MECHANICAL PROPERTIES OF JUTE FIBER USING THE HEAT TREATMENT METHOD

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ABSTRACT
Recently, there has been a serious environmental problem with waste disposal. For fiber reinforced composite, natural fibers such as bamboo kenaf, jute, and hemp fibers are focused on instead of using glass fibers. The study of mechanical properties of these composites has been conducted. The number of papers for green composite is much increased. Jute fibers have been used as reinforcement of composite because of the huge market and low cost. But natural fibers might have poor properties under high temperature environments. So, in this study, heat treatment was applied to jute fibers. TGA-50 (Shimadzu Co.) is also used to measure the mass loss of jute fiber. The temperature range is from room temperature to 550°C. The increase rate of the temperature is 10° per minute. The following conclusions have been obtained from this study: (1) The mass of jute fibers decreases over 260°C the mass-loss rate becomes small over 330°C. The cellulose decomposed between 290°C and 330°C. And lignin decomposed between 260°C and 450°C; (2) Debonding between longitudinal fibers occurs at 260°C. The debonding becomes big at 320°C; and (3) As the heat treatment temperature increases, tensile strength and stiffness decreases due to cracks at the fiber surface.
Keywords: natural fiber, jute fiber, heat treatment, tensile property, strength.

1 INTRODUCTION

Recently, mechanical properties of green composites whose reinforcement is natural fiber have been researched. Generally, natural fibers from plant have a nature of carbon neutral [1] which means that it absorbs carbon dioxide during its growth period. However, green composite has less strength compared with glass fiber reinforced composite. The main content of natural fiber is cellulose, volume fraction of cellulose depends on tensile strength of the natural fiber.

Klinke et al. [2] reported that the tensile strength is high as cellulose volume content is high or the align angle of cellulose micro fibril is small. The structure of natural fiber can be divided into three parts, that is, cell surface membrane, primary wall and secondary wall. The volume fraction of cellulose is small in cell surface membrane and primary wall. On the other hand, secondary wall has a high-volume fraction of cellulose and align angle of cellulose is high [3]. Thus, by removing cell surface membrane and primary wall, volume fraction of cellulose increases since only secondary wall remains, and it is possible to increase the strength of natural fiber.

As the methodology of cellulose extraction, heat treatment is effective in air or nitrogen atmosphere because chemical treatment for example alkali or acetone treatments has high cost [4]. Tanaka and Funaki [5] reported that the tensile strength of green composite, which consists from rice hull and biodegradable resin, increased by heat treatment of rice hull at 600°C. Ochi and Takagi [6] also reported that the tensile strength of green composite which contained bamboo or linen fibers increased by heat treatments. Okabe et al. [7] reported that bending strength and stiffness of wood plastic composites are improved by heat treatment under 800°C. Therefore, it is understood that the heat treatment of reinforcement for green composite is effective to its mechanical properties.

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In this study, jute fiber is used as reinforcement for green composite since Jute fiber has relatively higher volume fraction of cellulose compared with other natural fibers. So, the optimum temperature of heat treatment must be examined for removing the cell surface membrane and primary only to remain the secondary wall. In this study, the motivation is to find the effective temperature to obtain the high-volume content of cellulose in jute fiber. The decomposition temperature of jute fiber, surface morphology after heat treatment, tensile strength and stiffness are examined.

2 MATERIALS AND TEST CONDITIONS

2.1 Thermo gravimetric analysis (TGA) of jute fiber

TGA test was conducted in order to examine thermal decomposition behaviour from mass decrease by heat treatment. TGA-50 (Shimadzu Co. Ltd.) apparatus was used. The temperature range was from room temperature to 550°C. The increase rate of temperature was 10° per minute. The gas atmosphere was nitrogen. For removing moisture in jute fiber, temperature kept at 100°C for 40 minutes and subsequently the temperature also increased at 10° per minute rate.

2.2 Heat treatment and SEM observation of jute fiber

Heat treatment of jute fiber was conducted under nitrogen atmosphere by using electric furnace F0-510 (Yamato Science Co. Ltd.) which temperature profile is programable. The heating conditions was corresponded to TGA measurement. To evaporate the moisture of jute fiber, temperature kept at 100°C for 40 minutes. Subsequently, the temperature went up to end-point temperature (250°C, 260°C, 270°C, 280°C, 290°C, 320°C) with heating rate of 10° per minutes. After temperature reached to end-point temperature, heat-treated jute fiber was removed immediately from electric furnace and it was cooled in air.

The surface of jute fiber after this heat treatment was observed by scanning electron microscope (SEM) (VE-7800, KEYENCE Co.) in order to investigate the surface variation during heat treatment. Jute fiber is non-conductor in electrically, so the surface of jute fiber must be coated by gold particles using sputtering apparatus (Model SC-701MkII, Sanyu Electron Co. Ltd.). For SEM observation, jute fibers after heat treatment under four heat conditions were used. One is non-heat treatment, other condition of heat treatments is that the end-point temperatures are 260°C, 290°C and 320°C.

2.3 X ray diffraction (XRD) analysis of jute fiber

X ray diffraction (XRD) analysis was conducted in order to examine the formulations of the jute fiber. XRD analysis was conducted for heat-treated jute fiber under four heat conditions as mentioned in Section 2.2. RINT-Ultima III (Rigaku Co. Ltd.) apparatus was used for this test. Jute fibers are grinded into powder for preparing the sample for XRD analysis. The results of XRD analysis obtained as relationship between diffracted intensity and angle diffraction. The ordinate axis is diffracted intensity and is abscissa axis is angle of diffraction. The angle of diffraction was recorded at the peak point of diffracted intensity. As measurement condition, irradiation degrees were from 10° to 90°, the velocity of irradiation degree was 2° per minute, discharge slit was 0.1 mm and divergence vertical limit of diffusion slit was 10 mm. Scattered slit and light-receiving slit were open state.

2.4 Tensile test of jute fiber

Static tensile test was conducted by using tabletop test machine (STB-1225S, A&D Co. Ltd.). The specimens were used for untreated jute fibers and heat-treated jute fibers under following conditions of heat treatment as mentioned in Section 2.4. Please note that tensile test did not conduct for the heat-treated specimens under only 320°C condition due to brittle by thermal degradation. The gage length was 3 mm for tensile specimens. Number of samples at same test condition was 30. Moreover, stereomicroscope of zoom system SZX7 (Olympus Co. Ltd.) was used to determine the cross-sectional area of jute fiber. The cross-sectional area was calculated by length of major axis and minor axis of ellipse. The mean diameter was calculated by seven points for each jute fibers.

3 RESULTS AND DISCUSSION

3.1 TGA of jute fiber

The decomposition behaviour of jute fiber is shown in Fig. 1. From room temperature to 100°C, 10% of mass of jute fiber decreased, and from 260°C to 290°C 7% of mass decreased. In addition, the mass begins to decrease greatly above 290°C. Between 290°C to 320°C, 23% of the mass decreased. During 320°C to 340°C, 39% of the mass decreased. Above 340°C, the rate of mass reduction decreases, at 460°C, the mass reached zero.

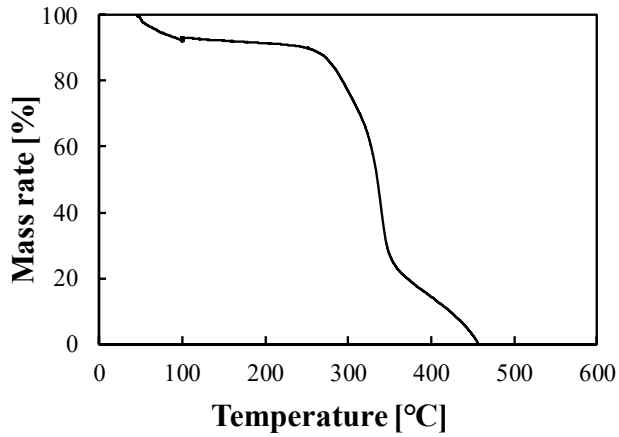

Figure 1: TGA curve of jute fiber.

The reason of the mass reduction of jute fiber from room temperature to 100°C is assumed that moisture in fiber evaporates by heating. From 260°C, thermal decomposition may begin. The great mass reduction between 290°C and 340°C is about 60% of original mass, so it is thought that the mass reduction is cellulose because about 65% of jute fiber is cellulose.

3.2 Surface observation of jute fiber (SEM)

The surface morphologies of untreated and heat-treated jute fibers under 260°C, 290°C, and 320°C are shown in Figs 2–5, respectively. The surface state of untreated surfaces is

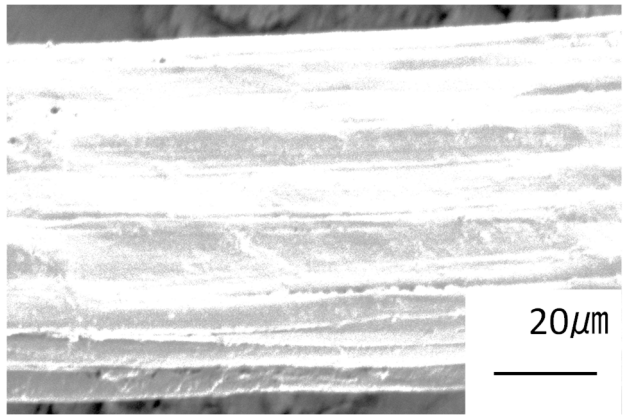

Figure 2: Surface of jute fiber (non-treatment).

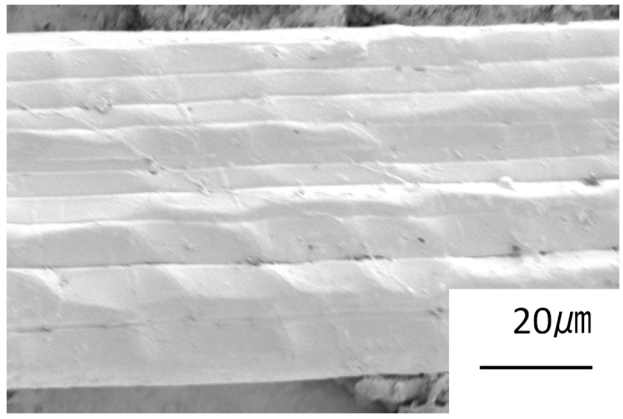

Figure 3: Surface of jute fiber (260°C).

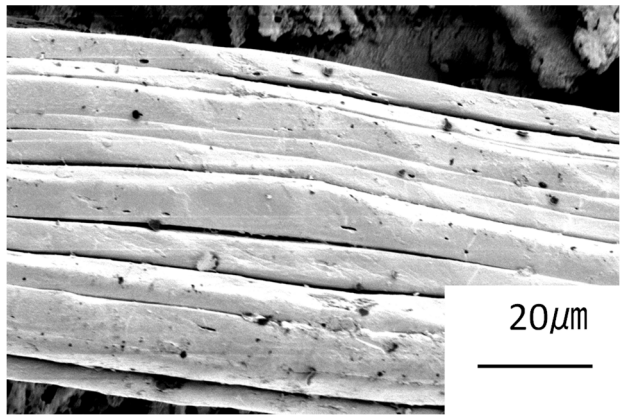

Figure 4: Surface of jute fiber (290°C).

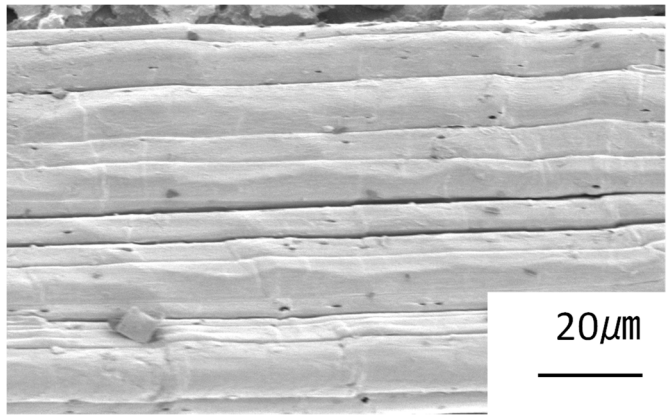

Figure 5: Surface of jute fiber (320°C).

compared to heat treated surfaces. There are some stripes are confirmed along the longitudinal direction of fibers by heat treatment of 260°C. On the other hand, there are no stripes in untreated surface. This is because that the surface of heat-treated jute fiber has decomposed and inner fiber bundles can be seen. Furthermore, the surface treated jute fiber at 290°C has debonding to the longitudinal direction and the surface has become rough. This is because that fiber bundle were expanded by high temperature, and debonding occurred. In the case of heat treatment under 320°C, the surface of jute fiber has debonding and small cracks to transverse direction of fibers. The length of cracks is about from 5 μm to 10 μm, and the cracks are in every fiber bundle. At 320°C treatment, much more cracks of jute fibers are found.

3.3 XRD analysis of jute fiber

The results of XRD for untreated, heat treatment under 260°C, 290°C, 320°C and 550°C treated are shown in Fig. 6. For the case of untreated, 260°C, 290°C, and 320°C, the distinct two peaks appeared at diffraction angle of 16° and 22°. On the other hand, for 550°C case, there is only one peak at 26°. Because the peak of diffraction angle for cellulose is 15° and 22.5° and peak of angle diffraction angle for carbon crystal is 26° [8], the cellulose still remained for the case of untreated, 260°, 290°, and 320°, and jute fiber is completely carbonized under 550°. The diffraction intensities are compared at the diffraction angle of 16° and 22°, diffraction intensities are 600 cps at 16° and 1000 cps at 22° for the case of untreated, 260°C and 290°C. On the other hand, diffraction intensities are 400 cps at 16° and 600 cps at 22° for the case of 320°C. So, the peak value at 16° and 22° completely decreased at 320°C by compared with the condition of untreated, 260°C and 290°C. Therefore, it is understood, cellulose begins to have thermal decomposition at 320°C. Because jute fiber for the case of 320°C has high diffraction intensity at 25° compared the jute fiber for other cases, it is understood that jute fiber begins to carbonize about 320°C.

3.4 Tensile test of jute fiber

Tensile properties of jute fiber are shown in Table 1 for untreated and heat-treated jute fiber. The tensile strength and Young's modulus also are summarized in Fig. 7, and elongation at

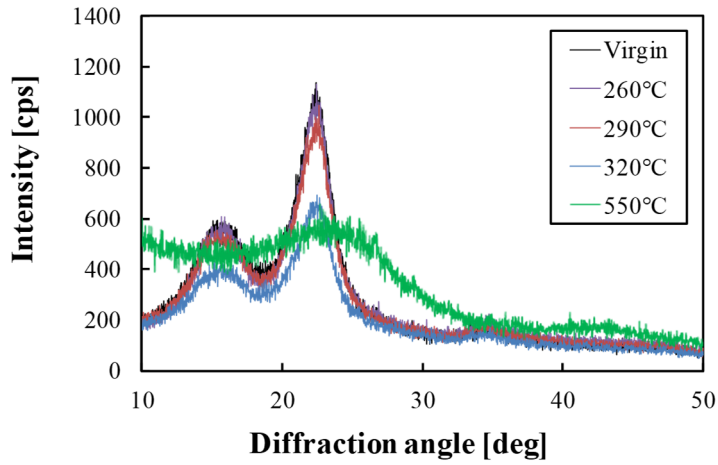

Figure 6: XRD patterns of jute fiber.

Table 1: Tensile properties of jute fiber.

	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)
Virgin	177.91	6.82	2.77
250℃	163.61	8.59	2.57
260℃	106.30	9.45	1.61
270℃	91.24	7.25	1.59
280℃	81.00	7.10	1.63
290℃	41.79	4.32	1.09

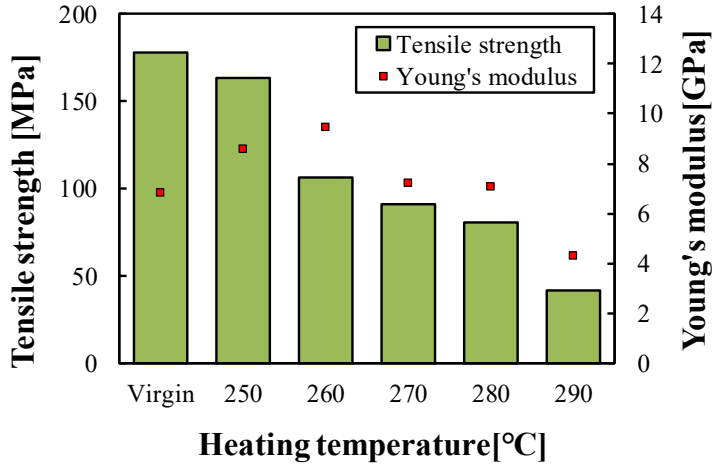

Figure 7: Tensile strength and Young's modulus of jute fiber.

break was represented in Fig. 8. The tensile strength and elongation at break decreased as the treatment temperature increased. As the thermal decomposition of jute fiber was discussed in Section 3.1, the mass of jute fiber decreased at 260°C for TGA test. So, the surfaces have thermal decomposition above 260°, volume fraction of cellulose increases, a few cracks and deboning occurred, stress concentration also occurred. Thus, the tensile strength and elongation at break decreased. Young's modulus increases of heat-treated jute fiber. The increase rates of Young's modulus are 26.1% at 250°C, 38.7% at 260°C. On the other hand, Young's modulus decreased above 270°C. The reason of increase of young's modulus at the case of 250° and 260° is that cell membrane and primary wall have heat decomposition, there is a little effect to secondary wall, so volume fraction of cellulose increases. Therefore, as Young's modulus decrease above 270° case, it is thought that moderate heat treatment temperature is 260°C.

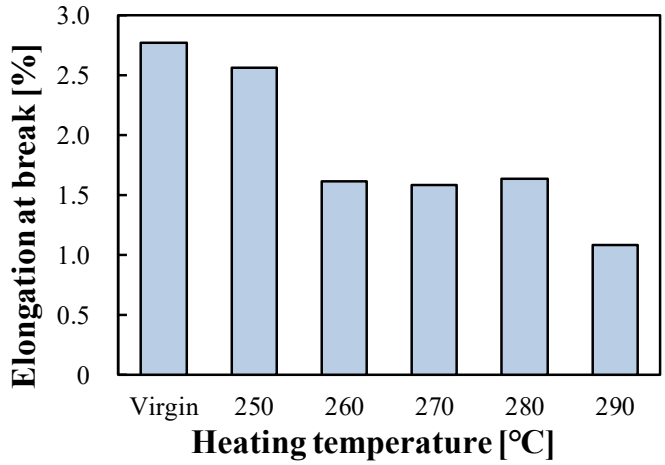

Figure 8: Elongation at break of jute fiber.

4 CONCLUSIONS

(1) For TGA test, above 260°C, the mass of jute fiber begins to decrease, and above 330°C, the mass gradually decreases. Between 290°C and 330°C, the reason of mass reduction is thermal decomposition of cellulose whose volume fraction is 70%.
(2) In the case of 260°C treatment, only surface of jute fiber has thermal decomposition. For 290° case, deboning occurs due to expanding of fiber bundle. For 320° case, deboning becomes big and small cracks occur to the transverse direction to fiber.
(3) In the case of 320°C treatment, the surface of jute fiber was carbonized.
(4) As the temperature of heat treatment increases, tensile strength decreases due to debonding and cracks on the fiber surface. On the other hand, Young's modulus increases 21.8% in the case of 260° treatment case compared non-treatment

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