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Diffusible hydrogen content in the deposited metal of multilayer welded joints

Zawartość wodoru dyfundującego w stopiwie wielościegowych złączy spawanych

Abstract
This article describes the manufacturing technology of multilayer joints in terms of controlling the diffusible hydrogen content. The diffusible hydrogen content in deposited metal for multilayer welded joints made of covered rutile electrodes or covered cellulosic and basic electrodes was determined. It was found that, after four beads, the diffusible hydrogen content decreases from 36 ml/100 g to 18 ml/100 g in the case of the first technology, and about 40 ml/100 g to a level of 12 ml/100 g in the second. The explanation of the mechanisms responsible for this phenomenon and directions for further study have been proposed.

Keywords: diffusible hydrogen, manual metal arc welding, rutile electrodes, cellulosic electrodes, basic electrodes

Streszczenie
W artykule scharakteryzowano technologię wytwarzania złączy wielościegowych w aspekcie kontroli ilości wodoru dyfundującego. Oznaczono zawartość wodoru dyfundującego w stopiwie dla wielościegowych złączy spawanych wykonanych dwoma technologiami: za pomocą elektrod o otulinie rutylowej oraz celulozowej i zasadowej. Ustalono, że po wykonaniu czterech ściegów ilość wodoru dyfundującego spada w przypadku pierwszej technologii z poziomu 36 ml/100 g do 18 ml/100 g, natomiast w drugim z około 40 ml/100 g do poziomu 12 ml/100 g. Wyjaśniono mechanizmy odpowiedzialne za to zjawisko i zasugerowano kierunki kontynuacji badań.

Słowa kluczowe: wodór dyfundujący, spawanie elektrodami otulonymi, elektrody rutylowe, elektrody celulozowe, elektrody zasadowe

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1. Introduction

The manufacturing of welded structures with semi-finished products of considerable thicknesses requires the qualification of an appropriate welding procedure. The basic technological procedures in this field rely on the selection of appropriate welding parameters, the shape of welding groove (bevel angle, the gap between elements), and the required number of beads. Multilayer welding is often carried out in the manufacture of building structures, railway rolling stock, transmission pipelines, and vessels, for example. Depending on the nature of the load, the conditions of welding and acceptance criteria rutile, basic or cellulosic-covered electrodes are used [1–5].

Electrodes with a rutile coating are currently less-frequently used in works related to the welding of advanced structures; however, they are widely used in the construction and transport industries. Their application is mainly due to very good welding properties, the possibility of welding in all positions except the PG position (with both DC and AC polarity), and a wide range of electrodes offered by manufacturers [6].

The application of cellulosic-covered electrodes to perform root runs in PG position is dictated by the high efficiency of welding and smaller requirements on the accuracy of the preparation of the edges for welding [1, 7–10]. A large amount of shielding gas generated from the organic components of covering enables an effective protection of the welding area. However, the use of cellulosic electrodes causes high hydrogen concentration in the weld pool 30–60 ml/100 g [1, 8, 11, 12].

Basic electrodes are used for the welding of advanced structures due to the high properties of the joints. Welding with basic electrodes is the low-hydrogen process: the electrode (as delivered and dried according to the manufacturer's instructions) contains less than 5 ml/100 g of diffusible hydrogen in the deposited metal [12–14].

In the case of transverse joints in transmission pipelines, typical technology used is welding with coated electrodes (process 111) as follows: the first (root) or the first two (root and "hot") beads are made of covered cellulosic electrodes (EC), and the subsequent (fill and cap) are made of basic electrodes (EB). From a metallurgical point of view, the technology used for pipelines is more complex than the conventional technology based on one type of electrode. One important aspect in this field is controlling the hydrogen content in the joint, which is one of the reasons for the increased tendency of cold-crack formation in welded joints [12–21]. The presence of a critical amount of hydrogen in steel weldments may determine its weldability. Such a dependence was noticed a long time ago and is still being intensively studied [12–14, 20–23]. The diffusible hydrogen amount in welded joints varies depending on the technology, and thus on the used process, consumables, and welding parameters. The main source of hydrogen for MMA welding is considered to be moisture coming from the covering and decay products from its organic ingredients.

With regard to multilayer welding, on the basis of theoretical analysis of the phenomenon and the information from literature [14], it is expected that an increase in the number of beads will result in a reduction of diffusible hydrogen content in the deposited metal. Despite the fact that the problem is of practical importance, it is only mentioned in a few publications [1, 8]. State-of-the-art in the relevant area requires additions of quantitative information in particular.

2. Experimental

The aim of this study was a quantitative assessment of the hydrogen level in deposited metal for multilayer joints made by conventional welding technologies for building and transport structures (rutile covered electrodes) and transmission pipelines (cellulosic and basic covered electrodes).

Research was carried out in two stages. The scope of the research work included:

1. Measuring the diffusible hydrogen content in deposited metal made with rutile electrodes:
   - samples with one bead made with a rutile electrode: ER,
   - samples with two beads made with rutile electrodes: ER + ER,
   - samples with three beads made with rutile electrodes: ER + ER + ER,
   - samples with four beads made with rutile electrodes: ER + ER + ER + ER.
2. Measuring the diffusible hydrogen content in deposited metal made with cellulosic and basic electrodes:
   - samples with one bead made with a cellulosic electrode: EC,
   - samples with one bead made with a cellulosic electrode and one bead made with a basic electrode: EC + EB,
   - samples with one bead made with a cellulosic electrode and two beads made with basic electrodes: EC + EB + EB,
   - samples with one bead made with a cellulosic electrode and three beads made with basic electrodes: EC + EB + EB + EB.

The diffusible hydrogen content in deposited metal was determined by the glycerin method [14, 16–21]. The measuring procedure includes the following procedures: weighing the sample before surfacing, making a test weld bead on the sample, weighing the sample after welding, placing it in the test stand, extracting the hydrogen in 72 h, reading the amount of hydrogen collected in the measurement part of test stand, converting of results to normal temperature and pressure, and referencing the obtained values to 100 g of deposited metal. The test stand is shown in Figure 1.

For determination of the diffusible hydrogen content in the multilayer welding, a sample with a modified shape is used [14]. Samples were made of carbon steel S235 square section bars, in which grooves were milled according to Figure 2.

The test padding welds were made using a welding station with an Aristo 4000i welding machine and electrodes with diameters of 4 mm: with rutile covering ESAB ER 1.46 (E 38 0 RC 11), with cellulosic covering Lincoln Electric Shield-Arc Hyp + (E 42 2 Mo C 25), and with basic covering Esab OK 48.08 (E 42 4 B 32 H5). Basic electrodes were dried before welding in 350°C for 2 h. Each bead was carried out using individual electrode with DC positive polarity. Padding welds were made with the welding current in the range 118–123 A, the arc voltage 23–29 V and the heat input 0.9–1.3 kJ / mm. After each bead, the samples were immediately cooled in ice water in order to stop the diffusion of hydrogen. The time to start the extraction in the case of one-bead welds was 180 s. This time was prolonged by a further 180 s for each bead. At the initial stage of the research, the effect of the time delay of the start of hydrogen extraction caused by multilayer welding on the results of experiments was examined [19]. From the obtained results, it was concluded that the effect is negligible. Figure 3 shows photographs of samples, and the detailed results of measuring the diffusible hydrogen content in deposited metal are presented in Tables 1 and 2.

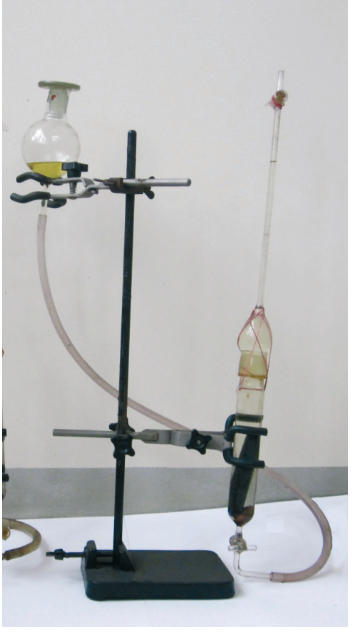

Fig. 1. Test stand for determination of diffusible hydrogen content by the glycerin method

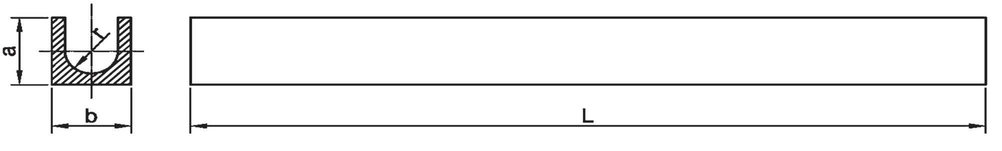

Fig. 2. Sample for determination of diffusible hydrogen content in multilayer joints: a = 12 mm, b = 12 mm, r = 4 mm, L = 120 mm

Fig. 3. Samples for diffusible hydrogen content determination: a) sample with four weld beads (ER + ER + ER + ER); b) sample with one weld bead (EC); c) sample with four weld beads (EC + EB + EB + EB)

Table 1. Results of determination of diffusible hydrogen content in deposited metal of rutile electrodes

No.	Sample	Diffusible hydrogen content in deposited metal H_D [ml/100 g]	Average diffusible hydrogen content in deposited metal H_D [ml/100 g]
1	ER	39.71	35.67
		33.32	
		33.98	
2	ER + ER	26.96	27.25
		27.98	
		26.81	
3	ER + ER + ER	21.84	22.05
		23.05	
		21.26	
4	ER + ER + ER + ER	19.87	18.40
		18.11	
		17.22	

Table 2. Results of determination of diffusible hydrogen content in deposited metal of cellulosic and basic electrodes [19]

No.	Sample	Diffusible hydrogen content in deposited metal H_D [ml/100 g]	Average diffusible hydrogen content in deposited metal H_D [ml/100 g]
1	EC	39.71	40.26
		40.85	
		40.23	
2	EC + EB	23.21	21.61
		19.06	
		22.57	
3	EC + EB + EB	17.84	16.70
		16.56	
		15.72	
4	EC + EB + EB + EB	13.77	11.75
		10.07	
		11.42	

3. Discussion

The analysis of the research results (Figs 4 and 5) shows that multilayer welding reduces the diffusible hydrogen content in deposited metal, as previously predicted. The intensity of this phenomenon is determined by two mechanisms. The first (occurring in both experiments) involves increased hydrogen diffusion from the sample to the environment caused by heat input during execution of subsequent beads. The second mechanism (occurring only in the second experiment) is mixing the deposited metal (from cellulosic and basic electrode), which has a significant difference (about 36 ml/100 g) in the hydrogen content. By this phenomenon, the fact that the difference between the diffusible hydrogen content of samples with one bead made with cellulosic electrodes (EC) and samples with the first bead made with cellulosic electrodes and the second with basic electrodes (EC + EB) is much higher (about 19 ml/100 g) than the difference of diffusible hydrogen content (about 5 ml/100 g) between successive samples made with cellulosic and basic electrodes (EC + EB and EC + EB + EB) can be explained. Nearly the same decrease in diffusible hydrogen content of approximately 5 ml/100 g can be observed when making one more bead with basic electrodes (EC + EB + EB + EB).

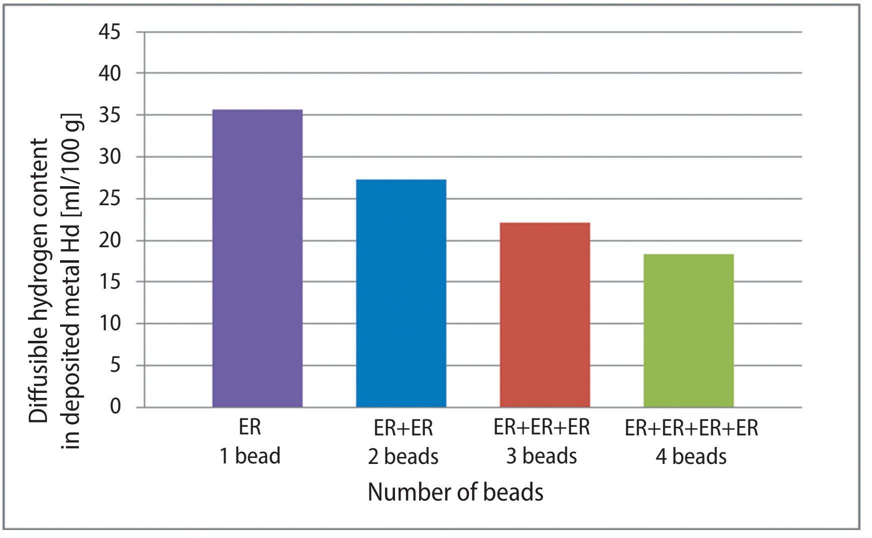

Fig. 4. Effect of number of weld beads on diffusible hydrogen content in deposited metal of rutile electrodes

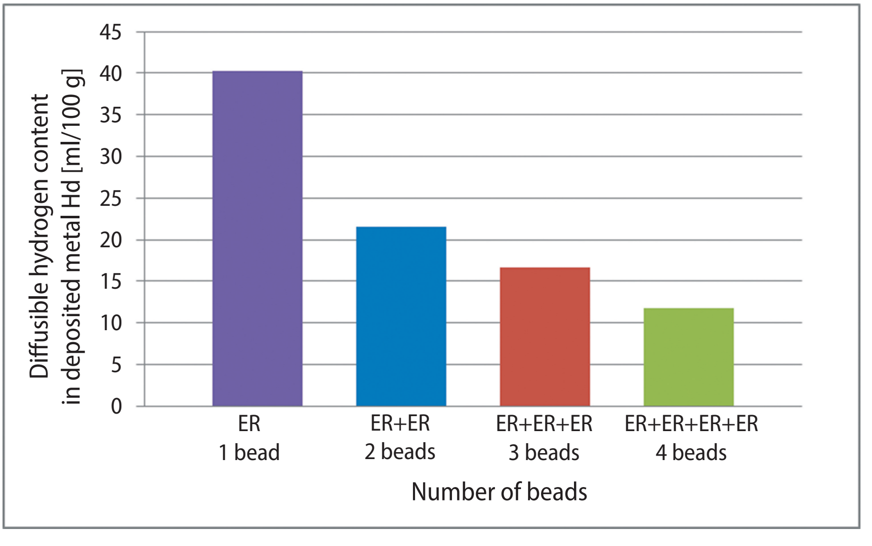

Fig. 5. Effect of number of weld beads on diffusible hydrogen content in deposited metal of cellulosic and basic electrodes

From the viewpoint of the mechanism of the formation of cold cracks, a more-appropriate measure of diffusible hydrogen content in the joint is to refer it to the weight of the melted metal (weld) [14]. Multilayer welding reduces the diffusible hydrogen amount and, at the same time, increases the volume of the weld and, therefore, affects reduction of the hydrogen level in two ways. Verification of this hypothesis requires the undertaking of further research.

It should also be noted that a level of low hydrogen processes (H5) was not reached in the range of examinations carried out. This implies the direction of further study to be made using the mercury method, which is recommended in studies of low hydrogen processes by the standard [24]. However, in this case, the shape of samples have to be redesigned to make more than four beads.

4. Conclusions

1. The hypothesis of a decrease in the diffusible hydrogen content in deposited metal during multilayer welding was experimentally confirmed.
2. In the case of the analyzed welding procedures, an increase in the number of beads caused a reduction of diffusible hydrogen in deposited metal from 35.67 to 18.40 ml/100 g (rutile electrodes) and from 40.26 to 11.75 ml/100 g (cellulosic and basic electrodes).
3. Reduction of diffusible hydrogen in deposited metal from rutile electrode results from enhanced hydrogen diffusion by the influence of heat from the subsequent beads, while in the case of complex technology (cellulosic and basic electrodes), the additional mechanism is mixing the deposited metal with different contents of hydrogen.
4. The research can be continued in the direction of verifying the possibility of achieving the level of low hydrogen processes, but this would require the application of mercury method and samples with different shapes suitable for making more beads.

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