INVESTIGATION OF THE CHARACTERISTICS OF AA6060 ALLOY UNDER THREE-POINT BENDING USING EXPERIMENTAL AND NUMERICAL METHODOLOGIES

Devran Demir[1]**, Bora Şener**[2]**, Emre Esener**[*1]

[*1] Department of Mechanical Engineering, Bilecik Şeyh Edebali University, Bilecik, Turkey

[2] Department of Mechanical Engineering, Yildiz Technical University, İstanbul, Turkey

devran.dmr41@gmail.com, borasen@yildiz.edu.tr, emre.esener@bilecik.edu.tr

Abstract

In this study, the deformation behavior of 6060 aluminum alloy profile structure under three-point bending load was investigated experimentally and numerically. In this purpose, the use of crash-critical profile structures, which are used to increase safety against collisions, especially in automobiles, are examined. Within the scope of the paper, three-point bending tests were carried out using aluminum 6060 alloy, which has elliptical cross-section geometry with 100 mm and 200 mm span distances and 5 mm punch radius has been obtained experimentally. As a result of the experimental studies, it has been determined that the force required for bending of the material is decreases when the distances beetwen the spans increase. In the second step of the study, finite element analyses were performed using σ-based Hill-48 (S) and r-based Hill-48 (r) plasticity models, and forming force-punch stroke curves and shaped product forms were compared with the experimental results. As a result of the comparisons, it was determined that the forming force-punch storke curves and product forms obtained from finite element analyses were compatible with the experimental results.

Keywords: Profiles; Three-point bending; Aluminum alloy, Finite element analyses.

1.INTRODUCTION

In recent years, the trend of the world has turned towards vehicles that are more resistant to collisions, lighter and more fuel efficient [1]. For this purpose, automobile manufacturers are working on features such as lightening vehicle parts by preserving their high strength properties at the time of collision and reducing carbon dioxide emissions [2]. On the other hand, automobile accidents such as front and side crashes occur frequently around the world, many reports of car crashes show that side crash has a secondary major accident rate after frontal crash [3]. For this reason, automobile manufacturers have produced components that increase safety in the event of a collision, such as airbags, energy-absorbing steering columns and side door impact beams [4]. In the early 1960s, a beam was placed inside the side door for the first time by General Motors, in order to prevent the instability of side collisions due to the minimum gap between the car side door and the passenger compartment [4]. The design of the side body elements such as the side door impact beam is rather complicated to arrange the side body elements, which can maintain their rigidity while absorbing the energy during a side impact compared to front and rear impacts [5, 6]. Damage to the side door impact beam during an accident can be simplified to a three-point bending mechanism. Fig. 1 shows a simulative of the three-point bending arrangement.

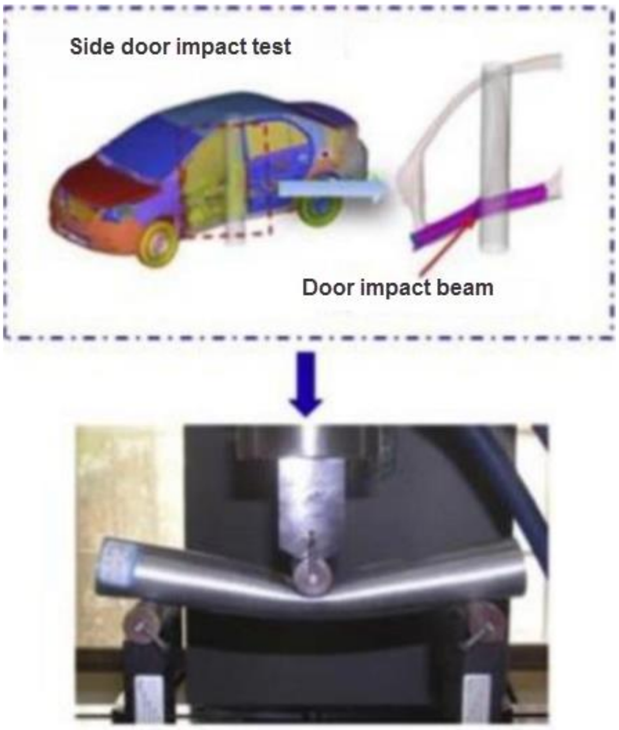

Fig. 1. Three point bending test of side door impact beam [7]

These elements are used both to provide safety during a side collision and to distribute the energy distribution more smoothly and effectively in front and rear collision situations [8, 9]. Impact beams are used to reduce the damage to the passengers in the passenger compartment by absorbing the kinetic energy that occurs with the deformation that will occur in the side door during the collision [10, 11].

In the light of the above, it is seen that the cause of death and injury in vehicle accidents today is a side collision with a rate of 25% after the frontal collision. Therefore, the side door impact beams have become a special and important element in vehicles due to important reasons such as the low contact distance with the passenger during a side collision and the change in the energy distribution on the vehicle during the collision. In this context, for an important element to be used for this purpose, a design that includes high energy absorption ability and formability features should be realized. Within the scope of the paper, three-point bending tests were carried out using AA6060 alloy, which has elliptical cross-section geometry with 100 mm and 200 mm span distances and 5 mm punch radius has been obtained experimentally. In the second step of the study, finite element analyzes were performed using σ-based Hill-48 (S) and r-based Hill-

48 (r) plasticity models, and force-elongation curves, thickness values and shaped product forms were compared with the experimental results.

2.GENERAL PROPERTIES OF METHOD

In this study, the behavior of aluminum 6060 material under three-point bending loading was investigated with different process parameters. In the first step of the study, three point bending tests were carried out to determine the bending behavior of the material. The test setup for the three-point bending test is given in Fig. 2.

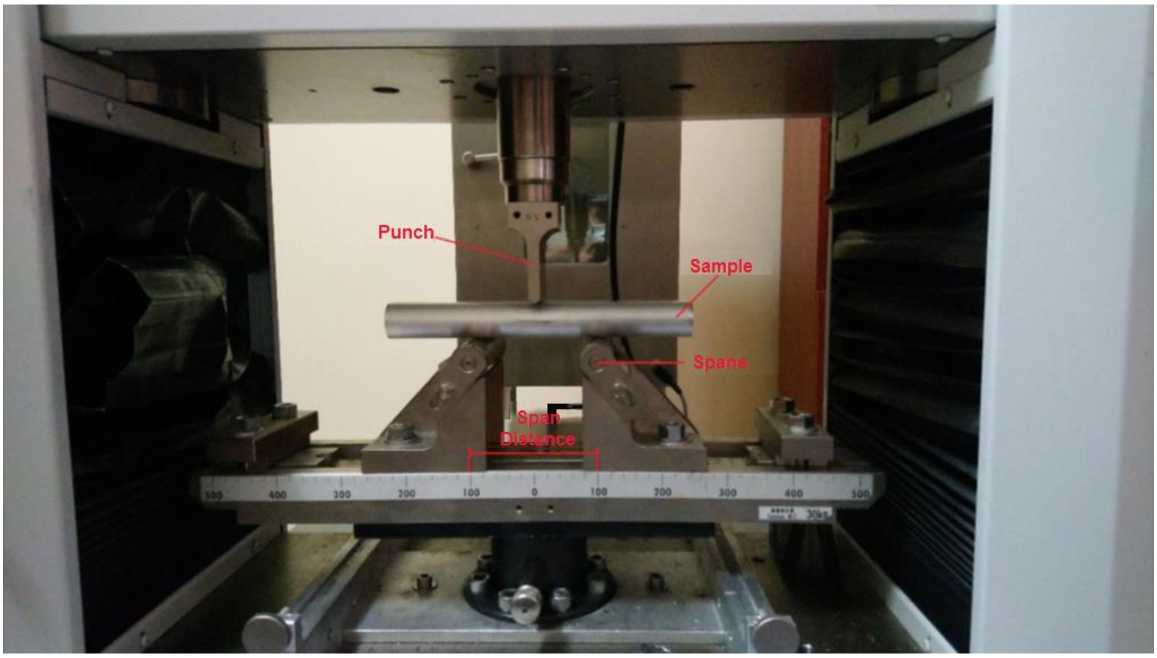

Fig. 2. The test setup for the three-point bending test

The radius of the supports used in the experiments is 15 mm. The experiments were carried out using a constant speed of 20 mm/min and a constant forming distance of 40 mm. Experimental studies were carried out using 250 mm long extrusion products with elliptical cross-section geometry, the dimensions of which are indicated in Figure 3.

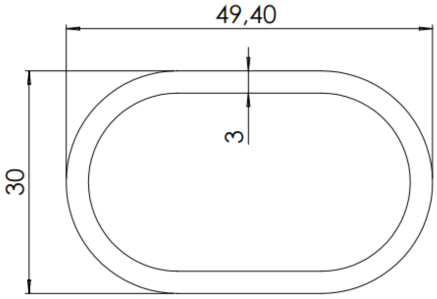

Fig. 3. Section geometry of the test sample (All dimension are in mm)

3.APPLICATIONS

Comparative images of profiles with different cross-section geometries deformed at different support intervals for 5 mm punch radius after the three-point bending test are given in Figure 4. The forming force vs punch stroke graph obtained during the experiments is shown in Figure 5.

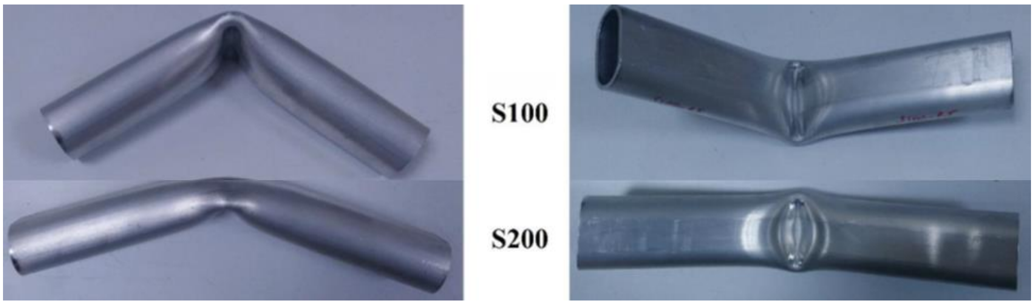

Fig 4. Deformed forms of ellipse section geometry at different support distances for 5 mm punch radius

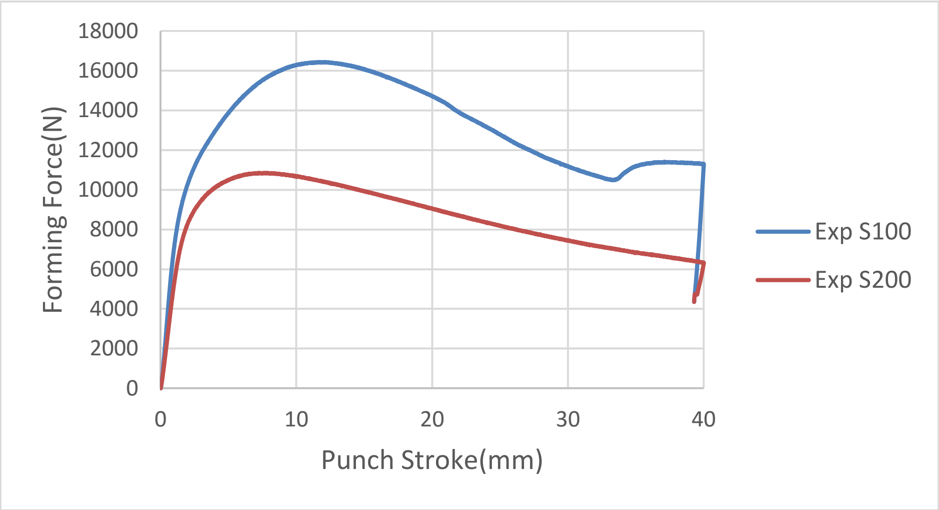

Fig. 5. Forming force vs Punch stroke curves of three-point bending samples

It has been observed that there is a decrease in the forming force with increasing span distances, and this effect is thought to be caused by the moment.

In the second stage of the study, the experimental processes were simulated using the finite element method. Dynaform commercial software was used to create the finite element model. Since all calculations are made on the profile and the die tool elements are considered as rigid, the mesh structure of the profile is generated more precisely than the die tool elements. The finite element model of profiles with elliptical section geometry is given in Fig. 6 and the calculation parameters of the finite element model are given in Table 1. The mechanical properties of 6060 aluminum alloy, which are given as input to the material models used in the finite element analysis, are shown in Table 2.

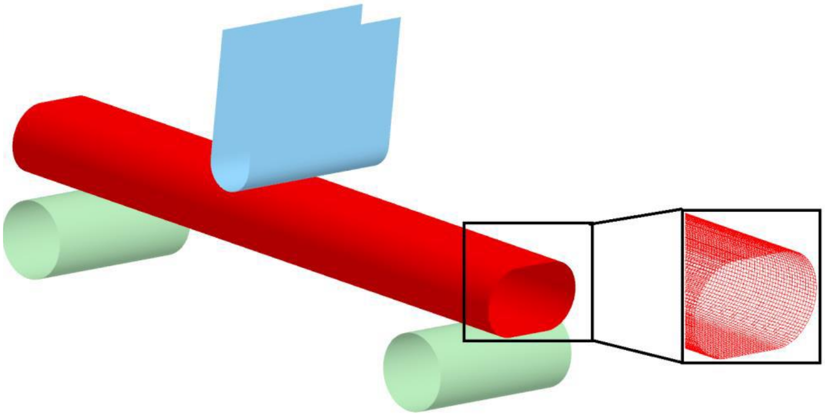

Fig. 6. Finite element model of the three-point bending process

Table 1. Finite element parameters of three-point bending process

Parameter	Value
Blank element size	1 mm
Number of blank elements	30500
Element formulation	Fully Integrated Shell Element
Number of integration point	7

Table 2. Mechanical properties of 6060 Aluminum alloy [12]

Parameter	Value
Modulus of elasticity (GPa)	51
Poisson ratio	0.33
Yield Strength (MPa)	111.8
Strength Coefficient	128.61
r_0	0.492
r_{45}	0.367
r_{90}	1.277

The Hill-48 model, which is the first anisotropic yield criterion, was used in two different versions as the material model in finite element analysis. In the first version, the plasticity parameters were calculated based on the yield stresses and this version was named Hill-48 (S). In the second version, the plasticity parameters were obtained depending on the anisotropy coefficients, and this version was named Hill-48 (r). The finite element analysis results are compared with the experimental forming force-punch stroke curves and are given in Fig. 7 and Fig. 8.

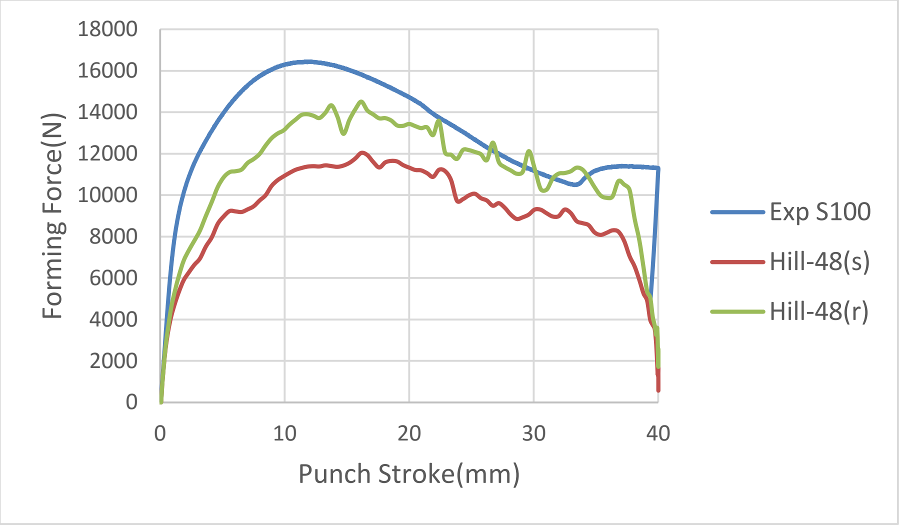

Fig. 7. Comparison of finite element analysis results with test results for 100 mm span distance

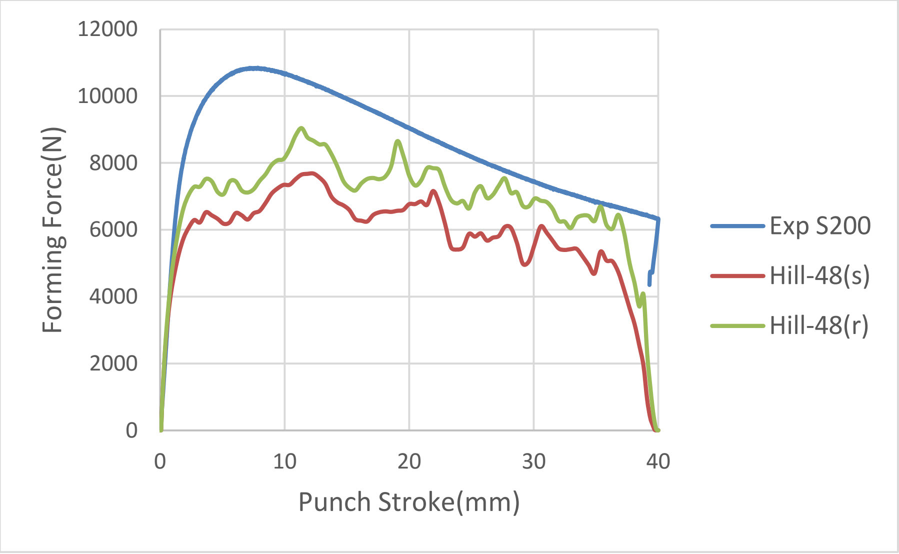

Fig. 8. Comparison of finite element analysis results with test results for 200 mm span distance

Finite element analysis results were evaluated on shaped geometries as well as forming force-punch stroke graphs. The deformed form of the profile with elliptical section geometry as a result of the finite element analysis and the experimentally obtained material forms are given in Fig. 9 and Fig. 10 with different span distances for 5 mm punch radius.

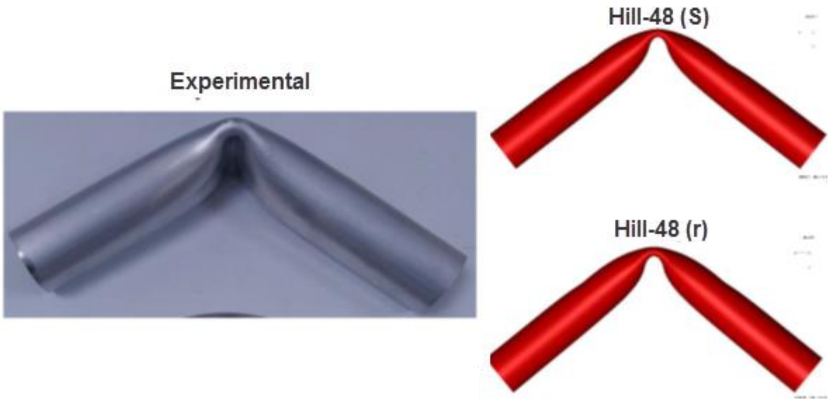

Fig. 9. Comparison of experimental and finite element analyzes of profile with elliptical section geometry with 100 mm span distance and 5 mm punch radius

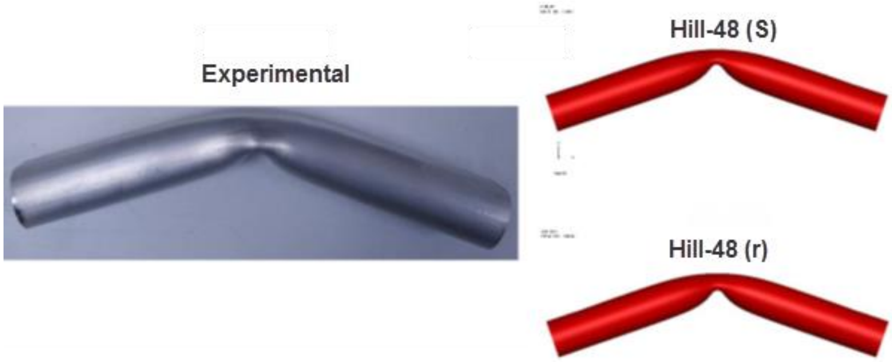

Fig. 10. Comparison of experimental and finite element analyzes of profile with elliptical section geometry with 200 mm span distance and 5 mm punch radius

4.CONCLUSIONS

In this study, profiles with elliptical cross-section geometry produced by extrusion method were investigated in experimental and finite element environments. Due to its low weight and high energy absorption capabilities, aluminum 6060 series alloy was used within the scope of the study and it was aimed to examine its usability as a side door impact beam and to examine the performance of plasticity models representing the plastic behavior of the material in the finite element environment. Side door impact beams have generally been subjected to three-point bending in research and testing. Therefore, within the scope of the study, three point bending tests were carried out using 100 mm and 200 mm support distances, 5 mm punch radius, constant speed and constant forming distance. As a result of the experiments carried out, forming force – punch stroke data, material forms after forming were obtained. Ls-Dyna/Dynaform commercial software was used to simulate the experiments performed in the next stage of the study with the finite element method. Stress-based Hill-48 (S) and anisotropy coefficient-based Hill-48 (r) plasticity models were used to determine the plastic behavior of materials in finite element analysis.

As a result of the experiments, it was determined that as the distance between the spans increases, the forming force decreases, and it is thought that this is due to the effect of the bending moment. When examined as forms after three-point bending, the angle between the two arms of the profiles exposed to bending increases as the distance between the spans increases. According to the results obtained as a result of the finite element analysis, it was determined that the Hill-48 (r) material model based on the anisotropy coefficient gave the accurate results to the experiments. When the results are summarized; It has been observed that the increase in the support distance has a dominant effect on the forming force.

REFERENCES

1. Nemani K. R. & Arakerimath R, Taguchi Based Design Optimization of Side Impact Beam for Energy Absorption, International Journal for Advance Research in Engineering and Technology, Vol:3, No: 9, 100-104, 2015.
2. Li M. F., Chiang T. S., Tseng J. H., Tsai C. N., Hot stamping of door impact beam, Procedia Engineering, 11th International Conference on Technology of Plasticity, 19-24 October 2014, Nagoya Congress Center, Nagoya, Japan, pp. 1786-1791, 2014.
3. Sookchanchai K. & Hlainh S.S & Uthaisangsuk V., A Geometrical Parametric Study of Side Door Reinforced Beams Under Lateral Impact Load, International Journal of Crashworthiness, Vol.:27, No: 6, 1662-1677, 2022.
4. Shaharuzaman M. A., Sapuan S. M., Mansor M. R., Zuhri M. Y. M., Passenger Car’s Side Door Impact Beam: A Review, Journal of Engineering and Technology, Vol.:9, No:1,2180-3811, 2018.
5. Xu H., Zhang M., Gu Z., Li X., Investigation on Hot Stamping Process for Door Beam of Ultra-High Strength Steel, International Journal of Enginerring Science and Innovative Technologhy, Vol.:3, No:1, 384-392, 2014.
6. Lim T.S., Lee D.G, Mechanically Fastened Composite Side-door Impact Beams for Passenger Cars Designed for Shear-out Failure Modes, Composite Structures, Vol.:56, 211-221, 2002.
7. Sun G., Pang T., Zheng G., Song J., Li Q., On Energy Absorption of Functially Graded Tubes Under Transverse Loading,ü International Journal of Mechanical Sciences, Vol.:115, 465-480, 2016.
8. Cerniauskas E., Kersys A., Lukosevicius V., Saproganas J., Investigation of Anti intrusion Beams in Vehicle Side Door. Mechanika, Vol.:6, No:86, 11-16, 2010.
9. Sonawane C.R & Shelar L.A., Strength Enhancement of Car Front Bumper for Slow Speed Impact by FEA Method as per IIHS Regulation, Journal of The Institution of Engineers, Vol.:99, No:5, 599-606, 2018.

10. Abdollah M., F., Hassan R., Preliminary Design of Side Door Impact Beam for Passenger Cars Using Aluminium Alloy, Center of Advanced Research on Energy, Vol.:5, No:1, 11-18, 2013.
11. Tanabe H., Yamazaki K., Akada H., Miyasaka A., Iwasaki T., High-Strength Steel Tubes for Automobile Door Impact Beams, Nippon Steel Technical Report., 55-60, 1995.
12. Liao J., Xue X., Barlat F. & Gracio J., Material Modelling and Springback Analysis for Multi-stage Rotary Draw Bending of Thin-walled Tube Using Homogeneous Anisotropic Hardening Model, International Conference on Technology of Plasticity, 1228-1233, 2014.