Design and FEM Calculation of New Foldable Bathtub

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Keywords: Foldable bathtub, Design, Stepped sidewall, FEM.

Abstract. In order to solve the contradiction between the increasing demand for bathtub and the large space occupied by traditional bathtubs in small or medium-sized bathroom, a new idea that design of collapsible bathtub was presented. The foldable bathtub adopted with stepped sidewall thickness and non-toxic, tasteless and easy to deform silicone rubber material to realize the folding. The finite element method was used to calculate the stress and deformation of bathtub under hydrostatic pressure. The results show that the rectangular section bathtub in two kinds of cross-section shape bathtub is more suitable for family use, while the round section bathtub is suitable for small size cases such as children and pets. The new bathtub is simple in structure, safe in folding process, small in volume after folding, light in weight and easy to carry. It provides possibility for popularizing sanitary ware in small and medium-sized apartments.

Introduction

With the progress of science and technology, people's living standard and the pursuit of quality of life are improving. Family sanitary bath, especially bathtub bath, besides its cleaning function, also has the function of promoting human body blood circulation, eliminating fatigue and so on. So the market of bathroom equipment bathtub which has been favored by consumers is expanding [1,2]. The highest sales are fiberglass, acrylic bathtub, whose annual sales reached 300,000 pieces [3]. However, traditional bathtubs are hard, bulky and especially laborious to move and store, which makes it not easy to utilize a large amount of space in bathroom. Nowadays, how to save living space has become a hot topic, and the traditional bathtub cannot be widely used in small and medium-sized houses due to the above shortcomings. In response to the contradiction between the increasing demand for bathtubs and too much space taken up by traditional bathtubs, this study presents a new design-foldable bathtub to solve above problem. The new bathtub can be folded and stored when not in use, greatly reducing the space occupied. At the same time, it will also reduce the use of materials such as fiberglass, ceramics, and acrylic, providing the possibility for popularization of bathtubs.

Dimensions and Structural Design of the Foldable Bathtub

Overall Dimensions

Referring to the size of most mid-sized bathtubs in the market and considering the use of human body in the bathtub, the dimensions of bathtub designed are shown in Figure 1, with length, width and height of 1500,720 and 580 mm respectively.

Foldable Part Structure of Bathtub Side Wall

The design utilizes stepped side wall thickness of bathtub. The thin side wall between two thick side walls is as a foldable layer, which can be folded. The shape and size of the fully unfolded side wall is shown in Figure 2, where the thin-wall thickness is 10 mm, the thickness of the thick-wall thickness 25 mm. The thin wall is easily bent and deformed and the two layers of thick wall are overlapped to
achieve folding. The diameter decreases from top to bottom of the corrugated lateral wall of the bathtub. The three-dimensional modeling of the folding and unfolding bathtub is shown in Figure 3.

![Figure 1. Medium-sized bathtub.](image1)

![Figure 2. Diagram of Side wall unfolding.](image2)

![Figure 3 3D modeling for unfolding and folding bathtub.](image3)

**Anti-rollover Bracket and Drain**

Because the shape of the bathtub gradually decreases from top to bottom and its mass is light, it is possible to overturn when used alone. Therefore a rigid plastic stand (1560x780x500mm) was designed to prevent the bathtub from overturning with detachable four-legs, as shown in Figure 4 (a). In actual use, in addition to solving the problem of overall overturning due to the change of gravity center of the bathtub, the stand can also protect the bathtub together with the PVC shell on the outside side wall of the bathtub to prevent the bathtub folding automatically.

![Figure 4. Anti-overturning four-leg brackets and outfall.](image4)

There is a drainage port with a diameter ø40mm at the lower part of the side wall of the bathtub, seen Figure4 (b). The drain and the hard sealing plug are fitted with shrink fit to ensure the sealing of the outlet under the action of water pressure. The drainage hose is connected to the outside of the
drain. When drainage is needed, the sealing plug is opened, and the water in the bathtub is guided by the plastic hose.

**Determination of Foldable Bathtub Material and Molding Method**

Silicone rubber is non-toxic and tasteless, chemically stable, and has high mechanical strength. It has important application in biomedical engineering. Due to unique molecular structure, silicone rubber exhibits higher thermal stability, softness, electrical insulation and chemical stability. The water temperature contacted by the bathtub ranges from 10 °C to 100 °C. Under such temperature, the mechanical properties of silicone rubber remain good and service life is quite long. Compared with the properties at normal temperature, the retention of tensile strength, elongation and 100% modulus for silicone rubber at 100 °C are 59, 82% and 71%, respectively [4]. The foldable bathtub is made of liquid silicone rubber by injection molding method [5], which can be used to produce high quality rubber products repeatedly.

**Stress Calculation for Two Shapes Foldable Bathtub**

**Deformation of Bathtub under Static Pressure**

In order to obtain a bathtub shape with small deformation, good stability, two bathtub cross section shapes of a rectangular shape and a circular are respectively designed. With the aid of the finite element software Abaqus [6], the stresses on the side wall of the bathtub and its deformation in use were calculated. Since the density of the human body is not much different from that of water, the static force calculation of the bathtub full of water was carried out.

According to the previous design, the finite element model of the foldable bathtub was established. According to the stress-strain experimental curve of the actual material, the Mooney-Rivlin double parameter constitutive model of rubber material was used to fit the model parameters: \( C_{10} = 0.12587 \), \( C_{01} = 0.07088 \). The bottom of the bathtub was set to a fixed restraint and the maximum hydrostatic pressure was applied to the inner wall of the bathtub. The calculation results of deformation and Mises stress distribution of the section where the maximum stress was located for two shapes, the rectangular shape and the circular, are shown in Figure 5, Figure 6 and Figure 7 respectively. The U in the figures refers to the equivalent displacement in three directions, whose value is the absolute value of the vector sum of the three directions x, y, and z.

As can be seen from Figure 5, the maximum displacement of the sidewall for the bathtub filled with water is 3.5 mm under hydrostatic pressure. This shape variable is very small and will not affect its use. The contact between human body and the bathtub maybe result in a certain degree of increase in the local force on the wall. For this reason, the bottom and top of the outside of the bathtub wall were fitted with rigid PVC shell, as shown in figure 4, which are bonded to the rubber bathtub body to enhance its strength and stability in use.

The circular bathtub was designed based on the same two indicators, area of the upper opening and volume, as the rectangular bathtub. The calculation results of the static pressure acting on a circular bathtub are shown in Figure 6 and Figure 7 (b). A comparison of the maximum deformation and maximum stress under static pressure and its positions for two bathtubs with rectangular and circular sections is given in Table 1.

| Section  | Maximum Stress (Pa) | Maximum Equivalent Displacement (mm) |
|----------|---------------------|--------------------------------------|
| Rectangular | 7561               | 3.5                                   |
| Circular  | 16140              | 4.4                                   |

Table 1. Comparison of maximum stresses and maximum deformation for two bathtubs.
Under the hydrostatic pressure, the maximum displacement of the sidewall for the circular section bathtub filled with water is 4.4 mm, which is more 0.9mm than that of the traditional rectangular section bathtub. The comparison of the two results shows that the traditional shape bathtub is more consistent with the body's ratio when human body lies down. The circular bathtub has the characteristics of more stable overall, uniform force and strong anti overturning ability. Therefore, when used for small objects such as children and pets, the circular cross-section bathtub can be
selected and the size of bathtub can be properly reduced to meet the requirements of safety, stability and economy.

**Measurement of Thin Wall Folding Deformation**

In order to measure the deformation of bathtub thin wall, two equivalent reduced bathtub models with the opening section circular and rectangular were made in silicon rubber, the same as the actual bathtub material, folded two models and measured the deformation of the thin wall after folding.

The length before folding of thin wall is taken as the initial length, the length after folding is the deformation length, and the ratio of the difference between the length before and after the folding and the initial length is the deformation rate. The elongation rate at the folded place of the circular section bathtub is 61.5%, and that at the flat segment and inflection point of the rectangular section bathtub is 65.2% and 73.2% respectively, which were within the allowable range [4]. This shows that the circular–section bathtub has smaller deformation when folded, the resistance to be overcome is smaller, the force bearing is uniform, and the function of folding storage can be realized more easily than rectangular section bathtub.

**Conclusions**

A collapsible bathtub with non-toxic and tasteless silicone rubber as the main material was designed. The finite element method was used to calculate the stress - strain distribution of the circular and rectangular two section shaped bathtubs under static pressure. The results show that the rectangular bathtub is more suitable for family bathtub, and the round section bathtub is suitable for small size cases such as children and pets. Compared with rectangular section, the deformation measurement experiment shows that circular section bathtub was easier to fold. Also, this design of bathtub is simple in structure and the injection molding method can be selected to form for one time. When used, the folding process is simple and safe, the volume is small and the quality is light after folding. It is easy to be carried and contributes to the popularity of foldable bathtub in small and medium-sized houses.

**Acknowledgement**

This research was financially supported by the University Student Science and Technology Innovation Project and cloud computing platform of Beijing University of Chemical and Technology.

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