Experimental Study on Resistance Characteristics of Three-Stranded Polyethylene Twines in Flow

Huang Liuyi
College of Fishery
Ocean University of China
Qingdao 266003, China
huangly@ouc.edu.cn

Zhang Lin
College of Fishery
Ocean University of China
Qingdao 266003, Chin
z.lin28@hotmail.com

Xu Qingchang
College of Fishery
Ocean University of China
Qingdao 266003, China
xuqcouc@gmail.com

Liang Zhenlin
College of Ocean
Shan Dong University (Weihai)
Weihai 264209, China
Liang@ouc.edu.cn

Wang Xinxin
College of Fishery
Ocean University of China
Qingdao 266003, China
Luckyxin@ouc.edu.cn

Wan Rong
College of Fishery
Ocean University of China
Qingdao 266003, China
rongwan@ouc.edu.cn

Zhao Fenfang
College of Fishery
Ocean University of China
Qingdao 266003, China
Zhaoff@ouc.edu.cn

Shi Jiangao
East China Sea Fisheries Research Institute
Shanghai 264209, China
jiangaoshi666@163.com

Abstract: Three-stranded polyethylene twine is one of the basic materials for woven mesh. It is popularly used to make net wing, net body, cod-end etc. The water resistance of the twines plays an important role in the shape and performance of these fishing gears. A testing device was designed to measure the hydrodynamic properties of twines, which is fixed on the towing carriage. The water resistance is measured for five types of twines with the attack angle equal to 90° and the towing speed is set within the range of 0.2m/s-1.6m/s. The results of the present study may provide basic parameters for the theoretical calculation and numerical simulation of meshes, netting gears, sea cages or other fishery facilities. It can be obtained the following results through data analysis.

At all the testing speeds, the drag force per unit twine length is proportional to the square of towing speed. The correlation coefficient is larger than 0.99, which is in agreement with the Morison equation.

Drag coefficient shows a slowly decreasing trend as the Reynolds number is within the range of 3.5×10^2~ 6.0×10^3. It can be expressed in a power function $Cx = 2.291R_d^{-0.051}$ through regression analysis.

Keywords: three stranded polyethylene twine; flume experiment; resistance; drag coefficient

I. INTRODUCTION

The three-strand polyethylene twine is one of the main materials for making meshes. It is the most widely used material for fishing netting, such as trawl, purse seine, fyke net and other fishing gears [1-2]. The hydrodynamic force and the shape of fishing gears are coupled. They are two main factors that affect both the operating performance of nets and energy consumption of fishing vessels [3]. Particularly in trawl fisheries, the net resistance accounts for the 38.7%-60.5% of total drag in trawl system according to the previous research [4]. So the study on hydrodynamic parameters of the basic components, i.e. the netting twine, has a great significance to the gear design and energy-saving of fishery [4-5]. Scholars at home and abroad had done a lot of research on hydrodynamics of ropes [6-12]. As the fiber twines are considered, relevant research reports have hardly been found because it is difficult to make accurate measurement due to the small diameter of twines (less than 4mm in diameter) and its flexibility. Consequently, the basic parameters such as drag coefficient and so on, which play an important role in the theoretical and numerical calculation of meshes, fishing gears, sea cages or other fishery facilities [13-15], can only be deduced from the experimental results of steel-wires or smooth cylinders as mentioned above. However, due to the tiny twine dimension, its hydrodynamic parameters may differ from smooth cylindrical or steel wires.

In the present paper, a special device to measure hydrodynamic force of twines is independently developed. The device is designed to reduce the effect on the flow pattern as much as possible. The force acting on a single twine is too small for a load cell to make accurate measurement. So, plural twines are measured at the same time and the results are easily converted to the value for a single twine. The present research enriched the theory of fishery gear. It provides the basic parameters for theoretical calculation and numerical simulation in the research of meshes, netting gears, sea cages or other fishing gears. It can be applied to the design of energy-saving and environment-friendly fishing gears.

II. MATERIALS AND METHODS

A. Experimental equipment

The experiments were carried out in the towing tank in the East China Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences. The main parameters of the tank are given as follows. The dimension of the test section is 90m×6m×3m（L×W×H）and the velocity of the tank carriage can be adjusted in the range of 0-4.0m/s. A uniform flow or current is realized by moving the carriage, together with the testing device fixed on it, at constant speed.

An underwater load cell measuring three axial components of force is independently developed by the authors, which can measure forces in the range of 0-50N with an error high than 1%. It was designed in a shape of elliptic cylinder to reduce the flow impact on the measurement of forces when working underwater. Its major axis, coinciding with the flow direction, is taken as the *X*-axis. The minor axis is defined as the *Y*-axis The cylindrical axis, perpendicular to the cross section, is the *Z*-axis (see Fig. 1). Two load cells, designated as No. 1 and No.3 respectively, are used underwater in the tests.

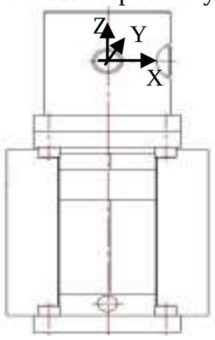


Figure1. Picture of three axial force sensors (load cell)

The load cell is firstly measured in current at idle condition, i.e. without loading any twines. The measured resistance against the current speed is plotted in Fig 2. The ordinate axis in Fig. 2 is scaled to 40N, which is the maximum resistance obtained in the loading tests. It can be observed that the force acting on the load cell in unloading tests is small. This implies that the effect of underwater instrument is very small.

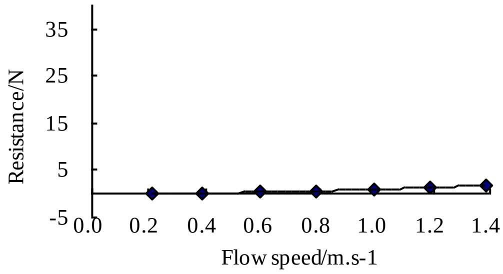


Figure2. Force impact on load cell by current at idle condition（No.1load cell）

B. Experimental material

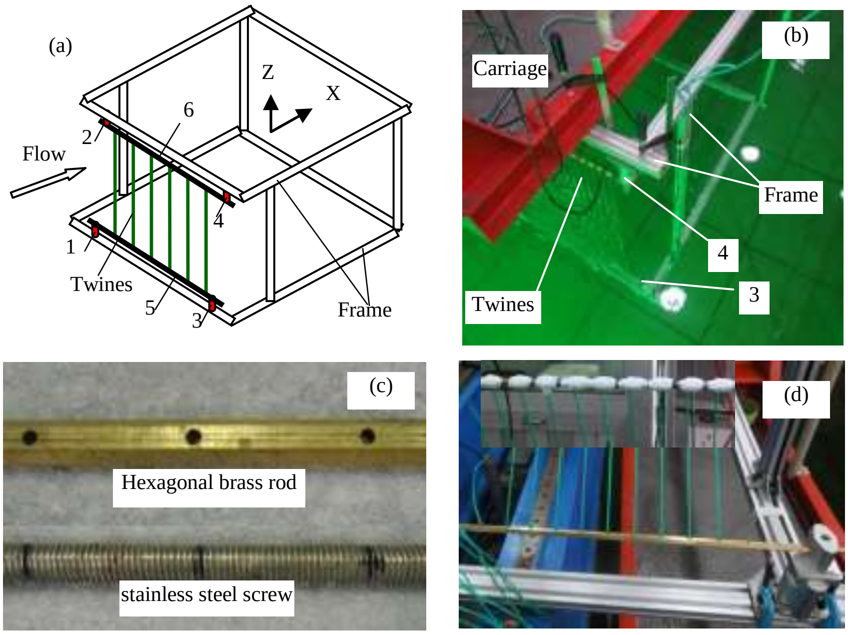
Wire diameter is measured using "around the stick method". The parameters of three-strand PE twines used in experiment is illustrated in Tab.1

TABLEI. PARAMETERS OF THREE-STRAND PE TWINES USED IN EXPERIMENT

No	Diameter /mm	Lay length /mm	Structure	Line density /Diner	Direction of twist
1	3.15	18.0	3×40	280	S
2	2.57	14.7	3×30	280	S
3	2.15	12.9	3×20	280	S
4	1.93	17.0	3×15	280	S
5	1.56	10.7	3×12	280	S

C. Experimental arrangement

A frame made of HF-3060 aluminum extrusion is constructed through connectors in the experiment, the dimension of which is 1.60m×1.25m×1.60m（L×W×H). In order to reduce the effect on the measurement, the front vertical rods of the frame, i.e. facing the flow, are installed at 0.30m behind the front crossbar (Fig. 3 (a)). The frame is fixed on the towing carriage with its front face perpendicular to the moving direction of the carriage so that the flow is normal to the twine axis (Fig.3 (b)). Four load cells are fixed in front of the frame to measure the tension of twines. A hexagonal brass rod is fixed between two load cells (No.1 and No.3) which are installed underwater. Its length is 1.10m and diameter is 1.0cm. Holes are drilled through two opposite faces of the hexagonal rod with an interval of 4.0cm. Testing twines are knotted at one end and passed through the holes from the bottom with knot hiding in the hole. One of the six corners of the rod is facing the flow direction to reduce the impact on the flow pattern. Using a hexagonal rod, instead of a circular rod, is to avoid vibration induced by flow, which might affect the accuracy of the measurement. The other two load cells are fixed above water and connected by a screw rod made of stainless steel with a length of 1.00m and a diameter of 1.0cm. The other end of testing twines is pasted on the screw rod with an interval of 4cm corresponding to the bottom brass rod. The fixed points of testing twines on two rods are adjusted to keep



Flow

the twines in a vertical position. A total of 20 twines are assembled in one test. A certain value of pretension, i.e. the pretension for measuring the twine diameter (about the weight of a twine 250m long), is loaded to the testing twines (Fig.3 (c, d)). According to the computer simulation before the experiment, the flow interference is negligible when the distance between two twines is more than 8-9 times of the twine diameter. The maximum twine diameter is 3.15mm in the present experiment. With a space of 4cm, the flow interference may be considered as negligibly small. Before each formal test, the tank carriage firstly runs without recording any data and let the flow act on the twines. When the system is stable, the carriage is stopped and all the instruments are reset. After the water calmed down, the test will then be started formally and measurement will be made.

In the present study, the flow direction is defined as the *X*-direction and the *Z*-direction is vertical and pointing upward.

D. Experimental cases

Only one attack angle is set in all the tests, i.e. the flow is perpendicular to the twine axis. The tests run at 6 flow speeds. The experimental cases are illustrated in Tab.2.

TABLEII. LIST OF EXPERIMENTAL TEST CASES

Attack angle	90°
Current velocity(m/s)	0.2, 0.4, 0.6, 0.8, 1.2,1.6
Length of experimental twines(m)	1.105
Number of experimental twines	20

E. Data processing

Hydrodynamic force and hydrodynamic coefficients

Hydrodynamic force can be decomposed into drag force and lift force in the two-dimension flow field as shown in Fig. 4. The component F_x coincides with the flow direction and is called as the drag force while the vertical one F_z is defined as lift force with α as the attack angle. The relationship between the forces and flow direction is shown in Fig.4.

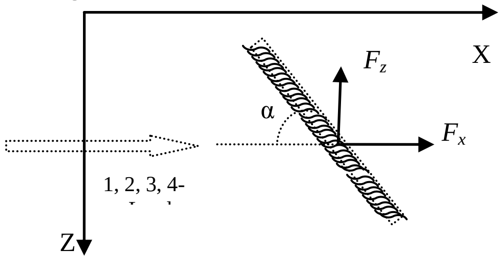


Figure4. The Definition of the hydrodynamic force components and flow direction

The purpose of this study is to investigate the drag force F_x and drag coefficient C_x at the attack angle equal to 90 °. The lift force is not considered in the present study as its measured value is very small for $\alpha = 90$ °.

The relation between drag and drag coefficient is given as follows:

$$F_x = \frac{1}{2} C_x \rho d l V^2 \qquad (1)$$

$$C_x = \frac{F}{\frac{1}{2}\rho d l V^2} \qquad (2)$$

where F_x- drag force (N);
C_x- drag coefficient (dimensionless);
ρ- water density (kg/m^3);
d- rope diameter (m); l- rope length (m);
V- current speed (m/s).

The Reynolds number Rd

The Reynolds number is defined as:

$$R_d = Vd / \nu \qquad (3)$$

where V- current speed (m/s);
ν-kinematic viscosity coefficient of water (m^2/s);
d- rope diameter(m).

During the experiment the water temperature is about 27°C. Hence, the kinematic viscosity coefficient of water is equal to $0.85409\times10^{-6}m^2/s$. The fresh water density is $996.49kg/m^3$. The Reynolds number of each experiment case can be calculated according to Eqn. (3).

Data acquisition for drag force

The frequency of data acquisition in the experiments is 100 *Hz*. The data is collected for a period of time after the towing speed of the carriage is stable. The average value is taken as the drag force of the whole system, from which the drag caused by the hexagonal brass rod is subtracted to obtain the drag acting on the testing twines. In order to standardize the study, all the measured results are converted to the drag force per unit twine length (N/m), which is used as the basic data for the later analysis.

The drag force acting on the hexagonal brass rod is pretested in the experiments without loading the twines at various test speeds. The results are plotted in Fig.5. It shows that this drag force is proportional to the square of current speed. A parabola curve F_x=11.01V^2 （R^2 = 0.997）is obtained after regression analysis.

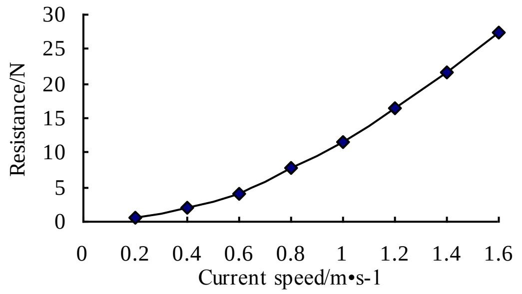


Figure5. Drag force acting on unloaded hexagonal brass rod in current

III. EXPERIMENT RESULTS

A. Measured drag force

Plotted in Fig.6 are the total measured drag forces acting on the 20 testing twines of five different sizes against the current speed varying from 0.2 to 1.6m/s. It shows that the drag force is a quadratic function of the current speed by means of regression analysis and the correlation coefficient R^2 is larger than 0.99 in all the cases.

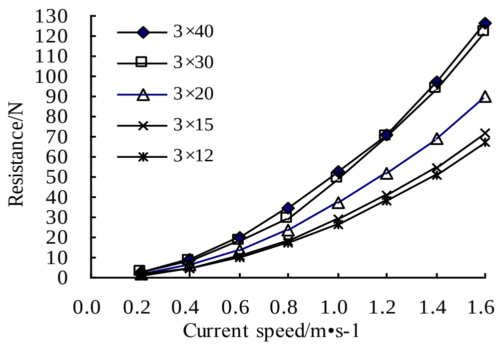


Figure6. Resistance of twines against the current speed

B. Drag force per unit twine length

The measured overall drag forces are converted to the force per unit twine length as mentioned earlier. The results are presented in Fig.7. The regression analysis shows that the drag force per unit length for all the five types of testing twines is proportional to the square of the current speed as well. The regression equations of drag force per unit length as a function of current speed are listed in Table3.

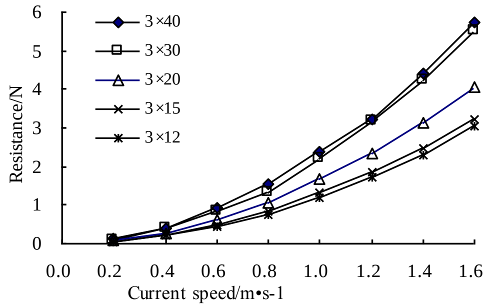


Figure7. Drag force per unit twine length against the current speed.

C. Drag coefficient

The relationship between drag coefficient and Reynolds number

According to the Eqn. (2) and (3), drag coefficient and Reynolds number are calculated and the results are plotted tin Fig.8. As seen from the figure, the drag coefficient shows a slowly downward trend within the testing range of $3.5\times10^2< R_d <6\times10^3$. It can be approximately expressed as C_x= 2.76 $R_d^{-0.075}$ after regression analysis.

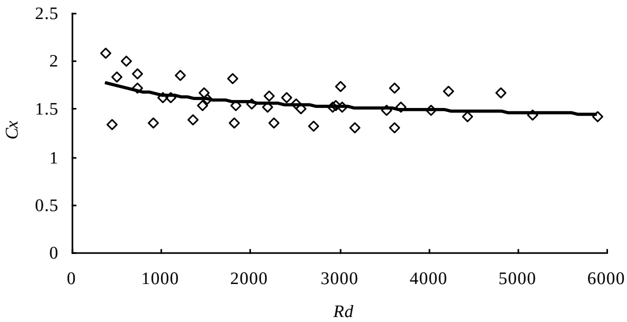


Figure8. Variation of drag coefficients C_x vs. the Reynolds number R_d

Drag coefficient against ratio between the twine diameter and length

[3] ZHOU Yingqi, The Dynamics of Fishing Gear， China Agriculture Press, Beijing, pp:1-2;27-29,2001.

Shown in Fig.9 is the relationship of drag coefficient with the ratio between the diameter and length of twines for five types of *D*/*L* (0.00315, 0.00257, 0.00215, 0.00193 and 0.00156) at various current speed. It can be seen from the figure that the drag coefficient C_x has the same change trend with the ratio *D*/*L* even at different testing speed. Under the same flow condition, C_x takes minimum value as D/L =0.00193 and this minimum value is close for different cases of current speed. For the same value of ratio D/L, The drag coefficient Cx decreases as the flow speed increases but the speed of 0.8 m/s is an exceptional case.

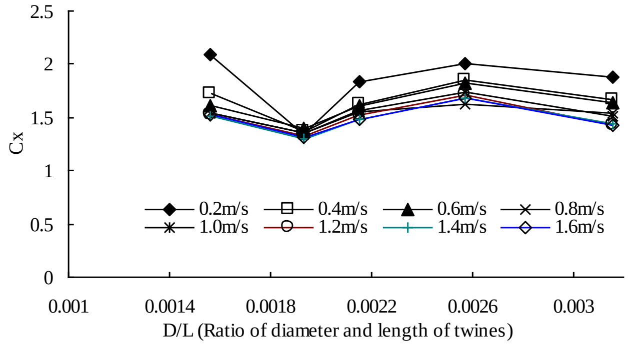


Figure9. The variation of drag coefficient vs. the ratio between the diameter and length of twines

IV. RESULTS AND DISCUSSION

(1) In the results for all the five types of test twines, the drag force per unit twine length is well proportional to the square of current speed. The correlation coefficient R^2 is larger than 0.99 in all the testing cases, which is in agreement with the Morison equation.

(2)Drag coefficient shows a slowly decreasing trend within the range of Reynolds number 3.5×10^2~ 6.0×10^3 and can be expressed as a power function $Cx=2.291R_d^{-0.051}$. A comparison is made in Fig.10 for the present results with those of Miyazaki et al. and Hoerner's studies of three-strand rope[8-10].It can be seen in Fig.10, the present results are close to that of Miyazaki et al, especially close to their results obtained from tests in wind tunnel. But, the present results are apparently greater than Hoerner's findings.

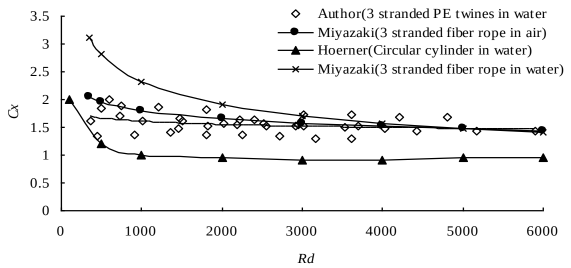


Figure10. A comparison of the relationship between drag coefficient and the Reynolds number.

(3)Under the same condition of D/L, The drag coefficient C_x decreases with the increasing of current speed. The same trend can be observed in the relation of drag coefficient and Reynolds number. With the same value of D/L, the smaller velocity means the smaller Reynolds number. The overall trend of drag coefficient decreases with the increasing Reynolds number. At the same current speed, the drag coefficient C_x is minimum when D/L =0.00193 and this value is very close for different flow speed. A reasonable explanation for this phenomenon has not yet been found.

(4) In the future work, the range of testing speed should be further increased to investigate the drag force in a wider range of Reynolds number. The effect of attack angle on the hydrodynamic characteristics should be considered in the future study.

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