Die design system for deep drawing and ironing of high pressure gas cylinder

Ji-Hun Yoon[1], Young-Choi[2,#] and Yoon-So Park[1]

1 NK Co. Ltd., Busan, South Korea
2 School of Mechanical and Automotive Engineering, Inje University, Gimhae, South Korea
Corresponding Author / E-mail: ychoi@inje.ac.kr, TEL: +82-55-320-3755, FAX: +82-55-324-1723

KEYWORDS : D. D. I. (Deep Drawing & Ironing, Die design, FTM(Flexible Tolerance Method), Inset, Shrink ring, Interface diameter, FE(Finite Element) analysis

This paper describes a research work on the die design for the deep drawing & ironing(D. D. I.) of high pressure gas cylinder. D. D. I die set is large-sized die used in horizontal press, which is usually composed of a drawing, and an ironing die. Design method of D. D. I. die set is very different from that of conventional cold forging die set. Outer diameter of the die set is fixed because of press specification and that of the insert should be as small as possible for saving material cost. In this study, D. D. I die set has been designed to consider those characteristics, and the feasibility of the designed die has been verified by FE-analysis. In addition, the automated system of die design has been developed in AutoCAD R14 by formulating the applied methods to the regular rules.

Manuscript received: October 1, 2004 / Accepted: February 2, 2005

1. Introduction

The D. D. I. (Deep Drawing &Ironing) process, which is one of new processes of such products as LPG gas cylinders and fire extinguishers, forms cylinders consecutively using dies of deep drawing & ironing by one stroke with one punch. Fig. 1 shows the D. D. I. forming process.

A horizontal press with large capacity and a long stroke is necessary in manufacturing gas cylinders by the D. D. I. process. Recently, fabrication of a high-pressure gas cylinder became possible by development of a horizontal press with a long stoke[1,2]. The horizontal press with the stoke of 650 [tonf] and 8.2[m] is introduced to meet the domestic needs, and fabrication of a high-pressure gas cylinder is being under development[1,3]. Fig. 2 and Table 1 show assembly of the D. D. I. press and functions of each part in the press, respectively.

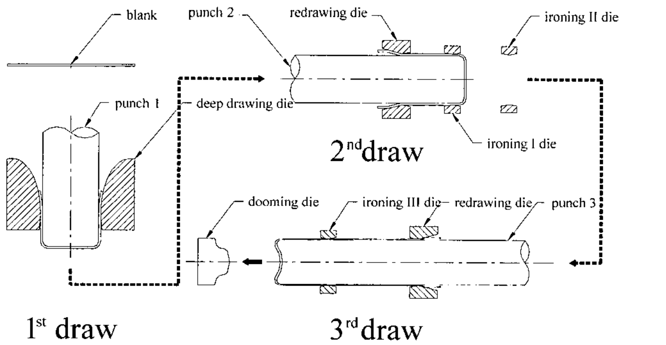


Fig. 1 D. D. I. forming process

A redrawing die and an ironing die shown in Fig.2 are used to fabricate the products under the condition of high pressure and is fabricating products.

In this study, to design the dies which are used in the D. D. I. process, various technologies will be formulated and verified by a FE-analysis of the designed dies. In addition, an automated die-design system will be constructed by AutoLISP under AutoCAD R14 environment.

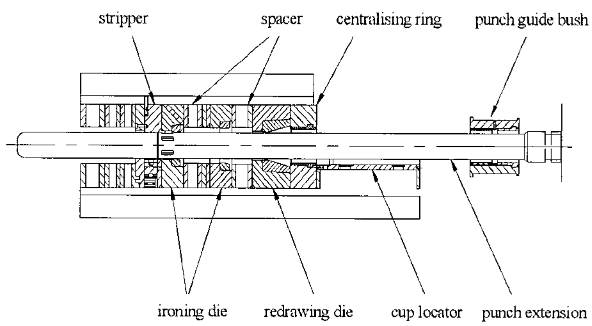


Fig. 2 Assembly of D. D. I. press[2]

Table 1 The functions of part list in each press

Part Name	Operation
stripper	separates the formed cup from the punch
punch extension	links the punch with the press
punch bush guide	prevents deflection of the punch
redrawing die	is used at redrawing
ironing die	forms constantly thickness of the cup
cup locator	locates the cup of the previous process
centralizing ring	prevents eccentricity of the cup
spacer	keep space between dies

2. Die Design

2.1 Characteristic of a D. D. I. die

Being different from the conventional cold-forging dies, Several points are to be reconsidered at designing dies of the D. D. I. process.

First, the conventional dies are of small-sized as shown in Table 2, so that the ratio of the inner diameter to the outer diameter is large and they have fewer restrictions[3]. However, the D. D. I. die has the same outer diameter in one draw as shown Fig. 2 and is located inside the press, so that the ratio of an inner diameter to an outer diameter is to be in between 2.0 and 3.0.

Second, one stroke matches one process for the conventional die, which leads to fewer restrictions about height of the die and stroke of the punch. On the contrary, the D. D. I. process is composed of drawing an ironing. In addition to dies of drawing and ironing, various parts to correct eccentricity and a striper to separate a blank and a punch are required, which causes more restrictions about the height and the stroke.

Third, due to the large size of the dies, the production cost becomes high and much more, especially for the ironing die, material of the insert should be tungsten-carbide. To reduce the cost, the outer diameter of the insert should be smaller than the conventional one.

2.2 Design of the D. D. I. die

When designing the conventional dies, the inner diameter determines the outer diameter according to the diameter ratio as shown in Table 2. However when designing the D. D. I. die, process planning determines an inner diameter and also specification of the press determines an outer diameter. After determination of the outer diameter, diameters and interference are determined by the equations (1) and (2)[4]. The equations are derived from the condition that all rings yield at the same time and no tensile stress in cylindrical direction is allowed for tungsten-carbide.

Table 2 Diameter ratio of general die[3]

Number of shrink rings	Diameter ratio d_o/d_i
0	4-5
1	4-6
2	4-6

(Here, d_o is an outer diameter of a die [mm], and d_i is an inner diameter of a die [mm].)

(1) the conventional tool steel for an insert

$$d_m = \frac{d_i}{Q\sqrt{\frac{\sigma_{y,2}}{\sigma_{y,1}}}} \tag{1}$$

(2) tungsten-carbide for an insert

$$d_m = \frac{d_i}{\sqrt{Q^2 + Q\sqrt{1+Q^2}}} \tag{2}$$

Here, d_m is interface diameter[mm], d_i inner diameter of an insert[mm], d_o outer diameter of a shrink ring[mm], Q the ratio of inner diameter of an insert to outer diameter of a shrink ring(d_i/d_o), $\sigma_{y,1}$ yield stress of an insert[kgf/mm^2], and $\sigma_{y,2}$ yield stress of a shrink ring[kgf/mm^2].

However, due to an advance in tungsten-carbide, it does not always yield in spite of tensile stress and all the rings do not yield at the same time. Thus, the design of cold-extrusion dies by FTM(lexible tolerance method) was adopted to reduce the cost of expensive material. The pre-stressed dies are fastened by press fitting. During the fitting, the dies can either be pre-stressed or yield. Therefore, diameter ratio and interference are to be safely determined by judging whether or not rings and the insert would yield at the final inner pressure and the fitting.

Displacement of the k-th ring can be calculated as shown in the equations (3) and (4).

(1) variation of d_{k-1} of an inner surface of a cylinder

$$U_{ki} = A_{ki}p_{k-1} - B_{ki}p_k \tag{3}$$

$$A_{ki} = \left\{ \frac{(1-\nu_k)Q_k^2 + (1+\nu_k)}{E_k(1-Q_k^2)} \right\} d_{k-1}$$

$$B_{ki} = \left\{ \frac{2}{E_k(1-Q_k^2)} \right\} d_{k-1}$$

(2) variation of d_k of an outer surface of a cylinder

$$U_{ko} = A_{ko}p_{k-1} - B_{ko}p_k \tag{4}$$

$$A_{ko} = \left\{ \frac{2Q_k^2}{E_k(1-Q_k^2)} \right\} d_k$$

$$B_{ko} = \left\{ \frac{(1-\nu_k) + (1+\nu_k)Q_k^2}{E_k(1-Q_k^2)} \right\} d_k$$

Here, p_k is contact pressure of the k-th contact surface, E_k elastic modules of the k-th ring, ν_k Poisson's ratio of the k-th ring, Q_k the diameter ratio of the k-th ring.

This study deals with the case of two rings including a die insert. Interference at the contact surface is calculated by the equations (5) and (6).

$$\begin{aligned} z_1 &= U_{2i} - U_{1o} \\ &= \{A_{2i} + B_{1o}\}p_1 - B_{2i}\,p_2 - A_{1o}\,p_0 \end{aligned} \tag{5}$$

The above equation can be simplified for pressure as follows :

$$p_1 = \frac{A_1}{C_1} + \frac{B_1}{C_1}p_0 \tag{6}$$

where, each parameter is calculated as follows :

$$A_1 = X_1 + Z_1p_2 = X_1,\ B_1 = Y_1,\ C_1 = 1$$

$$X_1 = \frac{z_1}{A_{2i} + B_{1o}},\ Y_1 = \frac{A_{1o}}{A_{2i} + B_{1o}},$$

$$Z_1 = \frac{B_{2i}}{A_{2i} + B_{1o}}$$

Contact pressures when dies are fitted are calculated by the conditions of $p_2 = 0$ and $p_0 = 0$.

Using equation (6), the diameter ratio and interference are optimally determined by reiteration, and the contact pressure after fitting is obtained, and yield is judged. Table 3 shows the yield strength. S_t is selected at tensile state, S_c at compressive state, and a little bit lower value than the yield strength for the most outer ring. A safety factor is considered by multiplying S_o.

Table 3 Yielding strength according to the state of hoop stress

Compressive ($\sigma_\theta < 0$)	Tensile ($\sigma_\theta \geq 0$)	n^{th} ring
$Y = S_c * S_Y$	$Y = S_t * S_Y$	$Y = S_o * S_Y$

Yielding of each ring follows Tresca yield criterion as shown in equation (7). The restrictions for diameter ratio, contact pressure, and interference are shown as equation (8). Here, Q_c and Z_c are limit values of diameter ratio and interference, respectively.

$$\begin{aligned} &\frac{Y_1}{2}(1-Q_1^2) - |p_0 - p_1| \geq 0 \\ &\frac{Y_2}{2}(1-Q_2^2) - |p_1 - p_2| \geq 0 \end{aligned} \tag{7}$$

$$\begin{aligned} &Q = Q_1Q_2 \\ &0 < Q_k \leq Q_c \\ &0 \leq p_0, p_1, p_2,\ 0 \leq z_1 \leq z_c \end{aligned} \tag{8}$$

After calculating contact pressure of the pre-stressed die by the equation (6), restrictions during the fitting is automatically constructed by equations (7) and (8).

The maximum inner pressure is assigned an objective function as shown in equation (9). Under the condition that one ring yields at the maximum inner pressure, the inner pressure where the die insert yields is assigned for the maximum inner pressure and the maximum pressure is overcome.

$$F(\{X\}) = -p_{o_{\max}} = -\frac{C_1 p_1 - A_1}{B_1} \tag{9}$$

$$\{X\} = \{Q_1, Q_2, z_1\} \tag{10}$$

Under the condition that the die insert yields at either compressive or tensile state at the maximum inner pressure, Inner and outer pressure of the insert is calculated by equation (11).

$$p_0 = \frac{A_1 + C_1 D_1}{C_1 - B_1}, \quad p_1 = \frac{A_1 + B_1 D_1}{C_1 - B_1} \tag{11}$$

$$D_1 = \frac{Y_1}{2}(1 - Q_1^2)$$

Inputting the above selected parameters to the equations (11), (7), and (8) constructs restrictions at the maximum inner pressure. The optimal design parameters were obtained by the FTM algorithm to satisfy the restrictions and minimize the objective function.

In this study, safety of the die was verified by two methods. One is to calculate distribution of stress[6]. The equations to calculated the distribution are shown in (12)~(19) and Fig. 3 shows one of the diagrams. Though these equations are easy to use, they are easy to err because the die is assumed cylindrical. The other is to use FE-analysis. Distribution of the applied pressure to the dies is obtained by using a commercial FE program, DEFORM and ANSYS in order to judge the safety[6,7]. Especially, tensile state is to be focused due to tungsten-carbide.

(1) stress on an inner diameter of a insert

$$\sigma_r = \frac{r_i^2 \cdot p_i - r_m^2 \cdot p}{r_m^2 - r_i^2} - \frac{(p_i - p) \cdot r_m^2}{(r_m^2 - r_i^2)} \tag{12}$$

$$\sigma_\theta = \frac{r_i^2 \cdot p_i - r_m^2 \cdot p}{r_m^2 - r_i^2} + \frac{(p_i - p) \cdot r_m^2}{(r_m^2 - r_i^2)} \tag{13}$$

Here, σ_r is radial stress and σ_θ cylindrical stress.

(2) stress on an outer diameter of a insert

$$\sigma_r = \frac{r_i^2 \cdot p_i - r_m^2 \cdot p}{r_m^2 - r_i^2} - \frac{(p_i - p) \cdot r_i^2}{(r_m^2 - r_i^2)} \tag{14}$$

$$\sigma_\theta = \frac{r_i^2 \cdot p_i - r_m^2 \cdot p}{r_m^2 - r_i^2} + \frac{(p_i - p) \cdot r_i^2}{(r_m^2 - r_i^2)} \tag{15}$$

(3) stress on an inner diameter of a shrink ring

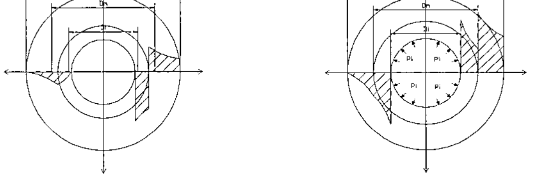
$$\sigma_r = \frac{r_m^2 \cdot p}{r_o^2 - r_m^2} - \frac{p \cdot r_o^2}{(r_o^2 - r_m^2)} \tag{16}$$

$$\sigma_\theta = \frac{r_m^2 \cdot p}{r_o^2 - r_m^2} + \frac{p \cdot r_o^2}{(r_o^2 - r_m^2)} \tag{17}$$

(4) stress on an outer diameter of a shrink ring

$$\sigma_r = \frac{r_m^2 \cdot p}{r_o^2 - r_m^2} - \frac{p \cdot r_m^2}{(r_o^2 - r_m^2)} = 0 \tag{18}$$

$$\sigma_\theta = 2 \cdot \frac{r_m^2 \cdot p}{r_o^2 - r_m^2} \tag{19}$$



(a) After press fitting (b) During working

Fig. 3 Stress distribution diagram in die(6) and (8)

3. Configuration of the system

In this study, an automated system of the D.D.I. die design for high pressure gas cylinders was developed. The system is operating under AutoCAD R14 environment and even beginners can handle the system. Fig. 4 shows configuration of the system.

The part inside dot line in Fig. 4 is about die design. The results from the process planning and the calculated values are input of the system and the user selects the kind of the part to be designed. After the system designs the parts of the punch, the user inputs the material information of insert and a shrink ring and selects either general design method or cost-saving one. And then, the design is performed and the drawing is operated. By using the drawing, FE-analysis can be performed and the problem can be solved by changing the process planning, if any errors occur from the FE-analysis.

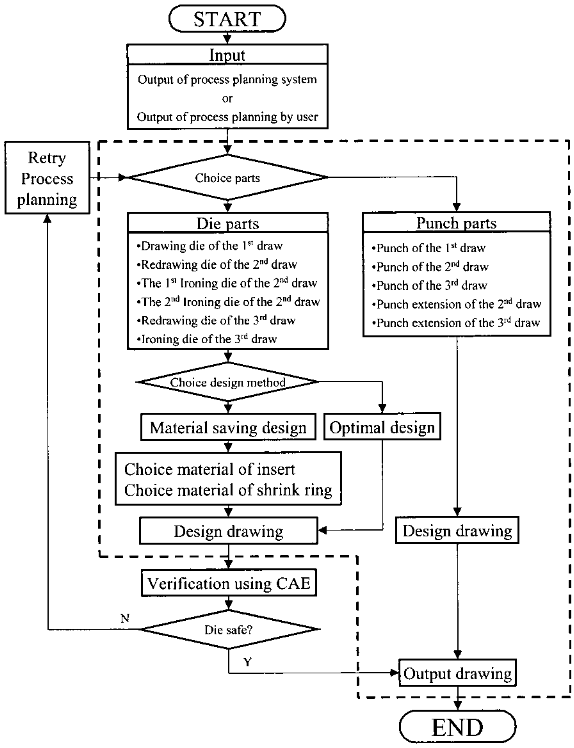


Fig. 4 Configuration of the system

3.1 Design rules

In the present system, plasticity theory and experts' experiences are formulated as design rules to perform the D. D. I. die design. The design rules are as follows.

3.1.1 Design rules

D Rule 1) Spherodizing heat treatment should be done before each forming process[2].

D Rule 2) Lubrication should be done before each forming process[2].

D Rule 3) Distance between a drawing and an ironing dies considers that an ironing process starts when the load drops after the maximum point at the drawing. In other words, when the material on the redrawing die remains 1/3, the ironing is to start[2].

D Rule 4) Distance between ironing dies is to be larger than the diameter of the cup at the former ironing[9].

D Rule 5) If the operation is a drawing, an ironing, and an ironing at the 2nd draw, distances among dies are to be determined for the cup not to form over the 3 processes at the same time[2].

D Rule 6) The sum of length of the punch and the punch holder at the 2^{nd} and the 3^{rd} draw is 4.2[m][2].

D Rule 7) The outer diameter of the punch holder at the 2^{nd} and the 3^{rd} draw is to be same as the outer diameter of the outer punch[2,9].

D Rule 8) The diameter of a stripper is to be larger than that of a cup formed at open state. And it is to be smaller than the outer diameter of a cup and larger than the outer diameter of a punch at close state[2].

D Rule 9) The length of a cup locator is to be larger than that of the cup formed at the previous process[2].

D Rule 10) The inner diameter of a cup locator is to be same as the outer diameter of the cup formed at the previous process[2].

D Rule 11) The inner diameter of a centralizing ring is to be same the outer diameter of the cup formed at the previous process[2].

D Rule 12) The inner diameter of a punch bush guide is to be same as the outer diameter of a punch and a punch holder[2,9].

D Rule 13) The outer diameter of the die at the 2nd and the 3rd draw is to be 700[mm] or 800[mm][2].

D Rule 14) Distance between dies is to be controlled by a spacer.

D Rule 15) A punch, dies, and various parts is to be designed and equipped concentrically[2].

D Rule 16) The diameters of a centralizing ring, a redrawing die, an ironing die and a stripper are to be same[2].

D Rule 17) Assembly of an insert and a shrink ring is to be shrink-fitting[2].

D Rule 18) At shrink-fitting, a shrink ring is to be heated and an insert is to be cooled[2,8].

D Rule 19) Stress relief of a die, a punch and a punch holder is to be performed[2].

D Rule 20) The upper diameter of the insert of a drawing and an ironing dies is larger than the diameter of the product of the previous process[2].

D Rule 21) The corner radius of the punch at the 1^{st} draw is determined by interpolation according to the thickness shown in Table 4.

D Rule 22) The corner radius of the punch after the 2^{nd} draw is to be calculated as the following equations shown in Fig. 5.

Table 4 Punch corner radius of the 1st Draw according to blank thickness

t	r_{p1}
4~6	3~4 t
6~10	1.8~2.6 t
10~15	1.6~1.8 t
15~20	1.3~1.6 t

where, t is thickness of a blank and r_{p1} is a corner radius of the punch at the 1^{st} draw[mm].

$$r_{p2} = \frac{d_{p2} - d_{p1}}{2} + r_{p1} \tag{20}$$

$$r_{p3} = \frac{d_{p3} - d_{p2}}{2} + \frac{r_{p2}}{4} \tag{21}$$

$$r_{p(n)} = \frac{d_{p(n)} - d_{p(n-1)}}{2} + \frac{r_{p(n-1)}}{4} \tag{22}$$

where, r_{p2} is the corner radius of the punch at the 2^{nd} draw[mm], r_{pn} the the corner radius of the punch at the nth draw[mm], d_{p1} the diameter of the punch at the 1^{st} draw[mm], d_{p2} the diameter of the punch at the 2^{nd} draw[mm], and d_{pn} the diameter of the punch at the n^{th} draw[mm].

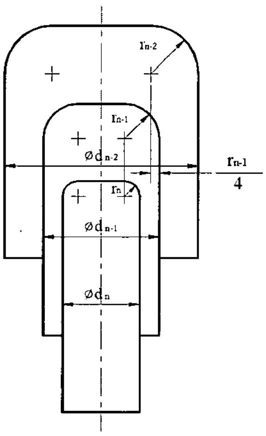


Fig. 5 Determination of punch corner radius after the 1^{st} Draw

D Rule 23) The corner radius of the punch at the final forming process is to be determined by the following equation.

$$r_{pn} = 0.075 d_o \tag{23}$$

where, d_o is the outer diameter of the product

D Rule 24) The shape of the punch at the final forming process is shown in Fig. 6 and is to meet the following condition.

$$a_1 \geq 2a, a_2 \geq 2a \tag{24}$$

$$h = 0.12D, r = 0.75D \tag{25}$$

where, a, a_1, a_2, D, h and r are shown in Fig. 6.

D Rule 25) Angle of a drawing die is to be 15°[2].

D Rule 26) Angle of an ironing die is to be 10°[2].

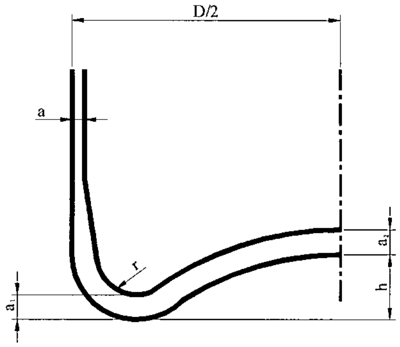


Fig. 6 Concave base ends

D Rule 27) The number of holes of an eye bolt for die movement is to be more than one[2].

D Rule 28) If clearance at the drawing of the next forming process is expected to be insufficient, taper of the punch at the previous forming process is to be deleted.

D Rule 29) At the final forming process, the punch is to be tapered.

3.1.2 Calculation Rule

C Rule 1) At die design of a drawing and an ironing, a diameter ratio of the optimal design is to follow the equations (1) and (2)[4].

C Rule 2) At die design of a drawing and an ironing, a diameter ratio, interference, and contact pressure of the material-savting design is to follow the equations (3)~(11)[2].

C Rule 3) Contact pressure at fitting is to follow the equation (7) and (8)[4].

C Rule 4) At fitting, stress of each part is to be smaller than allowable stress of an insert and a shrink ring[6,8].

C Rule 5) For convenience of die manufacturing, the numbers of a diameter ratio are rounded off to a decimal point and are shown at 5-mm intervals.

C Rule 6) For convenience of die manufacturing, interference is shown at 0.05mm intervals.

3.1.3 Test Rule

T Rule 1) Interference by shrink fitting follows the following equation.

$$t = \frac{z}{\alpha \cdot d_m} \tag{26}$$

where, α is coefficient of linear expansion[/℃] and t is hearing temperatrue of a shrink ring at the shrink fitting.

$$t < t_p \tag{27}$$

where, t_p is the temperature at the tempering of a shrink ring[℃].

T Rule 2) Temperature at the shrink fitting is to be lower than that of the heat treatment[8].

T Rule 3) Distribution of stress by interference follows the equations (9)~(16) and is to be lower than the allowable stress of the die[4].

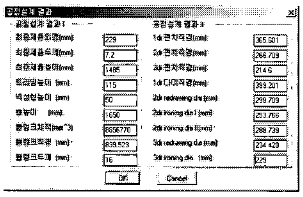
4. Application of the System and Discussion

The product of Φ 229.0×7.2t×1485.0h is applied to the developed system in the present study and the results will be discussed.

4.1 Application to the die design system

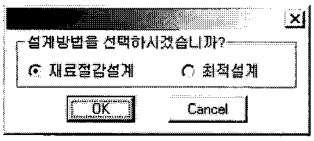
If a user selects the kind of the parts and inputs as shown in Fig. 7

(a), (b), (c), and (d), the system will operate. Fig. 7 (a) shows the calculated data of the process planning and the data can be edited by the user. Also the user inputs the file name to be saved and the path through (b) and chooses the design method as shown in Fig. 7 (c). Material of the die can be selected as shown Fig. 7 (d) and Fig. 7 (e) shows the path to be saved after die design.

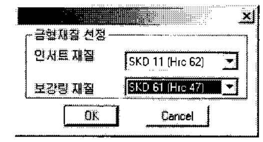


(a) Input data

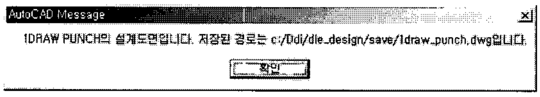
(b) Input filename



(c) Choice design method



(d) Choice material



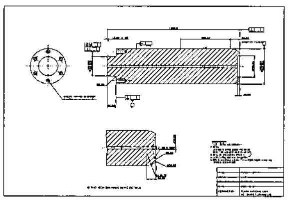
(e) Path of file saving

Fig. 7 DCL on die design system

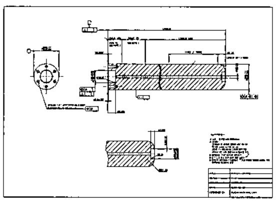
Table 5 Main size of each die set.[mm]

Dies	Inner dia.	Outer dia.	Interface dia.	Interference
Drawing die of the 1st draw	399.20	1149.92	871.52	0.90
Drawing die of the 2nd draw	298.71	699.84	505.00	1.05
The 1st ironing die of the 2nd draw	293.82	699.84	420.00	1.15
The 2nd ironing die of the 2nd draw	288.77	699.84	415.00	1.15
Drawing die of the 3rd draw	234.43	699.84	430.00	0.85
Ironing die of the 3rd draw	229.00	699.84	355.00	1.00

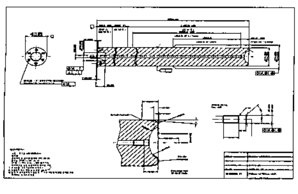
Table 5 and Fig. 8 shows the results of a die design. Design method was material-saving method and materials were selected as SKD 11 [HRC 62] for an insert of a drawing, SKD61 [HRC 47] for a shrink ring of a drawing, Gti 50 [HRC91] for an ironing die, and SKD61 [HRC 47] for a shrink ring of a ironing. In case of tungsten-carbide for an insert, safety factor was assigned to be 0.25 at tensile state and 0.75 in case of a shrink ring.



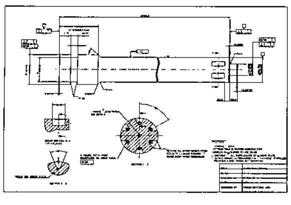
(a) Punch of the 1st draw



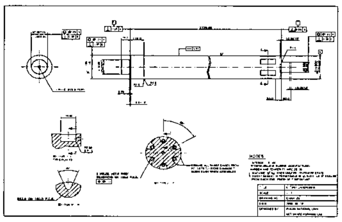
(b) Punch of the 2nd draw



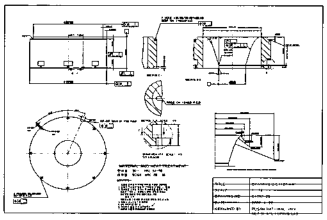
(c) Punch of 3rd draw



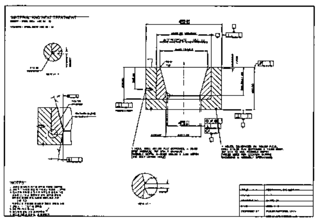
(d) Extension of 2nd draw



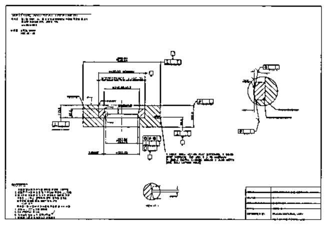
(e) Extension of the 3rd draw



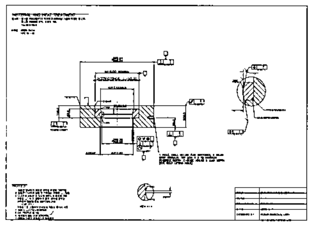
(f) Drawing die of 1st draw



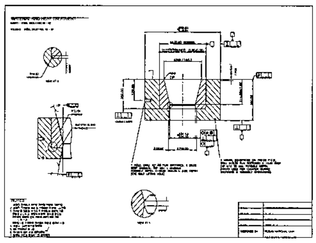
(g) Drawing die of 2nd draw



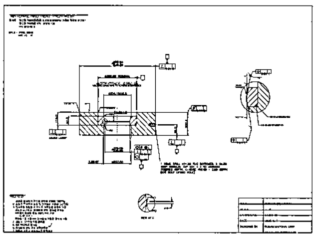
(h) 1st ironing die of 2nd draw



(i) 2nd ironing die of 2nd draw



(j) Drawing die of 3rd draw



(k) Ironing die of 3rd draw

Fig. 8 Drawing of Φ 229×7.2t. product

4.2 FE-Analysis

FE-analysis was performed by applying the designed drawing to DEFORM and distribution of the pressure was obtained as shown in Fig. 9 and 10. Using the results and ANSYS, safety of the dies during operation and after fitting was verified[10,11], especially when an insert of the ironing die was made of tungsten-carbide. Figs. 11 and 12 show the results of the analysis.

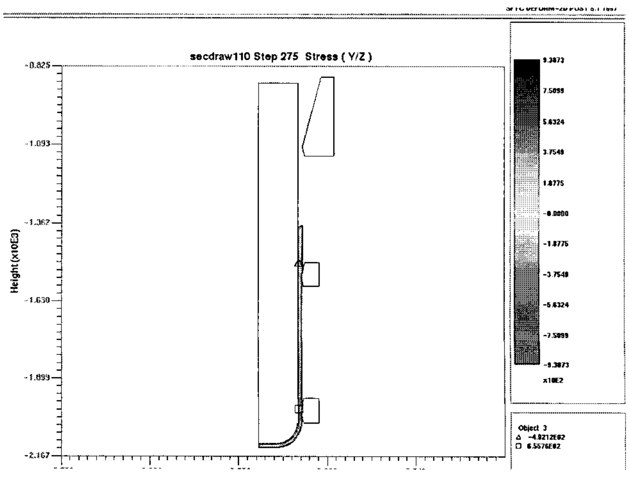


Fig. 9 FE simulation(DEFORM) for the 2nd draw

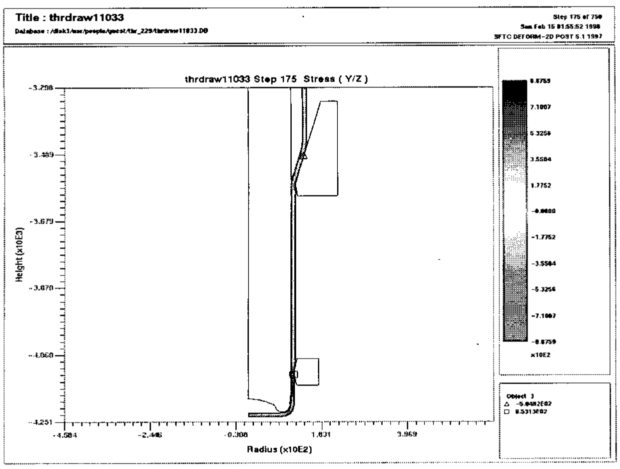
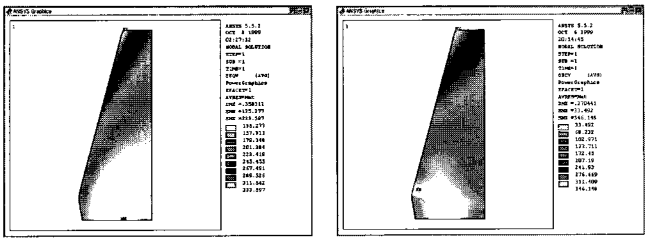
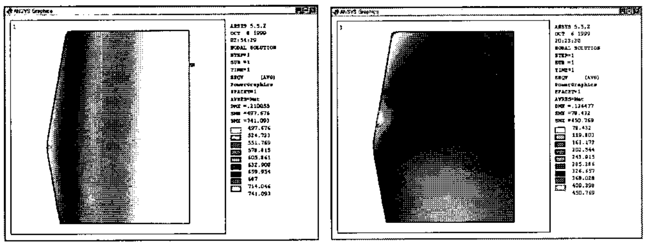


Fig. 10 FE simulation(DEFORM) for the 3^{rd} draw



(a) After press fitting (b) During redrawing

Fig. 11 FE analysis(ANSYS) of the redrawing die of the 2^{nd} draw



(a) After press fitting (b) During ironing

Fig. 12 Ansys analysis(ANSYS) of the 1^{st} ironing die of the 2^{nd} draw

4.3 Fabrication of a test product

By using the designed dies, a test product was successfully fabricated from a circular blank and is shown in Fig. 13.

Fig. 13 The cups formed in each draw

5. Conclusion

In this study, plasticity theory and experts' experiences for the D. D. I. process were formulated and the automated system of the die design for the process was developed. By using the system, even beginners can operate it and obtain the results such as drawings. In addition, through the automated system, various benefits are expected from the viewpoint of time reduction.

1. Die design rules of the D. D. I. process were formulated, which is very different from the conventional design.
2. Material-saving design is constructed for reduction of manufacturing costs of the D. D. I. dies and expensive dies can be protected during forming by applying the FE-analysis and various equations.
3. Through the developed system, an automated die design of the D. D. I. process is possible using the results from the process planning and the calculated data by a user.
4. The results of the developed system were verified by the FE-analysis and the test products were successfully applied and fabricated.

REFERENCES

1. Yoon, J. H., Jung, S. Y., Choi, Y., Kim, C., Choi, J. C., “A Study on the Development of Computer-Aided Process Planning System for the Deep Drawing & Ironing of High Pressure Gas Cylinder,” Journal of the Korean Society of Precision Engineering, Vol. 19, No. 2, pp. 177-186, 2002.
2. Brochure of Fielding Co. Ltd, UK, 1998.
3. Kurt, Lange, "HANDBOOK OF METAL FORM- ING," pp. 15.86～15.88, 1985.
4. Kurt, Lange, "Production of steel parts by cold forging," ICFG, pp. 1-8, 1978.
5. Yeo, H. T., "Study on the Design and Analysis of Precision Cold forging Dies with Stress Rings, " Dong Eui University, pp. 67-76, 2003.
6. Adler, G. and Walter, K., "Berechnung von einfachen und mehrfachen Preβpassungen," INDUSTRIE ANZEIGER, pp. 21-25, 1967.
7. Yeo, H. T., Choi, Y., Hur, K. D., "ANALYSIS AND DESIGN OF THE PRESTRESSED COLD EXTRUSION DIES BY FEM," Proc. of AFDM '99, Pusan, Korea September 7-9, pp. 431-436, 1999.
8. 澤辺弘, "冷間鍛造の基礎と應用," 株式會社産報, pp. 134-161, 1968.
9. National Machinery, "Tool Design and Part Shape Development for Multi-die Cold Forming".
10. Kim, S. H., Han, Y. H., Lee, S. H., "Die Design. Handbook," TaeKwang, pp. 247-366, 1992.
11. Brochure of NK Co. Ltd, "Pressure Vessels," pp . 8-9.