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SHEAR STRAIN ANALYSIS OF THE POLYMER POLYDIMETHYLSILOXANE (PDMS) USING DIGITAL IMAGE CORRELATION IN DIFFERENT TEMPERATURES

G.N. de Oliveira, gabinieva@if.uff.br[1]
L.C.S. Nunes, luizcsn@mec.uff.br[2]
P.A.M. dos Santos, pams@if.uff.br[3]

[1]Pós-graduação em Engenharia Mecânica, TEM/PGMEC, Universidade Federal Fluminense, Rua Passo da Pátria, 156, Niterói, R.J., Brazil, Cep.: 24.210-240.
[2]Laboratório de Mecânica Teórica e Aplicada, Departamento de Engenharia Mecânica, Universidade Federal Fluminense, Rua Passo da Pátria, 156, Niterói, R.J., Brazil, Cep.: 24.210-240.
[3]Instituto de Física, Laboratório de Óptica Não-linear e Aplicada, Universidade Federal Fluminense, Av. Gal. Nilton Tavares de Souza, s/n, Gragoatá, Niterói, R.J., Brazil, Cep.:24.210-346.

Resumo: *In the present work a new testing methodology to analyze the adhesive shear modulus of poly-dimethylsiloxane (PDMS) submitted to different loads and temperatures is described. A single lap joint testing is performed. This is a standard test specimen for characterizing adhesive properties and it is considered the simplest form of adhesive joints. For the single lap joint specimen, steel adherends are bonded using a flexible rubber elastic polymer (PDMS), which is a commercially available silicone elastic rubber. The experimental procedure is carried out using the digital image correlation (DIC) method. This is an optical-numerical full-field surface displacement measurement method. It is based on a comparison between two images of a specimen coated by a random speckled pattern in the undeformed and in the deformed states.*

Palavras-chave: *full-field displacement, digital image correlation, estimation parameter, polydimethylsiloxane polymer.*

1. INTRODUCTION

Polydimethylsiloxane (PDMS) is the most common and commercially available silicone rubber. Due to important characteristics, such as flexibility and stability, this material has a wide range of applications in mechanical sensors (Kim et al., 2008; Lin et al., 2009), electronic products (Tiercelin et al., 2006; Lee et al., 2009) and medical devises (Lawrence et al., 2009).

There are many different types of mechanical tests for determining properties of polymeric materials (Ward et al., 2004; Brinson et al., 2008; Mujika et al., 2006; Brown, 2002). In the present work, the experimental procedure is carried out using the digital image correlation (DIC) method. This is an optical-numerical full-field surface displacement measurement method. It is based on a comparison between two images of a specimen coated by a random speckled pattern in the undeformed and in the deformed states. Its special merits encompass non-contact measurements, simple optic setups, no special preparation of specimens and no special illumination (Nunes, 2009).

The PMDS is usually used in a range of temperature from 10 ^{o}C to 50 ^{o}C. Then, the question is: the adhesive shear parameters change when the temperature changes? The main idea of this work is to analyze the adhesive deformation in the single lap joint specimen using the DIC method in different temperatures considering different loads. The arrangement and the mechanical behavior of the single lap joint are taken into account obeying the Volkersen's model (da Silva et al., 2009; Dillard et al., 2002; Nunes et al., 2007, COBEM 2007; ASTM, 2001). An experimental configuration that generates pure shear is considered. This analysis assumes that the polymer (PDMS) is a perfectly elastic solid, i.e., typical viscoelastic behavior is avoided. In order to support this hypothesis, the experiments were conducted at room temperature considering small strain condition and quasi-static processes.

2. METHODS AND MATERIALS

The digital image correlation method (DIC) is an optical-numerical full-field surface displacement measurement method (Dally et al., 2005; Nunes et al., 2007, Solid Mech Brazil). It is based on a comparison between two images of a specimen coated by a random speckled pattern in the undeformed and in the deformed states. Its special merits encompass non-contact measurements, simple optic setups, no special preparation of specimens and no special illumination. The basic principle of the DIC method is to search for the maximum correlation between small zones (subsets) of the specimen in the undeformed and deformed states. From a given image-matching rule, the displacement field at different positions in the analysis region can be computed. The simplest image-matching procedure is the cross-correlation, which provides the in-plane displacement fields u(x, y) and v(x, y) by matching different zones of the two images (Nunes, 2009).

In order to obtain the experimental results, the geometry model for the single lap joint for load transfer from one adherend to another by a simple pure shearing mechanism is considered. In this model, the adherends are assumed in tension and the adhesive is in shear only, and both are constant across the thickness. Due to its simplicity, this model does not include the effect of the adherend bending and shear deformations.

In the present work, the following assumptions are considered: (i) the adherends do not deform in shear, implying that the shear modulus of the adherends is much greater than the adhesive; (ii) adhesive and adherends are assumed to behave in a linear elastic manner; (iii) bonding is assumed to be perfect along both bond planes; (iv) the effects of the bond terminus are ignored; (v) plane stress conditions are assumed, ignoring complications arising from different Poisson contractions in the bonded region and single adherend regions.

A simple shear can be obtained using the geometry presented in Fig. (1) and the previous assumptions, i.e., the shear stress cause sliding in an element of material as shown in Fig. (2).

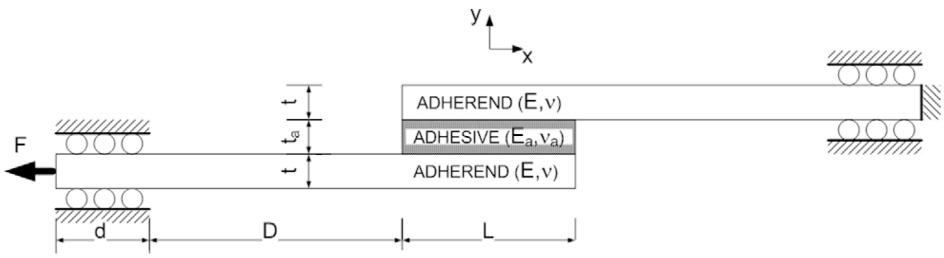

Figure 1. Simple shear condition.

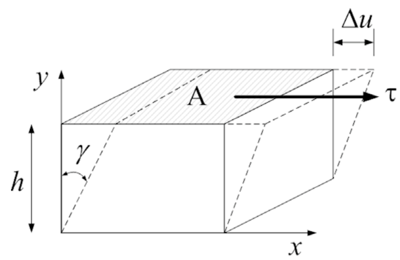

Figure 2. Typical single lap joints.

Considering small strain conditions, fixed temperature and a quasi-static process, the mechanical behavior of rubber elastic polymers can be assumed as perfectly elastic solids, i.e., the stress is directly proportional to the strain and not affected by the rate of strain, obeying Hooke's law. For isotropic and homogeneous materials undergoing small strains the following relationship, which is the definition of the shear modulus, is generally true.

$$G = \frac{\tau}{\gamma} \tag{1}$$

where the shear stress and angular distortion are given respectively by

$$\tau = \frac{F}{A} \tag{2}$$

$$\gamma = \frac{\Delta u}{h} \tag{3}$$

Thus, knowing the area A, the adhesive thickness h, the horizontal displacement Δu and the applied load F, the shear modulus G is readily found.

The experimental setup for conducting shear testing involves an apparatus developed for applying strain in a single lap joint, a CCD camera (Sony XCD-SX910) set perpendicularly to the specimen and a computer for capturing and processing the images, as shown in Fig. (3). It is used to record the images of the specimen has a resolution of 1376 x 1024 pixels. In this experimental configuration, one pixel of the CCD camera corresponds to an area approximately equal to 4.65 x 4.65 m^2 on the specimen.

The single lap joint, fixed in the strain apparatus, was covered with painted speckles (random black and white pattern). It is in agreement with the geometrical model, as seen in Fig. (1). The length of restraint against transversal motion is, d = 25 mm; segment of length, D = 55 mm; joint length, L = 25 mm; joint width, w = 20 mm; adherend and adhesive thickness, t = 1.9 mm and ta = 1.6 mm, respectively. The upper and lower adherends have the same characteristics and the material properties of adherends and adhesive are shown in Tab. (1). The bonded region of the adherend received a superficial treatment. The procedure consisted of abrading the adherend surface at the overlap region with fine sandpaper and cleaning with acetone before the application of the adhesive. In order to control and to guarantee adhesive thickness, the test specimen (single-lap joint) was manufactured in a mold (apparatus). The applied cure cycle was 24 h at room temperature.

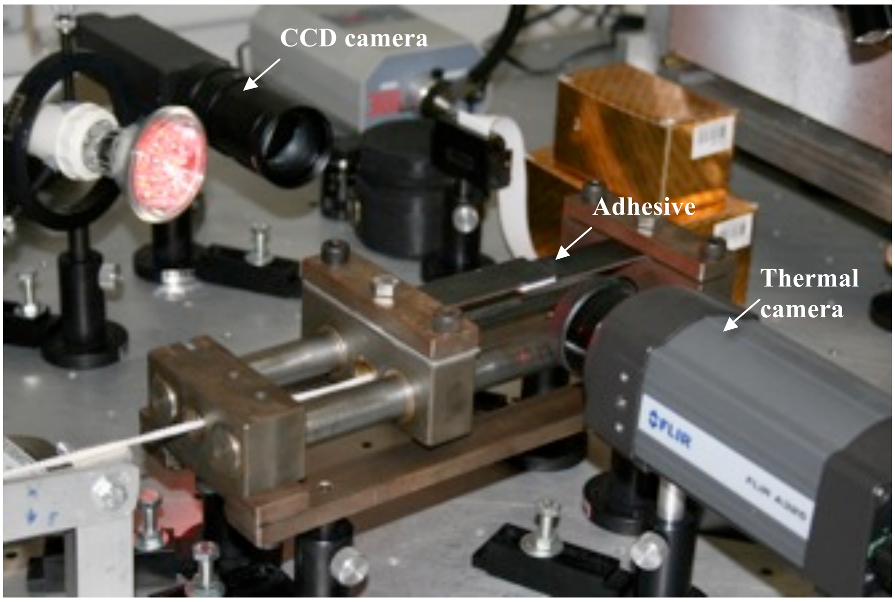

Figure 3. Experimental setup.

Table 1. Materials properties of adherend and adhesive

	Material	Shear modulus
Adherend	Steel A36	79.6 (GPa)
Adhesive	Silicone rubber (polydimethysiloxane)[a]	100 KPa – 3 MPa

[a] Rubberelastic materials: G~1 MPa

The basic idea of experimental procedure is to take the images of specimen in the undeformed and deformed states for different temperatures. A thermoeletric cooler was fixed on adherends in order to heat the system. A thermal camera (FLIR A325) is used to measure the adhesive temperature. The geometry model for the single lap joint, schematically illustrated in Fig. (2), was considered applying different forces, F = 10 N, 20 N, 30 N, 40 N, 50 N, 60 N, 70 N and 80 N, for each temperature value, θ = 23 ^{o}C, 31 ^{o}C, 40 ^{o}C, 50 ^{o}C. In the present methodology, the adhesion integrity can be guaranteed, taking into consideration the low loads applied and the dimension of the bonded area. For example, two images of the single lap joint cover with painted speckles are taken in the same region, considering two different loads of 0 and 80 N, as illustrated in Fig. (4a) and Fig. (4b). These images were used to compute full-field displacement, using the DIC method.

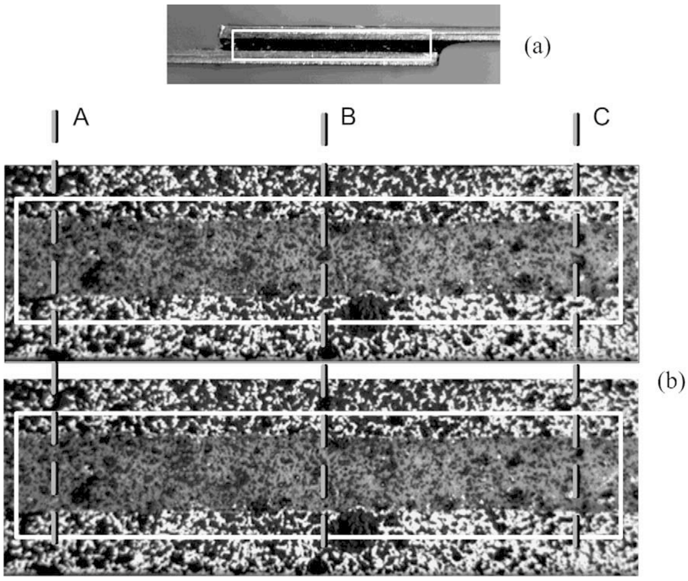

Figure 4. Single lap joint in the overlap: (a) analysis region and (b) pattern of the coating specimen.

Figure (4a) illustrates the single lap joint without the random speckle pattern, whereas Fig. (4b) shows the specimen painted. Clearly, it is observed the adhesive and adherent regions. The lines A, B and C draw in picture will be used to evaluate the adhesive deformation. The squares draw in Fig. (4a) and Fig. (4b) are considered as the analysis region.

3. RESULTS AND DISCUSSION

In this section, the results were obtained considering the procedure presented previously, i.e., two images of the single lap joint, in the undeformed and deformed states, were taken using the experimental arrangement and then were processed by means DIC program. The full-field displacement u(x,y) associated with the horizontal direction is analyzed in three different positions; x equal to A, B and C as shown in Fig. (4). How the adherends is much greater than the adhesive, i.e., it does not reflect the effect of the adherends bending and shear deformations, the vertical deformations v(x,y) can be neglected when compared with horizontal deformations (Nunes, 2009).

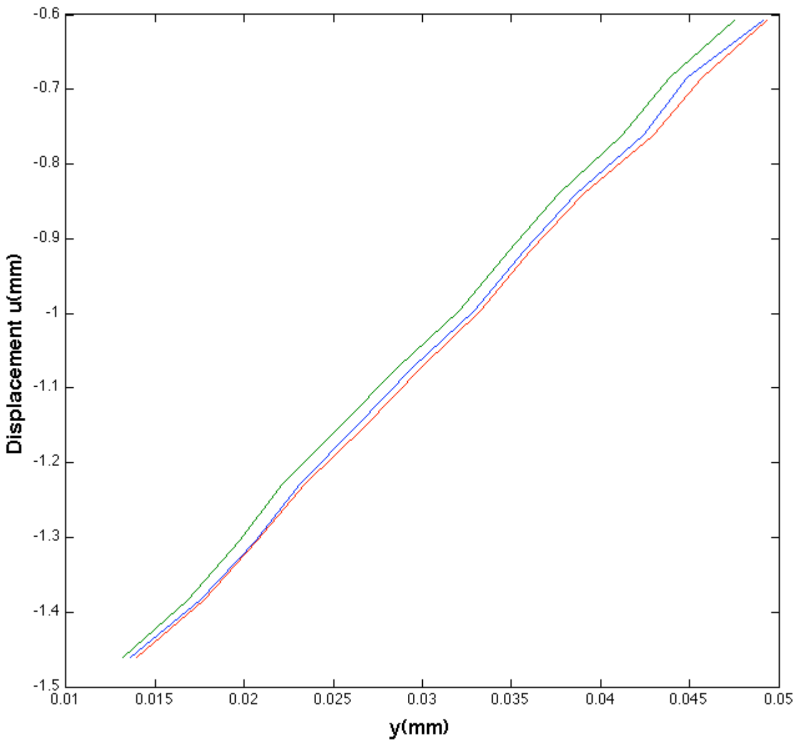

Figure 5. Horizontal displacement curves for applied load of 80 N, for different temperatures.

The curves u versus y in the adhesive range for different temperatures, submitted to a load of 80 N, is obtained (see Fig. (5)). We can observe that the angular coefficient γ of each curve do not change. Taking in account Eq. (1) and considering the same applied force 80 N, the shear modulus G will be the same for the temperature range of 23 ^{o}C to 50 ^{o}C.

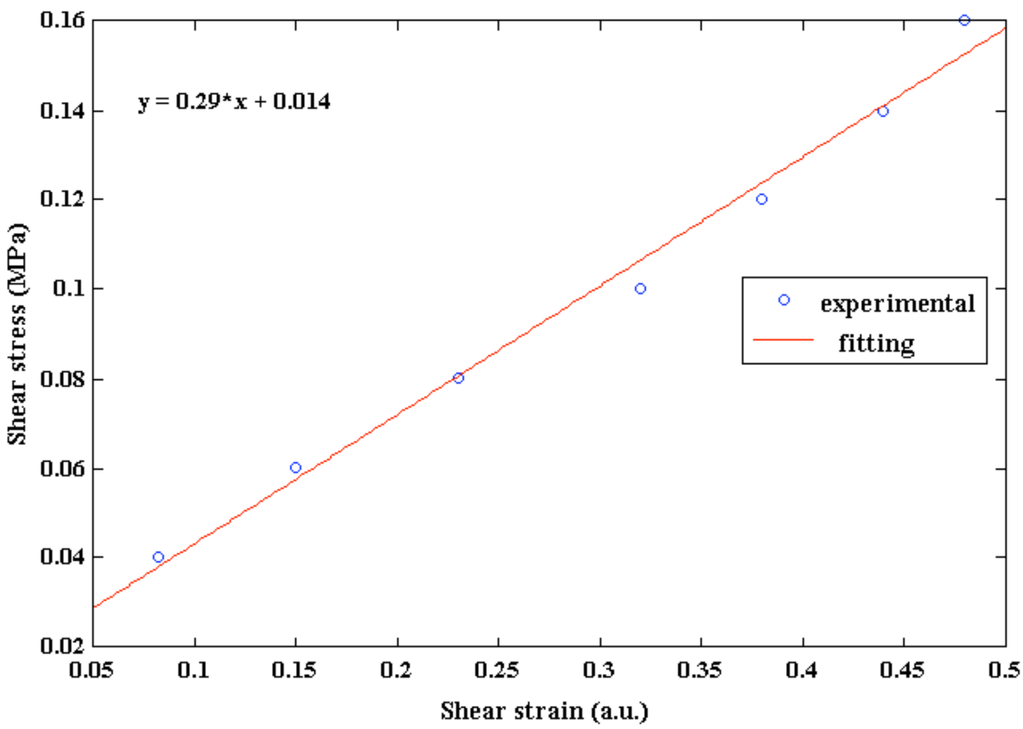

Figure 6. Stress x strain curve for different applied loads, for the temperature of 50 ^{o}C.

The Fig.(6) shows stress x angular distortion (γ) curve. For each applied load, for the temperature of 50 ^{o}C, the angular distortion was evaluated using

$$u = u_o + \frac{\partial u}{\partial y}\Delta y \tag{4}$$

onde

$$\gamma = \frac{\partial u}{\partial y} \tag{5}$$

We can observe, in Fig.(6), that shear modulus (G) is 0,29 MPa which can be evaluated according Eq.(1).

4. CONCLUSION

In the present work, the digital image correlation (DIC) measurement method was used to analyze the adhesive shear strain behavior submitted to different loads in different temperatures. The test is carried out using a single lap joint specimen, in which a simple shear is expected. The angular distortion was obtained through data of the adhesive shear deformation taken experimentally as a result of full-field displacement. For a temperature range of 23 ^{o}C to 50 ^{o}C, the angular distortion for a load of 80 N remained constant. Therefore, the known PDMS shear modulus can be considered the same since it does not show any significant changes for temperature range analyzed. This means that this material, widespread used in many different applications, is thermo mechanically stable at least in the temperature range here analyzed.

5. ACKNOWLEDGEMENTS

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