

Development of an In-Situ Tensile Testing Method for Fire-Resistant Resins at High Temperature and During Combustion

- Comparative Evaluation of Resin Composite Materials for Battery Packs -

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With the increasing adoption of xEVs, resin materials used around battery packs are required to provide not only weight reduction but also flame suppression and structural retention under fire exposure. In this study, an in-situ combustion tensile testing method was developed by integrating a cone calorimeter with a tensile testing machine. This method enables continuous evaluation of mechanical property changes in resin materials during high-temperature exposure and combustion. Conventional cone calorimeter tests can evaluate combustion properties such as heat release rate and smoke generation; however, it is difficult to directly evaluate the changes in mechanical properties during and after flame exposure. The developed method makes it possible to assess both combustion behavior and strength retention in a unified manner.

The evaluated materials consisted of PP-based short-glass-fiber-reinforced thermoplastic composites, TP-A and TP-B, and long-glass-fiber-reinforced thermosetting SMC composites, SMC-A, SMC-B, and SMC-C. TP-B contained an intumescent flame-retardant system, SMC-B contained a thermal-decomposition-suppression flame-retardant system, and SMC-C contained both a thermal-decomposition-suppression system and a protective-layer-forming fire-resistant system.

For the thermoplastic materials evaluated under a radiant heat flux of 30 kW/m², TP-A without flame retardant exhibited melting deformation and draw-down with increasing heat exposure time. In contrast, TP-B maintained its specimen shape after heating, and fracture occurred in the remaining lower solid layer. This behavior indicates that the intumescent char layer formed during heating effectively suppressed heat transfer and reduced heat penetration into the interior of the specimen. Therefore, TP-B was confirmed to be an effective flame-retardant system for maintaining component shape and suppressing flame spread after combustion.

For the SMC materials, combustion tensile tests were conducted under a radiant heat flux of 60 kW/m². SMC-A showed rapid flame spread and prolonged combustion, whereas SMC-B and SMC-C exhibited earlier flame extinction due to suppression of combustible volatile generation and flame propagation. In particular, SMC-C achieved the shortest extinction time and demonstrated excellent flame-spread suppression performance.

The relationship between heat exposure time and tensile strength retention showed that all SMC materials experienced a rapid reduction in strength during the initial heating period. However, SMC-B and SMC-C maintained higher strength retention than SMC-A. Among the materials, SMC-C retained the highest residual strength even after long-term exposure, suggesting that the protective-layer-forming fire-resistant system effectively suppresses thermal degradation and improves structural integrity after fire exposure. (Fig.1)

The HRR comparison further demonstrated the effectiveness of the flame-retardant systems. SMC-A exhibited a maximum HRR of approximately 66 W/cm² at around 130 s, whereas SMC-B and SMC-C reduced the maximum HRR to approximately 31 W/cm² and 26 W/cm², respectively. In addition, the HRR peak was delayed to approximately 205 s for SMC-B and 220 s for SMC-C. These results indicate that the flame-retardant and fire-resistant systems contributed to suppressing thermal decomposition and flame spread, reducing the maximum heat release rate and delaying its occurrence.

The developed in-situ combustion tensile testing method provides an effective approach for simultaneously evaluating combustion behavior and mechanical strength retention under fire exposure. Although TP-B demonstrated improved flame-spread resistance and maintained component integrity through the formation of an intumescent char layer, its mechanical strength retention under prolonged heat exposure remained limited. In contrast, the SMC materials exhibited superior structural stability under high-temperature and combustion conditions. Among them, SMC-C achieved both enhanced flame-spread suppression and the highest tensile strength retention, indicating that the protective-layer-forming fire-resistant system contributes to improving post-fire structural integrity. These results suggest that SMC materials, particularly SMC-C, are promising candidates for xEV battery pack covers where both fire resistance and structural retention are required.

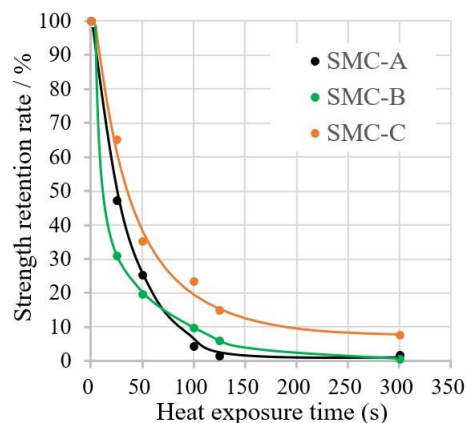


Fig.1 Comparison of tensile strength retention of SMC-A, SMC-B, and SMC-C under radiant heat exposureTime