EFFECT OF NATURAL FIBERS ON THE STRENGTH AND DAMAGE IN ADHESIVELY BONDED JOINTS.

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Keywords:

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Introduction:

Over the years, the applications of adhesively bonded joints in aerospace and marine engineering have increased due to their higher strength-to-weight ratio, joining of dissimilar materials and uniform stress distribution resulting in better load transfer. The adhesively bonded joints mostly fail due to adhesive failure because of their lower tensile strength compared to adherent plates. Hence, the current study focuses on adhesive failure. Hitherto, there have been failures of adhesively bonded joints due to micro-crack damages on the adherent plates that go unnoticed during the inspection and lead to catastrophe. These cracks arise due to poor surface finish or due to cut-out sections. Different failure modes of adhesively bonded joints are pictorially shown in Figure. 1.

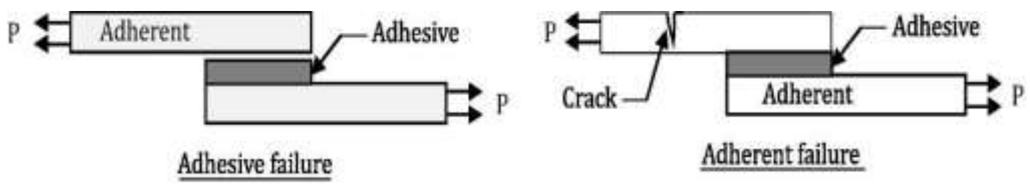

Figure 1: Bonded joint failure mode

Objective:

The key objectives include:

1. Analyzing the effect of natural fibers, Rachis and Petiole, on the static strength and failure load of adhesively bonded joints, emphasizing on how these fibers improve load distribution.
2. Determining the optimal number of fibers within the adhesive.
3. To study the impact of natural fibers on adherent failure due to crack like damages.

4. Evaluate the efficacy of fiber integration with various adhesives (UHU plus Endfest 300, FM 73, and Araldite 2015) and identify the combination that yields best results.

Methodology:

1. A single lap joint (Delzendehrooy et al. 2020) with UHU plus epoxy, FM 73, and Araldite 2015 adhesives, reinforced by natural date palm fibers, is analyzed considering geometric and material non-linearity.
2. A 3D finite element model is developed in ABAQUS using eight-node brick elements, assuming homogeneous, isotropic materials. One end is fixed, and the other is subjected to axial load ‘P’, ensuring displacement continuity.
3. Mesh refinement is applied at overlap corners with a maximum aspect ratio of 4. Cohesive Zone Modeling (CZM) with a bi-linear traction-separation law simulates adhesive behavior.
4. Failure load is identified by evaluating von Mises stress in the adhesive overlap; failure occurs when the average stress exceeds the adhesive yield strength over 2.7% of the overlap length.
5. Adherent plate failure is assessed using a fracture mechanics approach, introducing through-thickness cracks at various locations. Crack severity is evaluated via the Modified Virtual Crack Closure Integral (MVCCI) method.

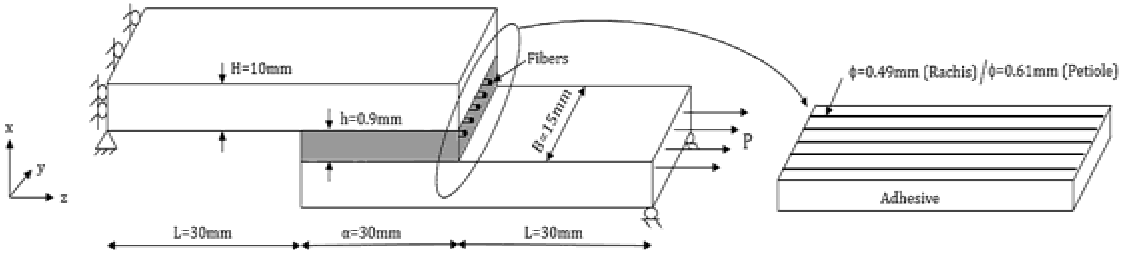

Figure 2: Lap Joint Configuration

Result and conclusion:

The study examined the effect of Rachis and Petiole fibers on adhesively bonded joints using FM 73, UHU Plus Endfest 300, and Araldite 2015 adhesives. The optimal setup used seven Rachis fibers, which significantly reduced shear stresses at overlap ends and enhanced joint strength. In FM 73, Rachis fibers reduced stress by 40% and Petiole by 32%; in Araldite 2015, both reduced stress by 33%. Due to higher stiffness and yield strength, fibers bore more stress than the adhesive. Failure loads increased significantly with fiber inclusion—Rachis fibers improved failure loads by 122% in UHU and 125% in FM 73, while Petiole fibers resulted in 12% and 28% increases, respectively (Fig. 5).

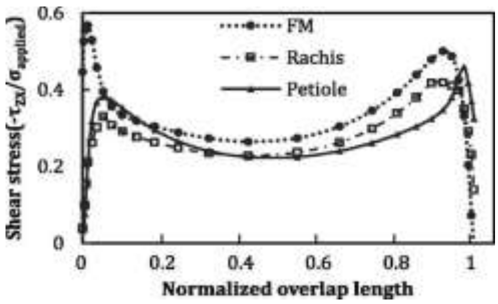

Figure 3: Variation of shear stress for FM73 model

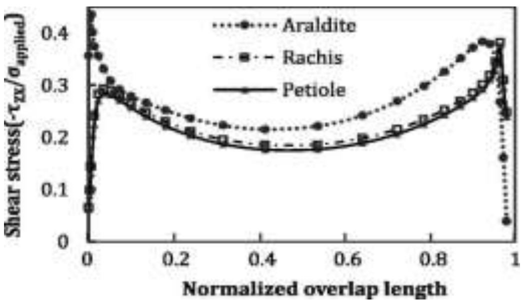

Figure 4: Variation of shear stress for Araldite model

Adherent failure analysis was conducted on joint with UHU adhesive and Rachis fiber by introducing a through-crack (α/β = 0.5) at various locations in the top adherent plate (Fig. 7). The crack locations included regions away from the overlap (a_1 = 0.5, a_2 = 0.6, a_3 = 0.8), at the overlap ends (a_4 = 1), and within the overlap region (a_5 = 1.33). Cracks away from the overlap (a_1, a_2) were less severe, while cracks near (a_3) and exactly at the overlap ends (a_4) were critical due to higher bending stresses at the crack tip. Cracks within the overlap region (a_5) showed a 37% reduction in severity due to the adhesive reducing plate bending. The presence of Rachis fibers further reduced crack intensity by 7% at the overlap ends (a_4) and 22% within the overlap region (a_5), as the fibers acted as stiffening elements, minimizing bending and crack severity. In conclusion, Rachis fibers significantly reduced overlap-end stresses and nearly doubled joint strength; Petiole fibers had minimal effect. Failure analysis aligned well with experimental results. Fibers also reduced crack severity, highlighting their potential for crack mitigation in thin-walled structures.

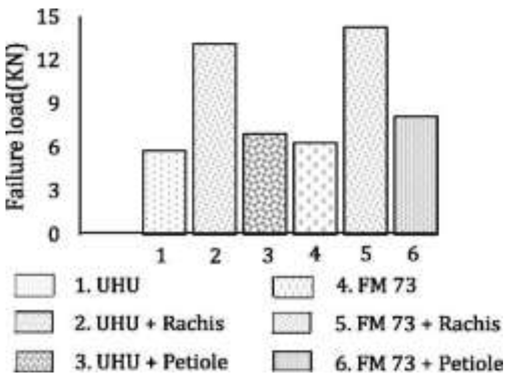

Figure 5: Comparison of failure load for UHU and FM73 with and without fibers

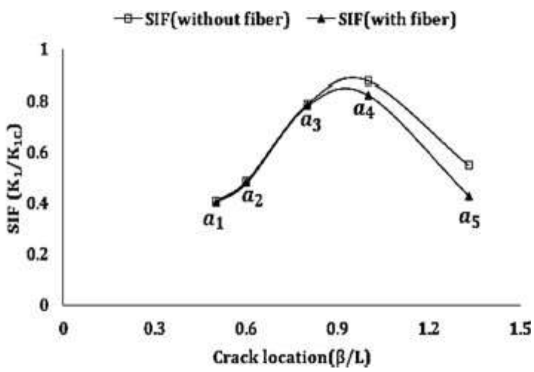

Figure 6: SIF variation at different crack locations

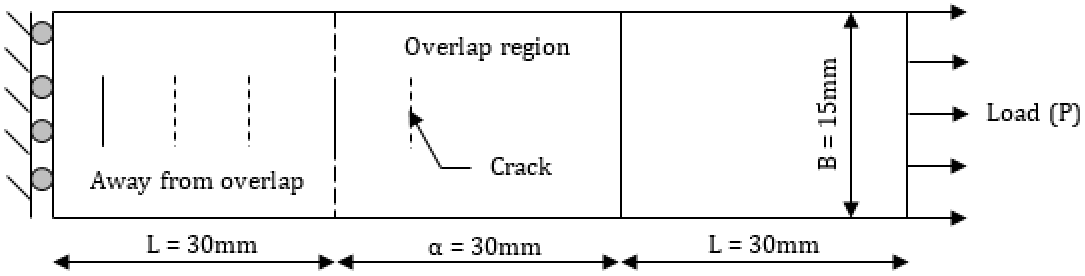

Figure 7: Location of crack evaluated for adherent failure mode

Project Outcome and Industry Relevance:

Incorporation of natural fibers significantly enhanced the strength of the joint and reduced crack severity. This demonstrates a sustainable and efficient approach to improving the performance and damage tolerance of bonded joints in aerospace, automotive and structural applications.

Simulation:

In the current study ABAQUS finite element program was employed to model and analyze the adhesively bonded joint. Eight node isoparametric brick elements and a structured mesh was used.

Project Outcomes and Learnings:

This project culminated in the successful enhancement of adhesively bonded joint performance through the integration of natural fibers. It provided a comprehensive learning experience in advanced finite element modeling using ABAQUS, cohesive zone and fracture mechanics approaches, and the application of sustainable materials in structural design.

Scope for future work:

1. Exploration of Hybrid Natural Fibers: Future studies can investigate the synergistic effects of combining multiple types of natural fibers within adhesive matrices to optimize strength.
2. Durability and Aging Analysis: Extensive testing under cyclic loading, temperature variations, and UV exposure is needed to evaluate the aging behavior and reliability of these joints
3. Integration with Structural Health Monitoring Systems: Embedding sensors within fiber-reinforced joints could enable real-time damage detection and life prediction, aiding smart, self-monitoring bonded assemblies in aerospace and infrastructure.