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Experimental Research for Open Die Polyurethane Forming of Corrugated Thin-walled Machinery Sealed Rings

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Abstract: In this paper, an open die polyurethane rubber forming test was selected to form corrugated thin-walled machinery sealed rings, which chose a polyurethane rubber as the pressure-carrying meduim to form the multi-convolution sealed rings one by one. The impact of different factors on the forming results was investigated. The test results showed that obtained part has relative uniform wall-thickness distribution. It showed that this forming method has feasibility.

Keywords: Corrugated machinery sealed rings, Thin-walled, Open die polyurethane forming.

1. Introduction

As a recently developed sealing part, corrugated thin-walled machinery sealed ring can fulfill advanced contact machinery sealing[1][3]. It is widely used in aerospace engines, for the reason that this device has the following advantages: simple and various structures, easy disassembly and assembly, strong wear resistant property, short production period, etc. M Bakhshi-Jooybari[4] investigated the forming of single-convolution bellows with a short wave length and high wave height using open die hydroforing process. While, because of the possible eccentricity in the middle of the forming part, it is difficult to handle the above forming process. Unstable deformation in the manufacturing process of thin-walled rings is the main form of failure that leads to thin wall thickness, and the problem can be solved by using viscous medium as the pressure-bearing medium and thus achieving stable metal flow. When the appropriate viscous medium is used as the core material, the viscous medium and the metal billet are deformed synchronously to form a composite billet. Yan et al.[5] used the problem of wall thickness control in multi-step three-dimensional hydroforming to reduce the rate of thinning by adjusting the stress states of axial compressive and circumferential tensile stresses during multi-pass three-dimensional hydraulic expansion feed expansion. With the axial and circumferential stress states properly matched, the required deformed material in the circumferential direction can be supplemented from the axial direction, thus effectively suppressing the wall thinning.Wang et al.[6] used this method to form two different shapes of corrugated meridian thin-walled rings, and the maximum wall thickness reduction of the formed parts was less than 8%. In this paper, we chose a polyurethane rubber as the pressure-carrying meduim to form the multi-convolution sealed rings one by one, and obtained a part with relative uniform wall-thickness distribution.

2. Experimental

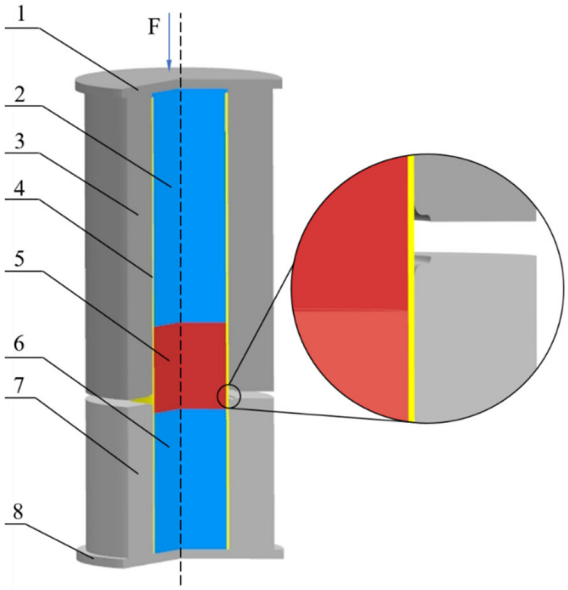
2.1. Forming principle

The open die forming using polyurethane rubber as the pressure-carrying meduim was adopted, the schematic of the proecss is shown in Fig.1. The cavity of either upper die or bottom die is half of a single convolution symmetrical shape. When they contact, these two cavities constitute one whole single convolution. In the forming process, separate the upper die and bottom die with a certain distance along the axis, the size of the distance, denoted by hc in the figure, is determined by the volume of the single convolution so that the formed part has a uniform wall-thickness distribution. Put the polyurethane rubber and pistons into the tube, then press the upper die and the piston towards the bottom die along the axis. Both the upper die and bottom die are acting on the tube, the polyurethane's compression under the pressure of the upper die also makes the tube generate outward deformation until the two dies contact. The formation process of the second convolution is similar to that of the first one, except that the first convolution is used as a locating part in the bottom die. And so on, for each of multi-convolution rings.

Forming process cylinder blank and internal polyurethane rubber at the same time by the role of pressure to promote the cylinder blank forming, the cylinder blank by a larger axial pressure and radial pressure, the deformation of the area of the billet continues to flow to the surface, the cylinder blank deformation area at the same time by the axial pressure and the circumferential tensile stress, the appropriate tensile and compressive stresses can be ensured that the deformation of the area of the wall thickness uniformity[7][9].

2.2. Experimental material and test machine

The tube is made of stainless steel 340 and its material properties is given in Table 1. The diameter of the original tube is 20.8mm, the wall-thickness is 0.5mm and the length of the tube is 97.6mm, as shown in Fig.2. The polyurethane used as the pressure-carrying meduim has a hardness of shore 85, and the Young's modulus is 80MPa. The geometry of one-convolution is 1.6mm in wave height and 0.6mm in wave radius[10][12]. the die-set mounted on the test machine that was designed and manufactured for two-convolution rings.



1 - Upper die-set; 2-Upper piston; 3-Upper die; 4-Tube blank; 5-Polyurethane rubber;6- Bottom piston; 7- Bottom die; 8- Bottom die-set

Figure 1. Schematic diagram of the forming process

Table 1. Property parameters of stainless steel 340

E/GPa	$\sigma_{0.2}$/ GPa	σ/ GPa	*n*
200	206	539	0.347

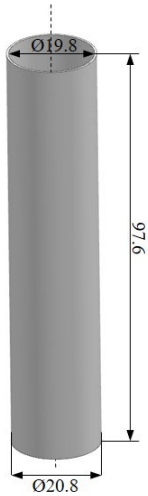


Figure 2. Blank and geometry of tube

2.3. Results and discussion

When the geometry of one-convolution and material are determined, the axial dimension of the polyurethane (h_p) and the height of deformation zone (h_c) become two key factors of the uniform-thickness forming process.

The tube blank and the polyurethane rubber fill into the cavity as a whole in the forming process, so the axial dimension of the polyurethane is determined by the volume of the deformation zone. As shown in Fig.3, the compressed volume of the polyurethane equals the voulme of the cavity, which is 5480.6mm^3. Because of volume reduction during compression process, according to Eq. 1, the original volume is about 5590.2 mm^3~5864.2 mm^3 given that the amount of compression is 2%~7%. Then the axial height of the polyurethane can be calculated, which is 18.1mm~20.1mm.

$$V_{original} = V_{cavity} + V_{compression}. \quad (1)$$

The height of deformation zone is another key factor of the forming process. In theory, it can be calculated based on the law of volume constancy. While, take variations of wall thickness and springback into consideration, the height of deformation zone should be adjusted on the basis of theoretical calculation, which is 1.9mm.

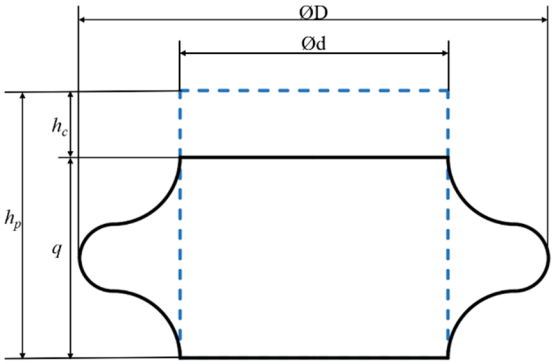


Figure 3. volume model of tube and polyurethane in deformation zone

2.4. Effect of different polyurethane heights

During the experiments, we chose three different axial heights: 18.5mm, 19.0mm and 20.0mm. First, we used the polyurethane that measured 20.0mm high, as shown in Fig. 4c), the geometry of formed single-convolution was much bigger than the desired one. This is because a higher polyurethane transfered pressure to the tube earlier, which resulted in deformation of the tube before the upper die and bottom die close. When the height of the polyurethane was shortened to 19.0mm, the situation had improved, seen in Fig. 4b). Finally, as shown in Fig. 4a), we obtained the ideal dimension with a 18.5mm high polyurethane.

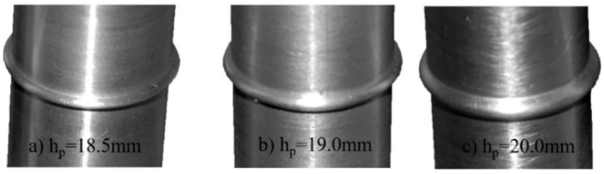


Figure 4. Effect of forming first convolution at different polyurethane heights

2.5. Effect of different deformation zone heights

During the forming process of the second convolution, we chose four different deformation zone heights:1.4mm, 1.9mm, 1.7mm and 1.6mm.

When the height of deformation zone was 1.4mm, deformation was complete before the upper die and bottom die closed (as shown in Fig. 5a)), the tube was not enough to fill the cavity. The second convolution was bigger than the first one, because the tube generated plastic deformation under the pressure and the convolution was formed along the cavity.

If the height was increased to 1.9mm, which was the theoretical value, the formed convolution was inward. This is because the height of deformation zone was too high so that a part of tube in deformation zone did not deform when the upper die and bottom die closed, which led to inward wrinkling under axial pressure, as shown in Fig. 5d).

The height of deformation zone was 1.7mm, the inward situation had improved (as shown in Fig. 5c)). We got the ideal geometry when the height of deformation zone was 1.6mm, as shown in Fig. 5b).

Figure 5. Effect of forming second convolution at different deformation zone heights

2.6. Wall- thickness distribution

Cut the first convolution along the central axis, the wall-thickness distribution is shown in Fig.6. The wall-thickness are 0.48mm in peaks and troughs, 0.50mm in the side wall, which is equal to the original wall-thickness. It means that the wall-thickness reduction rate is not more than 4%, the feasibility of this forming method has been verified.

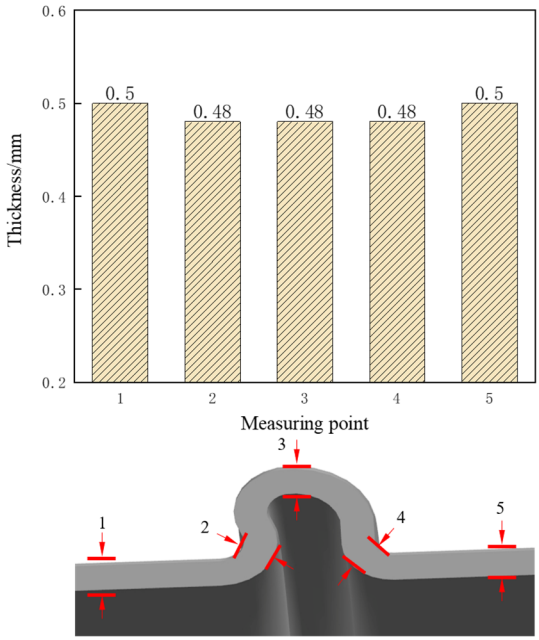


Figure 6. Wall-thickness distribution of formed part

3. Conclusion

In this paper, using a kind of polyurethane rubber as the pressure-carrying meduim, the open die forming method was adopted. The effect of two key factors on forming corrugated thin-walled machinery sealed rings have been presented by experiments. It was shown that the ideal height of the polyurethane was 18.5mm, if the height was higher than 18.5mm, the dimension of formed single-convolution would be bigger. The appropriate height of deformation zone was 1.6mm, if the height was less than 1.6mm, convolution was bigger than the desired one, and the formed convolution was inward if the it was more than 1.6mm. The wall-thickness reduction rate of the formed part was less than 6%, which verified the feasibility of this forming method.

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References

[1] I. Green: Mechanism and Machine Theory Vol. 43 (2008), p. 1

[2] N. Bnmetiere, B. Modolo: International Journal of Thermal Sciences Vol. 2(2008), p. 1

[3] A. Mühlratzer, K. Handrick and H. Pfeiffer: Acta Astronautica Vol. 42(1998), p. 533

[4] M. Bakhshi-Jooybari, M. Elyasi and A. Gorji: Journal of Engineering Manufacture Vol. 224 (2010), p. 95

[5] Yan. BY, Meng. B, "Wall thickness control in multi-stage hydroforming of multiwave seal ring with small diameter." IOP Conference Series: Materials Science and Engineering. Vol. 1270. No. 1. IOP Publishing, 2022.

[6] Wang. Zhong-jin, et al. "Forming thin-walled circular rings with corrugated meridians via quasi-bulk deformation of metal blank and viscous medium." Journal of Materials Processing Technology 236 (2016): 35-47.

[7] Talebi-Ghadikolaee, Hossein, et al. "Feasibility of Forming U-Shaped Microchannels by Flexible-Die Forming Process." Karafan Quarterly Scientific Journal 19.3 (2022): 53-70.

[8] Wang. Pengyi, et al. "Subregional flexible-die control in magnetorheological pressure forming." Journal of Materials Processing Technology 307 (2022): 117698.

[9] Zhang. Feifei, et al. "Experimental investigation on electro-hydraulic forming with flexible-die." Procedia Manufacturing 50 (2020): 324-327.

[10] L. Zhang, in: Structural Analysis and Forming Process for Thin-walled High Temperture Alloy Corrugated Parts, edtied by Harbin Institute of Technology, Harbin (2012) In ChineseW.-K. Chen, Linear Networks and Systems (Book style). Belmont, CA: Wadsworth, 1993, pp. 123-135.

[11] Yuan. Shijian, "Fundamentals and processes of fluid pressure forming technology for complex thin-walled components." Engineering 7.3 (2021): 358-366.

[12] Wang. Zhong-jin, and Gao. Tiejun, "Inner and outer pressure forming of nickel based super-alloy thin-walled part with variable diameter sections." Transactions of Nonferrous Metals Society of China 18.2 (2008): 285-290.