Acoustic Emission Investigation of Cracks on Engraving Tool Steel Inserts

Dragan KUSIĆ, Aleš HANČIČ, Rajko SVEČKO, Tomaž KEK, Janez GRUM

Abstract: In daily industrial production of different plastic products, we often have to deal with various defects that occur on the molds primarily as a result of material wear and tear, improper storage and improper settings on the injection molding machine. In the phase of testing plastic materials, we often use different inserts that are made from standard tool steels, such as OCR12VM. In the case of tool steel inserts, after a few years of usage, micro-cracks can occur and they can later quickly spread in proportion to the applied loading. We know that we can detect the formation of cracks on the tool steel inserts with the help of different non-destructive testing methods. Therefore, the purpose of this paper is to present a detailed review of the applicability of the acoustic emission (AE) method for the detection of cracks on a tool steel insert during a regular molding production cycle of standard test specimens. In this paper, we focused exclusively on the acoustic emission signal acquisition with the use of two resonant 150 kHz piezoelectric AE sensors on those tool steel inserts that were already affected by macro-cracks. The obtained acoustic emission results from such tool steel inserts were compared with those obtained from brand new tool steel insert. The final acoustic emission results from the crack defected tool steel insert revealed, as expected, that the energy and intensity of the captured AE signals are higher compared with the ones that were captured on the brand new engraving insert under the same processing conditions.

***Key words**:* Acoustic emission, tool steel insert, cracks, test specimens, PZT sensors.

1 Introduction

Injection molding is a well-known plastic manufacturing process where heated molten plastic material is forced into a mold cavity under high pressure. The plastic material solidifies into a shape that has conformed to the contour of the mold. Nowadays, it is still regarded as the most important and very popular manufacturing process because of the simple operation steps. A typical production cycle begins when the mold closes, followed by the injection of the plastic into the mold cavity. Once the cavity is filled, additional pressure compensates for 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 molded part is sufficiently cooled, the mold opens, and the part is finally ejected. An example of a typical injection molding machine is shown in *Fig. 1*. Like in all today's industrial manufacturing processes, the injection molding process can produce plastic parts which have poor quality and therefore are characterized as bad ones. In the field of injection molding, the first signs of micro-cracks can occur on the mold during long term production, and that usually causes the production of bad parts. In such cases, if a proper inspection inside the com-

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Figure 1. *Example of a typical injection molding machine*

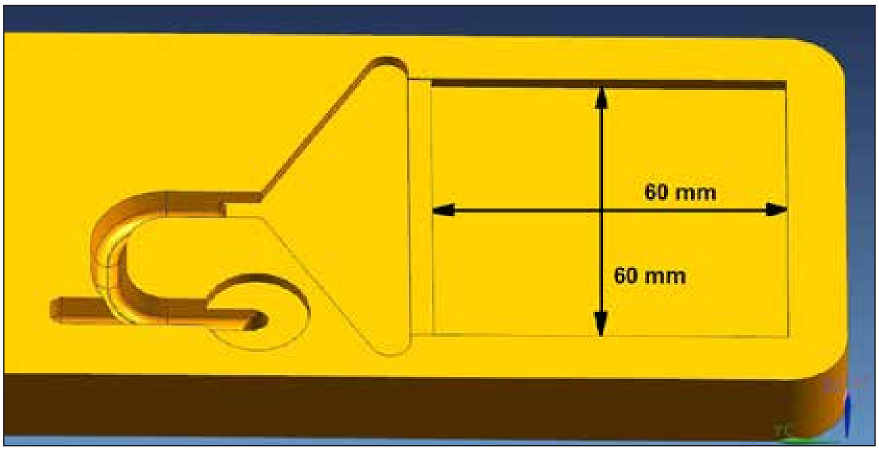

Figure 2. *CAD model of the tool steel insert that was used for experiments*

pany is not provided, a whole series of newly produced parts can be rejected. This can lead to a heavy economical loss for the production company. The location and advancement of a possible crack on the tool steel insert can be detected with the use of the acoustic emission technique, as was already reported by many researchers [1-5]. The primary objective of monitoring the crack advancement with the acoustic emission method is to obtain useful information about the quality of tool steel inserts which guarantees good quality of the produced test specimens.

2 Experimental procedure

Acoustic emission signals were captured during the production cycle of standard test specimens that were intended for the shrinkage evaluation of various plastic materials. The main aim was to analyze the influence of a possible crack located in the tool steel insert on the captured acoustic emission signals. After finishing the experiment on a tool steel insert with a macro-crack, we repeated the experiment under the same processing conditions on a brand new tool steel insert. In this way, we could compare the captured acoustic emission signals. The captured acoustic emission signals were then correlated with the quality of the produced test specimens. The acoustic emission measurement system AMSY-5 from Vallen-Systeme GmbH was used for capturing and analyzing the AE signals. Two piezoelectric AE sensors VS150-M (resonant at 150 kHz) were mounted with silicone grease and two sensor holders on the tool steel insert from both sides. Both PZT sensors were connected via two preamplifiers AEP4 with a fixed gain of 40dB on the first and second channel of the AMSY-5 measurement system. While evaluating the acquired AE signals, we focused on their maximal amplitudes and energy values during the filling and packing stages. The CAD model of the tool steel insert for the production of standard test specimens is shown in *Fig. 2*.

If we want to produce standard test specimens of good quality, the process parameters must be set correctly. Before the start of the experiment, it was necessary to select and fix the following process parameters: in the course of the experiment, the injection pressure was set to 1100 bar and the holding pressure was set to 500 bar. On the new tool steel insert, the melt temperature in the cylinder was set to 230 °C and the injection speed was set to 50 mm/s. On the tool steel 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 the produced test specimens was chosen to be the amount of shrinkage in longitudinal and transverse directions of the melt flow.

3 Experimental results

In the first part, we carried out the experiments on a brand new tool steel insert. In the second part, a tool steel insert with visible signs of a macro-crack was used. To provide similar processing conditions 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 after 24 hours with an optical 3D digitizer ATOS II SO. This industrial 3D optical digitizer has two high-resolution CCD cameras (1280x1024 pixels), as shown in *Fig. 3*.

Figure 3. *Optical 3D digitizer ATOS II SO with two high-resolution CCD cameras*

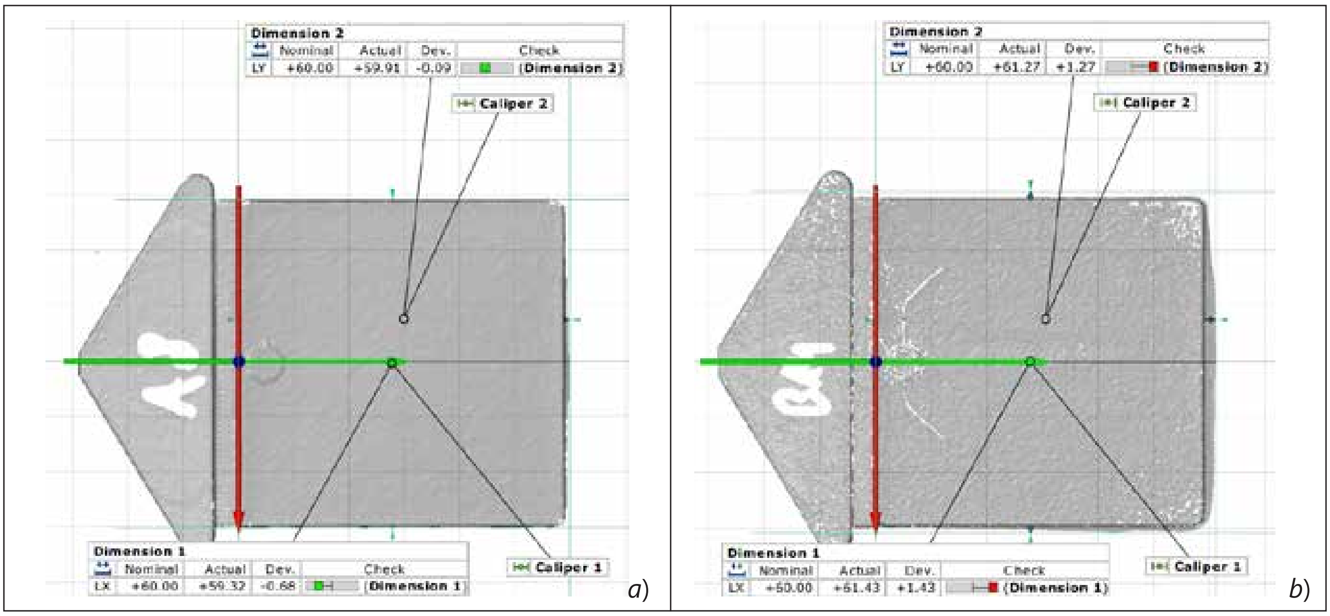

Figure 4. *Scanned test specimens (a) specimen 8 produced on a new tool steel insert, (b) specimen 14 produced on a tool steel insert with visible signs of a macro-crack.*

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 control. Optical 3D digitizer is based on the principle of capturing images with the camera which then, with the help of 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 also depends on the wavelength of the light. The biggest advantage of the 3D digitizer from Fig. 3 lies in the extremely rapid procedure of digitizing and excellent precision (the precision declared for very small objects is up to 2 microns). Examples of the produced and later scanned test specimens, one from a brand new tool steel insert and one from an insert with a visible macro-crack, are shown in *Fig. 4*.

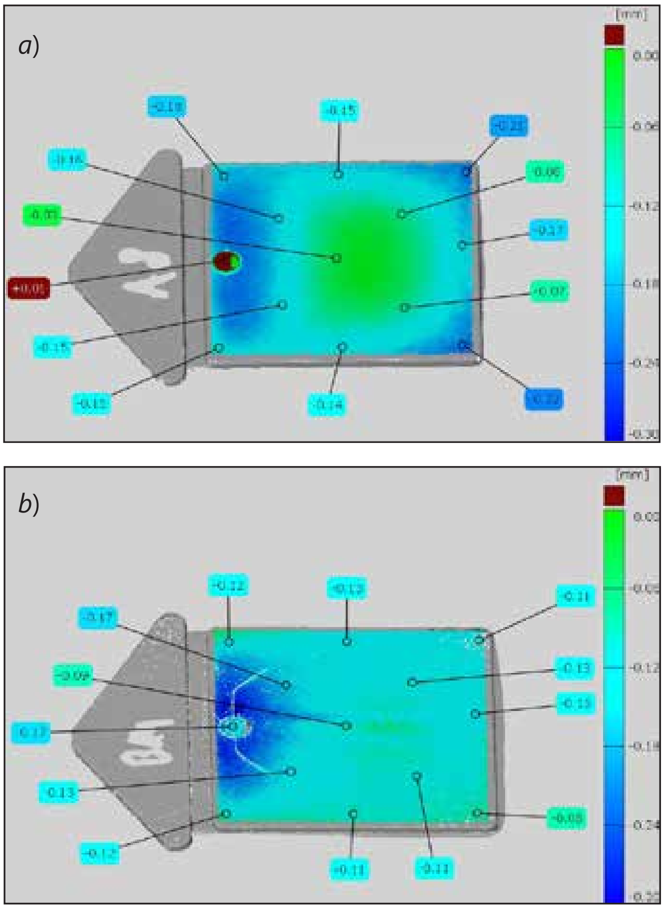

Figure 5. *Measuring surface deviations on (a) test specimen 8 produced on new tool steel insert, (b) test specimen 14 produced on tool steel insert with visible signs of a macro-crack.*

As can be seen in Fig. 4b, test specimen 14 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) directions. In Fig. 4a we can see that test specimen 8 is within the prescribed tolerances (59.91 mm in length and 59.32 mm in width) and with no visible defects.

The advantage of scanning the test specimens is that the quality of the surface and its deviations can be compared to the flat (ideal) surface, as shown in *Fig. 5*. By comparing both scanned test specimens in *Fig. 5*, we can see in Fig. 5b that–compared to the ideal surface–there are significant surface deviations which are within the range of 0.17 mm in the exact place of the macro-crack. The acoustic emission signal intensity is proportional to signal energy [6-7] and defined by an integral of signal square

$$E_{AE} = \int_0^{\infty} |V(t)|^2 dt \qquad (1)$$

The amplitudes of the acoustic emission signals can be given in

Filling phase (1)	Holding phase (2)	Cooling phase, mold opening and specimen ejection phase (3)

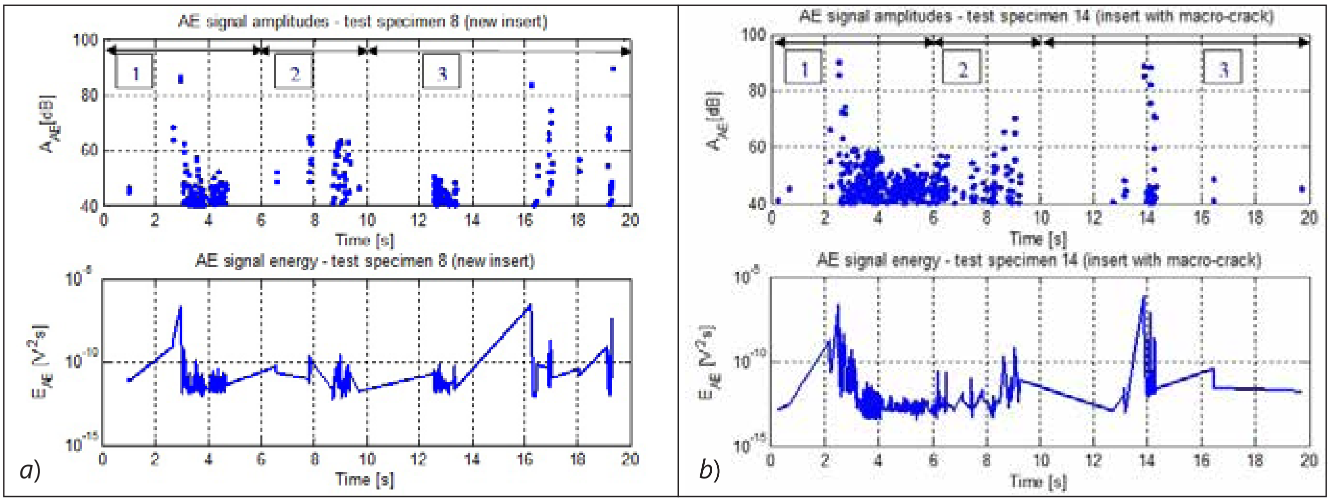

Figure 6. *Captured AE signals during the production of (a) test specimen 8 (new insert), (b) test specimen 14 (insert with a macro-crack).*

the form of voltage, but it is usually converted into decibels with the following equation

$$A_{AE} = 20 \log \left(\frac{|V(t)|}{V_r} \right) \qquad (2)$$

where *V(t)* is the maximal measured voltage of the AE signal and V_r is the reference input voltage on preamplifier which was in our case equal to 0.001 mV. By measuring the simple waveform parameters, such as energy, amplitude, hits, counts etc., of the 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 replace them in the near future. Acoustic emission energy measurements are important especially in those cases where the measured AE signal amplitudes are low. By squaring the captured AE signal burst, a simple pulse is produced and consequently the hit counting is simplified, which is clearly visible in *Fig. 6*. The peak AE signal amplitudes are normally related to the intensity of one or more AE sources which in our case are the macro-cracks located on the tool steel insert. In past research works [6], correlations between total counts, count rate and various fracture mechanics parameters (for example

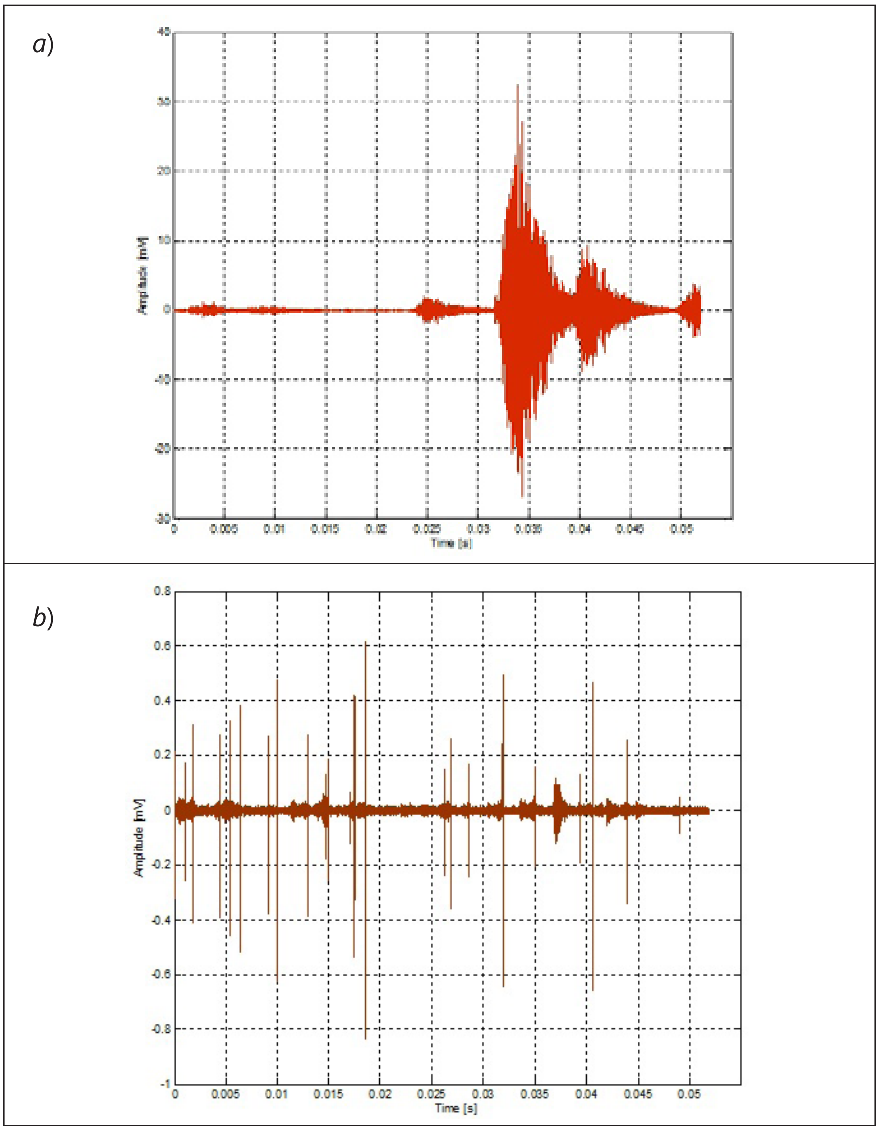

Figure 7. *Maximal amplitude values of the captured AE signals during the production of test specimen 14 (a) injectionphase, 1100 bar, (b) holding phase, 500 bar.*

the stress intensity factor) have been established and can be expressed by the following equation

$$N \cong K^n \quad (3)$$

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

$$\frac{dN}{dc} \cong \frac{da}{dc} \quad (4)$$

where a is the crack size, c is the number of cycles and N is the total number of counts.

Fig. 6 shows the amplitudes and the AE signal energy during the production of test specimens 8 and 14. On the tool steel insert with a macro--crack, a significant increase in the number of detected AE signals in the filling phase can be seen (*Fig. 7a*), which is due to the filling of the polymer melt through macro-cracks until the test specimen is filled. This transition of the melt through the macro-cracks is even more evident in *Fig. 7b* where rapid transitions of the AE signal from 0.2 mV (46dB) to 0.81 mV (58.2 dB) can be clearly seen.

Based on a detailed comparison of the captured AE signals from both tool steel inserts from Fig. 6, we found that a higher number of AE signals was present during the production of test specimen 14 on the tool steel insert with visible signs of macro-cracks. During the production of test specimen 14, we can clearly notice higher amplitude and energy values of the captured AE signal in the filling and packing phases (Fig. 7).

4 Conclusion

The aim of this research work was to determine to what an extent it is possible to detect the presence of macro-cracks on engraving tool steel inserts with the AE method by conducting a close comparison between the captured AE signals obtained from a new tool steel insert and those from a tool steel insert with visible cracks under the same processing conditions. From our experimental results, we were able to obtain useful information about the presence of macro-cracks during the production of standard test specimens. In the filling stage of the production of test specimens with both inserts, we found that there was a more apparent difference in the number of detected AE signals during the phase of the injection of the commercial polypropylene material in favor of the tool steel insert with visible signs of macro-cracks. Also, the results clearly show the difference in the maximum amplitudes during the filling and holding phases, as well as in the energies of the captured AE signals. As can be seen from the practically obtained results from the captured AE signals, we can successfully use the AE method for detecting fractures on tool steel inserts, which is an important advantage of this nondestructive testing method.

References

[1] Cao J., Luo H., Han Z.: Acoustic emission source mechanism analysis and crack length prediction during fatigue crack propagation in 16Mn steel and welds, Procedia Engineering, Vol. 27, 2012, 1524-1537.

[2] Biancolini M.E., Brutti C., Paparo G., Zanini A.: Fatigue cracks nucleation on steel, acoustic emission and fractal analysis, International Journal of Fatigue, Vol. 28, 2006, 1820-1825.

[3] Moorthy V., Jayakumar T., Raj B.: Influence of micro structure on acoustic emission behavior during stage 2 fatigue crack growth in solution annealed, thermally aged and weld specimens of AISI type 316 stainless steel, Materials Science and Engineering: A, Vol. 212, 1996, 273-280.

[4] Mukhopadhyay C.K., Sasikala G., Jayakumar T., Raj B.: Acoustic emission during fracture toughness tests of SA333 Gr.6 steel, Engineering Fracture Mechanics, Vol. 96, 2012, 294-306.

[5] Berkovits A., Fang D.: Study of fatigue crack characteristics by acoustic emission, Engineering Fracture Mechanics, Vol. 51, 1995, 401-416.

[6] Vallen H.: Acoustic Emission Testing: Fundamentals, Equipment, Applications, Vol. 6, Castell Publication Inc., Wuppertal, 2006.

[7] Miller R.K., Hill E.v.K., Moore P.O.: Nondestructive Testing Handbook, Third edition, Vol. 6, Acoustic Emission Testing, American Society for Nondestructive Testing, Inc., 2005.

Analiza signalovakustične emisije, ki so posledica razpok na vložkih orodij za brizganje plastike

Razširjeni povzetek

V vsakodnevni industrijski proizvodnji različnih plastičnih izdelkov imamo velikokrat opravka z raznimi napakami, ki nastanejo na brizgalnem orodju predvsem kot rezultat obrabe oz. luščenja materiala, nepravilnega skladiščenja brizgalnega orodja ter neustreznih nastavitev procesnih parametrov na brizgalnem stroju. V fazi testiranja raznovrstnih termoplastičnih materialov se običajno uporabljajo različni orodni vložki, ki so narejeni iz standardnega orodnega jekla, kot npr. OCR12VM. V primeru gravurnih orodnih vložkov se po nekaj letih uporabe lahko v zgodnji fazi pojavijo prve mikro- oz. makrorazpoke, ki se lahko kasneje hitro razširijo glede na stopnjo obremenitev pri nadaljnji uporabi. S pomočjo različnih neporušitvenih testnih metod lahko uspešno odkrivamo že obstoječe kot tudi novo nastale razpoke na gravurnih orodnih vložkih. Iz tega razloga je glavni namen tega prispevka nekoliko podrobneje predstaviti uporabnost metode akustične emisije (AE) za odkrivanje razpok na gravurnem orodnem vložku med klasičnim proizvodnim ciklom, tj. brizganjem standardnih testnih ploščic. V tem prispevku smo se osredotočili izključno na zajem signalov akustične emisije s pomočjo dveh resonančnih 150 kHz piezoelektričnih senzorjev akustične emisije na takšnem gravurnem orodnem vložku, ki je že načet z vidno makrorazpoko. Dobljeni rezultati akustične emisije na poškodovanem gravurnem orodnem vložku so bili nato primerjani pod istimi procesnimi pogoji še s popolnoma novim gravurnim orodnim vložkom. Končni rezultati akustične emisije, pridobljeni na gravurnem orodnem vložku z makrorazpoko, so pokazali, kot je bilo pričakovano, da sta energija in intenzivnost zajetih AE-signalov višji v primerjavi s tistimi, ki smo jih posneli na povsem novem gravurnem orodnem vložku pod enakimi procesnimi pogoji, kar potrjuje uporabnost metode akustične emisije za odkrivanje in kasnejše lociranje napak na gravurnih orodnih vložkih.

Ključne besede: akustična emisija, gravurni orodni vložek, razpoke, testni vzorci, piezoelektrični senzorji

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