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ORIGINAL ARTICLE

Numerical study on energy absorbing characteristics of thin-walled tube under axial and oblique impact

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Abstract Energy absorbing characteristics (EAC) of thin wall tube during the impact are important in the automobile and aerospace industries. In this paper, energy absorbing characteristics such as mean force, peak force, energy absorption and crash force efficiency (CFE) of three different cross-sections (square, rectangular and circular) at three different thicknesses (2 mm, 2.5 mm and 4 mm) were analyzed. The analysis was accomplished using ABAQUS/EXPLICIT, and aluminum alloy (AA6063) was used as a shell material. The result of impact (or) crash-worthiness against axial load indicates that the circular cross section of 2.5 mm thickness is optimum. During the oblique (15°, 30°, 45°) impact, increasing the angle leads to less energy absorption. Also, Multilinear regression analysis was carried out to predict the energy absorption characteristics at 90°.

1. Introduction

Energy absorption is the ability of a material or section that absorbs energy or force during various mechanical loading conditions. Energy absorbing technique is the methodology to evaluate or identify the EAC such as crash force efficiency, specific energy absorption, peak force and mean force. This EAC of various cross-sections and materials are very much important in several applications especially in high speed automobiles that cause severe impact to the passengers and non-recyclable damage to the vehicles [1]. Furthermore, global increase in the usage of fossil fuels downs the overall weight of the car, thus increase the fatalities and collisions vice versa. Energy absorption technique predominantly covers applications such as automobile, aerospace, blast industries and recently overwhelming speed of automobiles and their light weight increases concern over the roadside poles and their relative structures [2–13]. Thiyahuddin et al. studied the impact and energy absorption of portable water-filled road safety barrier system fitted with foam. To prevent the vehicle collision on the temporary construction zone, they developed the portable barrier to prevent the accident. This numerical model consisted of a steel frame, water, plastic shell and foam which was developed and validated against the experimental test. The result indicated reduction in initial impact because the foam absorbed high energy. In addition to that using different foam materials such as polymeric foams, Aluminum foam, polyurethane foam and XPS foam revealed different energy absorption characteristics [14].

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Nomenclature

EAC	energy absorbing characteristics
CFE	crash force efficiency

Numerical method or finite element analysis is very useful for analyzing various optimization methods to reduce the material wastage, time and cost [15–17]. In this paper, numerical study of square, rectangle and circular cross-sections with three different thicknesses was analyzed and optimum parameter was found out. The main objective of this work was to study the EAC of square, rectangle and circular for required parameter with optimum time and low cost.

2. Materials and methods

2.1. Numerical study

Three types of sections were used in numerical simulation such as square, rectangular and circular. The tube material used in all numerical simulations is AA6063 aluminum alloy. In this work three different thicknesses (2 mm, 2.5 mm, 4 mm) were used. Also, in this simulation ABAQUS/EXPLICIT finite element code was used. The specification of the tube which is used for this simulation is given in Table 1. The numerical input values of aluminum alloys are given as density = 2.71 kg/m^3, Elastic modulus = 68,200 N/mm^2, Poisson's ratio = 0.3 and plastic or engineering stress–strain value is provided in Table 2. In this numerical work, three objects were considered that is moving rigid striker, deformable aluminum tube and fixed rigid plate. The boundary conditions were fixed in all direction for bottom rigid plate, moving one direction for top rigid striker, and other directions and rotations were fixed. Finally, deformable shell tube in between those rigid plates was stuffed. In the assembly of tube and rigid striker with different angles of 0°, 15°, 30° and 45° with respect to the axis of the tube. The analysis type was given as DYNAMIC/EXPLICIT crash simulation. The contact between tube and rigid plate was given as tangential behavior of rough contact and there is no penetration between them. The moving rigid striker's velocity is 2 m/s parallel to the axis of tube. The thin wall tube was modeled by using quadrilateral element with structured mesh and element size of 2.5 mm was chosen for the tube(or) shell based on the mesh convergence study.

2.2. Statistical study

In this study, an attempt has been made to predict the crash force for 90° with aid of displacement and crash force data of 15°, 30° and 45° angle. Here, MINITAB is used as statistical tool in order to evaluate or predict the crash force of 90°. Multilinear regression analysis was chosen for this study and the generalized equation can be given by Eq. (1),

$$Y = AX_1 + BX_2 + C \tag{1}$$

where

A and B are slope of regression line
X_1 and X_2 are independent value (or) variable
C is intercept

For this study, displacement and angle were taken as independent variables denoted as X_1 and X_2. The value that is to be predicted as the dependent variable is the crash force which is denoted as Y.

$$Y = 357\ \text{Displacement (mm)} - 495\ \text{Oblique (Degree)} + 55,552 \tag{2}$$

$S = 20203.8 \quad R - \text{Sq} = 57.78\% \quad R - \text{Sq(adj)} = 57.64\%$

where

S = Standard deviation of error term

$R - \text{Sq}$ = Coefficient of determination

$R - \text{Sq(adj)}$ = need to go for next polynomial order

The predicted equation by statistical technique indicated negative impact on the dependent variable Y. So whenever the angle changes, the dependent variable crash force varies negatively.

Table 2 Stress strain value of aluminum alloy.

Yield stress	Plastic strain
80	0
115	0.024
139	0.049
150	0.079
158	0.099
167	0.124
171	0.149
173	0.174

Table 1 Geometrical properties of three different cross-sections.

Profile	Length (mm)	Dimension (mm)	Perimeter (mm)	Thickness (mm)
Square	245	80 × 80	320	2, 2.5, and 4
Circular	245	D = 102	320	2, 2.5, and 4
Rectangular	245	95 × 65	320	2, 2.5, and 4