Development of Manufacturing Method of Vessel for Keeping Warm by Hydraulic Bulging

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ABSTRACT

Bulging is a forming method to shape die cavity by using hydraulic pressure in tube or vessel. Bulging machine and die were developed in order to produce vessel for keeping warm. Bulging machine is a double type with two horizontal cylinders for bulging of two pieces at the same time. The developed die system has one bulging die and two drawing dies for necking at both ends of the tube. The diameter of tube expands by hydraulic pressure in tube. At the same time, thrust at both ends of the tube pushes tube in the direction of expansion to obtain high expansion rate with no crack. In this study, the bulging properties were investigated to solve tube crack and necking in manufacturing vessel by combining bulging and drawing. As a result, high expanding rate of tube radius without crack, precision necking and high productivity were obtained.

Keywords : Bulging, Die cavity, Vessel for keeping warm, Expanding rate, Die clamping force, Moving die, Membrane stress, Drawing, Necking, Nozzle, Thrust

1. Introduction

Bulging is a forming method for manufacuting products which have the same shape as the die cavity by applying pressure on the inner surfaces of cylindrical vessels or tubes which are inserted into the die cavity and by expanding them.

Liquids such as oil and water, and rubber are common media for pressurization. Each medium has different characteristics, and press machines are often used for bulging. Rubber has short life span and presents some difficulty manufacturing products with high radial expanding rate.

The conventional method for manufacturing vessels for keeping warm uses pipes with a radius of 67mm and employs spinning machininging in order to reduce to 44mm the diameter of necking area in pouring gate. This resulted in rough surface, crack, and loss of material due to the abrasion between tool and material. As a means for resolving these problems, hydraulic bulging method for manufacturing vessels for keeping warm, which also considers improvement of product quality and productivity, has been studied. Material properties, diameter, and thickness of the tube, shape of final product and machining precision have an impact on how difficult hydraulic bulging process is. Bulging method varies according to the type of final product, press machine, and die. Therefore research on these aspects is necessary.

Since the inner surface of the tube is subjected by the pressure generated in the interior of the tube and expands in radial direction, tensile deformation occurs in both radial and longitudinal direction, tube thickness becomes thinner and sometimes crack can be produced. Even after complete annealing of the bulging material, the rate of the increase of the radial dimension cannot be exceeded by 20~30%[1]. As the additional material is supplied to the deforming area in axial direction during bulging process in order to prevent crack in tube, it is necessary to increase expansion rate and at the same time to minimize the deformation in radial direction.

The objective of this work is to develop a new bulging technique in manufacturing vessel for keeping warm shown in Fig. 1 with stainless tube as measures for overcoming the difficulty of high speed forming and for enhancing precision forming.

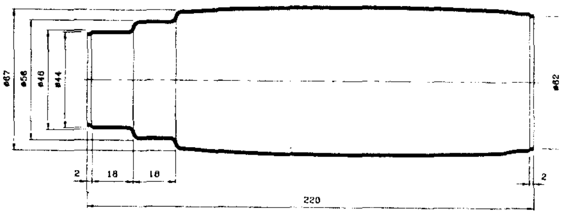

Fig. 1 Vessel for keeping warm

2. Bulging

2.1 Manufacturing Process

Fig. 2 shows the process of manufacturing vessel for keeping warm.

After making stainless tube 0.4mm in thickness and 44mm in radius, this tube is inserted into the die cavity. By applying hydraulic pressure the vessel for keeping warm is formed through bulging process. The forming method uses double-cavity die to increase productivity. After bulging, the tube is cut in two pieces.

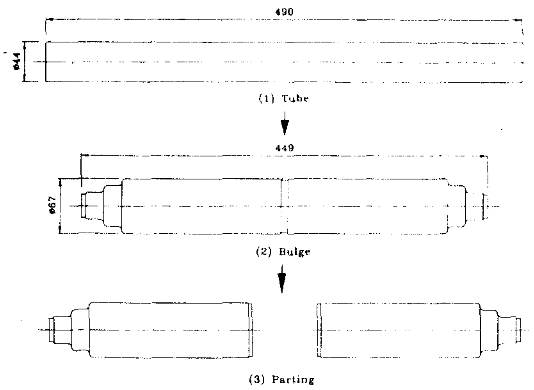

Fig. 2 Manufacturing process

The bulging processes are depicted in Fig. 3 in sequential order.

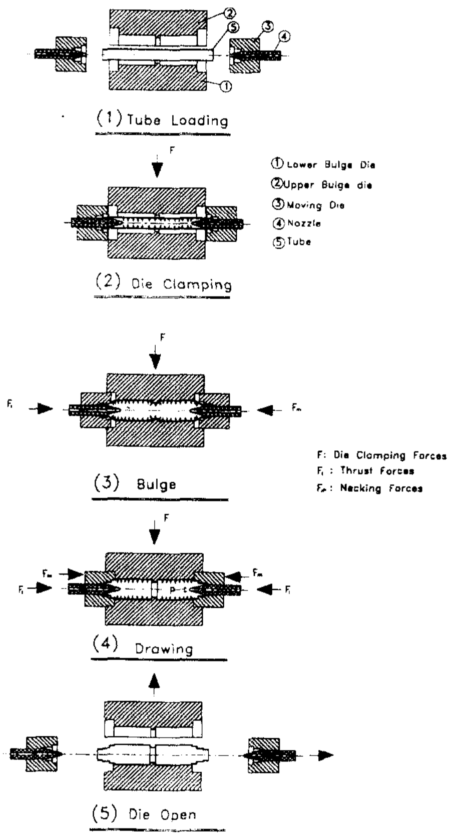

Fig. 3 Bulging process

The function of each is as follows.

1) Tube is loaded into the die.
2) After the die closes, the clamping force F is applied and then both left and right nozzles is fitted into the tube.
3) Hydraulic pressure p is applied. Then Tube expands and thrust force Ft is applied on both sides of the tube.
4) After tube expansion is complete, the force Fm is applied to the movable die installed on both sides of the tube and the neck part is formed by drawing process.
5) Hydraulic pressure is removed and dies opens and the product is taken out of the die.

The tube expands during bulging process once the hydraulic pressure reaches a certain value. If the hydraulic pressure rises too rapidly then the thickness of the expanding area becomes so thin that crack can be generated in the tube.

Therefore it is very important to set up appropriate bulging conditions which prevents crack and wrinkle while applying hydraulic pressure and thrust force.

Photo. 1 shows bulging machine and die.

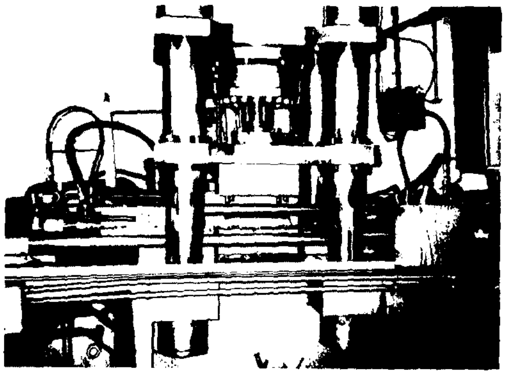

Photo. 1 Bulging machine and die

2.2 Required forces for bulging

When a cylindrical shell of radius r, length l, and thickness t is subjected to hydraulic pressure p as shown in Fig. 4, the normal stress components σ_1, σ_2 acting on tube in axial and circumferential directions are given by

$$\sigma_1 = \frac{pr}{2t} \tag{1}$$

$$\sigma_2 = \frac{pr}{t} \tag{2}$$

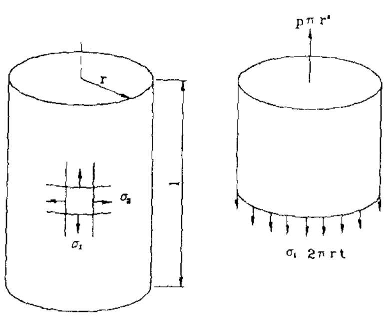

Fig. 4 Membrane stress

Comparing Eqn. (1) and (2), the magnitude of the circumferential normal stress component σ_2 is twice that of the axial stress component σ_1[2].

Since both ends of the tube are under free boundary conditions, only σ_2 should be considered in investigating crack problems as far as the bulging technique developed in this work is concerned.

Fig. 5 shows an examples of finding initial bulging pressure p_0 when the circumferential normal stress component σ_2 acts on the tube of inner diameter d and thickness t[3]. The final bulging pressure needed in real forming process will be higher than the initial pressure p_0 when the forming process proceeds under the free boundary conditions at both ends of the tube. The final bulging pressure P needed in bulging process is assumed to increase by a factor of α_1 according to the complexity of the final product shape and can be given by, when α_1 is considered to be a shape factor

$$P = \frac{\alpha_1 2\sigma t}{d} \tag{3}$$

In Fig. 6, the amount of thrust force applied on both ends of the tube should be such that buckling should not occur. Buckling load Pl can be predicted by

$$Pl = \alpha_2 \pi\sigma dt \tag{4}$$

where α_2 is a shape factor related with buckling and σ is the yield strength.

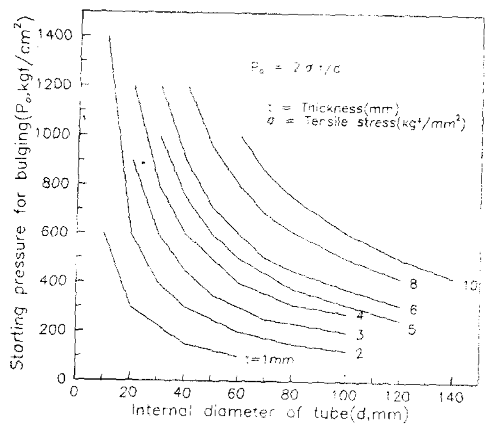

Fig. 5 Starting pressure for bulge

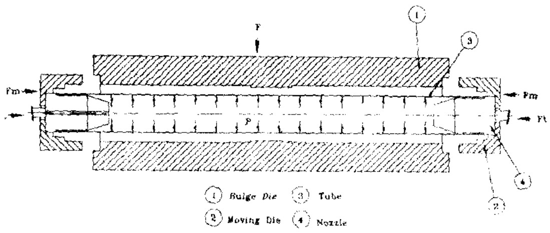

Fig. 6 Forces for bulge

In Fig. 6 the thrust force F_t applied on both ends of the tube can be given by

$$F_t = Pl + pa \tag{5}$$

where pa is the force pushing nozzle acted by internal hydraulic presure, when p is the hydraulic pressure and a is the nozzle area. Since the bulging machine used in this work is designed so that the same amount of hydraulic pressure is applied on the outer area of the nozzle in order to counteract the inner pressure, there is no need to account for the force pa.

In Fig. 6, the force F is the die clamping force which prevents the relative movement between the upper and lower die and should be greater than the cavity projection area S times the hydraulic pressure p[4]. This is given by

$$F \geq pS \tag{6}$$

In Fig. 7, the necking force Fm necessary for forming neck area is assumed to be sum of the drawing force Pd in the neck are and the force P_w on the neck area by the hydraulic force acting in opposite direction to that of the drawing force, and is given by

$$F_m = Pd + P_w \tag{7}$$

The force Pd necessary for drawing cylindrical shell with radius d, thickness t, and tensile stress σ is computed by the formula $P \approx \pi\sigma t d$[5].

Therefore the drawing force can be represented by

$$Pd = \pi\sigma t(d_2 + d_3) \tag{8}$$

The force P_w acting in oppositie direction to that of drawing is computed by multiplying inner pressure p and area and is given by

$$Pd = p\pi\frac{(d_4 - d_3)^2 + (d_3 - d_2)^2 + (d_2 - d_1)^2}{4} \tag{9}$$

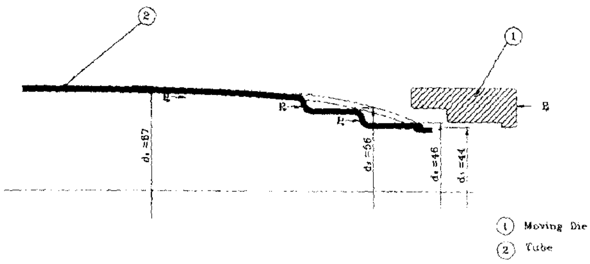

Fig. 7 Drawing force for necking

2.3 Bulging machine and die

Fig. 8 shows a schematic of a hydraulic bulging machine. Some important components and functions of the machine are described below. Cylinder⑤ generates a cramping force of 150 ton in capacity and is installed vertically. Cylinder⑥ is installed horizontally on both sides of the fixed die for generating thrust force which is used for pushing tube. Nozzle④ injecting pressurizing medium is installed on both sides of the tube. Movable die③ is used for forming the neck area is located next to the fixed die. Auxiliary cylinder⑧ supplies power to movable die③ .

The bulging machine is of a double-side type which supplies high-pressure water to the interior of the tube, forms the tube into the shape of the die cavity, and generates thrust force on both sides of the tube as well as high bulging pressure.

Hydraulic pressure can be further increased by the booster with conversion cylinder switching between water and oil. This machine is equipped with liquid supply unit which enables high-speed bulging and pressure control unit connected with thrust force.

The pressure control unit maintains optimal pressure increase rate and bulging speed, thus suppresses the generation of wrinkles and cracks on the deformed region.

The dies used for bulging process is composed of bulge die(Refer to Fig. 9) and moving die(Refer to Fig. 10) and of a double-cavity type for improving productivity.

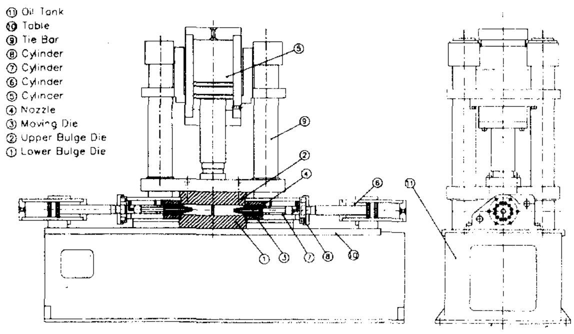

Fig. 8 Bluge machine

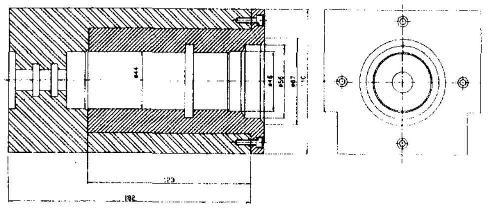

Fig. 9 Bulge die

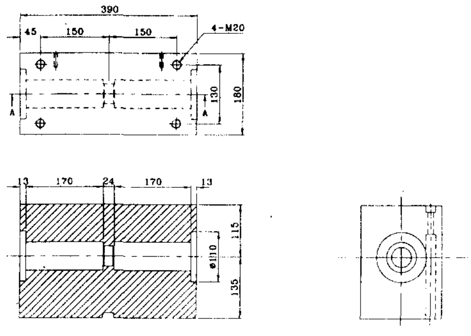

Fig. 10 Moving die for necking

Fig. 11 represents the final operating states for bulge die① and movable die②. Bulge die is used for forming body and movable die for forming neck area. Thus the bulging machine developed in this work employs combination of body forming with hydraulic pressure and drawing forming for necking. Movable die for necking is installed on both left and right side of the bulge die and moves toward the bulge die by hydraulic cylinder. Precise forming on neck and corner area is not possible solely by increasing inner hydraulic pressure. Drawing should be followed by pushing the movable die rapidly toward the bulge die as soon as the final expansion is completed.

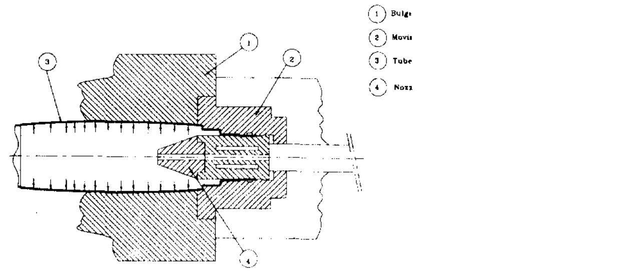

Fig. 11 Die combination for bulging

3. Characteristics and Consideratin of Bulging Process

By using previously mentioned bulging machine and dies, bulging process was carried out to manufacture the vessel for keeping warm with stainless tube with a thickness of 0.4mm.

The material used is STS304J1 and its material property is presented in Table 1. During the process the tube expands as the hydraulic pressure increases, and the relation between hydraulic pressure and expanded outer diameter is presented in Fig. 12. Bulging process represents the pressure change from the initial state to the forming of final product. It can be observed that the bulging pressure increases by the shape factor α_1 compared to the initial bulging pressure in relation to the expanded diameter.

By substituting yield strength into Eqn. (2), the initial bulging pressure P_0 becomes 46.7 Kg/cm^2.(d=44mm, t=0.4mm, σ=25.7Kg/mm^2)

In reality, when the tube diameter expands to 67mm the required bulging pressure P was 292kg/mm^2. From Eqn.(3) the shape factor α_1 becomes 6.1. The ratio t/D between thickness t and diameter D lies usually in the range of 0.5~1% when bulging process is proceeding[1].

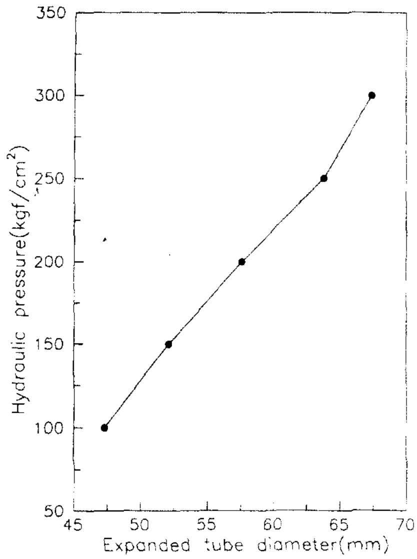

Fig. 12 Relation between pressure and tube diameter

Table 1 Properties of material

Section	Value	Section	Value
Yield stress (Kgf/㎟)	25.7	Possinon's ration	0.29
Tensile stress(Kgf/㎟)	62.8	Density (g/㎤)	8.03
Elongation(%)	57	Hardness(Hv)	12.65
Modulus of elasticity (Kgf/㎟)	20.3×10^3	Straining hardening index	0.34

In this work the ratio of 0.59% was obtained, which lies in the normal range. During bulging process, a thrust force of 1,600kg was applied to both ends of the tube and the amount of compression of the tube was 41mm in 6 seconds.(Compression rate of 6.8mm/sec)

The buckling load Pl = $\alpha_2\times 1420$ kg can be computed from Eqn.(4).(d=44mm, t=0.4mm, σ=25.7Kg/mm^2) In Eqn.(5) the thrust force pa is neglected since this force is counteracted by mechanical structure. Therefore

$$1600=\alpha_2\times 1420+0$$

$$\alpha_2=1.12$$

If buckling is assumed to occur at $\alpha_2=1$, a thrust force which is 1.12 times the buckling load could be used without any buckling. The shape factor α_2 will be different with tube shape. The thrust force applied in the tube axial direction will generate compressive normal stress during tube expansion, and this will prevent reduction of tube thickness due to the tensile stress. Therefore tube crack did not take place even with high expansion ratio.

Forming in the neck region was not possible solely by hydraulic bulging pressure. This was possible by drawing using movable die on the neck region. The force F_m required for necking, drawing force Pd, and the force Pw acting in direction opposite to that of drawing was computed by Eqn. (7), (8), and (9) and presented in Table 2. The required value of F_m is 8,557.6kg.

Table 2 Forces for forming

power	Equation	Value(kg)
F_m	(7)	8,557.6
P_d	(8)	8,045.4
P_w	(9)	512.2

When tested with a cylinder diameter of 100mm and hydraulic pressure of 100kg/mm^2, forming in the neck region was possible and the required value of F_m was 7,858kg and this corresponds to 92% of theoretical value.

Fig. 13 shows the measured thicknesses distributed around the various parts of the final product when bulging was carried out under the following operating conditions: hydraulic pressure of 292kg/mm^2, thrust force of 1,600kg acting on tube, necking force of 7,858kg acting on movable die, and tube compression speed of 6.8mm/sec. Reduction rate of thickness was 17% in the middle part of the tube, and the reduction rates decreased progressively toward both ends of the tube. The thickness in the neck area, however, increased by 0.7%.

Photo 2 shows tube crack generated during bulging when thrust was not applied. For this case, the applied hydraulic pressure was 245kg/cm^2 and the final expanded diameter was 58.6mm, and the tube expansion ratio was 33%.

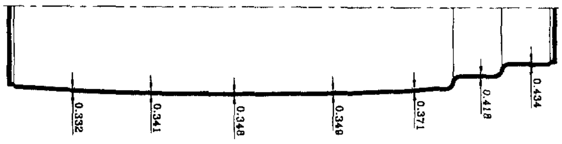

Fig. 13 Wall thickness

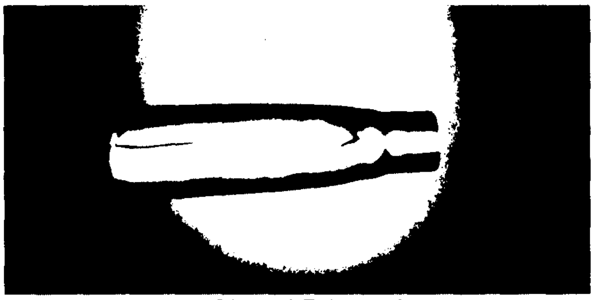

Photo. 2 Tube crack

Photo 3 shows the final state of the product when bulging was carried out under normal operating conditions. For this case, the precise forming was possible with expansion ratio of 52.2% and without any crack observed.

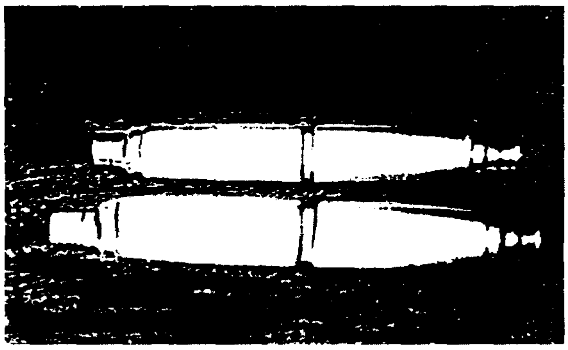

Photo. 3 Manufactured products by bulging

4. Conclusions

A new bulging machine and dies were developed for high-speed hydraulic bulging with water. After manufacturing vessels for keeping warm with a stainless tube of 44mm in diameter, 0.4mm in thickness, the following conclusions could be drawn.

(1) The hydraulic pressure acting on the inner surface of the tube is proportional to the normal stress in circumferential direction and tube thickness and inversely proportional to tube radius. Also the shape factor α_1 increases as hydraulic pressure increases. In this work, under the free conditions on both sides of the tube the manufacturing of vessels for keeping warm was made possible by applying 292kg/cm^2 of high pressure. As a result 52% of expansion ratio was obtained without generating any crack.

(2) The highest reduction ratio of 17% in thickness was observed in the middle part of the final product. The reduction ratio in thickness decreases toward both ends of the tube. The thickness in neck area, however, increases due to the supply of the new material.

(3) The degree of difficulty was highest in the neck and corner area, and forming in these areas were not possible solely by applying hydraulic pressure. By combining drawing forming by movable die and hydraulic bulging forming, high-speed forming in these difficult areas could be made possible.

Therefore in order to manufacture products in high-speed hydraulic bulging with high productivity and without generating any crack, it is required to select appropriate bulging method according to the shape of the final product and to carry out research on types of dies, thrust force and bulging speed related with operating conditions.

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