ENHANCEMENT OF ENERGY ABSORPTION OF THIN WALLED HEXAGONAL TUBE BY USING TRIGGER MECHANISMS

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Abstract

This paper presents the using of non-linear finite element simulations on the crash behavior and to enhance the energy absorption of the thin walled hexagonal tube subjected to dynamic loading and to decrease the peak load to ensure the occupants safety during front collisions. Triggers have been applied to the thin walled hexagonal tube. Three trigger geometries have been applied circular, rectangular and elliptical geometry. Three type of trigger distribution already have been studied. The positions and the size of triggers are also investigated. It was found that the 10% per cent reductions with elliptical trigger revealed the best choice, it shows enhancing in energy absorption about 8 percent and CFE about 13 percent and decreasing in peak force by 2.5 percent.

Index Terms: *energy absorption; Finite element modeling; trigger*

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1. INTRODUCTION

Human life is priceless, so researchers and manufacturers of the automobile industry emphasize deeply into the vehicle occupant safety [1]. To minimize the casualties there is a need to absorb as much as possible of the kinetic energy caused by collisions [2-4]. According to the 2004 World Health Organization report [5], 3000 people are killed daily due to road accidents these statistical ensured that the vehicle crashworthiness should continue in both academic and industrial researchers worldwide. [6-12]. Many studies [13-15] have done on the thin walled tubes, these studies summarized that the tubes under dynamic loading absorb more energy than quasi-static.

Generally the progressive buckling almost shows several collapses like axisymmetric (concertina), non-axisymmetric (diamond), mixed (concertina and diamond) and Euler-type buckling. Energy absorption depends on the collapse mode, and more energy absorbed in a progressive buckling than in an Euler-type buckling [15]. The applied of reductions (trigger) is one of the way that enhance the energy absorption of the thin walled tube and decrease the peak force [18-20].

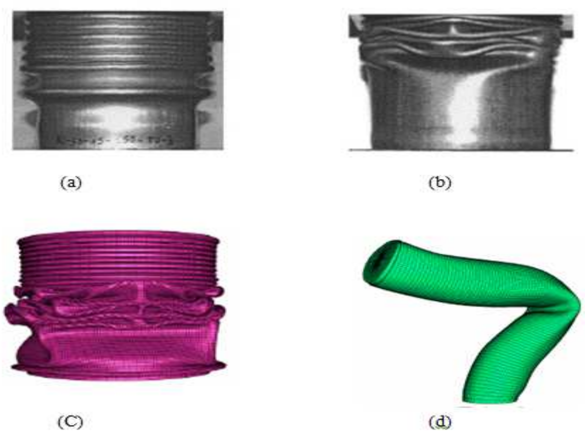

Fig 1 types of folding mode (a) axisymmetric (concertina), (b) non-axisymmetric (diamond) [16], (c) mixed (concertina and diamond), (d) Euler-type [17]

The triggers used in this study were circular, rectangular and elliptical reductions and the tubular structural material was modeled as A36 steel (mild steel).

2. CRASHWORTHINESS PARAMETERS

2.1 Crush Force Efficiency

The crush force efficiency (CFE) can be defined as a mean crushing force (Pmean) divided by peak crushing load (Pmax) as follows.

$$\text{CFE} = \frac{P_{mean}}{P_{max}} \quad (1)$$

The crush force efficiency is very important parameter used to evaluate the performance of energy absorbing structures [22]. A value of unity of the energy absorber member represents an ideal energy absorber which represents a value of the crush force efficiency corresponding to the constant load-displacement curve [23], while the low values indicate happening of greater peaks of force during crushing [24]. Low values of crush force efficiency means high peaks force which leads to increasing in acceleration and potential damage to the passengers during frontal impact which must be avoided. CFE is related to the structural effectiveness and it is an important measure for car structure to know how efficient it is [25]. A high value of CFE is desirable and must be maximized and this can be obtained by decreasing the peak load. Introducing trigger mechanism is usually used to decrease the peak load and thus increases the CFE value. G.M. Nagel, D.P. Thambiratnam, showed that the crush force efficiency can be increased by increasing the wall thickness of the tube [26].

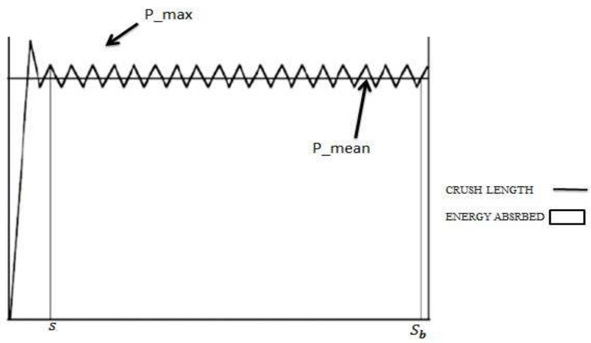

Fig 2 ideal load-displacement curves [21]

2.2 Energy Absorbers

The aim of energy absorbing (longitudinal member) is to convert the kinetic energy to other form of energy when it deform. Another objective of the longitudinal members is to reduce the peak reaction force associated during impact since greater peak values can cause large deceleration values that probably cause irrecoverable brain damage [27]. The energy absorption performance can be calculated from the load-displacement curve. Energy absorption EA is denoted as an integration of a load-displacement curve as below

$$\text{EA}=\int_0^{\delta b} p.\, d\delta \quad (2)$$

When p is an instantaneous crushing load, δb is the length of crushing specimen. From the equation (2)

$$\text{EA}=\int_0^{\delta b} p.\, d\delta = P_m\,(\delta b - \delta i) \quad (3)$$

Where P_m is the mean crushing load, δi is the initial length of the crushing specimen. Ideal energy absorption could achieve a maximum force and keep it constant during the entire deformation length.

2.3 Trigger Mechanisms Trigger Position and Location

Enhanced of energy absorption of a tube can be obtained by applying a specific trigger in a proper position. On the other hand the trigger will decrease the high peak load required to start the first fold. The fold becomes regular and more stable. Since the hexagonal profile has six sides, it should define the position and distribution of these triggers. Different reduction percentages have been used to verify the best reduction one. Beside the reduction percentage, the location on which side of the hexagonal profile must be triggered is also defined. Since the hexagonal profile perimeter was 300 mm then each side has 50 mm. three types of trigger have been used rectangular, elliptical and circular triggers. The reduction percentage of each type of trigger was equal and the area of them was also equal to verify the trigger shape effect.

Three types of distribution have been used called first, second and third type. The first type was done on the circular shape. Six holes have been done on the hexagonal profile. For this type of distribution, the trigger holes were distributed on the hexagonal sides, so each side has one hole in the middle with reduction percentage of 10 percent. The circular diameter was 5 mm the total reduction was 30 mm for all sides. The second type of distribution represented as two holes together. The distributing of the holes was distributed as three pairs. So three of tube sides will be triggered while the other three will not, and the holes distributed alternately on the sides. The trigger side has two holes which distributed regularly the distances from the end to the center of circle and the distance between the circle centers are equal. The third type of distribution was represented as two pairs of circular triggers. Each pair has three circular holes. So just two side of hexagonal profile have been triggered. The triggered side then will be opposite and facing each other. The distances between each centers and the distance from the end to the nearest circular centers are equal. The figure 3 shows the three types of trigger distributions.

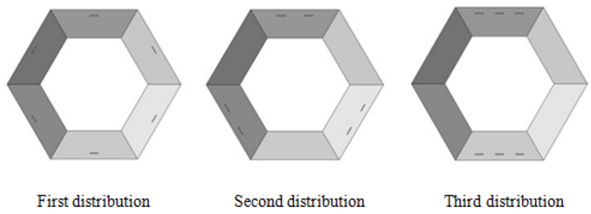

Fig 3 types of trigger holes distribution

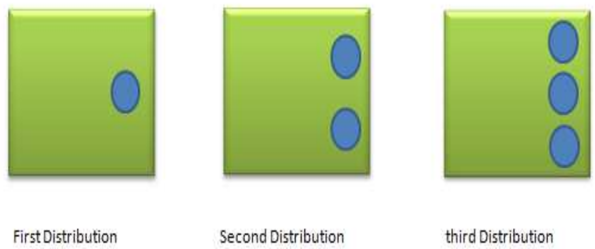

Fig 4 types of trigger holes distribution two dimension

Several distances have been studied to verify the best trigger position and to find the proper trigger distance. Trigger position denoted to the distance (d) from the front end of the hexagonal profile to the center of the trigger shape. The distances taken into consideration were 20, 30, 40, 50, 60 and 70 mm. The simulations was done have taken into consideration the profile thickness was 2 mm with the crash speed of 54 km/h and impact mass of 275 kg.

3. RESULTS AND DISCUSSIONS

3.1 Effect of Triggers on Force Level and Energy Absorption on the Steel

By applying weaknesses (trigger), it can be obtained more stable force along the deformed profile, reduce the peak force and enhance the energy absorption capability. Reducing force is one of crashworthiness demanded so keep the passengers safer by reducing the transferred force to them. Getting stable force is preferred to obtain more folding process so the energy absorption will increase and hence more impact energy caused by collisions can be dissipated.

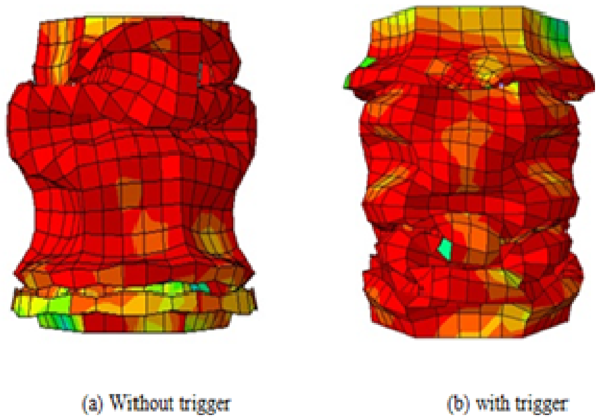

Fig 5 hexagonal profiles without (a) and with (b) trigger for steel

The energy absorption for both triggered and non-triggered profiles were compared as shown in figure 6. Non triggered profile is stiffer so it absorbs more energy at the beginning of deformation afterwards the triggered profile will absorb more energy and this may attribute to the more folding will generate because of the trigger.

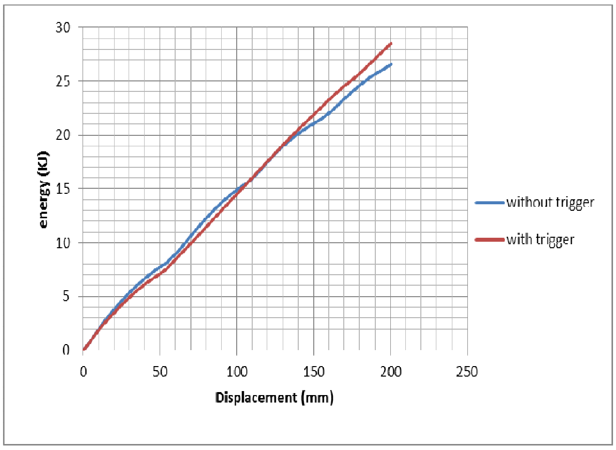

Fig 6 energy-displacement hexagonal profiles without and with trigger for steel

Lower peak force can be obtained by applying trigger as shown in figure 7 also by applying trigger the force level along the deformation length is more stable than non-triggered profile.

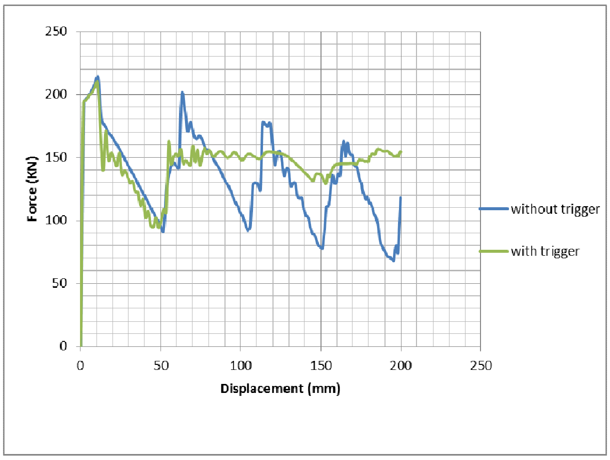

Fig 7 force-displacement hexagonal profiles without and with trigger

3.2 Trigger Position and Location

Weaknesses and trigger must be located in proper that obtained as much as possible lowering in peak force and increasing in energy absorption. At that position the more stable force level can be reached and fluctuating can be decreased. The best position for the trigger is when the first fold is formed. Six different positions have been taken to specify their effects.

3.3 Trigger Geometries

Circular, rectangular and elliptical trigger geometries have been studied. The simulations are done on the hexagonal profile with a rigid front end at 54 km/h. Simulations have been done on the triggered profile. Different shapes reveal different results. The most influence shape that affected both peak force and energy absorption will be taken as the best geometry.

3.4 Circular Trigger Distributions

Three different distributions have been implemented to select the best one. The distributions are shown in figure 8.

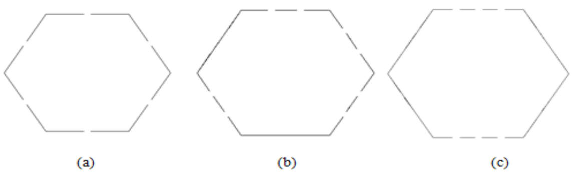

Fig 8 different distribution (a) first type (b) second type and (c) third type of distribution of steel material

The reduction percentages for all triggers were 10 percent since the hexagonal profile has a perimeter of 300 mm then the reduction percent will be 30 mm for all sides. Table 1 shows the simulations done on the hexagonal profile with circular hole triggers regarding the first type of distribution. The table included the effect of first distribution on the peak force, energy absorption and CFE. From the results shown in the table, it can be concluded that the first type of distribution has no significant effects on the parameters and these parameters reveal no influence by this type of distribution.

Table 1 effect of circular triggers with first type of distribution for steel

Criteria / Trigger distance	Energy absorption (KJ)	Peak force (KN)	CFE
Without trigger	26.6	2.14	59.8
20 mm	21.5	2.13	49.3
30 mm	21.8	2.12	50.5
40mm	22	2.12	50.5
50 mm	24.8	2.11	56.1
60 mm	22.8	2.13	53.5
70 mm	22.4	213	54.1

Tables 2 and 3 show the results obtained from simulations done with second and third type of distributions respectively. From the results obtained, it can be concluded that there were some increasing in energy absorption amount when the trigger position is 50 mm and some increasing in CFE value better than other distances. The second type of distribution at 50 mm distance reveals lower value in peak force than third one.

Table 2 effect of circular triggers with second type of distribution for steel

Criteria / Trigger distance	Energy absorption (KJ)	Peak force (KN)	CFE
Without trigger	26.6	2.14	59.8
20 mm	21.8	2.11	49.3
30 mm	21.7	2.11	49.7
40mm	21.5	2.11	49.5
50 mm	24.8	2.11	56.1
60 mm	23.6	2.11	53.8
70 mm	23.7	2.11	56

3.5 Rectangular and Elliptical Triggers

Rectangular and elliptical triggers have been applied on the hexagonal profile. Six different distances (position) were carried out on both. The trigger areas of all geometries were equals also the reduction percentages were equal. Both rectangular and elliptical triggers represented as the second type of distribution. So three alternating of hexagonal profile are triggered. The reduction percent was 10 percent of the whole perimeter. The trigger was represented as a hole in the center of the triggered side for both geometries. Tables 4 and 5 show the results obtained from simulations done with rectangular and elliptical triggers respectively.

Table 3 Effect of circular triggers with third type of distribution for steel

Trigger distance \ Criteria	Energy absorption (KJ)	Peak force (KN)	CFE
Without trigger	26.6	2.14	59.8
20 mm	22.12	2.12	50.5
30 mm	22.8	2.12	52.3
40mm	22.1	2.12	51.4
50 mm	24.7	2.12	55.7
60 mm	20.7	2.13	43.6
70 mm	22.7	2.13	53

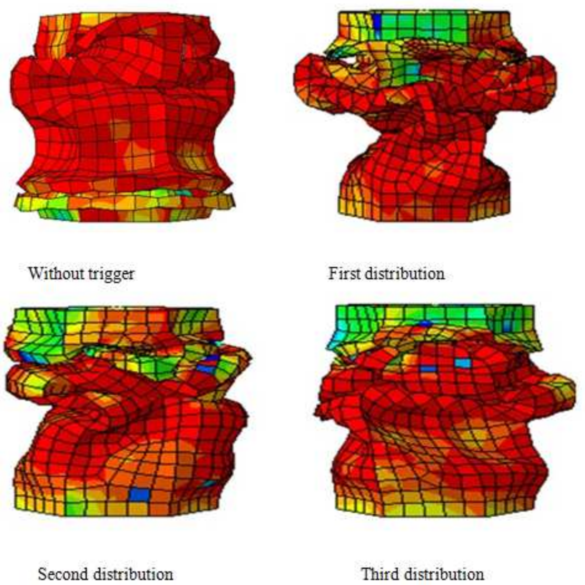

Fig 9 deformation profiles of non-triggered profile and circular trigger with different distribution for steel

From the results shown, it can be observed that the elliptical trigger at position 50 mm reveals the best choice. It offers increasing in energy absorption value about 8 percent and creasing the peak force by 2.5 percent, it also shows an enhancement in CFE value about 13 percent.

3.6 Determination of the Best Trigger Dimension

The purpose of the trigger is to develop the folding as much as could. Using small trigger reduction is not desired because the initial peak force does not reduce enough and the folding may not develop properly and get irregular fold. Unlike using large area trigger reduction causes decreasing in energy absorption and decreasing in stiffness and hence the bending resistance will be lower. Simulations were done using the hexagonal perimeter with 300 mm and 2 mm thickness. To specify the best trigger reduction percent, three different reduction percent have been used in addition to non-triggered profile of 0, 5, 10, and 15 percent. Figures 13 and 14 show the force and energy absorption levels. Table 6 shows the values of energy absorption, peak force and CFE.

Table 4 effect of rectangular triggers on the peak force and energy absorption for steel

Trigger distance \ Criteria	Energy absorption (KJ)	Peak force (KN)	CFE
Without trigger	26.6	2.14	59.8
20 mm	22.5	2.12	52.3
30 mm	22.6	2.11	53
40mm	24.6	2.11	57.8
50 mm	25.2	2.12	59
60 mm	26.8	2.12	62
70 mm	23.5	2.12	54.7

Table 5 effect of elliptical triggers on the peak force and energy absorption for steel

Trigger distance \ Criteria	Energy absorption (KJ)	Peak force (KN)	CFE
Without trigger	26.6	2.14	59.8
20 mm	24.58	2.11	56.4
30 mm	23.3	2.07	55.5
40mm	23.7	2.08	55.3
50 mm	28.7	2.09	67.5
60 mm	23.3	2.1	55.2
70 mm	23.5	2.07	55.5

Table 6 energy absorption, peak force and CFE values of hexagonal with different reduction percent for steel

Trigger type	Energy Absorption (KJ)	Peak force (KN)	CFE
No trigger	26.6	214	59.8
5% elliptical	25.3	214	55.5
10% elliptical	28.7	209	67.5
15% elliptical	22	203	54.5

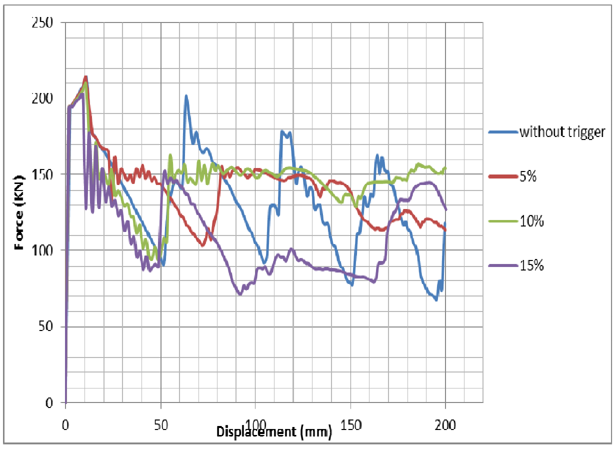

Fig 13 force-displacement levels of different reduction percent

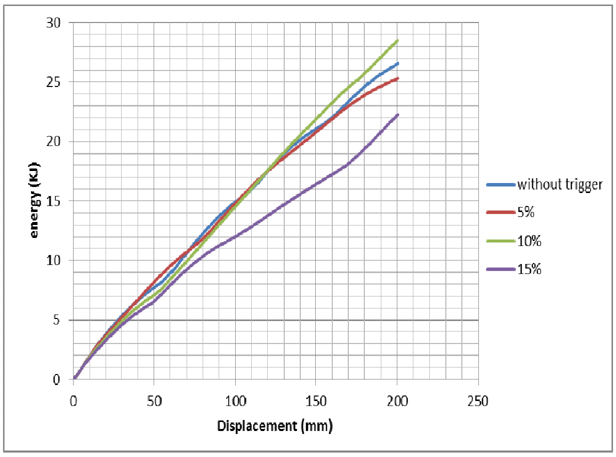

Fig 14 energy-displacement levels of different reduction percent

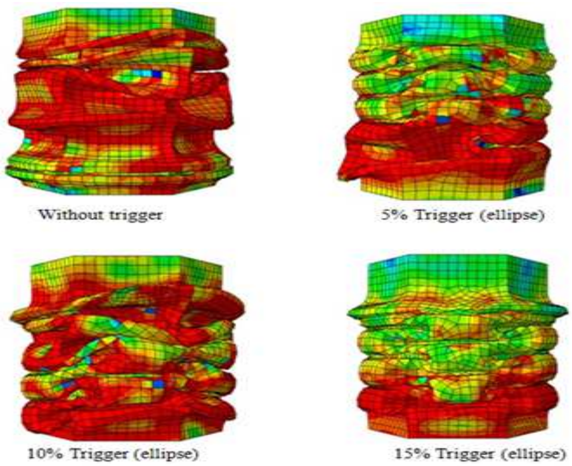

Fig 15 deformation profiles for different reduction per cent

CONCLUSIONS

Trigger which means to create weaknesses of tube to improve its performance in terms of energy absorption and crashworthiness. Different type of triggers gives different performance. To get the best qualification of the triggered tube, the trigger should be in a proper position with both specific geometry and reduction percent. Circular with different distribution, rectangular and elliptical geometries have been used in this study. The results show that the elliptical geometry reveal the best enhanced in energy absorption and CFE at the same time it offers lower in peak force and more regular folds. Six different positions of 20, 30, 40, 50, 60 and 70 mm also have been carried out. The results show that the position of 50mm was the best. Three reduction percent have been implemented of 5, 10 and 15 percent beside the 0 percent. The 5 percent shows the peak force still too high and the energy still at low level. The 15 percent shows deceasing in energy absorption and decreasing in peak force which may cause lowering in stiffness and hence lowering in bending resistance. The 10 percent reduction shows the best reduction percent it reveals enhancing in energy absorption about 8 per cent and CFE about 13 percent and decreasing in peak force by 2.5 percent.

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