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Experimental and Finite Element Analysis of Riveted Joints Structure of a Simplified Model of Aluminium Crash Box

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Abstract: In the automotive structure, a different type of components partly employing aluminium alloy sheets due to higher strength, better formability and crash worthiness. The structures are assembled from components and they are connected by various types of joints. However, the dynamic properties of the joints are difficult to incorporate in the model numerically accurately due to invalid assumption of the input value. The accuracy of the predicted result is significantly affected by the input properties of the joints themselves. In This study, the dynamic behaviour of a simplified model of a riveted crash box of double hat shape structure is investigated. Different types of connector elements are investigated and the accuracy of the connector elements are discussed in term natural frequencies and mode shapes and to achieve these goals, the predicted results will compare with the experimental data.

Key words: Riveted joints, crash box, EMA, local effects, irregularities

INTRODUCTION

The application of light weight based material is becoming crucial need in the automotive industries due to environment and social pressure. Even though, the usage of steel has allowed automotive manufacturers to achieve desired standards of strength and safety for their vehicles at relatively low costs in comparison with other materials. However, the rising in demand for more fuel efficient and light weight vehicle has push the automotive manufacturer to use the light weight material such as aluminium in their car production. Therefore, the aluminium is becoming the choice for many automotive components such as chassis, doors and panels due to its light weight, good formability and crash worthiness aspect. The automotive components that are made from aluminium either can be welded or riveted together in order to form the automotive structure.

The riveted joint technique is an alternative to the welding technology and is widely used in the automotive industry due it simplicity (Vivio, 2009). One of the advantages of the riveted joint is that they have more flexibility than welded joints where, the riveted joints can be used to assemble two or more components of a structure with dissimilar type of material. Moreover, the riveting process is very easy, fast and uncomplicated which is consisted of inserting the rivet in matching holes of the pieces to be joined and subsequently forming a head on the protruding end of the shank. On top of that, riveted joints have a better fatigue strength in comparison with the resistance spot welding (Avitabile, 2001; Palmonella *et al*., 2005; Schneider and Jones, 2003). Despite its simplicity, the riveted joint presents a local stiffness that is not easy to model within a large finite element analysis due to local effect of the riveted area itself such as local deformation and geometrical irregularities. For instance, to model the local effect precisely is impractical and requires a lot of computation efforts when performing simulations or calculations because the modelling process requires a local mesh refinement (Husain *et al*., 2010). Therefore, the riveted model needs to be replaced with non-idealised model of connector elements which should behave approximately like the idealized part. These non-idealised parts demand a lot less computing power (Yunus *et al*., 2011). Understandably, finite element modelling input data is merely based on the nominal value of the material properties and also the assumption of the boundary conditions. Modal analysis is an experimental approach for the investigation of the dynamic characteristics of a structure, such as the natural frequencies, damping factors and modal shapes of a structure. Therefore, the

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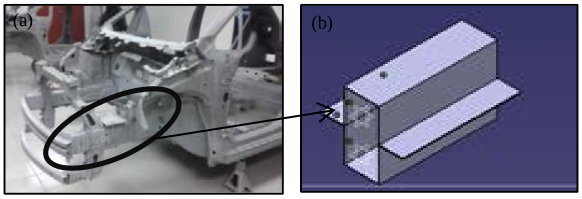


Fig. 1: Safety can in BIW; simplified model of double hat in CAD

initial finite element model will be compared with the experimental data in order to identify the accuracy in term natural frequencies and mode shapes.

In this study, the dynamic characteristic of the riveted joints structure is investigated. A number of connector elements that are available in the HyperMesh are investigated and their accuracy will be compared with the experimental data in term of natural frequencies and mode shapes. Meanwhile the frequency of interest for this study is based on 0-1000 Hz. The potential model of connector element with the least error in term of percentage will be updated and will be used for subsequence analysis such as crash analysis (Bograd *et al*., 2011; Ruijun and Xiangwen, 2011; Husain *et al*., 2010; Lee *et al*., 2006; Rani *et al*., 2011; Mark and Punt 2004; Scigliano *et al*., 2011; Herlufsen, 2004) (Fig. 1).

MATERIALS AND METHODS

Processes

FE Model: The simplified model of a safety can or crash box of a car is developed using HyperWork. In this finite element model of the crash box, the shell element with the meshing size of 2 mm is selected as shown in Fig. 1. The assembled structure of the safety can consists of two hat shape components which are assembled by a number of riveted joints.

Meshing:

- Size of element = 2 mm
- No of elements = 16398
- No of nodes = 16720
- Shape of elements = mixed (triad and quad)

The modelling of the connector element of the rivet is can be calculated based on fastener flexibility. The fastener flexibility is a measure of the influence of fasteners (rivets, bolts, etc.), on the flexibility of the whole joints in which F refers to the external force and Δl to the deflection of the joint due to the fastening. The flexibility can be defined as follows [NASTRAN 2005R2]:

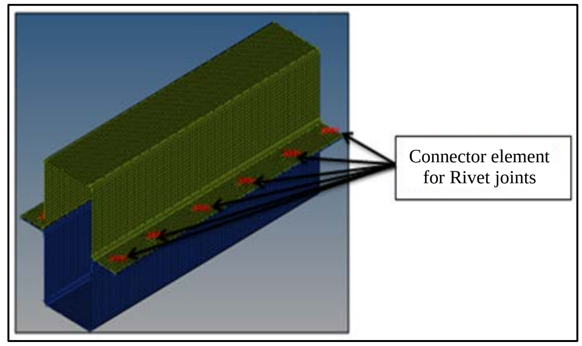


Fig. 2: FE Model crash box

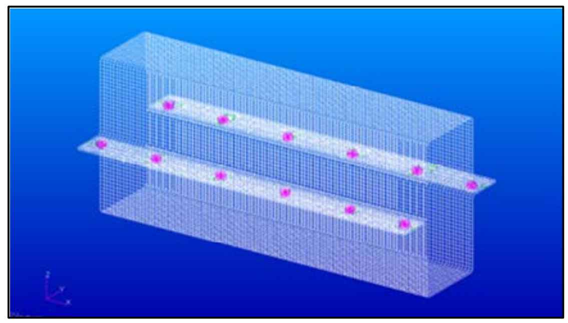


Fig. 3: Imported indel in Patran

$$\text{Flexibilit (f)} = \frac{1}{\text{Stifness (K)}} = \frac{\Delta l}{F} \quad (1)$$

Meanwhile, The fastener flexibility in shear direction based on Douglas equation:

$$f = \frac{5}{dfEf} + 0.8\left(\frac{1}{t_1E_1} + \frac{1}{t_2E_2}\right) \quad (2)$$

Where:

E_f = Young's modulus of bolt
d_f = Diameter of bolts
E_1 = Young's modulus of first property connected of the bolt
E_2 = Young's modulus of first property connected of the boltt$_1$
t_2 = Are thickness of the clamped plates

The available connector elements that available in the HyperWork are used to model the riveted joints. The elements are RBE, CBAR, CBEAM, CBEAM with Lump mass and CBEAM with Height as shown in Table 1. The normal mode analysis is calculated numerically based on the natural frequencies and mode shapes as shown in Table 2. From the general equation of motion (Fig. 2 and 3):

Table 1: Type of connector elements

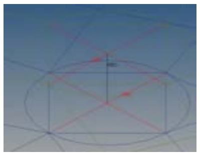
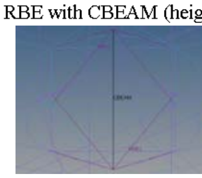
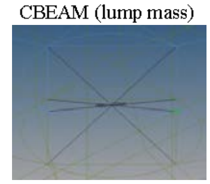
RBE with RBE	RBE with CBAR	RBE with CBEAM	RBE with CBEAM (height)	Bolted (spider) with CBEAM (lump mass)
				

Table 2: Natural frequencies

Experiment	RBE	Error (%)	Relative CBEAM (H)	Relative error (%)	CBAR	Relative error (%)	CBEAM (M)	Relative error (%)	CBEAM	Relative error (%)
295.54	293.00	0.86	287.50	2.72	291.32	1.43	287.99	2.55	291.32	1.43
317.46	322.00	1.43	317.22	0.08	320.70	1.02	315.91	0.49	320.70	1.02
381.73	380.00	0.45	379.90	0.48	380.09	0.43	380.29	0.38	380.07	0.43
386.58	389.10	0.65	388.84	0.58	389.04	0.64	388.03	0.38	389.04	0.64
645.32	609.00	5.63	603.04	6.55	606.79	5.97	601.86	6.73	606.79	5.97
655.44	624.00	4.80	619.20	5.53	622.16	5.08	614.11	6.31	622.16	5.08
Total error		13.82		15.94		14.56		16.84		14.57

$$Mx(t) + Cx(t) + Kx(t) = f(t) \quad (3)$$

M = mass, C = damping, K = stiffness, F = force. In this research the structure is considered likely damped and calculated in normal mode analysis, therefore damping and force are neglected:

$$Mx(t) + Kx(t) = 0 \quad (4)$$

By using complex notation can be expressed as:

$$x(t) = Xe^{n\omega t}$$
$$\ddot{X}(t) = -\omega^2 Xe^{n\omega t}$$

Substitute into Eq. 4, then natural frequencies are obtained:

$$\omega = \sqrt{(k/m)}$$

Experimental Modal Analysis (EMA): In this experiment, a riveted joined structure is analysed using LMS SCADAS in order to obtain the modal properties of the jointed structure. Meanwhile, the frequency of interest is set from 1-1000 Hz and roving accelerometer method is used because the complexities shape of the structure.

The experimental set up of the structure is shown in the Fig. 3 where the structure is hung by soft spring at four corners. Then, an impact hammer is used to excite the structure at the pre-defined point and the responding vibration signals are measured by four accelerometers at the predefined points.

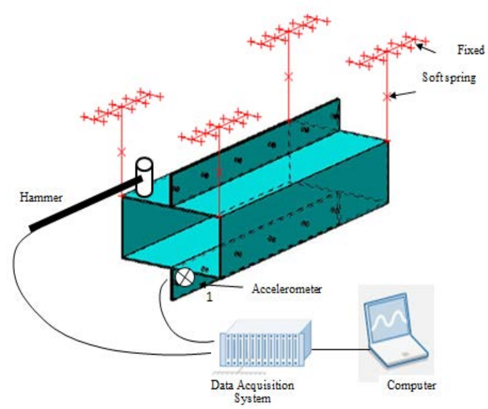


Fig. 4: Experimental setup

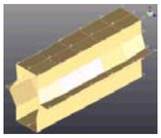
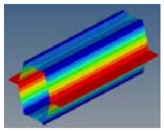
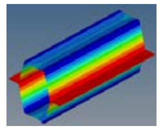
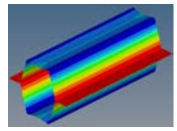
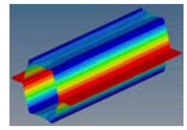
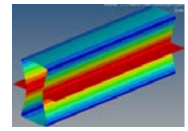
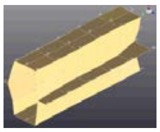
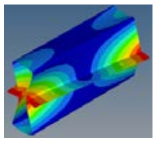
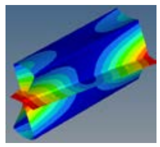
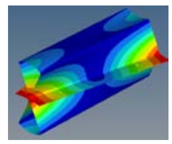
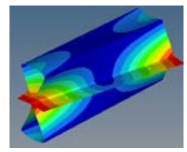
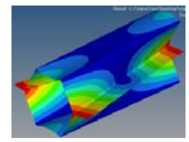
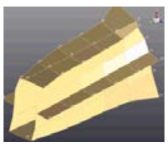
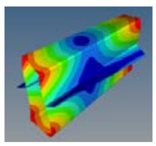
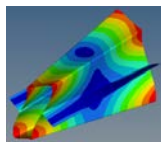
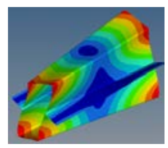
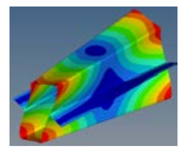
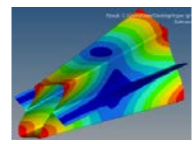
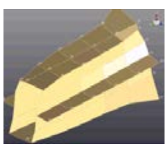
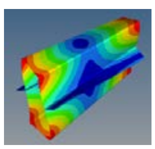
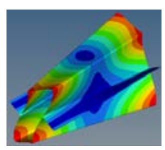
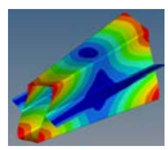
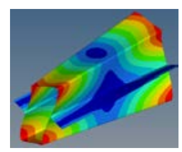
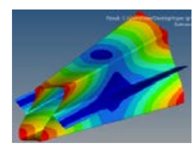
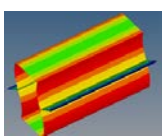
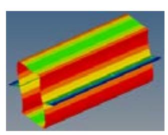
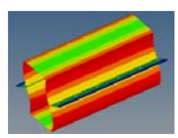
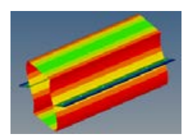
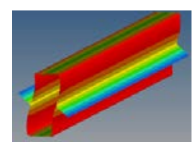
RESULTS AND DISCUSSION

Natural frequencies data: In this research,the potential connector elements that can be used to represent the riveted joint are investigated. The are several of connector elements have been used to represent the rivet joint, namely RBE2, CBEAM, CBEAM with height of rivet, CBEAM with lump mass and CBAR. The accuracy of these elements is compared in the Table 2. Table 2 shows the comparison between the connector elements with the experiment (Fig. 4).

From the table, it shows that rbe2 obtained the less relative error which is 13.82 %, whereas, CBAR in second place with 14.56 % ,followed by CBEAM with 14.57 %, CBEAM height 15.94 % and CBEAM mass with 16.84 %.

Mode shapes data: From the Table 3, it shows that RBE2, CBEAM, CBEAM with height and CBEAM with lump mass behave with the same mode shape. Whereas CBAR at certain frequencies behave different mode compared to the other connector elements. Also, from the table it shows that, the first and second mode are bending, the third mode is torsion whereas the forth until the last are in complex shape.

Table 3: Mode shapes

Experiment	RBE2	CBEAM	CBEAM (H)	CBEAM (M)	CBAR
295.54 Hz	293 Hz	291.32 Hz	287.5 Hz	287.99 Hz	291.32 Hz
					
317.46 Hz	322 Hz	320.69 Hz	317.23 Hz	315.91 Hz	320.69 Hz
					
381.73 Hz	380 Hz	380.09 Hz	379.90 Hz	380.29 Hz	380.09 Hz
					
386.54 Hz	389.1 Hz	389.04 Hz	388.84 Hz	388.03 Hz	389.04 Hz
					
645.32 Hz	609 Hz	606.79 Hz	603.04 Hz	601.86 Hz	606.79 Hz
					
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	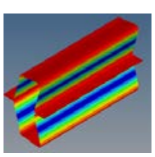	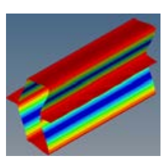	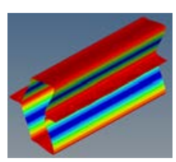	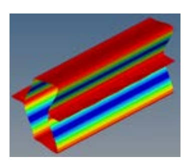	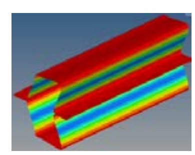

In this research, the comparisons between element connectors are verified by using experimental data. From the results, it shows that RBE has the lowest relative errors with 13.82 compared to the other element connectors where CBAR (14.56), CBEAM (14.57), HEIGHT CBEAM (15.94) and CBEAM LUMP MASS (16.84). From the mode shapes results, it shows that the first mode is in bending mode, second mode is in torsional mode and the third until the sixth mode is in complex mode.

CONCLUSION

As a conclusion, the goal of this experiment is to investigate the most reliable connector element that can be used to represent the rivet joint. Based on Finite Element (FE), the element connector of RBE gives the lowest errors compared to the others type connector elements. However, in order to minimize the errors the model updating method can be used to minimise the error between the FE and measured data so that it can be used for the consequence analysis.

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