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IMPROVING WELDED JOINT FATIGUE LIFE USING SHOT PEENING OR GRINDING

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ABSTRACT

Steel structures are mainly prone to two types of degradation: corrosion and fatigue particularly in the case of welded structures. The presented work aims at investigating two treatment methods to increase the fatigue life expectancy of welded steel joints in civil engineering structures. It includes both numerical and experimental investigations and is interested in the use of grinding and shot peening. As far as experimental investigations are concerned, for both treatment methods and for untreated samples, the stress concentration coefficients are determined, surface residual stresses are measured using X-ray diffraction and fatigue tests are conducted. The results allow explaining for both methods the observed improvements in fatigue behaviour. As far as numerical investigations are concerned, the presented work concerns the use of a finite element model to simulate welding process. This allows the determination of residual stresses due to welding operation and their comparison with the former experimental measures. Results are satisfactory enough, and, though some improvements regarding the initial stress state and the modelling are still under progress, it should be used in a following study to model treatment operations to get a better understanding of their potentiality and the parameters that affect their efficiency.

Manuscript text

INTRODUCTION

Welding in steel structures design is nowadays the most widely used assembly technology. In the case of bridge structures, it has replaced riveting and bolting since thirty years. It is well known that this kind of structure may be deteriorated because of corrosion but also of fatigue issues (1). In the case of corrosion, specific maintenance actions are currently being done by owners to increase the life span of their structures as painting operations for instance. Similar actions could certainly be done concerning fatigue issues at the condition that the existing strengthening methods are well mastered. It is therefore momentous to lead research works on the fatigue of welded joints and the existing strengthening methods.

This research work should focus on two main topics. The first concerns the understanding of fatigue mechanisms within welded joints. This is indeed due to two phenomena: the stress concentration at the assembly singularities, and the existence of residual stress created during the welding process. The second one is linked to the different available strengthening methods such as grinding, shot blasting, shot peening, thermal treatment, etc ... (2) (3). It is important to understand the effect of each of this method (on geometrical singularities and residual stresses) and their efficiency depending on the conditions during their application.

The present work focuses on two strengthening methods typically used in the industry to increase the life expectancy of welded joints: grinding and shot peening. The aimed application is linked to bridge or offshore structures and consequently the led investigations concern materials and geometry currently encountered in this domain. The first part is dedicated to describe the experimental investigations done on welded assembly before and after strengthening. It includes fatigue tests, residual stress measures, and geometrical measures. The second part introduces a finite element modelling approach used to simulate welding operation and to assess residual stress levels created during the welding process.

EXPERIMENTAL INVESTIGATIONS

It was chosen to work on a geometry typically encountered in steel bridges. The chosen steel material is S355 J2, the plate thicknesses are 15 mm, and the geometry corresponds to a classical T-joint. The welding process was the MAG one (Metal Active Gaz) often used for the realization of steel structures. Most of the parameters of the welding operations have been recorded and may be found in (4). A single steel plate has been used during welding operations in order to obtain similar samples after cutting the plate. Welding operations were led on one way, using a single pass and one side after the other at a speed of 7.5 mm/sec. The final samples geometry is similar to the one in (5) and is shown on figure 1. The samples width in the middle is 100 mm, their length is 900 mm, and the height of the additional plate is 100 mm.

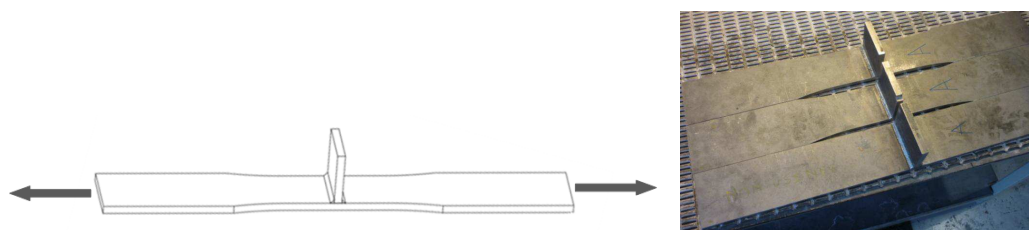


FIGURE 1 Samples geometry and photo of three of the samples

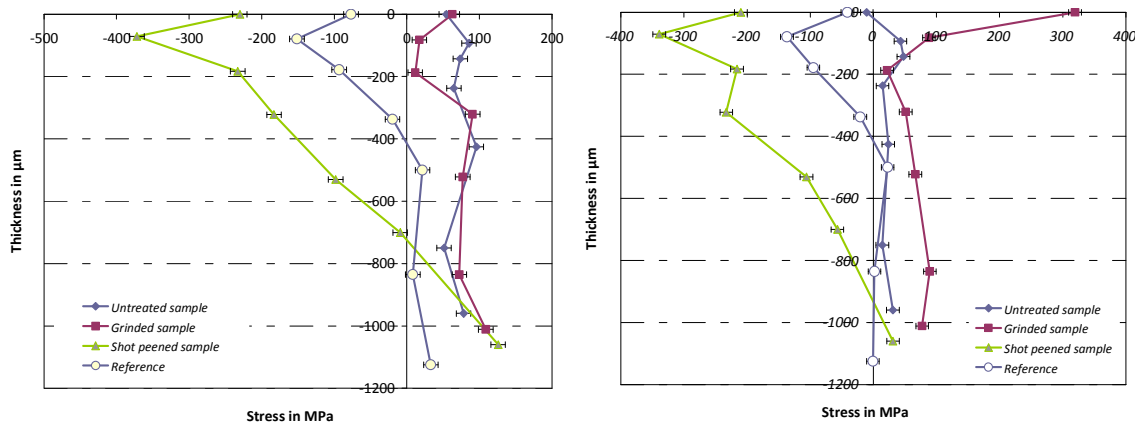
Nine similar samples were realized: three have not been treated, three have been grinded and three have been shot peened. Grinding operations took place at the weld toe and consisted in removing between 0.5 and 0.8 mm of the surface providing a smooth final shape. Shot peening operations were performed by the enterprise Metal Improvement Company (MIC).

1 Geometrical measures

2
3 Geometrical measures were conducted to study the geometrical influence of the different
4 reinforcement operations. Using silicon moulds, it was possible to realize prints of the welding
5 profiles and to compare them using a 3D measuring device. A stress concentration coefficient was
6 then possible to determine using the empirical formula of (6). The given equation uses the weld angle
7 and the weld toe radius. The determined coefficients were 2.49 for the untreated sample, 2.35 for the
8 shot peened sample, and 2.00 for the grinded sample. Though measures were only done on one sample
9 for each case, it is consistent with what is forecast from each of the studied reinforcement method:
10 grinding seems to be the most adapted method to reduce the stress concentration factor for such a kind
11 of welded assembly.

13 Residual stress measures

14
15 The residual stress measures were led by the enterprise Meliad using X-ray diffraction technique. It
16 was possible to measure residual stress profiles close to the weld toe (6 mm) and along 1 mm deep in
17 the steel plate using successive chemical abrasion operations. Measures were conducted on both sides
18 of the assembly, but no difference was seen. The obtained residual stress measures on one side of the
19 assembly are given in figure 2. Two measures were realized: longitudinal stress along the sample
20 direction, and transversal stress along the weld direction. A reference measure has been made on the
21 steel plate far from the welded joint to determine the initial stress state before welding operations took
22 place. It is important to note that the initial stress state is not zero. Sanding and laminating operations
23 apparently created compressive residual stresses. As expected, welding operations create tensile
24 residual stress at the weld toe. Grinding operations do not tend to decrease them as it only consists in
25 removing a small layer of material at the surface. It is interesting to note that it creates tensile residual
26 stress in the transverse direction due to the grind direction. On the contrary, shot peening operations
27 tend to create additional compressive residual stresses close to the elastic limit of the steel material.
28 Shot peening operations tend to influence residual stress profile until a depth of 1 mm.

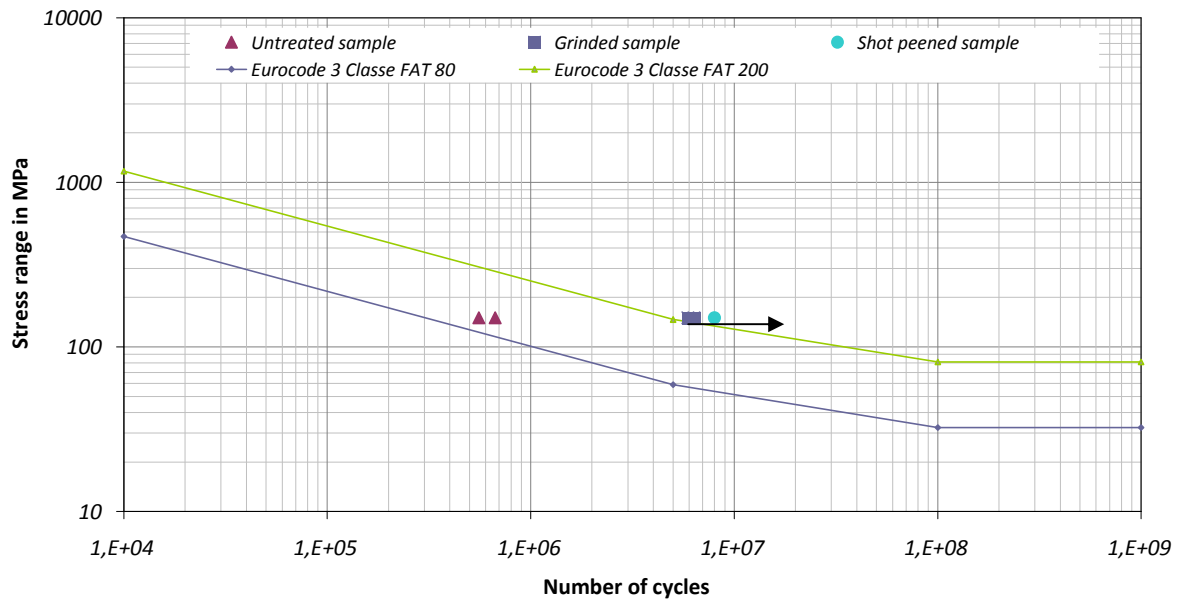


30
31 **FIGURE 2** Experimental measures of residual longitudinal stresses, on the left, and transversal stresses,
32 on the right, for the three samples and the reference

34 Fatigue tests

35
36 Two fatigue tests were led on each kind of samples to determine the improvement associated with the
37 reinforcement operations. Fatigue tests were conducted under a constant stress range of 150 MPa, and
38 with a stress ratio R of 0.1 to be able to compare the obtained results with Eurocode data (7). It is
39 indeed explained in (8) that R may have an influence on the obtained fatigue results. The used
40 frequency was 10 Hz. The first results are presented in figure 3. As far as the untreated sample is
41 concerned, repetitive results were obtained and these were close to the recommendations of Eurocode
42 where such a welded joint is classified in category FAT 80. Two grinded samples and one shot peened
43 sample were tested, and none did fail for the moment. Fatigue tests are still in progress for these

1 samples. For both cases, the improvement in terms of fatigue life is thus superior to a multiplicative
 2 factor of 10.
 3

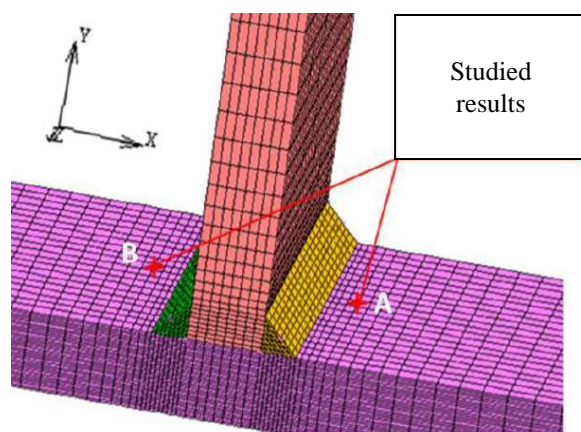


4 **FIGURE 3 First results of the fatigue tests**

5
 6
 7 As far as the experimental investigations are concerned, both reinforcing methods proved to be
 8 effective to increase greatly the fatigue life expectancy of welded joints. The realized experimental
 9 measures of residual stresses proved that welding modified the stress state within the steel plate
 10 creating tensile stresses at the weld toe. These can be detrimental for fatigue when associated with an
 11 important stress concentration effect. The geometrical measure investigations allowed checking that
 12 grinding was the most effective to reduce stress concentration while shot peening's influence was
 13 stronger on residual stresses on the top of the steel plate. Fatigue tests are still under way to compare
 14 both reinforcing methods. For this specific case, the improvement factor is superior to ten.
 15

16 NUMERICAL INVESTIGATIONS

17
 18 In order to get a complete understanding of the different phenomena encountered during welding, a
 19 modelling of welding operations has been carried out. The used method is based on finite element
 20 and developed under the software Marc and Mentat from MSC. This code proposes indeed specific
 21 procedures to model welding such as the commands WELD FLUX, WELD PATH and WELD FILL.
 22 The "birth and death" method is used to generate elements during welding, and the "double ellipsoid"
 23 method is taken into account to model the heat generation.
 24

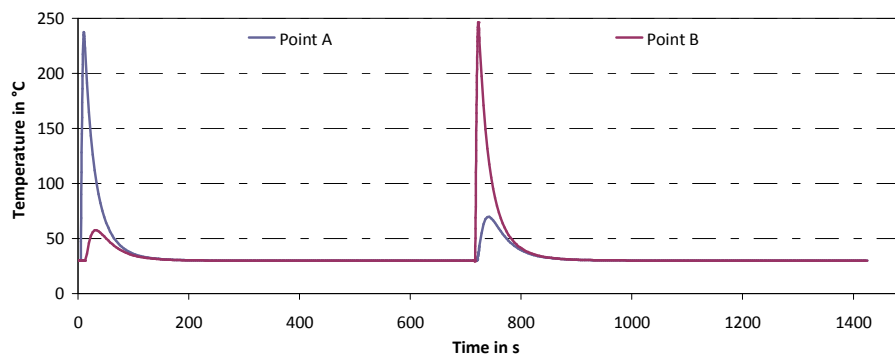


25 **FIGURE 4 Mesh and zones of interest**
 26

1 It was decided to adopt similar hypotheses than in (9) concerning the ultimate temperature reached
 2 during the welding operation (1200 °C) and the shape of the melting bath. As far as the steel plates
 3 and the welding material are concerned, it was decided to consider the same behaviour for both. The
 4 considered material properties are the one of a C22 existing in the database of Marc and Mentat. C22
 5 material is really closed to S355 J2 (10). It takes into account the dependency of the Young's
 6 modulus, the thermal expansion coefficient, the specific heat, the thermal conductivity, and the tensile
 7 behaviour with temperature. The used mesh is shown in figure 4. The results are studied on point A
 8 and B respectively corresponding to the first weld and to the second weld sides. The points are chosen
 9 to be at 6 mm from the weld toe to be able to compare numerical results to the experimental measures
 10 made previously.

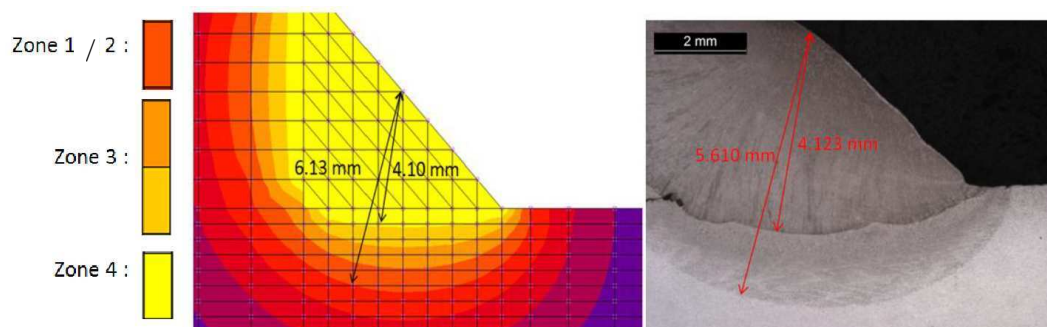
11 Temperature distribution

12 As points A and B are not within the weld zone (but 6 mm from the weld toe), the reached
 13 temperature is smaller than the ultimate temperature of the weld process. The evolution of the
 14 temperature at both points is given on figure 5. It can be checked that the weld process is carried out
 15 one side after the other and that points A and B are effectively affected by the weld process.
 16
 17
 18



19 **FIGURE 5 Evolution of the temperature during the modelling on points A and B**

20
 21 In order to check that the order of magnitude of temperature results is consistent, one can study the
 22 profile of the ultimate temperature within the cross-section. This is given in figure 6. Zone I
 23 corresponds to a temperature between 600 and 720 °C (start of the austenitic transformation), Zone II
 24 corresponds to a temperature between 720°C and 900 °C (end of the austenitic transformation). Zone
 25 III corresponds to temperatures situated between 900 and 1100 °C. Zone IV corresponds to
 26 temperatures above 1100°C. The well-known Thermally Affected Zone (TAZ) may be defined as the
 27 zones I, II and III. It is situated between the unmodified steel material and the additional welding
 28 material. Comparing temperature profile results at ultimate state with a microscopic observation on
 29 one of the sample, it is possible to check that both approaches are consistent as the size of the zones is
 30 similar.
 31
 32



33 **FIGURE 6 Comparison of the ultimate temperature distribution with cross-sectional observation**

Residual stress distribution

The determined residual stress distributions from the modelling are given on figure 7 on points A and B for longitudinal and transversal directions. It has been checked studying the other stresses, that these two were the most significant by a multiplicative factor of ten. It is important to note that initial residual stresses (such as the one induced by laminating or sanding operations) are not taken into account. The obtained results are consistent with other similar studies indicating that the modelling process is satisfactory (11). Tensile residual stresses are created at the top of the steel plate by welding operations (on a thickness of around 5mm for the studied case). Though no clear difference could be experimentally detected from the experimental measures, residual stresses at point A (first side) seem to be a little smaller than the one at point B. This could be explained by the fact that the welding of the second side could actually thermally relax residual stresses existing within the first weld path.

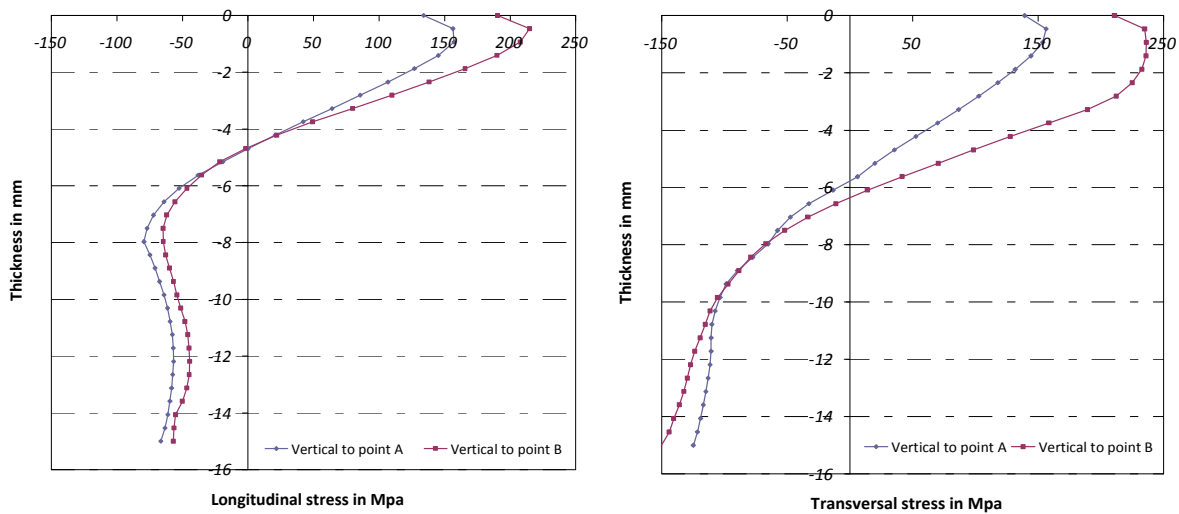


FIGURE 7 Residual longitudinal and transversal stresses at point A and B determined from the modelling at points A and B in the thickness of the plate

Comparison with the experimental measures

The obtained numerical residual stresses were compared to the experimental measures made on the untreated sample. Comparison is given on figure 8 for both longitudinal and transversal residual stresses. The comparison is only led for the top layer of the steel plate on a thickness of 1 mm. The observed difference between experimental and numerical results may be explained by the existing residual stresses within the steel plate between welding.

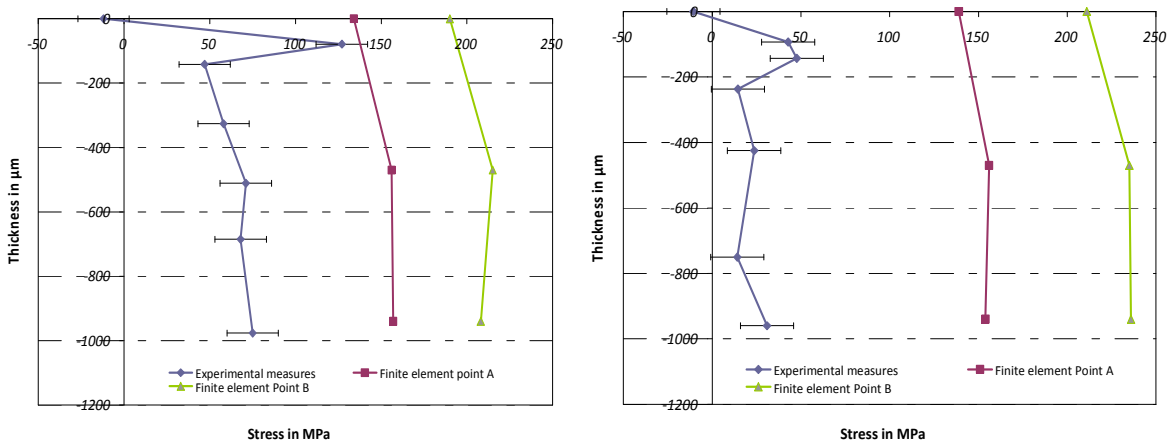


FIGURE 8 Comparison of numerical and experimental longitudinal residual stresses on the left, and transversal residual stresses on the right

CONCLUSIONS

This work is the first part of a study dedicated to the reinforcement methods of welded joints for fatigue issues. It aims at understanding fatigue phenomena and studying the possible reinforcing operations determining for each case quantitative improvement factors. The work associates experimental and numerical investigations.

As far as experimental investigations are concerned, they consist in testing in fatigue untreated and treated welded joints. In this article, two reinforcing methods are used: grinding of the weld toe and shot peening. The first method proved to be effective to decrease the stress concentration factor (based on geometrical measures), while the second one was shown to have a strong influence on residual stresses ensuring the existence of compressive ones at the top of the steel plate closed to the weld toe (base on experimental X ray measures). Though, the fatigue tests are still underway, both methods proved to be largely effective as they increase the life expectancy by a factor superior to ten. It would be interesting in future investigations to study the effect of the parameters of each of these two methods on the experimental observations made here.

As far as numerical modelling is concerned, the first task consisting in modelling the welding process is almost finished. Results proved to be consistent with microscopic observations (thermally affected zone) and qualitatively consistent with other studies led on similar topics. The obtained numerical stress values seem to be higher than the measured ones, but some work is under progress to improve the conditions taken into account. Besides, it must be noted that the initial residual stresses existing in the steel plate as shown by the X-ray measures made on the reference plate are not taken into account in the presented modelling. This can certainly explain some part of the observed differences. Next work will be interested in the modelling of the reinforcing operations such as shot peening for instance. Some work exist on the topic, but no common approach has been adopted so far (12) (13).

Acknowledgements

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References

- (1) Lieurade H.P., *Fatigue analysis in offshore structures*, Report IRSID RE 88 308, April 1988.
- (2) Sparfel Y., L'amélioration de la durée de vie en fatigue des assemblages soudés parachevés, *Soudage et techniques connexes*, Sept-Oct 1992.
- (3) Walbridge S., Nussbaumer A., A probabilistic assessment of the effect of post-weld treatment on the fatigue performance of tubular truss bridges, *Engineering structures*, Vol. 30, 2008, pp. 247-257.
- (4) Guiot K., *Amélioration de la tenue en fatigue des assemblages métalliques soudés*. Master report, LUNAM Nantes, 2011.
- (5) Le Quilliec G., *Application du martelage à haute fréquence à l'optimisation de la maintenance des ouvrages et des structures soudées*. Phd Thesis, LUNAM Nantes, 2011.
- (6) Niu X., Glinka G., The weld profile effect on stress intensity factors in weldments. *International Journal of Fracture*, Vol. 35, 1987, pp.3-20.
- (7) Eurocode 3, *Design of steel structures, part1-1: General and rules for building*, European committee for standardisation, Brussels, 1998.
- (8) Kihl D.P., Sarkani S., Mean stress effects in fatigue of welded steel joints, *Probabilistic engineering mechanics*, Vol. 14, 1997, pp. 97-104.
- (9) Kassab R.K., *Modélisation par la méthode des éléments finis des distortions dues au soudage d'un joint en T*, Phd Thesis, Montréal, 2007.
- (10) ATS OTUA, *La résistance à la fatigue des assemblages soudés à l'arc en acier de construction métallique*. Association technique de la sidérurgie Française, Office technique pour l'utilisation de l'acier, Propriétés d'emploi des aciers, 1982.

- 1 (11) Teng T.L., Fung C.P., Chang P.H., Yang W.C., Analysis of residual stresses and distortions in T-
2 joint fillet welds, *International Journal of Pressure Vessels and Piping*, Vol.78, 2001, pp. 523-538.
- 3 (12) Sidhom N., Laamouri A., Fathallah R., Braham C., Lieurade H.P., Fatigue strength improvement
4 of 5083 H11 Al-alloy T-welded joints by shot peening: experimental characterization and predictive
5 approach, *International journal of fatigue*, Vol. 27, 2005, pp.729-745.
- 6 (13) Miao H.Y., Larose S., Perron C. Levesque M., An analytical approach to relate shot peening
7 parameters to Almen intensity, *Surface and Coatings Technology*, Vol.205, 2010, pp.2055-2056.