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METHODOLOGY TO MEASURE STRAINS AT HIGH TEMPERATURES USING ELECTRICAL STRAIN GAGES WITH FREE FILAMENTS

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ABSTRACT

An experimental methodology used for strains measuring at high temperatures is shown in this work. In order to do the measurements, it was used electric strain gages with loose filaments attached to a stainless steel 304 beam with specific cements. The beam has triangular shape and a constant thickness, so the strain is the same along its length. Unless the beam surface be carefully prepared, the strain gage attachment is not efficient. The showed results are for temperatures ranging from 20 ^{o}C to 300 ^{o}C, but the experimental methodology could be used to measure strains at a temperature up to 900 ^{o}C. Analytical calculations based on solid mechanics were used to verify the strain gage electrical installation and the measured strains. At a first moment, beam deformations as a temperature function were plotted. After that, beam deformations with different weighs were plotted as a temperature function. The results shown allowed concluding that the experimental methodology is trustable to measure strains at temperatures up to 300 ^{o}C.

1. INTRODUCTION

Structures and components strain measuring at high temperatures (ranging from 300 ^oC to 900 ^oC) using electrical strain gages are frequently necessary nowadays. In order to succeed in obtain this measuring it is necessary to know each strain gage behaviour. It is important to know the structure or component to be analyzed and the environment conditions. Every step involved in the measuring process must be known including the part preparation, the adhesive final cure and the electrical circuit connection to data acquisition.

The strain measurement is a technique used to stress and strain experimental study in structures. These structures deform under mechanical or thermal loads or under a combination of both loads. Because of that it is important to know the range of these deformations and many times they need to be monitored constantly. Different ways could be used to monitoring the deformations and the strain measurement is the most versatile one.

The measurement is done gluing an electrical strain gage onto these structures. Electrical strain gages are measurement apparatus that transform small variations in its dimensions (deformations) in equivalent variations in its electrical resistance (R). The electrical resistance could be used directly or may be converted in other measureable factor like electrical tension (V). The electrical tension is amplified to obtain signal information in a remote place.

This is an accurate non-destructive measurement method that allows obtaining structural actual deformations in working conditions. With these measures is possible to do a stress or strain quantitative analyses in actual operational conditions.

In this work a series of deformation measures in instrumented specimens with free filaments electrical strain gages are shown. Using these measures, curves of apparent deformation changing with temperatures are plotted. The strain gages used in this work were type ZC made by Vishay Micro Measurements. Using these curves the authors would like to study the structure behaviour under static loads at room temperature and under static loads with changes in temperature.

The results will be compared with solid mechanics theoretical calculated values. After that new experiments will be done in order to develop an efficient measuring methodology that allows the CDTN to do trustable and cheap measurements at high temperatures. In this work the showed experiment results include temperature in the range of 20 ^oC to 300 ^oC. The experimental results for temperatures changes above that range are being done and will be published in the future.

2. METHODOLOGY

2.1. Materials and Equipments

- Capacitive discharge welding apparatus, W50R GAUGE INSTALLER model, made by Tokkio Sokki Kenkoyo ko, Ltda.
- Extensometer ZC-NC-G1266-120 made by Vishay Micro Measurements [1].
- Stainless stell AISI 304 isostatic beam
- H-cement glue made by Vishay Micro Measurements [2]
- M prep-A conditionator made by Vishay Micro Measurements
- Neutralizer 5A made by Vishay Micro Measurements
- Adhesive strip for high temperatures aplications made by Vishay Micro Measurements
- Acetone
- High temperatures electrical cables
- Oven for temperatures up to 320^{o}C
- Electric oven for temperatures up to 1200^{o}C
- Sistema de aquisição de dados Agilent 34470ª
- Agilent 3447A data acquisition system

2.2. General Considerations

H-Cement is a cement with a unique component used to fix the extensometer ZC-NC-G1266-120 [1] onto the part where one wants to measure the strains. This cement requires a final cure at 316 ^{o}C, with increasing temperature in steps that are depicted ahead. The long time duration cement work temperature range from -269 ^{o}C to 871 ^{o}C, for short time duration work (less than one hour) the temperature range is from -269 ^{o}C to 982 ^{o}C [1,2].

The extensometer ZC-NC-G1266-120 is of a special kind and it is different from all the other extensometers that are provided with an appropriated base to fasten them. Its fastening requires a base construction in the strain measurement region using the same H-Cement used to glue the extensometer.

2.3. Gluing Region Preparation

As the cement must be put directly onto the beam surface in order to fix the extensometer, the first step is to prepare the surface. At first, the ideal surface roughness must be achieved in order to obtain the best cement adherence. This is important because the adherence is mainly mechanical and not chemical. The proper roughness surface is acquired by shot penning the surface with glass spheres size ranging from 44 to 100 microns. Fig. 1 depicts the stainless still AISI 304 isostatic beam shot penned and prepared to be chemical cleaned.

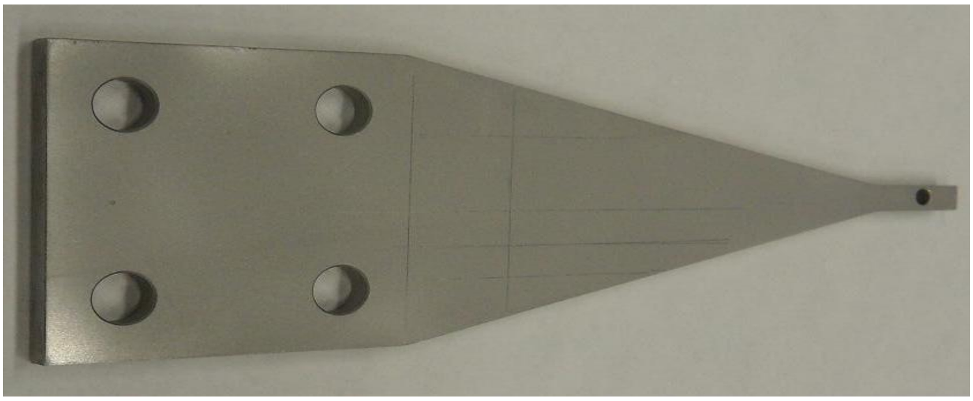

Figure 1 - Isostatic penned beam.

After been penned the gluing region must be chemical cleaned following the steps:

- Clean with acetone PA using cotton: wet the cotton and rub exhaustively the surface and wait to dry;
- Use the M prep-A: must rub exhaustively the cotton wetted with acetone and wait to dry;
- Use the Neutralizer 5A: must rub exhaustively the wetted cotton with acetone in order to neutralize the surface.

After cleaning the surface, touch in the extensometer gluing region must avoided.

2.4. Extensometer Base Fastening Preparation

One of the most important steps is the extensometer base fastening preparation because this base is the connection between the extensometer grid and the isostatic beam surface. The measurements quality depends on this perfect connection.

- Delimit the extensometer base region;
- The cement is very fluid and during application it is necessary delimit the gluing region using preferably a high temperature adhesive strip;
- Mark the gluing place;
- In order to mark the gluing place a thin line must be done at first. This line will determine where the longitudinal extensometer grade center will be placed. After, two parallel lines in both sides of this first line must be done. These two lines will delimit the width of the extensometer base where it will be fastened. A perpendicular line related to these ones must be done in order to determine the extensometer transversal center. Fig. 1 depicts these lines and the extensometer gluing place;

- Placing the adhesive strip: These two strips will delimit the cement application area and will define the extensometer fasten base thickness. Fig. 2 showed the strips and center lines in the isostatic beam.

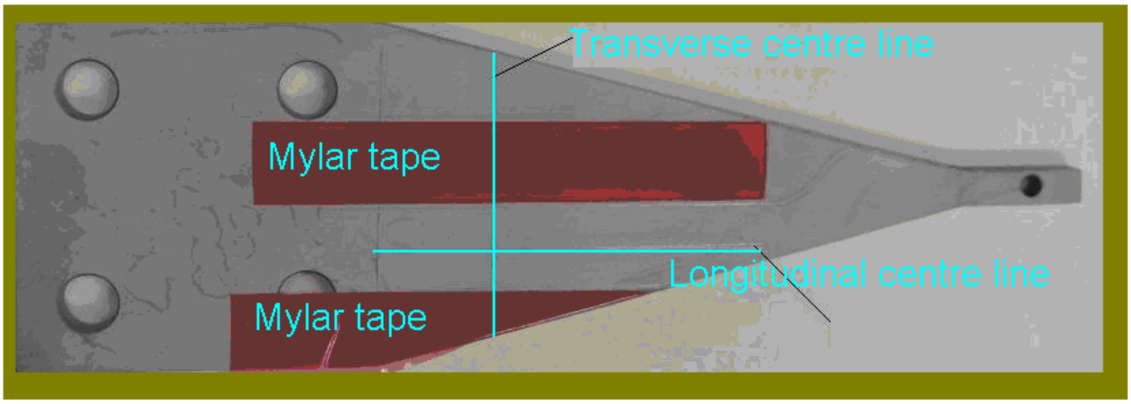

Figure 2 – Isostatic beam ready to base preparation.

- Cement application: The cement must be carefully mixed using a spade or a clean glass agitator. Pour an amount of cement in a gluing area end. Spread softly with the spade in a manner that the cement goes above each adhesive strip. Spreading the cement in this way it will have the same adhesive strip thickness which is approximately 0.08 mm. In Fig. 3 the isostatic beam with the extensometer fastening base prepared to be dried is showed.

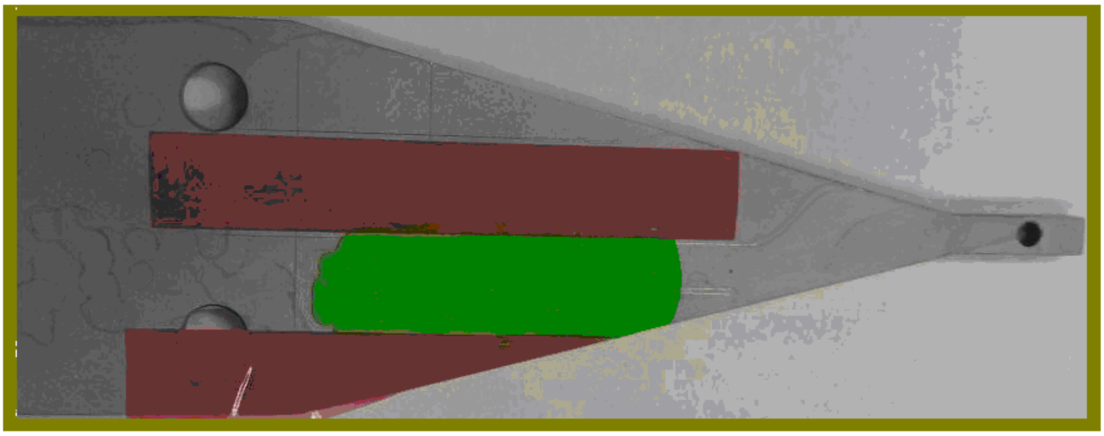

Figure 3 – Isostatic beam with the base prepared, before dry.

Observation: If the extensometer installing surface in plane in only one axis, like a cylinder, the two adhesive strips must be placed in the curved surface. This allows the spade to move along the curved surface.

- Cement drying: Let the cement dry for 30 minutes at room temperature. If the environment humidity is above 40 % it may be necessary a drying time of about 6 to 8 hours in room temperature. The base layer must be dried at 93 ^{o}C during 30 minutes and immediately a 177 ^{o}C during 30 minutes. Let cool down in the oven when it will be ready for the next step, which is gluing the extensometer. Fig. 4 shows the beams cooling down in the oven after being dried.

Figure 4 – Drying and cooling in the oven.

2.5. Gluing the Extensometer Grid

The extensometer type ZCA grid is fastened to a Teflon® base with glass fiber strip. These meshes are very thin, generally 0.013 mm to 0.019 mm, and very fragile. The glass fiber strip is used to avoid grid distortion during its handling and gluing.

Using a knife lift the glass fiber strip from the Teflon® base in a way that the grid and the glass fiber strip could be removed together. Fig. 5 shows this operation.

Put the extensometer grid onto the measuring position above the base layer, observing that its center must coincide with the cross point of the center lines marked in the isostatic beam. Use glass fiber strip to maintain the grid in position. With a soft brush put a cement layer above the mesh, observing that the extensometer wires and the grid junctions are under the cement. It could be observed that the cement will not be placed above the glass fiber strip, but only in the space between them.

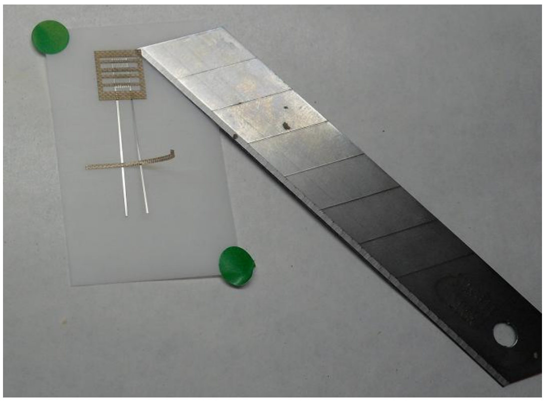

Figure 5 - Removinng the grid from the Teflon® base.

- Drying the cement: Let the cement dry for 30 minutes at room temperature. If the relative humidity is greater than 40 %, it could be necessary a longer drying time from 6 hours up to 8 hours at room temperatures. Dry the base layer at 90 ^{o}C for 30 minutes and immediately at 177 ^{o}C for 30 minutes. Let cool down in the oven, remove the glass fiber strip using tweezers and put the cement above the open grid extensometer areas.

2.6. Final Drying

Let the cement dry for 30 minutes at room temperatures. If the relative humidity is greater than 40 %, it could be necessary a longer drying time from 6 hours up to 8 hours at room temperatures. Dry the base layer at 93 ^{o}C for 30 minutes, after at 177 ^{o}C for 30 minutes and finally at 316 ^{o}C for 1 hour. Fig. 6 depicts the final extensometer mounting.

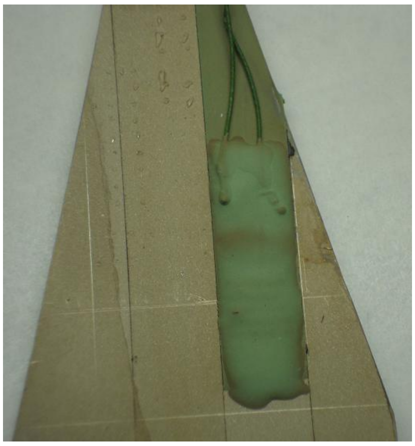

Figure 6 – Extensometer final mounting.

2.7. Extensometer grid terminals welding to the data signal wires

The data signal wires must be welded to the grid terminals using capacitive discharge apparatus appropriated to it. After being welded the whole extensometer grid and connection must be covered with cement as described previously. Do not use cement in excess because it could cause voids and cracks during the drying process. Fig. 7 depicts the grid terminal welded to the data signal acquisition wires.

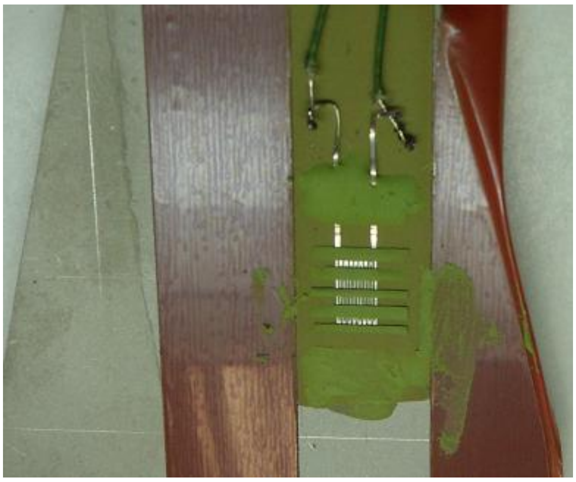

Figure 7 – Welding of data signal acquiring wires to the extensometer grid terminals

2.8. Strain Theoretical Calculations at Room Temperatures

The theoretical calculations were done using the solid mechanical equations [3]. The Eq. 1 was used to calculate the isostatic beam strains shown in Fig. 8.

$$\varepsilon = \frac{6Fl}{Ebh^2} \tag{1}$$

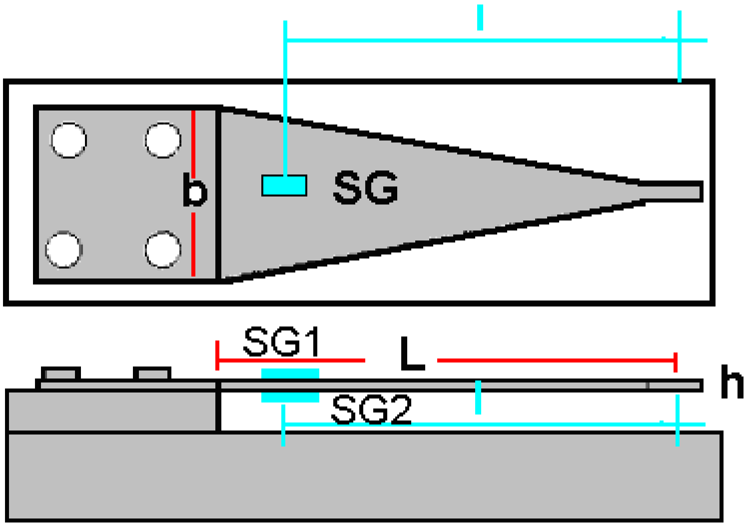

Figure 8 – Stainless steel isostatic beam sketch used in this work.

The calculated values considering only the beam dimension are shown in Table 1.

Table 1 – Strains theoretical values as force function.

Force (N)	L (mm)	b (mm)	h (mm)	E (MPa)	με
30.4	83	41	4.1	210.000	105
50.7	83	41	4.1	210.000	174
80.4	83	41	4.1	210.000	277

E = Young modulus; με = micro strain

2.9. Used Extensometric Circuit

In order to obtain the strains data the extensometric circuit shown in Fig. 9 was used.

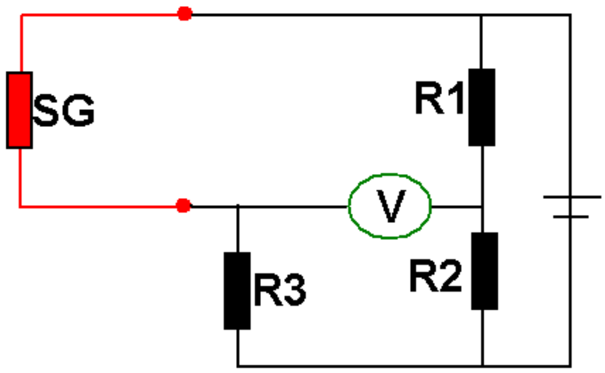

Figure 9 – Used extensometric circuit.

The Wheatstone bridge signal already transformed in strains is obtained sing the Eq. 2 [4]:

$$\varepsilon = \frac{4\Delta V}{VK \times 10^3} \tag{2}$$

In this Equation the parameters are:
ε is the electric extensometer output strain, ΔV is the Wheatstone bridge output signal in mV, V is the input Wheatstone bridge tension and K is the extensometer electric factor.

The strain results were obtained for the beam traction (SG1) and contraction (SG2) region. The strain final results are a half bridge combination of the measured values at the traction and compression region.

3. EXPERIMENTAL RESULTS

The obtained experimental results are shown in Figs. 10 and 11.

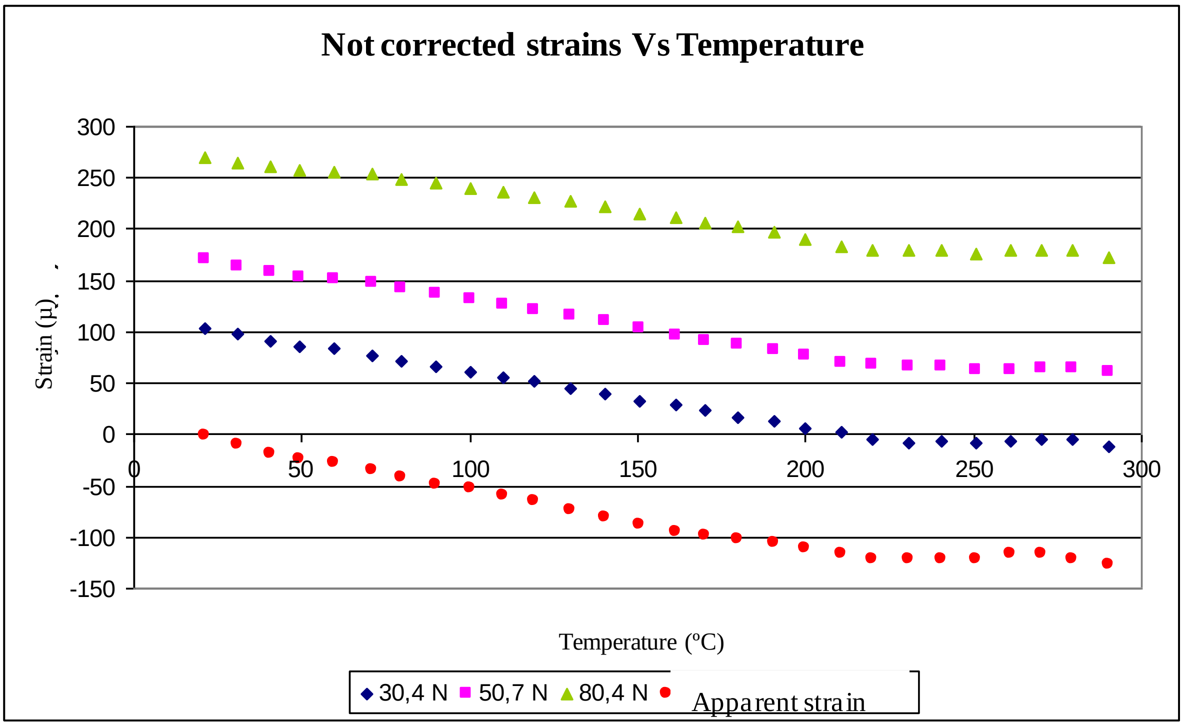

Figure 10 – Not corrected strains for the apparent strain as temperature function.

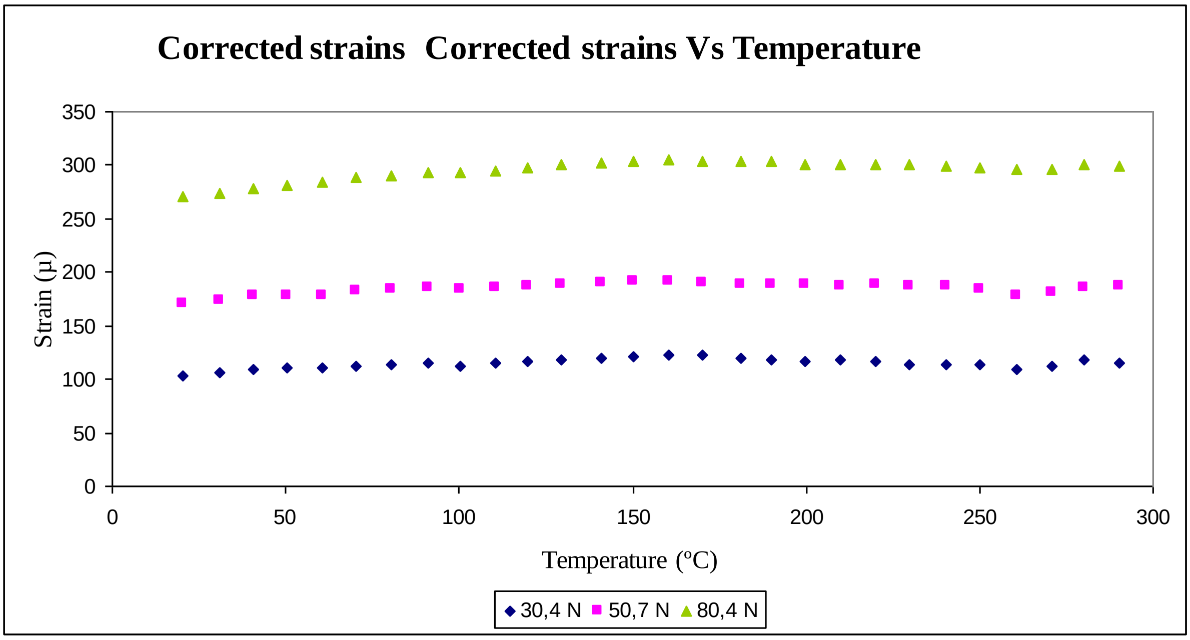

Figure 11 – Corrected strains for apparent strain as temperature function.

The obtained mean values of 30 measuring for each applied force are shown in Tab. 2.

Table 2 – Theoretical and mean experimental strain as a function of the applied force and the temperature.

Applied force (N)	Theoretical strain ($\mu\varepsilon$)	Experimental strain ($\mu\varepsilon$)	
		Mean	Standard deviation
30.4	105	115	4
50.7	174	185	5
80.4	277	295	9

4. DISCUSSION AND CONCLUSIONS

The values shown in Fig. 10 were obtained transforming the electric extensometers (SG) 1 and 2 results in the half Wheatstone bridge configuration.

The values shown in Fig. 11 are the corrected values to the apparent strain. Apparent strains are the ones due to only the temperature without the applied loads.

The Table 2 experimental data are the mean strains values shown in Fig. 11. It could be observed a good agreement between theoretical and experimental values. For minor loads the difference between these values is great, but only in 10 %. When considering the major loads the difference is 6 %.

Observing the procedures shown in item 2 and applying the appropriate care, the results obtained showed that the strain measuring technique used at temperatures up to 300 ^{o}C is trustable.

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