Research on determining the state of stress by the finite element method in rehabilitation the welded structure

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Abstract. The study of stress is a very important problem especially in the case of welded structures. Very often the main causes of their failure are represented by the overlap of the stresses during operation with the remaining ones during the welding process. The article presents in the first part the experimental activity that regarding the realization of some fillet welded joints remedied by two processes that aim at reducing the internal stress. In the second part of the article, starting from the experimental part presented, a model was made by the finite element method. Based on it the different states of tension resulted in the initial structure as well as in the rehabilitated ones were simulated.

1. Introduction
Welded structures are widespread in the industrial field and are found in various products in the form of metal fabrications such as farms, beams, bridges, support frames for machine tools, crane structures, resistance structures for various aircraft. We can therefore say that this non-removable assembly process by welding is very widespread in the industrial environment and has successfully replaced, as we well know, riveting.

Welding comes with a number of advantages such as material and labor savings, welding processes are easy to apply, offer high mechanical strength, welding processes can be automated, you can get a superior quality of welded joints, it offers the possibility in order to obtain lighter constructions and with simpler constructive forms, it is possible to use technological and processing additions that are 70-90% smaller than other manufacturing processes, for example compared to casting, complex parts can be made and not in the last instance, allows the realization of mixed or combined constructions, consisting of several parts made of different materials, by different processing processes and then assembled by welding.

The main disadvantages of welding are related to the following aspects: the introduction of stress concentrators, the quality of welded joints depends largely on the quality of materials used and the qualification of the welder, often the products obtained by welding must be subjected to post weld toe treatment and a rigorous control [1], welding machines and special equipment are required that have high costs, the equipment used for welding is complicated, difficult to maintain and have demanding work regimes and last but not least for welding there are radiations that are harmful to the human body.

Of all the disadvantages listed above, in industrial practice, the biggest disadvantage of welding is the introduction of stress concentrators. These stress concentrators are manifested as local stress peaks,
which overlap with the existing stress in the product, and can cause fracture damage, which in some cases can be catastrophic: bridge failures, failures of resistance structures of some equipment and so on [2]. Determining these stress concentrators is therefore of great importance. By knowing the values of the stress concentrators introduced by welding, we will know if they must be completely eliminated or if the respective welded structure can work safely with them, without the occurrence of failures. The welded structures required for fatigue are very sensitive to these stress concentrators [3]. These structures, fail to very low values of stress concentrators because the failure of these structures is made to low values of stresses, values located below the yield limit of the material from which the structure is made. For these fatigue loads, is very important the number of cycles with which the structure was load at a given time. Usually, at a number of stress cycles loads above $10^7$, we are dealing with gigacyclic stresses loads and the occurrence of fatigue. In order to occur the fatigue phenomenon, the loads must be variable, with a large number of stress cycles, more than $10^7$, the stresses in the structure must be below the yield limit and there must be a certain frequency of the stress.

The stress concentrators mentioned above can be internal such as cracks, pores, discontinuities in the material, metallic or non-metallic inclusions or external such as irregular or improper shape of the welding seams. A very great influence on the stress concentrators introduced by the welding seams, has their geometric shape. The geometric shape of the welding seams is important especially in the case of fillet and cruciform fillet welded joints, due to the uneven distribution of the lines of force. Unlike the case of fillet welded joints in which we have an uneven distribution of lines of force, in the case of butt joints, the distribution of lines of force is uniform and the influence of these stress concentrators is insignificant. Returning to the fillet welded joints, we can meet in practice welding seams with convex shape, with small radii of connection between the base and the filler material and therefore with high stress concentrators in that area, flat-shaped welding seams with connecting radii higher between the base and filler material and therefore with values of the stress concentrators lower than in the previous case and welding seams with concave shape, with large connection radii between the base and filler material and therefore with very small values of the stress concentrators. The three possible geometric shapes of the welding seams are shown in figure 1.

![Possible shapes of fillet welds: a - flat; b - convex, c - concave, k - welding bead leg; a - the apothem of the welding bead.](image)

Figure 1. Possible shapes of fillet welds: a - flat; b - convex, c - concave, k - welding bead leg; a - the apothem of the welding bead.

It is easy to understand that in industrial practice where we meet welded structures loaded for fatigue, we prefer fillet welded joints with concave geometric shape of welding seams.

Practice reveals many welded structures that have fillet welded joints with the convex geometric shape of the welding seams and that have been stressed over time with many stress cycles. Therefore, in the case of these structures, fatigue failure phenomena are expected to occur. Own research [4-6] has shown that the rehabilitation of these welded structures with fillet welded joints with convex geometric shape of the seams is possible and is cheaper than replacing that structure with a new one. There are several techniques for rehabilitating these welded structures, the most important of which are "Grinding weld toe technique" and "WIG remelting weld toe technique". The “Grinding weld toe” technique is described in figure 2.
Figure 2. Grinding weld toe technique 1 - finger cutter; 2 - vertical component; 3 - weld seam for rehabilitation; 4 - rehabilitated zone [5,6].

In this method, the grinding of the tip of the weld bead is done along the line of the intersection between the welded seam and the base material. The recommended tools for this technique are high speed finger cutters with tungsten carbide stones. Milling is done at a depth of 0.8-1.0 mm below the surface of the sheet or 0.5-0.8, below the deepest visible notch, at a total depth of 2 mm or 5% of the thickness of the sheet, which of them is smaller. Milling is done only at the top of the seam and not at the whole seam. The aim is to eliminate any surface defects. The angle of the milling cutter axis will be a maximum of 45° from the direction of travel, to ensure that the milling marks are perpendicular to the line of the welding tip.

The “WIG remelting weld toe” technique is described in figure 3.

Figure 3. WIG remelting weld toe technique 1- wolfram electrode; 2-gun protection nozzle; 3- inert gas flow; 4-rehabilitated piece; 5-area rehabilitated by WIG remelting [5,6].

The "WIG remelting weld toe" technique consists of melting the welding metal to a depth of about 2 mm along the welding tip, without adding filler material. The welding surface will be cleaned of rust and tundred. The tip of the electrode must be sharp and clean and must be positioned from 0.5 to 1.5 mm from the tip of the weld.

In the practical experiments the used parameters of the welding regime are presented in table 1.

| Row | Is [A] | Ua [V] | ts [s] | Lc [cm] | vs [cm/s] | Vas[m/min] | El [kJ/cm] |
|-----|--------|--------|--------|--------|----------|------------|------------|
| 1-3 | 225..230 | 20..22 | 90     | 40     | 0.5      | 5.5        | 8.1        |

In this paper we start from some experimental results published in other papers [4-6] and which are briefly presented in table 2.

Table 1. Used parameters of the welding regime.

The geometric elements of the welded seams, with and without reconditioning techniques applied are presented in figure 4.
Figure 4. The geometric elements of the welded seams with and without reconditioning techniques applied.

The values of the geometric elements of the welded seams, without reconditioning and with milling and WIG remelting reconditioning techniques are presented in table 2 [5,6].

Table 2. The value of the geometric elements of the welded seams with and without reconditioning.

| Without rehabilitation | Weld toe grinding | WIG remelting weld toe |
|------------------------|-------------------|------------------------|
| a = 11; K1 = K2 = 13   | a = 11; K1 = K2 = 13 | a = 11 K1 = K2 = 17  |
| R = 2                  | R = 3             | R = 9                  |

It is observed that: initially the K dimension had the value of 13 mm and the connection radius R = 2 mm; after milling the end of the cord, the legs remained the same, but the connection radius of the cord end was increased to R = 3 mm, and after the WIG remelting of the end of the cord, the dimensions of weld were increased to 17 mm and the connection radius at R = 9 mm. In all three cases, the thickness of the welded cord was a = 11 mm, and its shape was convex.

2. Stress calculation in the case of corner welding using FEM

The finite element method is currently a widely used research method that offers very useful numerical solutions in situations where the experimental part does not benefit from experimental working method [3]. Starting from the experimental data presented in table 2, the behaviour of a fillet weld was performed in several geometrical situations. Thus, figure 5 shows the state of S1 type stress in three situations. Figure 5(a) shows a convex fillet weld. Figure 5(b) shows the rehabilitation by “WIG remelting weld toe technique” in one part of the joint and in figure 5(c) the rehabilitation in both parts of the weld. As can be seen, at the interface between the base and the filler material, an important area appears in the first situation, which constitutes a stress concentrator (red colour) that decreases in size as the rehabilitation process takes place. The maximum value of the stress in this case is $S_1 = 0.1 \cdot E11 \text{ N/m}^2$.

Figure 5. S2 stress calculation: a – convex weld; b - WIG remelting on one side; c - WIG remelting on both sides.

The stress of type $S_1$ calculates mainly the tension state in the material. Figure 6 presents the $S_2$ stress (calculates an equilibrium stress between tensile and compression) first in the situation of normal welded seam. Here a stress concentrator on both sides can be observed.
In the figure 6(b) where a WIG rehabilitation is done, the stress concentrator is lower in width. In the third stage, with both rehabilitation zones, a relatively uniform stress is observed, stress concentrator disappeared and a $S_2 = 1.7 \cdot 10^6$ N/m$^2$ stress value is calculated.

![Figure 6](image)

**Figure 6.** S2 stress calculation: a – without WIG remelting; b – one side of the welded seam WIG remelting; c – two sides welding seam with WIG remelting.

The S3 stress (that mainly calculates the compression stress state) calculation shows the same dissipation state of stress when WIG remelting is performed. In the figure 7(c) the maximal stress value in the studied zone is $S_3 = 0.7 \cdot 10^9$ N/m$^2$.

![Figure 7](image)

**Figure 7.** S2 stress calculation: a – without WIG rehabilitation; b – one side of the welded seam rehabilitation; c – two side welding seam WIG remelting.

To decrease the stress level in the welded seam, the following technique provides two other seams deposited over the initial one. This is present in figure 8(a) and the WIG rehabilitation technology in figure 8(b). It can be seen how the value of the S1 stresses decreases from $0.99 \cdot 10^6$ N/m$^2$ to $0.8 \cdot 10^6$ N/m$^2$.

![Figure 8](image)

**Figure 8.** S1 stress calculation in the case of two supplementary welding seams: a - without rehabilitation; b - with WIG remelting.

For the S2 stress type, as we can see in figure 9, there is also a decrease of the values of the maximum tensile stresses, for example, from the value $S_2 = 0.3 \cdot 10^6$ N/m$^2$ to the value $S_2 = 0.15 \cdot 10^6$ N/m$^2$ in the case of WIG rehabilitation technology. If it is compared with the welding technique without the additional cords as we can see in figure 7, where the values of the maximum stresses S2 is $S_2 = 0.56 \cdot 10^6$ N/m$^2$ there is a decrease of the stresses at the value $S_2 = 0.15 \cdot 10^6$ N/m$^2$.

The deposition of the two additional cords followed by rehabilitation leads to a significant decrease in the level of stress.
From the point of view of the S3 type stress (figure 10), it is also noticed the decrease of their values in case of WIG rehabilitation from the value \( S_3 = 0.19 \cdot 10^9 \, \text{N/m}^2 \) to the value \( S_3 = 0.86 \cdot 10^9 \, \text{N/m}^2 \).

Figure 9. S2 stress calculation: a - two supplementary welding seams but without rehabilitation; b - with WIG rehabilitation.

Figure 10. S3 stress calculation: two supplementary welding seams but without rehabilitation; b – with WIG rehabilitation.

3. Conclusions
Rehabilitation techniques for welded seams are undoubtedly important methods needed to reduce the level of mechanical stress that are often the main cause of failure of welded structure failure [7]. Rehabilitation by the WIG remelting method is one of these working technologies and it is necessary to prove its validity. Do to this, the article presents the evaluation of the level of mechanical stresses in the situation of a fillet weld in which several types of welding seams were made followed by WIG rehabilitation. The evaluation of the stress layer was done successfully by the finite element method using the ANSYS software. There are thus significant decreases in stress values, discussed for each studied case.

4. References
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