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VERIFICATION OF THE QUALITY OF THE WELD WHEN UTILISING THE MAG/CO_2 METHOD

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Abstract

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In contribution there is described the process of welding by using MAG/CO2 method, mechanical (post fact) and nondestructivein situ) measurement including the discussion of results. The materials of various welding have been used for test. According to ČSN 420002 steel with mark 11 373 has been chosen as a material with guaranteed welding and steel with mark 19 312 has been chosen as a material with hard welding. The sheets with dimensions 30×5×250 mm have been used at welding. The source activity having affect in process of welding is caught on AE records. It is described as per affirmatived forms of individual hits and overshoots at active levels directly into obtained records. The discussion links the findings from visual monitoring of mechanical tests, metallographic and factual monitoring even the acoustic tests. In the field of welding verification stated by producer of steel semifinished products the difference between material with guaranteed welding and material with hard welding by using AE method has been confirmed.

Keywords: MAG/CO2 method, acoustic emission, welding, metallography

INTRODUCTION

The method utilised in fusion welding is mixing the base and the added metal so that by the subsequent recrystallisation of the weld metal they form a weld. Local fusion is achieved, for example, by means of a flame or by electric resistance. The weldability of the material plays a very important role. Weldability represents the capability of the material to create a weld, by means of which materials are joined together. This weld should have the same properties as the base material (Hluchý and Kolouch, 2002).

In accordance with the relevant standard, a weldment is created by combining two or more parts by welding. Before welding, the individual parts must have their weld surfaces, which are the parts of the surface on which the weld is to be formed, prepared. The relative positions of the welded surfaces are secured by using clamps, appropriate fittings and stitch welds (Doubravský *et al.*, 1985).

The basic types of welds are butt welds and lapped welds. The individual parts of these welds are located in a single plane and they are planar. Welds of which the surfaces intersect are called fillet welds, T-welds or cross welds.

In terms of their production fillet welds are inexpensive; however there is a need for both their structure and their technological process to be well designed. In some instances hole, grooved and penetration welds, which substitute for riveting, are required. The advantage of these welds is reduced interference with the structure, while the shape of the weld bead also means that it does not negatively affect its surroundings (Doubravský *et al.*, 1985).

The geometry of the weld surfaces is approved for a number of standards; additionally these standards specify identifying the weld in the technical documentation. For example, the ČSN EN 22553 standard specifies the rules used for the symbolic marking of welded and brazed joints on drawings, while ČSN EN ISO 6520-1 and ČSN EN ISO 6520-2 classify the geometric defects of certain metallic materials during welding.

Welding Using the TIG (WIG), MIG and MAG Methods

The TIG method evolved from coated electrode welding. Originally it was developed for welding highly reactive metals, and later on it started to be used for welding ferrous materials. In the TIG method an arc burns between the non-fusible (tungsten) electrode and the base material. Essential is the purity of the protective gas and equally important is the rate of the gas flow. When using this method in a small series, the wiring is implemented manually. The principal advantage of TIG welding is the quality of the weld and the possibility of being able to weld normally difficult-to-weld materials. The weld is protected by inert gases, in particular by argon, nitrogen and other mixed gases. More recent is the utilisation of the MAG/CO2 method, whereby the non-fusible electrode has been replaced by a filler material and the inert gas by an active gas, which, although it has an oxidising effect that influences the composition of the weld metal, it improves the geometry of the weld (greater penetration depth). The ongoing deoxidation of the weld must be augmented by the addition of Si and Mn (Doubravský *et al.*, 1985).

The technological properties of the weld – technological weldability will determine both the feasibility of the process and the quality of the weld that is implemented. Evaluated is the complexity of the measures required to create a quality weld. This is based on a series of independent factors. The influencing factors include, for example, geometric factors related to the welded parts, welding technology, material factors, etc. Technological weldability tests are designed to determine the risk of defects for varying combinations of toughness, welding technologies and materials (Hluchý and Kolouch, 2002).

Note: These tests do not have to be standardised, but some of the methods utilised are described in the ČSN or in the EN ISO standards. The tests include, for example, weldability tests with the forced deformation of the weld joint, the cracking of thin metal sheets, or the weld deposit test, during which, after splitting the welded sample, the hardness beneath the weld bead is measured (Hluchý and Kolouch, 2002).

The economic aspects of weldability – the weldability of the material influences the economics of production. For material with reduced weldability there are higher economic demands in regard to the equipment that can guarantee the requisite quality and the subsequent quality control of the weld. The actual production costs are influenced by the productivity of the welding method utilised, and any heat treatment and NDT inspections that are required (Hluchý and Kolouch, 2002).

The Weldability of Fe Alloys

Low carbon steels are suitable for welding provided that they have a carbon content of below 0.24% and contain only small amounts of phosphorus, nitrogen, impurities, etc. The higher carbon content would cause hardening of the heat affected zones (with a potential occurrence of defects). Impurities can cause a variety of deformations. Nitrogen, for example, causes embrittlement in association with deformation aging; carbon increases susceptibility to the occurrence of hardening structures and sulphur can be the cause of the formation of longitudinal cracks.

The weldability of high-strength steels is assured by complying with the welding procedure recommended by the manufacturer. In these steels high residual stress often occurs, with the possibility of a brittle fracture. In the event of their potential use in severely stressed environments, welds in steel must be thoroughly checked for any defects.

Hardenable steels are not suitable for welding because of the likelihood of the occurrence of cracks beneath the weld bead and of localised hardening. However, by implementing a suitable temperature regime and by reducing the amount of hydrogen in the weld, these steels can be welded in a sufficient quality (Hluchý and Kolouch, 2002).

Stainless steel is prone to cracking in the weld metal. In unstabilised steel, the $Cr_{23}C_6$ and Cr_7C_2 carbides reduce the Cr content at the grain boundaries, thereby causing a decrease in the corrosion resistance of these boundaries and consequently intergranular corrosion. The best method for welding is welding in a protective atmosphere, especially the TIG method (Hluchý and Kolouch, 2002).

Defects in Weld Joints

The admissibility of a specific defect is evaluated in accordance with the criterion of suitability for a particular purpose. Both the ČSN ISO 6520 standard and the ČSN EN 25817 standard classify defects in a general manner. These, however, are specific defects occurring in weld joints during fusion welding. The standards define the tolerated defect sizes in accordance with the prescribed levels of quality. Relation between the defects that actually occurred and a defined number of defects is checked by non-destructive testing. The result is that either the weld meets the specified criteria or it does not. Non-destructive inspection is carried out by a person who is qualified in accordance with the ČSN EN 473 standard (Dostál *et al.*, 2011).

Cracks can be formed by heat, by cold and during annealing. Hot cracks occur most frequently during the solidification and cooling of the weld pool at temperatures between 1280 and 800 °C. Their occurrence is related to the metallurgical purity of the materials. Additional chemical elements that can contribute to these defects are: carbon, manganese, an elevated sulphur content and other alloying elements (Hluchý and Kolouch, 2002).

After the termination of welding at temperatures of cca. 720 °C, austenite with the joint action of hydrogen transforms to decomposition structures. This creates tensile stress in the weld that may cause a cold crack (Norek, 2005).

Hot cracks also include lamellar cracks, which can occur in both the base material and in the heat affected zone. The cause of lamellar cracks during welding is the stress in the direction of the thickness of the sheet. This defect frequently occurs in fillet welds, for example. Although lamellar cracks mainly occur at high temperatures, they can continue to propagate even in cold (Norek, 2005).

When annealing, weld cracks occur either in the low-temperature zone (30 °C) due to the large temperature gradient between the surface and the centre of the weld joint, or in the zone of the lower annealing temperatures (500–600 °C), especially in chromium and vanadium steels. These cracks occur either during rapid heating to the annealing temperature or in multi-layer welds (Norek, 2005).

The pores and bubbles represent volume defects. They are either spherical or oblong in shape and are filled with gas. Their occurrence can be caused, for example, by poorly cleaned surfaces, a wet electrode or a poor protective atmosphere (Hluchý and Kolouch, 2002).

Slag inclusions can be formed in the course of coated electrode welding. They originate from the inefficient cleaning of the slag prior to welding the next layer (Hluchý and Kolouch, 2002).

There are several types of inclusions. Oxide inclusions occur in aluminium and magnesium oxides because of a high melting point. The origin of these inclusions is related to the surface insufficiently cleared from oxide layers. TIG welding can also cause other types of inclusions, e.g. metal inclusions. These occur, for example, as a result of high currents or based on a violation of the protective atmosphere (Doubravský *et al.*, 1985).

The imperfect fusion of a base material with a weld metal is called a cold joint. The cause of a cold joint can be a high welding speed, a low welding current or the too small diameter of an electrode or an incorrect use of the electrode (Doubravský *et al.*, 1985).

Incomplete root penetration occurs most commonly during the implementation of the MIG/MAG method, when welding materials of a greater thickness. The reason for the lack of penetration or for an incompletely penetrated root may be an incorrectly set current, an improperly assembled weldment, an overly high welding speed, etc. When the base material is not sufficiently fused, a cold weld also often occurs simultaneously (Norek, 2005).

The Testing of Welds

Precise functional characteristics can be determined by destructive testing, or, following the implementation of non-destructive tests, safety coefficients are utilised for the purpose of clarifying the dimensioning. Destructive tests are performed on specimens that result in the destruction of the test samples. The test is implemented once on the test sample in a series (in the case of large series the test may be repeated) and if the test sample meets the requirements of the test, the welding technology shall be deemed as properly selected. Tests are defined by the standards (Votava *et al.*, 2014).

Fracture mechanics became the basis of the concept of the admissibility of defects. Permissible defects are defects with which the products may be used as far as it is possible to ensure a constant size of these defects (Norek, 2005). Non-destructive tests are important in regard to quality at every stage of production. They are used for ensuring product quality and technological and safety features. Non-destructive quality tests are categorised in accordance with the point of detection of defects. They can be used for the detection of surface defects or of defects within the weld (Hluchý and Kolouch, 2002).

The Principles of Acoustic Emission

A stress source, when it is being released by either external or internal forces, causes expansion. The resultant wavelength incident produces irreversible processes in the material. These processes may be activated, not only during structural and phase changes, for example, but also during the escape of material or during cavitation, and also in regard to biological processes. The energy released during these processes becomes a mechanical stress pulse. This pulse propagates in a waveform in material. It may be a longitudinal or a transverse elastic stress wave. The stress wave propagates from its initiation point towards the AE sensor placed on the surface of the body. Most commonly manifested is the wave character of the development of dynamic elastic stress. The sensor detects both the size and the frequency of the waves and transforms them into an electric signal. This signal is processed in an analogue manner and then evaluated by the AE measurement system. Only in a few special cases a pulse beam is found, ideally propagating at the same speed at the shock edge of the wavefront. These include, for example, surface Rayleigh waves, longitudinal wave pulse propagation in a thin rod or the propagation of a symmetrical dilatation wave in a thin plate (Černý, Dostál, 2014).

In the real body each wavefront is eventually reflected from the surface and thereby the beams are not only reflected, but, according to Snell's law, also disintegrated. From each reflection an additional two new beams incur. The detection of the original sharp signal passes sequentially in a prolonged time sequence that is the result of both reflection and disintegration waves. With the distance from the source increasing the acoustic pressure of the AE event, which is carried by the waves, decreases. The main causes of the decrease in intensity and amplitude with distance are energy dissipation, pulse disintegration, energy attenuation. Another effect is that of the material surface. It is affected by roughness, surface treatment and corrosion. The decrease in intensity may also be associated with geometric obstacles or with acoustic shadowing (Kopec *et al.*, 2008).

Levels of Evaluation of the AE Signal

A number of measuring channels provide for different levels of signal evaluation. These are: the informational level, the standard level and the advanced level. At the informational level, we identify the presence and the intensity of the AE signal. Depending on the external stimulus we detect the start and the conclusion of the AE activity. At standard level we evaluate the typical parameters of the electric AE signal. This evaluation is based on the signal from a resonant transducer and the amplitude envelope parameters are evaluated. The time-frequency response of the AE signal is not evaluated in detail. Each structure and each body has an acoustic background, which manifests as a continuous noise background (Dostál, Communeau, 2014).

THE EXPERIMENTAL PART

The purpose of the measurements was to determine the relationship between the quality of the weld and acoustic emission. When welding, together with the simultaneous use of acoustic emission, it is possible to already detect a poor weld during the welding process and thereby to assess the weldability of the material from the AE record.

Selection of the Material

Due to the largest possible difference between the AE records and the mechanical properties of joints, materials with different weldability were selected for the test. A material with a guaranteed weldability is steel S235JR (1.0038), while steel 90MnCrV8 (1.2842) has a reduced weldability (ČSN 42 0002).

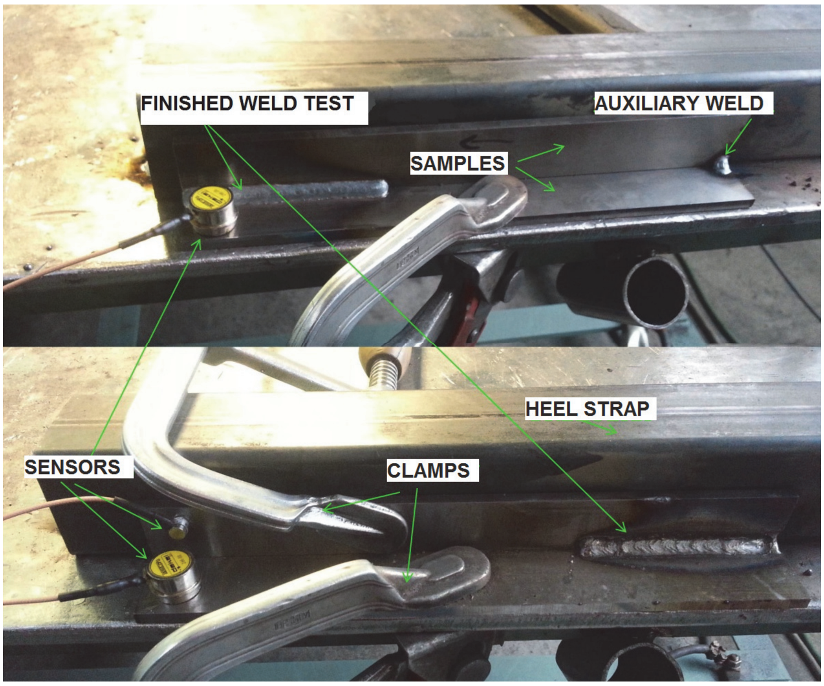
The Preparation of Samples

Samples of steel S235JR(1.0038) with the dimensions of 30×5×250 mm for coated electrode welding tests and for the MAG method test were cut from the rolled plate using the laser burning machine. The same technology was also utilised for cutting samples of steel S235JR, 1.0038 with dimensions of 30×2×100 mm for spot welding tests.

Tool steel 90MnCrV8 (1.2842) in sizes of 5×30×500 mm and 30×2×500 mm was supplied by a company specialising in tool steel. These flat test bars were manufactured by machining and their surface was polished. The bars were cut to the requisite length using a band saw.

A Dakel IPL acoustic emission analyser was used during the welding. This analyser was connected to the PC with a control system. An adhesive Dakel MIDI sensor and a Dakel MDK17 magnetic sensor were utilised for measuring.

A Fronius Vario Synergic 4000 welder was utilised for welding using the MAG/CO2 method. The welding current was set at 199 A and the voltage at 22.3 V. The HTW – 50 filler in the form of a wire with 1 mm diameter was utilised. The protective atmosphere was composed of a CO_2+Ar gas mixture in a ratio of 18:82, supplied under the CAR18 trade name.



1: *Sensor location in welding with coated electrode and MAG method*

The samples were attached to the welding table by a clamp. Subsequently AE sensors were glued to them (Fig. 1).

Testing the Strength of the Welds

Verification of their strength was carried out on the manually operated OMA 655 hydraulic press, with F_{max} = 250 kN and a piston stroke of 180 mm. Recorded during the testing were the progress of the applied pressure and the resulting deformation and/or fragmentation of the samples (Fig. 2).

The samples that were sliced on the metallographic abrasive cutting-off machine were processed in the usual manner (i.e. by grinding, polishing, etching) on the DAP - 34 Pedemin Struers and observed using the Neophot light microscope (Figs. 3 and 4).

DISCUSSION OF THE EXPERIMENTAL RESULTS

Visual Inspection

Direct visual inspection did not identify any incidence of external defects. The welds in all the samples were well executed, including the welds of steel 90MnCrV8 (1.2842). In the case of the welds implemented using the coated electrode method, typical tiny balls appeared in the vicinity of the weld, caused by the spatter of molten metal. These balls occurred in steel S235JR, 1.0038 in a larger number than when welding steel 90MnCrV8 (1.2842).

Mechanical Inspection

During the mechanical inspection the samples were loaded with pressure using the hydraulic press. Samples of steel S235JR, 1.0038 welded using the MAG method followed a similar pattern to the sample welded with a coated electrode. The force was gradually raised to 40 kN. Only then did the plastic changes start to occur. With the increasing of the loading force the sample began to bend until the occurrence of a crack in the vicinity of the weld (Fig. 7).

For samples of steel 90MNCRV8 (1.2842) the maximum force with which damage to the sample occurred was cca. 26 kN. This pattern was similar in both the welding methods. The final brittle fracture, which originated in the hardened part of the material just below the area of the interface between the molten metal alloys (HAZ), was accompanied by an audible expression. In the course of this a hardened part in the form of a chip was separated from sample number 3 (Fig. 8).

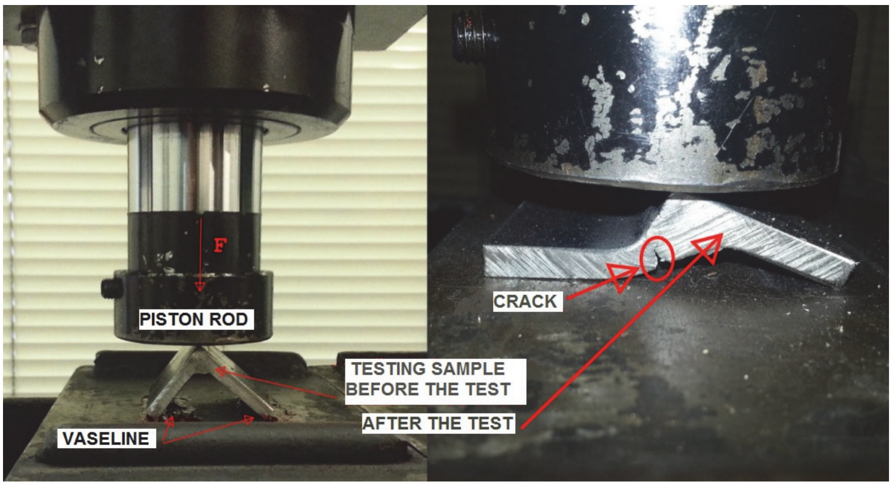
THE RESULTS OF THE AE MEASUREMENTS

The details of the AE activities obtained during the testing are described directly in the AE records.

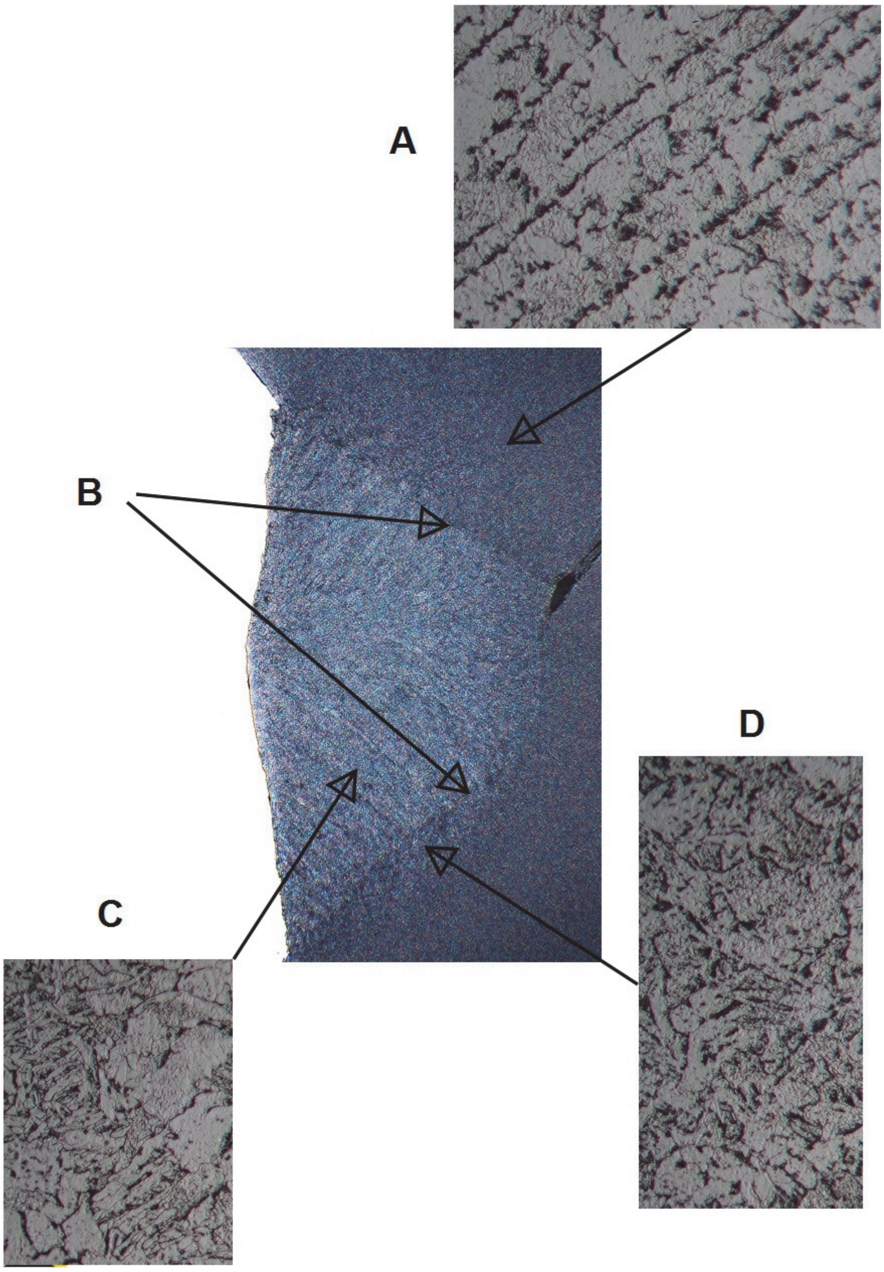
Swells above the threshold and the amplitude spectrum over time are related to the physico-metallurgical processes implemented in the weld, see Figs. 9 and 10. For the sake of comparison, also shown is the record from the second sensor, which indicates the nearly identical shape of the record.

COMPREHENSIVE DISCUSSION

Discussion of the results is carried out continuously, i.e. within images and by local description. This discussion that includes information derived directly from samples and records is accompanied by a comprehensive debate that aggregates the findings from all the individual inspections – i.e. the visual, mechanical, metallographic, fractographic and acoustic tests listed – as shown both in the images and in the records. In regard to the verification of the weldability of the steel semi-finished products indicated by the manufacturer, it was clearly confirmed that there is a difference between the material with guaranteed weldability, i.e. steel S235JR, 1.0038, and the material with reduced weldability, i.e. steel 90MnCrV8 (1.2842).



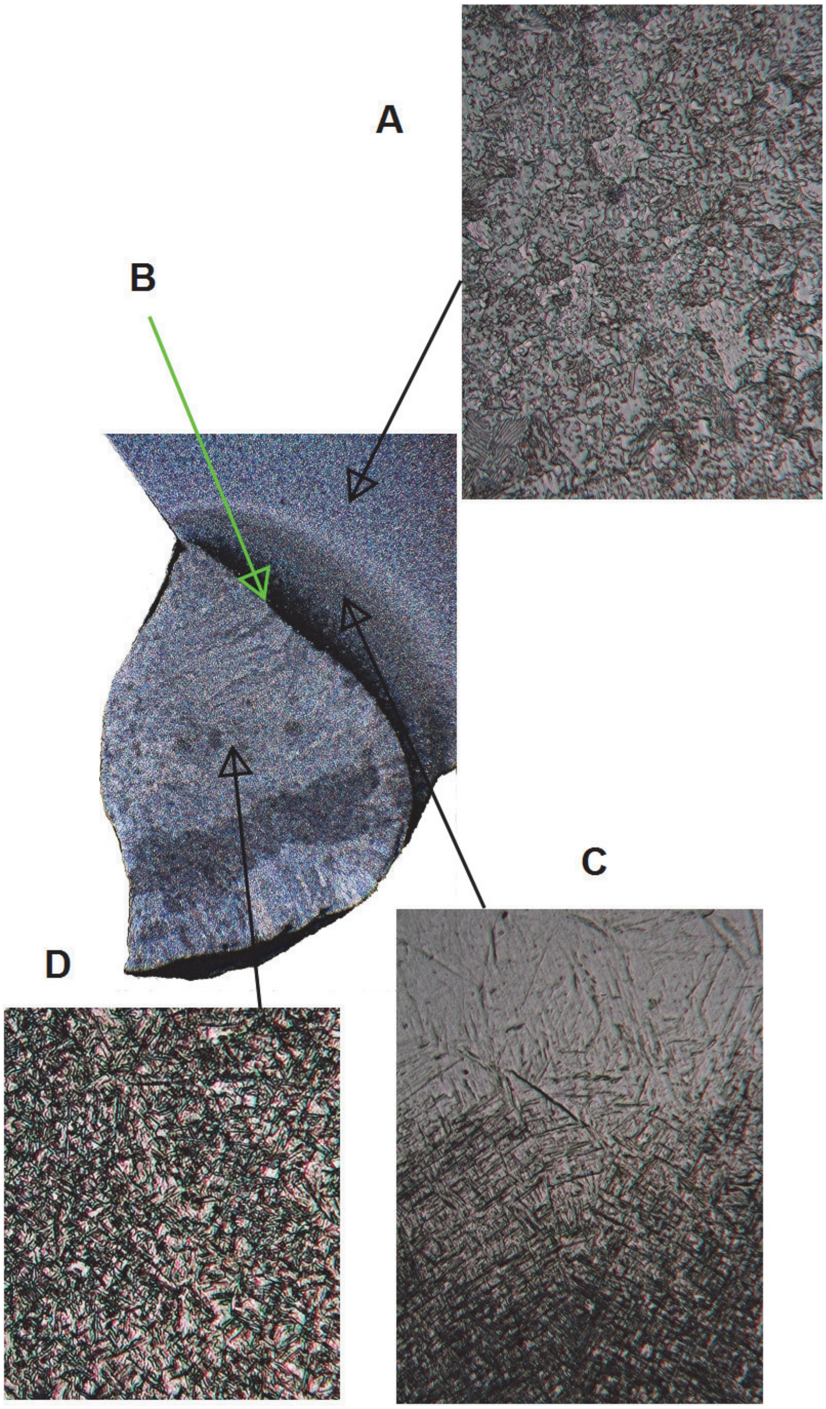
2: *Location of the sample at the beginning and end of the test*



3: *Metallographic cut of weld, CO_2, S235 JR steel (1.0038)*
A: Ferritic – pearlitic rolled structure base material with a distinctive banding
B: Belt melting partially melted structure
C: Drawing dendrites in the weld metal (ferrite pearlite)
D: Heat-affected zone with traces annealed ferrite

In terms of the quality of the welds made using steel S235JR, 1.0038 with guaranteed weldability it is evident from the records that, after melting, the deep weld pool is being gradually created, following its subsequent cooling and stress equalisation within the ferrite-pearlite structure se Fig. 5. The records are supplemented by images from the metallographic grinding of steel S235JR, 1.0038 (Fig. 3).

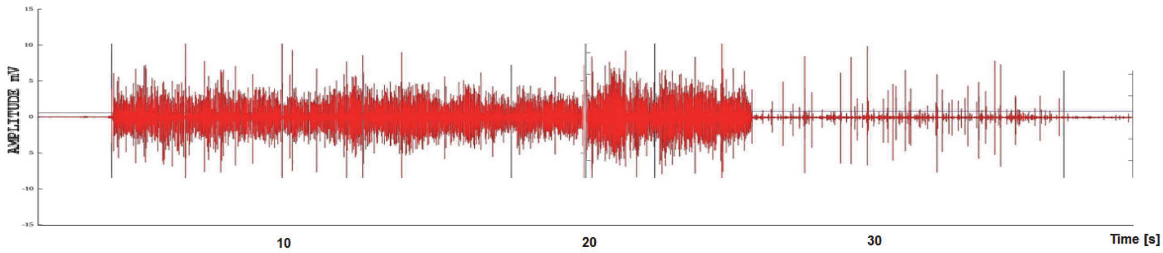
In material 90MnCrV8 (1.2842) there is a significant increase in the acoustic noise that accompanies the growth of long unidirectional dendrites. This is then accompanied by a shear transformation of austenite to martensite in the HAZ. The flat shape of the record (Fig. 6) after this transformation (e.g. without the motion of line defects) indicates the presence of blocked stress, i.e. calm in the slip planes, that causes the pseudo-fragility of the material. This results in the development of fissile microcracks, which is manifested by the apparent loss of toughness (Fig. 4). This is evident in the picture of the mechanical testing of welds of steel 90MnCrV8 (1.2842) (Fig. 8), which are, compared to the verification of



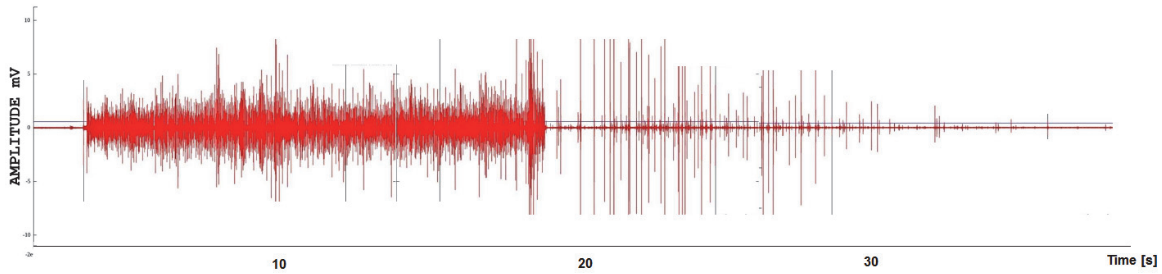
4: *Metallographic cut of weld, CO_2, 90MnCrV8 steel (1.2842)*
A: unaffected ferrite pearlite structure with a high proportion of cementite and carbides at the grain boundaries
B: martensitic band in the melting
C: a mixture of ferrite and martensite without recrystallization with transverse microcracks (cold)
D: long columnar dendritic boundary equiaxed grain structure with high voids, clusters, voids and cracks between dendritic

toughness of steel S235JR (1.0038) (Fig. 7), more than conclusive.

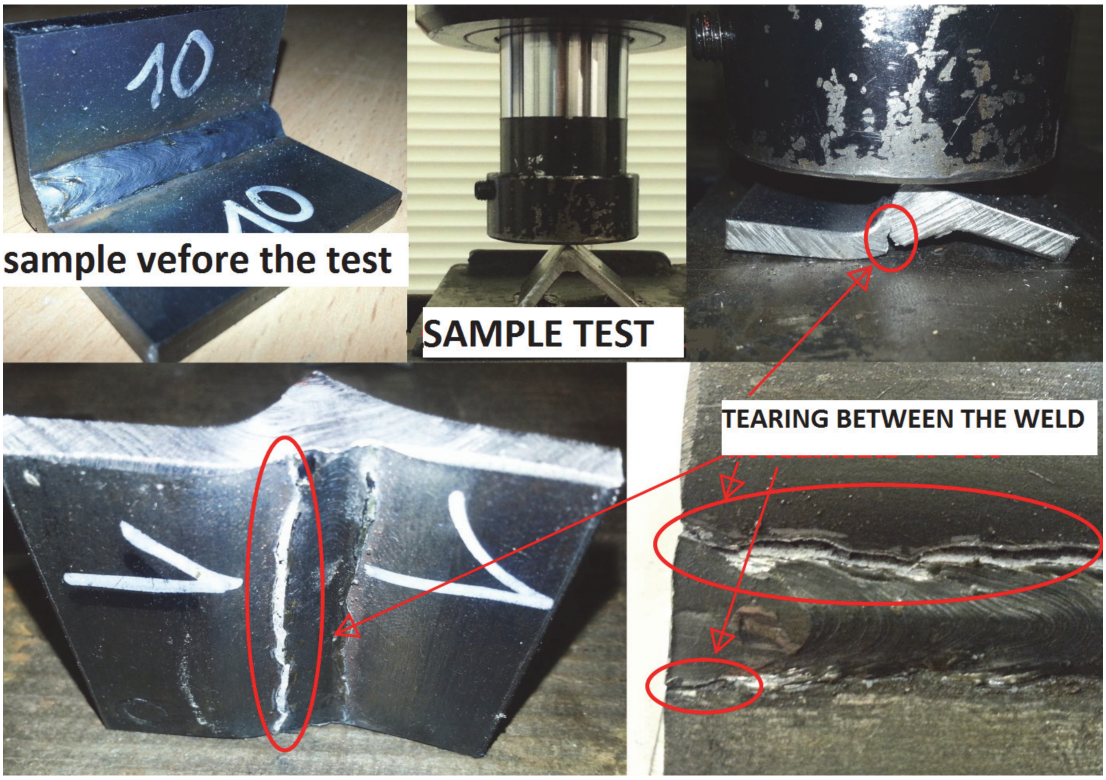
The mechanical tests indicate that the conditional weldability of steel 90MnCrV8 (1.2842) is accompanied by the fissile disruption of the joint, due to the development of brittle cracks in the materials. This experience shows the benefits of the application of AE in monitoring the creation



5: *Exemplary record of AE signal, S235 JR steel (1.0038),* CO_2
author



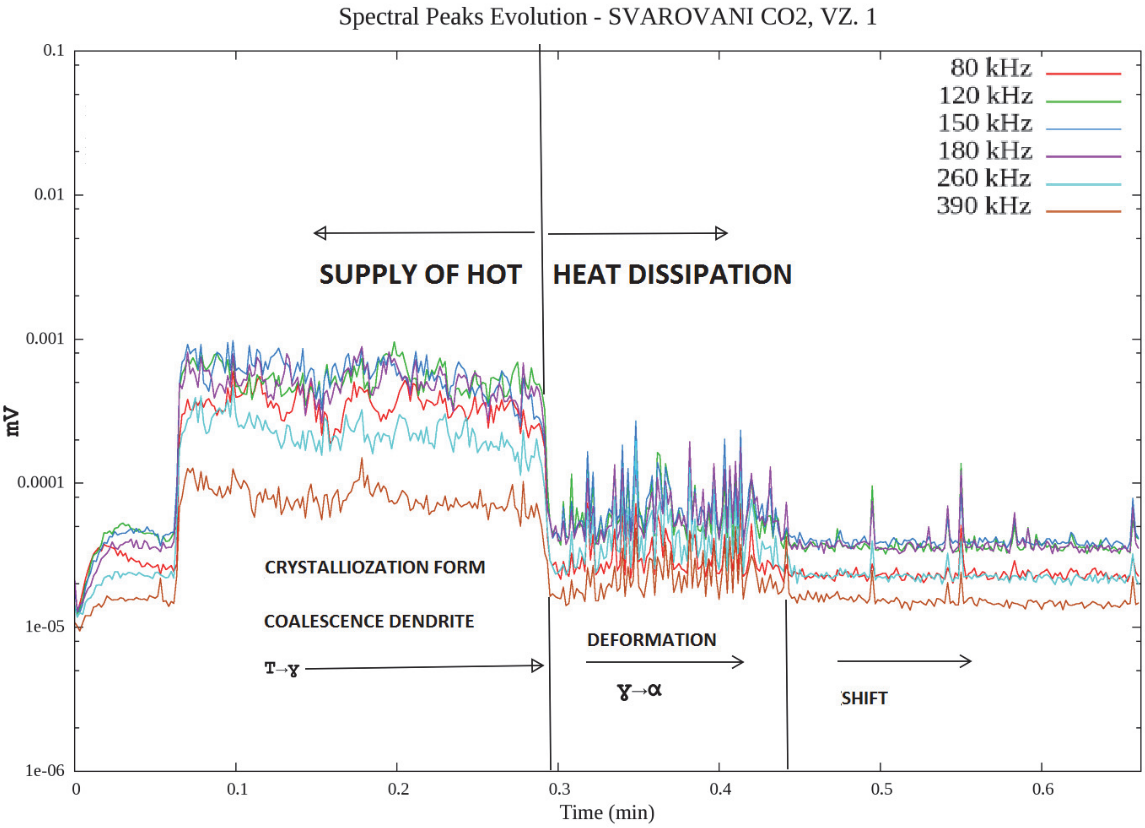
6: *Sample of AE record, 90MnCrV8 (1.2842),* CO_2 *– without stress relaxation after welding*
author



7: *Deformation of profiles for MAG method welds/*CO_2
author

of a weld joint using the MAG/CO2 method. As is also evident from recent domestic contributions that show the benefits of AE in the area of resistance welding (Nohál *et al.*, 2012) and that are already the subject of a draft standard in the USA (ASTM, 2001), the AE set of records has been gradually established within the framework of pilot and other related projects that describe the quality of the joint.

8: *Damage between weld bead and heat-affected zone of the weld – steel 90MnCrV8 (1.2842)*
author



9: *Typical appearance of record MAG welding / CO_2 – steel S235 JR (1.0038)*
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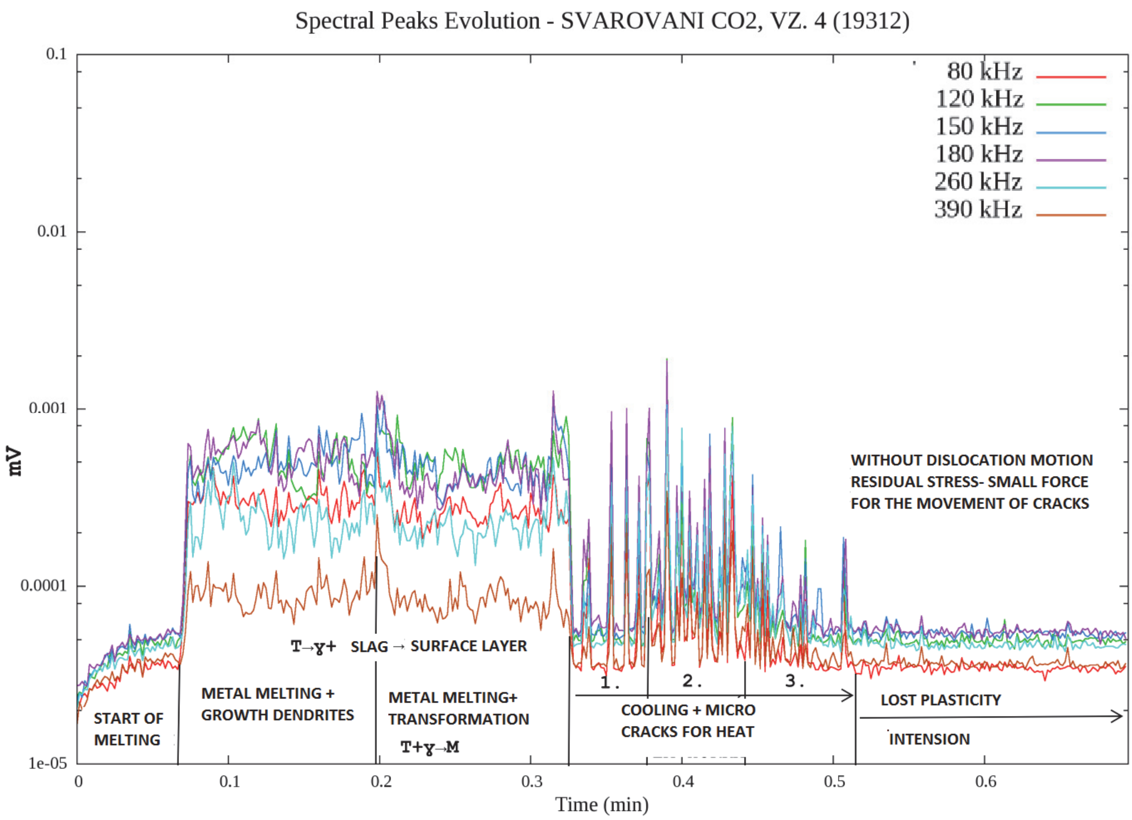

10: *Characteristic record for MAG welding / CO_2 – steel 90MnCrV8 (1.2842)*
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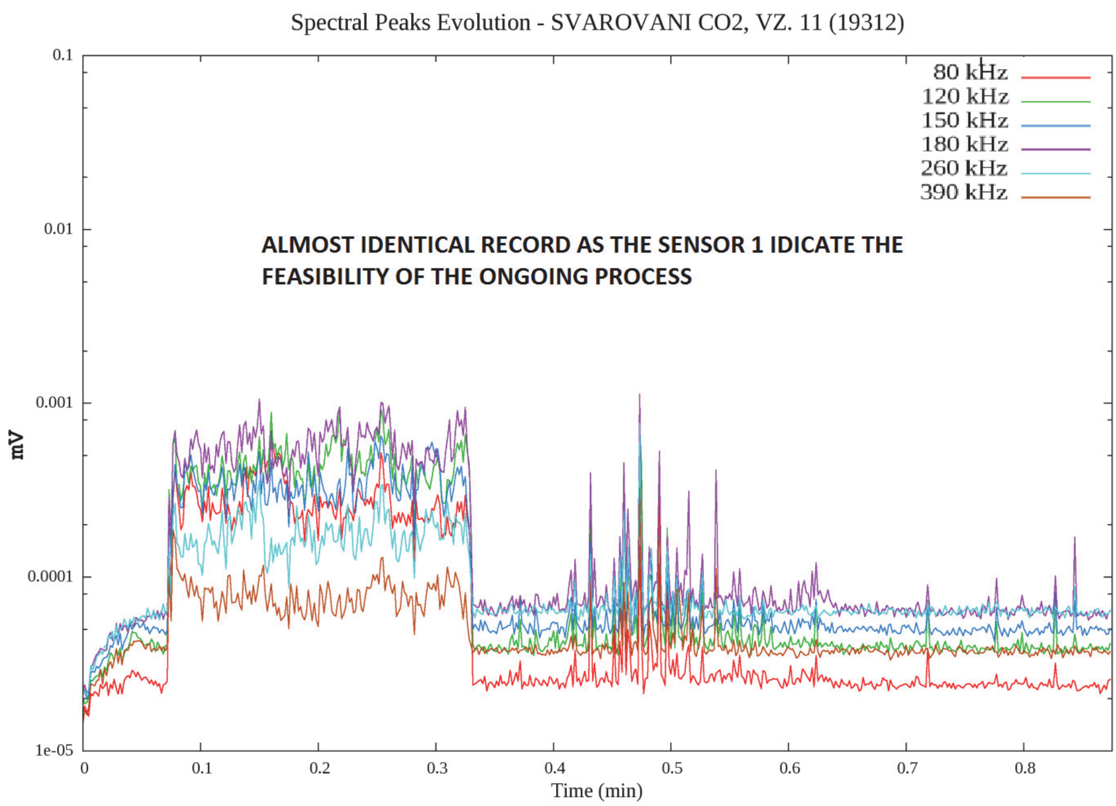

11: *Comparative record MAG / CO_2 – 90MnCrV8 (1.2842) for the second sensor*
author

CONCLUSION

The experimental part verifies the quality of the weld during the actual process. It is based on the concepts referred to in the literature (see the Theoretical part). This constitutes the basis for selecting the proposed experimental methodology and the evaluation of results.

Utilised for materials designated by the manufacturer as with guaranteed weldability and with reduced (conditional) weldability is the deep penetration MAG/CO2 technology to either confirm or to disprove this information.Utilised for strength verification of the quality joint after the welding are the mechanical tests (designed specifically for the purpose of the verification of weld strength) with subsequent metallographic and fractographic observations. This confirms the results of the non-destructive evaluation of the welding process and of the assessment of the weld formation within the AE measurements. In the AE records the activity of wave sources during welding is captured in detail and it is broken down in accordance with the number of concordant shapes of individual hits and swells in the active layer of individual materials and welding technologies utilised.

Findings are compared with the actual results in the professional literature. The evaluation of the joint quality has therefore shifted to an entirely new level, which represents the "in situ" assessment of the quality of the weld, while the actual welding process is taking place in comparison with its "post" assessment, whereby it is no longer possible to change the materials nor the input parameters for creating the joint. This makes this work extremely suitable for utilisation in technical practice. The leasing or purchase of AE recording apparatus does not represent any excessive cost increase in terms of the price of large welded structure. In the future the AE recording method could be used not only for assessing the quality of the weld but also, for example, for evaluating the quality of other types of connections (pressed joints).

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REFERENCES

AMBROŽ, O. 2005. *Technologie svařování*. 1. vyd. Ostrava: ZERROS.

ASTM. 2001. *Standard Practice for Acoustic Emission Monitoring During Resistance Spot-Welding*. E 751 – 01. West Conshohocken: The American Society for Testing and Materials.

ČERNÝ, M., DOSTÁL, P. 2014. Adhesion of Zinc Hot-dip Coatings. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 62(1): 53–64.

DOSTÁL, P., COMMUNEAU, P. 2014. Visualisation of Corrosion Acoustic Signals Using Quality Tools. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 62(1): 65–69. Available at: http://acta.mendelu.cz/62/1/0065/.

DOSTÁL, P., ČERNÝ, M., LEV, J., VARNER, D. 2011. Proportional monitoring of the acoustic emission in crypto-conditions. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 59(5): 31–38.

DOUBRAVSKÝ, M., MACÁČEK, I. and MACHÁČEK, Z., ŽÁK, J. 1985. *Technologie slévání, tváření a svařování*. Brno: Vysoké učení technické v Brně.

HLUCHÝ, M., KOLOUCH, J. 2002. *Strojírenská technologie 1 – 1. díl Nauka o materiálu*. 1. vyd. Praha: Scientia, spol. s r. o.

HLUCHÝ, M., MODRÁČEK, O., PAŇÁK R. 2002. *Strojírenská technologie 1 – 2. díl Metalografie a tepelné zpracování*. 1. vyd. Praha: Scientia, spol. s r. o.

KOPEC, B., FIALA, J., VLACH, B. et al. 2008. Nedestruktivní zkoušení materiálů a konstrukcí. In: *Nauka o materiálu 4*. Brno: Akademické nakladatelství CERM, s. r. o. Brno.

NDT. ©2013. *NDT*. [Online]. Available at: www.ndt.cz. [Accessed: 13 August 2013].

NOHÁL, L., MAZAL, P., TOPOLÁŘ, L., PAZDERA, L. 2012. Metoda akustické emise v hodnocení kvality odporového bodového svařování. In: *NDE for Safety/Defektoskopie 2012, 42. Mezinárodní konference – sborník příspěvků*.

NOREK, I. 2005. *Teoretický úvod k cvičení z předmětu Technologie I*. [Online]. Available at: http://u12133.fsid.cvut.cz/podklady/TE1/def_kontrola_sv.pdf. [Accessed: 15 May 2013].

PARIZEK, P. 2011. *Svářečská škola Česká Třebová*. [Online]. Available at: http://www.svarecskaskola.euweb.cz/. [Accessed: 12 August 2013].

SUCHÁNEK, J. 2009. *Shrnutí látky, 22. duben 2009*. [Online]. Available at: http://www.unium.cz/materialy/cvut/fs/shrnuti-latky-m5410-p3.html. [Accessed: 12 August 2013].

VOTAVA, J., KUMBÁR, V., DOSTÁL, P. 2014. Degradation processes of Al-Zn welded joints. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 62(3): 571–578.

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