

# Crack Growth Study in Welded Sheet Metal

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**Abstract** –This paper presents results of research on the propagation of fatigue cracks in structural steel sheet, subjected to a MIG welding process. The study was conducted on rectangular test pieces with 62.5 x 60 mm and 2 mm thick, MIG welded and non-welded. Samples were tested for fatigue crack propagation at the base material and welded metal. The results show a crack stop in the heat affected zone (HAZ), requiring greater amplitude of the stress intensity factor (KI) so the crack could propagate in a stable manner. Results indicate that the combination of adequate microstructure and residual stress in the HAZ are those factors which can stop the advance of the crack in MIG welded material.

**Keywords:** Sheet Metal, Crack Growth; Fatigue.

## I. INTRODUCTION

Fatigue failures were found in a structure of a bus due to the stress events to which it was subjected during the daily operation of the bus. The point of failure was detected and located. In this case, the cracks are observed in the points where the frame is welded in a “T” shape, with the horizontal PTR profiles. The specimens tested in this investigation were obtained from the element of the structural steel type from which the buses are made, which is a low carbon steel.

Previous investigations have been carried out by tests of crack propagation in welded sheet to determine the change in the amplitude of the stress intensity factor, K, in different sections of the area around the weld [1]. They have concluded that the resistance to crack growth is reduced when the applied load ratio decreases in the region of the weld, except in the heat affected zone. This may be due to non-uniformity in the crystalline structure caused by overheating during the application of the weld.

On the other hand, it has been reported that an important factor in the fatigue crack growth process is the influence of the thickness of the material to be tested. In another investigation [2], data were obtained that support the hypothesis that the propagation of cracks is an increasing function of the thickness of the material. In later researches, other analysis tools such as finite element or statistical tools and other approaches, have been incorporated into the study of

the fatigue crack growth of welded parts, which has allowed to obtain a more precise idea of the process of propagation of the cracks and the effect of various aspects of the materials involved; or even of the welding process itself such as microstructure, subsequent cooling, geometry, present stresses and other additional factors [3]; [4]; [5]; [6]; [7]; [8]; [9]; [10]; [11]; [12] and [13]. In what can be considered as an example of a new evolving paradigm in engineering research, a couple of paper presented in [14] and [15], show an analysis that combines a numerical model that incorporates experimental results of fracture propagation velocity in medium carbon steels submitted to loads of cyclical and constant type.

This analysis proposes the understanding of fracture mechanics phenomena through refined studies like the exposed.

The objective of this study is to determine the effect of the presence of a MIG weld in the propagation of fatigue cracks in a low carbon steel sheet, in order to be able to know if a crack starting in the area surrounding the welding will spread in an unstable way and can derive, from it, hints to reduce the risk in the transport industry.

## II. MATERIALS AND METHODS

The objective of the tests is to obtain information regarding the mechanical behavior of a material with a particular geometry. The fatigue test is necessary to obtain basic information on the properties of the material, in the same way that information on the yield strength and the Young's modulus of a material is obtained from a tensile test.

As far as possible, material conditions, stress ranges, and load type should be fairly similar to actual service conditions in order for the results to be useful for design.

### 2.1 Materials

The material used was obtained from the tubular profile used in a bus. The profile was sectioned by wire EDM to obtain the samples for the chemical analysis and to machine the test pieces for tensile and crack growth tests, Fig. 1.



Figure 1: Test pieces machining with EDM



Figure 3: Welded test pieces machining with wire EDM

## 2.2 Metallography

In order to know the microstructure of the material to be tested, a sample of the welded material was taken, which was prepared with conventional metallographic procedures with sandpapers from 180 to 600 and alumina of 3 and 0.5  $\mu\text{m}$  to obtain a mirror-polished surface. Then pieces were etched with 2% Nital to reveal the microstructure.

## 2.3 Manufacture of specimens for tensile tests

With of the process of wire EDM, 16 specimens of 14 gauge PTR steel were manufactured, according to ASTM E08 - 00 Standard [16], for the test, Fig. 2 shows the outline of the test pieces that were tested.



Figure 2: Steel specimen in tensile test

The tensile test of the original material was carried out on an Instron Servo-hydraulic machine, at a speed of 0.5 mm / s, at room temperature. The tests were carried out in load control mode.

## 2.4 Geometry of specimens for Fracture Mechanics tests.

All the test pieces were obtained from the same sheet and manufactured according to the recommendations of the ASTM E647-05 Standard [17], with the wire EDM process, Fig. 3.

The test specimens used for these tests are CT (Compact Tension) type, whose geometry is shown in Fig. 4, with the following dimensions: width  $W = 50$  mm and thickness  $B = 2$  mm. Fig. 4 shows a test piece of the material tested without weld.



Figure 4: Specimen for fatigue tests (Fracture Mechanics), without weld

The machining of the welded specimens consisted of placing the beginning of the notch on the edge of the weld, with the aim of generating the crack in this region. Figure 5 show details of the specimens with weld seam.

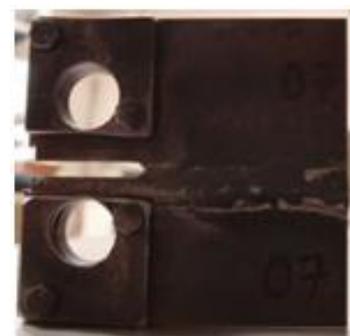


Figure 5: Specimen for fatigue tests with weld

The pre-cracking and fatigue crack propagation test were performed in the standard compact type (CT) test specimens, at room temperature.

The tests were performed according to ASTM E 647-05 Standard [17], at constant load and at a frequency of 10 Hz. The crack length was measured by the compliance function given in mentioned standard. The opening displacement was measured with an extensometer placed on the front face of the specimen, Fig. 6. 12 crack growth velocity tests were carried out: 7 tests on 2 mm thick specimens with 5 mm notch width and 5 tests on 2 mm thick specimens, increasing the load by 10% every 20,000 cycles.



Figure 6: Compact specimen submitted to the fatigue test

### III. RESULTS AND DISCUSSIONS

Figure 7 shows a sample of the curves obtained from the tensile test of the specimens of the original material as a result of performing these tests. The results show the typical behavior of a steel of this type.

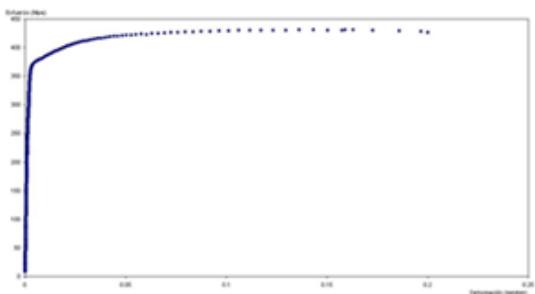


Figure 7: Stress-strain diagram of low carbon steel, 2 mm thick

Figure 8 shows an example of a specimen that has been subjected to the tensile test during and after the rupture of the specimen.



Figure 8: Steel specimen after having been tested in the tensile test

Figure 9 shows the moment of the Fracture Mechanics test in which an image that shows an advanced moment of that growth, close to the moment of separation of the sections (fracture (right side)). The crack, as can be seen, grew next to the weld, which is considered associated with phenomena of stress concentration in that region. On the other hand, the case of a test piece that was submitted to the Fracture Mechanics test it was analyzed, also during and after the aforementioned test. In that case, the crack grew until reaching a dimension of 23 mm and there was no marked distortion of the specimen.



Figure 9: The location of the crack to the side of the weld

The graphs shown in Fig. 10 illustrate the crack length curves (a) as a function of the number of fatigue cycles (N) for the samples tested without welding (left side) and with weld (right side), obtained from the data from the Fracture Mechanics tests carried out. It should be noted that in the case of non-welded specimens, crack size values are greater (close to 35 mm) than those shown in the case of pieces with weld.

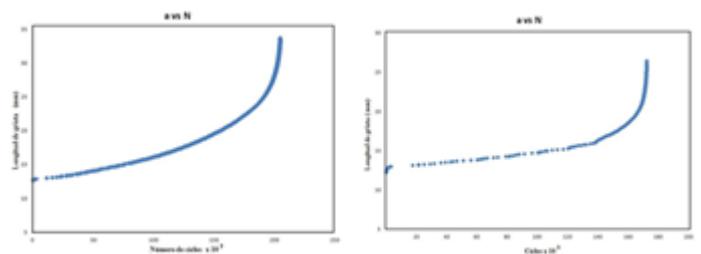


Figure 10: Curve lengths of crack (a) as a function of the number of cycles (N) for the specimens without welding (left side) and with welding (right side)

The graphs of the PGF specimens (fatigue crack tests, without welding), Fig. 11, done with the data obtained from the tests on specimens of the material without welds, show a similar tendency and express a certain discrepancy that is not considered important. The stable growth region of the crack starts at approximately  $25 \Delta K \text{ MPa}\sqrt{\text{m}}$  and ends on the order of  $50 \Delta K \text{ MPa}\sqrt{\text{m}}$ . The trend lines of the plotted data show a slope greater than that of the data obtained from the tests of the welded specimens.

IV. CONCLUSION

Fatigue crack propagation tests (Fracture Mechanics), performed on low carbon steel with and without welding, show significant differences in the Paris constants, which implies that it is more difficult to propagate a fatigue crack in the welded material, (at least in the conditions studied), than in the non-welded material.

It is possible to affirm that the greater resistance to fatigue in the welded material (in the conditions studied in this process) is given by the combination of a microstructure that shows a large grain size in the heat affected zone and the presence of residual compression stress, coming from the applied welding process (MIG).

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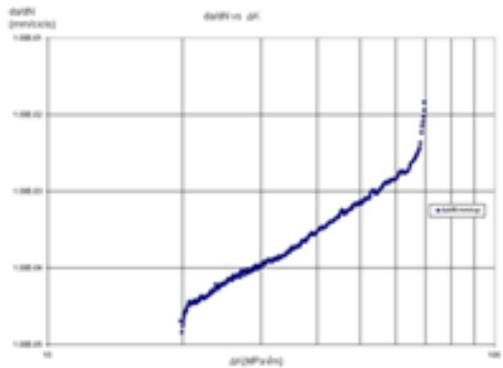


Figure 11: Graph of  $da/dN - \Delta K$  of the material without welding

The graphs of the CGS specimens, (specimens with welds, crack growth) shown in Figure 12, obtained with the data of the specimens with welds, show that, at the beginning, the velocity of propagation of fatigue cracks decreases, so it is considered that there is a crack stop zone, the velocity increases until it reaches a value of  $50 \Delta K \text{MPa}\sqrt{\text{m}}$  and ends at  $70 \Delta K \text{MPa}\sqrt{\text{m}}$ , this interval represents the area of stable crack growth. On the other hand, the trend lines show a lower slope than that of the trend line of the data from the tests of the material without welds.

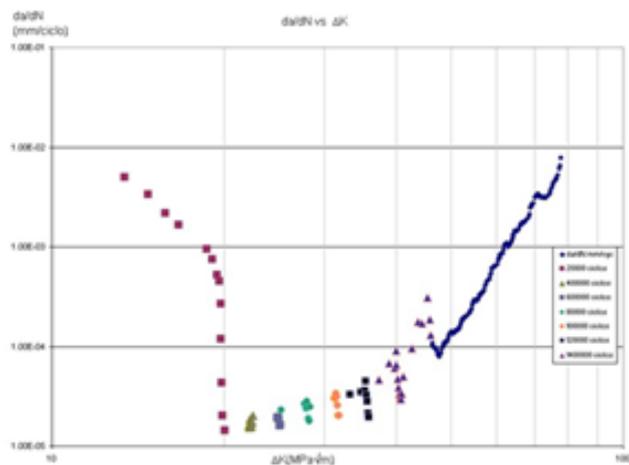


Figure 11: Graph of  $da/dN - \Delta K$  of the material with welding

It is considered probable that this initial behavior of decreasing the crack propagation velocity due to fatigue in the pieces with welding bead, may be due to a combination of the microstructure of the area affected by the heat and the presence of residual stresses. When the grain size of the steel is large, the velocity of propagation is lower than that of the fine grain size, due to the effect of the crack lock phenomenon induced by the roughness of the fracture surface [18]. Other factor are the residual stresses due to the welding process. Those are compressive stresses, which are counteracted by tensile stresses, producing an effective K less than that applied to the tip of the crack [19].

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