Abstract
This paper presents the experimental results regarding acoustic emission signals measured during the injection molding of those standard test specimens commonly used for examining the shrinkage behaviour of various thermoplastic materials. In daily industrial production of different plastic products we often have to deal with various errors that practically occur on the mold primarily as a result of tool wear and tear, improper storage and improper settings on the injection molding machine. In the testing phase of plastic materials we use many times different inserts that are made from standard tool steels, such as OCR12VM. In case of tool steel inserts after some years of usage a few micro-cracks can occur in the early stage, which can later quickly spread according to the applied loading. With the help of different non-destructive testing methods we know that we can most certainly detect possible formation of cracks on the tool steel inserts. The acoustic emission was measured on an injection mold with the visible sign of a crack on the cavity's surface, using two contact PZT sensors under normal and increased injection pressure loads. In this paper, we focused exclusively on the acoustic emission signal acquisition by using two resonant 150 kHz piezoelectric AE sensors on such tool steel inserts that are already affected by macro-cracks. On such tool steel insert the obtained acoustic emission results were compared with those obtained from a brand new tool steel insert. The final obtained acoustic emission results on the crack defected tool steel insert revealed as expected that the energy and intensity of the captured AE signals is higher compared with the ones that were captured on the brand new engraving insert under same processing conditions.

Keywords: Acoustic emission, injection molding, crack, mold, polypropylene

1. Introduction

Injection moulding is a well-known plastic manufacturing process where heated molten plastic material is forced into a mould cavity under high pressure. The plastic material solidifies into a shape that has conformed to the contour of the mould. Nowadays it is still regarded as the most important and very popular manufacturing process because of simple operation steps. A typical production cycle begins when the mould closes, followed by the injection of the plastic into the mould cavity. Once the cavity is filled, additional pressure compensates the material shrinkage. In the next step, the screw turns, feeding the next shot to the front screw tip. This causes the screw to retract as the next cycle is almost prepared. Once the moulded part is sufficiently cooled, the mould opens and the part is finally ejected. Chen and Turng [1] defined three categories of variables that describe the hierarchy and dependency of injection-moulding control. First level can be defined as machine variables.
that incorporate barrel temperature in several zones, pressure, sequence and motion, ... Second level variables are process dependent variables that incorporate melt temperature in the nozzle, runner, or mould cavity, melt pressure (in the nozzle, cavity), melt-front advancement, maximum shear stress, rate of heat dissipation and cooling. Third level of quality definitions are part weight and part thickness, shrinkage and warpage, ... Most of current work deals with the control tasks at the first two levels. For quality control, this is often achieved indirectly through online dynamic process control or off-line statistics process control (SPC). For monitoring second level variables majority of commercially available in mould sensors are pressure and temperature sensors. Muller et al. [2] presented a wireless sensor concept for injection moulding which uses structure born sound as transport medium. It is orientated on level two variables. The sound is generated by an acoustic actor which is activated by the passing flow front at certain predetermined positions in the cavity (or cavities). Lijuan Zhao et al. [3] developed ultrasonic diagnosing technique with a high-temperature ultrasonic transducer to real-time diagnose polymer processing and its morphology changes in injection moulding processing. Ultrasound diagnosis showed that longitudinal wave can real-time characterize the data of the injection process and polymer morphology changes, including melt flow arrival time, the part ejection time, filling and packing stages, polymer solidification process, and the morphology changes during polymer crystallization. Kusić et al. [4] analyzed measured AE signals and their correlation with the post-moulding shrinkage and warping. Experiments indicated the possibility of on-line monitoring and the adequacy of the process control by capturing AE signals. Location and advancement of a possible crack on the steel can be detected by the use of acoustic emission technique as already reported by many researchers [5-8]. But the detection of cracks in tools during injection moulding process is a topic that is not sufficiently presented in accessible literature. In this paper the results of AE monitoring to detect cracks in tool steel inserts are presented, that can upgrade the process control using AE signals presented by Kusić et al. [4]

2. Experimental procedure

Acoustic emission signals were captured during the production cycle of standard test specimens that are intended for shrinkage evaluation of various plastic materials. The main aim was to analyse the influence of a possible crack located in tool steel insert on the captured acoustic emission signals. After finishing the first experimental part on a tool steel insert with a macro-crack we repeated the experiment under the same processing conditions also on the brand new tool steel insert. In this way the captured acoustic emission signals could be compared. The captured acoustic emission signals were then correlated with the quality of the produced test specimens. Acoustic emission measurement system AMSY-5 from Vallen-Systeme GmbH was used for capturing and analysing the AE signals. Two piezoelectric AE sensors VS150-M (resonant at 150 kHz) were mounted using silicone grease with two sensor holders on the tool steel insert from both sides as shown on Fig. 1. Both PZT sensors were connected via two preamplifiers AEP4 with a fixed gain of 40 dB on the first and second channel of AMSY-5 measurement system.
If we want to produce standard test specimens with good quality, the process parameters must be correctly set. Before the start of the experiment, it was necessary to select and fix the following process parameters: injection pressure was set to 1100 bar in the course of the experiment, holding pressure was set to 500 bar. On the new tool steel insert the melt temperature in cylinder has been set to 230 °C and the injection speed was set to 50 mm/s. On the tool insert with a macro-crack the melt temperature was set to 240 °C and the injection speed was 45 mm/s. The main criterion for the quality of produced test specimens was chosen to be the size of the shrinkage in longitudinal and transverse direction of the melt flow.

3. Experimental results

We carried out the experiments on a brand new tool steel insert and on a tool steel insert with visible sign of macro-cracks. In both cases we used the same polypropylene material from Sirmax manufacturer (H40 C2 FNAT), which is mainly used in the automotive industry. After the test specimens were produced, they were scanned with an optical 3D digitizer ATOS II SO after 24 hours.

Once the test specimens are digitized the measured data can be saved and used later on. Usually we are interested in individual measuring values and sections across the test specimen. Larger deviations and/or dimensional changes compared to the nominal ones are easy to verify and to control. Optical 3D digitizer is based on the principle of capturing images through the camera, which then through an appropriate program prepares a computer model. The accuracy that can be achieved with these digitizers depends largely on the quality of the camera, which records the desired object. Of course, in a very small precision scale the accuracy itself also depends on the wavelength of the light. The biggest advantage of used 3D digitizer lies in extremely rapid procedure of digitizing and excellent precision (precision declared for very small objects are up to 2 microns). Example of produced and later scanned test specimens on a brand new tool steel insert and insert with a visible macro-crack is shown in Fig. 2.
Figure 2. (a) Scanned test specimens produced on a new tool steel insert and (b) specimen produced on a tool steel insert with a visible sign of macro-cracks

From Fig. 2a we can see that the produced test specimen is within the prescribed tolerances (59.91 mm in length and 59.32 mm in width) and with no visible defects. As can be seen from Fig. 2b the test specimen has a clearly visible macro-crack. Also both dimensions are outside of the nominal 60 mm in the longitudinal (1.27 mm) and transverse (1.43 mm) direction.

An advantage of scanning the test specimens is the fact that quality of surface and its deviation can be compared to the flat (ideal) surface. By comparing scanned test specimens we can notice also significant surface deviations with regard to the ideal surface, which are within the range of 0.17 mm exactly on the place of macro-cracks.

By measuring the simple waveform parameters such as energy, amplitude, hits, counts etc. on acquired AE signals, we can obtain useful information about the AE source intensity and its seriousness. In this way we can determine if the tool steel inserts quality is still good or if it is necessary to be replaced in the forthcoming future.

The peak AE signal amplitudes are normally related to the intensity of one or more AE sources, which are in our case macro-cracks located on the tool steel insert. In the past research works [9, 10] correlations between total counts, count rate and various fracture mechanics parameters (like for example the stress intensity factor) have been established and can be expressed by the following equation

$$N \equiv K^n$$  \hspace{1cm} (1)

where $K$ is the stress intensity factor, $N$ is the total number of counts and $n$ is a constant value between 2 and 10. The fatigue crack propagation rate is defined by

$$\frac{dN}{dc} \cong \frac{da}{dc}$$  \hspace{1cm} (2)

where $a$ is the crack size, $c$ is the number of cycles and $N$ is the total number of counts.
Figure 3. AE signals during production of (a) a test specimen with a new insert, and (b) a test specimen with a damaged insert

Figure 3 shows the amplitudes and AE signal energy during the production of a test specimens with a new tool insert and damaged tool insert. Presence of cracks in the insert can be detected by increase of amplitudes and energies of measured AE signals. On the tool steel insert with macro-crack a significant increase in the number of detected AE signals at the end of filling phase and beginning of holding phase can also be seen. Increase of AE activity is caused by increase of mechanical stresses in the injection moulding tool.

The analysis of the AE signal based on the spectrogram has been utilized to evaluate the behavior of injection molding process. A spectrogram is a visual representation of the spectrum of frequencies in an AE signal as they vary with time. Time–frequency analysis is based on the decomposition of one-dimensional signals into two dimensions, time and frequency, represented through the respective axes. The time–frequency diagram allows observation of the distribution of energy of the acoustic signal. Colours of the time frequency diagram represent the most important acoustic peaks for a given time frame, with red
representing the highest energies, then in decreasing order of importance, orange, yellow, green, cyan, blue, and black areas below a threshold decibel level. Fig. 4 shows AE signal waveform measured during filling phase 3 s after the beginning of injection molding of specimen with a new mold. Fig. 5 shows AE signal waveform measured during filling phase 6.5 s after the beginning of injection molding of specimen with a damaged mold and spectrogram of this signal. During the injection molding of a specimen with a new mold we measure predominantly signals with longer duration and not pronounced exponential decay of amplitude. These signals can be characterized as process orientated signals. During the injection molding in a tool with a crack we measured signals with an instant increase of amplitude and pronounced exponential decay of the amplitude. The acoustic emission burst rate during injection molding of specimen with a damaged mold is considerably higher and is a consequence of crack growth in steel tool insert. Pronounced frequency in the measured AE signals is 150 kHz, that is resonant frequency of the sensor.

Figure 4. Time frequency diagram (spectrogram) of AE signal during filling phase with a new mold.
Figure 5. Time frequency diagram (spectrogram) of AE signal during filling phase with a damaged mold.

4. Conclusions

The aim of this research work was to determine to which extent it is possible with AE method to detect the presence of macro-cracks on engraving tool steel inserts by conducting a closer comparison of captured AE signals obtained from new and damaged tool steel insert under the same processing conditions. We have found apparent difference in activity of detected AE signals during the filling phase of commercial polypropylene material in favor of the tool steel insert with visible sign of macro-cracks. The results clearly show also the difference in the maximum amplitudes during filling and holding phase, as well as in energies of captured AE signals. From our experimental results we were able to obtain useful information about the presence of macro-cracks during production of standard test specimens.

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References