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Diffusible hydrogen management in underwater wet self-shielded flux cored arc welding

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ABSTRACT

This article reports the effect of underwater wet welding parameters and conditions on the diffusible hydrogen content in deposited metal for welding with a self-shielded flux cored wire. The diffusible hydrogen content in deposited metal was determined using the glycerin method according to the Plackett-Burman design determining the significance of the effect of the stick out length, welding current, arc voltage, travel speed and water salinity. The results of the measurements of the diffusible hydrogen content in deposited metal ranged from 25.85 to 44.12 ml/100 g. The effect of all the tested factors is statistically significant. An equation was also developed, the analysis of which showed, that the hydrogen content cannot be reduced by technological methods below 21 ml/100 g.

Introduction

Underwater welding is a less expensive alternative to traditional methods of the repair of vessels and ocean engineering structures [1–3]. The adverse effect of water on welded joints properties is most strongly manifested in wet welding, in which the welding area is in direct contact with water [4–6]. Welding in wet conditions is typically performed using covered electrodes (111) and self-shielded flux cored wire (114), but other processes can also be employed: submerged arc welding (121), gas shielded metal arc welding (135, 136, 141, 15), laser welding, friction welding and explosive welding [7–12].

Development trends of underwater welding processes are determined by the difficulties posed by water as the working environment. To reduce the occurrence of such defects as geometric shape imperfections and porosity, works are required to improve the arc stability [13–15]. Mechanical properties of joints are improved by modifying the chemical composition of the core, covering and waterproof layer of the covered electrodes [16–19]. The most important roles, in this respect, are those of the choice of consumables and the development of welding technological conditions. Electrodes and self-shielded flux cored wires with ferritic-pearlitic and austenitic structure (commercial and dedicated to underwater welding) can be used for wet welding [20,21]. Wet welding

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with self-shielding wires can be semi-automatic or automatic. Studies of this process are now focused mainly on assessing the effect of the modes of metal transfer on the arc stability and the structure and properties of joints [9,13,15,21].

The water environment is a source of potential hydrogen, on the content of which the diffusible hydrogen amount in deposited metal proportionally depends. Diffusible hydrogen present in a welded joint significantly affects the susceptibility of steel to cold cracks formation and it is often crucial factor determining opportunity to improve the weldability of steel under given conditions [22–27]. This results in a particular interest in the role diffusible hydrogen plays in the formation of cold cracks, in the ability to control its content in weld metal and in the intensive development of knowledge about research methods and mechanisms of interaction of hydrogen with metals and non-metallic materials [28–32].

The susceptibility of steel to cold cracking is reduced through the use of technological and metallurgical methods of diffusible hydrogen content control and forming the weld structure [33–35]. Most of the ways to reduce the amount of hydrogen in welded joints are based on metallurgical methods, the application of which is up to manufacturers of welding consumables. It involve the modification of the chemical composition of the covering and powders to reduce the amount of potential hydrogen or the introduction of components that bind hydrogen to durable compounds at welding temperature, optionally limit its diffusion in the weld metal through the formation of hydrogen traps [36,37].

The second group of actions aimed at reducing the hydrogenation of welded joints are technological methods, intended to reduce the amount of potential hydrogen (drying of consumables) or to elongate the welding thermal cycle (preheating and post weld heat treatment) [38]. From a few literature reports, it has been found, that heat input (welding parameters) also has a significant influence on the diffusible hydrogen content in deposited metal obtained during welding in air environment [39]. Weld metal hydrogenation depends on the welding conditions (water salinity, filler and base material surface condition) and parameters (welding current and polarity, arc voltage, travel speed, stick out length, type and flow rate of shielding gas) [35,39–42]. In the case of wet welding with a self-shielded flux cored wire the arc voltage increase causes an increase in the diffusible hydrogen content in the deposited metal, whereas an increase in the welding current or the water salinity decreases its content [43]. This is a high-hydrogen process, which means that cold cracks can be formed in the case of welding steel with a higher value of carbon equivalent [44,45]. Cold cracking is still serious problem associated with welding of high strength steel structures designed for offshore drilling and transport of crude oil and natural gas, e.g.: offshore platforms and transmission pipelines [1–3].

Measurements of hydrogen content in welded joints are standardized. The ISO 3690 standard and other literature sources recommend the use of the mercury method or the hot extraction method for this purpose [46,47]. The mercury method applicability is limited due to the testing medium toxicity [48,49]. Some other methods can be used for high-hydrogen processes, for example glycerin method, provided that the relationship that enables results recalculation has been determined [50]. Recent research showed that results can be recalculated according to the following formula [50]:

$$HDme = 1.21 \times HDgl + 2.60 \quad (1)$$

where:

HDme-hydrogen content in deposited metal determined with mercury method [ml/100 g]
HDgl-hydrogen content in deposited metal determined with glycerin method [ml/100 g].

The analysis of the literature shows that no comprehensive solution has yet been developed for the problem of the effect of conditions and parameters of welding by the self-shielded flux cored process in wet conditions on the diffusible hydrogen content in welded joint.

Experimental

The aim of the study was to quantify the effect of the selected parameters and conditions of wet welding with a self-shielded flux cored wire on the diffusible hydrogen content in deposited metal, and to develop an equation to allow prediction of the diffusible hydrogen content in deposited metal for the assumed welding conditions. The problem was solved using the design of experiment theory according to the Plackett-Burman design [35,51,52]. The glycerin method was used to determine the content of diffusible hydrogen in the deposited metal (Fig. 1).

Samples with dimensions of 4 × 20 × 120 mm were made of S235JR steel. The test welds were made with negative polarity (DC-) at a depth of 200 mm at a test stand with the use of an welding power source Aristo 4000i (Fig. 2). A 1.7 mm flux cored self-shielded wire NR211MP (AWS A5.20/A5.20M:2005 – E71T-11, EN 758 T42 Z S N 1) was used as consumable. The chemical composition of the materials is shown in Tables 1 and 2. On the basis of literature survey, the independent variables were selected among technological parameters for the considered process together with one environmental condition: water salinity. The ranges of the tested factors: stick out length – L (12; 16; 20 mm), welding current – I (290; 330; 370 A), arc voltage – V (20; 21.5; 23 V), travel speed – TS (0.350; 0.475; 0.600 cm/s), water salinity – S (0; 18; 36‰) were adopted on the basis of own preliminary test conditions as to simultaneously ensure the feasibility of the design of experiment and the welding process stability. Preliminary tests showed, that those selected ranges of welding parameters provide repeatable weld beads without surface imperfections. The arc was unstable for parameters from outside ranges of parameters and conditions chosen for current studies. Welding in an ocean environment was simulated by using artificial sea water [42]. The maximum concentration of ingredients in the artificial water was equal to the average salinity of the world ocean. As the number of factors imposed by the test plan exceeded the number of factors that have been identified as having an effect on the diffusible hydrogen content in deposited metal, two fictitious factors were introduced to the experiment: F1 and F2. In order to prevent systematic errors,