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PRELIMINARY INVESTIGATION OF PASTA EXTRUSION PROCESS: RHEOLOGICAL CHARACTERIZATION OF SEMOLINA DOUGH

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1. Introduction

Extrusion is one of the most versatile and well-established industrial processes used in the food industry today. It is being increasingly applied worldwide to manufacture an ever-expanding list of food and feed materials including snacks, cereals, pastas, textured vegetable proteins and animal feeds. The process generally involves the conversion of a plasticized biopolymer-based formulation into a uniformly processed viscoelastic mass that is suitable for forming or shaping to products by a die. The extrusion process can be divided into two general types. First, non cooking or forming extrusion, where the pressure generated by the screw pushes the material throw the die. Second, cooking extrusion which, as the name implies, involves the raw ingredients being cooked by the combined action of heat, mechanical shearing and pressure. The pasta manufacturing process (forming extrusion) can be actually considered an established technology. Although the development of the knowledge dates back many centuries and the industrial plants for continuous processing have not mainly changed in the last fifty years, the mechanisms involved in the transformation of semolina to pasta by adding water and applying mechanical and thermal energy have been not completely investigated. Moreover the relationships among processing parameters and product quality are not fully understood [2, 12, 13, 16]. The literature on pasta extrusion is quite limited and mainly focused on the raw material [15, 11], drying process and quality of the final products [5, 10]. In many researches, the main objective was the selection of the more appropriate durum wheat cultivars by evaluating their performance when processed in the available plants, or the measurement of the physicochemical changes experienced by the components [9]. Very little attention has been paid to the process itself, and the studies on a single screw extrusion are almost restricted to extrusion cooking. Only more recently numerical simulation were considered as a feasible technique to better understand the physics of the process [3, 7].

The objective of the presented research was to obtain experimental data on semolina dough rheological properties in order to develop a numerical simulation model for pasta extrusion process.

2. Materials and methods

2.1 *Measurment device and conditions*

The materials used in this experimentation were the semolina, supplied by an italian factory that produce pasta and commercial durum wheat semolina. The industrial dough has a very low moisture content around 32%DB (dry basis). At this moisture content the dough is not cohesive and the mixing is possible only with special combination of water sprayer, high speed mixer and high pressure. This process is not affordably reproducible in lab scale, consequently a sample of 10 kg of dough were taken directly from the production line, just before the barrel. Moreover different moisture content were investigated with the purpose to find out a relationship between humidity and dough behavior, on a second dough sample prepared in laboratory. The semolina was mixed at 25°C with tab water at the required levels of hydration (40, 50, 60, 70% DB) for 15 min by using a household mixer (Kenwood Major, Hampshire - UK). AACC method was used to determine moisture [1]. Before the measurements all the doughs were rested in a plastic enclosure for 20 minutes at room temperature.

Fundamental rheological measurements were performed on a controlled stress-strain rheometer (MCR

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The lab test where carried on by dr. Angioloni, ing. Fabbri and de Stefano. Prof Guarnieri has co-ordinated the research. Prof. Lorenzini has revised the text, that was written by Angioloni, de Stefano and Fabbri.

300, by Physica/Anton Paar; Messtechnik GmbH Helmut-Hirth-Strasse, 6 D-73760 Ostfildern Germany-Europe), using parallel-plate geometry (25 mm diameter). The upper plate was lowered until the thickness of the sample reached 2 mm and the excess was trimmed out. The air exposed surface was covered with a thin layer of mineral oil, to prevent moisture loss during testing. Samples were rested for an additional 10 min after loading prior to testing. The rheological measurements were conducted at 20, 30 and 40 °C.

2.2 *Creep experiments*

The creep tests were conducted on the samples prepared in laboratory, mixing equal mass of semolina and water. All experiments were conducted applying a 30 Pa shear stress for 3000 s, as this time was sufficient to reach a state of constant shear rate for the last part of the test. The chosen shear stress (below the critical value) was based on the agreement of creep compliance curves obtained at different stresses. Creep test were obtained on three separately mixed dough for each sample.

2.3 *Flow experiments*

Treating the semolina dough as a purely viscous material, increasing shear rate ($\dot{\gamma}$) was applied to the samples and the shear stress (τ) at different fixed time was measured to obtain the flow curve. The hypothesis is supported by the experience of other researchers [4, 6, 14] that neglected the elastic component of deformation for extrusion studies. This permits to consider the semolina dough as a pseudoplastic material.

Tests were carried on at different temperature of 20, 30 and 40 °C and different rheological model were considered to fit the experimental data:

Power-law with temperature correction: $\eta = k\dot{\gamma}^{n-1}$, where $k = k_0 \exp(T_0/T)$ (1)
Power-law with humidity correction: $\eta = k\dot{\gamma}^{n-1}$, where $k = k_0 \exp(MC_0/MC)$ (2)
Carreau model:
$$\eta = \eta_1 + (\eta_0 - \eta_1) \cdot [1+(\dot{\gamma}\cdot\lambda\exp(T_0/T))^2]^{((n-1)/2)} \qquad (3)$$

where η [Pa s] is pseudo-viscosity; $\dot{\gamma}$ [s^{-1}] is the shear rate; k [Pa s] is the consistency index; n is a measure of the deviation of the fluid from Newtonian (the power-law index); MC is moisture content of the fluid; T is the fluid temperature and λ [s] is a time constant.

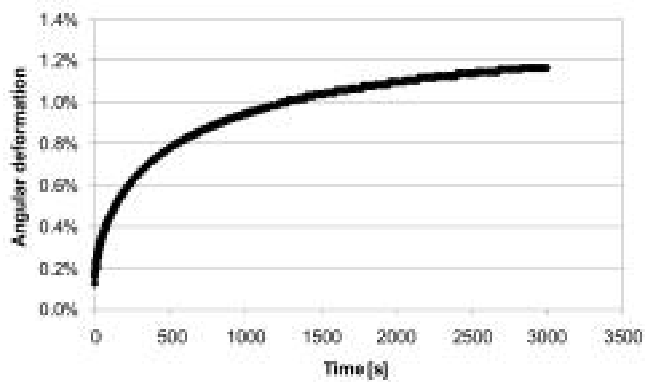

Fig. 1 - Creep test on the lab mixed semolina. A 30 Pa shear stress was applied for 3000 s.

3. Results and comments

3.1 *Creep Test*

The results of creep test is reported in fig.1 were, as a measure of repeatability, it may be seen that curves relative to different replications are overlapped in the scale of the plot. The very first segment of the curve, that is vertical, represents the elastic response to the force impulse, while the end of the curve represents the steady flow. As already observed by [8] the viscosity of semolina dough tends to a zero-shear viscosity for shear rates smaller than $10^{-5\ s-1}$.

The creep results were fitted to the usual creep compliance model, to obtain the value of the following parameters:

$$J(t) = J_0(t) + J_1(t) + J_2(t) = \left\{\frac{1}{G_0}\right\} + \left\{\frac{1}{G_1}\left[1 - e^{-t\frac{G_1}{\eta_1}}\right]\right\} + \left\{\frac{t}{\eta_2}\right\} = J_0 + J_1\left(1 - e^{-\frac{t}{\lambda}}\right) + \frac{t}{\eta_2} \qquad (4)$$

Where J^0 represents the instantaneous compliance, J^1 is usually referred as retarded elastic compliance, and J^2 is ill be referred to as viscous flow. The test has confirmed the viscoelastic behavior of the pasta, but the important observation for the purpose of the present research is that the elastic component of the deformation is very small if compared with the flow condition. As a consequence, the extrusion may be studied, for engineering purposes, with reference to the pure viscous flow models.

	estimated value	lower confidence limit 95%	upper confidence limit 95%
k_0 [Pa s]	2567.8	2238.1	2897.5
n	0.70	0.69	0.72
T_0 [K]	26.6	23.9	29.4

TABLE 1 - Power-law model parameters for lab mixed dough (MC=50%) R^2=0.97.

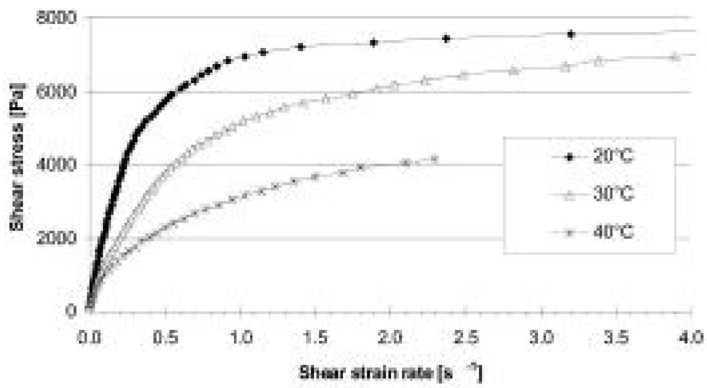

Fig. 2 - Flow curves of the lab mixed dough, for three temperature values.

3.2 *Flow curves*

The flow curves of the dough mixed in lab conditions are reported in Fig. 2, for different temperature values. Three replication was made, even if the error of repeatability was hidden by the measurement error, so the curves are overlapped in the scale of the plot.

It is remarkable how the shear stress decrease for higher temperatures at the same deformation rate. In the tables 1 and 2 are reported the parameters of the power-law and Carreau rheological model.

As regard the measurement on the dough supplied by industry, the flow curves obtained by different samples of the same dough were instead largely different. This is probably the effect of a great variability of the dough, probably due to the low value of the moisture content (MC=32%) that does not permit an efficient mixing of the semolina. At this moisture content the dough can became cohesive only under high pressure value, but remain substantially non homogeneous in normal conditions.

In figure 3 the flow curves are reported as mean on three replications for each temperature. The maximum deviation from the mean shear stress was about 30%.

Comparing the industrial dough with that mixed in lab condition, it is notable for the first one an the higher consistence (higher shear stress tension for the same shear rate). Moreover the steady flow condition was reached for a lower strain rate.

For the industrial dough the power-law rheological model fitted better than the Carreau, so only the former is reported in the figure.

The influence of moisture content on the rheology of the laboratory mixed dough, at a constant temperature of 20°C, is shown in fig. 4 and the power-law parameters are reported in table 4.

As it was not possible to mix the semolina in lab conditions with a moisture content lower than 40%, the model of table 4 was used to estimate the rheology of lab mixed dough for the hypothetical moisture content of 32% at 20°C. The parameters value is rather different from that relative to the industrial dough. The difference in the behavior of the two doughs may be due to the mechanical treatment and to the large heterogeneity of the semolina that came to industry

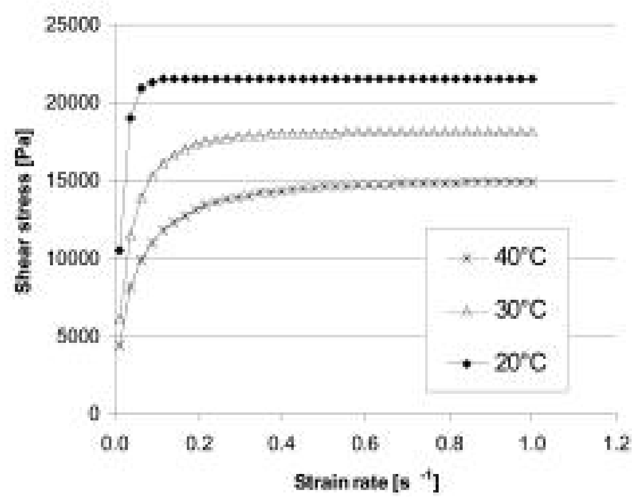

Fig. 3 - Flow curves measured on industrial dough, for three temperature values.

	estimated value	lower confidence limit 95%	upper confidence limit 95%
η_1 [Pa s]	-3909.5	-5092.9	-2725.9
η_0 [Pa s]	38811.7	37282.2	40341.3
λ [s]	-4133.9	-5405.2	-2862.8
T_0 [K]	-82.9	-87.3	-78.4
n	0.72	0.69	0.74

TABLE 2 - Carreau model parameters for lab mixed dough (MC=50%) R^2=0.99.

	estimated value	lower confidence limit 95%	upper confidence limit 95%
k_0 [Pa s]	0.029	0.013	0.046
n	0.602	0.588	0.617
T_0 [K]	4192.1	4018.9	4365.3

TABLE 3 - Power-law parameters for industrial dough (MC=32%) R^2=0.99.

	estimated value	lower confidence limit 95%	upper confidence limit 95%
k_0 [Pa s]	89.9	57.2	122.7
n	0.724	0.711	0.737
MC_0	237.7	218.9	256.5

TABLE 4 - Power-law parameters with correction on the moisture content at a temperature of 20°C (R^2=0.97).

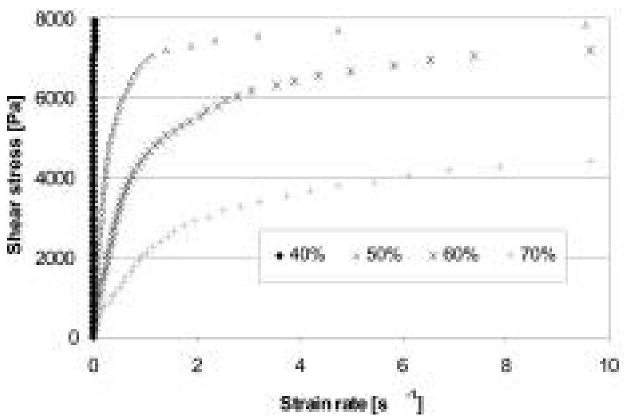

Fig. 4 - Flow curves measured on the lab mixed dough for three moisture content values.

from Canada, Russia and Europe.

The developed rheological models will be used to simulate the behavior of the extrusion plant with computational fluid dynamics technology and to test some design improvement.

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SUMMARY

Rheological measurements were conducted on semolina doughs. Two doughs were considered, one directly taken from an extrusion plant and another mixed in lab conditions. A rotational viscometer was used in the plate-plate configuration. Creep tests were carried on too, to verify the possibility to neglect the elastic component of strain.

It was investigated the influence of the temperature on the viscous behaviour of both doughs, while only on the lab mixed dough was tested the influence of moisture content. The aim of this research is the determination of a rheological model useful for a subsequent CFD analysis of the extrusion process.

Key words: Semolina dough, Pasta, Rheology, Extrusion.