INVESTIGATION IN MECHANICAL AND THERMAL PROPERTIES FOR THREE-DIMENSIONAL HOLLOW KNITTED FABRIC COMPOSITES

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Abstract

In this study, 3-D hollow knitted fabrics (i.e. Double-Needle Bar Raschel (DNR)) reinforced composites were developed as structural materials and thermal insulators. The effect of the different thickness of DNR and 2 types of molding methods; hollow molding and resin foaming molding, on the mechanical and thermal properties of DNR were investigated. Bending modulus and strength of hollow DNR composites decreased with increase in the pile length, while that of foamed DNR composites increase with increase in the pile length. The results of achievement rates of theoretical bending stiffness indicated that local deformation under the indenter was the dominant factors for the bending properties. Thermal conductivity of the hollow and foamed specimens was almost the same, and decreased with increase in the pile length. The results obtained in this study should be the basic data for designing better structural materials and thermal insulators.

1 Introduction

Generally, knitted fabrics are classified into two kinds, i.e. weft and warp knitted fabrics. By using warp knitting technology, useful reinforcement configurations are available. One of these examples is multi-axial warp knitted fabric known as non-crimp fabric. 3-D hollow knitted fabrics (i.e. Double-Needle Bar Raschel (DNR)) are also based on the warp knitting. Two surfaces of knitted fabrics are connected by the pile fibers to form a 3-D hollow structure. In DNR, fiber structures of both surface layers and orientation of pile yarns can be designed. In addition, uni-directional fiber bundles can be inserted in surface layers by using knitted technique, therefore DNR is superior fiber structural reinforcement for Fiber Reinforced Plastics (FRP). Therefore FRP reinforced by DNR should have the high potential for lightweight, high bending properties, flowing air, flowing liquid, thermal insulator, sound absorbent and shock absorption and etc.
However, DNR has not been produced with typical reinforcing fiber for FRP such as carbon fibers, glass fibers, etc., because of difficulties of fabrication. So, more flexible fibers such as polyester and nylon fibers have been used for DNR to produce cushion for a car sheet, bed pats, and etc. Recently, we successfully developed DNR with glass fibers by improving the surface treatment and the fabrication condition to avoid breakages of the fibers.

In this study, mechanical and thermal properties of DNR composites were investigated in order to develop structural materials and thermal insulators. 3 types of DNR with different lengths of pile yarns were prepared, and 2 types of molding methods, hollow molding and resin foaming molding, were chosen. Effects of different pile lengths and molding methods on the mechanical properties was investigated by bending tests. Furthermore, thermal conductivity was also investigated to estimate thermal insulation properties of DNR composite in the thickness direction.

2 Materials and Specimen preparation

3 kinds of different DNR were prepared in this study. These DNR were fabricated with glass yarns (Nitto boseki Co.,Ltd., 137.4tex, 800filament). Schematic drawing of DNR and the side views of DNR from warp and weft direction with a pile yarn length of 8mm were shown in Fig.1 and 2. From the warp side, the pile yarns were oriented straight and diagonally in the thickness direction, while almost same arc shapes were shown from the weft side. Noncombustible fran resin (VF302, Hitachi Chemical Co., Ltd.) was used as the matrix resin. DNR reinforced hollow specimens were fabricated by hand lay-up method. The specimens were impregnated with the resin to create a hollow core. In the case of fabrication for DNR reinforced foamed specimens, impregnated resin, which was the same as the resin for the hollow specimens, were foamed with chemical foaming agents (Sankyo Kasei Co.,Ltd.) to fill up the hollow part with foamed resin.

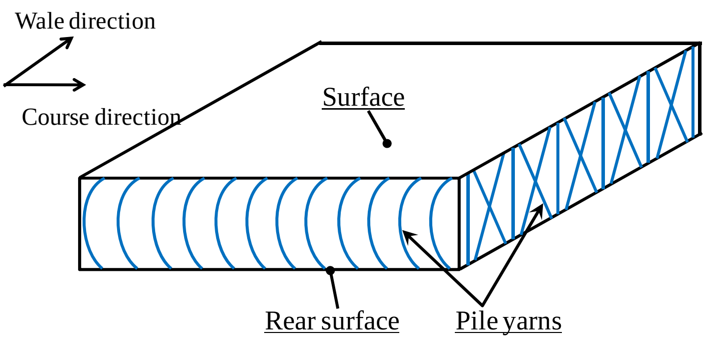


Figure 1. Schematic of DNR

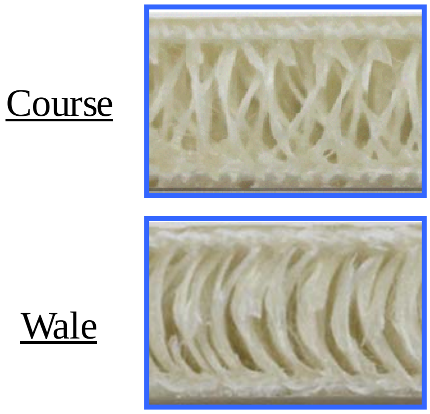


Figure 2. Side views of DNR

Bending test specimens were cut into 20mm in width in wale direction. Bending tests were carried out by using universal testing machine (Instron, Type55R4206) with crosshead speed of 3mm/min. Span lengths for the tests were 16 times larger than the thickness of the specimens. Thermal conductivity was measured by a steady state method with 2 pieces of the specimens cut in a size of 40 millimeters square.

3 References Results and discussions

3.1 Bending test

Load-Displacement curves of hollow and foamed specimens with 8mm thickness were shown in Fig.3. After the linear behavior in the beginning of the curves, the specimens showed non-linear behavior up to the maximum load. Bending modulus and strength for each specimen were shown in Fig.4. The modulus of hollow specimens increased with decrease in pile length, while the modulus of foamed specimen increased with increase in pile length. The strength of hollow specimens increased with decrease in the length of pile yarn, while the modulus of foamed specimen increased with increase in the pile length.

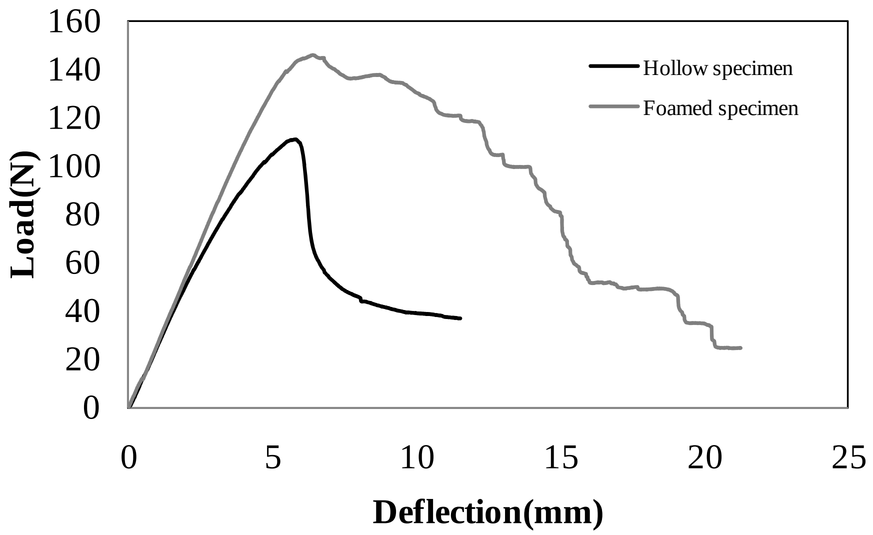


Figure 3. Load-Displacement curves of hollow and foamed specimens

In order to estimate the local deformation of the specimen under the indenter, achievement rates to theoretical bending stiffness rach, which were calculated by actual bending stiffness divided by theoretical bending stiffness, were shown in Fig.5. The theoretical bending stiffness was calculated by multiplying the modulus of surface layers, which had been previously measured, by the moment of inertia. Therefore, the lower achievement rates mean larger local deformation under the indenter because of constant moment of inertia for calculation of rach. Achievement rates of all specimens were less than 30%, and the tendency of the results was corresponding to the results of the modulus and the strength. These results show that the local deformation heavily affected on the bending properties, and was inhibited by the foamed resin.

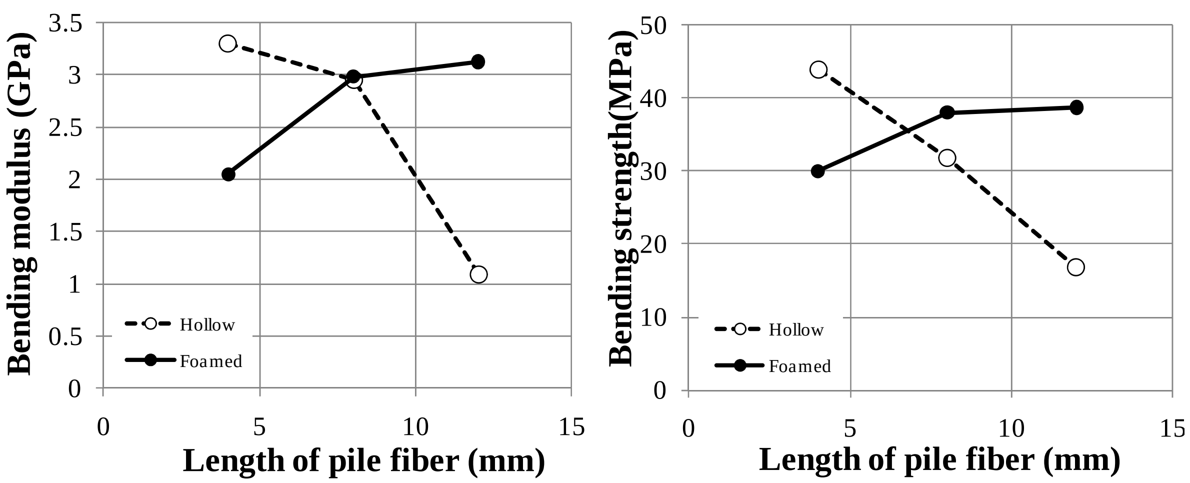


Figure 4. Bending modulus and strength as a function of pile length

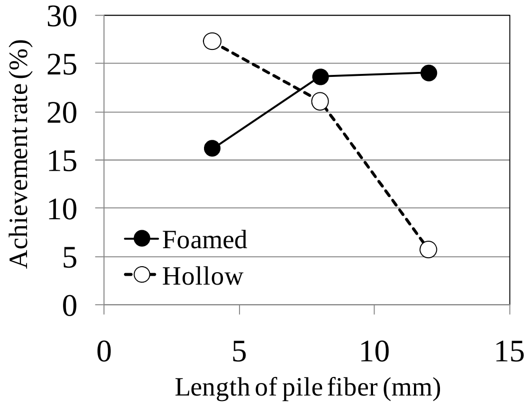
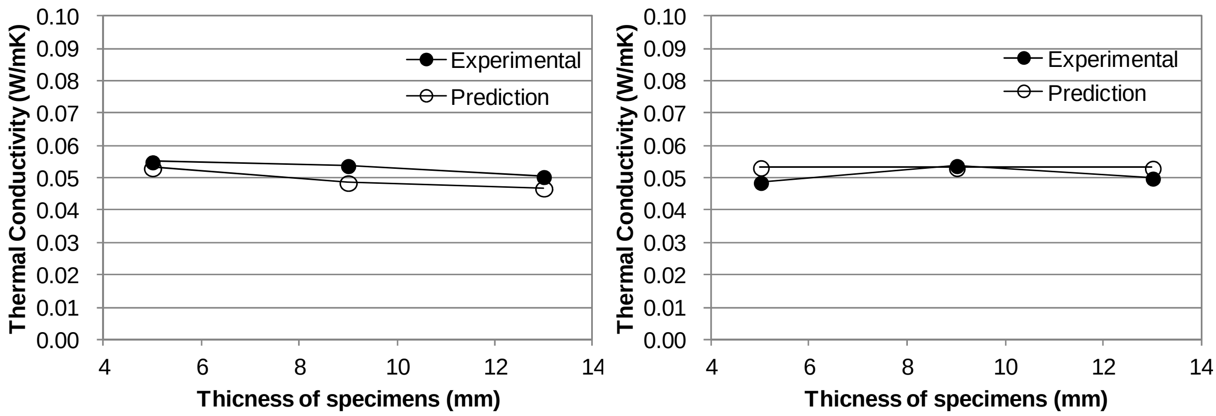


Figure 5. Achievement rates as a function of pile length

3.2 Thermal properties

Thermal conductivities as a function of the pile yarn length for hollow and formed specimen were shown in Fig.6. Predicted values of each specimen calculated by using rule of mixture for thermal conductivities were also shown in these figures. Experimental values of the hollow and foamed specimens showed almost same value 0.05W/mK regardless of pile length. These values were close to typical thermal insulators such as foamed polyurethanes and polystyrenes. Predicted values were almost the same as experimental values. From the results, thermal conductivities of DNR composite can be predicted by using rule of mixture.



(a) Hollow specimens (b)Foamed specimens

Figure 6. Thermal conductivity as a function of pile length

4 Conclusion

In this study, mechanical and thermal properties of DNR reinforced composites were investigated. Bending modulus and strength of hollow DNR composites decreased with increase in the pile length, while that of foamed DNR composites increased with increase in the pile length. The bending properties of foamed specimens were larger than that of hollow one in a thickness with more than 8mm. Achievement rates of bending stiffness showed same current of the bending properties. These results indicated that local deformations of the hollow specimens under indenter were larger than that of the foamed specimens. From the results of achievement ratio of theoretical bending stiffness, the local deformation of the bending specimens was the dominant factors for the bending properties. Thermal conductivities of the hollow and foamed specimens were almost same, and can be predicted by using rule of mixture.