The optimization of welding regimes for obtaining corrosion resistant welded constructions

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Abstract. Most of the technological equipment has welded metal structures in its composition, which are strongly affected by the corrosion phenomenon. In order to achieve a reduction of the corrosion phenomenon it is very important that the welded joints are made using optimal parameters of the welding regime. In the research were made 6 different welded specimens, respectively 3 for the welded T-shaped joint and 3 for the cross-welded joint. The welded joints were made of 10 mm thick using S 355JR steel by the MAG welding process and using welding wire G4 Si 1 as an additive. For the 6 specimens were made analyzes of the metallographic structure thus observing what are parameters of the welding regime that allows to obtain the welded joints with high corrosion resistance.

1 Introduction

The presence of the corrosion phenomenon is influenced by environmental conditions and manufacturing technologies and may result in the dismantling of very large equipment. Also, the metallographic studies performed in the case of low alloyed steels have shown that the size, shape and orientation of the crystalline grains have an influence on the corrosion behavior, and the size and orientation of the grains is influenced by the parameters of the welding process [1-3]. It is known that reducing the size of the metallographic grains leads to improved wear and corrosion resistance of a low-alloy steel. By reducing the grain size, a change is made both in the volume and the shape of the surface of the material, which ultimately results in changes in the density at the limit of the metallographic grains, the orientation and the residual stresses [4]. Changes in shape of the surface of the materials can have an impact on electrochemical behavior and therefore on corrosion susceptibility, as evidenced by the large number of studies on the effect of granule size on corrosion, covering a range of materials and test environments [5, 6]. However, there are still limited studies on the development of a fundamental understanding of how the size of a metallographic grain affects the corrosion resistance of a steel. The results of experimental research are often contradictory, even within the same alloy class, and a coherent understanding of how the crystalline grain dimension influences the corrosion resistance of materials is largely missing [7].

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An analysis of the research on the relation between granule size and corrosion resistance for a number of light metals (Mg, Al and Ti) and transition metals (Fe / Steel, Co, Ni, Cu and Zn) has allowed identifying a number of critical factors such as environment, texture, residual stress and segregation of impurities, that should be considered to assess whether and how the variation in the size of crystalline grains may affect the electrochemical behavior of a specific alloy in a particular environment [8-10].

Thus, the best corrosion resistance of welded joints was obtained for two steels having a chemical composition of 1.92 % Mn and 0.02 % Ti respectively 1.40 % Mn and 0.08 % Ti. For these types of steels, an increase in the proportion of acicular ferrite in the microstructure was obtained by the addition of titanium in the range of 0.02-0.08 %. Also by the addition of manganese in the chemical composition a refining and homogenization of the welding wire microstructures was obtained [11-12]. The increase in welding capacity is due to the addition of titanium or manganese, and this encouraged to obtain a bainite structure with a higher frequency than a metallographic structure made of acicular ferrite. Also, the amount of manganese in inclusions decreased by adding titanium to the welding. Impact resistance of the welded structure can increase if the chemical composition has been improved by the addition of titanium, but also under these conditions the tendency of fracturing does not completely disappear [13-15].

On the basis of the analyzed ones, the main objective of the paper is the establishment of optimal parameters of the welding regime, allowing the obtaining of metallographic structures made of grains as smooth as possible to create the conditions for a higher corrosion resistance. Thus, 6 specimens of S355JR steel were made in the shape of a cross and T-shape with different welding regimes and thus there could be established the welding regimes which allow an increase in corrosion resistance.

2 Materials and methods

Thus, in order to obtain the most corrosion-resistant metallic constructions, in the research there was aimed to obtain the optimization of the parameters of the welding technological process. This is due to the fact that for certain parameters of the welding process, metallographic structures for the welded joint can be obtained providing a high corrosion resistance. In the experimental research, S355JR steel was used as the base material. Thus, the base material used to make the welded joints was a low alloyed steel S355JR having the mechanical properties shown in Table 1.

Table 1. The mechanical properties of S355JR steel.

Yield strength MPa	Tensile strength, MPa	Elongation %	Breaking energy KV J
355	470 - 630	22	27

The specimens were made by applying the MAG welding method using welding wire type G4 Si 1 as an addition material according to EN ISO 14341-A with a diameter of Ø 1.2 mm, and the characteristics of the additive material are shown in Table 2, chemical composition, respectively Table 3 mechanical properties.

Table 2. The chemical composition of the welding wire G4 Si 1.

C %	Si %	Mn %
0.06 – 0.14	0.8 – 1.2	1.6 – 1.9

Table 3. The mechanical properties of the welding wire G4 Si 1.

Yield strength MPa	Tensile strength MPa	Impact resistance (ISO – V/40°) J	Elongation at break (Lo=5Do) %
min. 500	560 - 720	min. 47	min. 25

The choice of the MAG welding process has been made taking into account its degree of universality as well as the variety of base materials that can be welded. It is worth mentioning that in this process, depending on the diameter of the welding wire, a high deposition rate of material can be achieved which can reach up to about 10 kg/h. Another characteristic of this welding process is the efficient use of the addition material, which leads to the obtaining of suitable welding wires. The MAG welding process is currently most commonly used in industrial applications due to economic advantages compared to other welding processes.

In order to obtain a high efficiency of the welding process and an adequate penetration, in the experimental researches the welding parameters presented in the Table 4 were used.

Table 4. The parameters of the welding process.

CO_2 protective gas / %	Type of transfer	Wire feed speed, V_f/ m/min	Welding speed, V_w / cm/min	Protective gas flow rate D_g / l/min	Linear energy / KJ / mm
100	spray-arc	10	70	20	0.86

There were made 6 specimens of 10 mm thick sheets with different values for the welding current intensity I_w respectively the welding voltage U_w and various constructive forms:

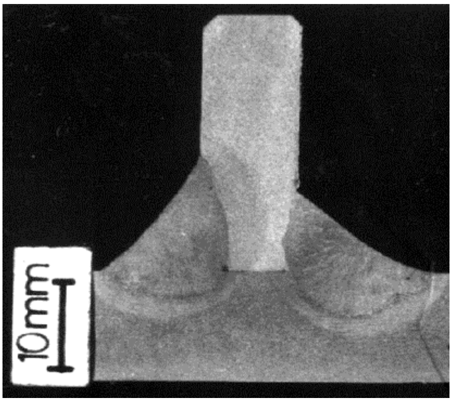
- sample 1 - welding of the corner in T, the welding regime being; I_w = 195 - 210 A; U_w = 21 - 22 V, so a low welding regime;
- sample 2 - welding of the corner in T, the welding regime being: I_w = 210 - 220 A, U_w = 23 - 24 V, so a low welding regime;
- sample 3 - welding of the corner in T, with intense welding regime, I_w = 220 - 235 A, U_w = 25 - 27 V,
- sample 4 - welding in the form of a cross, the welding regime being; I_w = 195 - 210 A; U_w = 21 - 22 V, so a low welding regime;
- sample 5 - welding in the form of a cross, the welding regime being; I_w = 210 - 220 A; U_w = 22 - 24 V, deci un regim redus de sudare;
- sample 6 - welding in the form of a cross, with intense welding regime, I_w = 220-235 A, U_w= 25-27 V.

3 Results and discussions

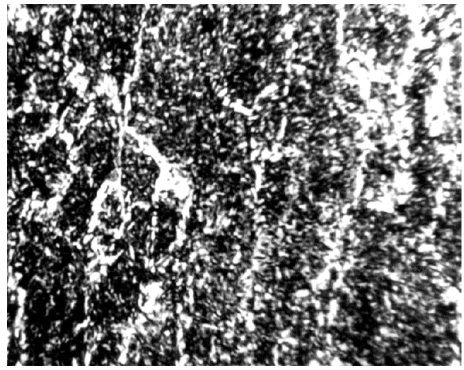
The realization of the 6 samples with the welding regimes and in the constructive forms presented was decided because the most corrosion-damaged welds are T-shaped and cross-welded joints. Also, three different welding regimes were considered in the research to determine the welding regime that would allow metal welding structures to achieve the best corrosion resistance.

All 6 samples were subjected to an analysis of the metallographic structure and the results obtained were the following:

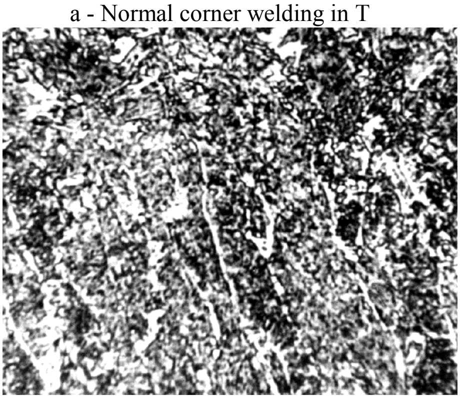
Sample 1 - From the analysis of the metallographic structure of the sample the following were observed: in the addition material, Figure 1.b, in addition to ferrite and perlite with acicular ferrite, fine sorbite appears; the same constituents also appear in the HAZ, Figure 1.c, in a proportion of 60/40% to 35/65%, and an increase of the actual grain size from 6 - 7 to 8 is observed as get away from the area of the addition material; in the base material, Figure 1.d., is presented the ferrite and perlite in rows with the proportion of 30/70%, with grains of size 6-7, but also with some acicular ferrite intercalations.



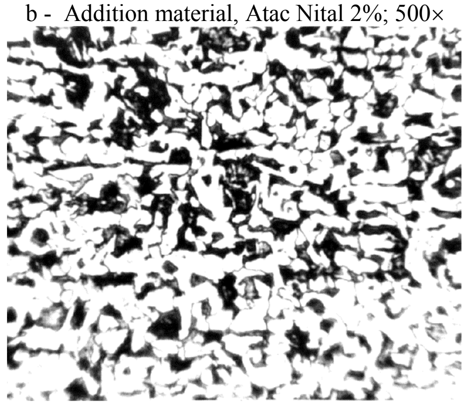
a - Normal corner welding in T



b - Addition material, Atac Nital 2%; 500×



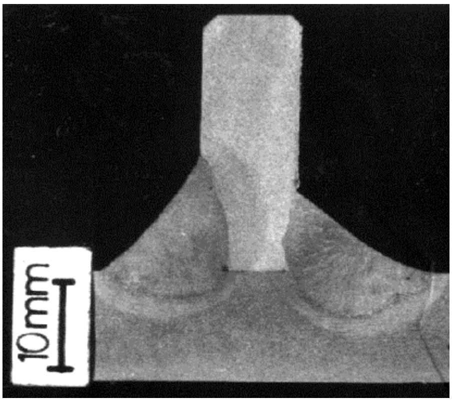
c - the heat-affected zone, HAZ, Atac Nital 2%; 500×



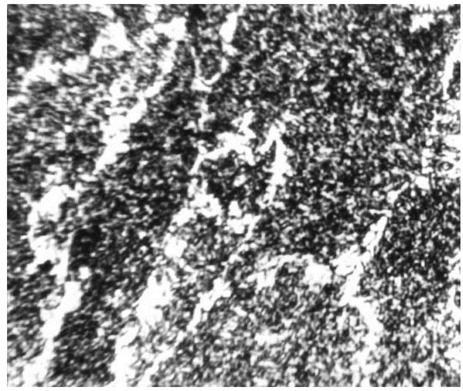
d - Base material, Atac Nital 2%; 500×

Fig. 1. The metallographic structure of the materials from the corner welded joint in T - sample 1.

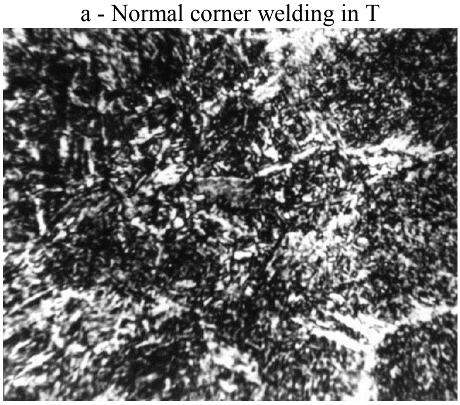
Sample 2 - The welded joint, obtained under the specified technological conditions, was subjected to metallographic analysis and there were observed the following: in the addition material, Figure 2.b, appears ferrite, perlite and fine grain sorbite with elongated grains; in the heat-affected zone (HAZ), Figure 2.c, structural elements of ferrite, perlite and acicular ferrite type with fine bainite are present, the proportions being between 30/70% to 60/40% in different areas, with the real grain size 6 - 7 and even 8 in the overheating sub-zone; in the base material shown in Figure 2.d, the ferrite and perlite are present in laminating strings with a proportion of 25 - 30/75 - 70% with a real grain size of 5 - 6.



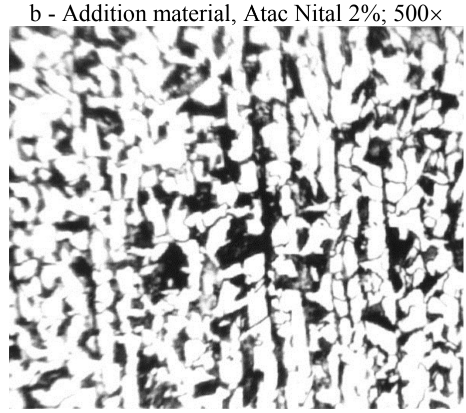
a - Normal corner welding in T



b - Addition material, Atac Nital 2%; 500×



c – the heat-affected zone, HAZ, Atac Nital 2%; 500×

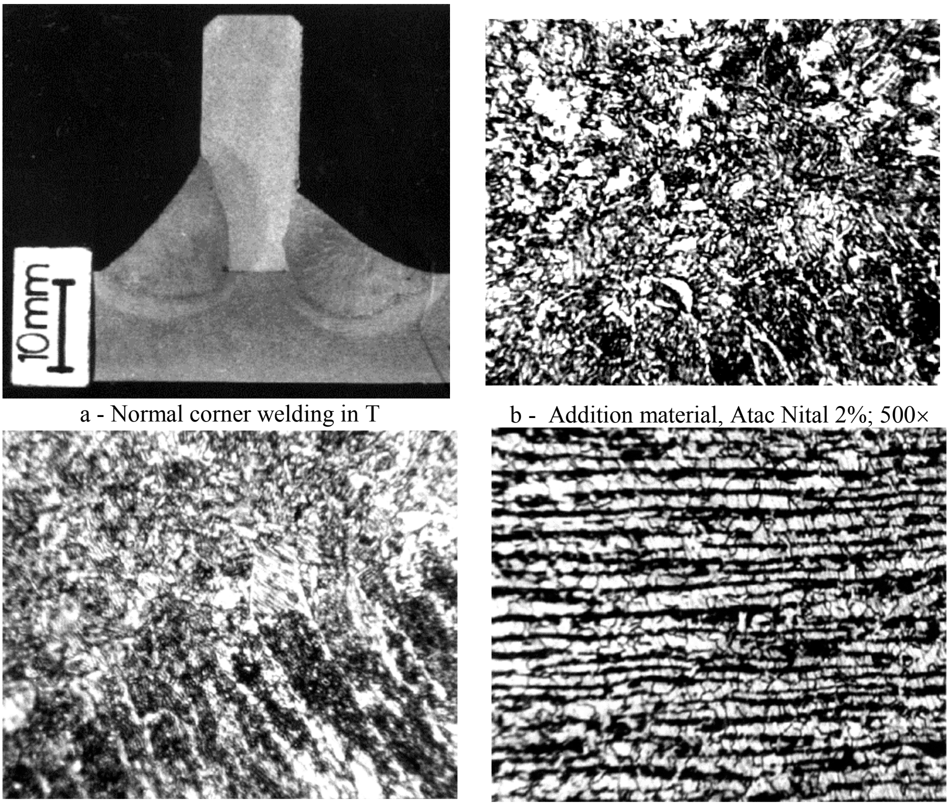


d - Base material, Atac Nital 2%; 500×

Fig. 2. The metallographic structure of the materials from the corner welded joint in T - sample 2.

Sample 3 - The metallographic analysis of the welded joint obtained under the specified technological conditions allowed the following findings to be issued: in the heat affected zone, HAZ, Figure 3.c, the structure presented is formed by perlite and acicular ferrite, grains of size 5-6 in proportion 50/50% , also in the heat affected zone it was found that the ferrite / perlite ratio drops from 50/50% to 35/65% to the peripheral areas; in the addition material, Figure 2b, there are presented perlite strings in ferrite clouds and a grain size of 7; the basic material Figure 3.d has a metallographic structure formed ferrite and perlite in 30/70% laminating strings with a real grain size of 3-4.

Sample 4 - From the analysis of the metallographic structure of the welded joint the following were found: the material of addition, Figure 4.b has elongated grain of ferrite, perlite and fine sorbite, the size of the real grain being 7 - 8 but reaching in some areas even 9-10; in the heat-affected zone (HAZ), Figure 9.c is presented the ferrite and perlite in rows in the proportion of 20/80 - 35/65% with a grain size 3-4; the basic material, Figure 9.d, has a metallographic structure made of ferrite and perlite in a proportion of 30/70 - 40/60% with a real grain size of 7 - 8.



a - Normal corner welding in T

b - Addition material, Atac Nital 2%; 500×

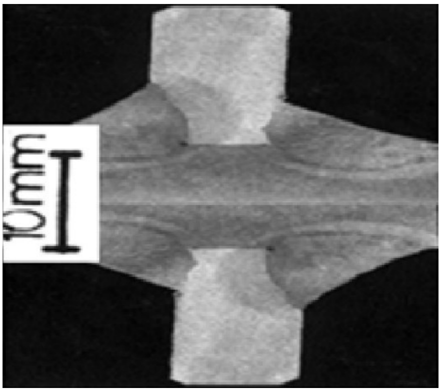
c – the heat-affected zone, HAZ, Atac Nital 2%; 100×

d - Base material, Atac Nital 2%; 500×

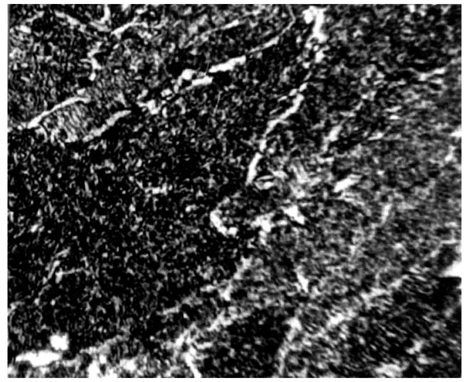
Fig. 3. The metallographic structure of the materials from the corner welded joint in T - sample 3.

Sample 5 - The welded joint obtained was subjected to a metallographic analysis and the following was found: the addition material, Figure 5.a, has a metallographic structure made of ferrite, perlite and sorbite with elongated grains in the direction of cooling; the metallographic structure of the heat-affected zone (HAZ), Figure 5.b, is made of ferrite and perlite with lamellar ferrite and sorbite close to the addition material, but with removal from the metal bath area the proportion increases from 35/65 to 70 / 30% with a real grain size between 5 - 6 to 7 - 8; the base material whose metallographic structure is shown in Figure 5.d is made of ferrite and perlite in a proportion of 30/70 - 40/60% with a real grain size of 6 - 7.

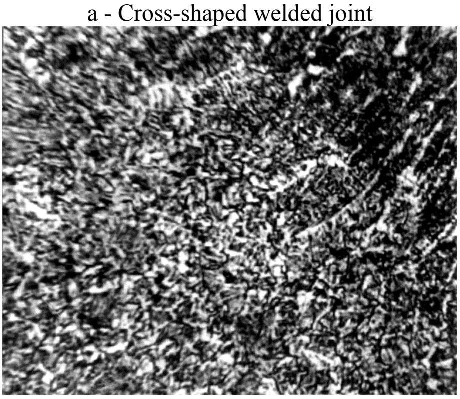
Sample 6 - From the analysis of the metallographic structure of the welded joint thus obtained, the following were found: addition material, Figure 6. b has a metallographic structure made of elongated ferrite and perlite grains, but there is also fine sorbite due to intense cooling; in the heat-affected zone (HAZ) there is ferrite and perlite which occur in a proportion of 20/80 to 70/30% with a real grain size of 4 - 5 to 6 - 7 and to the metal bath area the acicular ferrite appears; in the base material, Figure 6.d, there is a metallographic structure made of ferrite and perlite in a proportion of 25/75% with a real grain size of 4 - 5, and in certain areas there is also acicular ferrite.



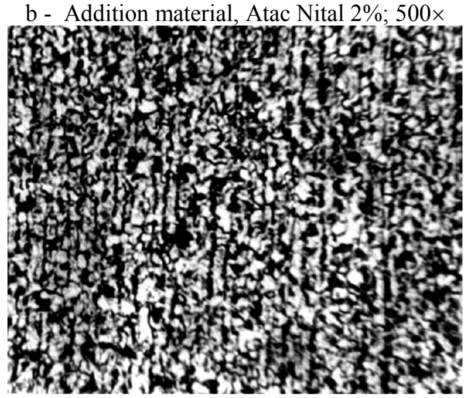
a - Cross-shaped welded joint



b - Addition material, Atac Nital 2%; 500×



c – the heat-affected zone, HAZ, Atac Nital 2%; 500×

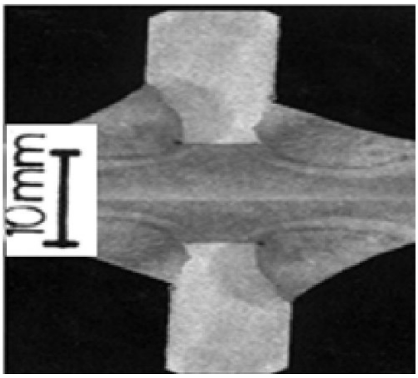


d - Base material, Atac Nital 2%; 500×

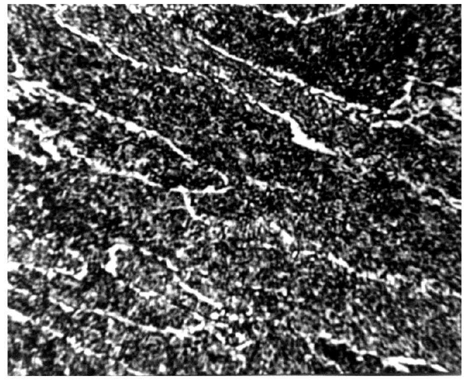
Fig. 4. The metallographic structure of materials in the cross-shaped welded joint - sample 4.

By applying the MAG welding process and the various welding regimes for obtaining the 6 samples, it was established that the parameters of the welding regime substantially influence the proportion of the constituents in the metallographic structure of the welded joints. Thus, depending on the metallographic analysis area, different proportions of ferrite, perlite, fine sorbite, fine bainite have been identified. Also, in some welding regimes, metallographic structures with elongated grains have been obtained in the direction where the cooling rate is maximal.

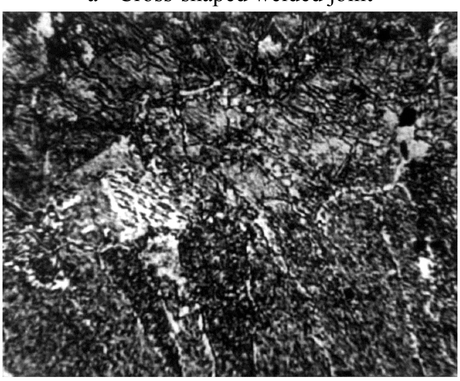
Thus, welded constructions must be made in compliance with certain parameters of the welding regimes. It has also been observed that in the case of the use of certain welding regimes, fine granulations can be obtained in the area of the welded construction which allow the creation of the conditions for the slowing of the phenomenon of cracking corrosion. It has been noted that the size of the grains in the cross-welded joint is greater than in the case of the T-shaped corner joint. This can be explained by the fact that the deposition of a larger number of welding cords causes an increase in the temperature of the material in the welding zone bath. This temperature rise may cause the limit of the AC3 curve to be exceeded, and if the temperature is maintained for a long time beyond this limit then conditions for increasing the crystalline grains are created. In order to obtain a metallurgical structure with fine corrosion resistant grains, besides optimization of the welding regimes, it is necessary to determine the succession of depositing the welding cords so that the temperature in the welding area is as small as possible.



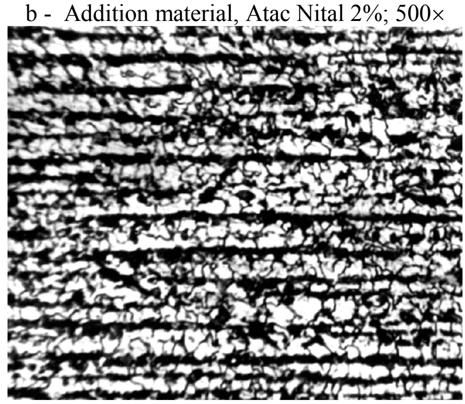
a - Cross-shaped welded joint



b - Addition material, Atac Nital 2%; 500×



c – the heat-affected zone, HAZ,
Atac Nital 2%; 100×



d - Base material, Atac Nital 2%; 500×

Fig. 5. The metallographic structure of materials in the cross-shaped welded joint - sample 5.

4 Conclusions

From the analysis of the results obtained in the research it was possible to conclude the following:

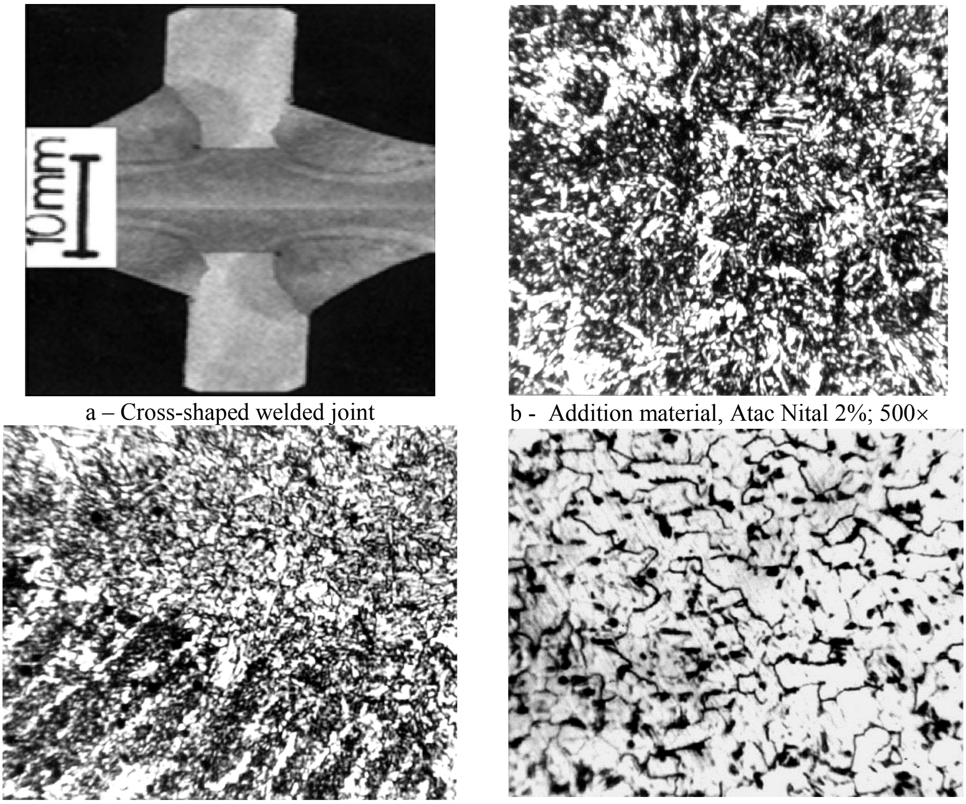
- in order to show the corrosion phenomenon to manifest itself with the lowest possible intensity, it is indicated in the area of welded joints to obtain metallographic structures with grains as fine as possible;

- the use of intense welding regimes may allow fine grain to be obtained in the welded joint area, but provided that the deposition of the welding cords is done in a certain succession in order to avoid the occurrence of the overheating phenomenon;

- from the analysis of the metallographic structure of corner T-shaped and cross-shaped welded joints made with certain welding regimes, it has been observed that an increase in the value of welding parameters results in a fine grain in the welded joint area but up to a certain limit;

- the crystalline grains are smaller in the case of T-shaped welded joints than cross-welded welded joints, and this can be explained by the fact that cross-welded joints may cause overheating of the welded joint area;

- in order to reduce the corrosion phenomenon of welded constructions it is necessary to use semi-finished products of steel with the finest grain and the welded joints to be made with optimal welding regimes with the deposition of the welding cords in a certain sequence in order to avoid the appearance of overheating.



a – Cross-shaped welded joint

b - Addition material, Atac Nital 2%; 500×

c – the heat-affected zone, HAZ, Atac Nital 2%; 500×

d - Base material, Atac Nital 2%; 500×

Fig. 6. The metallographic structure of materials in the cross-shaped welded joint - sample 6.

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