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# Corrosion and stress corrosion cracking behaviour of 2050 aluminium-lithium alloy joined by friction stir welding (FSW)

Vincent Proton<sup>1</sup>, Joël Alexis<sup>2</sup>, Eric Andrieu<sup>1</sup>, Grégory Odemer<sup>1</sup>, Christine Blanc<sup>1</sup>,  
Jérôme Delfosse<sup>3</sup>

<sup>1</sup>Université de Toulouse, CIRIMAT, UPS/ CNRS/INPT, Toulouse cedex 04, France

<sup>2</sup>Université de Toulouse, INPT/ENIT, LGP, Tarbes, France

<sup>3</sup>EADS France IW, Suresnes, France

## Summary

The present work deals with the influence of an external mechanical stress on the corrosion behaviour of a Friction Stir Welding butt joint. In order to understand the corrosion behaviour of the whole welded joint, some zones have been removed and studied individually.

A welded joint was obtained by joining together two plates of aluminium-lithium alloy 2050-T3 and then has been submitted to an additional T8 post-welding heat treatment. Actually a typical friction stir weld consists of the unaffected base material (BM), a heat affected zone (HAZ), a thermo-mechanically affected zone (TMAZ) and a dynamically recrystallized zone (nugget).

Some samples were removed from the BM and the nugget of the welded joint in order to study the corrosion and stress corrosion cracking behaviour of these two zones individually. Immersion tests with and without an external mechanical stress were performed in a 0.7 M NaCl solution to study the corrosion behaviour of the two zones and the influence of the stress. For both kinds of experiments, the corrosion damage was determined by measuring the average depth and the maximal depth of the corrosion defects.

The results showed that the two zones presented different corrosion morphologies. The BM exhibited susceptibility to intragranular corrosion while the nugget presented both intragranular and intergranular corrosion. The external mechanical stress did not modify the corrosion morphologies and the open circuit potential. Nevertheless, as they present different corrosion morphologies, the external mechanical stress did not have the same influence on the propagation of the corrosion damage. Indeed, the external mechanical stress did not promote the propagation of the corrosion in the BM whereas it does in the Nugget.

Considering the whole welded joint, the corrosion morphologies of the BM and the nugget were the same than those observed for each zone considered individually. A previous work [1] has shown that galvanic coupling phenomena existed between the different parts of the welded joint and the BM acted as a sacrificial anode. As the external stress did not change the OCP of the different parts, no modification of the galvanic coupling phenomena was expected and the BM was found to be more damaged than the other zones.

## 1 Introduction

To reduce in weight the aircraft metallic structures, the industry has considered the combined use of 3<sup>rd</sup> generation aluminium-lithium alloys and the friction stir welding process. The Friction Stir Welding (FSW) process has been developed by The Welding Institute in 1991. It consists of the use of a non-consumable cylindrical, ro-

tating tool (usually hardened steel) which moves over the seam of two butted plates and stirs them together [2].

Actually a typical friction stir weld consists of the unaffected base material (BM), a heat affected zone (HAZ), a thermo-mechanically affected zone (TMAZ) and a dynamically recrystallized zone (nugget). The welded joint obtained presents a heterogeneous microstructure which would be critical for its corrosion behaviour.

A previous study performed on FSW joints of AA 2050-T3 has brought to light that galvanic coupling phenomena occur between the different zones of the welded joint during immersion in chloride-containing environment without mechanical stress [1]. This study showed that the different zones of the welded joint have different electrochemical potential which lead to galvanic coupling. Current densities of these galvanic coupling are measured and highlight that the base metal presents near the welded joint will act as a sacrificial anode.

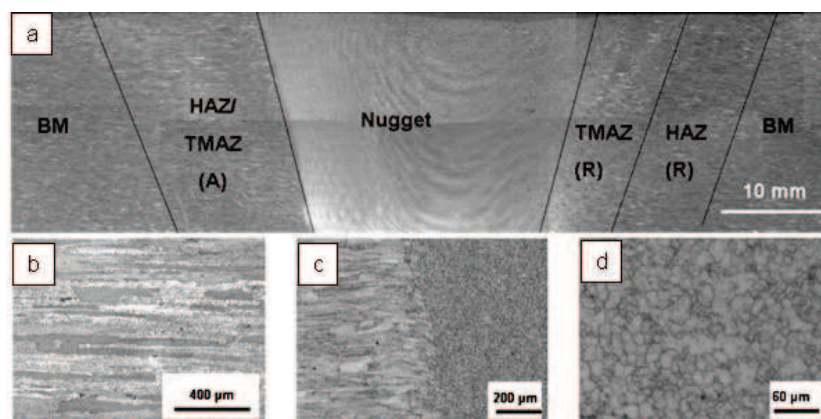
Very few studies have been led on the stress corrosion cracking behaviour of FSW joint and even less on AA2050. This paper presents results on the stress corrosion behavior in global FSW welded joint of AA2050 and its component parts.

## 2 Results

### 2.1 Corrosion behaviour of the FSW joint

#### *..1 Corrosion behaviour of the whole welded joint*

A typical friction stir welding microstructure is presented in Figure 1-a. The process involves the apparition of four different zones which are clearly identifiable after etching with Keller agent. The first one is the base metal (BM) which presents elongated grains due to the rolling process (figure 1-b). Then, when moving through the center of the weld, an Heat Affected Zone is encountered (HAZ) which does not exhibit differences with the BM in grain size but only in hardening precipitation. Closer to the center of the weld, the thermomechanically affected zone (TMAZ) is present, which is constituted by sheared grains (Figure 2-c). Finally, the center of the welded joint, which has seen relatively high temperature and great shear process, exhibits small equiaxed grains which size varies from 16  $\mu\text{m}$  from the top to 4  $\mu\text{m}$  in the bottom.

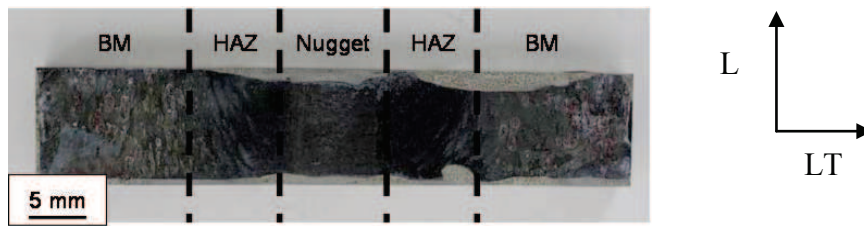


**Figure 1:** Optical microscopy observations of (a) the whole welded joint (b) the Base Metal (BM) (c) the Thermomechanically Affected Zone (d) the Nugget after etching with Keller agent in the plane LT-ST.

These observations in optical microscopy allow the identification of four different zones, which present different microstructures. Thus, when the whole welded joint

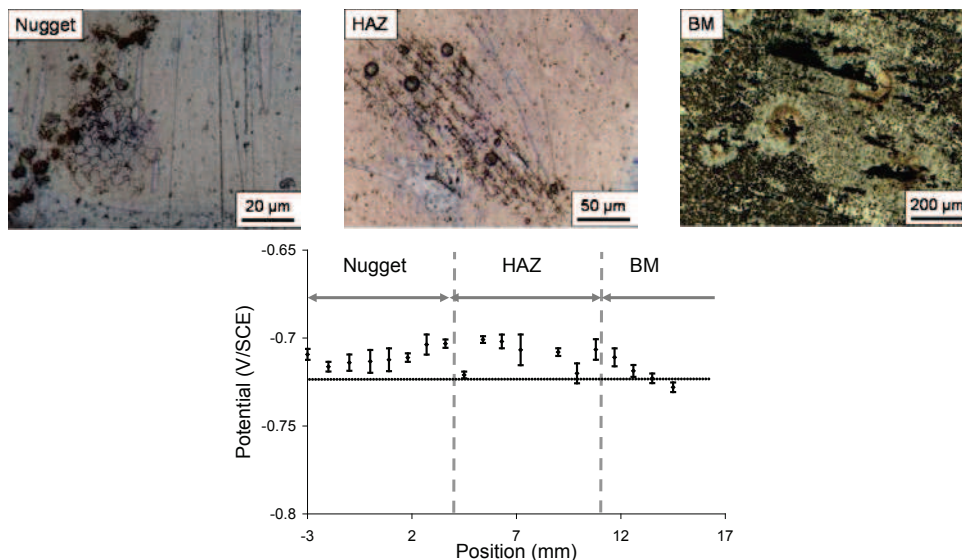
will be exposed to an aggressive environment, these zones could have different corrosion behavior.

The plane L-LT of the welded joint has been exposed to a 0.7 M sodium chloride solution during seven days. The final aspect of the joint is presented in Figure 2.



**Figure 2:** Observation of the whole welded joint after 7 days of immersion in 0.7 M NaCl at 25°C.

This test revealed that, as we could expect from the heterogeneous microstructure, the corrosion damage is not the same in each zone. Actually, the BM seems to be more damaged. On the contrary, from these observations, the HAZ and the Nugget do not exhibit severe corrosion damage. The BM has acted like a sacrificial anode. In order to confirm this hypothesis, the Open Circuit Potential (OCP) along the whole welded joint has been performed in the L-LT plane. The results are shown in figure 3. The dot line symbolizes the OCP of the whole welded joint measured in the same conditions. As we can see, the OCP of the BM is more cathodic comparing to the HAZ and the Nugget. So, when the whole welded joint will be exposed to an aggressive environment, the BM will act as a sacrificial anode. A complete study of the phenomenon has been performed by Proton *et al* [1]. At the end of the two hours of potential measurements, the surface of the samples has been observed by optical microscopy. This reveals that the BM is sensitive to intragranular corrosion, the HAZ to intergranular corrosion and the Nugget to a mix of intergranular and intragranular corrosion.

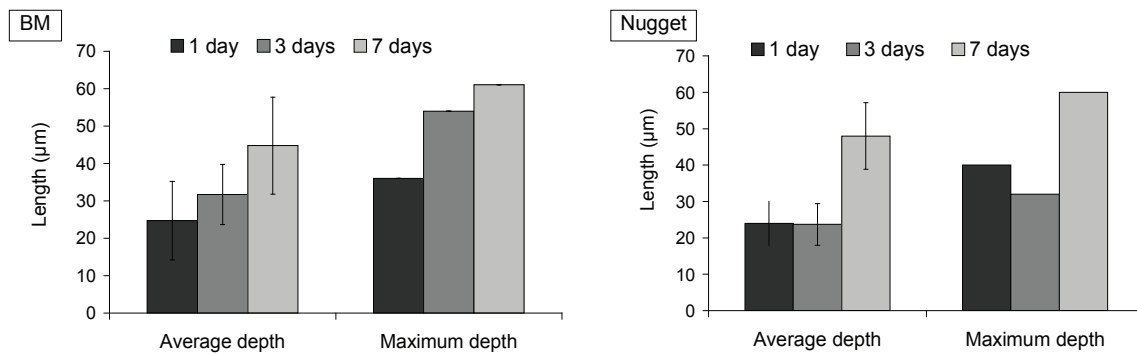


**Figure 3:** Open circuit Potential (OCP) evolution across the whole welded joint.

### 2.1.2 Corrosion behaviour of the base metal and the Nugget

In order to predict how the different zones will behave, kinetics of corrosion damage have been evaluated for the BM and the Nugget. The statistical study has been done by measuring the average depth and the maximal depth reached by the corrosion damage after 1, 3 and 7 days of immersion in 0.7 M NaCl. The plane exposed to the

electrolyte is the L-LT plane. The results of the statistical study are synthesized in the Figure 4.



**Figure 4:** Quantification of the corrosion damage for the BM and the Nugget after 1, 3 and 7 days of immersion in 0.7 M NaCl at 25°C.

The corrosion damage of both the BM and the Nugget increases with the immersion time. The average depth for the BM varies from 25 µm after 1 day of immersion to 44 µm after 7 days of immersion. The same conclusion is made when considering the maximum depth reached by the corrosion damage. This indicator which is around 35 µm after 1 day of immersion reaches a depth of 60 µm after 7 days.

The average depth of the corrosion damage in the Nugget is about 24 µm after 1 day of immersion whereas it is 48 µm after 7 days. The same evolution is observed concerning the maximal depth, varying from 42 µm to 60 µm for respectively 1 day and 7 days of immersion.

### 3.1 Stress corrosion cracking behaviour of the FSW joint

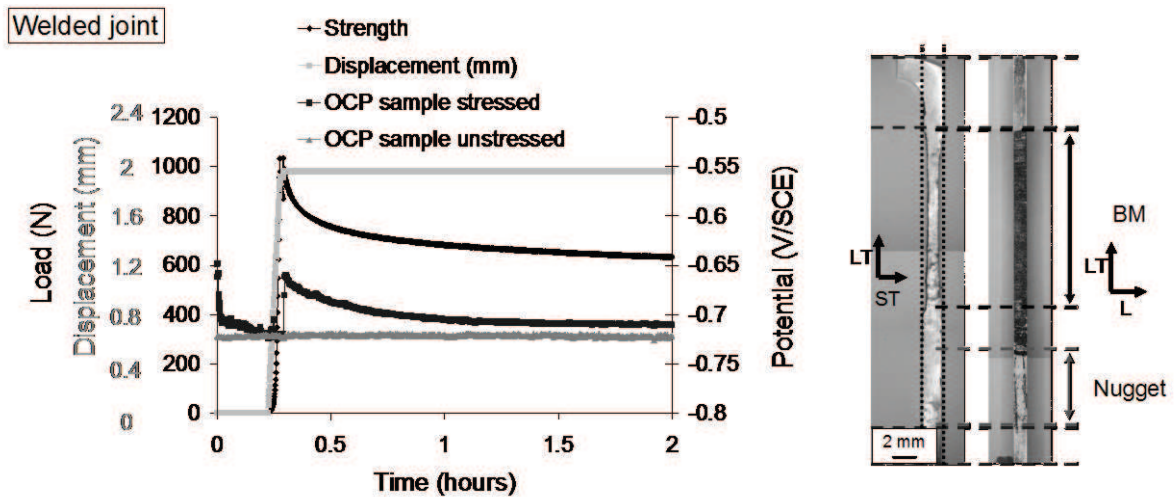
A stress corrosion cracking set up has been developed in the laboratory to perform stress corrosion cracking tests at constant displacement and to measure the OCP of the material along the time. The initial displacement applied induces a stress equal to 80% of the yield stress of the tested material.

#### 3.1.1 Stress corrosion cracking behaviour of the whole welded joint

The whole welded joint has been submitted to a constant strain which during 3 days in a 0.7 M sodium chloride solution at 25°C. This strain corresponds to an initial stress of 80% of the yield stress of the material.

The OCP of the stressed and unstressed sample is reported in the Figure 5. During the first 10 minutes, no stress is applied on the sample. After this waiting time, the initial stress is applied and the displacement is fixed. Due to the presence of the stress, the potential is shift toward more anodic potentials. When unstressed, the OCP value is equal to -0.723 V/ECS whereas when the stress is applied it is equal to -0.705 V/ECS.

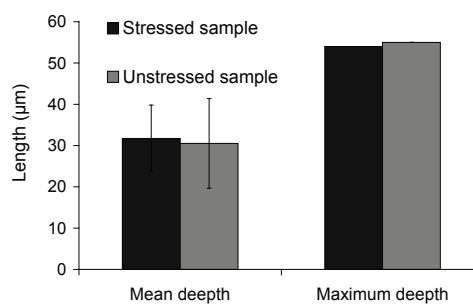
At the end of the test, the surface of the sample is observed. The BM is more damage than the other zones. It seems that there are no changes in galvanic coupling phenomena. A thickness of 500 µm from each side of the BM has been corroded.



**Figure 5:** Stress corrosion cracking test of the Nugget in 0.7 M NaCl during 3 days and quantification of the corrosion damage after the test

### 3.1.2 Stress corrosion cracking behaviour of the Base metal and the Nugget

The stress corrosion cracking behaviour of the BM taken individually has been studied and is reported in Figure 6. The protocol used is the same as previously. Contrary to what happened in the whole welded joint, there is no modification of its OCP value when the stress is applied. The external mechanical stress does not change the corrosion morphology of the base metal which is still susceptible to intragranular corrosion. After the stress corrosion cracking test, the corrosion damage is quantified using the same indicators used in figure 4.

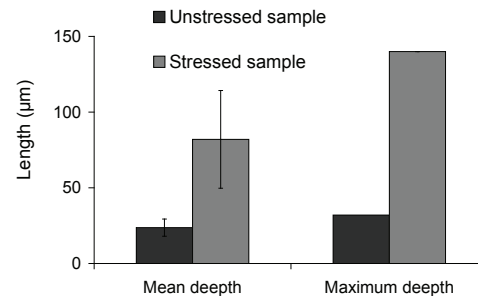


**Figure 6:** Stress corrosion cracking test of the Nugget in 0.7 M NaCl during 3 days and quantification of the corrosion damage after the test.

In order to understand the influence of the stress, the results in presence of an external mechanical stress is presented in figure 6. For both samples, the average depth and the maximum depth are unchanged and respectively equal to 32 µm and 56 µm. The fact that the stress does not propagate the corrosion damage deeper in the material is due to the fact that the BM is susceptible to intragranular corrosion (Figure 3). Thus, the stress applied does not open the defects and do not promote the propagation of the corrosion damages.

The Nugget was also studied individually and the results are reported in figure 7. At the end of the test, the Nugget is still susceptible to a mix of intergranular and intragranular corrosion. The OCP of the Nugget is not modified by the external mechanical stress applied and is constant at -0,705 V/ECS.

The corrosion damage due to the presence of the stress is compared to the corrosion damage of the Nugget without any stress. It emerges from this comparison that the external mechanical stress increases the damage of the Nugget. The average depth reaches 82  $\mu\text{m}$  whereas without stress, this depth was around 24  $\mu\text{m}$ . The same evolution is noticed about the maximum depth which increases from 32  $\mu\text{m}$  to 140  $\mu\text{m}$ .



**Figure 7:** Stress corrosion cracking test of the Nugget in 0.7 M NaCl during 3 days and quantification of the corrosion damage after the test.

The increase of the corrosion damage in the thickness of the sample in the presence of an external mechanical stress is link to the susceptibility to intergranular corrosion of the Nugget. Indeed, the stress is going to open the defects present and promotes the propagation of the defect in the thickness.

As the OCP of the two zones are not modified by the stress, when a stress is applied on the whole welded joint, there are no modifications of the galvanic coupling and thus the BM is more damage. Moreover, as the figure 5 show it, the external mechanical stress polarizes the sample, more precisely the BM, and so increases the damage in the BM

## Conclusion

The FSW joint present a heterogeneous microstructure which induces different corrosion behaviour. The BM is sensitive to intragranular corrosion whereas the Nugget exhibits a susceptibility to intergranular and intragranular corrosion. When an external mechanical stress is applied, these two zones react differently. The external mechanical stress does not propagate the corrosion damage in the thickness of the sample in the case of the base metal whereas it increases the average depth in the case of the nugget. Nevertheless, the external mechanical stress does not change the OCP of the two zones. So when an external mechanical stress is applied on the whole welded joint, there are no modifications of the order of galvanic coupling. The external stress induces a shift of the OCP toward more anodic values and so, the Bm is anodically polarized.

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## 3 References

- [1] V. Proton, J. Alexis, E. Andrieu, C. Blanc, J. Delfosse, L. Lacroix and G. Odemer, *Journal of the Electrochemical. Society*, 158 (5) C139 – C147 (2011)
- [2] W. M. Thomas, E. D. Nicholas, J. C. Needham, M. G. Murch, P. Templesmith, and C. J. Dawes, *International Pat. Appl.*, PCT/GB92/02203 (1991).