The Optimization of Comeld^{TM} Joints: a Novel Technique for Bonding Composites and Metal

Wei Tu, Pihua Wen and Felicity Guild

Abstract— **Current and future structural applications for composite laminates frequently involve design solutions combining composite laminates and metal; the materials must be joined. A novel surface treatment for metals developed at TWI, Surfi-Sculpt™, leads to the formation of surface protrusions on metal surfaces. The surface modified metal can be bonded with composite laminates to form a Comeld™ joint. Finite element modeling has been used to study this novel joining system.**

Index Terms—**Adhesive joints, composite laminates, metals.**

I. INTRODUCTION

Composite materials are slowly gaining acceptance as structural materials particularly in applications when weight saving is a critical consideration. However, in general, the uptake in structural applications for composites during the last decade has been disappointingly slow. In many large-scale applications, a total composite solution may be unrealistic; composites must be joined to metals. Reliable use of composite materials therefore relies on reliable joining technologies. The development of good joining methods between metals and composites may be described as a pre-requisite for increased applications for composites.

There is an intrinsic dilemma for the design of composite joints, since the two alternatives of mechanical or adhesive bonding both show significant disadvantages [e.g 1-2]. The most promising way forward may **be** a combination of adhesive and mechanical bonding. This combination of joining methods may now be attained following the development of Surfi-Sculpt® technology by TWI. This technology uses a power electron beam to create various surface textures through the manipulation of the electron beam. This technique is applicable to a wide range of materials, allowing the creation of a range of hole and patterns, which can be precisely controlled.

Bonding of the sculpted metal surface to composite laminates forms a Comeld^{TM} joint. Various joint geometries could be manufactured using this technology; we have chosen a double-lap joint stressed in tension as a reasonable analogue of typical joints between composites and metals. This paper describes the strategy for finite element modeling of stress concentration around the protrusions. The strategy for modeling within the row has already been established using repetitive boundary conditions [3]. Methods to analyze the protrusion at the end of the row are explored.

II. JOINT GEOMETRY

The analysis presented here is for a two-step joint double-lap joint in quasi-static tension; the geometry of the joint is shown in Fig.1. The total length of the joint is 150 mm, width 25 mm, and the total thickness is 3 mm. The height of both steps is 1 mm.

The metal adherends are Titanium Ti-6Al-4V and the composite is carbon fibre prepreg AS4/8552 from Hexcel. The laminate lay-up was $[0/90]_{4s}$, with ply thickness of approximately 0.125mm. The material properties for the Titanium and the unidirectional CFRP were gained from the literature [4].

The height and diameter of the protrusions were gained from experimental measurements and remained constant: height 1mm, diameter 0.6mm. All results presented in this paper have been gained assuming a square array of protrusions. The measured density of the protrusions, D, was 0.54 per mm^2.

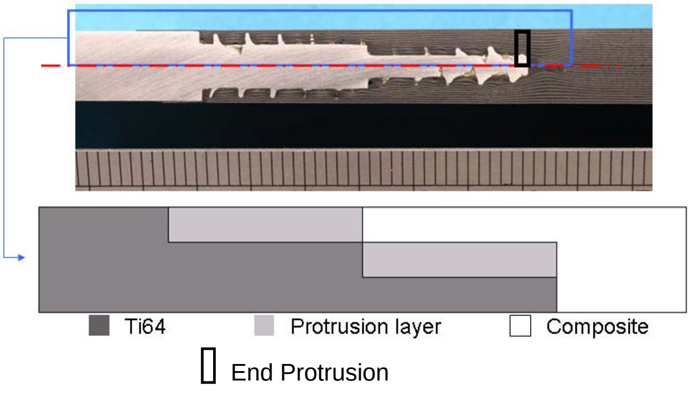

Fig.1 Geometry of the Joint

Manuscript received March 31 2010. Wei Tu was with the Department of Materials, Queen Mary University of London, London E1 4NS, UK. He is now with Nanoforce Technology Ltd, Queen Mary University of London, London E1 4NS, UK. (phone: +44 (0)20 7882 8138; fax: +44(0)20 7882 3390; e-mail: w.tu@nanoforce.co.uk).

Pihua Wen is with the School of Engineering and Materials Science, Queen Mary University of London, London E1 4NS, UK. (e-mail: p.h.wen@qmul.ac.uk).

Felicity Guild was with the Department of Materials, Queen Mary University of London, London E1 4NS, UK. She is now with the Department of Mechanical Engineering, Imperial College London, London SW7 2AZ, UK. (e-mail: f.guild@imperial.ac.uk).

The analysis of the protrusions within the row can be achieved using repetitive boundary conditions [3]. However, the highest stress concentrations initiating joint failure are expected to occur for the end protrusion (see Fig. 1). The boundary conditions for the end protrusion must be established.

All analyses have been carried out in 2-dimensions using plane strain elements. The accuracy of this formulation has been checked using generalized plain strain elements; identical results were obtained. All results in this paper are for 1 MPa global tensile load.

III. FINITE ELEMENT MODELS

The most complex finite element model is a detailed global model including individual protrusions (see Fig.1). This model is used to compare results from our simpler strategies to model the end protrusion. These strategies are:

1. Row of two protrusions with twice the length of composite for loading (see Fig.2).

2. Single end protrusion with region of homogenized properties representing the neighboring protrusion with twice the length of composite for loading (see Fig.3).

3. Row of six protrusions loaded at the end using values of displacement extracted from the global model (see Fig.4).

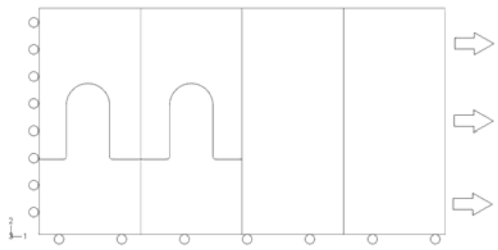

Fig.2 Schematic illustration of model 1

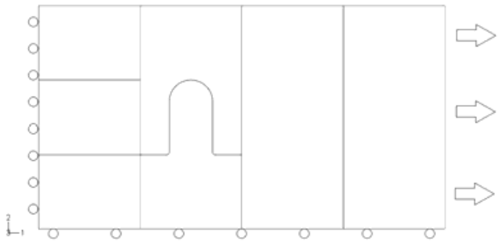

Fig.3 Schematic illustration of model 2

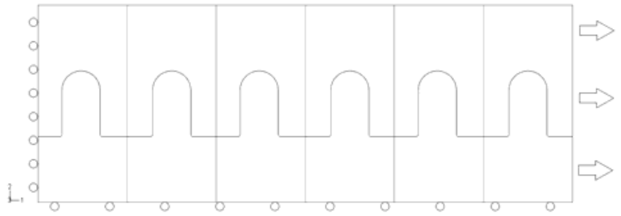

Fig.4 Schematic illustration of model 3

The loading and boundary conditions for the models are shown on Figs 2-4. The loading for models 1 and 2 is 1 MPa pressure load on the edge of the composite. The loading for Model 3 are the displacements extracted from the global model. The boundary condition on the top of all models is free. On the left edge of all models, opposing the load, displacement is restrained in the loading direction but displacement is allowed in the vertical direction. Along the bottom edge of all models, which is the symmetry plane of the joint (see Fig.1) displacement is restrained in the vertical direction but allowed in the horizontal direction.

IV. RESULTS

Results from the global model for the end protrusion are shown in Fig.5. Fig.5a shows contours of axial stress, S11. Maximum value for the whole model is found within the titanium at the base of the protrusion. This stress concentration is not expected to cause failure. Fig.5b shows contours of transverse peel stress, S22. The highest value is found within the titanium in the same location, which is not expected to cause failure. However, a further stress concentration of transverse peel stress is found around the top of the protrusion region within the composite. Composites are very weak in transverse tension and this stress concentration could easily initiate failure. Similarly, the maximum stress concentration of shear stress, S12, is in the titanium at the base, but there is a stress concentration around the top of the protrusion within the composite layer. This stress concentration could contribute to the initiation of failure.

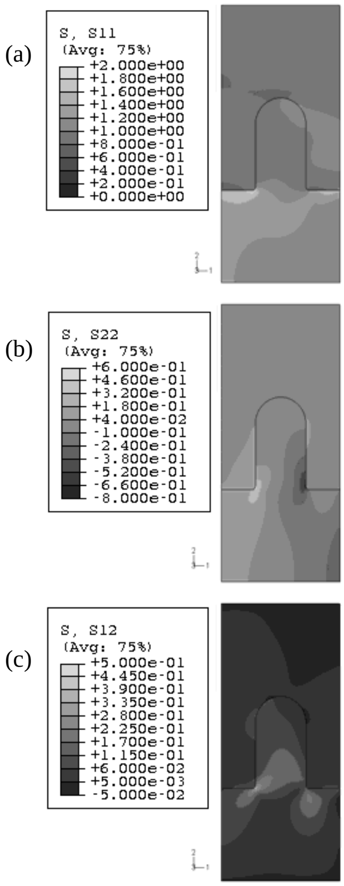

Fig.5 Contour results of the global model, (a) axial stress, (b)

transverse peel stress, (c) shear stress

Results of the protrusion next to the joint step from Model 1, the row of two protrusions loaded via composite, are shown in Fig.6. These contours are drawn on the same scales as the results from the global model in Fig.5. There is generally very good agreement between these results and the results from the global model. However, the values of stresses are all slightly higher than values found in the global model. Almost identical results were obtained from Model 2 when the second protrusion was replaced by a homogenized region, see Fig.6.

Results from Model 3, the row of six protrusions loaded by displacement, are shown in Fig.7. These contours are drawn on the same scales as the previous results. There is very good agreement between these results and the results from Models 1 and 2. All values are slightly higher than found in the global model.

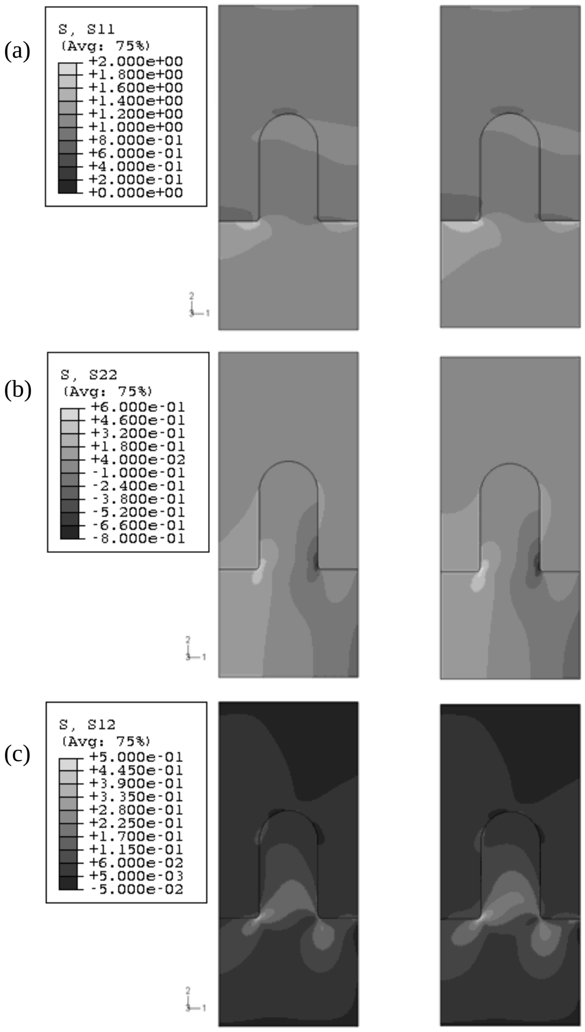

Fig.6 Contour results of Model 1 (on the left) and Model 2 (on the right), (a) axial stress, (b) transverse peel stress, (c) shear stress.

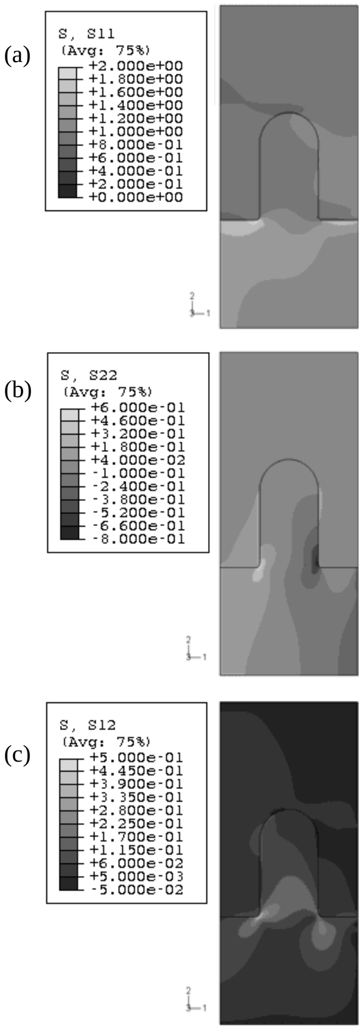

Fig.7 Contour results of Model 3, (a) axial stress, (b) transverse peel stress, (c) shear stress.

V. CONCLUDING REMARKS

This novel method of bonding composites and metal shows considerable potential. Failure is expected to initiate around the end protrusion. Successful strategies have been established to analyze the stress concentrations around the end protrusion. These methods can now be applied to varying geometry and distribution of the protrusions allowing the optimization of this joining technology.

ACKNOWLEDGMENT

This work was supported by TWI, UK, and the School of Engineering and Materials Science, Queen Mary University of London, UK. The authors thank TWI for the provision of specimens and useful discussions.

REFERENCES

[1] A. J. Kinloch, “Adhesives in Engineering,” *Proc. Inst. Mech. Eng. Part G, J. Aero. Eng.* vol. 211, 1997, pp 307-335.
[2] Y. Xiao, “Bearing deformation behavior of carbon/bismaleimide composites containing one and two bolted joints,” *J. Reinf, Plastics & Comp.* vol.22, 2003, pp 169-182.
[3] P. Wen, W. Tu, F. J. Guild, “Multi-region mesh free method for Comeld™ joints,” *Computational Materials Science*, to be published.
[4] D.M. McGowan and D.R. Ambur, “Damage characteristics and residual strength of composite panels impacted with and without a compression loading”, *39th AIAA Conf.* 1998, Paper No.98-1783