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Online evaluation of ultrasonically welded carbon fiber reinforced thermoplastic laminates by means of infrared vibrothermography

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1 Abstract

Recent advances in thermoplastic matrix composite manufacturing are enabling their increased use in primary structural applications, owing to advantages such as processability, weldability, and recyclability [1]. Among the available joining techniques, ultrasonic welding is particularly attractive for producing high-quality joints with short cycle times and high repeatability. However, its adoption in primary structures requires reliable and efficient non-destructive testing (NDT) methods to ensure weld integrity.

This work examines ultrasonic spot welding (UW) of thermoplastic composite laminates in a sequential, online process. Welding is achieved using sonotrodes that apply pressure and high-frequency vibrations to promote interfacial bonding, assisted by a thermoplastic energy director layer. The proposed IR-NDT approach reuses the same welding setup and sonotrode to periodically apply lower-energy vibrations, generating a thermal response suitable for infrared-based online NDT inspection.

The method is inspired by conventional Vibrothermography IR-NDT [2], where mechanical excitation produces thermal signatures that reveal defective zones. The application in the UW context is found to provide signatures allowing the identification of welded area, as well as the assessment of weld quality. Partially welded regions exhibit localized heating, while fully consolidated welds appear colder due to more efficient heat dissipation between adherends [3].

Keywords: Ultrasonic Welding, Carbon-Fibre Reinforced Thermoplastic Composites, Infrared Non-Destructive Testing, Vibro-Thermography.

2 Introduction

In this work, a Vibro-Thermography inspection strategy is proposed for carbon-fibre-reinforced, thermoplastic-matrix composite laminates joined by ultrasonic spot welding (UW). The composites employ an LM-PAEK thermoplastic matrix [4] and an LM-PAEK thermoplastic net layer used as an energy director at the welding interface. Panels with different widths and thickness combinations have been manufactured by varying the welding time within a process window specifically defined for LM-PAEK matrix adherends. The same setup used to fabricate the joints is subsequently employed as a low-power vibration source to excite localized inspection regions, while a cooled-sensor infrared camera records the transient thermal response.

3 Materials, methodology and experimental plan of experiments

The campaign is performed on flat CFRP/LM-PAEK panels (areal dimensions 400×40 mm^2) joined through 12 equally spaced weld spots. Ultrasonic welding is conducted at constant amplitude and pressure, while the welding time t_w is varied from 1 to 6 s to generate under/over welded joints, achieving different grades of sound and defective conditions. For the vibro-thermography NDT inspection, the same sonotrode is run at a low-power and shorter time vibratory mode. Figure 1 provides a thermogram map during the Vibrothermography transitory stage. Preliminary evidence shows sound spots appearing colder than defective ones, consistent with more efficient heat dissipation versus voided or lack-of-fusion regions.

4 Expected outcomes

The work quantifies how panel geometry and welding parameters affect Vibrothermographic metrics and, in turn, the achievable thermal contrast. The methodology is based on extracting ROI-based thermal metrics, evaluating heating and cooling profiles, and analysing the morphology of the related 3D maps. These results are used to identify thermal patterns linked to different joint conditions and to define detection thresholds for lack-of-fusion defects and other welding discontinuities. Ultimately, the study will deliver practical guidelines for selecting excitation parameters compatible with inline use and for developing automated inspection procedures for ultrasonically welded thermoplastic composite panels.

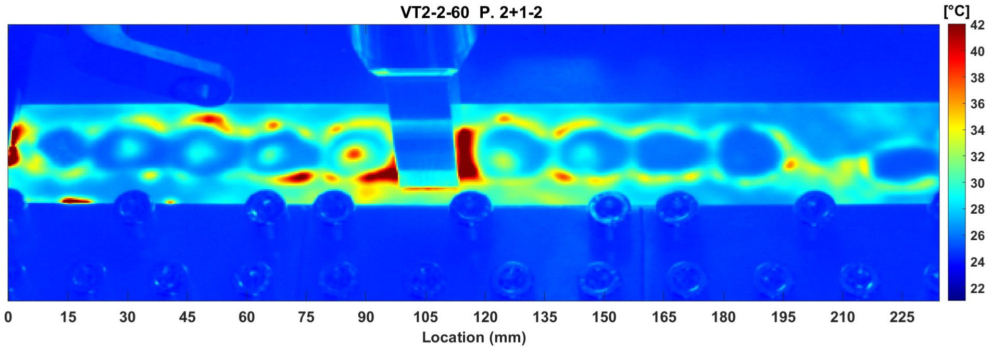

Fig. 1: thermogram acquired during the IR-NDT Vibrothermography stage. The central sonotrode induces temperature signatures able to identify the boundaries of the welded regions. Colder weld spots identify sound weldings.

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