

VISUALIZATION OF THE COATED ELECTRODE WELDING

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Abstract

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This work is dedicated to the evaluation of the welding process in terms of assessing the impact of weldability based on the recording of the non-destructive testing of the acoustic emission (AE). Measurements are performed utilising both materials with guaranteed weldability and materials with reduced weldability. In addition to welding, the thesis also discusses the material (metallographic and fractographic) and mechanical verification of joint formation and the variations in behaviour of metals of differing chemical composition. It also includes an analysis of AE records in relation to the condition of the material during the developing of fusion and resistance joints.

Keywords: welding, weldability, acoustic emission, defects of weld

INTRODUCTION

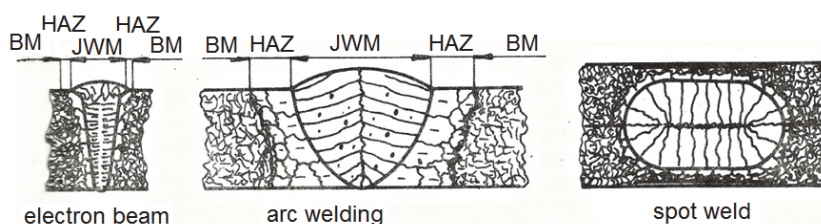
A weld joint is generated by heat or by a combination of heat and pressure. Discussed in the work is the quality derived from creating the joint using the arc welding process, comprising the stages of melting, solidification and cooling. Experimental measurements were implemented on steels with different levels of weldability using a coated electrode (welding using both materials with guaranteed weldability and materials with conditional weldability). After the welding, both a visual inspection and a mechanical stress test were carried out, followed by fractographic and metallographic verification. Contribution to the evaluation of the quality of the welds in both types of steels and detection of conditions with the

potential for the incidence of weld defects based on recording the acoustic emission. To achieve this it was necessary to detect the AE both while creating the weld pool and during its cooling, to assess the quality of the resulting joint and to deduce the probable level of the residual stress in the welded construction (Hluchý *et al.*, 2002).

The Physical and the Metallurgical Fundamentals of Fusion Welding

A weld joint has three distinct structural zones (Fig. 1).

1. JWM – joint-weld metal, which is created by the crystallisation of the mixed base material together with the added material (i.e. the weld pool).



1: Structural areas of melt joints
Doubravský *et al.*, 1985

2. HAZ – heat affected zone describes any area comprising the base material that has been directly affected by the joint-weld metal. Based on the temperature-strain cycle, both the structure and the properties were altered in this zone.
3. BM – is base material that has been affected by welding.

The Crystallisation of the Weld Metal

Directional solidification, during which impurities are still displaced into the liquid metal and further into the slag, can be implemented in a relatively shallow weld pool of an oval shape. Conversely, in a weld pool of an arrow shape or that is narrow and deep, the weakening of the centre of the weld zone caused by dendrites that are growing opposite each other is commonplace. If the liquid metal enclosed between the developed dendrites solidifies, micro shrink holes will occur in the weld. This creates the risk of hot cracking. The main factors causing the emergence of dendrites are the volume and the shape of the weld pool. These two variables are particularly influenced by the specific heat input, the areal density of the energy input and also the welding speed (Doubavský *et al.*, 1985).

Metallurgical defects can be caused during either cooling or crystallisation. Gas cavities are formed if the liquid metal comprises an amount of gas that is in excess of its solid solubility. If the metal is thickly flowing the expelled gas remains enclosed within the weld metal. This gives rise to pores, bubbles and to clusters of both, while in areas of non-compatibility with directional solidification shrinkage occurs. Shrinkage occurs most frequently at the beginning and/or at the end of the weld bead. It also occurs during welding, whereby the volume of metal that is enclosed solidifies.

The unqualified status of the welders is responsible for another entire category of defects. These defects comprise cold joints, coarse slag inclusions, lack of penetration, etc. (Ambrož, 2005).

Classified amongst the particularly dangerous defects are those with a significant notch effect. These defects cause fatigue cracks that can later result into a brittle fracture. It is the high-strength materials that are the most susceptible in this regard. Extensive plastic deformations occur in the heat affected zone. During the cooling of the material, the material shrinks while the yield increases, which results in residual stress remaining in the weld even after it has cooled. After cooling, the residual stress in stiffer structures and in stronger materials can even attain the yield point of the base material.

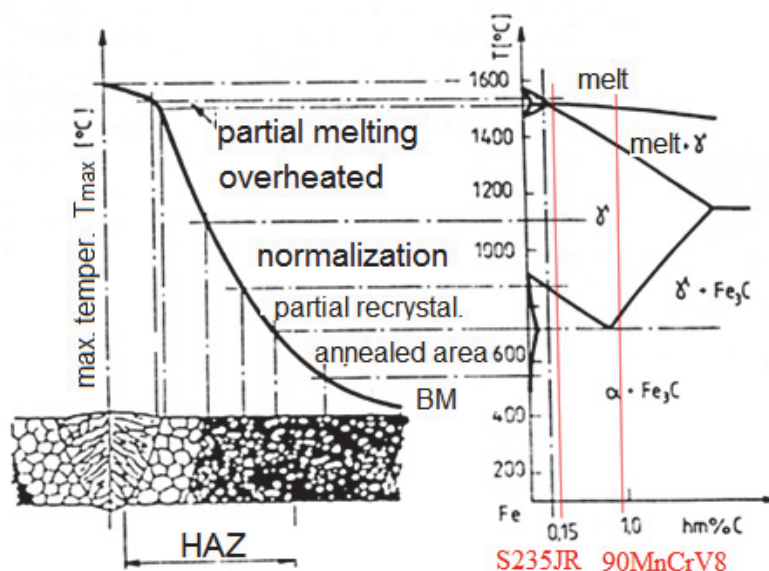
Structural stress, i.e. stress of the second order, may also be of a pressure and tension nature, and it can be combined with thermal stress. The result of this is that all the deformation is restricted to the area closest to the weld, including the actual weld metal (Fig. 2) (Doubavský *et al.*, 1985).

Defects and the Testing of Welded Joints

Any defects are categorised and are indicated numerically in accordance with the ČSN EN ISO 6520-1 standard. The most frequently used tests of welded joints are of a non-destructive nature, whereas precise functional characteristics are determined by destructive testing. For more complex weldments, both destructive tests of specimens and NDT testing of the product are implemented (Norek, 2005).

Destructive Testing

- Transverse tensile test (ČSN EN 895).
- Bend test (ČSN EN 910).
- Impact test (ČSN EN 875).



2: Structural changes; (Suchánek, 2009) the experimental materials are indicated author

- Breakage test (ČSN EN 1320).
- Test of the micro- and the macrostructure (ČSN EN 1321).
- Hardness test (ČSN EN 1043-1).

Non-destructive Testing of Welding

Non-destructive tests are important in terms of assessing quality at every stage of production. They are used to ensure the product's quality and its technological and safety features. Non-destructive quality testing can be utilised for the detection of surface defects or of defects within the weld. The following methods may be used for the detection of surface defects: visual, penetration (capillary), magnetic, powder. For detecting internal defects it is possible to utilise the following methods: ultrasound (the impedance method, reflective resonance), radiography (X-ray) and the acoustic emission method.

The acoustic emission method is used not only for testing for media leakage and for fluid flow, but also for the determination of processes. The energy released during these processes is transformed into a mechanical stress pulse. The stress pulse can be propagated as a longitudinal or transverse elastic stress wave (Kopeck *et al.*, 2008; NDT, 2013).

THE EXPERIMENTAL PART

Due to the largest possible degree of variance in the AE records and also in the mechanical properties of joints, materials with different degrees of weldability were selected for the test. Steel S235JR (1.0038) is a material with guaranteed weldability, whereas steel 90MnCrV8 (1.2842) has reduced weldability (ČSN 42 0002).

Samples of steel S235JR with dimensions of 30×5×250mm for coated electrode welding tests were cut on the laser burning machine. Tool steel 90MnCrV8 was supplied in the 30×5×500mm and 30×2×500mm dimensions. Its surface was polished.

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

A WTU800 welder was used for the coated electrode welding. The welding current was set at 110 A. E - B121 electrodes with a diameter of 2,5 mm and a length of 350 mm were utilised.

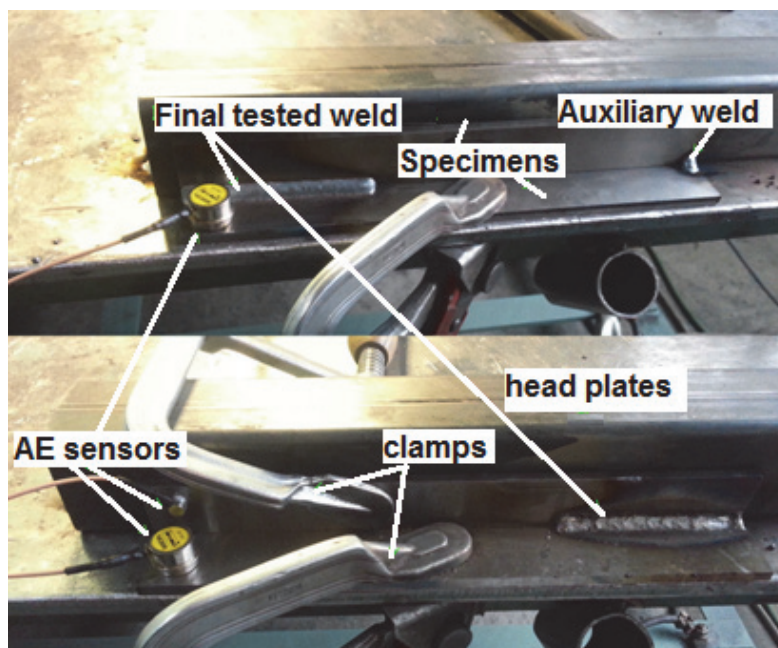
The samples were attached to the welding table by means of a clamp. Subsequently AE sensors were connected to them, always as far away as possible from the welding area, in order to avoid damage to the sensor by high temperature. For both methods the weld length selected was 80 mm.

Verification of strength was carried out on a manually operated hydraulic press, OMA 655, with $F_{\max} = 250$ kN and a piston stroke of 180 mm (Fig. 4).

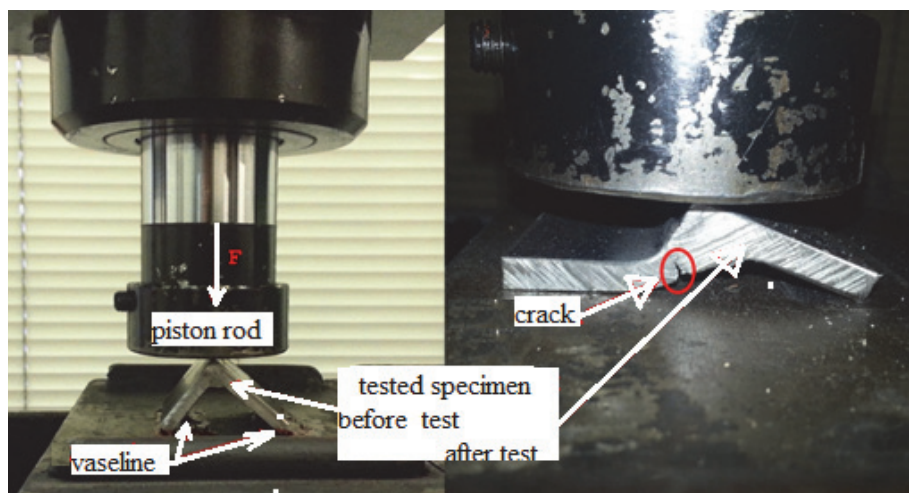
The samples were prepared on DAP-34 Pedemin metallographic grinding and polishing device and were observed using the Neophot. The results of the observations are shown in Figs. 5 and 6.

DISCUSSION OF THE EXPERIMENTAL RESULTS

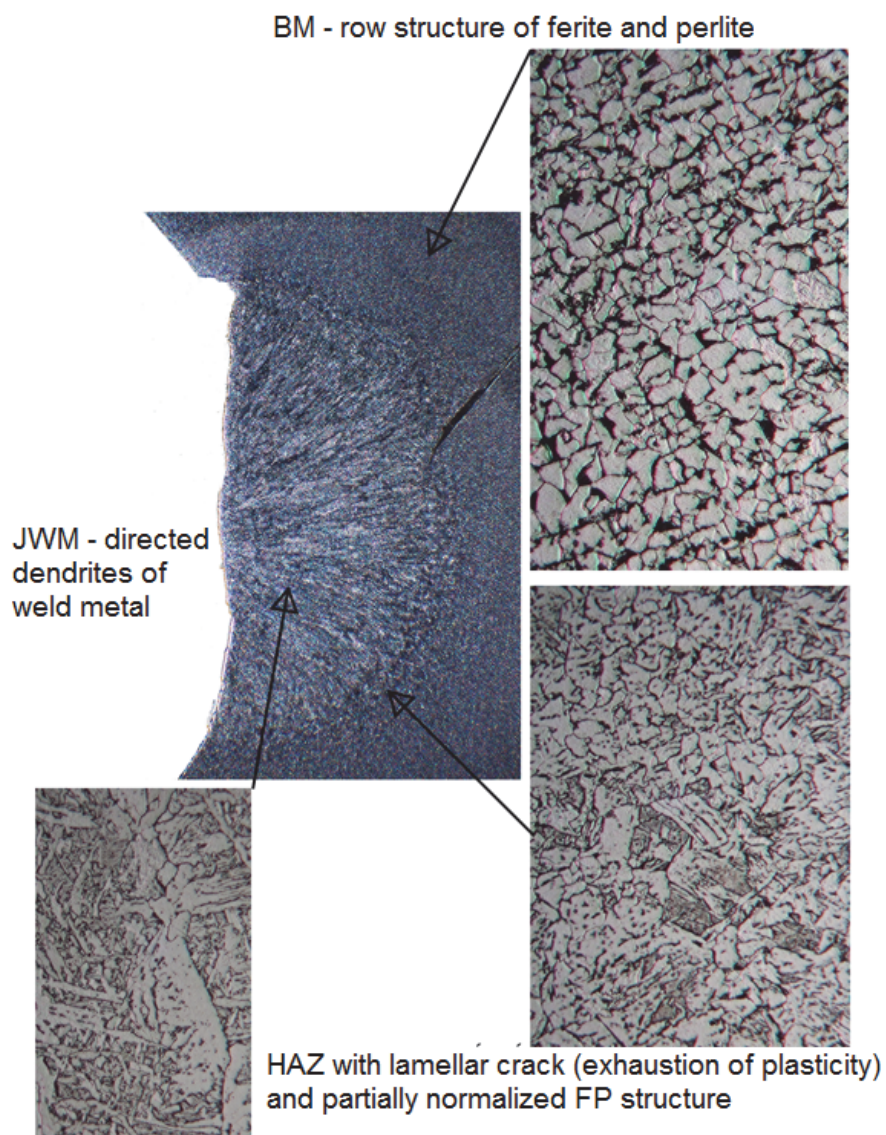
The experiment is designed for evaluating the weldability and possibly also the weld quality already during the welding and also in the course of the acoustic emission recording. The weld



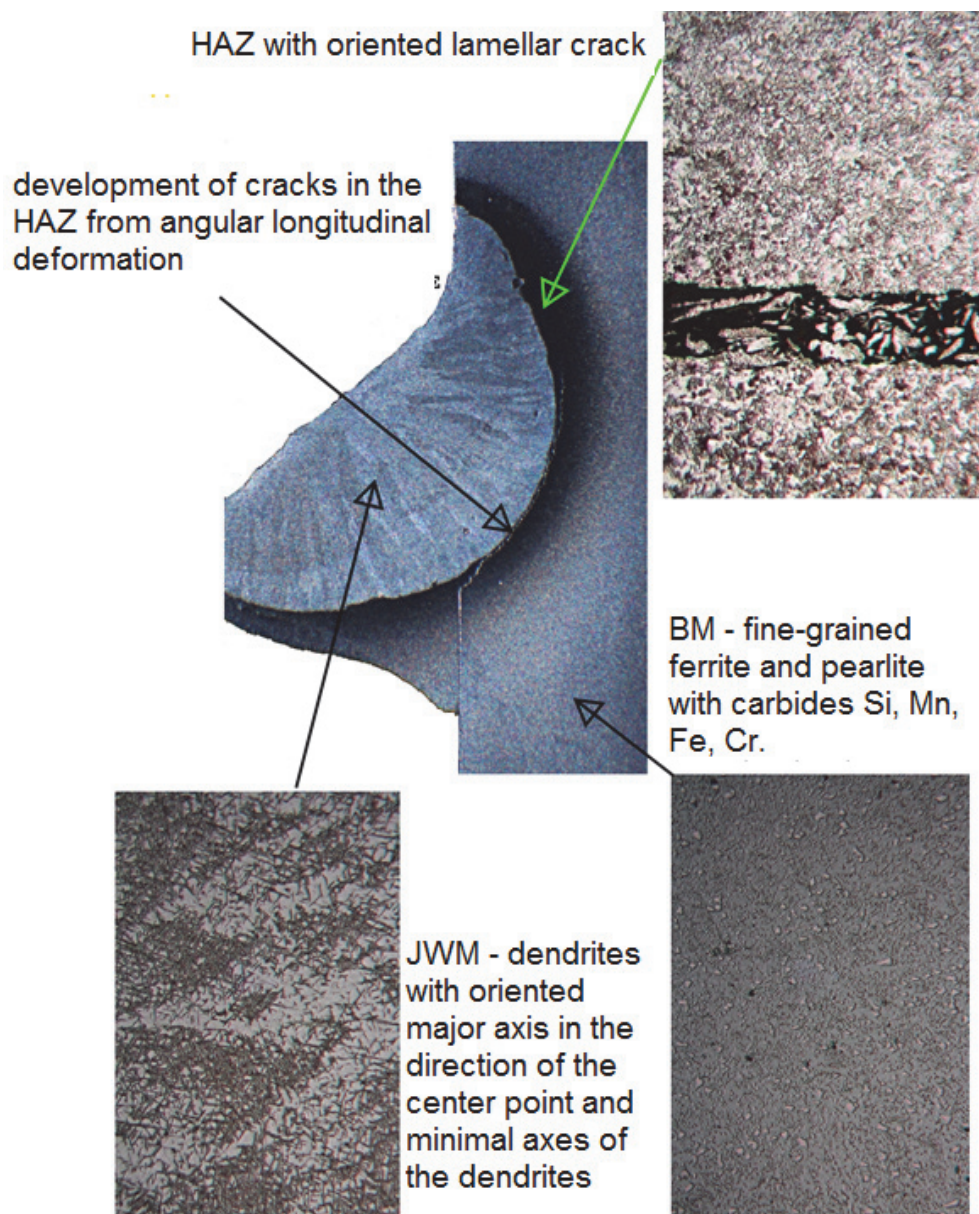
3: Location of the sensor during coated electrode welding and when utilising the MAG method
author



4: Location of the sample at the beginning and at the end of the test
author



5: Metallographic grinding of the weld, utilising steel S235 JR
author



6: Metallographic grinding of the weld, utilising steel 90MnCrV8
author

quality was additionally assessed, both visually and mechanically.

Direct visual inspection did not identify any incidence of external defects. The welds of all the samples had been well-executed, including the welds of steel 90MnCrV8. Molten metal spatter occurred more frequently with steel S235JR than when welding steel 90MnCrV8.

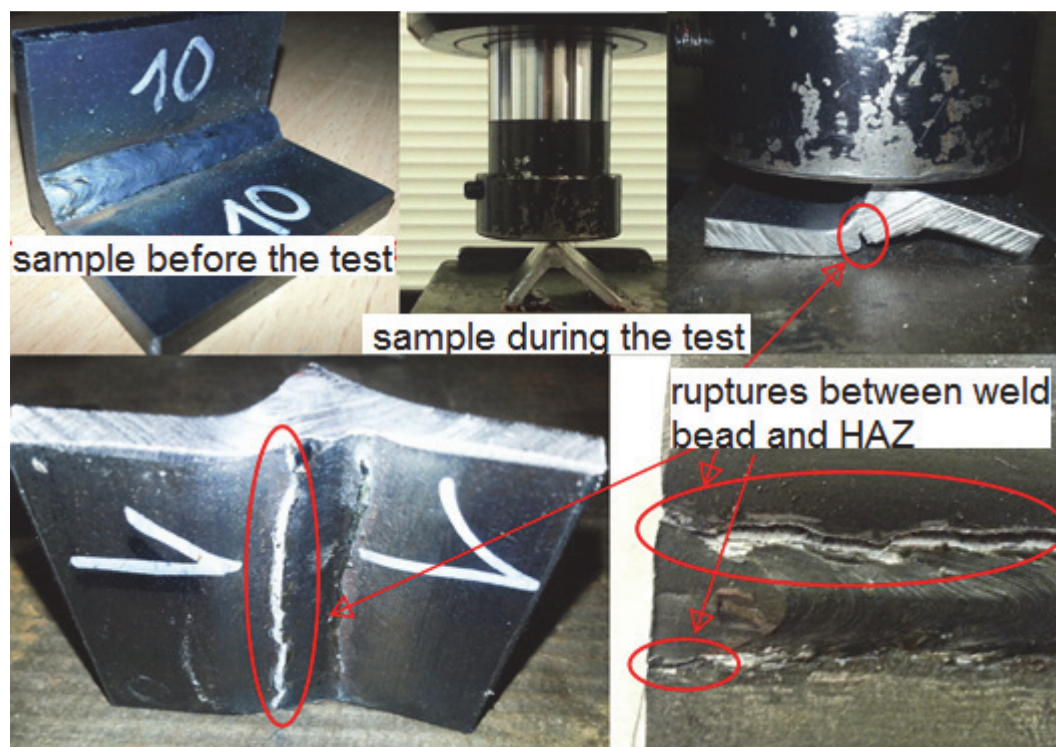
Mechanical Inspection

The progress of the testing of samples of steel S235JR, welded using a coated electrode was analogous to the deformation of ductile materials when they are compressed. The force was gradually raised to 40 kN. Only then did plastic changes start to occur. When increasing the loading force, the

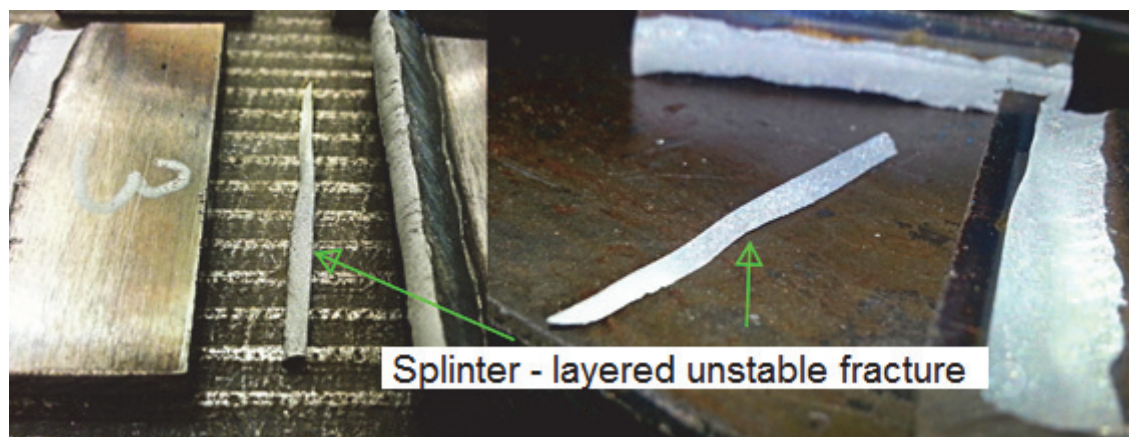
sample began to bend until a crack in the weld root occurred (Fig. 7).

For samples of steel steel 90MnCrV8, the maximum force at which damage to the sample occurred was cca. 26 kN. The final brittle fracture, which originated in the hardened part of the material just below 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 separated from sample number 3 (Fig. 8).

The AE activities that occurred during the testing were described in detail directly in the records of maximum activity of hits on the measured channel, showing the activity of selected levels.



7: Deformation and tearing at the point of the weld root
author



8: Fissile fracture of the weld in steel 90MnCrV8
author

The records of the hits for both steels are evaluated in Figs. 11 and 12 in connection with the metallurgical processes in welds and metallographic results.

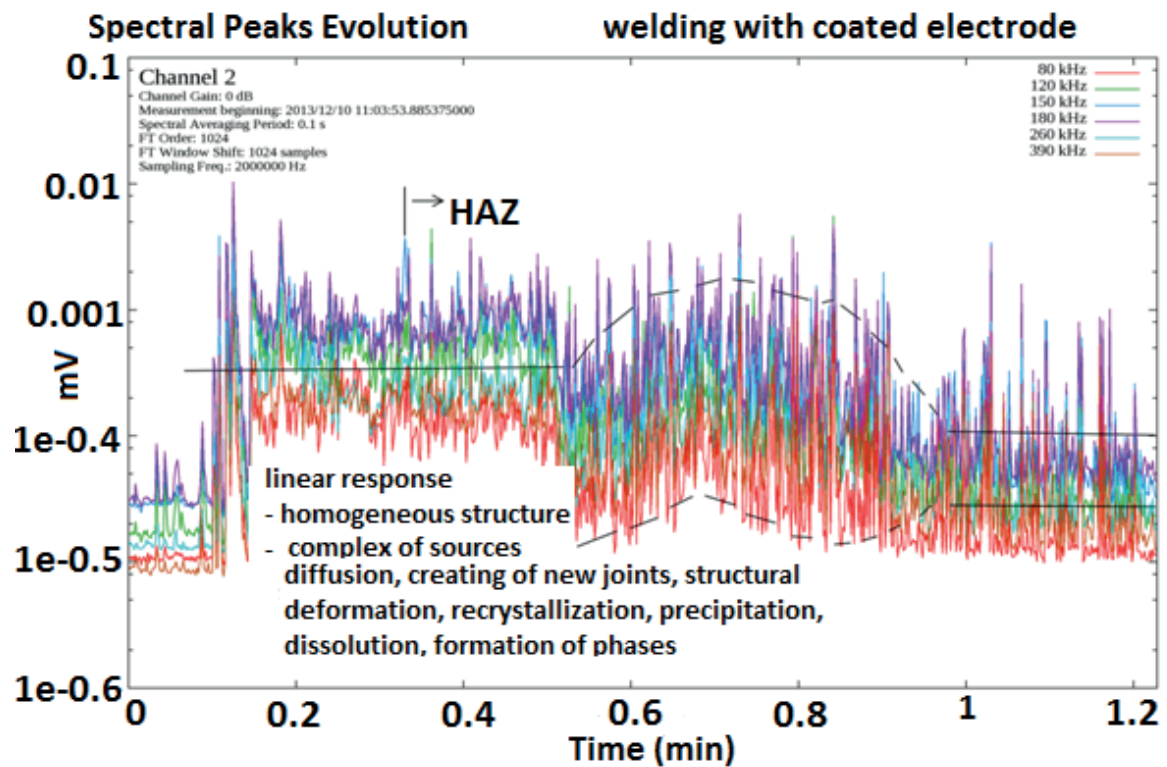
COMPREHENSIVE DISCUSSION

Concurrent discussion of the results is carried out continuously within images (by local description). These results are complemented by the subsequent comprehensive discussion, which extrapolates the findings from the individual inspections – i.e. visual, mechanical, metallographic, fractographic and acoustic – shown in the images and in the

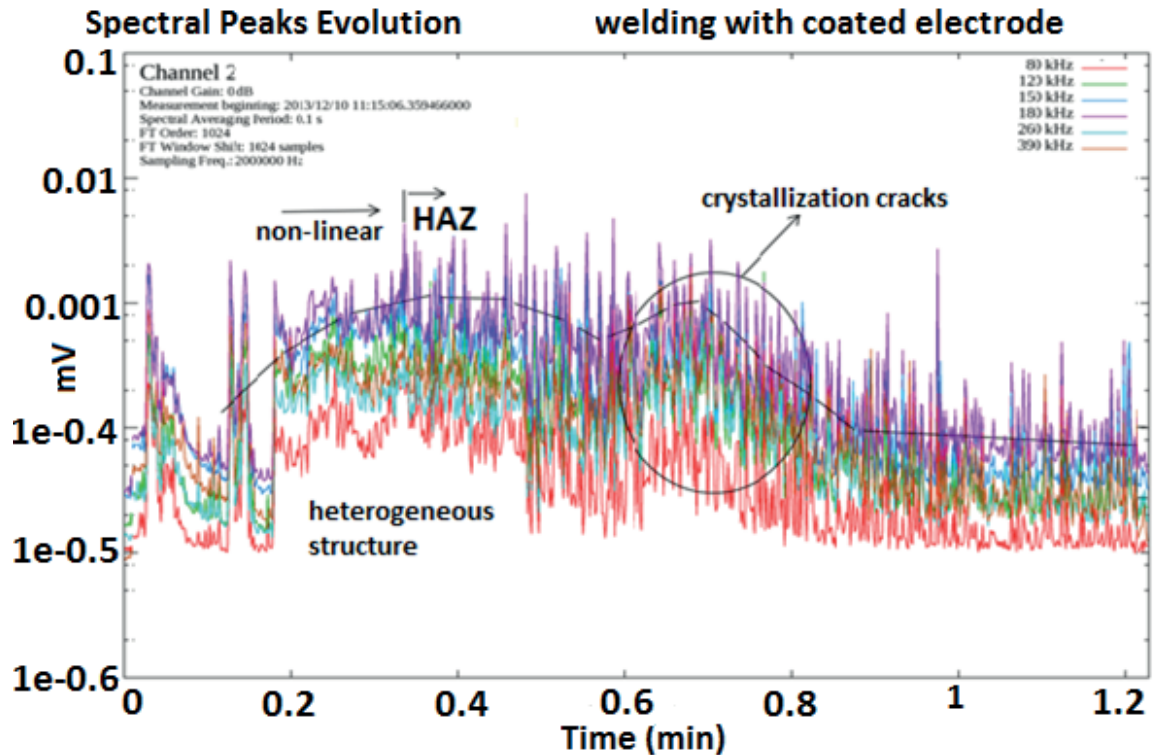
records. In regard to the verification of weldability clear confirmation was obtained of the difference between the material with guaranteed weldability and the material with reduced weldability.

In terms of the quality of the welds made using steel S235JR – with guaranteed weldability – it is evident from the records that after the melting the weld pool is continually being mixed, followed by the subsequent cooling of the weld pool and the stress equalisation within the ferrite-pearlite structure. The records are supplemented by images from the metallographic grinding of steel S235JR.

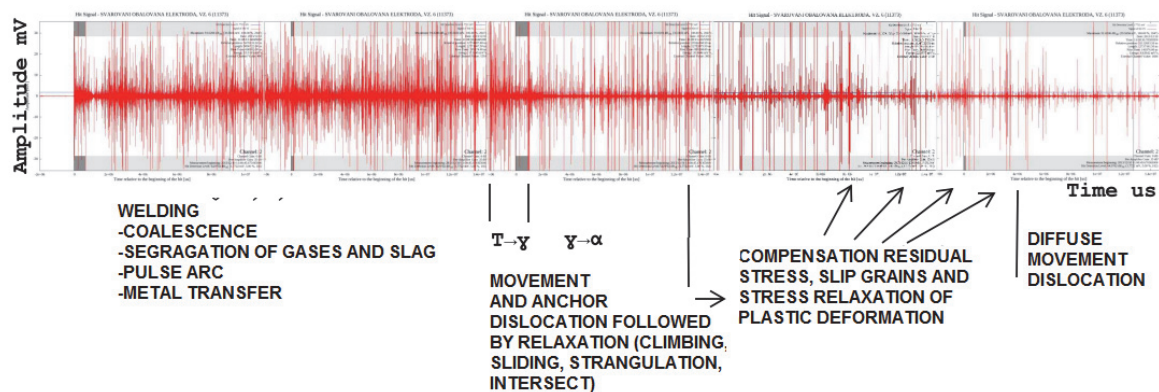
In steel 90MnCrV8 there is an enormous increase in the acoustic noise that accompanies



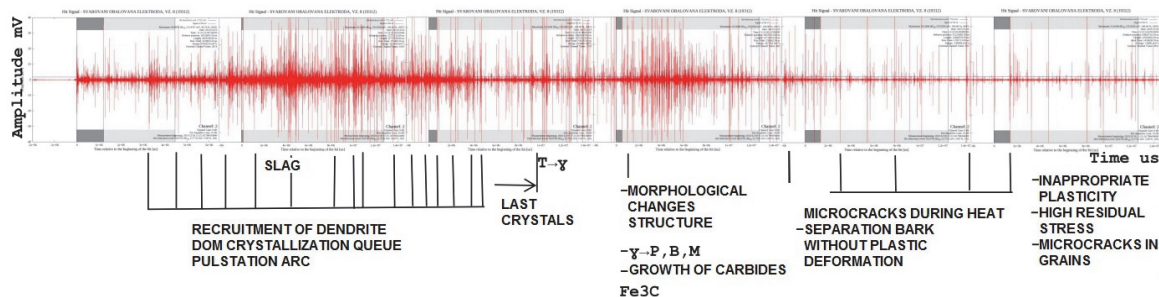
9: Coated electrode welding of steel S235JR
 author



10: Coated electrode welding of steel 90MnCrV8
 author



11: The AE hits record during the welding of steel S235 JR, with significant movement of dislocations
author



12: The AE hits record during welding of steel 90MnCrV8, without the relaxation of structural tension

the growth of long unidirectional dendrites. This is then accompanied by a shear transformation of austenite to martensite in the HAZ. The flat profile of the record subsequent to this transformation (e.g. without any motion of the line defects) indicates the presence of high residual stress, i.e. calm in the slip planes, which causes the pseudo-fragility of the material. This results in the development of fissile microcracks which is manifested by the apparent loss of toughness which is evident from the picture of the mechanical testing of welds of steel

90MnCrV8, which are more than conclusive when compared with the verification of the toughness of steel S235JR.

As is also evident from recent domestic contributions which show the benefits of AE in the field of resistance welding and which are already the subject of an approved standard in the USA, the AE set of records has been developing gradually within pilot and other related projects that describe the quality of the joint "in situ".

CONCLUSION

Utilised for testing materials designated by the manufacturer as being of guaranteed weldability and of reduced weldability is the method of electrical fusion welding with a coated electrode to confirm this information. After the welding, mechanical tests with subsequent metallographic and fractographic observation are utilised for verifying the strength of the quality joint. These confirm the results of the non-destructive evaluation of the welding process and the assessment of the weld formation recorded by the AE measurements. Also captured in detail in the AE records (a total of 20 entries!) is the typical activity of sources during welding and this is broken down in accordance with the number of concordant shapes of individual hits and swells in the active layer of each material and in the welding technology utilised.

These findings are compared with actual results reported in the local professional literature and with the standards under preparation in the USA. The evaluation of the joint quality has therefore shifted to an entirely new level, which is represented by the "in situ" assessment of the quality of the weld during the actual welding process, in comparison with its previous "post" assessment, whereby it is no longer possible to change the materials and the input parameters for creating the joint. This makes this work extremely suitable for use in technical practice. Leasing or even purchasing AE recording apparatus, including instructional training at some of the accredited centres in the Czech Republic, does not represent an excessive cost increase as compared to the price of large welded structure or to the mass production scenario.

Acknowledgement

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