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Effects of Storing Flux-Cored Wires under Various Conditions

Abstract: Welding processes involving the use of flux-cored wires are becoming increasingly popular, particularly in shipbuilding as well as in off-shore and civil engineering. The article presents characteristics of the welding process, its areas of application as well as advantages and disadvantages (e.g. necessity of ensuring appropriate conditions for the storage of filler metal wires). The satisfaction of quality-related requirements concerning welded joints necessitates controlling the quality of flux-cored wires as their condition (apart from welding conditions) is one of the most important factors affecting the welding process and the quality of joints. The analysis of related reference publications and individual study revealed that the storage of wires under conditions inconsistent with requirements specified by producers affects welding process stability and weld deposit properties. Visual tests (VT) tasked with assessing the quality of wire surface do not always provide sufficient information as regards the usability of filler metal wires in welding processes.

Keywords: FCAW, flux-cored wires, weather conditions, storage

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Introduction

Flux-cored wires are used in numerous joining processes including welding, brazing and cladding [1, 2]. Because of their form, flux-cored wires enable the continuous feeding of the filler metal to the base material as well as the use of non-metallic (e.g. gas-forming, slag-forming, arc stabilising or deoxidising) components, making it possible to adapt the filler metal to the requirements of a specific technology [3, 4]. One of the processes, where flux-cored wires are commonly used is flux-cored arc welding (FCAW). The aforesaid method involves the continuous feeding of the flux-cored wire from the feed reel to the welding arc area, where the wire melts forming the weld pool and, subsequently, the weld. The FCAW method is characterised by high efficiency, favourable penetration depth and usability in areas where solid wire arc welding processes are performed

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[5]. Because of the above-named advantages, flux-cored arc welding is often used in the production of structural elements, in the welding of high-strength and corrosion-resistant steels exposed to low temperature, in robotic joining processes as well as in various repairs [5, 6]. Flux-cored wires are divided into self-shielded flux-cored wires as well as filler metal wires used in gas-shielded welding processes. The latter are further divided into rutile, basic and metallic flux-cored wires. The application of appropriate flux combined with the use of appropriate shielding gas enables the obtainment of required properties of welded joints [7]. Very popular rutile-cored wires can be used in welding processes performed in restricted positions and are characterised by high arc stability. Basic flux-cored wires enable the obtainment of weld deposit characterised by very good mechanical properties. Metallic flux-cored wires are often used in robotic processes as, because of relatively slow contents of mineral components in their core, they are characterised by high melting efficiency and the absence of slag. Flux-cored wires are also used to make combined joints, root runs (metallic flux-cored wires), filling runs or face runs (rutile flux-cored wires).

One of the factors restricting the use of flux-cored wires is their sensitivity to environmental conditions during storage [8]. Manufacturers of filler metal wires provide information concerning maximum values of temperature and relative humidity, in which fully wrapped and unwrapped wires can be stored and continue to guarantee the high quality of welded joints [9, 10]. Following information provided by wire producers and complying with the aforesaid guidelines ensures the repeatability and appropriate properties of welds. Regrettably, welding practice shows that the above-named conditions are not always satisfied in production plants, particularly during welding works performed outdoors (e.g. in shipyards or when building pipelines). Reels with wire are sometimes kept outside stores and, in situations requiring the continuous availability of FCAW processes, for a long time after unwrapping. Particularly detrimental conditions include continuous exposure to humidity, high temperature and light or the vicinity of seawater [11]. An additional risk factor is the presence of dust, fume and other contaminants which settle on the surface of wires and contribute to their accelerated degradation.

Storage-triggered changes taking place in wires are often perceived as phenomena affecting only external coils. For this reason, one of the most typical recommendations is the removal of the external coils, after which it is possible to perform welding processes in accordance with related welding procedure specifications. The above-presented procedure is proper in cases of joints which are not crucial or in cases of slight changes affecting the wire surface. In other cases it is necessary to consider possible storage-related effects and how they might influence the quality of welded joints. Based on the overview of reference publications (including the analysis of recommendations formulated by manufacturers of filler metal wires) and scientific articles, the authors' primary objective was to characterise main problems resulting from the storage of flux-cored wires. The aforesaid overview included issues concerning the condition of flux-cored wires, the course of the welding process and the properties of welded joints.

External surface of flux-cored wires

The first easily noticeable and negative effect resulting from the storage of flux-cored wires is the changed appearance of their external surface (Fig. 1). The aforesaid phenomenon does not affect the functional properties of the material, yet it may indicate changes which have taken place in the material. Obviously, changes depend on types of wires; e.g. the reaction of copper-clad wires to environmental factors could be different to that of non-copper-clad wires. The most common change is surface

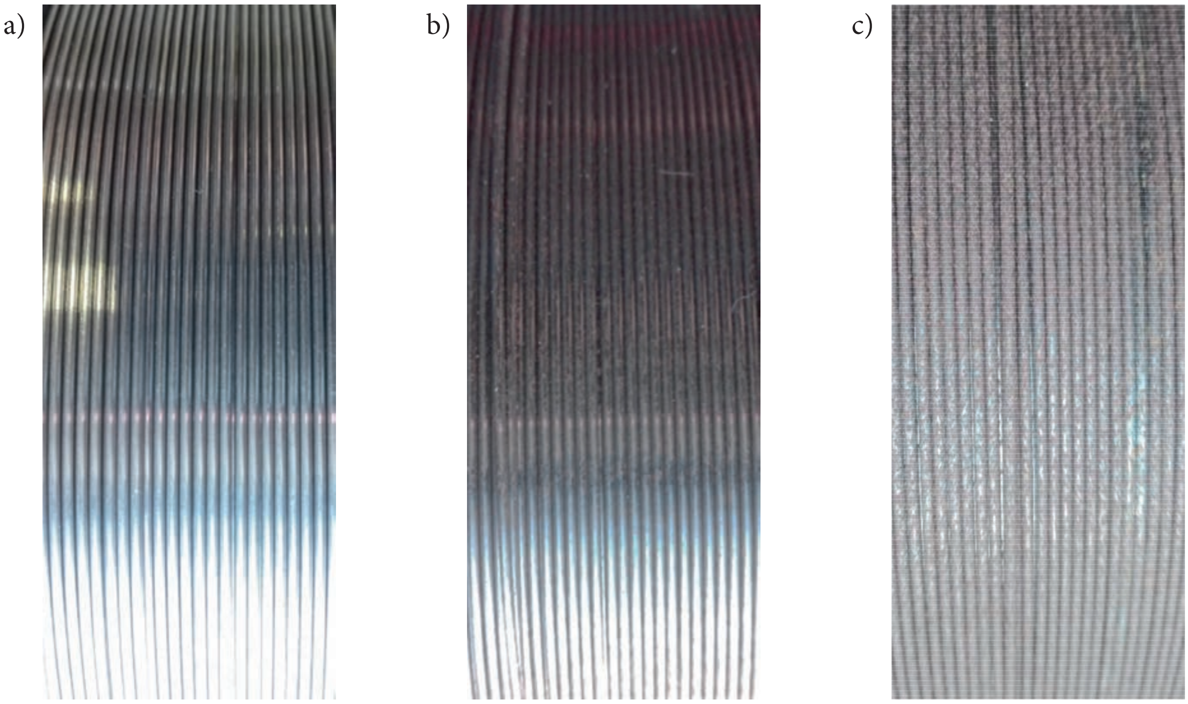

Fig. 1. Flux-cored wire surface: a) in the as-received state, b) after 1 month of storage and c) after 6 months of storage

tarnish (presented in Figure 1b). The aforesaid change is sometimes invisible for users as it is a gradual process requiring the comparison of the wire surface with that of new wires. Other changes noticeable on the wire surface are corrosion spots, resulting from the exposure of wires to environmental factors (e.g. water condensing on the wire surface) or users' inattention (fingerprints left on wire reels) (Fig. 2). In cases of more aggressive conditions or longer storage times, corrosion processes affect not only the entire external surface of coils but also reach internal coils of the wire (Fig. 1c).

Surface changes are also noticeable in the microscopic scale. Some of such changes can be seen both by the unaided eye and under the microscope (although it is not always possible). Interestingly, some wires, the surface of which does not contain any traces of degradation are covered with fine precipitates of corrosion products. In cases of coper-clad wires, the outer layer of copper may become thinner and, gradually, contain defects (Fig. 3). Similar changes were observed on coper-clad wires after monthly storage under industrial and rural conditions [12]. The surface of wires stored in

Fig. 2. Corrosion products on the wire surface in the area touched with the finger

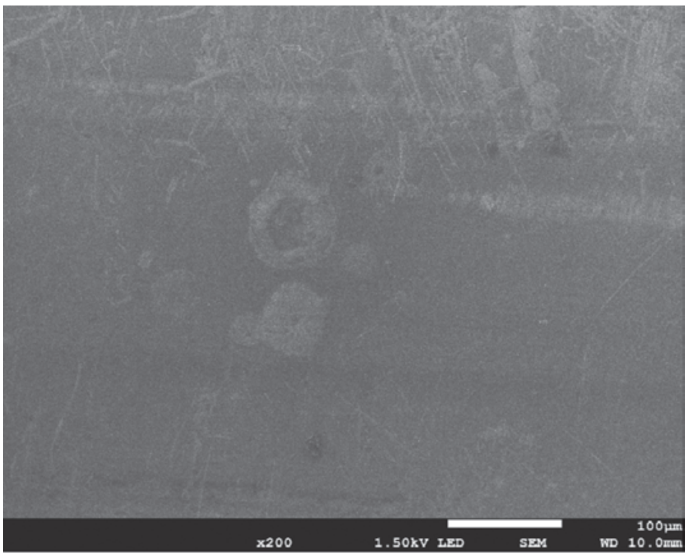

Fig. 3. Photograph (SEM) of the copper-clad wire surface

the less aggressive environment did not, seemingly, contain any traces, yet observations performed using a scanning microscope revealed the presence of corrosion products, particularly in microcracks located on the wire surface.

Properties of flux-cored wires

One of the storage-triggered effects, not always easily verifiable by the welder, is the change of properties including, electric conductivity, tensile strength, plasticity, etc. It should be noted that the aforementioned changes may affect the wire along its entire length (which could be particularly problematic in cases of automated or robotic welding processes). Storage conditions may also affect the "targetability" of the wire, manifested by a higher tendency to break in the feeder or "curling" in the spiral, thus generating down time, necessitating the retooling of machines or leading to the formation of imperfections.

Mechanical properties of flux-cored wires depend primarily on the chemical composition of the cover and the wire manufacturing process. The rolling or drawing of wires requires the adjustment of appropriate plastic working parameters enabling the obtainment of product free from imperfections and characterised by properties allowing application in various feeders [13, 14]. Improper storage conditions may lead to wire properties other than those designed by the manufacturer. The change of wire plasticity and strength is presented in Figure 4. During 6 month long storage, the non-coper-clad wire with the seam (used in the welding of unalloyed steels) was exposed to variable humidity and temperature, other than those recommended by the producer. The storage led to a slight increase in tensile strength and, at the same time, a decrease in elongation (from an average value of 3.45 mm to that of 2.95 mm). The aforesaid change should not directly affect the strength or plasticity of joints made with such a wire, yet it could potentially result in increased joint heterogeneity caused by the impeded leading of the wire in the feeder.

Wires stored under improper conditions may "develop" different electric conductivity. After unwrapping, two grades of rutile flux-cored non-copper-clad wires were stored in a production shop for a period of 1 and 3 months. After the aforesaid time, the wires were checked for their resistance. To eliminate the effect of temperature, the measurement was performed simultaneously in relation to the new and stored wires, where the result was presented as a relative value (Fig. 5). Already one month long storage increased the resistance of both wire grades. Protracted storage led to the further growth of resistance of the stored wire in comparison with that of the new wire. Although the changes were slight, they clearly indicated

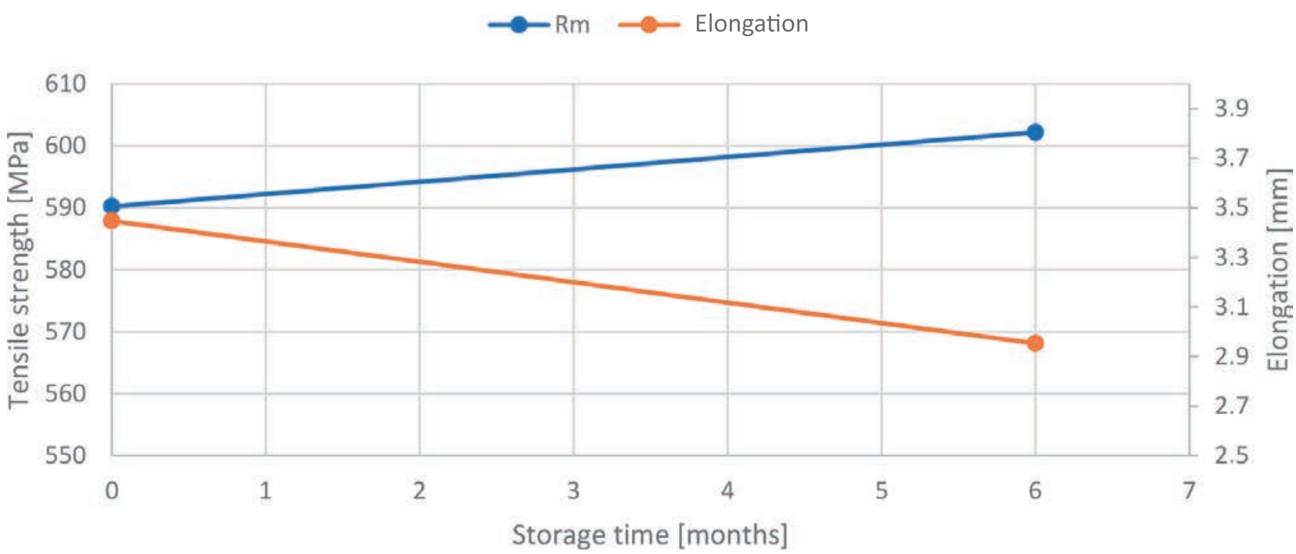

Fig. 4. Change of the tensile strength and elongation of the flux-cored wire

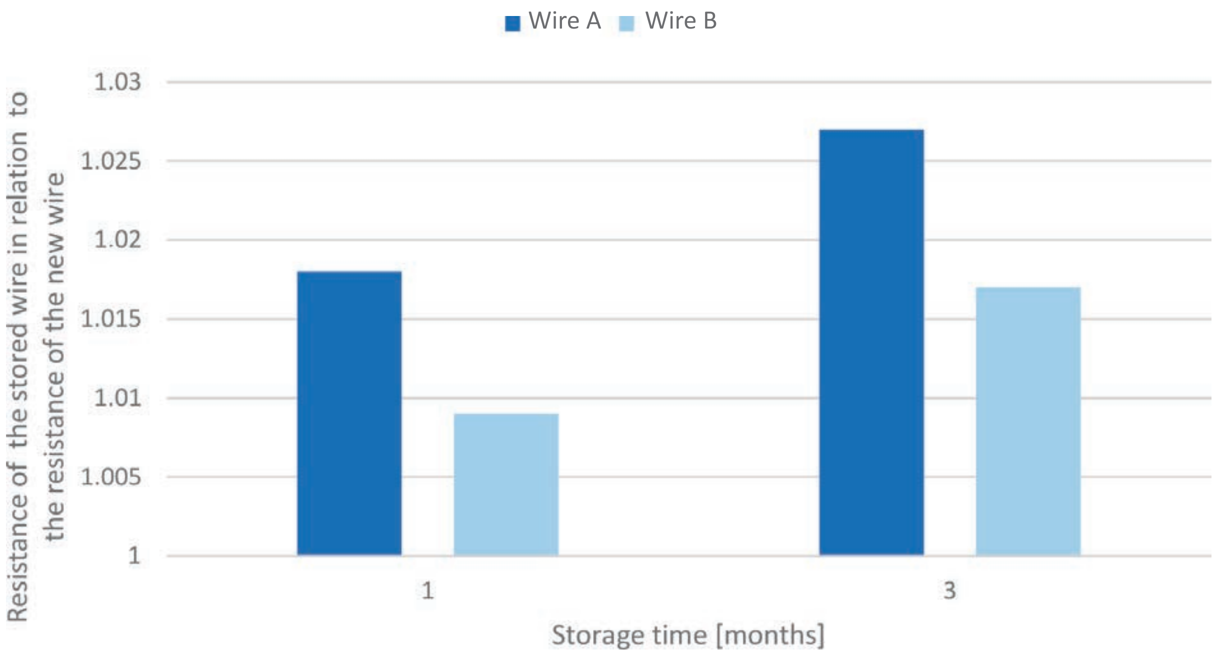

Fig. 5. Change of the relative resistance of the two wire grades after storage

the mechanism occurring during the storage of wires. Appropriate electric conductivity is a key material characteristic as regards arc burning stability. The increased resistance of the filler metal wire translates into greater heat emitted during the burning of arc, thus accelerating the melting of the wire.

Arc burning stability

Because of the fact that flux-cored wires are not finished products of manufacturing processes, their changed appearance or properties do not necessarily affect the quality of welded joints. However, the aforesaid changes may influence the course of the welding process and, as a result, also have an impact on joints. High arc burning stability is the precondition ensuring the continuous welding process and the repeatability of production parameters and conditions. The assessment of dynamic changes of parameters necessitates the determination of various indicators such as, for instance, the coefficient of variability [15, 16]. Related tests revealed that even one month long storage of wires under improper conditions could affect arc burning stability. Figure 6 presents changes of arc voltage during welding performed using two different flux-cored wires. One of the wires (blue) was stored under conditions recommended by the producer. Changes of voltage were restricted within the range of +/- 0.2 V, whereas the value of variability coefficient amounted to 0.41. The welding process is always accompanied by slight changes of parameters, e.g. resulting from the

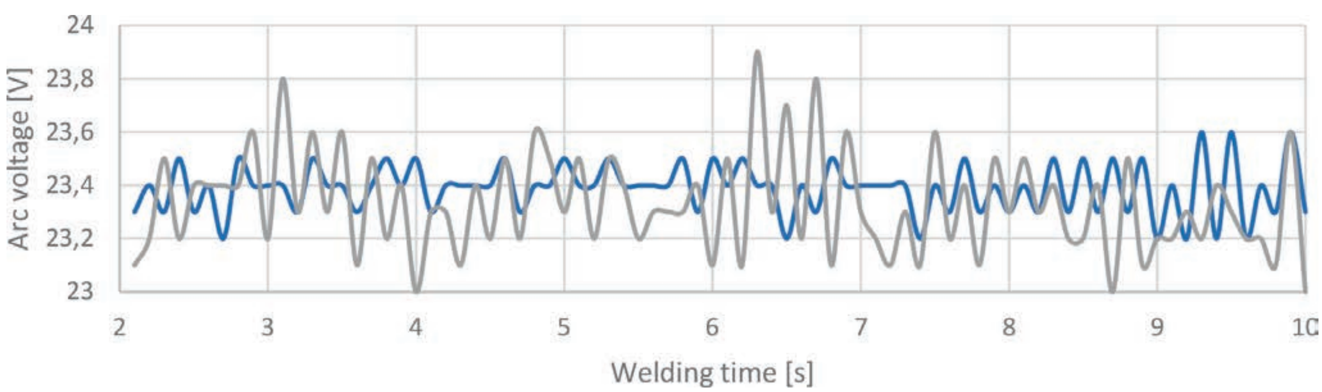

Fig. 6. Changes of welding arc voltage

transfer of liquid metal drops to the weld pool. However, the smaller the above-named changes and the lower the value of the variability coefficient, the more stable the process. The second wire (grey) was not stored under recommended conditions. In this case, the difference between the maximum and minimum value of arc voltage amounted to 0.9 V, whereas the value of the variability coefficient increased to 0.83. The above-presented change indicated the worsening of arc burning stability in comparison with that "offered" by the first wire.

Content of diffusive hydrogen

An important factor affecting properties of welded joints is the content of hydrogen diffusing in the weld deposit [17, 18]. In turn, the most important factors influencing the content of hydrogen include the condition of the base material, the condition of the filler metal as well as conditions and parameters of the welding process [19, 20]. Flux-cored wires used in FCAW processes are usually produced in class H5 or H10, which means that the amount of hydrogen cannot exceed 5 ml or 10 ml in 100 grams of the weld deposit. The storage of the wire outside its wrapping may also significantly affect the hydriding of the weld deposit. The intensity of hydrogen seepage into the flux-cored wire depends on the time of exposure to environmental factors including, among other things, relative humidity and ambient temperature. Other important factors include the form of the wire (e.g. a tube or a rolled strip filled with flux) and the fact that producers use various strip closing techniques. Figure 7 presents results of measurements concerning hydrogen diffusing in the weld deposit in relation to five different flux-cored wires both new and stored for some time. The initial hydrogen content in the wires did not exceed 6 ml/100 g. After 2 months following the unwrapping of the wires, all hydrogen content-related values were higher; in cases of three wires the aforesaid value grew by more than twice. In three cases, the limit value (amounting to H10) was exceeded.

Weld deposit strength

In welding practice, significant emphasis is given to mechanical properties of welded joints, determining the applicability of a related welding procedure specification. As regards regular-strength and high-strength steels, value Rm of the weld should be higher than that of the base material. The foregoing indicates that the assessment of weld deposit strength constitutes

Fig. 7. Content of diffusive hydrogen in the weld deposit in relation to new and stored flux-cored wires

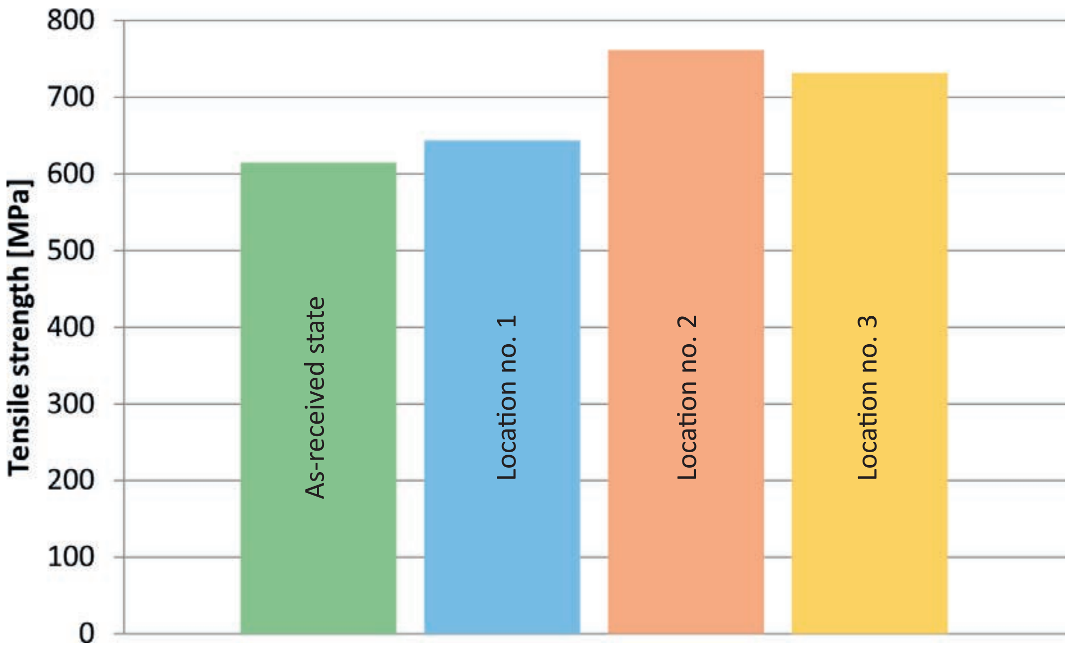

Fig. 8. Tensile strength of the weld deposit obtained using the rutile flux-cored wire

an important factor affecting the selection of filler metals. Welding performed using flux-cored wires may lead to the obtainment of joints characterised by higher strength, yet by lower toughness than that obtainable using solid wires [21]. A rutile flux-cored wire with the seam was used in investigation aimed to prepare specimens for weld deposit-related tensile tests performed in accordance with the procedure described in article [12]. For one month, a given wire grade was stored in three different locations, i.e. location no. 1 – industrial area, location no. 2 – shipyard area and location no. 3 – urban area. The average values concerning the strength of weld deposits obtained using the wires are presented in Figure 8. The wires which underwent partial degradation resulting from storage under uncontrolled conditions did not tend to worsen value R_m of weld deposit. In relation to each location it was possible to observe an increase in value R_m. The lowest increase, i.e. by approximately 30 MPa, was observed in location no. 1. In turn, the shipyard location was connected with the greatest increase of R_m (i.e. by more than 100 MPa). The above-presented values were very favourable as regards the applicability of the filler metal wires, yet it should be remembered that strength is one of many factors affecting the selection of filler metal wires.

Summary

The use of flux-cored wires under conditions inconsistent with producers' guidelines carries the significant risk connected with the worsened quality of welded joints. The storage of wires may change their surface condition, resistance, strength, plasticity as well as affect arc burning stability, the content of hydrogen diffusing in the weld deposit and its tensile strength.

Related tests aim to identify correlations between environmental conditions, chemical compositions and the development of corrosion changes [22]. Factors triggering changes of properties of flux-cored wires are numerous and include, among other things, the form of the wire and its chemical composition, temperature and relative humidity in the area of storage, air pollution, time of exposure to environmental factors, user's carelessness, etc. The aforesaid factors often lead to the non-homogenous degradation of wires. Most of the changes visible on the surface can be noticed by the welder before welding, thus enabling the removal of a damaged wire fragment before the process. However, in cases of certain materials, the condition of the surface reflected by microscopic changes does not directly translate into changes of properties of the wire and those of weld deposit. Wires satisfying criteria of visual tests are characterised by high contents of hydrogen diffusing in weld deposit or by inferior plasticity. It may also happen that wires with the visibly tarnished surface (implying degradation) will only slightly affect arc burning stability in comparison with new wires.

The storage of flux-cored wires under various conditions will not always have the same significance as, for instance, the level of process automation may require different wire characteristics affecting the course of the process. Robotic welding requires the significantly higher repeatability of parameters, which may change dynamically along with the locally changed resistance of the wire. In the above-named case, down time resulting from the breaking of the wires (characterised by changed strength or plasticity) could be more expensive than that occurring during manual welding.

The above-presented summary of the current state-of-the-art as well as the results of individual studies confirm that the proper storage and transport of welding materials are preconditions which must be met in order to make welded joints satisfy strict requirements specified in related standards, regulations and guidelines. Taking into account the widespread use of flux-cored wires and frequently reported steel weldability-related problems resulting from the improper handling of flux-cored wires it is important to perform related tests and disseminate test results concerning the storage of wires and its consequences.

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