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Investigation of Dynamic Properties of PA6 and PA6.6 Carpet Pile Yarns

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Tensile and cycle loading processes of PA6 and PA6.6 pile yarns, designed for carpets, were investigated. Tensile and cycle loading tests were conducted on Statimat M tension device. Elongation at break, tenacity, work of rupture was assessed during tensile tests. Dynamic modulus and dynamic strain (after 10 cycles loading), were assessed during cycle load tests. Cycle loading was performed between two force levels. Results of tensile tests showed that PA6 yarns are stronger than PA6.6 yarns, and can be distinguished because of better dynamic parameters. Therefore it is better to use PA6 yarns for carpets designed for places of intensive load.

Keywords: polyamide, carpet, dynamic modulus, dynamic strain.

1. INTRODUCTION

Five types of fibers are used for carpets pile: polyamide, polypropylene, polyester, acrylic and wool. Today polyamide occupies almost half of carpet market. There are several industrial types of polyamide, such as 6, 11, 12, 6.6, 6.10, 6.12. Polyamide 6 and polyamide 6.6 are most widely used in textile industry. PA6.6 has greater strain resistance than PA6 but PA6 has better resistance to light, better dyeability, elastic recovery, wear resistance and thermal stability. Polyamide is used for floor coverings because of good resilience properties, friction and color resistance.

Resiliency of pile and carpet, pilling and friction resistance of pile, tuft bind are assigned to mechanical properties of carpets. Resiliency can be defined as ability of carpets and pile to return to their original state after loading. Resilience properties of carpets vary in static and dynamic loading.

There are a lot of factors which have influence on resilience properties of carpet pile - fiber type, properties of pile yarns (type of yarns and manufacture), finishing of yarns, twist, moisture, etc. Also structural characteristics of carpet have influence on resilience properties of carpet pile (height of pile, density, and type of pile (cut or loop)), resilience of carpet backing, etc. [1].

When fibers and yarns are deformed, part of their energy is stored as potential energy and part of it is dissipated due to internal friction in yarns. The higher is internal friction, the greater are heat losses and the lower is resiliency. Big energy losses of yarns result in their lower resiliency and lower resistance of pile. This condition has to be hold to obtain better resilience properties of pile – energy stored in pile yarn has to be bigger than energy dissipated in tension.

Lee [2] used micro-mechanical approach based on mathematical models to analyse the compressional energy in fibers. Physical dimensions and energy required to bend each fiber segment is calculated from compressional strain. Komori [3] used the energy method.

Also there is method [4] in which the strain and the resultant stress of polymeric material is not in the same phase due to the viscoelasticity nature of polymer, when polymeric material is under cyclic loading. Modulus of polymer is expressed by real part and imaginary part of modulus, which can be calculated by dynamic mechanical analysis instrument. Dynamical characteristics of polymer system are expressed by loss factor.

The goal of this article is the investigation and comparison of dynamic properties of PA6 and PA6.6 yarns, widely used in carpet manufacture.

2. MATERIALS AND METHODS OF INVESTIGATION

For the investigation of pile yarns resiliency properties tensile tests are performed, which give the data of the mechanical properties of pile yarns – strength, resiliency, stiffness. The purpose of tensile tests is to investigate yarn properties and to estimate their suitability for pile, to estimate how strength has influence on resiliency properties during cycle loading.

There is method for carpets pile yarns properties measurements during cycle loading ("Measurement of resilience properties of carpet yarns") developed by Department of Textiles (University of Gent) [5 – 7]. It is known, that stresses in fiber during cycle loading change in time, when strain is constant. When fiber is loaded, stress decreases with time. This can be an expression of visco–elastic behavior of the specimen. Repeated stressing limited by two certain force values simulates dynamic loading of carpets, e.g. walking. Recovery of a fiber depends on the amount of stress applied and resulted strain. Greater number of cycles leads the dissipation of energy, which leads to a temperature rise within the fiber and consequently more inter-molecular bonds get broken, finally leading to the reduction of fibers elastic modulus.

After cycle loading (in traction) of yarns and before relaxation we can obtain their dynamical-mechanical properties (Fig. 1).

Important characteristic is modulus, which express the relationship between the force applied and the resultant elongation.

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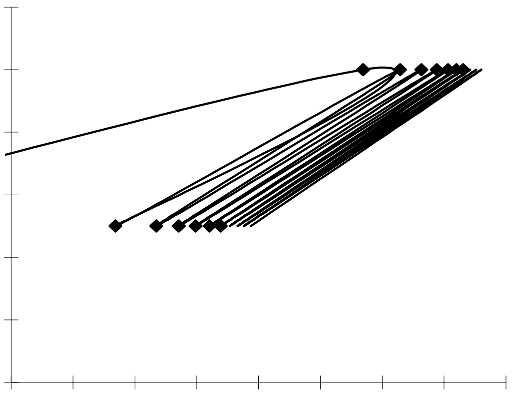

Fig. 1. An example of dynamic load between two force levels of PA6 yarn

Modulus is resistance to tension and dynamic loading, which describes mechanical properties of the test specimen. The dynamic modulus (ratio between maximum tenacity and strain) gives an indication of the stiffness and fiber resilience.

Dynamic modulus (cN/tex) during dynamic load between two force levels can be expressed:

$$E_d = \frac{F_u - F_l}{(\varepsilon_u - \varepsilon_l)T_t}\ , \qquad (1)$$

where: F_u, F_l are the force (cN) of upper and lower levels of cyclic loading, ε_u, ε_l are the elongation of upper and lower force level of cyclic loading, T_t are the yarn linear density.

The dynamic strain is the percentage elongation due to each cycle of stress:

$$\varepsilon_d = \frac{\varepsilon_u + \varepsilon_l}{2}\ , \qquad (2)$$

where: ε_u, ε_l are the corresponding elongations of upper and lower force levels.

Also modulus E, mechanical loss factor (qualificatory resilience properties of yarns) can be estimated using dynamical thermal analysis (DMTA) Eplexor 25N DMAe [8], dynamical mechanical analysis (DMA) Du Pont dynamical mechanical analyser [9], also Perkin-Elmer DMA-7 [10], Rheovibron [11] equipment. Using Statimat M it can be obtained resilience properties of yarns using bending method and compression in mass [5 – 7].

This work test method for measurement properties of yarns was chosen according to the University of Gent project because it is fast and reliable test method for measuring resilience properties of pile yarns. Test method is accessible to spinners, carpet manufacturers and etc. Information can be obtained on the influence of fiber and yarns characteristics on the mechanical properties of yarns and resilience and compressive behaviour of different types of carpets. Test method is fully automated.

Tensile and cycle loading tests were performed using Statimat M device. The mode of operation of the Statimat is based on the constant rate of elongation (CRE) [5] The testing speed changes from 500 to 5000 mm/min. Higher testing speed simulates real loading conditions, because application of load, e.g. walking on a carpet, is of enough high rate. 5000 mm/min speed was chosen for tensile tests. 1000 mm/min rate was chosen in this work for cycle loading, because such rate is enough to simulate dynamic loading of carpet.

In this work cycle loading was performed between two force levels. The repeated stressing between two force levels simulates dynamic loading on a carpet. Force of yarns was measured at upper and lower clamps levels. In [5 – 7] dynamic loading tests have been carried out between different levels of dynamic loading (1 – 3.5, 1.5 – 4 and etc.). Loading levels of 2.5 cN/tex (lower loading level) and 5 cN/tex (upper loading level) were chosen according this project as the yarns are quite well loaded but not overloaded with these loading levels. Also results of the tests showed that dynamic modulus increase with increasing values of dynamic loading levels.

During tensile tests elongation at break, tenacity and work of rupture were established, their testing parameters are presented in Table 1.

Table 1. Tensile testing parameters

Testing parameters	Number value
Number of tests	100
Preload, cN/tex	0.5
Gauge length, mm	500
Test speed, mm/min	5000

During the tests of cycle loading parameters were established – dynamic modulus (after 1 cycle and after 10 cycles load), dynamic strain (after 1 cycle load and after 10 cycles load), and residual force. Parameters of cycle loading are presented in Table 2. PA6.6 95 tex × 2 and PA6 100 tex × 3 multifilament twistless yarns were used for investigation. Tests were carried out in a standardized test environment (ISO139: 1973).

Table 2. Parameters of cycle loading

Testing parameters	Number value
Number of tests	25
Upper loading level, cN/tex	5
Lower loading level, cN/tex	2.5
Number of cycles	10
Testing speed, mm/min	1000

3. RESULTS AND DISCUSSION

Results carried out according to methodology of tensile and cycle loading testing are presented in Table 3. Coefficients of variation of all properties values were not higher than 10 %, except work of rupture coefficient of variation, which reached 18 %. As it can be seen from Table 3, tenacity, work of rupture and dynamic modulus (after 1 cycle and after 10 cycles) of PA6 yarns are higher than those of PA6.6 yarns.

Since dynamic modulus describes resistance of pile to dynamic loading, and their higher values for PA6 yarns allow to expect better results of carpet of these yarns, during compressional loading. During compressional

Table 3. Results of tensile and cycle loading tests

Characteristics	PA6.6 pile yarns	PA6 pile yarns
Elongation at break, %	69.4	47.6
Tenacity, cN/tex	18.,2	26.7
Work of rupture, Nm	9.0	11.8
Dynamic modulus, cN/tex After 1 cycle load After 10 cycles load	 79.5 86.6	 130.4 143.9
Dynamic strain, % After 1 cycle load After 10 cycles load	 14.7 16.1	 8.8 9.9

loading at real conditions, yarns are affected by rubbing, torsion, tensile, and etc. loading.

The higher is dynamic strain, the less carpets will deform during compressional loading, and the bigger probability is that deformed fiber will return to the original state with lower residual elongation. Dynamic strain of PA6.6 yarns is found to be higher than that of PA6 yarns during tensile and cycle loading tests but tenacity of PA6.6 yarns is lower than PA6 yarns. So we can state that PA6.6 yarns are weaker and are not so resistant to loading. Consequently PA6 yarns as stronger yarns that can be used for carpets designed for places of intensive walking.

Figure 2 and Figure 3 show that increasing number of load cycles dynamic modulus of PA6 yarns, which describes stiffness of yarns, tends to grow. Stiffness of yarns is growing by increasing number of cycles i.e. with greater number of cycle's dynamic modulus increases too. The resultant effect is the stiffening of the fiber in question caused by relaxation of stresses introduced in the process, and the reformation of new bonds. It has to be noted that increasing force (loading) levels produces similar effect. Dynamic strain is growing, i.e. yarns stand to lengthen with the increase cycle numbers.

As it can be seen from Figure 4, the variation intensity of dynamic modulus of PA6.6 yarns is higher than for PA6 yarns at initial cycles. While afterwards it changes fractionally. Whereas dynamic modulus of PA6 yarns changes more intensively during last cycles.

We can state as well that PA6 dynamic modulus increases more intensively than that for PA6.6 yarns with increase number of cycles. Moreover PA6 yarns are stiffer and they can be used for carpets designed for intensive places of loading.

Examining the variation of PA6 yarns dynamic modulus, we can see that process is uneven. Changes are still ongoing and dynamic modulus grows unsteady. While PA6.6 yarns dynamic modulus variation process is steady, coefficient of determination is very high $R^2 = 0.9923$.

Figure 5 shows higher intensity of change of PA6 yarns dynamic strain than PA6.6 yarns. This can be explained by the change of dynamic modulus – stiffness of yarns changes, so elongation of yarns changes too. Also we can notice that change ranges of dynamic modulus differ. Dynamic modulus of PA6 yarns is considerably higher and it varies in more wide range than that for PA6.6 yarns.

Dynamic strain of PA6 and PA6.6 yarns changes according to the straight line, both coefficients of determination are very high. Therefore this process is steady for both yarns even after 10 cycles loading, but for PA6 yarns this change is more intensive than PA6.6.

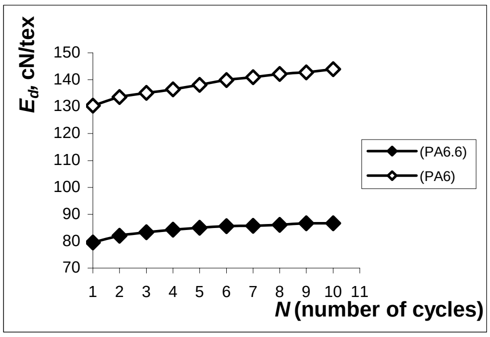

Fig. 2. The dependence of dynamic modulus on number of loading cycles

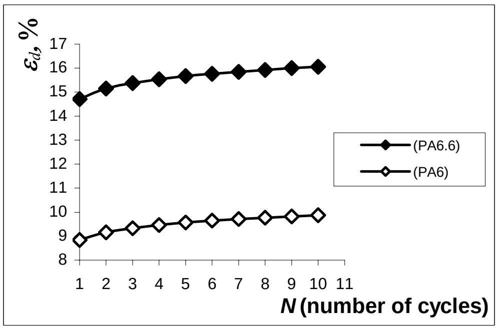

Fig. 3. The dependence of dynamic strain on number of loading cycles

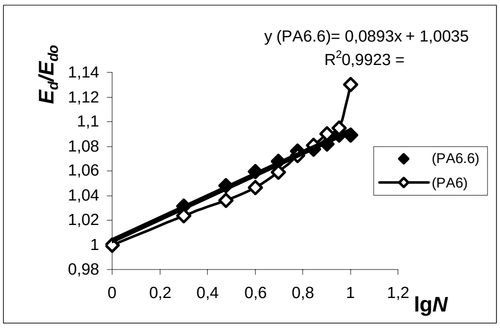

Fig. 4. The dependence of modulus values ratio on number of loading cycles

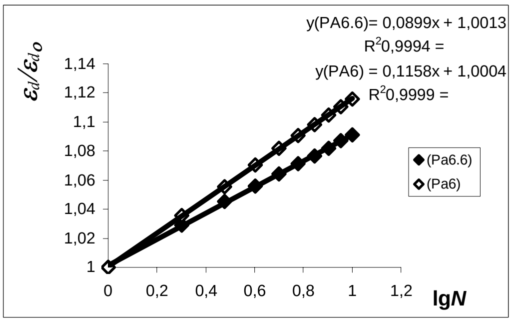

Fig. 5. The dependence of strain values ratio on number of loading cycles

4. CONCLUSIONS

The higher dynamic strain, the less carpet has to be deformed during compressional loading in real conditions, the bigger probability that fiber after deformation will return to the original state with lower residual elongation. Dynamic strain and quasistatic elongation of PA6.6 is higher than PA6. PA6.6 yarns are weaker and their tensile resistance is comparatively low. Besides dynamic modulus of PA6 yarns grows more intensively (after 10 cycles it does not reach levelling off) than PA6.6 yarns and its value is higher. PA6 yarns as stronger and stiffer can be used for carpets designed for intensive places of loading.

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