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# High Temperature Strain Measurements using Welded Strain Gages

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## ABSTRACT

This work presents strain measurements in A 516-grade 65 carbon steel and AISI 304 austenitic stainless steel, using HTW russian strain gages. The measurement was done using a half Wheatstone bridge with two distinct configurations:
a - two fixed strain gages,
b - one fixed and other not rigidly attached to the specimen.

The experimental results were compared with that obtained theoretically for two distinct loads.

The temperature influence on the results was also verified.

## INTRODUCTION

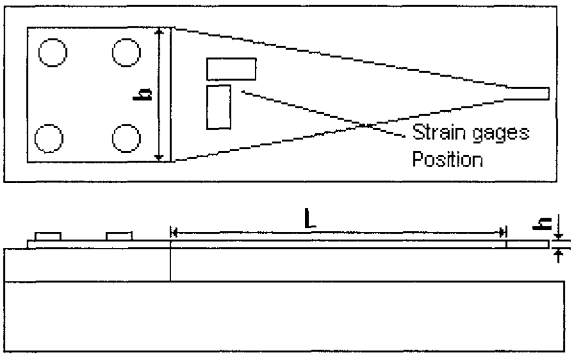
The experimental stress analysis using electric strain gages in high temperature atmospheres requests the previous knowledge of the strain gage installation behavior, mainly in what it concerns the strain gage electric resistance variation. In such case, the electric strain gages resistance R must be considered as function of the temperature T, time t and strain ε, i.e., R = f (T, t, ε) [1]. Many problems in the high temperature strain gage measurement are generated by environmental condition like erosion and oxidation. Humidity and chemical agents will attack the strain gage installation more severely in high temperature.

After fixed on adapted specimen one or more strain gages from the same lot are submitted to known loading under known environmental conditions. Starting from simultaneous measurements of temperature and strain is possible to construct curves that characterize the strain gages behavior in the test conditions.

The objective of this work is to analyze the strain in two different strain gage installations under loading and temperature variation.

## METODOLOGY

It was used two constant-stress beams built in A 516-grade 65 carbon steel and AISI 304 austenitic stainless steel. Fig. 1 shows a constant-stress cantilever beam drawing with the dimensions and the strain gages location.



| Beam | Dimension (mm) | | |
|---|---|---|---|
| | L | b | h |
| Carbon steel | 100 | 50 | 4.22 |
| Stainless steel | 100 | 50 | 4.40 |

**Fig. 1 Constant-stress cantilever beam**

Each beam was prepared with strain gages of Russian production and thermocouples K, to obtain simultaneous temperature and strain readings. The fixed strain gages were welded on the beam by capacitive discharge process and connected in two different electric configuration (Fig. 2):

- Two fixed strain gages connected in half Wheatstone bridge- the connection named “installation A” (Fig. 2-a) is constituted of two welded strain gages (fixed) with their longitudinal axes making an angle of 90° to each other.
- A fixed strain gage and a passive strain gage connected in half Wheatstone bridge- the connection named “installation B” (Fig. 2-b) is constituted of one welded strain gage (fixed) and one non welded strain gage (passive). This passive strain gage is positioned only in contact with the beam surface. As it is not welded, it will not accompany the beam deformation and it will just measure the temperature variation.

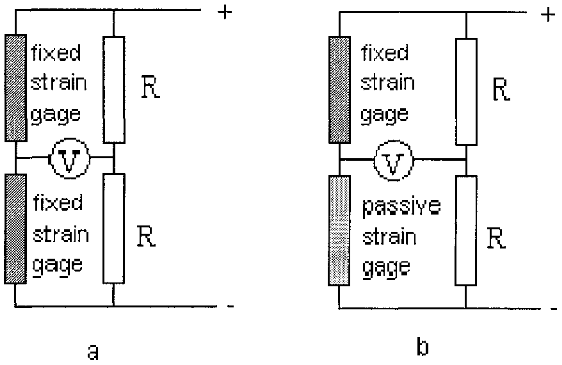


**Fig. 2 Scheme of strain gages connection**

To verify the strain gages installations performance, tests were made at room temperature with loads of 5 kgf, 10 kgf e 15 kgf.

Then, the strain gages installations were submitted to the temperature variation between 20°C e 420°C to apparent strain determination. At last, tests were made under load and temperature variation.

## THEORETICAL CALCULATIONS

The stresses in the constant-stress cantilever beams were obtained from the strength of materials theory, using the following equations [2]:

$$\sigma = \frac{M}{W} = \frac{6FL}{bh^2} \tag{1}$$

$$\sigma = E\varepsilon \Rightarrow \varepsilon = \frac{\sigma}{E} = \frac{6FL}{Ebh^2} \tag{2}$$

Where:
F is the applied force;
L is the distance from the force to the considered transverse section;
E is the modulus of elasticity of the beam material, E = 210000 MPa;
B is the width of the beam transverse section;
h is the height of the beam transverse section;
σ is the normal stress;
ε is the normal strain.

The strain gages technique calculations were made with the followings equations [3]:
a) ½ Wheatstone bridge connection with one fixed strain gage and one passive strain gage:

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

b) ½ Wheatstone bridge connection with two fixed strain gages:

$$\varepsilon = \frac{4\Delta V}{VK(1+\mu)\times 10^3} \tag{4}$$

Where:
ε is the measured strain;
μ is the Poisson's coefficient of the beam material;
ΔV is the Wheatstone bridge output tension in mV;
V is the Wheatstone bridge input tension in V.

## MATERIALS AND EQUIPMENTS

The furnace used for the constant-stress cantilever beam heating has the following characteristics:

- Maximum temperature: 1200°C;
- Heating control: 25°C;
- Heating rate: 3.8°C/min.

The strain gage used has the following characteristics:

- Russian strain gage specification: HTW;
- Nominal resistance: 100 ± 1 Ω;
- Gage factor (K): 2.0;
- Maximum service temperature: 500°C.

The measurement equipment were:

- Source of constant tension: 0 a 5 Volt;
- Digital voltmeter of 4 ½ digit;
- Channels selector to 10 Wheatstone bridges.

## EXPERIMENTAL RESULTS

Table 1 shows the calculated strain values for both beams under loads of 4 kgf e 10 kgf, from Eq. (2). The differences of the calculated values for the same load are related to the different dimensions of the beams.

**Table 1. Theoretical values of strain under loads of 4 kgf e 10 kgf**

| Constant-stress cantilever beam | Strain (μ m/m) | |
|---|---|---|
| | Load: 4 kgf | Load: 10 kgf |
| Carbon steel | 128 | 320 |
| Stainless steel | 118 | 296 |

Fig. 3 shows both installations A and B behaviors, under loading of 5 kgf, 10 kgf, and 15 kgf at room temperature.

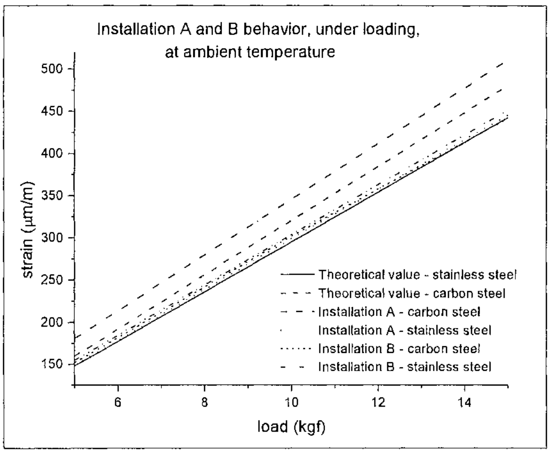


**Fig. 3 Installations A and B behaviors, under different loads, at room temperature**

Fig. 4 and 5 show the apparent strain in both installations A and B, for the carbon steel and stainless steel beams, respectively.

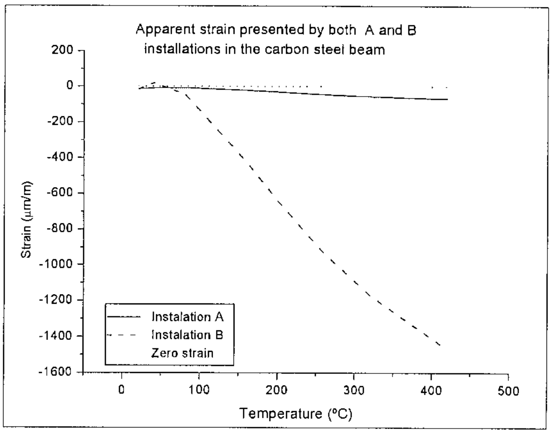


Fig. 4 Apparent strain presented by installations A and B in the carbon steel beam

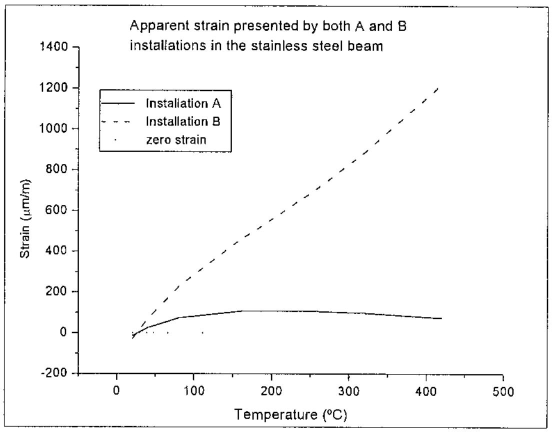


Fig. 5 Apparent strain presented by installations A and B in the stainless steel beam

Fig. 6 and 7 show both installations A and B behaviors, in the carbon steel beam, under loading of 4 kgf and 10 kgf, respectively.

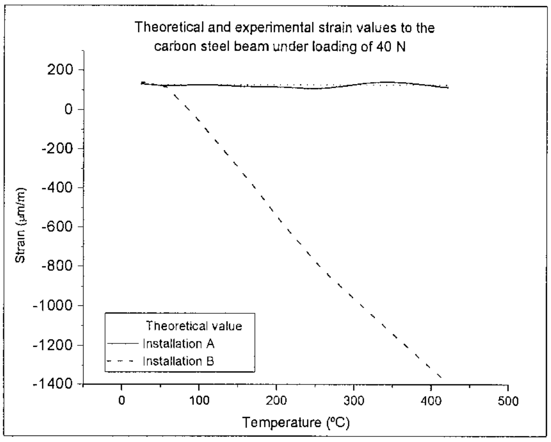


Fig. 6 Theoretical and experimental values for the carbon steel beam under load of 4 kgf

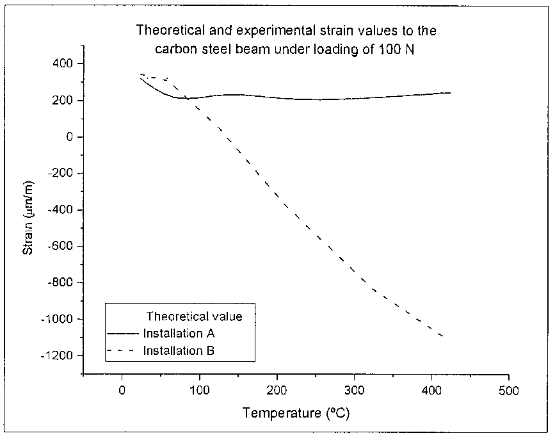


**Fig. 7 Theoretical and experimental values for the carbon steel beam under load of 10 kgf**

Fig. 8 and 9 show both installations A and B behaviors, of the stainless steel beam, under loading of 4 kgf and 10 kgf, respectively.

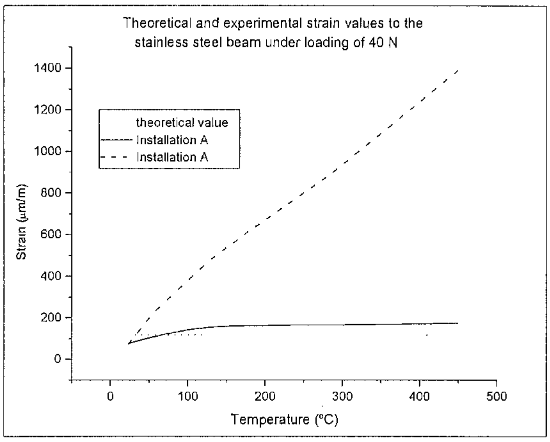


**Fig. 8 Theoretical and experimental values for the carbon steel beam under load of 4 kgf**

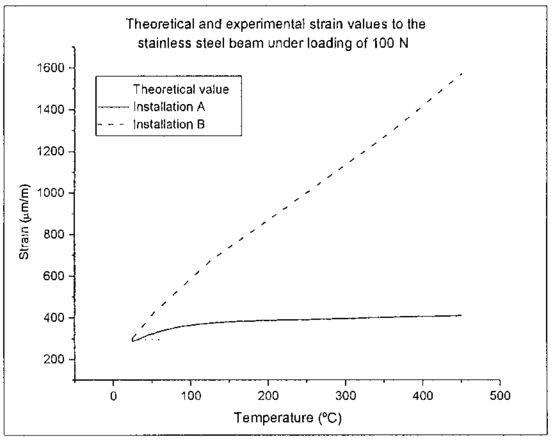


**Fig. 9 Theoretical and experimental values for the stainless steel beam under load of 10 kgf**

## RESULTS DISCUSSION

According to Fig. 3 both installation A and B show good behavior for strain measurement at room temperature.

The apparent strain values obtained with the installation A show its efficiency to eliminate the temperature effect over the strain gage installation.

Between 40°C and 420°C, the apparent strain decrease (absolute values) presented by the carbon steel beam was between 95% and 98%. For the stainless steel beam it was between 90% and 98%.

The difference observed between calculated and experimental values presented by the installation B, is due, probably, to the great stiffness of the passive strain gage fixation system that restricted its mobility beyond the expected.

The results obtained with installation A were very close to the calculated values for both stainless steel and carbon steel beams. It is important to observe that the difference remained constant to each load during the temperature variation.

## CONCLUSIONS

- Although the theory shows the viability of the use of movable strain gages, we should search for methods that guarantee the total mobility of them.
- The installation A in the carbon steel beam presented better behavior for strain measurement relative to the load and temperature.

## REFERENCES

1. Dally, James W. & Riley, William F., "Experimental Stress analysis", 2ed. New York, NY, McGrall-Hill, 1978.
2. Beer, F.P., Johnston, E.R., "Resistência dos Materiais", São Paulo, SP, McGrall-Hill, 1982.
3. Hannah, R.L., Reed, S.E., "Strain Gage User's Handbook", Betherl, USA, Elsevier Science Publishers Ltda and Society of Experimental Mechanics, 1992.
4. Sergeev, A., Hursudov, G.H., Senin, V.S., Mijlev, J.U.K., Maslov, S.V., Comitê Governamental da Rússia para Normalização. "Cálculos e testes em Resistência Mecânica", Centro de Investigações Científicas da URSS para Normalização e Estruturação de Máquinas, Moscou, 1989.
5. "Une Solution à Léxtensométrie Haute Temperature: Le procedé Rokide", Schenk, France: Mesures, 1972.