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TESTING OF THERMOCOUPLES IN THE HIGH GRADIENT TEMPERATURE FIELD

Two identical thermocouples were placed in the fields of different temperature gradients. The comparison of thermocouple readings revealed that the traditional method of temperature measurement is unfit for high gradient temperature fields.

INTRODUCTION

A thermocouple is a simple device for measuring temperatures. The working principle of a thermocouple is based on the Thomas Seebeck effect discovered by him in 1821. A schematic drawing of a thermocouple is shown in Fig.1.

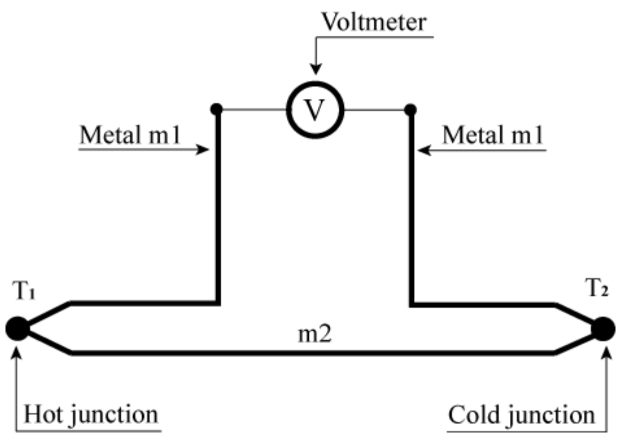

Fig.1. Scheme of a thermocouple.

The essence of the Seebeck effect consists in the following: if the electrical circuit of a thermocouple is closed, the thermoelectric current arises; if the circuit is open, the thermal electromotive force is observed between the points 1 and 2. A value of dV depends on materials of the thermocouple arms and also on the temperatures T_1 and T_2 of each junction. If the temperature difference between the points 1 and 2 is insignificant, the thermal electromotive force is determined by using the empirical equation (1):

$$dV = \alpha \cdot dT\,, \qquad (1)$$

where

$$dT = T_1 - T_2 .$$

(Symbols and abbreviations, used in this paper, are listed in Table 1).

In the simplest case, $\alpha = const$, the equation (1) has a shape

$$dV = \alpha \cdot (T_1 - T_2) \quad (2)$$

Table 1. Symbols and abbreviations

Symbols	
α	Seebeck coefficient
G	temperature gradient
dV	thermal electromotive force of a thermocouple electromotive force
T_∞	temperature of the environment (air)
Abbreviations	
HGTF	high gradient temperature field
LGTF	low gradient temperature field
HHMJ	homogeneously Heated Measuring Junction
IHMJ	inhomogeneously Heated Measuring Junction

Modern thermocouples are more perfect than the first thermocouple XIX века, what is due to the optimal selection of metals m_1 and m_2 (materials of arms). As to the nameless empirical equation (1), it continues to remain the same since the time of Seebeck. This equation is used widely in temperature measuring devices for the recalculation of the registered thermal electromotive force into the temperature.

It is important to note that researchers always considered the junction temperature field as homogeneous, and the equation (1) has been developed exactly for this case [1, 3]. In practice, the junction temperature field of the thermocouple usually is not homogeneous. In this case, a temperature measuring device calculates the conventional (averaged) temperature of the IHMJ.

It is obvious that the application of the equation (1) to the IHMJ thermocouples is not justified.

INFLUENCE OF THE IHMJ ON READINGS OF A TEMPERATURE MEASURING DEVICE

Influence of the IHMJ on readings of a temperature measuring device can be evaluated by comparing the temperatures of the same object, obtained by using the HHMJ and IHMJ thermocouples. Data for such evaluation have been obtained in the experiment described below.

Experimental set-up

Experimental set-up (Fig.2) for the evaluation of the influence of the IHMJ consists of the following components:

- Two metal-sheathed thermocouples type K (exposed junction; 1.0 mm in external diameter);
- Steel ABNT 1045 cylindrical test piece, ∅54x54mm;
- Temperature measuring device "USB-TC" for the record of the junction temperatures.

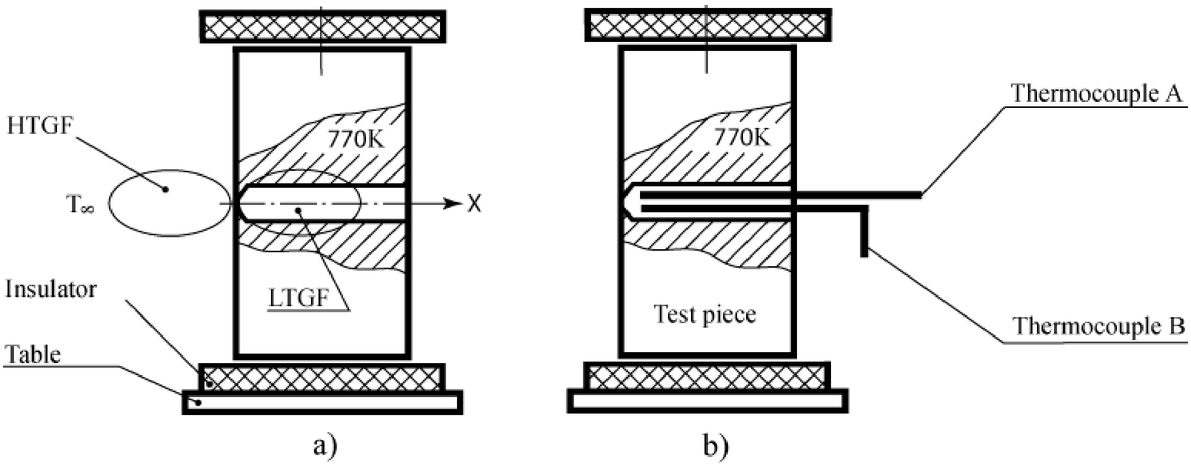

Fig.2. Experimental set-up

Test procedure

Test procedure consisted of three steps. A goal of the first step was the simultaneous generation of LGTF and HGTF by the same object.

The second step was the verification of the thermocouple A and B identity under the same conditions.

The third step was aimed at the simultaneous recording of the thermocouples A and B readings, by placing them in the LGTF and HGTF of the same object.

Step 1. The steel test piece with a deep horizontal hole was heated into the muffle oven to 800K. Then, the test piece was placed between two heated asbestos plates. While in this position, it was cooled by natural convection, conduction and radiation. Two different temperature fields generated by the test piece are shown in Fig. 2a.

Step 2. Two identical thermocouples A and B were placed in the hole at the lateral surface of the test piece and were pressed to the bottom of the hole, as it shown in Fig.2b. The contact of the thermocouples with the test piece was maintained manually. Temperature gradient along the horizontal axis of the LGTF (axis X in Fig. 2) was determined experimentally, and it turned out to be to 1000K/m. Temperature gradient along the vertical axis of this field has been evaluated as negligible (<<1000K/m).

Step 3. Thirty seconds later, the thermocouple A was removed from the hole and was pressed to the test piece surface fragment CDEF, as it shown in Fig.3. Temperature gradient along the axis X of the HGTF has been evaluated as high [2]:

$$G = \frac{770K - T_\infty}{L} >> 1000\frac{K}{m}, \qquad (3)$$

where L is the thickness of the hot air layer which provides the conventional cooling of the cylindrical lateral surface of the test piece; T_∞=300K.
Like to the previous step, the contact of the thermocouples with the test piece was maintained manually.

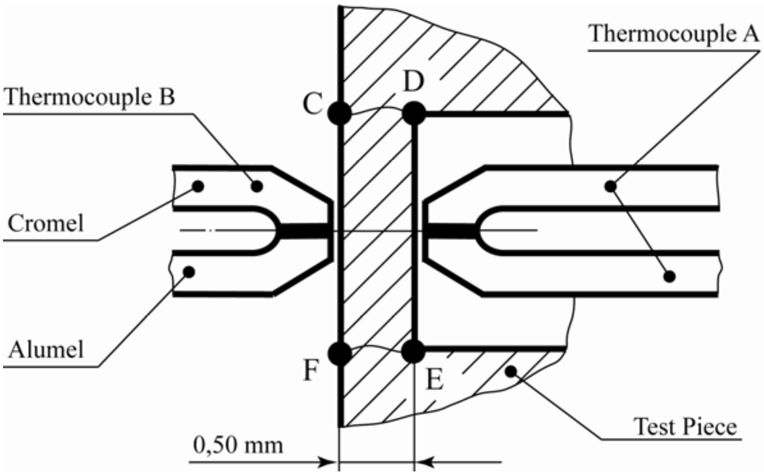

Fig.3. Schema of the set-up for measuring of the temperature of the test piece surface fragment CDEF.

Readings of the thermocouples A and B were recorded by temperature measuring device "USB-TC".

Experimental results

The results of the experiment are presented in Fig. 4.

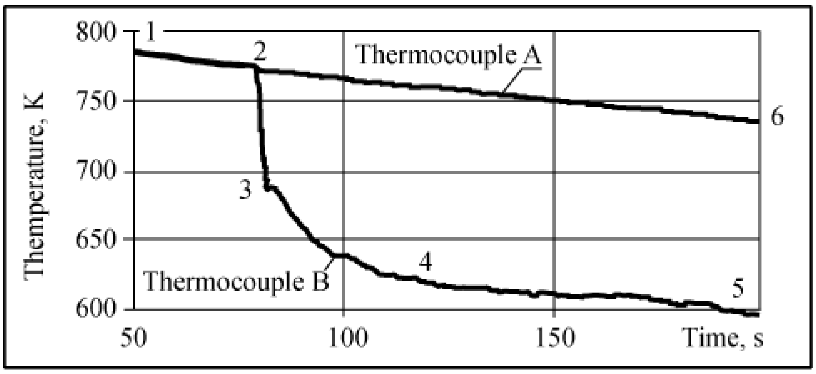

Fig.4. Cooling curves of the thermocouple A and B junctions.

Explanations to Fig. 4 are as follows.

- “1-2” – cooling curves of the thermocouple A and B junctions, obtained for the LGTF in the bottom of the hole. This part of the cooling curves shows certain non-identity of the thermocouples A and B;

- "2-3-4" – a part of the cooling curve of the thermocouple B junction, obtained while replacing this thermocouple from the hole to the external test piece surface;
- "2-6" – a part of the cooling curve of the thermocouple A junction, obtained for the LGTF in the bottom of the hole.
- "4-5" – a part of the cooling curve of the thermocouple B junction, obtained in the HGTF during the contact of this thermocouple with the external cylindrical lateral surface of the test piece.

  Irregularities in the shape of the cooling curve "4-5" and "2-6" have been provoked by manual maintenance of contacts between the thermocouples and the test piece. These irregularities correspond to variations of the "thermocouple junction - test piece" interface pressure as well as to variations of geometric parameters of this interface.

Analysis of the experimental results

Measured *dV* values generated by the IHMJ thermocouple A and HHMJ thermocouple B were used by the "USB-TC" device for the calculation of the CDEF fragment temperatures. The calculation was performed according to the equation (1). The difference between the calculated temperatures was about 140K, as one can see in Fig.4.
Such great difference between the cooling curves of the thermocouple A and B junctions can not be provoked by variations of the "thermocouple junction - test piece" interface characteristics, what follows from the insignificant variations of cooling curve shapes. Therefore, this difference was resulted by inhomogeneous heating of the thermocouple B measuring junction in the HGTF.

CONCLUSION AND FUTURE WORK

Obtained results show that in case of using the IHMJ thermocouples, the equation (1) is inapplicable to the recalculation of the measured *dV* values to temperatures.
Unfortunately, the insufficient development of the thermoelectricity theory [1, 3] also does not allow to predict (calculate) the value of the thermal electromotive force, generated by IHMJ thermocouples. Therefore, the study of IHMJ properties is useful both for the development of the thermoelectricity theory and practical purposes, for example, for the study of high gradient temperature fields, including the temperature fields of micro-objects.
This kind of investigations was performed at the Laboratory for Mechanical Conformation, Federal University of Rio Grande do Sul (Brazil), within the framework of the project on the experimental determination of the thermal contact resistance in metal forging.
Some of the obtained experimental data allow to conclude that an IHMJ thermocouple is equivalent in thermoelectric properties in thermoelectric properties to a beam of microthermocouples connected in parallel which have the same physical characteristics (material, length, integral cross section) as the initial IHMJ thermocouple. The empirical formula of the relation between the thermal

electromotive force of a thermocouple and temperatures of its IHMJ has been developed and is under verification.

ACKNOWLEDGMENTS

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