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Review

Thermoplastic–epoxy interactions and their potential applications in joining composite structures – A review

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ABSTRACT

This paper presents a literature survey on the theoretical backgrounds and the past research efforts in relation to the interactions between certain thermoplastics and epoxies, and their applications in polymer blending, epoxy toughening and composite joining. The main objectives are to understand the possible mechanisms of interfacial adhesion between thermoplastic and thermoset polymers, and also to explore the feasible approaches to improve interfacial adhesion for the purposes of joining fibre reinforced polymer (FRP) composite structures by fusion bonding. Further, it is expected that the review would provide some visions to the potential applications of the thermoplastic–thermoset interfacial interactions for the quick assembly of composite structures in cost-effective manufacturing of composite structures, through the uses of the technologies, such as thermoset composite fusion bonding, welding of thermoplastic composites with thermoset composites, and thermoplastic article attachment on thermoset composites.

Contents

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1. Introduction

FRP composites have emerged as a new range of materials, due to their ability to offer substantial advantages over traditional metallic materials in terms of density and fatigue properties. Particularly, aerospace industry has found the increased use of composites in aeroplanes, especially in airliners, because of the reduced weight compared to equivalent metal structures. Currently, FRP composites have taken up major part of the structural mass of some civil and military aircraft [1–4].

However, one of main aspects currently limiting the applications of the FRP composites on large scales is their relatively high cost in relation to the raw materials, manufacturing and assembly [5]. In particular, the joining cost of composite components remains one of the major cost drivers, due to the different characteristics of FRP composites from the traditional metallic materials [6]. Consequently, efficient joining of composite structures is a critical step for cost-effective manufacture of modern aircraft components [7–10]. Successful applications of advanced joining technologies will allow cost savings in production, as well as achieving new levels of flexibility in the assembly, repair and replacement of composite components, and even in the disassembly of the structures at end of their lives. As the use of composite materials grows, so does the need for fast and reliable methods for joining and repairing of FRP composite structures.

Three major joining technologies exist for aerospace composite structures, namely mechanical fastening, adhesive bonding, and welding (fusion bonding). Mechanical fastening using screws, rivets, bolts, etc. has some disadvantages in joining FRP composite parts due to expensive hole-locating, drilling, shimming, and fastener installation, and also the problems in association with stress concentrations and fibre breakage due to hole drilling, although some composite components are still being assembled using mechanical fasteners [10].

Adhesive bonding using mainly epoxy adhesives is another technique to assemble composite parts, which has some advantages over mechanical fastening [8,9,11], but it is labour intensive, as it requires surface preparation and long curing time, as well as elevated cure temperatures if thermoset adhesives are used [12].

As a long established technology for joining metals or thermoplastics, welding or fusion bonding is performed through coalescence of the materials to be joined. With the help of pressure and heat, welding is often done by melting the work pieces or by adding a filler material to form a pool of molten material (the weld pool) that cools to become a strong joint. Composite welding, using thermoplastics as hot-melt adhesives with minimum or little, if any, pre-treatment, is a high efficient process for joining FRP composite components, capable of producing high performance joints, which are equivalent or better than adhesively bonded or mechanically fastened joints [13,14]. The main advantages of thermoplastic welding over thermosetting adhesive bonding method are the high speed at which composite components can be assembled at the relative short cycle time and the environmentally friendly condition as it can reduce and even eliminate the need for surface preparations [15–17].

Thermoset and thermoplastic polymers, as well as their composites, can be adhesively bonded or mechanically fastened, while welding can only be performed on thermoplastics and their composites, other than metals. Direct joining of fully cured thermoset composite structural components has been limited to the use of mechanical fasteners and the traditional thermoset adhesives. Due to the highly cross-linked structure, no welding can be performed to directly join the thermoset-based composite parts. To take the advantages of fusion bonding, several approaches have been undertaken to indirectly join thermosetting composites by welding, including the uses of thermoplastic–thermoset hybrid adhesives or the thermoplastic medium layer to join thermoset composite components [15,18–20]. In these investigations, a special sheet of thermoplastic was incorporated on the surface of the thermoset composite components to be joined. The thermoplastic and thermoset polymers intermingle before the cure of the thermoset polymer was complete to provide a strongly attached thermoplastic surface on the composite laminate. Subsequently, fusion bonding of thermoset composites (FBTC) could be rapidly performed by means of various fusion bonding methods to weld the thermoplastic surface layers together, giving a robust joint with less sensitivity to aggressive environments than adhesive bonded joints [13,14,19,20].

As FBTC is actually achieved by fusion bonding of thermoplastic medium layers on the surfaces of the thermoset composite parts to be joined, a strong thermoplastic–thermoset interface is thus very critical. Since the degree of thermoplastic–thermoset interfacial adhesion depends on a number of physical and chemical aspects, a deep understanding to these factors is of importance to the successful applications of FBTC in composite assembly. In this paper, a literature survey is conducted to review the principles and technologies in relation to thermoplastic–thermoset interfacial adhesion and the fusion bonding techniques of FRP composite structures, with the main focus being on the thermoplastic–epoxy interfacial interactions and their potential applications in joining composite structures by welding.

2. Theoretical background of thermoplastic/thermoset adhesion

2.1. Adhesive bonding of engineering components

In adhesive bonding, the forces, which are involved in holding adhesive to its adherends (or substrates) or in keeping the adhesive together as a bulk material, are from the same origins. Although there are a number of forces that take effects across the interface, basically adhesive and cohesive forces determine the strength of a