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# Initial Research into the Structure and Working Conditions of Textile Thermocouples

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**Abstract**
*The article presents initial research into the structure and working conditions of textile thermocouples used as temperature sensors. Textile thermocouples differ from traditional ones, not only in the kind of materials used for manufacturing both thermoelectrods, but also in the construction of the electrodes themselves and the measuring junctions. Within the scope of this work, different kinds of textile thermocouples were tested and their incremental thermometric characteristic determined.*

**Key words:** *temperature sensors, textile thermocouples, thermometric characteristics, textronics.*

## Introduction

Temperature measurements with thermocouples are based on the Seebeck phenomenon, as described in 1821. A difference of electrical potential, called the thermal electromotive force, occurs at the free ends of two different materials whose other ends are joined together - a temperature difference exists between the junction and free ends. Different sets of two materials, called thermocouples, are generally used as temperature sensors. In the majority of cases, the thermocouples are made from different metals. However, for measuring high temperatures, nonmetallic materials are also used, often with the application of carbon, for example graphite – carborundum or graphite – graphite with the addition of beryllium [4]. Information about the application of thermocouples made from semiconductors used for measuring in low temperatures, within the range of 200 - 600 °C, can be found in literature publications. At the same time all these publications emphasise that thermocouples have a significant disadvantage, which is their fragility. In modern textile products, especially in textronic clothing, an important role is played by different sensors including temperature sensors for monitoring the human being, environmental temperatures and those of microclimates, for example between particular layers of clothing. It should be emphasised that the traditional commonly used thermocouples are often too rigid to stand great deformations of the clothing.

Classical thermocouples placed in clothing for monitoring the temperature of human skin, that of the clothing surface and the temperature of interlayer microenvironments can cause significant discomfort to the user, which can even be the result of skin irritations. In order to eliminate this disadvantage, the structure of the thermocouples should be maximally similar to the structure of the clothing, which means weaving a textile structure. A comprehensive review of present scientific literature regarding patience and patent applications indicated that no information about textile thermocouples exists. This was the reason that the authors undertook the attempt to design and test a new kind of textile thermocouple, which was patented by them [1]. The authors accepted the definition that a textile thermocouple has thermoelectrodes that are manufactured from textile structures such as threads, yarns, fibres, twisted or non- twisted multifilaments, woven & knitted fabrics and nonwovens. The fibres used to manufacture the textile structure can be those of electroconductive polymers, fibres with electroconductive nanoparticles inserted in the polymer matrix and fibres with a surface coated by an electroconductive material. Unfortunately, in the majority such thermoelectrodes have high electrical resistance resulting from the structure in which the particular individual elements form discontinuous electrical circuits, where the resistance of the contact of individual elements plays a great role. This fact, as well as the rather small sensitivity, (discussed later in the article) caused the authors to design not only pure textile thermocouples but also hybrid thermocouples in which one of the thermoelectrodes is of the classical metallic wire variety. Taking this into account, a thermocouple in which a textile thermoelectrode in the form of a knitted fabric is connected with a thermoelectrode manufactured from staple iron fibres (wires) should be considered as a textile thermocouple, whereas if the second thermoelectrode is manufactured from conductive monofilament metallic wires, it should be considered as a hybrid thermocouple.

The textile electrodes are connected together in an unconventional way: using electroconductive glue to form the measuring junction. The shape and the dimensions of the measuring junction depend on the kind of thermoelectrodes used. The free ends of the thermoelectrodes are joined with the connecting leads also using an electroconductive glue, creat-

***Table 1.*** *Characteristic of flat textile materials used for the construction of textile thermocouples; * - electrical insulation.*

| Material | Mass per square meter, g/m$^2$ | Thickness, mm | Dimensions (l × w), mm × mm | Electrical resistance, Ω |
|---|---|---|---|---|
| Graphite nowoven | 64.9 | 0.64 | 400 × 25 | 25 × 10$^3$ |
| Woven fabric of Nitril – Static fibres | 95.3 | 0.74 | 400 × 25 | 2 × 10$^3$ |
| Steel knitting | 1093.7 | 2.3 | 400 × 25 | 184 |
| Cotton nonwoven | 3.29 | 0.28 | 400 × 25 | -* |

***Table 2.*** *Characteristic of linear textile materials used for the manufacturing of textile thermocouples.*

| Property | Linear density, tex | Length, mm | Electrical resistance, Ω |
|---|---|---|---|
| Steel thread Bekinox | 18.4 | 400 | 40 |
| Thread of Nitril – Static | 1.82 | 400 | 200 × 10$^3$ |
| Thread of Xsilver | 18.2 | 400 | 250 |



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ing reference junctions. The connectors are manufactured from metallic wires and lead to the voltage measuring instrument. The reference junctions are placed in a device providing a stable reference temperature.

The designing of textile thermocouples forming sensors for temperature measurements will increase the traditional functions of clothing making it textronic. This article presents preliminary research into the designing, manufacturing and use of textile thermocouples. The research described does not claim to create a final product with optimised features.

## Materials designated for testing

Conductive textile products of different materials were used for manufacturing the prototype thermocouples. The materials were selected in such a way that composed in pairs they produced an electromotive force under the influence of a temperature difference between the junction point and free ends. The following textile products were used in our tests:

- thread of electroconductive poliacrylonitrile staple fibres (Nitril – Static),
- thread of steel staple fires( Bekinox),
- poliamide thread with a silver coating (Xsilver)
- woven fabric with warp of poliacrylonitrile yarn composed of Nitril – Static,
- knitted fabric manufactured from steel fibres (Bekinox),
- graphite nonwoven.

Additionally, the following were used for manufacturing textile and textile-hybrid thermocouples:

- constantan wire of 0.2 mm diameter, electrically isolated,
- cotton nonwoven as electrical layer isolation.

The above-mentioned materials are characterised in ***Tables 1, 2*** and ***Figure 1***.

To prepare the junctions, the following electroconductive glue was used: Circuit Works Conductive Epoxy CW 2400 made by Chemtronics, characterised by an electrical resistivity of $10^{-5}$ Ωm and thermal conductivity of 62.49 $Wm^{-2}K$. The shape and dimensions of the junctions depend on the kind of textile materials used. Examples of junction points manufactured with the use of thermoconductive glue and linear textile materials are presented in ***Figure 2***.

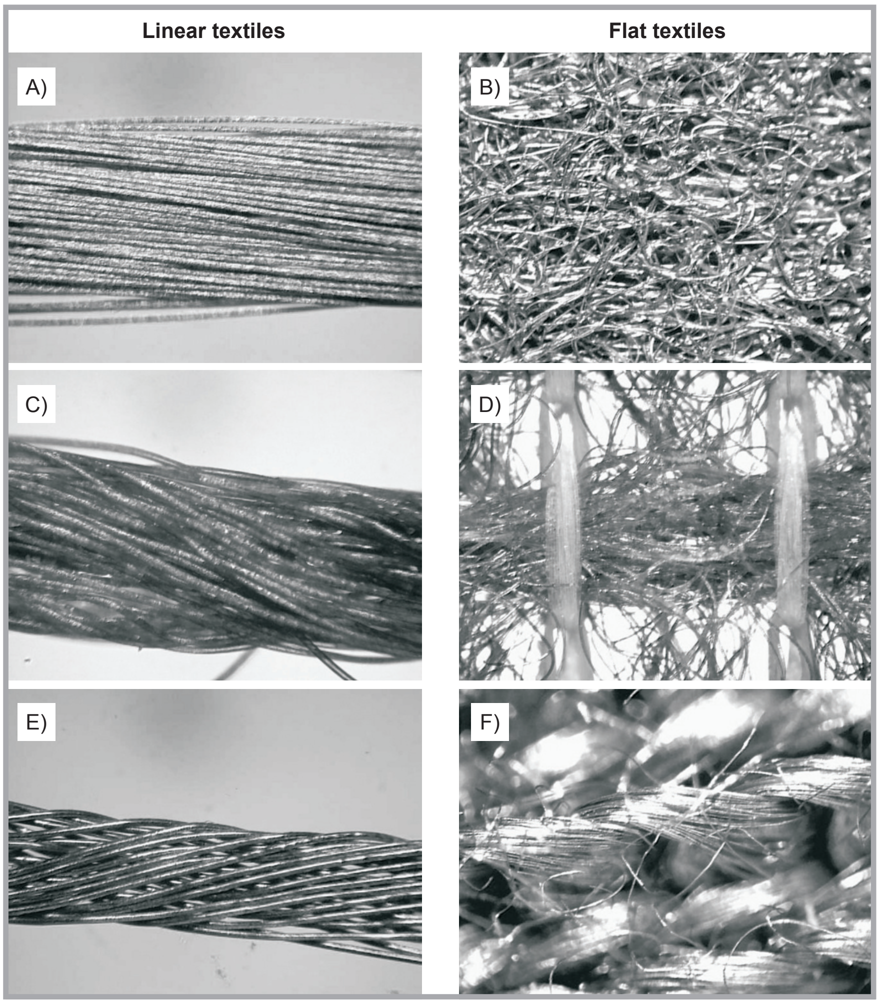


***Figure 1.*** *Microscopic photographs of textile materials used for manufacturing the textile thermocouples; magnification 10×; A – steel thread Bekinox; B – Thread of Nitril –Static fibres; C – thread of Xsilver; D – graphite nonwoven; E – woven fabric with Nitril – Static fibres; F – steel knitting.*

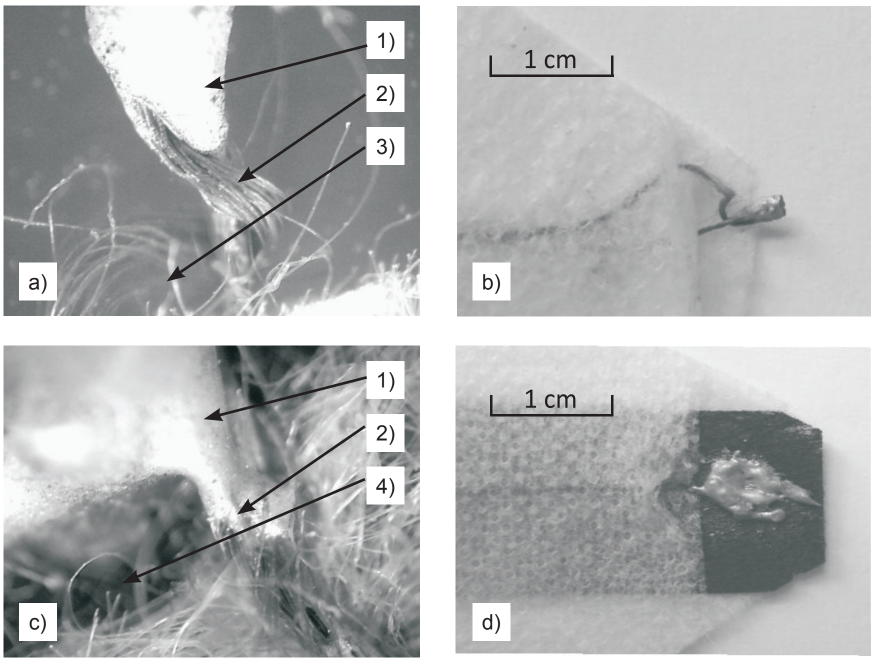


***Figure 2.*** *Examples of measuring junctions of textile thermocouples: a & b – linear thermocouples; c & d – flat thermocouples; a & c – microscopic photography, magnification 10×; b & d – real image; 1 - measuring junction (glue), 2 - textile electrode 1 (thread), 3 - textile electrode 2 (thread), 4 - textile electrode 2 (nonwoven).*

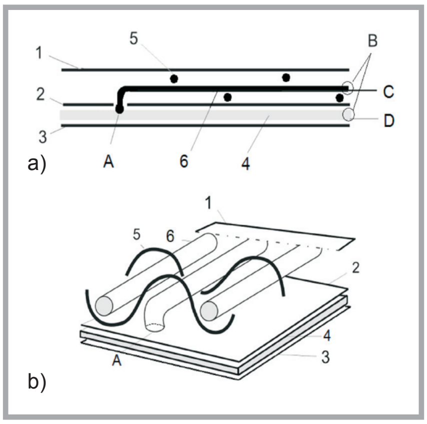


*Figure 3. Schematic view of the structure of a textile thermocouple of the TTF type; a) cross-section along the warp, b) view: 1, 2, 3 – nonwoven electrical isolation, 4 – electroconductive metallic nonwoven, 5 – nonconductive weft threads, 6 – electroconductive warp threads, D – electroconductive connecting wires of the electroconductive nonwoven 4, C – electroconductive connecting wires of the woven fabric 6, A – measuring junction, B – reference junction.*

## Thermocouple structure

In order to carry out the tests, the authors proposed four kinds of thermocouple structure for testing:

- TTF (Textile Thermocouple – Flat) – a textile thermocouple manufactured from flat textile products composed of the following pairs of textile electrodes: graphite nonwoven – woven fabric with Nirtil – Static fibres.
- TTL (Textile Thermocouple – Linear) – a textile thermocouple manufactured from linear textiles composed of the following pairs of textile electrodes: thread of Nitril – Static fibres – thread of steel Bekinox fibres.
- TTFL (Textile Thermocouple – Flat Linear) – a textile thermocouple manufactured from the following pair of electrodes: graphite nonwoven – silver covered thread (Xsilver).
- TTH (Textile Thermocouple – Hybrid) – a hybrid thermocouple composed of the following pair of electrodes: steel knitted fabric – konstantan wire.

A schematic view of the TTF thermocouple sensor is presented in ***Figures 3.a*** and ***3.b***. The sensor is constructed from two parallel conductive textile layers - 4 and 6. Layer 4 consists of an electroconductive nonwoven, whereas layer 6 is a woven fabric of plain weave with parallel polymer warp threads covered with a copper sulfide. These threads are connected by weft cotton threads. Layers 4 and 6 are positioned between two layers of cotton nonwoven (1 and 3) and separated by a nonwoven cotton layer (2). Electroconductive layers 4 and 6 are connected together by a drop of electroconductive glue which forms measuring junction point A. At wires D and C of layers 4 and 6, junctions are arranged with copper wires to connect them to the measuring instrument (voltmeter). Points B consists of the reference junctions of the thermocouple. When a temperature difference occurs between point A and point B, an electromotive force is created and can be measured.

The thermocouple presented in ***Figure 3*** is characterised by the most complex structure of all thermocouples tested within the scope of this research. The structure of sensors TTL, TTH & TTFL are presented in ***Figure 4***.

## Temperature measurements

In order to carry out temperature measurements with the use of textile thermocouples, a testing stand was designed, as presented in ***Figure 5***.

Temperature measurements were performed in the following way: Measuring junction A and monitoring thermometer 4 were placed in heating space 1, whose temperature T*m* was set at different values and controlled. Reference junctions C and B and monitoring thermometer 5 were placed in thermostat 2 to set reference temperature T*r*. The electromotive force E created by the temperature difference was measured by measuring device 3. Additionally, the relative humidity RH with use of device 6 and the ambient temperature T*a* by thermometer 7 were measured. The electromotive force E depends on temperature Tm, which can be described by equation 1:

$$E = f(Tm), \text{ for } Tr = \text{constant} \quad (1)$$

The measurements were carried out within the measuring range of T*m* = 30 – 120 $^0$C at a relative humidity of 57 ± 2% and ambient temperature of T*a* = 23 ± 1$^0$C. Measurements carried out at a reference temperature T*r* = 0 $^o$C yielded a negative result caused by the textile thermoelectrodes being wetted. Therefore all subsequent temperature measurements were carried out at a temperature of the reference points higher thann the dew-point in order to eliminate water vapour condensation. As a result, we accepted the incremental characteristics described by equation 2:

$$\Delta E = f(\Delta T) \quad (2)$$

where:

$\Delta E = E(Tm) – E(Tr)$

$\Delta T = Tm – Tr$

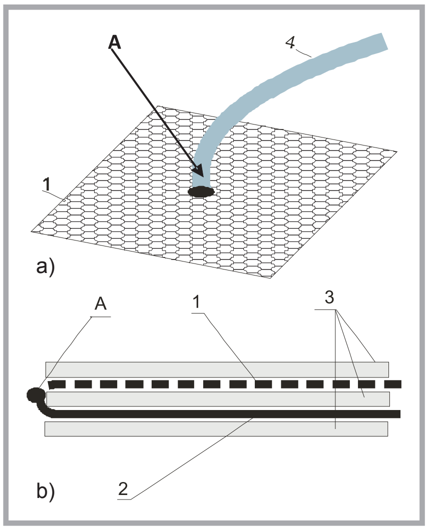


*Figure 4. Schematic view of the structure of sensors TTH & TTFL (a) and TTL (b); 1 – steel knitted fabric, 2 – metallic wire, 3 – non-metalic textile thread, 4 – metallic textile thread, 5 – textile electric isolation, C – measuring junction.*

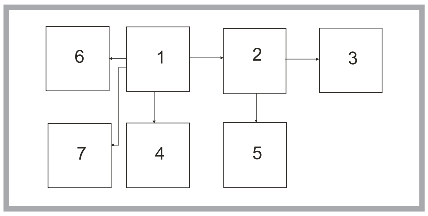


*Figure 5. Block diagram of the measuring stand; 1. Heating space with temperature monitoring and control (temperature measured by the textile thermocouple tested and monitoring electronic thermometer); 2. Reference temperature: MicroCal 100 calibration furnace (-28 – 150 °C) ± 0.15 °C; 3. Electromotive force measurement: Multimeter Agillent 3114A 6,5 digits; 4. Temperature monitoring: AMD 90A Thermometer (± 0.2 °C); 5. Reference temperature measurement: Tempmaster Thermometer (± 0.015 °C); 6. Relative humidity measurement: capacity hygrometer (5% - 95% RH ± 1% ); 7. Ambient temperature measurement: laboratory thermometer with 0.2 °C resolution.*

## Results

Tests were carried out for two samples of every kind of textile thermocouple of analogical structure parameters. Two measurements were carried out for each of the samples. The maximal dispersion of the measurements results in a relation to the average value in μV and related

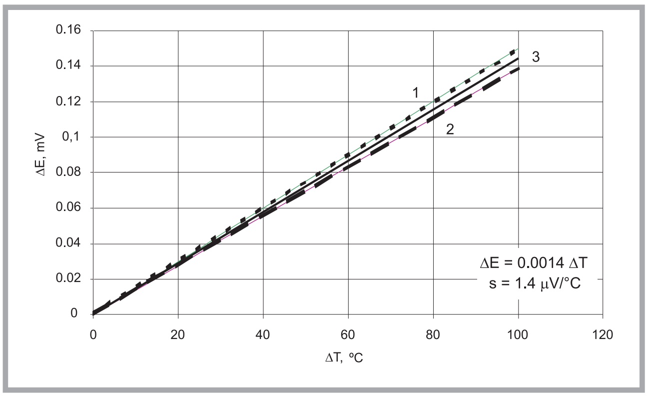


***Figure 6.*** *Thermometric characteristic of the TTFL sensor, composed of a graphite nonwoven and Xsilver thread; 1,2 – characteristics of particular sensors, 3 – characteristic of average values.*

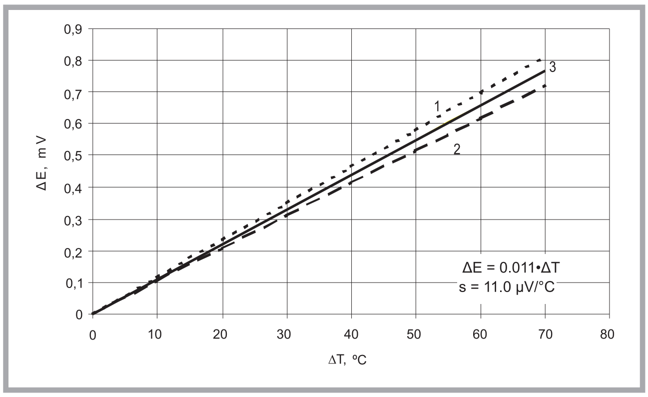


***Figure 8.*** *Thermometric characteristic of the TTL sensor, composed of a steel yarn and Nitril – Static yarn; 1,2 – characteristics of particular sensors, 3 – characteristic of average values.*

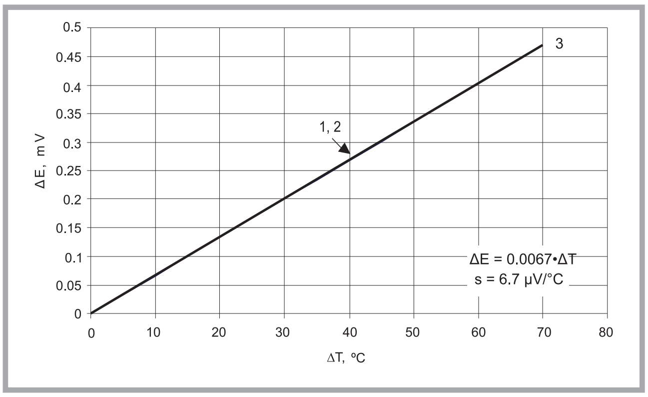


***Figure 7.*** *Thermometric characteristic of the TTF sensor, composed of a graphite nonwoven and woven fabric with Nitril-Static fibres; 1,2 – characteristics of particular sensors, 3 – characteristic of average values. Characteristics 1 and 2 match together.*

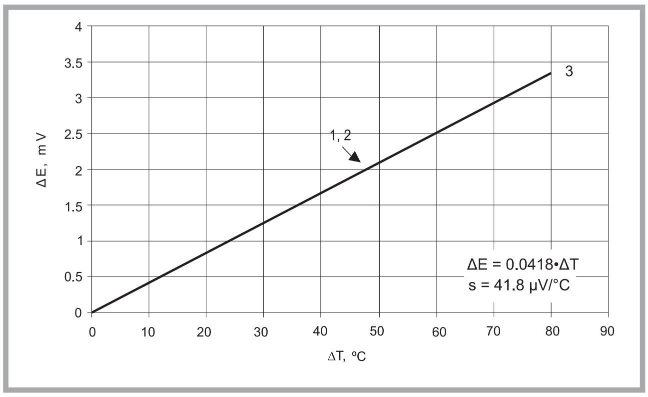


***Figure 9.*** *Characteristic of the TTH sensor, composed of steel knitted fabric and konstantan wire (hybrid sensor); 1,2 – characteristics of particular sensors, 3 – characteristic of average values. Characteristics 1 and 2 match together.*

temperature differences in $^0$C as measurement errors, based on the temperature indication of thermometer 4 (***Figure 5***) for particular thermocouple pairs, as presented in ***Figure 10***. The errors caused by the measurement equipment are many times smaller than the error evaluated as mentioned above and can be omitted. Dependencies of the electromotive force on the temperature difference between the measurement junction and reference points as incremental thermometric characteristics for particular sensors are presented in ***Figures 6, 7, 8*** and ***9***. The particular characteristics 1&2 for ***Figure 7*** & ***9*** do not differ and only one curve was drawn. A comparison of all thermometric characteristics (only for the total average values) is presented in ***Figure 10***, all drawn at the same scale.

An analysis of the characteristics presented in Figures 6-10 allow to state that the sensitivity of textile thermocouples are relatively low and comparable with the sensitivity value of classical PtRh-Pt thermocouples or is even smaller. Only the hybrid thermocouple TTH is characterised by a higher sensitivity comparable with the classical Fe-constantan thermocouple, which is understandable taking into account the materials used for constructing the thermocouple – constantan wire and knitted fabric from steel serving as the iron (Fe) electrode.

## Conclusions

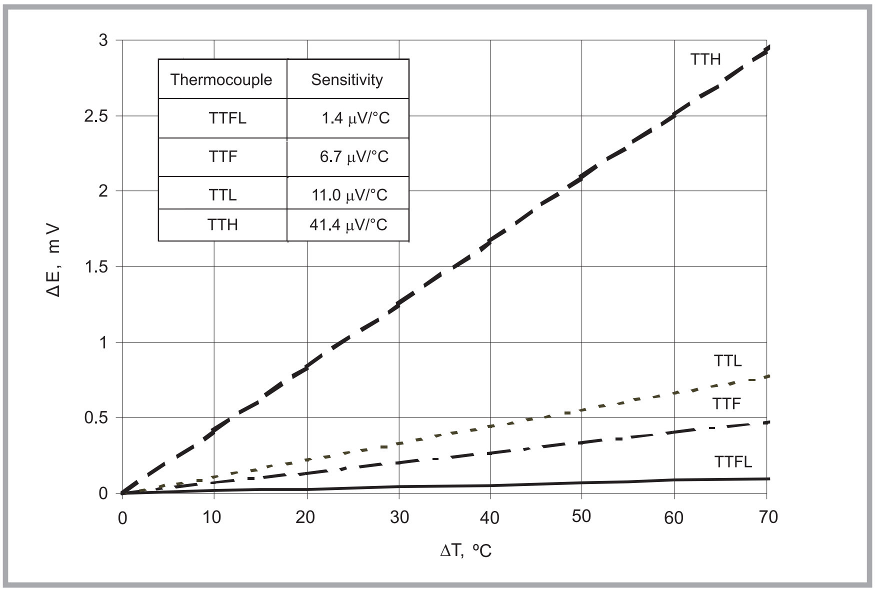


***Figure 10.*** *Comparison of the thermometric characteristics ( for the average values only) illustrating differences in the sensitivity of the sensors.*

- The research carried out confirmed the possibility of temperature measurements with the use of textile thermocouples.
- Electroconducive textiles used as thermoelectrodes for the textile thermocouple can have a linear or flat form.
- A possibility exists of creating textile thermocouples as a complex structure of linear and flat textile forms, as well as the connection of textilethermoelectrodes with traditional electrodes of metallic wires.
- The textiles used for thermocouple textile thermoelectrodes can be manufactured not only from mono- or multifilaments but also from staple fibres.
- Owing to the structure of textile thermocouples, which is similar to those of textile products, they can be easily used as parts of textronic clothing.
- An essential feature of textile thermocouples is their high electrical resistance within the range of $10^3 – 10^5$ Ω.
- The application of prototype thermocouples not isolated from environmental influences caused the disadvantage of limiting use above the temperature of the dew-point.
- The thermocouples tested are characterised by small accuracy and low sensitivity when compared with classical metallic wire thermocouples.
- Further investigations will be conducted in order to decrease the dispersion of measurement results, increase the accuracy and protect the thermocouples against changes in the relative humidity of the environment.

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# The Latest News

As a result of restructuring the Faculty of Material Engineering and Textile Design, Technical University of Lodz, the **Department of Automation of Textile Processes** and the **Department of Clothing Technology** integrated and formed a new organisation unit, called

## the **Department of Clothing Technology and Textronics**

(designated as K-414 in the University organisation system). The scientific activity of the new department will cover the following fields (defined by the Ministry of Science and Higher Education):

- Textile science
- Material engineering
- Automation and robotics
- Electronics

The staff of the new department have experience in the following fields, which are the basis of their future activity:

- Clothing technology and material science
- Textronics and textronic systems
- Technology and organisation of production processes of ready made textiles
- Ready made textile products of new generations
- Identification and optimisation of machines and equipment used in manufacturing processes or ready-made textile products
- Properties of flat textile products
- Clothing comfort
- Fashion and design
- Automation of textile processes
- Electrical engineering and electronics in textile science and technology
- Technical metrology and instrumentation of measurement systems
- Methodology of experiments in scientific investigations

We kindly invite all who are interested in the fields of our activity to cooperate with us.


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