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ANALYSIS OF THIN WALLED TUBE AL 3003 H12 UNDER QUASI-STATIC AXIAL CRUSH MODE USING FINITE ELEMENT METHOD

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ABSTRACT

Experimental crashworthiness investigation on thin walled tube structure always contribute into a complicated process with huge amount of cost is wasted on specimen preparation perfection. Advance numerical solution has been found as a significant option in order to simplify the process while enhancing the understanding of this crashworthiness behavior. Therefore, current works have been carried out based on finite element method to perform a quasi-static axial crush on selected thin walled tube structures. Here, the circular and rectangular tubes of aluminium alloys Al 3003 H12 sections are selected based on its wide application on front chassis rail component. Essential boundary conditions have been applied in order to accurately simulate the quasi-static axial crush behavior. Preliminary verification results has shown that current numerical method is capable to produce a good correlation results with selected experimental data in terms of energy absorption, crushing length and collapse starting point. However, there is also a slight discrepancy observed in cylindrical 1.5 mm deformation mode behavior.

Keywords: crashworthiness; finite element method; thin-walled tube; energy absorption; quasi-static axial crush.

1. INTRODUCTION

Front chassis rail structure can be identified through the forward extend structure on a vehicle frame, example shown in Figure 1. Technically, front chassis rails are assembled and constructed based on thin walled tube structure and the design can be varied accordingly not just to meet certain design criterions but also standard rules and obligations. Energy absorption characterization of thin-walled tubes have been the most common subject of many experimental and theoretical studies because they have been identified as one of the most efficient impact energy absorbing elements, due to their progressive axial folding (Jones, 1989; Lu & Yu, 2003). However, another issue arises in terms of vehicle mass in which high-

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strength steel and thicker panels brings into an increase in overall weight vehicle structure. As a result, the vehicle will need more fuel consumption and release higher CO_2 emission to the atmosphere (Goede, Stehlin, Rafflenbeul, Kopp, & Beeh, 2008). Therefore, a detail study of energy absorption capacity and collapsed behavior study on thin-walled tube is very significant in order to design less weight (Obradovic, Boria, & Belingardi, 2012), less fuel consumption (Moghaddam & Ahmadian, 2011) and excellent crashworthiness performance structures (Zhang & Huh, 2009). Experimental investigation procedures always contribute into a complicated process with huge amount of cost is wasted on specimen preparation perfection. Emerging of advance numerical solution has provided a significant option in order to simplify the investigation process and enhance the understanding of this crashworthiness behavior. Therefore, this current works have been carried out based on finite element method to perform a quasi-static axial crush on selected thin-walled tube structures. Current study has concentrated on the circular and rectangular tubes of aluminum alloys, Al 3003 H12 sections. This selection is done based on their broad application as the front chassis rail component.

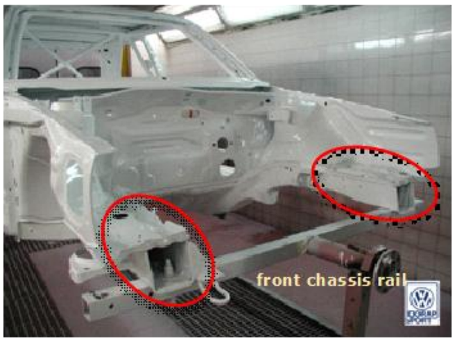

Figure 1: Front chassis rail structure (Olabi, Morris, & Hashmi, 2007).

1.1 Boundary Condition And Hyperworks Setup

The circular and rectangular thin walled tube model was created by using CATIA V5R18. The dimensions of both models are given in Table 1. The two model developed are shown in Figure 2 and 3. Both models have equal length of 100 mm. 2D structured mesh has been created on the model by using the HyperMesh mesh module. Based on a mesh independent study, the optimized quad elements are achieved at 5491 elements (for circular tube) and 11200 elements (for rectangular tube) as summarized in Table 2. The optimized mesh development for circular and rectangular tubes is shown in Figure 4.

Table 1: Specifications of the numerical simulation specimens.

Specimen Shape	Dimensions (mm)	
	Length (mm)	Diameter (mm)
Cylindrical	100	60
Rectangular	100	Cross section 31.4 x 62.8

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Table 2: Summary of Mesh Independent Study.

Sample Shape	No of Mesh Elements			
Cylindrical (1.5 mm)	1497	2667	5491	10124
Energy Absorbed (J)	983	1035	1216	1214
Cylindrical (1.0 mm)	1497	2667	5491	10124
Energy Absorbed (J)	508	561	657	656
Rectangular (1.5 mm)	2834	5498	11200	22340
Energy Absorbed (J)	572	638	745	742

Aluminium alloys Al 3003 H12 has been used as the material for the thin walled tubes model. The thin walled tube material is assumed to be an elasto-plastic material with piecewise linear material law applied. The material properties and stress-strain curve (Alavi Nia & Haddad Hamedani, 2010) for Al 3003 H12 is given in Table 3 and Figure 5, respectively. The thickness for cylindrical model is set at 1.0 mm and 1.5 mm thicknesses while the rectangular model is fixed at 1.5 mm. The selection of these thicknesses is basically to follow the same model used in reference (Alavi Nia & Haddad Hamedani, 2010) for verification purpose.

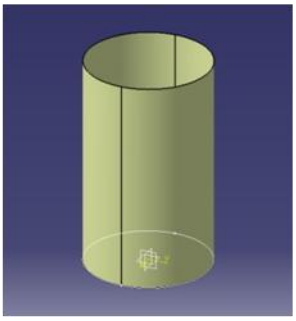

Figure 2: Cylindrical thin walled tube model performed by using CATIA.

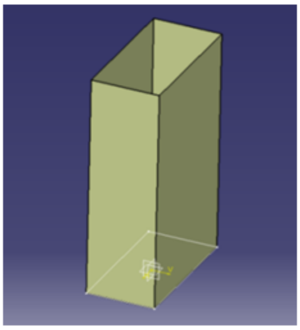

Figure 3: Rectangular thin walled tube model performed by using CATIA.

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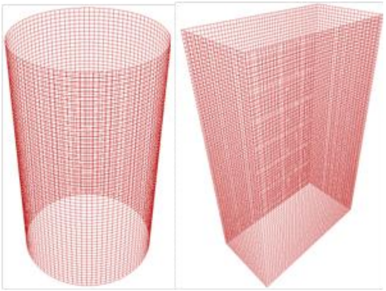

Figure 4: The optimized mesh development for circular (left) and rectangular (right) tube.

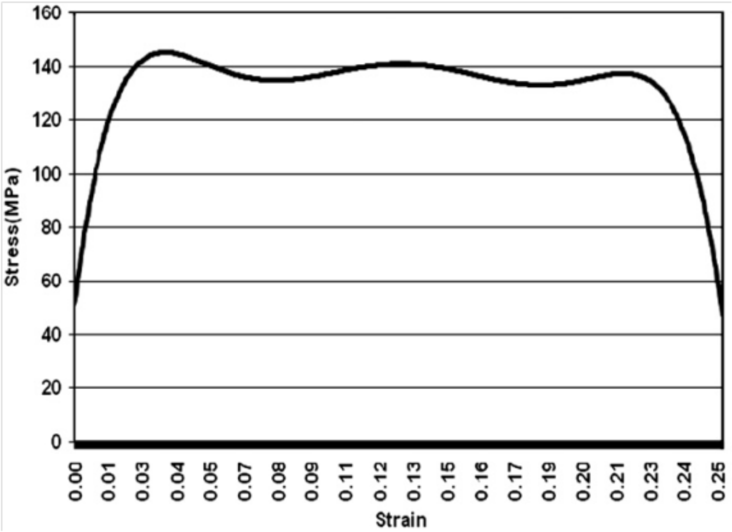

Figure 5: Stress-strain curve of the samples in (Alavi Nia & Haddad Hamedani, 2010).

Table 3: Material Properties of Aluminium Alloy, Al 3003 H12 sheets.

Physical Properties	**Metric**
Density	2730 Kg/m^3
Young Modulus	80 Gpa
Poisson's Ratio	0.33
Hardening Coefficient	35

The essential boundary conditions have been used to setup the quasi-static axial crush analysis. The boundary conditions setup for quasi-static axial crush analysis is summarized in Figure 6 and Figure 7, respectively. Other important parameters to simulate this quasi-static axial crush are listed in Table 4.

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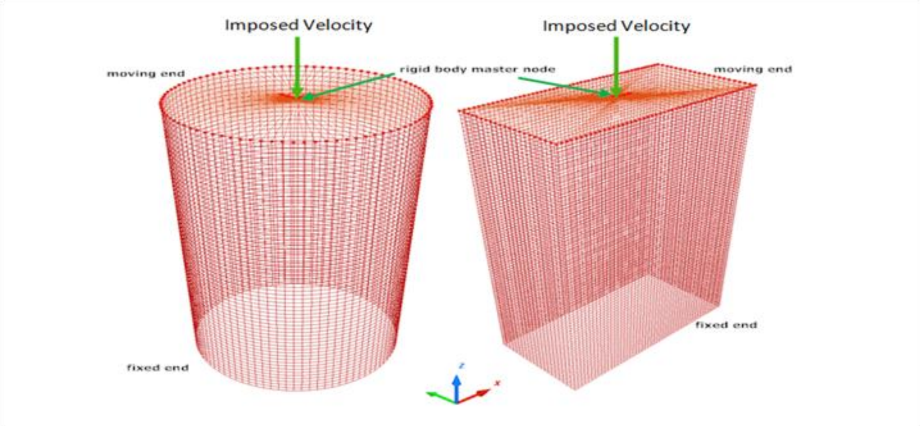

Figure 6: The rigid body condition on circular (left) and rectangular (right) tube.

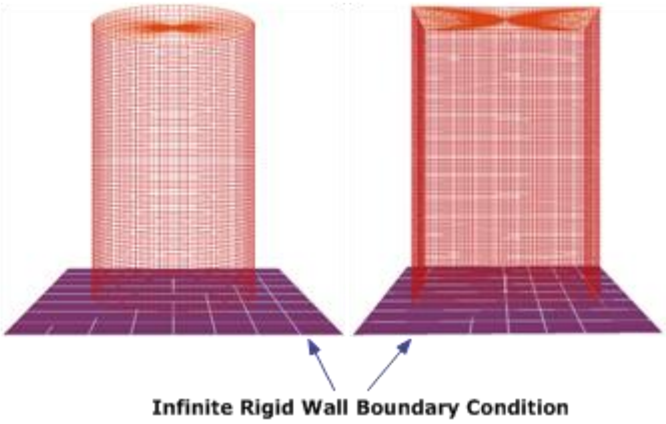

Figure 7: Rigid wall boundary condition applied on circular (left) and rectangular (right) tube.

In order to solve this numerical problem, Altair RADIOSS solver has been fully utilized to solve this quasi-static axial crush analysis. After that, the qualitative and quantitative results are presented and visualized in the integrated HyperView module.

Table 4: Units and Inputs.

Parameters	Units/Value Used
Length Unit	Millimetre (mm)
Time	0.1 Seconds per analysis
Mass Unit	100 kg
Velocity	100 mm/sec
Total Time step	1s

2. SIMULATION RESULTS AND DISCUSSION

2.1 Verification Of The Thin Walled Tube Models

In this current study, results are presented for verification purpose, in which the numerical results are compared to experimental data provided by reference (Alavi Nia & Haddad

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Hamedani, 2010). The results are basically evaluated based on quantitative (energy absorbed and crushing length) and qualitative (collapse mode and collapse starting point) criteria. Summary of this verification result is listed in Table 5 and Table 6 represents the comparison analysis between the numerical and experimental results.

Table 5: Results of simulation for the three samples.

Sample Shape	Thickness	Energy Absorbed (J)		Crushing Length (mm)		Collapse Mode		Collapse Starting Point	
		Experimental	Numerical	Experimental	Numerical	Experimental	Numerical	Experimental	Numerical
Cylindrical	1.5 mm	1168	1216	79.25	80.00	Concertina and diamond	Concertina	Fixed end	Fixed end
Cylindrical	1.0 mm	630	657	78.40	80.00	Concertina	Concertina	Fixed end	Fixed end
Rectangular	1.5 mm	702	745	79.44	78.00	Concertina and diamond	Concertina and diamond	Fixed end	Fixed end

Table 6: Comparison between the results of experimental and simulations for the three samples.

Specimen Shape	Thickness	Difference %		Collapse Mode	Collapse Starting Point
		Energy Absorbed	Crushing Length		
Cylindrical	1.5 mm	4.1	1.0	Almost similar	Similar
Cylindrical	1.0 mm	4.1	2.0	Similar	Similar
Rectangular	1.5 mm	6.1	1.8	Similar	Similar

2.2 Absorbed Energy

Absorbed energy (E) of a thin walled tube is defined from the area under the load-displacement curve. Referring to Table 5 and Table 6, one shall find that the energy absorption capacity for numerical is comparable to the experimental results. The percentage differences between them is well below 10% which is the typical discrepancy percentage for energy absorption study (Alavi Nia & Haddad Hamedani, 2010). The closest energy absorption capacity value is established by cylindrical shapes (at thicknesses 1.5mm and 1.0mm) where each case was recorded at 4.1% difference. Both methods also agreed well where cylindrical 1.5mm always has the highest energy absorption capacity. The rectangular 1.5 mm has consistently shown to have better energy absorption capacity compared to cylinder 1.0 mm thickness in numerical and experimental results. In overall, one can conclude that the numerical results have shown a good correlation with experimental value in terms of energy absorption capacity.

2.3 Crushing Length/Fold Length

Crushing length is the total collapse length of the thin walled tube subjected to quasi-static axial crush mode. Based on this verification results (Table 5 and 6), one shall find that both method produce almost similar value of crushing length where the highest discrepancy between them is marked at 2% which is cylindrical 1.0mm case study. Comparison shows that the closest value of crushing length is produced by cylindrical 1.5mm case where the

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discrepancy is recorded at 1%. Derived from this comparison, one shall presume that the numerical method is able to predict correctly the crushing length for this thin wall tube model.

2.4 Collapse Starting Point

The collapse starting point is a qualitative result where it is related to the starting position of collapse behavior on the thin walled tube subjected to the axial crush. Observation has apparently shown that all three cases have recorded a consistent and well agreement with the experimental results. All cases show similar starting point at the fixed end of the thin walled tube. The visualization of this collapse starting point for cylindrical and rectangular tube is clearly depicted in Figure 8 to Figure 11. The investigation is unable to show a clear discrepancy between both methods in term of the collapses starting point. Therefore, one shall assume that the numerical results have a good capability to predict correctly the collapse starting point. Based on literature study, the starting point of the collapse deformation is mainly subjected by the geometrical change in elastic and initiation of plastic deformation, the accuracy shape of the tube, and other experimental conditions (Yamashita, Kenmotsu, & Hattori, 2012).

2.5 Deformation Mode

Deformation mode is the type of collapsing behavior of the thin walled tube when it is subjected under axial crush situation. Deformation mode are categorized into two main types; concertina and diamond mode. However, in certain condition both types of deformation mode can be occurred concurrently. Based on the results presented in Table 5 and Table 6, which clearly shown that there is a slight difference of deformation mode between experimental and numerical results. The rectangular tube and cylindrical 1.0mm cases have shown a clear identical deformation mode compared to experimental observation. However, the cylindrical 1.5mm tube only managed to show a slight similarity where it is only able to perform the concertina deformation mode without any diamond mode behavior. This observation inconsistency is possibly due to welding process that effect on the experimental test samples which is highly influenced by the deformation mode behavior. Clear observations on this deformation mode behavior are depicted in Figure 8 to Figure 11.

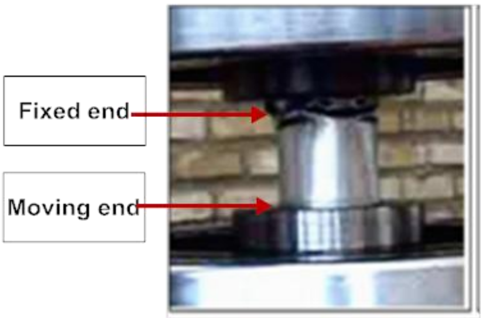

Figure 8: Specimen of Cylindrical 1.5 mm thickness during loading (Alavi Nia & Haddad Hamedani, 2010).

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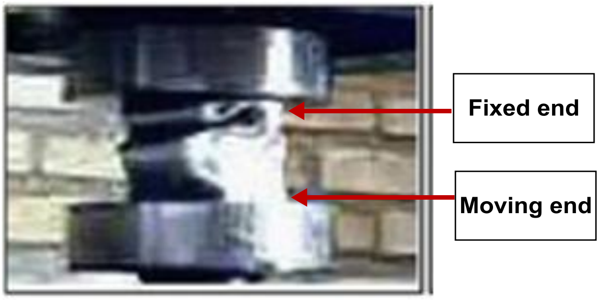

Figure 9: Specimen of Rectangular 1.5 mm thickness during loading (Alavi Nia & Haddad Hamedani, 2010).

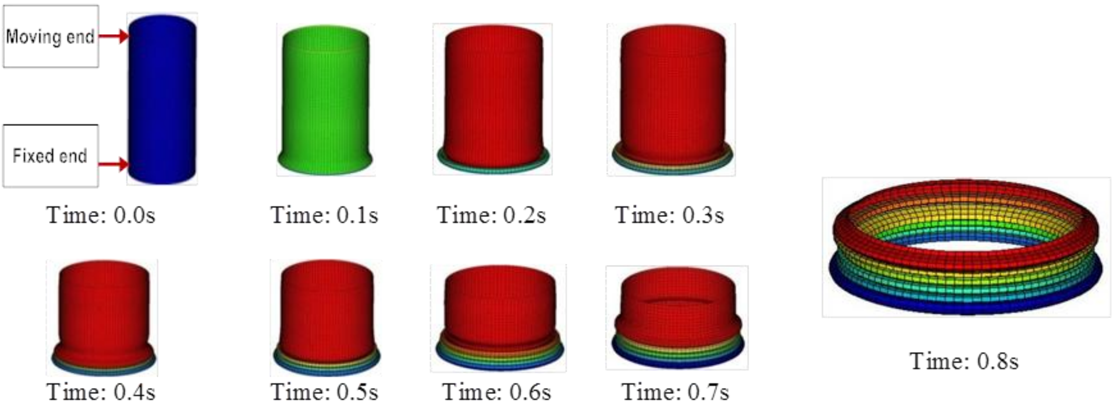

Figure 10: Crush pattern of Cylindrical 1.5 mm thickness tube at different time step.

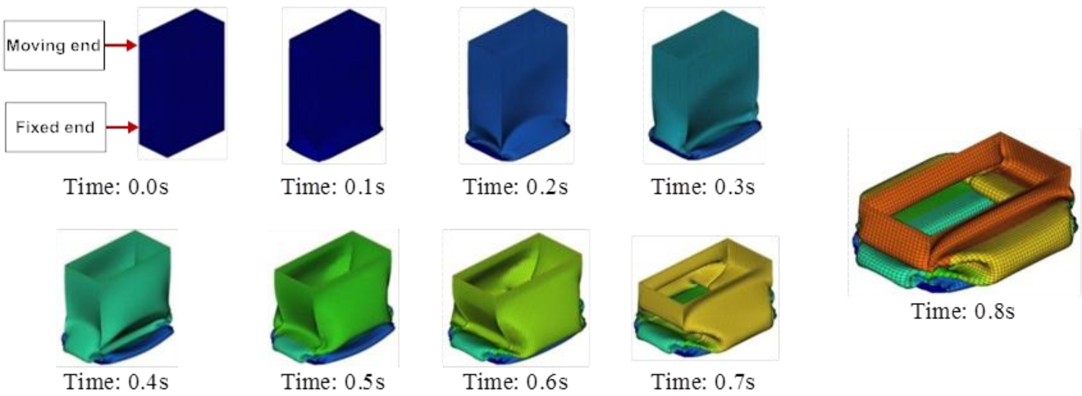

Figure 11: Rectangular 1.5 mm thickness tube at different time step deformed as concertina and diamond mode.

3. CONCLUSION

Experimental investigation procedures always contribute into a complicated process with huge amount of cost is wasted on specimen preparation perfection. Emerging of advance numerical solution has provided a significant option in order to simplify the investigation process and enhance the understanding of this crashworthiness behavior. Therefore, current works have been done based on finite element method in HyperWorks to perform a quasi-static axial crush on selected thin walled tube structures. The cylindrical (1.5 mm and 1.0 mm thicknesses) and rectangular tube (1.5mm thickness) tubes made from aluminum alloys Al

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3003 H12 are chosen and purposely to follow previous experimental works. The verification tasks are evaluated based on quantitative (energy absorbed and crushing length) and qualitative (collapse mode and collapse starting point) criteria. Verification results have shown that current numerical method has a high capability to predict a good correlation results compared to experimental data. Both methods agree well in terms of energy absorption, crushing length and collapse starting point. However, there is also a slight discrepancy observed in cylindrical 1.5 mm deformation mode behavior. This is probably due to welding element during the preparation of experimental test samples which is highly influenced by the deformation mode behavior.

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