Abstract

Fiber reinforced polymers (FRPs) are known to have tailorable and superior mechanical properties as compared to metals and can, therefore, be used to construct components with equal or better performance at a lower mass. This has led to their increased use in the automotive industry as vehicle manufacturers rush to comply with stricter emission norms. Composite materials can also be used to manufacture primary crash structures such as crash boxes that absorb energy in case of crash preventing it from being transmitted to the passengers on account of their superior specific energy absorption capabilities. However, the lack of standardization of testing protocols and efficient predictive capability amongst the upper levels of the building block approach hampered their integration into these primary crash structures. Although, numerical capabilities do exist they require either a trial-and-error approach in calibrating the numerical model or an analytical approach, which are expensive, time consuming and subjective. Subjectivity of analytical approaches is limited to the assumptions and can be eliminated if the same set of assumptions are followed between different approaches. Off-late optimization techniques have gained traction, but calibration of the numerical model is limited to certain parameters of the force-displacement curve and not its entirety. Additionally, calibrations conducted with optimizations have only shown limited predictive capability for large scale composite components.

This dissertation presents a numerical methodology that takes advantage of element level crashworthiness tests, finite element analysis and parametric optimization to predict component level damage automatically and efficiently. Element level crashworthiness tests were performed by impacting flat composite plates made of carbon-fiber reinforced epoxy material (GG630T-37 2x2 twill) in the in-plane direction in collaboration with another researcher within the same group in order to obtain information about the crashworthiness properties of the material, hence widening the quality of experimental data beyond characterization tests that are typically performed. A new anti-buckling fixture that can be seamlessly integrated with the impact testing machines developed by Instron was designed with the use of finite element analysis, which was used to test the aforementioned flat composite plates. The effects of various design parameters such as unsupported heights and anti-buckling column diameters and distances were studied as a part of the design process of the fixture. Additionally, the impactor thickness was optimized in order to avoid any plastic deformation at the maximum energy level of 1800 J of the Instron testing apparatus. The robustness of the fixture under this energy level was also studied by numerically testing a specimen of the same material with the maximum allowable thickness. The fixture was designed to address some of the major deficiencies of the ones designed previously and reported in literature, such as inabilities to: test specimen with different thicknesses and unsupported heights, initiate frond formation or allow multiple failure modes, test specimens with dimensions equal to those of specimens used for compression after impact tests and to conduct testing with ease.

Macroscale and mesoscale models were developed to ensure methodologies provided the required information quickly and in detail, respectively, for use in both the industry and academia. Entire force-displacement curves obtained from the tests conducted on composite flat plates were used to calibrate numerical models, especially the material card, using the HyperWorks suite. Calibrations were performed through the use of two parametric optimization techniques and response functions each. The optimization algorithms and response functions were compared to arrive at the most accurate and robust combination. Optimizations were conducted for three numerical parameters, values of which could not be obtained directly from typical crashworthiness tests. The resulting virtual model was able to predict, both qualitatively and quantitatively, the crushing behavior of a Formula SAE crash box impacted at 9700J under a drop tower. Macroscale and mesoscale models were, both, able to predict the mean crush force, stroke displacement and energy absorbed within 10% of the experimental results and accurately predict the post-impact damage. The use of automated optimization techniques significantly reduced the model calibration time. The resulting timesaving combined with the predictive capability could speed up the implementation of composite materials for use in primary crash structures by reducing component level testing. This would help automakers reduce the mass of future vehicles making them safer and more environment friendly.

Keywords: crashworthiness; impact behavior prediction; automated parametric identification; composite materials; finite element analysis