Development of a CAE Method to Predict the Fatigue Life of Aluminium Panels Joined by Self Piercing Rivets

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Abstract

Jaguar Land Rover were the lead partner in a three and a half year Technology Strategy Board (TSB) project to develop commercially available software simulation tools to predict the fatigue life of joints in aluminium (AA5754) sheet materials. Five joining technologies were investigated; Self-Piercing Rivets (Henrob SPR), Medium Frequency Direct Current Resistance Spot Welds (RSW), Structural Adhesives (Dow4601) and two combinations of these joining methods (Weld Bonded & Riv-Bonded). This project successfully developed fatigue damage models for all of these technologies.

The generation of a damage model is not just a one off activity, but a continuous process of development and improvement. Each time a new material is included into an SPR joint, fatigue tests are conducted and the damage model revisited to verify whether the model is still valid or whether a new model is required. Changes in CAE joining methodologies used to model the SPR's, as well as difference in the CAE solvers used all require reconfirmation of the models.

This paper reports the overall approach that was used order to establish and develop the fatigue damage model for just one of these joining technologies, Self-Piercing Rivets. The approach produced substantial execution and implementation time savings. This has enabled Jaguar Land Rover to improve their capability in terms of virtual CAE assessment of joint behaviour and performance. The acquired understanding of load propagation through the structure allows joint and part optimisation, while maintaining or even improving the overall product quality. This enables weight reduction with the environmental benefits this brings.

Keywords: - HyperMesh, HyperMorph, OptiStruct, , HyperStudy, HBMnCode Designlife Fatigue , SPR
1.0 Introduction

The body structure of a modern light weight vehicle is made from hundreds of individual parts that are joined together with thousands of Self Piercing Rivets, see Figure 1.

*Figure 1: Light Weight Aluminium Body Structure – Panels (LHS), SPR joints (RHS)*

The design of an efficient lightweight aluminium body structure requires understanding of the behaviour of the thousands of joints used to assemble the individual parts together when they are subjected to demanding and repeated loadings, as our customers travel in luxury both on and off road. Improving the fatigue prediction will enable greater optimisation of the joints and the parts they join. This will simplify the manufacturing and reduce weight of parts, which will improve fuel consumption of the vehicle and retain the quality that our customers expect.

This paper details the methodology used to develop the fatigue prediction of SPR. See Figure 2.

*Figure 2: Diagram showing process flow for damage model creation*
2.0 Fatigue Damage Model

2.1 Coupon Selection, Production Representative Manuf. & Fatigue Testing

The selection of the coupons and how they are to be loaded in the fatigue test is very important, as they need to replicate the loading modes seen in the vehicle structure. Two coupon types were selected for the testing; Lap Shear and Coach T-Peel Joints. The coupons need to be assembled with production representative manufacturing equipment and to be thermally treated to replicate the temperatures in the paint ovens. In addition the load ranges used for the fatigue tests need to replicate the values seen in a vehicle structure. The correct number of coupons must be made and tested to provide a statistically representative sample at each of the load levels tested.

From the coupon testing for SPR there are two primary fatigue modes. The fatigue cracks initiate from inside the joint, one in the top sheet and another in the bottom sheet, Figure 3. The cracks initiate inside the joints and grow to the outside, and as the cracks grow they cause a stiffness change to the joint.

![SPR Top Sheet Interior Failure Mode](image1)

![SPR Bottom Sheet Interior Failure Mode](image2)

Figure 3 – SPR primary failure modes – internal fatigue cracks

The fatigue life of the coupons is very dependent on the geometry, sheet material thickness and also how it is loaded. The majority of joints on a car body structure are coach peel joints as these are the most easily manufactured; however the majority of these joints are loaded in shear and not in peel. Figure 4 illustrates how for the same external force the fatigue life for a Coach peel joint was 5000 cycles were as the lap shear was 2 million.

The loading conditions applied to a vehicle are complex; it is then not trivial to establish which joints are in coach peel and those that are in shear. A method therefore is needed to do this.
2.2 Internal Joint Force Extraction from coupons fatigue tested

By measuring the force in the individual joint connections within a coupon (internal forces) rather than the force applied to the coupon (external forces) and converting this into the most appropriate stress component we removed the need to pre-determine the type of joint e.g. a lap shear joint or a coach peel joint.

The grips used in the fatigue tests were included in the CAE models to ensure that the internal forces were modelled in as much detail as necessary, Figure 6.

This involved the use of HyperMesh to create a HyperMorph parametric model of the coupons, which was run in OptiStruct by HyperStudy. The internal joint forces of the different joining methodologies were extracted using HBM nCode Designlife.
Runs for different thicknesses from 0.5 to 3 mm in steps of 0.1mm were conducted. The use of the parametric morphed model insures that the geometry of the coupons, which varies with thickness and the relationship to the grips they are mounted to are always correct.

![Image](image1.png)

**Figure 6 – Parametric CAE Model of Coupon Fatigue Specimens.**

### 2.3 Formulation of equations converting Force into Stress

Internal forces at the joint were converted into a radial stress component using the equations developed by A. Rupp [1], LHS of **Figure 7**.

![Image](image2.png)

**Figure 7 – Joint Forces to Radial Stress (LHS).  Un-optimised stress for SPR RHS**

The external forces applied to the coupons in the physical fatigue tests were converted to the internal joint forces with the aid of the CAE models developed in 2.2. The resulting stress component was plotted against the physical fatigue test life to produce a Stress Life curve, RHS of **Figure 7**.

### 2.4 Determination of parameters to produce the best fit of Stress to Physical data

Within this project a method was developed to analyse the large quantity of processed test data to optimise the joint fatigue constants. This enabled the production of a single stress versus life curve from the different families of test data, with the minimum of scatter. This method explored the full range of possible solutions, within the user supplied limits, to ensure that a global solution and not a local solution was found. This ensured that the
variation in stress and fatigue life was minimised, Figure 8. The resulting slope and intercept of the best fit curve to the test data is the SN Curve for CAE.

It was found that for the range of loads that the car body structure is typically subjected to, the locations prediction by the unmodified A.Rupp equations produced a very good damage model for Top and Bottom sheet failure modes.

**Figure 8 – Stress Life Curve for SPR Joint.**

### 5.0 Conclusion

The new optimisation method enabled these constants to be established for SPR’s within one day of receiving the test data, a major improvement over the manual methods previously employed.
6.0 References


7.0 Acknowledgements

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