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Mechanical and permeability properties of NCF with different knitting condition

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Abstract. A Non-Crimp Fabric (NCF) is composed of some layers which have large number of fiber bundles aligning in a certain direction and are stacked and fixed with a thin thread compared with the reinforcing fiber bundle by warp knitting technology. In the reinforced form of the composite material, there is no crimp of the fiber bundle compared with other fabric such as woven, knitted fabric or etc., and composite materials reinforced by NCF shows better mechanical properties. Since it is easy to control the orientation angle, it is also possible to control the mechanical properties as required. Therefore, in recent years, it has been widely used as a reinforcement of large-sized composite material structural members such as watercraft, automobile, wind turbine blades, and etc. Many studies on the mechanical properties of composite materials using NCF have been made so far, however, little attention has been paid to the difference in the tension and structure of the warp knitting yarn binding the reinforcing fiber bundles in NCF.
In this study, the effect of difference of tension and structure of warp knitting yarn on the structure of reinforcing fibers and the mechanical properties of composite materials were investigated. In addition, the effects of those differences in NCF on permeability properties were also investigated.

1. Introduction

A Non-Crimp Fabric (NCF) is one of a textile in which some layers of aligned large number of fiber bundles in same direction were stacked in different direction according to the requirement for the reinforcement of composite materials. These stacked layers are fixed together with a thin thread by using warp knitting technique. In the reinforcement of the composite material, there is no crimp of the fiber bundle compared to the woven fabric, and it shows better mechanical properties. Since the orientation angle can be controlled, it is also possible to control the mechanical properties according to the requirement. Therefore, in recent years, it has been widely used as a reinforcement of large-sized composite material structural members such as watercraft, automobile, blades of windmill, and etc. Many studies on the mechanical properties of composite materials using NCF have been made so far, however, little attention has been paid to the difference in the tension of the knitting yarn and the warp knit structure during the production of NCF [1].

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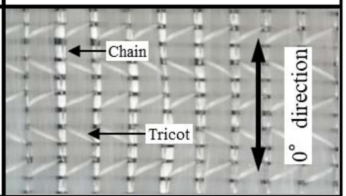
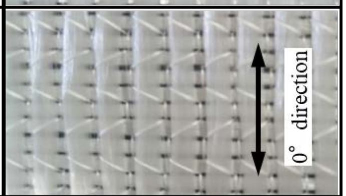
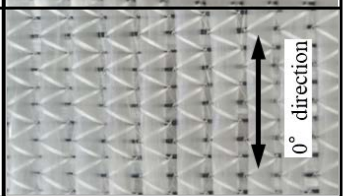
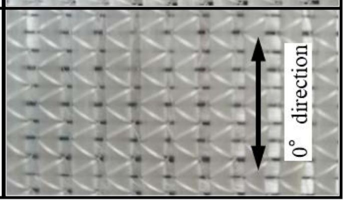
In this study, the effect of the difference of the tension of warp knitted thread and its structure on the structure of reinforcing fiber bundles and the mechanical properties of the composite was investigated. In addition, permeability of the resin during the RTM process was also investigated.

2. Experimental method

2.1 Reinforced substrate

Table 1 shows details and appearance photographs of four types of NCFs with different warp knitting structure and knitting tension used in this study. In both cases, glass fibers were used as reinforcing fibers and reinforcing fibers were oriented in directions of 0° and 90°. The weight per unit area was 480 g/m^2 for the warp yarns and 480 g/m^2 for the weft yarns. When manufacturing 0°/90° NCF, 90° fiber bundle is crossed with a large number of 0° fiber bundles that are aligned and both are fixed by knitting yarn. At that time, the knitting yarn is crossed obliquely with respect to the 0° fiber bundle to fix the 90° fiber bundle. The warp knitting structure at this time is called tricot. On the other hand, it is also possible to fix the 90° fiber bundle by a warp knit structure called a chain, in which case the knitting yarns do not intersect the 0° fiber. Among the four types in Table 1, the upper two are NCFs that alternately apply tricot and chain, and this NCF is called Combination and represented by “C”. On the other hand, NCF in which 90° fiber bundles are fixed only with tricot structure is called Tricot and represented by “T”. Therefore, the amount of knitting yarn crossing over the 0° fiber bundle (referred to as the knitting yarn density for convenience) is twice that of the combination of tricot. The knitting yarn tension during NCF preparation was 1.8 cN and 7.0 cN. Due to the difference between these structures and tension, those with warp knitting structures in combination of 1.8 cN and 7.0 cN are called C_W and C_S, respectively, and tricot is likewise called T_W and T_S.

Table 1. Detail of each NCF.

	Construction	Tension [cN]	Picture
Cw	Combination	1.8	
Cs		7	
Tw	Tricot	1.8	
Ts		7	

2.2 Test specimen preparation method and experiment method

The specimen used in this study was molded by Va-RTM using unsaturated polyester resin (Ligolac 150 HR BQNTNW manufactured by Showa Denko K.K.) as the matrix resin (Figure 1). Two layers of NCF shown in Table 1 were stacked symmetrically and the spiral tubes for supplying resin were arranged at both ends in the 0° direction of the reinforcement and covered with a vacuum bag and evacuated, and then impregnated with a resin and cured at room temperature. The permeability K_x was calculated by the following formula based on the Darcy's rule.

$$K_x = \frac{k \cdot \mu \cdot \phi}{2P}$$

Here, k [m^2/s] is the slope of the graph of the square of the flow front position and time, μ [Pa · s] is the viscosity of the resin, φ [-] is the porosity, and P [Pa] is the injection pressure is there. Flow front position was acquired from moving images shot at resin injection. Both the case where the curing agent was added and the case where it was not added were examined.

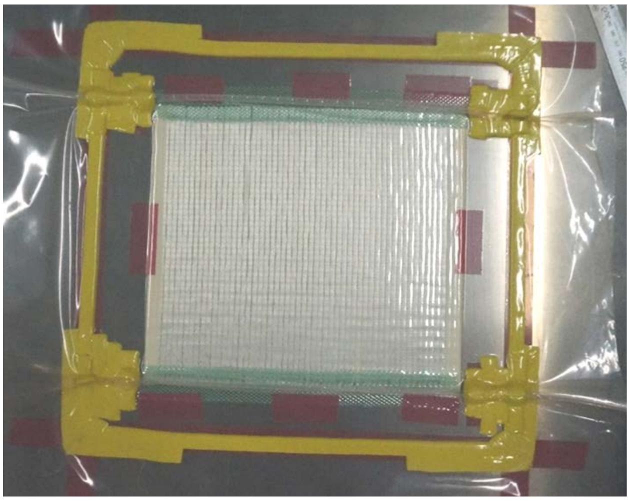


Figure 1. Va-RTM.

3. Experiment Result

An example of the relationship between the square of flow front position and time is shown in Figure 2. The plot was approximated to the least squares and the slope of the obtained straight line was substituted into the above equation to calculate the permeability. The obtained results are shown in Figure 3.

It was found that the permeability was higher in any of the specimens when the curing agent was added. It can be said that this is because the reaction heat was generated by adding the curing agent and the resin became easy to flow because the resin viscosity decreased. In both C and T, it was found that the higher the knitting yarn tension, the higher the permeability and the higher the permeability of T than C.

Next, the relationship between the permeability and the test piece thickness is shown in Figure 4. As the thickness increased, the permeability tended to increase. From the above results, it was found that when the thickness of the test piece is small, it is difficult for the resin to flow, and when the thickness of the test piece is large, the resin flows easily. This is because the higher the knitting yarn density and the higher the knitting yarn tension is, the more the fiber bundle converges and the fiber bundle sectional shape becomes closer to a circle, so the thickness of the test piece increases and the area of the resin flowing between the fiber bundles As a result, the permeability became higher.

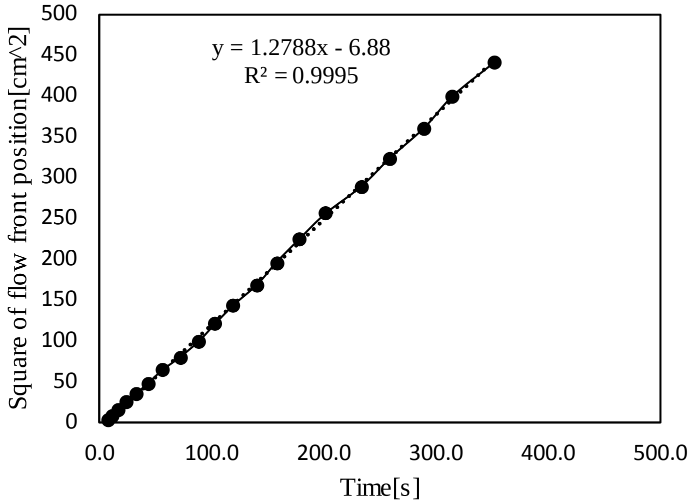


Figure 2. Relationship between square flow front position and time (C_W).

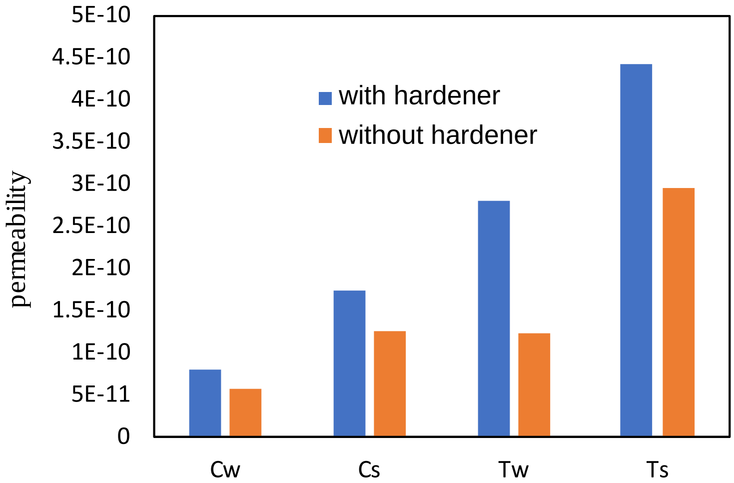


Figure 3. Permeability of each specimen

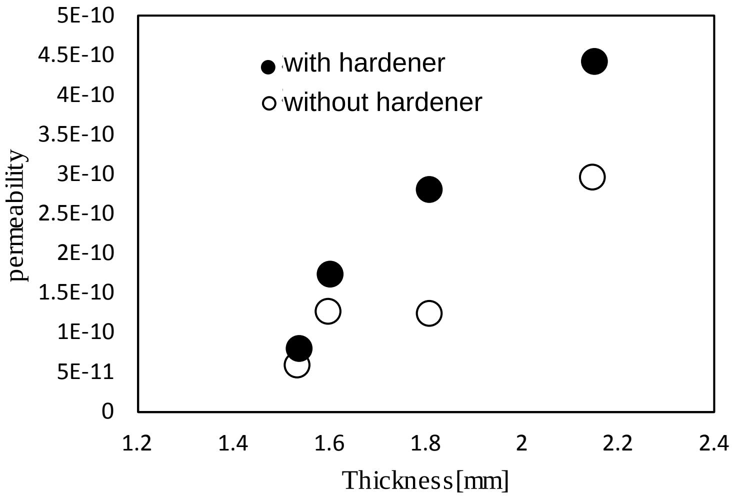


Figure 4. Relationship between permeability and thickness.

Next, the relationship between the strength obtained by the tensile test and the permeability coefficient is shown in Figure 5. Since Vf of each specimen is different, this intensity is a value normalized using Vf. It became clear that the strength decreases as the permeability increases. As the knitting yarn density and the knitting yarn tension increase, the force for converging the fiber bundle increases, so that nonuniformity in the test piece becomes conspicuous, local fibrous meandering is promoted , The permeability increased but at the same time the strength decreased.

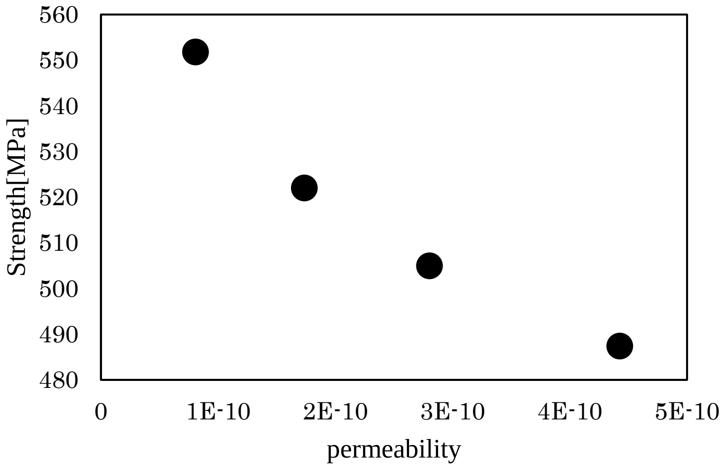


Figure 5. Relationship between strength and permeability.

References

[1] Lomov S V, 2011, *Non-crimp fabric composites: manufacturing, properties and applications*, p. 42-83.