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Parametric study of the finite element modeling of shot peening on welded joints

Lamine Dieng*, Darine Amine, Yannick Falaise, Sylvain Chataigner

IFSTTAR, MAST, SMC, Bouguenais F-44344, France

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ABSTRACT

Nowadays, welding in steel structure design is the most widely used assembly technology. In the case of bridge structures, it has replaced riveting and bolting for the past thirty years. It is well known that this type of structure may deteriorate not just because of corrosion but also because of fatigue issues. In the case of corrosion, specific maintenance actions are currently being undertaken by bridge owners to increase the life span of their structures, such as painting operations. In the case of fatigue issues, it is well known that the high level of residual stresses due to the welding process may increase fatigue hazards. Several techniques may be used to reduce the high level of tensile stresses in the top layer of the weld near the welding toe. In this paper, the influence of welding and shot-peening parameters is investigated. A 3D finite element model is proposed and improved. The model results are compared to the residual stresses measured on several samples using X-ray diffraction method. Effects of the shot diameter, speed and angle impact are investigated. The transverse and longitudinal residual stresses near the welded joint, with a peak tensile stress value of 250 MPa and 280 MPa respectively, drop to a compressive stress value of more than 50 MPa and fit with the experimental results.

1. Introduction

Welding technology has been widely applied in the last 30 years on metallic infrastructures in different domains such as bridges, marine, mining, rail, oil and gas platform. Civil engineering infrastructures in the world are often challenged by deterioration problems. Multiple sources such as climate stress, fatigue, accidental events, and vandalism may cause degradation of the performance in roadway infrastructure assets. Nevertheless the two main sources of damages on metallic structures (welded or not) remain corrosion and fatigue [1].

Regarding fatigue aspect, the method of assembly by fusion induces the creation of post-assembly internal stresses due to the intense heat input by the heat source and can create local geometric irregularities responsible for significant stresses during service loading [2–5]. The created internal stresses can reach and exceed the elastic limit locally. According to recent literature, the tensile residual stresses are the most damaging as they reduce the fatigue life while those in compression will more often have a beneficial effect particularly for fatigue lifespan. According to [6], tensile residual stresses play a significant role in fatigue crack propagation since they enable cracks to propagate up to at least half of the chord wall thickness under applied compressive stresses. Several techniques were then used to reduce the high level of tensile stresses in the top layer of the weld near the welded joint [7,8]. These methods are currently used in industry in the construction of new welded elements. According to [9], shot peening of welded joints contributed significantly to the improvement of corrosion resistance. More recently, Micro-Arc Oxidation (MAO) process is applied to the surface treatment of A7N01 alloy welded joint to improve the residual-stress distribution and its properties. The fatigue test shows that the fatigue performance is improved due to the resulting compressive stress during MAO processing [10]. It would be interesting to consider their use in rehabilitation of existing structures suffering an insufficient consideration of fatigue. To do this, it is necessary to be able to provide quantitative methods for evaluating the effectiveness of these treatments. It would also be appropriate to propose a numerical model of welding and surface treatment. Numerical modeling has become increasingly important in recent years due to the growing application using metallic structure assembly by welding. Rapid fluctuations in temperature and continuous phase change occurring during welding make it difficult to monitor and experimentally measure properties during the process, making computational modeling invaluable for determining the dynamics within such systems.

* Corresponding author.
E-mail address: lamine.dieng@ifsttar.fr (L. Dieng).

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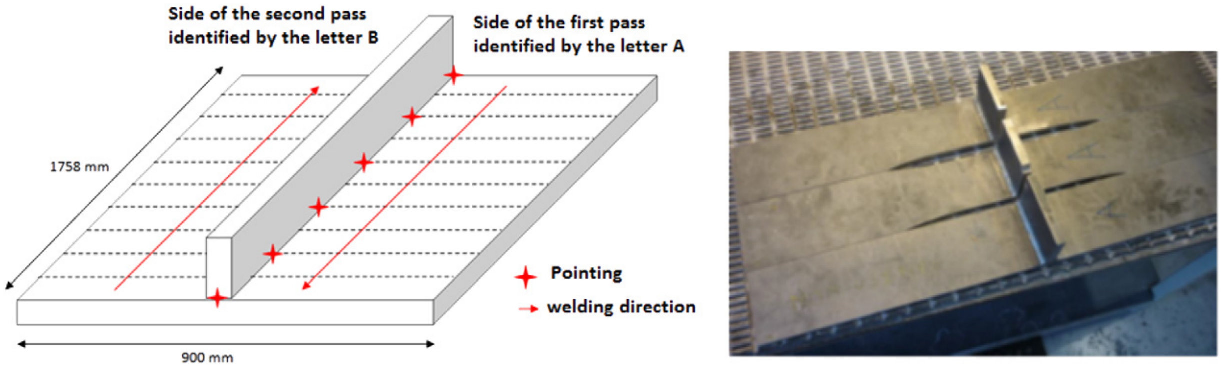

Fig. 1. Single plate geometry (left) and sample photo (right).

Several computational models have been proposed to help in understanding the mechanisms of welding and to predict residual stress after welding process [11–15].

To date, no significant study has evaluated the condition and effectiveness of existing strengthening methods using experimental and numerical tests on full scale samples. To address this problem, the development of a 3D-numerical model was carried out using Marc Mentat software [16]. This paper focuses on the use of 3D finite element modeling of both welding process and shot-peening operation to evaluate the transverse and longitudinal stresses after welding process. The effectiveness issue of shot-peening surface treatment to improve welds is addressed. Finite element parametric study is done to improve understanding of the influence of welding and surface treatment parameters. The first section of this paper is dedicated to describe the experimental investigations done on welded assembly before and after post-welding operations. The second section introduces a 3D-finite element modeling approach used to simulate the welding process and third section presents the shot-peening process using single shot and multi-shots.

2. Experimental investigation

In this paper a full scale geometry typically encountered in steel bridges is chosen for experimental tests. It corresponds to a classical T-joint sample. The sample material is S355 J2 steel material. The plate thicknesses are 15 mm. The welding process was the MAG (Metal Active Gaz) often used for the realisation of steel structures. Most of the parameters of the welding operations have been recorded and may be found in [17]. A single steel plate (1750 × 900 mm^2) has been used during welding operations in order to obtain similar samples. The filler material is a copper-coated AWS ER70S-6 solid wire with a diameter of 10 mm, suited for manual and semiautomatic applications in most industries. The speed was 5.5 mmn with a power supply of 200 A and a voltage of 30.9 V. The weld direction is represented in Fig. 1. The single plate was subdivided in 10 samples. The samples width in the middle is 100 mm, their length is 900 mm, and the height of the additional plate (stiffener) is 100 mm. Welding operations were led on one way, using a single pass and one side after the other at lower speed. The final samples geometry is shown in Fig. 1.

A total of 9 similar samples were tested in this experimental program. The main test parameter was surface treatment application to reduce residual stresses - 3 samples have not been treated, 3 others have been ground and the last 3 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 Metal Improvement Company (MIC [18]). One sample of each series of three samples was used to measure the residual stress using X-ray diffraction method.

2.1. Residual stress measurement

Residual stress measurements were led by the enterprise Meliad [19] using X-ray diffraction technique. Details of the technique and used parameters are detailed in [20]. It was realised 3 different samples. Samples numbered by 1, 2 and 3 were just welded without any surface treatment, samples numbered by 4, 5 and 6 were shot-peened and samples numbered by 7, 8, and 9 were grounded. Residual stress profiles were measured on three points (C, I, and B), located in the steel plate at a distance of 6 mm from the weld toe, for both left and right side as shown in Fig. 2. For easy identification, each curve was assigned with a code according to its side position on the plate (L - left side, R - right side), followed by the sample number, corresponding to surface treatment, and followed by the location of the point (C - center, I - intermediate or B - bank). Longitudinal stress along the sample direction and transversal stress along the weld direction were measured close to the weld toe (6 mm) and along 1 mm deep in the steel plate using successive chemical abrasion operations. A reference measurement has been made on the steel plate far from the welded toe (approximatively at a distance of 150 mm from the weld toe) to determine the initial stress state before welding operations took place. It is important to note that the initial stress state is not zero. Measurements were realised on both sides of the assembly, but no significant difference was observed. The residual stress measures on the right side of the assembly and reference

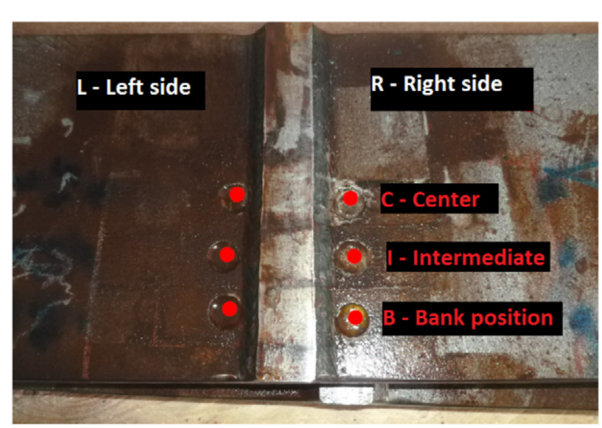

Fig. 2. Residual stress measurement locations.