theoretical model

An analysis of the equation (1) shows us that the deformation obtained at a given time t0 is proportional to the force applied. In fact, this is only true for the crushing forces for which the product compression limits have not yet been reached. Beyond a certain force, the product is totally crushed, and the proportional relationship should no longer be true. In order to determine the maximum force beyond which the model is no longer valid, we have traced the crushing according to the force applied for four times t0, 0.5s, 0.8s, 1.5s and 3s. (Figure 2).

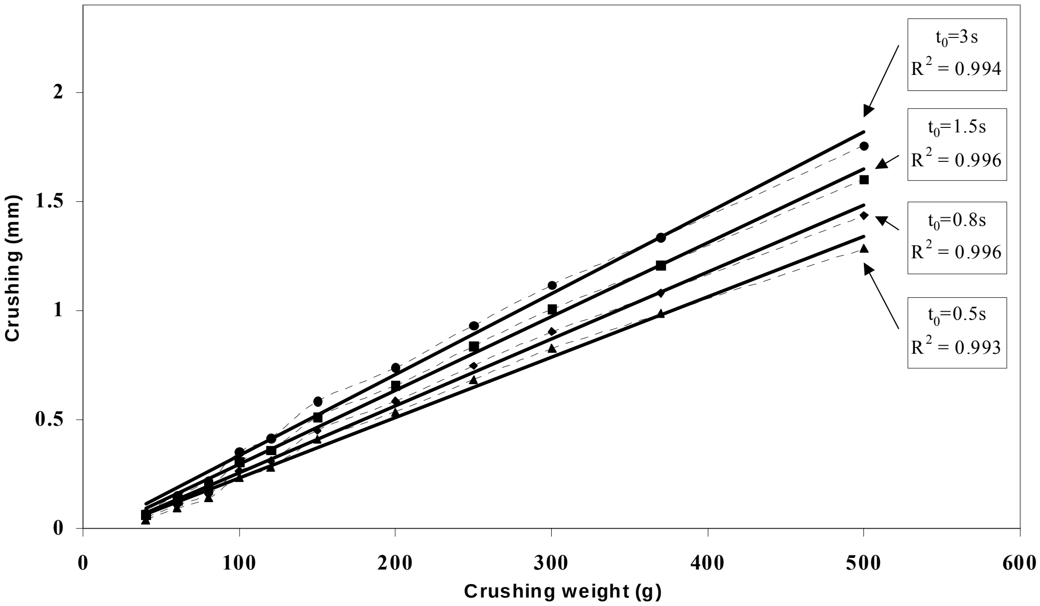

Figure 2 - Change in crushing effect according to the load for different crushing times

We note that the linear relationship between force and movement is valid for loads ranging up to at least 500 g. To remain in the area of validity, we thus subsequently chose a force 250 g crushing force.

### 3.3. Universal aspect of the method

The theoretical approach followed is intended to provide the means for predicting the deformation over time whatever the force applied (within the limits seen in 3.2). In order to check it, and thus to show the universal aspect of the method, we tested a column of tobacco under a 250 g load (Figure 3), and predict, from this specification, the deformation obtained under loads of 150 g, 200 g, 300 g and 370 g. We then compared these predictions with experience (Figure 4).

It is noted that the deformation predicted over a period of time is very close to the measurements. This shows that the model used is capable of describing the forms of deformation obtained under different loads, but also of predicting them accurately.

This result could be useful when you want to link two methods which differ through their load and compression time.

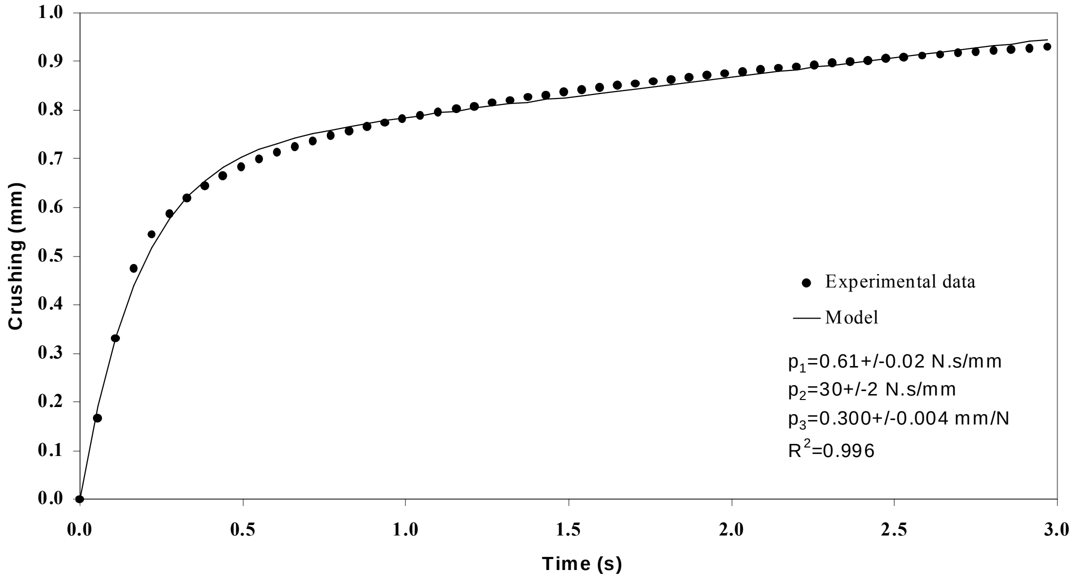

**Figure 3 - Specifying a tobacco segment by adjusting the theoretical model to the deformation measurement over a period of time**

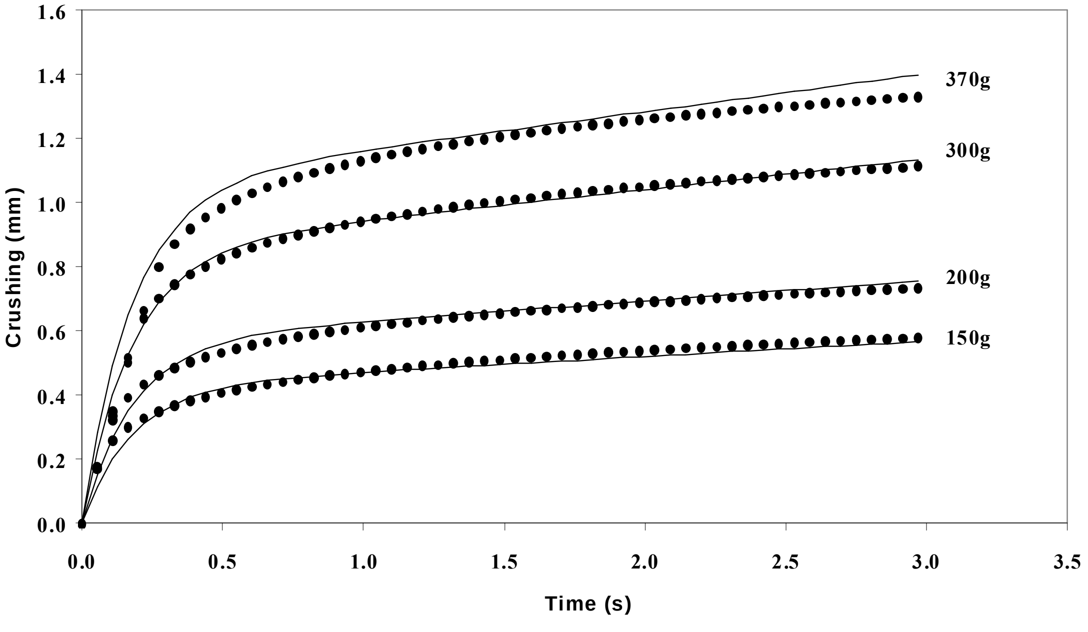

**Figure 4 - Prediction (line) of the deformation over a period of time and comparison with experience (dotted line), under different crushing loads**

### 3.4. Application to a comparison of two blends

A firm product is above all a product which has high resistance to deformation, i.e. a high parameter $p_1$ value. The sensation of firmness is felt by the consumer in the first moments of crushing, not after 10 or 30 seconds. On an equal deformation extent at the end of a given time, a product will appear more firm the more the parameter $p_1$ which measures it is high.

In order to underline the interest of the method and the device used for the firmness study, we compared the resistance to crushing of two tobacco blends, "A" and "B".

Using these two blends, we made several tobacco rods with different weights, ranging from 670 mg to 850 mg, with a constant diameter of 7.9 mm. The value of parameter $p_1$ was then determined according to the tobacco weight (Figure 5).

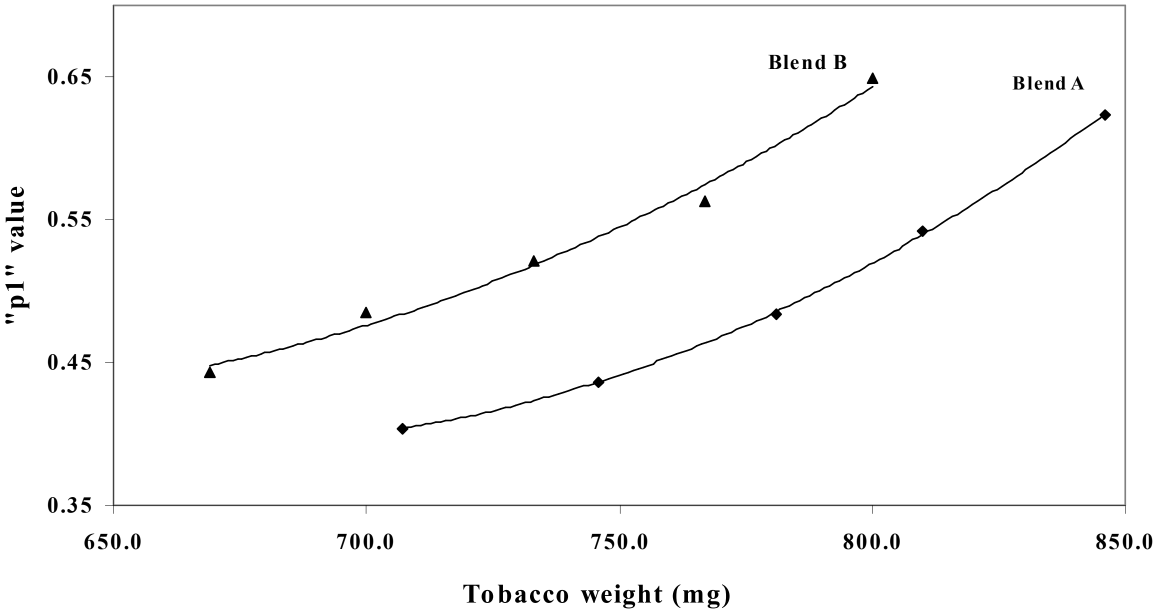

**Figure 5 - Change in parameter p1 according to the weight for the two blends "A" and "B"**

Logically it is noted that the increase in weight results in an increase in resistance to crushing. One more interesting result is that it shows clearly that, for a given weight of tobacco, the resistance to crushing of blend "B" is greater than that for blend "A". This observation can be formulated in a different way by saying that an identical resistance to crushing is obtained with a weight difference of 80 mg.

## 4. Conclusion

The method proposed for specifying the firmness and the device used have many advantages compared with normal methods. Whilst significantly reducing the measurement time, a very complete series of information is obtained on the mechanical specifications of the product tested. We have both a very synthesised piece of data through the amplitude of crushing after 3 seconds, and also more descriptive data in particular on resistance to crushing and resistance to relaxation. The first synthesised piece of data can be used very simply in the context of quality control, while the other data can be usefully used by Research and Development for improving the mechanical properties of the blends.

## References

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