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Energy Absorption Characteristic of Compress-Expand Tensile Mechanism Using Finite Element Analysis.

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Abstract. Thin-walled tube was applicable as energy absorption in impact structural. Deformation ideally flows along tube's axis in compression direction resulted plastic deformation. The deformation required external energy which taken from excessive source. Limitation of thin-walled tube was at collapse direction flows only in compression condition parallel to tube axis. Distortion of direction will trigger unstable collapse which reduce and blocked deformation flow. In real condition it is difficult to create perfect collapse deformation due to misalignment of flow. Compress-expand thin walled tube has wide stable area of collapse deformation compared with several tubes in compression direction. This research introduces conversion mechanism to thin-walled structure to adapt tensile direction which release from its service limitation. Tensile mechanism which called as tensile crash box using compress-expand cylindrical thin-walled tube consist of three main parts are able to absorb energy of deformation in tensile direction. Result from finite element analysis of tensile crash box was obtained that geometric parameter of compress-expand tube was highly influenced to energy absorption of tensile crash box.

Keywords: compress-expand tube, tensile mechanism, energy absorption

1. Introduction

Thin walled tubes have many functions as structural frame in wide industrial application. It has advantage in load carrying capacity and low weight [1]. One example of application is at automotive industry using thin walled structure as body part to reduce weight of vehicles [2]. Ability of thin walled tube obtains as resistance in bending and axial compress behaviors [3]. External load caused deformation and led to cracks and buckling at certain area made the energy is not absorbed by the permanent plastic deformation of the body [4].

Thin walled structures consists of many shape for different purposes, supporting structure usually assembly of bars or kind of tubular tubes [5]. Furthermore many researches on characteristic of tubular tube were investigated. Rectangular tube was found as pillar in cab frame has specific deformation type. Those tubes withstands buckling load due to bending and was influenced by cross sectional geometric parameter (thickness and width) of tube [6]. Approximation of deformation mode of rectangular tube was modeled as kinematic approach [7] and [8]. Another research investigation on cylindrical tubes due bending also showed that behavior of buckling was influenced by geometric parameter (thickness and radius) of tubes [4] and [9]. Behavior of tubular tubes also investigated base on axial loading, rectangular



tube has specific collapse mode under axial loading which stable collapse condition was nearly closed to unstable region [10]. Comparison of many tubular tubes under axial loading was further investigated and showed that cylindrical tubes tend to produce stable collapse condition [11].

The method to verify deformation of tube is conducted similarly to the actual situation becomes the most basic comprehensive evaluating performance. However its repeatability is poor and needs large resources [12]. Computer simulation to verify deformation of tubular tube in structural design help to overcome the problem in real experiment test [13]. Finite element analysis performed analysis and imitate non-linear boundary condition of the problem [14] and [15].

This study focus on investigate the deformation and energy absorption on tubular tube under axial loading and compare with various shape of tube. A new mechanism to convert axial loading direction from compress become tensile also introduce in this research. The mechanism using compress-expand tubular tube which consist of three main parts was assembly as new mechanism called tensile crash box which installed as integral part inside the structure. Tensile crash box help to expand ability of compress-expand tubular tube in absorb energy not only in compression but also tensile. Finite element method was performed in this study using commercial software MSC Marc to produce simulation and analysis of tensile crash box.

2. Finite Element Model of Study

Tubular tube model was modeled as quadrilateral element type. Material properties are considered as isotropic elastic-plastic. Work hardening of material follows bilinear isotropic hardening in uniaxial stress. Stress-strain relationship of material according to bilinear law is assumed according to equation (1) and (2).

$$\sigma = E \times \varepsilon \quad \left[\varepsilon < \frac{\sigma_y}{E \times \varepsilon} \right] \quad (1)$$

$$\sigma = \sigma_y + E_h \left(\varepsilon - \frac{\sigma_y}{E} \right) \quad \left[\varepsilon > \frac{\sigma_y}{E \times \varepsilon} \right] \quad (2)$$

Detail of material properties of tubular tube are listed in Table 1. Figure 1 shows detail parameter of compress-expand tube. Parameter of compress-expand tube can be seen in Table 2.

Table 1. Material properties of tubular tube

Elastic	E= 205.9 [GPa] $\sigma_y = E/1000$ [MPa] $\nu = 0.3$
Plastic	$E_{h1} = E/100$ [GPa]; $E_{h2} = E/20$ [GPa]

Table 2. Compress-expand tube parameter

Properties	Value
Thickness (t) [mm]	1.0; 2.0; 3.0
Radius (R) [mm]	20.0; 30.0; 40.0; 50.0
Total length (L) [mm]	200.0
Ratio ($L_0 : L_1 : L_2$)	1 : 2 : 1
Angle (α) [$^\circ$]	30 $^\circ$

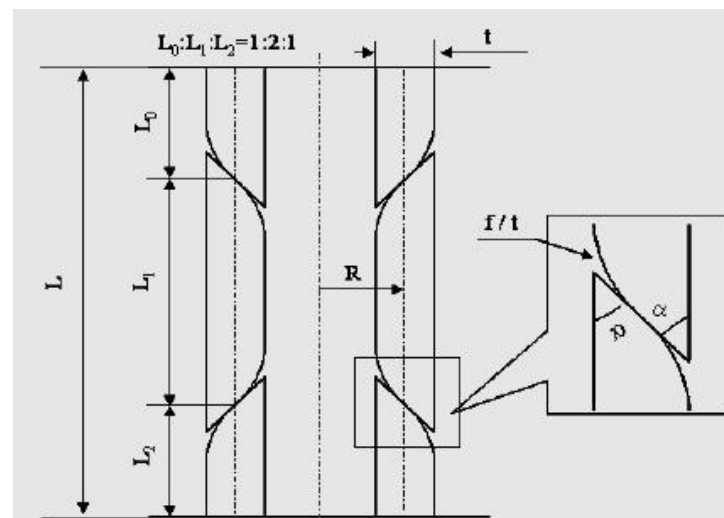


Figure 1. Compress-expand tube parameter.

Finite element type of tubular tube is 3D shell type. Meshing size is 5x5 [mm]. MSC Marc register this finite element model as ID class Quad 4, ID type 75. Simulation process considered as static condition. Total displacement is 100 [mm], and incremental step is 2 [mm]. Rigid body acts as a load applicator to tensile crash box. Simulation will stop when 1 cycle time is complete in 100 [mm] within 50 steps. Outputs of simulation are load in [kN] and displacement in [mm].

3. New Mechanism of Tensile Crash box

Tensile crash box consist of several part and its main core was compress-expand tube. The mechanism support energy absorption in tensile direction. Finite element model of tensile crash box is arbitrary hexahedral, where 1 element consists of 8 nodes iso-parametric. Meshing size is 5x5 [mm]. MSC Marc registers this finite element as ID class hex 8, ID type 7. Figure 2(a) shows Load – Displacement curved of various tubular tubes in axially compress condition and Figure 2(b) shows comparison deformation characteristic mode of several tubular tubes. Stable condition obtain at compress-expand tubular tube. The limitation of this tube is absorption direction only at axial compress condition. The advantage of deformation at compress-expand tube consider as core of tensile crash box and help to expand its ability in tensile direction, see Figure 3.

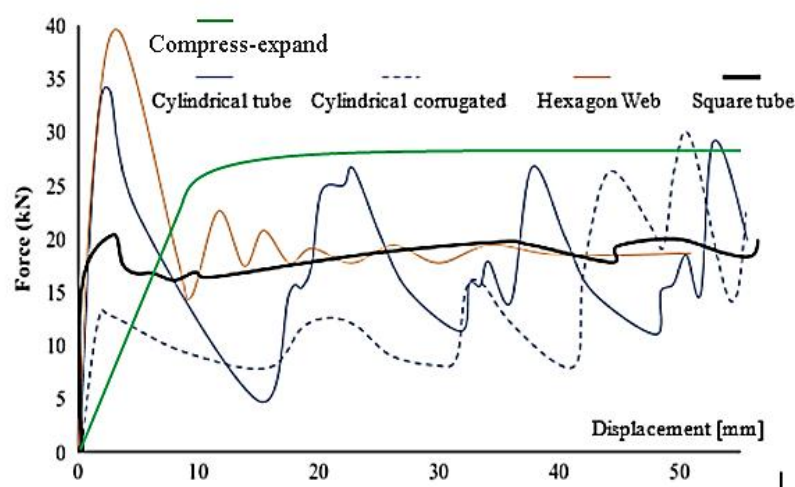


Figure 2(a). Load – Displacement curved of various tubular tubes in axially compress condition.

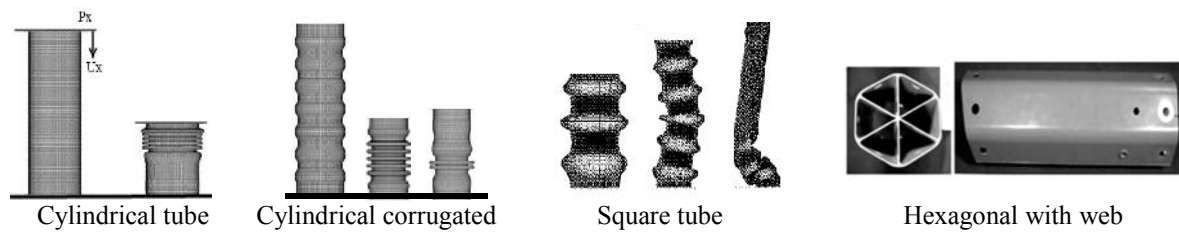


Figure 2(b). Shape of various tubular tube.

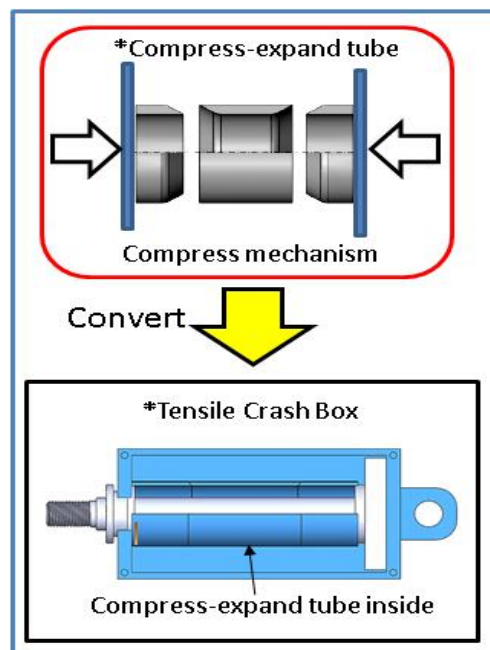


Figure 3. New mechanism of tensile crash box.

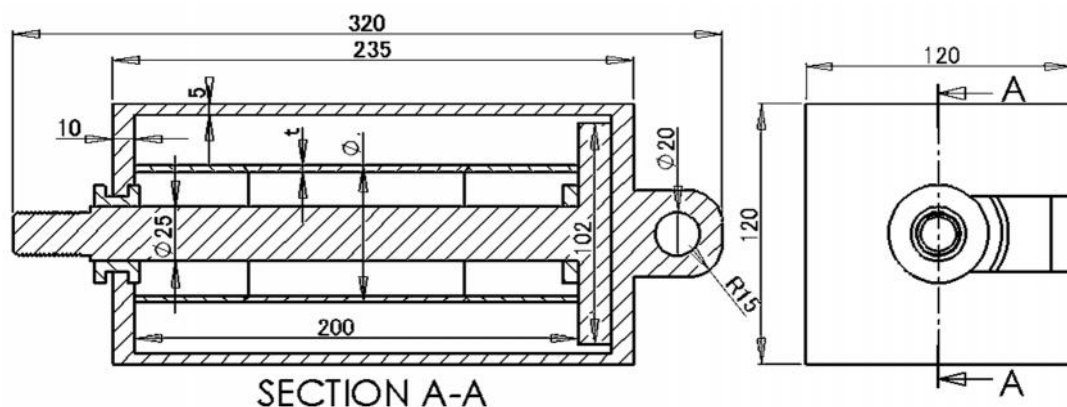


Figure 4. Design of tensile crash box (half section view).

Compress-expand tube stiffness material is lower than tensile crash box material. The purpose is to assure that deformation and energy initially absorb by those compress-expand tube rather than tensile crash box body. While on tensile crash box higher stiffness is to reduce deformation at the body. Material properties of tensile crash box see Table 3 and design of tensile crash box see Figure 4.

Table 3. Tensile crash box material properties (exclude compress-expand tube)

Elastic	$E = 400$ [GPa] $\nu = 0.284$ $\sigma_y = E/500$ [MPa]
Plastic	$E_h = E/100$ [GPa]

4. Analysis of Finite Element Results

Simulation of tensile crash box with compress-expand tube thickness from 1 [mm] until 3 [mm], radius from 10 [mm] until 50 [mm], and hardening ratio (E_h/E) 1/20 and 1/100. Result of simulation load-displacement curve of tensile crash box shown at Figure 6 until Figure 8 for $E_h/E=1/20$ and $E_h/E=1/100$. When the tensile load applied to tensile crash box, pressure jig will moved along with tensile direction and push the compress-expand tube inside the chamber. Deformation occurs at tube required energy to plastically deformation, this mechanism able to absorb energy at tensile direction (Figure 5). Compress parts penetrate inside the expand part and move stable, this condition consider as stable deformation until the both edge of compress parts contact each other and this condition becomes unstable. Due the design of compress-expand tube has length ratio (1:2:1), stable condition of absorption energy only obtain at half of total length of tube.

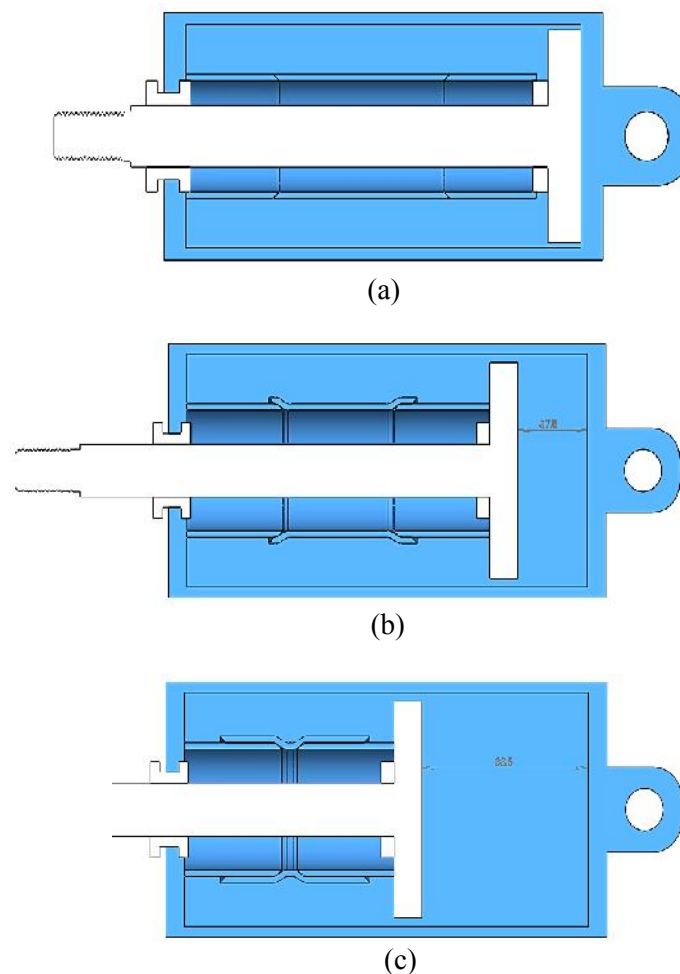
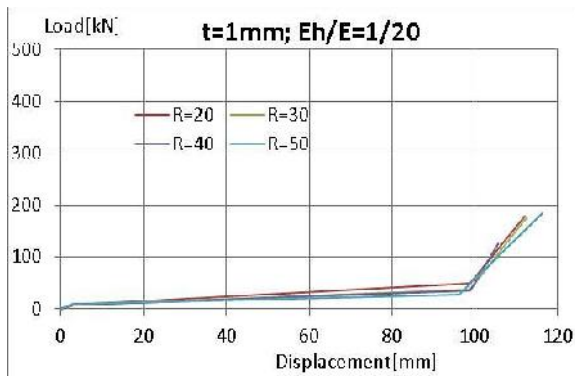
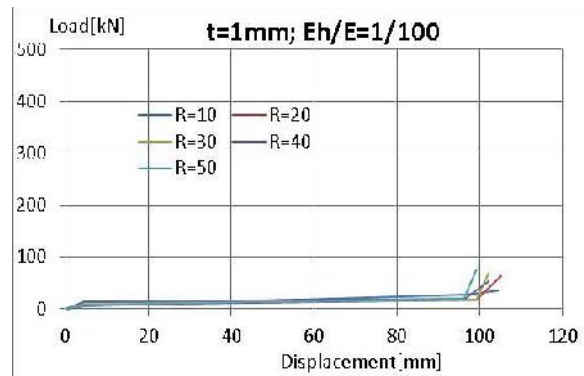


Figure 5. Tensile crash box (a) at initial condition (b) at displacement 37.5 [mm] (c) at displacement 88.5 [mm]

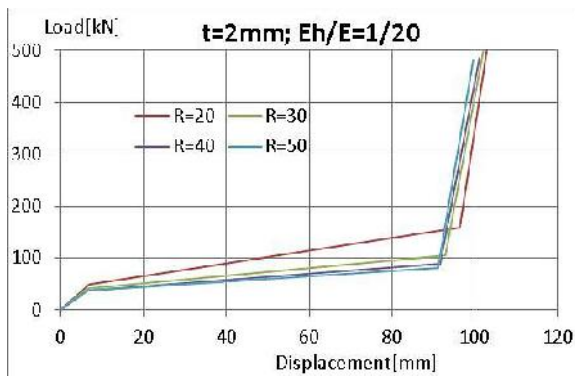


(a). Load-displacement curve ($t=1$ [mm], $E_h/E=1/20$).

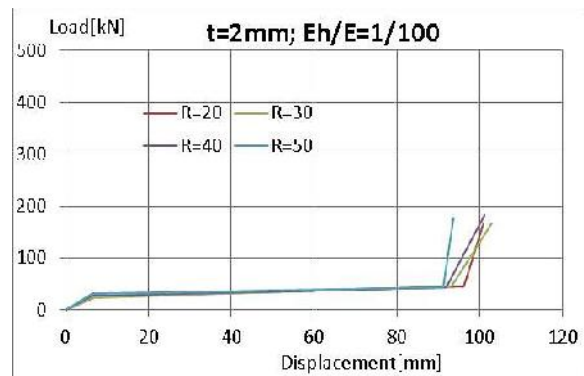


(b). Load-displacement curve ($t=1$ [mm], $E_h/E=1/100$).

Figure 6. Load-displacement curve of tensile crash box (compress-expand $t=1$ [mm]).

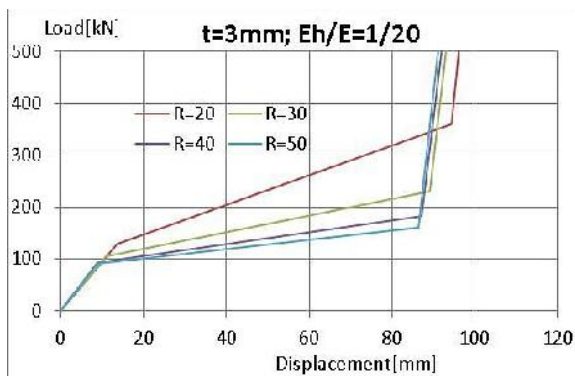


(a). Load-displacement curve ($t=2$ [mm], $E_h/E=1/20$).

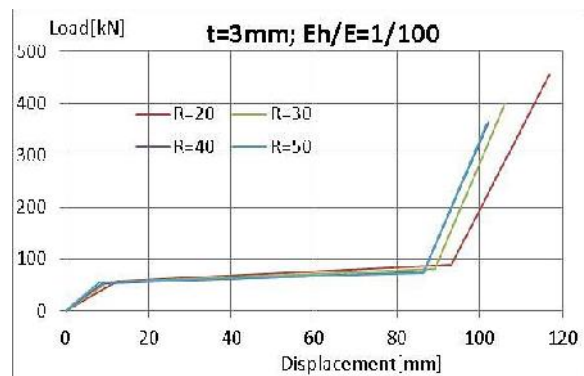


(b). Load-displacement curve ($t=2$ [mm], $E_h/E=1/100$).

Figure 7. Load-displacement curve of tensile crash box (compress-expand $t=2$ [mm]).



(a). Load-displacement curve ($t=3$ [mm], $E_h/E=1/20$).



(b). Load-displacement curve ($t=3$ [mm], $E_h/E=1/100$).

Figure 8. Load-displacement curve of tensile crash box (compress-expand $t=3$ [mm]).

The highest result of tensile crash box obtains at thickness condition of tube 3 [mm], radius 20 [mm], and $E_h/E=1/20$ (Table 4). And the lowest condition obtain at thickness 1 [mm], radius 40 [mm], and $E_h/E=1/100$. Unstable condition obtain when deformation of compress-expand tube inside the tensile crash box become not fully compressed and yielded to bending rather than compress condition. According to deformation shape of compress-expand tube, energy absorption only effective at maximum

half of total length (100 [mm]). More than half length deformation becomes unstable. Energy equation calculates only until approximately deformation occurs at half of total length of compress-expand tube.

Table 4. Result of simulation of tensile crash box using compress-expand tube.

Radius [mm]	Thickness [mm]	Energy [kJ]	
		$E_h/E=1/20$	$E_h/E=1/100$
10	1	unstable	1.94
20		3.96	0.94
30		2.94	0.79
40		2.71	0.58
50		1.83	1.09
10	2	unstable	unstable
20		10.28	2.10
30		5.80	2.09
40		4.68	1.53
50		4.05	1.25
10	3	unstable	unstable
20		20.41	3.23
30		10.98	2.61
40		7.78	2.14
50		6.18	1.79

Figure 9 shows that energy absorption of tensile crash box highly influenced by two parameters condition; they are thickness (t) and hardening ratio (E_h/E) of compress-expand tube. Radius of tube slightly influence at energy absorption, different radius showed almost similar energy absorption, otherwise different thickness level showed much different in energy. Lower hardening ratio showed lower energy absorption at same thickness and radius level, means that stiffness material of tube determines energy absorption of tensile crash box.

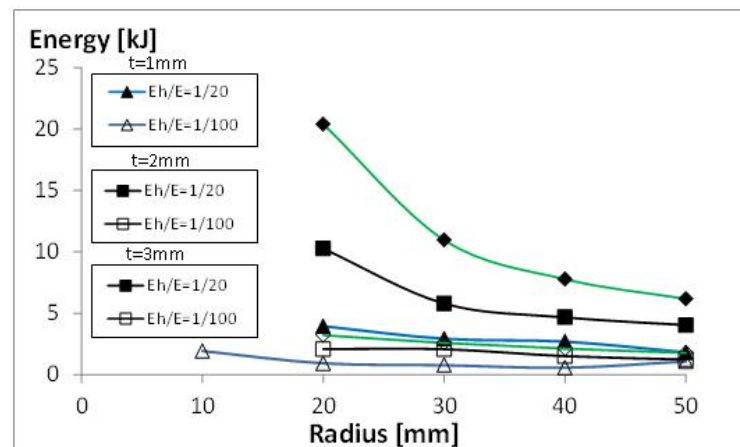


Figure 9. Energy – Radius curve of tensile crash box using compress-expand tube.

Important results of this research that determined energy absorption of tensile crash box are thickness level (t) and hardening ratio of compress-expand tube (E_h/E). Deformation of tube at radius 10 [mm] at thickness 2 [mm] and 3 [mm] at both hardening ratio ignored due to deformation of compress-expand tube become unstable, and only at thickness 1 [mm] hardening ($E_h/E=1/100$) is considered stable.

5. Conclusions

The study of new mechanism of energy absorption is investigated using finite element analysis. The new mechanism introduce tensile crash box as energy absorption using compress-expand tube model to absorb energy at tensile direction. Research conclusions of this study are following:

1. Compress-expand tubular tube was ideal as core of tensile crash box due to its stable deformation characteristic. Tensile crash box could expand ability of compress-expand tube to absorb energy not only at axially compress direction but also tensile direction.
2. Parameters that determined energy absorption of tensile crash box are thickness level (t) and hardening ratio (E_h/E) of compress-expand tube.
3. Radius of compress-expand tube was small influence at energy absorption of tensile crash box and tent to ignored than others two previous parameters.

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