FABRICATION AND MECHANICAL PROPERTIES OF PE/PE COMPOSITE

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SUMMARY: In this study, UHMWPE fiber reinforced PE film by film stacking method was prepared. Reinforcement configuration was chosen unidirectional material and knitted fabrics. The effects of molding temperature on mechanical properties were investigated. Nevertheless specimens had low fiber volume fraction, the higher strength was obtained due to high interfacial strength. The most important fabrication point of this composite was molding temperature. The molding temperature should be determined between the melting temperature of fiber and matrix.

KEYWORDS: Interface-less Composite/ Tensile Properties/ Interphase Condition/ Polyethylene/ Fabrication Properties / UHMWPE Fiber/ Knitted Fabric/ Injection Molding

1. INTRODUCTION

The demand of thermoplastics composite materials has been increasing from a viewpoint of the ecological issue. In composite materials, interface construction is very important on the design of composite materials. For example, in the case of glass fiber reinforced thermoplastics composites, interface is generally designed by silane coupling agent or matrix modification with additional or binder agent. In the case of composite materials with polyethylene fiber and epoxy resin, the adhesion between fiber and matrix was not so good and the strength of UHMWPE/Epoxy (PE/EP) composites were lower than epoxy resin only.

Therefore composites that consist of same materials but different shape such as fiber shape and matrix phase can create high interfacial strength. When its fibrous shape is remained in the composites, reinforcing effects are expected. This concept can be applied any kinds of thermoplastic materials. The advantage of this material is not needed to pay any attention, the adhesion between fiber and matrix because the interface disappears. This is essential for construction of this composite. Therefore we call this composite “Interface-less Composites”. In this paper the fabrication and mechanical properties of “Interface-less Composite” were demonstrated.

2. INTERFACE-LESS COMPOSITE

Generally, melting temperature of fibrous shape material is higher than that of bulk material due to molecular orientation in thermoplastic materials. Therefore processing temperature between two melting temperature enable fabrication of composites with high interfacial

strength and maintaining reinforcing effects of fibers.

As for these applications, injection molded also can be considered composites. ***Figure 1*** shows flow chart of injection molding method. This is prepared by inserted high-strength fiber reinforcement and same material is injected as matrix (e.g PE/PE or PP/PP composite).

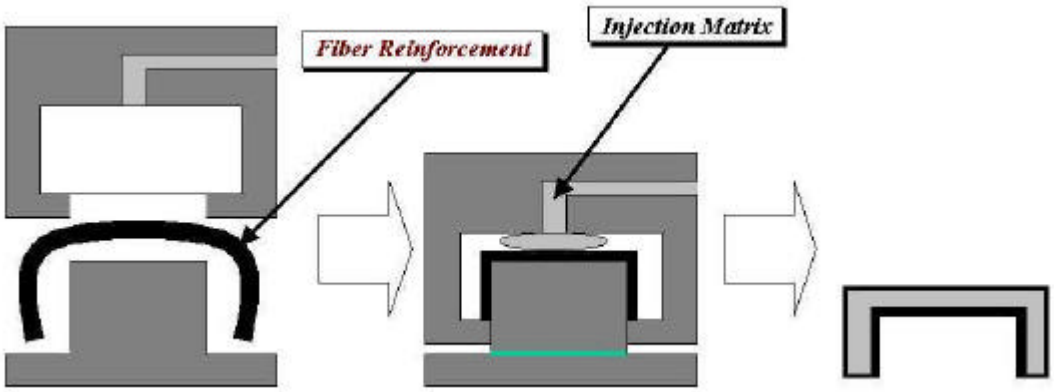

Fig. 1: Flow chart of Injection Molding method.

3. FABRICATION AND EXPERIMENTS

UHMWPE fibers (Dyneema SK60, 400d, 390 filaments, TOYOBO Co., Ltd.) were used in this study as a reinforcement. Matrix resin used was a linear-low-density polyethylene film supplied by Sumitomo Chemical Industry Co., Ltd. Unidirectional fiber orientation and knitted fabric were prepared as a reinforcement configuration. ***Figure 2*** shows knitting structure of plain and welt stitch used in this paper.

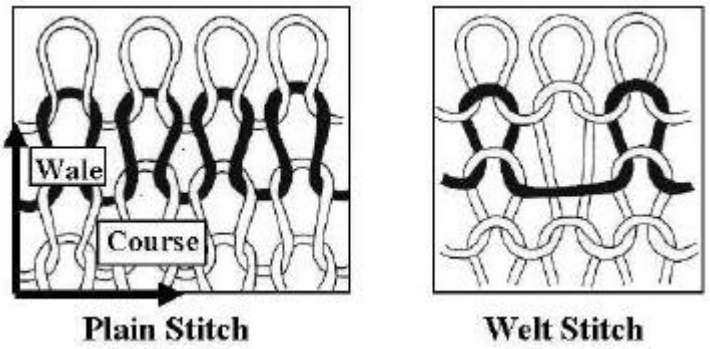

Fig. 2: Knitting structure of Plain and Welt Stitch.

In the case of fabrication of PE/PE composites, the most important processing parameter would be molding temperature (Die temperature) because of achieving higher adhesion and maintaining reinforcing effects of fibers. In order to determine the molding temperature, DSC measurement was conducted both reinforcement and matrix. According to DSC measurements melting temperature of PE film was 120°C and that of PE fiber was 147°C.

Here, melting condition of PE fiber was discussed. Melting condition of the fiber was examined in heated oven. The fiber was exposed for approximately 20 min in the oven. At the 135°C fiber did not melt, at the 145°C it was melted a little, and at the 155°C most of fiber was melted.

In film stacking method the die was heated to 70°C and the reinforcements and films were inserted, after that the die was heated to the appointed temperature. Molding pressure was 1.2 MPa, holding times were 20 min., and die temperature was changed 135, 145, 155°C under

vacuum condition. A gradual cooling condition for 2 hours was applied to obtain high degree of crystallinity.

3.2 TENSILE TEST AND SPECIMEN GEOMETRY

Tensile tests were carried out under a stroke of 20 mm/min at room temperature by using an Instron 4206 universal testing machine under the condition with 150mm span length.
The specimens geometry are 250×25×0.5mm. Fiber volume fraction of all specimens were about 12 vol%.

4. EXPERIMENTAL RESULTS & DISCUSSION

4.1 PE/PE COMPOSITE OF UNIDIRECTIONAL REINFORCEMENT

Figure 3 shows the transverse tensile Stress-Strain curves in which die temperature was the parameter. Tensile stress of every specimen increased lineally in the initial strain. In the case of specimens at 145 and 155℃ stress increased gradually until the maximum stress was occurred. Against it, in the case of specimens at 135℃ final fracture occurred after remaining constant stress region. Therefore fracture strain was highest than the others. The fracture aspects were observed bridging at 145 and 155℃, and the final fracture of all specimens was occurred in the fiber bundles.

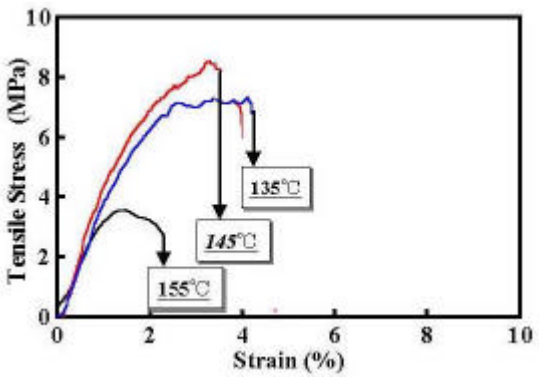

Fig. 3: Stress-Strain Curves Between Fabrication Temperature in 90-degrees Direction.

Table.1 shows the transverse and longitudinal tensile modulus and strength. In the transverse direction, the tensile modulus in 145℃ increased 4% and that in 155℃ decreased 11% than that in 135℃.

Tab 1: 90 and 0-degrees Tensile Properties of PE/PE Composites.

	90–degrees Direction		**0-degree Direction**	
Molding Die Temp(℃)	Tensile Modulus(MPa)	Tensile Strength(MPa)	Tensile Modulus(GPa)	Tensile Strength(MPa)
135	494	8.3	8.3	302
145	517	9.2	6.8	267
155	437	3.7	5.3	184
160	------	------	------	------

Figure 4 shows the relationship between die temperature and (a) Tensile Modulus and (b) Tensile Strength of PE/PE Composites in 90-degrees and 0-degree direction. In the transverse direction, both the tensile modulus and tensile strength were higher values than the others in

145°C and decreased dramatically in 155°C. In the longitudinal direction, both the tensile strength and modulus were decreased lineally with increasing of die temperature. These reasons were considered that diameter of fiber bundles were decreased due to melting of the surface area in the fiber bundles. Furthermore in 160°C melting of the fibers occurred, so that mechanical properties were expected very low values.

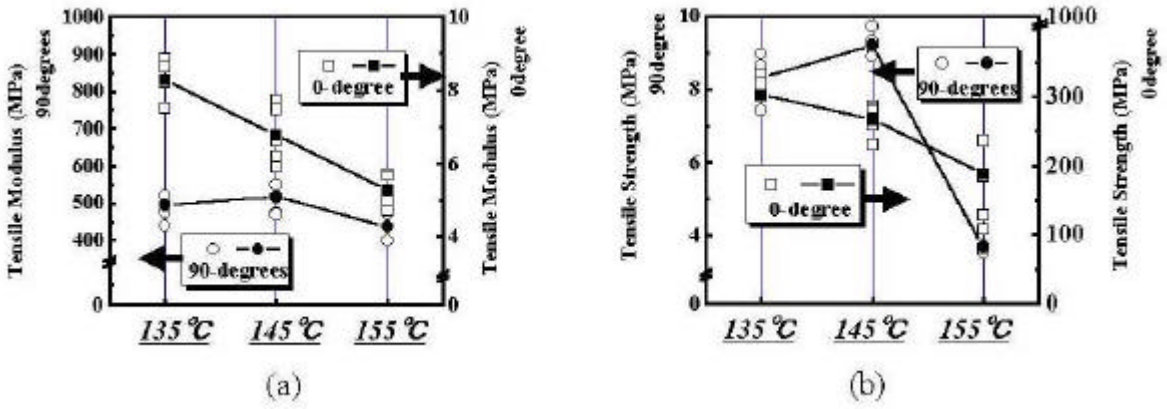

Fig. 4: Relationship Between Molding die Temperature and (a) Tensile Modulus and (b) Tensile Strength of PE/PE Composites in 90 and 0-degrees Direction.

From these results of tensile modulus and strength in 90-degrees, die temperature around 145°C was considered that the interphase condition between UHMWPE fiber and PE matrix was totally good.

4.2 PE/PE COMPOSITE OF KNITTED FABRIC REINFORCEMENT

Knitted fabrics were also used as reinforcement configuration so that UHMWPE fiber possesses high dreapebility. For comparison with PE/PE composites UHMWPE fiber reinforced epoxy resin was also fabricated.

The stress-strain curves of the "Plain" and "Welt" knitted composites are shown in ***Figure 5***. The fracture aspects of both PE/PE and PE/EP composites are shown in ***Figure 6***.

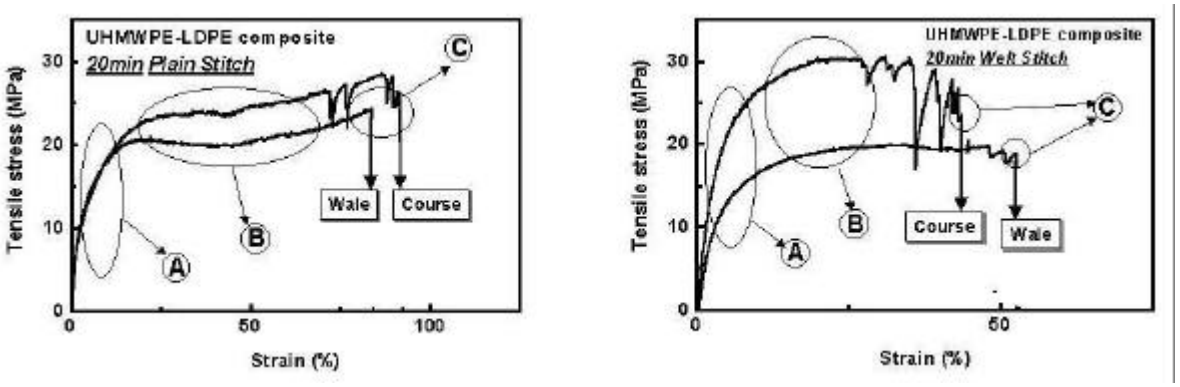

Fig. 5: Stress-Strain Curves (a) Plain Stitch (b) Welt Stitch.

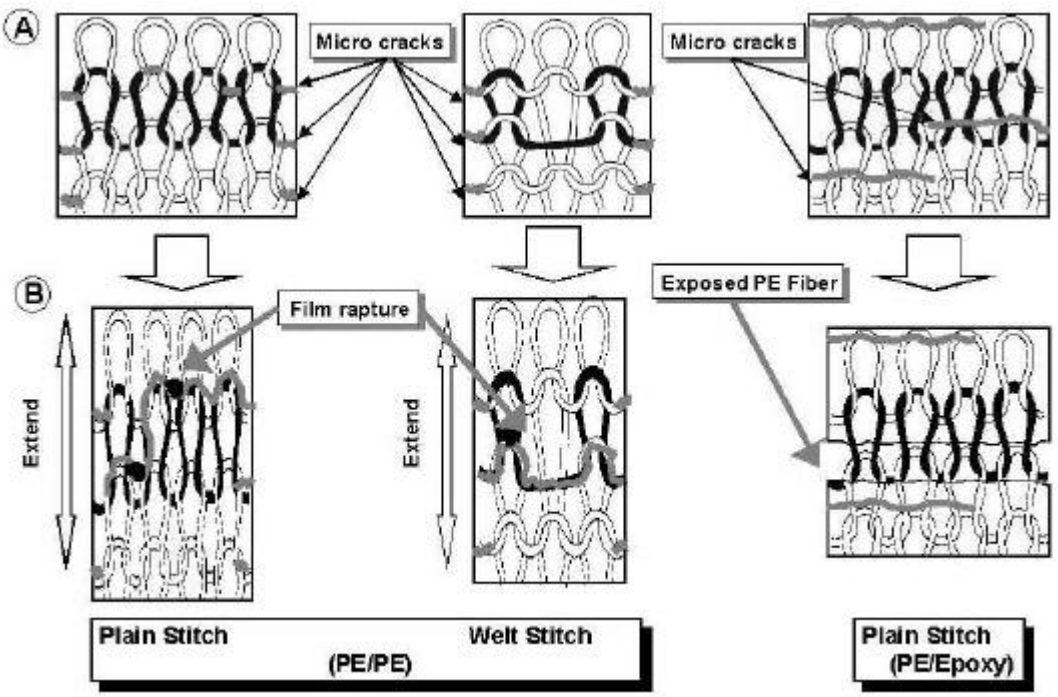

Fig. 6: Fracture Aspects.

UHMWPE/Epoxy

Fracture aspects of PE/EP composites are divided into three stages, namely, stage A, B and C. Many microcracks were generated at a surface of specimen at stage A, in which initial stress lineally increases. The microcracks generation spots were recognized at cross-parts on both wale and course specimen. At the next stage, B, the bundles of a knitted fabric were exposed at cross-parts due to the propagation of microcracks through the resin. Finally, fracture of all bundles was found at stage C.

UHMWPE/PE

Fracture aspects of Plain knitted PE/PE are also divided into three stages as well as PE/EP composites. After applying the load to the specimen (stage A), cracks ran from the edge of the specimen and stopped at the cross-parts of a knitted fabric. The failures of film were observed at the middle part of specimen with increasing strain, and many crack propagations through the cross parts of bundles from the edge to middle and from middle to the edge were observed at stage B. Finally, the specimen rupture was recognized. Fracture aspects of Welt knitted PE/PE are as well as Plain knitted PE/PE specimens. At stage B. the crack propagated into the bundles of Welt part from the edge to the middle part of the specimens and leads to a final rupture.

The most important differences between both materials were interfacial fracture in PE/EP, whereas fracture inside of UHMWPE fiber bundles in PE/PE composites. This simple observation suggested strong interfacial strength was created in PE/PE.

Figure 7 shows tensile strength of each composite. In spite of low fiber volume fraction (12%) PE/PE composites showed from two or three times higher strength than PE matrix only. On the other hand, tensile strength of PE/EP composites was lower than that of Epoxy resin only.

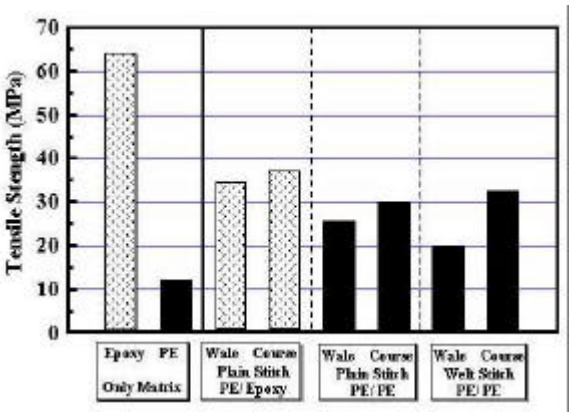

Fig. 7: Comparison of Tensile Strength for Each Composite.

5. APPLICATION - PE/PE INJECTION MOLDING METHOD

Tensile specimens were prepared dumbbell shape by using inline screw system injection molding machine (TOYO Machine Metal Co., Ltd, Plaster Ti-6). The film stacking plate (PE/PE film) with reinforcement was inserted in injection molding specimen. The injection matrix resin used was liner-low-density-polyethylene (LLDPE, MFR=8g/10min) and low-density-polyethylene (LDPE, MFR=7g/10min), high-density-polyethylene (HDPE, MFR=5g/10min). A reinforcement configuration was knitted fabric. Specimen geometry and fabrication flow chart is show in ***Figure 8***. Two types of specimen were fabricated as shown in ***Figure 9***.

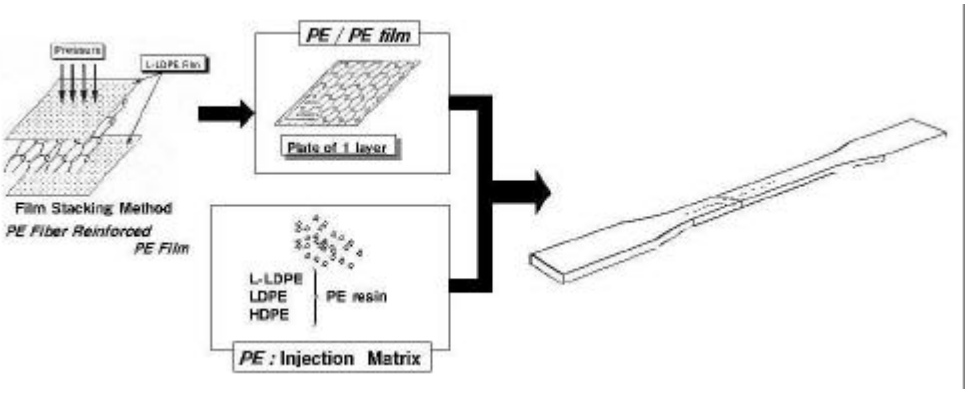

Fig. 8: Flow Chart of PE/PE Injection Molding Method.

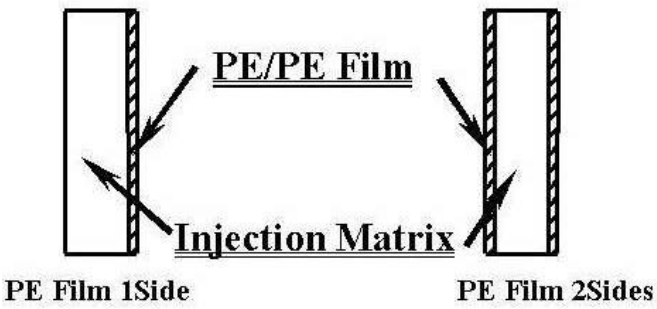

Fig. 9: Cross section of specimen.

Fracture aspects of all specimens after tensile tests were similar each other. The small amount of delamination between the film and the injection part was observed at the specimen edge part. At the same time cracks ran from the edge of the specimen and stopped at the cross-parts of a knitted fabric in the inserted PE/PE film. Finally, many cracks propagated through the cross part of strands from the edge to middle and from middle to the edge.

Figure 10 shows tensile strength of each specimen. In the case of using LLDPE for injection matrix, tensile strength was increased 62% higher than matrix only. In the case of the others specimens was also increased a little.

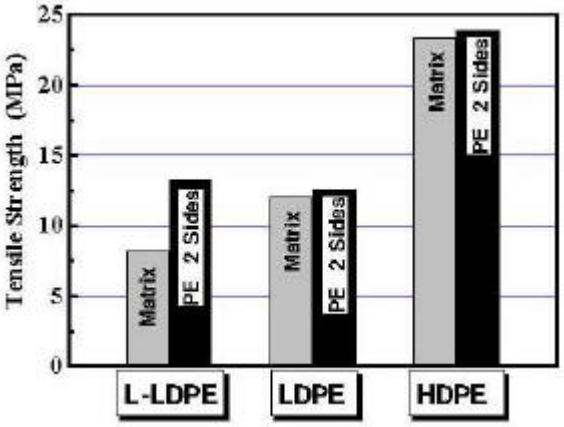

Fig.10: Comparison of Tensile Strength for Each Injection Matrix.

Reinforcement PE film by knitted fabric composite strength was better than only matrix one and crack propagation was stopped by knitted fabric's configuration. Although the approximate volume fraction of the injected molded specimen was only 4%, higher tensile strength can be obtained.

6. APPLICATION - PP/PP COMPOSITE

PP/PP tensile specimens were prepared as well as PE/PE specimens with unidirectional reinforcements. Polypropylene (multi-filament) fibers were used as reinforcement. The matrix resin was used a Polypropylene film (Random Copolymer, Ethylene = 6.3%). DSC measurement was conducted both reinforcement and matrix. According to DSC measurements melting temperature of PP fiber was 167°C and that of PP film was 135°C. Therefore 165°C was selected as die temperature.

Figure 11 shows tensile strength of PP/PP Composites in 0-degree direction. PP/PP composites showed three times higher strength than PP matrix only. From these results, PP/PP composites were can be fabricated.

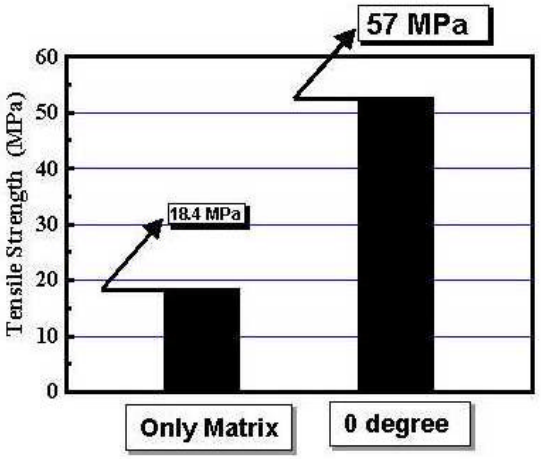

Fig.11: Comparison of Tensile Strength in 0-degree direction.

7. CONCLUSION

In this study, unidirectional and a knitted fabric were selected as reinforcements, and the effects of molding temperature on mechanical properties were investigated in "Interface-less Composite" by using PE materials. PE/PE composites showed high interfacial strength and led high mechanical properties in spite of low volume fraction of the fibers. Injection molding could be used as fabrication method of "Interface-less Composite" and also mechanical properties of PP/PP composites were demonstrated. According to these results, it was cleared that "Interface-less Composite" could be a new type of composites with high interfacial strength.

8. REFERENCE

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