ON-LINE PNEUMATIC COMPACTION SYSTEM FOR CONSOLIDATION ON A POWDER POLYMER TOWPREG PROCESSING LINE

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Abstract

Composite manufacturing methods of tape laying and filament winding rely on pre-impregnated tow, commonly known as towpreg, as its feed material. Despite the widespread use of wet processing with liquid polymer to fabricate towpreg, this method faces several challenges in producing high-quality towpreg. To address these issues, the composite group at the University of Sheffield is developing a towpregging processing line (tapeline), which uses dry polymer powder. This innovative approach aims to provide a versatile solution for producing high-quality towpreg.

The powder polymer is electrostatically sprayed onto the fibre tow. The tape is then heated to melt and sinter the powder, producing towpreg with controlled fibre volume fraction (FVF) and minimal defects. Currently, the polymer used on the tapeline is a low melt viscosity of 1.26 Pa·s powder epoxy allowing effective consolidation of powder on fibre without needing additional measures, other than regulating its heating temperature.

With the growing focus on thermoplastic polymers in composite manufacturing due to their recyclability and other benefits, the tapeline must be adapted to accommodate the production of towpreg from various polymers. Processing thermoplastics is typically expensive because of their higher melt viscosity–requiring more energy. On the tapeline, additional measures must be implemented to apply force onto the tape to facilitate the consolidation of high-melt viscosity thermoplastics onto the fibre. Ensuring high-quality towpreg of optimal FVF and minimal void content is important as it has a direct influence on the mechanical performance of the final composite part.

In this study, a compaction roller system was designed and installed on the powder tapeline to facilitate towpreg consolidation through pneumatic compaction pressure. The pneumatic compaction system operates using a nip roller mechanism, with its design influenced by factors such as roller material conformity, geometry, and nip angle. Previous research on the impact of compaction rollers on towpreg consolidation demonstrated the effectiveness of an on-line compaction system. In that study, an experimental spring-loaded compaction system was used to correlate towpreg void content and fibre volume fraction (FVF) with the applied compaction force. The results revealed two key findings: first, there is a minimum force threshold that the compaction system must apply to effectively reduce void content; second, the reduction in tape void content shows diminishing returns, especially when maintaining a FVF, as illustrated in Figure 1. However, the spring-loaded system had limitations, including the maximum achievable compaction force, which constrained the understanding of the optimal force required

for minimal void content. Despite these limitations, the results provided a strong foundational understanding and proof of concept for the influence of compaction on towpreg consolidation.

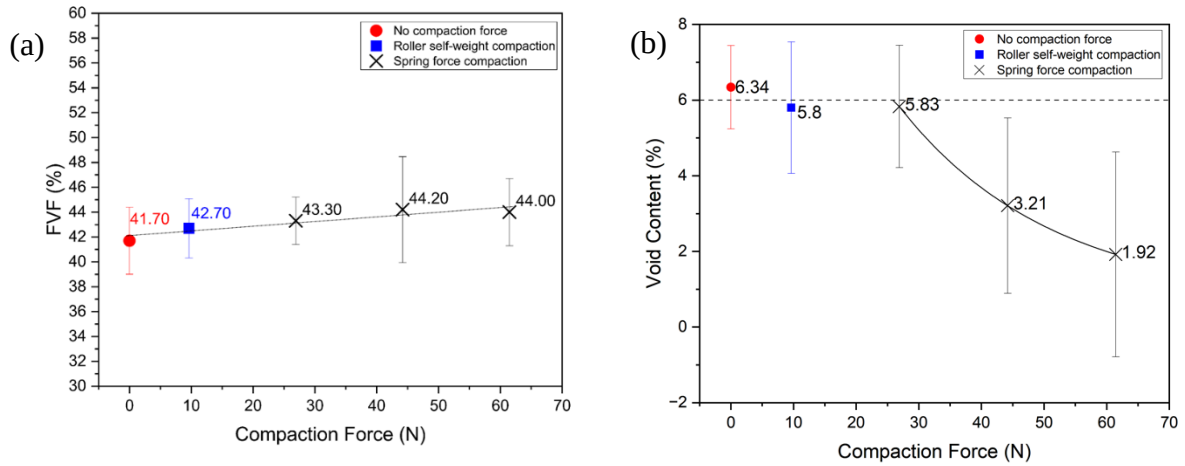

Figure 1: Impact of the on-line compaction system on towpreg FVF (%) with a small range or 2.5% deemed negligible (a) and void content (%), demonstrating a minimum threshold for compaction effectiveness and diminishing returns in void reduction with increased compaction force (b)

In the current study, the same materials will be used: Toray T700S-24K-50C carbon fibre tow and FreiLacke PE6405 powder epoxy. To accurately assess the impact of processing parameters on towpreg fibre volume fraction (FVF) and void content, three main processing parameters—heating temperature, web tension, and line speed—were kept constant. The unique properties of the powder epoxy allow for high-quality tape with low void content without additional force. However, since this study aims to compare results from powder epoxy experiments to those with thermoplastics, it is crucial to select processing parameters that isolate the influence of compaction on consolidation. Previous research has shown that FVF is primarily influenced by line speed, as it is the only factor influencing the duration of fibre tow exposure to powder deposition. A line speed of 3 m/min achieves approximately 55% FVF, which is suitable for investigating tape quality. For line tension and temperature, settings will ensure that the powder is sufficiently molten for effective compaction but not overly fluid, allowing for a clear examination of the compaction's effect on consolidation.

Sets of towpreg were produced with varying compaction pressures by adjusting the pneumatic force applied to the system. The resulting towpreg samples will be prepared for analysis using scanning electron microscopy (SEM) and image processing with ImageJ. It is important to note that the towpreg produced is uncured and brittle, requiring careful handling. The samples will be potted in low-viscosity resin pots and polished following a polishing sequence established in a previous study to minimize disturbance to the uncured tow.

Although this paper focuses on powder epoxy, the compaction system's mechanism for facilitating consolidation is also relevant for thermoplastic processing. Determining the optimal compaction force for minimal void content is crucial for understanding how factors such as material conformity, geometry, and applied force of the compaction system influence the quality of towpreg. This, in turn, affects the quality of the final composite part manufactured using this towpreg.