Investigation of Ultrasonic-Assisted Consolidation in Multi-Layered Thermoplastic Composites

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Abstract. Delamination remains a significant challenge in multi-layered composite structures, adversely affecting their mechanical performance in industries such as aerospace, automotive, and renewable energy. Ultrasonic-assisted manufacturing presents a promising solution by enhancing interlayer bonding, particularly through ultrasonic consolidation. This study investigates the potential of ultrasonic consolidation to improve the structural integrity of thermoplastic composites manufactured using two methods: hot press forming and vacuum bag curing in an oven. The mechanical properties of the fabricated samples, with and without ultrasonic assistance, were assessed through short beam shear testing to evaluate interlaminar strength. The results indicate that the application of ultrasonic pressure appears to enhance interlaminar strength in hot press samples and improve manufacturing reliability and repeatability of vacuum bag samples.

Introduction

The mechanical performance of thermoplastic laminated composites is strongly dependent on the adhesion between individual plies. Inadequate adhesion can lead to delamination, reduced mechanical strength, and compromised structural integrity. These issues often stem from inadequate interlayer bonding in conventional manufacturing, resulting in weak interfaces between adjacent layers [1]. Poor adhesion in thermoplastic composites can arise from factors such as surface contamination, suboptimal processing conditions (temperature, pressure), and material characteristics. Traditional consolidation methods, such as hot pressing and autoclave curing, may not fully mitigate these challenges, often resulting in suboptimal adhesion and mechanical performance. One promising approach to improving ply consolidation in thermoplastic composites is ultrasonic-assisted manufacturing. Ultrasonic technology enhances interlayer bonding by optimising key process parameters such as pressure, duration, and frequency [2]. The application of ultrasonic energy during consolidation enables more uniform heating and pressure distribution, leading to improved interlayer adhesion [3]. Moreover, ultrasonic-assisted methods can reduce processing time and energy consumption relative to conventional techniques, presenting a viable approach for enhancing the performance and reliability of thermoplastic composites. This study investigates the influence of ultrasonic-assisted consolidation on the short-beam shear strength of thermoplastic composites, assessing its impact on interlaminar adhesion and manufacturing consistency.

Experiments, Results and Conclusions

Two processing methods, hot press and vacuum bag in the oven, were explored for manufacturing PP60/Glass Twintex fabrics composite samples with 12 plies, following ASTM D2344/D2344M-16 standards. The hot press method applied 50 bar pressure for 3 min, while the vacuum bag method used 180°C for 60 min. The manufactured samples were cut into standard coupon test dimensions. Following manufacturing, ultrasonic and short-beam shear tests were conducted (Fig. 1). Ultrasonic parameters were set at 50 N, 120 s, and 20 kHz, with a thermal camera used to monitor temperature changes during ultrasonic vibration application. Hot press samples exhibited superior curing and consolidation compared to vacuum bag samples, which showed ductile behaviour under the short beam shear test. Ultrasonic-assisted samples demonstrated improved mechanical response, as evidenced by a higher first load drop in hot press samples, suggesting enhanced consolidation. While the effect of ultrasonics on mechanical response of vacuum bag samples was inconclusive, the results showed improved consistency, highlighting its potential for process reliability (Fig. 2). Thermal analysis revealed that ultrasonic application elevated local temperatures from 25°C to 80°C, which could positively influence curing and consolidation. Although the effect on resin melting (180°C) was limited, future studies could optimise ultrasonic parameters to achieve optimal temperatures for specific resin systems. Further research could also focus on refining ultrasonic horn design and exploring additional mechanical tests, such as the end-notched flexure (ENF) test, to assess the broader impact of ultrasonic-assisted manufacturing on thermoplastic composites.

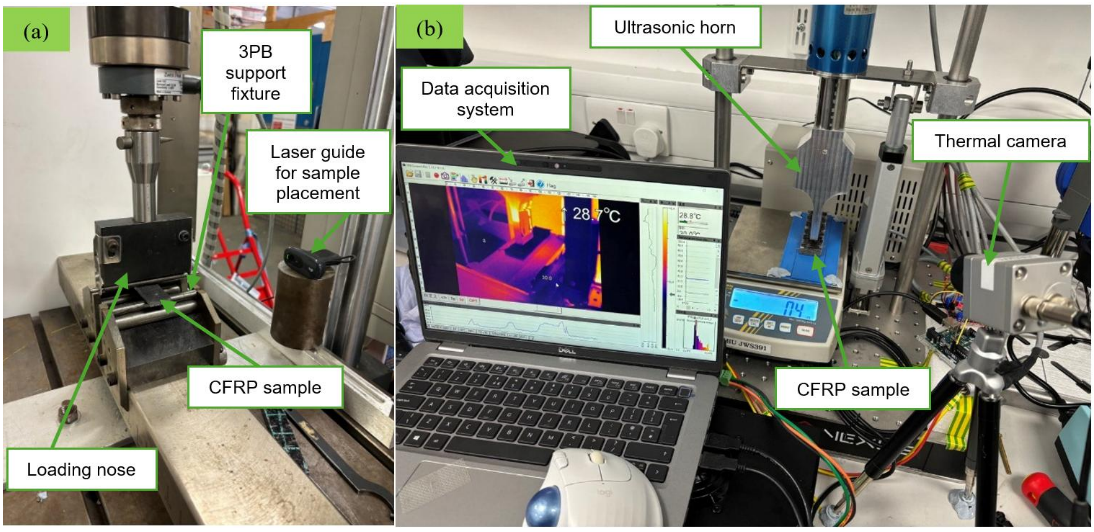

Fig. 1: Experimental procedure: a) experimental setup of short beam shear test, c) application of thermal camera during ultrasonic-assisted consolidation

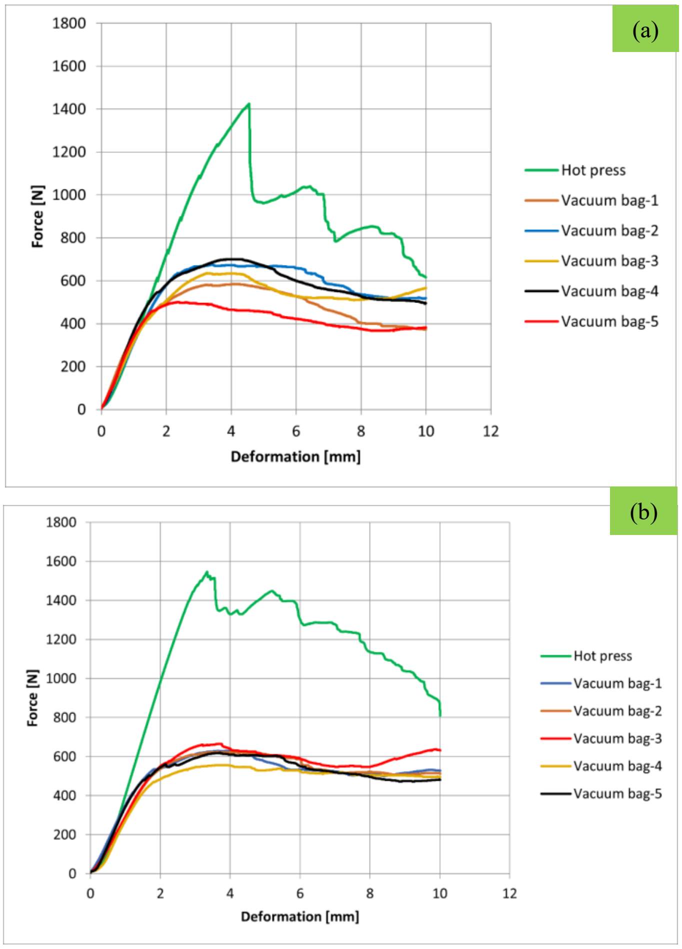

Fig. 2: Short beam shear test results: a) without ultrasonic application, b) with ultrasonic application

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