

## THE UTILIZATION OF PET WASTE AS RAW MATERIAL FOR PRODUCING MONOFILAMENT YARN : THE EFFECT OF WINDING SPEED ON THE PHYSICAL AND MECHANICAL PROPERTIES OF THE YARN

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### ABSTRACT

**THE UTILIZATION OF PET WASTE AS RAW MATERIAL FOR PRODUCING MONOFILAMENT YARN : THE EFFECT OF WINDING SPEED ON THE PHYSICAL AND MECHANICAL PROPERTIES OF THE YARN.** Plastic waste production in Indonesia is quite high, reaching 15% to the total national waste production or 189-kilo tons/day with an average growth of 14.7% per year, the second biggest contributor after organic waste. This fact greatly affects human health and the environment since plastic is difficult to degrade, estimated to require 100 to 500 years for the plastic to decompose completely. Therefore, recycling becomes a popular solution to reduce waste or plastic waste by turning it into new products that have added value. Plastic materials, such as PET, have thermoplastic properties which become a special potential to use as recycled materials. The aim of this research was to study the ability of PET plastic waste as a raw material for making monofilament yarn by melt-spinning methods. PET plastic waste is melted at 250-260°C, then is extruded using a prototype melt-spinning tool with a single spinneret hole which the diameter is 3 mm into a monofilament yarn using three variations of winding speed (a) 43.33 m/min, (b) 59.35 m/min and (c) 72.72 m/min. The results showed that the yarn with the highest winding speed (variation C) produced yarn with the highest fineness, reaching  $(30.06 \pm 4.82)$  denier, and the best tensile strength compared with the other, reaching  $(47.7 \pm 14.97)$  MPa with elongation of  $(10 \pm 9.65)$  %.

**Keywords:** plastic waste, PET, Melt Spinning, Monofilament yarn.

### ABSTRAK

**PEMANFAATAN LIMBAH PET SEBAGAI BAHAN PEMBUATAN BENANG MONOFILAMEN : PENGARUH KECEPATAN PENGGULUNGAN TERHADAP SIFAT FISIK DAN MEKANIK BENANG.** Produksi sampah plastik di Indonesia cukuplah tinggi, tercatat kontribusi sampah plastik terhadap total produksi sampah nasional mencapai 15% atau sebesar 189 kilo ton/hari dengan pertumbuhan rata-rata mencapai 14,7% per tahun dan menempatkan sampah plastik sebagai kontributor terbesar kedua setelah sampah organik. Penggunaan plastik dengan jumlah yang besar akan sangat berdampak terhadap kesehatan manusia dan lingkungan. Hal ini karena plastik mempunyai sifat sulit terdegradasi, diperkirakan membutuhkan 100 hingga 500 tahun agar plastik dapat terdekomposisi dengan sempurna. Oleh karena itu daur ulang menjadi solusi yang populer untuk mengurangi sampah atau limbah plastik dengan memanfaatkannya menjadi produk baru yang memiliki nilai tambah. Bahan plastik khususnya yang memiliki sifat termoplastik seperti PET memiliki daya tarik tersendiri untuk digunakan sebagai bahan daur ulang. Tujuan dari penelitian ini adalah untuk mengetahui kemampuan limbah plastik jenis PET sebagai bahan baku pembuatan benang monofilamen dengan metode pemintalan leleh. Limbah plastik jenis PET dilelehkan pada suhu 250-260°C yang kemudian diekstrusi menggunakan alat prototipe pemintalan leleh dengan lubang spinneret tunggal berukuran 3 mm menjadi benang monofilamen dengan tiga variasi kecepatan penggulangan

(a) 43,33 m/mnt, (b) 59,35 m/mnt, dan (c) 72,72 m/mnt. Hasil penelitian menunjukkan bahwa benang dengan kecepatan penggulangan paling tinggi dalam hal ini variasi C menghasilkan benang dengan kehalusan paling tinggi yaitu mencapai  $(30,06 \pm 4,82)$  denier dan kekuatan tarik terbaik dibandingkan dengan variasi kecepatan penggulangan yang lain yakni mencapai  $(47,71 \pm 4,97)$  MPa dengan mulur  $(10 \pm 9.65)\%$ .

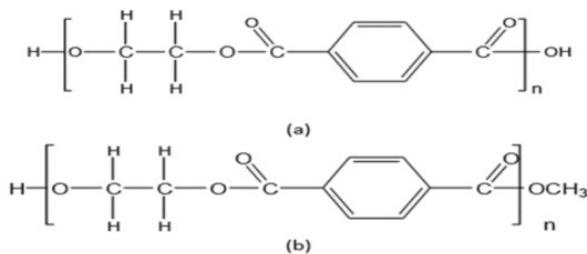
**Kata kunci:** limbah plastik, PET, Pemintalan leleh, Benang Monofilamen.

## INTRODUCTION

Waste is a cultural problem which is one of the side products of human activities and its volume is directly proportional to the number of human populations in the area. This problem, if it is not handled properly, will damage the surrounding life. The largest source of waste is residential areas, comprising 75% organic waste and 25% inorganic waste [1]. Organic waste has been widely used for making compost, biogas, briquettes, etc. while inorganic waste is still rarely utilized due to its difficulty to degrade naturally. The largest type of inorganic waste that are often found in the environment is plastics [2].

Plastic is a very popular material to be used as material for making most household appliances, from beverage bottles, cups, plates, plastic bags, etc. [3]. Based on the type of product, there are 6 types of plastic namely PET (Polyethylene Terephthalate), HDPE (High-Density Polyethylene), PVC (Polyvinyl Chloride), LDPE (Low-Density Polyethylene), PP (Polypropylene), and PS (Polystyrene) [4]. Generally, plastic waste has a composition of 46% Polyethylene (HDPE and LDPE), 16% Polypropylene (PP), 16% Polystyrene (PS), 7% Polyvinyl Chloride (PVC), 5% Polyethylene Terephthalate (PET), 5% Acrylonitrile-Butadiene-Styrene (ABS) and other polymers.

PET is one of the most widely used man-made fibers since the mid-twentieth century [5]. PET with the trade name Dacron is made from *terephthalic* acid and ethylene glycol, while *terylene* is made from dimethyl terephthalate and ethylene glycol, the structure of Dacron and Terylene can be seen in Figure 1 below.



**Figure 1.** The properties of PET generally have been known as shown at Table 1

PET is a type of plastic that has thermoplastic properties [6]. PET would be soft if it heated, in revers it would harden if it cooled and this process can be done repeatedly. Thermoplastics are a type of plastic that can be recycled using heat [7,8]. The plastic recycling

process that has thermoplastic properties (in this case PET) can be done in several ways : injection molding [9,10], blow molding [10,11], extrusion and melt-spinning[10]. Melt-spinning is one of the most widely used industrial processes to produce polymeric fibers [12]

**Table 1.** Properties of PET[5]

Property	Value
<b>Mechanical Properties</b>	
Tensile Strength	45 - 70 MPa
Elongation	11% to 40%
Young Modulus	2.8 to 3.5 GPa
<b>Chemical Properties</b>	
Weak Acid	Resistant
Strong cold acids	Resistant
Insecticides	Resistant
Oxidizing agents, alcohols, ketones, and soaps	Resistant
Moisture regain	0,4 % (Standar Condition) 0.6 - 0.8% (100% Relative Humidity)

Aizenshtein (2015) explains the ways of utilizing used PET bottles as raw material to make less important products as staple fiber, fiber filler, etc. To get high-quality fibers or yarn, PET flakes must through the granulation process and special treatment first before it is extruded become POY, DTY, or staple yarn by melt-spinning process[13]. Noerati (2016) worked to the utilization of plastic bags waste which was made from polyethylene polymer as material for making of non-apparel textile fibers to enhance the economic value of plastic waste. This study used plastic bags waste that was processed into filament fibers by melt spinning method[14]. Qiaoli (2019) worked to the recycling of polyethylene bags into high-strength yarns without using melt processing. Only simple cutting and yarn processing devices are needed[15]. First, HDPE grocery bags were cut into stripes through the direction of bag sealing become loop shape. Next, loops were knotted together to form a long chain. Afterward, the chain-like material is twisted to form a precursor yarn. Finally, the precursor was drawn to form a continuous yarn of a fine diameter. These fibers and yarns can then be used as constituent materials for ropes, ruggers, and textile products that are valuable to end-users.

Different with all research reference at paragraph before, this research has aims to utilize PET type plastic waste was used as raw material for making monofilament

yarn by the melt-spinning process and to know how the effect of the winding speed on physical and mechanical properties of the yarn. Monofilament yarn is a yarn which is made from a single filament [5]. Generally, this process consists of extrusion of a molten polymer through small capillary holes (spinneret) followed by quenching with air flow while being drawn and taking up of the solidified fibers at high velocity [16][2]. Actually, melt-spinning process involves complex interactions of convective heat-transfer, polymer rheological behavior and fiber quenching process [17-21]. Monofilament yarns are widely used as textile materials, conductive yarn [22], fishing lines, toothbrush bristles, and other applications [23].

## EXPERIMENTAL METHOD

### Materials and Instruments

The raw material used in making monofilament yarn was commercial PET waste from Bukalapak.com. The form of PET waste used was a little chop like a chip from plastic bottle waste (Figure 2). The material has been characterized in advance by ATR-FTIR with the



Figure 2. PET waste from plastic bottle

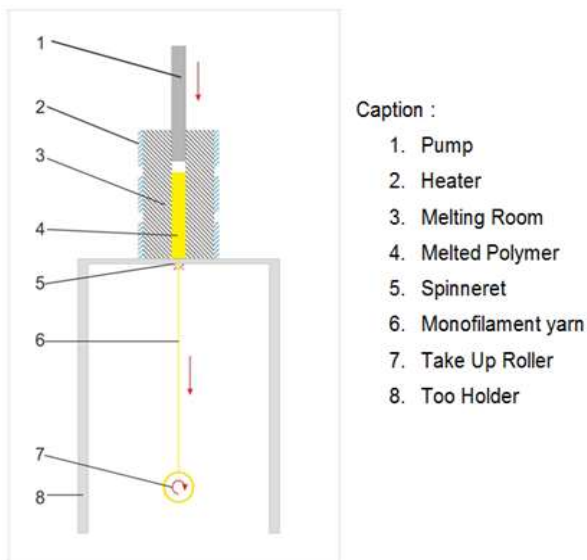


Figure 3. Melt-spinning prototype mechanism

IRAffinity-1S (Shimadzu) spectrometer belonging to the Evaluation Laboratory Politeknik STTT Bandung.

The monofilament yarn making process was carried out using a prototype melt spinning [24] at Politeknik STTT Bandung. The working mechanism of the melt-spinning prototype used in this study was different from the melt spinning in general that uses screw-type extruders as equipment to flow the molten polymer [25] but uses a pump mechanism as shown in Figure 3.

## Method and Procedure

### Melt Spinning

In this research, extruding PET waste into monofilament yarn was adjusted according to the character of the material. After several attempts and adjustments, the ideal conditions for melt spinning was carried out with procedure as Table 2.

Table 2. Melt spinning process parameters

Parameter	Condition
Extrusion Temperature	250-260 °C
Spinneret Diameter	3 mm
Winding Distance	47 cm

In this study, three groups of monofilament yarn produced from the melting spun of PET waste. the melt-spinning process was done by variation winding speed could become three variations as Table 3 to know how the effect of winding speed on the physical and mechanical properties of the yarn. The winding speed variation were chosen based on availability speed of the melt spinning machine.

Table 3. Variaton of Winding Speed

Type Yarn	Winding Speed (m/min)
A	43.33
B	59.35
C	72.72

## Physical and Mechanical Properties Test

The yarn's physical property which has been evaluated is the fineness of the yarn. The fineness of yarn is known as a linear density of the yarn. It is also called yarn count. Yarn count is expressed by comparing the yarn mass (g) per unit of length. Denier is most commonly used top expressed the count of continuous filament yarn of man made fiber. It show the weight of yarn in grams of 9000 meters [26]. As an example, a 40 denier yarn means that the mass of 9000 m of yarn is 40 g.

Characterization of surface morphology and yarn cross-section was carried out using a Scanning Electron Microscope (SEM) brand JEOL belonging to the

Research Unit for Clean Technology, Indonesian Institute of Science (LIPI) Bandung. Mechanical properties test of yarn was done by measured the tensile strength and elongation testing using Tensile Strength Tester brand Instron belonging to the Evaluation Laboratory Politeknik STTT Bandung with a speed of 50 mm/min and used a weight of 50 grams. All the obtained results represent average values of ten measurements.

## RESULT AND DISCUSSION

### Material Characterization using FTIR

From the Transmittance graph of the FTIR test results in Figure 4, it was confirmed that the result of FTIR test was similar to bond type data in the Table 4. It can be concluded that the material used was PET although not pure PET.

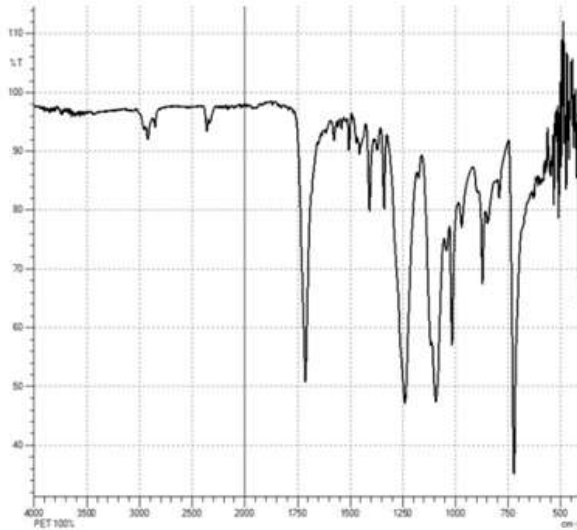


Figure 4. Transmittance graph of FTIR test results on plastic waste materials.

Table 4. The type of bond in each absorption band (cm-1) from the FTIR Spectrum Test results on a sample of 100% PET [27].

Absorption bands (cm <sup>-1</sup> )	Bands
3432	OH group (hydroxyl)
3054	Symmetrical stretch of CH
2969, 2908	C-H Symmetrical stretching
2350	Axial symmetrical deformation of CO <sub>2</sub>
1730	Stretching of C=O of carboxylate acid group
1577, 1504	Vibrations aromatic skeleton with stretching C=C
1453, 1410, 1432	Stretching of the C-O group deformation of the O-H group and bending and wagging vibrational modes of the ethylene glycol segment
1240, 1124	Terephthalate group (OOC <sub>6</sub> H <sub>4</sub> -COO)
1096, 1050	Methylene group and vibrations of the ester C-O bond
972, 872, 848	Aromatic rings 1,2,4,5.Tetra replaced
1960, 795	Vibration of adjacent two aromatic H in p-substituted compounds and aromatic bands
712	Interaction of polar ester group and benzene rings

### Physical and Mechanical Properties Test Result

The effect of winding speed on the physical properties of monofilament yarn is shown in Figures 5 and 6. In this study the variation of winding speed from 43.33 m/min (yarn A), 59.35 m/min (yarn B), to 72.72 m/min (yarn C) affected the fineness and yarn diameter became finer from (52.36 ± 5.61) denier to (30.06 ± 4.82) denier (Figure 5) and yarn diameter from (85 ± 9.17) μm to (53 ± 9.86) μm (Figure 6).

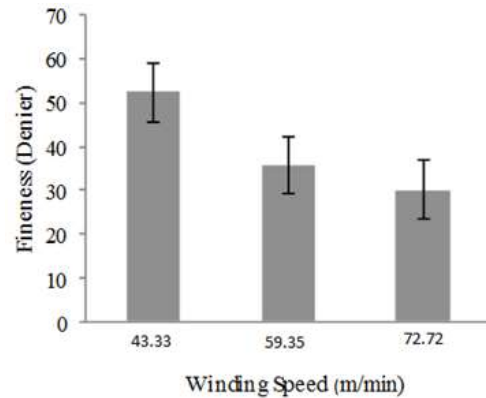


Figure 5. Fineness yarn (denier) of monofilament yarn with different winding speed (m/min).

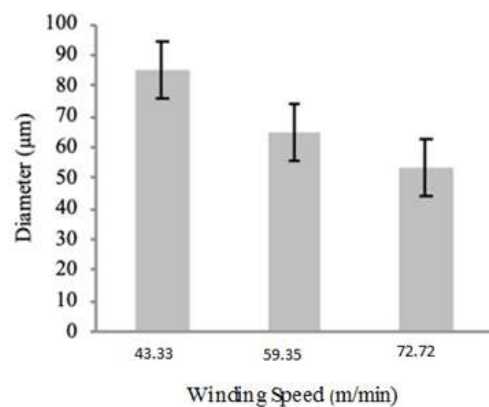


Figure 6. Yarn diameter (μm) of monofilament yarn with different winding speed (m/min)

This result suggested that the higher of the winding speed, the finer is the yarn fineness as well as the yarn diameter. In constant throughput speed ( $V_1$ ) condition, the increasing of winding speed ( $V_2$ ) will increase the drafting ratio so the strain of yarn will become longer. It will affect to increase the area depreciation of yarn and caused decreased yarn diameter after the draft ( $D_2$ ) so the fineness of yarn will become finer. The mechanism of decreasing the diameter of yarn is shown in Figure 7.

The result of the yarn mechanical properties test shown in Figure 10. The higher the increase of winding speed from 43.33 m/min to 72.72 m/min, the higher is the tensile strength of yarn from (34.62 ± 5.01)MPa to (47.71 ±

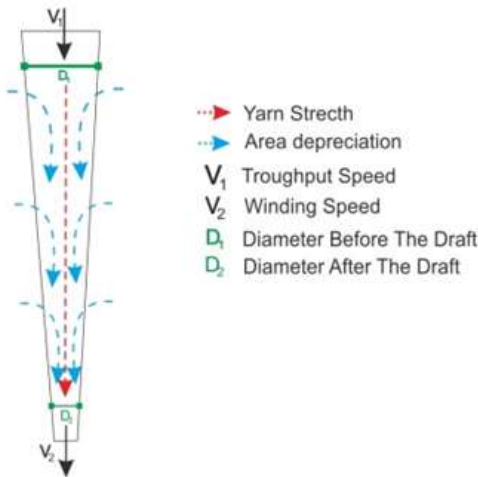


Figure 7. The mechanism of decreasing diameter of yarn.

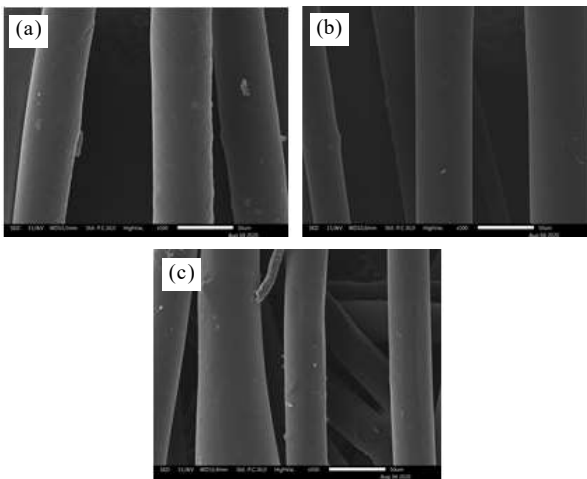


Figure 8. Surface of the monofilament yarn with different winding speed variation by SEM with a magnification of 500x (a) 43.33 m/min, (b) 59.35 m/min, (c) 72.72 m/min.

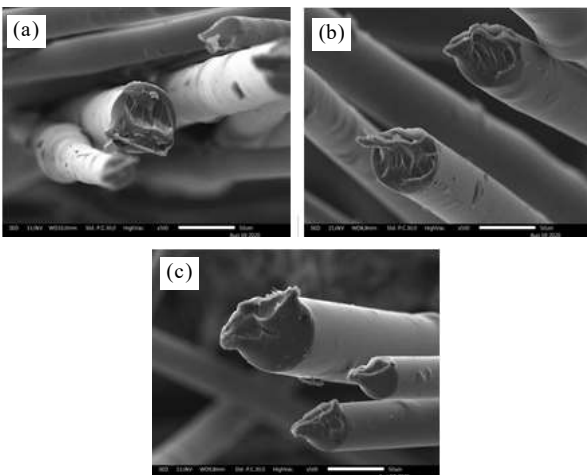


Figure 9. Cross-section of the monofilament yarn with different winding speed variation by SEM with a magnification of 500x (a) 43.33 m/min, (b) 59.35 m/min, (c) 72.72 m/min.

4.97) MPa (Figure 9a). This result suggested that the increase of winding speed increased tensile strength yarn. Tensile strength yarn was influenced by the degree of orientation. Yarn with a better orientation degree had better tensile strength[28]. The drafting process that caused by winding speed affected the orientation process of the yarn structure, if the cooling rate is slower than winding speed, the stretch of yarn will be higher so that the crystal structure of the yarn will be better oriented and amorphous phase will decrease[29].

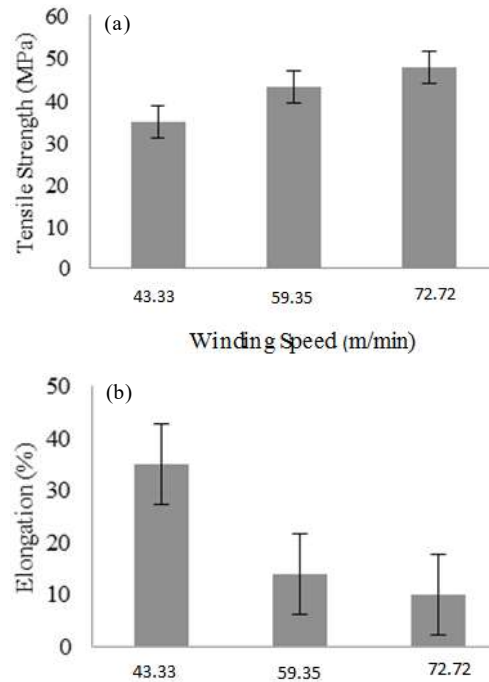


Figure 11. (a) Tensile strength and (b) Elongation at break of monofilament yarn with different winding speed.

In contrast, the elongation at break of monofilament yarn showed contrariwise. The increase of winding speed from 43.33 m/min to 72.72 m/min decreased elongation from (35 ± 9.89) % to (10 ± 9.65) % (figure 9b). It caused by increasing winding speed, orientation degree will increase and the amorphous

Table 5. Relationship between winding speed with fineness and diameter, tensile strength, and elongation of monofilament yarn.

Sample	Winding Speed (m/min)	Fineness (denier)	Diameter (µm)
Yarn A	43.33	(52.36 ± 5.61)	(85 ± 9.17)
Yarn B	59.35	(35.74 ± 5.40)	(65 ± 9.23)
Yarn C	72.72	(30.06 ± 4.82)	(53 ± 9.86)

Table 6. Relationship between winding speed with tensile strength, and elongation of monofilament yarn.

Sample	Winding Speed (m/min)	Tensile Strength (MPa)	Elongation at Break (%)
Yarn A	43.33	(34.62 ± 5.01)	(35 ± 9.89)
Yarn B	59.35	(43.10 ± 4.88)	(14 ± 9.78)
Yarn C	72.72	(47.71 ± 4.97)	(10 ± 9.65)

phase will decrease[28]. If the amorphous phase decreases, it will affect space for a stretch at yarn structure to become less.

## CONCLUSION

In this research, monofilament yarn was produced from PET waste via the melt-spinning process. The effect of winding speed (43.33 m/min, 59.35 m/min, and 72.72 m/min) on the physical and mechanical properties of the yarn produced were investigated. The test results showed that the increasing winding speed improved the fineness of the yarn and reduce the diameter of yarn from  $(52.36 \pm 5.61)$  denier to  $(30.06 \pm 4.82)$  denier and from  $(85 \pm 9.89)$  mm to  $(53 \pm 9.65)$   $\mu$ m as well as improved the tensile strength of yarn and reduce elongation at break of yarn from  $(34.62 \pm 5.01)$ MPa to  $(47.71 \pm 4.97)$ MPa and from 35% to 10% .

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