Real-time quality monitoring of MIG/MAG welding using acoustic emission monitoring

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<u>Context</u>

Acoustic emission quality monitoring as a non-destructive and comparative test method has been developed based on the fact that every material exhibits natural vibrations and that machines and processes emit sounds. The main goal of acoustic emission monitoring (AEM) is to surveil industrial processes or structures in a non-destructive way. By using AEM as an in-line quality control system, it is possible to listen to the sounds emitted by materials during the application of the investigated process. Nowadays, AEM is widely used for many different applications, ranging from monitoring of industrial processes to the control of bridges during their lifespan.

The AEM technique is based on the detection and conversion of high-frequency waves into electrical signals. When a metal is stressed, for example during plastic deformation, low-level sounds are emitted. The energy for these sounds originates from the stored elastic energy in the object or from externally performed work. The generated waves can be longitudinal, transverse or surface waves. The waves cause a displacement at the surface that can be measured with a sensor. In order to accurately distinguish the signals originating from the AEM source, external sounds should be excluded. This can be done for example by looking into the frequency domain, since the sound waves of the material have relatively high frequencies.

AEM is currently being used for the surveillance of industrial processes or structures:

- crack detection,
- vessel inspection,
- leak detection.

<u>Application of AEM for welding</u>

Welding industries are faced with the need to monitor the weld quality and system integrity more frequently, in order to guarantee the structural functionality of the products. Hence, weld quality is becoming increasingly important as customer expectations increase. A primary concern is to detect weld defects fast, reliable and cost-effectively. Current destructive and non-destructive techniques are time-consuming and expensive and are not always appropriate for assessing the weld quality. AEM as an in-line quality control system allows to overcome the current limitations of conventional characterisation techniques. AEM can eliminate or considerably reduce the post-production selective inspection, reduce the number of destructive tests and increase the reliability of the assembly process.

During welding, acoustic emissions are emitted as a result of the formation of the weld, the development of defects or other disturbing influences. The form in which acoustic emission occurs depends on the welding process, the material, the temperature and the geometry of the workpiece. The fundamental objective of AEM during welding is to obtain useful information about the quality of the joints and the suitability of the parameters used during welding. By using the correct measurement equipment and settings and the accompanying analysis software, the different sources of acoustic emission can be distinguished and possible welding imperfections can be detected.

It will therefore contribute to a higher productivity, lower cost and greater reliability of the produced components. AEM will monitor and control the quality of the product during or after the process. This results in a reduction in re-work and in an increase of the quality.

If a sufficient accuracy and precision of the measurement techniques is achieved, the weld quality can be guaranteed synchronous with production. Real-time control of the weld quality allows to make parameter adjustments during the process itself. Other materials or geometries requiring adjustment of the welding parameters can be welded using process control loops.

Application of artificial intelligence methods for weld quality monitoring

The sensors generate large amounts of data that must be processed in a fast and effective manner. Intelligent software solutions can analyse large amounts of data generated by a welding process to identify trends and patterns, which can then be used to detect weld defects, or to adjust the welding parameters, and to make the processes more efficient. In this way, welding equipment can continuously adapt to new conditions and are optimised without the need for operator input. In addition, cloud-based, Internet of Things operating systems (IoT) can be used to connect products, installations, systems and machines and to make the enormous amounts of data generated by the welding processes useful for optimisation, simulation and decision-making.

Artificial Intelligence offers an enormous potential for analysing measurement data and monitoring of the quality of welds and welded products. It makes production more efficient, flexible, reliable and cheaper. This offers great opportunities for companies; cost reduction, greater flexibility, mass production tailored to the customer, new business models, ...

Project "SoundWeld"

In the frame of the "SoundWeld" project executed at the Belgian Welding Institute, investments were made in acoustic emission measurement systems, which can be used as a non-destructive technique for assessing the weld quality. SoundWeld investigates this new promising real-time NDT method in a structured way for a variety of welding processes:

- arc welding (MIG/MAG),
- resistance spot welding,
- magnetic pulse welding,
- refill friction stir spot welding.

The resulting interface in the welds produced with magnetic pulse and refill friction stir spot welding differ significantly from conventional welds, resulting in a higher risk for overlooking defects when using conventional NDT methods.

The following sub-objectives were targeted :

- investigation of the reproducibility of the AEM signals,
- determination of the appropriate AEM sensors and settings,
- investigation of the detection capabilities of weld defects based on AEM measurements,
- development of a non-destructive weld quality monitoring system based on AEM.

To achieve these goals, a cooperation was set up with the company OQTON, who is specialised in the development of advanced self-learning data-driven AI models.

Project website : https://bil-ibs.be/en/project/soundweld-quality-inspection-using-acoustic-emission-monitoring

Experimental investigations

During the SoundWeld project, experiments were carried out for monitoring robotic MIG/MAG-welding, based on acoustic emissions. Different types of sensors were used; piezoelectric sensors as well as a microphone. Welding experiments were performed for 2 types of welds:

- bead on plat welds,
- fillet welds.

Welds were performed with the different arc types of the MIG/MAG process; short arc welding, globular welding, spray arc welding and pulsed welding. Welds executed with optimal parameters served as a reference. In addition, welds were also performed in which one particular parameter was varied; for example the welding speed, stick out length, torch position or angle and the welding direction (pulling or pushing), with the aim of introducing welding defects. Welds were also performed without shielding gas.

Equipment

The sensors positioned on the object transform the AE-pulse into an electrical signal. Piezoelectric sensors are mostly used, which can reach up to 1000 V/mm displacement of the surface. Underneath, the sensor has a clay base to protect it against the heat at the surface of the object. The maximum operating temperature of the sensor is one of the most important properties when selecting a sensor.

The AE signals in this experimental work were recorded with 3 different types of sensors: the first type is a WD sensor with a resonance frequency of 450 kHz, the second type is a R50D sensor with a resonance frequency of 500 kHz. The WD sensor has a high bandwidth and is therefore suitable to be used for frequency analysis. The optimal operating frequency response range is between 100 - 900 kHz (see Figure 1).

The R50D sensor (manufacturer: Mistras) is a differential sensor, which is made to isolate the sensing terminals electrically from the cavity. These characteristics make the sensor suitable for applications with high electrical background noises. The frequency response range normally lies around 100 - 700 kHz. In this work, a digital filter configuration is used which ranges from 400 to 800 kHz. The difference of the upper limit makes sure that all the signals are obtained, measured by the sensor (see Figure 2).

Besides these sensors, also a microphone has been used (see Figure 3).

All specifications are mentioned in Table 1.

Table 1: Specifications of the sensors used in the experiments

Sensor	Operating range	Peak frequency	Filter in pre-amplifier	Sampling frequency
Microphone	0,04 - 20 kHz	6 kHz	None	48 kHz
R6I sensor	40 - 100 kHz	98 kHz	None (internal pre-amplifier of 40dB)	2 MHz
WD sensor	125 - 1000 kHz	278 kHz	30 - 700 kHz	2 MHz

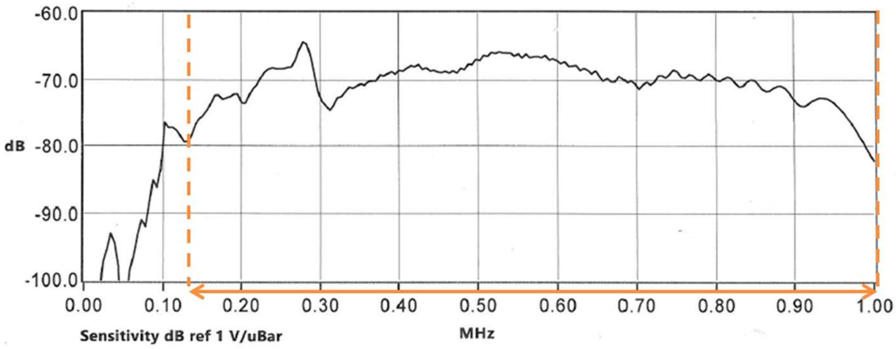


Figure 1: Wideband Differential (WD) sensor

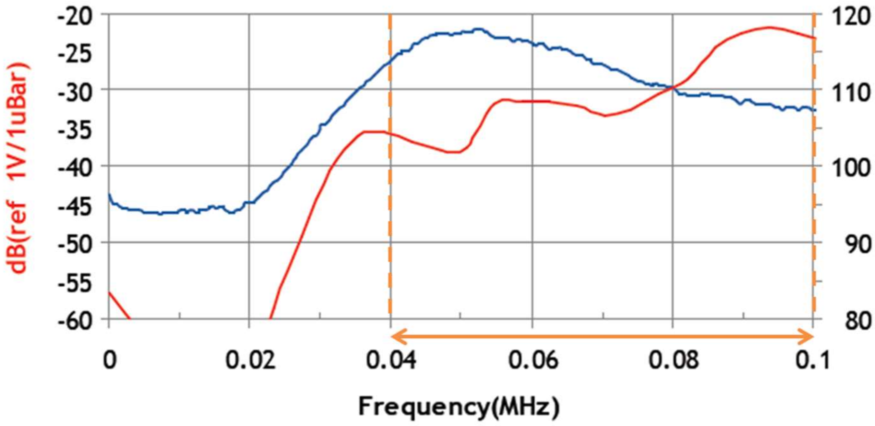


Figure 2: R6I sensor (low freq)

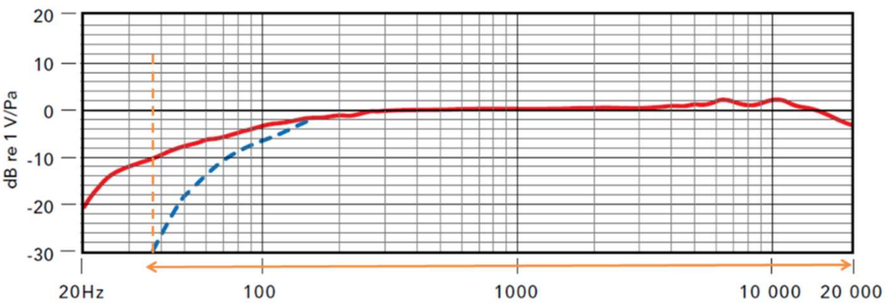


Figure 3: Microphone

The sensor is connected to the material or equipment using a couplant. This couplant needs to provide a good acoustic path between them. Moreover, it needs to be a fluid, since fluids will not transmit shear waves and needs to have chemical compatibility.

The welding robot used for the experimental work is a KUKA robot (type KR 15/2; see Figure 4). The robot was used to weld onto a steel plate that was placed on a working table. The sensors for recording the AE signals were clamped at the corner of the plate, in order to avoid high temperatures at the sensor location. This is shown in Figure 5 and Figure 6.

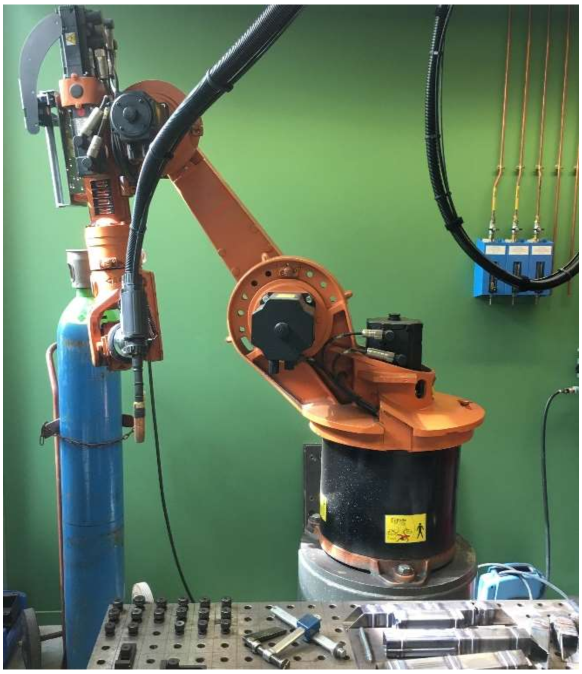


Figure 4: Robot used to create the welds @ BWI

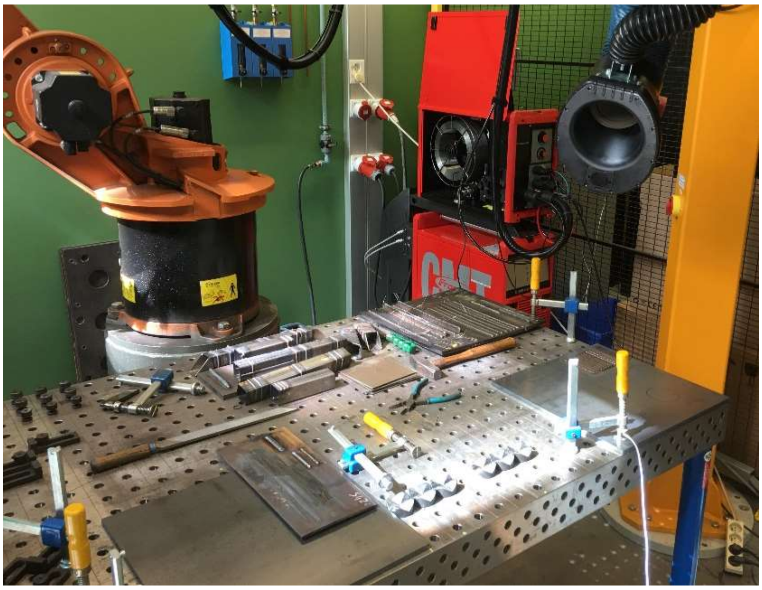


Figure 5: Set-up for arc welding @ BWI

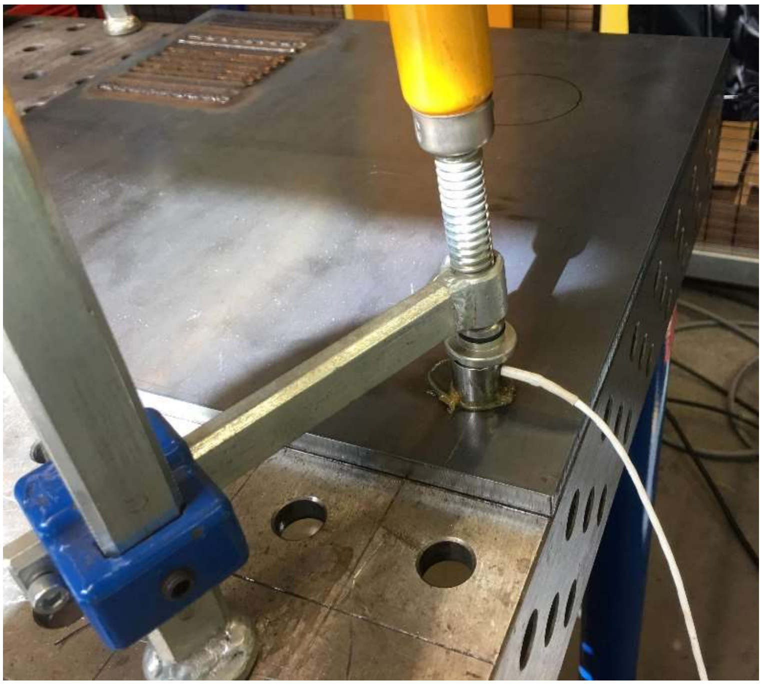


Figure 6: Placement of the sensor (Source: BWI)

Results for bead-on-plate welds

Bead-on-plate welds were realised using different welding modes; more specific the short circuit, spray arc, globular and pulsed welding mode. For each of these 4 welding modes, different parameter settings have been used in order to influence the joint properties (see Table 2). The used material was the carbon steel S235. The test set-up is shown in Figure 7.

Table 2: Overview of the parameter settings used for the bead-on-plate welds

Test series No.	Standard welding parameters	Too large stick-out (10 ⇢ 25 mm)	Too low welding speed (0,3 ⇢ 0,1 m/min)	Too high welding speed (0,3 ⇢ 0,75 m/min)	Change of torch angle and direction (80° pulling ⇢ 25° pushing)
Short circuit	R18	R19	R20	R21	R22
Globular	R23	R24	R25	R26	R27
Spray	R33	R34	R35	R36	R37
Pulsed	R28	R29	R30	R31	R32

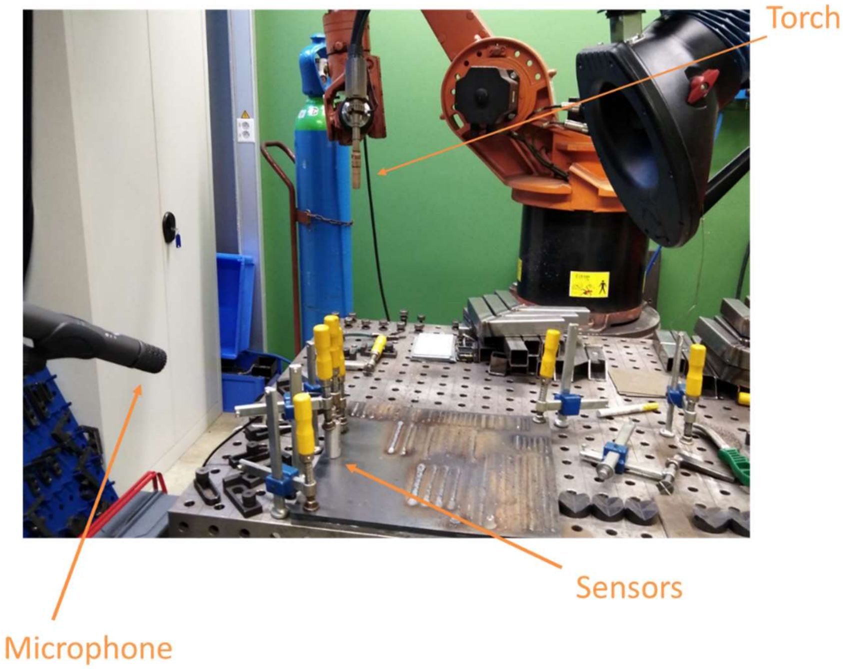


Figure 7: Test set-up used for the bead-on-plate welds (Source : BWI)

For all welds, the height, the width and the penetration were measured based on metallographic examinations. Also the presence of porosities and undercut defects was investigated.

A lower travel speed results in a wider weld, a larger overthickness and a deeper penetration, and this for all arc types. At a higher speed, the opposite effect is observed, with the possible introduction of welding defects such as porosities, especially in spray arc welding and pulsed welding. When increasing the stick-out length of the filler material, the weld becomes slightly narrower and the overthickness is slightly larger. Particularly for spray arc welding, porosities are introduced via these parameter settings and undercut defects are also detected (see Figure 8). An overview of the measured joint properties is summarised in Table 3.

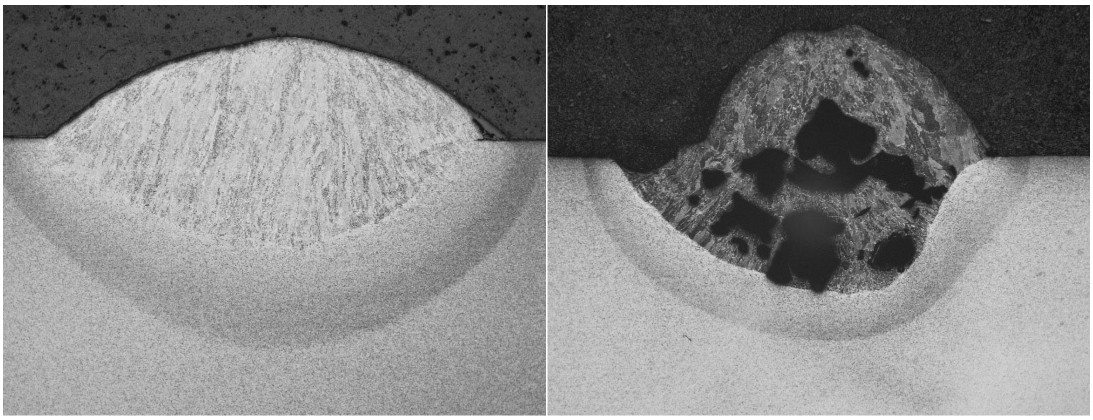


Figure 8 : Left: Cross-section of a weld (reference condition; spray arc welding)
Right: Weld with imperfections (spray arc welding performed with too large stick-out) (Source : BWI)

Table 3: Overview of the joint properties of the bead-on-plate welds

<table>
<tr><th>Transfer mode</th><th>Large stick-out</th><th>Low welding speed</th><th>High welding speed</th><th>Different torch direction</th></tr>
<tr><td>DC short circuit</td><td rowspan="2">No porosities
↗ height
↘ width
↘ penetration</td><td rowspan="4">No porosities
↗ height
↗ width
↗ penetration</td><td rowspan="4">No porosities
↘ height
↘ width
↘ penetration</td><td rowspan="2">No porosities
≈ height
≈ width
≈ penetration</td></tr>
<tr><td>Globular</td></tr>
<tr><td>Spray arc</td><td rowspan="2">Porosities
↗ height
↗ width
↗ penetration</td><td rowspan="2">No porosities
↘ height
↗ width
↘ penetration</td></tr>
<tr><td>Pulsed</td></tr>
</table>

<u>Bead-on-plate welds : Results AI/ML models</u>

Artificial intelligence has in recent years revolutionised processes in various industries where automation was previously not considered possible. These processes were generally considered simple for a human but impossible for a computer. An example of this is detecting the objects in a photo: a computer today can recognize thousands of different objects, such as the dog in your vacation photo.

Automating these processes is made possible by systems that learn from examples. A computer learns to recognise objects in a photo by having many photos with known objects processed by the system. Internally, a model will detect patterns and will link these patterns to certain objects. Learning patterns from examples is called a data-driven system.

In the past, people worked differently: an expert had to repeatedly define the pattern for each object. It is evident that this process was very labour-intensive and in many cases delivered worse results than the new, data-driven learning methods.

This data-driven method was used to determine the weld quality based on the noise produced by a weld, and to recognize and classify defects that occur. To detect patterns in the sound samples, the sound is converted to a spectrogram (see Figure 9). In this spectrogram, the model learns to recognise patterns that determine the quality of the weld, the arc type and possibly the weld defects. A spectrogram is a representation of the sounds, where time is plotted on the horizontal axis and the frequency on the vertical axis. The amount of energy at a given time instant in a given frequency band is represented by the coloration in the diagram.

Due to the two-dimensional nature of a spectrogram, it can be represented in the same way as a traditional photo, with a matrix of pixels. This makes it possible to use AI models developed for analysing photos to analyse the sounds recorded during welding. The models recognise patterns in the 2-dimensional matrix in a similar way.

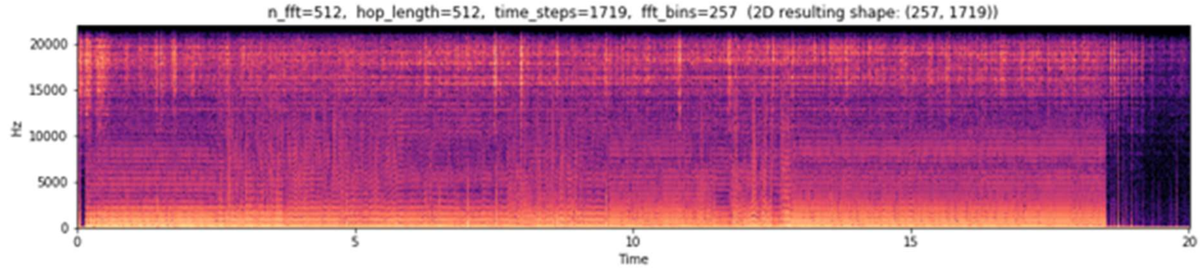


Figure 9: Spectrogram of a sound fragment (Source : OQTON)

Self-learning models based on artificial intelligence were used to recognize and predict the used process conditions (arc type and the welding parameters, which may or may not give rise to welding defects). The predicted welding conditions based on the acoustic emission measurements were compared with the effectively used conditions in practice. Models used during the tests thereby achieved an accuracy of 85%. The table shown in Figure 10 shows the accuracy of the predictions of the used welding conditions. The X axis shows the predictions, the Y axis shows the effectively used condition during welding. The diagonal from top left to bottom right represents the fragments where the prediction corresponds to the actually used mode. The other fragments received a wrong prediction. Some of the used welding conditions effectively gave rise to welding defects, determined by the metallographic examination of the welded joints. Welding defects that occur through the use of these welding conditions can therefore be detected by the models.

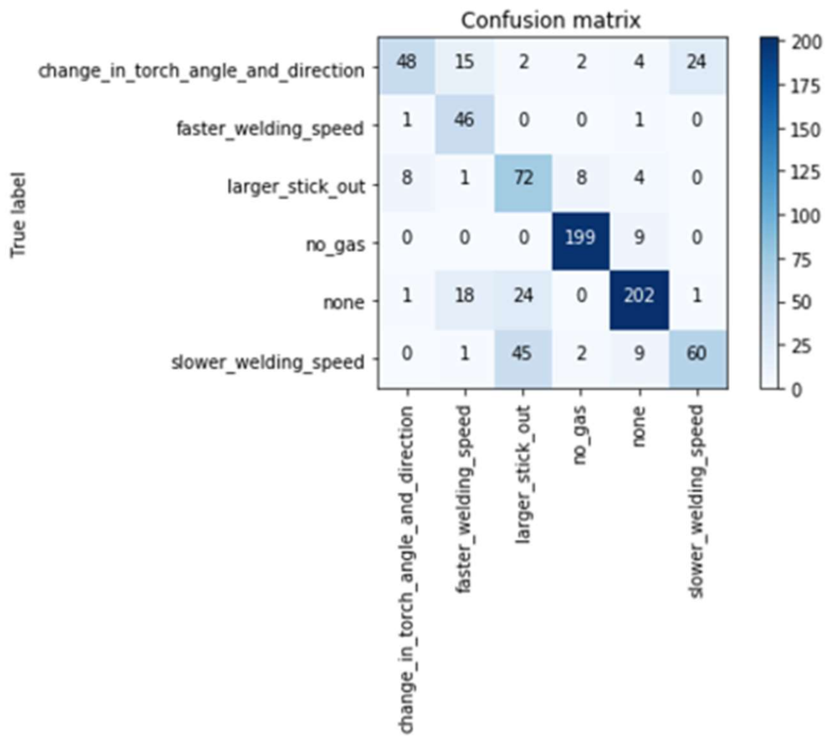


Figure 10: Prediction of the used welding conditions based on the AI model (Source : OQTON)

Results fillet welds

Similar as for the bead-on-plate welds, also fillet welds in the steel S235 were produced using different parameter conditions in order to create welds with good quality and welds with defects. The test set-up is shown in Figure 11. Table 4 details the parameter settings that have been used.

The fillet welds were executed with 6 different parameter settings. When using the parameter settings FWa4-STA, FWa4-HA and FWa4-LA, welds were executed with standard parameter settings, and settings with high and low values of current and voltage, respectively. When using the parameter settings FWa4-26, FWa4-36 and FWa4-46, the travel speed of the torch was varied at respectively 26, 36 and 46 cm/min. The intention was to create welds with a throat thickness (a-value) of 4 mm. As can be seen in Table 7, not all welds executed with the standard settings fulfilled this requirement.

Using these 6 standard parameter settings, welding defects were introduced by for example varying the torch position (categories 2, 3, 5, 6 and 8), or by using even lower values of the voltage and current (categories 4 and 7). The welds performed with standard settings were repeated 3 times (category 1). The welds containing weld defects were repeated twice. In total, approximately 20 minutes of sound was recorded during these welding trials.

Table 4 : Overview of the parameter settings used for the fillet welds

			Cat. 1	**Cat. 2**	**Cat. 3**	**Cat. 4**	**Cat. 5**	**Cat. 6**	**Cat. 7**	**Cat. 8**
	Test series No.		**Standard parameter set**	**Hor. Pos + 4 mm**	**Vert. pos. + 4 mm**	**Lower current**	**Vert. Pos + 2 mm + 30-35°**	**Forehand welding (45° pushing)**	**Extremely low current**	**Hor. Pos + 2 mm + 30-35° + lower current**
FWa4-STA	Standard parameter settings		1 / 2 / 3	4 / 7	5 / 8	-	6 / 9	-	-	-
FWa4-HA	Standard parameter settings with high current		1 / 2 / 3	4 / 7	5 / 8	-	6 / 9	-	-	-
FWa4-LA	Standard parameter settings with low current		1 / 2 / 3	4 / 7	5 / 8	-	6 / 9	-	-	-
FWa4-36	Standard parameter settings with travel speed = 36 cm/min		1 / 2 / 3	4 / 10	5 / 11	6	7 / 15	8 / 16	13	14
FWa4-26	Standard parameter settings with travel speed = 26 cm/min		1 / 2 / 3	4 / 10	5 / 11	6	7 / 15	8 / 16	13	14
FWa4-46	Standard parameter settings with travel speed = 46 cm/min		1 / 2 / 3	4 / 10	5 / 11	6	7 / 15	8 / 16	13	14

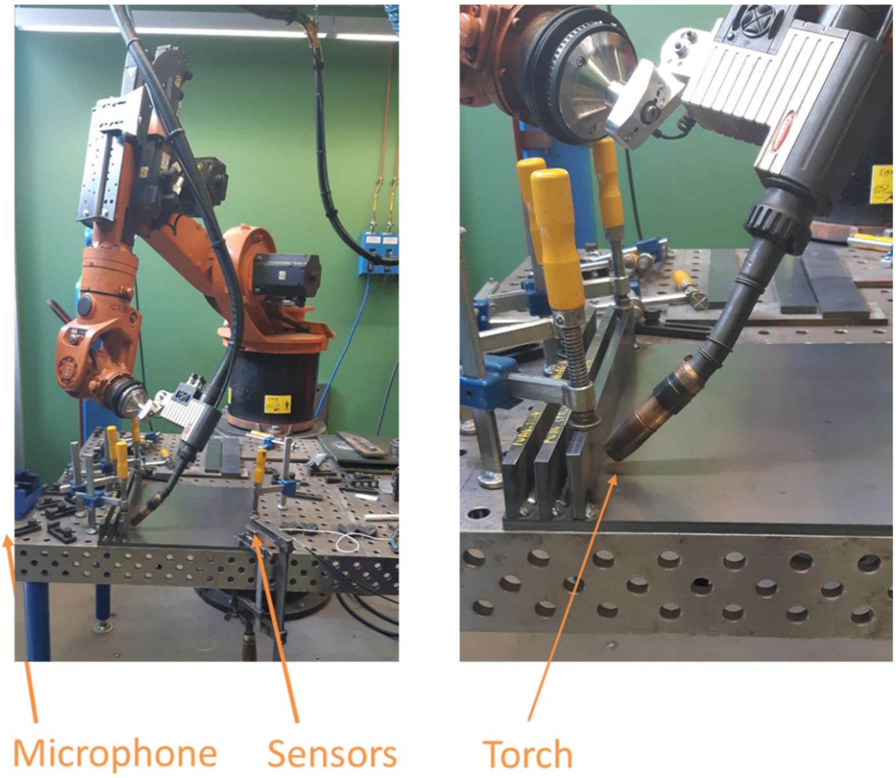


Figure 11: Test set-up used for fillet welds (Source : BWI)

For the assessment of the weld quality, the standard ISO 5817 [1] has been used. This International standard provides quality levels for imperfections in fusion-welded joints in steels.

ISO 5817 is generally used within a quality system for the production of satisfactory welded joints. It provides three sets of dimensional values, from which a selection can be made for a particular application. The necessary quality level in each case should be defined by the application standard or the responsible designer in conjunction with the manufacturer, user and/or other parties concerned.

ISO 5817 covers the limits for weld imperfections for quality levels as stringent (B), intermediate (C) and moderate (D) (see Table 5). The quality levels given in this international standard are intended to provide basic reference data and are not specifically related to any particular application. They refer to the types of welded joints in a fabrication and not to the complete product or component itself.

Table 5: Quality levels for weld imperfections in ISO 5817

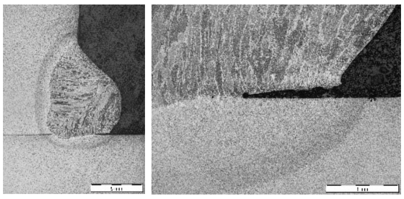
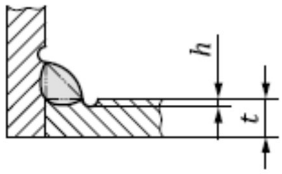
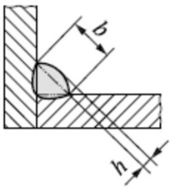
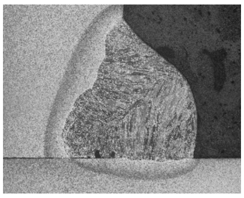
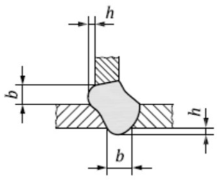
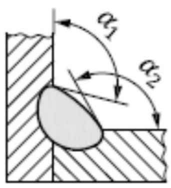
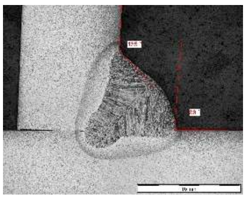
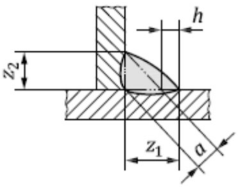
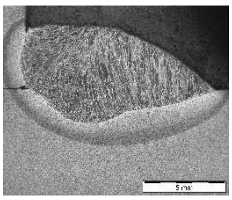
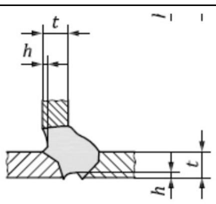
Level symbol	Quality level
D	Moderate
C	Intermediate
B	Stringent

In ISO 5817, 26 imperfections are classified, like cracks, porosities and cavities, solid inclusions, lack of fusion and incomplete penetration, shape imperfections and multiple imperfections. The considered

[1] : ISO 5817:2014 : Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections

imperfections based on ISO 5817 are specified in Table 6, together with their imperfection designation number defined in ISO 5817. The other defects mentioned in ISO 5817 were not relevant or not found in the welds. For assessment of the weld quality, level C was utilised.

Table 6 : Limits for imperfections (according to ISO 5817)

Weld imperfection	Description	Example	Quality criteria (level C)
Lack of fusion (1.5)	Incomplete fusion		Not permitted
Undercut (1.7)		Defect not found	h ≤ 0,1×t, but max. 0,5 mm
Excessive convexity (1.10)			h ≤ 1 mm + 0,15×b, but max. 4 mm
Excess penetration (1.11)		Defect not found	h ≤ 1 mm + 1,0×b, but max. 5 mm
Incorrect weld toe (1.12)			α ≥ 100°
Excessive asymmetry (1.16)			h ≤ 2 mm + 0,15×a
Root concavity (1.17)		Defect not found	h ≤ 0,1×t, but max. 1 mm

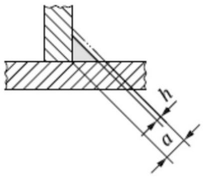
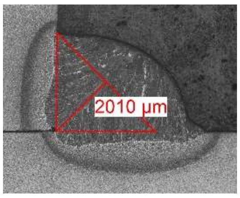
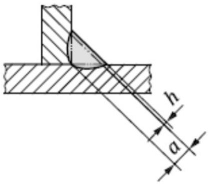
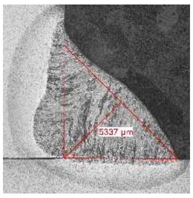
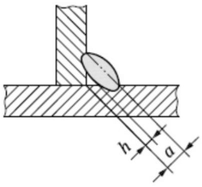
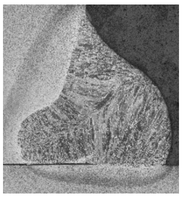
Weld imperfection	**Description**	**Example**	**Quality criteria (level C)**
Insufficient throat thickness (1.20)			h ≤ 0,3 mm + 0,1×a, but max. 1 mm (a = 4 mm)
Excessive throat thickness (1.21)			h ≤ 1 mm + 0,2×a, but max. 4 mm (a = 4 mm)
Gas pores (2.3)		Defect not found	See ISO 5817
Lack of penetration (2.13)			Not permitted

Table 7 shows the results of the quality assessment of all welds. Each weld has been checked using the criteria mentioned in Table 6. If a weld doesn’t fulfil at least one of the criteria, the weld is not acceptable according ISO 5817 (these welds are indicated in red in the first column of Table 6). These results were used as input for the AI-models, as discussed below. Examples of welds fulfilling the criteria of ISO 5817 are shown in Figure 12 and Figure 13. Examples of welds with defects are shown in Figure 14 and Figure 15.

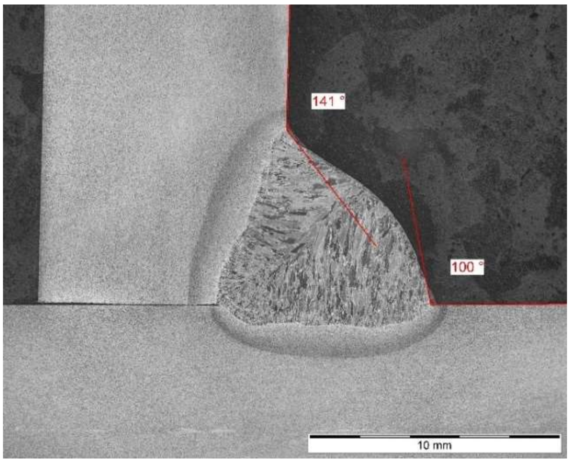


Figure 12: Cross section of weld FWa4-STA1

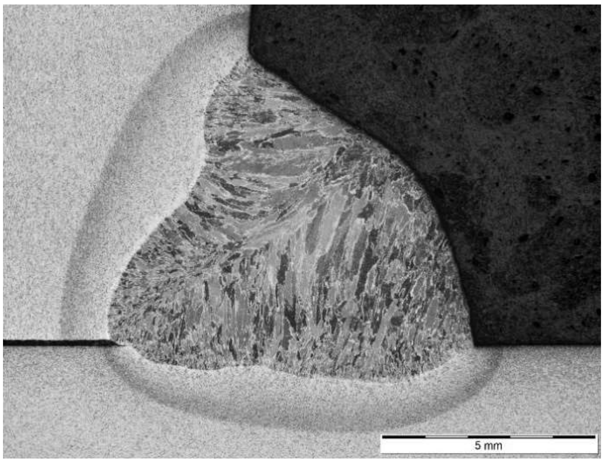


Figure 13: Cross section of weld FWa4-36-1

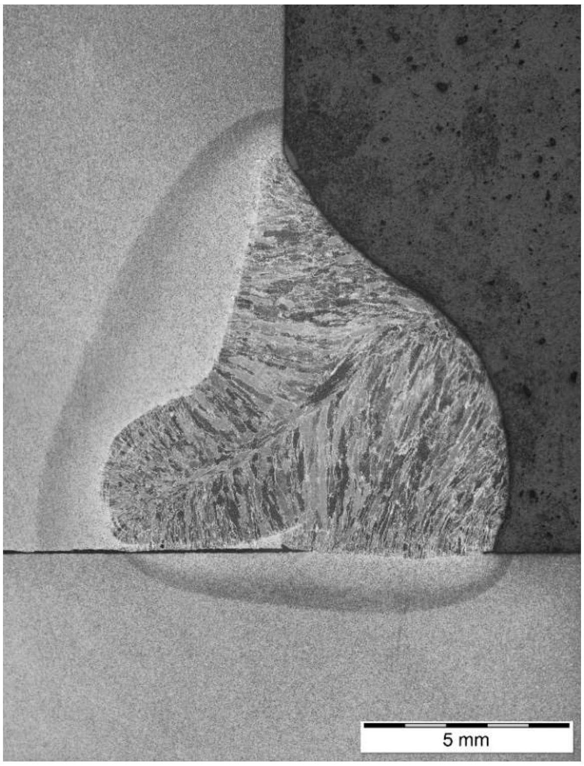


Figure 14: Cross section of weld FWa4-26-7

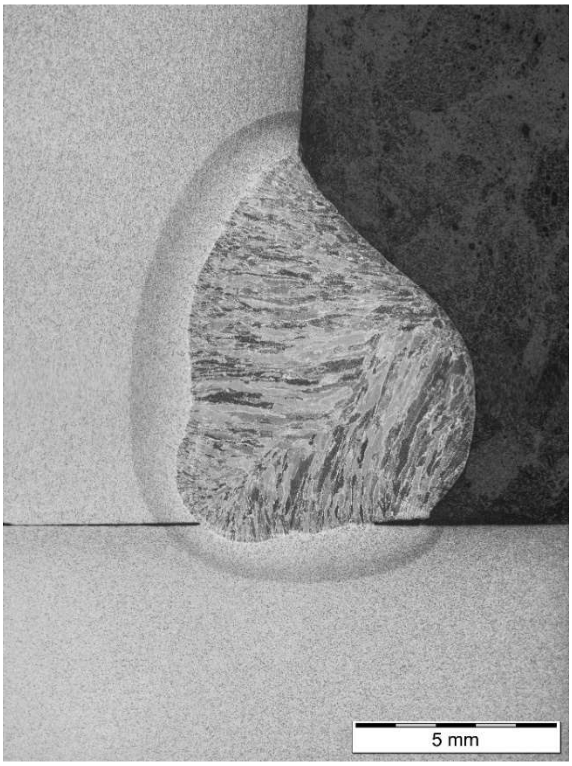


Figure 15: Cross section of weld FWa4-HA-5

Table 7: Overview of the quality of the fillets welds

Weld No.		Weld quality										
		1.5. Lack of fusion	1.7. Undercut	1.10. Excessive convexity	1.11. Excess penetration	1.12. Incorrect weld toe	1.16. Excessive assymmetry	1.17. Root concavity	1.20. Insufficient throat thickness	1.21. Excessive throat thickness	2.3. Gas pore	2.13. Lack of penetration
FWa4-STA-1		OK	OK	OK	OK	Ok	OK	OK	OK	OK	OK	OK
FWa4-STA-4		OK	OK	OK	OK	OK	NOK	OK	NOK	NOK	OK	OK
FWa4-STA-5		NOK	OK	NOK	OK	NOK	NOK	OK	NOK	NOK	OK	OK
FWa4-STA-6		NOK	OK	NOK	OK	NOK	NOK	OK	NOK	NOK	OK	NOK
FWa4-HA-1		OK	OK	OK	OK	NOK	OK	OK	OK	OK	OK	OK
FWa4-HA-4		NOK	OK	OK	OK	NOK	NOK	OK	NOK	NOK	OK	OK
FWa4-HA-5		NOK	OK	NOK	OK	NOK	NOK	OK	NOK	NOK	OK	OK
FWa4-HA-6		NOK	OK	OK	OK	NOK	NOK	OK	NOK	NOK	Ok	OK
FWa4-LA-1		OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
FWa4-LA-4		NOK	OK	NOK	OK	NOK	NOK	OK	NOK	NOK	OK	OK
FWa4-LA-5		NOK	OK	NOK	OK	NOK	NOK	OK	NOK	NOK	OK	OK
FWa4-LA-6		NOK	OK	NOK	OK	NOK	NOK	OK	NOK	NOK	OK	NOK
FWa4-36-1		OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
FWa4-36-4		NOK	OK	OK	OK	NOK	NOK	OK	NOK	NOK	OK	NOK
FWa4-36-5		NOK	OK	NOK	OK	NOK	NOK	OK	NOK	NOK	OK	NOK
FWa4-36-6		OK	OK	OK	OK	OK	OK	OK	NOK	NOK	OK	OK
FWa4-36-7		NOK	OK	OK	OK	OK	NOK	OK	NOK	NOK	OK	NOK
FWa4-36-8		OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
FWa4-36-13		OK	OK	OK	OK	OK	OK	OK	NOK	NOK	OK	OK
FWa4-36-14		NOK	OK	NOK	OK	NOK	NOK	OK	NOK	nOK	OK	NOK
FWa4-26-1		OK	OK	OK	OK	NOK	OK	OK	OK	OK	OK	OK
FWa4-26-4		NOK	OK	OK	OK	NOK	NOK	OK	NOK	NOK	OK	NOK
FWa4-26-5		NOK	OK	OK	OK	NOK	NOK	OK	OK	NOK	OK	NOK
FWa4-26-6		OK	OK	OK	OK	NOK	OK	OK	NOK	NOK	OK	OK
FWa4-26-7		NOK	OK	OK	OK	NOK	NOK	OK	NOK	NOK	OK	NOK
FWa4-26-8		OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	NOK
FWa4-26-13		OK	OK	OK	OK	NOK	OK	OK	NOK	NOK	OK	OK
FWa4-26-14		NOK	OK	OK	OK	NOK	NOK	OK	NOK	NOK	OK	NOK
FWa4-46-1		OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
FWa4-46-4		NOK	OK	NOK	OK	NOK	NOK	OK	OK	NOK	OK	NOK
FWa4-46-5		OK	OK	NOK	OK	NOK	NOK	OK	NOK	NOK	OK	OK
FWa4-46-6		OK	OK	OK	OK	NOK	OK	OK	NOK	NOK	OK	OK
FWa4-46-7		NOK	OK	NOK	OK	NOK	NOK	OK	NOK	NOK	OK	OK
FWa4-46-8		OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
FWa4-46-13		OK	OK	OK	OK	OK	OK	OK	NOK	NOK	OK	OK
FWa4-46-14		NOK	OK	OK	OK	NOK	NOK	OK	NOk	NOK	OK	NOK

Fillet welds : Results AI/ML models

For monitoring of fillet welds, the same model architecture was used as for the bead-on-plate experiments. The models had to be retrained with the new data that was collected during the experiments. This is an advantage of the data-driven approach.

What differs from the bead-on-plate welding experiments are the labels. For the bead-on-plate welds, the welding parameters that can cause a weld imperfection were predicted. For the fillet welds, the different welding imperfections were directly predicted.

The model also used the current and voltage measurements that were generated during the welding process. For these measurements, the model architecture didn't have to be changed, because the measurements are presented in the same format as the sound waves.

Data exploration of the current and voltage measurements

The current and voltage measurements were explored and inspected if some patterns in those signals can be detected that can be correlated to the weld imperfections. If Figure 16 and Figure 17 are compared, it is concluded that the voltage wave of the high quality weld has less noise.

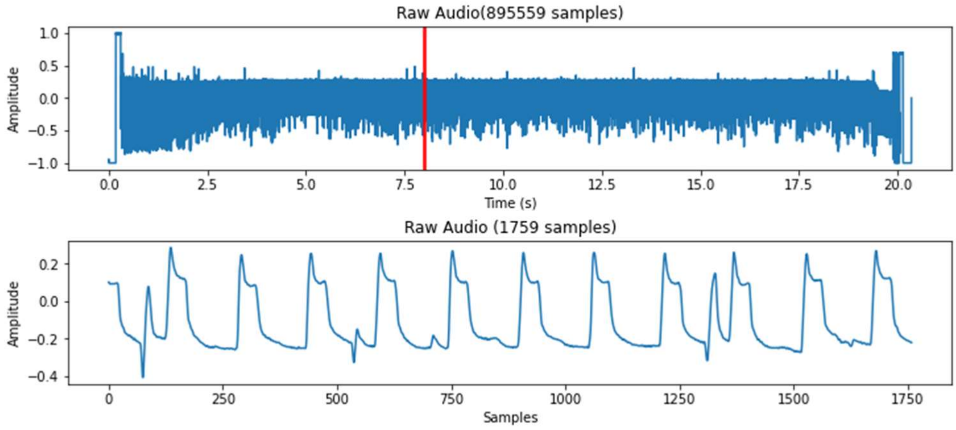


Figure 16 : Measured voltage signal of a high quality weld (FWa4-STA-1)

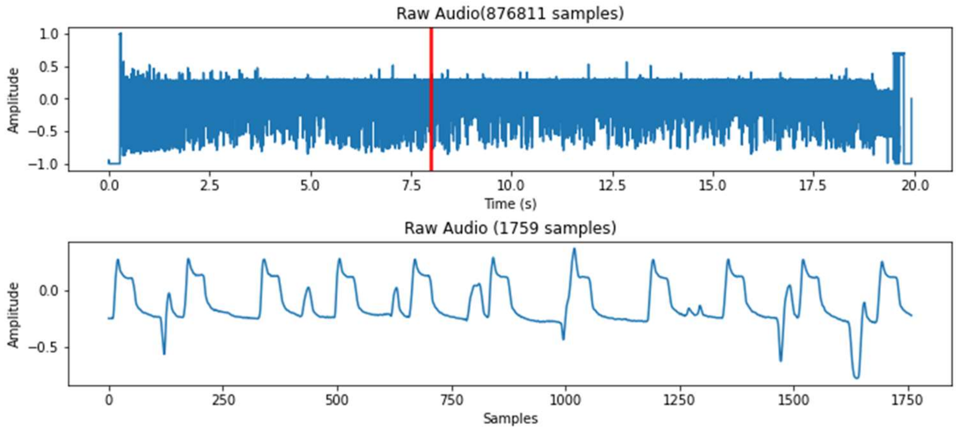


Figure 17: Measured voltage signal of a low quality weld (FWa4-STA-6) (Source : OQTON)

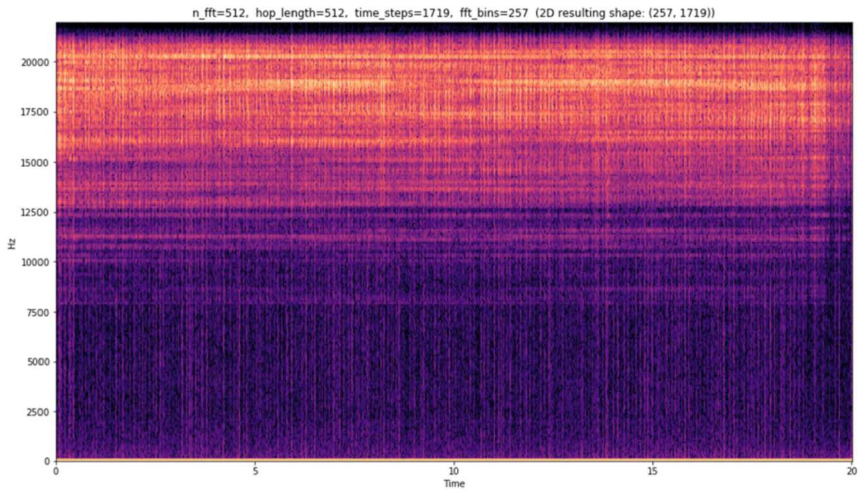


Figure 18 : Spectogram of a sound fragment (Source : OQTON)

Experiments

It was investigated to what extent deviations in the acoustic spectrum can be linked to the type of weld imperfection, defined according to ISO 5817. In other words, can the observed acoustic spectrum make a statement about the type of weld imperfection present in the weld and where in the weld this imperfection occurs.

Furthermore, based on the relevant acoustic spectra, it was also investigated whether a weld imperfection is acceptable or not, according to EN ISO 5817 (quality level C). For the results, see Table 8.

The information in the voltage, current and sound spectra are also compared by training a model on each of these modalities. The accuracy of these models are used as a metric for the information that is present and extractable by the model from each of these signals.

In this way, it is not only possible to detect weld imperfections in real time, but also immediately assign an appreciation to them, based on the transmitted acoustic spectrum. If the welding imperfection is not acceptable, it is possible in continuous installations (e.g. robot installations) to let the system respond adaptively based on this data, by adjusting the welding parameters.

Table 8: Prediction of the presence of the welding defects based on the AI model (Source : OQTON)

	Microphone	Tranducer 1	Tranducer 2	Voltage	Current
Overall quality	79.6%	76.3%	77.8%	75.1%	77.4%
Lack of fusion	52.8%	46.3%	62.4%	52.9%	51.1%
Lack of penetration	74.5%	74.1%	74.2%	67.4%	66.0%
Insufficient throat thickness	74.8%	70.0%	75.1%	70.4%	69.9%
Incorrect weld toe	65.7%	64.5%	66.4%	68.4%	68.8%
Excessive convexity	68.0%	67.2%	67.1%	68.3%	68.1%
Excessive asymmetry	64.7%	54.9%	67.3%	63.6%	63.0%
MEAN	68.6%	64.8%	70.4%	66.5%	66.3%

We can conclude from this table that we can extract more information from the auditive signals than from the process parameters. This is a great validation that the addition of sound monitoring can enhance real time monitoring of the weld quality

It has to be noted that these results were obtained based on a limited amount of data (20 min's of sound). The performance of the model will be increased if more measurements can be performed.

Conclusions

A promising quality assurance method is acoustic emission monitoring. This method is a non-destructive testing technique, which can be used during the production process, and offers the possibility to test the quality of all welds. Acoustic emission monitoring as a non-destructive and comparative test method has been developed based on the fact that every material exhibits natural vibrations and that machines and processes emit sounds.

The Belgian Welding Institute is conducting a research project to investigate the possibilities of this technique and to test it in practice. The aim is to evaluate this technology for different welding processes, including robotic arc welding. Weld tests were performed with different process conditions to produce welds with different quality levels. Data-driven models are used to predict the weld quality and the possible defects based on the sounds recorded during welding.

Artificial intelligence models were used to recognize and predict the process conditions used for realising bead-on-plate welds (arc type and the used welding parameters, which may or may not give rise to weld imperfections). These models achieved an accuracy of 85%.

For robotic MIG/MAG welding of fillet welds, the acoustic emission measurements were linked to the type of weld imperfections, defined according to ISO 5817. The observed acoustic spectrum is able to make a statement about the type of weld imperfection present in the weld and where in the weld this imperfection occurs. With the AI models, it is also possible to predict whether a certain weld imperfection is acceptable or not according to EN ISO 5817 (quality level C).

Further investigations - Call for participation in further research

The experiments were performed in a lab environment with a minimal amount of data. More data is required to improve the accuracy of these types of data-driven models, but the experiment already indicates that it is possible to extract information from the noise produced during welding. In a next step, more data will be collected and the operation of the model will also be validated in a factory environment, where ambient noise will be an important disturbance factor.

It is also being investigated whether combining different sensors can yield a better analysis. The architecture of the used AI models makes it easy to combine signals from different sensors with different representations.

Interested companies can always contact the Belgian Welding Institute for more information about this. Contact: Koen Faes (E-mail: Koen.Faes@bil-ibs.be - Tel.: +32 (0) 9 292 14 03).