The influence of welding parameters and welding rehabilitation techniques on the static loads resistance

C Babis¹, A Dimitrescu, O Chivu¹, A Semenescu¹ and V Petrescu²
¹University Politehnica of Bucharest-Romania, Department of Materials Technology and Welding, Blvd. Splaiul Independentei, No. 202, 060021, Bucharest, Romania
²University Lucian Blaga of Sibiu, 10 Victoriei Blvd., 550024 Sibiu, Romania

E-mail: claudiubbs@gmail.com

Abstract. It is well known and widely debated in the world literature the issue of improving the fatigue life of welded structures by applying “welding toe grinding” and “WIG remelting welding toe” rehabilitation techniques. With the aid of these techniques, we practically on the one hand decrease the stress concentrators from the intersection between the base material and the filler material, and on the other hand we obtain an increased fatigue life. At the same time, the welded structures and in particular the bridges in the welded construction are subjected to the variable loads that generate the fatigue phenomenon but also to the static loads, to which it have to satisfy some certain resistance conditions. In this regard, the present paper aims is to study the influence of the welding regime and of those two welding rehabilitation techniques “weld toe grinding” and “WIG remelting welding toe” on macrostructure, micro-hardness and static tensile test resistance. The above-mentioned influences will be studied in the case of cruciform welded samples, welded by the shielded gas welding process in a vertical position. It was chosen to study the cruciform fillet weld, because on the one hand this is the most common welded joint, and on the other hand it is one of the most susceptible to cracks and failures.

1. Introduction

Besides variable loads applied on welded structures, even static loads are another destabilizing factor.

In contrast to the case of variable loads that failure occur after a large number of load cycles, at tension values below the yield limit, caused by the fatigue phenomenon, in the case of static loads, for the occurrence of the damage, must be exceeded yield point and touch the tear resistance [1],[2],[3].

We considered this research to be done on the cruciform fillet welded joints, because in a welded structure, this type of joint shows biggest failure susceptibility.

Research is extracted from a large study in which 5 cruciform samples were used for welding, denoted by A; B; C; D and E, depending on the welding procedure used. On all samples were applied “weld toe grinding” and “WIG remelting weld toe” reconditioning techniques, and after that from each samples were extracted specimens for static tests [4],[5],[6],[7],[8].

The cruciform welded sample which is the subject of this paper is denoted B, which was welded with shielded gas welding process, in vertical position.

To study the influence of those two rehabilitation techniques on the behavior of welded structures at static loads, in the paper we will make determinations of macrostructures, micro-hardness, measurements of geometric elements of the welding seams in cross-section and static tensile testing.
2. Experimental procedure
The shape and dimensions of the samples for the static tensile test is shown in figure 1.

![Figure 1. The sample shape for the static tensile test: a-main view; b-frontal view.](image)

These samples were obtained by cutting strips of 30 mm width from a cruciform welded sample denoted by sign B. From B sample, nine specimens were cut up denoted B1 to B9. Of these specimens, the subject of this work are only B1, B4 and B7 that will be subject of static tensile test. The other specimens B2; B3; B5; B6; B8 and B9 were tested at variable loads and are not subject to this paper. The shape from figure 1 of these specimens after they were cut from welded sample B was obtained by milling, reducing the cross-section of 300 mm$^2$ to 100 mm$^2$, to conduct failure in welding seam or in heat affected zone HAZ of this. Those three specimens differ in the geometry of the weld cross-section as a result of not applying or applying rehabilitation techniques as follows: on the specimen B1 did not apply any technique rehabilitation, on the specimen B4 applied technique “weld toe grinding” and on the B7 specimen was applied “WIG remelting weld toe”.

The material that the specimens are fabricated is S 235 JR steel type. The welding procedure used was shielded gas welding procedure and the filler material used was G3Si1 according to EN-440. Welding regime parameters used for welding the B sample are presented in table 1, were Is is the intensity of the welding current, Ua-is voltage, ts-welding time, Lc-seam length, Vs-welding speed, Vas- wire feed speed and El- the linear energy.

| Row | Is (A) | Ua (V) | ts (s) | Lc (cm) | Vs (cm/s) | Vas (m/min) | El (kJ/cm) |
|-----|-------|--------|--------|---------|----------|-------------|------------|
| 1-3 | 220-228 | 19.9-20.1 | 85 | 35 | 0.41 | 5.3 | 7.67 |

The steps we have followed in this research to study the specimens B1, B4 and B7 are described below. Thus, at first, it was conducted a research on the macrostructure by measuring the geometric elements of the welding seams in three cases B1; B4 and B7. This is done by taking pictures at metallographic attacked specimens and entering them in SWORKS, by bringing them to scale 1: 1 and measuring the geometric elements with a specialized software. After completing the measurements, the results are centralized in table and graphs and show the variation of the geometric elements of the three specimens. The next step is the measurement of the micro-hardness on each of the specimens B1, B4 and B7 corresponding to the welded sample denoted with B, according with the schemes that will be presented in this paper. It is known that these micro-hardness values are influenced by the structure of the area in which the measurement is taken. At the end of the experiment, we determine the tear resistance in case of static tensile tests. In this sense each of the specimens B1, B4 and B7 will be subjected to static tensile stress, until breaking up. Static tensile tests will be performed using the test...
machine LFV 100 – HM used for variable and static tensile tests. During the test, we will mark the force that appears to break of each specimen and will highlight the position where breakage occurs by means of frames taken from data analysis software. Welding seams geometrical elements whose variation we want to examine and their scoring are presented in figure 2. The value variations of these geometric elements will be tabulated below and will draw graphs illustrating the variation curves of the measured values of geometric elements described in figure 2, for specimens B1; B4 and B7.

**Figure 2.** Geometric elements of cross welded seams that are subject of the study. 1-horizontal plate; 2- vertical plate; p- penetration weld; p\text{v}-vertical seam penetration; p\text{h}-horizontal seam penetration; s- heightening welding seam; K\text{V}-vertical leg of welding seam; K\text{H}-horizontal leg of welding seam; g\text{ZIT}-diagonal thickness of the heat affected zone; g\text{HZIT}-horizontal thickness of the heat affected zone; g\text{VZIT}-vertical thickness of the heat affected zone; R/r-connection radius at the top of welding seam.

In order to simplify graphics, geometric elements will be divided into two series. Series 1 will feature elements: B; p; s; p\text{v} and p\text{h} and the second series will include the other geometric elements: K\text{H}; K\text{V}; r/R; g\text{ZIT}; g\text{HZIT}; g\text{VZIT}. When the text will refer to seam apothem then we refer that thickness “a” is equal to penetration ‘p’.

Micro-hardness measurement for specimens B1, B4 and B7 is presented in the figures 3 and 4.

**Figure 3.** Micro-hardness measurements for specimens B1 and B4.

**Figure 4.** Micro-hardness measuring for specimen B7.

HV 0.1 micro-hardness measuring according to STAS 1043 will be made by the method of finger printing in rows on two perpendicular directions along the plate (horizontal and vertical axis I) and a diagonal direction oriented at 120° to the horizontal sheet plane (axis II), which should contain the root
of the welding seam, as shown in figure 3 for specimens B1 and B4. Micro-hardness measuring for specimen B7 is made under the scheme in figure 4.

3. Results and discussions
The geometric elements highlighted on the macroscopic analysis are shown in figure 5 for specimens B1, B4 and B7. As shown in figure 5 a, b and c, the thickness of the welding seam on the test piece B1 without any rehabilitation techniques applied is $a = 5$ mm, the weld legs is $K = 7$ mm, the connection radius $R$ between the filler and base material is very small, around 0.5 mm and the shape of the seam is convex. After applying the “weld toe grinding” of the specimen B4, as we can see in figure 5.b, the weld legs $K$ and thickness $a$, are constant and radius $R$ increases to 2 mm. After applying “WIG remelting weld toe” to the specimen B7, as we can see from figure 5.c, the weld thickness $a$ remains constant, the weld legs $K$ increase to 10 mm and the radius $R$ reaches 4 mm. Variation of other geometric parameters are shown in figures 6 and 7 and this is due to human factor. The values of series 1 and 2 of geometric elements as we discussed in section 2, is presented in tables 2 and 3.

![Figure 5](image)

**Figure 5.** Macroscopic analysis for pentru B1, B4 and B7: a-B1; b-B4 and c-B7.

| Denotation | B (mm) | p (mm) | s (mm) | a (mm) | pv(mm) | pH(mm) |
|------------|--------|--------|--------|--------|--------|--------|
| B1         | 10.604 | 5.396  | 1.053  | 5.000  | 1.308  | 0.554  |
| B4         | 7.974  | 5.153  | 0.732  | 5.000  | 1.399  | 0.709  |
| B7         | 12.206 | 5.311  | 0.360  | 5.000  | 0.782  | 0.893  |

| Denotation | $K_H$(mm) | $K_V$(mm) | r/R(mm) | $g_{ZIT}$ [mm] | $g_{HZIT}$ [mm] | $g_{VZIT}$ [mm] |
|------------|-----------|-----------|---------|----------------|----------------|-----------------|
| B1         | 7.391     | 7.605     | 0.500   | 2.070          | 2.175          | 2.978           |
| B4         | 7.071     | 7.249     | 2.000   | 2.275          | 1.756          | 1.722           |
| B7         | 10.323    | 10.489    | 4.500   | 2.735          | 1.901          | 1.592           |

The graphical variation of the values of those two series of geometric elements discussed in section 2 are presented in figures 6 and 7.
The graphical variation of the micro-hardness values measured after axes I and II, from specimens B1, B4 and B7 as we discussed in section 2, are presented in figures 8 and 9.

Figure 6. Variation of series 1 of geometric elements.  
Figure 7. Variation of series 2 of geometric elements.

Figure 8. Micro-hardness variation for specimens C1;C4 and C7 according to axis I.  
Figure 9. Micro-hardness variation for specimens C1;C4 and C7 according to axis II.

The static traction broken specimens B1, B4 and B7 are shown in figure 10 a, b and c, and the stress strain curves plotted by the machine software for the same specimens, in figure 11 a, b and c.

Figure 10. The static traction broken specimens B1, B4 and B7.
4. Conclusions
As for the measured micro-hardness for B1, B4 and B7 specimens for the I axis in figure 8, we find that the highest value of 232 HV is found in the weld seam area C, in point 10 of the specimen B4. This value being below 350 HV does not raise any cracking problems. In the heat affected zone HAZ, both in the horizontal and vertical plates, the values of the micro-hardness are between 160 and 230 HV, while the areas of the basic material, both in the horizontal and the vertical plate, keep the micro-hardness below 200 HV. It is interesting to note that the highest values of hardness are recorded for the B4 specimen, with “weld toe grinding”, the red curve. The values of the micro-hardness measured at the same points decrease the most for the B7 specimen, with “WIG remelting weld toe”, the green curve, having an intermediate value for the B1, specimen without reconditioning, the blue curve. Increasing the hardness of the B4 specimen is explained by an inclusion in the molten welding bath.

Concerning the micro-hardness measured in axis II for B1, B4 and B7 specimens, according to figure 9, we find that in the representative area of the welded joint, the 250 HV value is not reached, so we are much below the 350 HV line from which the danger of cracking starts. The highest value of the micro-hardness is reached in point 8 in the weld seam for the B4 specimen, with “weld toe grinding”, the red curve. It is an unusual thing and the explanation could be due to the appearance of a hardening compound, such as an inclusion or non-homogeneity in the welding. In the heat affected zones HAZ of both horizontal and vertical plates the micro-hardness is at a value slightly above 200 HV, and in the areas of the base material both horizontally and vertically they are below 200 HV. Overall, in the horizontal and vertical plate in the heat affected zone HAZ, from figure 9, we find that the highest weight of the points with low hardness is in the case of the green curve, for the B7 specimen with “WIG remelting weld toe”. From micro-hardness results measured from axes I and II, we do not have crack hazardous areas. Also micro-hardness values in axis II are below the micro-hardness values in axis I, probably because the axis II is situated at a greater distance than welding areas from axis I.

After static tensile testing, as seen in the figures 10 and 11, we find that the breaking occurred each time in the base material or in the area of the heat affected zone HAZ of the seam, at levels between 59 and 62 kN breaking strength, the largest strength of 62 kN being recorded for specimen B7 with “WIG remelting weld toe” and the lowest for specimen B4 with “grinding weld toe”. This small difference between the breaking strength rehabilitated specimens, show that these reconditioning techniques are not justified in the case of static stress, because in this case the stress concentrators between filler and base material are not very important. Also, from figure 11 we can see a specific strain at break between 5.8 mm and 7 mm and the differences between these strains depending on applied rehabilitation techniques, are very small. So, in this case too, we can say that the rehabilitation techniques applied on cruciform specimens, shielded gas welded in vertical position, have not a significant influence on the tensile tests fracture behaviour as in case of the fatigue fracture tests.
5. References

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