32nd International Conference
ENGINEERING MECHANICS 2026
Medlov, Czech Republic, May 11 – 13, 2026

DESIGN OF AN INFRARED HEATING SYSTEM FOR AUTOMATED FIBER PLACEMENT OF THERMOPLASTIC TAPES

Vomáčko V.[1]**, Miller V.**[2]

Abstract: *This paper presents the design and development of an infrared heating system for automated thermoplastic tape winding with in-situ consolidation. The primary objective is to develop a cost-effective alternative to laser-based heating by concentrating infrared radiation from a low-cost source using optical elements. Ray-tracing simulations of several focusing configurations (lenses and mirrors) are performed and their suitability for integration into a compact placement head is evaluated. In parallel with the heating system, a dedicated four-degree-of-freedom tape winding machine is being developed to enable controlled placement on rotationally symmetric components as well as closed-section composite profiles. The system is intended for processing carbon fiber reinforced polypropylene and polyamide tapes.*

Keywords: Automated Fiber Placement, Thermoplastic composites, Infrared heating, In-situ consolidation, Tape winding

1. Introduction

Long fiber-reinforced thermoplastic (TP) polymer composites are gaining importance across aerospace, automotive and energy sectors due to their high specific strength, short consolidation cycles, weldability, and potential for recycling (Boon et al., 2021). Unlike thermoset-based composites that require lengthy autoclave curing, thermoplastic matrices can be processed by local melting and consolidation under heat and pressure, enabling single-step manufacturing without post-curing (Yassin and Hojjati, 2018). Additional advantages include virtually unlimited shelf life of the prepreg material and inherent resistance to most solvents and chemicals.

Automated Fiber Placement (AFP) and thermoplastic tape winding are computer-aided manufacturing processes for automated lamination of TP composites. In AFP, a prepreg tape is deposited onto a tool surface by a placement head mounted on a robotic manipulator. The tape and the substrate are simultaneously heated at the nip point, while a consolidation roller applies pressure to achieve in-situ consolidation (ISC). AFP is predominantly used in aerospace for large, complex structures (Lukaszewicz et al., 2012). When the same principle is applied to rotational parts — tubes, pressure vessels, drive shafts — the process is commonly referred to as thermoplastic tape winding (TTW). TTW is distinguished from classical filament winding by the use of fully impregnated prepreg tapes and ISC rather than wet winding with subsequent curing (Yassin and Hojjati, 2018). A key advantage of TTW is that the continuous nature of the winding process eliminates the need for tape cutting between courses, simplifying head design and increasing process efficiency for axisymmetric geometries.

The quality of in-situ consolidated parts depends critically on the thermal history at the nip point. The tape must be heated above the melting temperature of the semi-crystalline matrix to enable intimate contact and molecular diffusion between layers. Insufficient heating leads to poor interlaminar bonding, while excessive temperatures cause thermal degradation of the polymer (Stokes-Griffin and Compston, 2015). The achievable placement speed is therefore directly limited by the power density and controllability of the heat source. Common heat sources for ISC include hot-gas torches, diode lasers, xenon flash lamps,

[1] Ing. Václav Vomáčko, Ph.D.: VUTS, a.s., Svárovská 619 1, 460 01 Liberec; CZ, vaclav.vomacko@vuts.cz
[2] Ing. Vojtěch Miller: Technical University of Liberec, Faculty of Mechanical Engineering, Studentská 1402/2, 461 17 Liberec; CZ, vojtech.miller@tul.cz

ISSN: 1805-8256, doi: 10.21495/em2026-145

and infrared heaters (Yassin and Hojjati, 2018; Calawa and Nancarrow, 2007). Hot-gas torches offer low capital cost but suffer from poor energy efficiency, slow thermal response, and difficulty in confining the heated zone. Diode lasers provide high power density, precise beam shaping, and fast response, making them the dominant choice for high-performance applications in the aerospace industry, but their capital cost remains a significant barrier to wider adoption. Standard infrared heaters are the most affordable option; however, their extended radiating area and limited focusing capability result in insufficient power density at the nip point for practical placement speeds (Calawa and Nancarrow, 2007). This motivates the development of optimized IR heating systems that could bridge the gap between cost and performance. The goal is to concentrate the radiation from a low-cost IR source onto the nip point area using a system of optical elements, achieving the power density needed for ISC while keeping investment costs at a fraction of laser-based systems.

2. IR heating – optical simulation study

To evaluate the feasibility of focused IR heating, ray-tracing simulations were performed in Zemax OpticStudio. A medium-wave flat-panel ceramic IR emitter was used as the source model. The key metric was the irradiance distribution on a target area representative of the tape at the nip point. Several optical configurations were investigated. A dual-lens refractive system (Fig. 1a) and an off-axis parabolic mirror (Fig. 1b) were modeled. Both configurations demonstrated an increase in power density at the tape of approximately 10–15 % compared to the unfocused emitter; however, the resulting concentration remained below what is needed for practical winding speeds with thermoplastic matrices. In addition, both configurations presented practical limitations: the lens system suffered from broadband chromatic aberration, absorption losses at elevated temperatures, and difficulty fitting within the compact placement head envelope; the mirror offered better spectral efficiency but required a physically large reflector that obstructed the tape path. These results indicated that conventional focusing elements alone are insufficient, and further optimization of the heating system design is ongoing.

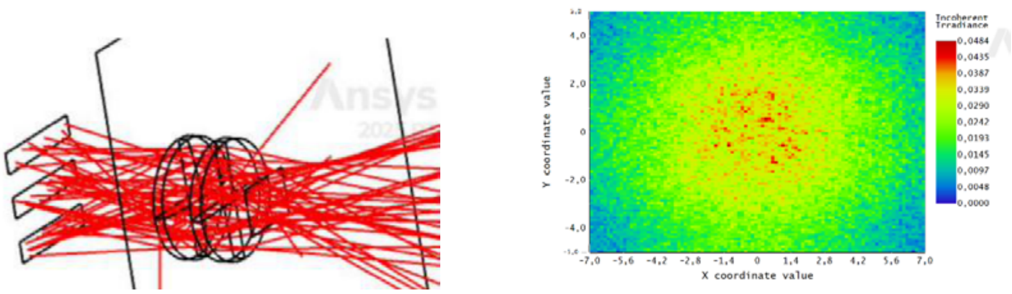

Fig. 1: Ray-tracing simulations of evaluated IR focusing configurations (Zemax OpticStudio): (a) refractive lens configuration, (b) intensity distribution on the tape.

3. Tape winding machine design

A dedicated tape winding test bench has been designed as a self-contained station for manufacturing rotationally symmetric TP composite parts such as tubes and cylindrical shells (Fig. 2). Four-degree-of-freedom configuration was selected: mandrel rotation, horizontal and vertical traverse of the placement head, and head rotation about a vertical axis. The station accommodates mandrels of 30–300 mm diameter and 300–1,500 mm length, with tape placement angles from 0° (axial placement) to ±90° (hoop winding) relative to the mandrel axis.

The machine frame is constructed from aluminum profiles and supports a precision-machined base plate carrying the mandrel drive and support system. The mandrel is held between a three-jaw chuck and a tailstock with a pneumatic quill that accommodates thermal expansion during processing. The mandrel rotation is driven by a servo motor through a gearbox to provide sufficient torque across the full range of winding speeds. The placement head integrates a tape unwinding and feeding mechanism with servo-driven rollers and controlled spool braking, a pneumatic consolidation roller, and the IR heating assembly. The entire head is mounted on a servo-driven vertical linear guide for automatic adaptation to varying mandrel

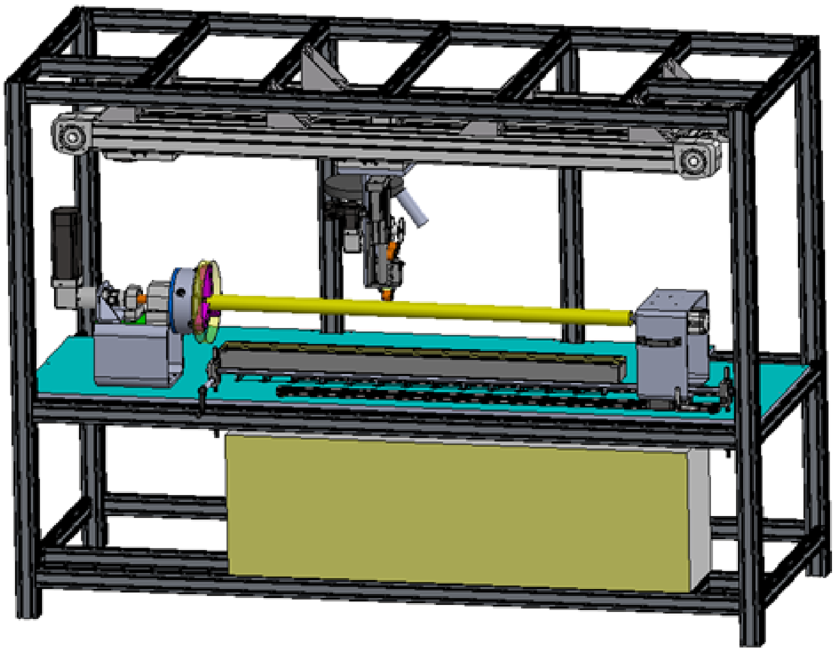

Fig. 2: 3D model of the tape winding test bench for thermoplastic composite manufacturing with IR heating.

diameters and for production of slightly tapered geometries. The working space is enclosed by transparent polycarbonate safety panels with interlocked doors.

Similar to the heated build plate used in fused filament fabrication, the mandrel is heated to maintain an elevated substrate temperature during winding. This is particularly important for semi-crystalline thermoplastic matrices, where controlled cooling influences the degree of crystallinity and consequently the mechanical properties of the final laminate (James and Black, 1996). Temperature monitoring is performed by a non-contact IR pyrometer integrated into the placement head, providing real-time feedback for closed-loop power regulation of the heating system.

4. Target applications and materials

The machine is designed to produce rotationally symmetric parts (tubes, cylindrical shells, conical sections) as well as open profiles, with a maximum part length of 1,500 mm. While the primary focus is on thermoplastic tape winding with in-situ consolidation, the machine architecture is also compatible with thermoset prepreg tapes. The initial target thermoplastic materials are carbon fiber reinforced polypropylene (CF-PP) tapes and carbon fiber reinforced polyamide (CF-PA6, CF-PA12) tapes. These materials are increasingly relevant for automotive, sporting goods and industrial applications where good mechanical properties, chemical resistance, and short cycle times are required (Boon et al., 2021).

5. Conclusion

An automated tape winding machine with a novel infrared heating system for in-situ consolidation of thermoplastic composites is under development. The optical simulation study confirmed that conventional focusing elements (lenses, mirrors) can increase the IR power density at the tape surface compared to an unfocused emitter, but the achievable concentration remains below the threshold required for practical winding speeds with thermoplastic matrices. The project is therefore pursuing an alternative optical delivery concept that promises significantly higher energy concentration at the nip point. The four-degree-of-freedom test bench provides the flexibility needed for a wide range of laminate geometries on rotationally symmetric and profiled parts.

Acknowledgments

This work is co-financed with the state support of the Technology Agency of the Czech Republic within the SIGMA Programme, project No. TQ15000291.

References

Boon, Y. D., Joshi, S. C., and Bhudolia, S. K. (2021) Review: Filament winding and automated fiber placement with in situ consolidation for fiber reinforced thermoplastic polymer composites. *Polymers*, 13, 12, pp. 1951.

Calawa, R. and Nancarrow, J. (2007) Medium wave infrared heater for high-speed fiber placement. In *SAE Technical Paper*. pp. 2007–01–3843.

James, D. L. and Black, W. Z. (1996) Thermal analysis of continuous filament-wound composites. *Journal of Thermoplastic Composite Materials*, 9, 1, pp. 54–75.

Lukaszewicz, D. H.-J. A., Ward, C., and Potter, K. D. (2012) The engineering aspects of automated prepreg layup: History, present and future. *Composites Part B: Engineering*, 43, 3, pp. 997–1009.

Stokes-Griffin, C. M. and Compston, P. (2015) The effect of processing temperature and placement rate on the short beam strength of carbon fibre–peek manufactured using a laser tape placement process. *Composites Part A: Applied Science and Manufacturing*, 78, pp. 274–283.

Yassin, K. and Hojjati, M. (2018) Processing of thermoplastic matrix composites through automated fiber placement and tape laying methods. *Journal of Thermoplastic Composite Materials*, 31, 12, pp. 1676–1725.