

Fabrication and mechanical properties of multi-axial warp knitted thermoplastic composites using Micro-braided yarn

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Abstract

In this study, multi-axial warp knitted thermoplastic composites were fabricated by our-developed Micro-braiding technique. Cross-sectional observation, tensile test and 3 point bending test were performed. The composite with good impregnation state and high mechanical properties was obtained under appropriate molding conditions. The multi-axial warp knitted fabric composite without unimpregnated region had the equivalent mechanical properties with unidirectional composite laminates. From these results, continuous fiber reinforced thermoplastic panel was realized by combining braiding and knitting technique.

Background

FRP (Fiber Reinforced Plastic) is attracted in various fields, due to the lightweight and high strength. Especially, continues fiber reinforced composites has been focused in automobile, sports, aerospace industries. For the matrix, thermoplastic resin has been required because of the excellent properties and wide selectivity. Moreover, in the automobile industry, recycling matter is one of the keys for selection of resin, and thermoplastic resin should be used. However, the main problem with using thermoplastic matrices for continues fiber reinforced composites is the difficulty in impregnating the reinforcing fiber bundles with the high molten viscosity resin. This has led to the development of a number of different manufacturing techniques, such as Commingled Yarn and Powder Impregnated Yarn etc.

An intermediate material for fabrication of continues fiber reinforced thermoplastic composites called “Micro-braided Yarn” was introduced in this study[1]. Micro-braided yarn is fabricated using tubular braiding machine as shown in Figure 1. In Micro-braided yarn, the reinforcement fiber bundle is straightly inserted in the

center (‘axial fiber’) and the matrix resin fiber bundles are braided around reinforcing fiber bundle as shown in Figure 2. Resin fiber is melted by heating with appropriate temperature and becomes matrix for FRP. Resin fibers could directly contact with reinforcing fiber, so that melted thermoplastic resin is easy to impregnate into reinforcing fiber. Moreover, Micro-braided yarn can be treated as a single fiber bundle, so that textile processed goods can be easily fabricated.

In this study, as application of textile composites using Micro-braided yarn, multi-axial warp knitted thermoplastic composites were fabricated. Multi-axial warp knitted fabric is one of the textiles suitable for mass production. In order to investigate the mechanical properties of the multi-axial warp knitted thermoplastic composites, 3 point bending test, tensile test and microscopic observation were performed.

Experimental Setup

Micro-braided Yarn

Materials used in Micro-braided yarn were carbon fiber bundles (T300, 3000 filaments, TORAY Co., Ltd.) as reinforcement and PA6 resin fiber bundles as matrix resin. The fiber volume fraction and diameter of Micro braided yarn were about 37% and 0.6 mm respectively.

Multi-axial warp knitted fabric

Schematic drawing of multi-axial warp knitted fabric is shown in Figure 3. The structure of multi-axial warp knitted fabric is that unidirectional fiber bundles are aligned in multi direction and linked with knitted yarn. In this study, the multi-axial warp knitted fabric with structure of $[0^\circ / +45^\circ / 90^\circ / -45^\circ]$ was used and the stacking sequence of composites plate was $[0^\circ / +45^\circ / 90^\circ / -45^\circ / +45^\circ / 90^\circ / -45^\circ / 0^\circ]$.

Molding conditions

Multi-axial warp knitted thermoplastics composites were fabricated using compression molding with the change of processing condition as shown in Table I. In all cases, preheating and pre-molding were performed. Preheating temperature was 260°C or 280°C. Then, pre-molding pressure was 1MPa and pre-molding time was 5min. Immediately after the pre-molding, the molding pressure which was higher than pre-molding pressure was applied for molding time (20 or 40min.). After consolidation, the composites plate was gradually cooled to room temperature with molding pressure.

Next, repeat compression was tried in order to improve the productivity by repeating short-time molding. For first compression, only preheating and pre-molding pressure were applied (specimen FC). For the second compression, specimen FC was used. Thus, molding pressure of 4MPa was applied without pre-heating and without pre-molding pressure (specimen SC).

Experimental procedures

Microscopic observation of the cross section perpendicular to 0° direction in unloaded specimens was performed with optical microscopy. 3-point bending test and tensile test were also performed using Instron Universal Testing Machine (Type 4206) at crosshead speed of 1mm/min. The specimens for 3 point bending test and tensile test were cut along the 0° direction. Geometry of the specimens for bending test and tensile test were about 2.5mm in thickness, 30mm in width, and the span length was 43mm and 180mm, respectively.

Experimental Results

Figures 4 and 5 show cross-sectional photograph for specimen 260-40 and 280-40. In the case of molding temperature of 260°C, unimpregnated region and resin rich region were observed at the inside of fiber bundle. On the other hand, there is no unimpregnated region and the resin rich region became smaller with increase in molding temperature from 260°C to 280°C.

Figure 6 shows the cross-sectional photograph for specimen FC, that is specimen before repeat compression. There is much unimpregnated region inside of fiber bundle. The results of SC are shown in Fig. 7 and 8 with different molding time. No unimpregnated region can be observed both for molding time of 10min. and 40min.

Table II shows tensile and bending properties of each multi-axial warp knitted composites. Here, the theoretical elastic modulus was calculated by lamination theory on assumption that the multi-axial warp knitted composites

could be regarded as laminated plate with unidirectional composite. The value, in which elastic modulus obtained by experiments (E_{exp}) was divided by theoretical value (E_{theo}), was also listed in table II.

In the case of molding temperature of 260°C, all properties were almost same regardless of the molding time. However, the values were much lower than those of specimens molded at 280°C.

The specimen FC with only preheating and pre-molding pressure had lowest value among all specimens. However, these values were improved by second compression. It is noteworthy that the E_{exp}/E_{theo} was almost 100% in case of specimen SC regardless of the molding time. This result means that repeat compression is effective molding method to improve the productivity with short-time molding.

From these results, multi-axial warp knitted fabric without unimpregnated region can achieve the equivalent mechanical properties with unidirectional composite laminates. Needless to say, multi-axial warp knitted fabric has better ability of usage and handling than unidirectional composite laminates and also have near-net-shape ability suitable for 3 dimensional shape and short time molding in automobile applications.

Conclusion

In this study, long fiber reinforced thermoplastic composites was fabricated. By using Micro-brained yarn, which consists of the reinforcement fiber bundle and the matrix resin fiber bundles braided around reinforcing fiber bundle, the multi-axial warp knitted thermoplastic composite can be realized. Multi-axial warp knitted fabric is one of the textiles suitable for mass production.

From the results of cross-sectional observation, tensile test and 3 point bending test, the composite with good impregnation and mechanical properties was obtained by appropriate molding conditions. The multi-axial warp knitted fabric without unimpregnated region had the equivalent mechanical properties with unidirectional composite laminates. Moreover, it was confirmed that repeat compression molding improve the productivity with short-time molding.

References

- [1] Masahide Sakaguchi, Asami Nakai, Hiroyuki Hamada and Nobuo Takeda, Mechanical Properties of Thermoplastic Unidirectional Composites using Micro-braiding Technique, Composite Science and Technology, 60(2000), pp.717-722.

Tables & Figures

Table I: Molding conditions

Specimens name	Pre-Molding			Molding		
	Preheating Temperature (°C)	Pre-Molding Pressure (MPa)	Pre-Molding time (min.)	Molding Temperature (°C)	Molding Pressure (MPa)	Molding time (min.)
260-0	260	1	5	-	-	-
260-20	260	1	5	260	4	20
260-40	260	1	5	260	4	40
280-40	280	1	5	280	4	40
FC	280	1	5	-	-	-
SC-10	-	-	-	280	4	10
SC-20	-	-	-	280	4	20
SC-40	-	-	-	280	4	40

Table II: Mechanical properties

Specimens name	V _f (%)	Tensile Modulus (GPa)	Tensile Strength (MPa)	Tensile Modulus E _{exp} /E _{theo} (%)	Bending Modulus (GPa)	Bending Strength (MPa)
260-0	36	33	282	79	50	596
260-20	34	34	261	83	47	510
260-40	34	30	290	73	53	560
280-40	38	45	371	93	61	778
FC	32	29	186	76	28	363
SC-10	38	45	334	94	66	859
SC-20	42	47	408	95	65	837
SC-40	51	54	447	96	74	772

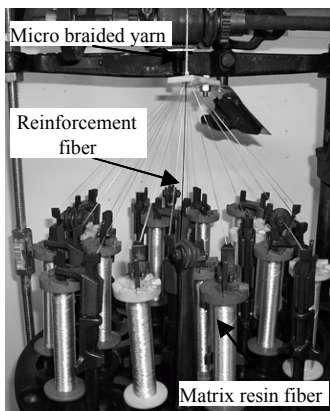
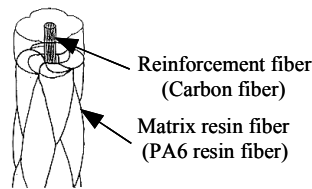


Figure 1: Photograph of tubular braiding machine



Characteristics of Micro braided yarn

- Micro braided yarn can be treated as a single fiber bundle.
- Damage to reinforcement fiber bundle is small in making Micro braided yarn .
- Various resin as matrix can be adopted.

Figure 2: Schematic diagram and characteristic of Micro braided yarn

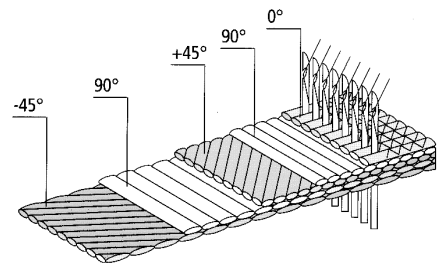


Figure 3: Schematic diagram of multi-axial warp knitted fabric

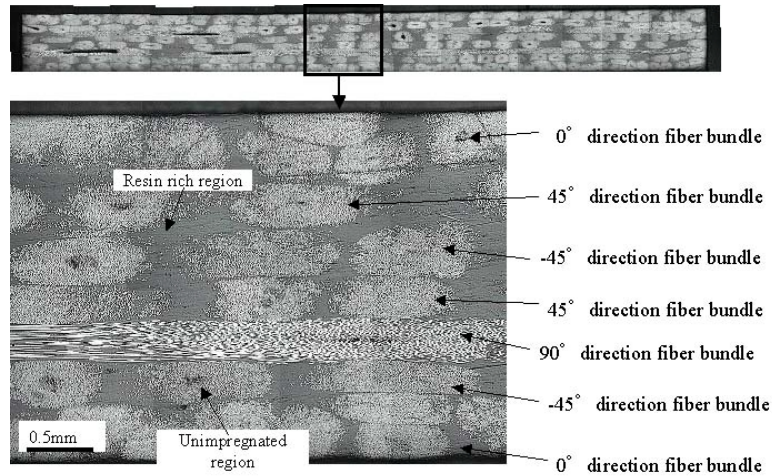


Figure 4: Cross-sectional photograph of multi-axial warp knitted PA6 composites (Molding temperature of 260°, Molding pressure of 4MPa, Molding time of 40min.)

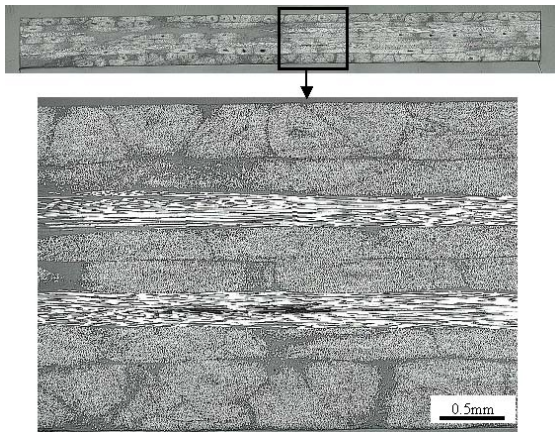


Figure 5: Cross-sectional photograph of multi-axial warp knitted PA6 composites (Molding temperature of 280°, Molding pressure of 4MPa, Molding time of 40min.)

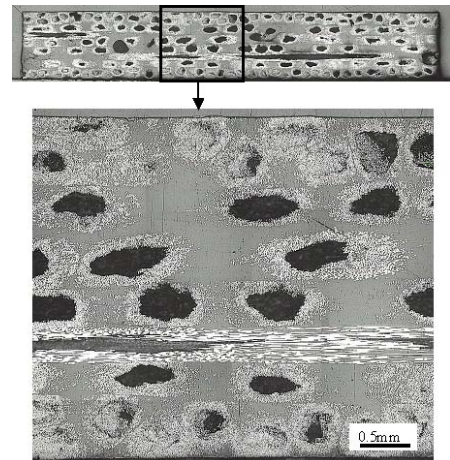


Figure 6: Cross-sectional photograph of multi-axial warp knitted PA6 composites (Molding temperature of 280°, Pre-Molding pressure of 1MPa, Pre-Molding time of 5min.)

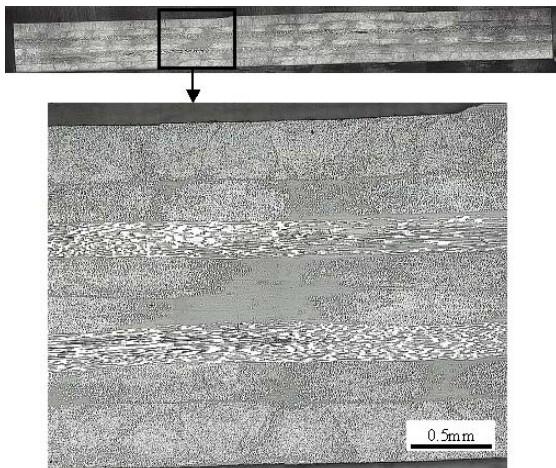


Figure 7: Cross-sectional photograph of multi-axial warp knitted PA6 (After Second compression) (Molding temperature of 280°, Molding pressure of 4MPa, Molding time of 10min.)

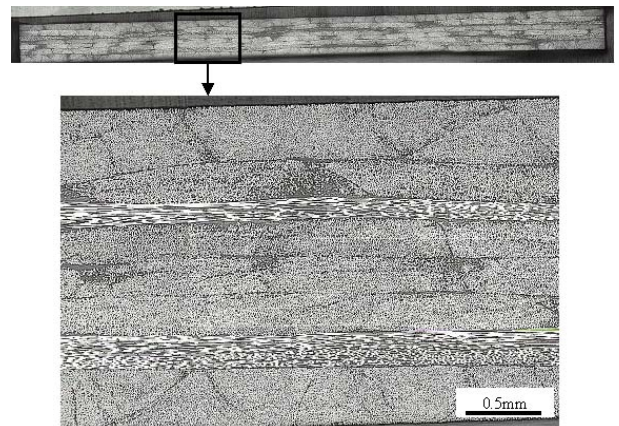


Figure 8: Cross-sectional photograph of multi-axial warp knitted PA6 (After Second compression) (Molding temperature of 280°, Molding pressure of 4MPa, Molding time of 40min.)