Monitoring of the Process of Flash-Butt Welding

(Monitoramento do processo de soldagem de topo por faiscamento)

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Abstract

Statistical methods of analysis are currently widely used to develop control and monitoring systems for different welding processes. These methods allow to obtain information about the process including effect of all factors on its results, which is often difficult to evaluate due to the complexity of the process. The authors made efforts to apply these methods to develop the system for monitoring the parameters of flash-butt welding in real-time mode. The paper gives brief information about the features of flash-butt welding of reinforcement bars and some basic limitation of this process application. The main reasons of formation of defects in welded joints are given as well as analysis of possibility of application of monitoring systems for their determination. The on-line monitoring system based on neural networks was developed for evaluation of process deviations. This system is believed to be adequate for determination of process violations resulting in disturbances of welding parameter and can be used for prediction of possible defects in the welded joints.

Key-words: *Flash-butt welding, Defects in joints, Neural networks, Quality monitoring*

Resumo: *Análises estatísticas são normalmente utilizadas para desenvolver sistemas de controle e monitoramento de diferentes processos de soldagem. Estes métodos permitem obter informação sobre o processo, incluindo o efeito de todos os fatores sobre o resultado, os quais são difíceis de avaliar devido a complexidade do processo. Os autores do presente trabalho tentaram aplicar estes métodos para desenvolver um sistema de monitoração dos parâmetros da soldagem de topo por faiscamento em tempo real. O artigo dá uma ideia resumida sobre as características do processo de soldagem por faiscamento de vergalhões, assim como some limitações básicas da aplicação do processo. As razões principais para formação de defeitos na junta soldada são apresentadas, assim como a análise da possibilidade da aplicação de um sistema de monitoração para suas determinações. Um sistema em tempo real baseado em redes neurais para avaliar as variações do processo foi desenvolvido e apresentado. Este sistema é considerado adequado para determinar as não conformidades do processo, e pode ser usado para predizer possíveis defeitos na junta soldada.*

Palavras-chave: *Soldagem de topo por faiscamento, Defeitos, Redes neurais, Qualidade monitoração*

1. Introduction

At the present time the welding process is considered to consist of three operations [1]: the welding procedure specification, welding itself and after-welding check. All the operations mentioned require application of different methods of control and monitring. During the welding procedure specification the preparation of parts to be welded is checked as well as preliminary cleaning, heat-treatment, welding consumables and process parameters. The process of welding is followed by selective or continuous monitoring. The after-welding check includes determination of quality parameters, analysis of posiible reasons of formation of defects and as a result updating the welding procedure and parameters (if needed).

Evaluation methods based on statistical analysis and statistical quality control technologies are often used in welding, especially for after-welding check. Such quality control methods allow to improve the system and organization of control [2]. Statistical methods do not replace the other methods of control, but they significantly improve their effectiveness, adequacy and economical characteristics.

Every welding process consists of two components: one is determined by the pre-set welding parameters and resources used, the second one appears due to different physical processes occuring during welding (they depend on the process nature, conditions in which welfing is run and all the internal and external disturbances). It is almost impossible to determine all such "side" processes, meaning the exact influence of each factor on the quality of the welded joint cannot be definitely described. Statistical analysis allows to evaluate the process in whole and in such way to take into consideration the effect of all factors irrelatively to their nature.

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Some prospective studies are devoted to evaluation of quality characteristics by energetic parameters of the welding process. This approach is believed to be the most applicable in case of mass production because these parameters are easy to measure without additional equipment and human resources. The analysis results are used mainly for three purposes: to predict the quality characteristics of the welded joint (possible defects, mechanical properties and geometry), to define the disturbances occuring during the process and for continuous process monitoring. Such analysis if often performed by means of intellectual systems which allow to remove the human from the procedure of control and thus to reduce the subjectivity of its results and the process cost. At the present time such monitoring systems are used for arc welding and resistance spot welding [3, 4].

The objective of this work was to investigate the posibility of application of methods of statistical analysis as well as artificial intelligence systems for monitoring of flash-butt welding process of concrete reinforcement bars. The monitoring will be based on the analysis of energetic parameters of the welding process.

2. The monitoring of the process of flash-butt welding of reinforcement bars

2.1. Technology of flash-butt welding of reinforcement bars in construction of structures of monolithic reinforced concrete

*I*n construction and repair of reinforced concrete structures the different methods of arc welding of concrete reinforcement are used. The manual and semi-automatic electric arc welding, bath-arc welding and others have found the widest spreading. It should be noted that at plants and industrial groups of as-assembled reinforced concrete a flash-butt welding with a continuous flashing is widely used, except the above-mentioned methods. Now, it is one of main methods of producing the butt joints of concrete reinforcement under the shop conditions.

The flash-butt welding is characterized by a high stable quality of welded joints, almost equal in strength to the parent metal that makes it possible to increase greatly the reliability and service life of reinforced concrete structures and to provide the high productivity. The process of welding is performed in the automatic conditions, combines the assembly and welding operations in a single cycle, does not require application of auxiliary consumables (electrodes, welding wire, fluxes, gases, etc.). Moreover, special requirements to the welder's qualification are not specified.

At the present time, special technologies and equipment are being developed to make it possible to use this welding method in on-site and semi-stationary conditions [6]. The method application is also partially limited by existing quality control procedures [5]. This rises the problem of development of technologies of non-destructive real-time monitoring.

As a rule, the concrete reinforcement, bars of up to 22 mm are joined by the flash-butt welding with a continuous flashing, and the large-diameter bars are joined by using a flashing with a preliminary resistance preheating. The latter is characterized by a wide instable HAZ. The flash-butt welding with a pulsed flashing allows joining all the assortment of reinforced bars and has advantages over the above-mentioned methods. Mechanical characteristics of these steels in hot-rolled state are given in Table 1, and chemical composition is given in Table 2.

The carried out technological investigations of welding the hot-rolled reinforcement bars made it possible to establish the values of main parameters of welding conditions: adjusting length L_{adj}, tolerances for flashing L_{flash} and upsetting L_{upset}, open-circuit secondary voltage $U_{2o.-c}$ rates of flashing v_{flash}, and upsetting v_{upset}, time of welding and time of upsetting with current t_{upsetI} [6, 8].

The increased sensitivity to heating of heat-hardened reinforcement bars specifies the additional requirements to thermal cycles of heating in welding and increases greatly the requirements to the selection of its heating conditions during welding. Using the welding parameters with smaller tolerances for flashing usually causes the brittle fracture because of an intensive heat dissipation into welding machine electrodes being cooled. The recent technological investigations resulted in development of welding cycles for heat-hardened reinforcement bars which allow to produce welded joints almost equal in strength to the parent metal [6].

Table 1. Mechanical characteristics of bar reinforcing steels

Steel grade	$\sigma_{0.2}$, MPa	σ_t, MPa	δ, %
35GS	370 – 500	610 – 670	18 – 30
25G2S	380 – 400	590 – 620	23 – 31
St3Gsp	235	370 - 490	25

Table 2. Chemical composition of bar reinforcing steels, wt.%

Steel grade	C	Mn	Si	Cr	Ni	S	P	Cu
35GS	0.20 – 0.29	1.20 – 1.60	0.60 – 0.90	<0.30	<0.30	<0.045	<0.040	<0.30
25G2S	0.30 – 0.37	0.80 – 1.20	0.60 – 0.90	<0.30	<0.30	<0.045	<0.040	<0.30
St3Gsp	0.14 – 0.22	0.80 – 1.10	<0.15	<0.30	<0.30	<0.050	<0.040	<0.30

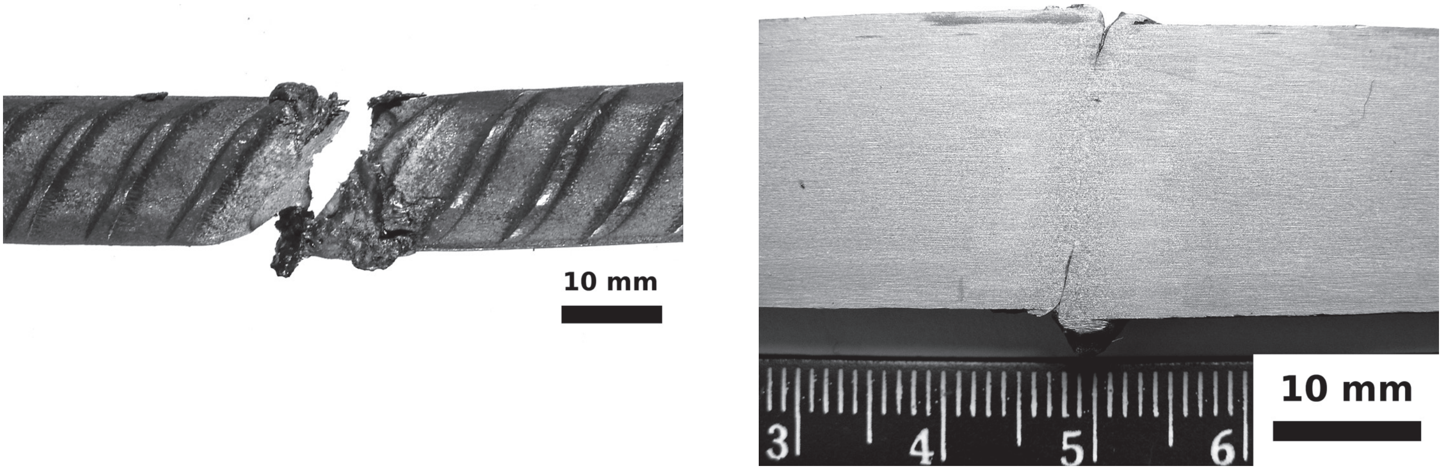
2.2. Analysis of possibility of application of the system of monitoring for determination of defects

*I*n general the defects in the welded joints of reinforcement bars appear as a result of three main reasons [9]: violation of technological process parameters (including the results of different disturbances), violation of technology and rules of the welding equipment operation and internal parent metal defects.

Violation of technological process parameters is often a result of different disturbances (energetic, kinematic and technological). They may result in significant difference between the pre-set and real values of welding parameters even in case of proper welding equipment operation and preparations of parts to be welded. In general, two variants of process are possible in this case: one causing the decrease of heat input, the second leading to overheating of bars.

In case of low heat input the plastic characteristics of the welded bars are reduced especially if they were preliminarily heat-hardened. The joint is formed only on the part of butt and often discontinuities are detected. Mechanical loads cause brittle fracture of the weld itself. Typical welded joint fracture and its macrosection are shown on Fig. 1. Overheating of the welded joint results in decreasing of microhardness in the HAZ due to local heat treatment occurring during the welding cycle. Application of the external load causes formation of two necks proving the hardness loss (see Fig. 2, a). Further increase of heat-input causes formation of hot cracks in the joint plane. The structure strength is reduced to 100 … 140 MPa.

Violation of any technological process parameter results in changes of the electric parameters, meaning the monitoring system can be effectively used to detect them.



a b

Figure 1. The reinforcement bars welded with low heat-input:
a – fracture after tensile tests; b – macrosection

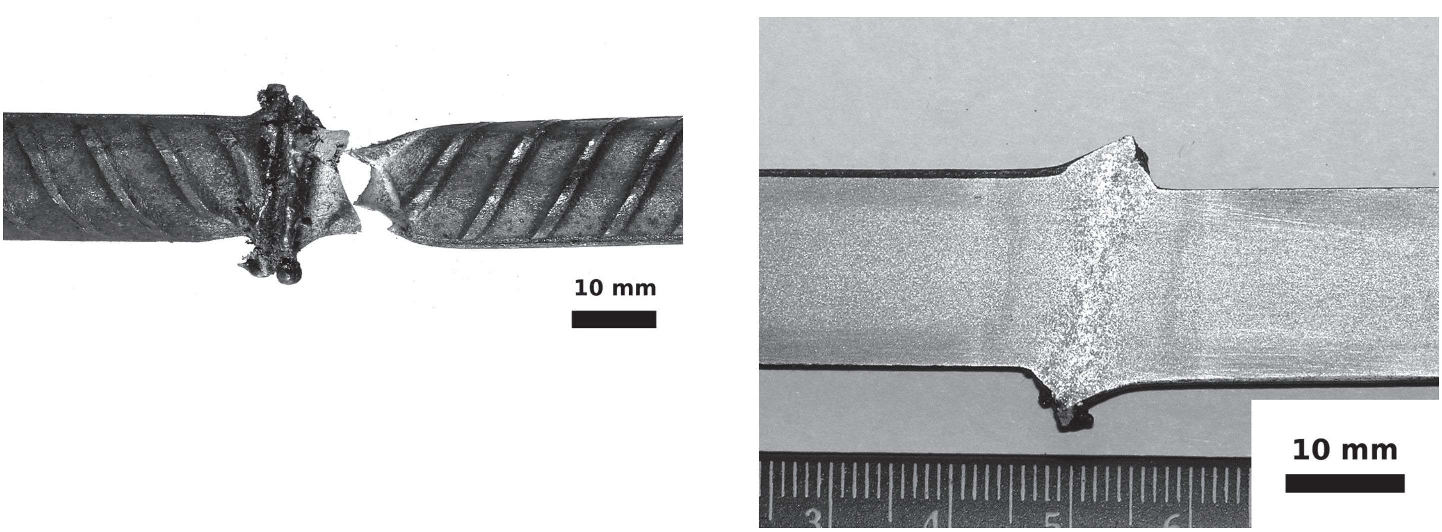


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Figure 2. The overheated reinforcement bars:
a – fracture after tensile tests; b – macrosection

Violation of technology and rules of the welding equipment operation in general lead to disturbances of the welding parameters in comparison to their values specified in the welding procedure specification and also to disturbances related to improper preparation of parts to be welded.

These disturbances are very similar to those caused by the violation of technological process parameters and they result in formation of the same defects in the welded joints. Sometimes the burnt spots are detected on the sides of workpieces reducing the cross-section and causing the strength decreasing (Fig. 3). As a rule, the burnt spots appear in case of low clamping force or heavy contamination of current-carrying jaws. In place when the part is not tightly adjacent to the electrode the transient electric resistance is increased to the value exceeding the resistance of flash gap and the process of a local flashing along the part-electrode contact surface begins. The formation of burnt spots is also caused by an increased electrical resistance between the profiled lateral surface of the concrete reinforcement and electrode.

Violation of technology and rules of the welding equipment operation also result in changes of the welding process parameters making it possible to detect them by means of the monitoring system.

Figure 3. Fracture of reinforcement with a burnt spot

Internal defects of the parent metal (those caused by the process of reinforcement bars production) sometines are also detected in the welded joints. Mostly they are blackfins which are formed during the bar rolling process. They often appear on the edges of slabs and blooms as a thick oxide film inside the workpiece (see Fig. 4). It is completely impossible to detect such defects by means of the monitoring system. To prevent their presence in the welded structure a full-scale incoming control of bars should be applied.

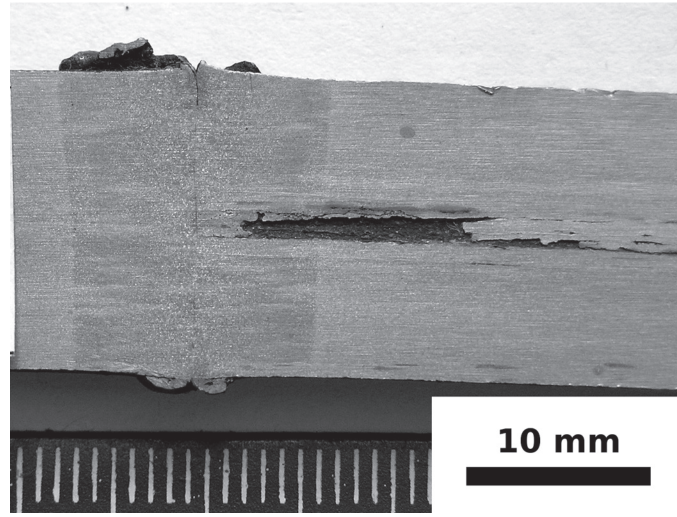


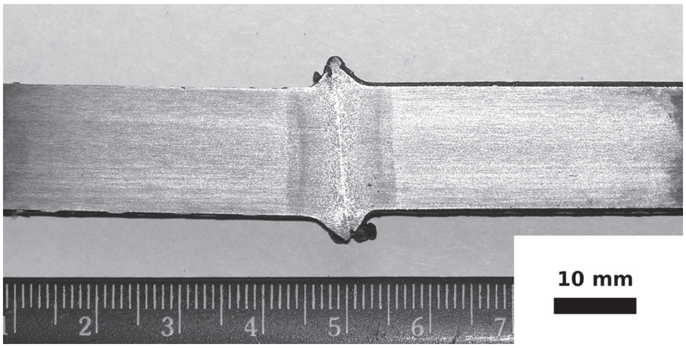
Figure 4. Internal defect of the reinforcement bar

2.3. Development of the technology of monitoring for flash-butt welding process

Most of defects which occur as a result of the welding process can be identified by means of real time monitoring of welding parameters (without or in addition to after-welding mechanical testing). In case of flash-butt welding of concrete reinforcement bars a simple monitoring procedure was used with a single measured parameter – secondary voltage. Welding voltage itself is one of the welding process parameters that is most sensitive to disturbances. The optimal conditions (as described in [6]) as well as three cases of deviation of the process parameters deteriorating quality characteristics of the joints, which most often occur during welding, such as decrease in workpiece feed speed v_{flash}, decrease in machine open-circuit voltage $U_{2o.-c}$, and change in workpiece extension L_{adj}, were evaluated. The joints produced as a result of the experiments differed in the heating zone and presence of defects, such as discontinuities (Fig. 5).

It can be seen from oscillograms of the welding voltage obtained under different welding conditions (Fig. 6) that the sufficiently informative signal reflecting the course of the explosive-spark process is a high-frequency component. The low-pass Butterworth filter was applied to reveal this component.

The obtained arrays were divided into blocks equal to ten periods of the industrial mains voltage (0.2 s), based on permissible duration of deviations during the flashing process [8]. Mathematical expectation of a random quantity module reflecting the intensity of flashing at a given stage of oscillogram was determined for each block. This resulted in the data arrays reflecting the intensity of flashing (Fig. 7).



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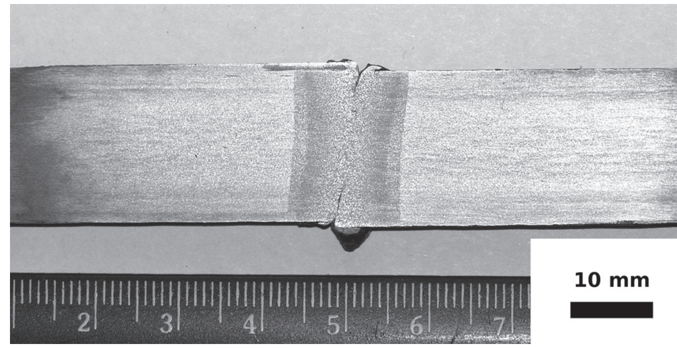

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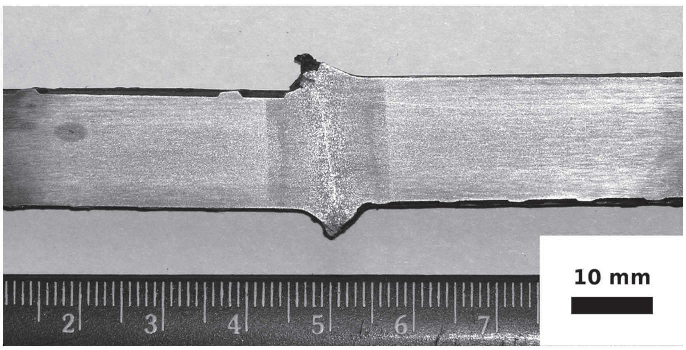

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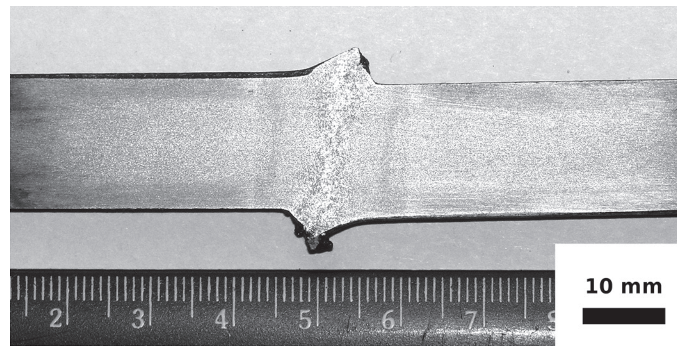
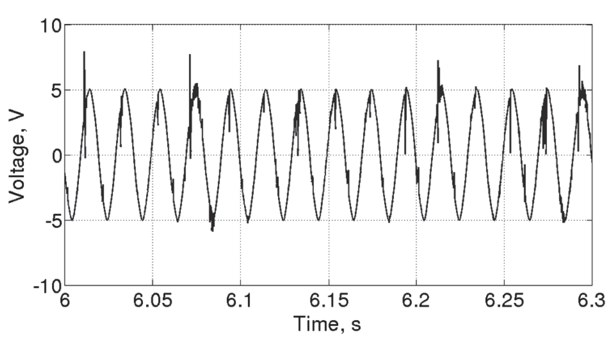


d

Figure 5. Macrosection of the joints produced under different welding conditions:
here and below in Figures 6 and 7:
a – optimal conditions, b – decreased speed, c – decreased voltage, d – increased extension



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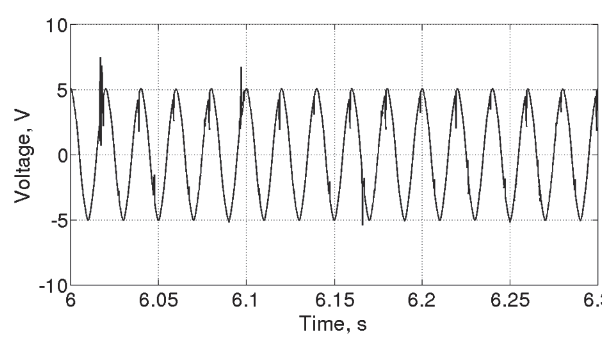

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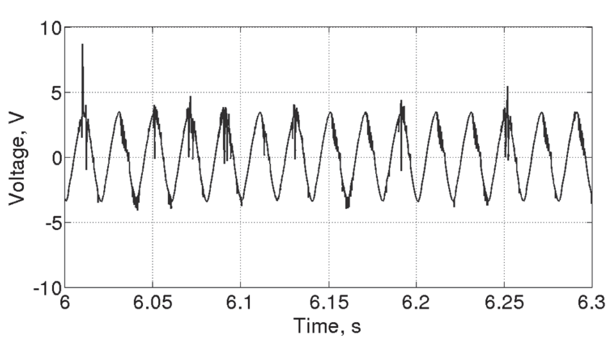

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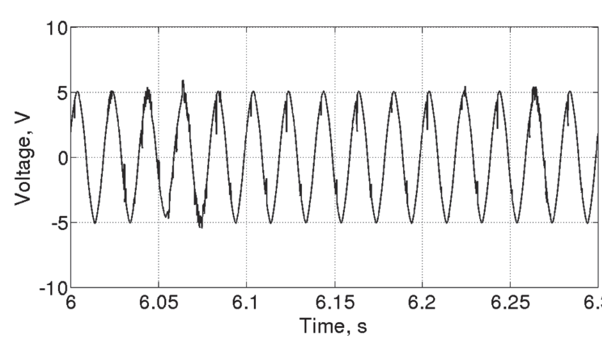

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Figure 6. Typical voltage oscillograms at different welding parameters

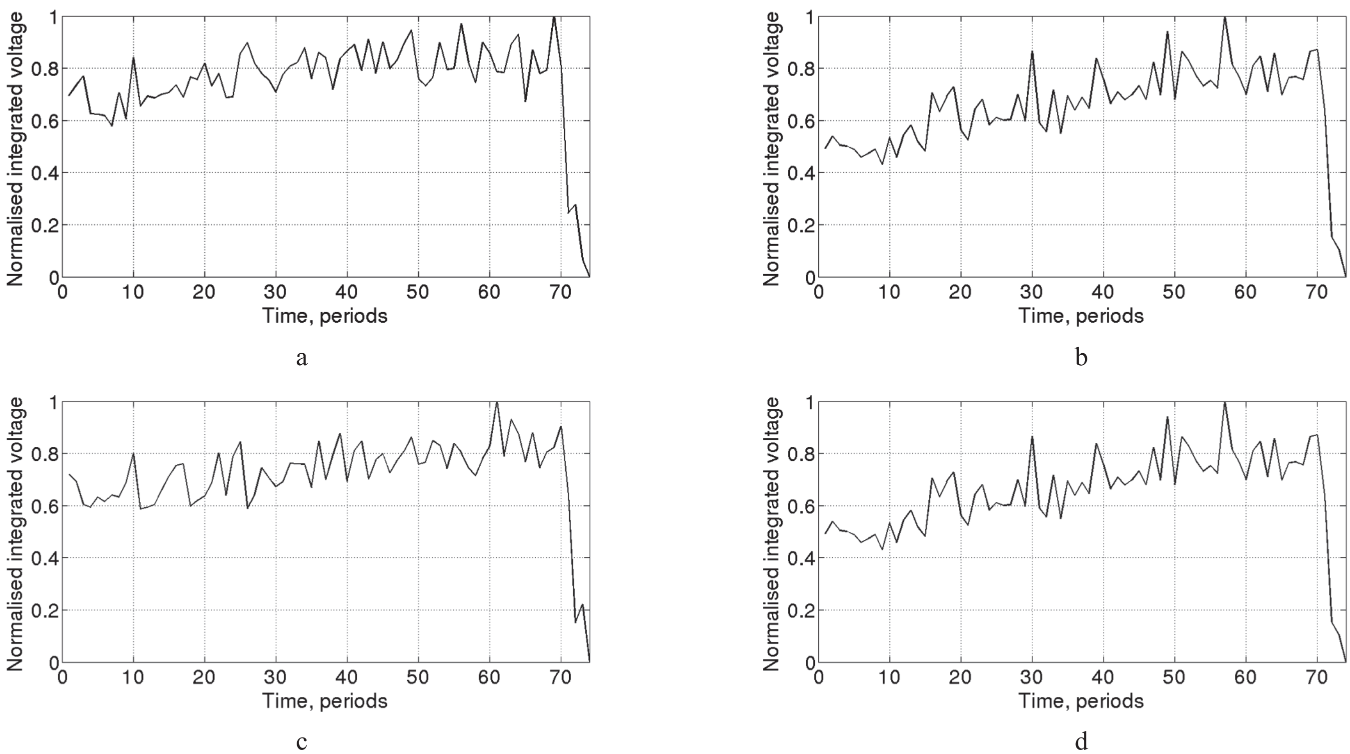


Figure 7. Typical data arrays reflecting the intensity of flashing for groups of joints

The problem of automatic classification of the data arrays can be successfully solved by using neural networks. The Probability Neural Network (PNN) and Learning Vector Quantization (LVQ) were used for classification based on the criterion of the presence of deviation of one of the process parameters (v_{flash}, $U_{2o.-c}$, L_{adj}). The data obtained during experiments were used for network training, the same training sequence was applied for both types of networks.

The error in identification of disturbances was not in excess of 8 % for LVQ and 13 % for PNN (Fig. 8). This proves a possibility of the developed system application for most determining of typical distubances of the welding process.

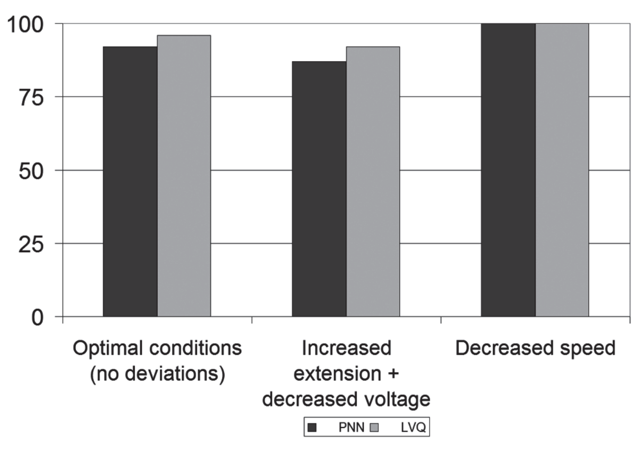
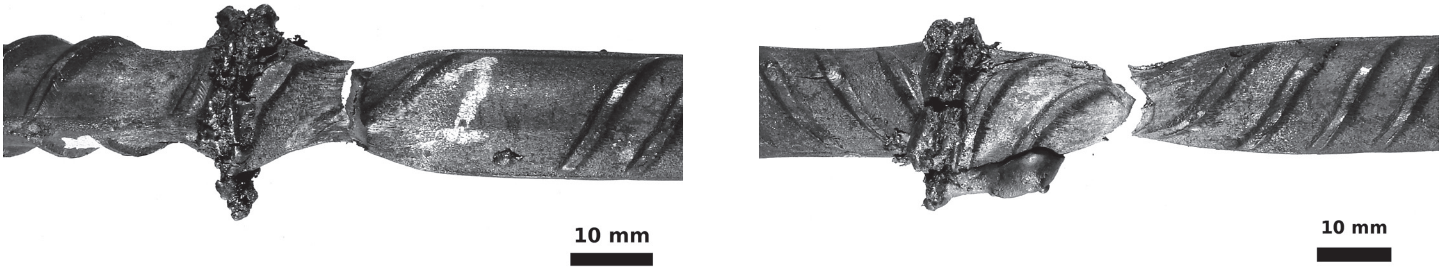


Figure 8. Results of operation of PNN and LVQ networks

To determine the general quality characteristics for each group of welded joints the mechanical testing of full-scale specimens of joints of hot-rolled reinforcement bars of steel 35GS were performed in accordance with requirements [5]. Fracture of all specimens occurred in the parent metal at a large distance from the welded joint and HAZ (Fig. 9). Macrosection of the joint and distribution of microhardness (Vickers hardness test, load 0.05 MPa) are shown in Fig. 10, microstructure of zone of joint and parent metal is given in Fig. 11.

Similar results were obtained also on steels St3Gps and 25G2S in heat-hardened state. The fracture of most specimens (about 90 %) occurred in parent metal beyond HAZ. Macrosection of such joint and distribution of hardness in it are given in Fig. 12.

The mechanical tests have proved that deviations of the parameters of welding process result in the reducing of the joint quality: the tensile strength reduces, areas with significantly lowered microhardness appear in HAZ.



a b

Figure 9. Welded specimens of hot-rolled (a) and heat-hardened (b) concrete reinforcement after tensile tests

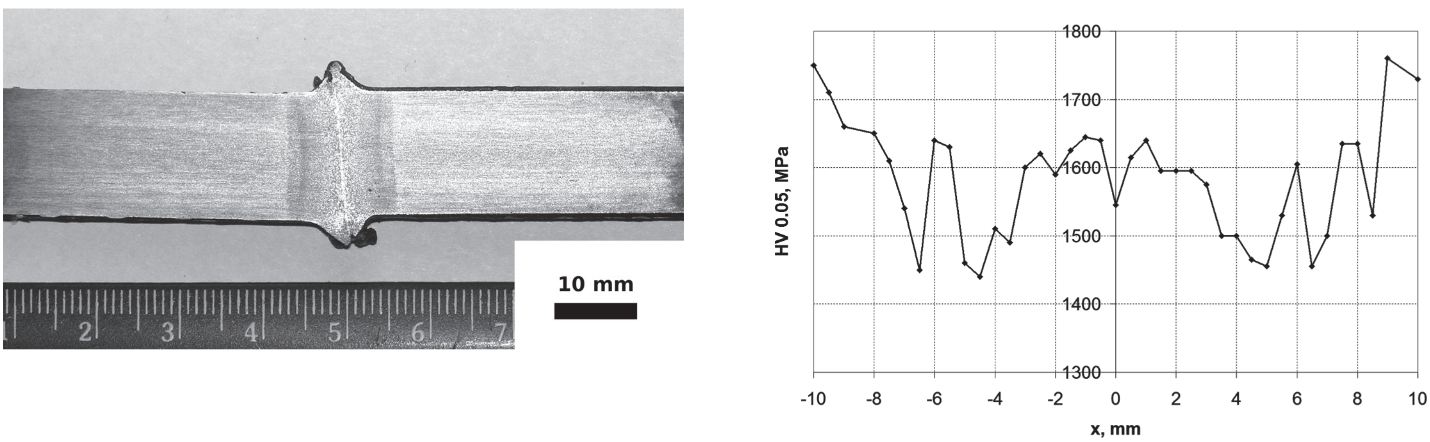


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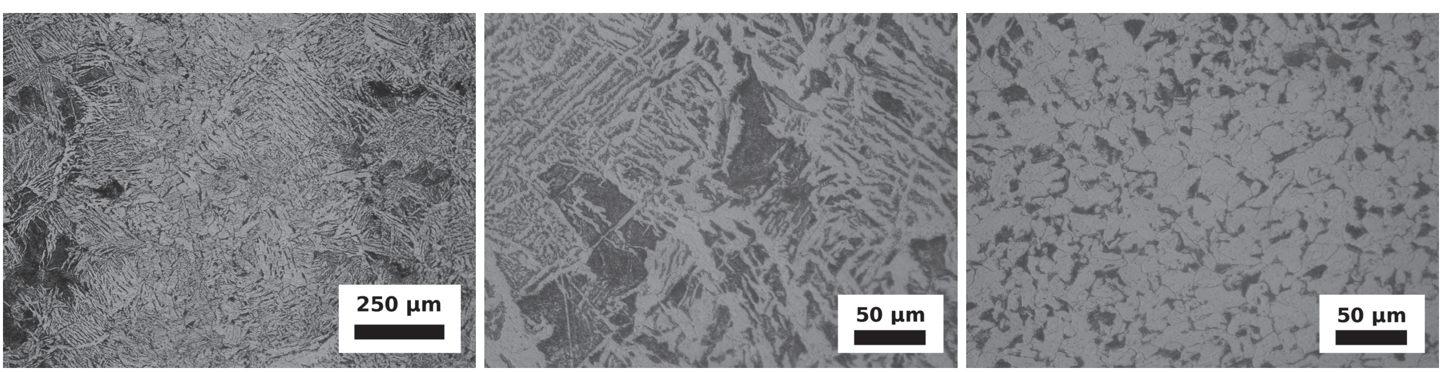
Figure 10. Macrosection (a) and distribution of microhardness (b) in the zone of welded joint of reinforcement bar of steel St3Gps

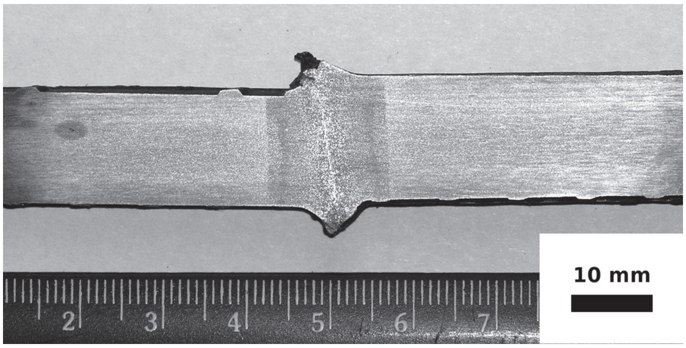


a b

Figure 11. Microstructure of welded joint (a), HAZ (b) and parent metal (c) of reinforcement bar of St3Gps

The developed method of monitoring can be used to predict the defects caused by the violation of technological process parameters. It is also possible to detect disturbances caused by violation of technology and rules of the welding equipment operation. But in this case the monitoring system will definitely fail to determine the reason of these disturbances. It will classify them as if they were caused by the violation of the process parameters. In any case, these disturbances will result in formation of the same defects in the joint, so the results of data analysis will be useful to predict them. The internal defects of the parent metal are completely impossible to be detected by means of the monitoring procedure developed. To prevent their presence in the welded structure a full-scale incoming control of bars should be applied.

Application of technologies of joining of hot-rolled and heat-hardened concrete reinforcement will make it possible to produce butt joints equal in strength to the parent metal under the site and semi-stationary conditions, to increase the service life of reinforced concrete structures, to increase their reliability and to guarantee the high service life. The results obtained proved the feasibility of using of artificial neural networks for quality monitoring in flash-butt welding.



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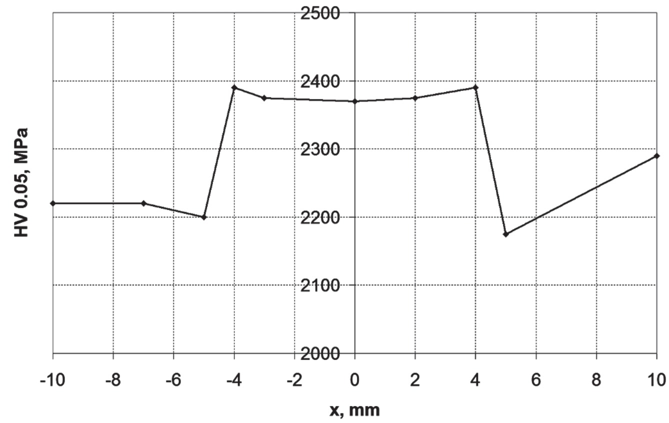

b

Figure 12. Macrosection (a) and distribution of hardness (b) in the zone of welded joint of reinforcement bar of steel 25G2S

3. Conclusion

1 Application of the system of monitoring of the welding parameters allows to determine disturbances caused by violation of technological process parameters and of technology and rules of the welding equipment operation. Therefore such systems allow to predict related defects in the welded joints. The internal defects of the parent metal cannot be detected by electrical parameters of the welding process.

2. The monitoring of the welding process is based on the analysis of high-frequency component of the welding voltage. The PNN and LVQ artificial neural networks are successfully used for automatic monitoring. Such monitoring systems can be effectively used together with or instead of mechanical tests in industrial conditions to determine the possibility of defect formation in the joint depending on deviances occuring during the joining process.

4. Acknowledgements

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5. References

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