INVESTIGATION OF THE STRUCTURE AND PROPERTIES OF FLEXIBLE POLYMERIC MATERIALS FOR INTEGRATION WITH THIN HEAT CONDUCTORS

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Summary: This article presents the results of analysis of the methods of connecting heaters with materials. Limitations and disadvantages of the ways of integration of materials with heat conductors are revealed. The method of glueless thermoplastic fixing has been proposed. The thermophysical characteristics of the selected polymeric materials were experimentally determined. Experimental studies of the maximum strength for selected materials were carried out. Recommendations for creating heat-protective garments with polymeric materials have been obtained.

Climatic conditions are severe for most parts of Russia, Canada, Finland, Sweden, Norway, as well as Iceland, Greenland, Alaska [1]. People work and live in cold conditions. Cold adversely affect on the human body. It reduces the motor activity of a person and causes impaired coordination [2]. There is a risk of frostbite during a short stay in conditions of low temperatures, strong wind and high humidity [2,3].

Nowadays the development of the cold regions is an actual direction. A particularly important direction is the development of materials adapted to the conditions of cold regions. The development of technical means that they can work in the cold is also relevant [4].

There is a large number of garments that protect people from the cold. They have disadvantages. First, most of these products are made of textiles with heat conductors. Such products give heat to the cold environment [5,6]. Secondly, most of these products heat the entire surface. Here are the features of human physiology are not taken into account [7-9]. The solution is the integration of flexible polymeric materials with heat conductors according to a given contour.

Polymers exhibit low thermal conductivity due to their relatively fair atomic density [10].

The tasks of supplying heat to specified areas of products are relevant for many industries. This is not only the creation of clothing, but also footwear, gloves, covers for storage and transportation of equipment, and others [11,12].

The goal of this work is studying the properties of polymeric materials for integrating technologies with heat conductors.

The tasks are:

- research and classification of heat conductors;
- analysis of the methods of connecting heaters with materials;
- selection of materials for research;
- research of thermophysical properties of the selected materials.

According to the data of [13], the classification of flexible heaters into three groups is given: type of heating element, purpose, type of shell around the heating element. However, there is no information on how to join the heat conductors to the material.

The literary analysis [14-18] revealed the main materials to join with heat conductors: silicone, polyamide, polyester. This increases the cost of heating the garments. The analysis of the methods of fixing the heating elements is presented (Table 1).

Table 1: Analysis of the methods of fixing the heating elements

Heat conductor type	Basis material	The method to join the heater to the base material	Method of attachment to the details of garments	Disadvantages
Metal/carbon thread	silicone	vulcanization	glue	costs for glue; the heater is covered with a layer of material, which reduces the heat transfer
Metal/carbon thread	polyamide	lamination	glue	costs for glue; two layers of laminating material
Metal/carbon thread	polyester	lamination	glue	costs for glue; two layers of laminating material
Metal/carbon thread	foil heaters	lamination	glue	costs for glue; two layers of laminating material
Metal/carbon thread/ thermally conductive polymer	textile, non-textile	topstitch, woven with a conductive thread, gluing	production of heating part of garment from a heating element	quickly give heat to the cold environment

The limitations of creating a heat-conducting contour of the required depth in the material structure are revealed. It is necessary for more efficient heat transfer.

Today, the use of 3d printing technologies is increasing to apply thermal conductive polymer to materials. It is possible due to the development of the thermal conductivity of filaments. Technology of 3d printing is used for manufacturing low cost thermally conducting devices[19]. Also, it is known the laser engraving technology [20]. It allows to get depressions in the structure of the material - canals of the necessary configuration and depth. We propose to string together the technologies of 3d printing and laser engraving in order to obtain a method of glueless thermoplastic fixing of heat conductors in the structure of the polymeric materials. This method eliminates the cost of glue, provides a higher contact of the heater with the material (however, it is possible to change the technical characteristics of the modified material).

The method of glueless thermoplastic fixing: the canal of required depth and configuration is cut out in the structure of the material using laser engraving technology. At the same time, the polymer thermo-conductive thread is laid in this canal. The internal surface of the canal is a fixing surface based on the established physical and chemical conditions (Figure 1).

The technical characteristics were experimentally established in order to obtain the canal of required depth. Thermally conductive polymer thread (ITP Textile Materialien, Germany) was selected to conduct experiments [21].

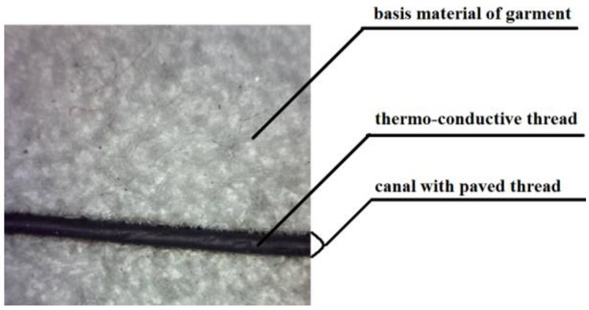

Figure 1: Thermo-conductive thread in a canal

There were selected some polymeric materials such as: neoprene, genuine leather, faux leather, silicone plate for the research. The selection criteria are: thermal conductivity, the possibility of using glueless fixing of the heater, the possibility of using laser engraving technologies, availability in the market.

The thermophysical characteristics of the selected materials were experimentally determined (Table 2).

Table 2: Thermophysical characteristics of selected garment materials

Name of material	Thickness, m	Bulk density, kg/m^3	Thermal conductivity coefficient, W/(m*K)
Neoprene	0,001	314,46	0,1064
	0,002	471,7	0,1018
	0,003	523,83	0,0677
	0,004	550,1	0,0797
	0,005	565,8	0,0801
Genuine leather	0,001	157,23	0,1111

	0,002	235,85	0,0932
	0,003	209,53	0,0789
Faux leather	0,001	314,30	0,1831
	0,002	314,34	0,1512
	0,003	550,31	0,1174
	0,004	628,93	0,1276
	0,005	1572,33	0,1339
Silicone plate	0,001	1152,43	0,0404
	0,002	1194,6	0,0335
	0,003	1257,37	0,0327
	0,004	1336,48	0,0329
	0,005	1428,58	0,0341

The canal in structure of material might change the overall tensile strength. Experimental studies of the maximum strength for selected materials were carried out. Studies were conducted in two forms: with a cutted out canal and without.

Using the laser engraving technology, according to GOST [22-25], the samples of the following kind were made:

- "duble-shoulder blade" with and without a canal ((silicone plate, neoprene, genuine leather) Figure 2);
- rectangular appearance (faux leather);
- round appearance (all materials for abrasion tests) [6-9].

a) with a canal b) without a canal

Figure 2: Scheme of the material sample "duble-shoulder blade" with (a) and without (b) a canal

It was established that the tensile strength for samples with a canal has not decreased for neoprene and a silicone plate (Figure 3).

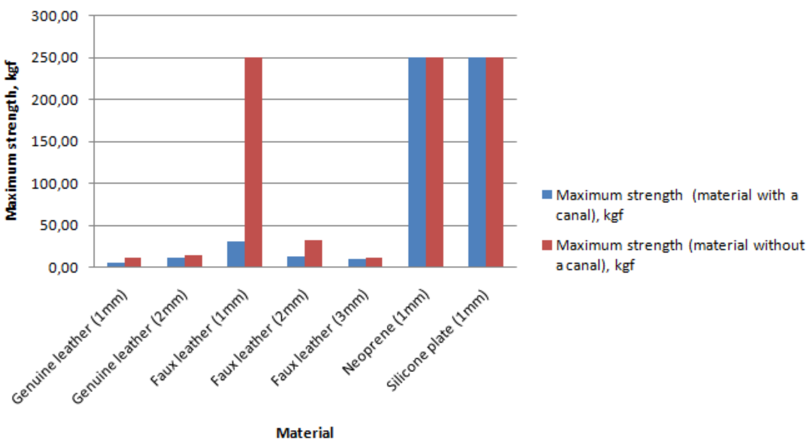

Figure 3: Characteristics of maximum strength of materials

Neoprene was less resistant to abrasion, in contrast to the genuine leather and silicone plate. Silicone plate thickness of 3 mm and genuine leather thickness of 3 mm have shown the highest values of thermal protection and wear resistance.

It was revealed the deviation of sizes of finished samples of materials (thickness 1 mm) from projected dimensions (Table 3).

Table 3: Deviation of sizes of finished samples of materials from projected dimensions

Name of material	Deviation by length, %	Deviation by width, %
Genuine leather	0,5	0
Faux leather	0,5	0
Neoprene	0,9	4,0
Silicone plate	0,5	0

It has amounted to 4% for neoprene; 0.5% for genuine leather; 0.5% for the silicone plate. Neoprene has shown high melting and charring.

Samples of materials thicker than 1 mm have shown a deviation more than 3%. This error has exceeded the permissible norm in accordance with the relevant standards [22-25].

According to [20, 26] the laser radiation power is recommended to be from 500 W to ensure a minimum deviation in the dimensions of samples of materials with a thickness of more than 1 mm.

During the evaluation of the quality of the contour laser treatment, it has been revealed that the canal surface in the structure of the silicone plate has been slightly damaged. It has remained smooth without charring.

The processing of neoprene and genuine leather have resulted in a strong charring. The surface structure of the canal has been severely damaged.

The surface of the canal in the structure of the faux leather had inclusions of textile material. It does not match to the proposed technology of glueless thermoplastic fixing [12-14].

As a result, limitations and disadvantages of the ways of integration of materials with heat conductors are revealed. The method of glueless thermoplastic fixing has been proposed, which was based on laser engraving technology and filament feeding using 3d printing technology. The thermal and physical characteristics of the selected polymer materials were experimentally established.

It was recommended:

- use a silicone plate or genuine leather as the main material to join with the heat conductor;
- take into account the power of the laser-engraving equipment;
- take into account the established deviations in the dimensions of the finished sample of the material from the projected one.

Integration of polymer materials with heaters allows to reduce the weight, volume and cost of heat-protective garments (clothes, shoes, gloves, covers). It also expands the use of such products. They become more mobile and ergonomic, with an extended time resource for continuous use. Despite this, many tasks of supplying heat to specified areas of polymer materials remain unresolved. It requires additional research.

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