Investigation on sheet flexible-die drawing process

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Abstract: The characteristics of sheet flexible-die drawing process were discussed, compared with traditional sheet drawing process, sheet flexible-die drawing process can improve the limit drawing ratio, reduce the forming force, balance the thickness distribution and enhance the formability of the sheet. In this paper, the forming principle, research status and the forming characteristics of hydroforming, viscous pressure and solid granules sheet drawing process were demonstrated. In addition, the improvement of forming quality and efficiency under the aid of ultrasonic vibration, electricity, magnetic field and the mixture of them were also reviewed.

1. Introduction
Sheet flexible-die drawing process is the use of hydraulic water, oil, viscous polymer, rubber and solid particles as a force transfer medium, and then a rigid mold as a punch or die, under the action of this force transfer medium for the sheet deep drawing process. Sheet flexible-die drawing process first appeared in the 1890s, and after the Second World War, Japan and Germany conducted a lot of research on it. After more than 70 years of development, it has been found that the forming parts obtained by soft die drawing have not only good surface quality and small wrinkle, but also lower cost and less time.

In order to improve the formability of sheet, some researchers focus their attention on ultrasonic vibration, electric current assistance, magnetic field assistance, other physical field assistance and physical field combination. Ultrasonic vibration is not only applicable to easy to be machined materials, but also difficult to be machined materials such as titanium alloy. It can solve the problem of micro-size processing and hardening, and the accuracy is also greatly improved. As a means of strengthening the material of plate drawing, the current auxiliary can improve the resistance of some difficult material in the process of machining deformation; Laser-assisted sheet drawing technology can make use of the thermal effect generated by laser to produce smaller forming force in the drawing process of the sheet. Magnetic field assistance technology has advantages of high efficiency, flexible and convenient control of electromagnetic force and high precision.

Based on the introduction of sheet flexible-die drawing process, the paper summarized the forming principle, research status, advantages and disadvantages of hydraulic, viscous medium, solid granules drawing process. It also introduces the ultrasonic vibration, current and magnetic field assisted sheet forming technique for flexible-die drawing the improvement of technology has brought the formability.

2. Sheet Hydraulic Deep Drawing Process
Sheet hydraulic drawing process is a special sheet metal drawing technology, In the process of drawing, when the liquid as a die, the metal sheet is not only subjected to the punch pressure, but also subjected to the reverse pressure of the high-pressure liquid, so that the sheet is formed by joining the punch. The principle is shown in Figure 1(a). When the hydraulic oil is used as a punch, the drawing schematic
diagram is shown in Figure 1(b). In the drawing process, the positive pressure is only carried out by the action of high-pressure liquid, and the whole process is very slow. At the same time to control the size of the liquid pressure, the liquid pressure is too small, the sheet in the forming process by the positive driving force is not enough will occur wrinkle phenomenon. When the liquid pressure is too high, the driving force of sheet metal is greater than its yield strength during the forming process, which will result in the fracture of sheet metal. Through the research of researchers, it is founded that radial thrust can be added in the process of sheet metal hydraulic drawing technology when hydraulic oil is used as the die, and its forming principle is shown in Figure 2. In the process of drawing, the sheet is not only pulled by punch, but also pushed by liquid pressure from the side, which can further improve the forming precision of the sheet and reduce the forming force.

![Fig.1 Schematic diagram of sheet hydraulic deep drawing](image1)

![Fig.2 Schematic diagram of sheet radial hydraulic deep drawing](image2)

In 2010, Yang Lianfa et al. [1] conducted a hydraulic deep drawing experiment at room temperature, measured magnesium alloy sheet limit drawing ratio of ordinary deep drawing, and then compared with the hydraulic deep drawing sheet under the limit drawing ratio, the results found that the hydraulic deep drawing process can improve the limit drawing ratio of plate. In 2011, Kulkarni et al. [2] conducted the hydraulic warm drawing experiment, and the experimental results showed that the ultimate drawing ratio could be increased from 2.06 to 2.16 in the case of low blank holder force. In 2012, Huang et al. [3] discussed the relationship between punch load and stroke and thickness variation of elliptic cup parts, and the experimental results showed that the ultimate drawing ratio of elliptic cup parts could reach 2.056 after hydraulic deep drawing. In 2014, Hwang et al. [4] conducted relevant research on hydraulic drawing of square cup parts, and compared the hydraulic drawing with the method of finite element simulation and experiment, and obtained the relationship between the pre-bulging height and the pressure.

In 2012, Tao Zhongnan et al. [5] proposed that ultrasonic waves should be added in the process of hydraulic forming to obtain ultrasonic signals to predict the upcoming defects. However, due to some defects in the pipe itself, further research is needed. In 2010, when Merklein [6] used hydraulic forming with complex geometric shapes, it used magnetorheological fluid as the force transmission medium and carried out experiments under the auxiliary action of magnetic field. The experimental results provided some basic data for obtaining accurate forming later.
3. Viscous medium deep drawing process

Viscous medium deep drawing technology is a kind of sheet metal forming technology, viscous medium pressure deep drawing is commonly used in forming process of semi-solid, can flow, and strain rate sensitive polymer as a medium. EVA plastic powder after melting will have a certain elasticity and viscosity, elasticity and viscosity will make the flexible punch shape distortion in the spring-back, what we need to do is to hold the pressure for a long time can also get an excellent punch shape, the efficiency is a little low. Its forming principle diagram is shown in Figure 3. Its forming principle is: the plate is placed above the die, close the die, add viscous medium to both sides of the sheet metal, the cavity on the side of the sheet metal through the piston slowly downward movement, to provide a pressure to the sheet metal. There are also several pistons under the sheet metal to control the pressure distribution, which can adjust the pressure of each piece under the sheet metal, so as to achieve the forming accuracy of each part. As the end of the shape, release the plate under the concave cavity medium, continue to push pressure to the upper piston, pressure to make the sheet better die.

![Fig.3 Schematic diagram of viscous medium deep drawing](image)

In 2014, Li[7] et al. studied the formability of automobile aluminum alloy, and the experimental results showed that the viscous medium technology could promote the flow of plates. Compared with the traditional rigid mold, the deformation of plates was more uniform and the rebound amount was smaller. In 2016, Gao[8] applied viscous medium forming technology to the forming of polyether imide plates. The experimental results showed that the ultimate bulging height of polyether imide plates would increase with the increase of temperature under the condition of viscous thermo-compression bulging. In 2017, Gao[9] observed the changes of mechanical properties of AZ31B magnesium alloy at different temperatures. The experimental results showed that the forming properties of the material would first increase and then decrease with the increase of temperature, and the ultimate swelling height also first increased and then decreased. It was believed that the material had the best forming properties at 200℃.

In 2012, Wang Bo et al. [10] used pulse current assisted thermal drawing to conduct the drawing experiment on a composite material, and found that the wall thickness of the forming part was evenly distributed, the surface quality was smooth, and the forming performance was good.

4. Solid granules medium deep drawing process

Hydraulic deep drawing technology and viscous medium deep drawing technology is the key to the flexible power transmission medium, both liquid and viscous medium in the forming process can be as different rigid mold show that the liquidity, the solid particles under the action of high pressure also showed a good liquidity, so solid granules medium deep drawing technology is also arises at the historic moment. Chen Guoliang found that spherical ceramic particles not only have good fluidity, but also have high hardness, low cost and high temperature resistance, so he chose different diameters as the transmission medium for the experiment. Dong Guojiang [11] used a non-metallic GM particle as the transmission medium and successfully obtained the box-shaped forming parts. Researchers at Shenyang Aerospace University used steel balls of different diameters to conduct experiments and found that the surface quality of the formed pieces was better. The forming principle diagram is shown in Figure 4.
Solid granules medium forming technology by Zhao Changcai in 2005, the technology used in the first tube bulging technology, on this basis, the researchers will use the technology on deep drawing taper, and sheet of granules medium forming characteristics of deep drawing technology are reviewed, and the numerical simulation of the analysis of strain law of sheet metal, and using the finite element simulation, and the simulation results compared with the results of theoretical analysis. Cao Meiyan [12] carried out ultrasonic vibration drawing test on magnesium alloy sheet, and the results showed that ultrasonic vibration could improve the forming performance of the sheet and the pressure transfer performance of the particle media, and the forming load would decrease with the increase of the ultrasonic amplitude in the drawing process. Next, the device was used to conduct the friction test of the plate with ultrasonic vibration, and the causes of the surface effect were analyzed. From the results of the friction test, it can be concluded that ultrasonic vibration can reduce the friction coefficient. The reduced amount obtained in the test is consistent with the theoretical value, and the friction coefficient is reduced by about 40%. Ultrasonic vibration can help reduce the wear of materials and improve the surface quality of parts. In 2016, Jia [13] conducted relevant studies on the formability of paraboloid parts. By adjusting different forming conditions, the experiment concluded that the ultimate forming height of parts could be improved.

Ultrasonic assisted solids deep drawing technology to a certain extent, can improve the formability of sheet, CAO by simulation and experiment comparison, found that applying ultrasonic vibration can reduce the forming force, improve the wall thickness distribution of plate to improve the sheet metal forming limit, the distribution of amplitude of mold on 5.6 μm and 7.7 μm compared with ultrasonic vibration do not found after ultrasonic vibration forming force decreased by 26% and 36.5%.

In 2012, Gao Rui [14] conducted ultrasonic vibration experiments on magnesium alloy plates, compared the changes of ultimate drawing ratio of plates with or without ultrasonic vibration at different ultrasonic amplitudes, and analyzed the influence of ultrasonic vibration on the forming properties of magnesium alloy plates. Peng Yaxin [15] added ultrasonic vibration to the forming of solid particle medium, analyzed the influence of different parameters on the forming performance of sheet metal, and found that ultrasonic amplitude had the greatest influence on the forming force and wall thickness distribution. In 2013, Xiao Qiong [16] conducted a stamping experiment on rolled sheet with electromagnetic assisted forming technology, and the experimental results showed that electromagnetic assisted could effectively improve the sheet sheet's forming performance, and its maximum drawing ratio reached 2.0.

5. Conclusion and prospect
In conclusion, compared with traditional sheet drawing, sheet soft die drawing has better forming performance and better surface quality, which is suitable for mass production. Among them, plate hydraulic drawing is still difficult to seal, plate viscous medium drawing has the problem of low cost and high efficiency, solid particle medium drawing has the problem of insufficient theory and research. Although the single physical-assisted sheet deep drawing technology can help to reduce the sheet forming force, improve the wall thickness distribution and increase the ultimate drawing ratio, the improvement of some forming properties will also cause the decline of other forming properties. In the
future research, it is a developing trend to comprehensively improve the overall forming performance of sheet metal drawing by comprehensively utilizing various auxiliary methods.

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