RETROFITTING OF WELDED STRUCTURES BY TIG AND PLASMA DRESSING

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RESUMEN

Debido a las limitaciones económicas y medioambientales, la tendencia actual es utilizar las estructuras soldadas más allá de su vida útil de diseño. La causa predominante de falla en servicio de estas estructuras envejecidas es la fatiga de las uniones soldadas. El uso de técnicas de mejora en uniones soldadas, como técnica de reparación, viene siendo sugerido por varios autores. El refundición TIG es una de las técnicas de reparación más prometedoras. Sin embargo, la eficacia de la refundición TIG está estrechamente relacionada con la profundidad de la fisura reparada. El uso de galgas extensiométricas puede ser eficaz para detectar la presencia de fisuras por fatiga en su fase inicial de propagación, sin embargo, es necesario demostrar su eficacia en los programas de inspección en obra. Algunas variantes TIG asociadas a las recientes innovaciones tecnológicas de la soldadura por arco de fusión, están destinadas a mejorar la penetración y la sostenibilidad del proceso de refundición.

En este artículo se presentan algunos resultados del trabajo desarrollado por los autores en los últimos años, relevantes para evaluar la eficiencia de la reparación sostenible, por refundición TIG y plasma, de estructuras soldadas. Se da relevancia a la reparación, completa o defectuosa, de grietas profundas, así como la posible ventaja de utilizar variantes TIG.

PALABRAS CLAVE: Reequipamiento de juntas soldadas, refundición TIG, refundición plasma, juntas soldadas, Fatiga

ABSTRACT

Due to economic and environmental constrains, the currently trend is to use the welded structures beyond their design lives. The predominant cause of in service failure of these aged structures is the fatigue of the welded joints. The use of improvement techniques in welded joints, as a repair technique, has been suggested by several authors. TIG dressing is one of the most promising of these repair techniques. However, the effectiveness of TIG remelting is closely linked to the depth of the repaired crack. The use of strain gauges can be effective to detect the presence of fatigue cracks in their initial phase of propagation, however their effectiveness in inspection programs on jobsite needs to be proven. Some TIG variants associated to recent technological innovations of fusion arc welding, are appointed to improve the penetration and the sustainability of the remelting process.

In this article are presented some results of the work developed by the authors in the last years, relevant to assess the efficiency of sustainable repair, by TIG and plasma dressing, of welded structures. Relevance is given to the repair, complete or defective, of deep cracks, as well as the possible advantage of using TIG variants.

KEYWORDS: Retrofitting of welded joints, TIG dressing, Plasma dressing, Welded joints, Fatigue

INTRODUCTION

Currently, due to economic and environmental constrains, the trend to use the welded structures beyond their design lives is increasingly frequent [1, 2]. So that this situation is not catastrophic and can be within the regulatory framework, an extra effort should be paid to inspection, monitoring and rehabilitation of damaged details.

The predominant cause of failure in service of these aged structures is the fatigue of the welded joints [1]. Fatigue life of welded joints is mainly influenced by pre-existing cracks in the weld toe. The presence of such defects, together with the stress concentration at the weld toe and the existing residual stress fields induced by welding, explains the poor fatigue strengths of welded joints [3].

Post weld treatments can be applied to the weld fillet in medium and high-strength steels, to improve the fatigue performance of welded joints [4]. The use of these improvement treatments, as a repair techniques, has been reported by some authors: C.M. Branco *et al.* [5], used hammer peening; A. Ramalho *et al.* [3], used TIG and plasma dressing; M. Edgren *et al.* [6], used High Frequency Mechanical Impact; H. Al-Karawi *et al.* [7], used TIG remelting fallowed by High Frequency Mechanical Impact.

Maintenance programmes using the improvement treatments in welded joints as a repair technique, have been considered in some manuals and reports [2, 8].

The effectiveness of using TIG remelting as a repair technique for pre-cracked welded joints by fatigue loading has been reported by several authors [3, 9, 10]. A. Manai [9], proposes a methodology to assess and improve the performance of these damaged structures using TIG dressing, including procedures for the inspection, monitoring and rehabilitation processes. However, the effectiveness of TIG remelting is closely linked to the depth of the repaired crack [3], and the penetration level associated to the welding parameters and the variant of TIG technique [11]. K.P. Mehta [11] identifies three variants of TIG associated to recent technological innovations of fusion arc welding, the activated TIG (A-TIG) welding, the hot wire TIG (HW-TIG) welding and the keyhole TIG (K-TIG) welding. The TIG variants improve the penetration and the sustainability of the welding process. A. Loureiro and A. Rodrigues [12], reports a substantial increasing of penetration of the A-TIG (activated with TiO2 commercial flux) in austenitic steels.

In inspection and monitoring programs, it is crucial to have a process that allows assessing the depth of cracks, in order to decide on the timing to carry out a TIG refusion that promotes their efficient repair. Many of the non-destructive methods used in inspection programs on jobsite, to assess cracks in welded joints, are not suitable for real-time monitoring of crack growth [13, 14]. However, the use of strain gauges can be effective for this purpose [8, 15]. H. Al-Karawi *et al.* [15] reports the use of strain gauges to detect cracks deeper less than 1 mm. When the cracks are shallow the usual TIG repair is effective [1, 3, 10], however, when the cracks are deeper, some TIG variants should be required. Even using these variants, when the pre-existing cracks are deeper, their complete repair is often not achieved and some residual cracks may remain in the deeper layers.

The repair efficiency by TIG remelting is usually evaluated using the simulation of crack growth at the weld toe, through numerical finite element models [9].

In this article is presented the results of the work developed by the authors in the last years, relevant to assess the efficiency of sustainable repair, by TIG remelting, of welded structures. Relevance is given to the repair, complete or defective, of deep cracks, as well as the possible advantage of use of TIG variants.

MATERIALS AND METHODS

2.1. Materials and specimens

The base material used in this study was medium strength steel, St 52-3 DIN 17100, in the form of plates with 12.5 mm of thickness, and with the chemical composition presented in table 1.

Table 1. Chemical composition of used S355 AR steel (wt %).

C	Si	Mn	Cr	Mo	Ni	Ti
0.131	0.413	1.44	0.063	0.024	0.034	0.009
Al	V	Cu	Co	Nb	P	S
0.029	0.043	0.018	0.013	0.005	0.011	0.005

The welds were made by covered electrode process, electrode ESAB OK 75.75. The chemical composition of the weld metal is presented in table 2.

Table 2. Chemical composition of the used weld metal (wt %).

C	Si	Mn	Cr	Ni	Mo	P	S
0.08	0.45	1.28	0.5	1.87	0.37	0.017	0.01

The welding T specimens were produced from main plates with 12.5 mm thickness and low penetration fillet welded with an attachment of equal thickness. From this plate, specimens with 70 mm width and 270 mm length were cut. The weld leg length presented a medium value of 9 mm. The specimens were made with the geometry shown in Fig. 1.

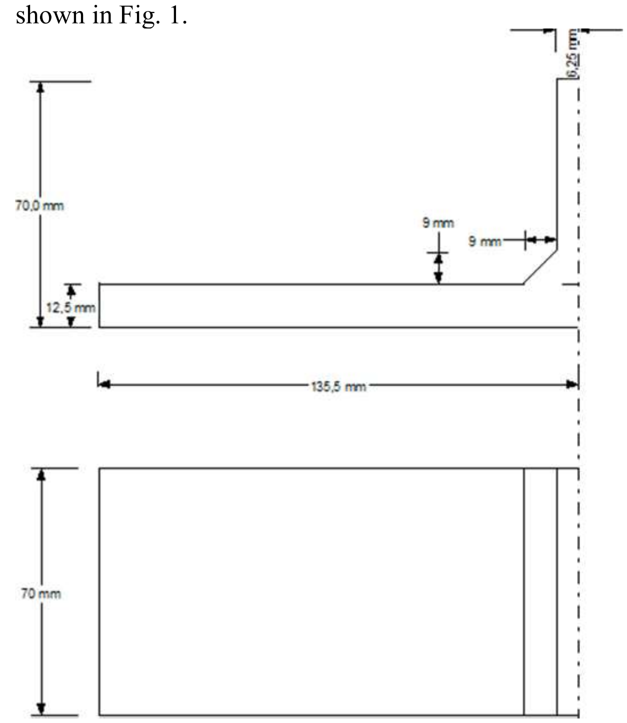


Figure 1. Geometry of T-welded specimens.

2.2. Rehabilitation techniques

The welded joints with fatigue cracks at the weld toe were re-habilitated by TIG and plasma dressing techniques, using the parameters indicated in table 3. For the TIG dressing were used two sets of welding parameters, and one of them, with more 50% of power, produced deeper penetration. For the plasma dressing was used the keyhole variant in order to obtain a deeper penetration. The pre-cracks were previously induced by fatigue loading carried out in three-point bending.

Table 3. TIG and plasma dressing parameters.

TIG dressing (TR)	Deeper TIG dressing (TR-D)	Plasma keyhole dressing (PR)
Argon flux; Current intensity 110 A; Tension DC 19 V; Linear rate 1.08 mm/s.	Argon flux; Current intensity 135 A; Tension DC 15 V; Linear rate 0.66 mm/s.	Argon flux; Current intensity 200 A; Tension DC 30 V; Linear rate 2.47 mm/s.

2.3. Fatigue tests

The fatigue tests were carried out in the servo-hydraulic Instron machine with a load control (R=0), frequency of 7 Hz with a sinusoidal wave loading. The tests were carried out in three-point bending as shown in Fig. 2.

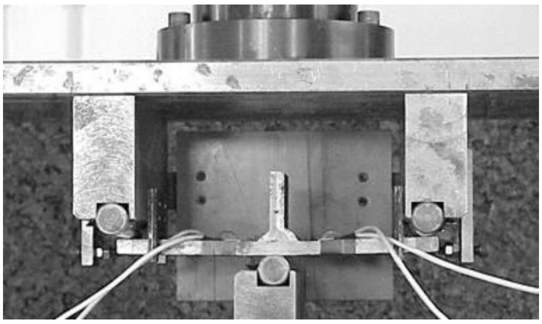


Figure 2. Fatigue loading setup.

Twenty specimens were tested distributed in three series: the TR, the TR-D and the PR.

The TR set was formed by specimens that were obtained by the following procedure:

As welded specimens are submitted to a fatigue loading until the generation of big deep cracks; this loading is performed in load or in displacement control; The process of detecting cracks was not rigorous, and the loading was conducted without accurate record of the number of cycles until registering an increase of 10% of the initial deformation; After this initial fatigue loading, the specimens are repaired by TIG re-melting using the welding parameters presented in table 3.

The TR-D set was formed by a specimen that was obtained by the same procedure of the TR specimens, but the re-melting repair was done with the welding parameters presented in table 3. In this specimen the pre-crack procedure was controlled by strain-gauges, having a deeper lesser than 2.5 mm.

The PR set was formed by specimens that are obtained by the following procedure:

The same as the TR specimens, but the re-melting repair was done by plasma; For the plasma re-melting, in order to improve the depth of fusion, was adopted the keyhole technique and the welding parameters are presented in table 3.

The curvature radius at the weld toe of the welded joints was measured using a Maxtascan model micrometry table XY, with an accuracy of 0.01 mm.

RESULTS AND DISCUSSION

The fatigue results are presented in tables 4, 5 and 6, for the TR, TR-D and PR series respectively.

The crack depth before the reparation is represented by a_r.

The S-N curves for the TR, PR series and for the as welded specimens (AW) was been published in A. Ramalho et al. 2011 and are represented by equation (1).

$$\begin{aligned} AW&: \quad \Delta\sigma = 4848.6N_r^{-0.210} \\ TR&: \quad \Delta\sigma = 3744.5N_r^{-0.236} \\ PR&: \quad \Delta\sigma = 5566.2N_r^{-0.233} \end{aligned} \qquad (1)$$

where Δσ is the stress range at the weld toe, applied to the specimen and N_r is the fatigue life. For comparison purposes, in tables 4 to 6, are presented the lives obtained by the S-N curve for the AW Serie, designated by $N_{AW\ S\text{-}N}$. The fracture surfaces of the specimens are also presented.

From the results presented in table 4 for the TR specimens, the rehabilitation of deep fatigue cracks at the weld toe (a_r greater than 4 mm) by TIG dressing, leads to very small post-repair fatigue lives (varies from 4% to 10%), when compared to the lives of as welded specimens. Therefore, it can be drawn that TIG remelting is not suitable for promoting the repair of deep cracks.

From the results presented in table 5 for the TR-D specimen, the rehabilitation of shallow fatigue cracks at the weld toe (a_r lesser than 2.5 mm) by TIG dressing, leads to higher post-repair fatigue life (245%), when compared to the life of as welded specimens. Therefore, it can be drawn that TIG remelting is suitable for promoting the repair of shallow cracks.

The use of TIG remelting as a fatigue crack repair technique must be associated with an adequate monitoring technique to ensure that the repair is carried out at an early stage of propagation, when the cracks are still shallow. When try to extend the lifespan of aged welded structures, or in other repairs, may come across deeper cracks. In this case, TIG variants associated to higher penetration may be considered, like the activated TIG (A-TIG) welding, the hot wire TIG (HW-TIG) welding or the keyhole TIG (K-TIG). However, there are no studies that support the use of these TIG remelting variants in the repair of fatigue cracks.

Table 4. Fatigue results for the TR series.

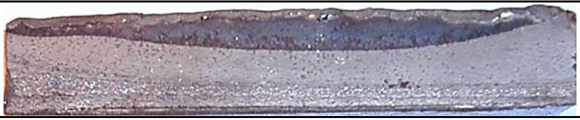
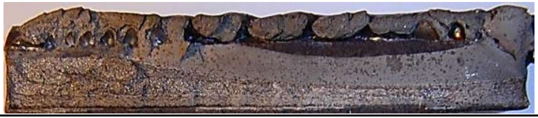
Specimen	a_r [mm]	$\Delta\sigma$ [MPa]	N_r	$N_{AW\ S\text{-}N}$	Fracture surface
TR1	6.50	354.2	22680	251134	
TR2	5.10	151.2	329711	14343932	
TR3	4.80	204.7	361890	3400004	
TR4	5.40	122.0	1998624	39765559	
TR5	5.90	143.9	691645	18146433	
TR6	4.70	235.5	159236	1746694	
TR7	4.83	293.3	61808	615546	
TR8	4.35	182.8	521075	5820975	
TR9	4.72	177.1	582198	6766601	
TR10	6.90	228.1	92327	2095975	

Table 5. Fatigue results for the TR-D series

Specimen	a_r [mm]	$\Delta\sigma$ [MPa]	N	$N_{AW\ S\text{-}N}$	Fracture surface
TR-D	<2.5	352.6	628739	256596	

From the results presented in table 6 for the PR specimens, the rehabilitation of deep fatigue cracks at the weld toe (a_r varying from 2.2 to 5.9 mm) by keyhole plasma, leads to small post-repair fatigue lives, when compared to the lives of as-welded specimens. The lives obtained for the PR 5 to PR9 specimens vary from 67% to 112% of the experimental ones, but for the remaining specimens are much lower (14% to 34%). Although the results have a great scatter, it can be drawn that keyhole plasma promotes a reasonable repair of deep cracks. However, a very high porosity density is observed. This porosity is not acceptable for the vast majority of applications, being rejected by welding codes. To avoid the porosity, the TIG and plasma keyhole welding technology should be applied in full penetration welds [16]. The porosity formation on laser keyhole welds have less density and has been the subject of several studies, [17, 18]. For this reason, despite the increased penetration, the use of the plasma or TIG in keyhole variants do not prove to be suitable to promote the repair of fatigue cracks generated in welded joints.

Table 6. Fatigue results for the PR series

Specimen	a_r [mm]	$\Delta\sigma$ [MPa]	**N**	$N_{AW\ S\text{-}N}$	Fracture surface
PR1	2.20	203.4	1185720	3504512	
PR2	5.18	176.6	988050	6858123	
PR3	4.83	226.7	615786	2093198	
PR4	5.43	294.4	127110	604693	
PR5	4.74	289.1	550079	659213	
PR6	5.90	346.5	311338	278782	
PR7	5.06	349.8	178495	266504	
PR8	3.63	237.1	1482055	1691387	
PR9	5.80	393.0	116388	153245	

CONCLUSIONS

TIG remelting is a good rehabilitation technique for welded joints with shallow cracks (up to 2.5 mm depth) at the weld toe, contributing significantly to fatigue life extension.
The use of TIG remelting as a fatigue crack repair technique must be associated with an adequate monitoring technique to ensure that the repair is carried out at an early stage of propagation, assuring the cracks are still shallow.
There are no studies that support the use of TIG welding variants, namely the activated TIG, as a suitable remelting technique to promote the repair of welded joints with cracks.
Plasma remelting in the keyhole variant promotes a reasonable fatigue live recovery in the repair of deep cracks (up to 5.9 mm depth), however due to a very high pore density generated, is not acceptable as an rehabilitation technique for welded joints.

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