Maximizing bonded joint performance with the use of additively manufactured adherends and adhesives

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Introduction

A larger variety of Additive Manufacturing (AM) based tailoring methods allow to improve the performance of bonded joints with additively manufactured adherends, leading to improved stress distribution along the bondline (Figure 1). This work assesses the experimental achievements in the design for additive manufacturing of bonded joints, providing a summary of the current state of art and identifying new opportunities.

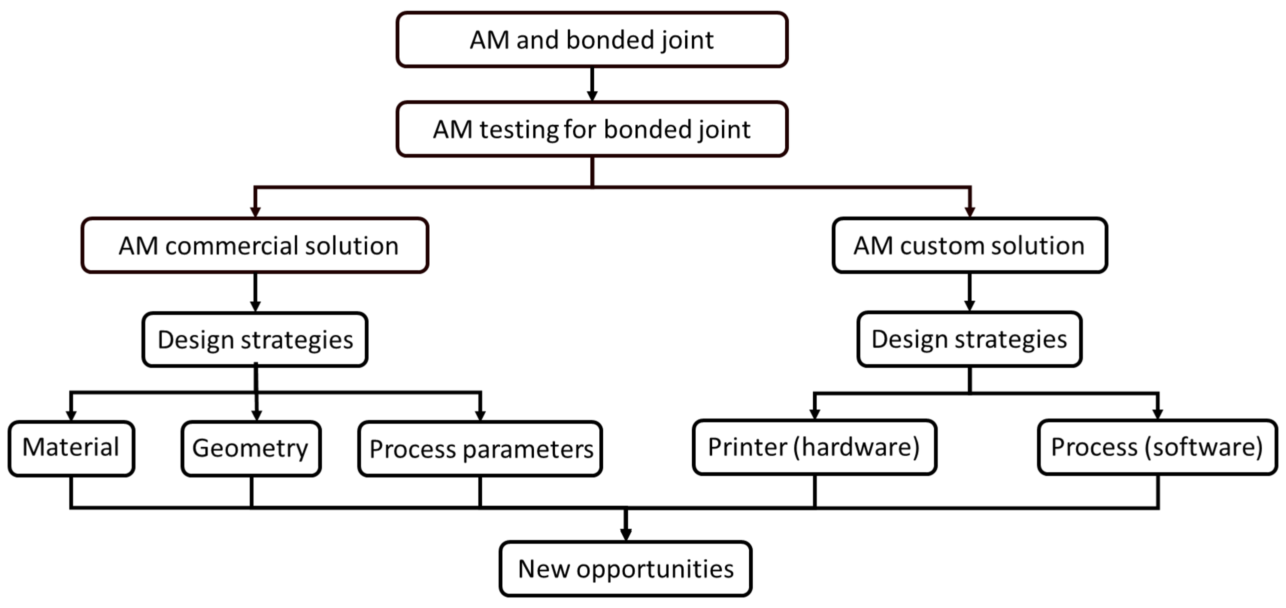

Figure 1 – Research topics on additive manufacturing and bonded joints

Additive manufacturing methodologies allow for a minute control of material deposition patters. When describing its use with bonded joints, three different approaches are possible. The use of multi material additive manufacturing (MMAA), the use of geometrical features for localized control of the material properties and lastly, the direct tailoring of adhesive properties, achieving, for example functionally graded adhesives (FGAs)

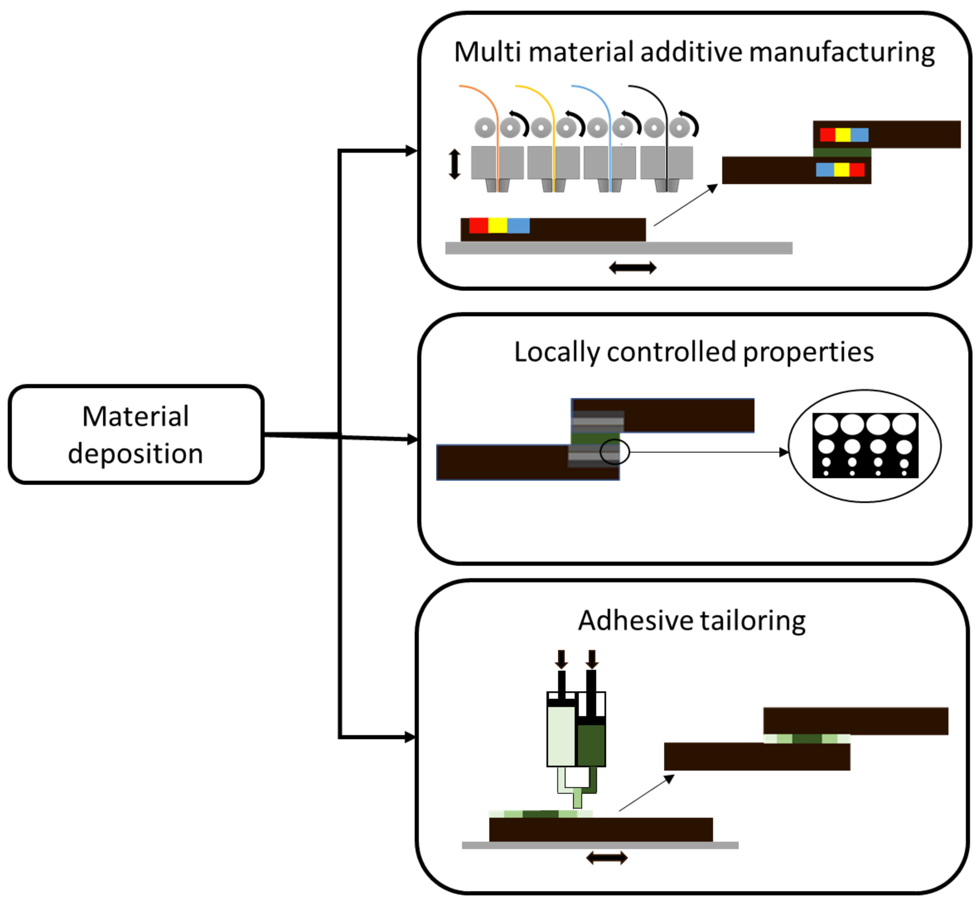

Figure 2 – Voxel oriented material deposition design strategies for AM bonded joints

Multi-material additive manufacturing

Diverse properties can be tailored using MMAM, such as modulus tailoring, seeking a gradual variation along the overlap (Figure 3) mimicking with the DMs the structure of a second phase dispersion in the adhesive. For example, it is possible to increase the modulus of a compliant material with stiffer spheres in the middle of the overlap, obtaining an equivalent modulus that follows a normal distribution shape [1]. Alternatively, the modulus of a stiff material at the overlap ends can be reduced with the use of spheres of a more compliant material, obtaining an equivalent modulus that follows a parabolic shape.

The use of stiffness tailoring of the adherend to affect the stress distribution in the bond line and improve the overall joint carrying capacity [2]. It has been shown that DMs can control the material properties of the adherends. 2D FEM models were implemented in order to investigate different tailoring configurations in x and y directions for the SLJ geometry.

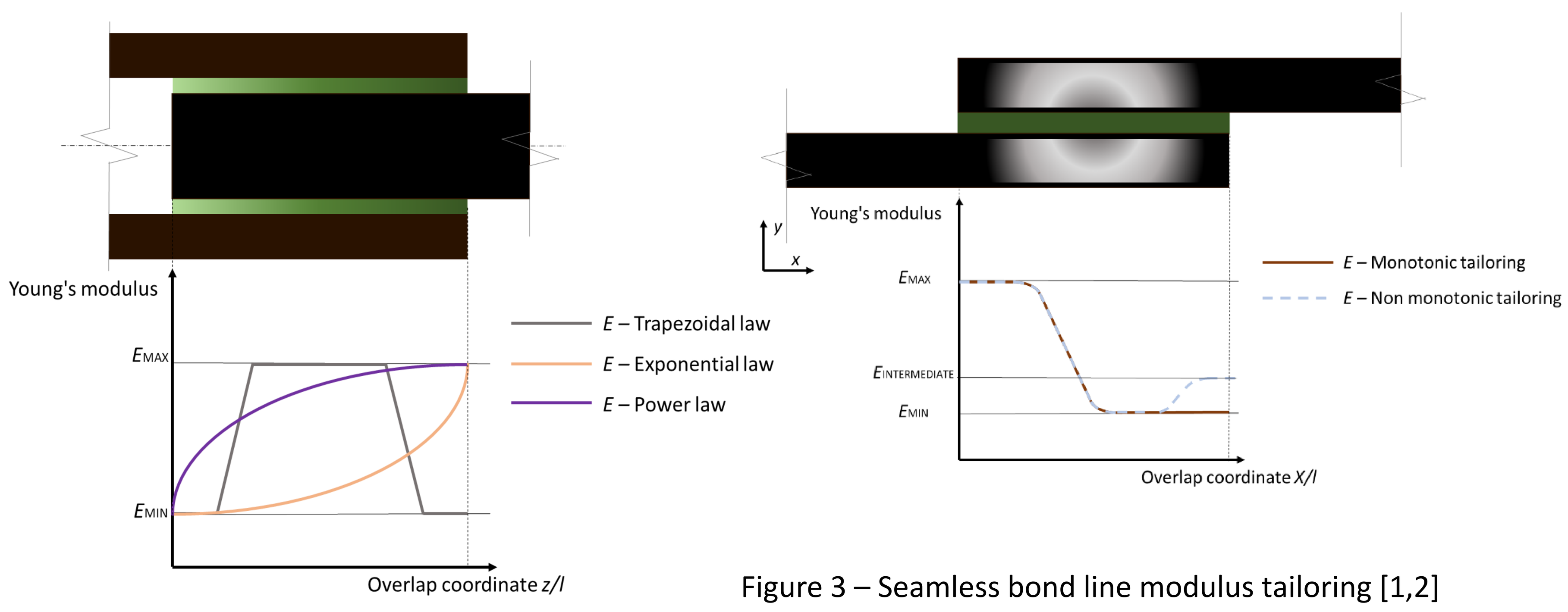

Figure 3 – Seamless bond line modulus tailoring [1,2]

Locally controlled properties

Nowadays, it is possible to locally vary the material density and thus modify the overall joint response under loading. These design approaches can be considered an extension of the concept of varied densification from functionally graded additive manufacturing (FGAM), the voxel-oriented material modelling that shifts the design focus from the geometrical dimensions to through-the-thickness structures in order to maximize the performance of the components [3]. Figure 4 shows an example based on the integration of sub-surface geometry to achieve variable adherent performance.

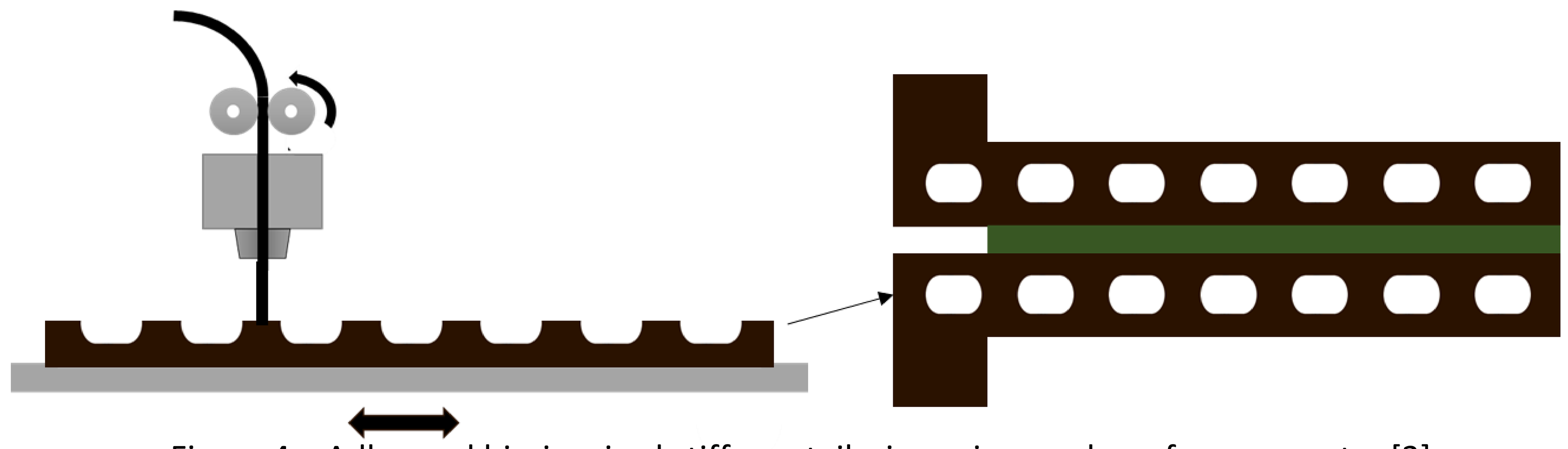

Figure 4 – Adherend bio-inspired stiffness tailoring using a sub-surface geometry [3].

Adhesive tailoring

The practical methods to obtain FGA adhesives are to mix adhesives with different properties in different volumetric percentages, to create a non-uniform reinforcement distribution in the bond line or to apply different localized curing cycles. Usually, the aim is to optimize the stress distribution in the bondline, lowering peel stresses at the overlap ends.

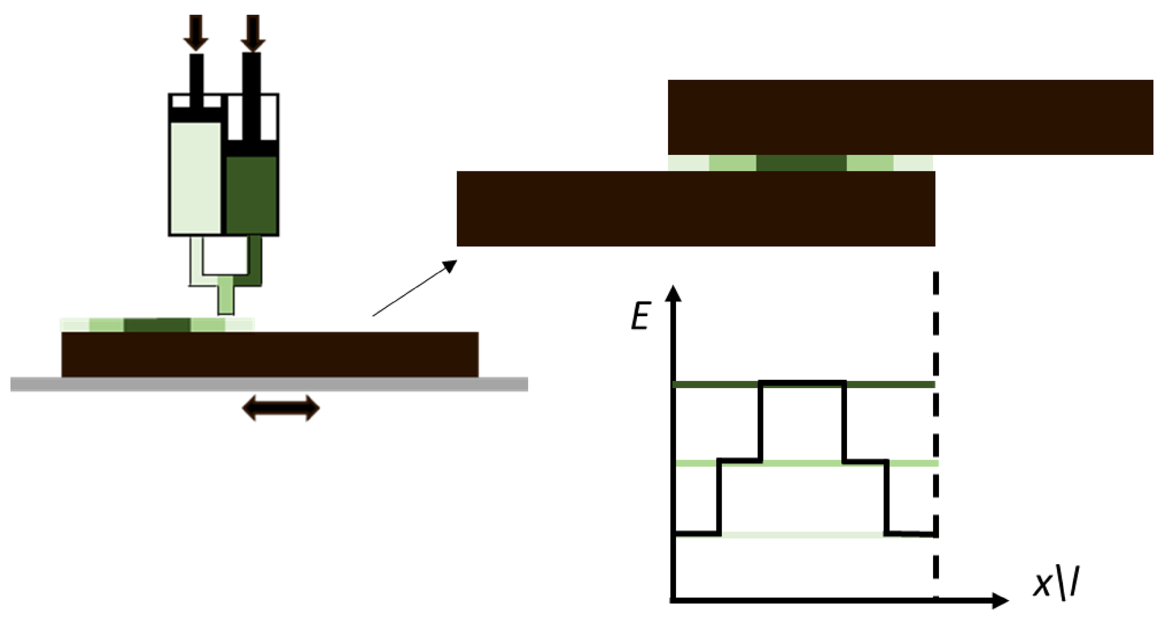

Figure 5 – Adhesive modulus tailoring using a step-wise design strategies and second-generation acrylic adhesives [4].

To control the mixing ratio of agents during the adhesive deposition at the overlap, a special apparatus can be purposely developed [4], using a dedicated actuator to control the amount of each agent extruded towards a mixer (Figure 5).

Conclusions

Joint design strategies must take in account AM process resolutions and the interaction effects of the AM settings used as design parameters. New materials, both in bulk or reinforced states, and the use of MMAM provide further tailoring opportunities, but material compatibility should be taken in account. Tailoring AM adherends and adhesives, has proven to be an extremely useful, yet relatively unexplored solution to improve the performance of adhesively bonded joint. An important conclusion of this work is that aspects related to the degradation and long-term durability of polymeric AM bonded joint are relatively unstudied. This represents a topic of great interest for industrial applications and must certainly be an important subject of research in the coming years.

References

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