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Abstract of the Ph.D. dissertation

‘Active textile systems with elements with two-way shape memory effect for clothing protecting against cold’

Clothing protecting against cold that is characterized by constant thermal insulation does not ensure appropriate protection level for people working in variable ambient temperature or, in the case of changeable physical activity level, in cold environment. Therefore, research work aimed at the application of smart materials (shape memory alloys – SMA) for active regulation of thermal resistance of textile systems intended for clothing protecting against cold has been undertaken in order to reduce thermal discomfort of people working in variable temperature conditions in cold environment.

State-of-the-art analysis has indicated that the attempts aimed at solving this issue that have been performed up to now concerned milder conditions, i.e. cool environment. There are no literature reports available in which SMA active elements were used for thickness regulation of highly resilient thermal insulating layer in order to reduce convective heat losses and increase thermal resistance of active textile system. Literature analysis also showed that the influence of the number and distribution of active elements made of SMA in the textile system in respect to shaping its thermal resistance has not been discussed so far.

In view of the above, the purpose of the Ph.D. dissertation was to verify the validity of the following thesis: ***‘Active textile systems intended for clothing protecting against cold by means of properly prepared and distributed elements with a two-way shape memory effect in the highly resilient down layer are characterized by self-regulating thermal resistance properties under the assumed temperature conditions in cold environment.’***

The research carried out to prove the above thesis included shaping of thermal resistance properties of textile systems with highly resilient down layer, numerical modeling of temperature field distribution in the area of active textile system, shaping of physical properties of SMA active elements, development and validation of program for the preparation of SMA active elements characterized by two-was shape memory effect, as well as development of active textile systems and performing tests of dynamical changes of their properties.

It was found that with the increase of the volumetric mass of the down used in the textile system its thermal conductivity decreases. Based on the results of the research, the amount of down to be used in the active textile system was selected. It has been shown that the selected textile system with down content has a higher level of thermal resistance and a wider range of changes than the empty textile systems with air chamber without down.

As a result of numerical modeling of the temperature field in the area of the active textile system using the finite element method, the temperature values in which the shape change of the SMA active elements for a use in the textile system with down content should occur were estimated: 3 °C - for low-temperature phase and 6 °C - in the case of high-temperature phase respectively.

The analysis of the impact of formation processes (wire diameter, spring diameter, clearance between the coils of the spring), annealing (annealing temperature) and thermomechanical treatment (treatment method) of SMA active elements on their selected thermal and mechanical properties allowed for the development of a preparation program of SMA active elements to be used in the developed textile system. This program enabled the preparation of SMA active elements characterized by durable and repeatable two-way shape memory effect with spontaneous deformation of approximately 60% due to the assumed temperature change.

As a result of the study, 3 variants of active textile systems with down content were developed: AUP6, AUP12 and AUP18 with respectively 6, 12 and 18 SMA active elements distributed on the surface of 30 cm x 35 cm. In order to assess dynamic changes of thermal resistance and maximum thickness of active textile systems, a modification of the testing stand called ‘skin model’ was made. This modification made it possible to perform tests of textile systems characterized by variable thickness in cold environment in temperature (-20) °C with continuous measurement data recording. The research methodology that allowed for a simulation of real utility conditions of active textile systems as applied in clothing protecting against cold intended for a use in the freezer room was developed. This methodology included measurements of changes in thermal resistance and maximum thickness, as well as temperature above and below the active textile system under variable ambient temperature conditions (i.e. at temperature change from +20° C to -20° C) and variable measuring plate temperature imitating the human skin (i.e. with gradual temperature change from 31 °C to 29 °C). Laboratory tests in the climatic chamber with the use of the modified ‘skin model’ stand were carried out on sets of materials that corresponded to the specific layers of all clothing items used during work in cold, starting from underwear to protective clothing, for which active textile systems were designed. Two reference variants were additionally included in the study: AUBP18 - with 18 SMA elements and without down content, as well as BUP - without active elements and with down content. Studies have shown that in the case of active textile systems with more SMA elements (i.e. AUP12 and AUP18), an increase in the thermal resistance associated with a certain change in temperature conditions was of lower level than in the case of the AUP6 variant with 6 SMA active elements. All developed active textile systems are characterized by the ability of self-regulation of their thermal resistance, while the AUP6 active textile system is characterized by the largest range of achievable changes. This variant provides higher increase of thermal resistance of approximately 0.184 $m^2 \times K/W$ under the assumed temperature conditions in cold environment than the textile system with down content and no SMA elements.

The obtained research results confirmed the validity of the thesis adopted in the dissertation as the developed active textile systems with two-way shape memory elements intended for clothing protecting against cold are characterized by self-regulation of thermal resistance under the assumed temperature conditions in cold environment.