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Olive hue visible–near infrared camouflage properties of high speed melt spun poly(ethylene terephthalate) multifilament yarn

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ABSTRACT

High speed melt spinning process was used to produce near infrared (NIR) camouflage poly(ethylene terephthalate) (PET) partially oriented yarns (POY) against natural olive hue by using C.I. Pigment Green 7 (0.1% weight fraction), C.I. Pigment Yellow 184 (0.05% weight fraction) and carbon black (CB) (0.01% weight fraction). The effect of drawing, texturizing and knitting processes on the reflectance properties of produced sample was evaluated, and it was concluded that knitted fabric by texturized yarns provides optimum simulation with natural olive hue. Also the effect of pigments and the process on the yarns' structure by using the thermal and mechanical tests of yarns was investigated. It was observed that the thermal and mechanical properties of all samples are in an acceptable range.

1. Introduction

Near infrared (NIR) detection devices are among the most important tools that are used by armies throughout the world, and without using these detection devices, night military operations would be almost impossible [1]. So it is necessary to consider surface reflectance of all objects and bodies used in military operations at the range of 700–1200 nm [2,3]. There are many reports in the literature regarding the use of dyes and pigments by employing dying and printing methods to camouflage textile surfaces [4–8]. However, there are few research results about the camouflage produced fibers during the chemical spinning process though production of such yarns has various advantages such as higher uniformity and fastness [9]. Frankel [10] manufactured modified polyamide 6 filament yarns (containing a CB additive) and fabrics. The fabrics made from these yarns may be advantageously dyed or printed to provide a camouflage fabric. Poly(ethylene terephthalate) (PET) fibers are among the most important fibers, which their camouflage properties were investigated [9]. In our previous work, production of camouflage PET filament yarn (containing pigments and dye for visible–NIR camouflage) during low speed melt spinning method was reported. Since the structure of produced fiber by high speed spinning (industrial conventional) method is different from that of the fibers produced by low speed spinning method, and it can be effective on reflectance properties, in the present research, high speed melt spinning was used to manufacture camouflage partially oriented yarns (POY). Then the reflectance properties of POY, drawn, and texturized multifilament yarns and knitted fabrics by the produced camouflage multifilament yarn were studied. Three different pigments (C.I. Pigment Green 7, C.I. Pigment Yellow 184 and CB) were used to obtain NIR's camouflage property in the forest zones (olive hue). Also the thermal and mechanical properties of the produced samples were characterized.

2. Experimental

2.1. Material

Textile grade PET semi-dull granules were supplied by Tondgoyan Petrochemical Co. (Iran) with the intrinsic viscosity of 0.66–0.68 g/mol (molecular weight ~18,000 g/mol [11]), melting temperature of 250 ± 2 °C, and glass transition temperature (*Tg*) of about 80 °C [12]. Green phthalocyanine pigment (C.I. Pigment Green 7) with the molecular weight of 1127.2 and yellow pigment (C.I. Pigment Yellow 184) with the molecular weight of 322.92 were

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made by former Ciba Geigy Co. (Switzerland). CB (series N-330) was supplied from Dodeh Pars Co. (Iran) with the maximum ash content of 0.75%, pour density of 355–405 g/cm^3 and maximum sulfur content of 2.5%, and pH of 7.

The mixture of the applied pigments has some advantages such as high infrared absorbance (similar to natural olive green hue) and high thermal stability during the spinning process.

2.2. Methods

2.2.1. Pre-drying of PET granules

PET granules were crystallized and dried at 120 °C (for 2 h) and 160 °C (for 4 h), respectively, before feeding to the extruders for melt spinning and masterbatch production processes. A standard hot air electrical oven was used for drying of the raw materials.

2.2.2. Masterbatch production for mass dyeing

Production of blended pigments masterbatch was carried out by ZSK 25 co-rotating twin screw extruder made by Coperion Co. (Germany).The diameter of screws was 25 mm with length by ratio (L/D) of 40. The screws speed and extrusion temperature were adjusted to 250 rpm and 280 °C respectively. The dried PET granules, C.I. Pigment Green (0.63% weight of granules), C.I. Pigment Yellow 184 (0.31% weight of granules) and CB (0.063% weight of granules) were fed into the barrel of the extruder. These amounts of pigments were selected to produce fibers containing 0.1% green pigment, 0.05% yellow pigment and 0.01% CB that were used in our previous work [9]. The mixed molten thread between the extruder die to the pelletizer was cooled by fresh cold water.

In our previous work, in order to produce camouflage PET filament yarn, C.I. Pigment Green 7, C.I. Disperse Orange 149 and CB were used [9]. In this work, C.I. Pigment Yellow 184, an appropriate pigment for melt spinning, was used instead of C.I. Disperse Orange 149 firstly for preventing the fueling of candle and screen filters in the melt spinning machine (which occurs by C.I. Disperse Orange 149 due to the aggregation of dye molecules in high speed melt spinning) and secondly higher visible–infrared absorbance of yellow pigment compared to orange dye.

Chemical structures of C.I. Pigment Green 7 and C.I. Pigment Yellow 184 are given in Fig. 1.

2.2.3. Melt spinning and drawing process

In order to produce infrared camouflage PET multifilament yarns containing green pigment (0.1% weight fraction), yellow pigment (0.05% weight fraction) and CB (0.01% weight fraction) by high speed melt spinning method, the produced masterbatch and PET granules were fed into the feeding hopper of an Automatic pilot plant melt spinning machine, type POY-1 EX35125D, made by Automatic Co. (Germany). The PET granules were fed into an extruder where, through heating, their melting temperature is exceeded. The polymeric melt is then transported, under pressure, into the spinneret with a mass content flow rate by a metering pump. After the melt flow passes through the spinneret orifices into the solidification airflow, the filaments cool off, solidify, and are collected into a filaments bundle that is finally wound up as a POY yarn. The POY yarns were drawn using an industrial scale draw-twister machine, Model 520-3, made by Zinser Co. (Germany).The adjusted melt spinning and drawing parameters are presented in Table 1.

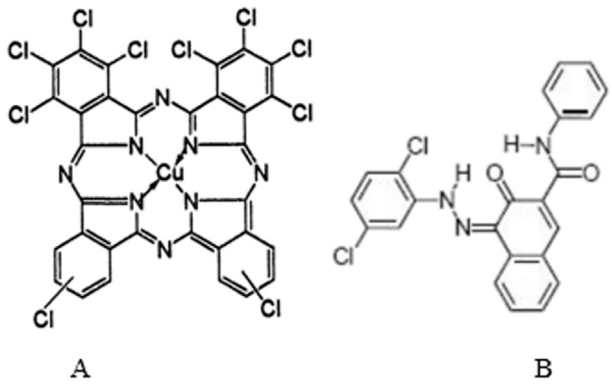

Fig. 1. Chemical structures of green and yellow pigments. A) C.I. Pigment Green 7, and B) C.I. Pigment Yellow 184.

2.2.4. Texturizing and knitting

The drawn yarns were texturized by Minibulk false-twist texturizing machine, Model CS-12 600 made by Scragg Co. (England). Total draw ratio, heater temperature and twister spindle were adjusted to 1.1, 190 °C and 2950 rpm, respectively.

The drawn and texturized multifilament yarns were knitted by weft knitting single cylinder hosiery machine (3.5 inches diameter, 120 needles) that is manufactured in a local company (Iran).

2.2.5. Spectral reflectance evaluation

Spectral reflectance of the samples was measured with a reflectance spectrophotometer made by SPECORD Co. model 250-222P168 (Japan) in visible/NIR bandwidth (400–1100 nm). The observation geometry in the above spectrophotometer was set to d/0 in which a diffused light was detected after reflecting back from the surface. The scan speed was 20 nm/s.

2.2.6. Thermal NIR detection

In order to investigate the final application of the produced sample for creation of camouflage against thermal detection cameras, a professional thermal imager made by NEC Co. model Avio NEC Thermo GEAR G120EX (Germany) was used.

2.2.7. Mechanical properties

A constant rate of elongation tensile tester made by Elima Co. model EMT-3050 (Iran) was used for evaluation of the mechanical

Table 1
Parameters applied for high speed melt spinning and drawing processes of the PET POY and drawn multifilament yarns.

Parameter	Value
Melt spinning	
Screw speed	32 rpm
Extruder temperature zone 1	245 °C
Extruder temperature zone 2	260 °C
Extruder temperature zone 3	270 °C
Extruder temperature zone 4	275 °C
Extruder temperature zone 5	280 °C
Spinning head temperature	280 °C
Spinning pump round	10 rpm
Melt pressure before spinning pump	50 bar
Quenching air flow pressure	60 N/m^2
Spin finish pump round	42 rpm
Winding (take-up) speed	3200 m/min
Drawing	
Total draw ratio	1.480
Feed roller temperature (drawing temp.)	90 °C
Contact heater temperature (heat setting temp.)	180 °C
Drawing speed	400 m/min
Twister spindle round	4000 rpm