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Viri akustične emisije pri uporovnem točkovnem varjenju

Sources of Acoustic Emission in Resistance Spot Welding

Ivan Polajnar - Elsayed Ahmed Esmail

Akustična emisija uporovnega točkovnega varjenja vsebuje nekatere koristne informacije o procesu varjenja in o kakovosti nastalega točkovnega zvara. Te informacije lahko v veliki meri podkrepijo ali zavrnejo sklepanja o uspešnosti varjenja, ki izhajajo samo iz spremljanja ene fizikalne veličine, značilne za ta varilni postopek.

Članek prikazuje osnovne značilnosti in princip detekcije akustične emisije, opisan je način spremljanja značilnih faz postopka uporovnega točkovnega varjenja in nakazane so možnosti koristne uporabe detektiranih signalov akustične emisije pri tem postopku varjenja.

(Ključne besede: emisija akustična, varjenje uporovno, varjenje točkovno, kakovost varov)

Acoustic emission is an outlet parameter which provides some information about the process of resistance spot welding, as well as about the quality of the weld spot. The information gained from acoustic emission can strongly support or reject conclusions about weld quality by simply monitoring a single physical property.

In this paper we describe the basic characteristisc principles of acoustic emission, and an approach to monitoring the characteristic phases of the resistance spot welding process. Alternative useful applications of the acoustic emission signal are mentioned

(Keywords: acoustic emission, resistance welding, spot welding, weld quality)

0 UVOD

Za vse postopke varjenja je značilna velika dinamika različnih virov zvoka. Zato so bili postopki varjenja deležni razmeroma velike pozornosti številnih raziskovalcev akustične emisije (AE), med njimi tudi postopek uporovnega točkovnega varjenja, [1] in [2].

Sodeč po dostopni literaturi so bile raziskave AE opravljene domala v vseh značilnih fazah varjenja: med samim varjenjem, neposredno po varjenju in med obremenjevanjem varjencev, [3] in [4]. Glavni namen spremljanja aktivnosti AE med postopkom varjenja in med ohlajanjem, oziroma med preizkušanjem varjencev, je: dobiti koristne podatke o kakovosti zvara oziroma o primernosti izbranih varilnih parametrov.

Če opazujemo nastanek enega samega točkovnega zvara, je uporovno točkovno varjenje (UTV) izrazito kratkotrajen tehnološki postopek. Za izdelavo varjenca je praviloma potrebno večje število točkovnih zvarov, ki jih zvarimo v nizu s kratkotrajnimi časovnimi presledki. Ta dejstva narekujejo nekoliko drugačno razmišljanje in tudi drugačne prijeme pri raziskavah AE pri UTV v primerjavi s postopki talilnega varjenja.

0 INTRODUCTION

Almost all welding processes involve dynamic phenomena which have different characteristic sound sources. As a result, numerous researchers were soon attracted to the field of acoustic emission (AE) for evaluating the process of resistance spot welding, [1] and [2].

Judging from the available literature, research with AE has been performed on almost all characteristic phases of welding: during the welding process itself, immediately after welding and during the load testing of the weld, [3] and [4]. The basic aim of monitoring the AE activity during the process of welding, during the cooling process, or during the testing of the welds is to collect useful information about the quality of the weld and the convenience of chosen welding parameters.

Monitoring the creation of one single spot weld shows that resistance spot welding (RSW) is an extremely short technological process. But to produce a welded piece a large number of spot welds are generally needed, which are created sequentially in short time periods. This accounts for a different approach to research with AE in RSW as compared to the processes of fusion welding.

Pri analizi detektiranih signalov je bistvenega pomena pravilno sklepanje o virih signalov akustične emisije. V članku je narejena razmejitev detektiranih signalov akustične emisije na: moteče in koristne; podan je postopek razmejitve virov AE v značilnih fazah UTV. Za posamezne faze varjenja so posneti ojačani signali AE in nekateri od zanesljivih virov koristnih signalov akustične emisije so dokumentirani z metalografskimi posnetki zvarov.

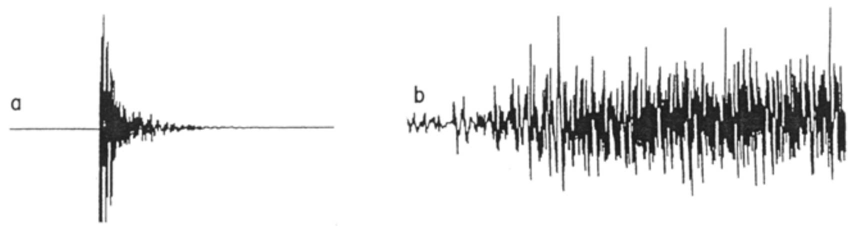
The essential goal of analysing acoustic emission signals is the appropriate determination of acoustic emission sources. Here, we distinguish between useful acoustic emission signals and disturbances recorded during resistance spot welding. Some of the causes of useful acoustic emission signals are documented by metallographic photos of welds.

1 GLAVNE ZNAČILNOSTI DETEKCIJE AE

AE je izraz, uporabljen za pojav elastičnih valov, ki so posledica hipnega sproščanja nakopičene energije pri strukturnih spremembah v materialu. Takšne strukturne spremembe so lahko povzročene z notranjimi ali zunanjimi mehanskimi ali termičnimi napetostmi. Opazovani signali AE so praviloma razvrščeni v dva osnovna tipa: impulzni in zvezni [5]. Impulzni tip emisije je podoben signalu dušenega nihanja, medtem ko se zvezni tip emisije pojavlja pri zaporednem prekrivanju posamičnih impulznih signalov (sl. 1).

1 BASIC CHARACTERISTICS OF AE DETECTION

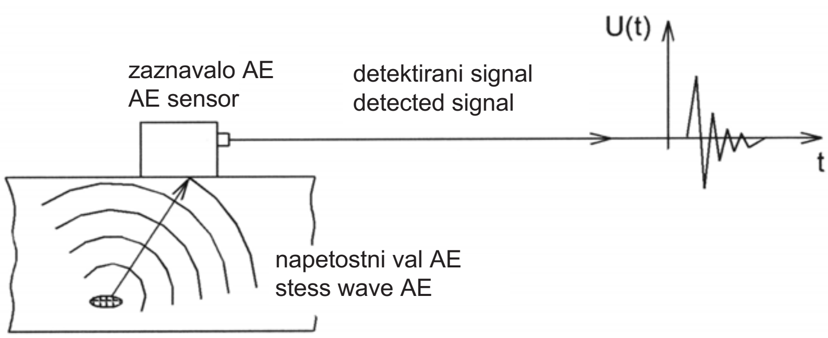
AE is the phenomenon of transient elastic wave generation due to a rapid release of strain energy caused by a structural alteration in a solid material. These structural alterations can be the result of either an internally or externally applied mechanical or thermal stress. Often the observed AE signals are classified by one of two types: burst or continuous [5]. The burst-type emission resembles a damped oscillation, while the continuous-type emission appears to consist of an overlapping sequence of individual bursts (Fig. 1).



Sl. 1. *Značilni vrsti signalov AE: a) impulzni, b) zvezni*
Fig. 1. *Two typical acoustic emission signals: a) burst-type; b) continuous-type*

Signale AE povzročajo viri različnih velikosti in moči: od sprememb v atomski zgradbi do makroskopskih sprememb v materialu. Značilna dogajanja v tehnologiji materialov kot virov AE so: potovanje dislokacij, večanje kristalnih zrn, pojav mikro- in makrorazpok, fazne transformacije [6]. Če na mejo trdnega telesa, v katerem se vzbujajo zvočni signali, namestimo zaznavalo AE, bo le-ta detektirani zvočni signal spremenil v električni impulz (sl. 2).

There are a variety of sources of AE signals ranging from atomic scale to macrostructural changes in material. Typical sources of AE include movement of dislocations along grain boundaries, microcracks and cracks, and phase transformations [6]. If an AE sensor is placed on boundaries of the body in which sound signals are generated, it will transform the detected sound signal into an electrical one (Fig. 2).



Sl. 2. *Enostavni model detekcije signalov AE*
Fig. 2. *Simple model for the AE signals detection*

Pri tem se zaznavalo AE odziva le na zvočni tlak v določenem frekvenčnem območju. Ozkopasovno zaznavalo se odziva na zvok v bližini frekvenc ν_o, medtem ko se širokopasovno zaznavalo odziva v širini frekvenčnega spektra med ν_i in ν_s [7].

The sensor will, however, react only to a sound pressure of a certain frequency length. A narrow band sensor reacts only to sound in the vincity of ν_o, while a wide band sensor reacts to sound in the frequency range between ν_i and ν_s [7].

2 AE PRI UPOROVNEM TOČKOVNEM VARJENJU

2 AE IN RESISTANCE SPOT WELDING

2.1 Opis varilnega postopka

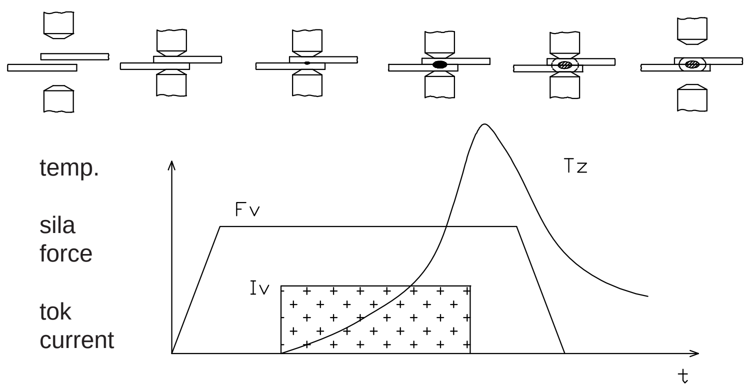
Uporovni točkovni zvar se najpogosteje doseže tako, da dva varjenca v prekrivnem spoju prek bakrenih elektrod stiskamo s pritisno silo F_v in v kratkem časovnem intervalu t_v skozi elektrode prevajamo tok visoke jakosti I_v. Zaradi sproščanja toplote, ki je največje na mestu stika varjencev pod elektrodama, pride do strmega dvigovanja temperature in do zlitja varjencev v obliki značilne zvarne leče [8].

Slika 3 prikazuje načelni potek uporovnega točkovnega varjenja. Po stisnitvi varjencev - predpritisku sledi varilni impulz, v katerem se natali in oblikuje zvarna leča. Po ustavitvi varilnega toka sledi čas zadrževanja elektrod oziroma kovanja, v katerem pride do ohladitve in utrditve točkovnega zvara [9].

2.1 Description of the welding process

A resistance spot weld is usually produced by pressing two welding pieces together in an overlapping joint with the force F_v, and then passing a high electrical current I_v through the attached electrodes for a short time period t_v. Due to release of heat, which is most intense at the point of contact of the welding pieces under the electrodes, a steep rise in temperature and a welding of the pieces takes place, producing the characteristic shape of a weld nugget [8].

Fig. 3 shows a schematic display of the resistance spot welding process. After pressing the welding pieces together, a welding pulse follows which causes the melting and formation of the weld nugget. After stopping the welding current, the holding and forging period follows, during which cooling and solidifying of the spot weld takes place [9].



Sl. 3. *Shematični prikaz tvorbe točkovnega zvara*
Fig. 3. *Schematic representation of spot welding process*

2.2 Viri in detekcija AE

Pri detekciji AE ločimo dve vrsti signalov: koristne in motilne.

Za koristne signale AE štejemo tiste, ki nastajajo zaradi vsebinskih sprememb v področju natalitve točkovnega zvara in v toplotno vplivanem področju. Ti signali se vzbujajo v obeh značilnih fazah: v času nastajanja zvarne leče, ko teče varilni tok, in v fazi ohlajanja.

Motilne signale AE povzročajo različna dogajanja, ki niso v neposredni povezavi s spremembami varjenega materiala: zvočni hrup okolice, motnje v električnem omrežju, pretok hladilne tekočine in udarci elektrod.

2.2 AE sources and detection

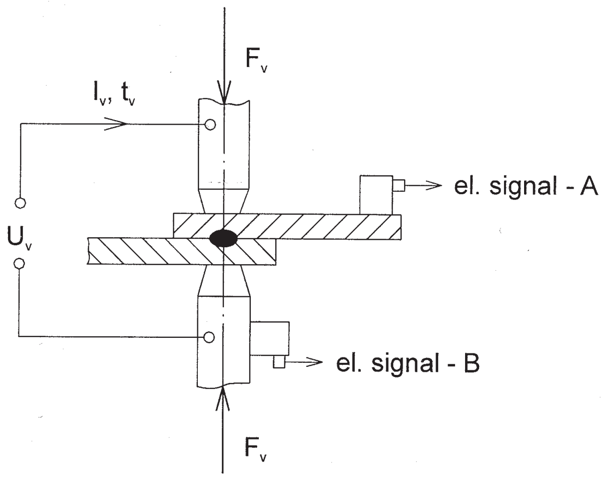
During the welding process two types of AE signals appear: useful signals and disturbances.

The useful signals contain information about events which take place due to the essential changes in the melted region of the spot weld and in the heat affected zone. These signals are generated in both characteristic phases: during the creation of the spot weld (while the welding current is running), and in the cooling phase.

The disturbance signals are various noises which are not directly connected with changes in the weld formation; they are caused by noises from the surroundings, noises in the electrical network, noise of the cooling liquid, and knocks of the electrodes.

V splošnem lahko pri raziskavah UTV zaznavalo AE namestimo na dva načina (sl. 4):
A - zaznavalo na varjencu
B - zaznavalo na elektrodi

The AE sensor can be placed in two different ways during RSW (Fig. 4):
A - sensor on the welding piece
B - sensor on the electrode



Sl. 4. *Možne namestitve AE zaznavala pri UTV*
Fig. 4. *Possible methods of placing the AE sensors during RSW*

Kateri namestitvi damo prednost, je odvisno od namena raziskav oziroma od tega, kateri pojav v postopku varjenja nas prednostno zanima. Pri tem so mišljeni predvsem tisti pojavi, ki so v kakšni povezavi s kakovostjo točkovnih zvarov [10].

Choosing one of the two methods depends on the purpose of the research and also on which of the phenomena in the welding process is of the most concern. Here we refer to those phenomena which are connected to the quality of the spot welds [10].

2.3 Signali AE v značilnih fazah varilnega postopka

Glede na čas vzbujanja zvočnih signalov v varjencu lahko varilni ciklus UTV razdelimo v naslednje značilne faze (sl. 5):

1. *Prosto ležeči varjenec*: zaznavalo je pritrjeno na varjenec - A ali na elektrodo - B (sl. 4). Prevladuje šum iz okolice, (sl. 5-1) (pri vključenem pretoku hladilne vode in namestitvi zaznavala na elektrodo - B je šum pretoka vode daleč močnejši od drugih šumov iz okolice).
2. *Primikanje elektrode in predpritisk*: zaznavalo se odziva že na začetku gibanja elektrode, predvsem pa na udarec elektrode ob varjenca (sl. 5-2a). Po stisnitvi varjencev z elektrodama je intenzivnost detektiranega šuma večja kakor v fazi prosto ležečega varjenca (sl. 5-2b).
3. *Varjenje*: v celotnem intervalu prevajanja električnega toka dobimo signale velike intenzivnosti (sl. 5-3). Tu še ni razmejeno, kolikšne deleže prispevajo k tej dejavnosti fizikalne spremembe na mestu varjenja in koliko elektromagnetni vplivi na zaznavalo ter motnje iz okolice.
4. *Zadrževanje elektrod*: ob koristnih signalih, zaradi strukturnih sprememb v področju zvara, je opazen tudi znaten šum iz okolice, ki se prek še vedno stisnjenih elektrod in prek varjencev prenaša na zaznavalo (sl. 5-4).

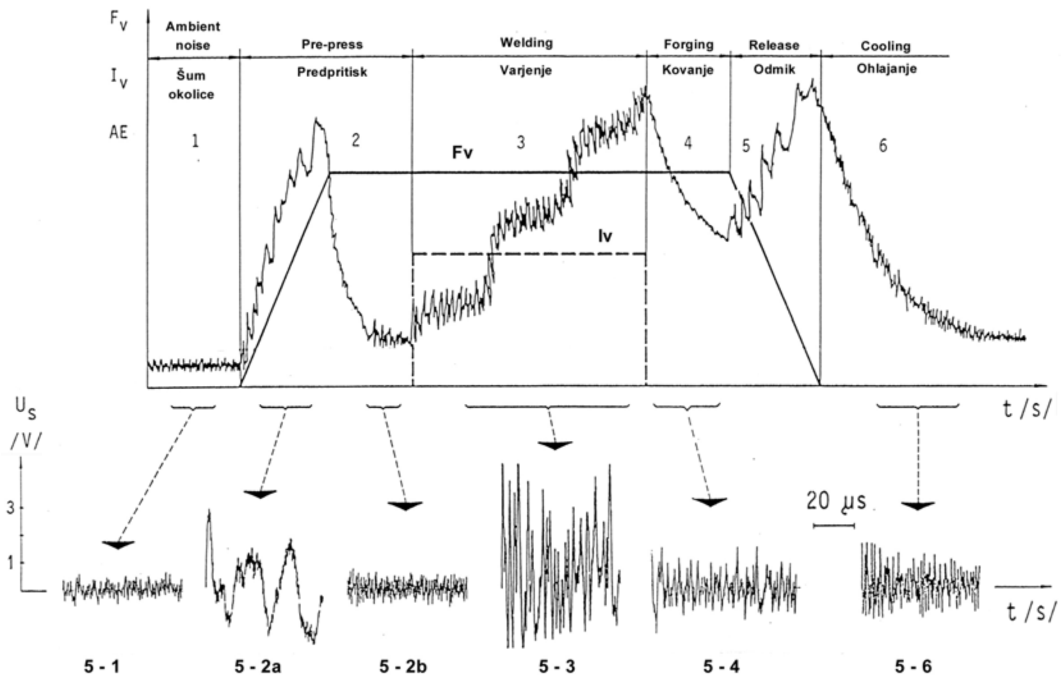
2.3 AE signals in the the characteristic phases of welding cycle

With regard to generation of sound in the workpiece, a welding cycle in RSW can be divided into the following phases (Fig. 5):

1. *Free-laying of the welding piece*: The sensor is attached to the welding piece (A) or to the electrode (B) (Fig. 4). Noise from the surroundings prevails (Fig. 5-1) (with flow of the cooling water turned on and placement of the sensor on the electrode (B), the noise of running water prevails over the other noises from the surroundings).
2. *Approach of the electrode and pre-pressure*: The sensor reacts to the initial knock of the electrode and especially to the impact of the electrode on the welding piece (Fig. 5-2a). After the welding pieces are pressed together with the electrodes, the intensity of the detected signal is larger than in the phase of free-laying of the welding piece (Fig. 5-2b).
3. *Welding*: The whole period of electrical current exhibits emissions of a large intensity (Fig. 5-3). The shares of the signal caused by the physical changes in the welding spot, electromagnetic influences on the sensors, and noise from the surroundings have not been specified yet.
4. *Electrode forging*: Useful signals caused by structural changes taking place in the weld are mixed with substantial background noises and are transmitted to the sensor via the pressed electrodes and the welding piece (Fig. 5-4).

5. *Dvig elektrod*: pri vračanju elektrod v izhodiščno lego je posneti signal približno enake intenzivnosti kakor pri približevanju elektrod (sl. 5-5).
6. *Prosto položen varjenec med ohlajanjem*: po odmiku elektrod, ko varjenec ni več v kovinskem stiku s strojem, dobimo neoporečne informacije o zvočni intenzivnosti ohlajajočega se zvara (sl. 5-6). Posneti signali so neposredno odvisni od vrste materiala varjencev in od varilnih parametrov.

5. *Electrode release*: The signal caused by the return of the electrodes to the starting position is of a comparable intensity to that caused by the approach of electrodes (Fig. 5-5).
6. *Free-laying of the welding piece during the cooling phase*: After electrode release, when the welding piece is no longer in contact with the machine, information about the sound intensity of the cooling weld is obtained (Fig. 5-6). The recorded signal is dependant on the welding material and the welding parameters.



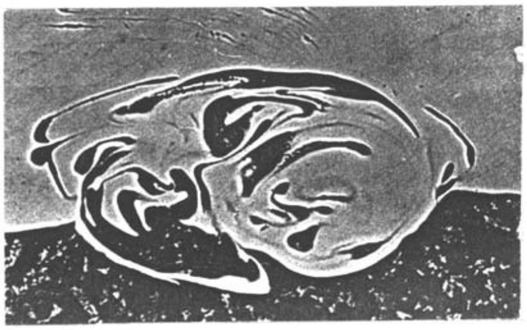
Sl. 5. *Značilni signali AE med procesom UTV*
Fig. 5. *Typical AE signals during RSW*

2.4 Opredelitev koristnih virov AE

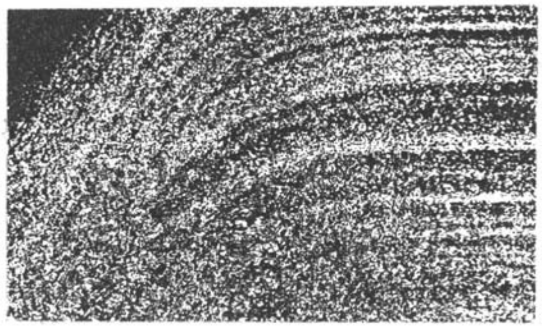
V posameznih fazah procesa UTV si sledijo različna dogajanja, povezana z mehanskimi, fizikalnimi in kemičnimi spremembami, ki povzročajo zvočne valovne impulze in so torej vir koristnih signalov AE. Dogajanja, ki povzročajo te zvočne impulze, so različna tako po številčnosti in sproščeni energiji kakor tudi po kraju in času nastanka. Dogajanja, ki odločujoče prispevajo k nastanku, večanju in oblikovanju zvarne leče, obenem pa so zanesljivi generatorji zvočnih signalov, se zvrstijo v fazi varjenja in fazi kovanja pod pritiskom elektrod. Takšna dogajanja so: mešanje taline v področju nastajanja zvarne leče, potovanja dislokacij pri plastičnih deformacijah (zaradi temperaturnih sprememb v zvaru in pri ugrezanju elektrod v varjenca), nastajanje in večanje mikro in makro-razpok ter različne strukturne premene. Izrazite primere nekaterih takšnih "zamrznjenih" dogodkov kažejo metalografski posnetki na sl. 6a do 6d [10].

2.4 Identification of the AE sources

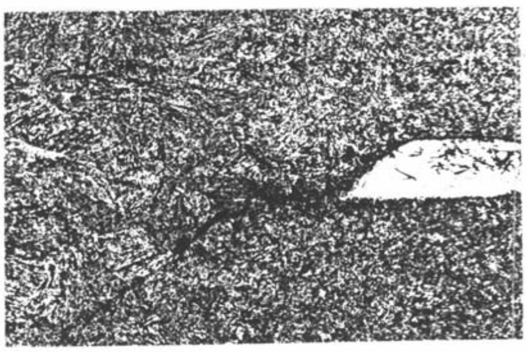
In the individual phases of the resistance RSW process, a sequence of events occurs that are connected with mechanical, physical and chemical processes; these cause sound wave impulses, and are thus AE sources. The events which cause the sound impulses differ in their number, their energy output, and in the time and place of their generation. The events that most significantly contribute to the formation and growth of the weld nugget, and which are at the same time reliable sources of sound signals, take place in the welding phase and in the phase of cooling under electrode pressure. Such events include: mixing of the pool in the area of weld nugget formation, travel of dislocations by plastic deformations (due to temperature change in the weld and by immersing the electrodes into welding pieces), formation of micro- and macro-cracks and various other structural changes. Examples of such "frozen" events are shown in metallographic pictures (Fig. 6a to 6d) [10].



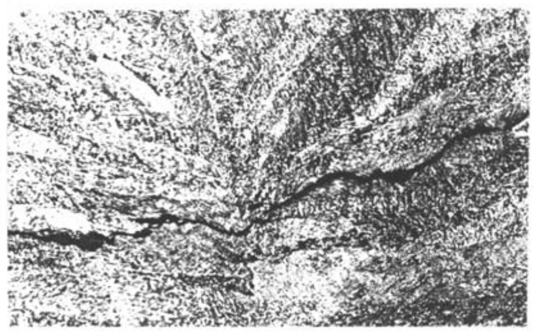
a) *povečava 50 krat;* spodnji varjenec Č.0147, d=1,6 mm, zgornji Č.4973; δ=0,8 mm, F_v=4,0 kN, I_v=8,5kA; t_v=0,1s; (dobro razvidna "zamrznjena" dinamika mešanja taline)
a) *magnified (50:1)*; lower piece Č.0147, upper Č.4973; δ=0.8 mm, F_v=4.0kN, I_v=8.5 kA; t_v=0.1 s; ("frozen" dynamics of the molten material mixing is clearly visible)



b) *povečava 100 krat;* varjenca Č.0147 δ=2x2,0 mm; F_v=2,8 kN I_v=7,15kA; t_v=0,8 s; (področje plastičnih deformacij med zvarno lečo in osnovnim materialom)
b) *magnified (100:1)*; piece Č.0147, δ=2x2.0 mm, F_v=2.8 kN, I_v=7.15 kA; t_v=0.8 s; (area of plastic deformation between the weld nugget and base material)



c) *povečava 100 krat;* varjenca Č.1531 δ=2x2,0 mm F_v=2,8 kN; I_v=8,13 kA; t_v= 0,4s; (meja zvarne leče z amorfnim vključkom in kalilno razpoko)
c) *magnified (100:1)*; piece Č.1531, δ=2x2.0 mm, F_v=2.8 kN, I_v=8.13 kA; t_v=0.4 s; (the border of the weld nugget with an amorph insert and a hardening crack)



d) *povečava 50 krat;* varjenca Č.1531 δ=2x2,0 mm F_v=2,8kN I_v= 8,13 kA; t_v=0,4s; (prečna razpoka na robu zvarne leče z martenzitno sestavo)
d) *magnified (50:1)*; piece Č.1531, δ=2x2.0 mm, F_v=2.8 kN, I_v=8.13 kA; t_v=0.4 s; (a crack on the edge of weld nugget with martensite structure)

Sl. 6. *Makroobrusi prečnih prerezov različnih točkovnih zvarov*
Fig. 6. *Cross sections of different spot weld macro-grinds*

3 SKLEPI

Z raziskavami AE pri UTV želimo ugotoviti, v kolikšni meri je mogoče iz detektiranih signalov AE med varjenjem in/ali po njem izluščiti koristne informacije o velikosti in kakovosti točkovnega zvara. Dosedanji rezultati analize AE med varjenjem in po njem namreč kažejo na to, da detektirani signali vsebujejo nekatere koristne informacije o poteku procesa varjenja in tudi o kakovosti zvara, da pa se samo iz rezultatov detektirane AE ne da zanesljivo sklepati o uspešnosti nastajanja in o kakovosti točkovnega zvara. Sedanje stanje tehnike na tem področju raziskav in razpoložljiva oprema namreč (še) ne omogočata

3 CONCLUSIONS

Research of RSW by AE is aimed at establishing if it is possible to deduce the quality of a spot weld from the detected AE signals, recorded during and/or after the welding process. Previous results of AE analysis during and after the welding process show that the detected signals include some useful information about the welding process and about the quality of the weld. A further conclusion is that it is not possible to establish the quality of the spot weld only from the detected AE. The present state of technology in this field of research and the available equipment do not (yet) enable us to reliably distinguish between the useful signals and those due to the zanesljivega razmejevanja med koristnimi in motilnimi signali. Obenem so motilni signali pogosto znatno intenzivnejši od signalov, ki vsebujejo sporočila o poteku dogodkov v varilnem procesu. Zato je pri spremljanju procesa UTV z detekcijo AE treba posebno pozornost posvetiti prav motilnim signalom.

Opisana metoda spremljanja procesa uporovnega točkovnega varjenja torej še ni zrela za uporabo v industrijskih razmerah. Rezultate detekcije AE pa je mogoče že sedaj koristno uporabljati v laboratorijih kot dodatni kriterij pri uveljavljenih metodah varivosti in pri razvoju ustrezne merilne opreme.

disturbances. Furthermore, the disturbance signals are usually of a larger intensity than signals containing information about the events in welding process. Thus it is necessary to pay attention to the disturbances during monitoring of the RSW process with the AE detection.

The described method of monitoring the RSW process is therefore not yet ready for implementation in the industry environment. However, the results of the AE detection can be useful under laboratory conditions as supplemental criteria by which standard methods of weldability and the design of appropriate measuring equipment can be determined.

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