MANUFACTURING AND PROPERTIES OF NONWOVENS BASED ON WASTE FROM ELASTIC FIBERS

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The article proposes and implements the use of highly flexible combined filament yarns (Nylon 6.6/Lycra) as the main raw material for the production of needle-punched nonwoven materials for technical purposes. It has been found that the addition of PET fibers to the feedstock makes it possible to regulate the mechanical properties of the resulting nonwoven materials over a wide range. It is shown that an increase in the content of PET fibers from 20 to 50 wt. % increases the relative strength of non-woven fabric samples by a factor of $1.5 \div 3$. In this case, the anisotropy of this index along and across the direction of carding decreases substantially, which indicates an increase in the homogeneity of the material. The addition of other fibrous components to the initial mixture makes it possible to adjust the amount of water absorption of the nonwovens. The greatest positive effect on the value of this indicator is the addition of hemp fibers (increases ~ 1.7 times), and the largest negative – PET fibers (reduces ~ 2 times). The introduction of a 50 wt. % flax fibers into the starting mixture by 20% reduces the overall heterogeneity of the distribution of fibers in the nonwoven material. The obtained results can be used to produce elastic nonwoven materials intended for insulating surfaces of complex shape under dynamic loading conditions.

Keywords: chemical fibers, nonwoven materials, fibrous waste.

INTRODUCTION

Daily in the world 3.5 million tons of garbage is thrown out. This number continues to grow and along with it the quantity of the discarded textiles continues to expand. For the biodegradation of natural fibers in a landfill it may take hundreds of years. At the same time, methane and CO₂ are released into the atmosphere during decomposition. The decomposition of synthetic fibers in the landfill lasts an order of magnitude longer, and poisonous substances can be released into the soil and groundwater (Wang, 2010). A rational option for the recycling of secondary raw materials is suggested by using of crushed fabrics as fillers of polymer composite materials, which are widely used in various industries (Briga-Sá *et al.*, 2013).

Ensuring the most efficient processing of textile waste products consumption and the further production of useful products and materials for society is a priority task of scientific and technical progress in the sphere of application of recyclable materials. This will help not only to avoid the negative impact of waste on the environment and consequently on human health, but also provide significant savings in natural resources, as well as funds for their development (Sparks, 2012).

The recovered fiber is a valuable raw material for the chemical and light industry (production of high-quality yarn (Chen *et al.*, 2016), fillers of polymer composite materials (Chen *et al.*, 2012), heat-insulating materials and others) (Bartl, 2011). In addition to fibrous waste, the composites include a binding reagent (polyethylene, polypropylene, polyamide, etc.). In this way, the strength and density of the fibrous materials and other properties can be controlled. Most types of textile waste, and in

particular those made from chemical fibers, do not concede to primary raw materials in terms of their characteristics, but sometimes even exceed them.

The aim of the work was to develop a method for fibrous waste processing to produce nonwoven materials intended for insulating surfaces of complex shapes under dynamic loading conditions.

MATERIAL AND METHODS

Fibrous waste polyurethane/polyamide-6.6 (PU/PA-6.6) was preliminarily chopped on a staple machine with rotary knives. The cutting length was 30 mm. Then, the staple fibers were mixed with additional fibrous components in certain ratios. For the formation of a fibrous tissue, the carding machine (ChBV brand) was used. Working gaps between the parts of the carding machine were 0.3-0.4 mm. After preliminary carding, the canvas was removed from the take-up drum (diameter 200 mm). Depending on the composition and quality of the material obtained, the carding operation was repeated 2-3 times. The direction of the following carding operations coincided with the direction of the preliminary carding. Staple fibers of polyethyleneterephthalate (PET), polyacrylonitrile (PAN), linen (L), hemp (H) were introduced as an additional fibrous component in an amount of up to 50 wt, %.

Nonwoven materials were evaluated by such indicators as: surface density (ρ , g/m²), water absorption (W_6 , %), breaking load (P , H/5cm). The method of optical polarization microscopy was used to study the structure of fibers. To determine the heterogeneity of nonwovens, an image analysis method was used, followed by statistical processing of the obtained data.

Different ways for calculation of indicators for nonwoven materials heterogeneity were used (Ajmeri *et al.*, 2016; Ghassemieh *et al.*, 2002):

- standard error of the concentration of structural elements in the samples:

$$S = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1}^n (P_i - P_{cp})^2} \quad (1)$$

- the relative mean error of the structural elements concentration in the samples (confidence level 0.95, Student's value 2.06), %:

$$\Delta P = \frac{t_{\gamma, f} \cdot S}{\sqrt{n} \cdot P_{cp}} \cdot 100\% \quad (2)$$

- coefficient heterogeneity, (K_n , %), which is the standard error, given the average concentration of structural elements in the sample:

$$K_H = \left(\frac{S}{P_{cp}} \right) \cdot 100\% \quad (3)$$

The fibrous PU/PA wastes before and after stapling operation is shown on the fig 1.

Figure 1. The fibrous PU/PA wastes before (a) and after (b) stapling operation

The slight cutting length (30 mm), which was used for stapling, is explained by the specific ability of PU fibers in the raw material to have large reversible deformations (~500%). Previous studies have shown that with a longer cutting length, a stable carding process is impossible because of the winding of separate, highly stretched filaments of PU fibers to the main shaft of the carding machine (Kucherenko, 2016).

The obtained tissue was stitched by a needle-punched operation on the OP-1 machine. For the finished nonwoven materials, the surface density, breaking load and water absorption were determined according to the procedure (Russell, 2006).

RESULTS AND DISCUSSION

Fig. 2a presents a microphotograph in polarized light of a combined PU/PA fiber structure.

Figure 2. Microphotographs in polarized light: a) the structure of the original combined PU/PA fiber; b) PU/PA fibers after treatment with a selective solvent

It can be seen from the figure that the fiber consists of several central polyurethane filaments twisted with polyamide fibers having a loop structure. It is found that in fiber processing with PU selective solvent, there is the possibility of complete removal of the PU component (Fig. 2b). Further, a PU solution in an organic solvent can be used to produce paint and varnish compositions. The results of the study of the nonwoven materials properties in various compositions are presented in Table 1.

Table 1. Properties of non-woven samples

Fibrous composition of the material, wt. %	S, cm ²	ρ , g/m ²	W _f , %	W _f (relative)
PU/PA	25	128	415.6	1.00
(PU/PA)/L, 50/50	25	192	452.1	1.09
(PU/PA)/H, 50/50	25	128	684.4	1.65
(PU/PA)/PET, 50/50	25	320	203.8	0.49
(PU/PA)/PAN, 50/50	25	140	391.4	0.94

The obtained data indicates that the addition to the initial PU/PA mixture of other fibrous components changes the water absorption of the nonwoven fabric thus allowing to regulate this index in a sufficiently wide range. In this case the greatest positive effect on the value of water absorption is caused by the addition of hemp fibers, and the most

negative - PET fibers. In the first case, the water absorption increases by 1,7 times, while in the second case it decreases 2 times. The results obtained can be explained by the significant influence of other fibrous components on the structure and sorption capacity of nonwoven materials.

It was of some interest to evaluate the effect of additional fibrous components on the uniformity of fiber distribution in nonwoven materials. For comparison were used sample No. 1 (PU/PA) and sample No. 2 (PU/PA)/L, 50/50 wt. % (fig.3).

Figure 3. Image of the surface of samples of nonwoven materials: No. 1 (PU/PA) (a) and No. 2 (PU/PA)/L, 50/50 wt. %. (b)

The uniformity of the distribution in the sample as a whole and along and across the needle-punching direction determined by method of analysis of surface images. The results of the determination are given in Table 2 and in Fig. 4.

Table 2. Indicators of heterogeneity of non-woven samples

Sample material	Mixture composition	$S, \cdot 10^2$	$\Delta P, \%$	$K_H, \%$
1	PU/PA	3.23	5.07	12.29
1H	PU/PA(horizontal direction)	3.03	4.76	11.56
1V	PU/PA(vertical direction)	1.74	2.72	6.60
2	(PU/PA)/L	2.13	3.72	9.03
2H	(PU/PA)/L(horizontal direction)	2.10	3.68	8.94
2V	(PU/PA)/L(vertical direction)	0.99	1.73	4.21

From the results presented, it can be seen that the addition of flax fibers to the original mixture reduces the coefficient of heterogeneity in the material as a whole 12.3 to 9%. This indicates an improvement in the overall homogeneity of fiber distribution in nonwoven materials.

As for the first and second samples, the heterogeneity coefficients in both directions are significantly different (approximately 2-fold). In this case, the heterogeneity of the material in the transverse direction is much less than in the direction of material movement in the case of needle-punched.

Figure 4. Comparison of the values of the uniformity for the distribution of fibers, in samples of non-woven materials: 1 - (PU / PA); 2 - (PII / PA) / I. 50/50 wt % along (horizontally) and transverse

The dependence of the tensile load of non-woven materials from the content of PET in the feedstock is shown on the Fig. 5.

Figure 5. Dependence of the breaking load of nonwoven materials along and across the direction of carding from the PET content

It can be seen that with the addition of 20% PET, the strength along the direction of carding is almost unchanged, while in the transverse direction it increases ~ 3-fold. As a result, the anisotropy index decreases substantially, which indicates an increase in the homogeneity of the nonwoven material.

With an increase in the PET content to 30%, there is a significant increase in strength both along and across the direction of carding (2.5 times). As a consequence, the anisotropy for this indicator is almost unchanged in comparison with the previous sample. The increase in PET in the non-woven fabric to 40-50% leads to a further

increase in its strength. But this growth is not as significant as in the previous sample. At the same time, the breaking load in the transverse direction continues to increase by 1.5-2 times compared to sample (PU/PA-6.6)/PET, 70/30).

For samples containing 40-50% PET, the strength growth rate in the direction perpendicular to carding (~ 1.9-2 times) begins to exceed the strength in the longitudinal direction (~ 1.2-1.3 times). This leads to a decrease in the anisotropy of this index, which reaches its minimum value for sample (PU/PA-6.6)/PET, 50/50).

CONCLUSION

It has been found that the addition of PET fibers to the feedstock makes it possible to regulate the physic-mechanical properties of the resulting nonwoven materials over a wide range. It is shown that an increase in the content of PET fibers from 20 to 50% increases the relative strength of nonwoven fabric samples by 1,5-3 times. In this case, the anisotropy of this index along and across the direction of carding decreases substantially, which indicates an increase in the homogeneity of the material. The addition of other fibrous components to the initial mixture makes it possible to adjust the amount of water absorption of the nonwoven fabric. The greatest positive effect on the value of this indicator is the addition of hemp fibers (increases ~ 1.7 times), and the largest negative - PET fibers (reduces ~ 2 times). The introduction of a 50% linen into the starting mixture reduces the overall heterogeneity of the fibers distribution by 20% in the nonwoven material. The obtained results can be used in the development of technology for elastic nonwoven materials intended for insulating surfaces of complex shape under dynamic loading conditions.

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