EXPERIMENTAL STUDY ON FATIGUE PERFORMANCE OF A DISSIMILAR WELDED JOINT USED IN AUTOMOTIVE EXHAUST SYSTEM *

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Abstract
Different types of welding wire are found in the market in general, but one of the most used by the automotive market is solid wire. On the other hand, tubular wire, known as "metal core" began to be also used by this industry, but with a much lower proportion due to lack of studies on it. This study was conceived with the purpose of contributing with further clarification regarding the use of tubular wires AISI 439Ti, in automotive exhausts welding, composed of AISI 1018 carbon steel and stainless steel AISI 409 and AISI 439 instead of solid welding wire AISI 307Si. To analyze the test specimens produced during this study, the following tests were used: micrographical analysis, fatigue, thermal fatigue, penetrating liquid and sensitization according to ASTM A763. The obtained results demonstrated the greater efficiency of the tubular wire compared to the solid wire.
Keywords: Thermal Fatigue; Mechanic Fatigue; Tubular Wire; Automotive Exhaust System.

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1 INTRODUCTION

Welding of dissimilar metals is more complex than welding between similar materials due to the different physical, chemical and mechanical properties presented by the metals involved [1]. These differences also hinder the definition of the addition material that is compatible with the different base materials and which can generate a joint that best meets the basic purpose of welding which is to obtain continuity of the characteristics in the joint.
One of the most representative ways to evaluate a dissimilar joint is by performing fatigue tests [2]. Fatigue is a localized, progressive and permanent degradation process that occurs in material subject to variations in stresses and deformations. One of the main characteristics of the fatigue is the initiation of damages and nucleation of cracks in the regions where structural or mechanical heterogeneities are located, such as inclusions, microstructural imperfections or mechanical notches [3]. Due to this fatigue sensitivity characteristic with the heterogeneity of the materials, a fatigue test can be employed as an effective way of comparing the performance and quality of the joint by welding dissimilar materials.
There is a growing interest in the welding of dissimilar materials in the automotive industry, since in this sector there is a great increase in the use of dissimilar metals, including stainless steel. This is due to the conciliation, in the stainless steel, of mechanical properties, suitable for its structural use, with its exceptional resistance to corrosion in different environments, as well as good weldability. However, due to their particular conditions, the amount of information regarding the characteristics of dissimilar joints obtained from these steels is still limited [2].
The purpose of this study is to evaluate the use of a solid and tubular welding wire in the union of dissimilar materials, between carbon steel SAE 1018 and stainless steel AISI 409, using as performance criterion, fatigue tests simulating the typical situation of the behavior of an automotive exhaust system.

2 MATERIALS AND METHODS

In this work eight fatigue specimens were prepared from the AISI 409 ferritic stainless steel tubes and SAE 1018 low carbon steel flanges. These materials were joined through the GMAW (Gas Metal Arc Welding) welding process. The filler metal (consumables) applied were AISI 307Si solid wire and AISI 439Ti tubular wire. Table 1 shows the nominal (average) chemical composition of the materials involved.

Table 1. Nominal chemical composition of the metals employed in this work

Steel type	%C	%Mn	%Si	%P	%S	%Cr	%Ni	%Mo	%Ti
AISI 1018	0,18	0,75	–	≤ 0,04	≤ 0,05	–	–	–	–
AISI 409	≤ 0,03	≤ 0,75	≤ 1,00	≤ 0,04	≤ 0,02	11,00	≤ 0,50	–	0,30
AISI 307Si	0,10	6,50	0,80	≤ 0,03	≤ 0,03	18,50	8,5	0,05	–
AISI 439Ti	0,02	0,70	0,55	0,010	0,010	17,90	–	–	0,80

The specimens were produced from stainless steel tubes with a length of 250 mm, a diameter of 45 mm and a thickness of 1.2 mm. The carbon steel flanges were 10 mm thick and 127.4 by 127.8 mm in area, as shown in the schematic drawing shown in Figure 1 and in detail in Figure 2.

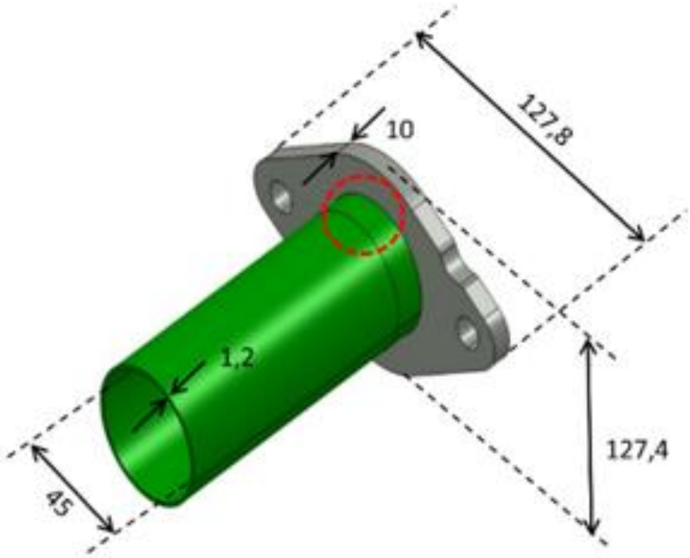


Figure 1. Schematic drawing (dimensions in mm) of the test piece used in this study.

For the preparation of dissimilar weld samples between carbon steel / stainless steel (AISI 1018 / AIS 409), it was used a power source, model Transpuls Synergic 5.000MV manufactured by Fronius. Table 2 presents the welding parameters used to obtain the test specimens, as already shown in Figure 1.

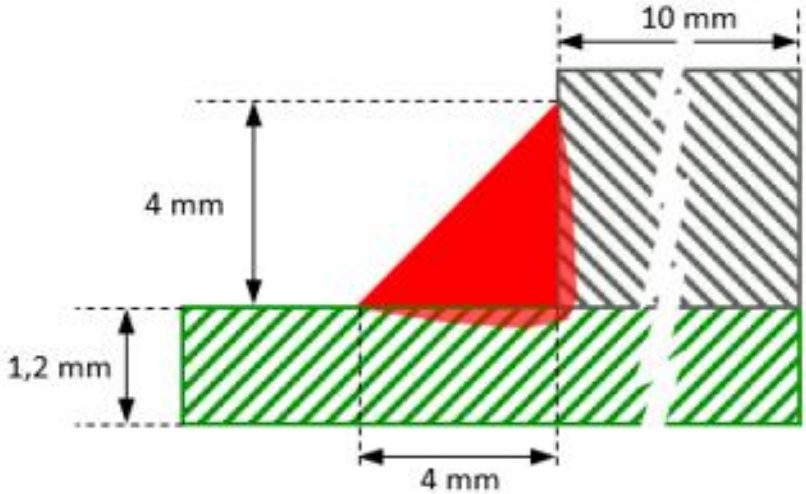
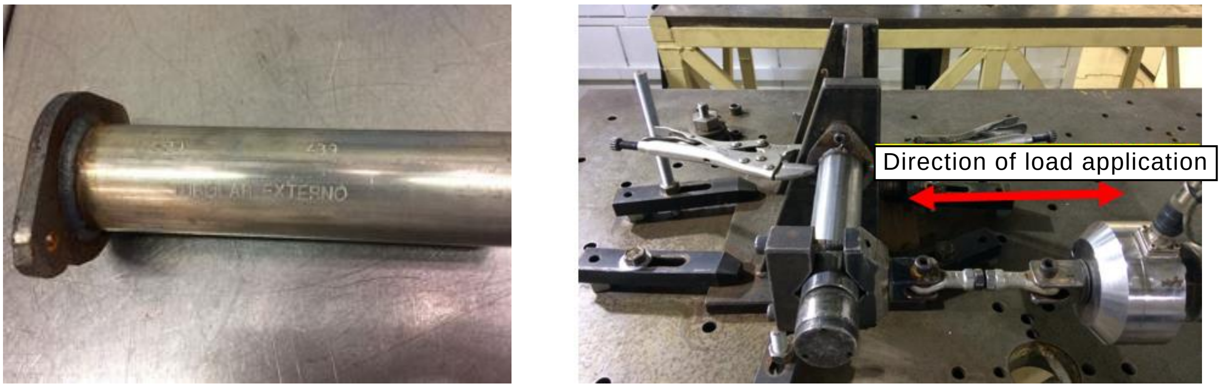


Figure 2. Detail of the welded joint with the minimum dimensions of the weld deposit. The green area represents the pipe and gray area the flange (see Fig. 1).

Table 2. Tensile tests main results from TS of USI-CP 800 steel with and without hole notches

Consumable (wire type)	Current, I (A)	Voltage, U (V)	Gas flow, v (l/min.)	Gas type	Gas Composition	Wire diameter, D (mm)
AISI 307Si (solid)	220	23,7	12	AG12	98% Ar e 2% CO_2	1,0
AISI 439Ti (tubular)	288	21,4				1,2

Fatigue tests were performed according to the recommendations of a Brazilian automotive manufacturer using an amplitude of 1,200 N equal in tensile and compression, constituting a Wöhler type load (Rabbi, 2009) in which the mean stress is zero, $\sigma_m = 0$; and the stress ratio, R = -1. The load was applied to the test set directly on the tube at a frequency of 8 Hz. The tests were performed on a fatigue test equipment, manufactured by company MOOG, servo-actuator model G446-1024 as showed by Figure 3.



(a) (b)

Figure 3. (a) Test piece aspect and (b) fatigue test configuration.

3 RESULTS AND DISCUSSION

Table 3 presents the results obtained from the fatigue tests. The tests showed a greater longevity of the joint obtained with tubular wire (AISI 439Ti), in relation to the joints obtained with solid wire (AISI 307Si): 150 thousand cycles against 72 thousand cycles, approximately. In this way, the tubular wire caused the joint to present a life 2.07 times greater than the same joint obtained with the solid wire.

Table 3. Results of Welding Execution and Fatigue Testing

Consumable (wire type)	Test piece	Welding execution time (s)	Number of cycles for Fatigue rupture
AISI 307Si (solid)	S1	18	92,284
	S2	17	100,335
	S3	18	42,883
	S4	18	53,956
	Average (deviation)	**17 (0,5)**	**72,365 (28,208)**
AISI 439Ti (tubular)	T1	8	148,031
	T2	7	189,325
	T3	8	112,621
	T4	7	149,767
	Average (deviation)	**7,5 (0,6)**	**149,936 (31,345)**

Additionally, another relevant result was the time for the execution of the welding using the tubular wire. In this case, the use of the AISI 439Ti consumables allowed a

reduction of approximately 58% in the union execution time, according to the data obtained and presented in Table 3.
AISI 439Ti tubular wire has very advantageous metallurgical and process characteristics and is well recognized in the literature [4]. The presence of the microalloying element titanium in this steel promotes grain refining, which helps toughness increasing and especially in the greater resistance to crack initiation in the mode I (initiation) of fatigue [3].
In addition, the tubular wire geometry avoids the splashes in the region of the weld, which are notorious points of initiation of cracks by fatigue, which leads to the material presenting less life in fatigue. In addition, the absence of the element nickel and lower manganese contend, in relation to the solid consumable (see Table 1), can allows the material to avoid enter in the austenitic field during welding heating, avoiding the formation of undesirable fragile microstructures (martensitic phase) originated from rapid cooling of the welded joint.
Metallographic observations have not been highlighted in this work, but it was detected a strength tendency of lack of penetration in welded samples with poor fatigue performance.

4 CONCLUSIONS

After analyzing the results obtained in the fatigue test, it can be concluded that the use of AISI 439Ti tubular welding wire presented higher results than AISI 307Si solid welding wire, considering that the joint obtained with the tubular wire presented a durability of about twice that obtained with the joint with the solid wire. Another benefit of the use of the tubular wire was the speed of operation, being almost 60% higher than the solid wire.
However, there is a need for further testing and consideration, as the cost of consumables, equipment and logistics for the availability of these resources should be considered in a comprehensive manner, together with the experimental results. In addition, it is of great importance to evaluate the occurrence of thermal fatigue and corrosion for the application of these joints in exhaust gas systems.

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