

## CHARACTERIZATION OF BREAKING STRENGTH AND ELONGATION IN POLYAMIDE MULTIFILAMENT TWINES USED FOR PURSE SEINE CONSTRUCTION

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### ABSTRACT

The operational efficiency and maintenance costs of purse seine fisheries in Indonesia depend strongly on the mechanical integrity of netting materials, for which polyamide (PA) multifilament twines are widely used but remain insufficiently characterized across denier sizes applied in different net sections. This study aimed to systematically quantify the breaking strength and elongation of PA multifilament twines (d/6, d/9, d/12, and d/18) used in purse seine fisheries and to examine their relationships and implications for net design. Laboratory experiments were conducted in January 2026 at PT. Arteria Daya Mulia (Cirebon, Indonesia) using a completely randomized design with denier as a single factor and 10 replicates per level. White, Z-twist PA twines were conditioned for  $\geq 24$  h ( $25 \pm 2^\circ\text{C}$ ; RH  $50 \pm 5\%$ ) and tested on a Shimadzu Autograph AGS-J 10 kN universal testing machine (gauge length 250 mm) following SNI ISO 1805:2010, with the crosshead speed set to achieve failure within  $20 \pm 3$  s; invalid tests due to slippage or improper break location were repeated. The mean breaking strength increased with denier ( $8.76 \pm 0.32$  kgf for d/6;  $15.14 \pm 0.28$  kgf for d/9;  $20.99 \pm 0.41$  kgf for d/12; and  $29.05 \pm 0.34$  kgf for d/18), whereas the mean elongation decreased ( $44.71 \pm 5.96\%$ ;  $37.99 \pm 0.96\%$ ;  $32.63 \pm 0.60\%$ ; and  $28.41 \pm 0.54\%$ ), with greater variability observed in the finest twine. Denier showed a very strong positive correlation with breaking strength ( $r=0.997$ ,  $p=0.003$ ;  $BS = -0.265 + 1.682D$ ;  $R^2=0.994$ ) and a very strong negative correlation with elongation ( $r=-0.983$ ,  $p=0.017$ ;  $E = 53.13 - 1.439D$ ;  $R^2=0.966$ ). These baseline data support evidence-based twine selection: d/18 for high-load bunt and

headropes to maintain shape stability, d/9–d/12 for body and wings to balance strength and flexibility, and d/6 for low-stress areas where compliance is prioritized, while highlighting that service-life predictions must additionally account for degradation from sunlight exposure, friction during hauling, and dynamic loads from fish and hydrodynamics.

**KEYWORDS:** Correlation, denier, twine, and universal testing machine.

## 1. INTRODUCTION

The fisheries industry is a fundamental sector that supports national food security and economic stability in Indonesia. Among the various fishing methods developed commercially in Indonesian waters, purse seine is the most productive gear for catching pelagic fish, such as scads, mackerel, and skipjack tuna. The operational effectiveness of purse seine fishing highly depends on the structural integrity of the gear and the characteristics of its constituent materials. Polyamide (PA) multifilament yarn has emerged as the dominant material in purse seine construction. This material demonstrates good tensile strength, high abrasion resistance, and adequate elasticity for operational needs [1, 2]. The breaking strength determines the cost of repairs; the faster the net's breaking strength decreases, the higher the cost of repair and net replacement [3, 4].

The mechanical properties of PA multifilament yarn vary significantly. In the construction of purse seines for small pelagic fish in Indonesia, yarns with higher denier (typically d/12 and d/18) are used in parts of the net that experience the greatest mechanical stress, such as the bunt (where the catch accumulates), along the floatline, and along the leadline [5]. This demonstrates that the structural performance and economic value of the material are important considerations for Indonesian fishers when constructing purse seines. Therefore, selecting the appropriate denier value for each part of the net is a fundamental consideration in optimizing the design and functionality of purse seines.

Although this material has been widely utilized by the Indonesian fisheries industry, a comprehensive characterization of the fundamental mechanical properties (breaking strength and elongation) of multifilament PA yarn still requires in-depth study. Breaking strength represents the maximum tensile load that a single strand of yarn can withstand before breaking [6]. Elongation is defined as the capacity to undergo dimensional elongation under tensile loading before breaking [7, 8]. There is a significant gap in the current scientific literature regarding the characterization of the breaking strength and elongation of multifilament polyamide yarn in the range of denier values specifically used in purse seine

construction in Indonesian waters. Without an understanding of how yarns with different deniers respond to tensile loading, the Indonesian fisheries industry faces decreased catching efficiency, increased operational costs, and reduced economic benefits for fishers.

This study aims to fill the knowledge gap through a systematic characterization of the breaking strength and elongation in polyamide (PA) multifilament yarns representing a range of denier values (d/6, d/9, d/12, d/18) used in the construction of ring nets for small pelagic fish by the Indonesian fishing fleet. Specifically, this study seeks to quantitatively determine the average breaking strength and elongation values for each selected denier variant, followed by an analysis of the relationship between these two parameters and their practical implications for application in specific parts of the net, including the bunt, body, and wings. The findings of this study are expected to provide a deeper understanding of the basis for more precise net selection to improve operational efficiency.

## 2. METHODOLOGY

### 2.1. Time and Location of Research

This study was conducted in January 2026 at PT. Arteria Daya Mulia (Arida), Jl. Dukuh Duwur No. 46, Cirebon City, West Java – Indonesia. The selection of the research site was based on the availability of material testing equipment that meets standards, as well as the controlled laboratory environment to minimize external factors that could affect the test results.

### 2.2. Research Materials and Tools

**Table 1. Specifications of PA multifilament yarn research material.**

Parameters	Spesification
Material type	100% polyamide (PA) or nylon 6
Yarn construction	Multifilament (consisting of fine twisted fibers)
Denier variation	d/6, d/9, d/12, d/18
Color	white
Twist direction	<i>Z-twist</i>
Source	PT. Arida
Storage conditions	Room temperature (25±2°C), controlled humidity, protected from direct sunlight

The primary material used in this study is multifilament polyamide (PA) yarn, which is commonly employed in the construction of purse seines in Indonesia. The yarns were selected based on variations in denier value, representing their use in different parts of the

purse seine: d/6, d/9, d/12, and d/18. The detailed material specifications are presented in Table 1.

### 2.2.2 Research Tools

The equipment used in this study is similar to that used in previous studies [9] and has been adjusted to meet the applicable testing standards. Details of the equipment are presented in Table 2.

**Tabel 2. Research equipment and its functions.**

No.	Name of Tools	Type	Function
1.	<i>Autograph</i> Universal Testing Machine	AGS-J 10 kN (Shimadzu, Jepang)	Measuring the breaking strength and elongation of yarn
2.	<i>Load cell</i>	10 kN (integrated with UTM)	Detecting and recording pulling force
3.	<i>Grips/clamps</i>	Manual type for thread	Clamping the sample during testing
4.	<i>Teclock</i>	Accuracy 0.01 mm	Measuring thread diameter
5.	Slidding caliper	Accuracy 0.1 mm	Measuring mesh size
6.	Testing software	<i>Trapezium II</i> (Shimadzu)	Operating the UTM and recording data
7.	Statistical software	SPSS	Analyzing data statistically

### 2.3. Research Design

This study used a quantitative approach with a laboratory experimental method. The research design applied was a completely randomized design with one treatment factor, namely, variations in yarn denier values (d/6, d/9, d/12, and d/18). Each treatment was repeated ten times to meet the statistical assumptions and ensure data reliability. The variables observed in this study are as follows:

The variables observed in this study are as follows:

1. Independent variable: Yarn denier value (d/6, d/9, d/12, d/18)
2. Dependent variables:
  - Breaking strength in kilograms-force (kgf)
  - Elongation at break in percentage (%)

### 2.4. Research Procedures

#### 2.4.1. Test Sample Preparation

The test sample preparation stages are as follows:

1. Yarn from each denier variation was taken from the parent roll and cut to a length of  $\pm 50$  cm.

2. Both ends of each sample were treated specially to prevent fiber splaying and ensure a strong grip during testing.
3. Each prepared sample was assigned an identification code based on the denier type and repetition number.
4. All samples were conditioned in the test room for at least 24 h at a controlled temperature and humidity ( $25\pm 2^{\circ}\text{C}$ , RH  $50\pm 5\%$ ) to stabilize the moisture content of the material.

#### **2.4.2. Calibration and Setting of Testing Equipment**

Before testing, the following calibration and equipment setting procedures were performed:

1. An autograph AGS-J 10 kN was turned on and allowed to warm up for 15–20 min.
2. The wizard method display appears on the computer screen and consists of start, system, testing, specimen, data processing, chart, and finish.
3. The distance between the grips (gauge length) was set according to the length of the sample to be tested. For yarn testing, the distance between the grips was set at 250 mm.
4. The load cell was calibrated using force and position calibration procedures to neutralize the equipment so that the force was 0 kgf and the position was 0 cm.
5. The crosshead speed was set such that the time required for the sample to break was  $20 \pm 3$  s, in accordance with the provisions of SNI ISO 1805:2010.

#### **2.4.3. Implementation of Breaking Strength and Elongation Testing**

Breaking strength and elongation testing was conducted in accordance with the international standard ISO 1805:2006 (Fishing nets — Determination of breaking force and knot breaking force of netting yarns), which has also been adopted as the SNI ISO 1805:2010 Indonesian standard.

The testing procedure was conducted as follows:

1. The yarn sample was attached to the upper and lower load clamps, and the adjustment lock was then tightened.
2. The sample position was adjusted to be in a straight vertical position without excessive tension.
3. The start button was pressed to begin the test, and the crosshead moved upward at a constant speed until the yarn broke.
4. During the test, the autograph automatically recorded the load (force) and elongation (displacement/stroke) data at each time interval.

5. After the test material breaks, the computer automatically reads and records the results of the yarn breaking strength and change in length or elongation.
6. If the sample does not break at the intended area or slippage occurs at the clamp, the test results are deemed invalid and must be repeated with a new sample, in accordance with SNI ISO 1805:2010.
7. The same procedure was repeated for all samples (10 repetitions per denier type).

## 2.5. Data Analysis

### 2.5.1. Test Parameter Calculation

The raw data obtained from the UTM is processed to determine the following parameters. The breaking strength is determined by the maximum load recorded before the thread breaks. This value is expressed in Newtons (N) or can be converted to kilograms-force (kgf) using a conversion factor of 1 kgf = 9.81 N. Elongation at the break is expressed in two forms:

1. Absolute elongation (mm): the difference between the final length at breaking and the initial length.
2. Relative elongation (%): calculated using the formula.

$$E = \frac{(L_f - L_o)}{L_o} \times 100\%$$

Information:

E = elongation (%)

$L_f$  = final length at break (mm)

$L_o$  = initial length (mm) = *gauge length*

### 2.5.3. Inferential Statistical Analysis

To test the effect of denier variation on breaking strength and elongation, the following statistical analysis was performed:

#### 1. Normality and Homogeneity Test

Before further analysis, the data were tested for normality using the Kolmogorov-Smirnov test and for variance homogeneity using the Levene test. The assumptions of normality and homogeneity must be met in order to use parametric statistics.

#### 2. Pearson Correlation Test

To determine the relationship between denier variation and breaking strength and elongation, a Pearson correlation test was performed. The hypotheses tested were:

$H_0$ : There is no relationship between denier variation and breaking strength/elongation.

$H_1$ : There is a relationship between denier variation and breaking strength/elongation.

The significance level ( $\alpha$ ) used was 0.05. If the p-value was  $< 0.05$ , then  $H_0$  was rejected. The correlation coefficient ( $r$ ) indicated the strength and direction of the relationship between variables [9].

### 3. RESULTS AND DISCUSSIONS

#### 3.1. Characteristics of the breaking strength of polyamide multifilament yarn

The results of the breaking strength tests of the multifilament polyamide yarns for each size variation are presented in Table 3. The tests were conducted in 10 replicates for each type of yarn, following the procedures based on SNI ISO 1805:2010. As shown in Table 3, the breaking strength of the yarn increased with increasing density. Yarn with a d/6 size has the lowest average breaking strength, which is 8.76 kgf, whereas d/18 yarn has the highest average breaking strength at 29.05 kgf. These findings indicate that the greater the denier value (the thicker the yarn), the higher the yarn's ability to withstand tensile loads before breaking [10]. This is because yarns with a higher density have either more constituent fibers or larger fiber diameters, resulting in a greater cross-sectional area to bear the tensile load. The breaking strength is directly proportional to the cross-sectional area of the material. These results are also consistent with those of Azzahra et al. (2021), who reported that thicker yarns have a higher ability to withstand tensile loads, although their study focused on the effect of usage duration on the decrease in breaking strength.

The d/18 thread, which has the highest breaking strength (29.05 kgf), is most suitable for use in parts of the purse seine that experience the highest loads, such as the bunt, where the catch accumulates, as well as on the upper and lower headropes that receive concentrated tension from the hauling components. Conversely, the d/6 thread, with the lowest breaking strength (8.76 kgf), is more appropriate for use in the body or wing sections of the net that do not undergo extreme loads [5, 11-12]. Selecting the correct thread size for each part of the net is a crucial factor in optimizing purse seine designs.

**Table 3. Results of breaking strength testing of PA multifilament yarn. (kgf)**

No.	d/6	d/9	d/12	d/18
1	8.24	15.30	20.15	28.42
2	8.99	14.72	21.30	29.15
3	8.76	15.55	20.85	28.90
4	9.24	14.90	21.45	29.50
5	8.50	15.10	20.60	28.75
6	8.65	15.40	21.10	29.20
7	8.90	14.85	20.95	28.85
8	8.45	15.20	21.25	29.30

9	8.80	15.05	20.80	29.00
10	9.10	15.35	21.40	29.40
<b>Average</b>	8.76	15.14	20.99	29.05
<b>Std Dev</b>	5.96	0.96	0.60	0.54

### 3.2. Characteristics of Multifilament Polyamide Yarn Elongation

The data in Table 4 show that the elongation value of the yarn tends to decrease as the denier size increases. The d/6 yarn had the highest average elongation (44.71 %), whereas the d/18 yarn had the lowest average elongation (28.41 %).

**Table 4. Test results of PA multifilament yarn elongation.(%)**

No.	d/6	d/9	d/12	d/18
1	44.26	38.26	32.45	28.30
2	50.74	36.74	33.20	27.85
3	47.26	37.33	31.90	29.10
4	38.33	39.41	32.75	28.45
5	56.74	37.69	33.50	27.60
6	36.41	38.50	32.10	28.90
7	42.69	36.90	31.80	29.05
8	41.58	38.15	33.15	28.15
9	45.20	37.80	32.40	28.70
10	43.85	39.10	33.05	27.95
<b>Average</b>	44.71	37.99	32.63	28.41
<b>Std Dev</b>	5.96	0.96	0.60	0.54

Yarns with smaller deniers generally have higher flexibility because they consist of fine filaments that are easily deformed elastically before breaking. The d/6 yarn showed considerable data variation, with a standard deviation of 5.96, indicating higher heterogeneity in the smaller yarns. Conversely, yarns of larger sizes (d/12 and d/18) showed less data variation, with standard deviations of 0.60 and 0.54, respectively, indicating better quality consistency in yarns of larger sizes. The elongation property is important in the construction of purse seine nets because it plays a role in absorbing impact energy during dynamic loading. Threads with too little elongation are prone to sudden breakage, whereas excessive extension can reduce net control and cause excessive mesh size deformation. Therefore, selecting threads with appropriate extension values for each part of the net is crucial.

### 3.3. Analysis of the Relationship Between Denier Size and Breaking Strength

To determine the strength and direction of the relationship between the denier size and yarn breaking strength, a Pearson correlation test was conducted. The analysis results show a correlation coefficient value of 0.997 with a p-value of 0.003 ( $< 0.05$ ). This indicates that

there is a very strong, positive, and significant relationship between denier size and thread breaking strength. A positive relationship indicates that the larger the denier size (the thicker the thread), the greater its breaking strength. A correlation coefficient value close to 1 indicates an almost perfect relationship, in line with the study by Azzahra [9], which also found a strong correlation between the duration of net usage and the decrease in breaking strength in the opposite direction (negative).

A simple linear regression analysis was conducted to determine the extent to which the denier size affects the yarn breaking strength. An R-squared value of 0.994 indicates that 99.4% of the variation in the breaking strength can be explained by variations in denier size, whereas the remaining 0.6% is influenced by other factors. The positive regression coefficient of 1.682 indicates that a one-unit increase in denier increases the breaking strength by 1.682 kgf. The significance value of 0.003 ( $< 0.05$ ) proves that the effect of denier size on breaking strength is statistically significant. These findings reinforce the results of Mondal [13], who stated that the physical characteristics of polyamide yarn/netting, including cross-sectional size, number of filaments, and construction (monofilament vs. multifilament, twist, and knots), are the main determinants of the mechanical strength of netting materials.

### **3.4. Analysis of the Relationship Between Denier Size and Elongation**

Pearson 's correlation analysis was also conducted to determine the relationship between denier size and yarn elongation. The analysis results showed a correlation coefficient value of  $- 0.983$  with a p-value of 0.017 ( $< 0.05$ ). This indicates a very strong, negative, and significant relationship between denier size and yarn elongation. A negative relationship indicates that the larger the denier size (the thicker the yarn), the lower its elongation value. This relationship pattern is consistent with the findings of Azzahra [9], who reported a negative correlation between the duration of net usage and elongation value, wherein the longer the net is used, the lower its elongation value becomes. These results are supported by Boesono [14], who stated that the elongation value of tested nets decreased after use not because their elasticity improved, but because the nets no longer underwent elongation as they did in their initial condition.

A simple linear regression analysis of the relationship between denier size and elongation produced the data. An R square value of 0.966 indicates that 96.6% of the variation in elongation can be explained by variations in denier size, whereas the remaining 3.4% is influenced by other factors. The negative regression coefficient of  $- 1.439$  indicates that each

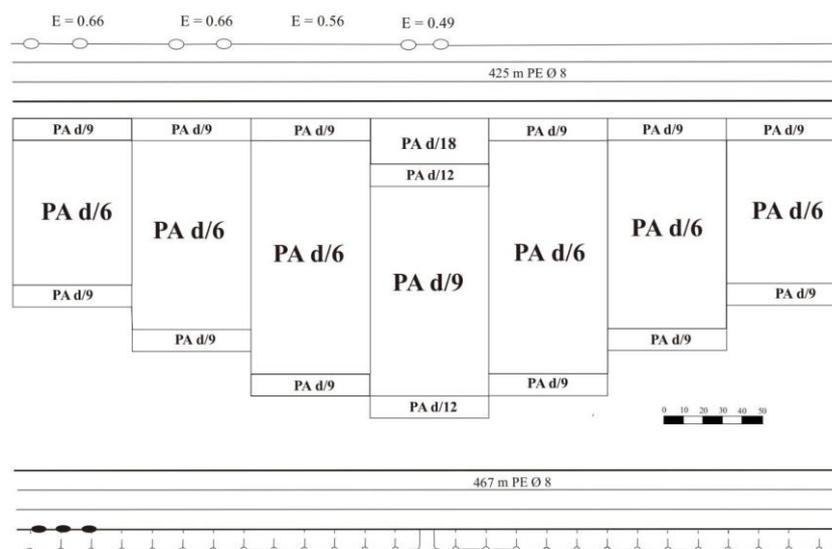
one-unit increase in denier decreases the elongation value by 1.439%. A significance value of 0.017 ( $< 0.05$ ) proves that the effect of denier size on elongation is statistically significant.

### 3.5. Practical Implications for the Construction of Purse Seine Nets

The practical implications for the construction of purse seine nets based on the research findings presented are shown in Figure 1. High-strength d/18 yarn (29.05 kgf) is highly suitable for use in parts of the purse seine net that experience the highest loads, such as the bunt, where the catch accumulates, and the upper and lower ropes that receive concentrated tension from the hauling mechanism. The lower elongation (28.41%) in these parts is beneficial because it maintains the stability of the bunt shape and prevents mesh deformation, which could allow fish to escape.

For the body and wing sections of the net, threads d/9 to d/12 with a medium breaking strength (15.14–20.99 kgf) and moderate elongation (32.63–37.99%) provide the balance between the strength and flexibility needed to follow the movement of water and form an effective pocket. Thread d/6, with the lowest breaking strength (8.76 kgf) and the highest elongation (44.71%), is more suitable for parts of the body or wings of the net that do not experience extreme loads, where flexibility is prioritized.

Although denier size has been shown to have a dominant influence on breaking strength (99.4%) and elongation (96.6%), other factors, such as exposure to sunlight, must be considered in practical applications. The breaking strength value of nets stored in the open decreases; therefore, with the same strength, the net will break before reaching the standard breaking strength, and the elongation value will be small [14]. Azzahra [9] also reported that nets placed outdoors and exposed to direct sunlight experience a significant decrease in breaking strength over time. Operational factors, such as friction during net retrieval, tension caused by fish movement, and tension due to currents or waves, also contribute to the decline in thread quality over time [9]. Therefore, a comprehensive understanding of the basic characteristics of the threads produced in this study is an important first step before considering these degradation factors in estimating the service life of nets.



**Figure 1. Purse Seine Design with Differences in Net Thread Diameter Usage.**

#### 4. CONCLUSION

This study successfully characterized the breaking strength and elongation of polyamide multifilament twines (d/6, d/9, d/12, and d/18) used in purse seine construction, revealing that breaking strength increased proportionally with denier size (from 8.76 kgf for d/6 to 29.05 kgf for d/18), while elongation decreased inversely (from 44.71% for d/6 to 28.41% for d/18), with statistical analysis confirming strong correlations for both parameters. These findings provide quantitative baseline data that enable evidence-based selection of appropriate twine sizes for specific net sections—d/18 for high-stress areas such as bunt and rope lines, d/12 for net bodies, and d/9 with d/6 for wing sections requiring greater flexibility.

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