Društvo za tehniku zavarivanja Slavonski Brod

12. Međunarodno znanstveno-stručno savjetovanje SBZ 2023

„STROJARSKE TEHNOLOGIJE U IZRADI ZAVARENIH KONSTRUKCIJA I PROIZVODA, SBZ 2023."
Slavonski Brod, 26. i 27. 04. 2023. i Požega 28. 04. 2023.

DEVELOPMENT OF A MODEL FOR ASSESSING THE QUALITY OF WELDED JOINTS

I. Dunđer[1,*], Z. Tonković[1], P. Konjatić[1], D. Marić[1], A. Konjatić[2], M. Dunđer[1]

[1]Mechanical Engineering Faculty in Slavonski Brod, University of Slavonski Brod, Croatia
[2]Industrial and Trade School Slavonski Brod, Croatia

[*] Corresponding Author. E-mail: idunder@unisb.hr

Abstract

In this paper, a model was developed to evaluate the quality of welded joint. To improve the welding process, the influence of the welding process parameters on the achievement of satisfactory quality of the welded layer was studied. Machine learning tools were used to test the quality of the welded joint. The material used for test sample is steel 16Mo3 which is commonly used for steam boiler construction. MAG-CMT welding technology was used to make the specimens. In this paper the dynamic characteristics of the welding process parameters were described and monitored with on-line monitoring. The dynamic characteristics were recorded with the WeldAnalyst device and the recorded data were used to create a model that classifies the quality of the welded joint.

Keywords: welding process parameters, quality of the welded joint, quality assessment model, steel for boiler construction

1. Introduction

Numerous factors and parameters have an important impact in the performance of a quality welded joint. The main parameters that are selected before the actual welding process are: welding voltage (*U*), welding current strength (*I*), welding speed (*v*), shielding gas flow (l / min) [1]. There is often an error in parameter selection, which causes poor performance of the welded joint. Therefore, the machine learning approach can prove useful for establishing favorable parameters when performing the welding process. Tasks such as machine translation or planning are assumed to be solved by relatively simple algorithms trained on large amounts of data, applying the ability to learn. It follows that artificial intelligence does not originate from a complex formula, but from the frequent application of simple and straightforward algorithms [1-3].

The company "Fronius" patented the CMT process in 2004. Cold metal welding (CMT) is a modified MAG welding process based on the short circuit transfer process. The MAG-CMT process enables

low heat input, and by controlling the transfer of a drop of material into the bath, the occurrence of splashes is prevented [4,5].
There are two main phases of the CMT process, one is the arcing phase, while the other is the short circuit phase. In the first phase, an electric arc is ignited with a constant voltage, which corresponds to high currents, and in this way the additional and basic material is heated. After that, the welding current is reduced and some time is waited to ensure the separation of the droplet in the bath of the welded joint. The second phase is characterized by the short-circuit phase, where the droplet is first separated by reducing the welding voltage. After that, the wire is pulled and the short circuit period is interrupted, where the frequency of the wire can go up to 70Hz. When the tip of the electrode wire comes into contact with the bath, the welding torch servo motor is rotated by the digital control processor. During welding, the current drops to almost zero and thus avoids the formation of spatters. [6]. The welding parameters that have a significant impact on the MAG-CMT welding process are: welding voltage (*U*), welding current strength (*I*), gas flow rate (f_g), welding wire speed, welding speed, arc length correction (*ALC*), dynamic control (*DC*), droplet separation frequency (f_{drop}) and distance of contact conductor from basic material (*l*) [1-3]. One of the main problems faced by the welding process is difficult quality monitoring. Also, there is always a chance that the welder will make mistakes while welding. However, machine learning techniques are used in various welding processes, which has led to a significant increase in their efficiency and accuracy. Problems such as quality control, welder skill requirements, time consumption, etc., are solved using machine learning [5,6].

2. Experimental procedure

To produce test samples, the MAG CMT process of welding nickel alloy to the base material of the test sample was performed. Nickel alloys during welding usually result in a very high heat affected zone (HAZ), large deformations and residual stresses. In order to avoid poor welding performance, it was recommended to use MAG-CMT (Metal Active Gas – Cold Metal Transfer), which allows reducing heat input during welding by applying some variations of welding parameters, but also by controlling the wire flow in the bath.Samples of steel for boiler construction 16Mo3 (W. Nr. 1.5415) were used for the basic material. The samples were removed from the membrane wall and prepared for the experiment. The chemical composition and mechanical properties are presented in tables 1 and 2.The basic material has a ferrite-pearlite structure, where the crystal grain size is 8-9 according to standards (ASTM EE12). According to the HRN EN ISO 15614-7 standard, the samples were prepared for the welding procedure.

Table 1. Chemical composition of the basic material 16Mo3

Steel	C	Mn	Si	N	Cr	Cu	Mo	Ni	P	S
16Mo3	0,12-0,20	0,40-0,90	≤0,35	≤0,012	≤0,30	≤0,30	0,25-0,35	≤0,30	≤0,025	≤0,010

Table 2. Mechanical properties of the basic material 16Mo3

Steel	R_m / N/mm^2	R_{eH} / N/mm^2	*HV10*	*A* / %
16Mo3	440-590	275	130 – 170	22

Thermanit 625 wire with a diameter of 1.2 mm (NiCr22Mo9Nb) was used for additional material. The specified additional material is resistant to the appearance of the heat cracks of the high-temperature corrosion. The chemical composition and mechanical properties of the additional material are presented in tables 3 and 4.

Table 3. Chemical composition of the additional material NiCr22Mo9Nb

Fe	C	Si	Mn	Ni	P	S	Cr	Mo	Co	Ti	Al
max 5	0,03 -0,1	max 0,5	max 0,5	min 58	max 0,02	max 0,015	20 – 23	8 – 10	max 1	max 0,4	max 0,4

Table 4. Mechanical properties of the additional material NiCr22Mo9Nb

R_m / N/mm^2	HB	$R_{p0,2}$ / N/mm^2	*A* / %
760-1050	240	380-415	25-30

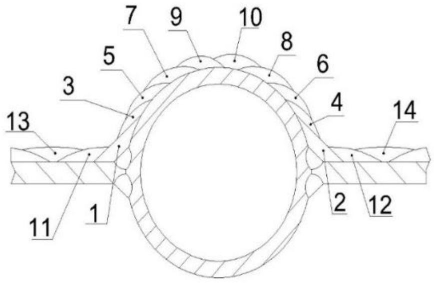
For shielding gas during the MAG-CMT process of nickel alloy welding, CRONIGON Ni10 gas was used. CRONIGON Ni10 is a four-component shield gas. In Table 5 is presented the ratios of gases that were used in the experiment for the mixture gas. The ratio of CO2 to H2 did not change during the test.

Table 5. The mixture of CRONIGON four-component gases

Mixture	H_2 / %	CO_2 / %	Ar / %	He / %
Gas mixture	2	0,5	67,95	30

Before performing the experiment, it is necessary to determine the stability of the arc transfer when cladding nickel alloy. Then it is also necessary to determine the parameters that have the greatest influence on the quality of the welded layer without disturbing the stability of the process, all to achieve a continuous cladded layer. The appearance of the cladded surface of the nickel alloy and the macro sample, as one of the indicators of the quality of stable arc transmission determined by the MAG-CMT process, are shown in Figure 1 a), while the parameters of each pass according to Figure 1 b) are shown in Table 6.

a)



b)

Figure 1. Cladded layer of Ni-alloy: a) Appearance of cladded layer of Ni-alloy with stable CMT-MAG process, b) Sketch of pass execution

Table 6. Parameters for a single pass of nickel alloy cladding

Passages	Gas flow / l/min	Swinging /mm	Angle / °	Welding wire speed / m/min	Overlap of the next track /mm
1	20	9	+35	4,5	-
2	20	9	-35	4,5	-
3	20	10,2	+50	4,5	2
4	20	10,2	-50	4,5	2
5	20	10,2	+35	3,5	2
6	20	10,2	-35	3,5	2
7	20	10,2	+20	3,5	2
8	20	10,2	-20	3,5	2
9	20	10,2	0	3,5	2
10	20	10,2	0	3,5	2
11	20	10,2	+20	4,5	2
12	20	10,2	-20	4,5	2
13	20	10,2	0	3,5	2
14	20	10,2	0	3,5	2

3. Test results

The assessment of the stability of the nickel alloy cladding process and possible errors in the estimation of the measured welding parameters (welding current and welding voltage) includes a comparison of the measured values with reference values. During the welding process, the equipment shown in Figure 2, was used to record on-line monitoring and recording of all welding parameters (surface current strength, welding voltage, wire speed, gas flow) via the WeldAnalyst device. On-line monitoring can detect errors in the welded joint. The frequency of recording parameters is 10870 Hz. In Figure 3 is showed the recorded characteristics of all parameters (surface current strength, surface voltage, wire speed, gas flow). The device is characterized by the fact that it has the possibility of fast data recording and can record up to 1 MHz of data. For connecting different sensors, the device has 12 analog channels, where 4 channels are very fast.

a) b)

c) d)

Figure 2. On-line monitoring of data collection devices: a) WeldAnalyst-S3 device, b) gas flow monitoring sensor, c) wire speed monitoring sensor, d) welding current and voltage monitoring sensor

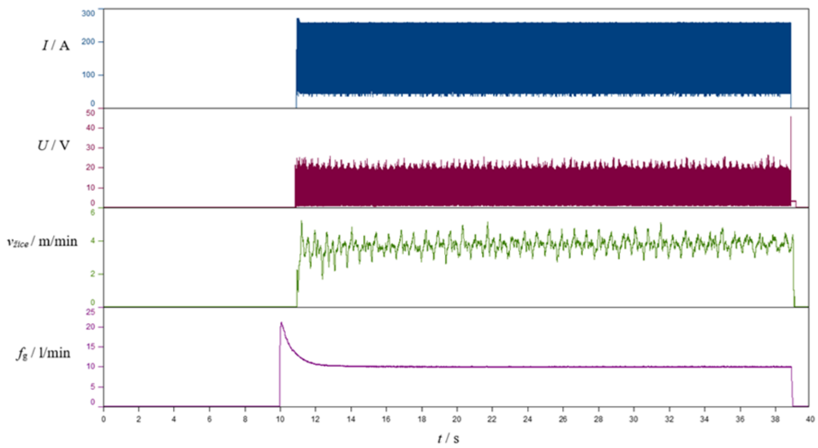
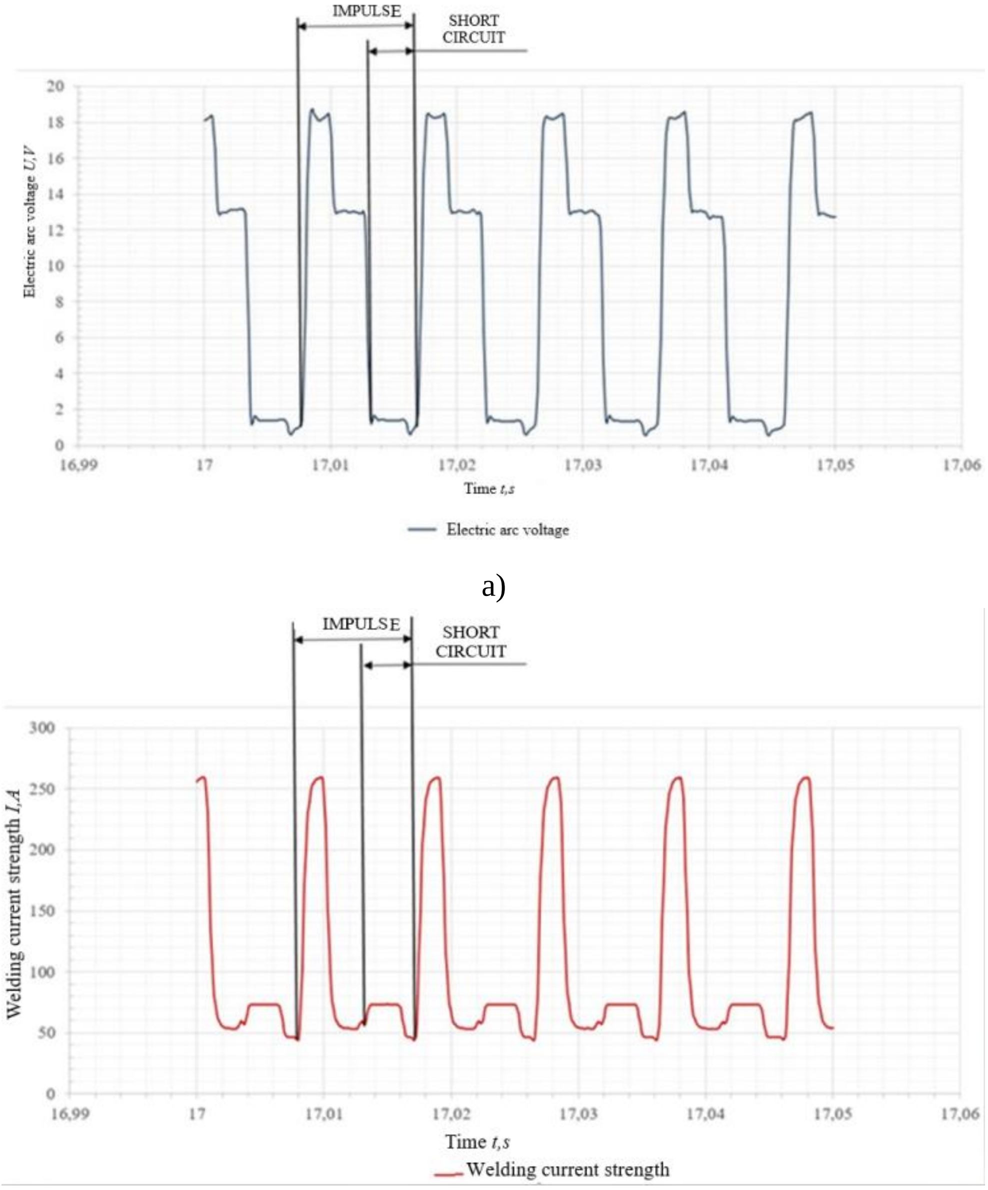


Figure 3. The records of welding parameters using the WeldAnalyst device

The appearance of the dynamic characteristics for the period from 17 to 17.05 seconds with short circuit and impulse duration markers is shown in Figure 4. The segments are only shown in the period from 17 to 17.05 seconds, for the purpose of displaying clearer results and a clearer analysis of the parameters. Passage 10, which is marked in Figure 1b, was the only one analyzed. The results of the welding current and voltage measurements after the recordings are shown in Table 7, where all the characteristic values for the MAG-CMT welding process are shown.

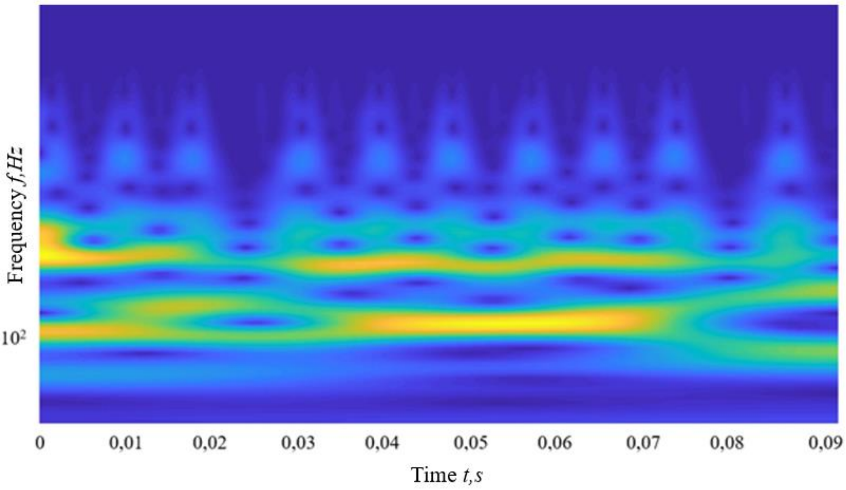


a)

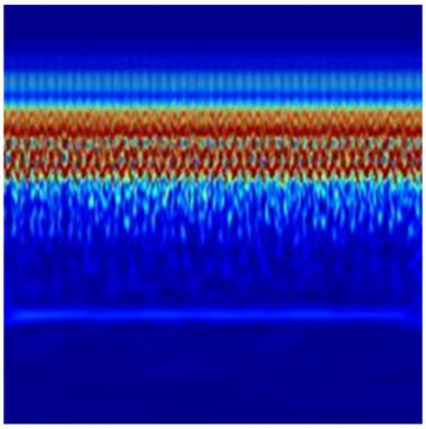
b)

Figure 4. Dynamic characteristics for the period 17-17,05 with impulse and short circuit marks: a) depending on the electric arc voltage, b) depending on the welding current strength

Since the stability assessment and detection of weld defects is not a standardized and well-defined process, and the welding process system is very complex, a weld classification model was created to predict the appearance of welds using different neural networks. Based on the recorded current intensity values, continuous wavelet transform (CWT) and conventional neural networks (CNN) were used. In situations where a small amount of data is not sufficient to train a CNN, it is necessary to use already created neural networks capable of handling large data sets for conceptually similar tasks. For this purpose, GoogleNet and AlexNet native neural networks were used to classify images into 1000 classes. Signals that are converted into scalograms in the time domain by applying continuous wave transformation, which can be good or bad, are shown in Figure 6. The scalograms are recorded as images in RGB format. The specified scalograms are trained, where certain scalograms are randomly taken from the total number of samples in the value of 80% from the created database, and the rest of the scalograms are applied for the validity of the trained model. In Figure 5 a) is showed the image of the scalogram appearance, while Figure 5 b) is showed the image of the scalogram appearance reduced to the size of the recorded image, i.e. to the dimension required for further analysis.



a)



b)

Figure 5. Scalograms: a) scalogram based on all dana, b) reduced scalogram to the size of the recorded image

In Figure 6 is showed the appearance of the dynamic characteristics of the current strength of the welded sample, in which the welded joints are divided into two groups, good and bad, where defects (bad) are determined by visual inspection, and the other case is if the welded joint is a sample with no surface defects (good). In Table 7, with a 30% helium content in the gas mixture, is showed the characteristic values for surfacing parameters.

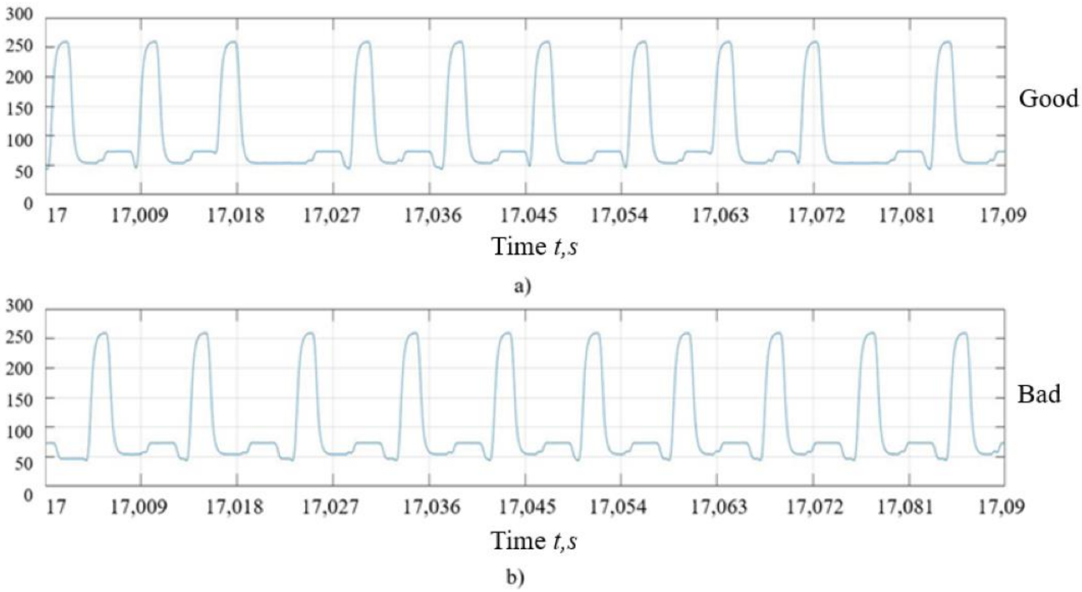


Figure 6. Dynamic characteristics of power strength a) welding current signal in the case of evaluating the welded joint as good, b) welding current signal in the case of evaluating the welded joint as bad

Table 7. Results of welding parameters processing for gas mixture with 30% helium content

Sample mark	Duration of peak currents t_b / ms	Short-circuit current strengths I_n / A	Separation current strengths I_d / A	The duration of the short-circuit current strength t_n/ ms	Short circuit cycle time t_s/ ms	Mean value - pulse duration t / ms	Peak strengths of welding voltage U_b / V	Short circuit standby voltage U_w / V	Short circuit voltage U_n / V	Short-circuit standby current strengths I_w / A	Peak strengths of welding currents I_b / A
1	1,84	73,14	42,70	2,30	4,05	13,89	18,89	13,07	1,34	53,57	259,70
2	1,93	73,20	44,10	2,48	4,51	10,86	18,62	12,55	1,47	53,72	259,80
3	1,84	73,72	44,70	1,47	2,85	9,20	18,28	13,16	1,66	54,09	260,20
4	1,84	73,20	44,00	2,12	3,86	10,86	18,41	13,24	1,56	53,55	259,6

Using the GoogLeNet model, a model with 75% verification accuracy was created. To improve the model, AlexNet was used to verify the values with 100% accuracy. In Figure 7 is showed the signal

that was classified using the model created in Matlab software into two created groups, good and bad, which is shown in Figure 8.
By classifying the data obtained by the online system from the graph in Figure 9, the helium content is 30%, the gas flow variation (10, 20, 30 l/min), the electric arc correction (0, 30%). Those samples that have an arc correction parameter of 30% (1,3,4) are classified as good, while the only sample 2, which has an arc correction parameter of 0%, is classified as bad, with an increase in the value of the parameter gas flow at 30 l/min.

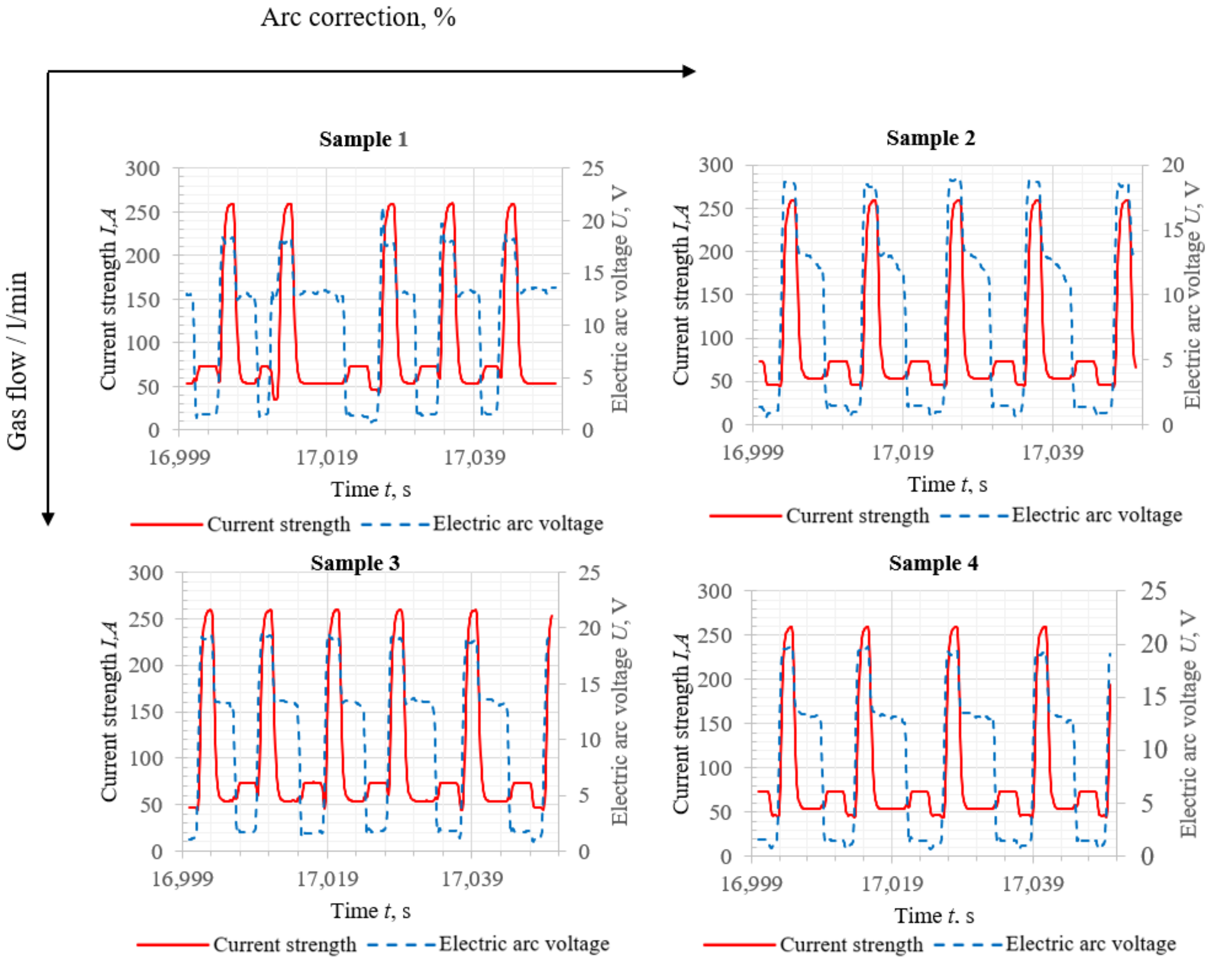


Figure 7. Change in current strength and welding voltage of nickel alloy in the time period from 17 to 17.05 seconds during the welding process with a gas mixture with 30% helium

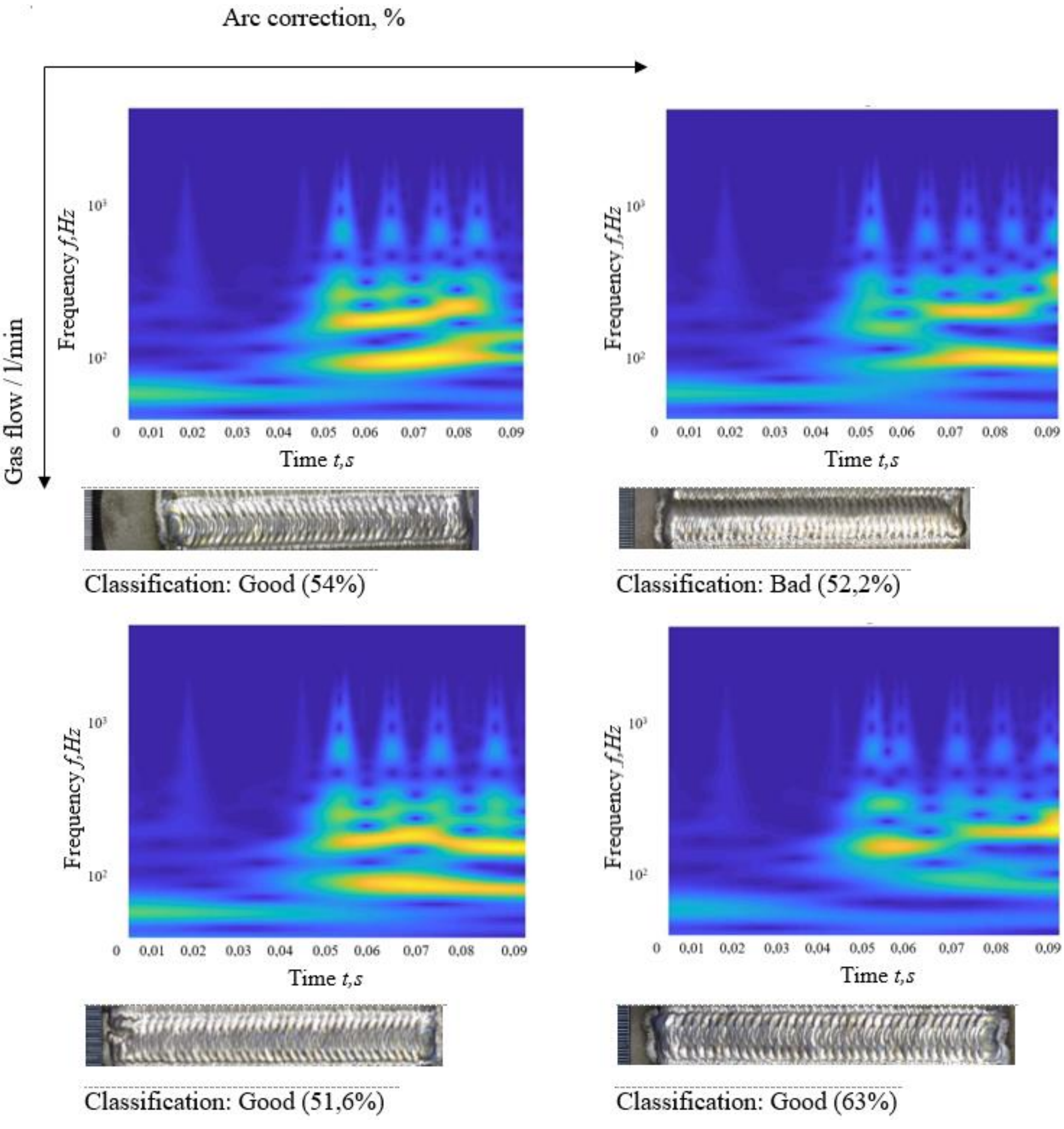


Figure 8. Spectrogram of the welding current strength at a helium content of 30%

4. Conclusion

In this paper is described how the proportion of helium in the shielding gas mixture affects the width, height and angle between individual passes of the welded layer as it increases. ALC arc height correction and gas flow change also affect the mechanical, geometrical properties when welding nickel alloy with the MAG-CMT process. Increasing the percentage from 0% to 30% ALC of the arc correction also affects the increase in the value of the geometric features (height of the cladded layer and the angle between the passes). Also in the observed area when the ALC arc correction value is 0%, the hardness value also decreases.The gas flow change from 10 l/min to 30 l/min also affects on increasing geometrical properties (height and width of the cladding layer). In the observed area, hardness values decrease with decreasing gas flow values. Based on the model created by the neural network obtained by online mointoring of the MAG-CMT welding process (welding current strength), it is possible to evaluete the stablity of the process and classify the welded joints into two groups (good, bad) according to the visual assessment of the appearance of the welded nickel alloy. It can be seen that the arc height correction parameter ALC has an impact on welding process stability. A more stable arch is achieved when the height of the arc correction is corrected to 30%.

5. References

[1] Marić, Dejan; Šolić, Tomislav; Kondić, Veljko; Samardžić, Ivan. (2022). Statistical analysis of MAG-CMT welding parameters and their influence on the Ni-alloy weld overlay quality on 16Mo3 base material. *Welding in the World, 66,* 815-831. https://doi.org/10.1007/s40194-022-01256-x

[2] Soltysiak, S.;Selent, M.; Roh, S.; Abendroth, M.; Hoffmann, M.; Biermann, H.(2014). High - temperature small punch test for mechanical characterization of nickel-base super alloy. *Materials Science and Engineering: A, 613,* 259-263. https://doi.org/10.1016/j.msea.2014.06.105

[3] Imoudu, N., E.; Ayele, Y.,Z.; Barabadi, A. (2017). The characteristic of cold metal transfer (CMT) and its application for cladding. *IEEE International Conference on Industrial Engineering and Engineering Management (IEEM).* Singapore. 2017, pp. 1883-1887. https://doi.org/10.1109/IEEM.2017.8290218

[4] Meco,Sónia; Pardal,Gonçalo;Eder, Alexander;Quintino, L.(2013.). Software development for prediction of the weld bead in CMT and pulsed-MAG processes. *The International Journal of Advanced Manufacturing Technology, 64,*171–178. https://doi.org/10.1007/s00170-012-3990-x

[5] Mahadevan, R. Rishikesh; Jagan, Avinaash; Pavithran, Lakshmi; Shrivastava, Ashutosh; Selvaraj, Senthil Kumaran.(2021). Intelligent welding by using machine learning techniques. *Materials Today: Proceedings, 46,* 7402-7410. https://doi.org/10.1016/j.matpr.2020.12.1149

[6] Selvi,S.; Vishvaksenan, A.; Rajasekar, E.(2018). Cold metal transfer (CMT) technology - An overview. *Defence Technology, 14,* 28-44. https://doi.org/10.1016/j.dt.2017.08.002