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Analysis of interfacial debonding in metal-polymer joints fabricated via thermal direct joining technique

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In various industrial sectors—such as automotive, aerospace, and robotics—there is an increasing demand to reduce energy consumption and, consequently, limit CO_2 emissions. One effective strategy to achieve this goal involves the use of a combination of lightweight materials, such as polymers, composites, and metals, to create structurally efficient designs that minimize weight. However, this approach requires the development of advanced joining techniques that maintain the integrity of these materials without adding unnecessary weight.

Traditional joining methods, like bolts or rivets, can compromise the structural properties of composites and increase weight, thus undermining the benefits of lightweight materials. A promising alternative is adhesive bonding. While adhesive bonding offers several advantages, it can present challenges when bonding certain material combinations, such as metals to thermoplastics. These challenges are often related to factors like material compatibility and environmental concerns during both production and disposal.

In this context, a promising approach is direct thermal joining, which utilizes the polymer itself as the bonding element. By applying heat to the contact area, the polymer transitions into a semi-liquid state, forming a bond with the metallic substrate. This method enables the creation of lightweight, reversible, and recyclable joints, which aligns with the principles of a circular economy. However, challenges may arise during production due to insufficient polymer adhesion to the metal, which can lead to reduced mechanical performance. Recent studies have shown that surface treatments designed to enhance mechanical interlocking between the substrates offer an effective strategy to improve toughness and damage tolerance in these joints.

A previous study by the authors demonstrated that a properly calibrated laser treatment significantly enhances the shear strength of metal-polymer joints. In this work, the impact of this laser treatment on the mechanical behavior of metal-polymer joints was analyzed, focusing on peeling stress across the interface. Structural aluminum alloy and polylactic acid (PLA) were selected as base materials for joint fabrication. The polymer substrates were produced through 3D printing, and the base material properties were characterized through dedicated mechanical tests. The joint was fabricated using the direct thermal joining technique, building upon the authors' previous results.

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