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Strength of Synthetic Fiber Ropes Degraded by Repetitive Bending

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A synthetic fiber rope which has lightweight, high tensile strength and flexibility is receiving a lot of attention as the replacement for a stainless steel wire rope. This paper takes note of durability of repetitive bending. We performed an experiment with two synthetic fiber ropes and one stainless steel wire rope in conformity with Japanese Industrial Standards. As a result, the stainless steel wire rope and one synthetic fiber rope which has high resistance to frictional wear didn't get loss of tensile strength. However, repeated bending causes the tensile strength deterioration of the other synthetic fiber rope which is weak in frictional wear.

1 Introduction

Recently, synthetic fiber ropes which have high performance are actively developed. Some of them have the same or larger strength than a stainless steel wire rope, moreover, they are particularly lightweight such that their density is 1/5 to 1/8 as a stainless steel wire rope. In addition, we can easily handle them such as making knot for the end part fixation because they are more flexible than a stainless steel wire rope. Taking advantages of the above features, many researchers apply them for tendon-driven robots[1][2], artificial muscles[3] and so forth.

In case of designing tendon-driven mechanism with metal wire ropes, many characters of them, e.g. tensile strength, are provided by International Organization for Standardization (ISO) or books[4] because a drive mechanism with a metal wire rope has been widely applied for robots, elevators, cranes and so forth for a very long time. On the other hand, concerning synthetic fiber ropes, although manufacturers provide some characters of original yarn[5], they also provide only tensile strength as physical properties when it is constructed as a rope. Although there are some researches which study about physical properties of synthetic fiber rope[6], there is no research which provide systematic design guideline and there is less physical data to develop a truly practical drive mechanism now. Advancing the study of physical properties of the synthetic fiber rope in the future, we can get great opportunity for developing new lightweight, compact and robust drive mechanisms which have not been achieved with conventional metal wire rope.

The ultimate goal of this research is developing a design methodology with a synthetic fiber rope, and this research would be a groundwork for all researches which use synthetic fiber ropes. As one step of the research, in this paper, we clarify the influence of repetitive bending on tensile strength.

2 Durability against Repetitive Bending

Many tendon-driven mechanism consist of ropes and pulleys. In this case, some part of a rope get bended and stretched repeatedly by rotating pulley. It is considered that fatigue of this part cause tensile strength reduction.

The Japanese Industrial Standards (JIS) of wire ropes for an airplane provides tensile strength of a rope after getting repetitive bending under the specific experiment, such as over 50% of the original tensile strength with a carbon steel wire rope and over 60% with a stainless steel wire rope. On the other hand, there isn't such a regulation of an experiment method and tensile strength with a synthetic fiber rope, therefore, we can't say that it is strictly possible to operate tendon-driven mechanism with a synthetic fiber rope on a long-term basis. This research makes a repetitive bending experiment with a synthetic fiber rope and measures the durability exprimentally.

3 Experiment Device and Samples

In order to make the experiment result generic, we carried out the experiment in accordance with JIS. Fig. 1 shows an experiment device we developed. We can get four samples per one experiment because this device has four testing pulleys. This device has two experiment devices, which is provided by JIS as shown in Fig. 2, on both sides of linear actuator (T6L-20-600-3L-SR1-X05N-B, YAMAHA). Two testing ropes in each device are drawn as red and blue lines in Fig. 1. In the experiment, the testing rope which is set to the device performs reciprocating motion over 343 mm and gets repetitive bending. After specific number of reciprocating motion, we evaluate durability by measuring tensile strength. We use a linear actuator instead of a cylinder JIS provided because we can set the distance and the speed of the reciprocating motion and count repeated number easily and precisely. We also changed a cylinder as a driving source in JIS to a sheave

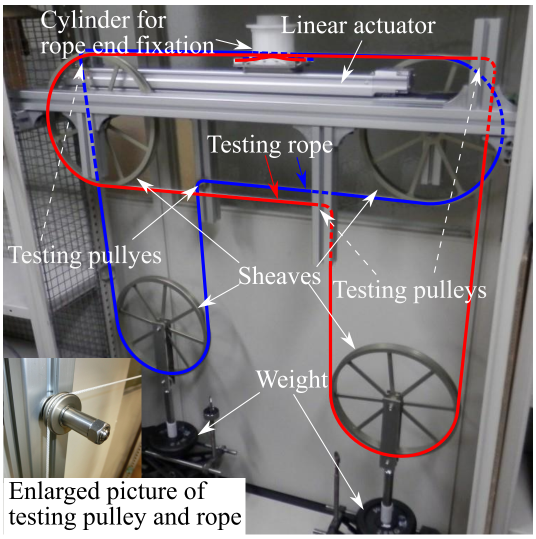

Fig. 1 Durability experiment device

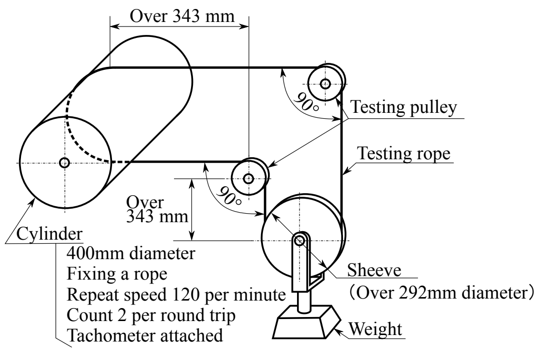

Fig. 2 Model of durability experiment device provided by JIS G3535[1]

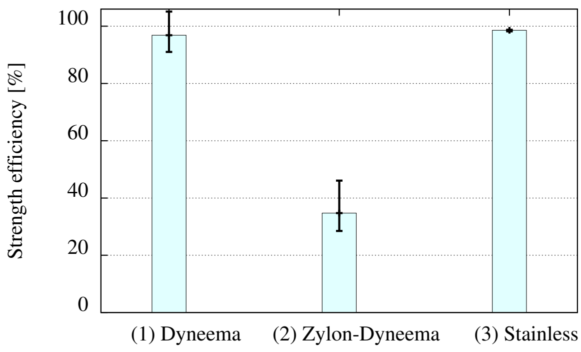

Fig. 3 Strength efficiency of durability tested ropes

of 300 mm diameter.

We carried out the experiments with three types of ropes of 2.0 mm diameter, (1) Dyneema (ultra high molecular weight polyethylene fiber rope, DB-60, Hayami Industry Co., Ltd.), (2) Zylon-Dyneema (Zylon, PBO fiber rope, covered with Dyneema, DY-20ZL, Hayami Industry Co., Ltd.) and (3) Stainless (stainless steel wire rope, 7×19, Asahi Intecc Co., Ltd). Table 1 shows experiment conditions. This conditions are calculated by linear interpolation with conditions of 1.59 mm and 2.38 mm rope diameter provided by JIS. In this research we performed 70,000 repetitive motion and it requires around 9 hours and 43 minutes per one experiment.

4 Experiment Results

We measure tensile strength of the ropes with tensile testing device (AG-I, Shimadzu co., 100 kN maximum load) and calculate strength efficiency by the following equation:

$$\text{Strength efficiency} = \frac{\text{Tensile strength after repetitive bending}}{\text{Tensile strength before repetitive bending}} [\%]$$

Now, the tensile strength before repetitive bending of (1), (2) and (3) ropes are 2.14 kN, 2.99 kN and 3.50 kN respectively. Fig. 3 shows strength efficiency of three types of ropes with four samples respectively. Since (1) and (3) show over 95 % strength efficiency, they don't get strength reduction from repetitive bending. On the other hand, the strength efficiency of (2) is around 30 %. This is because the friction occurs in the rubbing of fibers when a rope get bended and stretched, and Zylon which is weak at friction gets degradation.

5 Conclusion

We paid attention to the strength reduction by repetitive bending of a synthetic fiber rope and measured durability with the experiment JIS provided. We disclosed that Dyneema which is strong at friction didn't cause strength reduction, however, Zylon which is weak at friction causes large strength reduction by repetitive bending experiment. In our future works, we will perform the same experiment with the other synthetic fiber ropes, moreover, get generic data by changing the experiment conditions to the one close to the real tendon-driven mechanism.

Table 1 Experiment conditions at 2.0 mm rope diameter

Tension	Repeat number	Transfer distance	Testing pulley diameter
31.3 N	70000	343 mm	24.0 mm

[1] By reference to [7]

Acknowledgement

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