Simulation Analysis of Shell Aluminum Alloy Tube For Neck-In Spinning Process

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Abstract: Spinning has many advantages, such as good metal malleability, high product utilities, better dimension tolerance, high material efficiency, wider product range, and saving human resources .It has already been widely applied on complex tubular products manufacturing. In the past, this technique was focused on trials of equipment and product. In this study, a three-dimensional elastic-plastic finite element numerical simulation technology will be used to do the inner rib forming analysis by three different mandrel span, and to discuss the distribution of stress and strain during the neck-in inner rib spinning. The effects of support span on neck-in inner rib, mandrel, and product are also studied by different span mandrel forming. The result shows that when the mandrel sustaining span is 50mm, the stress of draw-neck inner rib will exceed its yield material stress and get permanent deformation.

Key-Words: Neck-In Spinning, Rib, Finite Element Method

1 Introduction

Spinning is a kind of mechanical plastic deformation process that extrudes high strength and fine material into symmetric shape work piece. The shape of spinning mandrel can be processed by lathe or machine center. Spinning can be applied on high ductility metals, such as steel, aluminum alloy or copper, and there are some advantages, such as high utilization, good quality, easy mandrel preparing, elastic production process and shorter process time. It is suitable not only for large dimension and thin thickness tube manufacturing process, but also for researcher to do development trails because of its time-saving process and high economic factor. Besides, it is particularly suitable for those work metal pieces with variable shapes or drawing.

Spinning is a process that extrudes the metal by rollers. In the past, most of academic studies focused on dynamic analysis and discussed topics about spinning stress or strain failure. Quigley and Monaghan [1] analyzed the metal's stress and strain factors in different spinning ways. By comparing the strain from theoretic calculations and experiment results, it shows that the strain of the single-spinning- process metal is significant different from that of the multiple-spinning- process. By taking reference notch on the surface of tube before spinning, the strain values can be figured out form record geometry changes.

Quigley and Monaghan [2] also proposed the Finite Element Analysis mandrel for spinning process. Some factors should be concerned, including blank, rotation speed, forming ratio, feeding parameter and speed. The characteristics of blank and heat treatment condition will directly affect the surface of work piece. Normally, the blank should be high ductile with multiple anneal processes. The process parameters, such as spinning speed, feeding rate, forming ratio, working pressure, and rollers angle, can be gotten form try-and-error trails. Different parameters should be modified according to different conditions, and they must be carefully adjusted to avoid material cracking [3]. How to get the reasonable parameters is the most critical issue because it is very likely to get failures, such as cracking, corrugation, bulge, or dimension variables.

Liu [4] had established a finite element analysis model for elastic and plastic deformation, and analyzed the stress and strain distribution on different roller path for spinning process. It also shows the variations in the linear, volute and quadratic function curve. The volute curve will get the minimal stress and strain in both radial and tangential ways. By comparing with the stress and strain distribution from three different span paths, this provides theoretical base for choosing better spinning path. Hong [5] simulated flowing spinning

process, and discussed how to choose quality factors and time increment in order to improve simulation efficiency. He had also used Taguchi's Method to discuss how the parameters will affect flow spinning, and find the most significant factors to adjust the parameters. By doing so, the contact force on the three rollers will be minimal, and the vibration and heat causing from unbalanced forces in the spinning machine will be reduced.

Spinning is a plastic deformation process that comes from a chunk of blank, and has many complex characteristics, including Geometric non-linear, Physical non-linear and contact non-linear. Simple analytic approach methodology can't solve the three-dimension deformation problem. The roller design and manufacturing processes usually depend on the try-and- error trails. It is time-consuming and wastes valuable resources.

As computer technology has been improved, spinning simulating process by finite element analysis is a suitable method. When manufacturing parts, the computer simulation results[6] determines the possible defect of the predicted technology before the part is really manufactured, reducing the costs of preparing production [7]. By observing spinning simulation process, the stress and strain variations can be clearly shown. ANSYS/LS-DYNA adopts an explicit method, which can overcome some disadvantages in implicit method, such as difficult convergence and long calculation. It is very suitable for solving problems, including collision, metal forming and falling simulation. It can process non-linear metal forming process equations, and do the whole spinning process simulation on a shell aluminum alloy tube.

In this paper, ANSYS/LS-DYNA will be used to do 3-dimension finite element analysis for shell aluminum alloy tube (6061-T6) spinning neck-in process, and discuss the flowing, stress and strain variations during deformation. It can also analyze how the mandrel sustaining span changes will influence inner frame forming on a thin wall aluminum alloy tube.

2 Basic theory
Forward flow forming and backward flow forming are two main spinning types today, as shown in Fig 1. The short and thick tubular blank is put on the top of a mandrel. As the blank contacts with the mandrel, static friction force makes both of them revolve. The rollers keep a constant gap with mandrel. When moving forward along the mandrel,

the blank will be extruded between the gap of rollers and mandrel. [8] The thickness of blank is shrinking and the length is extended, but the inner dimension remains the same. Usually, Forward flow forming process is suitable for manufacturing shell parts, such as motor, hydraulic cylinder, or high pressure container. Backward flow forming process, however, is suitable for manufacturing large tubular parts or low ductility material because it vulnerable to endure the extend stress during spinning process, such as casting or wielding parts [11]. Neck-in is a spinning process that shrinks the diameter of a tube on the end or middle part. The rollers will move forward along with the axial of blank and then finally get the neck-in shape component, as shown in Fig 2.
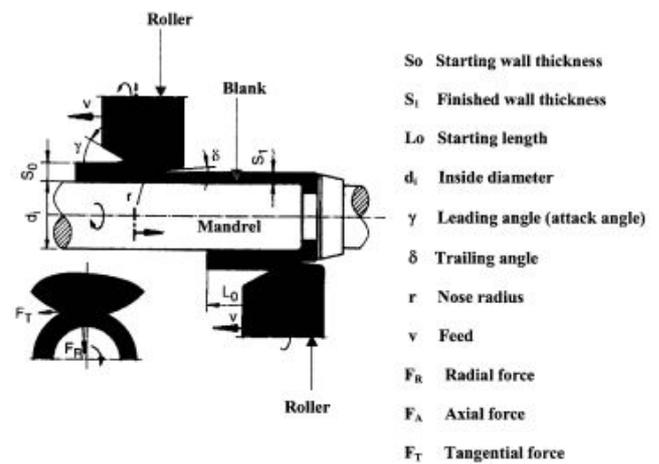
Fig.1 Flow forming theory [9-10]
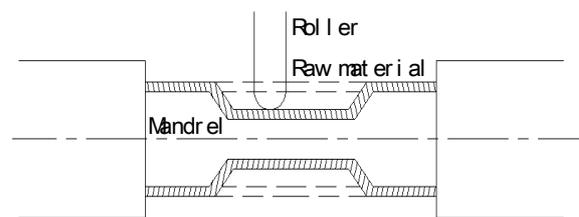
Fig.2 Neck-In Spinning

3 Finite Element Method Theory
3.1 Finite Element Method for non-linear deformation
When solving non-linear equation, Newton-Raphson method is usually adopted to approach the roots of non-linear equation. A non-linear relation between forces and displacements ($F - u$ relation)

is shown as Fig 3. The equation of displacement u and the applied force F_{app} can be defined as $F(u) = F_{app}$. Newton-Raphson method is used to approach the root, as shown in Fig 2. First, let's begin with P_o. For the 1st approach, make a tangent line (the slop is K_T, which means tangent stiffness) to intersect with the vertical line at P_1. Repeat the same process until P_4 is found, and its corresponding displacement $u^{(4)}$ and force $F(u^{(4)})$. If the process is convergence, it is defined as (1)

$$\left| F_{app} - F\left(u^{(k)}\right) \right| \le \delta \tag{1}$$

The δ means tolerance. The $u^{(4)}$ is approaching root of equation $F(u) = F_{app}$, and means displacement under force F_{app}. Usually, finite element method can solve not only single equation but also a serious of non-linear simultaneous equations, such as $[K_T]\{\Delta u\} = \{\Delta F\}$. When compared with linear analysis; on-linear analysis consumes more time and simulation resources.
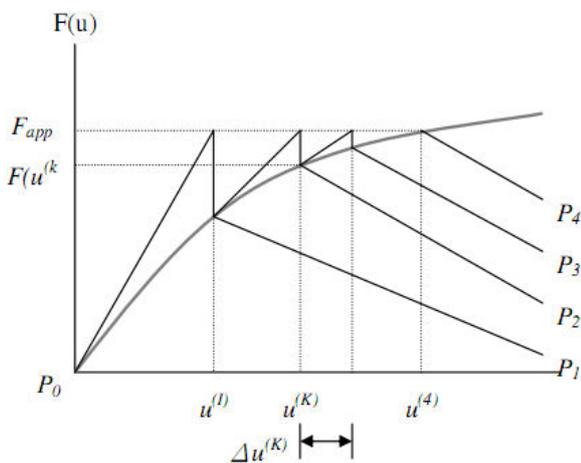
Fig.3 Non-linear loading-displacement diagram [12]

3.2 Explicit method

According to finite element method theory for mental flowing dynamic analysis, the displacement means velocity and acceleration. Let t be the time and the finite element equation can be expressed as:

$$[M]\ddot{u} + [C]\dot{u} + [K]u = F(t) \tag{2}$$

Where $[M]$ the Mass matrix, $[C]$ the damping matrix, $[K]$ the rigidity matrix, $F(t)$ the loading, u the displacement, $\dot{u}$ the velocity, $\ddot{u}$ the acceleration, t the time。

Central difference method suggests that the variation of displacement can be seemed as linear at a very short period of time. During formula deducting process, velocity and acceleration can be expressed as the formula of displacement, as shown in (3) and (4)

$$\dot{u}_n = \frac{1}{2t}(u_{n+1} - u_{n-1}) \tag{3}$$

$$\ddot{u}_n = \frac{1}{t^2}(u_{n+1} - 2u_n + u_{n-1}) \tag{4}$$

Put (2) and (3) into (4), and there is (5)

$$[F]_n = \frac{[M]}{t^2}(u_{n+1} - 2u_n + u_{n-1})$$
$$+ \frac{[C]}{2t}(u_{n+1} - u_{n-1}) + [K]u_n \tag{5}$$

$$\left[\frac{1}{t^2}[M] + \frac{[C]}{2t} \right]u_{n+1} = \tag{6}$$

$$[F]_n - \left[[K] - \frac{2}{t^2}[M] \right]u_n - \left[\frac{1}{t^2}[M] - \frac{1}{2t}[C] \right]u_{n-1}$$

4 Finite element simulation analysis
4.1 Mandrel Establishing

Fig 4 shows a diagram of spinning process. Three rollers are the same dimension, and each makes 120° with others in a circle, as shown in Fig 5. Let the mandrel span be variables, and then change it into 40mm、50mm、60mm, respectively.
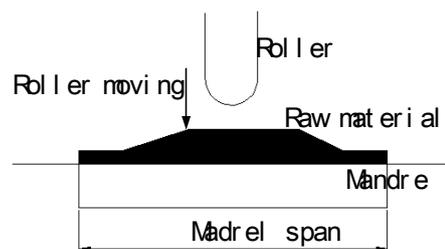
Fig.4 Simulation diagram
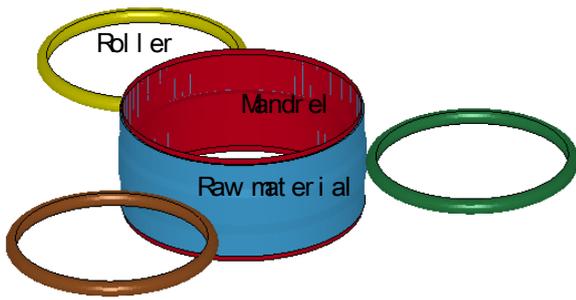
Fig.5 Finite element mandrel

The finite element simulating meshes are shown as Fig 6. To prevent meshes distortion from being oversize and resulting in failing simulation or lowering calculation precision, segment mapping meshes are applied on the blank. Division free mapping meshes are applied on mandrels and rollers. By using segment mapping meshes, the size of each element can be equal. This can also prevent from getting smaller elements and consuming CPU resource. When considering the accuracy and efficiency of simulation, different density of meshes is used on the raw material, mandrel, and roller. Because spinning process is a stable deformation process, only one inner reinforcing rib is simulated in this paper in order to save simulation time.

Fig.6 Finite element simulating meshes

4.2 The mechanical property of raw material

Aluminium alloy can be categorized as casting aluminium and forging aluminium alloy. The strength of casting aluminium is about one-third as that of forging aluminium alloy. Among all the forging aluminium alloys, 6-serious and 7-serious

alloys are better. The manufacturing processes include extruding, milling, and surface treatment. When considering some properties, including material strength, usage, anti-erosion, electric conductivity, and thermo conductivity, aluminium alloy 6061-T6 is chosen in this study. The stress-strain relationship diagram is shown as Fig 7, and mechanical properties are shown as Tab 1.
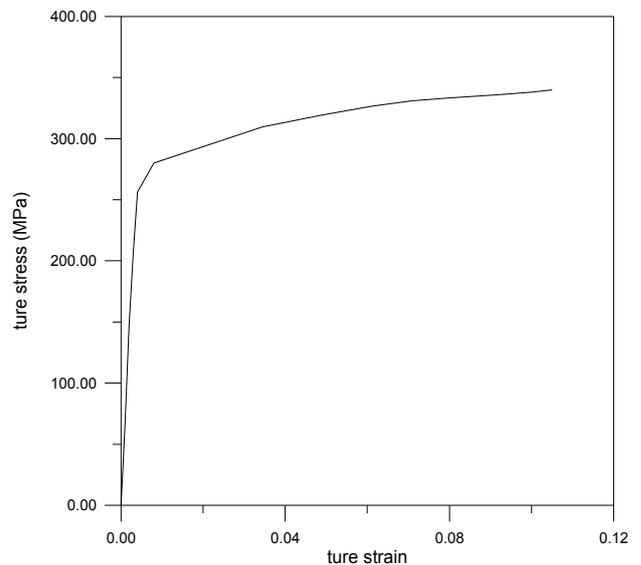
Fig.7 Stress-strain relationship for aluminum alloy 6061-T6

Tab 1 Mechanical property of aluminum alloy 6061-T6

Elastic Modulus	63.79 GPa
Poisson's Ratio	0.33
Yield Strength	267.42 MPa
Ultimate Strength	307.16 MPa
Density	2700 kg/m^3

During spinning process, there is no deformation on mandrel and rollers. Therefore, they are seemed as rigid to save calculation and analysis time. When using ANSYS/LS-DYNA, a rigid material mandrel is applied, and some parameters are put in. The material properties are shown as Tab 2[13].

Tab 2 rigid material properties

Elastic Modulus	210 GPa
Poisson's Ratio	0.3
Density	7850 kg/m^3

When doing finite element analysis, blank pattern is SOLID164 solid unit, as shown in Fig 8. SOLID164 is a 3-D hexahedron structure element with 8 nods. Each nod on the structure has 9 degree of freedom, which includes displacement, velocity, and acceleration on X、Y、Z axis. SHELL163 element is applied on mandrel and rollers, as shown in Fig 9. SHELL163 is a shell element with 4 nods, and each nod has 12 degree of freedom, which includes the displacement, velocity, acceleration, and angle of rotation on X、Y、Z axis.
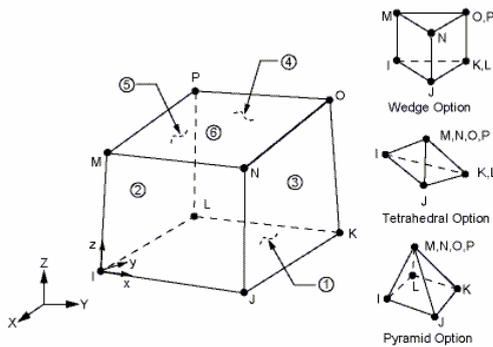
Fig.8 SOLID 164 element mandrel
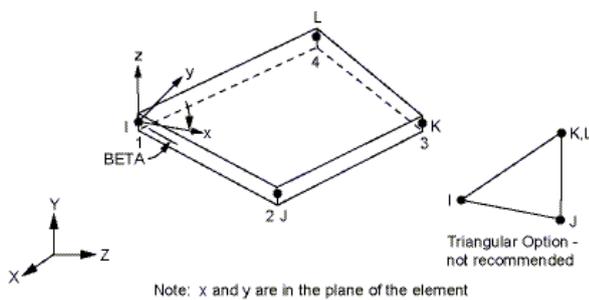
Fig.9 SHELL 163 element mandrel

4.3 Boundary Condition
4.3.1 Contact definition
The PART should be created before contact definition. There are five PARTs in this study. PART 1 is the mandrel. PART 2 is the blank. PART3, PART4, and PART5 are the three rollers, respectively.

The mandrel will turn during the spinning process to make the blank better deformation and

relative sliding. Because the blank is flexible, it is defined as contact surface, and the rollers and mandrel are defined as the target surface. Because there is no contact element in ANSYS/LS-DYNA, there will be no penetration phenomenon during this simulation if the possible contact surface, contact type, and some other parameters have been defined [14].

The dynamic friction coefficient between blank and mandrel is 0.1, so is the blank and rollers.

4.3.2 Strain and loading
During simulation process, a strain is applied on both ends of blank. The mandrel turns in Y-axis at 60 rev/min(6.28 rad/s), and the rollers, keeping a constant gap with mandrel, move forward to the mandrel at the rate of 0.165mm/s and turn along Y-axis at rev/min (7.09 rad/s). The loading on mandrel lasted for 5 seconds.

5 Conclusion and discussion
5.1 material deformation and flowing
The deformation during spinning process shows as Fig 10. It begins from outer rib shrinking because of the rollers moving forward, getting the neck-in spinning thin tube.
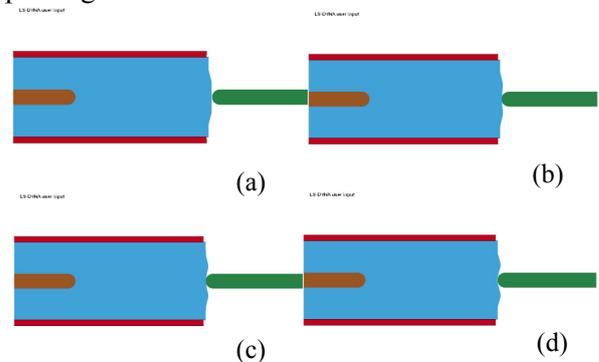
Fig.10 Each step change of neck-in rib forming process

5.2 Spinning pressure analysis
Spinning pressure means the anti-force applied on blank from rollers. When the inner rib of a shell forms, the spinning pressure evenly distribute on the blank through rollers. Fig 11 shows the relationship of curves for different mandrels and spinning pressures. The wider the span, the smaller the pressure will be. Also, the wider mandrel span will result in small spinning pressure, which is not favour for neck-in inner rib forming.
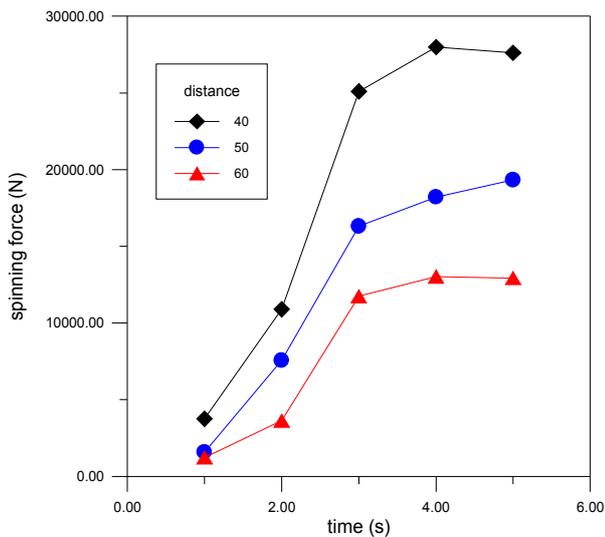
Fig.11 The affection between different mandrel span and spinning pressure
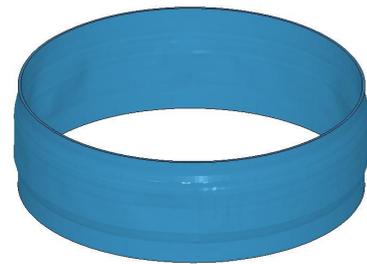
(c) Mandrel span 60mm

Fig.12 aluminium alloy shells with inner rib

The inner rib thickness is increasing when the mandrel span is between 40-50 mm, but decreasing when it is over 50mm, as shown in Fig 13. It is obvious that when the span is about 50 mm, the thickness of inner rib will be maximum and the neck-in rib will be easily formed.

5.3 Inner rib forming analysis

Three tubular inner rib neck-in spinning parts are shown as Fig 12.The shapes can be controlled by changing mandrel span. When span is 50mm, the quality is the optimum. The neck-in effect is critical quality for shell spinning work piece, and the rib thickness of tube is also very important for spinning. The relationship of the rib thickness and mandrel shapes is shows as Fig 13.
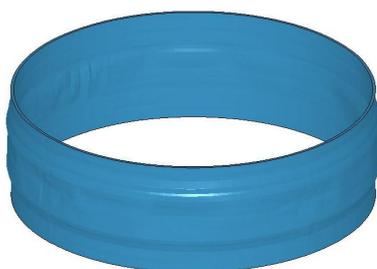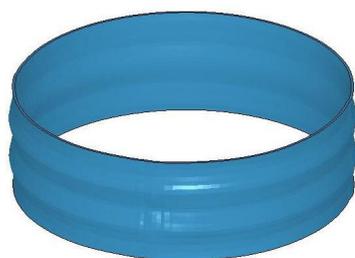
(a) Mandrel span 40mm
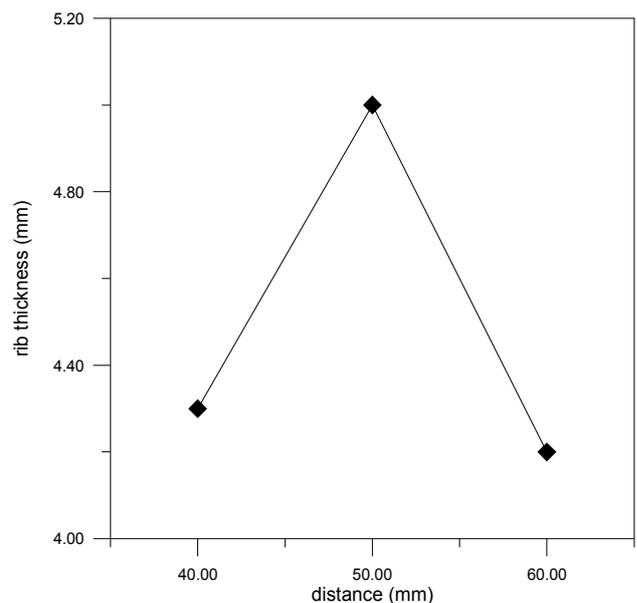
Fig.13 The change between the rib thickness and mandrel span

5.4 Equivalent stress analysis

The equivalent stress distribution diagram can be shown by way of finite element analysis. It can not only show the stress scale and distribution between different mandrels, but also get the rules of deformation on blank. The equivalent stress distribution cases for different mandrel span are shown as Fig 14
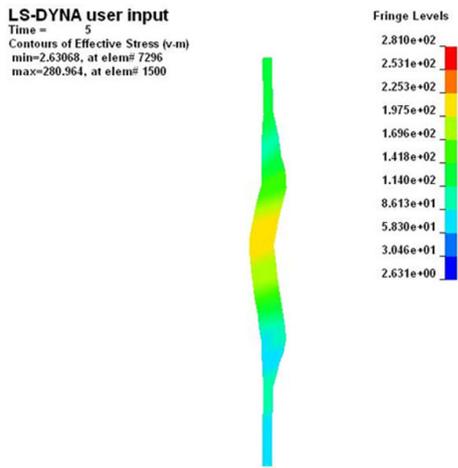
(b) Mandrel span 50mm
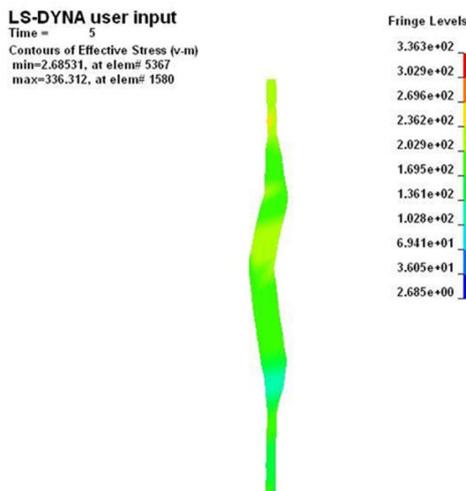
(a) Mandrel span 40mm
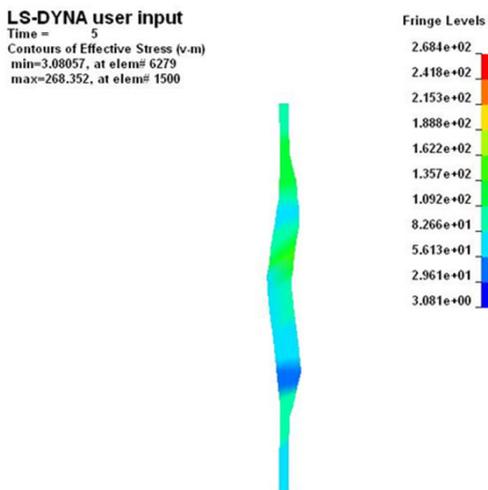
(b) Mandrel span 50mm

(c) Mandrel span 60mm

Fig.14 Diagrams of different mandrel span and equivalent stress

As shown in Fig 14, the equivalent stress distributes along the radial layer, and keeps the same on the same layer of circumference. When the span of mandrel is increasing, the equivalent stress will not increase proportionally. When the mandrel span is 50 mm, the maximum equivalent stress is about 336 Mpa, which is over the yield stress of material. Also, the stress concentration effect is more and more significant as the feeding processing continues.

5.4.1 radial stress analyis

The relationship between different mandrel span and radical stress are shown as Fig 15. It is obvious that when the span of mandrel is 50 mm, the neck-in stress on inner rib is maximum, and the blank gets permanent deformation because the stress has reached its yield stress. When the mandrel span is 40 or 60 mm, the radical stress will be lower, and the efficiency of spinning declines.
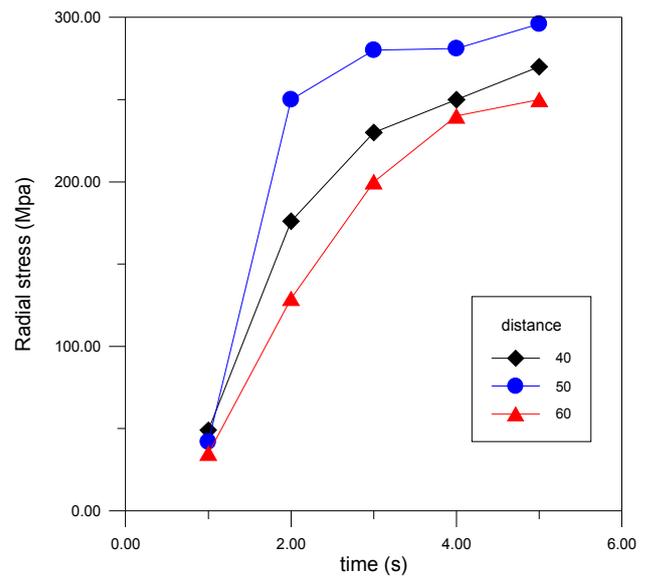
Fig.15 The affection between different mandrel span and radical stress

5.4.2 Stress variation

By way of stress analysis on each point of raw material, the deformation during the spinning process can be clearly observed, as shown in Fig 16.
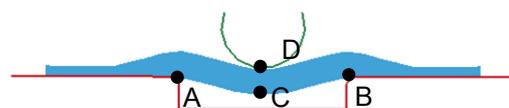
Fig.16 Element's serial number and position

Element A,B,C,D are the contact points that move forward along with the rollers in radical direction. Each element gets different radical stress, but the maximum stress is on the top of the neck-in point, as shown in Tab 3. All the maximum radical stresses are over yield stress and get permanent deformation when the inner span is 50 mm. The stress distribution will be maximum on the top of inner rib, and less on both ends of the mandrel.

Tab 3 Element-span and radical stress

Element Span	A	B	C	D
40mm	176	119	250	235
50mm	221	148	282	243
60mm	210	135	241	230

unit: Mpa

5.5 Equivalent strain analysis

Equivalent strain means the degree of plastic deformation. Fig 17 and Fig 18 show the relationship between plastic strain and time for different mandrel span. As the neck-in inner rib forms, the equivalent strain will decrease when the mandrel span increases. More equivalent strain means more uneven deformation on the inner rib. If the mandrel span is too small, it is very possible to get some defects, such as crack and chap.
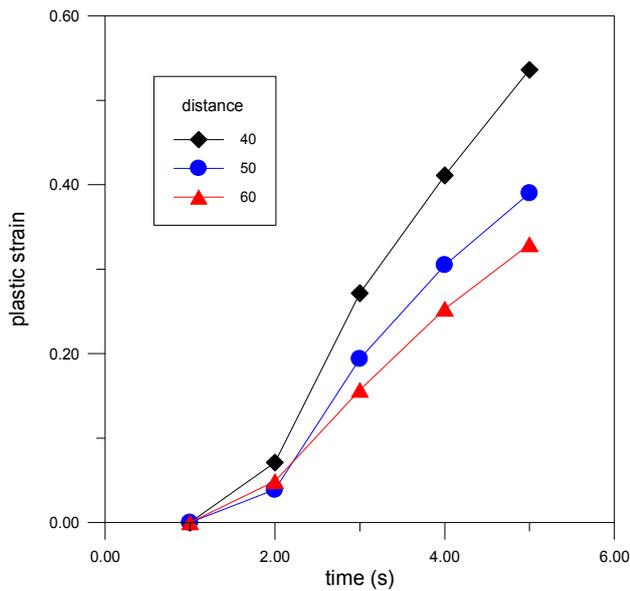
Fig.17 Equivalent strain
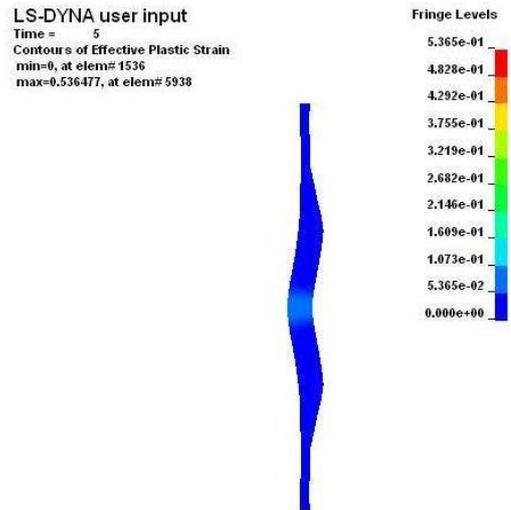
(a) Mandrel span 40mm
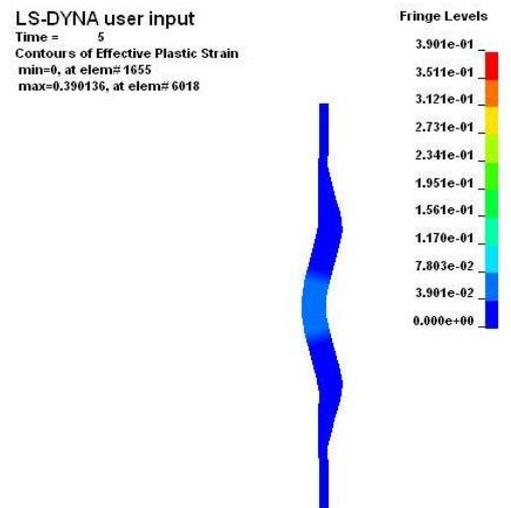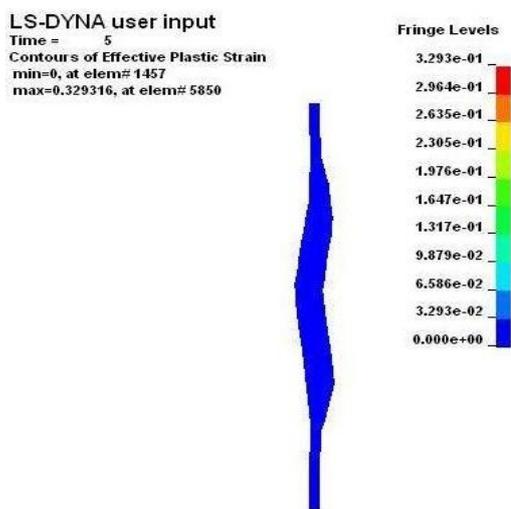
(b) Mandrel span 50mm

(c) Mandrel span 60mm

Fig.18 Diagrams of different mandrel span and equivalent strain

6 Spinning process parameters analysis

6.1 Taguchi method

Taguchi method [15] is a kind of statistic and experiment method which was developed by professor Taguchi in 1950. It has been successfully applied on industry manufacturing and quality improvement in Japan, and is used to improve quality by designed experiment. The purpose is to seek the highest quality product by finding "designing parameters" through computer simulation or actual operation at lowest cost and shortest time.

The algorithm of Taguchi method is to find the optimal parameter estimation problem [16] design through orthogonal array experiment statistic analysis and Signal Noise Ratio(S/N). The combination result of each parameter and level can be estimated from the average mean.

Dr. Taguchi had participated in communication quality improvement project in his early time. The output ratio of signal / noise ratio had always been used as a quality index then .For this reason, the signal / noise ratio (S/N, or η) has been used as Taguchi method whether the work is actually relate to signal / noise or not. There is a close relationship between S/N and loss function. The higher the S/N, the lower the expectation loss will be. Otherwise, the lower the S/N, the higher the expectation loss will be. The S/N and loss function are really the index for product manufacturing and quality, and they not only are close relation, but also have three different quality characteristics, including smaller-the-better, larger-the-better, and nominal-the-better.

The orthogonal array is used to reduce experimental times. More parameter lever will lead in less experimental times. The concept of Taguchi emphasizes on that the high quality product can achieve through low cost components, materials and manufacturing process, and the product variation can be reduced by finding suitable designing or process. This is a simple, fast, and convenient analysis method, and has been widely used in many engineering industries because the affection between design parameters and target function is clear, and easily to get the optimal parameters combination. In this study, the experiment results will be substituted for simulation analysis, so Taguchi method is the optimal method.

6.2 Taguchi experiment of Neck-in spinnin

The theory of Taguchi quality method has been discussed in previous sections. Next, a Taguchi method experiment will be designed to improve the quality of a shell aluminium alloy with neck-in shape frame, and to find a set of optimal parameter under a reasonable tolerance range for the operators.

For Taguchi method, the first step is to define the quality characteristics of subject. The purpose of this study is to find a specific thickness of rib with the same outside diameter. So, the thickness of rib is defined as the quality characteristic and when it is 5mm, the result will be optimal, shown as Fig 19.

" Nominal-the-better" means that the quality characteristic can reach a specific target. As the target of this experiment is decided, the next step is to analyze all the parameters of the neck-in spinning process, and to setup the factors and levels of orthogonal array. After that, experiments can be processed according the parameters setup in orthogonal array. When all the experiments have been done, the next step is to analyze data, which can rival if the experiment can satisfy the required target, and then do the further study.
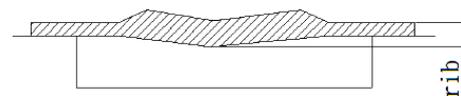
Fig.19 Quality target diagram

The neck-in spinning process problem can be solved by Taguchi method as the following steps:
(1)To decide the control factors and its level
(2)To choose a suitable orthogonal array
(3)To do all the experiments on the orthogonal array
(4)To solve the S/N ratio and its response
(5)To get the optimal combination
In order to choose a suitable orthogonal array, the control factors and its level must be set. For the shell aluminium alloy neck-in spinning experiment, the control levels can be defined as the support span, mandrel rotation rate, roller feeding rate and roller diameter. There are three levels for each factor, and the parameters for each level are shown as Tab 4.

Tab 4 the control factors and levels table

level / control factor	Level 1	Level 2	Level 3
A support span	40 mm	50 mm	60 mm
B mandrel rotation rate	50 rpm	60 rpm	70 rpm
C rollar feeding rate	0.135 mm/s	0.165 mm/s	0.195 mm/s
D rollar diameter	300 mm	350 mm	400 mm

The L_9 (3^4) orthogonal array is employed in this study. For the four factors(A、B、C、D), each contains its level(1,2,3), and for each case , there are 9 experiments.For each factor in the orthogonal array,there is always the same frequency for each level,which is called balance.So, the response variables between each factor and level can be evaluated.For example, in row 2,5,and 8, there is 1 times for level 2 of factor B ,level 3 of factor C ,and level 3 of factor D. The orthogonality between each row means there is a total relationship between random two selected rows (the combination of each level, such as 11、12、13、21、22、23、31、32、33), as shown in Tab 5.

Tab 5 $L_9(3^4)$ orthogonal array

Experiment sequence	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

By putting each value of level into the orthogonal array according the experiment parameters in Tab 5, the experiment parameters table can be shown as Tab 6.

Tab 6 the experiment parameters Tab

Experiment sequence	A support span (mm)	B mandrel rotation rate (rpm)	C rollar feeding rate (mm/s)	D rollar diameter (mm)
1	40	50	0.135	300
2	40	60	0.165	350
3	40	70	0.195	400
4	50	50	0.165	400
5	50	60	0.195	300
6	50	70	0.135	350
7	60	50	0.195	350
8	60	60	0.135	400
9	60	70	0.165	300

6.3 Taguchi method testings and results.

The target indicator is thickness of rib, which is the nominal-the-better characteristic for Taguchi method. So, the quality analysis of nominal-the-better characteristic must be used in this study. From (7)

$$\eta = -10\log\frac{\sum_{i=1}^{n}(y_i - m)^2}{n} \qquad (7)$$

For the first experiment on the orthogonal array, when the thickness of rib is 1.96 mm and target value is 5mm, the S/N Ratio can be calculated by following formula.

$$\eta = -10\log[\frac{(1.95-5)^2}{1}] = -9.66(db) \qquad (8)$$

By using the same steps, other 8 sets of experiment results can be found, and then list as Tab 6. The average output response table, S/N Ratio response table, and S/N ratio chart can also be created from Tab 7.

The purpose of average analysis is to reveal the affection and tendency of the target function under each variable parameter of levels, and find the optimal combination. The calculation list as following:

$$\bar{y} = \frac{\sum\limits_{i=1}^{n} y_i}{n} \qquad (9)$$

Where $\bar{y}$ is the average of y

According to the experiment arrangement on orthogonal array, the thickness of rib can be found by experiment analysis process [17]. By using average analysis, there come out the quality characteristic response table. Taking characteristic A, for example, the experiment 3 means the same level, and the average value comes from the average of each three S/N Ratio. It can be calculated as following.

$$A(level1) = \left[\frac{1.96 + 4.53 + 6.05}{3}\right] = 4.18 \qquad (10)$$

Tab 7 S/N Ratios

Experiment sequence	A	B	C	D	δ	S/N
1	40	50	0.135	300	1.96	-9.66
2	40	60	0.165	350	4.53	6.56
3	40	70	0.195	400	6.05	-0.42
4	50	50	0.165	400	5.31	10.17
5	50	60	0.195	300	5.57	4.88
6	50	70	0.135	350	2.81	-6.81
7	60	50	0.195	350	5.88	1.11
8	60	60	0.135	400	2.01	-9.51
9	60	70	0.165	300	4.32	3.53

The effect of factors means the maxium value of each factor minus that of the minimum one, and the Rank is the order for each effect of factor. The maximun effect value of feeding rate (factor C) is 15.35, as shown in Tab 8 S/N factor response table, and the maximun effect value of feeding rate (factor C) is 3.57, as shown in Tab 9 quality characteristic factor response table.

Tab 8 S/N factor response table

	A	B	C	D
Level 1	-1.17	0.54	-8.66	-0.48
Level 2	2.75	0.64	6.69	0.29
Level 3	-1.68	-1.29	1.86	0.08
Level difference	4.43	1.94	15.35	0.76
Rank	2	3	1	4
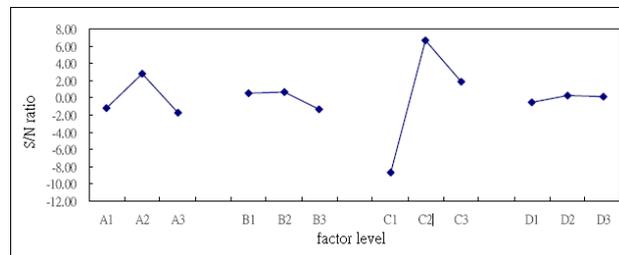
Fig.20 S/N Ratio response chart

Tab 9 quality characteristic factor response table

	A	B	C	D
Level 1	4.18	4.38	2.26	3.95
Level 2	4.56	4.04	4.72	4.41
Level 3	4.07	4.39	5.83	4.46
Level difference	0.49	0.35	3.57	0.51
Rank	3	4	1	2
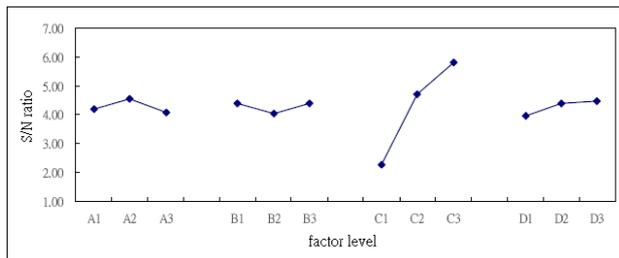
Fig.21 average response chart

By transforming Tab 8 and Tab 9 into line chart, the effect of each factor can be obvious. As the target function is rib thickness and the target characteristic is nominal-the-better, the maximum effect factor is the feeding rate, and next the support span. The optimal condition will happen when the support span is 50mm, the mandrel speeding is 60rpm, the feeding rate is 0.165mm/s ,and the roller diameter is 350mm, or it means A2B2C2D2. The S/N Ratio response and average response are respectively shown as Fig 20 and Fig 21.

7 Conclusion

In this study, a 3-D plastic finite element simulation method (FEM) [18,19] is adopted to analyze the neck-in inner rib spinning process. The conclusions are following:

1. When neck-in inner rib forms in spinning process, spinning pressure passes through contact surface and distributes evenly on the lank. The spinning pressure decreases as the mandrel space increases. The wider supporting span will result in smaller pressure on the blank, and not be suitable for neck-in forming.

2. The span of support will significantly affect the neck-in rib thickness. At the same feeding rate, when the support span is 50 mm, the stress will be over the material's yield stress, and the blank will get permanent deformation. Suitable mandrel supporting space can make equivalent stress distribution more evenly in the inner rib, improving its quality.

3. In this study, there gets the rules of stress and strain distributions in different mandrel supporting for the neck-in rib forming, and reveals the following rules of plastic deformation process.

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