ANALYSIS OF SPOT-WELDING PITCH ON TOP HAT STRUCTURE AGAINST CRASHWORTHINESS CRITERIA

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ABSTRACT

The application of spot-welding in the automotive industry, especially the electric-based vehicle frame structure, has been optimized to meet passenger and battery compartment safety factors. The present numerical study of the electric-based vehicle frame structure with the top hat cross-sectional model validated the experimental results of reference, which then modified the spot-welding pitch to determine the crashworthiness effect and criteria. The numerical simulation results show that reducing spot-welding pitch in vertical direction can increase energy absorption (EA) by 1.70% - 9.91%, while bringing spot-welding pitch closer to the flange's outer edge can reduce its maximum force (Fmax) by 8.11% - 21.67%.

Keywords: Spot-welding; Top Hat Structure; Crashworthiness; Numerical Simulation; Electric Vehicle.

INTRODUCTION

The trend of environmentally sustainable vehicles is generating electric vehicle technologies that are supposed to overtake internal combustion-based vehicles. However, the development of electric vehicles is concerned with the safety factors for occupants and the battery compartment that could explode when an accident happens [1]. The safety factor of electric vehicles cannot be distinguished from the structural design of the joints of the vehicle frame.

The spot-welding in plate joints on vehicle frames is very dominant and still being carried out, even though there is a new plate connection method by combining lancing and shearing processes to assemble the crash box as an energy absorber due to frontal collision [2]. Considering the strength and lightness of vehicle frame structures, especially electric-based vehicles, is an important factor for the automotive industry in choosing spot-welding. It has been studied to find the number and layout of spot-welding on vehicle frame structures to balance structural performance and production costs [3] [4].

The thin-walled structure with a top hat cross-section is a simple model of frame components in a vehicle has been investigated for crash worthiness effects [5-7]. In a parametric study using finite element method, Dimas [8] modelling beam elements and solid elements as spot-welding with the ratio of the spot-welding pitch to the half folding length of the top hat can affect the crashworthiness characteristics. It also varies the length of top hat flange applied to the S-rail structures [9].

In the end, the purpose of this present study is to determine the effect of vertical and horizontal spot-welding pitch on energy absorption (EA), maximum force (Fmax), average force (Fmean) so that it can consider the application of structural design to electric-based vehicle frames, especially the top hat-shaped frame structure.

METHODS

This numerical simulation is based on an experimental study from reference [10], then the top hat geometric modelling can be seen as in **Figure 1** with detailed dimensions in **Table 1.** While the materials also used refer to references [10] are mild steel FEE355.

An answer to this study aims to modify the spot-welding pitch both parallel (p) and perpendicular (x) direction of the axial impact to determine crashworthiness characteristics. As a reference for that, the spot-welding pitch in the parallel direction of the axial impact called the vertical pitch (p1, p2), and the spot-welding pitch in the perpendicular direction of the axial impact, called the horizontal pitch (x1, x2, x3), where the value of horizontal pitch measured from the edge of outer flange. Details of the value of spot-welding pitch can be seen in **Table 2**.

In contrast to the numerical simulation in the reference [10], which uses the LS-Dyna software, but as seen in **Figure 2.** numerical simulation of this study uses a quasi-static explicit time integration ABAQUS by modelling the type of shell element S4R on the top hat with mesh size of 2x2 mm and R3D4 in the section. Impactor and base support. As mentioned in the reference [11], spot-welding has used the rigid-node model as the best model for modelling spot-welding contacts.

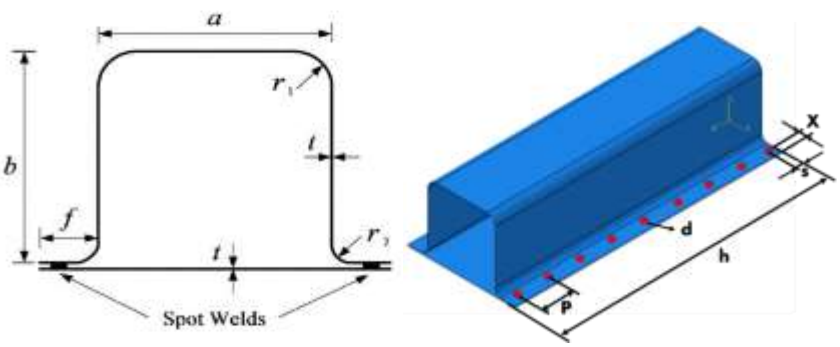

Figure 1. Geometry of top hat cross-section [10]

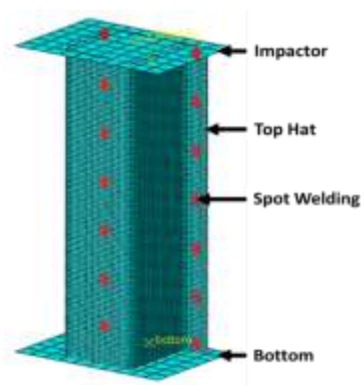

Figure 2. Numerical simulation model.

Table 1. Dimension detail of top hat.

Wall Thickness t (mm)	Width a (mm)	Width b (mm)	Height h (mm)	Flange f (mm)	Inner radius r_1 (mm)	Outer radius r_2 (mm)	Edge spacing s (mm)	Spot-weld diameter d (mm)	Spot-weld spacing p (mm)
1.5	50	50	200	15	6	4	5.5	6	27

Table 2. Modification of spot-welding pitch.

Spot-weld spacing vertical p1 (mm)	Spot-weld spacing vertical p2 (mm)	Spot-weld spacing horizontal x1 (mm)	Spot-weld spacing horizontal x2 (mm)	Spot-weld spacing horizontal x3 (mm)
27	13.5	7.5	6	4.5

The simulation's crashworthiness criteria is extracted from the force-deformation curve to give the following equations, which are commonly described in various references.

Energy absorption (EA):

$$EA = \int_{0}^{\delta_{max}} F(\delta)d\delta \qquad (1)$$

Where F is instantaneous crushing force, δ is vertical displacement of impactor mass.

Average Force (Fmean):

$$Fmean = \frac{EA}{\delta_{max}} \qquad (2)$$

VALIDATION

The numerical simulation result in this study shows good agreement with experimental and simulation results conducted by [10]. In **Figure 3.** the force-deformation curve shows the peak force of the three tests shows a slight difference, the simulation test conducted by Song [10] is the highest at 113 kN, compared to the experimental test of 107 kN, while the simulation test in the current study is the lowest at 104 kN. If

it is related to the structural strength, it should be that both simulations and experimental tests show the same results, this difference could be that the simulation test parameters cannot be close to the experimental test parameters due to geometric imperfections, strain rate of material properties, discretization, contact model, etc. Whereas in **Table 3**, the average force (Fmean) results show that the error result between the simulation of present study and experimental is 5.85%, this value is better than the simulation and experimental results conducted by Song [10] which is equal to 13.37%.

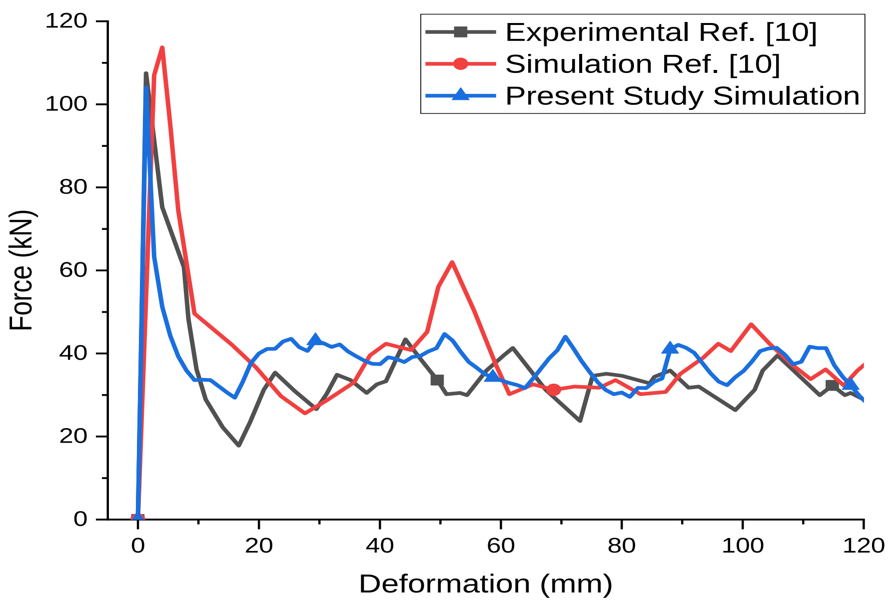

Figure 3. Force-deformation curve of experimental and simulation.

Table 3. Average force (Fmean).

Experimental (kN)	Simulation (kN)	Present study Simulation (kN)	Error experimental-simulation (%)	Error experimental-present study simulation (%)
36.20	41.04	38.32	13.37	5.85

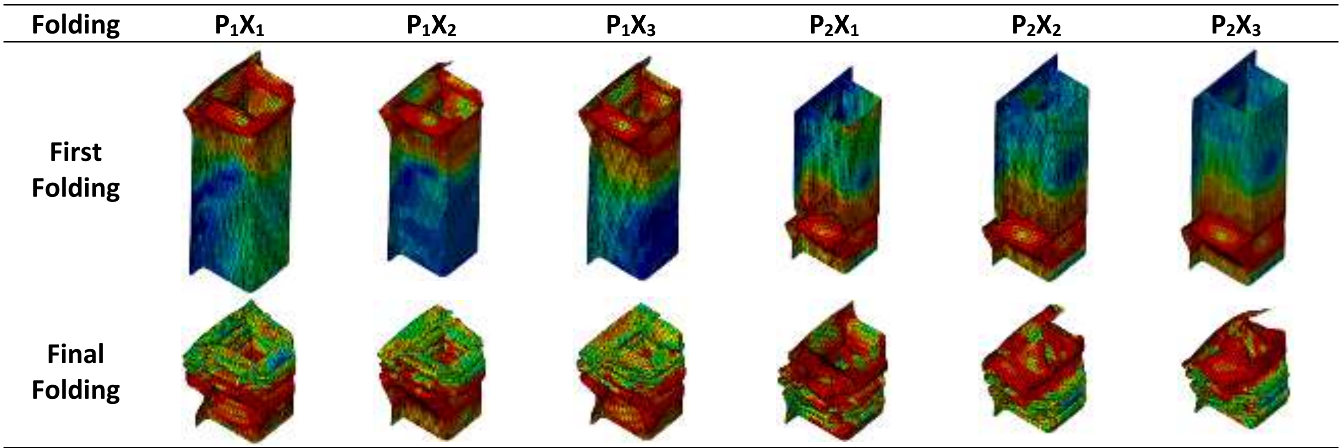

Figure 4. First and final folding of top hat structure.

RESULTS AND DISCUSSION

The simulation results in **Figure 4** show that with a spot-welding pitch (P1) of 27 mm, the first folding starts at the top of the top hat. Whereas at the spot-welding pitch (P2) of 13.5 mm, the first folding starts at the centre of the top hat structure. This shows that the tighter the spot-welding pitch will change the first folding location although it can be ascertained that the folding mode's shape is asymmetric as mentioned in the reference [8].

Specifically, **Figure 5** shows that from the simulation results between P1X1, P1X2, and P1X3, different shapes in the first folding, which P1X1 experiences the opposite folding direction, the top hat looks open, while on P1X2, P1X3 has a unidirectional folding so that not open. From the results, the construction of spot-welding that is closer to the edge of the flange will create a perfect direction of the folding and allow the decrease in Fmax.

In the curve of **Figure 6**, there is a significant difference between the spot-welding pitch model P1 and P2, where the curve shows that for P1 after the maximum force occurs, the curve tends to slope at the height of 44 kN and to reach the second peak the deformation distance is 16 mm. In comparison, for P2, after the maximum force of the curve height is more than 60 kN and the second peak distance of the deformation distance is 40 mm, almost twice the deformation distance of the P1 model.

The detailed values in **Table 4** show that the spot-welding pitch P1 has EA, Fmax, Fmean smaller than the spot-welding pitch P2. This condition is also same as the reference condition [8], although Tarigopula [12] states that the amount of spot-welding, which means the pitch of spot-welding, does not have much effect on the value of EA, Fmax and Fmean.

In more detail, the effect of horizontal spot-welding distances X1, X2, and X3 is that the closer the spot-welding is to the flange's outer edge, the lower the value of EA, Fmax, and Fmean

Table 4. Value of EA, Fmax, Fmean for each spot-welding pitch

Spot-welding Pitch	EA (kJ)	Fmax (kN)	Fmean (kN)
P1X1	4.62	104.03	38.32
P1X2	4.18	95.86	34.73
P1X3	4.12	81.48	34.24
P2X1	4.70	129.41	39.22
P2X2	4.64	122.25	38.64
P2X3	4.36	118.92	36.32

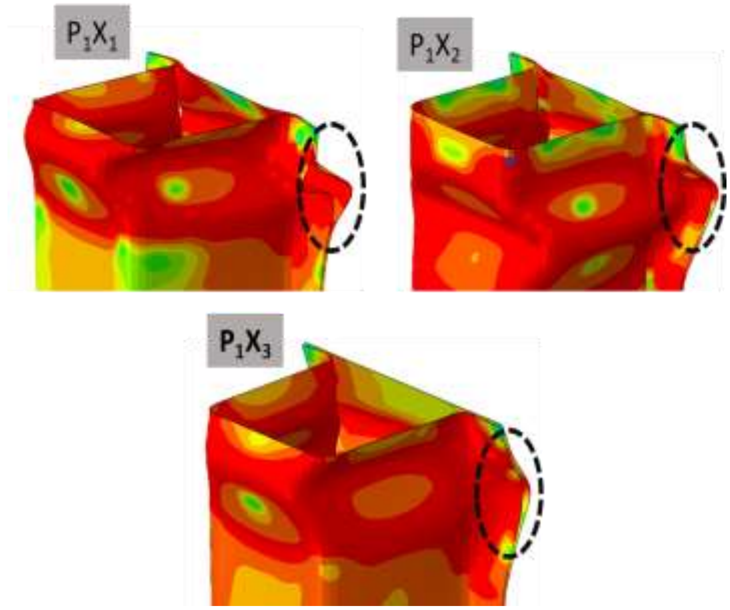

Figure 5. First folding phenomena of top hat.

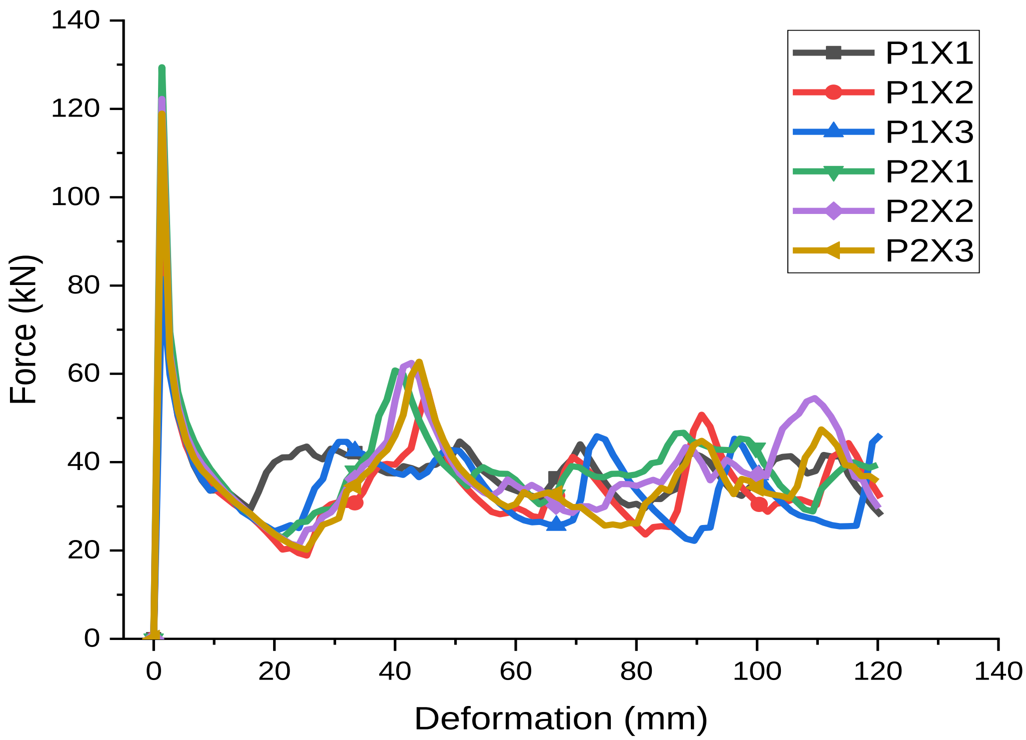

Figure 6. Force-deformation curve for each spot-welding pitch.

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CONCLUSION

Numerical simulations have been carried out on experimental and simulation results in reference [10] with acceptable results with an error of 5.85%. Meanwhile, the spot-welding pitch investigation found that reducing the spot-welding pitch vertically can increase the value of the crashworthiness criteria. This is related to the theoretical of half wavelength (H) that should occur in the top hat structure studied by White [13]. where the first folding follows the value of half wavelength (H)

Modifying the spot-welding pitch horizontally can reduce the value of the crashworthiness criteria and the modification that is often used, namely by using a crush initiator. This can be an input for further research to combine the pitch between spot-welding and crush initiator to obtain optimum crashworthiness criteria.

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First Author and Second Author have contributed equally to this work to design the model and the computational, numerical framework and analysed the data. All authors contributed to the final version of the manuscript.

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