A NEW TECHNIQUE OF FRICTION STIRS FOR REPAIRING CORROSION OF ALUMINUM PLATE

B. Lakli[1], M. Berrahou[1],* and M. Serier[2]
[1] Department of Mechanical Engineering, University of Relizane. Bourmadia 48000, Algeria
[2] Department of Mechanical Engineering, University of Temouchent 46000, Algeria
**Corresponding author, email: berrahou22@yahoo.com*

ABSTRACT: *In the present paper, a new technique from the working principle of Friction stir technologies is introduced and investigated which can be used as a repair corrosion method for aluminum plates. That is to say, this method is based on friction. The pin less tool with its high rotation speed through friction cleans the area affected by corrosion well, and this is also a clear advantage for generating heat between the plate and tool. For repairing pitting corrosion, we added the filler material in the zone affected by corrosion, the rotating tool exerted frictional heat on the filler material and the work piece, which created a thermal field to treat corrosion by fusion and mixing in the corrosion zone. The generated heat comes from frictional and plastic dissipations, in which the friction contributes to the fusion of the filling material with the base metal. Tensile tests were performed to evaluate the mechanical properties of the repaired, corroded, and normal specimens. The mechanical properties of specimens are discussed so that the results of the tensile test showed a significant decrease in the mechanical resistance of the corroded plate, while the results for the repaired plate showed a significant improvement in mechanical properties, indicating that the repaired plate can once again perform its function satisfactorily. The tensile test demonstrated the effectiveness of the applied friction stir repair technique in restoring satisfactory properties, thereby improving the service life of the structure.*

KEYWORDS: *Friction Stir technologies, FS, FSP, Repairing, Corrosion, Aluminum alloy, Tensile test, Mechanical properties.*

1 INTRODUCTION

Structural damage is a major issue in many industrial sectors. Manufacturing processes, vibrations, shocks and severe environmental conditions can all contribute to the progressive degradation of structural components. In the aerospace industry, for example, aircraft wings are subjected to high cyclical loads that can result in cracks and delamination of composite materials [1, 2]. Similarly, in the oil and gas industry, offshore platforms are subjected to significant mechanical stress due to waves and weather, accelerating corrosion and fatigue of metal structures [3, 4].Premature damage to industrial equipment represents considerable maintenance and replacement costs, not to mention the potential risks to safety and the environment.

When damage occurs and defects appear, sophisticated repair techniques come into play. Welding, bonding and replacing defective parts are all part of the arsenal deployed to restore structural integrity and extend plant life. Repairing these different types of defects is critical. Currently, cutting-edge research focuses on the repair of metal defects, with an emphasis on methods such as fusion and solid-state welding [5, 6].

Innovation also plays a crucial role in this battle against damage. New materials with remarkable properties, cutting-edge manufacturing techniques and novel repair methods are the subject of ceaseless research.

Friction is an extraordinary heat source that is critical to the welding, deposition, and processing of structural metals and alloys [7,8]. The basic principles of friction stir technologies include the use of critical tool parameters, such as axial force and rotational speed, to create friction at the tool-work piece interface that causes material plasticization in the weld zone [7]. In order to provide researchers with a thorough understanding of the processes, variables, operating ranges, materials, tool profiles, tool-work piece interfaces, advantages, limitations and characteristics, a thorough investigation of each friction stir technique is necessary. The potential applications in a number of fields are strengthened by this understanding. Friction stir is widely used in the manufacture of structural components for the automotive, aircraft, and shipbuilding industries, as well as for surface painting, cladding, and component repair.

Friction stir technologies have been used for joining and processing since their inception. In contemporary research, there is a notable emphasis on the use of these FS technologies for defect repair, driven by their demonstrated feasibility.

By leveraging the principles of frictional heat generation, these techniques can effectively address and rectify defects such as cracks, pores, or inclusions in structural components. This innovative application of Friction Stir Technologies holds the potential to enhance the integrity and functionality of various materials, making it a valuable method in defect repair for industries such as automotive, aerospace, and shipbuilding.

Friction Stir Processing (FSP) was used in study by Miles, M. P., et al. [9] to repair cracks in 304L stainless steel. Their research showed that FSP may effectively repair a collection of uniformly sequenced cracks with different widths as well as a tapered crack. The feasibility of repairing these fractures was demonstrated, demonstrating that a tension crack in an already-formed weld may be successfully repaired by using a tool around the existing weld or Heat-Affected Zone (HAZ).

Friction plug welding (FPW) was used by Du et al. (2016) [10] to address and fix a keyhole. Moreover, Huang et al. (2009) [11] have offered an alternate method called friction bit joining (FBJ), which uses a consumable bit as the filler material.

Zhang et al. (2014) [12] described a method that allows the keyhole to be repaired with a pin less tool by adding a filler material to the hole. Furthermore, Ji and colleagues (2016) [13] proposed a novel method called active-passive filling friction stir repairing (A-PFFSR). This method uses many pin less tools with different shoulder diameters to correct volume faults in Friction Stir Welding (FSW) connections.

Friction stir technology has drawn interest because it can enhance material qualities without causing the problems that come with conventional welding methods. It is particularly helpful for aluminum alloys used in marine, automotive, and aerospace applications where strong, lightweight materials that are resistant to corrosion are essential. Alloys like 2024 and 2017 from the 2xxxx range are well-known and frequently used in aeronautical applications. They become high-strength alloys when copper is added, which increases their strength. It's important to keep in mind, though, that in comparison to certain other aluminum alloys, their corrosion resistance is somewhat compromised.

From friction stir technologies, we have developed a method to repair corrosion. This method uses the working principle of Friction stir to repair corrosion. In other words, this method is based on friction. The pin less tool with its high rotation speed, by friction cleans the area affected by corrosion. This process offers a distinct advantage as the generated heat between the tool and the work piece establishes a thermal field. This field enables the treatment of corrosion through fusion and mixing in the corrosion zone.

In the present study, a friction stir repairing corrosion technique, which was a variant of the FS technologies, was proposed to repair the corrosion defects. We will see the effectiveness of this technique and confirm it by carrying out tests on the specimens obtained.

2 EXPERIMENTAL PROCEDURES

2.1 Repairing method process

Figure 1 indicates the schematic of the repairing pitting corrosion process. A rotating tool was composed of a shoulder without a pin (pin less tool). Processing parameters of rotational speed of 1000 rpm and a travel speed of 50 mm/min were employed. The repairing process included the cleaning, filling, and mixing stages.

Firstly, Aluminum should be cleaned until the metal is exposed; removing rust (alumina) and any impurities, the metal surface should be clean, so that the pin less tool with its high rotation speed through friction cleans the zone affected by corrosion.

Secondly, the filling material was put into the pitting corrosion-affected zone Figure 1-b, the rotating tool exerted frictional heat on the filling material and work piece for a dwell time of several seconds, and this produces the frictional heat between the tool shoulder, filling material, and work piece, ensuring softening of the material. Then the tool traverses along the corrosion-affected zone, material is plastically deformed, and it starts getting deposited on the corroded zone Figure 1-c.

Finally, the tool retracts, and the repairing of the pitting corrosion defects is completed Figure 1-d.

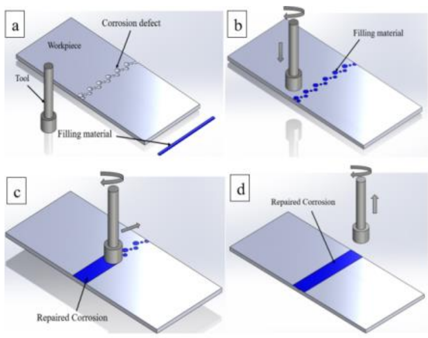

Fig.1 Schematic of the repairing corrosion process

2.2 Materials

The repair experiments were carried out on a conventional milling machine. This milling machine is widely used for machining operations in industry.

Work piece material used in present study was aluminum alloy A2017, this alloy is also known as AlCu4MgSi and has the chemical composition presented in Table 1.

The plates were corroded by putting them in salt water. The form of corrosion is pitting corrosion.

The size of the plate is 140 × 60 × 3 mm^3Figure2. The diameter of the tool shoulder is 12 mm Figure3.

H13 steel is selected for the tool as used in the repair method and has the chemical composition presented in Table 2.

ER4043 with a diameter of 3 mm was selected as the filling material. ER4043 aluminum filler materials are silicon-aluminum types for welding. The nominal composition of the filler meets the ASTM B209 standard, as reported in Table 3.

Tab.1 Chemical composition of A2017 aluminum alloy (%wt)[14]

Al	91.5- 95.5
Si	0.20-0.8
Fe	0.7 max
Cu	3.5-4.5
Mn	0.40-1.0
Mg	0.40-0.8
Cr	0.10max
Zn	0.25max
Ti	0.15max
Other each	0.05max
Othertotal	0.15max

Tab.2 Chemical composition of H13 (%wt)[15]

C	0.32–0.45
Mn	0.20–0.50
Si	0.80–1.20
Cr	4.75–5.50
Ni	0.30max
Mo	1.10–1.75
V	0.80–1.20

Tab.3 Chemical composition of ER4043 filler (%wt)[16]

Al	93.09
Si	5.60
Fe	0.80
Cu	0.30
Mn	0.05
Mg	0.04
Zn	0.10
Ti	0.02

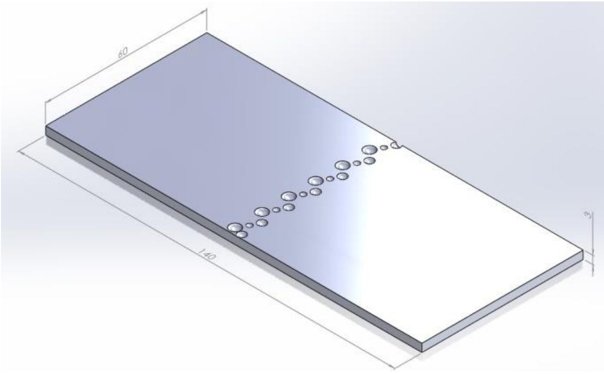

Fig.2 Geometry of corroded plate

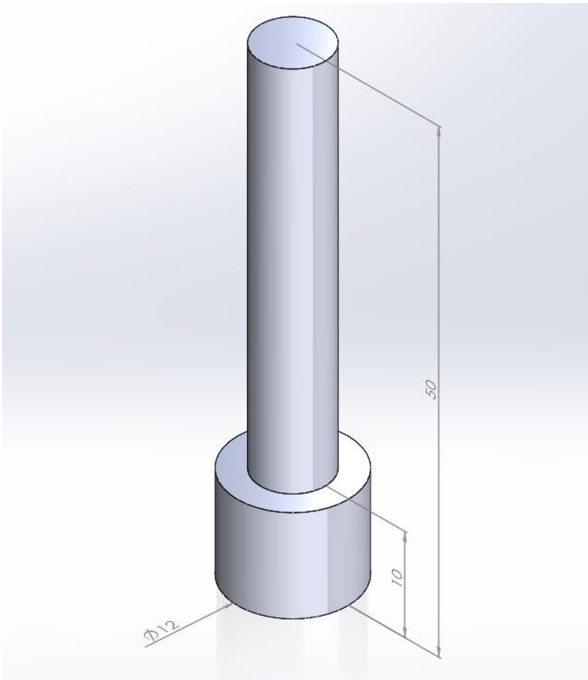

Fig.3 Geometry of pin less tool

3 CHARACTERIZATION

3.1 Tensile tests

Tensile tests were conducted at room temperature to assess the mechanical properties of the repaired specimen, corroded specimen and normal specimen (without defects). The test specimens are rectangular with dimensions of140×60×3 mm^3Figure 4-6.

The traction machine (INSTRON) is used with an extensometer. The test procedure involves subjecting these standardized specimens to increasing unidirectional tensile force in order to determine the material's characteristic curve by measuring the force and elongation. The measurement of this elongation in the useful zone is done using an extensometer.The test continued until rupture will allow us to measure the ultimate elongation.

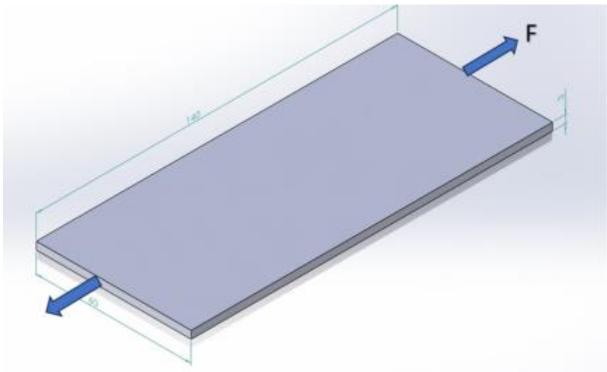

Fig.4 Normal test specimen

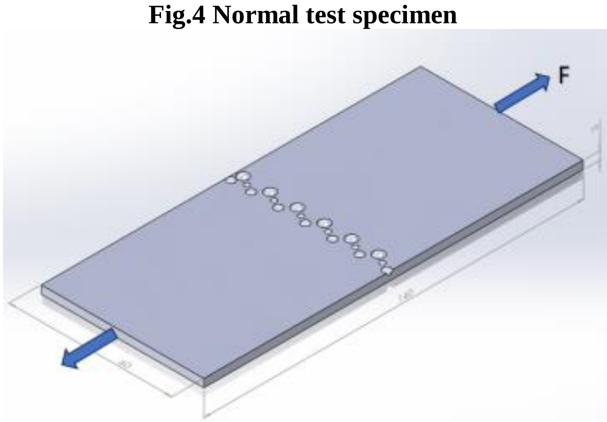

Fig.5 Corroded test specimen

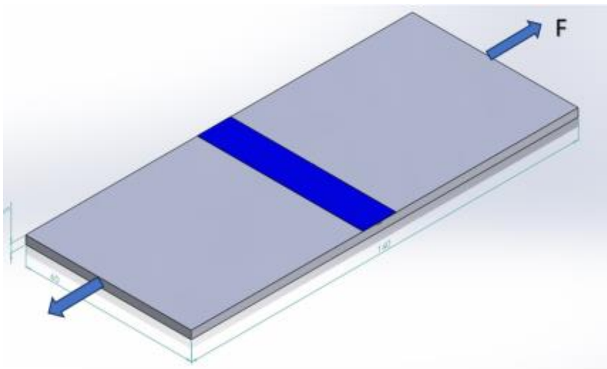

Fig.6 Repaired test specimen

4 RESULTS AND DISCUSSION

4.1 Visual inspection

Figure 7shows the surface condition of corroded plates before and after cleaning the area affected by corrosion. The first, the one on the left of the figure, represents the corroded plate before cleaning; the surface of the corroded plate shows signs of rust, deterioration, and pitting resulting from corrosion. The second, the one on the right, represents the corroded plate after cleaning. The pin less tool, with its high friction rotation speed, cleans the area affected by corrosion. Thus, we obtain a clean surface condition, removed from rust (alumina) and impurities.

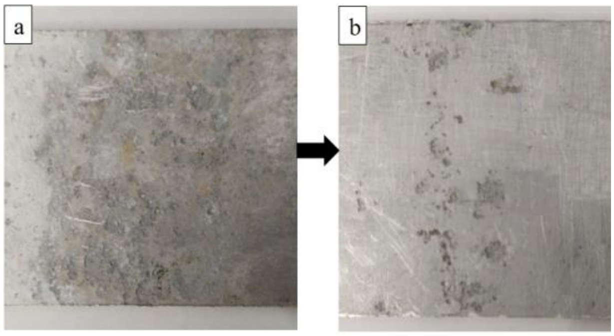

Fig.7 removing rust (alumina): (a)before cleaning, (b)after cleaning

After cleaning the corroded plate, we noticed pitting on the surface of the plate Figure 8-a. We can clearly distinguish defects on the surface of corroded plates, this is called pitting corrosion. This defect was repaired by placing the filler material in the zone affected by pitting corrosion, the rotating tool exerted frictional heat on the filler material and the work piece. The generated heat comes from frictional and plastic dissipations, in which the friction contributes to the fusion of the filling material with the base metal.

To obtain a good surface condition of the plate, we ensured that the temperature was sufficient to melt the filling material and integrate it into the base metal. Higher tool rotation rates generate higher temperature because of higher friction heating and result in a more intense mixing of material. Figure 8-bshowsthe result of the repair. The pits in the plate are completely filled and repaired.

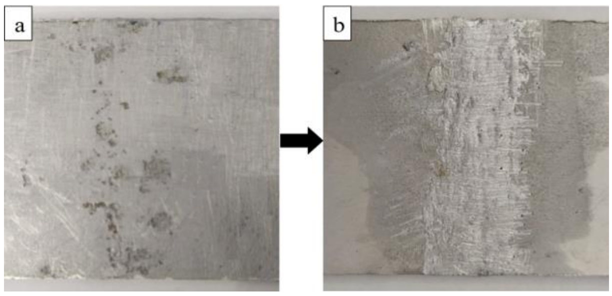

Fig.8 Corrosion repairing: (a)before repairing, (b)after repairing

4.2 Characterization

4.2.1 Comparison of mechanical characteristics

The results of the tensile test of the specimens (corroded, repaired, and normal) are summarized in Table 4, where the measured load, tensile strengths, and elongation. Different mechanical properties were obtained. Corrosion weakens the structure by reducing the thickness of the plate, causing cracks or perforations, or altering the material's mechanical properties. It appears that the repaired plate has the best mechanical properties.

Tab.4Tensile test results

Specimens	Load max (KN)	Ultimate strength (MPa)	Elongation %
Normal	61	421	27,6
Repaired	60,9	442	38,6
Corroded	56	417	7,9

Figure 9 compares the load-displacement curves of a corroded, normal, and repaired plate. The maximum load capacity was determined for the repaired, corroded, and normal specimens (without defects) in Table 4.

Before repair, the corroded plate exhibits a load-displacement curve that indicates structural weakness due to corrosion. This curve shows a reduction in maximum load compared to a normal plate, due to pitting corrosion which weakens the structure by reducing the thickness of the plate.

The geometric characteristics of the load-displacement curve for the repaired specimen are similar to the normal specimen, this is an indication that the repair technique is estimated to increase stiffness and tensile strength.

Friction stir corrosion repair strengthens the structure by filling the corroded zone and reinforcing weakened zones.

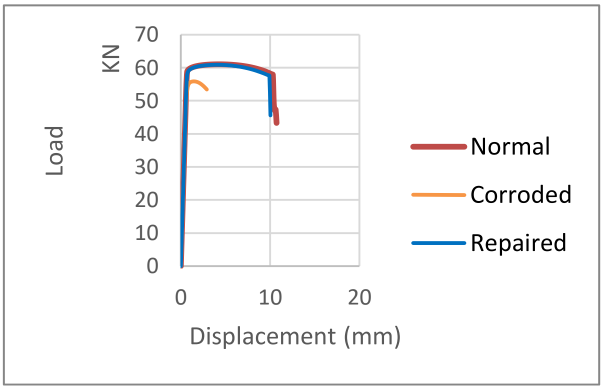

Fig.9 Load-displacement curves of the repaired specimen, corroded specimen and normal specimen.

Figure 10 shows the stress versus strain curves from the tensile testing. The tensile curve shows the relationship between the stress and strain of a material when it is subjected to a tensile force. The benefit of the repair technique is clearly visible. The tensile strength and ductility of the plate are strongly improved by filling the corroded zone and reinforcing weakened zones, this allows improving the service life of the structure.

The corroded plate curve shows a reduction in mechanical resistance compared to a normal plate due to corrosion. Depending on the severity of the corrosion, the corroded plate exhibits increased brittleness, which results in more sudden rupture and less prior plastic deformation.

The stress-strain curve of the repaired plate shows an improvement compared to the corroded plate. The repair technique restores some of the mechanical strength lost due to corrosion.

The quality of the repair is also an important factor. Effective repair brought the mechanical performance of the repaired plate as close as possible to that of a normal plate, and even better than that.

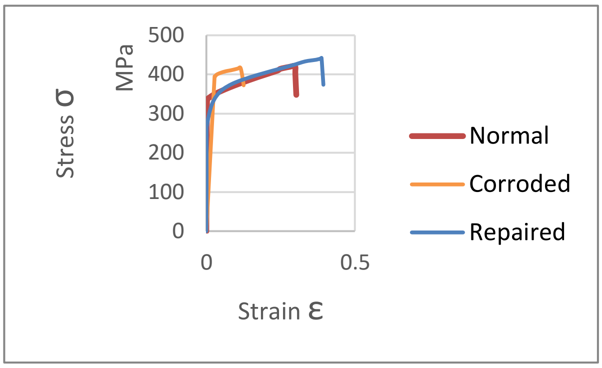

Fig.10nStress-strain curves of the repaired specimen, corroded specimen and normal specimen

4.2.2 Comparison of ultimate strength

Ultimate strength is the maximum stress a material can withstand before breaking or failing, it is determined through tensile testing.

Figure 11 shows the histogram of ultimate strength values. This study proved that the repair technique increases the value of the ultimate strength of the plate so that the untreated corroded plate failed by a value of only 417 MPa, while using the friction stir repair this value increased to reach the value of 442 MPa.

The ultimate strength of a corroded plate is lower than that of a normal plate due to the corrosion, which changes its mechanical properties by weakening the material.

The repaired plate has a higher ultimate strength compared to a corroded plate. The repair process aims to address the weaknesses introduced by corrosion and restore the plate's structural integrity.

The repaired plate has improved mechanical strength, ensuring it can withstand higher loads than a normal plate, due to filling the corroded zone and reinforcing weakened zones.

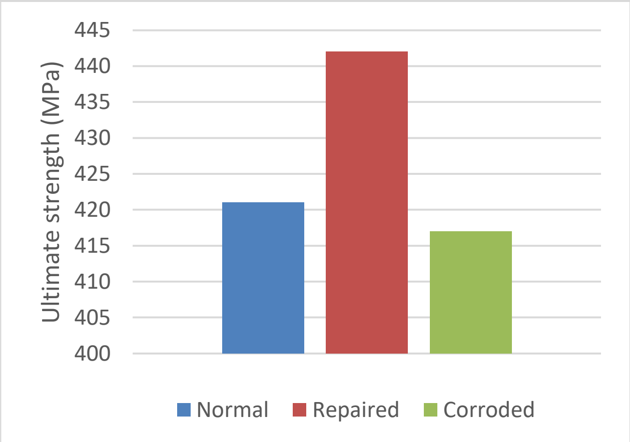

Fig.11 Comparison of ultimate strength of the repaired, corroded and normal specimens

4.2.3 Comparison of elongation

Elongation refers to the ability of aluminum to stretch before breaking under tension. It's a measure of its ductility.

Figure 12 shows the histogram of elongation values for the corroded, repaired, and normal specimens, where the elongation value obtained for the corroded specimen is 7,9%, while using the friction stir repair this value increased to reach the value of 38,6%.

The corroded plate has less ductility than the normal plate, meaning it has a reduced ability to deform plastically before breaking. This increases the risk of brittle fracture, that is to say, a brutal rupture without visible deformation.

The friction stir repair process significantly impacts elongation due to the heat generated by friction and also due to the filler material that is added, this made the elongation value rise significantly.

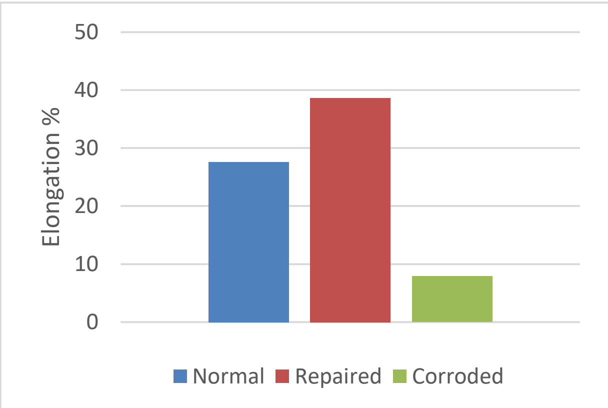

Fig.12 Comparison of elongation of the repaired, corroded and normal specimens

5 CONCLUSION

A novel technique for repairing corrosion for aluminum plates was successfully demonstrated. This technique was developed from friction stir technologies. The process is able to repair corrosion using a pinless tool and filling material. The rotating tool exerted frictional heat on the filler material and the workpiece. the generated heat comes from frictional and plastic dissipations, in which the friction contributes to the fusion of the filling material with the base metal.

The repair quality analyzed using a tensile test showed and improved mechanical strength over the corroded plate. The following conclusions can be drawn from the study:

- Through visual analysis of the repaired plate, we can say that we have a good surface condition, as the pits in the corroded plate have been completely filled and repaired.
- The results of the tensile test showed a significant decrease in the mechanical resistance of the corroded plate compared to a new plate, indicating a deterioration of the mechanical properties due to corrosion, this means that the corroded plate can no longer perform its function reliably.
- Corrosion has damaged the material, causing a significant reduction in its ultimate strength. This reduction means that the corroded plate can no longer support the same level of load without risk of failure.
- Corrosion reduces the thickness of the metal plates, leading to a decrease in the overall ductility and elongation capability of the material.
- After the friction stir repair corrosion, the tensile test results show a significant improvement in the mechanical properties of the plate, indicating that the repaired plate can once again perform its function satisfactorily.
- This repair technique has significantly improved the ultimate strength, compensating for the damage caused by corrosion. This indicates that the repaired plate can support higher loads before failure.

- Friction stir repair increases the thickness of the corroded plate by adding filler material to the pits and thus improves elongation performance.

In conclusion, the tensile test demonstrated the effectiveness of the applied repair technique in restoring satisfactory properties, thereby improving the service life of the structure. This result validates the approach adopted for the repair of corroded aluminum plates.

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