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Resistive embedded heating for homogeneous curing of adhesively bonded joints

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ABSTRACT

Adhesively bonded single-lap joints with laminated composite adherends were cured using heat generated by passing an electrical current through a carbon fiber fabric embedded in the bondline. Resistance heating using the embedded fabric resulted in a uniform temperature distribution in the bondline, as compared to temperature fields typically generated using more conventional surface heating methods such as heat blankets or heat lamps. Composite single-lap joint specimens were created using the proposed embedded heating approach, via an oven cure under a vacuum and through the use of an autoclave. The bond strengths of all specimens were measured and found to be comparable. The proposed embedded curing technique results in bond strengths that equal or exceed those achieved with conventional methods, and at potentially lower cost.

1. Introduction

Composites have better strength-to-weight and stiffness-to-weight ratios when compared to metals, and therefore, composite structures enable aircraft to be more fuel-efficient. The increased use of high-strength Carbon Fiber Reinforced Polymers (CFRP) in passenger aircraft has resulted in an escalation of maintenance issues associated with composite structures. Hence, the repair of damage to composites has become an important issue in the aerospace industry. A common requirement is to rapidly repair a composite structure without removing it from the aircraft. Repair of thick structures while still on the aircraft can be difficult to achieve. For example, the thermal energy necessary to cure the repair adhesive must diffuse through the composite layers to reach the joint repair interfaces, resulting in long and expensive processing times as well as wasted energy [1–3]. Surrounding heat-sensitive materials or equipment may also be damaged. The most popular approach is to use a surface heater such as heat blanket (s) and/or heat lamps to generate the heat needed to cure the repair adhesive. In these approaches the entire structure is heated to initiate cure of the repair adhesive, typically a high-strength thermoset such as an epoxy. CFRPs typically exhibit poor thermal conductivities and consequently the temperature of the heated surface can be much higher than the temperature at the subsurface repair bondline. Large thermal gradients are inevitably created, resulting in an inefficient repair process.

We proposed to overcome these difficulties by passing an electrical current through a carbon fiber fabric sandwiched between two layers of structural adhesive film and embedded in the bondline. The carbon fabric serves as an embedded a resistance heater. A substantial advantage of this approach is that the carbon fibers that initially serve as heating elements remain in the bondline as reinforcing materials. Since many types of carbon fibers have already been certified for use in transport aircraft (e.g., AS4 or IM7 fibers), which could facilitate certification of the proposed approach for use in commercial aircraft. The epoxy adhesive electrically insulates the embedded heater from the electrically conductive adherends. Moreover, it will be shown that bonded joints cured via an embedded resistive heating method have single-lap shear strengths comparable to the strengths of samples cured in an autoclave.

In the past literature, efforts have been reported to reduce the cost of producing thermoset/thermoplastic composites by avoiding the need for expensive autoclaves or ovens. These methods could conceptually be used during composite repair, as discussed in reference [1]. As a case in point, UV photo-curable adhesives were utilized in the past and cured through, transmission of the UV light through the laminate [4,5]. Microwave curing of composite materials has been considered as a highly efficient volume-heating radiation manufacturing process; however, heating efficiency of the microwave depends greatly on the dielectric properties of the material [6,7]. Inductive heating or welding has proven to be effectively employed in an epoxy adhesive between composite adherends to cure the bond and produce strong joints [2,8]. Nonetheless there are difficulties associated with edge and local heating effects that have limited large scale applications [1,8–10].

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Studies have been performed in the past to improve cure homogeneity by taking advantage of the conductivity of the carbon fibers embedded in the matrix to cure the carbon-fiber/epoxy pre-pegs internally [11–15]. References [12–14] utilized carbon fibers in the pre-pegs as resistive heaters to cure the composite laminates. In contrast, references [10,11] reported the use of a carbon-fiber mesh sandwiched between resin/resin saturated fiber layers to create composite parts. The current paper focuses on adapting such use of carbon-fiber resistive heaters to bond composite materials, which can be potentially used in composite repair applications. Resistive heating in bonding applications is a relatively new technique, and very few studies are available in the literature. Rider et al. [1] reported the use of a stainless steel mesh as an embedded resistive heater to achieve shear strength similar to the joints cured by the conventional methods; however, shear strength was proven to be highly dependent on the stainless steel mesh surface treatment. Additionally, Mas et al. [16] reported curing epoxy resins through Joule heating of dispersed carbon nanotubes (CNTs) which were deposited on the epoxy using a three roll mill. Subsequently, the epoxy resin was used as an

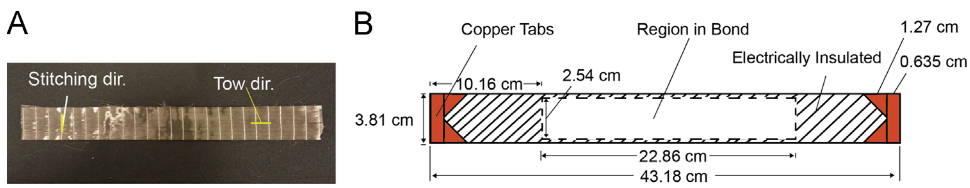

Fig. 1. (A) Uni-directional carbon fiber mesh used as the embedded heater and (B) schematic of the embedded carbon fiber mesh.

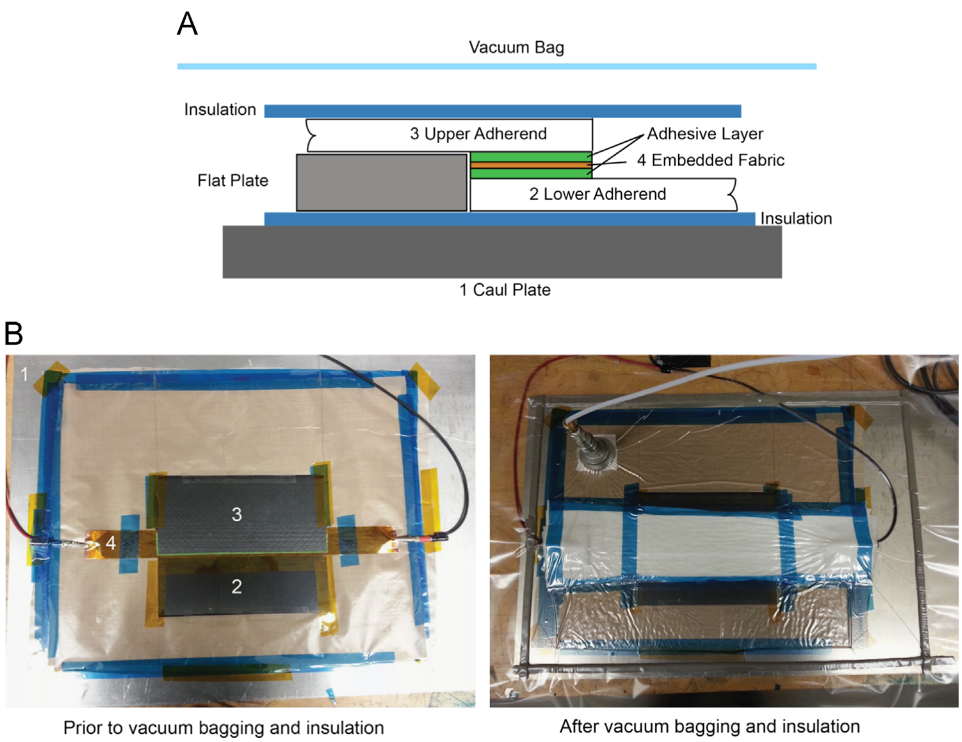

Fig. 2. (A) Schematic of the experimental setup for embedded resistive curing of a single lap joint and (B) photograph of the experimental setup prior to and after vacuum bagging and insulation.

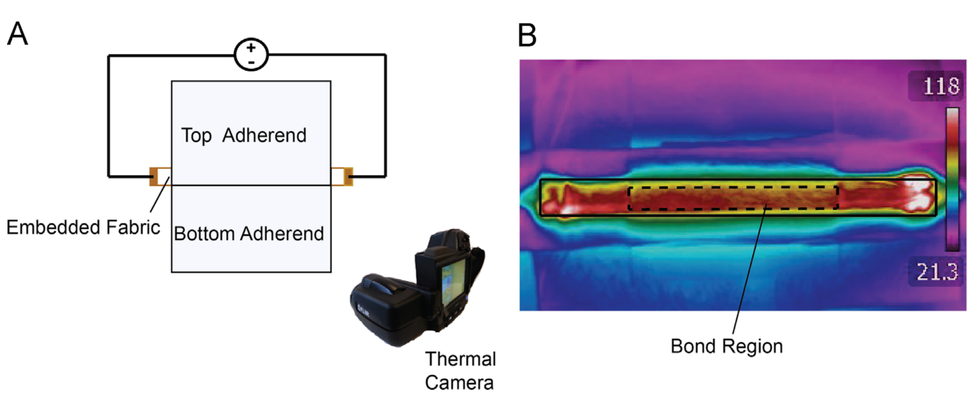

Fig. 3. (A)Schematic of the closed-loop control using an embedded temperature sensor and (B) thermal picture of the bond region shows that the temperature range in the overlap was about 15 °C.