[Article ID] 1003- 6326(2002)01- 0109- 06

Effect of blank holder pressure on viscous pressure forming aluminum alloy ladder parts①

WANG Zhong-jin(王忠金), WANG Xin-yun(王新云), WANG Zhong-ren(王仲仁)
(School of Materials Science and Engineering, Harbin Institute of Technology, Harbin 150001, China)

[Abstract] Viscous pressure forming (VPF), is suitable for forming difficult-to-form sheet metal parts. An investigation in the effect of blank holder pressure (BHP) on VPF aluminum alloy ladder parts was conducted. Based on experimental and numerical simulation results of the effect of BHP on dimensional accuracy, wall-thickness reduction, forming pressure, material flow and defects (such as wrinkling and fracture) of specimens, the effect patterns of BHP load path on VPF ladder parts were explained. The limits of BHP corresponding to specimens with no defect and with wrinkling or fracture defect were determined. In the limits of formable BHP, the variable load path of BHP was beneficial to drawing blank into the die and decreasing wall-thickness reduction of specimens. The experimental results show that the ladder parts of good surface fineness and high dimensional accuracy can be obtained by variable load paths of BHP.

[Key words] viscous pressure forming; ladder parts; blank holder pressure; aluminum alloy

[CLC number] TG316 **[Document code]** A

1 INTRODUCTION

Sheet metal forming technology plays an important role in the modern industry, especially in electronics, automobiles, and aerospace fields[1,2]. Since the requirements for surface configuration, sheet metal properties, wall-thickness uniformity, dimensional accuracy and surface fineness of sheet metal parts are becoming increasingly higher, a series of new questions appear, such as serious wall-thickness reduction and low dimensional accuracy of sheet metal parts with complicated shape and difficult-to-form sheet metal. Conventional forming methods can not meet the needs of these mentioned above. So it is high time to develop new sheet metal forming technologies, the viscous pressure forming (VPF) is a viscous flexible punch forming method among other things[3,4].

The main difference between VPF and other sheet metal flexible-die forming technology is that a semi-solid, flowable, viscous and rate sensitive material (called as viscous medium) is used as carrying-pressure medium. The schematic diagram of VPF is shown in Fig. 1. In forming process, viscous medium is pumped into the medium chamber by pumped medium cylinder and applied to sheet blank. By controlling the relationship between the viscous medium pressure and blank holder pressure (BHP), sheet metal deformation is conducted, and the sheet metal formability can be improved.

Because of using viscous carry-pressure medium, VPF has unique advantages: firstly, standing high pressure and good filling property, so that parts

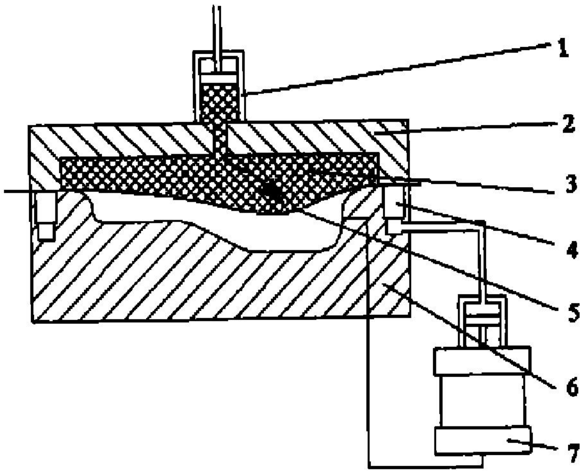

Fig. 1 Schematic diagram of VPF
1—Pumped medium cylinder; 2—Medium chamber; 3—Viscous medium; 4—Blank holder; 5—Sheet blank; 6—Die; 7—Blank hold hydraulic cylinder

formed can fit die well and have high dimensional accuracy; secondly, no harmful to sheet metal surface so that parts retain the original surface fineness; and finally, the semi-solid property so that viscous medium is sealed easily to the benefit of controlling viscous medium pressure and BHP. Before now, the studies of VPF were concentrated on numerical simulations on formability of aluminum alloy and superalloy[5~11].

To improve wall-thickness uniformity of forming ladder parts, it is required to control sheet metal flow reasonably, and the multi-operation forming is needed for steel punch forming. With VPF, parts can be

① [Foundation item] Project (Z0400c001- 2) supported by National Defensive Fundamental Research Funds
[Received date] 2001- 07- 31; [Accepted date] 2001- 11- 07

formed by one-operation through controlling the relationship between viscous medium pressure and BHP to adjust sheet blank flowing-in die and decrease wall-thickness reduction, and the parts got have high dimensional accuracy and good surface fineness[12, 13].

2 MAIN DIMENSIONS AND SHEET METAL OF LADDER PART

The main dimensions of the aluminum alloy ladder part are shown in Fig. 2. The diameter of the center ladder convex (marked by A) is 20 mm and the depth is 4.8 mm, and the maximum depth of the lateral ladder convex (marked by B) is 8.3 mm. The diameter ratio of these two ladders is 0.18, and the relative thickness is 0.71. If the ladder part is formed with steel punch forming, the multi-operation forming is needed[13], and the forming parts fracture easily at corner segment of A area because of serious wall-thickness reduction.

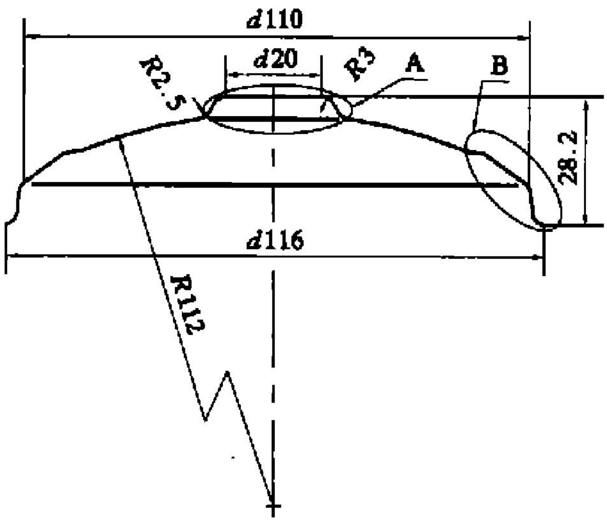

Fig. 2 Main dimensions of ladder part

LF5M is used as experimental sheet metal, whose property parameters are shown in Table 1. Sheet blank diameter $D = 150$ mm and thickness $t = 1.05$ mm.

Table 1 LF5M property parameters

Yield stress / MPa	Elongation / %	Young's modulus / GPa	Poisson's ratio	Strain hardening exponent	Thickness anisotropy
145	16	71	0.3	0.2	0.61

3 EXPERIMENTAL

3.1 Experimental VPF die setting

A set of VPF die setting has been built and installed in 1 000 kN hydraulic Minster press, and is show in Fig. 3. BHP F_1 is controlled by upper slide (1). The viscous medium is pushed into viscous chamber by piston (6) and generates pressure within it, which acts on sheet blank surface. Viscous medium pressure is called as forming pressure. BHP and forming pressure (or piston stroke) are controlled during forming process.

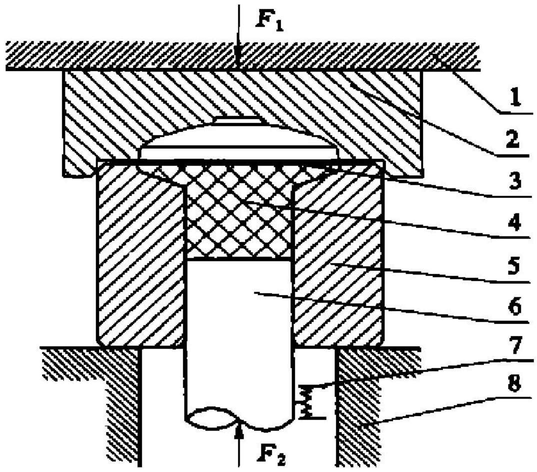

Fig. 3 Sketch of VPF die setting
1 —Upper slide; 2 —Die; 3 —Sheet;
4 —Viscous medium; 5 —Viscous medium chamber;
6 —Piston; 7 —Position sensor; 8 —Worktable

3.2 Process parameters and deformation status

Load paths of BHP used in experiments are shown in Fig. 4. Path a and c stand for constant BHP, path a for smaller BHP P_1 and path c for larger BHP P_4, and path b stands for variable BHP, a smaller pressure P_2 at initial stage and a larger BHP P_3 at final stage respectively. Four typical forming parameters and deformation status are shown in Table 2.

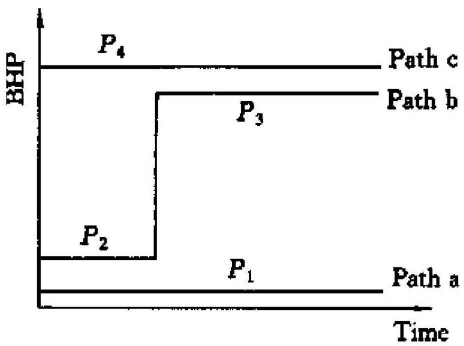

Fig. 4 Load paths of BHP used in experiments

4 RESULTS AND ANALYSES

4.1 Effect of BHP on forming of ladder convexes

The forming process of ladder parts was simulated by numerical simulation software DEFORM[14], and the numerical simulation model is shown in Fig. 5. The viscous medium used is a kind of macromolecule polymer, the relationship between stress and strain are shown in Fig. 6. Sheet metal deformation flow velocity fields of ladder convex corner (marked by A) during forming process are shown in Fig. 7.

Table 2 Experimental parameters and forming results

Specimen	Substep 1 Max forming pressure / MPa	Substep 1 BHP / MPa	Substep 2 Max forming pressure / MPa	Substep 2 BHP / MPa	Deformation status
1	5.4	0.8	–	–	Wrinkling
2	21.2	10.5	–	–	Fracture
3	9.2	1.8	–	–	No wrinkling, not touching die surface entirely
4	9.2	1.8	21.2	10.5	No defect

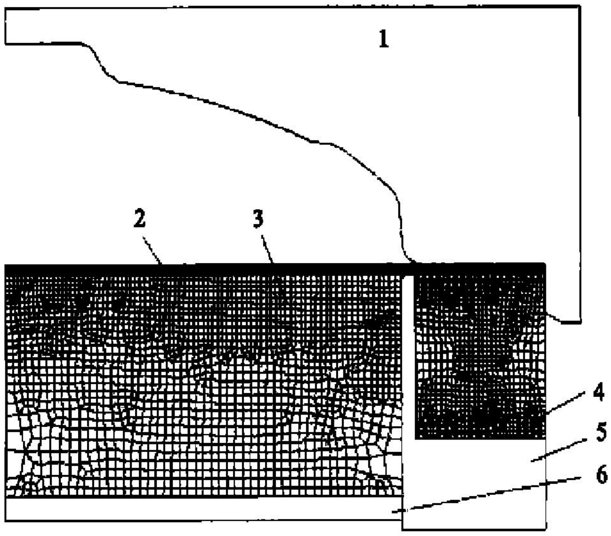

Fig. 5 FEM model used in VPF process numerical simulation
1 —Die; 2 —Sheet blank; 3 —Viscous medium; 4 —Blank holder; 5 —Guiding device; 6 —Piston

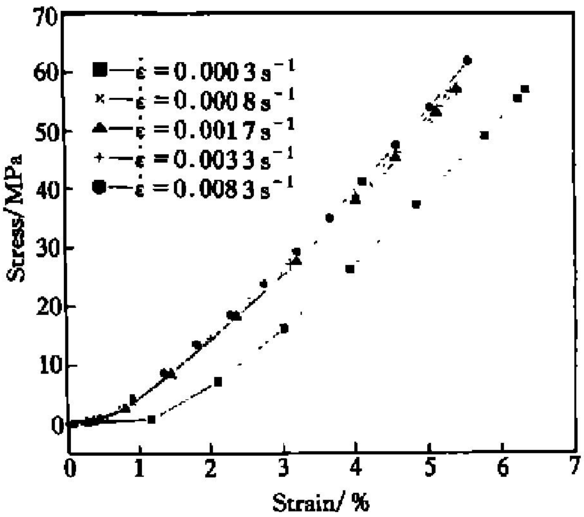

Fig. 6 Relationship between stress and strain of viscous medium used by experiments

Filling with viscous medium and increasing viscous medium pressure, sheet blank was stretched to ladder corner ($r = 3$ mm) of die gradually, wall-thickness in ladder convex corner thinned. The wall-thickness and dimensional accuracy of ladder corner became the key effect factors to forming. Specimens formed by load paths of BHP (Fig. 4) are shown in Fig. 8 and the ladder dimensions are shown in Fig. 9 respectively. The specimen formed with load path a is shown in Fig. 8(b). Because of too small BHP, sheet blank flange wrinkled due to tangential compression stress so that viscous medium leaked and the ladder diameter was far less than 20 mm (Fig. 9(a)). Even BHP reached 0.8 MPa, ladder diameter was still very small (Fig. 9(b)). When BHP was too large (load Path c in Fig. 4), radial stress exceeded tensile stress limit of sheet metal at the die entrance (danger section) and sheet blank fractured (Fig. 8 (c)), the ladder convex diameter was smaller than 20 mm yet. BHP load curve was optimized by variable load path of BHP (Path b in Fig. 4). At first, sheet blank was applied by smaller BHP (about 1.8 MPa) and drawn into die without flange wrinkling and local wall-thickness thinning, the hemispherical specimen was formed in this stage; then the two ladders were formed under higher BHP (about 10.8 MPa) from the hemispherical shape specimen, and the specimen was obtained with the requirements of dimensional accuracy finally (Fig. 8(a) and Fig. 9(d)). The surface fineness of specimens reaches IT9-10.

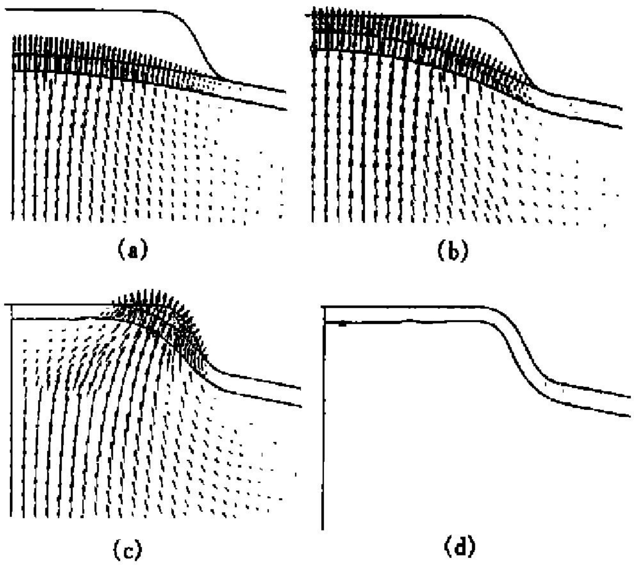

Fig. 7 Deformation velocity fields in ladder convex during forming process
(a) —Stroke= 15 mm; (b) —Stroke= 16 mm; (c) —Stroke= 16.3 mm; (d) —Final state

4.2 Effect of BHP on forming pressure

In the first stage of variable load path of BHP (Path b), BHP was 1.8 MPa, sheet blank was drawn into die easily, and forming pressure varied slowly. When piston stroke reached 14.5 mm, sheet blank became hemispherical shape and began to form

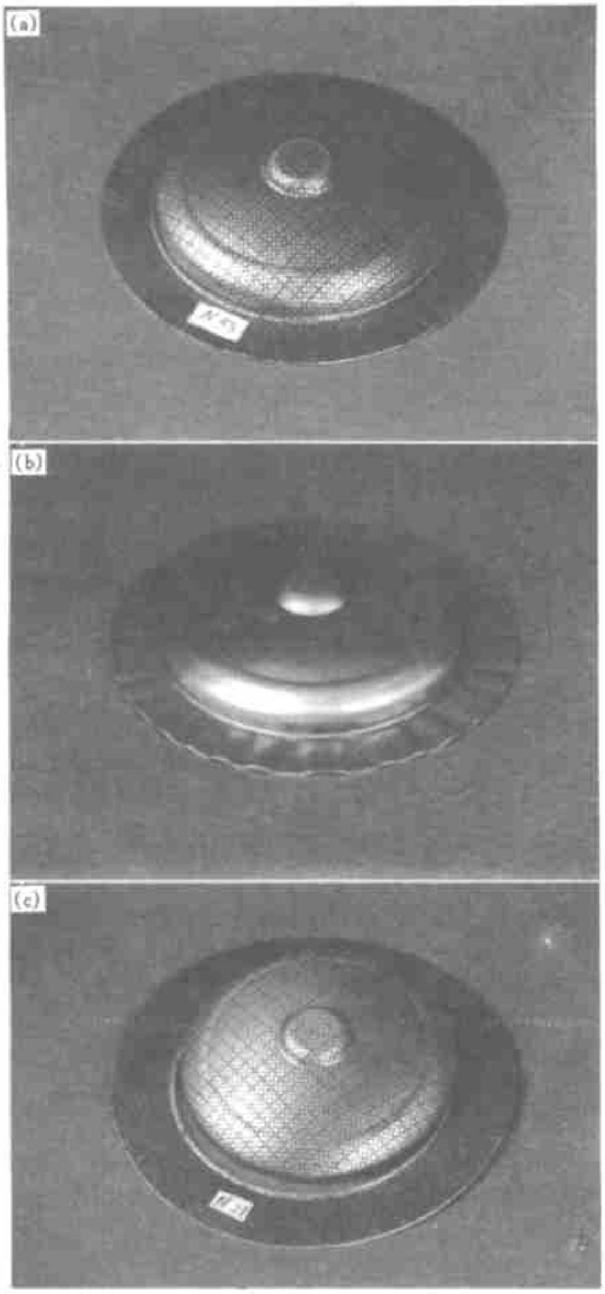

Fig. 8 Ladder specimens obtained by VPF
(a) —No defect (Path b, BHP= 1.8, 10.5 MPa);
(b) —Wrinkling (Path a, BHP= 0.6 MPa);
(c) —Fracture (Path c, BHP= 10.5 MPa)

the two ladder convexes so that the forming pressure increased quickly, and BHP was increased to 10.5 MPa also in this stage. At the same piston stroke, sheet blank flange wrinkled with path a (BHP = 0.8 MPa) or sheet flange corner fractured with path c (BHP= 10.5 MPa). The relationship between forming pressure and piston stroke obtained by experiments and simulations under different load paths of BHP are shown in Fig. 10.

Corresponding to experiments under load path a and c, forming pressure in simulations still increased even though wrinkling or fracture occurred (see Fig. 10). The reason is that the viscous medium leakage was not taken into consideration in the numerical simulation model. As to variable load path of BHP (path b), the relationship between forming pressure and BHP was chosen well and wrinkling and fracture could be avoided. Simulation data were in good agreement with experimental results. The optimum load path of BHP and BHP range were predicted well by numerical simulation, and forming pressure range under formable BHP was also predicted.

4.3 Effect of BHP on sheet metal formability

The main forming defects of ladder parts are wrinkling and fracture. Theses two kinds of defects are related to BHP and the rate of sheet blank flowing-in die, which are mainly affected by tangential compression stress and radial tensile stress during forming process. If BHP is too small, flange will wrinkle due to excessive tangential compression stress; and if BHP is too large, sheet blank will fracture at die entrance because of excessive radial tensile stress. In a certain range of BHP, sheet blank is drawn into die fully without wrinkling and fracture. The limits of BHP corresponding to specimens with no defect and with wrinkling or fracture defect can be determined by the relationship between BHP and sheet blank flange reduction, such as the safe, wrinkling and fracture zones, these zones got by experiments and numerical simulations are shown in Fig. 11.

The BHP range of fracture forming is larger than 10.2 MPa, the BHP range of wrinkling forming is smaller than 0.8 MPa, and the safe zone is between these two zones mentioned above. Under the condition of variable load path of BHP, the rate at which sheet blank drawn into die is larger due to smaller BHP at the first stage, so that sheet deformation locates the safe zone still even under larger BHP at the second stage, which increases dimensional accuracy of the parts and improves the sheet metal formability. Simulation data do not show agreement with experimental results in wrinkle zone, the reason is that viscous medium leakage is not taken into consideration in the numerical simulation model so that sheet blank flange reduction increases with the decreasing of BHP. The effect of viscous medium leakage on forming process is very important in experiments, once viscous medium was leaked, forming pressure will drop quickly and the sheet blank flange will stop reducing.

4.4 Effect of BHP on wall-thickness distribution of specimens

Under the prerequisite of no defects (wrinkling and fracture), the wall-thickness distribution of specimens should be more uniform. The wall-thickness reduction ratio distribution curves of specimens obtained by different load paths of BHP are shown in Fig. 12.

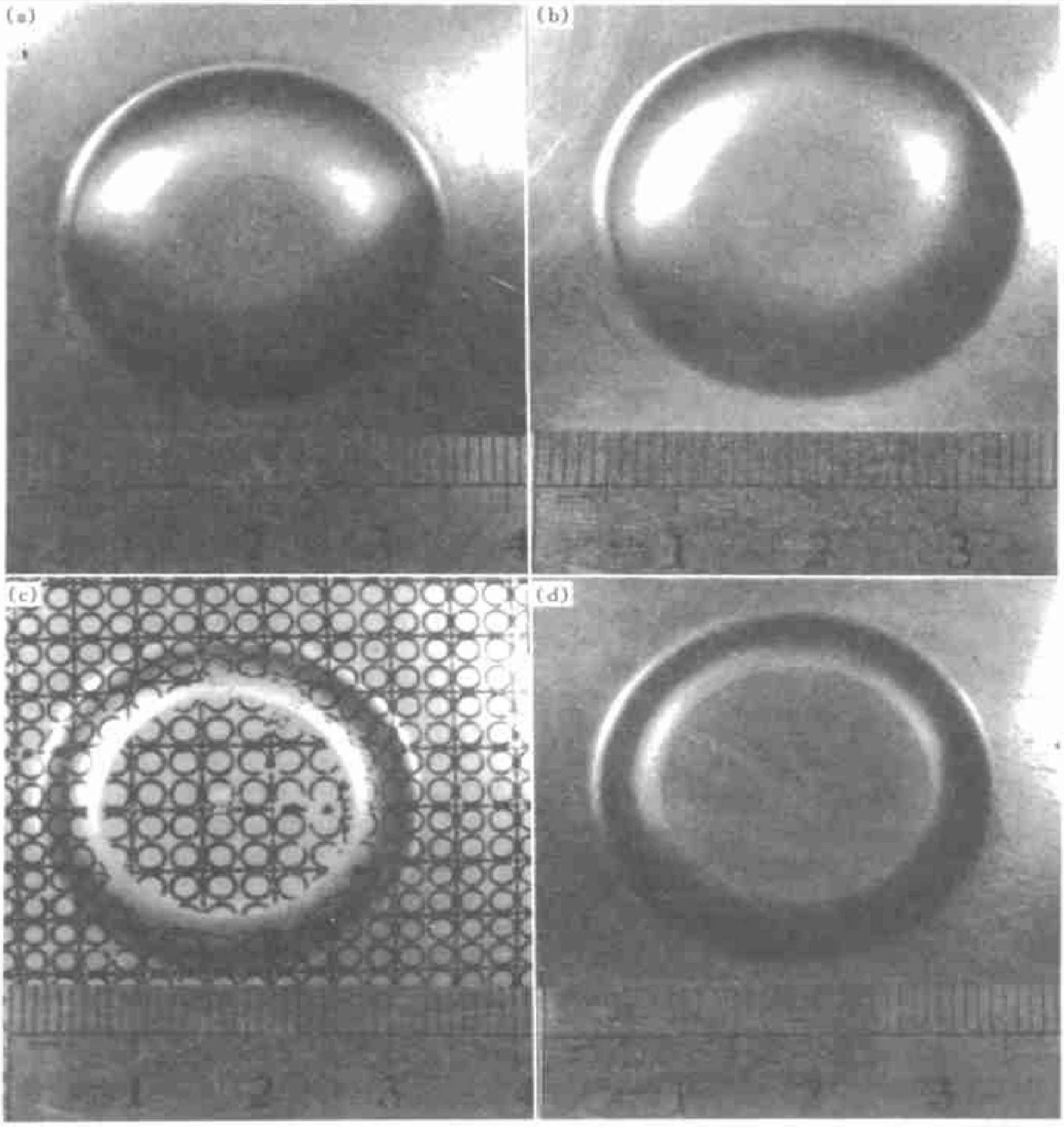

Fig. 9 Ladder convex diameters of specimens obtained with different load paths of BHP
(a) —Path a (BHP= 0.6 MPa); (b) —Path a (BHP= 0.8 MPa);
(c) —Path c (BHP= 10.5 MPa); (d) —Path b (BHP= 1.8, 10.5 MPa)

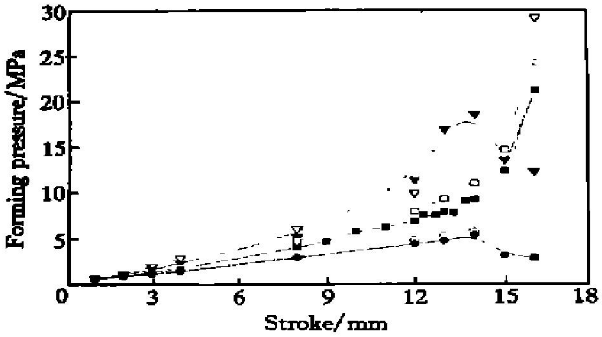

Fig. 10 Relationship between forming pressure and piston stroke obtained by experiments and simulations
○ —Simulation (Path a, BHP= 0.8 MPa);
● —Experiment (Path a, BHP= 0.8 MPa);
▽ —Simulation (Path c, BHP= 10.5 MPa);
▼ —Experiment (Path c, BHP= 10.5 MPa);
□ —Simulation (Path b, BHP= 1.8, 10.5 MPa);
■ —Experiment (Path b, BHP= 1.8, 10.5 MPa)

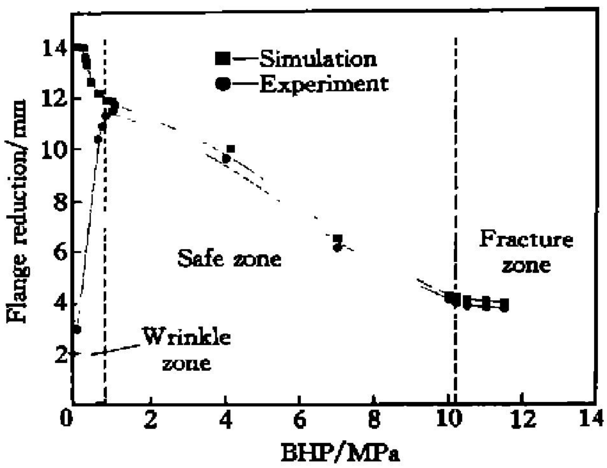

Fig. 11 Safe, wrinkle and fracture zones of specimens influenced by BHP and sheet blank flange reduction

BHP of Path a was too small and sheet blank flange wrinkled so that the ladder convex (marked by

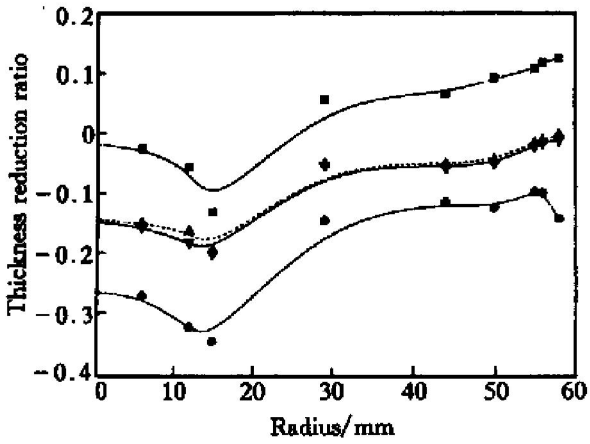

Fig. 12 Wall-thickness reduction ratio distribution curves of specimens obtained by different load paths of BHP

■ —Path a, BHP= 0.8 MPa;
● —Path c, BHP= 10.5 MPa;
▲ —Path b (Substep 1), BHP= 1.8 MPa;
▼ —Path b (Substep 2), BHP= 10.5 MPa

A in Fig. 2) was not formed fully and the wall-thickness reduction of the specimen was small, but wall-thickness increased somewhat at die entrance. BHP of Path c was too large, sheet blank was bugled nearly, and the wall-thickness of ladder convex corner (marked by A in Fig. 2) thinned seriously, the specimen fractured at die entrance finally due to excessive radial tensile. With respect to variable load path of BHP (Path b), wall-thickness reduction ratio of the second stage was larger than that of the first stage only at the two ladder convexes. The maximum wall thickness reduction ratio was less than 20%.

5 CONCLUSIONS

1) Ladder parts can be formed by VPF with one operation to replace multi-operation steel punch forming. Optimum process parameters and variable load paths of BHP avoid forming defects such as wrinkling, fracture, local serious wall-thickness reduction and dimensional inaccuracy.

2) There are three BHP load ranges corresponding to safe zone, wrinkle zone and fracture zone of VPF ladder parts respectively, and the parts formed in safe zone by variable load path of BHP meet the requirement of dimensional accuracy. The variable load path of BHP can be predicted by numerical simulation.

3) Dimensional accuracy of the aluminum alloy ladder parts manufactured by VPF can reach IT9-10, and surface fineness retains the original surface fineness of the sheet metal.

[REFERENCES]

[1] Lange K. Modern metal forming technology for industrial production [J]. J Mater Process Technol, 1997, 71: 2 - 13.

[2] XU Shu-qin, FU Yuan. FEM analysis and experimental research on complex forming [J]. J Mater Process Technol, 1997, 69: 208- 211.

[3] Liu J, Westhoff B, Ahmetogla M, et al. Application of viscous pressure forming (VPF) to low volume stamping of difficult-to-forming alloys —Results of preliminary FEM simulations [J]. J Mater Process Technol, 1996, 53(1): 49- 58.

[4] Roades M L, Roades L J. Method and Apparatus for Die Forming Sheet Materials [P]. US5085058. Feb. 4, 1992.

[5] Shulkin L B, Posteraro R A, Ahmetoglu M A, et al. Blank holder force (BHF) control in viscous pressure forming (VPF) of sheet metal [J]. J Mater Process Technol, 2000, 98: 7- 16.

[6] Liu J, Ahmetogla M, Altan T. Evaluation of sheet metal formability, viscous pressure forming (VPF) dome test [J]. J Mater Process Technol, 2000, 98: 1- 6.

[7] WANG Zhong-jin, WANG Zhong-ren. Analysis of strain rate variations during viscous pressure bulging of sheet metal [J]. Journal of Plasticity Engineering, (in Chinese), 1999, 6(3): 46- 48.

[8] WANG Zhong-jin, WANG Zhong-ren, YANG Hai-feng. Experimental investigation for viscous medium drawing of sheet metal under the condition of non-uniform blank holder force [J]. Journal of Plasticity Engineering, (in Chinese), 1999, 6(2): 50- 52.

[9] Ahmetoglu M A, Kinzel G, Altan T. Forming of aluminum alloys —Application of computer simulations and blank holding force control [J]. J Mater Process Technol, 1997, 71: 147- 151.

[10] Murata A, Ebine Y, Matsui M. Effect of blank holding force control on deep drawability of square sheet [J]. JSTP, (in Japanese), 1992, 33: 411- 416.

[11] Siegert K. CNC-hydraulic multipoint blankholder systems for sheet metal forming presses [J]. Annals of the CIRP, 1993, 42(1): 319- 322.

[12] YANG Yu-ying. Large-sized thin sheet forming technology [M], (in Chinese). Beijing: National Defensive Industry Press, 1996. 146- 184

[13] WU Shi-dun, HE Sheng-jian. Stamping and Forging Technology [M], (in Chinese). Xi′an: Northwestern Polytechnical University Press, 1987. 170- 189.

[14] DEFORM2D Manuals (Version 7.0) [M]. Columbus, Ohio: Scientific Forming Technologies Corporation, 2000.

(Edited by YUAN Sai-qian)