23rd ABCM International Congress of Mechanical Engineering
December 6-11, 2015, Rio de Janeiro, RJ, Brazil

THE USE OF DIGITAL IMAGE CORRELATION TO OBSERVE MECHANICAL CHANGES CAUSED BY WELDING

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Abstract. *The welding of steel always causes changes in its mechanical properties. Knowing the extent of this influence is of vital importance for industrial applications. This work proposes the use of digital image correlation (DIC) to analyze this effect. Tensile tests were carried out (with the aid of an optical extensometer) in the SAE 1020 steel, using test samples welded with the aid of automatic welding equipment MIG / MAG. DIC is based on software to measure the displacement field and has its routine implemented in Matlab^{TM} software, Correli Q4^{LMT}. By using this method it could be noted that the region of the weld, as well as its surroundings (HAZ) performed in a different way, from its performance in the base metal area, when exposed to tensile stress. Basically, the weld region had a lower deformation and ductility than the regions of the base metal.*

Keywords: *Welding. Traction. Image correlation. Mechanical Properties*

1. INTRODUCTION

Fusion welding processes are generally associated with high thermal gradients. These thermal gradients are responsible for phase transformations that are often directly related to future failures of welded joints. The region where these kinds of phase transformations occur is known as the heat-affected zone (HAZ). A wide range of mechanical and metallurgical properties can be found, even in very small HAZ extensions, as a result of the welding process. Thus, in certain respects, welding can be regarded as a violent thermo-mechanical treatment, and account must be taken of its effect on the metallurgical characteristics of the material (Marques et al., 2006).

There are several ways of measuring the range of mechanical properties in a welded joint; among the most common are the Charpy-V impact test, the Vickers hardness test, tensile testing and metallographic tests.

Tensile testing exposes the material to an increasing axial force that tends to lengthen the tensile specimen until its break. In this test, the tensile specimen was fixed on a machine that applies the axial force. This machine is also able to measure the amount of this stress and the deformation undergone by the material (Souza, 1982). The precision of tensile testing depends on the accuracy of the measuring devices used and the proper use of this equipment (Souza, 1982).

In welding studies, tensile testing can be conducted by using a tensile specimen taken crosswise to the weld bead, to evaluate the properties of the welded joint and the fracture point, as performed in Lins et al. (2014). Alternatively, the tensile testing can be carried out with a tensile specimen taken lengthwise to the weld bead, for evaluation of weld metal tensile properties, as performed in Jorge et al. (2013).

The main objective of this work is to test the use of the digital image correlation (DIC) technique on tensile test, using a tensile specimen taken crosswise to the weld bead. It also seeks to measure the extent of the affected area by fusion welding and to analyze the mechanical behavior of the base metal and heat affected zone (HAZ).

According to Hild et al (2006), digital image correlation is a non-destructive, non-contact method used to examine the surface deformation fields of a loaded object, and was first proposed in the early 1980s. This technique is simple to use and can be employed in different experiments and with various materials. It has many applications and can replace strain gauges to obtain local deformation and displacement not only in a restricted area, but also over the whole surface.

The basic operating procedure of the DIC technique involves comparing images of the studied body obtained under different loading conditions. This comparison is made by dividing the obtained images into small sub-areas, where the movement is analyzed and compared with the “zero position” (before the load is applied). According to Fayyad et al. (2014) and Ivana et al. (2015), the use of this technique makes it possible to measure the deformation fields of the analyzed area, and is a useful means of determining the fracture mechanism of various types of materials.

According to Hedan et al. (2015) in studying the displacement field, the DIC method analyzes the change in position of a “standard stains” located within the analyzed area. This “standard stains” is usually the result of a random spatial variation of light intensity and may be obtained artificially by painting the sample surface.

The digital image correlation is based on a computer program that measures displacement fields and has its routine implemented in Matlab™ software. In this study, we use the Correli Q4^{LMT} software (Hild et al., 2008). Through this technique it is possible to identify the displacement fields that are related to two instants during a deformation process.

2. MATERIALS AND METHODS

2.1 Materials

As base metal, the SAE 1020 steel was used; its chemical composition can be seen in Tab. 1. The welding wire used was copper-plated carbon steel of 1.0 mm diameter. In addition, the protective gas used was a mixture of argon (85%) and CO_2 (25%).

Table 1. Chemical composition of SAE 1020 steel, according to ABNT NBR NM 87: 2000

ABNT/SAE/AISI	Carbon (c)	Manganese (Mn)	P máx.	S máx.
1020	0.18 – 0.23	0.30 – 0.60	0.030	0.050

2.2 Equipment

The tensile testing was performed in an EMIC DL10000 universal testing machine, which has a maximum load of 100 KN. The camera used to capture the images was a Nikon D40 and the program used to analyze the images was Correli Q4^{LMT} (Hild, et al., 2008).

(a) (b) (c)

Figure 1. Used equipment. (a) Nikon D40 (b) MIG / MAG equipment (c) Tartílope V1

The camera was positioned in front of the testing machine, with the help of a tripod, as shown in Fig. 1a. This camera must be able to cover the entire gauge length of the specimen. The universal testing machine is connected to a common computer, where the program for data acquisition has been installed.

MIG / MAG equipment was used to perform the weld (Fig. 1b), and this consists of a constant voltage power source and a FEED ORIG 302 wire feeder. The welding process was assisted by, an automatic torch movement system - Tartílope V1 (Fig. 1c).

2.3. Test procedure

Table 2 shows the dimensions and test speed that was used to conduct the tensile testing in the welded joint.

Table 2. Characteristics of the tensile testing sample and its cross-head velocity.

Material	Width (mm)	Thickness (mm)	Total length (mm)	Working length (mm)	Cross-head velocity (mm/s)	Strain rate (s^{-1})
SAE 1020 steel	12.5	7	200	100	0.05	0.5×10^{-3}

With the specimens in proper dimensions, a chamfer (opened up in a U shape) was carried out in the center of the tensile specimen (crosswise), then a weld bead was made, which filled out the chamfer with the aid of MIG/MAG welding equipment (Fig. 1). The predominant metal transfer mode in the welding process was short-circuiting. Table 3 shows the welding parameters used to perform the weld.

Table 3. Welding parameters.

Welding speed (cm/min)	Current (A)	Voltage (V)	Welding energy (J/mm)
45	220	24	563,2

A standard texture was applied to the tensile specimen. Without this texture the Correli Q4^{LMT} is not able to analyze the images obtained by the camera. This standard texture was performed by painting the whole surface uniformly with black ink, followed by a random deposition of white ink droplets.

Figure 2 shows the tensile specimen completed, with the appropriate texture.

Figure 2. Standard texture necessary for the digital image correlation application.

During the test, the camera was programmed with an image acquisition period of three seconds. Afterwards, the obtained images were cut into proper sizes so that the program would only examine the study area.

It is necessary to carry out several procedures and set out a few parameters to ensure the Correli Q4^{LMT} program is used correctly. A basic guide on how to handle the described program is available in “CorreliQ4: A Software for “Finite element” Displacement Field Measurements by Digital Image Correlation” (Hild, et al., 2008). The ZOI (zone of interest) size and number of iterations are among the important parameters that must be chosen.

Table 4 shows the parameters used to analyze the images and the total number of images examined.

Table 4. Parameters used to analyze the images in the Correli Q4 program.

ZOI size (pixels)	Number of analyzed images	Maximum number of iterations
16	127	5

At the end of the analysis, the Correli Q4^{LMT} program returns a set of images with a comparison between the “reference image” and the image that represents the examined instant. It is possible to choose what kind of comparison will be performed. The software is able to provide the longitudinal and transverse displacement fields, longitudinal and transverse deformation fields and the error associated with the measurements performed.

3. RESULTS AND DISCUSSION

A set of images, representing the obtained results, is shown below. Each image is accompanied by a set of colors that are related to a numerical value. The program generates the displacement results in pixels, which means it must be transformed to millimeters. In this test, the pixel conversion factor is 1 pixel = 0. 06 mm.

Figure 5 shows the longitudinal displacement undergone by each region. It should be noted that the weld bead and HAZ moves almost the same amount (-12.36 mm), while the base metal is undergoing several different displacements. Note also that the weld bead is the portion of the specimen with the largest displacement (about 4.86 mm more than the base metal).

Figure 6 shows the strain in the longitudinal direction (Direction 1). It should be noted that the weld bead underwent less longitudinal deformation than the base metal. This was expected, since the weld bead and HAZ have a lower ductility due to the microstructural changes caused by the welding process.

When Figures 5 and 6 are compared, it can be seen that the test piece zone where there is a bigger variation in the longitudinal displacement field is also the region that has the highest strain in the longitudinal direction. This region is known as the necking zone, and experiences a reduction of the cross-sectional area during testing until it becomes unstable and the specimen fractures. Within the necking zone a rapid change of color occurs (representing different displacements), while the color near the weld bead remains virtually the same. The necking zone is within the region of the base metal.

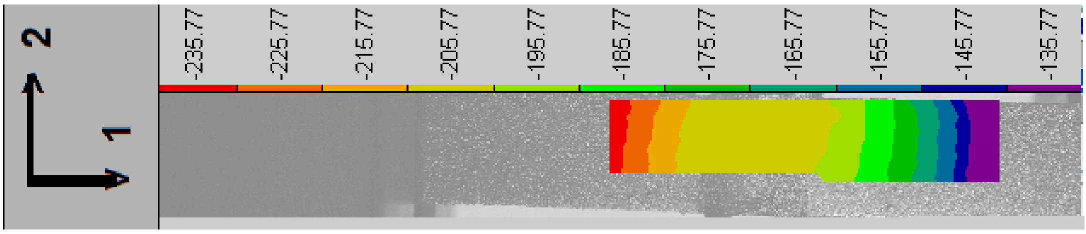

Figure 5. Longitudinal displacement – Direction 1 (pixels).

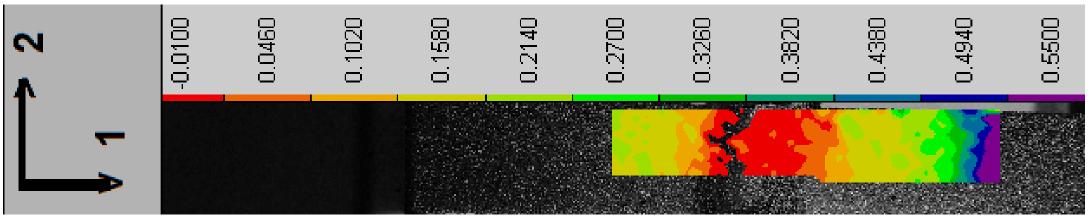

Figure 6. Longitudinal deformation – Direction 1

Figure 7 shows the transversal displacement field. Unlike the longitudinal displacement, the base metal is the portion of the specimen with the highest degree of displacement. As in the longitudinal displacement, there was also a large variation of the transversal displacement at the necking zone, while the entire weld bead practically did not experience any displacement. Note that the left part of the necking zone undergoes a positive displacement while the right side has a negative displacement.

Figure 8 shows the strain in the transversal direction (Direction 2). It should be pointed out that the weld bead undergoes less transversal deformation than the base metal. Again, the test piece zone where there is a greater variation in the transversal displacement field is also the region that has the highest deformation.

Figure 9 shows the chart of errors. It can be observed that this ranges from 2% up to 9%.

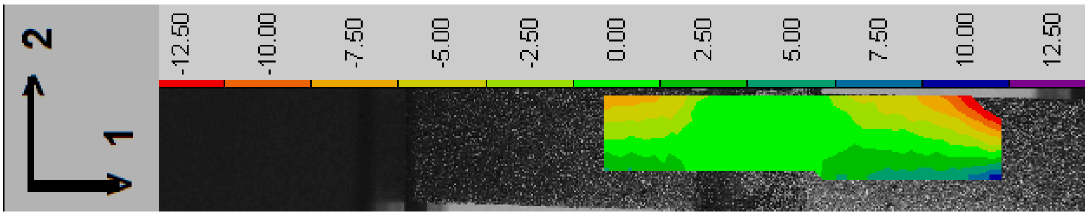

Figure 7. Transversal displacement – Direction 2 (pixels).

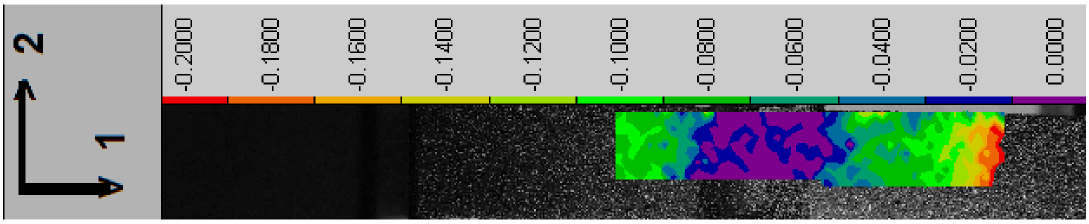

Figure 8. Transversal deformation – Direction 2.

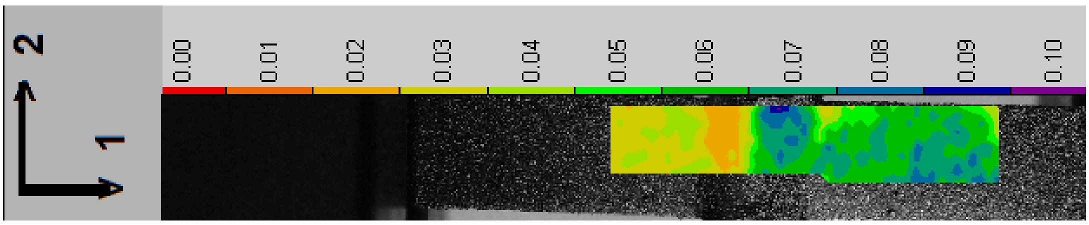

Figure 9. Error.

4. CONCLUSION

By means of the DIC method, it was possible to study the behavior of a welded joint when exposed to tensile testing. It could be noted that the region of the weld, as well as its surroundings (HAZ), had a small longitudinal and transverse deformation, when this was compared with the base metal.

When exposed to axial stress, the weld bead and the HAZ had a uniform longitudinal displacement, while the base metal had a large variation in the strain data. It was also apparent that the weld bead does not undergo transverse displacement, while the base metal has a wide range of values because of its necking zone, which can be examined in greater detail in this work.

5. FURTHER WORK

The Correli Q4^{LMT} program also has a command "gauge", which is quite useful to analyze the behavior of a welded joint. The gauge function works as a strain gauge, and has been used to calculate the strains in different small regions of the specimen. It is important to obtain the strain data and, hence, the mechanical properties of the different zones in the welded joint: in the HAZ and base metal.

6. REFERENCES

ABNT NBR NM 87. Carbon steel and alloy steel for general engineering purpose - Designation and chemical composition. ABNT-Associação Brasileira de Normas Técnicas, 2000.

Fayyad, Tahreer M.; Lees, Janet M. Application of Digital Image Correlation to reinforced concrete fracture. Procedia Materials Science, v.3, p.1585-1590, 2014.

Hedan, S., et al., Measurement of the elastic properties of swelling clay minerals using the digital image correlation method on a single macroscopic crystal, Appl. Clay Sci. (2015)

Hild F, Roux S. Digital image correlation: from displacement measurement to identification of elastic properties – a review. Strain 2006;42(2):69–80.

Hild, François; Roux, Stéphane. Correli Q4: A Software for “Finite-element” Displacement Field Measurements by Digital Image Correlation. Cachan: Ecole Normale Supérieure de Cachan, 2008. Disponível em: < wwwpriv.lmt.ens-cachan.fr/PDFs/HILD.2008.7.pdf> Acesso em: 18 jan. 2014.

Ivana Barisic, Tihomir Doksanovic, Hrvoje Draganic. Characterization of hydraulically bound base materials through digital image correlation. Construction and Building Materials, v. 83, p. 299–307, 2015.

Jorge, Jorge Carlos Ferreira; Faragasso, Sérgio Maciel; Souza, Luís Felipe Guimarães de; Bott, Ivaní de Souza. Efeito do tratamento térmico pós-soldagem nas propriedades mecânicas e microestruturais de metal de solda de aço de extra alta resistência para utilização em equipamentos de ancoragem. Soldag. insp., São Paulo , v. 18, n. 2, p. 138-148, June 2013 .

Lins Junior, Amilton Sousa; Costa, Hector Reynaldo Meneses; Souza, Luís Felipe Guimarães de; Jorge, Jorge Carlos Ferreira. Propriedades mecânicas e microestruturais de juntas soldadas do aço HY-80 pelos processos eletrodo revestido e GMAW. Soldag. insp., São Paulo , v. 19, n. 3, p. 200-211, Sept. 2014.

Marques, P.V; Modenesi, P.J.; Bracarense, A.Q. Soldagem: fundamentos e tecnologia. 3ª ed. Belo Horizonte: Editora UFMG, 2009. 363 p.

Souza, S. A. Ensaios mecânicos de materiais metálicos: fundamentos teóricos e práticos. 5.ed. São Paulo: Edgar Blüncher, 1982. 286p.

7. RESPONSIBILITY NOTICE