COB-2021-1015
DETERMINATION OF PHYSICAL COEFFICIENTS BY MONITORING DEFORMATION

Fernanda Novaes Santos
Department of Mechanics, Federal Institute of São Paulo (IFSP), São Paulo, Brazil
fernanda.novaes@aluno.ifsp.edu.br

Paulo Henrique Lixandrão Fernando
Department of Mechanics, Federal Institute of São Paulo (IFSP), São Paulo, Brazil
Federal University of ABC (UFABC), Santo André, Brazil
paulohlf@yahoo.com.br

Kelly Cristina de Lira Lixandrão
Federal University of ABC (UFABC), Santo André, Brazil.
kelly.silva@ufabc.edu.br

Daniel Pezza Tchernov
Department of Mechanics, Federal Institute of São Paulo (IFSP), São Paulo, Brazil
danieltchernov@gmail.com

Mauro Machado de Oliveira
Department of Mechanics, Federal Institute of São Paulo (IFSP), São Paulo, Brazil
mauro.mo@ifsp.edu.br

Abstract *The digital image correlation (DIC) is a non-contact optical measurement technique. This technique consists of comparing sequential images of a surface filled with a random pattern, that can be to allow information to deformation and displacement of components body. The aim of this works is to determine the mechanical properties of different materials trough the analysis of deformation in a free software that uses DIC technology. Therefore, samples were obtained from ordinary plastic bags, in which the random pattern was applied. The tests were then carried out by subjecting the specimens to traction in a manual device and capturing images during the process. This procedure allowed observing the deformation region through a color scale and obtaining quantitative data on the deformation along a given cross section. The results show that the samples underwent a high elongation, within the maximum extension allowed by the device, being visible of the phenomenon of constriction. It is concluded that such observations are in agreement with the typical behavior of the tests material, that for plastic bags it is mainly high-density polyethylene (HDPE) and that adequate surface preparation is essential to determine reliable results. In addition, it was possible to confirm that the application of the DIC can be carried out at a low cost to determine the properties of certain material, in this case, in a simple manual device.*

Keywords: *Digital image correlation, traction tests, deformation analysis*

1. INTRODUCTION

The study of materials involves performing mechanical tests to determine their properties. Technological advances, extending to the field of experimental mechanics, have enabled the emergence of different methods for obtaining data on materials and components, including the technique of Digital Image Correlation (DIC) (Barreto, 2008).

This procedure consists of comparing sequential images (or video frames) from which surface displacements are analyzed, based on a pattern of points represented in the area to be studied. The method comprises, in general, three steps: first the samples are prepared by applying a random pattern of points, then the acquisition of images is carried out, taking as the initial reference the one that represents the body without any deformation and, finally, calculations are performed from the displacements, resulting in the deformation (Ramírez, 2017).

Tensile and compression tests allow the determination of various mechanical properties, such as yield strength, tensile (or compression) strength, ductility, resilience, among others (Callister; Rethwisch, 2015). In this context, the DIC technique can be applied to replace or complement the deformation measurements of the samples used in these tests, with the advantages of determining measurements without physical contact with the part and relatively low cost (Beleza, 2017).

The main objective of this work was, therefore, to film mechanical tensile tests of various materials, for further analysis in DIC software and determination of their mechanical properties, covering the steps of experimental data capture, recording and organization of experimental data, data analysis in free software, comparison of the results with the relevant literature in the area and discussion of the obtained results.

2. DIGITAL IMAGE CORRELATION

The DIC Digital Image Correlation technique emerged in the 1980s and was developed by researchers at the University of North Carolina. This technology allows measuring the deformation of objects in two and three dimensions, without the need for physical contact. Its application is based on the analysis of points on a surface filled with a random pattern, also called stochastic pattern (Beleza, 2017).

Its working principle is based on digital images, made up of units called pixels, to which the algorithm will associate a position and an intensity value, forming a matrix, a block of pixels, which will be located from one image to another. The software is then able to follow the movement of these blocks through sequential photographs (Figure 1), correlating them and determining the deformation (Beleza, 2017).
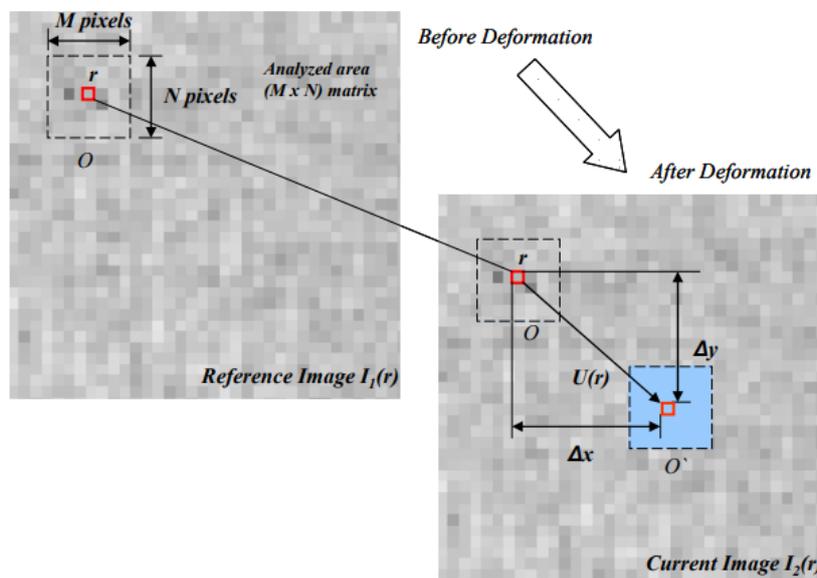

Figure 1. Digital Image Correlation principle (Lall *et al.*, 2007).

The DIC technique has been widely used for, among other things, the analysis of deformation in various areas of Engineering, such as civil, materials, biomechanics, automotive, among others, such as the works of Eriksen, Berggreen, Boyd and Dulieu-Barton (2010) in which it was used to measure metallic and composite samples tested at high speed, Tyson, Schmidt and Galanulis (2002) to analyze a ligament revealing a different deformation profile than expected, Manach, Thuillier, Yoon , Coer and Laurent (2013) who observed strain bands related to the Portevin-Le Chatelier effect in 5000 series aluminum alloys, Santos, Pitangueira, Ribeiro and Carrasco (2015) used the technology to determine the modulus of elasticity of concrete and Chu and Poudel (2014) who promoted a comprehensive discussion on the use of this technology in the aerospace field. These examples reveal the great diversity of possible applications making use of the DIC technique and its growing development and improvement in recent years.

The DIC technique has been widely used for, among other things, the analysis of deformation in various areas of Engineering, such as civil, materials, biomechanics, automotive, among others, such as the works of Eriksen, Berggreen, Boyd and Dulieu-Barton (2010) in which this technology was applied to measure metallic and composite samples tested at high speed, Tyson, Schmidt and Galanulis (2002) for analysis of a ligament revealing a different deformation profile than expected, Manach , Thuillier, Yoon, Coer and Laurent (2013) who observed deformation bands related to the Portevin-Le Chatelier effect in aluminum alloys of the 5000 series, Santos, Pitangueira, Ribeiro and Carrasco (2015) used the technology to determine the modulus of Concrete Elasticity and Chu and Poudel (2014) who promoted a comprehensive discussion on the use of this technology in the aerospace field. These examples reveal the great diversity of possible applications using the ICD technique and its growing development and improvement in recent years.

3. EXPERIMENTAL PROCEDURE

3.1 Device making

Initially, a manual device was developed to submit the samples to traction. The mechanism was designed in Inventor™ 3D modeling software, as shown in item (a) of Figure 2. Its structure was made of solid wood, forming the base, sides and "grips" for fixing the specimens. An aluminum type T track supports the movable grip and ensures the sample is pulled uniaxially. The movement is performed by rotating the plastic handle, attached to an axis made from an M8 threaded bar. Item (b) of Figure 2 shows the final device.
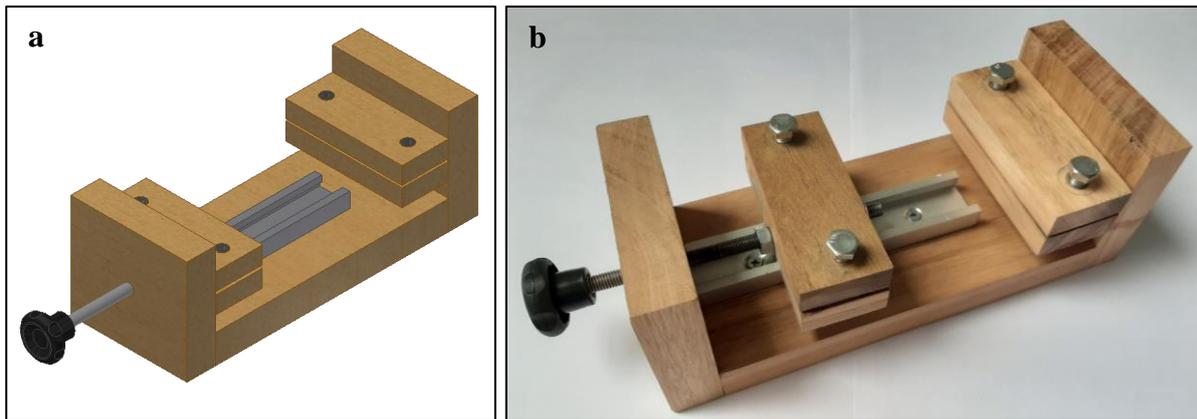

Figure 2. Manual traction device. (a) 3D Model. (b) Final device (The authors).

3.2 Sample preparation and pattern verification

The specimens were obtained from common plastic bags, following instructions contained in the ASTM D882 standard (Standard Test Method for Tensile Properties of Thin Plastic Sheeting), used for plastics whose thickness is less than 1 mm. Thus, ten specimens were cut in strip format, 140 mm long and 25 mm wide. Then, the random pattern was applied using a brush and acrylic paint, until the surface was covered by "speckles", as shown in Figure 3. For a proper analysis, it was important to ensure that the bottom layer of the sample was matte and that there was a high contrast with the dot pattern ink, in addition to appropriate lighting, in order to avoid reflections on the images to be captured, as this phenomenon compromises the correlation.

Figure 3. Sample with random pattern applied (The authors).

The next step consisted of checking the quality of the pattern applied in the GOM Correlate™ software. Kosmann, Klapp, *et al.* (2018) had already discussed the possibility of using point displacement, consequently deformation, to evaluate the mechanical properties of tubular adhesive joints by butt joints. Figure 4 shows the software screen, in which the delimited surface appears in green, which indicates that the pattern is suitable for analysis, that is, it has good quality. Before starting the deformation of the samples in the device, the pattern applied to each one of them was tested.
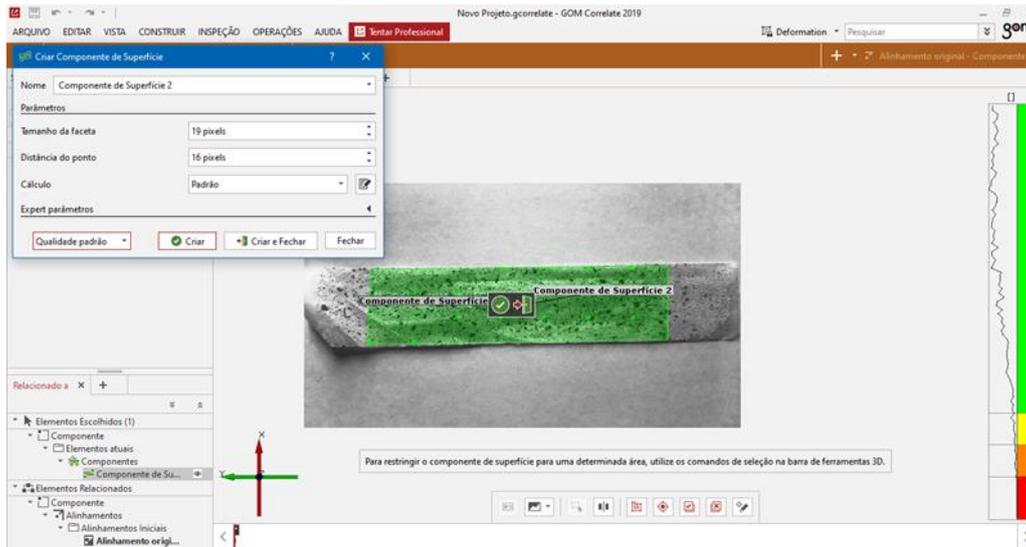
Figure 4. Checking the quality of the pattern (The authors).

3.3 Testing and deformation analysis

Once the specimens were prepared and the quality of the standards applied was verified, the tests proceeded. One end of the plastic strip was attached to the fixed grip, while the other to the mobile grip, seeking to keep the sample as aligned as possible. After attaching the specimen, the recording began, which was made using a cell phone, with a 25 MP camera, resolution of 1920 x 1080 and 30 fps, in gray scale, attached to a support, preventing move during the task. The handle was then rotated, displacing the movable grip and pulling the specimen. All specimens were deformed up to the limit of the device, when the grip touched the side piece. A ruler was placed in the video, for later definition of the scale.
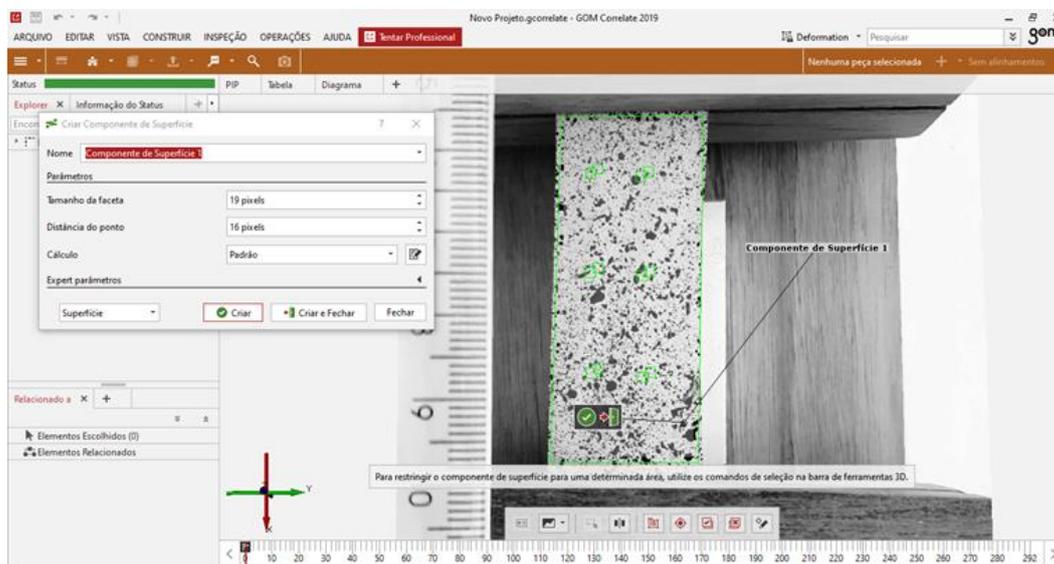

Figure 5. Surface component demarcation (The authors).

Images were obtained from the videos, at a rate of 1 every 10 frames and later renamed with sequential numbers, as it is a requirement of the program that the names of the imported image files are numbered. Then, in the software work environment, the scale was defined, marking two points on the ruler at a distance of 10 mm and inserting this data in the respective field, and the surface component, observed in Figure 5, which is the region in which the random pattern was applied and in which the deformation will be analyzed.

To determine the deformation, the option "Major *strain*" was chosen, which allows to obtain the location and value of the deformations, generating a colored surface according to a predefined legend, indicating the value of the deformation of the specimen in μm/m or in %, from one image to another, along the entire surface component.

4. RESULTS AND DISCUSSION

For each sample, the observations made were similar to those seen in Figure 6. The left side shows the first image of one of the specimens, the blue color indicates that the body has not suffered any deformation, while the right side shows the last frame, in which the yellow, orange and red colors show that the sample has already deformed considerably.
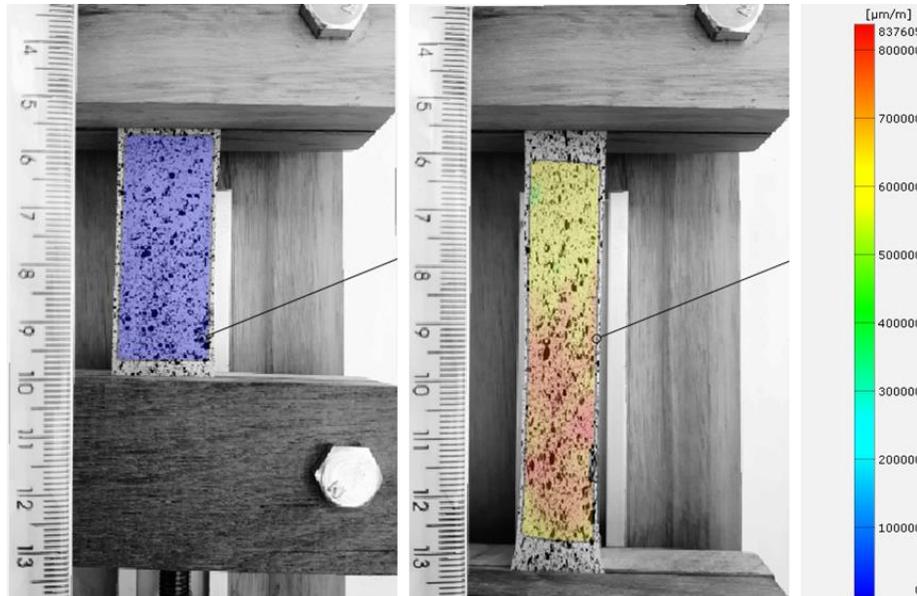

Figure 6. Specimen deformation (The authors).

Regarding the material used, according to Coutinho, Mello and Santa Maria (2003), supermarket bags are produced with high-density polyethylene (HDPE), through the extrusion process. In the tensile test, commercial HDPE usually shows the formation of a "neck" (stricture) and, according to data presented in the article, they have high elongations, indicating their high ductility.

Along the longitudinal direction of the samples, a section was created, which for 2D analysis is a line. In this, the so-called "deviation labels" (Figure 7) were applied, which allow the visualization of the instantaneous deformation values in μm/m at the highlighted points along this straight line. The deformations observed are not constant along the section, being more accentuated in the region close to the mobile grip. This observation is mainly due to the viscoelastoplastic behavior of HDPE, which manifests itself even at room temperature and at low stress levels, as in the case studied, being dependent on both stress and time values, presenting a non-linear behavior (Kühl , 2014).
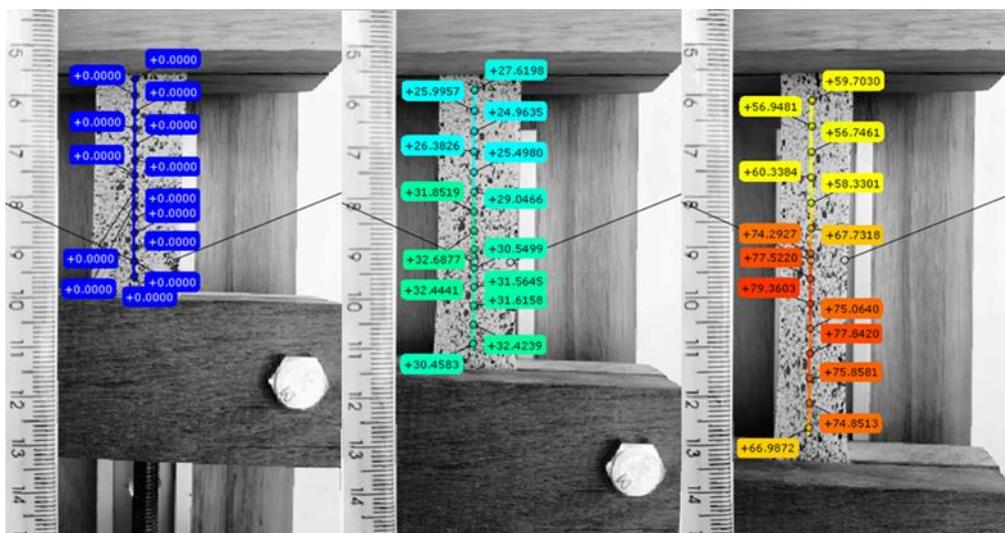

Figure 7. Section analysis and application of deviation labels (The authors).

From this procedure, quantitative deformation data were determined. In Table 1, the maximum values found in the sections for all tested samples were gathered.

Table 1. Maximum deformation in section

Specimen	Maximum deformation in section (%)
1	83
2	79
3	59
4	63
5	75
6	86
7	85
8	70
9	83
10	79
Average	**76**
Standard Deviation	**9**

From the Student's t-test, a confidence interval at the 95% level was determined for the population mean of (76 ± 6,44) %.

5. CONCLUSION

To achieve the objectives of the work, initially the making of the traction device involved several stages of a project, from its planning, 3D modeling, assembly and finally, its use. This procedure covered the use of several concepts and is related to the procedures performed in engineering practice. The preparation of specimens for the tests showed that the proper application of the pattern on a surface is essential for the correct results to be achieved.

Regarding the tests, although the specimens were pulled by the device at a small distance, it was observed that they presented a relatively high elongation, determined by an average maximum deformation along a cross section drawn in the software, whose value was of (76 ± 6,44) %, in addition to this there was also a reduction in the width of the specimen, which points to the beginning of a narrowing. Such observations are in agreement with what is seen in the literature. Furthermore, the values found showed that the deformation does not remain constant along the examined straight section, which shows the viscoelastoplastic behavior of this material.

Finally, the work demonstrated that the Digital Image Correlation (DIC) technique, associated with a free software, can be performed at a low cost, for didactic purposes or to obtain easily deformable material properties in a simple manual device.

6. REFERENCES

Barreto, E., 2008. *Use of the image correlation method in the characterization of metallic and polymeric materials* (in Portuguese). Master's Thesis, Graduate Program in Mechanical Engineering, Federal Fluminense University, Niterói, Brazil.

Beleza, S. C. A., 2017. *Deformation measurement using the Digital Image Correlation technique* (in Portuguese). Master's Thesis, Graduate Program in Mechanical Engineering, University Nova de Lisboa, Caparica, Portugal.

Callister, W. D., Rethwisch, D. G., 2015. *Fundamentals of Materials Science and Engineering: An Integrated Approach* (in Portuguese). Editora LTC, Rio de Janeiro.

Chu, T. P., Poudel, A., 2014. *Digital Image Correlation Techniques for Aerospace Applications*. https://www.researchgate.net/publication/282658109_Digital_Image_Correlation_Techniques_for_Aerospace_Appl ications. Accessed 09 December 2020.

Coutinho, F. M. B., Mello, I. L., Santa Maria, L. C., 2003. "Polyethylene: main types, properties and applications" (in Portuguese). *Polymers: Science and Technology*. Vol. 13, No. 1, pp. 1–13.

Kühl, A., 2014. A non-linear viscoelastoplatic formulation applied to high density polyethylene (HDPE) (in Portuguese). Master's Thesis, Graduate Program in Mechanical Engineering, State University of Santa Catarina, Joinville, Brazil.

Eriksen, R., Berggreen, C., Boyd, S. W.; Dulieu-Barton, J. M., 2010. "Towards high velocity deformation characterisation of metals and composites using Digital Image Correlation". Epj Web Of Conferences. Vol. 6, pp. 14-21

Halim, H., Wilkinson, D. S., Niewczas, M., 2007. The Portevin–Le Chatelier (PLC) effect and shear band formation in an AA5754 alloy. *Acta Materialia*. Vol. 55, No. 5, pp. 4151-4160.

Kosmann, J., Klapp, O., Holzhuter, D., et al. "Measurement of epoxy film adhesive properties in torsion and tension using tubular butt joints". *International Journal of Adhesion and Adhesives*, v. 83, n. xxxx, p. 50–58, 2018. DOI: 10.1016/j.ijadhadh.2018.02.020. Disponível em: http://dx.doi.org/10.1016/j.ijadhadh.2018.02.020.

Lall, P., Panchagade, D., Iyengar, D., Shantaram, S., Suhling, J., Schrier, H., 2007. "High Speed Digital Image Correlation for Transient-Shock Reliability of Electronics". In *Proceedings of Electronic Components and Technology Conference*. Nevada, USA.

Manach, P. Y., Thuillier, S., Yoon, J. W., Coër, J., Laurent, H., 2014. "Kinematics of Portevin–Le Chatelier bands in simple shear". *International Journal Of Plasticity*. Vol. 58, No. 7, pp. 66-83.

Ramírez, R. E. R., 2017. *Mechanical tests and digital correlation of images applied to the characterization of the mechanical properties of a cast iron and polystyrene* (in Portuguese). Master's Thesis, Graduate Program of Engineering Materials Integrity. University of Brasília, Brasília, Brazil.

Santos, A. H. A., Pitangueira, R. L. S., Ribeiro, G. O., Carrasco, E. V. M., 2016. "Concrete modulus of elasticity assessment using digital image correlation". *Ibracon Structures And Materials Journal*. Vol. 9, No. 4, pp. 587-594.

Tyson, J., Schmidt, T., Galanulis, K., 2002. "Biomechanics deformation and strain measurements with 3D image correlation photogrammetry". *Experimental Techniques*. Vol. 26, No. 5, pp. 39-42.

7. RESPONSIBILITY NOTICE

The authors declare that they have no conflict of interest.