Strength and Strain Distributions in Single Lap Joints with Engineered Disbonds

Jong-Hwa Ahn [1], Ibrahim Adediran [2], Christopher Muhlstein [1], Timothy Truster [2], Dongang Yao [1]

[1]Materials Science and Engineering, Georgia Institute of Technology
[2]Civil and Environmental Engineering, University of Tennessee, Knoxville
** Presenting Author email: jhahn89@gatech.edu*

Abstract
This study investigated the accumulation of damage in periodic, engineered disbond arrays and its effect on the shear strength and failure mode of single lap joints. The impact of surface contamination on shear strength was also analyzed. Experimental results showed that surface contamination had a significant negative impact on shear strength, with a reduction of up to 98% in specimens with 100% contamination. The use of a disbond stripe resulted in a slight reduction of only 3.89% in shear strength. However, no progressive accumulation of damage in bonds was observed in the current set of experiments. Further investigation is required to examine the relationship between crack mode and design configuration. This study highlights the importance of addressing these factors in the design and analysis of bonded structures to ensure their lifetime and durability.

1. Introduction
Single lap joint test coupons are commonly used to characterize adhesive joints and qualify manufacturing processes using standard methods such as ASTM D1002. Analytical and finite element modes (e.g.,Guess, T.R., R.E. Allred, and F.P. Gerstle, Journal of Testing and Evaluation. 5(2): p. 84-93) have quantified the relative importance of adherend and adhesive materials properties and specimen geometry on the apparent shear strength of single lap joints. Here we explore how damage accumulates in periodic, engineered damage (disbond) arrays. Progressive damage accumulation can occur when a linear, periodic array of disbonds is loaded in mode I, displacement controlled conditions. Cracks in these arrays arrest when the applied force (and driving force) rapidly decreases as a bonded region at the crack tip fails. Here we experimentally evaluated damage accumulation in a linear disbond array under the mixed mode conditions of a single-lap adhesive bonded joint. We analyzed the force- displacement curves of the joints and anticipated observing an instantaneous force decrease in the disbond region, followed by a continuous increase, in a process that repeats across the array until catastrophic failure. Controlled damage accumulation experiments provide valuable insights into the failure mechanisms of adhesive joints and guide the design of more robust and durable structures.

2. Materials and Methods
Single lap joints were prepared using aluminum 2024-T3 adherends with dimensions of 1 inch width, 4 inch length, and 0.0195 inch thickness. Scotch-Weld AF 163-2OST adhesive with a thickness of 0.0095 inch was used to bond the adherends. The curing condition was 121 °C for 90 min using an HCS9000B hot bonder with a pressure of 11.3 psi. Surface contamination was introduced using a mold release agent (Frekote 44-NC) at three different levels: non-contaminated in the bond area, half the amount of contamination in the bond area, and the full amount of contamination in the bond area. The specimens were tested for shear strength and stiffness with a load cell capacity of 20kN and a displacement rate of 5 mm/min in a laboratory air-preconditioned environment. Additionally, embedded disbond strope was fabricated and the resulting shear strength and stiffness of the single lap joints were analyzed. The bond failure images were captured using a Nikon D3300 DSLR camera with a macro lens. The percentage of cohesive and adhesive failure was analyzed by measuring the adhesive areas on the substrate, using Microsoft Photoshop software.

2. Results

The experiments revealed a consistent stiffness in the specimens, as demonstrated in Fig. 1a and Fig. 2a, across all levels of surface contamination and disbond stripe use. However, the shear strength of the specimens, as shown in Fig. 1b, was found to be significantly affected by surface contamination, with a reduction of 68% in specimens containing 50% contamination and 98% reduction in specimens with 100% contamination. The use of a disbond stripe resulted in a slight reduction of only 3.89% in shear strength, as shown in Fig. 2b, as the total area of the pristine stripe was consistent between the two specimens. Contrary to our expectations, no progressive accumulation of damage was observed in the disbond region under the mixed mode conditions of the single lap joint. As illustrated in Fig. 1a and Fig. 2a, no instantaneous force decrease point was observed in the plot.

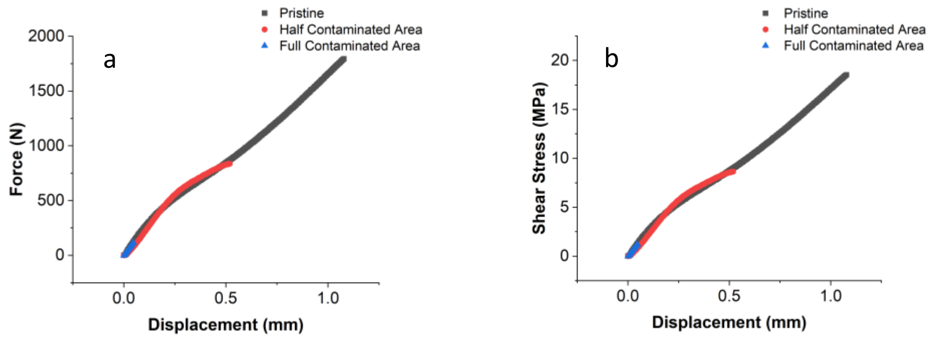

Fig.1- Comparison of different levels of contamination

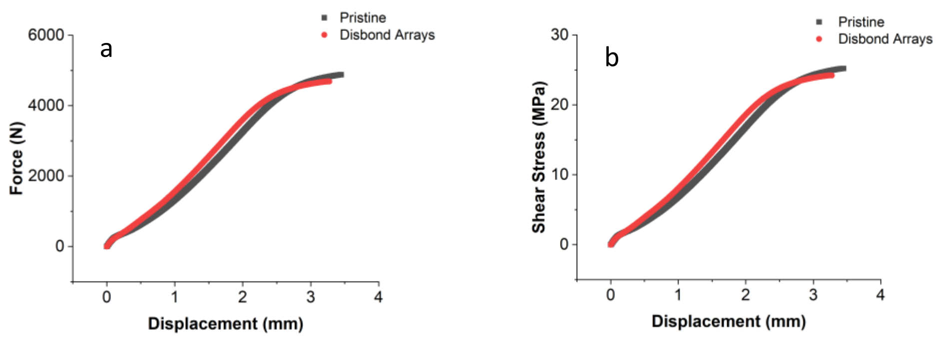

Fig.2- Comparison of pristine and Disbond Stripe Specimens

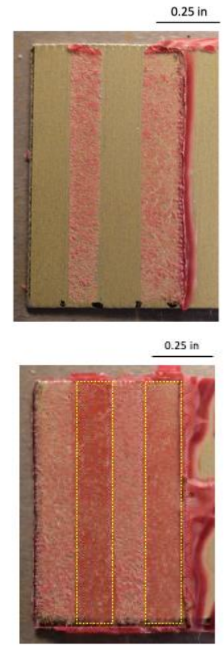

Fig.3- Failure modes in disbond stripes specimen

4. Conclusions

The fundamental concept explored in this study is the accumulation of damage in periodic, engineered disbond arrays and its impact on the shear strength and failure mode of single lap joints. The study revealed that surface contamination has a significant impact on shear strength, with a reduction of up to 98% in specimens with 100% contamination. The use of a disbond stripe resulted in a slight reduction of only 3.89% in shear strength, suggesting that the amount of bond present directly influences the strength of the bond. However, the current set of experiments did not reveal any progressive accumulation of damage in bonds, indicating the absence of damage evolution. Further investigation is needed to examine the relationship between crack mode and design configuration. Understanding the damage evolution process can help predict the lifetime and durability of materials and structures.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. 2052714. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. The authors gratefully acknowledge the additional support of the Georgia Institute of Technology, CHMI (Composite and Hybrid Materials Interfacing I/UCRC) center and its members.