論文 / 著書情報
Article / Book Information

論題(和文)	衝撃力を受ける合成繊維ロープの剛性
Title(English)	Stiffness of Synthetic Fiber Ropes under Impact Loading
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出典(和文)	, , , pp. 5-10
Citation(English)	The Japnese Society for Non-Destructive Inspection, , , pp. 5-10
発行日 / Pub. date	2017, 3

衝撃力を受ける合成繊維ロープの剛性

Stiffness of Synthetic Fiber Ropes under Impact Loading

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Abstract(概　要)

The aim of this research is to study the effect of consecutive impact loading on the Synthetic Fiber Ropes. Five different high tensile strength synthetic fiber ropes which are typically employed in robotic fields are used in this research namely, High Modulus Polyethylene (HMPE) (Dyneema SK-60, SK-71), Aramid (Kevlar 308, Technora 308), and a combination of poly(p-phenylene-2,6-benzobisoxazole) (Zylon) with polyethylene terephthalate (Polyester), i.e., Zylon-polyester SZ-20. Five consecutive impact loading (5 drops) are applied to those ropes and the stiffness is evaluated for each drop. The stiffness corresponding to the 1^{st} drop has smallest value compare to those of the 2^{nd} to 5^{th} drops for each rope and it tends to be constant from 4^{th} to 5^{th} drops for HMPE Dyneema SK-60 while the others have almost the same stiffness from the 3^{rd} to 5^{th} drop respectively. In order to compare with synthetic fiber ropes, consecutive impact loading also performs for wire rope and it shows that the stiffness of wire rope has almost the same value for each drop which means that consecutive impact loading has no influence to change stiffness of wire rope. Unlike wire rope, synthetic fiber ropes are affected by the consecutive impact loading by changing the stiffness with the number of drops.

Keywords: Synthetic Fiber Rope, HMPE, Aramid, Consecutive Impact Loading, Wire Rope, Stiffness.

１．Introduction

Synthetic Fiber Ropes like High Modulus Polythylene (HMPE), Polyester, Polyamid and Aramid have been developed decades ago and recently they became an alternative material to replace wire ropes because they could offer many advantages such as light weight, high strength, more flexibility, low coefficient of friction, abrasion, etc. Based on these advantages, they have been used in many applications such as offshore mooring systems, climbing mountaineering ropes and recently they have widely been used in the robotic domain as in artificial muscles [1], tendon-driven robots [2-3] and active endoscopes [4].

Although synthetic fiber ropes have been applied in many applications, their mechanical behaviors are still in complicated perhaps mainly due to polymeric nature of fibers used to make them and geometry construction of the ropes. Therefore, many researchers had studied mechanical characteristic of fiber ropes in both theoretically and experimentally [5-9]. It is well-known that synthetic fiber ropes are inelastic and viscos-elastic properties, hence, W. Huang et al. [5] had modelled nonlinear creep and recovery behaviors of fiber ropes for deep water mooring system under complex loading by considering both viscoelastic and viscoplastic behaviors. The mechanical behavior of HMPE and aramid fiber ropes for deep sea handling operations were investigated by P. Davies et al. [6] in which they had performed experiments to find the dynamic stiffness and creep behaviors in the case of dry and soaked conditions. J.F.Beltran et al. [7] evaluated degradation of fiber ropes that experienced under both monotonic and cyclic loads in numerical simulation then compared with experimental results. It is believed that the strength of fiber rope is reduced if it is bended over a small radius. Thus, A. Horigome et al. [8] had conducted an experiment in order to figure out relationship between tensile strength and bending ratio D/d, where D/2 is the curvature radius and d is the rope diameter. In another practical case for mountain climbers, it is very crucial in choosing a high quality ropes since their lives are strongly rely on the rope when climbing. Hence, A. Nikonov et al. [9], evaluated the functional properties of climbing ropes experienced to an impact loading with and without the presence of moisture.

Again refer to the used of fiber rope in robotic fields, mostly they are used in the arms of robot to lift or transfer objects from one place to another and as a result, the rope will degrade its strength with time and in addition it may encounter an impact force as well while in operation. Thus the objective of this research is to find out mechanical properties of fiber ropes including HMPE, Aramid, Zylon, and Polyester by determining the changing in stiffness of the ropes when subjected to consecutive impact loading. Moreover, stiffness of wire rope also investigated in order to compare with those of fiber ropes.

2. Materials and Experimental Setup

Materials used in the experiment are high strength of ropes which are HMPE (Dynnema SK-60, 71), Aramid (Kevlar-308, Technora 308), a combination of poly (p-phenylene-2, 6-benzobisoxazole) (Zylon) with polyethylene terephthalate (Polyester), i.e.,Zylon-polyester SZ-20 (Zylon inside, Polyester covered outside), and wire rope (SC-200). The properties and picture of these ropes are listed in Table1 and Fig.1 respectively.

Dyneema is made from High Modulus Polyethylene fiber that has low friction coefficient, high strength, lightweight, water resistance and abrasion resistance but it yields a large elongation and low melting temperature amount the ropes used in this research. Kevlar 308 and Technora 308 are aramid which has high tensile strength, abrasion resistance, low elongation, heat and chemical resistance. However, they are affected by UV light and water absorption. Zylon known as PBO (Poly (p-phenylene-2,6-benzibisoxazole)) is liquid crystal polymer developed by Japan-based Toyobo Co.,Ltd. It has the highest tensile strength, smallest elongation and heat resistance. Nonetheless, it has low abrasion, low light resistance and moisture absorption, thus normally it is protected by other materials covering outside and in this case it is covered by polyester due to


a) b) c) d) e) f)

Figure 1: Synthetic fiber ropes a) HMPE Dyneema SK-60, b) HMPE Dyneema SK-71, c) Aramid Kevlar 308, d) Aramid Technora 308, e) Zylon-Polyester SZ-20, f) Wire Rope SC-200

its resistance to abrasion, moisture and low elongation. Wire rope SC-200 is made by stainless steel which has 7 strands and each strand consists of 19 fibers. This rope is constructed in regular right lay.

Table 1: Properties of Synthetic Fiber Ropes and Stainless Steel Rope

Rope Model	DB-60	DB-96HSL	KB-308	TNB-308	SZ-20		SC-200
Fiber	Dyneema		Kevlar	Technora	Zylon (Inside)	Polyester (Outside)	SUS304
Fiber Model	SK-60	SK-71	Standard	Standard	AS		-
Tensile Strength (KN)	1.76	4.29	4.08	4.37	2.86		3.56
Structure	1760 dtex, 8 braids	2640 dtex, 8 braids	3340 dtex, 8 braids	3340 dtex, 8 braids	1670 dtex, 6 strands	1100 dtex, 16 braids	7 x 19 Right Regular Lay
Diameter (mm)	2						
Supplier	HAYAMI Industry						SHINYO

Impact tester as shown in Fig.2 was developed in order to conduct an impact testing of the ropes. There are 5 main components in this apparatus, first is the drop mass with the weight of 5.10 kg used to generate as an impact load by dropping at the height of 1.2m. Second part located beneath of drop mass is the steel plate used to fix the ropes at the bottom end. The third component used in this experiment is rotating winch at the right side of structure that is used to lift and release the drop mass by connecting with rope.
To record impact load due to drop mass experienced on fiber/wire ropes, the fourth component loadcell LUK-A-10 KN is utilized by mounting on the top of structure and fiber/wire ropes are fixed with load cell as well. The fifth component is the draw-wire displacement sensor (DP-500E) used to measure the elongation of ropes. All the ropes are

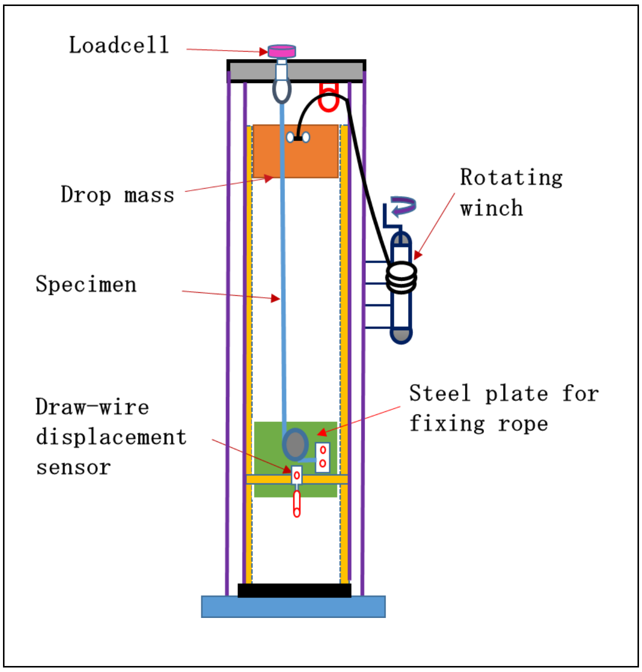

Figure 2: Impact testing structure

tested at room temperature and experienced to 5 consecutive drops.

3. Experimental Results and Analysis

The obtained results are force and displacement with respect to time for each drop then the stiffness can be determined by using linear curve fitting in the linear region of plotting force versus displacement. Figure 3 shows the plot of force versus displacement for 1st to 5th drop for HMPE Dyneema SK-60 with respect to each drop. Results in Fig.3 show that at the 1st drop, there is a huge displacement value compare to the rest of the drops (2nd to 5th drops) whereas the force corresponds to the 1st drop has the smallest value compare to the others. As a consequence, the stiffness of the 1st impact loading has the smallest value compare those to the rest and the stiffness is drastically increased with the number of consecutive impact loading. The results of HMPE Dynnema SK-71, Aramid (Kevalr 308, Technora 308), and Zylon-polyester SZ-20 are shown in Fig.4, Fig.5, Fig. 6 and Fig. 7 respectively. All results show the similarity that displacement at the 1st drop has biggest value compare to those of the 2nd to 5th drops which implies that at the 1st drop the stiffness has smallest value compare to the others. However, in general case the stiffness tends to be constant from the 3rd to 5th drop except the HMPE Dyneema SK-60 which need one more drop in order to have stiffness constant. Unlike synthetic fiber ropes, the wire rope yields almost the same elongation and force for all drops as depicted in Fig. 8. As results wire rope has almost the same stiffness regardless the number of drop applied. Table 2 shows the results of stiffness for all synthetic fiber ropes and

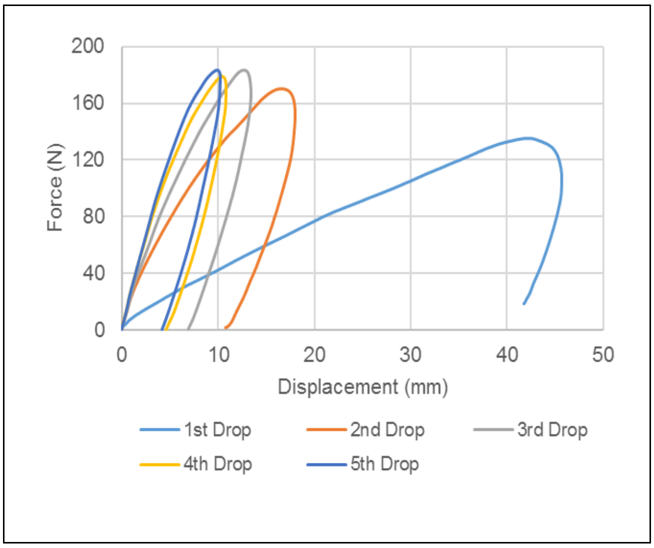

Figure 3: Force Vs displacement of HMPE Dyneema SK-60

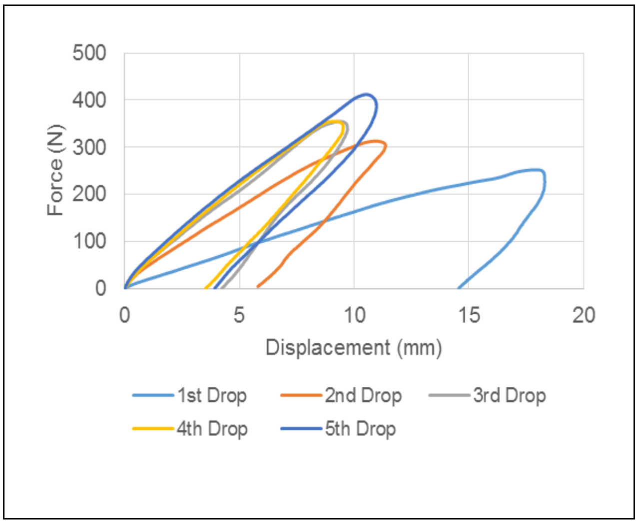

Figure 4: Force Vs displacement of HMPE Dyneema SK-71

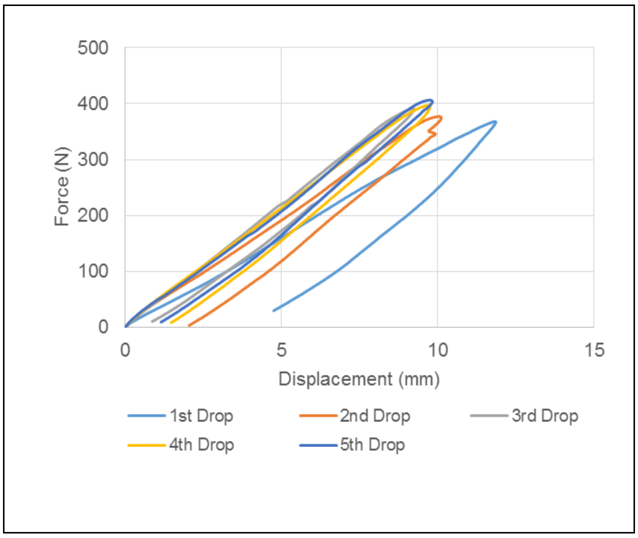

Figure 5: Force Vs displacement of Aramid Kevlar 308

wire rope for each drops. According to the results of all fiber ropes and wire rope, the stiffness due to consecutive impact loading has significantly effect to change properties of synthetic fiber rope in such a way that stiffness increase with the number of drops especially at the first drop the stiffness have lowest value compare to those of the next drops. These phenomena occur in all viscoelastic ropes due to materials used to produce them and especially the construction geometry of the ropes. Once the ropes experience the first loading, all fibers, strands in the ropes tend to move toward to loading direction. Therefore, ropes become more compact and tighten after the first loading then they will be stiffer and stiffer for the next loading. Their strength will be reduced if loading still present due to the internal friction between fiber and fiber and/or stand and strand. Unlike synthetic fiber rope, wire rope does not exist the same properties since its geometry is already compact and there is no gap between strands. Moreover, the material used to produce wire rope is not viscoelastic like fiber rope.

4. Conclusion

Conclusion can be extracted from the above results as follows:

- Synthetic Fiber Ropes are strongly affected by consecutive impact loading by changing the stiffness in such a way that stiffness is increased with the number of drops. Nonetheless, the stiffness becomes stable from the 4th to 5th drops in case of HMPE Dyneema SK-60 and from 3rd to 5th for the others. Increasing in stiffness occurs after the rearrangement of microstructure as well as macrostructure of rope's components.
- Stainless steel rope is not affected by

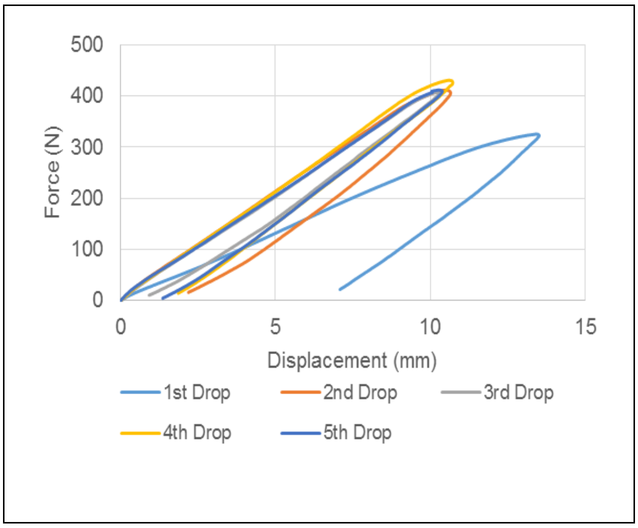

Figure 6: Force Vs displacement of Aramid Technora 308

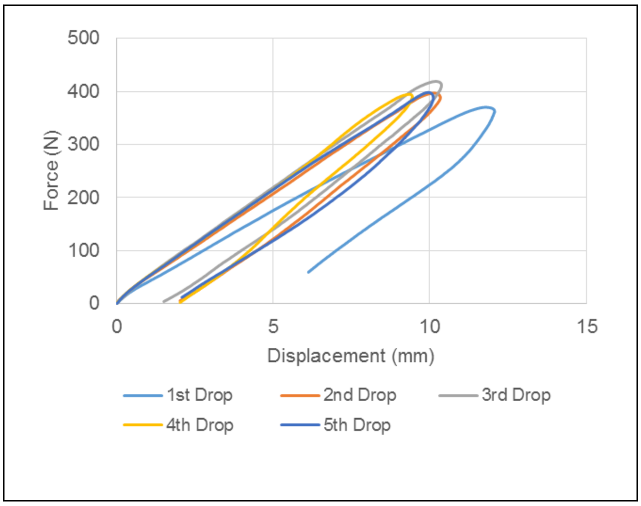

Figure 7: Force Vs displacement of Zylon-Polyester SZ-20

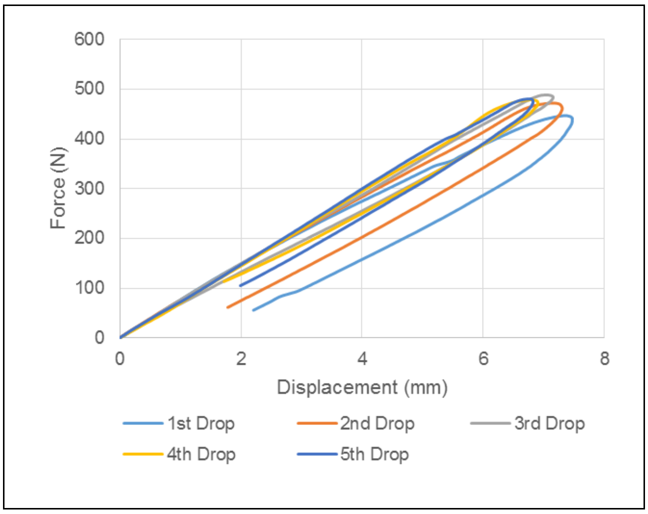

Figure 8: Force Vs displacement of Wire rope SC-200

consecutive impact loading since its stiffness is almost constant in each drop.

Table 2: Stiffness of all ropes due to 5 consecutive impact loading

N. of Drop	1	2	3	4	5
Stiffness	K_1 (N/mm)	K_2 (N/mm)	K_3 (N/mm)	K_4 (N/mm)	K_5 (N/mm)
HMPE Dyneema SK-60	4.38	14.52	18.61	22.6	24.24
HMPE Dyneema SK-71	16.23	32.26	39.67	41.98	41.76
Aramid Kevlar KB-308	31.00	37.32	43.61	41.71	40.59
Aramid Technora TNB-308	26.06	41.73	39.97	41.79	39.84
Zylon-Polyester SZ-20	33.86	40.16	42.76	41.87	41.75
Wire rope SC-200	70.27	70.24	71.47	74.01	74.58

Acknowledgement

This paper is based on results obtained from a project commissioned by the New Energy and Industrial Technology Development Organization (NEDO)

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