EFFECT OF NEEDLE PUNCHING ON STRENGTH OF STAMPABLE SANDWICH SHEET FABRICATED WITH BAMBOO FIBER AND RECYCLED CARBON FIBER MAT

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1 Introduction

Bamboo fiber mats can be an alternative material for stampable sheets which have been usually processed with glass mats and have been widely used for commodious interior in automobiles [1-3], since bamboo fiber is a naturally grown material with many superior specific properties, such as low cost, low density, renewable character, high specific strength and modulus [4-5]. Stampable sheets fabricated with bamboo fiber mats, however, do not have sufficient mechanical properties as interior material in which high flexural strength is expected [3].

To improve the mechanical properties of stampable sheets under bending condition for some applications in which lateral force should be considered, one of the ideas is to apply needle punching technique to the non-woven mat [6]. The other idea is also using synthetic fibers for the surface layers of the stampable sheet. In that case, to maintain its considerable character as ecological material, eco-friendly material should be selected for the material of the skin layer. Recycled carbon fiber mat is one of such materials developed recently in order to re-use the carbon fibers in the waste fiber composite. The recovery of carbon fibers from the composite material has been attempted using a range of process, including chemical, mechanical, thermal and even its use as a fuel after incineration has been investigated [7]. The mechanical properties of the recycled carbon fiber were enough to use as a surface layer of the stampable sheet while they are inferior to the virgin carbon fiber. However, few studies mention the effect of the application of needle punching technique on the mechanical properties of the stampable sheets when they are fabricated with bamboo fiber and recycled carbon fiber mats.

The purpose of this study is to investigate the effect of needle punching on the flexural properties of the coupon specimen cut from the bamboo fiber mat and also to investigate the effect of the use of recycled carbon fibers for the skin layer. To fabricate the bamboo fiber mat, flexible bamboo fibers were prepared with a blender machine to be mixed with commercial available PP fibers. Then the non-woven cloth was also prepared with the mixed fiber mat by a conventional carding process. The non-woven clothes made were pressed after laying-up on a heat press machine to make the stampable sheet. The recycled carbon fibers were introduced to construct the surface layers of the hybrid stampable sheet. In making the surface layer of recycled carbon fibers, similar process in fabricating bamboo fiber mat was utilized for the compatibility of fabrication.

The effect of the needle density (defined as the number of needles per unit area) at punching on the flexural properties of coupon specimen under four-point bending was investigated for bamboo fiber and hybrid stampable sheets. In order to evaluate the change of the probability distribution of fiber directions due to needle punching, the fiber orientation angle of the stampable sheet was analyzed by an image software. The effective process for stampable sheet with hybrid structure of bamboo and recycled carbon fiber was discussed.

2. Material and fabrication method

2.1 Material

Commercially available extracted bamboo fibers were imported from China (Fig.1). Recycled carbon fibers (length 15-25mm, diameter 7μm) were provided by Fukuoka Research Center for Recycling System (Fig.2). PP sliver (length 50mm, diameter 18μm, Chisso Polypro Fiber Co.) (Fig.3) was used as the binder for bamboo and recycled carbon fibers.

2.2 Process of stampable sheet with bamboo fiber

The stampable sheet was fabricated by the following process.

(1) Flexible bamboo fibers were prepared with a blender machine to be mixed with PP fibers in the sliver, in which the weight content of bamboo fiber was 70wt%.
(2) The non-woven cloth was fabricated by a conventional carding process with the mixed fibers prepared in (1). The weight per unit area of non-woven cloth was 1000g/m^2 for bamboo fiber stampable sheet.
(3) The non-woven cloth was needle punched by the machine shown in Fig.4. The punching density was changed to 0, 20, 40 and 60/cm^2.
(4) The non-woven clothes made in (2) (3) were pressed after laying-up on conventional heat press machine at 190°C under 0.5MPa for 5 min.

2.3 Process of hybrid sheets with bamboo and recycled carbon fibers

The hybrid sheet was fabricated by following process.
(1) Recycled carbon fiber and PP fiber were mixed by the same process as 2.2-(1). The weight content of recycled carbon fiber was 20wt% in the material.
(2) The non-woven cloth was fabricated by a conventional carding process with the mixed fibers prepared in (1). The weight per unit area of non-woven cloth was 100g/m^2.
(3) Bamboo fiber and PP were also mixed in which the weight content of bamboo and the weight per unit area were 70wt% and 800g/cm^2, respectively.
(4) The non-woven mats processed by 2.3-(2) (3) were needle punched after they were symmetrically laid up. The punching density was changed to 0, 20, 40 and 60/cm^2.
(5) The sandwich clothes made in (4) were pressed on a heat press machine to fabricate the hybrid sheet. The weight percents of bamboo fiber, recycled carbon fiber and PP fiber were 56%, 40% and 4%, respectively. Through these conditions, the same weight per unit of the hybrid sheet was obtained with that of bamboo fiber stampable sheet (1000g/m^2).

3. Experimental method

3.1 Flexural test

Flexural tests were performed in four-point bending mode with a conventional testing machine (Autograph AG100, Shimadzu Co.) as per the JISK6850. The span length and test speed were 81mm and 30mm/min, where the length and width of the specimen were 100mm and 30mm, respectively. Test data were obtained for 5 times under the same test conditions.

3.2 Change of fiber angle

In order to evaluate the effect of needle punching, the change of the fiber orientation angle in the stampable sheet shown in the image of X-ray CT (TOSCANER-32250) was analyzed by an image software (TRI/3D-VOL-FBR) (Fig.5).

3.3 Tensile shear test

To investigate the interfacial shear strength between observed layers of the laminated non-woven cloths in the sandwich sheet, tensile shear test was performed with a testing machine (Ez-test500, Shimadzu Co.). The width and the length of the nominal shear area between core and surface layer was 20 by 10mm. In this test, nominal shear strength was determined by the shear stress at the failure between skin and core part under 2mm/min of the test speed. Five test data were obtained for each test condition.

4. Results and discussion

4.1 Strength of bamboo fiber core

Fig.6 shows the example of load-deflection curves for the four point bending test. The maximum load was improved when the needle punching technique was applied to the specimen.

Fig.7 shows the change of the flexural strength of coupon specimen cut from the stampable sheet with bamboo fibers with respect to punching density. In this case, the strength was determined as the maximum load before the reaction force was decreased. The flexural strength of stampable sheet was slightly improved by needle punching.

Fig.8 shows the cross-section of the bamboo fiber non-woven cloth after needle punching, where the density of punching was (a) 0/cm^2, (b) 40/cm^2. Compared with them, PP fibers (white lines on the picture) were penetrated into the space between bamboo fibers when the needle punching density was 40/cm^2. It was considered that little affects were obtained when the needles were inserted to the bamboo mat, because only sliding slip was happened between the needle and PP fiber. However, when the needles were returned from the bamboo mat, some PP fibers were caught by combs on the needles and brought into the space between the bamboo fibers in the working direction.

Fig.9 shows the probability distributions of the bamboo fiber direction of (a) original stampable sheet (0/cm^2) and (b) that after needle punching (40/cm^2). When the needle punching process was not applied, directions of almost all bamboo fibers were uniform to 0 deg in the plane of the stampable sheet. This means that almost bamboo fibers were laid up

and disposed in plane during the press process. In contrast, in case of 40/cm^2 of punching density, bamboo fibers of many percentages were turned close to the thickness direction by the needle punching.

4.2 Strength of hybrid sheet (recycled carbon fiber skin and bamboo fiber core)

Fig.10 shows load-displacement curves under four point bending test. The maximum load was improved when the needle punching technique was applied. Fig.11 shows the change of four-point bending strength of the hybrid stampable sheets fabricated with recycled carbon fiber and bamboo fiber. The highest flexural strength was obtained when the punching density was 40/cm^2. The improved ratio of the flexural strength was about 15% compared with that of a simply fabricated hybrid sandwich sheet.

Fig.12 shows the cross-section of the hybrid non-woven sheets after needle punching (0/cm^2 and 40/cm^2). Compared with them, recycled carbon fibers were penetrated into the space between bamboo fibers when the needle punching density was 40/cm^2. It was confirmed that some recycled carbon fibers set in the surface layer had been caught by combs on the needles and turned close to the thickness direction as well as in the bamboo fiber stampable sheet.

Fig.13 shows the change of interfacial shear strength between laminated non-woven cloths in the hybrid sheet where the punching density on the process was 0, 20, 40 and 60/cm^2, respectively. The interlaminar shear strength was promoted with the needle punching technique.It was said that the flexural strength of the stampable sheets should be improved by the improvement of the interfacial strength in the case of 40/cm^2.

Fig.14 shows the change of elastic modulus of the surface layer extracted from the hybrid sheet where the punching density was 0, 20, 40 and 60/cm^2. The tensile modulus of a surface layer was simply decreased with increasing the punching density. To explain the experimental result of bending strength, it was said that, when the punching density was over 40/cm^2, the flexural strength of the hybrid sheet should be controlled by the buckling of surface layer. By this reason, the flexural strength of the hybrid sheet was decreased due to the decrease of elastic modulus of surface layer when the punching density was over 40/cm^2.

4.3 **Advantage of hybrid stampable sheet**

Fig.15 summarizes the comparison of flexural strengths of the stampable sheets of bamboo and that of hybrid one. The improved ratio of the flexural strength was about 13.9% when the needle punching technique was applied to the conventional bamboo fiber mat. The improvement ratio was also 87.6% when the recycled carbon fibers were applied to the surface layer without needle punching process. Through the study, 112% of final improvement ratio was obtained by applying the needle punching technique to the proposed stampable mat constructed with the surface layers of carbon fibers, even though the stampable sheet did not gain its weight per unit area.

This paper showed that it is most effective to apply the needle punching technique after the bamboo fiber core was sandwiched between the surface layers of recycled carbon fibers to construct the hybrid stampable sheet.

5. CONCLUSION

(1) The highest flexural strength of the stampable sheet with bamboo fiber and hybrid stampable sheet were obtained when the needle punching density was 40/cm^2.

(2) Interfacial shear strength between bamboo fiber core and surface layer of recycled carbon fibers was promoted with the needle punching.

(3) The flexural strength of the hybrid sheet was decreased due to the decrease of elastic modulus of the surface layer when the punching density was over 40/cm^2.

(4) By applying the needle punching technique to the proposed stampable mat with the surface layers of carbon fibers, 112% of final improvement ratio was obtained, even though the stampable sheet did not gain its weight per unit area.

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Fig.1 Bamboo fibers.

Fig.2 Recycled carbon fibers.

Fig.3 Polypropylene sliver.

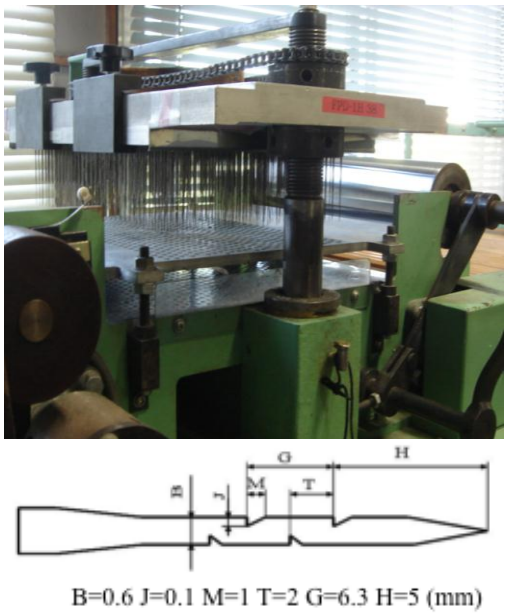


Fig.4 Needle punching machine and geometry of needle.

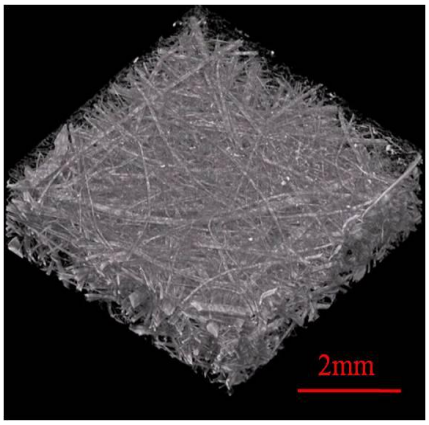


Fig.5 Image of X-ray CT of stampable sheet with bamboo fibers for measuring fiber orientation angles.

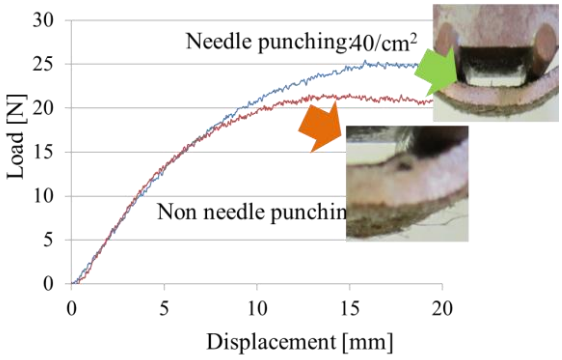


Fig.6 Example of load-deflection curves by four point bending test.

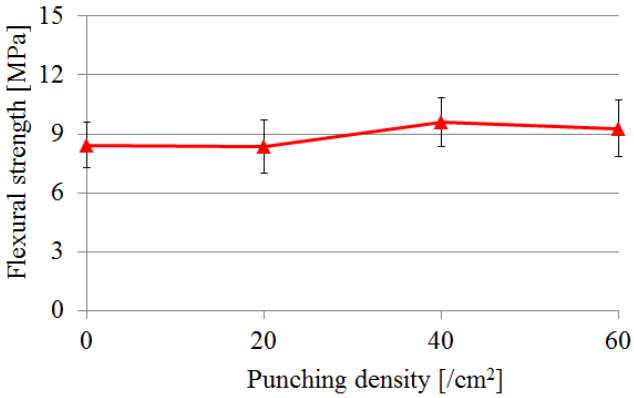
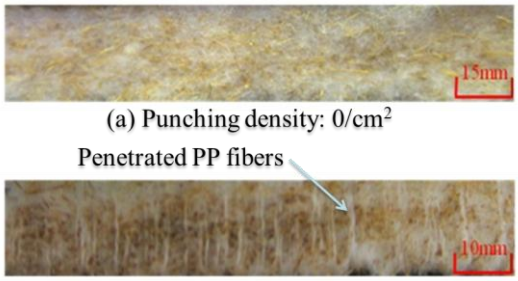


Fig.7 Change of flexural strength of coupon specimen cut from stampable sheet with bamboo fiber with respect to punching density.



(a) Punching density: 0/cm²

(b) Punching density: 40/cm²

Fig.8 Cross-section of (a) original non-woven cloth of bamboo fibers and (b) that after needle punching (density of punching was 40/cm^2).

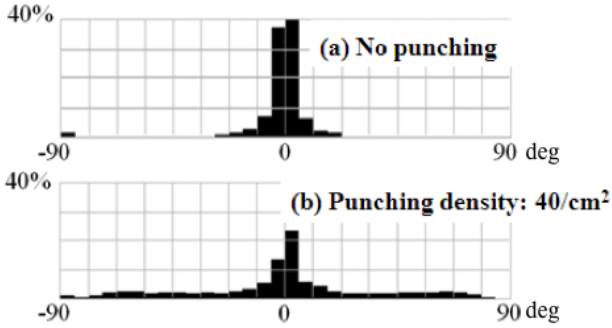


Fig.9 Probability distribution of bamboo fiber orientation angle in stampable sheet of bamboo fibers when density of punching was (a) 0/cm^2(b) 40/cm^2.

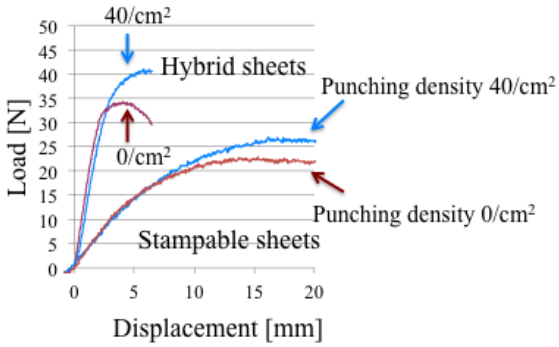


Fig.10 Load-displacement curves by four-point bending test.

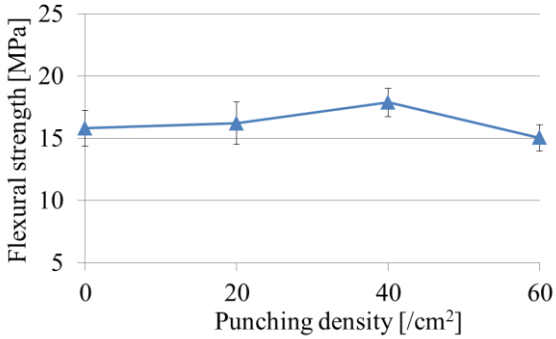
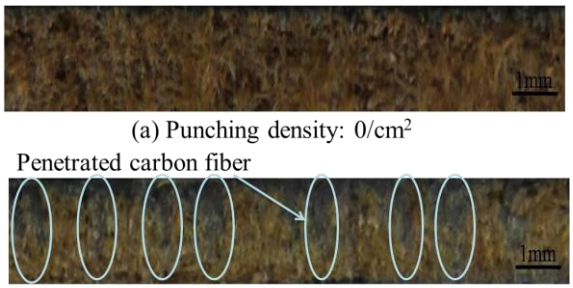


Fig.11 Change of flexural strength of coupon specimen cut from hybrid stampable sheet with respect to punching density.



(a) Punching density: 0/cm²

(b) Punching density: 40/cm²

Fig.12 Cross-section of (a) original hybrid sheet of bamboo fiber and recycled carbon fibers and (b) that after needle punching (density of punching was (b) 40/cm^2).

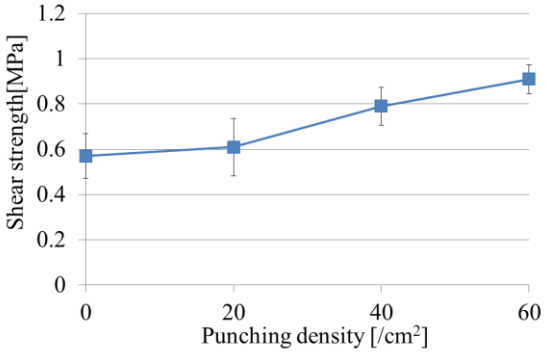


Fig.13 Change of interfacial shear strength between bamboo fiber core and surface layer of recycled carbon fibers with respect to punching density.

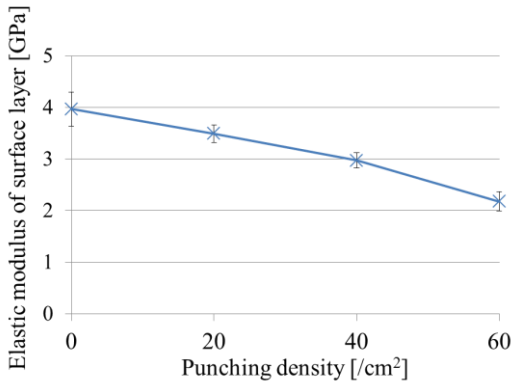


Fig.14 Change of elastic modulus of surface layer with respect to punching density.

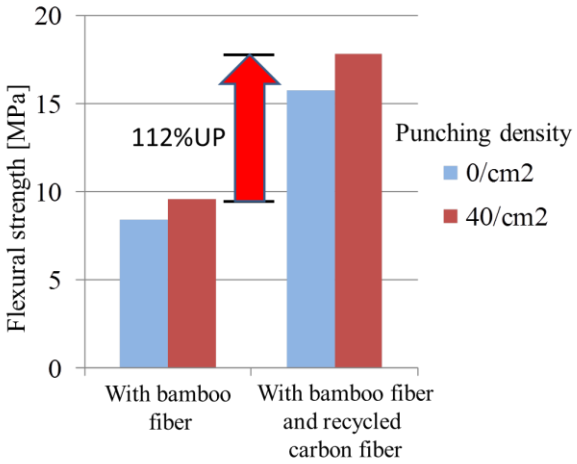


Fig.15 Comparison of flexural strength of stampable sheets.

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