Design of the Brake Device Using the Axial Crushing of Truncated Cone Type Cylinder

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A brake device for the high-speed impacting object is designed using an axial crushing of thin-walled metal cylinder. Thickness of the cylinder is increased smoothly from the impacting end to the fixed end, resulting in the truncated cone shape. Truncated cone shape ensures that plastic hinges are formed sequentially from impacting end. This increases the reliability of brake device working. Computational and real experiments were performed to verify the effects of conical angle. Results indicate that undesirable sudden rise of crushing load can be prevented by applying appropriate conical angle.

Keywords : Brake Device, Truncated Cone Type Cylinder, Plastic Deformation, Conical Angle.

1. INTRODUCTION

There have been many researches on using axial crushing behavior of round or square tubes as shock absorbing devices[1-3]. Despite its simple structure and high energy absorption capacity, it is well known that axially loaded cylinders are notoriously imperfection-sensitive structures and first peak load is usually much greater than subsequent peak loads due to global elasto-plastic buckles occurring just prior to the first wrinkle formation[4,5].

To overcome such shortcomings, truncated cone type cylinder, thickness of which is increased smoothly from the impacting end to the fixed end, is proposed.

2. BASELINE DESIGN

2.1 Requirements for brake device

Basic requirement for the cylindrical brake device is its mean axial crushing load(P_m). It is determined from the equilibrium of kinetic energy of the impacting object and work done by braking device during compression.

$$P_m = \frac{1}{l_b}\left(\frac{1}{2}mv^2\right) \qquad (1)$$

where m and v are mass and velocity of the impacting object, respectively, and l_b is allowable braking distance. Table 1 shows specification of the impacting object and following requirements for brake device, which used in this study.

2.2 Materials

Three types of materials are considered: Solution treated stainless steel(AISI 304), AISI 304 with no heat treatment, and mild steel(AISI 1020).

2.3 Design parameters

Figure 1 shows design parameters of truncated cone type brake device. Mean thickness of the cylinder is determined using the equation proposed by Jones and Abramowicz[6], which relates the mean axial crushing force of the cylinder with the thickness and radius of the cylinder, and yield stress of the material. From the equation, required mean thickness of the cylinder is found to be 1.2 mm. Conical angle is set to 0.5°, considering manufacturability.

3. Experiments

3.1 Specimens

Static axial compression tests for the several truncated cone type brake devices have been performed to verify influences of the conical angle, thickness, and material property to the crushing load of the cylinder. Dimensions of the specimens manufactured for static axial compression tests are listed in table 2. SPEC1 is the baseline model.

3.2 Results & discussions

Figure 2 and 3 show the load-displacement curves during compression and final deformed shape of specimens, respectively. Due to the conical angle, first plastic wrinkle always occurs at the impacting end, and there is no global elasto-plastic buckling. So first peak load is smallest of all peak loads and subsequent peak loads increase, as the compression proceeds. Conical angle determines this rate of peak load increment.

Conical angle also affects the sequence of wrinkle generation. In case of SPEC1, first to fifth wrinkles are generated sequentially from the impacting end. But next two wrinkles are initialized simultaneously (see Fig. 5). Among two, the one near the fixed end is completed first, and the other. Such simultaneous generation of wrinkles is not desirable, because it leads to the increase of the peak load. When plastic wrinkles are forming at the upper part of the cylinder, there is also change in thickness and radius of the lower cylinder due to plastic deformation(see Fig. 3, SPEC2 & 3). So the effect of the conical angle decreases as the compression proceeds. This is the reason of the simultaneous wrinkles generation observed at the lower part of SPEC1 and SPEC2 specimens. To prevent such phenomenon, conical angle needs to be increased(SPEC3) or other material with higher yield stress needs to be used. Although dimension of SPEC4 is identical to SPEC1, there is no simultaneous wrinkles generation in SPEC4. As yield stress of AISI 304 with no heat treatment is about 2 times higher than AISI 304 with heat treatment, lower part of the cylinder is not affected by the wrinkle generation at the upper part. So the effect of conical angle is maintained during compression.

In case of SPEC5, there was fracture of the specimen after 4th wrinkle generation. Very low elongation(15%) property of AISI 1020 is the cause of this fracture[7].

By integrating load-displacement curve, energy dissipation capability of each specimen can be obtained. Comparing this with the kinetic energy of impacting object, total braking distance of each specimen is estimated in table 3. SPEC1 shows smallest mean crushing load and longest braking distance, which is most desirable characteristics of braking device.

3.3 Finite element analysis

Experimental results are compared with finite element analysis results obtained using ABAQUS/Standard commercial FEA package. Load-displacement curve and deformatio , shape of SPEC1 from FEA show fairly good similarity with experimental results(Fig. 4 and 5).

4. CONCLUSION

From the static axial compression tests for the truncated cone type brake devices, it was verified that truncated cone shape has the effect of preventing simultaneous wrinkles generation (or global elasto-plastic buckling) and undesirable sudden rise of crushing load. Accuracy of the FEM analysis was also verified.

5. REFERENCES

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Table 1 Requirements for brake device

Impacting Object		l_b (mm)	P_m (ton)
m (kg)	v (m/s)		
1.0	30.0	40.0	1.15

Table 2 Specimen details (L=100.0 mm, R_t=7.5 mm)

	Material	t_t/t_b (mm)	θ_c (deg)	Heat treatment
SPEC1	AISI 304	0.8/1.6	0.5	Solution treated
SPEC2	AISI 304	1.2/2.0	0.5	"
SPEC3	AISI 304	0.8/2.4	1.0	"
SPEC4	AISI 304	0.8/1.6	0.5	As received
SPEC5	AISI 1020	1.0/3.4	1.5	"

Table 3 Summary of braking forces and estimated braking distances

	SPEC1	SPEC2	SPEC3	SPEC4	SPEC5
l_b (mm)	28.7	18.4	26.4	25.1	15.2
P_m (ton)	1.11	1.73	1.21	1.27	2.10
P_{max}	2.75	3.70	2.80	3.02	4.50

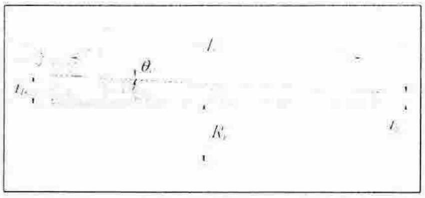

Fig. 1 Shape design parameters of truncated cone type brake device

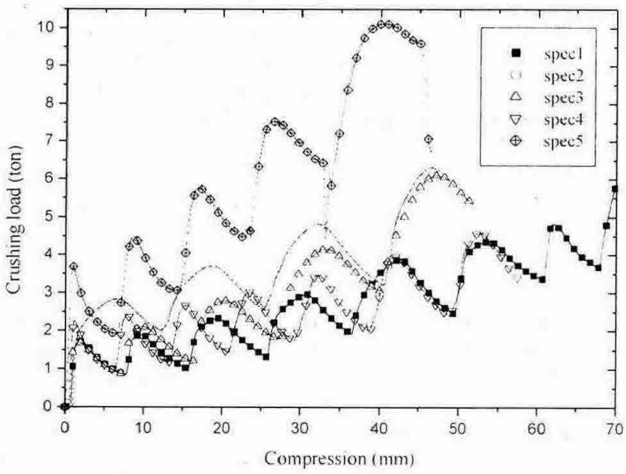

Fig. 2 Load-displacement curves of specimens (experiments)

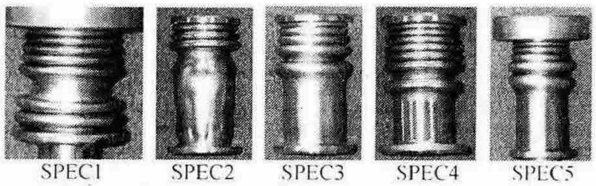

Fig. 3 Final deformed shapes of the specimens

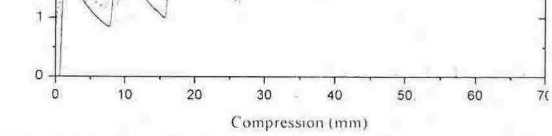

Fig. 4 Crushing load of SPEC1 (experiment vs. FEM)

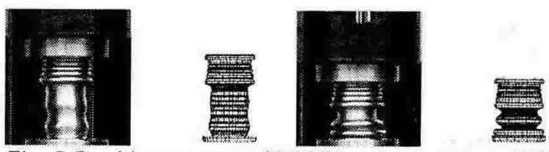

Fig. 5 Crushing process of SPEC1 (experiment vs. FEM)