Acoustic Emission Detection and Measurement of the Voltage Drop during the Crack Propagation in Weld Metal

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Introduction.

The application of linear fracture mechanics principels has provided considerable knowledge about the field of crack propagation during the subcritical crack growth or during the failure.
Even an extrem carefulness welding process with or without filler metal can not avoid the formation of different defects, material discontinuities like micro cracks in weld metal often induced by hydrogen.
These defects as also any kind of crack like structural defects are today one of the burning engineering problems.
It is vitally important to know what severity of defect, by weld cracking , in case of tendency of hydrogen induced cracking, also what amount of hydrogen at a localized stress is still tolerable to prevent the slow crack propagation in subcritical interval, leading to a catastrophic failure.
Hydrogen induced delayed cracking is slow propagating, discontinuous and vary in both rate and dimensions.
Normally the micro cracks are to small to be detected with existing nondestructive test methods and the crack length will exceed the critical size since the welded construction will fail.

Experiment.

In experimental work explained as follows, the detection of acoustic emission was used to identify the slow crack propagation in the root run of the high tensile weld metal.
The detection of acoustic emission during the formation of different kinds of weld discontinuities is one of the most successful method for nondestructive testing. A comprehensive reports have been given already from the authors (1,2) about the acoustic emission analysis of hydrogen induced delayed cracking, particulary of the root layer in low and high tensile weld metals.
To avoid completely the interfierence of the background noise and to provide an adequate stress in the weld metal two different welding specimens have been used.
First one shown in Fig.1 was the specimen with high residual stresses. In the root run of the weld metal the acoustic emission was detected during the welding process, immediately after the welding during the solidification and phase transformation processes and bellow 200°C during the formation of hydrogen induced delayed cracking. With this specimen was also possible simultaneously to acoustic emission a measurement of the change of the electrical resistance during the crack propagation. In Fig.2 can be seen acoustic emission rate delayed after the welding dependant on the amount of the hydrogen in the weld metal. Fig.3 shows the second weld specimen with the one side welded root run for two poin bending test. Fig.4 shows the block diagram of the circuit. The system of acoustic analysis used for our puposes includs piezoelectric transducer K for acoustic emission detection. The electrical output signal from the transducer K is amplified through high gain , low noise, filtered preamplifier V_1. The signal, from the V_1 is amplified additionally by a second set

of special purpose, frequency filtered, adjustable amplifier V_2, with which the necessary additional gain is obtained prior to the further processing of the detected signals free of any rendam noises.
Output signal from the impuls converter I will be controled by NF-amplifier V and made audible in a loud speaker L. The audible signals simplified the whole control System. Digital signal passing the gate A, controled by master generator is entering the impuls storage Sp_1. The clock impulses are summarized in storage Sp_2, they are continuously registered through the multiplexer M in a digital printer. The storage content will be with the use of the display D repeatedly indicated and further through the digital impuls converter D/A led into the level recorder S for recording an analog diagram. With this system it is possible a continuous digital indication of the summation of the impulse counts or of the impulse rates with a simultaneous registration of the experiment duration.
Because of the formation of the micro cracks in weld metal a change of electrical resistance was expected. To register this change a DC current of 100 amps was passed through the weld metal. A drop of the voltage was measured with the analogeous oscilograph indicator. The indication of the weld discontinuities were proved simultaneously by acoustic emission analysis and voltage drop measurements. Both diagrams, Fig.5 show a change of the measured value at the same time. The acoustic emission analysis and the measurements of the drop of electrical voltage during the crack propagation were accompanied by continuous recording of notch opening displacement as a function of time , realized by means of a clip gauge fitted between knife edges attached to the specimen surface. The received values measured

at the surface were not converted to notch tip COD values, so that the intensity of acoustic emission relates to the notch displacement on the surface as a function of time.
For welding of two types of high tensile strength steels with yield strength 70 and 100 kp/mm^2 of the thickniss 10 mm and arc energy 8,9 kJ/cm a MAG welding process was used. The filler metal cooper coated, solid Ni-Mo wire (D_3) was hydrogenated in H_2SO_4 electrolyt at $i=150$ mA/cm^2 and at different time to reach the correspondent concentrations of the hydrogen in the weld metal. Fig.6 is showing the placement of the weld specimens during the testing and the placement of the instruments used for recording of acoustic emission, electrical resistance and crack opening displacement. Fig 7 and 8 are showing the summation of acoustic counts as a function of time by high tensile steels of yield strength 70 and 100 kp/mm^2. The difference of summarized counts at both steels is obvious. The delayed failure related to the maximum of the rate of acoustic emission depend on the amount of hydrogen in filler weld metal. In relation of acoustic emission to notch opening displacement shows Fig.9 by more brittle material steeper increas of both curves.

Results.

The acoustic emission has been used to study slow discontinuous crack propagation induced by hydrogen in the root run of the high tensile weld metal.

A rougher increas of the acoustic intensity was detected by higher amount of hydrogen, higher yield strength of the weld metal and at higher applied stress.

The incubation time of the delayed cracking, which could be correlated with detected acoustic emission varied due to the different amount of hydrogen at a given metal structure and at a constant load.

The delayed cracks in the weld specimen with high residual stresses were located in the middle of the weld metal; by two poin preflawed, bending weld specimen the initiated crack split in two runs following the heat affected zones. The location was transglanural and grain boundaries orientated, by material with higher yield strength in the middle of the heat affected zone or near to the parent metal and by lower yield strength material more near to the weld metal. The different locations of the propagating cracks were followed by different intensity of acoustic emission. Discontinuously propagating slow cracks developed into the total fracture after exceeding the critical magnitude.

The fractographs were taken from the fracture surface of the specimens and an extensive hydrogen cracking can be seen in Fig. 10 .

The drop of the voltage was recorded during crack propagation and the change of the voltage in micro volts was registered. A correlation between the crack opening displacement COD with acoustic emission was possible only by high yield strength materials.

Acknowledgement.

We wish to thank DFG for financial suport by research work on the field of the detection of acoustic emission during the weld cracking.

Discussion after the lecture.

Is it possible to make a relation between the crack length and the acoustic emission?

I hope, it is. Our researching stopped actually at this stage and there were some experiments made so far also with optical observation (magnification X40) of the crack propagation from the side view of the polished two point bending weld specimen. It is possible to show Fig.11 the lengthening of the crack related to the intensity of acoustic emission measured as a number of counts per crack length. Utilizing metallographic analysis, which show on an average a constant penetration of crack through the whole width of the specimen, can be the intensity of acoustic emission related also to the crack area.

Did metalographic analysis prove the discontinuity of the cracks?

The Fig.12 shows above the acoustic diagrams up to the off-loading of the weld specimen. At this stage the specimens were metalographic analysed through the whole width as seen on the right side of the picture. The interupted cracks on the down pictures are results of this investigation. On the left side strong grain boundaries orientated crack on the right more weld metal side localized. In both cases interupted islands can be seen, which are lengthening most probably in both directions.

References.

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(2) Erdmann-Jesnitzer,F., J. Beges, D. Rehfeldt : Akustische Analyse in Schweißforschung und Praxis als neue Methode der Gütesicherung. Schweißtechnik, Wien, 27 (1973), H. 2, S. 25-28, H. 3, S. 45-48

Captions to Figures

Fig.1: Welding specimen 1.

Fig.2: Acoustic emission rate as a function of time.

Fig.3: Welding specimen 2.

Fig.4: Block diagram of acoustic emission monitoring system.

Fig.5: Acoustic emission and drop of the voltage as a function of time.

Fig.6: The placement of the welding specimen and the instruments used during the experiments.

Fig.7: Acoustic emission counts as a function of time; yield strength of steel 70 kp/mm^2.

Fig.8: Acoustic emission counts as a function of time; yield strength of steel 100 kp/mm^2.

Fig.9: Acoustic emission and notch opening displacement as a function of time for two different steels.

Fig.10: Fractographs of the fracture surface.

Fig.11: Intensity of acoustic emission, notch opening displacement and crack length (area) as a function of time.

Fig.12: Metalographic analysis (X500,X200).

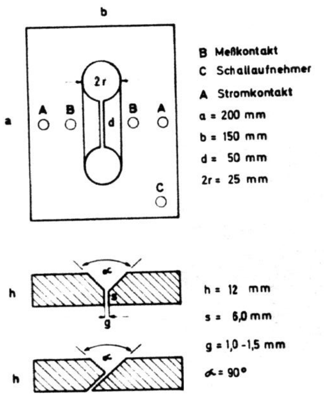


Fig.1: Welding specimen 1 .

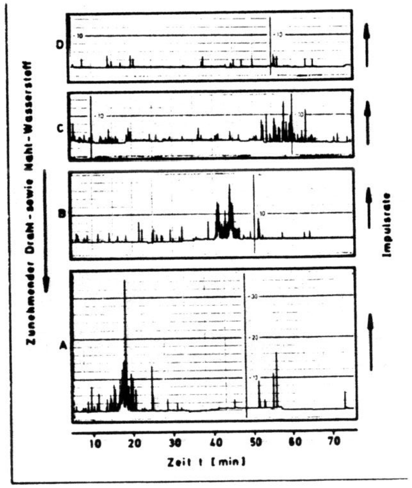
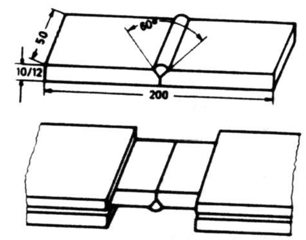


Fig.2: Acoustic emission rate as a function of time.



Schweißgrundmaterial:

Stahl	C	Si	Mn	Al	Mo	Cr	Ni	V	σ_S	σ_B kp/mm²
A	0,14	0,59	0,78	0,043	0,25	0,80			77,8	83,8
B	0,17	0,28	0,74	0,024	0,36	0,54	1,55	0,07	101,8	107,0
C	0,11	0,40	1,16	0,026	0,20	0,20			55,7	68,0

Schweißzusatzmaterial: ⌀ 1,2 mm

Draht		Si	Mn		Mo	Cr	Ni	V		
D 1		0,90	1,20							
D 2		1,15	1,65							
D 3			1,10		0,45		1,15	0,09		
D 4			0,90			1,0				

Fig.3: Welding specimen 2.

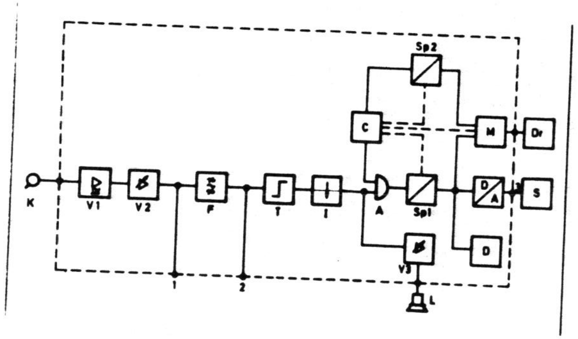


Fig.4: Block diagram of acoustic emission monitoring system.

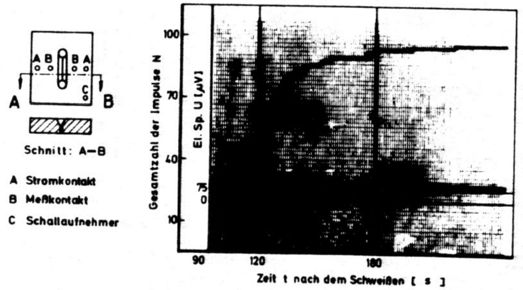


Fig.5: Acoustic emission and drop of the voltage as a function of time.

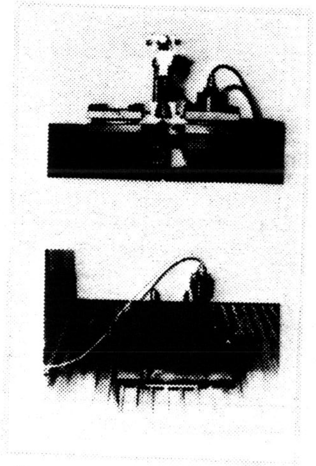
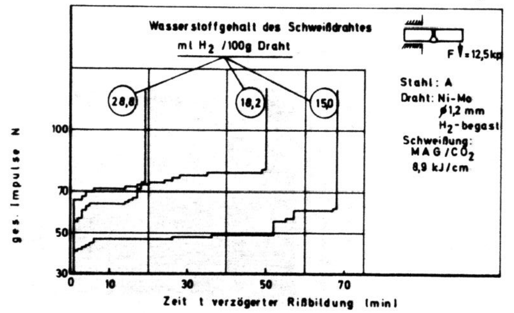
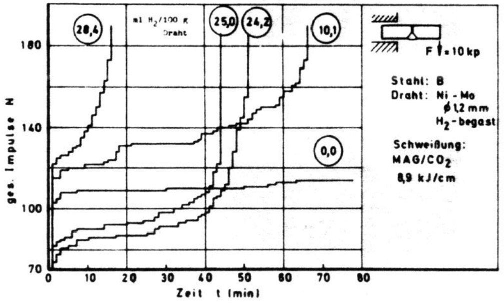


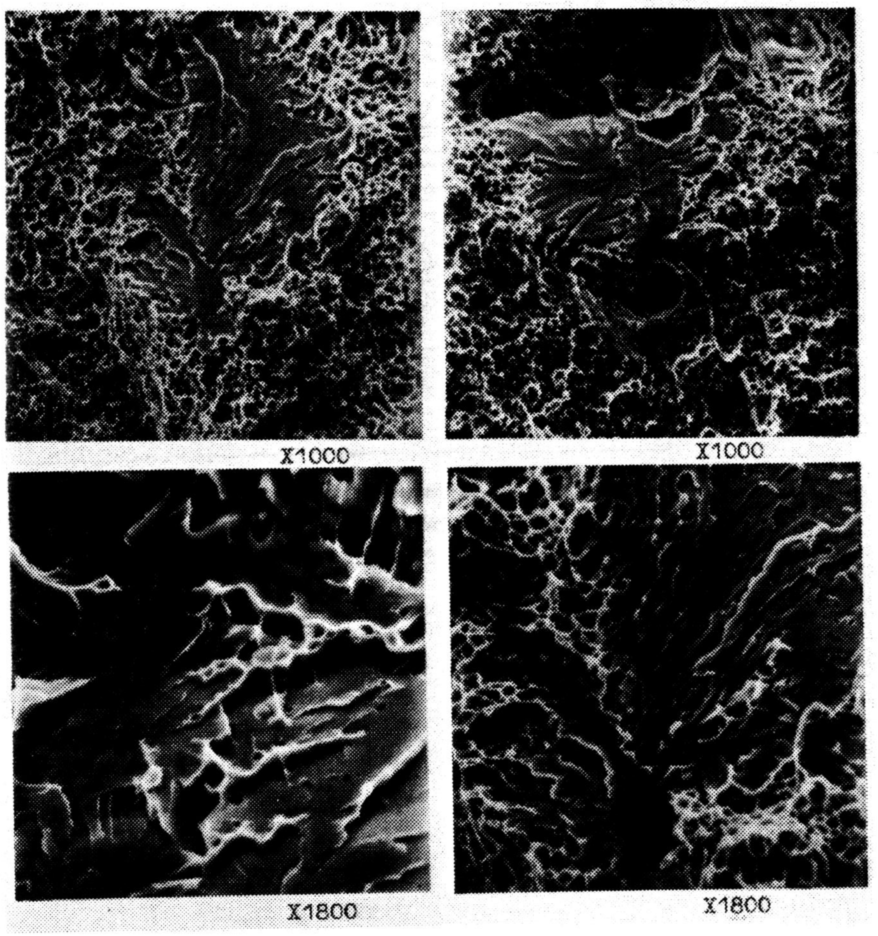
Fig.6: The placement of the welding specimen and the instruments used during the experiment.



<u>Fig.7:</u> Acoustic emission counts as a function of time; yield strength of steel 70 kp/mm^2.



<u>Fig.8:</u> Acoustic emission counts as a function of time; yield strength of steel 100 kp/mm^2.



<u>Fig.10:</u> Fractographs of fracture surface.

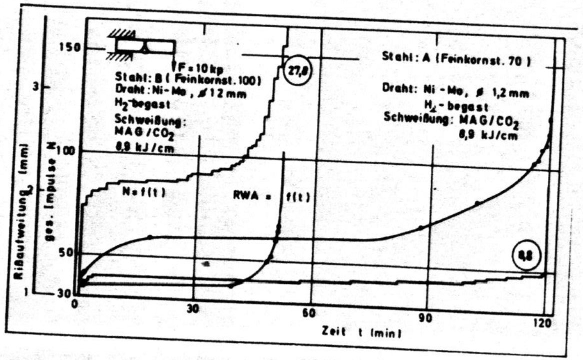


Fig.9: Acoustic emission and notch opening displacement as a function of time for two different steels.

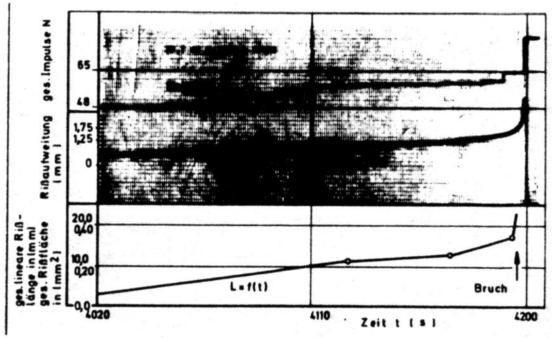


Fig.11: Intensity of acoustic emission, notch opening displacement and crack length (area) as a funktion of time.

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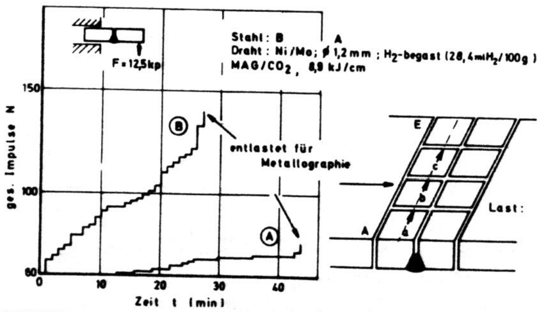

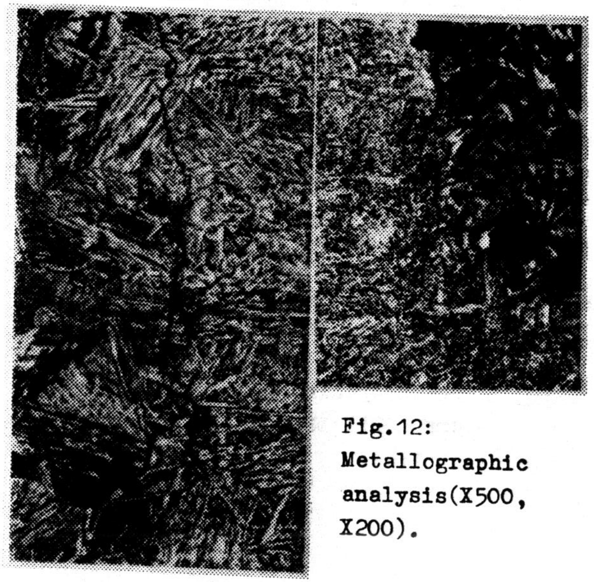

Fig.12: Metallographic analysis(X500, X200).