IMPROVEMENT OF ENERGY ABSORPTION OF THIN WALLED HEXAGONAL TUBE MADE OF MAGNESIUM ALLOY BY USING TRIGGER MECHANISMS

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Abstract

This paper describes potentially the using of magnesium alloy as an energy longitudinal member used in crashworthiness applications. Since magnesium alloys are lighter weight material, they are preferred to use to decrease the environmental pollution and fuel consumptions. Non-linear finite element was used to simulate the crash behaviour of the thin walled hexagonal tube. The tube was subjected to both direct and oblique loading. Trigger mechanism was applied in this study. The aim of using trigger is to decrease the initial peak load and to enhance the energy absorption capability of the tube and also crash force efficiency. 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 and CFE about10 per cent and decreasing in peak force by 10 per cent too.

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1. INTRODUCTION

There is a high focusing on greenhouse gas reductions and improving fuel efficiency in the transportation sector. All car manufacturers, suppliers, assemblers, and component Producers are investing significantly in lightweight materials to obtain more market penetration by manufacturing components and vehicle structures made from lightweight materials. The single main obstacle in application of lightweight materials is their high cost. The weight reduction is still the most cost-effective means to reduce fuel consumption and greenhouse gases from the transportation sector. It has been estimated that for every 10% of weight eliminated from a vehicle's total weight, fuel economy improves by 7%. This also means that for every kilogram of weight reduced in a vehicle, there is about 20 kg of carbon dioxide reduction. [1]. However the reduction of the vehicle mass is preferred, it must be known that the fatality of occupants of the lighter vehicle is higher than the occupants of heavier vehicle in a collision [Advanced Automotive Technology 1995]. Magnesium alloy will take into consideration in this study as a light weight material.

Manufacturers and researchers are focusing on the occupant life safeties. [2]. Many studies have done regarding thin walled tubes which concluded that the energy absorption due to dynamic loading is higher than static loading. [3-12].

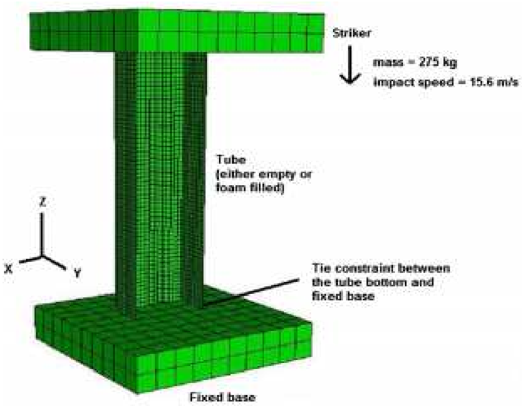

Figure -1- Frontal longitudinal thin wall structure [13]

2. CRASHWORTHINESS PARAMETERS

In general, when the tubes are subjected to dynamic load, several deformation modes can be obtained like concertina, diamond, mixed (concertina and diamond) and Euler-type mode modes. The amount of energy absorption depends on the type of deformation mode. More energy absorbed can be obtained in progressive mode than Euler-type [16]. Applying trigger can enhance the energy absorption of the thin tube, enhance crash force efficiency (CFE) and decrease the initial peak load [17-19].

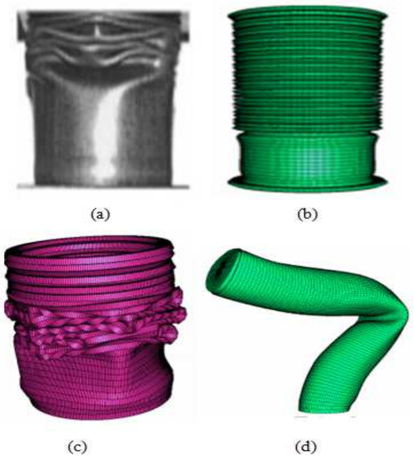

Figure-2-deformation mode (a) diamond [14], (b) concertina mode, (c) mixed mode (diamond and concertina) and (d) Euler-type [15]

The triggers used in this study were circular, rectangular and elliptical, and the tabular structure material was modelled as magnesium alloy AZ3, room temperature of 293 - 297 ° K. The summary of the Johnson Cook parameters are given in Table 1 [20]

Table-1-Summary of Johnson-cook parameters for AZ31 magnesium alloy [20]

Parameter	Value	Description
A	279.827 MPa	Material parameter
B	159 MPa	Material parameter
N	0.327	Strain power coefficient
C	0.013	Material parameter
M	1.573	Temperature power coefficient
$\dot{\varepsilon}_0$	1.0 sec^{-1}	Reference strain rate
ρ	1800 kg/m^3	Density
Tm	923 °K	Melting Temperature
Cp	1.05 kJ/kg.K	Specific Heat

2.1 Energy Absorption

The purpose of the thin walled tube is to convert the kinetic energy due to collision to other that can be absorbed by the tube due to plastic deformation. Other purpose of the tube is to reduce the peak force associated during impact. High level force results high deceleration value that cause irrecoverable brain damage [21]. The energy absorption can be calculated from the load-displacement curve as shown in figure 3. Energy absorption is denoted as an integration of a load-displacement curve.

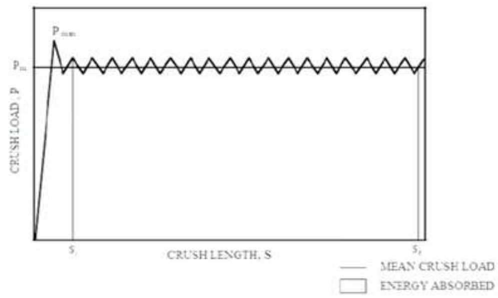

Figure 3: Typical load vs. displacement crushing [22]

$$EA=\int_0^{sb} p.\,ds \qquad (1)$$

When p is an instantaneous crushing load, sb is the length of crushing tube. Equation (1) can be written as

$$EA=\int_0^{sb} p.\,ds = P_m\,(sb-si) \qquad (2)$$

When P_m is the mean crushing load, si is the initial length of the crushing tube and sb is the maximum deformation of the tube

2.2 Crush Force Efficiency (CFE)

The mean and peak forces are important parameters to be determined as they are directly related to the deceleration that will be experienced by the vehicle occupants. The best way to quantify this is by defining a crush force efficiency parameter, which is the ratio of the mean force to the peak force. This ratio is defined as the crush force efficiency. If the ratio is close to unity, the absorber is crushing at a value close to the peak load, hence minimizing the changes in deceleration, as desired from any absorber design. On the other hand, if this ratio is away from unity, there are rapid changes in the deceleration and this is dangerous to have in the design of a vehicle. In general, as the CFE value approaches unity, the better is the performance of the energy absorbing structure [23].

2.3. Effect of Triggers on Force Level and Energy Absorption on the AZ31.

By applying weaknesses (trigger), stable force can be obtained along the deformed profile, reduce the peak force and enhance the energy absorption capability. Reducing force is one of crashworthiness demanded keep the passengers safer by reducing the transferee force to them. Getting stable force is preferred figure 4, to obtain more folding process so the energy absorption will increase and hence more impact energy caused by collisions can be dissipated.

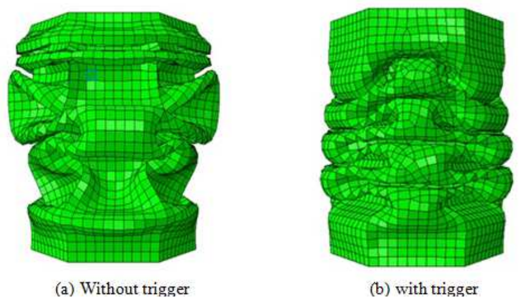

Figure-4-Hexagonal profiles without (a) and with (b) trigger for AZ31

In comparison of energy absorption of both triggered and non-triggered profiles, it can be observed as shown in figure 5 that the triggered profile has higher energy absorption from non-triggered one and this attributed to the folding mode failure.

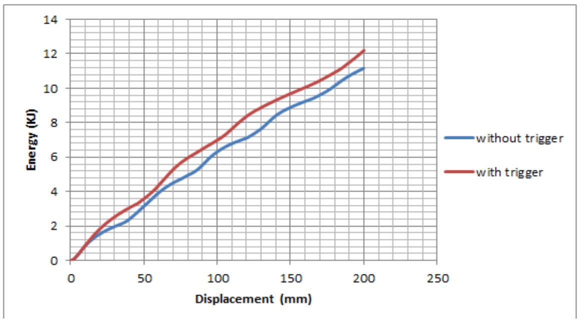

Figure 5 Energy-displacement curve for trigger and non-trigger hexagonal profile for AZ31

Beside the triggered profile absorb more energy than non-triggered one; the force in triggered profile has a lower level than non-triggered as shown in figure 6.

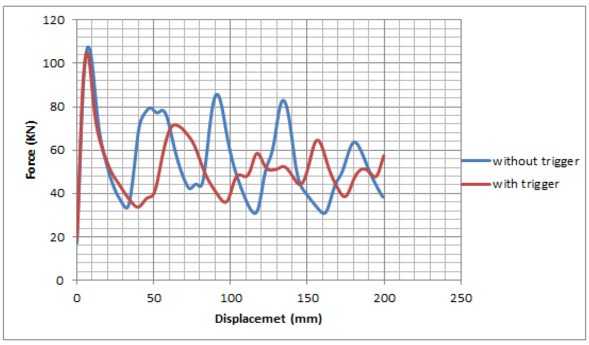

Figure-6-Force-displacement curve for trigger and non-trigger hexagonal profile for AZ31

2.3.1 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.

2.3.2 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.

2.3.3 Circular Trigger Distributions

Three different distributions have been implemented to select the best one. The distributions are shown in figure 7.

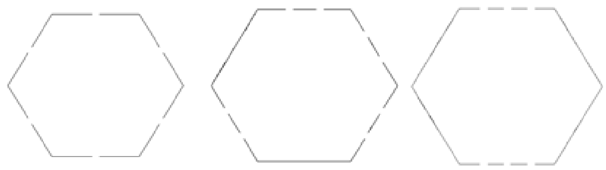

Figure 7 Different trigger distributions (a) first type (b) second type and (c) third type of distribution

The reduction percentages for all triggers were 10 per cent since the hexagonal profile has a perimeter of 300 mm then the reduction per cent will be 30 mm for all sides. Table 2 shows the simulations done on the hexagonal profile with circular whole 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-2-Effect of circular triggers with first type of distribution for AZ31

Criteria / Trigger distance	Energy absorption (kJ)	Peak force (kN)	CFE
Without trigger	12.2	115	55.8
20 mm	10.72	106	50.6
30 mm	10.4	107	48.7
40mm	11.12	110	50.8
50 mm	12	110	54.8
60 mm	11.4	110	52
70 mm	11	109	51

Table-3-Effect of circular trigger with the second distribution on the energy absorption, peak force and CFE

Criteria / Trigger distance	Energy absorption (kJ)	Peak force (kN)	CFE
Without trigger	12.2	115	55.8
20 mm	10.88	107	51
30 mm	10.9	108	50.8
40mm	13	108	61
50 mm	13.1	107	61.2
60 mm	13	107	60.7
70 mm	13.1	108	61

It can be observed that the results stated in table 3 show that there is enhancing in CFE value and increasing in energy absorption and somewhat decreasing in peak force when using triggers in comparison with non-triggered profile. The distances 40, 50, 60, and 70 mm show the best results. From these positions, the distance 50 mm reveals a good energy absorption value and the lowest peak force the highest CFE value. Table 4 shows the effect of circular triggers with third type of distribution on the energy absorption values, peak forces and CFE values.

Table-4-Effect of circular triggers with third type of distribution for AZ31

Criteria / Trigger distance	Energy absorption (kJ)	Peak force (kN)	CFE
Without trigger	12.2	108	55.8
20 mm	10.76	109	50.3
30 mm	11.14	109	51.5
40mm	10.7	109	49.3
50 mm	11.33	109	52.1
60 mm	10.4	109	48
70 mm	11	110	50.8

It can be observed that the third type of distribution does not give good results as shown even in energy absorption, peak force and CFE. Figure 8 shows the load-displacement curve for three distribution triggers using circular trigger.

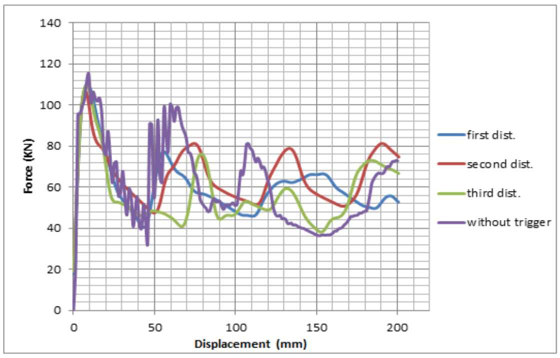

Figure 8 Force-displacement curves for circular triggers at 50 mm from the end for AZ31

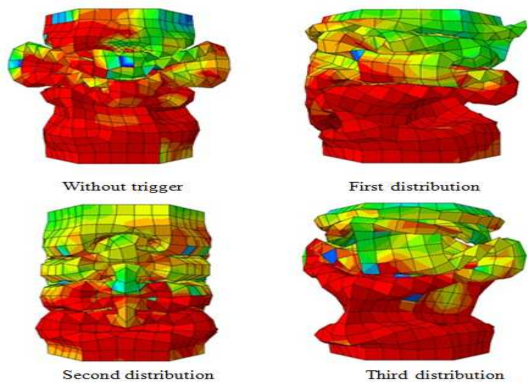

Figure-9-Deformation profiles of triggered and non-triggered profiles for hexagonal made of AZ31

From the figure 9 the second distribution of circular triggers the deformation mode is more regular and stable and also shows a lower in peak force in comparison with other distributions.

2.3.4 Discussion of Distribution Types

From the results obtained, it can be concluded that the first and third type of triggers distribution did not give a significant effects on the hexagonal profile. And the results show there were no enhancements when using these types of distribution on the hexagonal profiles.

The second type of distribution reveals a significant enhancement when apply the triggers on the hexagonal profile. The distances 40, 50, 60 and 70 mm show good results and also show enhancement of energy absorption values, peak forces and CFE values. The trigger position of 50 mm was the best distance among them. Since this distance reveals the best energy absorption, lowest peak force and highest CFE value.

2.3.5 Rectangular and Elliptical Trigger

Beside the circular trigger, elliptical and circular triggers have been studied to obtain which of these triggers have the best performance and exhibit the effect on both energy absorption and peak force. The trigger areas and the percentage reduction are the equal for the all triggers. For both rectangular and elliptical triggers six different distances have been taken to specify the best trigger position. For the rectangular trigger, it was represented as three triggers distributed on the three side of hexagonal profile so three sides only will be triggered and the distribution like the second type of distribution done on the circular triggers.

Table 5 shows the effect of rectangular trigger on the energy absorption

Criteria / Trigger distance	Energy absorption (kJ)	Peak force (kN)	CFE
Without trigger	12.2	115	55.8
20 mm	11.4	108	52.5
30 mm	12.86	110	59.5
40mm	12.47	110	56.8
50 mm	13	111	63.2
60 mm	13.2	111	64.1
70 mm	11.9	110	54.3

From the results shown, it can be observed that there was an increasing in energy absorption especially in position 50 mm and 60 mm but synchronously with the increasing in peak force value which is not desire and must be avoided.

For the elliptical triggers as shown in table 6 the results show there were increasing in the energy absorption and CFE values especially when the trigger positions were 50mm and 60 mm. the increasing in energy absorption and CFE values accompanied with non-significant decreasing in the peak force values which must be avoided.

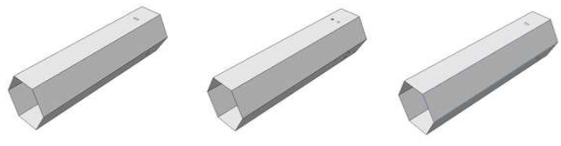

Figure-10-Types of trigger holes geometry

Figure-11-Rectangular and elliptical trigger holes in two dimensions

Table 6 Effect of elliptical triggers for AZ31

Criteria / Trigger distance	Energy absorption (kJ)	Peak force (kN)	CFE
Without trigger	12.2	115	55.8
20 mm	11.33	108	51.8
30 mm	11.43	108	53.4
40mm	11.78	110	54
50 mm	13.4	108	61.5
60 mm	13.2	109	62
70 mm	11.17	110	51

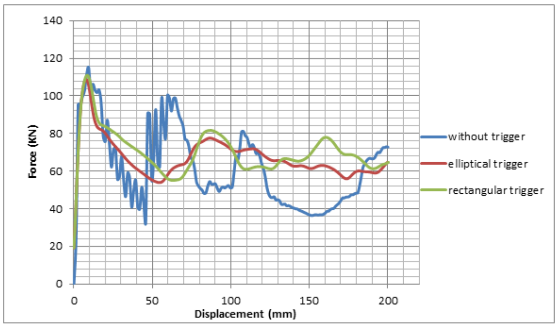

Figure 12 Force-displacement for elliptical, rectangular trigger and non-triggered profile for AZ31

Figure 13 shows the deformation profiles of the elliptical, rectangular and non-triggered hexagonal profiles for AZ31.

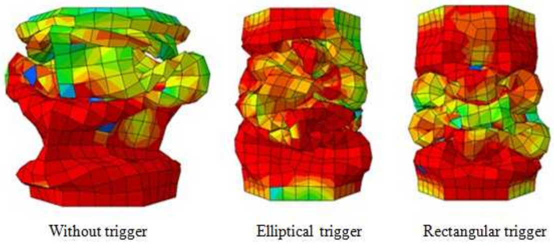

Figure 13 Deformation profiles of rectangular, elliptical and non-triggered profile for AZ31

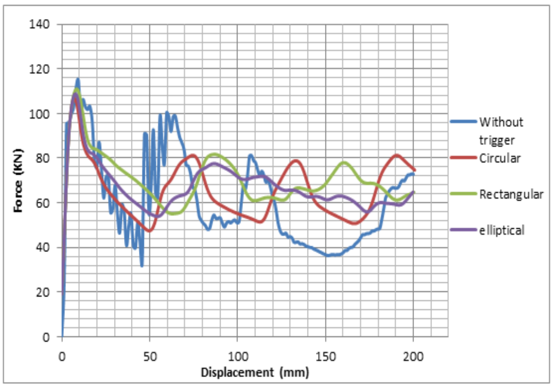

Figure 14 force-displacement curve for three triggers shape at distance 50 mm for AZ31

Table-8-shows the simulation results for the different trigger geometries. It can be observed that the circular trigger with second type of distribution, elliptical and rectangular triggers reveal highest energy absorption and high CFE values. Just the circular trigger offers the lowest peak force.

Table 8 Effect of trigger geometries on the hexagonal profile at distance of 50 mm for AZ31

Trigger type	Energy Absorption (kJ)	Peak force (kN)	CFE
No trigger	12.2	115	55.8
Circular first dist.	12	110	54.8
Circular second dist.	13.1	107	61.2
Circular third dist.	11.3	109	52.1
Rectangular	14	111	63.2
Ellipse	13.4	108	61.5

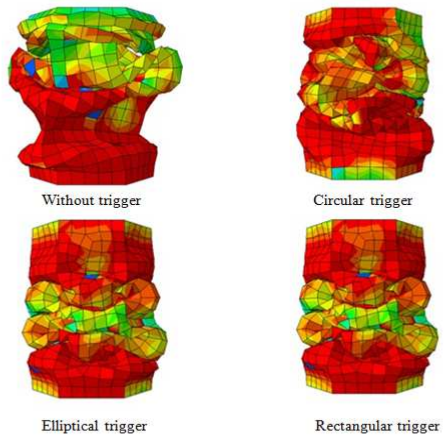

Figure 15 Deformation profiles of rectangular, elliptical, circular and non-triggered profile for AZ31

2.3.6 Determination of the Best Trigger Dimension

The aim of using trigger is to weaken the tube as an energy absorber so that the folding develops along the tube. Little weaken may give non-regular form and non-decreasing in peak force which causes the non-regular fold. Too much weaken can cause reducing in energy absorption and stiffness and hence low bending resistance. Figure 15 shows the force-displacement curve for 0, 50, 10 and 15 per cent reductions. Table 7 shows the energy absorption level for all reduction percentages. Results show that too much reduction causes lower peak force. The energy absorption values in 0 and 5 per cent are lower than 10 per cent because of instability of folding while in 10 per cent the folding seems more regular. In 15 per cent reduction, the folding are regular and the energy absorption is lower because the peak force is lower.

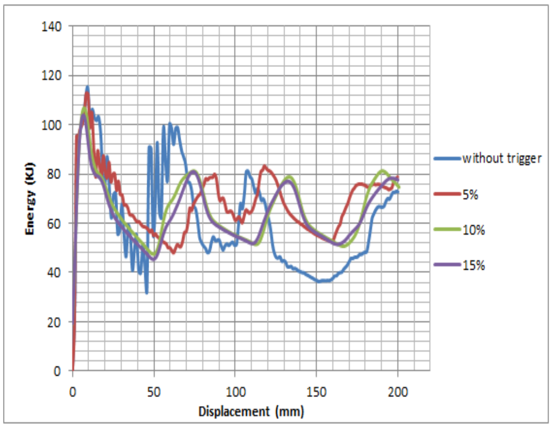

Figure-16-Force-displacement levels of different reduction percentages of AZ31

Table 9 Peak force and energy absorption of hexagonal with different elliptical size for AZ31

Trigger type	Energy Absorption (kJ)	Peak force (kN)
No trigger	12.2	115
5% elliptical	13	113
10% elliptical	13.4	108
15% elliptical	12.7	104

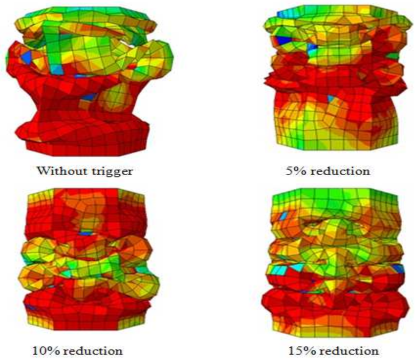

Figure-16-Deformation profiles for elliptical triggers for different size for AZ31

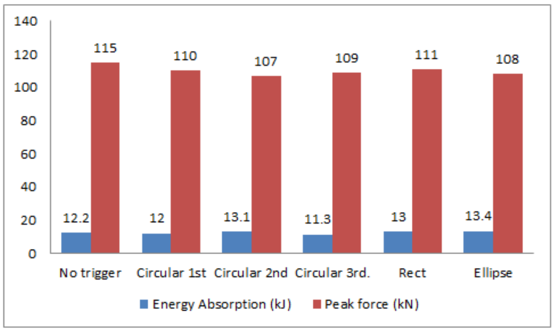

Figure 17 different trigger and distributions

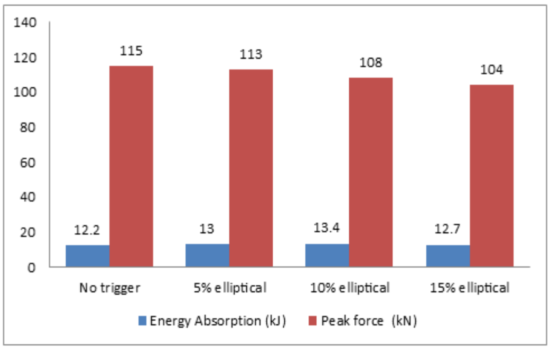

Figure 18 different trigger percentages

2.3.7 Discussion of Triggers Geometries for AZ31

Trigger of the tube means apply specific weaknesses in a proper position. The purpose of trigger is to get a stable force and regular folding along the deformation tube length. By applying triggers, lower peak force can be obtained and increased the energy absorption value. Three types of trigger geometries have studied circular, rectangular and elliptical shapes. Three different distribution of the trigger also have been studied. And finally three reduction percentages were taken into consideration. The results obtained showed that the second type of distribution offers best results. Highest energy absorption and lower peak force can be observed in second type of distribution. In comparison of elliptical trigger with circular and rectangular, the elliptical trigger showed higher energy absorption values and higher CFE with acceptable reduction of peak force. So the elliptical trigger with second type of distribution reveals the best choice it offers an increasing in energy absorption and CFE about 10 per cent and at the same time shows decreasing in peak force by 10 per cent.

Little weaknesses showed non-regular folding and do not show decreasing enough in the peak force. While weaknesses much as desire in spite of giving regular folding process but shows decreasing in energy absorption and stiffness and hence decreasing in bending resistance. The results show that 10 per cent reductions show the best trigger dimensions.

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