Post-test simulation of airliner wing access panel subject to tyre debris impact

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1 ABSTRACT

The purpose of the investigations described in this paper is a simulation approach for tyre debris impact on wing access panels. Aircraft tyre rubber has a complex structure containing directional layers of nylon reinforcement embedded in the rubber matrix. Material properties of the compound have been derived from quasistatic compression and tensile tests with specimen cut in circumferential and axial direction of the tyre, i.e. with various reinforcement orientations.

The Mooney-Rivlin material model describing the structural response of rubber, with embedded layers of elastic reinforcement cables, are used for the idealization of the tyre material. The material constants and reinforcement properties have been calibrated by the quasistatic specimen tests. The tyre mode then has been validated by dynamic impact tests of tyre fragments shot onto aluminium plates under an angle of 45 degrees. Measurements of transient strains of the aluminium plate shows good agreement with the simulation.

For the full scale tests, tyre specimen with dimensions of 425x100x27mm were shot onto an access panel, fixed on a steel holding plate, at a velocity of about 110m/s and an angle of 45 degrees. Measurements were taken from strain gauges fixed to the inner surface of the outer cover and to the outer surface of the inner cover. Three tests with approximately the same parameters were carried out and showed good reproducibility of the strain curves.

The mesh dependent parameters of the tyre model had to be re-calibrated for the full scale impact test simulation, to obtain a reasonable mesh density. The geometry of the tyre specimen has been matched according to the test. Simplifications that are assumed for the access panel idealization are e.g. the modelling of screws by a tiebreak contact formulation and the neglected rubber seal.

The simulation results show a tyre deformation that is quite similar to the test. Also the calculation of the dynamic strains correlates well with the test.

The tyre model proves to be robust and can be used for future analyses.

2 INTRODUCTION

Within the European research programme CRAHVI (Crashworthiness of Aircraft for High Velocity Impact) fuel tank access panels subject to debris impact have been investigated. The overall aim of this subject was to achieve a method to predict the structural response by numerical simulation. Lacking detailed information about the complex structural behaviour of reinforced rubber, tyre specimen tests were carried out. The material parameters that have been achieved, have been used for the explicit analyses with LS-DYNA. Further calibration of the tyre model has been done for a full scale impact test simulation of tyre debris impact on an access panel.

The modelling approach for the tyre model and the derivation of material parameters has been accomplished by the University of Liverpool (ULIV), soft debris impact tests on the access panel have been carried out by the Toulouse Aeronautical Test Centre (CEAT), and the numerical simulation for tyre impact pre- and post test analyses have been done by ULIV and CADFEM.

3 Experimental Investigations

3.1 Quasistatic Tensile Tests [1]

Material testing was performed on specimens from two different tyres. Compressive and tensile tests were conducted for an unused Michelin tyre. Further specimen were taken from a Dunlop tyre, that has flown with a Concorde for a number of years.

The tested tyre material has a very complex structure consisting of a rubber-like material reinforced with cords. The cords are placed at different angles, but in general these angles are smaller than 30° with respect to the circumferential axis of the tyre. The reinforcing cords are ropes twisted from fibres and their stiffness in compression is significantly lower then the stiffness in tension. This material structure results in anisotropic properties and a non-linear behaviour when subjected to large deformations.

Parallel tensile test specimen was chosen as having the most appropriate geometry for this type of material. Figure 3.1.1 shows the orientation axes relative to the tyre and failed specimen that were cut in x-direction, resp. in y-direction. Corresponding stress-strain curves are shown in 3.1.2. Maximum material strength appears to be in the circumferential x-direction. The actual failure mode of the specimen is reminiscent of the failure of ±45° composite laminates.

3.2 Quasistatic Compression Tests [1]

Cylindrical compression specimens were taken as cores from the through thickness of the central region of the tyre form in the *z*-axis only. Specimen diameters of between 15 and 33.5 mm were considered but, it was found that only a diameter of 25mm or larger would behave in a stable way under compression. The length of the specimen was maintained as the full through thickness of the tyre. The curved nature of the inner and outer tyre form meant that the ends of the specimen had a slight curvature. Specimens were compressed between flat platens of an INSTRON testing machine at a crosshead displacement rate of 5mm/min.

The engineering stress-strain graphs of two compression tests of 25mm and 26.5mm diameter are presented in 3.2.1.The curved geometry of the specimen ends meant that the initial 2mm to 3mm of displacement (approx.10% strain) was taken up in compressing this form flat prior to true loading of the material.

3.3 Dynamic Tests[1]

In order to investigate the strain rate effects for rubber material, dynamic tests of tyre specimen have been conducted. Assuming an impact speed of 106ms^{-1} and typical missile dimensions of 30mm, a typical strain rate is 1000s^{-1}.

Strain rate sensitivity of the tyre material was tested over impact velocities ranging from 7m/s to 50m/s, corresponding to strain rates of 200s^{-1} to 2000s^{-1}. Drop hammer tests were performed for the lower impact velocities, whilst a gas gun was used for the high velocities. The recorded velocity of the impact during a test was integrated to give displacements, whilst the voltage recorded by a load cell was converted to load using the results of an earlier calibration test performed on the load cell itself.

For the drop hammer tests the impact energy was ~300J and for the gas gun test the impact energy was ~400J. As the projectile mass decelerates during the impact, variable strain rates are obtained from the tests.

Two types of specimen have been used for the dynamic compression tests. Through the thickness specimen, consisting of reinforced core-material and tread material, showed as good as no strain rate dependency up to ~40% strain. At higher strains, the measured load curves diverged due to the different failure progression that is observed for varying test velocities. For the core only material, the load vs. displacement curves increases considerably with increasing strain rate.

Due to the inertia effects, a similar behaviour is observed for the simulation of the dynamic compression tests, although strain rate dependency has not been taken into account. Thus, strain rate dependency has not been implemented for the current simulation model for the tyre.

3.4 Tyre Specimen Impact Tests on a Wing Access Cover [4]

Impact tests of tyre specimen shot onto an aluminium access panel fixed to a steel holding plate have been accomplished by CEAT (FRA). The test configuration and parameters as e.g. impact velocity, tyre characteristics and impact location were agreed between CEAT, Airbus UK and ULIV according to the pre test simulations. Figure 3.4.1 shows the test configuration. The tyre fragment is fired from a gas gun barrel with a velocity of approximately 110m/s. A polystyrene case initially carries the tyre specimen and is removed after the shot by a specific mechanical device. The tyre geometry shows a groove the has been machined to allow its initial bending.

Video sequences of the tyre deformation were recorded with a high speed camera, capturing 1000 frames/s. For measurement of the structural response of the panel and for comparison with the numerical simulation, strain gauges were fixed to the inner side of the outer panel and the outer side of the inner panel. Load transducers were further installed to record reaction loads at the test rig. The test rig is currently not modelled for the numerical simulation. Thus the reaction forces have not been compared to numerical simulation yet.

The curves of reaction forces and the unfiltered strain curves, measured at three tests, indicate a very good repeatability of the structural response. No perforation occurred at any of the tests. Maximum deformation of the outer cover occurred near the edge of the access panel in impact direction along the impact line, where partial screw failure could be observed (see Figure 3.4.2). For the inner panel, plastic deformation of the stiffeners was obtained. Leakage checking has not been specified for the tests.

4 Post-Test Simulations

4.1 FE-Model in LS-DYNA

The Finite Element model of the access panel structure and the tyre has been accomplished by ULIV and CADFEM according to foregoing proposals [1, 2]. Pre-test simulations with various tyre geometries were run to calibrate the model and to verify test parameters [3].

The LS-DYNA FE-Model for the tyre specimen in the full scale test simulation consists of a solid mesh with layers of cable elements connecting solid mesh nodes. The Mooney-Rivlin material model [6, 7] (MAT_27 in LS-DYNA) has been applied to describe the rubber material response of the tyre. Figure 4.4.1 depicts stress-strain curves for uniaxial load with the according material parameters for the rubber and aluminium material. The layers of directional reinforcement are modelled with solid node connecting cable elements, that are calibrated for the current mesh density. The LS-DYNA option to constrain Lagrange elements in solids, has been applied.

The structure of the test configuration is reduced to the constrained holding plate and the access panel. The wing access panel is modelled with shell elements and solid elements for the screw nests (see Figure 4.1.2). A gasket that is mounted between the outer panel and the aircraft wing skin has not been taken into account for the impact test, resp. the present analyses. The inner panel has a groove with a rubber seal, that is not modelled, as it is assumed not to reduce the panel stiffness considerably.

The screws, fixing the outer panel to the inner panel are not modelled and are idealized by a tiebreak contact between the outer cover and the screw nests. Contact failure was not intended to be modelled, thus only one tiebreak nodes to surface contact formulation has been defined and tensile and shear failure forces are set to a high value. Nevertheless, a force transducer contact formulation has been applied to determine the contact forces between each screw nest and outer panel, representing the bolt loads. A tied contact is defined to fix the bolt nests to the inner panel.

Further contact formulations are defined between tyre and structure (nodes to surface) as between the access panel and the fixture.

4.2 Simulation Results

The deformation sequences of the tyre debris impact on an access panel – test and simulation, depicted in Figure 4.2.1 show a good similarity to the structural response. Due to the large flexibility of the tyre, the majority of the impact energy transforms into deformation energy of the projectile. A very small proportion of the initial kinetic energy transforms into a kinetic energy of the panel.

Directional strain calculation results were obtained at the respective shell element surfaces. Figures 4.2.2 up to 4.2.5 show the calculated and measured strain curves for one of three strain gauge positions for each cover. The unfiltered calculated strain curves fit well the measured strains, considering peaks and strain levels.

Displacement measurements to describe a possible leakage of the outer and inner panel were not taken for the impact tests. Thus, a comparison with the simulation has not been possible. The simulation predicts maximum displacements of the inner cover edge relative to the holding plate of approximately 8mm, thus it can be concluded that there might well be a leakage.

The maximum axial tensile load for the bolts is calculated as 8kN, at the position where the tyre slides off the structure, following the impact line. For the two bolts at this position, the numerical analyses foresees a maximum shear load of about 15kN. For the other bolts, the maximum shear load has about the same magnitude as the axial load. The partial failure that is observed in the test for two screws at the correspondent position, is also assumed to be initiated by a combination of axial load and mainly shear load.

5 Summary and Conclusions

The tyre rubber impact model has shown to be robust and to be able to model the general large scale deformation of the full scale tyre fragment during impact. The strain curves from the numerical simulation correlate well with the strain gauge measurements. The structural response of the access panel is dependent on the tyre fragment shape. Further load cases and future analyses may be investigated based on the developed models for tyre specimen and access panel.

6 References

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