Abstract

Composites and composite adhesive joints are experiencing growing application across various industries, with a notable emphasis in the automotive sector. This is due to the fact that composite materials provide an exceptional mix of lightweight characteristics and structural reliability, making them very attractive for automotive uses that prioritize fuel economy and performance. In addition, progress in adhesive technologies has resulted in the creation of high-performance adhesives that can effectively join a wide range of materials with outstanding durability and dependability. In the automotive industry specifically, Single-Lap Joints (SLJs) find extensive use in joining components such as body panels, chassis parts, and interior elements, offering manufacturers the benefits of improved vehicle aesthetics, reduced weight, enhanced structural integrity, and simplified assembly processes. Therefore, it necessitates to be more aware of the behavior of this type of joining materials.

This dissertation, firstly, investigates the mechanical behaviors of two different types of adhesives, Epoxy-based and Polyurethane-based. To do so, the bulk adhesive dogbone subjected to tensile tests are performed to obtain the properties like Young modulus, elongation, and ultimate strength. Furthermore, to be aware of the fracture behavior and obtain the adhesives' energy release rate in Mode I and Mode II, respectively, Double cantilever Beam (DCB) and End Notch Flexural (ENF) tests were conducted using composite substrates and analyzed. This information could be later employed in finite element modelling to simulate and predict the behavior of adhesively bonded joints.

Secondly, different application of adhesively bonded joints necessitates considering joints with different dimensions. Therefore, the effects of joint geometry parameters, such as adherend thickness (T=1.76, 3.52 mm), joint width (W=10, 20, 30 mm), and overlap length (L=10, 20 mm), on the behavior of single-lap joints (SLJs) under tensile loading are studied in this research activity. Peak force, joint stiffness, adhesive shear stress, and substrate normal stress are the investigated properties. SLJs are manufactured with carbon fiber composite adherends and two different types of adhesives, polyurethane and epoxy, which respectively present a flexible and rigid mechanical response. The results showed that increasing all 3 geometric parameters (L, W, T) leads to a significant increase in the load capacity of polyurethane joints (on average, 88.4, 101.5, and 16.9%, respectively). For epoxy joints, these increases were 47.7, 100, and 46%, respectively. According to these results, W is the parameter with the most influence on the load capacity of the joints. However, it was observed that an increase in joint width has no significant effect on adhesive shear and a substrate's normal

stresses. Epoxy SLJs behave approximately elastically until failure, while polyurethane SLJ load-displacement curves include an initial linear elastic part followed by a more ductile behavior before the failure. Joint stiffness is affected by all the parameters for both adhesive types, except for overlap length, which led to a negligible effect on epoxy joints. Moreover, the damage surfaces for both types of joints are analyzed.

Thirdly, having done the adhesive characterization tests it is understood that due to the fact that the polyurethane adhesives are relatively flexible, the ENF tests might not always be possible to be performed. This is because that this flexibility may result in a substrate interlaminar propagation of a crack before the crack starts propagating in the adhesive layer. Therefore, another alternative is proposed in this research to estimate the fracture properties of polyurethane adhesive by using SLJs experimental test results and performing Finite Element Modelling (FEM) of those tests. By calibrating the model with the SLJs experimental results the adhesive properties can be estimated. LS_Dyna is used for the simulation together with LS_OPT as an optimizer. In addition, after the model is calibrated, the effect of geometric parameters has been analyzed once at 25% of ultimate load and once at a fixed load for each sample. At 25% of ultimate load, it was observed that the increase in the joint width has nearly no significant effect on adhesive shear and peel stresses. However, at fixed load increasing L, W, and T resulted in a decrease in adhesive shear and peel stresses.

Lastly, this growing application of adhesively bonded joints in different industries demands employing structural health monitoring (SHM) technics. In this study, the backface strain (BFS) method, applied by both digital image correlation (DIC) and Fiber Optic Sensors (FOS), is used to detect crack initiation and propagation in adhesively bonded single-lap joints (SLJ). By comparing the positive strain, due to the tensile load, and negative strain related to the bending moment, a point, called zero strain point (ZSP), can be detected on the substrate surface of the SLJ. Using the Bigwood and Crocombe analytical model, the presence of the ZSP on the backface is explained and the experimental results are used to detect it. The monitoring of the ZSP reveals useful information about the health condition of the joint. The main aim of this research is to investigate how the ZSP position varies by changing adhesive type (epoxy and polyurethane) and bonding area dimensions both in elastic conditions and damage progression. The results illustrate that the position of the ZSP in polyurethane SLJs is closer to the middle of the joint compared to epoxy SLJs. Additionally, the ZSP is more easily recognizable in epoxy adhesive SLJs when substrates are thicker. Finally, the ZSP showed negligible sensitivity to joint width for both types of adhesive joints regardless of the adhesive type. In conclusion, it is shown that the ZSP can be used as a monitoring index to detect damage initiation and propagation in SLJ specimens. Afterward, the applicability of ZSP method is investigated when the joint is subjected cyclic loadings. Having confirmed the functionality and effectiveness of the ZSP method as an index to monitor a joint healthiness, it can be proposed to use this method with (FOS) on real components to have an in-situ monitoring of the joint. Therefore, the component or the joint can be repaired or substituted before the rupture.