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Use of AE Method for Detecting Quality Of Injection-Mold Engraving Inserts

Dragan KUSIĆ [1], Tomaž KEK [2], Janez M. SLABE [1], Rajko SVEČKO [3], Janez GRUM [2]

[1] TECOS Slovenian Tool and Die Development Centre,
Kidričeva 25, 3000 Celje, Slovenia; dragan.kusic@tecos.si, janezmarko.slabe@tecos.si,
tel.: +386 (0)34 900 920, fax: +386 (0)34 264 611
[2] University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva 6, 1000 Ljubljana, Slovenia;
tomaz.kek@fs.uni-lj.si, janez.grum@fs.uni-lj.si
[3] University of Maribor, Faculty of Electrical Engineering and Computer Science, Smetanova 17,
2000 Maribor, Slovenia; rajko.svecko@uni-mb.si

Abstract
The main objective of this article was to investigate whether it is possible to detect with AE measurements a difference between the new and already used injection mold engraving inserts and what is their impact on the quality of the produced plastic parts. The used injection-mold engraving insert was not in operation for almost one year and was thus affected by surface corrosion. Experimental test results obtained with acoustic emission method on an unused and already used injection-mold engraving insert are presented. The investigation was mainly focused on analysis of the measured AE signals obtained from one resonant 150 kHz piezoelectric acoustic emission sensor mounted on the top of the tool. The AE signals were captured during injection-molding cycle. From these measurements we gained valuable information about the presence of corrosion on the tool steel surface.

Keywords: Acoustic emission, injection molding process, tool steel engraving insert, surface corrosion, condition monitoring, polypropylene

1. Introduction

Acoustic Emission (AE) is a non-destructive testing (NDT) method used for monitoring structures or components to detect actively propagating flaws. By applying stresses to a test specimen, an active flaw releases acoustic energy as an elastic waveform, which is detected, located and characterized by the AE measurement system. Acoustic emission is different compared to other non-destructive testing methods. The reason lies in the fact that AE signal originates within material and that it can detect movement while most other testing methods detect existing geometric discontinuities. AE's most important advantage as an NDT method is the capability of providing complete flaw site information on the entire volume of the structure. Therefore it can be used for locating structural discontinuities and flaws without losing time with point-to-point search method over the entire structures surface. Sources of AE in case of tool steel may be different for example, from crack advance, corrosion reactions to deformation during production etc.

In daily industrial production corrosion can cause serious failures that can lead in near future to a large economic loss or even worse to an increased risk of personnel injuries that can become a nightmare for every company dealing with such situation. Before this scenario occurs some most important steps have to be undertaken, which can ensure that such failures don't actually happen. It is necessary therefore to ensure early detection, effective prevention measures and proper diagnosis of current situation in daily production at the right time before it is too late. In real industrial environment corrosion attacks can be detected under different situations and conditions. When the consequences and expected risk of corrosion is high, then a systematic periodic inspection or continuous corrosion monitoring has to be carried out.

With the use of proper equipment the inspection, control, maintenance and operating procedures should ensure safe performance and operation of the production. In the case of periodic inspection the main goal is to determine if there are any indications of mechanical or corrosion influenced cracks, which can lead to failure. Experienced inspectors can often determine from visual inspection the type of corrosion, such as surface (general) corrosion, pitting corrosion, weld and heat affected zone corrosion and erosion corrosion. However, corrosion itself usually causes acoustic emission as a result of the gradual destruction of metal material.

In the last two decades a lot of research work has been published in the field of detection, monitoring and diagnosis of tool defects and also corrosion by using acoustic emission method. For example, Li [1] used AE method for tool wear monitoring. For processing the AE signals he used various methodologies, including time series analysis, FFT and wavelet transform. Van Dijck and Van Hulle [2] proposed a hybrid filter–wrapper genetic algorithm for corrosion identification using AE. They were able to identify the absence of corrosion, uniform corrosion, pitting and stress corrosion cracking, with an accuracy of up to 87.20%. Jemielniak and Otman [3] used a statistical analysis method for tool failure detection, which is based on the distributions of the root mean squared AE signals. With this method they obtained promising results for tool breakage detection. Wilcox et al. [4] used acoustic emission signals and cutting force for monitoring tool insert geometry during rough face milling. Their results indicate that both cutting force and AE can be used as indicators of changes in cutting tool geometry, which is therefore suitable for diagnose and wear detection.

Injection molding is one of the most widely used techniques for the polymer material processing. It is a cyclic process that offers production of complicated plastic products with complex geometries. The process operation is conceptually simple. The plastic in the form of pellets or granules are fed to the injection-molding machine through the hopper. At the entrance into the barrel (cylinder), the screw rotates and moves the granules forward in the screw channels. The granules are forced against the wall of the heated barrel and then melt due to both the conduction from the heating units, which are mounted along the barrel, and the friction heat generated by the rotating screw. The molten material is conveyed to the tip of the screw. During this time, pressure develops against the nozzle and the screw moves backward to accumulate sufficient amount of melt at the front end of the screw barrel. When the desired volume of melt is obtained, the screw rotation stops and the plastification stage has ended. Then the injection (filling) stage begins, where the clamp unit keeps the empty mold closed and the screw moves forward as a ram and forces the melt into the mold cavity. When the mold is filled (filling stage ends and the packing stage starts), the screw is held in the forward position or moves with a small displacement to maintain a holding pressure. During that time material cools down and shrinks, which allows a little more material to enter into the mold to compensate the volumetric shrinkage of the material. After certain time the gates have completely frozen and eventually the cavity pressure is reduced to a very low value. The plastic parts continue to cool down and to solidify. Meanwhile, the screw starts rotating and moving backwards (start of the new plastification stage). When the defined cooling time for the plastic parts to solidify and to become stiff enough, has elapsed the mold opens and ejects them. After that the mold is closed and the cycle repeats [5].

2. Experimental procedure

Acoustic emission was measured during the injection molding cycle to analyze the corrosion attack of injection-mold engraving inserts on measured AE signals. The corroded injection-mold engraving insert was found to be slightly deformed after a few experiments. AE signals are also compared with quality of the produced plastic parts. Acoustic emission measurement system AMSY-5 from Vallen-Systeme GmbH was used for capturing and analyzing the AE signals. One piezoelectric AE sensor VS150-M (resonant at 150 kHz) was mounted with silicone grease to a sensor holder on the top of the tool as shown in Fig. 1. The sensor was connected to the preamplifiers AEP4 with a fixed gain of 40dB.

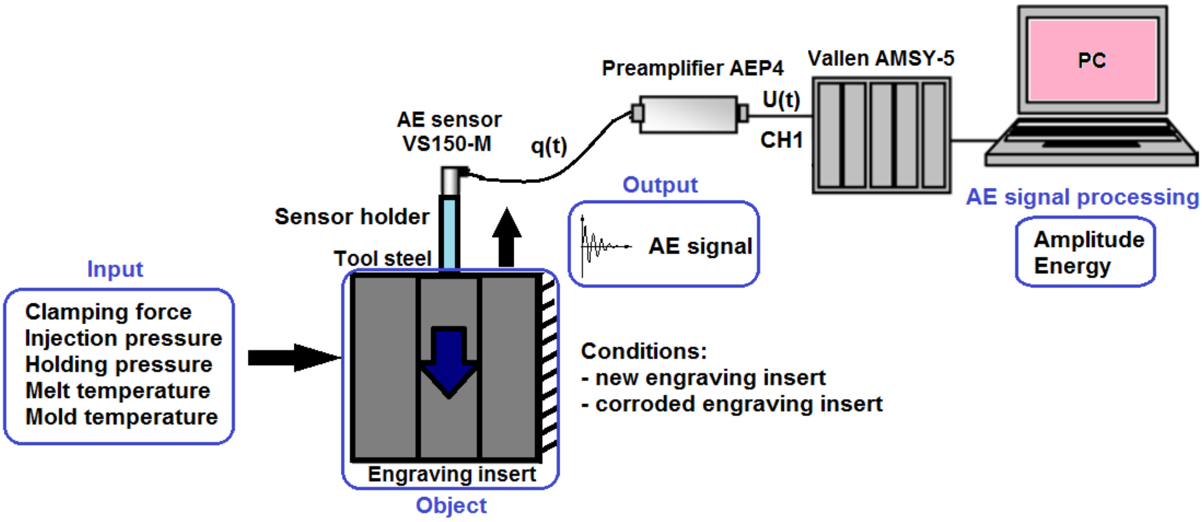

Fig.1. Diagram of the experimental setup.

As can be seen from Fig. 1 the clamping force, injection pressure, holding pressure, melt and mold temperature all act like an input into the process. The output of the process is the amplitude and energy of captured AE signals. The AE signals are amplified through preamplifier AEP4 and brought to analog input of AMSY-5 measurement system. A schematic drawing in Fig. 2 shows a more detailed view of mold's ejection side and the AE sensor placement.

The injection molding process parameters have to be set properly in order to produce plastic parts with good quality and without major defects. Before the start of experiments it was necessary to select and fix the following injection molding process parameters: injection pressure was set on a constant 800 bar all the time during tests, the melt temperature was approximately 230 °C and the injection speed 40 mm/s. The AE signals were captured during the injection molding cycle in which holding pressure was first set to 200 bar and in the next cycle increased to 240 bar. For the main quality criteria of the plastic part we choose flash. Flash is a type of defect, which is characterized by excessive material attached to a molded product and must usually be removed.

We performed 3 consecutive cycles multiple times with both injection mold engraving inserts and captured the AE signals during increased loading where holding pressure was changed from 200 bar to 240 bar in the next cycle. We noticed on some parts the traces of the corroded surface that peeled of from the defected engraving insert.

3. Experimental results and discussion

The first part of experimental tests was performed with unused injection-mold engraving insert as shown in Fig. 3. In the second part we repeated the experimental tests with already used injection-mold engraving insert that was not in operation for almost one year and thus also affected by surface corrosion as shown in Fig. 4. In both cases we used a polypropylene (PP) material ISOFIL H40 C2 F NAT, which is a lightweight, heat resistance, high chemical resistance, scratch resistance, tough, stiff and low cost polymer material. This polypropylene material is usually used in automotive industry for radiator expansion tanks, steering wheel covers, tool boxes, etc.

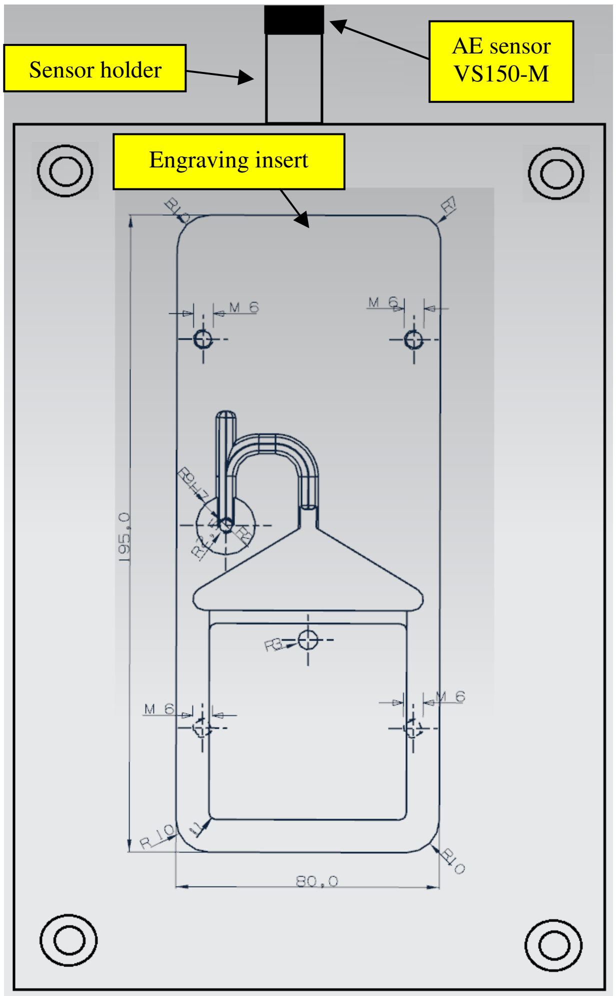

Fig.2. Schematic drawing of the mold’s ejection side.

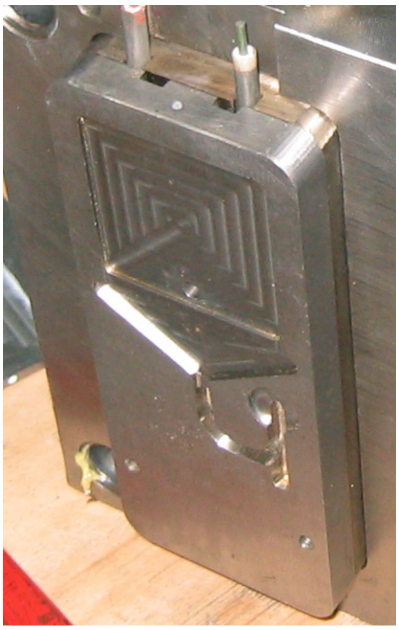

Fig.3. Unused injection mold engraving insert

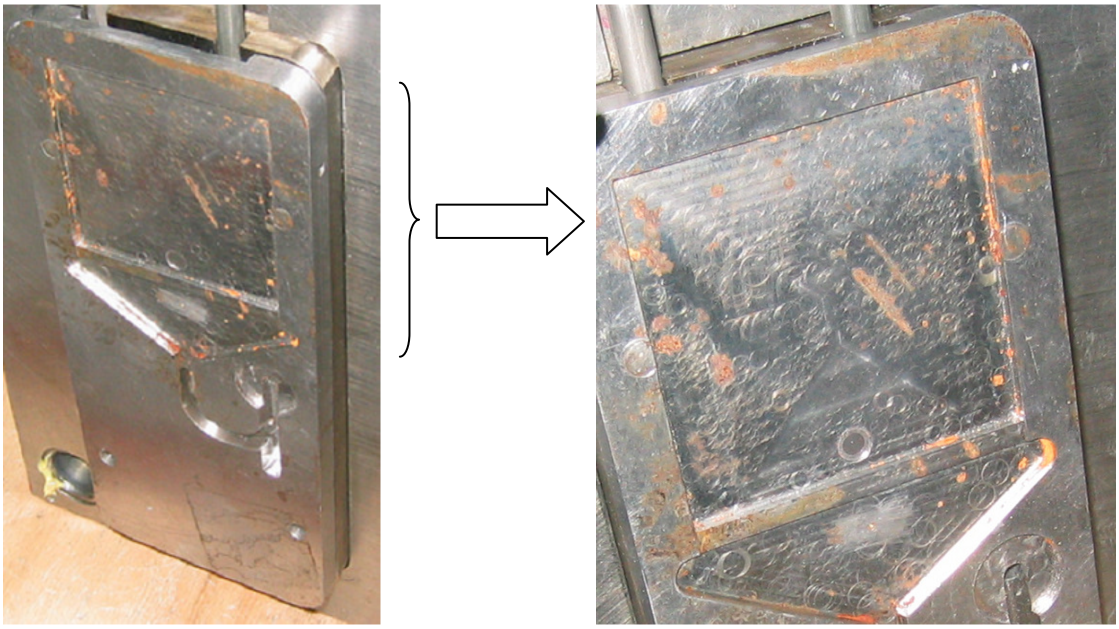

Fig.4. A closer look on the (corroded) injection mold engraving insert’s front side.

An example of molded test specimens is shown in Fig. 5. The first two test specimens that are marked with 10 and 14 were produced on unused injection-mold engraving insert but with different holding pressures. The same procedure was applied for production of the next two test specimens marked with 1 and 12 but with a different already used corroded injection-mold engraving insert. As can be seen from Fig. 5 the difference in quality of the produced test specimens is obvious. Nevertheless, before the start of experimental tests we didn’t expect to get such defective test specimens on corroded injection-mold engraving insert. One cycle lasted for approximately 20 seconds, which includes all phases of a typical injection molding cycle such as:

- mold closing,
- injection phase,
- holding phase,
- cooling phase,
- mold opening and
- ejection of the test specimen.

With unchanged injection pressure of 800 bar the test specimens were around 95% volume filled before the switch-over to holding pressure stage began. On test specimens 1 and 10 we applied 200 bar of holding pressure, which was later increased to 240 bars for production of test specimen 12 and 14. As can be seen on Fig. 5 we had a flash on both test specimen (1 and 12) that were produced on a corroded injection mold engraving insert. If we take a closer look back to Fig. 4 we can see that the surface on the top of the used injection mold engraving insert’s front side, where the flash occurred, is largely affected by the corrosion. Flash occurs if the parting surface doesn’t contact completely, due to a deformed mold structure or parting surface defect because of corrosion.

On test specimen 1 we can also see a sink mark, which is a local surface depression that typically occurs if the heat removal is unbalanced. Test specimens 10 and 14 from Fig. 5 were produced without defects.

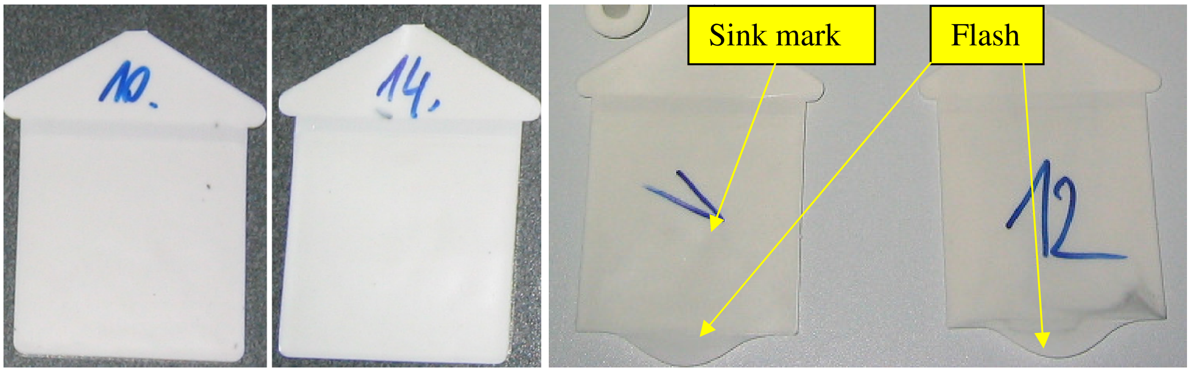

Fig.5. Specimens produced with unused (10 and 14) and corroded (1 and 12) injection mold engraving insert.

The acoustic emission signal intensity is proportional to signal energy [6-7] and defined by an integral of signal square

$$I_{ISS} = \int_0^\infty |V(t)|^2 dt \tag{1}$$

Fig. 6 shows the amplitude and energy of captured AE signals for test specimen 1 and 12. Both specimens were produced on a corroded injection-mold engraving insert. Fig. 7 shows also the amplitude and energy of captured AE signals for test specimen 10 and 14. Both test specimens were produced on an unused injection-mold engraving insert. By comparing captured AE signals on both injection-mold engraving inserts we noticed that more events occur on the used (corroded) insert during three consecutive injection molding cycles.

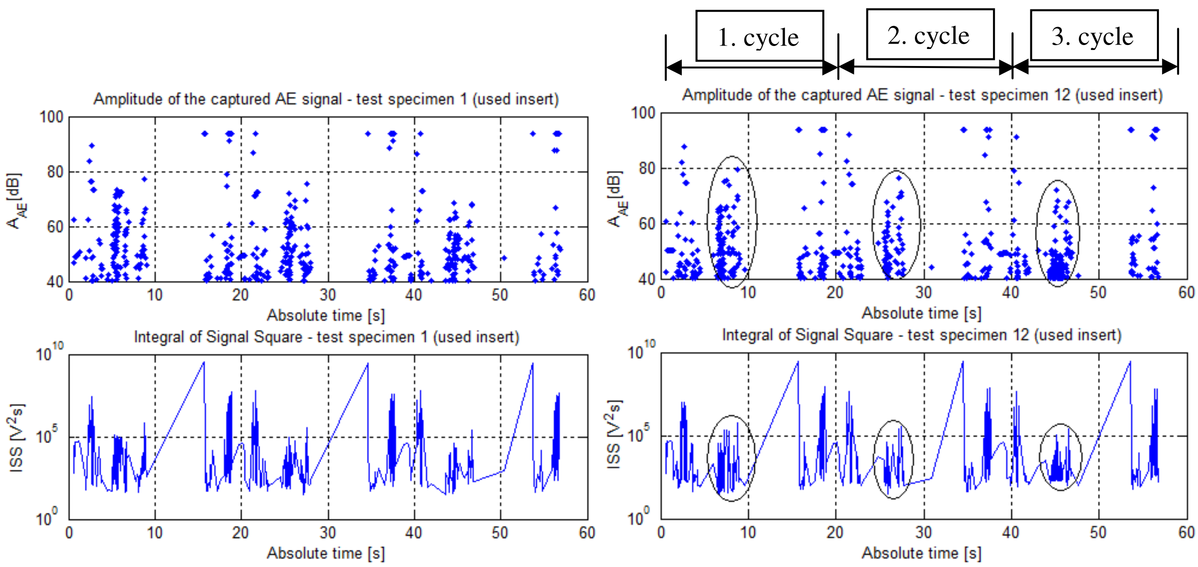

Fig.6. Captured AE signals for test specimen 1 and 12 on a used injection mold insert

If we take a closer look on the captured AE signals for test specimens 12 and 14 we can notice that the amplitudes and energies of AE signals, which are marked, are similar for three consecutive cycles during production of test specimen 14 on a new insert. For test specimen 12 we can see that the amplitude and energy values are falling in each of the three cycles on a corroded engraving insert. This can be related to the mold temperature increase with each shot, which in addition to holding pressure loading resulted in a slight deformation of the corroded engraving insert. For this reason we produced defective parts with flash. During production of defective test specimens we noticed that the specimens had traces of the corroded surface, which peeled of from the corroded insert. Consequently, this could also be an additional reason for smaller amplitude and energy values of AE signal in each cycle. Similarly, we can conclude by comparing AE signal amplitudes and energies of the test specimens 1 and 10.

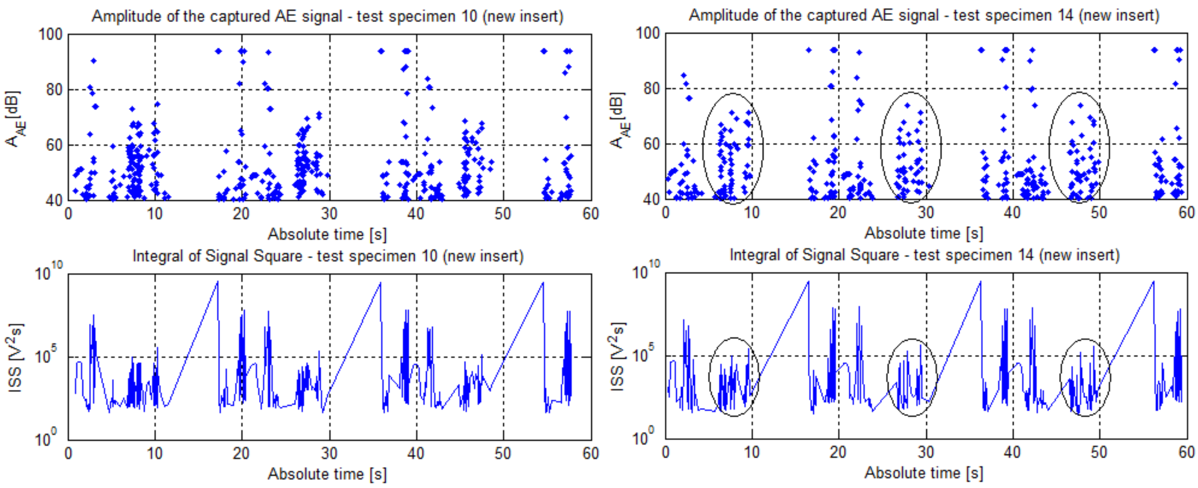

Fig.7. Captured AE signals for test specimen 10 and 14 on a new injection mold insert

Since the differences in detected events may not be entirely clear at first look on Fig. 6 and Fig. 7 for three cycles, we decided to show the difference inside one cycle. Fig. 8 shows an example of the captured AE signals during production of test specimens 12 and 14 in first cycle. As can be seen from Fig. 8 we divided the injection cycle into three most significant stages, which are marked on the upper side of Fig. 8. The difference in amplitude and energy is marked for both test specimens. Now it is possible to see clearly that during production of test specimen 12 in first cycle there was higher amplitude present slightly below 80 dB compared to the amplitude values of test specimen 14. Also the energy value for the test specimen 12 was found to be higher compared to the marked energy values of test specimen 14. As can be seen from Fig. 8 this is true only for holding stage because on the other two stages there are no apparent differences.

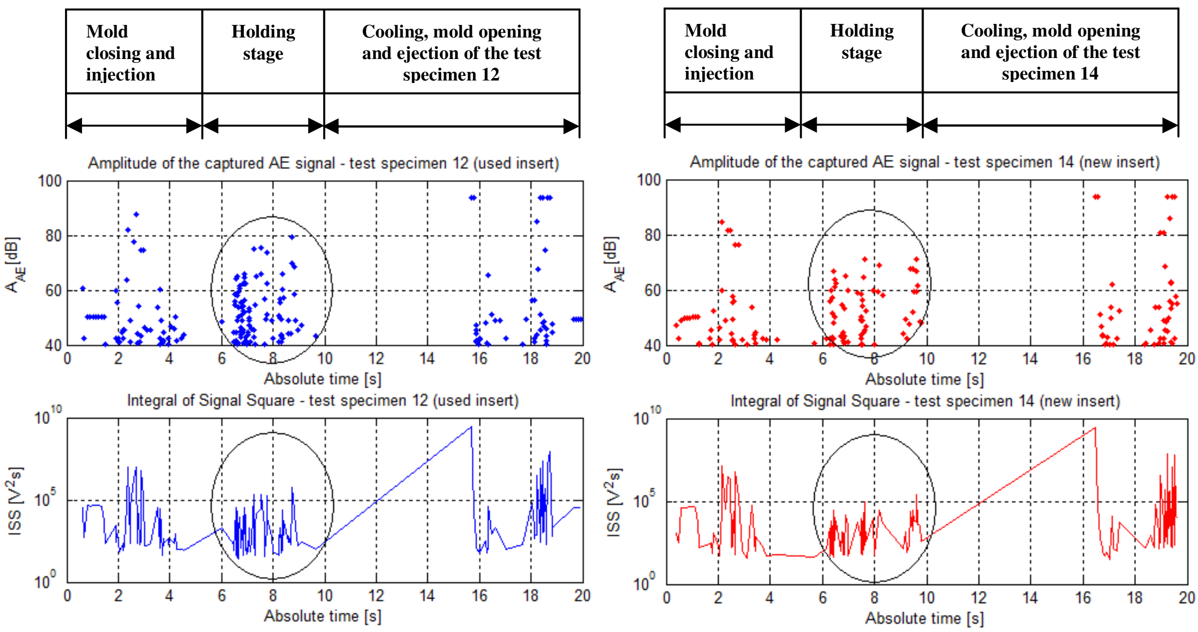

Fig.8. Captured AE signals for test specimen 12 and 14 inside one production cycle

From Fig. 8 it can also be noticed from marked area of captured AE signal amplitudes that in case of test specimen 12 the number of detected signals was significantly greater. This is also a clear sign of a corrosion defect, which results in a large number of events in case of a defective part as can be seen in Fig. 5. In case of test specimen 14 the number of detective signals is much lower on a practically new injection-mold engraving insert, which logically corresponds to small number of detected events. The acoustic emission activity is normally associated with the rapid release of energy from the tool steel. As can be seen from the marked energy values in Fig. 8 for holding stage the peek values of energy are higher in case of corroded engraving insert. In the other two stages the energy levels are quite similar and as such insignificant for detailed evaluation.

4. Conclusion

In this paper the measurement results of AE signals during injection-molding process of PP material with unused mold engraving insert and corroded mold engraving insert are presented. By conducting a detailed comparison of captured AE signals we can state that the amplitudes of AE signals between unused and used injection-mold engraving insert are very different.
The AE results obtained from corroded engraving insert are in correspondence with published work of Cole and Watson [8] or Beggan et al. [9] for instance. Both were dealing with detection, monitoring and diagnosis of corroded tools. They noticed more activity of AE signals in case of corroded tools.
In our case differences were detected in amplitudes, energies and also in detected events on the used (corroded) insert. This can be further correlated to the difference in plastic parts quality during serial production. Such obvious differences were practically shown on the produced test specimens, which were defective by flash only in the case of corroded insert. The results clearly show that the holding stage was the most important in which the amplitudes and energies changed in case of corroded engraving insert while producing test specimens 1 and 12. Sink mark was noticed only on test specimen 1 because of lower holding pressure. In case of unused engraving insert the amplitudes and energies of captured AE signal were almost constant. This means that the test specimens were produced normally without any defect, which is in accordance with a smaller number of detected events.

Acknowledgement

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