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Carbon Containing Material in Non-Woven Fabrics for Thermoinsulation of Winter Apparel

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Abstract Nowadays different types of carbon containing fibers become more and more popular in textile. Pure carbon fibers, fibers with carbon particles, graphene and even carbon containing dyes began to apply in textile for different purposes. Fibers may contain from about 1% of black carbon for antistatic property up to 40% of graphene for special mechanical and moisture management properties. Carbon has pro and contra as thermoinsulating material. It possesses great ability to absorb heat but, at the same time, carbon is good thermoconductive material, and heat escapes quickly due to high thermal conductivity. Heat loss from human body is realized through several channels. For example, thermoconductive heat loss is only 10-15%, whereas irradiative heat loss can reach up to 80% from total heat loss value. Based on this information, we developed non-woven carbon containing compositions which is targeted for maximizing capture of outgoing irradiation heat and minimizing heat loss in thermoconductive channel. In this work, we presented result of development of different carbon containing non-woven compositions for insulation. As a result, some of our non-woven paddings with density 100 g/m² have clothing insulation value (CLO) equal 4, which makes them close to natural down insulation. We also provided wide characterizations of non-woven samples such as stiffness, IR absorption and reflection, washing stability, analysis of economic feasibility of industrial production.

Keywords—Thermoinsulation, Non-Woven, Carbon Fibers, Winter Apparel

I. INTRODUCTION

Sales of winter apparel in countries with cold climate may take up to 35% of total sport apparel, and up to 60% of total casual apparel sales. And income level of buyers does not play a significant role in these numbers because winter apparel is a necessity [1, 2]. Shell fabric is the most expensive component in winter apparel. Thermoinsulation padding normally takes second place in price constituent of winter apparel at mass market. But thermoinsulation can be the most expensive part of special apparel, for example if winter jacket is designed for specific types of winter sport [3].

10-20 years ago, there were no specific requirements to synthetic thermoinsulations paddings. Nowadays there is sharp jump of interest to special textile insulation materials with series of functions and new properties. The most valuable and required properties of non-woven insulation is the decrease of stiffness and thickness, keeping at the same time high value of thermoinsulation. Special materials began to be used to achieve such requirements. The application of polyelefins and acrylic fibers is growing; carbon containing fibers start to be applied more and more widely; fibers with special additives like aerogel are manufactured already [4-5].

Heat loss of a person is realized by five main channels, three of which - radiation, convection and heat conductivity should be taken into considered at the development of non-woven paddings for thermoinsulation. The distribution of heat losses in the three above-mentioned channels depends on many factors, and primarily, the intensity of physical activity plays decisive role in this distribution. Approximately, in a state of rest or insignificant activity, the heat loss is distributed as follows: by irradiation channel - 50-60%; by convection - 20-30%; by thermoconductivity - 10-20%. However, during high physical activity heat loss by radiation can grow up to 80% [6]. The use of carbon-containing materials makes possible effective blocking of irradiation heat loss, because carbon perfectly absorbs waves in a wide range of spectrum. In this work, we presented the results of researches on development of non-woven thermoinsulation with the application of carbon-containing materials, directed for the improvement of heat-insulating capability.

II. METHODS AND MATERIALS

Carbon fibers made based on polyacrylonitrile (PAN) with 10 um in diameter and 50 mm in cut length were supplied by Haining Anjie Composite Material Co. LTD (China). Arselon fabric, carbon fabric and carbon fibers made based on viscose with diameter of 10 um in form of wisp were purchased from OJSC “SvetlogorskKhimvolokno” (Belarus). The rest of carbon containing fibers were supplied from Ziran Non-Vowen Co. Ltd (China). Polyester fibers with 0.8 denier and 38 mm length, bicomponent fibers PE/PP (PE- shell, PP - core) with 2 denier and 51 mm length, and polypropylene fibers with 6 denier and 51 mm length were purchased from
OJSC Mogilevkhimvolokno (Belarus). Textile fabrics were purchased from Gim Joo Textile Fabric Pte Ltd (Singapore).

Measurement of thermoinsulation property/clothing insulation or CLO has been done using Thermetrics Sweating Guarded Hotplate SGHP-8.2 according to ASTM D1518-14. Absorption and reflection measurement have been done using PerkinElmer UV/Vis spectrometer LAMBDa 950. The structure of carbon fibers was studied via Field Emission Scanning Electron Microscopy (FE-SEM, jsm-6340F).

Heat retention test has been done at room temperature by the following way. Sample of non-woven was placed under 30 W lamp with 10 cm distance. Lamp was on during first 20 minutes of observation, and off during second 20 minutes of observation. Temperature of the surface of non-woven was detected by IR camera Optris PI640. The stiffness of non-woven samples was measured by means of digital Pneumatic stiffness tester (GT-C70B/GESTER) according to ASTM D4032-94.

Samples of non-woven fabric were prepared using laboratory Carding Machine (Mesdan). The weight density for each nonwoven padding was maintained at 100±5 g/m². After that, 3 pieces of 30 x 30cm samples were cut from the large rectangular piece collected by the roller drum, then followed by glue spraying. If bicomponent fibers are applied, thermobonding of samples has been realized at 140°C during 10 min in fabric laboratory drier (Mesdan).

III. RESULTS

Carbon containing materials possess different abilities to absorb and reflect heat in different parts of spectrum. We have chosen a few types of carbon-containing fibers for the preparation of samples of non-woven fabrics. Our target was to identify materials which absorb the heat by the most effective way. The ability to absorb and reflect waves in visible and near IR parts of spectrum by different carbon containing fibers is presented on Fig. 1.

Fig. 1. Reflection (top) and absorption (bottom) of visible and near IR spectrum by different carbon-containing materials.

Considering the data presented in Fig. 1, we can see separation of carbon containing material into two groups: absorbing and reflecting heat. Obviously, general carbon fibers have good capability to absorb heat, which is very beneficial for usage in thermoinsulation. Based on our measurements, any traditional material used in textiles cannot compete with carbon fibers in heat absorption (Fig. 2).
However, unlike widely used textile materials, carbon fibers have very high thermal conductivity [7-8]. Therefore, absorbed heat trapped by carbon fibers does not stay long time in the material and runs away, i.e. carbon layer quickly heats up but it cools down quickly as well. Fabric made of pure carbon fiber cedes in thermal insulation compared to traditional textile materials (Table I).

TABLE I

| Type of material | Density, g/m² | CLO  |
|------------------|---------------|------|
| Nylon            | 120           | 0.82 |
| Polyester        | 130           | 0.81 |
| Carbon fabric    | 250           | 0.88 |
| Linen            | 190           | 0.92 |
| Wool             | 180           | 0.88 |
| Viscose          | 115           | 0.83 |
| Silk             | 90            | 0.88 |

Regardless on different densities of fabrics presented in Table I, it is seen that carbon fabric should be at least twice heavier to be comparable in thermostimulation with other traditional textile materials. Evidently, the application of carbon fibers and fabric in pure version is not rational. In our study we used carbon fibers manufactures on the base of polyacrylonitrile. Diameter of carbon fibers was about 10 μm (Fig. 3).
Carbon fibers should be combined with other materials which should be able to decrease the heat loss realized by thermal conductivity channel. To find out the optimum amount of carbon fibers in non-woven, we made first series of non-woven composites by thermobonding. Composition included two components: bicomponent fibers PE/PP with 2 denier 51 mm and carbon fibers. All non-woven samples had the same density – 100 g/m². Results of CLO measurement and stiffness of obtained samples are presented in Table II.

| Amount of carbon fibers, % wt | 0  | 2.5 | 5  | 10 | 15 | 20 | 40 | 60 |
|------------------------------|----|-----|----|----|----|----|----|----|
| CLO                          | 1.89 | 2.38 | 2.48 | 2.59 | 2.55 | 2.29 | 2.08 | 1.94 |
| Stiffness, N                 | 12.2 | 12.0 | 8.5 | 6.9 | 5.2 | 3.8 | 3.2 | 2.9 |

Based on the data presented in Table II, it is logically seen, that there is no reason to add more than 10% of carbon fibers into non-woven structure. If the quantity of carbon fibers is higher than 10%, the fabric loses the capability to keep the heat.

We prepared one non-woven composite with carbon fibers adding third component – glass fibers which possess good capability to reflect heat [9]. The ratio of bicomponent, glass and carbon fibers was 1:2:1. Measured CLO of this composite was equal to 3.0. It gave us an idea to develop composite non-woven material each component of which would capture the heat escaping by certain heat loss channel: irradiation, convection or thermal conductivity. As a result, we prepared non-woven sample using three following materials. Polyester microfibers with 0.8 denier and 38 mm length were used to decrease heat loss by convection. Polypropylene fibers with 6 denier and 51 mm length were taken to reduce heat loss by thermal conductivity, because polyolefines possess highest thermal capacity among all common polymers: thermal capacity of polypropylene exceeds one of polyester by more than 40% (Cp(PET) = 0.4393 kJ/kg*K, Cp(PP)=0.6238 kJ/kg*K) [10]. Carbon fibers were added to catch the heat going out by irradiation.

The ratio of components was defined based on our experience and existing rules of mixing thin and thick fibers in non-woven paddings as 75:25 to obtain high insulation property [11]. Weight ratio among microfibers, polypropylene and carbon fibers in our sample was taken as 70:20:10. CLO value for this composite with weight density 100 g/m² was equal to 4.0, which is very high for synthetic non-woven insulation.

Developed composite revealed another interesting property. It was able to absorb heat with fast increase of temperature. This property is valuable at the market of non-woven insulation. To compare our development with existing industrial analogue, we prepared another non-woven composite replacing carbon fibers (10% wt) into fast heat fibers obtained from Ziran Non-Woven Co. Ltd and leaving 90% of microfibers. This composition did not contain polypropylene fibers. Both non-woven composites were checked for the capability to retain heat at the irradiation by lamp with power of 30 W from the distance of 10 cm. First 20 minutes lamp was on and surface of
non-woven was heated up; second 20 minutes lamp was off, and the surface was cooled down. Temperature of non-woven surface was detected by infrared camera. Results of experiments are presented in Fig. 4.

This test has shown the fact that carbon fibers provided the ability to heat up to higher temperatures compared with commercially available additives. Second valuable conclusion is about importance of addition of polypropylene fibers which played a role of heat retention component, providing lower cooling speed of non-woven composite. This non-woven fabric was prototyped at the industrial level at the factory Ziran Non-Woven Co. Ltd (China). Samples obtained at industrial equipment have less regular than ones obtained at laboratory conditions by means of carding machine. Therefore, measured thermal insulation (CLO) of industrial samples is all time lower compared with one for non-woven samples prepared in laboratory conditions. But our non-woven composition prototyped at industrial level has shown CLO value equal to 3.03, which is extremely good for industrial paddings. Practically, based on our own experience, all industrial non-woven paddings with density 100 g/m² have CLO values below 2.3. Threshold value of stiffness for non-woven paddings with weight 100 g/m² after which material is losing the attractiveness is 3.5-3.8 N. Stiffness of our industrial prototype was 3.2 N. Thus, it fits to request of designers and technologist. Industrial sample was tested on washing stability according to the standard GB/T 8629-2001, receiving grade 4, which is acceptable. Economical evaluation of production of our developed non-woven padding was positive. Considering market price of carbon fibers made based on PAN as 15 USD/kg, the manufacturing of such non-woven padding for apparel is justified. The price of manufacturing, based on the factory evaluation, will be about 0.6-0.62 USD per running meter.

IV. CONCLUSION

In this paper, we presented the result of the development of nonwoven thermal insulation with the addition of carbon fibers. Carbon fibers, added to non-woven composite in the amount of 10% by weight allowed the effective capture of irradiation heat loss from the human body. Since this type of heat loss is dominant, its reduction is strongly beneficial in the development of winter apparel. At the development of non-woven thermal insulation, polypropylene fibers were added to level heat loss specified by high thermal conductivity of carbon fibers. Non-woven sample containing 10% by weight of carbon fibers showed CLO value of 3.03. The sample passed well washing stability test. The stiffness of obtained non-woven sample was 3.2 N, which allows for usage in winter clothing without restrictions. Economic evaluation showed the efficiency of production of this non-woven thermal insulation.

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