# The Influence of Forming Effects on The Bending Crush Behavior of Top-Hat Thin–Walled Beams

**Nguyen Van Nhat Vu, Sigit P. Santosa*, Leonardo Gunawan, Annisa Jusuf**

Lightweight Structures Research Group,
Faculty of Mechanical and Aerospace Engineering. Institut Teknologi Bandung,
Jl. Ganesha 10 Bandung 40132, Indonesia
*Email: sigit.santosa@ftmd.itb.ac.id

**Abstract.** This paper presents a study on the effects of forming process of a top–hat thin–walled beams to its bending crush resistance under dynamic bending load. The thin–walled beam was formed using a one step deep drawing. HyperForm software simulated the forming process and mapped its effects such as thickness variations and residual plastic strains in to the crash analysis models. Then the dynamic bending crush analysis was carried out using LS–DYNA by using the geometry and materials data obtained from the forming analysis results. For each material model, the analyses were carried out for model with and without the forming effects. The bending crush behavior of the top–hat thin–walled beams were then analyzed to compare between the simulations with and without forming effects. The results show that by incorporating the effect of forming process, the bending crush resistance of the thin–walled beams is increase by 4.7%. The introduction of strain rates to the material model increases even further on the bending crush resistance of the thin–walled beam.

**Kata kunci:** *bending crush; deep drawing; forming effect; top–hat.*

## 1 Introduction

Automotive industries use thin–walled columns as components of car structures including the crash boxes that will absorb kinetic energy during frontal crash and side impact beams that will do the similar function during side crash. Those components are usually made from using sheet metal forming processes such as bending, deep drawing and shearing. They have various cross sections such as top–hats, L shapes, etc.

In designing columns for safety purposes, the accuracy of simulations to predict the bending crush resistance of the columns is very important. The model used in the simulations should represent the real condition of the columns as much as possible, such as its geometry, boundary conditions, material data, and loading conditions. The ability to identify which parameters should be included in the crash simulation in order to obtain results which represents the real situations is very important in crashworthiness study.

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This paper presents a study on the influence of forming process of a top–hat beam to its bending crush resistance under dynamic bending loads. The top–hat beam was formed using a one step deep drawing. HyperForm software simulated the forming process and mapped its effects such as the wall thickness variations and the residual plastic strains onto the crash analysis model. Then dynamic bending crash analysis simulation using LS–DYNA were conducted for crash box model with and without the effect of forming process. The beam were supported at two points and the load was applied in the middle of the beam. The final results including forming effects are compared with the results without forming to analyze the advantages of forming effects in bending crush resistance, which is one of the objectives of crashworthiness.

## 2 Finite Element Model

### 2.1 Material Data

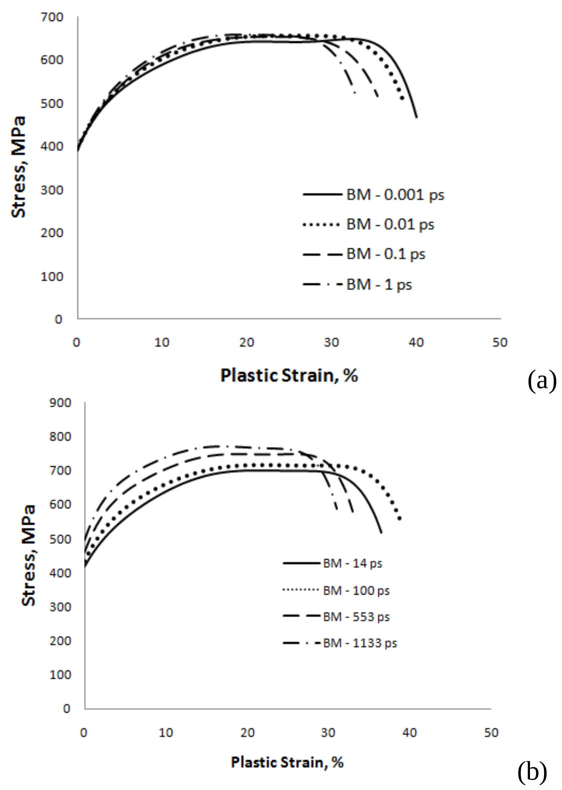


**Figure 1** Engineering stress–strain curves of DP600 BM tested at (a) strain rates from 0.001 to 1 $s^{-1}$, (b) strain rates from 14 to 1133 $s^{-1}$ [1]

The columns used in this study were made of DP600 high strength steel. It has a Young's Modulus $E$ = 210 GPa, Poisson ratio $\nu$ = 0.3 and Density $\rho$ = 7.89 kg/m3. The true stress–strain curves of the material at different strain rates are shown in Fig. 1. These curves were taken from a series of static tensile tests conducted by Danyang et al. [1]. In the dynamic bending simulations, two material models were used, one without and the other with the effect of strain rates.

## 2.2 Geometry

The beam used in the bending impact simulation was a top–hat beam joined by spot weld with a flat lid as shown in Fig. 2. The thickness of both the top–hat beam and the lid were 1.5 mm and the length of the column was 500 mm. The corner radii of the top–hat beam were $R$ = 5 mm.

The total number of the spot welds joining the hat shape beam and the lid was which were distributed uniformly at both opposite flanges. The distance between two adjacent spot welds was 30 mm as shown in Fig. 3 [2]. The dimensions for this geometry are referenced from [2].

## 2.3 Load and Boundary Condition

In the dynamic bending simulations, each beam was supported at two positions 320 mm apart, as shown in Fig. 4. The load was applied in the mid span of the beam by using a 100 kg impactor mass moving downward with an initial speed of 8 m/s.

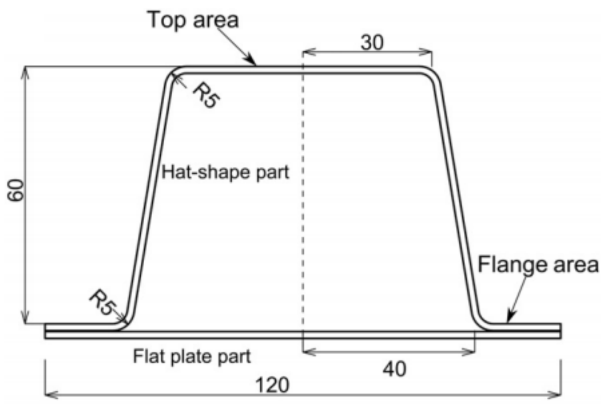


**Figure 2** Cross section of the component used in the bending impact simulation (dimensions are in mm)

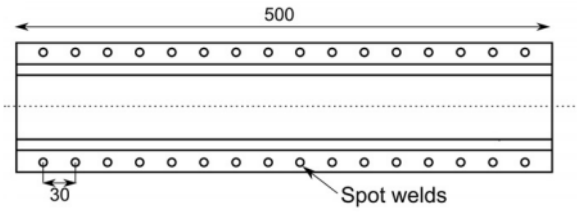


**Figure 3** Locations of spot welds

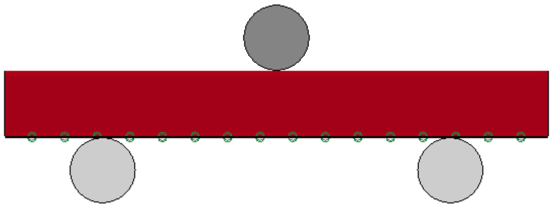

**Figure 4** Bending impact model

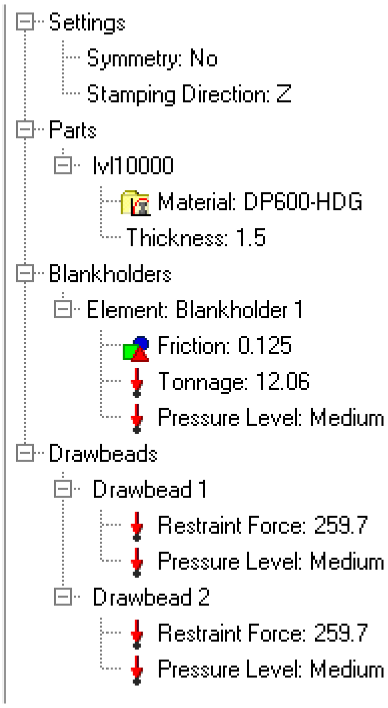


**Figure 5** Pre–forming parameters

## 2.4 Deep Drawing Simulation

In order to generate the forming effects that were included in the beam model for crash simulations, a forming simulation of the top–hat thin–walled beam using a one-step deep drawing process was carried out by using the software HyperForm. The top–hat beam was created in CATIA and then was imported into HyperForm. The pre–forming parameters with material, blankholder forces and drawbead forces are listed in Fig. 5.

After running the one step forming analysis, the top–hat beam model with residual strains and wall thickness distribution was obtained. Fig. 6 shows the effective residual strains of the top–hat beam and Fig.7 shows its wall thickness distributions after being formed. Fig. 8 shows the Forming Limit Diagram of the result as compared to the criteria Forming Limit Diagram in Fig. 9 [3].

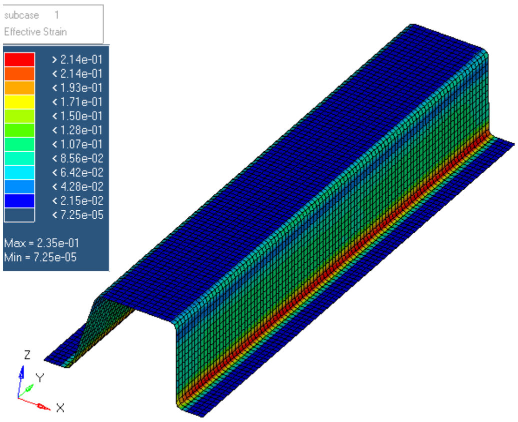


**Figure 6** Effective strain result

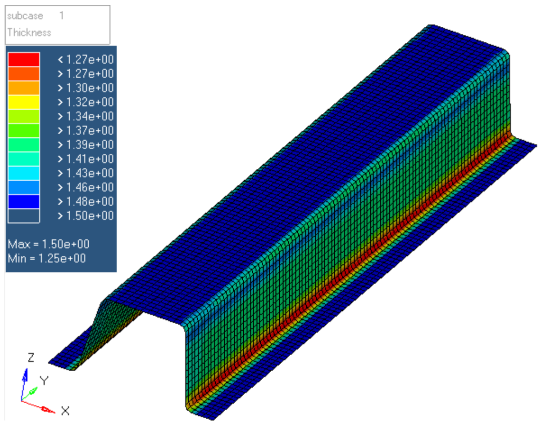


**Figure 7** Thickness of beam after being stamped

This model which already containing information of the initial plastic strain and thickness variation were outputted in LS–DYNA k file for crash analysis.

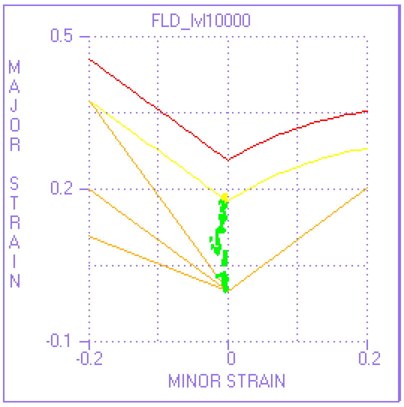


**Figure 8** Forming Limit Diagram of Result

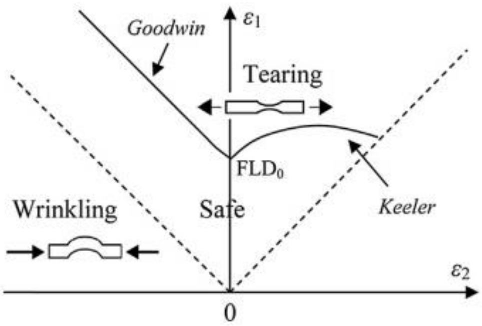


**Figure 9** Criteria Forming Limit Diagram [3]

## 3 Bending Impact Analysis

The dynamic bending simulations were performed for two cases, the first case was for material model without strain rates effects and the other with strain rates effects. For each case, two simulations were performed, i.e. for model with and without forming effects. For all cases, the crushing force versus stroke data was filtered by SAE 180 Hz during dynamic bending deformation.

### 3.1 Bending Impact without Strain Rate Effect

The deformation of the top–hat beam subjected to dynamic bending load using material model without strain rate effect for the case with and without forming effects are shown in Fig.10 and Fig.11, respectively. The instantaneous crushing force versus stroke are depicted in Fig. 12. As can be seen from the results, for bending impact without strain rate effect, the crushing force with forming effects (the bold continuous line) is higher than the one without forming (the light continuous line). The peak force of the case with forming is 30 kN, whereas the case without forming is 27 kN. The mean crushing force of the beam that includes the forming effects is 17.23 kN, which is 4.7% higher than that without forming effects. The maximum deflection of each beam in both cases is 21 mm.

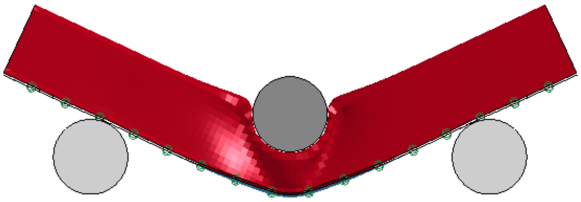

**Figure 10** Deformation of the beam without forming effects for material model without strain rates effects

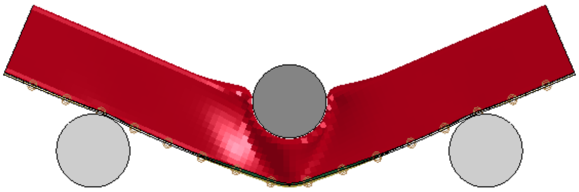

**Figure 11** Deformation of the beam with forming effects for material model without strain rates effects

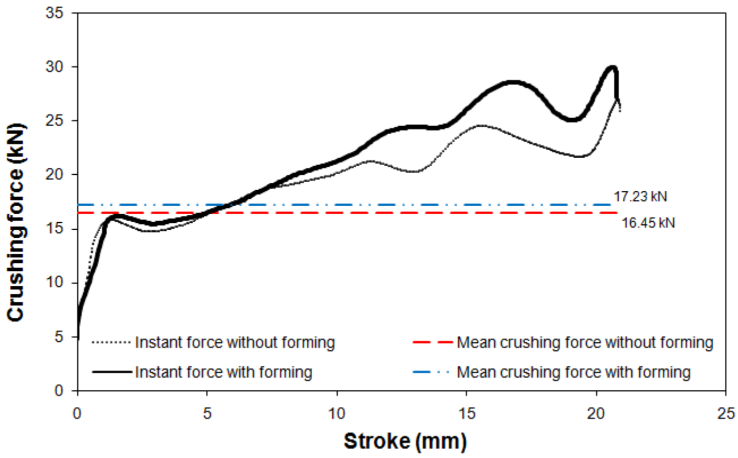


**Figure 12** Comparison between results with and without forming effects for the case without strain rate effect

### 3.2 Bending Impact with Strain Rate Effect

The deformation of the top–hat beam subjected to dynamic bending load using material model with strain rate effect for the case with and without forming effects are shown in Fig.13 and Fig.14, respectively. The instantaneous crushing force versus stroke are depicted in Fig. 15. Similar with previous case, for bending impact with strain rate effect, the crushing force with forming effects (the bold continuous line) is higher than the one without forming (the light continuous line). The peak force of the case with forming is 43 kN, whereas the case without forming is 37 kN. The mean crushing force of the beam that includes the forming effects is 23.52 kN, which is 11.8% higher than that without forming effects.

The maximum displacement of the beam for the case without forming effects (Fig. 13) is 50 mm, whereas the maximum displacement of the beam for the case with forming effects (Fig. 14) is 43 mm. This difference arises because of the effect of strain rate being used during the simulation.

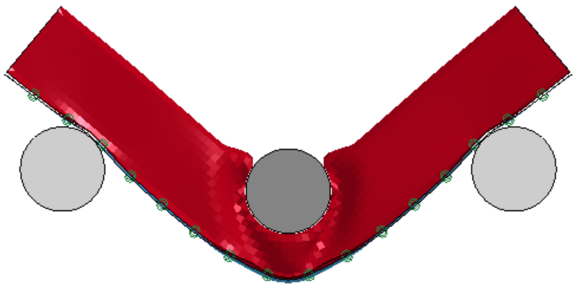

**Figure 13** Deformation of the beam without forming effects for material model with strain rates effects

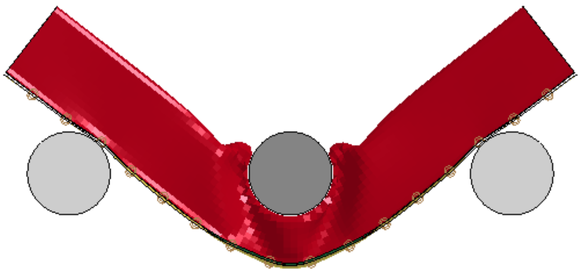

**Figure 14** Deformation of the beam with forming effects for material model with strain rates effects

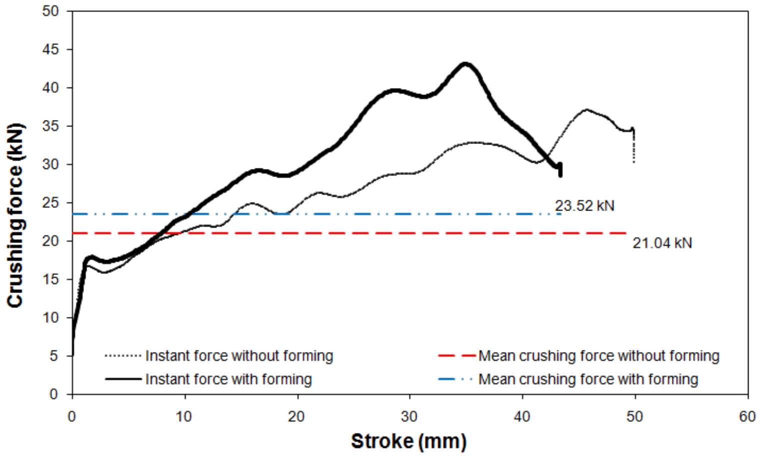


**Figure 15** Comparison between results with and without forming effects for the case with strain rate effect

## 4 Conclusions

In this paper, the effects of the forming process on the dynamic bending crash performance of a thin–walled top–hat beam has been examined by mapping the forming effects onto the crash simulation models. The forming effects, i.e. the residual plastic strains and the thickness variations, calculated by deep drawing simulation of the top–hat beam were considered. Followings are the conclusions obtained in this numerical study:

- The results of crushing force for the cases with strain rate effect are higher than those without strain rate effect. This means that, the introduction of strain rate effect to the finite element model will increase the bending crush resistance of the top–hat beam.
- Adding the forming effects in the form of residual strains and wall thickness distribution to the crash analysis model will give higher mean crushing force than those without forming effects. Therefore, the forming effects contribute significantly in increasing the bending crush resistance of the prismatic top–hat beam under bending load.

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