Influence of the Ultrasonic Microvibrations under the Processing of the HDPE Thermoplastic Material

NICUSOR ALIN SIRBU[1,2]*, VIOREL-AUREL SERBAN[1], SORIN SAVU[3]

[1]Politehnica University of Timisoara, Faculty of Mechanical Engineering, 1 Mihai Viteazu Blv., 300222, Timisoara, Romania

[2]National Research and Development Institute for Welding and Material Testing, 30 Mihai Viteazu Blv., 300222, Timisoara, Romania

[3]University of Craiova, Faculty of Mechanics, Department of Engineering and Management of Technological Systems, 107 Calea Bucuresti, 200512, Craiova, Romania

The paper present the experimental results of a comparative research study between classical and ultrasonically processing by extrusion of the HDPE-220J (High Density Polyethylene) polymeric material. For this material, often used in engineering, have been obtained, in flow activated using ultrasonic waves, relatives increases of the flow rate up to 77% of polymer flowing through extrusion compared with the processing without ultrasounds. These results have been obtained in laminar flowing and no imperfections have been presented due to the extrusion process. The experimental results of the state transition using the differential scanning calorimetry analysis DSC (Differential Scanning Calorimeter), realized for classical and ultrasonically flow activation, confirms that ultrasonic microvibrations produced no changes in the internal structure of the polymer. The ultrasonic device used in this research is subject to a patent application registered at OSIM with number A/00979/2013.

Keywords: polymeric materials, extrusion, ultrasounds, flow rate

The need of a modern society stimulates, in this case the intensive development of the polymeric materials, and assign them as useful and neccessary in many fields of the human activity. HDPE polymeric materials are more and more used in applications [1].

Global production of polymeric material has increased from 1.5 mil tons (Mt) since 1950 to 245 Mt till 2008. About 60 Mt are produced only in Europe. The production of the last 10 years has been equal with the production recorded during the entire XX century. It is estimated (in a *status quo* scenario) that about 66,5 Mt of polymeric materials will be introduced in EU market till 2020 and the global production of polymeric materials will increase three times till 2050 [2].

In the serious competition of global market framework, the manufacturers seek constantly new methods to reduce the manufacturing time and to improve the quality of their products. In an effort to improve the flow rate of the polymeric materials and to reject the imperfections (wrinkling or cracking of the product surface and/or induction of some inner stresses which determine the deformation by bending of the final product) which can appear in many cases during the processing of the polymeric materials, some researches have to be done and during these researches it has been observed that the present of ultrasonic oscillations, during the processing of the polymeric materials, has a positive influence on flowing behaviour of the polymeric materials. These results obtained by some researchers recognised at worldwide level [3-10] and national level [11-18], sustain the technical proposal of ultrasonic activation in processes which implies the flowing of melted polymer (injection respectively extrusion).

Experimental part

In order to realize experimental researches regarding the influence of the ultrasonic activation of the HDPE melt, during the flowing processes, an ultrasonic device, presented in figure 1c, has been realized. This device is composed from a classical equipment for injection-extrusion with piston (1), with a panel used to adjust the temperature of the extrusion cylinder, the air cooling system (2), the temperature monitoring system at extrusion die (3), an ultrasonic device for flowing and ultrasonic assembly kit (4), an ultrasounds generator (5) specially built for that application (40 kHz, 900 W), of the ultrasonic system composed from a compressor used for obtaining compressed

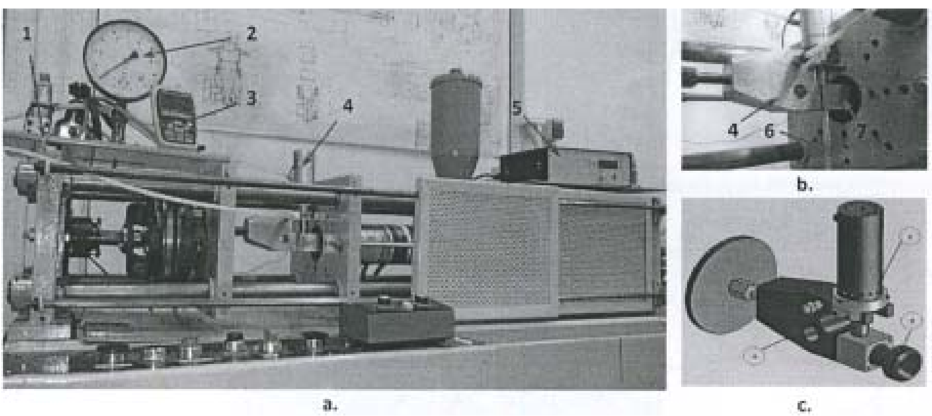


Fig. 1. Experimental stand for ultrasonic activation of polymers melt flow: a. assembled form of the experimental stand with and without ultrasonic activation; b. detail of the active area of the experimental stand; c. ultrasonic devices

* email: asirbu@isim.ro

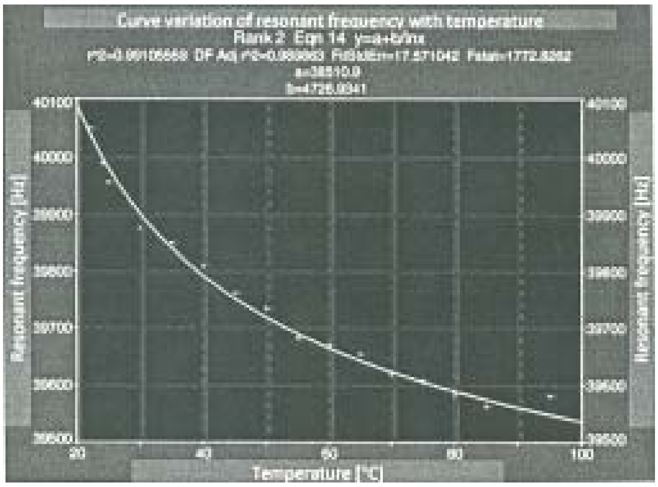


Fig. 2. The graph of resonant frequency variation depending on the work temperature

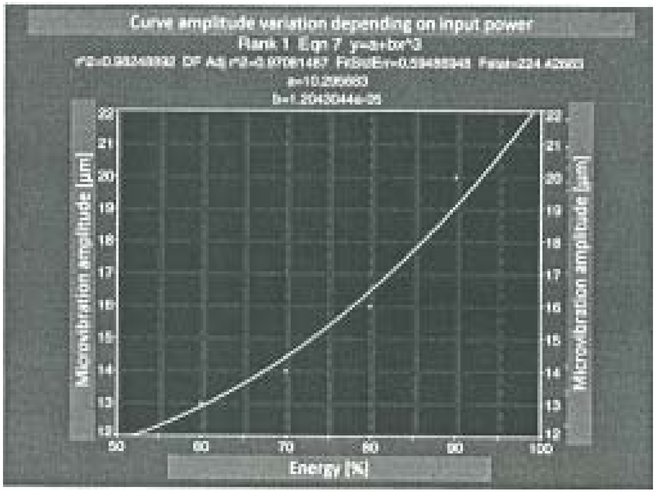


Fig. 3. The graph change of the microvibration amplitude depending on the energy introduced into system

air. To realize the thermal contribution at the exit area from device, a generator with hot air has been used.

In figure 1.b is presented the flowing zone (6) of the melted polymeric material, at the exit from extrusion die (7) of the ultrasonic devices for polymeric flow activation of the polymeric and composites materials, and in figure 1.c is presented the assembled form of the projected flowing device, highlighting the actual body of the device (A), the nozzle of the classic device used for injection-extrusion (B) and the ultrasonic assembly (C). The ultrasonic flowing device used in researches is a new technical solution and a subject patented at OSIM with number A/00979/2013.

There were realized more experimental tests with the aim to identify the areas with optimal relative growth of the flow rate, in accordance with the structural changes due to ultrasonic activation and the amelioration level of the imperfections. Also, it was identified the critical zone of the ultrasonic process. The temperatures gap used for test have been between 120÷175°C. This gap has allowed identifying of the critical and optimal areas.

Because the experimental researches with ultrasonic activation of the flowing of the melted HDPE are run at high temperatures (≥100°C), it was imposed the experimental determining of the correlation between the change of the resonant frequency and the regime of temperature, measured in the top of ultrasonic horn which is immersed in the working environment (fig. 2).

For the experimental tests has been built a special ultrasounds generator in order to ensure an adjustable power up to 900 W from the generator panel, the resonant frequency 40 kHz and automatic continue calibration of the frequency depending by the specific conditions of the working temperature of the ultrasonic assembly (fig. 2). The experimental flow tests with ultrasonic activation have been realized using a peak adjusted by generator at 50% of the amount energy introduced into system. The conversion of the energy into dimensional unit (µm) has been realized by experimental method, through measurement of the microvibrations amplitude at the top of the ultrasonic horn. The variation curve of the microvibrations amplitude depending on the energy introduced into system is presented in figure 3.

There have been realized many experimental tests. The results of the experimental tests considered that an experimental programme with 15 tests for each batch is conclusive highlighting the relative growth of the flow rate (ΔQ), the stable and reproductible experimental tests of the flowing activated or not by ultrasounds. Good results of the research, regarding the ultrasonic activation from point of view of relative growth of the flow rate (ΔQ), have been obtained for temperatures of extrusion die between 140°C - 175°C. These relative growths of the flow rate are up to 77 %. Over that temperature, in the presence of the ultrasounds, has been observed the appearance of the thermal degradation at the level of the extrudated material. For temperatures below 120°C, the flowing has been possible only if it was activated with ultrasounds.

Next will be presented and analyzed the results obtained for the values of the temperature (120, 140 and 175°C) of the extrusion die, temperatures where have been obtained the best results for ultrasonic activation, respectively a laminar flow, without imperfection. The relative growth of the flow rate ΔQ was calculated through the formula:

$$\Delta Q = \frac{\overline{Q}_{us} - \overline{Q}}{\overline{Q}} \cdot 100 \qquad (1)$$

in which: $\overline{Q}_{vs}$ – arithmetical average of the polymeric material flow rate process for a work cycle, for the experiments with ultrasonic activation; $\overline{Q}$ – arithmetical average of the polymeric material flow rate process for a work cycle, for the experiments without ultrasonic activation.

Based on experimental results for ultrasonic activation of flowing of HDPE in melted phase, presented in figure 4, specific for the experiment type I, in which the extrusion die temperature was 175°C, the relative growth of the flow rate was calculated:

$$\Delta Q = \frac{0{,}3847 - 0{,}2176}{0{,}2176} \cdot 100 \approx 77\% \qquad (2)$$

From results obtained, it can be observed that has been obtained a relative growth, about 77%, of the flow rate as a follow of the effects of the ultrasound microvibrations, compared with the growth obtained in flowing tests without ultrasonic activation.

Based on experimental results for ultrasonic activation of flowing of HDPE in melted phase, presented in figure 4, specific for the experiment type II, in which the extrusion die temperature was 175°C, the relative growth of the flow rate ΔQ was calculated:

$$\Delta Q = \frac{0{,}2399 - 0{,}1381}{0{,}1381} \cdot 100 \approx 74\% \qquad (3)$$

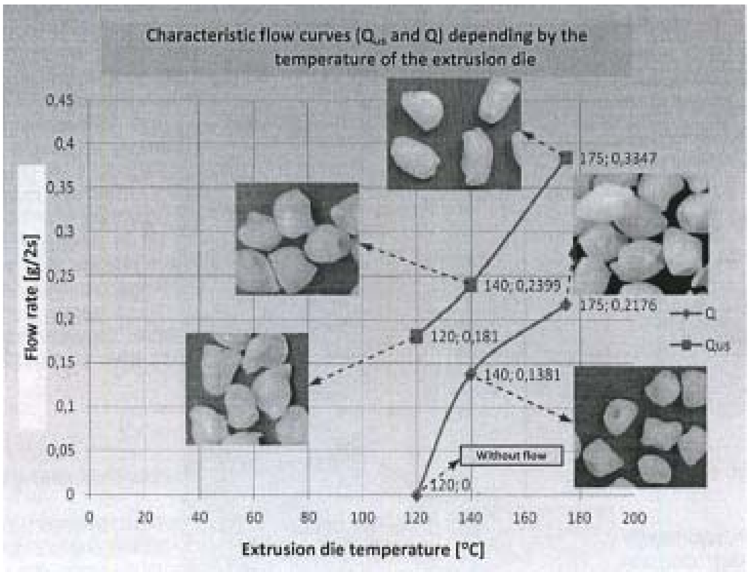
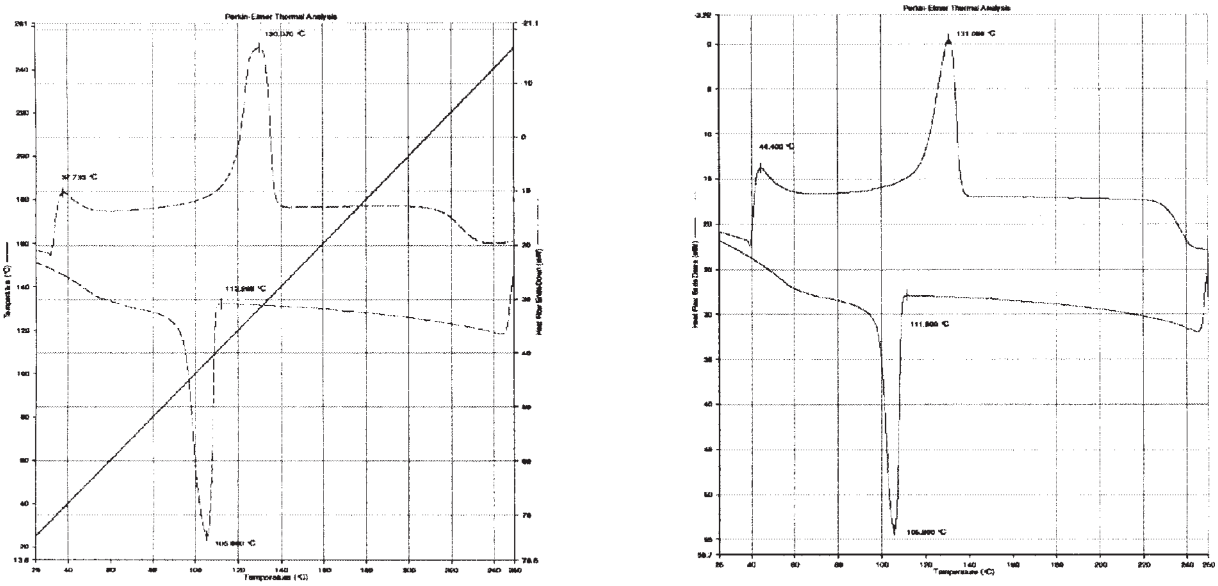


Fig. 4. The graph of flow rate variation depending on the temperature of extrusion die: Q_{us} – flowing activated with ultrasounds; Q – classical flow



a.   b.

Fig. 5. The graphs of state transition (from semicrystalline to amorphous state) of HDPE polymer, realized for classical (a.) and ultrasonically flow activation (b.)

From the obtained results, it can be observed that there is obtained a relative growth, about 74%, of the flow rate as a result of the effects of the ultrasonic microvibrations, compared with the growth from the flowing tests without ultrasonic activation.

The experimental results of the HDPE flow rate in melt phase, by ultrasonic activation, characteristic for experiment type III have highlighted that the processing of the melt HDPE has been possible only in the presence of the ultrasounds.

Based on the experimental results obtained during the experiments, have been realized graphs with the curves which characterize the flow rate of HDPE extrudated material depending on the temperature of the extrusion die (fig. 4). The analysis of the change curves (Q_{us} and Q) highlights the advantages of the using of ultrasounds into flowing processes of HDPE polymeric material.

The experimental results of the state transition using the differential scanning calorimetry analysis DSC (Differential Scanning Calorimeter), realized for classical (fig. 5.a) and ultrasonically flow activation (fig. 5.b), confirm that ultrasonic microvibrations produced no changes in the internal structure of the polymer.

Results and discussions

The results of the research have highlighted relative growth of the flow rate up to 77% for temperatures of the die 140 and 175°C, for laminar flowing, without imperfections, compared with normal flow without ultrasonic activation. Over this temperature (175°C) and with ultrasonic activation it was observed the appearance of the thermal degradations of the surface of the extrudated material. Below temperatures of 120°C, the flow has been possible only with ultrasounds activation.

The results, regarding the growth of the flow rate and the amelioration of the imperfections, obtained through experimental method, are based on beneficial effects (thermal and surface) of the ultrasonic microvibrations which appear into the flowing processes activated with ultrasounds of the polymeric materials. These results are applied to the polymeric materials, in melt phase, at the level of the active working area.

The structural analysis realized through differential calorimetry DSC has highlighted that the ultrasonic microvibrations did not made changes to the internal structure of the polymer.

Conclusions

The experimetal stand, realized during the researches for ultrasonic activation of the flowing of polymeric materials, is robust and ensures stability from point of view of energy and process parameters. Also, the stand ensures a good reproductibility of the experimental tests.

After experimental research for ultrasonic activation of the flowing of the melt polymer, have been obtained relative growths of flow rate up to 77% compared with classical flow without ultrasonic activation.

The experimental researches have allowed establishing the optimal gap regarding the activation with ultrasounds and also the boundaries from point of view of temperatures for technological process of ultrasounds activation.

The procedure can be applied for boundaries conditions of the flowing process, at low temperatures when the flowing cannot be possible, or for polymeric materials or polymeric composites which present flow difficulties and shape processing.

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