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Study of the mechanical behavior of high performance polypropylene yarn for geotextile application

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Abstract –The textiles used in geotechnical application require long-term durability and high strength under tough conditions. The selected high tenacity polypropylene yarn was studied for its characteristics regarding geotextile application. The tensile strength found in the range of high tenacity and the stress relaxation increased with increase in load applied, these properties were studied under the Lloyd universal strength tester. Polypropylene has found more stable in primary creep and secondary creep behavior, was studied to see the deformation under constant load. The torsional rigidity was tested on torsional pendulum and found increased with increase in tension applied, which is an indication of maintaining constant tension during twisting process.

Keywords –Polypropylene yarn, tensile strength, creep properties, stress relaxation, torsional rigidity, primary creep, secondary creep

INTRODUCTION

Polypropylene and polyester fibers are still the most commonly used raw material for production of geofabrics in international market [1]. The deformation behavior under load with time called as creep behavior of these yarns adds to its usability for geotextiles. It has been stated that for a fabric to be dimensionally stable, it has not only to be stiff, low stretch and shrinkage, but it should have good recovery properties [2]. Polypropylene fibers are of advantage for their inertness, low gravity, low cost and ease of processability [3]. It has excellent mechanical properties, chemical and fungal resistance [4-6]. Polypropylene has found its applications related to filtration, separation, reinforcement and drainage [7, 8]. PP being chemically inert doesn't lose its strength when buried under the soil for geotechnical applications. The mechanical durability of the fabrics is of prime concern in a reinforcing geotextiles and tensile creep data provides a good index of its durability [9, 10].

When a plastic material is subjected to a constant load, it deforms continuously. The initial strain is roughly predicted by its stress-strain modulus. The material will continue to deform slowly with time indefinitely or until rupture or yielding causes failure. The primary region is the early stage of loading when the creep rate decreases rapidly with time. Then it reaches a steady state which is called the secondary creep stage followed by a rapid increase (tertiary stage) and fracture. This phenomenon of deformation under load with time is called creep [11]. Stress relaxation is a gradual decrease in stress with time under a constant deformation or strain. This behavior of polymer is studied by applying a constant deformation to the specimen and measuring the stress required to maintain that strain as a function of time. The torsional rigidity is a measure of the initial resistance of fibres to twist. This affects the behavior of fibre during twisting process. In this paper, the high tenacity polypropylene yarn characteristics have been studied for geotextile application such as tensile strength, creep behavior, stress relaxation and torsional rigidity.

MATERIAL & METHOD

Materials

Polypropylene multifilament 867.89 Denier yarn with 155 filaments having tenacity of 6.49 g/den was used in the present study.

Methods

Polypropylene multifilament conditioned for 24 hours at standard atmosphere for tropical regions, 65% ± 2% relative humidity and 27°C ± 2°C temperature before testing [12]. Denier was measured by BISFA method [13]. Tenacity and breaking extension were tested on Lloyd tensile tester as per ASTM Standards D 2256-02 [14]. Five samples of 5 cm gauge length with five different loads were used to study the creep behavior of polypropylene filament. The extension at various time intervals was measured.

For Stress Relaxation specimen of gauge length 200 mm was mounted on a board on LIoyd tensile tester and applied load equivalent to 10%, 20% and 30% of breaking load. Time taken for load relaxation at all the three stages was measured. Torsional rigidity was measured on torsion pendulum instrument as shown in figure 1 [15]. Fiber was hanged on the stand with dead weight and a small deflection of θ<40 was given to the end of pendulum and the average time period for oscillation was measured. The moment of inertia is calculated as per equation 1. Four pendulums of different lengths were used. The length, weight and moment of inertia for the four torsion pendulums are tabulated in Table 1. On the basis of the time period measured, the torsional rigidity and modulus of rigidity were calculated as per equation 2 and 3.

Table 1 Parameters for the torsional pendulums

Pendulum No.	**Weight (gm)**	**Length (cm)**	**Radius (mm)**	**Moment of Inertia (I)**
I1	0.4193	1.05	2.13	0.51338
I2	0.8196	2.1	2.13	1.2294
I3	1.22351	3.05	2.14	2.349
I4	1.58379	3.95	2.15	3.8895

$$Moment\ of\ Inertia\ (I) = m\left[\left(\frac{R^2}{4}\right) + \left(\frac{l^2}{12}\right)\right] \quad \ldots\ldots Equation\ 1$$

$$Torsional\ Rigidity\ (\tau) = \frac{8\pi^3 IL}{T^2} \quad \ldots\ldots Equation\ 2$$

$$Modulus\ of\ Rigidity\ (G) = \frac{\tau}{S^3\varepsilon} \quad \ldots\ldots Equation\ 3$$

Where, m= Mass of rod, l= length of rod, R= Radius of rod, L= Free length of fiber, T=Period of oscillation in sec, S= Area of cross section of fiber, ε =Shape factor.

Figure 1 Torsional pendulum

RESULTS AND DISCUSSION

Tensile Behavior

The physical and mechanical properties of the polypropylene filament yarn are summarized in Table 2. The tensile behavior of the yarn is shown in figure 2. The result is showing that the polypropylene yarn is of high tenacity. The curve's initial part is a straight line and hence it can be inferred that crystalline structure of pp is contributing towards the tensile property of fiber.

Table 2 Physical and Mechanical parameters of the polypropylene filament tested.

Physical Parameters		**Mechanical parameters**		
Denier	**No. of filaments**	**Tenacity (gpd)**	**Elongation at break (%)**	**Initial modulus (gpd)**
867.89	155	6.49	21.95	33.33

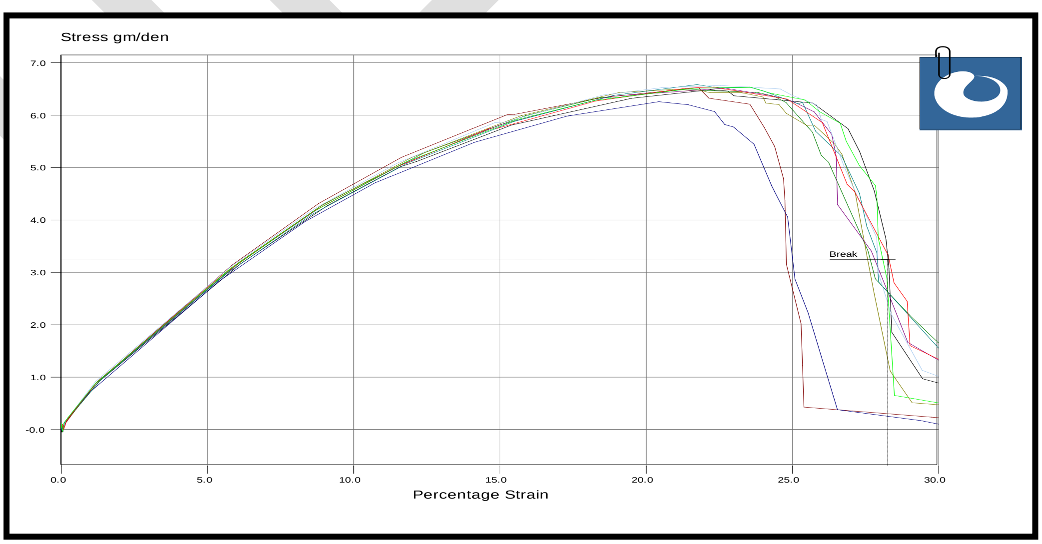

Figure 2 Mechanical behavior of high tenacity polypropylene filament

Normally the stress or tenacity is used to compare the strengths of different polymers. However, from reinforcing point of view, initial modulus which indicates the initial resistance to extension of a polymer is of greater significance. When a polymer has resistance to stretching, it will have high Modulus indicating fiber's inextensibility and stiffness (3). Higher tenacity and higher Elongation are the pre-requisites for a good quality geotextiles, where this fibre is showing the similar properties as per the requirements.

Creep Behavior

The creep behavior of polypropylene yarn is shown in Table 3. For 2, 3, 4 gm load, it has shown no change in primary creep and then it increases. The secondary creep i.e. permanent deformation initially increases and then has shown constant creep at higher load. The instantaneous recovery should be equal to instantaneous extension which was not found, this may be due to the samples were kept under tension for a long time between 30 to 60 minutes.

Table 3 Creep behavior of Polypropylene yarn

Sample No	**Gauge Length (cm)**	**Load (gm)**	**Instantaneous Extension (cm)**	**Total Creep (cm)**	**Instantaneous Contraction (cm)**	**Primary creep (cm)**	**Secondary creep (cm)**
1	5	1	0.17	0.43	0.33	0.02	0.26
2	5	2	0.25	0.4	0.28	0.05	0.3
3	5	3	0.35	0.25	0.1	0.05	0.43
4	5	4	0.35	0.35	0.1	0.05	0.5
5	5	5	0.35	0.4	0.05	0.1	0.5

Stress Relaxation

Stress relaxation behavior of the polypropylene yarn is shown in table 4. The study of stress relaxation behavior of polypropylene yarn is showing 40% relaxation in load at 10% of maximum breaking load. But at 20% and 30% of maximum breaking load it shows only 2.7% and 8.6% additional stress relaxation as compare to 10% specimen.

Table 4 Stress Relaxation behavior of polypropylene yarn

Sr. no	**Load applied (gm)**	**Extension (mm)**	**Time (min)**	**Load relaxation (%)**
1	560.00	2.5	40	40
2	1110	6.6	60	41.09
3	1699.7	8.33	50	43.45

Torsional Behavior

The torsional rigidity of polypropylene fibre found increased with increase in tension upto 1.22 gms and then decreases with further increased tension i.e. 1.58 gms as shown in table 5. Overall the tension applied is high as compare to Meredith [16], therefore it may be affecting the configuration of the fibre and possibly producing a comparatively large change in measured torsional rigidity. From this change in torsional rigidity it can be said that the spinning tension during staple yarn spinning of polypropylene should be maintained constant to have the advantage of consistent torsional rigidity. This will help in maintaining yarn twist per unit length constant. Similarly, this factor will also affect the twisting process of filament yarn.

Table 5 Torsional property of polypropylene yarn.

Sr. No.	**Inertia bar**	**Length of Fibre (cm)**	**Period (sec)**	**Torsional rigidity dyn.cm^2 (τ)**	**modulus of rigidity in dyn/cm^2 (G)**
1	I1	4	40	0.03	$4.40*10^3$
2	I1	6	40	0.48	$7.04*10^4$
3	I2	4	120	1.94	$2.84*10^5$
4	I2	6	120	1.53	$2.22*10^5$
5	I3	4	120	2.3	$3.37*10^5$
6	I3	6	180	2.4	$3.5*10^5$
7	I4	4	240	1.5	$2.2*10^5$
8	I4	6	260	2	$2.93*10^5$
				τ=1.52	**G=2.23*10^5**

The effect of change in length of fibre on torsional rigidity is not showing any change in trend. The Torsional rigidity and modulus of rigidity is found low as compare to the Morton and Permanyer findings. Lower rigidity requires lower twist multiplier (TM) to be put for same count of yarn. Overall the torsional rigidity of polypropylene is less as compare to other fibres [16]; this may be because of presence of the small methane group present in the propylene monomer as compare to other textile polymers.

CONCLUSION

The yarn selected was of heavy denier high modulus and tenacity. The primary creep is found almost constant, similar trend is observed at high load incase of secondary creep. This high tenacity and creep makes the yarn suitable for geotextile application. Stress relaxation is found increasing with increase in load applied. The torsional rigidity has increased with increase in tension which is an indication of maintaining constant tension during twisting process.

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