Functionally graded adherends by additive manufacturing

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Introduction

The use of adhesive joints and additive manufacturing in the transportation industry can provide several advantages over conventional fabrication methods. A few of these advantages are the ability to easily join different materials with complex shapes, permit the manufacture of stiffer assemblies with a more uniform stress field, create more opportunities for part consolidation that allow for increased design flexibility [1,2]. Single lap joint (SLJ) are the most common configuration used by industries as they are simple to manufacture and are very efficient if loaded in shear, the most preferable loading mode for adhesive joints [3]. One of the major drawbacks associated with these kinds of joints is the stress distribution along the bond line as they tend to exhibit high stress concentration at the ends of overlap length, which can significantly limit joint strength [4]. One of the techniques that could be used to minimize this problem is the use of functionally graded adherends and one way to accomplish this is by using additive manufacturing. This technology as grown immensely in recent years but there are still many unknown variables regarding the material behavior and printing orientations and thus a thorough analysis of many engineering materials and there printing orientations has to be done as a means to allow a flawless integration of additive manufacturing and adhesive joints

Methodology

A numerical model was developed in Abaqus® to predict the failure load and strength on adhesive joints with functionally graded adherends.

Cohesive zone modelling (CZM):

- Adherends: High strength steel (HSS), fibre reinforced polymer (FRP) and transverse graded adherends with different gradient factors.
- Adhesives: 3M Scotch Weld AF-163-2K (epoxy film) and the Nagase Denatite XNR 6852E-3 by Nagase-ChemteX (epoxy paste).

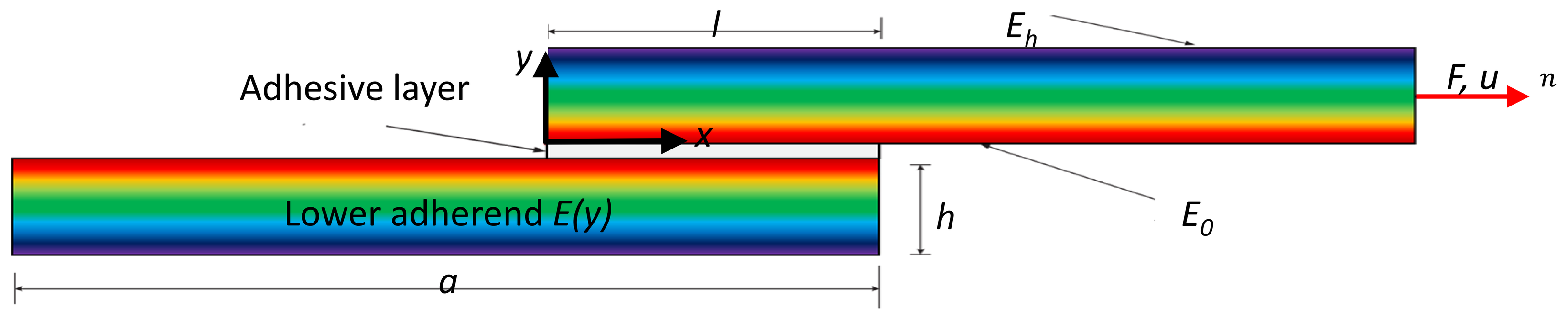

Figure 1 – Analytical scheme of a functionally graded adherend

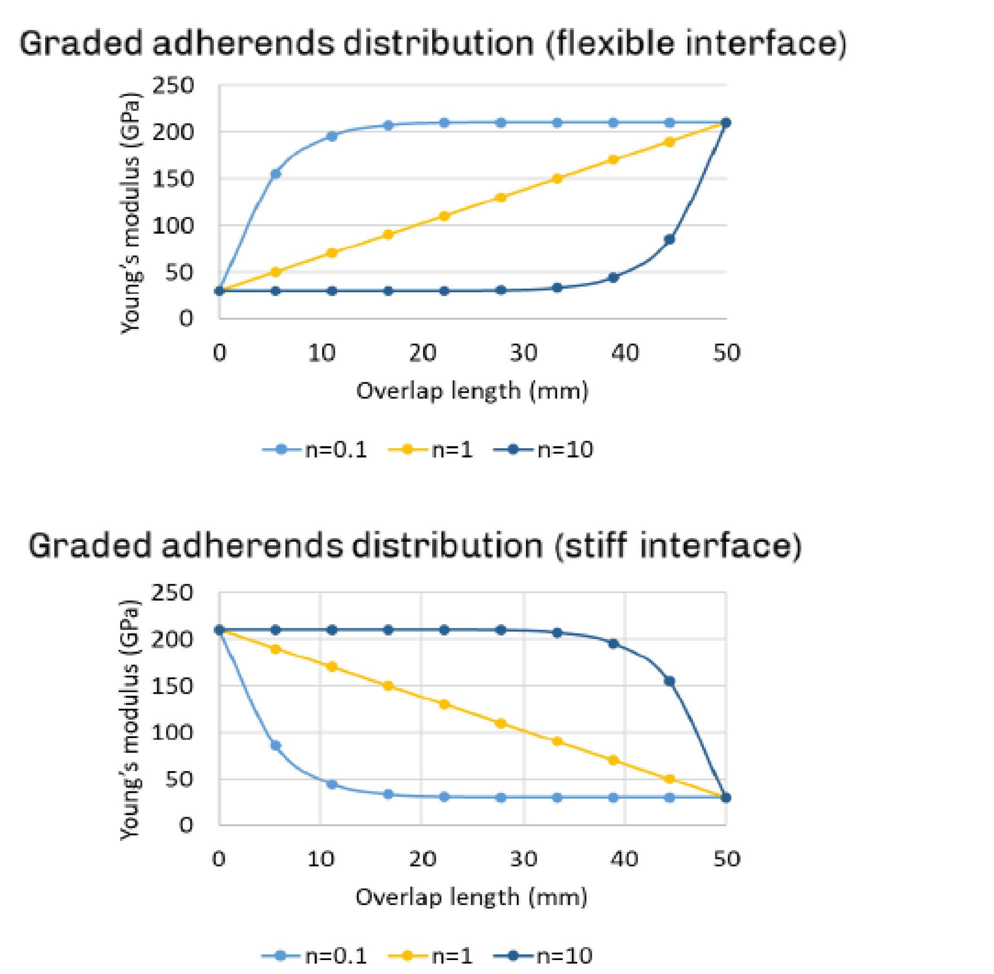

Figure 2 – Graded stiffness distribution for flexible and stiff interface with different gradient factors used on CZM

$1 \leq n \leq \infty$

Equation 1 – Young's modulus distribution law for $1 \leq n \leq \infty$

$$E(y) = E_h + (E_0 - E_h) \cdot \left(\frac{y-h}{h}\right)^{\left(\frac{1}{n}\right)}$$

$0 < n < 1$

Equation 2 – Young's modulus distribution law for $0 < n < 1$

Table 1 – Adhesives properties [2, 3]

Adhesive	AF-163-2K	XNR 6852 E-3
σ (MPa)	46.93	51.50
τ (MPa)	46.86	44.90
E (MPa)	1521.87	1728.00
G (MPa)	563.67	665.00
G_{Ic} (N/mm)	4.05	9.20
G_{IIc} (N/mm)	9.77	51.00

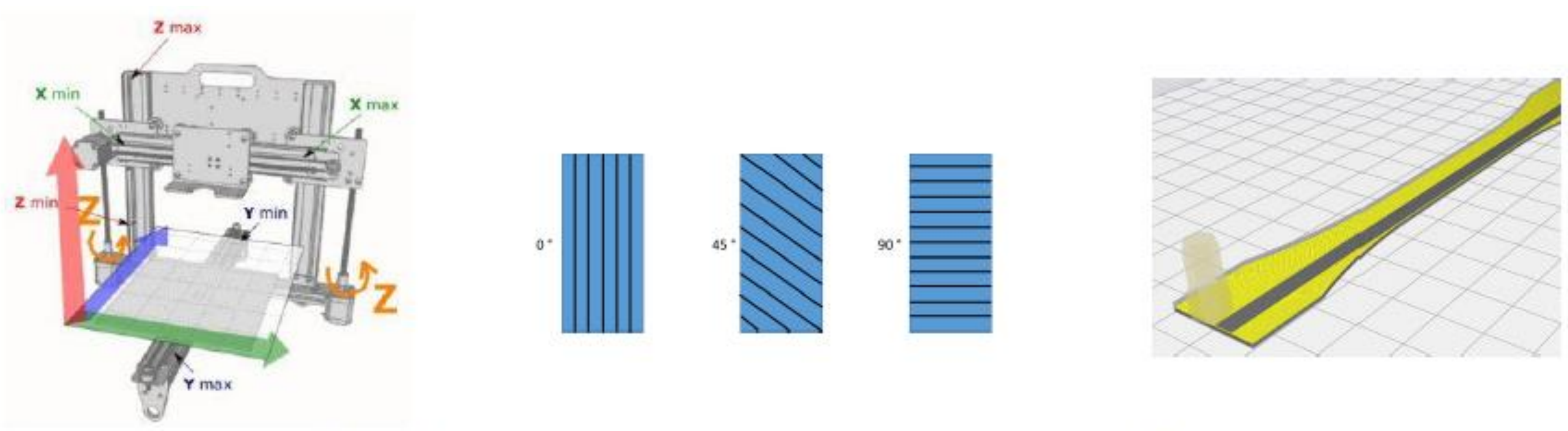

Figure 3 – Graded adherends obtained by additive manufacturing (varying the materials and orientations

Numerical Results

2D cohesive damage model
Static general analysis
CPE4R plain strain elements
COH2D4 cohesive elements
Triangular damage law

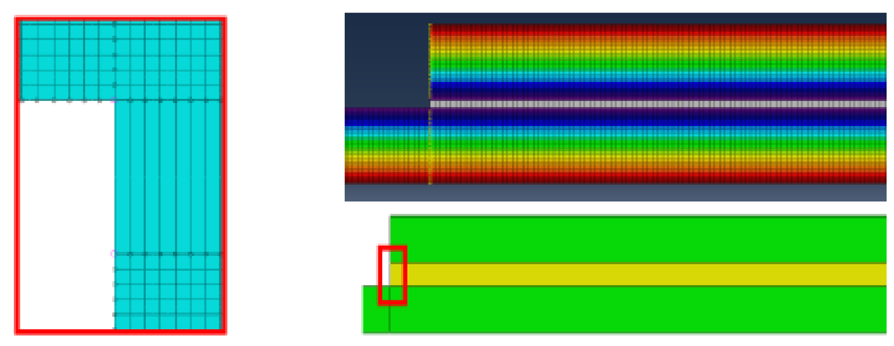

Figure 4 – Detailed parameters used on the CZM analysis

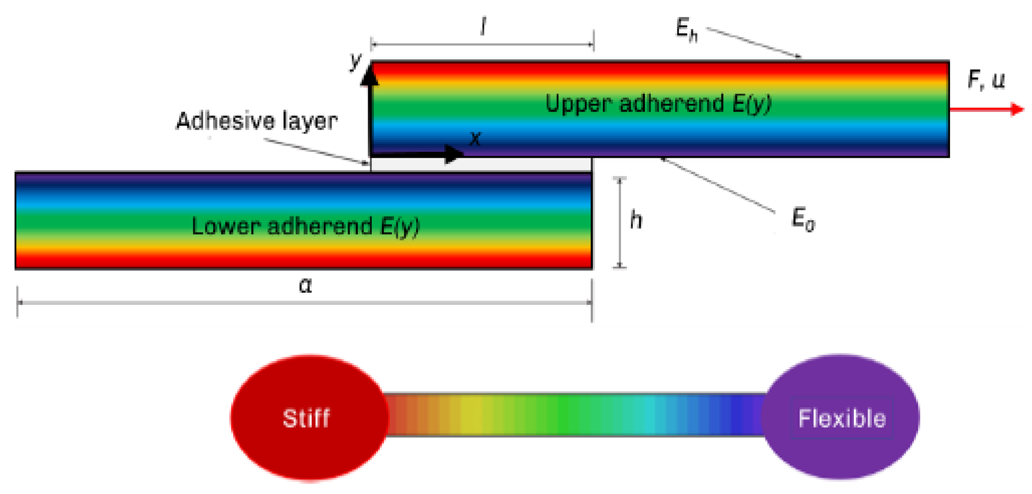

Figure 5 – Graded adherends of the joints

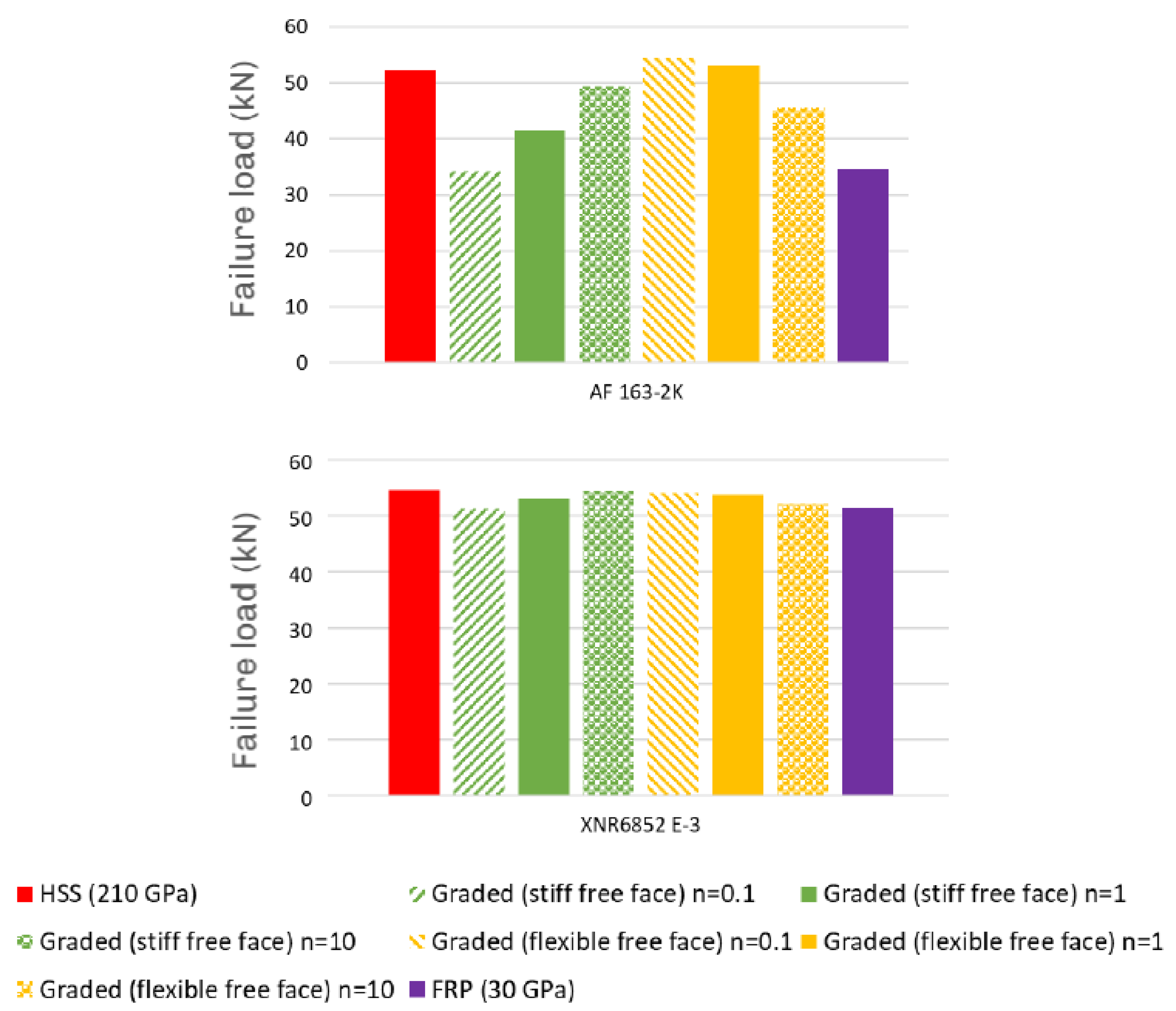

Figure 6 – Failure loads obtained for both adhesives with homogenous and graded adherends for several compositional distribution factors

References

1- Banea, M.D. and L.F.M. Da Silva, The effect of temperature on the mechanical properties of adhesives for the automotive industry. Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 2010. 224(2): p. 51-62.
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Conclusions

Additive manufacturing opens windows for fabrication of many geometries and ideas that could not be done before. There is a significant limitation in material properties depending on printing direction and layer lines directions that cause a 3d print to be considered anisotropic. In this paper each possible printing direction was tested and possible graded joints were proposed with simulations to validate the results. This thorough comparison allows for a better understanding when designing 3d printed parts and allows for future single lap joints to be 3d printed with a minimization in stress lines by using multiple materials and the properties of 3d printing directions.

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