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Selection of the optimal holed structure in the axial loading of aluminum thin-walled tubes using the COPRAS method

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Abstract
The use of holed designs in the manufacturing of thin-walled cylindrical metallic tubes is very common as a suitable option for absorbing energy. In this research, six different geometric designs have been presented to investigate the energy absorption capability of cylindrical thin-walled tubes made of aluminum alloy. The COPPRAS multi-criteria decision-making method has been used to select the best geometric design. Initial peak force (IPF), total absorbed energy (E_t), and the specific energy absorption (SEA) of the tubes were considered as selection criteria for the best alternative. The obtained results showed that the holed tube with unequal circular holes arranged one in the middle is the best option for absorbing energy while simultaneously considering all the criteria. In this optimal design, the arrangement of circular holes is one in the middle with 3 rows of holes, 8 holes in each row, a diameter of the small hole of 5 mm, and a diameter of the large hole of 6 mm. In this tube, the IPF, E_t, and SEA values were obtained as 32.04 kN, 1.20 kJ, and 20.88 kJ/kg, respectively.

Keywords: Holed tubes; Energy absorption; Axial loading; COPRAS method; Ranking.

1. Introduction

The aim of multi-criteria decision-making (MCDM) methods is to select the best option among several alternatives with simultaneous attention to several criteria [1]. Some of the most important MCDM methods are TOPSIS [2], MOORA [3], VIKOR [4], and COPRAS [5]. It is common to use holed thin-walled tubes in vehicles as energy absorbers under axial compression. Different energy absorption properties including the IPF, E_t, and SEA should be considered in the selection of the most proper structure of these tubes [6-8].

In this paper, the COPRAS method is applied to select the best holed structure in the axial compression of thin-walled tubes made of aluminum alloy. Six tubes with four different designs including perforated with regular non-size holes, perforated with irregular non-size holes, perforated with same-size holes, and solid without holes were assumed to be alternatives. On the other hand, the IPF, E_t, and SEA of tubes were considered as selection criteria.

2. Experiments

In this research, AA6061 holed tubes were used for axial compression experiments. The cross-section of the tubes and their holes is circular. Table 1 shows the geometrical dimensions of the used tubes. A SANTAM press machine with 250 kN capacity was used for performing the experiments. Six tubes with a total of four types of designs were considered. Figures 1-4 illustrate the schematic of the considered designs. It should be noted that NR, NH, SD, and BD are the number of rows, the number of holes in each row, the small diameter, and the big diameter of the holes. Tubes 1 and 2 are perforated with regular non-size holes while the number 1 is NR3:NH6:SD4:BD:4.8 and the number 2 is NR7:NH6:SD5:BD:7. Tubes 3 and 4 are perforated with irregular non-size holes while the number 3 and the number 4 are NR3:NH8:SD5:BD:6 and NR3:NH12:SD5:BD:7, respectively. Also, tube 5 (NR5:NH6:SD6:BD:0) is perforated with same-size holes, and tube 6 is solid without holes. Eqs. (1) and (2) were used to measure the E_t and SEA [8]. Also, the IPF implies the first peak of the force-displacement curve. In the equations, P, L, and m are the applied force, displacement, and mass of the tube, respectively.

Table 1. Geometrical dimensions of the used tubes

Parameter	Value (unit)
Thickness	2 (mm)
Outer diameter	55 (mm)
Length	96 (mm)

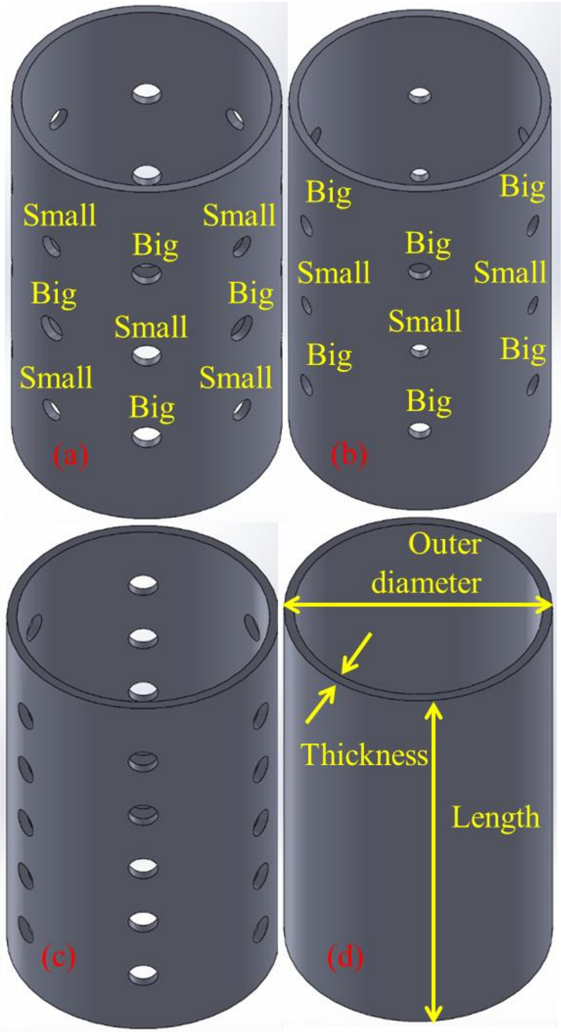

Figure 1. (a): Perforated tube with irregular non-size holes, (b): Perforated tube with regular non-size holes, (c): Perforated tube with same-size holes, (d): Solid tube without holes

$$E_t = \int_0^L P(x)dx \tag{1}$$

$$SEA = \frac{\int_0^L P(x)dx}{m} \tag{2}$$

3. COPRAS Method

In this research, COPRAS (Complex Proportional Assessment) method was applied for selecting the best holed design in the axial compression of AA6061 thin-walled tubes. In this method, the first step is to form a decision matrix. Then, the decision matrix will be dimensionless by Eq. (3). In the following, the values of the dimensionless matrix are multiplied by the weight of each criterion to form the weighted matrix (Eq. (4)). In this research, a same weight of 0.333 was considered for all three energy absorption criteria. In the next step, the sum of positive criteria and the sum of negative criteria for each alternative are determined using Eqs. (5) and (6), respectively. In this research, the IPF is a negative criterion, and the E_t and SEA are positive criteria. Then, the comprehensive evaluation value of each alternative is calculated using Eq. (7). In the last step, the comprehensive score of each alternative is determined using Eq. (8). The best selection will be assigned a value of 100 and the worst will be assigned a value of 1 [5]. It should be noted that in the above equations, parameter i is the number of alternatives (m=6) and parameter j is the number of criteria (n=3).

$$R = [r_{ij}]_{m\times n} = \frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}} \tag{3}$$

$$D = [y_{ij}]_{m\times n} = r_{ij} \times w_j \tag{4}$$

$$S_i^+ = \sum_{j=1}^{n} y_{ij}^+ \tag{5}$$

$$S_i^- = \sum_{j=1}^{n} y_{ij}^- \tag{6}$$

$$Q_i = S_i^+ + \frac{S_{min}^- \sum_{i=1}^{m} S_i^-}{S_i^- \sum_{i=1}^{m} (S_{min}^-/S_i^-)} \tag{7}$$

$$U_i = \frac{Q_i}{Q_{max}} \times 100\% \tag{8}$$

4. Results and Discussion

Figure 5 shows the force-displacement curves of the six tubes (alternatives) after axial compression experiments. All the criteria i.e. IPF, E_t, and SEA were then measured for all the alternatives. Then, the results were analyzed using the COPRAS method and the ranking result is depicted in Figure 6. As is seen, tube number 3 was selected as the best alternative. This tube design is NR3:NH8:SD5:BD:6 and its outputs are IPF=32.04 kN, E_t=1.20 kJ, and SEA= 20.88 kJ/kg.

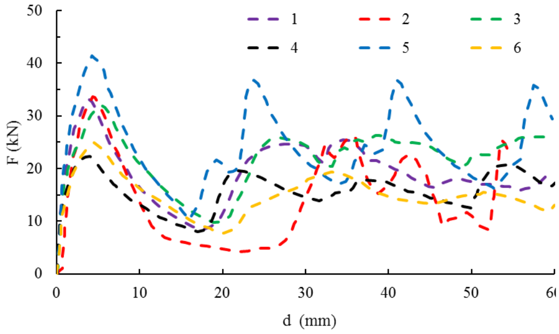

Figure 5. Force-displacement curves of the six tubes (alternatives)

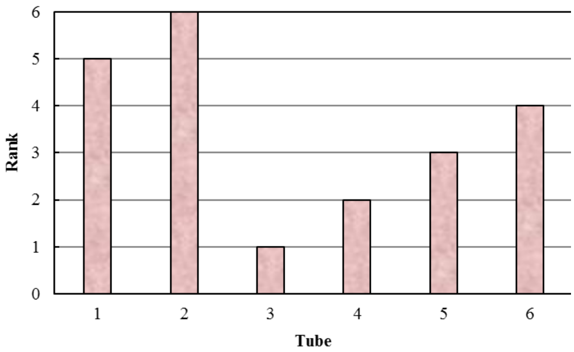

Figure 6. Ranking result using the COPRAS method

5. Conclusions

This research used the COPRAS method to select the best holed structure in the axial compression of AA6061 thin-walled tubes. The decision problem was considered with 6 alternatives and 3 criteria (energy absorption properties). The results showed that if the IPF is separately considered, tube number 4 (NR3:NH12:SD5:BD:7) is the best selection. For separately considering the E_t, and the SEA, tubes number 5 and 3 are the best selection, respectively. All in all, by simultaneously considering all the criteria, tube number 3 (NR3:NH8:SD5:BD:6) is the best selection. In this design, the IPF, E_t, and SEA are 32.04 kN, 1.20 kJ, and 20.88 kJ/kg, respectively.

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