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The Behavior of Thin-Walled Cylinders with Ribs Regarding the Energy Absorption Capability on High-Velocity Impact

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Abstract. Many industries and automotive companies use thin-walled cylinders as energy-absorbing devices. Researchers have previously investigated various parameters related to thin-walled cylinders and their behavior under impact loads. When the impactor hits the thin-walled cylinder from the axial direction, it causes the bending of the cylinder wall on an axisymmetric or non-axisymmetric pattern, depending on the ratio of diameter divided by wall thickness. In addition, the length of the specimen influences the deformation mode that occurs. This study discusses how installing ribs on the cylinder walls affects energy absorption capabilities. We conducted the research by making modeling based on the finite element method by making various specimens according to the experimental scenarios. We experimented with an aluminum alloy cylinder with a diameter of 50 cm, a thickness of 1.5 mm, and a length of 200 mm. Then, successively, we installed ribs with a length of 2 mm and a thickness of 3.5 mm, one rib, two ribs, three ribs, four ribs, and five ribs. The impactor hits the specimen from the axial direction to one end at high speed while the other is given fixed support. The results obtained from the experiment are total deformation, reaction force, absorbed energy, and deformation pattern. The experimental results show that adding ribs changes the deformation pattern from previously non-axis-symmetric to axis-symmetric. The total deformation decreases, the reaction force becomes smaller, and the ability to absorb energy equals the total kinetic energy. This result is a recommendation for manufacturing in an energy absorption structural system.

Introduction

Thin-walled structures have been widely used in impact energy absorption. This occurs because thin-walled structures have a unique behavior concerning energy absorption. Automotive technology has long used thin-walled structures as frames that not only make the structure lighter but also improve its ability to absorb energy.

Research related to railway vehicles by adding a crash box to the Indonesian high-speed train and testing using FEM on the 2019 SNI 8826 standard. The simulation results show that installing a crash box can reduce the damage due to impact and improve passenger safety [1]. Computer modeling is used to analyze impacts on city cars with ANSYS LS DYNA, obtaining a safe chassis structure from the side of max deformation according to MFSS (Motor Vehicle Safety Standard) [2]. In addition, various methods of energy absorption in automotive systems have also been studied. [3]. In automotive, some parts are deliberately sacrificed during a collision. It must absorb as much energy as possible while protecting passengers. Research on improving design crashworthiness by controlling energy absorption in different collision situations obtained an optimal design. [4]. In addition, aluminum composites are also used to enhance crashworthiness performance in analyzing aluminum tube composites in automotive use [5], including filling the tube with rubber and leaving it empty [6].

In an impact structure, energy results from force multiplication and deformation. A good system has a low and uniform reaction force throughout the collision. In addition, deformation is also attempted long enough so that the energy absorbed is considerable. [7] When a thin tube gets an axially impeping force, there will be a bend in the wall. This wrinkle is axisymmetric or non-axisymmetric depending on the ratio of diameter and wall thickness [8]

Experimental and numerical studies related to thin aluminum tubes were also carried out and obtained compatibility between simulation and testing [8]. The shape of the cross-section dramatically affects the energy absorption ability of thin-walled prisms. The circle has the best power of the various cross-section shapes 9]. Some of the research on the response of thin-walled tubes to impact includes behavior under different dimensional and loading conditions [11], buckling dynamics on shell cylinders when exposed to impact loads [11], And analysis of aluminum tubes with and without caps [13]. Energy absorption on thin walls occurs by the method of folding walls in various types of equipment [14]

The effect of impact speed on reaction force, deformation mode, and deformation length on thin aluminum tubes has been studied. In general, high rates cause less deformation than low speeds [15] Selain itu higher initial impact velocity could enlarge the absorbed energy because of compressive deformation just after impact, as indicated by the FEA [16]

Applying multiple segments in the cylinder has improved the energy absorption ability[17]. Multi-cell hexagonal crash box using the Taguchi method with the quality characteristics of the ability to absorb impact energy significantly better, namely the position of the hole (P), inner wall, hole position distance, crash box thickness, and hole diameter. The thickness of the crash box (t) has the highest contribution of 98.10% in increasing the impact energy absorption value [18]. Research on Two Segment Crash Box Optimization using rubber joints with the Response Surface Methodology method to get optimal deals compared to only one segment [19]. In addition, rubber variations are also carried out to determine their effect on maximum energy absorption [20].

The use of lattice structures also increases energy absorption, as in the Experimental and numerical crushing performance of crash boxes filled with re-entrant and anti-tetrarchical auxetic designs [21] and multi-cell tubes [22]

In several studies, stiffeners were used to improve energy absorption performance and obtain the effect of stiffeners on thin-walled tubes made of composites on lateral loading [23]

Research on the effect of ribs on aluminum tubes was carried out experimentally, and simulations found that the presence of ribs could control the behavior of the tubes when getting impact loading [24]. This study discusses The Behavior of Thin-Walled Cylinders with Ribs Regarding the Energy Absorption Capability on High-Velocity Impact. By adding ribs, we expect a change in deformation mode to control the specimen's behavior to get the best performance.

Methodology

The research was carried out by the following method. We are modeling aluminum cylinders with a length of 200 mm, diameter of 50 mm, and thickness of 1.5 mm. The impactor is steel measuring 75 mm x 75 mm x 50 mm, as shown below.

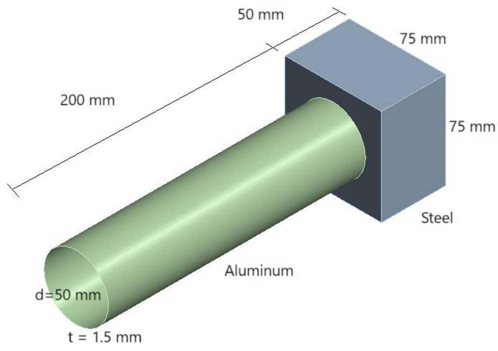

Fig. 1 Specimen and Impactor

Ribs having a thickness of 3.5 mm are installed around the walls of the tube. We make eight specimens consisting of no ribs, one rib, two ribs, three ribs, four ribs, five ribs, six ribs, and seven ribs mounted at equal distances along the specimen.

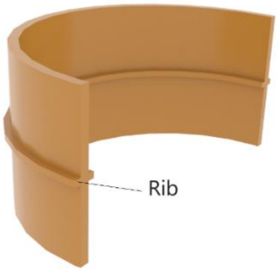

Fig. 2 Rib

Discretization or meshing divides the structure into small elements with a finite number.

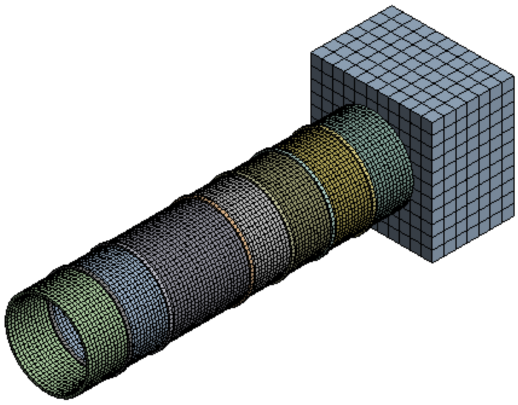

Fig. 3 Meshing

One end of the specimen is fastened with a fixed pedestal, and a steel impactor impacts the other. A steel collider weighing 2.2078 kg hit the model from the axial direction at 50 m/s. The final result of the experiment is as follows.

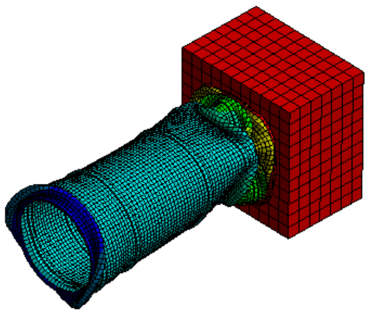

Fig. 4 Result

This analysis obtains each specimen's maximum deformation value, maximum reaction force, absorbed energy, and deformation mode.

Table 1 Material Properties

Properties	Specimen	Impactor
Material	Al 6063	Structural Steel
Young's modulus (GPa)	68.3	211
Yield stress (MPa)	245	
Poisson Ratio	0.3	0.3
Tensile strength (MPa)	295	
Density (kg/m3)	2710	7850

Result and Discussion

The impactor hits the specimen in the axial direction at a speed of 50 m/s. The reaction force response as a function of time is shown in the following Fig..

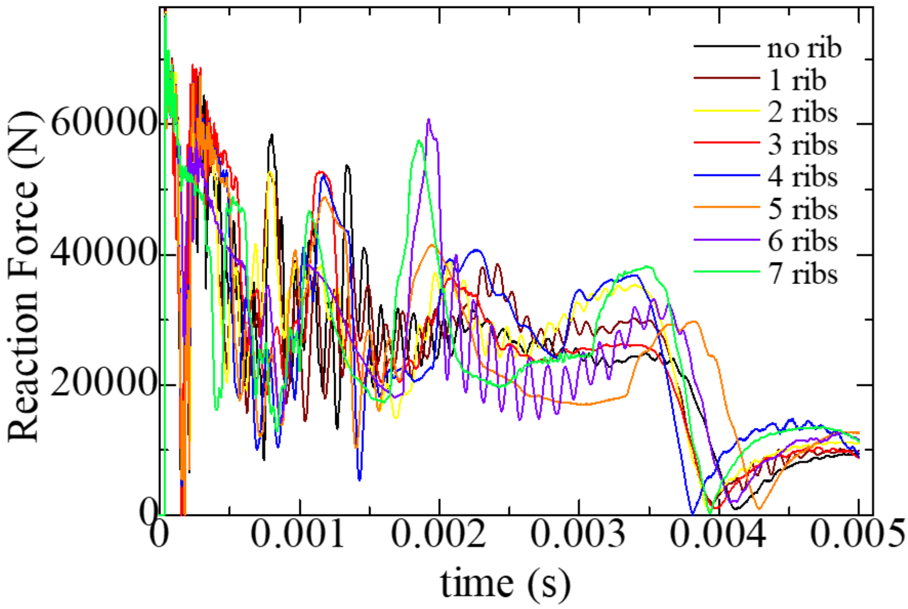

Fig. 5 Reaction Force History

Fig. 5 represents reaction force history. During the energy absorption process, the reaction force must be constant and not too fluctuating. This study measured the reaction force at 0.005 seconds until the entire energy absorption process was completed. The maximum reaction force is kept low and maintained constant during the energy absorption process [7]

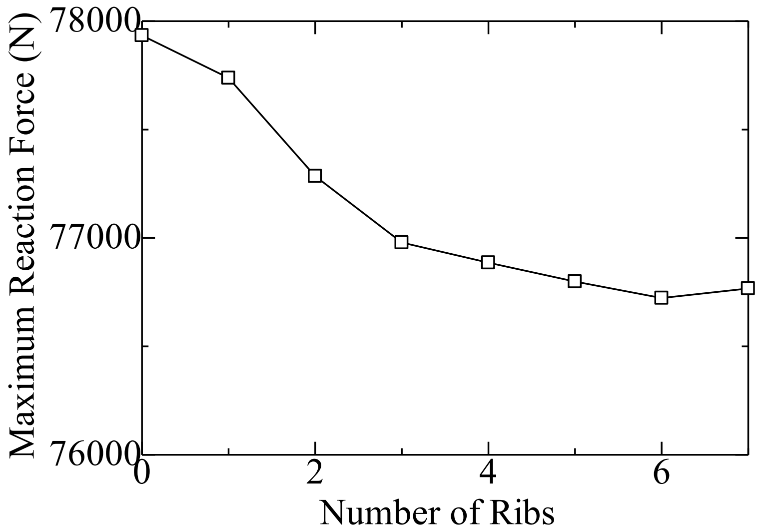

Fig. 6 Maximum Reaction Force

Maximum Reaction Force, or Initial Peak Force (Pmax), is the ultimate force on the specimen during loading. An energy-absorbing structure must have a relatively small P_{max}. In Fig. 6, it can be seen that the greater the number of ribs, the smaller the maximum force that occurs.

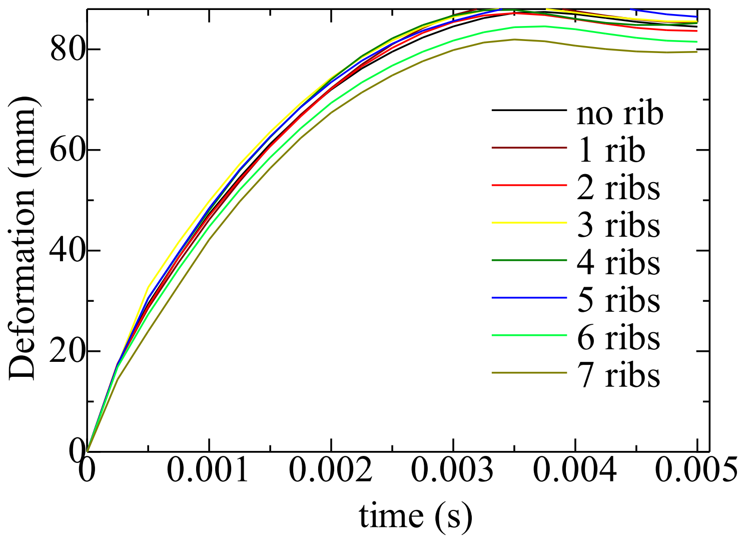

Fig. 7 Deformation History

After the collision is complete, the specimen undergoes permanent plastic deformation. Fig. 7 shows the deformation history of all models with a time of 0.005 seconds.
Fig. 8 shows the maximum deformation on all specimens. The greater the number of ribs that occur, the ultimate tendency to deformation decreases.

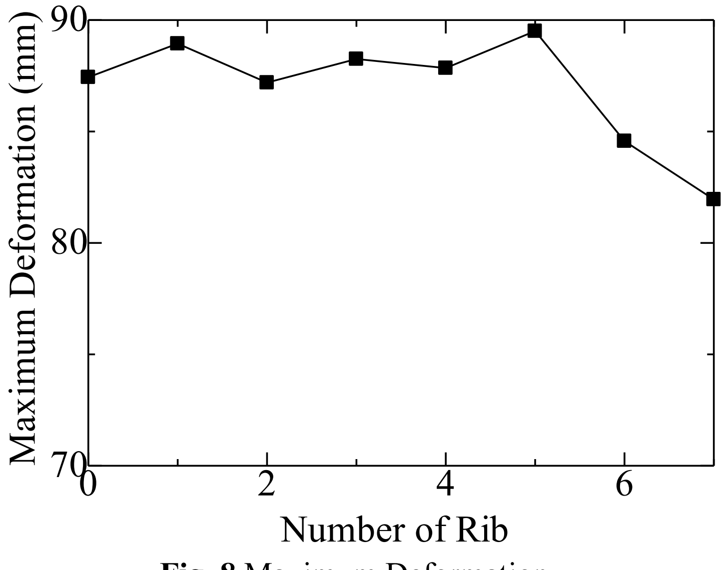

Fig. 8 Maximum Deformation

The absorbed energy is the area under the force curve as a deformation function occurs during specimen deformation, both elastic and plastic deformation. Plastic deformation predominates at the time of energy absorption. Absorbed energy (EA) is formulated as follows:

$$EA = \int_0^d P(\delta)d\delta \tag{1}$$

Where P is the force and δ is the deformation that occurs during the crushing process.

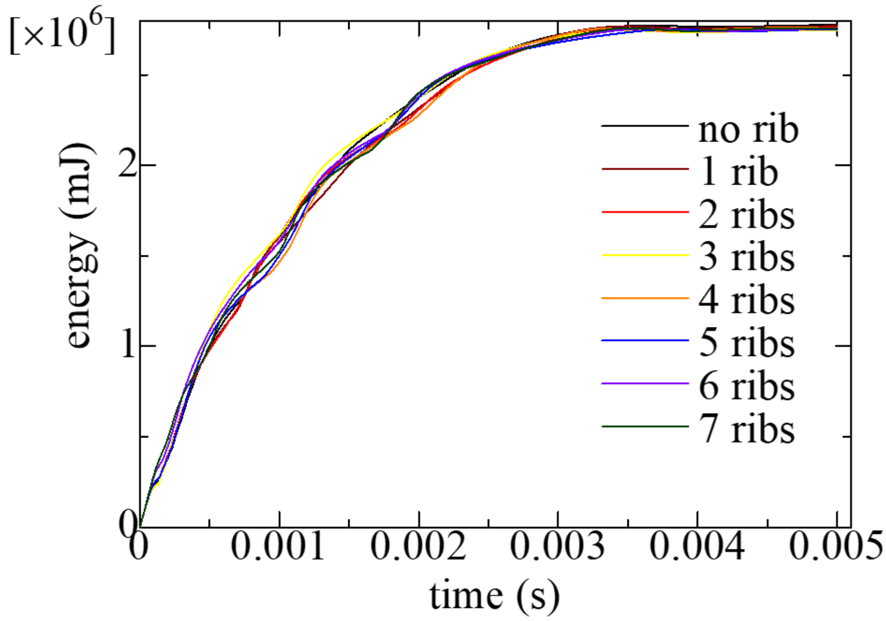

Fig. 9 Energy Absorption History

Maximum energy is defined as the energy absorbed until the crushing process ends. The following Fig. is the ultimate energy in each specimen.

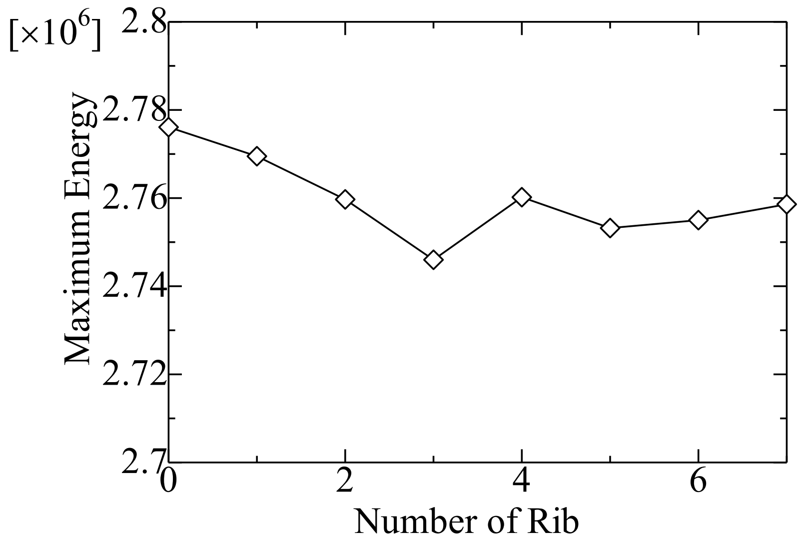

Fig. 10 Maximum Energy

The Mean Crushing Force or MCF parameter is defined as EA divided by the maximum deformation of the specimen (δ). It is formulated as follows.

$$MCF = \frac{EA}{\delta} \tag{2}$$

Fig. 11 represents the MCF on all specimens. MCF is the average force required during the energy absorption process. When a thin-walled cylinder is exposed to an impact force, it usually fluctuates due to bending on the thin wall. A large MCF indicates the average force required in an energy absorption process.

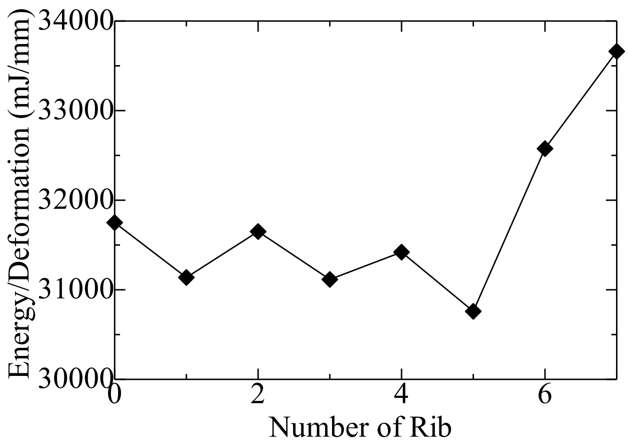

Fig. 11 MCF as Energy/ Deformation

The following parameter is Crush Force Efficiency (CFE), which compares MCF with P_{max}. It is defined as follows.

$$CFE = \frac{MCF}{P_{MAX}} x\ 100\% \tag{3}$$

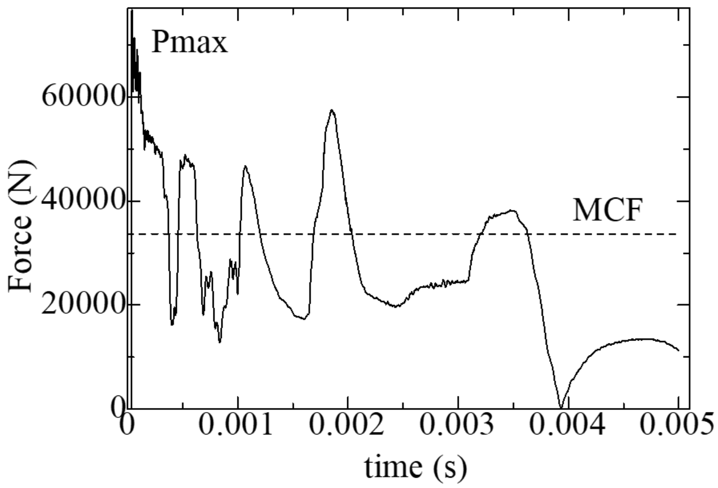

Fig. 12 P_{max} and MCF

The following is a graph of CFE on all specimens that have been examined in this study.

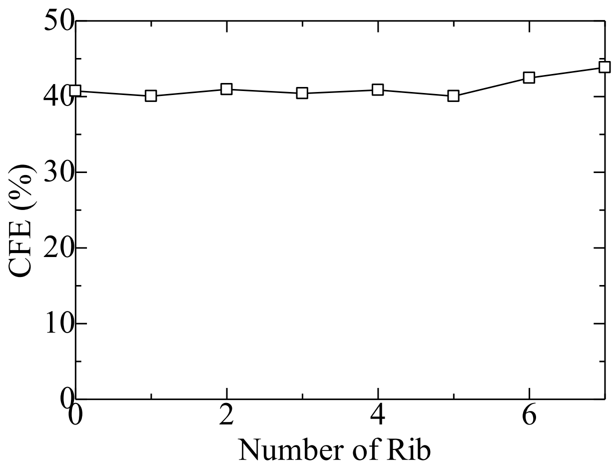

Fig. 13 Crush Force Efficiency (CFE)

Specimen 8 (7 ribs) has the most considerable CFE value, indicating this specimen can absorb energy optimally and uniformly during crashworthy structures [25]
SEA (Specific Energy Absorption) is defined as the absorbed energy divided by the mass of the specimen. Formulated as:

$$SEA = \frac{EA}{m} \quad (4)$$

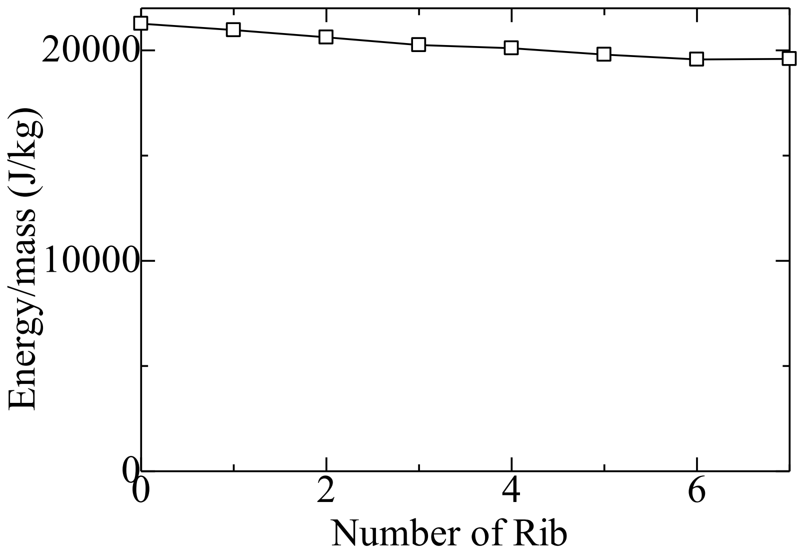

Fig. 14 SEA (Specific Energy Absorption)

As the number of ribs increases, the specific energy absorption decreases. This is because the installation of ribs also increases the mass amount of the specimen.

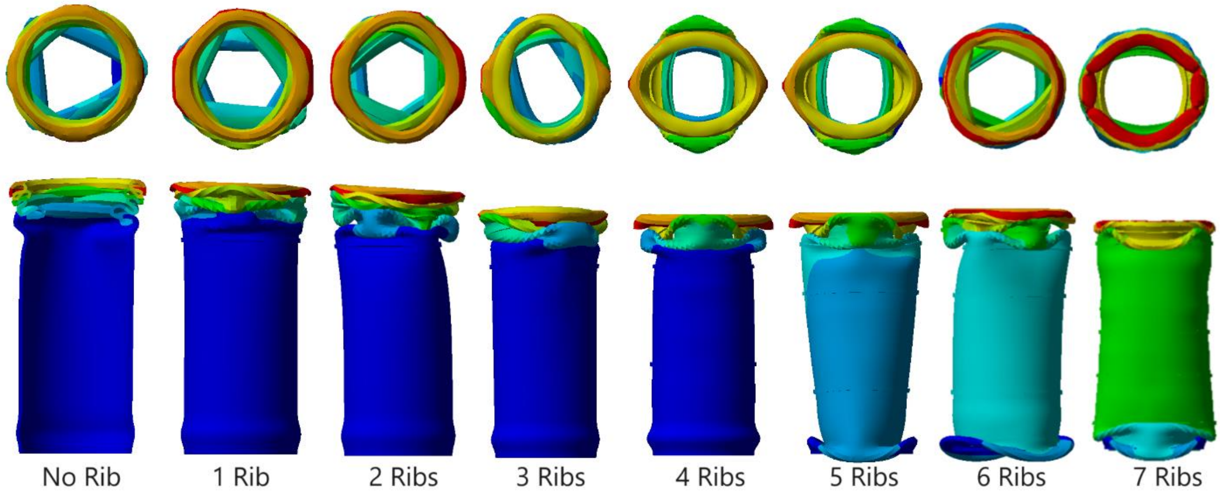

Fig. 15 Deformation Mode

Fig. 15 shows the deformation mode on all specimens after undergoing plastic deformation. More ribs tend to deform modes of axisymmetry than others. This is because ribs block the occurrence of non-axis-symmetry deformations. The presence of ribs makes the tube wall bend by axisymmetry [24]

Conclusion

Our research by placing stiff ribs on thin-walled cylinders has been shown to affect the ability to absorb energy. Stiff ribs can change the deformation mode from non-axisymmetric to axisymmetric. The placement of ribs can regulate the characteristic ability of energy absorption.

The maximum reaction force decreases with increasing number of ribs, as does the total deformation. The mean crushing force experienced a significant increase in ribs equal to seven. Crush force efficiency has increased, and specific energy absorption has decreased. This result is a recommendation for manufacturing crash boxes as impact energy-absorbing structures.

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