1. Introduction

Self-reinforcing composite (SRC) is a new class of thermoplastic composite, in which the matrix and fibers are composed of the same polymer. SRCs are expected to retain good mechanical performance due to better interfacial bonding between fiber and matrix and furthermore to be free of recycling issues [1]. However, there has been little literature about processing and mechanical performance of this new kind of composite [2,3]. Therefore, this study aims at finding the optimized processing path to consolidate the SRCs and investigating their mechanical performance, in particular focusing on time dependent deformation.

The optimum consolidation of SRCs was studied using a hot press. Resulting molecular structure was determined using differential scanning calorimeter (DSC), wide-angle X-ray diffraction (WAXD), scanning electron microscope (SEM), and time-independent tensile test. Then, the time-dependent deformation behavior of the consolidated SRC was characterized. Finally, a time dependent deformation theory is developed and applied to SRC, enabling the prediction of the performance of composite parts made from SRCs.

2. Optimum consolidation of SRCs

In the current study, woven preforms with self-reinforcing polypropylene (PP) tapes from Don & Low Ltd were used. The tapes are a two component material consisting of dense and highly-crystalline drawn PP tapes (fibers), coated with a thin layer of low-crystalline PP co-polymer, which has a significantly lower glass transition and melting temperature than the drawn tapes and thus acts as the matrix phase of the SRC. Four layers of woven preforms (0°/0°/0°/0°) were fabricated into a consolidated sheet using a hot-press. DSC analysis was first performed to establish the initial condition of the process temperature (see Fig. 1). In this consolidation process, the temperature control is a key factor because two PP materials in the fibers and matrix surrounding the fibers do not show a significant difference in the melting temperature as shown in Fig. 1.

![Fig. 1. DSC thermograms of SRC preform](image_url)
matrix around fiber is seen melted for both consolidated condition, however, for the high temperature case (153°C) some core fibers were also melted (see Fig. 2 (a) and (b) ) as the temperature increases. The melted core fiber may deteriorate the reinforcement effect and should be minimized.

Fig. 2 SEM photographs of consolidated SRCs according to the consolidation temperature: (a) 150°C, (b) 153°C (upper: ×200, lower: ×2000 )

The stress and strain curves of the consolidated SRC sheets were obtained using a tensile tester at the room temperature. As shown in Fig. 3, as the consolidation temperature increases the stiffness is reduced. This decrease in the stiffness may be attributed to the melted core fibers. The directional dependence of the stiffness can be confirmed in woven SRCs, i.e., the fiber direction (0 degree) is more resistant to deformation than the bias direction (45 degree). From the preliminary experiments, it can be concluded that the consolidation condition of SRC is very susceptible to the temperature, influencing the mechanical properties of the consolidated SRC.

3. Time dependent deformation theory and its application to SRCs

Since SRCs in this study consists of PP fibers and co-polymer PP matrix, it is expected to show time-dependent deformation behavior. Furthermore, the woven structure causes it to deform in an anisotropic manner when loaded. Many studies have been carried out to formulate the visco-elastic constitutive equation for the isotropic materials; however little research has been dedicated to the orthotropic deformation behavior. The current study has made an attempt to formulate an orthotropic viscoelastic constitutive equation using the convolution integral as follows.

\[
\begin{align*}
\sigma_{11} &= G_{11} * d\varepsilon_{11} + G_{12} * d\varepsilon_{22} \\
\sigma_{22} &= G_{21} * d\varepsilon_{11} + G_{22} * d\varepsilon_{22} \\
\sigma_{12} &= G_{66} * 2d\varepsilon_{12}
\end{align*}
\]

where \( \sigma_{ij} \) and \( \varepsilon_{ij} \) are stress and strain, respectively. Note that ‘*’ operator represents the convolution integral. The stress relaxation functions, \( G_{ij} \), can be determined experimentally using a biaxial tensile tester with an environmental chamber. The constitutive equation will be implemented in commercial FE software, from which the validity of Eqn (1) can be checked. Details on the formulation and implementation of the constitutive equation will be presented and simulation predictions will be compared with various validation experiments.

Fig. 3 Stress-strain curves of consolidated SRCs according to the consolidation condition.

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