The effects of Trigger Mechanism on the Energy Absorption of Thin-Walled Rectangular Steel Tubes

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Abstract— **The current study examines the energy absorber capacities of mild steel A36 material in frontal longitudinal members of the crashworthiness applications. The mild steel was subject of various studies because of its good mechanical properties, which helps to increase the energy absorber properties for crashworthiness application. The simulations were based on the non-linear finite element (ABAQUC CAD 6.10). The thin walled rectangular tube, enhanced by trigger mechanism, was subjected to direct loading. Elliptical, square, and circular trigger geometries were combined with different trigger positions and reductions. The best achieved result was the energy absorption enhanced by 8.9%, and the CFE enhanced by 7.3%, which results contributes to the safety of the passengers. This outcome has been given by the elliptical trigger situated at the distance of 40 mm from the free end of the tube with 10% reduction.**

Keywords— direct load, mild steel A36, trigger, energy absorption.

I. INTRODUCTION

Crashworthiness is one of the basic properties in the protection of passengers and being so, no one can ignore its essential role while designing any kind of vehicle. This is the feature that provides security by absorbing crash at the moment of the accident. The concept of crashworthiness deals with the ability of the car structure in keeping passengers safe at the moment of the accident [1]. It can be defined as appropriate structure to protect the travelers from the effects of the impact [2]. One of the significant factors to be considered in the design of the vehicles is the weight reduction of the vehicle, which has a direct effect on the more economical fuel consumption. Crashworthiness is responsible for the improvement of the structure in order to absorb the impact energy and protect the auto cabin [3, 4]. Parametric study on the windowed square tube under dynamic oblique loading has been conducted. The parameters are the width and height of window, the load angle and the impact velocity. The results are summarized as follows. The windowed tube collapses axially at load angles less than or equal to the critical value. At load angles larger than the critical value, the tube collapses in bending mode. The energy absorption of the tube decreases as the load angle increases, and drops significantly when the collapse mode transits from axial collapse to bending collapse. In general, the critical load angle decreases as the width of window increases, and the height of window and impact velocity do not have significant influence on the critical load angle [5]. The result shows the increasing the wall thickness increases the mean crushing force. This is because with increasing wall thickness, the initial stiffness and the average stiffness of the structure of each specimen are enhanced too. The research of Peixinho [6] investigates how the crashworthiness properties of aluminum tubular structures can be increased in case of using initiators. Based on both quasi-static and dynamic tests that were deducted, the conclusion is that the usage if trigger decreases the initial maximum load and increases the energy absorption [6].

II. CRASHWORTHINESS PARAMETERS

The crash box of the vehicle, situated at the front end of the front side frame, has a crucial role in absorbing the energy at the moment of the crush. The high level of energy absorption is the basic feature in providing crashworthiness to the crash box. The characteristics of crashworthiness, crash behavior, impact energy absorption and reaction of maximum repulsive force, crash box development design variables and trigger cuts.

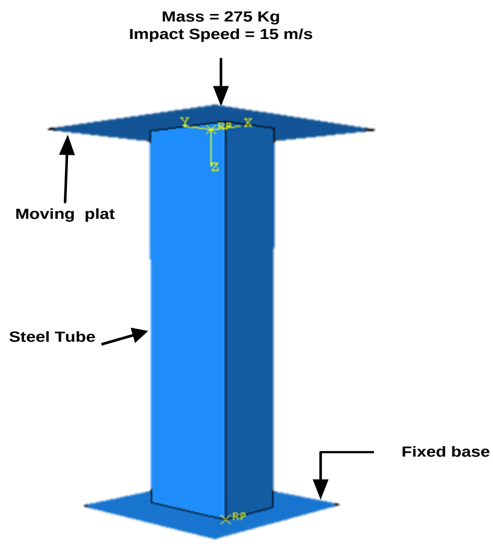


Fig. 1 Frontal longitudinal member of thin-walled structure

A. *Crushing Load*

The thin-walled energy absorbers, subjected to the load and responsible for the energy absorption at the moment of the crash, are influenced by the applied load, the inertia and strain rate effects. The maximum force means the supreme impact, and the deformation that the members of the passenger car can absorb, maintaining the passenger cabin safe. The goal to achieve is to have vehicle members able to absorb the low-energy and low-velocity mass loads without constant deformation of the structure [7].

B. *Cruch Force Efficiency (CFE)*

Crush Force Efficiency is the ratio between the average and the maximum crushing load, which helps to measure the performance of an absorber [8]. The crush force efficiency (CFE) is defined as:

$$CFE = \frac{F_{av}}{F_{\max}} \qquad \text{(Eq. 1)}$$

Where F_{av} is the average peak load and F_{max} is the maximum peak load.

C. *Total Energy Absorbed (EA)*

The total energy absorbed (EA) is located under the load-displacement curve, resulted by the cross-sectional area and the material density and calculated by the integration if the load-displacement curves [8].

$$EA = \int_{S_i}^{S_f} F_i ds \Rightarrow F_{av}\left(s_f - s_i\right) \qquad \text{(Eq. 2)}$$

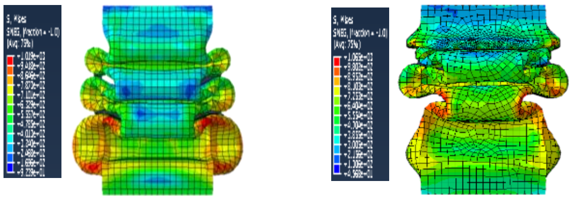
Where F_{av} is the main crushing load and (S_f, S_i) are the ending and beginning of the crushing distance respectively.
The role of the energy absorption of the longitudinal members is the conversion of kinetic energy to other form of energy at the moment of the deformation. The reduction of the related peak reaction force at the moment of the crash is also one of the functions of the longitudinal members, in order to minimize the deceleration [9].

III. EFFECT OF TRIGGER MECHANISEM ON CRASHWORTHINESS PARAMETERS

The reason for using the triggering technique is to have the stability of the force level along the crushing length. This technique is simply applied to a specific weakness in a suitable position on the member's length; the first folding process starts with a lower yield load on the position of the triggering area. The importance of the triggering technique is to prevent the high load, which causes bending failure for the non-crash area. The applied load has been concentrated at the front end, which is closed to the impactor and has received the triggering. This technique leads to similarity at the wavelength areas, which exhibits a stable energy absorption by the total length of the modeled tubes. In this paper rectangular tube with difference triggers have been simulated with 15 m/s velocity. Three geometries of initiators have been designed: ellipse, square and circular initiators. The triggering technique has been used to improve the crashing behavior of the rectangular tube.

A. *Effect of Triggers on Peak Force and Absober Energy*

The purpose of using triggers is to diminish the initial high force caused by impactor and to protect the passenger compartment from the transmitted high load. The trigger on the profile will provide a stable force on the whole length of the profile. Triggers can be attained with the application of specific weaknesses in specific positions, precisely at the front end of the profile. This will result a more stable folding, as it will start to fold with a lower peak load. The decreased peak force will decrease the probability of the profile to collapse, and it will diminish the energy absorption, as in case of the bending collapse just a few folding will be deformed. As shown in Fig.2 the folding process starts from the triggered end proceeding towards the rear end, and provides more stability. This process will provide higher energy absorption.



a) Without trigger b) with trigger

Fig.2 The crush of rectangular profile of mild steel

Fig.3 and Fig.4 show the comparison between the energy absorption capabilities and peak load with displacement of the triggered and non-triggered profiles respectively. The non-triggered profile is stiffer, and being so, it has higher energy absorption capacity in the beginning of deformation. The triggered profile, caused by the folding generated because of the presence of the triggers, will absorb more energy after the beginning phase.

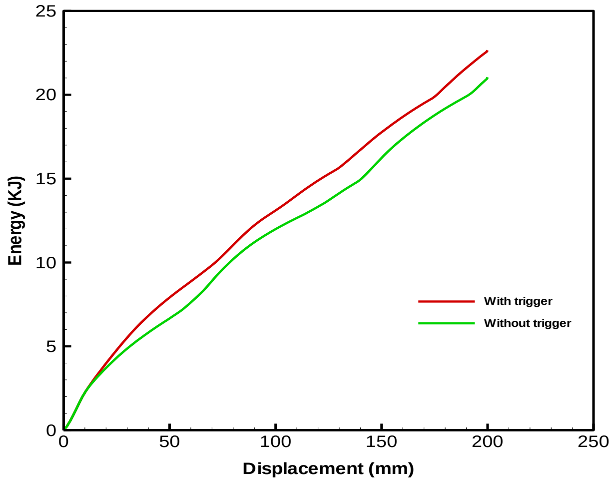


Fig. 3 Energy-displacement of rectangular profiles with and without trigger in case of mild steel material

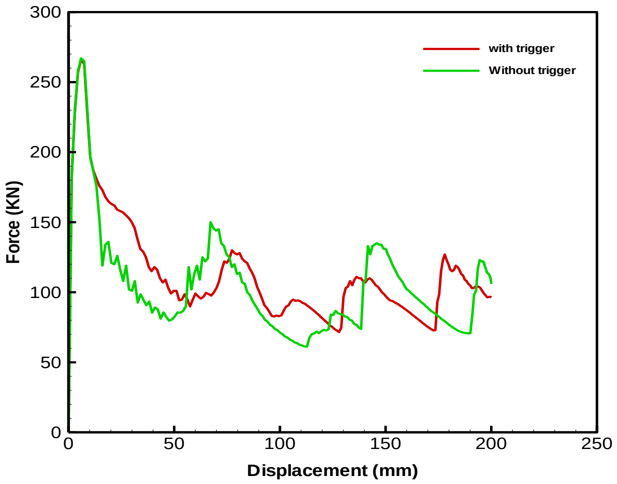


Fig. 4 Force-displacement of rectangular profile with and without trigger in case of mild steel material

B. Trigger Geomtries

The examined trigger geometries, in order to find the optimal performance of peak load, CFE and energy absorption, are elliptical, circular, and square. The trigger area and percentage of reduction are identical for both triggers. The simulations are completed on rectangular, triggered profile with rigid front end, at 54 km/h. The shapes of the various trigger holes give different results. The purpose is to find the shape with the best effect on the peak force and on the energy absorption.

C. Trigger Position and Location

Enhanced of energy absorption of an extrusion tube can be obtained by applying a specific trigger a proper position. One the other hand the trigger will decrease the high peak force required to start the first fold. The fold becomes regular and more stable. Since the rectangular profile has four 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 rectangular profile must be triggered is also defined. Since the rectangular profile perimeter was 300 mm then two of sides have 90 mm for each one and another two of sides have 60 mm for each one. The percentage reduction of each type of trigger was equal. The area of them was also equal to verify the trigger shape effect.
This study examines three types of trigger and three types of distribution, called first, second and third distribution. The first type is based on circular, elliptical and square shape. The number of trigger holes is two, and they are positioned on the longer sides of the rectangular profile, in a way that each side has one hole in the middle with reduction percentage of 10 percent. The circular diameter is 15 mm, with the total of 30 mm for both sides. The second type of distribution uses two holes together, so in total four trigger holes have been created on the longer sides of the rectangular profile. The distance between the end and the center of the circle is distributed regularly, having equal distance between the centers of the holes. The holes on the two sides have a reduction of 10 percent. The circular diameter is 7.5 mm, with a total of 30 mm for both sides. The third type of distribution is represented by three holes together. Six holes have been created on the longer sides of the rectangular profile. The distance between the end and the center of the circle is distributed regularly, having equal distance between the centers of the holes. The holes on the two sides have a reduction of 10 percent. The circular diameter is 5 mm, with a total of 30 mm for both sides. The Figure.5 illustrates the three types of trigger distributions.

(a) first dis. (b) second dis. (c) third dis.

Fig.5 Types of trigger holes distribution

Various distances have been examined on order to verify the best trigger position and the proper trigger distance. The trigger position specifies the distance (d) between the front end of the rectangular profile, and the center of the trigger shape. The studied distances are 20, 30, 40, 50, 60, and 70 mm. The simulations are based on profile thickness of 2 mm, crash speed of 54 km/h, and impact mass of 275 kg.

IV. RESULTS

A. Effect of trigger geomtries on P_{max} , EA and CFE

Based on the results in Table.1 with Figure.6 and Figure.7, we can conclude, that in case of the third type of distribution, with trigger position of 50 mm from the free end of the tube, the elliptical trigger shows better results than the circular and square triggers. It results the energy absorption value increased by 8.9 %, the peak load value increased by 0.37 %, and the crush force efficiency (CFE) value increased by 7.3 %.

Table.1 Effect triggers geometries on the rectangular mild steel tube at 40 mm

Criteria / Trigger Distance	Energy Absorption (KJ)	P_{max} (KN)	CFE
Without trigger	20.90	267	0.383
Circular trigger first dist.	21.69	265	0.400
Circular trigger second dist.	22.00	267	0.402
Circular trigger third dist.	22.21	266	0.404
Elliptical trigger first dist.	21.89	265	0.398
Elliptical trigger second dist.	22.11	266	0.405
Elliptical trigger third dist.	22.65	266	0.411
Square trigger first dist.	20.92	264	0.385
Square trigger second dist.	22.10	266	0.390
Square trigger third dist.	22.37	266	0.407

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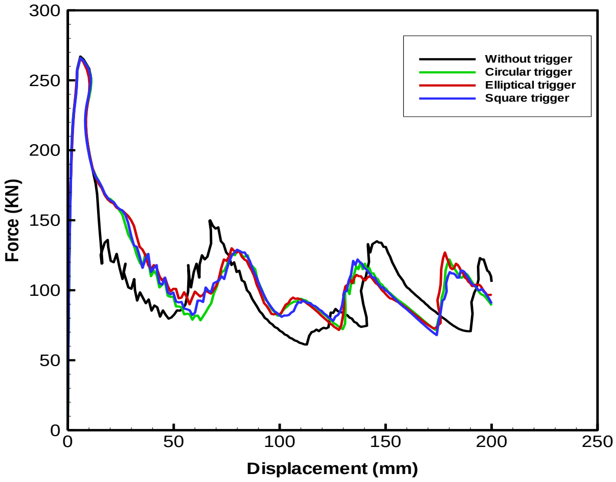


Fig.6 Force-displacement curve for non-triggered profile, and profile with various trigger geometries at the position of 40 mm for third type distribution

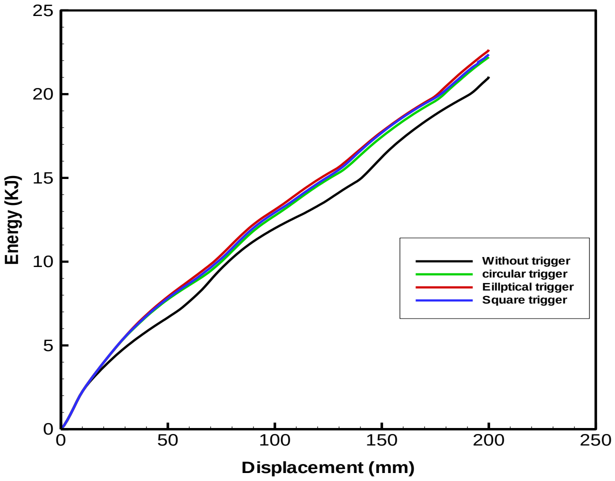
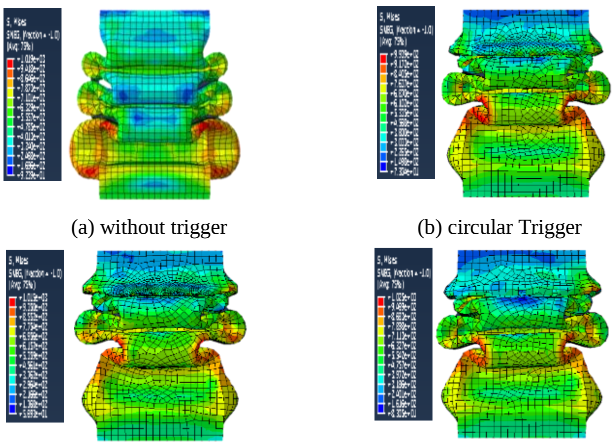


Fig.7 Energy-displacement curve for non-triggered profile, and profile with various trigger geometries in the position of 40 mm for third type distribution



(a) without trigger (b) circular Trigger

(d) elliptical trigger (E) square trigger

Fig.8 Deformation of non-triggered rectangular profile, and profile with various trigger geometries

B. Determintion the best trigger dimenstion

The role of the trigger is to form the highest possible rate of folding. The usage of small triggers is impractical, as these will not reduce effectively the initial peak force, and the folding might not develop appropriately. From the other side, the usage of large area of trigger reduction causes diminished energy absorption and stiffness, and by this lower bending resistance. The simulation is based on rectangular profile with 300 mm of perimeter, and 2 mm of thickness. In order to find the most effective trigger reduction percentage, the simulation was applied on five reduction percentages of 5, 7.5, 10, 15, and 20 percent. Figure.9 and Figure.10 show the energy absorption and the peak force level. Table 2 show the energy absorption, peak force, and CFE values. Figure.11 shows the crush deformation of rectangular tube with various triggers reduction in case elliptical trigger.

Table.2 shows the energy absorption, peak force and CFE values of tube with various trigger reduction percentage.

Criteria / Trigger Red.	Energy Absorption (KJ)	P_{max} (KN)	CFE
Without trigger	20.90	267	0.383
5% elliptical	21.19	267	0.387
7.5% elliptical	21.55	267	0.393
10% elliptical	22.65	266	0.411
15% elliptical	21.12	265	0.390
20% elliptical	20.86	264	0.391

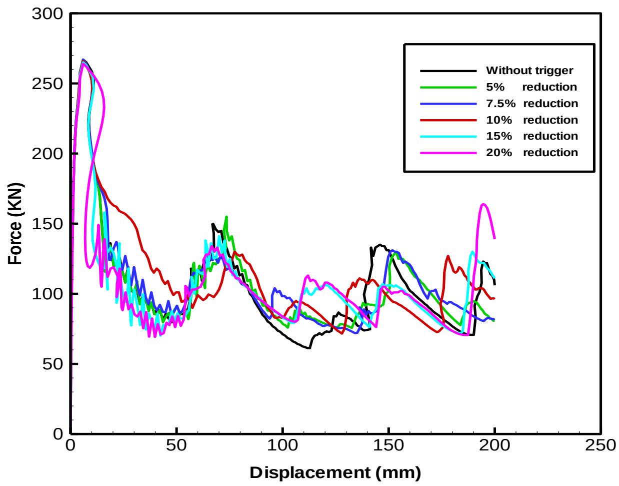


Fig.9 Force- displacement level of different trigger reduction

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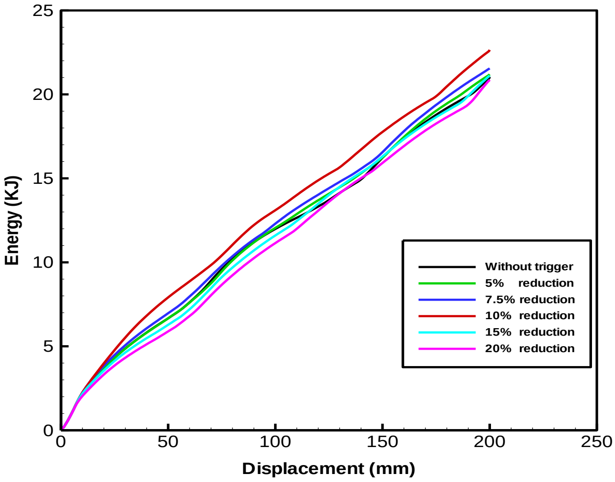
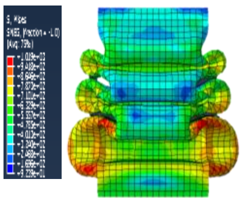
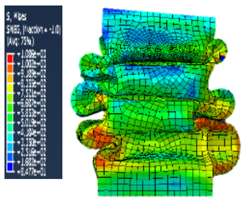


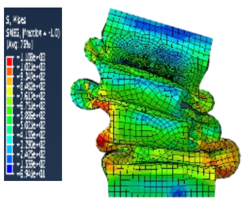
Fig.10 Energy-displacement level of different trigger reduction



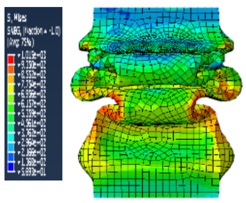
(a) without trigger



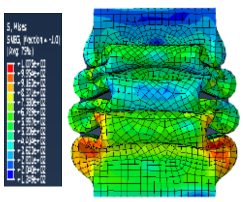
(b) 5% Trigger reduction (Ellipse)



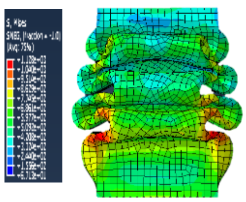
(c)7.5% Trigger reduction (Ellipse)



(d) 10% Trigger reduction (Ellipse)



(e) 15% Trigger reduction (Ellipse)



(f) 20% Trigger reduction (Ellipse)

Fig.11 Deformation of rectangular extrusion tube with various trigger reduction

CONCLUSION

This study investigates the results of the direct impact load of the crush on the rectangular profile of ductile material of mild steel A36 to examine the effect of trigger mechanism on the crashworthiness parameters. Trigger means to weaken the tube in order to improve its performance. The distribution of the triggers affects their performance. To obtain the best results with a triggered tube, we need to find the proper position, geometry, and reduction percentage of the trigger. The geometries studied in this paper are the square, circular, and elliptical, all of them with various types of distribution. The best result in energy absorption enhancement and crush force efficiency (CFE) is shown by the elliptical trigger, which in the same time provides lower peak force value and regular folds. From the studied distances of 20, 30, 40, 50, 60, and 70 mm, the position of 40 mm revealed to be the most appropriate position for the trigger in case of mild steel A36 material. The types of reduction percentages that have been implemented are 5, 7.5, 10, 15, and 20, percent. The profile without trigger has been investigated as well. The best reduction of trigger resulted to be the 10 percent

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