

Dariusz Fydrych, Aleksandra Świerczyńska, Michał Landowski

Preliminary studies of seamless flux-cored wires stored in extreme conditions

Badania wstępne bezszwowych drutów proszkowych przechowywanych w ekstremalnych warunkach

Abstract

In this paper, we describe the preliminary experimental studies of flux-cored wires moisturized under controlled conditions. Three seamless wires of different grades have been placed in an environmental chamber and moisturized in extremely adverse conditions (temperature $T = 60^{\circ}\text{C}$, relative humidity $H = 90\%$) for 240 hours. During this time, measurements of weight gain as well as surface observations of the wires have been carried out. Also, the amount of diffusible hydrogen in deposited metal was determined by the mercury method for one of the moisturized wires. A significant increase in the level of hydrogen was observed (from H5 to H10). Further research will aim to determine the effect of storage conditions on the hydrogenation of deposited metal and quality of flux-cored wires.

Keywords: FCAW, cored wires, diffusible hydrogen, storage conditions

Streszczenie

Praca dotyczy badań drutów proszkowych nawilżanych w kontrolowanych warunkach. Trzy gatunki drutów bezszwowych umieszczono w komorze klimatycznej i nawilżano w niekorzystnych warunkach (temperatura $T = 60^{\circ}\text{C}$, wilgotność względna $H = 90\%$) przez 240 h. Badania polegały na pomiarze nasiąkliwości i ocenie stanu powierzchni badanych drutów. Ponadto dla jednego z nawilżanych drutów oznaczono metodą rtęciową zawartość wodoru dyfundującego w stopiwie. Stwierdzono znaczny wzrost poziomu wodoru (z H5 do H10). Dalsze badania powinny zmierzać do ilościowego ustalenia wpływu warunków przechowywania na nawodorowanie stopiwa i jakość badanych drutów.

Słowa kluczowe: FCAW, druty proszkowe, wodór dyfundujący, warunki przechowywania

1. Introduction

One of the fundamental issues related to welding metallurgy is the behavior of hydrogen in the welding area and welded joint [1–3]. Very small diameters of hydrogen atoms (compared to the size of metal lattice parameters) often cause occurrences of the phenomenon of hydrogen penetration and diffusion to metallic materials [4–6]. This process is intense, widespread, and constitutes a special threat (especially in steel materials). Moisture and water vapor that penetrate the welding pool during the welding process react with the liquid metal, oxidize it, and at the same time saturate it with hydrogen. After the end of welding, hydrogen penetrates material discontinuities caused by the presence of porosity, microcracks, or slag. As a result of the cooperation of many mechanisms, this may cause the formation of welding cracks (mainly cold cracks) [1, 2, 7–9].

Hydrogen that penetrates into a welded joint can be divided into diffusible hydrogen (the part of hydrogen that, under normal temperature and pressure, can escape into the atmosphere by diffusion) and residual hydrogen (remains in free form and in the hydrides inside the hydrogen traps).

Gas shielded Flux Cored Arc Welding (FCAW, 136 acc. to standard PN-EN ISO 4063) is one of the most-intensively developing metal joining processes [10, 11]. This process has many advantages, such as high efficiency, low diffusible hydrogen content in the deposited metal, and relative simplicity in learning the welding technique. Flux-cored wires are simultaneously the electrode and the welding consumable. They are built of a steel tube filled with powder (flux). They are usually manufactured from a steel strip rolled in a tube, filled with flux, and mechanically closed (in the case of wires with seams) or through the process of welding (producing seamless wires) (Fig. 1). Subsequently, the wires are drawn until achieving a predetermined diameter (usually in the range of 0.8 to 2.4 mm).

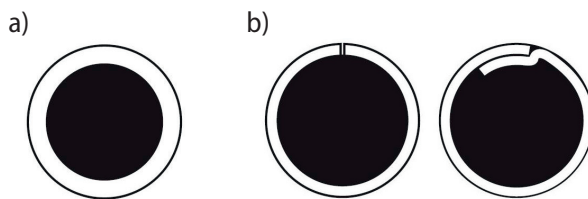


Fig. 1. Cross-sections of flux-cored wires: a) seamless wire; b) wires with seams [12]

Welded joints made with flux-cored wires can be susceptible to cold cracking. When other factors that cause cold-crack formation remain unchanged, the increasing amount of diffusible hydrogen is the reason for the presence or absence of cracks. The effect of the technological regime (e.g., correct welding parameters, adequate pre-heating temperature, appropriate storage conditions) has been studied by many researchers and reported in numerous publications [13–24].

The factors associated with the storage of wires that could have a significant effect on the diffusible hydrogen content in deposited metal may be: atmospheric moisture and temperature, time, type of packaging, chemical composition of the flux, and type (method of production) of the wire. Typical recommendations for storage of flux-cored wires require that the following atmospheric conditions in the consumables warehouse must be achieved: maximum temperature 27°C and relative humidity max. 60%, or maximum temperature 37°C and relative humidity max. 50% [25].

The specific structure of flux-cored wires determined the directions and intensity of the penetration of moisture (and with it, the hydrogen). Theoretical and literature analysis about the phenomenon of moisturizing flux-cored wires shows that, in the case of wires with a seam, the basic path for penetration of moisture into the flux is the seam, while a minor role may be played by the open end of the wire.

The aim of this study was to determine the effect of the time of storage in adverse conditions on the possibility of the further use of the materials studied, based on the diffusible hydrogen content evolved from the deposited metal, wires surface conditions, and their absorbability.

2. Experimental

Studies were carried out in two stages. The first was the determination of the diffusible hydrogen content in the deposited metal of wire Nittetsu SF-3A moisturized in an environmental chamber under the following conditions: temperature $T = 60^{\circ}\text{C}$, relative humidity = 90% H, time range $t = 0$ to 240 h. This was concluded by an observation of its surface. The second part of the study was the determination of the weight gain of wires moisturized under the same conditions. For the purposes of second part of the study, three grades of Nittetsu seamless flux-cored wires of 1.2 mm diameter with rutile cores have been selected (Tab. 1).

Table 1. Consumables used in experiment

No.	Trade name	Grade	R_e [MPa]	R_m [MPa]	A_5 [%]
1	Nittetsu SF-3A	AWS: A5-20 E71T-9M-J; PN-EN ISO 17632: T 46 4 Z P 1 H5	547	612	25
2	Nittetsu SM-1F	PN-EN ISO 17632: T 42 0 ZRC 3 H5	490	570	27
3	NST FC-1A	AWS: A5-20 E71T1-M; PN-EN ISO 17632: T 46 2 P M 1 H5	>460	>530	>22

In the first experiment, a spool of wire was moisturized in a Binder 115 E3.1 climatic chamber. To prepare the samples, a welding station with Aristo 4000i welding machine

was used. In studies of the measurement of diffusible hydrogen, the mercury method was method of choice. The advantages of the mercury method over other measurement methods include accuracy, precision of measurement, and high inter-laboratory reproducibility [26, 27]. The test stand is shown in Figure 2. As a base metal, non-alloy steel samples S235JR were prepared in accordance with guidelines [27, 28]. To determine the amount of diffusible hydrogen in the deposited metal, the following steps were undertaken:

- performing a padding weld on a test sample (welding current 200-250 A, arc voltage 25–30 V and flow rate of M21 shielding gas 18–22 l/min),
- cooling the sample rapidly in ice water to stop the diffusion of hydrogen,
- putting the sample in a scaled vessel which allows it to collect hydrogen,
- measuring the length of the column of hydrogen gas and the difference of mercury levels in the arms of the test stand,
- calculating the diffusible hydrogen content referred to the weight of the deposited metal and normal temperature and pressure.



Fig. 2. Test stand for determination of diffusible hydrogen content by mercury method

Microscopic observations have been carried out on a Philips XL 30 ESEM (a scanning electron microscope). The aim of the microscopic tests was to determine the influence of time and storage conditions on the state of the surface of the wire as well as the quality of the closing of its tube.

Precise laboratory balance AXIS with an accuracy of 0.001 g was used to measure the change of weight of the wires due to the moisturizing process. Samples of wires in delivery conditions were placed in a climatic chamber and moistened at temperature $T = 60^{\circ}\text{C}$ and relative humidity $H = 90\%$. Absorbability was calculated from the following formula [21]:

$$N = \frac{(m_n - m_0)}{m_0} \times 100\%$$

where:

- N – absorbability [%],
- m_0 – initial weight of the sample [g],
- m_n – weight of the sample after moisturizing [g].

3. Results

The diffusible hydrogen content in Nittetsu SF-3A deposited metal in delivery conditions obtained using the mercury method is 3.18 ml/100 g; thus, the tested wires comply to a level guaranteed by the manufacturer (H5 level). Figure 3 shows the results of measurements of diffusible hydrogen content in deposited metal of the wire moistened in extreme conditions: temperature $T = 60^{\circ}\text{C}$, humidity $H = 90\%$.

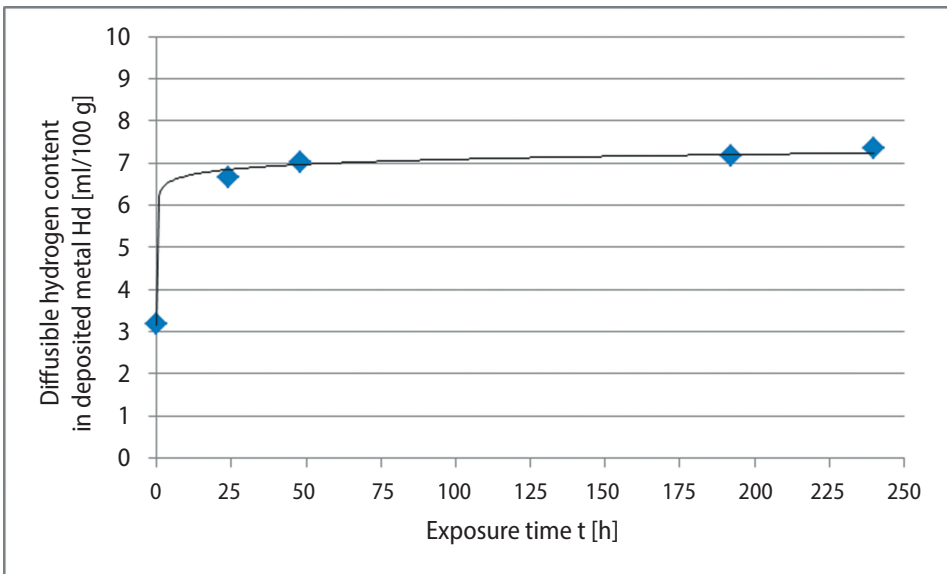


Fig. 3. Relation between moisturizing time of flux-cored wire Nittetsu SF-3A and diffusible hydrogen content in deposited metal

The results are shown as the average of 3 determinations. A strong non-linear effect of moisturizing time on the diffusible hydrogen content in deposited metal of the tested wire was found. However, after a rapid increase of diffusible hydrogen during the two first days, the growth of its content decreased. After 240 h in aggressive conditions, it reached a value of 7.36 ml/100 g (H10 level).

The metallographic examination of wires in delivery conditions and moisturized have been done. In Figure 4, photographs of seamless wire Nittetsu SF-3A in delivery conditions and after moisturizing are shown. From the point of view of the implementation of further research, an important observation is the fact that in the case of pre-coiled spool corrosion occurs mainly on the external coils. As can be seen in Figure 5, moisturizing causes the formation of corrosion products on the surface of the wire. There was no effect of storage on the condition of the seam.

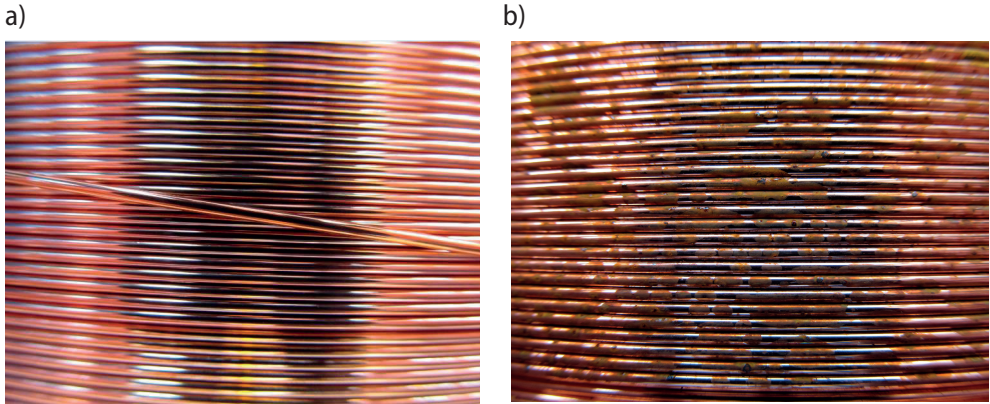


Fig. 4. Seamless flux-cored wire Nittetsu SF-3A: a) in delivery conditions; b) after 192 h of moisturizing

As moisturizing an entire spool of wire is pointless due to the fact that the phenomenon is mainly subjected to the external coils, the manner of collecting samples for testing was determined (including the length of the wire prior to moisturization). Figure 6 shows the wires during moisturizing in the climatic chamber. Each wire was weighed during moisturization, and the results of the measurements specifying their absorbability are shown in Figure 7.

The examined wires are characterized by varied absorbability. The observed weight gain of seamless wires is probably due to the presence of moisture in the products of corrosion. This increases the amount of potential hydrogen, which is responsible for increasing the amount of diffusible hydrogen. Verification of this hypothesis requires further study. Studies can be continued in the direction of quantitative assessment of the effect of storage conditions of flux-cored wires on diffusible hydrogen content in deposited metal.

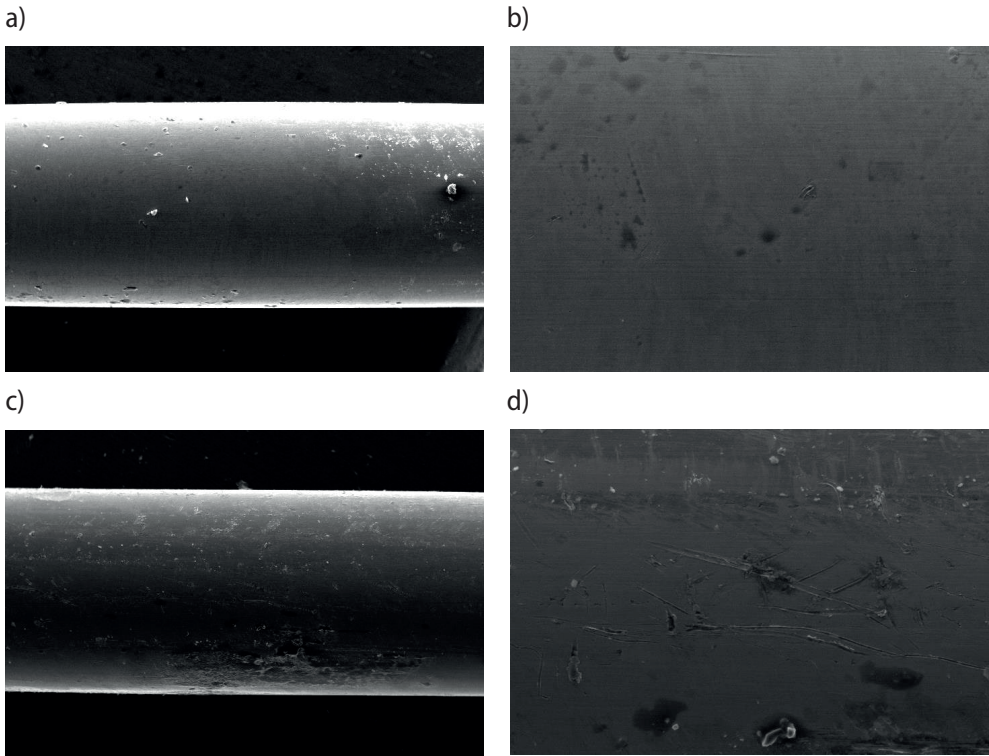


Fig. 5. View of cored wire Nittetsu SF-3A: a) in delivery conditions, magn. 50x; b) in delivery conditions, magn. 200x; c) moisturized by 240 h in temperature $T = 60^{\circ}\text{C}$, humidity $H = 90\%$, magn. 50x; d) moisturized by 240 h in temperature $T = 60^{\circ}\text{C}$, humidity $H = 90\%$, magn. 200x



Fig. 6. Wires during moisturizing in an climatic chamber

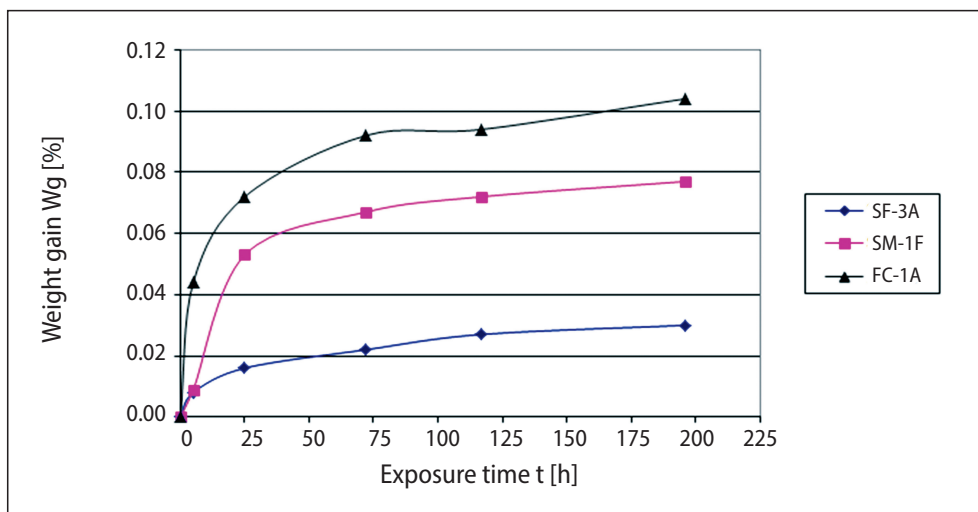


Fig. 7. The effect of moisturizing time on the moisture absorption of rutile FCAW wires

4. Conclusions

- 1) During the execution of preliminary studies, the conditions and methodology of moisturizing of wires (including parameters as well as the methods of sampling and placing wires in the chamber) were specified.
- 2) Moisturizing rutile flux-cored wires caused an increase in the amount of potential hydrogen, and this was the cause of the increase of the diffusible hydrogen content in deposited metal (from H5 to H10).
- 3) Storage of flux-cored wires under the tested conditions caused corrosion of their surfaces, but degradation of the seams was not noticed.
- 4) The examined wires are characterized by varied absorbability.
- 5) Studies can be continued in the direction of assessing the effect of storage conditions of flux-cored wires on diffusible hydrogen content in deposited metal.

Acknowledgements

The authors thank Jacek Zajęczkowski from NST Company for providing flux-cored wires and discussions about the preparation for and execution of research.

References

- [1] Pokhodnya I.K., Yavdishchin I.R., Paltsevich A.P., Shvachko V.I., Kotelchuk A.S.: Metallurgy of arc welding. Interaction metal with gases. Naukova Dumka, Kiev, 2004
- [2] Tasak E.: Metalurgia spawania. JAK, Kraków, 2008 [in Polish]

- [3] Fydrych D., Tomków J., Świerczyńska A.: Determination of diffusible hydrogen content in deposited metal of rutile electrodes by glycerin method. *Metallurgy and Foundry Engineering*, 1 (2013), 47–54
- [4] Michalska J., Sozańska M., Hetmańczyk M.: Application of quantitative fractography in the assessment of hydrogen damage of duplex stainless steel. *Materials Characterization*, 60 (2009), 1100–1106
- [5] Ćwiek J.: Hydrogen assisted cracking of high-strength weldable steels in sea-water. *Journal of Materials Processing Technology*, 164–165 (2005), 1007–1013
- [6] Zakroczyński T., Glowacka A., Swiatnicki W.: Effect of hydrogen concentration on the embrittlement of a duplex stainless steel. *Corrosion Science*, 46 (2005), 1403–1414
- [7] Pańcikiewicz K., Zielińska-Lipiec A., Tasak E.: Cracking of high-strength steel welded joints. *Advances in Materials Science*, 3 (2013), 76–85
- [8] Kozak T.: Resistance to cold cracking of welded joints made of P460NL1 steel. *Advances in Materials Science*, 3 (2011), 20–27
- [9] Fydrych D., Rogalski G., Tomków J., Łabanowski J.: Skłonność do tworzenia pęknięć zimnych złączy ze stali S420G2+M spawanej pod wodą metodą mokrą. *Przegląd Spawalnictwa*, 10 (2013), 65–72 [in Polish]
- [10] Pilarczyk J., Zeman W.: Spawalnictwo dziś i jutro. *Biuletyn Instytutu Spawalnictwa w Gliwicach*, 6 (2012), 25–32 [in Polish]
- [11] Marmołowski A., Piątkowski T.: Znaczenie wolnego wylotu elektrody przy spawaniu drutami proszkowymi. *Przegląd Spawalnictwa*, 11 (2009), 55–58
- [12] Zajączkowski J., Fydrych D.: Zastosowanie drutów proszkowych w przemyśle okrętowym i offshore. *Proceedings of 55th Welding Conference, Gdańsk Sobieszewo*, 14–16.10.2013 [in Polish]
- [13] Mee van der V.: Effect of atmospheric storage condition on weld metal diffusible hydrogen content of gas shielded cored wires. *Doc. IIW II-1437-01/IIA-082-01*
- [14] White D., Pollard G., Gee R.: The effect of welding parameters on diffusible hydrogen levels in cored wire welding. *Welding and Metal Fabrication*, 60 (1992), 209–210
- [15] Pitrun M., Nolan D., Dunne D.: Diffusible hydrogen content in rutile flux cored arc welds as a function of the welding parameters. *Doc. IIW IX-2064-03*
- [16] Harwig D.D., Longenecker D.P., Cruz J.H.: Effects of welding parameters and electrode atmospheric exposure on the diffusible hydrogen content of gas flux cored arc welds. *Welding Journal*, 9 (1999), 314–321
- [17] Kiefer J.H.: Effects of moisture contamination and welding parameters on diffusible hydrogen. *Welding Journal*, 5 (1996), 155–161
- [18] Bracarense A.Q., Lacerada de Souza R., de Souza Costa M.C.M., Faria P.E., Liu S.: Welding current effect on diffusible hydrogen content in flux cored arc weld metal. *Journal of the Brazilian Society of Mechanical Sciences*, 4 (2002), 278–285
- [19] Michael S., Sierdzinski M., Ferree E.: New flux cored wires control diffusible hydrogen levels. *Welding Journal*, 2 (1998), 45–48
- [20] Veinot D.E., Fraser P.E., MacGregor L.W.: Measurement of diffusible hydrogen in seamed flux cored wires for welding of high strength steels. *DRDC Atlantic Report on TTCP MAT-TP1 Operating Assignment*, 2007
- [21] Kuebler R., Pitrun M., Pitrun I.: The effect of welding parameters and hydrogen levels on the weldability of high strength Q & T steel welded with FCAW consumables. *Australasian Welding Journal*, 45 (2000), 38–47
- [22] Świerczyńska A., Fydrych D., Łabanowski J.: The effect of welding conditions on diffusible hydrogen content in deposited metal. *Diffusion and Defect Data Pt.B. Solid State Phenomena*, 183 (2012), 193–200
- [23] Świerczyńska A.: Effect of technological factors on diffusing hydrogen content in the weld deposit of rutile flux-cored wires. *Institute of Welding Bulletin*, 5 (2013), 66–71

- [24] Fydrych D., Świerczyńska A., Tomków J.: Diffusible Hydrogen Control in Flux Cored Arc Welding Process. *Key Engineering Materials*, 597 (2014), 171–178
- [25] Zajączkowski J., Fydrych D.: Przechowywanie materiałów dodatkowych z uwzględnieniem drutów proszkowych. *Proceedings of XVIII National Welding Conference, Międzyzdroje 22–24.05.2012* [in Polish]
- [26] Kotecki D.J.: Hydrogen reconsidered. *Welding Journal*, 8 (1992), 35–43
- [27] Fydrych D., Łabanowski J.: Determining diffusible hydrogen amounts using the mercury method. *Welding International*, 26 (2012), 697–702
- [28] PN-EN ISO 3690:2012 Welding and allied processes – Determination of hydrogen content in arc weld metal