

Thick Plate Bending and Image Processing Algorithms Assistant for Deformation Process Discretization Analyses

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1. Introduction

Spring-back will be the first word comes to mind at the mere mention of bending. As a basic problem in bending, spring-back affects the dimensional accuracy of sheet metal parts during unloading. The vast majority of the purpose of this field is to study the factors influencing spring-back. With that general outlook, the spring-back angle of thick sheet was obviously larger than that of thin plate. On the other hand, it was not influenced clearly by the sheet width [1].

Regarding the fundamental importance of the deformation process of the bending, numerous experimental and theoretical investigations have been carried out to calculate its spring-back. Both simulation and measurement of spring-back are investigated in these two papers respectively, and taking automotive materials as their study subject, such as DQSK steel, 6022-T4, HSLA steel, etc. Analyzing the simulation results, K.P. Li et al. [2] thought that the presence of a Bauschinger effect changes the results significantly, and taking it into account provided good agreement. Shell elements were adequate to predict spring-back accurately for R/t greater than 5 or 6, while solid elements were required for higher curvatures. As R/t approaches 2, spring-back simulated with solid elements tends to disappear, in agreement with measurements presented in the companion paper and in the literature. And analyzing the measurement results, W.D. Carden et al. [3] thought that strip tension dominates the spring-back sensitivity, with higher forces reducing spring-back. And spring-back decreases for larger tool radii (R/t greater than about 5).

The team's K.P. Li and W.D. Carden work was focused on the draw-bend tests, and more research is needed to elucidate the potential mechanisms by which a common bending forming may influence outcomes in many more formats. Because of the bending's central role in the plastic forming, a plenty of research work aimed for revealing its forming mechanism in various forms. Rasoul Esmaeilpour et al. [4] revealed significant physical differences between two-dimensional (2D) and three-dimensional (3D) yield. In their paper, a detailed comparison of the three yield functions' predictions were made with respect to the effective plastic strain distribution, part thickness, tool force and moment, and development of stress and strain tensor components. KP Li et al. [5] summarizes a length analysis of spring-back of the draw/bend test, conducted using three sheet materials, several friction coefficients, die radii, and

draw-in restraining forces. The simulation results show the finite element analysis (FEA) of spring-back is shown to be very sensitive to numerical parameters, including the number of through-thickness integration points, the angle of contact per shell element, and the tolerances for equilibrium and contact. T Ohwue et al. [6] made some experiments on bend forming of a bumper model with a 9.8-MN oil-hydraulic press and FEM analysis with the static code MARC were carried out in order to investigate spring-back behavior. Experimental spring-back shapes were investigated using a 3-D measuring machine in their paper. They found that the spring-back of a formed bumper increased with an increase in yield stress (YS) of the material, coinciding with the results of 2-D FEM Simulation. MG Lee et al. [7] derived and implemented a practical two-surface plasticity model based on classical Dafalias/Popov and Krieg concepts to incorporate yield anisotropy and three hardening effects for non-monotonous deformation paths: the Bauschinger effect, transient hardening and permanent softening. And they proposed and implemented a simple-but-effective stress-update scheme avoiding overshooting [8]. They found that two-surface model improved such predictions significantly as compared with single-surface models, while the differences between two-surface simulations and experiments were insignificant.

Although many research results and achievements have been found for summarizing various empirical formulas to predict the stress and strain changes of material plastic forming, the bending complex process also could be simulation by FEM [9]. However, there is no accurate theory of material spring back that considered various influencing factors, especially with thick plate. Bending mechanism in the process of thick plate is an extremely complicated multi element non-linear relationship. It is similar in some ways to thin plate, but there are several differences in the view of micro-dynamic mechanism, such as grain bending, grain delamination, crack deflection inside the layered grain, crack deflection and branch, and so on [10].

Based on gridding method, the deformation process discretization analysis can be implemented. And reveal the observed phenomenon by summarizing some rules, just like summarizing the rebound prediction formula. This should have been the basic method of scientific research [11]. The process of bending can't be controlled precision and quality without deeper cognition about its mechanisms [12]. But almost all of them approached to the problem only from one of its aspects and their internal relation were often

neglected, especially in view of the increasing demand of various non-ferrous metals bending parts. So it is necessary for the plastic performance good non-ferrous metal forming an in-depth research.

2. Experiment condition

This article applies the design method and theory of modern mechanical system to design the new three-point bending tester for forming principle. The dynamic test model could be used to predict the variation of the system characteristic parameters of various uncertain factors and support structure system for the process of the metal plastic forming [13]. There are materials performances, lubrication condition, bending mode, etc. Analysis of the forming process of bending shows that the proposed method required the test bench have a simpler structure, which provides the foundation for detection and classification of defects accurately [14]. And schematic drawing of test bench was used in this paper as shown in Fig. 1.

In order to avoid the influence of various factors on the forming process of bending, the experimental apparatus has simplified the design of dimension chain [15-16]. The bending action of the punch driven by the hydraulic cylinder is controlled. The concave die is replaced by a 45 steel baffle, which is much harder than the experimental material. However, the angle of the bending parts processed by the above experimental device is only determined by three parameters, namely, the distance between the two rotating modes, the radius of the convex dies and the distance between the baffle and the sample [17].

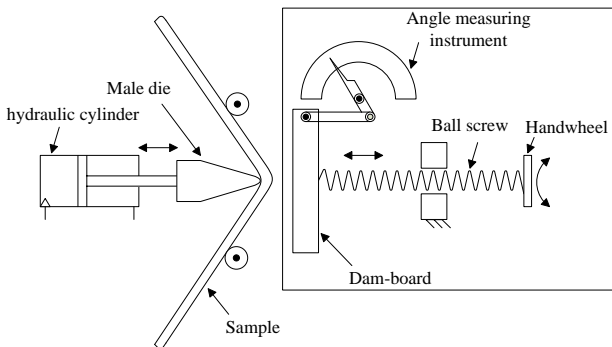


Fig. 1 Schematic drawing of test bench

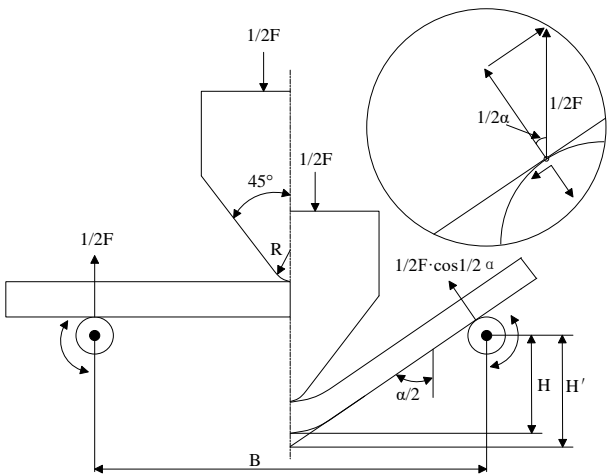


Fig. 2 The analysis chart of the loaded part in three point free bending

Friction coefficient and R/t (ratio of die-radius to thickness of the plate) less than 2 have modest but measurable effects over the ranges tested. As expected, strip tension dominates the spring-back sensitivity, with higher forces reducing spring-back. Optimal design of bending sequence is the key link in sheet metal free bending process planning, and it has important influence on simplifying operation and bending precision guarantee. This thesis establishes the quantitative descriptive model of mathematical analysis in V-shape free bending of thick sheet metal by using theoretical analysis method [18-19]. The external and connection dimensions show in the Fig. 2.

Preparation of the above is to ensure that our objective and fair judgments to avoid for other reasons affecting the all the variables on bucking. Using the definition and calculation formula of the measurable variables, and adopt some equation, the bending angle could be calculated. All variables are shown in Fig. 2, and the bending angle α could be calculated via Eqs. (1-5).

$$\tan \frac{\alpha}{2} = \frac{B}{2H'}, \tag{1}$$

$$\sin \frac{\alpha}{2} = \frac{R}{R+(H'-H)}, \tag{2}$$

$$(R-H)\sin \frac{\alpha}{2} + \frac{1}{2}B\cos \frac{\alpha}{2} = R, \tag{3}$$

$$A\sin\beta + B\cos\beta = \sqrt{A^2 + B^2} \sin(\beta + \varphi) \quad \varphi = \tan^{-1} \frac{B}{A}, \tag{4}$$

$$\sqrt{(R-H)^2 + \frac{B^2}{A} \sin \left[\frac{\alpha}{2} + \tan^{-1} \frac{B}{2(R-H)} \right]} = R, \tag{5}$$

$$\alpha = 2 \left[\sin^{-1} \frac{R}{(R-H)^2 + \frac{B^2}{4}} - \tan^{-1} \frac{B}{2(R-H)} \right] \dots \tag{6}$$

The value of B is fixed, and the bending angle can be changed by changing the radius of the punch and the distance between the baffle and the sample. In this experiment, the radius of rotating die is 10 mm, and the distance between two rotating dies is 100 mm.

Installation of the digital camera on the top of the sample with 12 million pixels, with functions of mechanical image stabilization, photo resolution is 4000*3000, while filming process is using a video recording, the data for a high-definition video. The photos used later in this article are all video screenshots, all of which have been cropped, leaving only useful information. And the photo of the experiment device shows in Fig. 3.

Experimental apparatus in order to avoid the influence of various influence factors on the forming process; on the design of the dimension chain did simplify processing. Punch bending action under the impetus of the hydraulic oil cylinder, schedule control. Die using a baffle instead of 45# steel, hardness is greater than the experimental materials. In the above experiment device processing bending angle only decided by three parameters, namely the spacing of two molds, punch radius and the distance from the sample.



Fig. 3 The photo of the experiment

The testing optimization parameters were obtained by means of experiment. Therefore, the surface of the sample polished with 600# sandpaper for shooting clearer images. Although the surface obtained in this way is flat, it is easy to see the phenomenon of local over-reflection due to the characteristics of pure copper. Therefore, local lighting should be avoided during the experiment. Table 1 shows the mechanical property of pure T2 copper.

Table 1

Mechanical property of pure T2 copper

Items	Parameters
Tensile strength	$R_m/\text{MPa} \geq 295$
HRF	$\text{HRF} \geq 65$
Elongation	$\% \geq 3$
Modulus of elasticity	$1.08 \times 10^{11}, \text{Pa}$
Yield point	$(6 \times 10^7, \text{P})$
Poisson's ratio	0.326

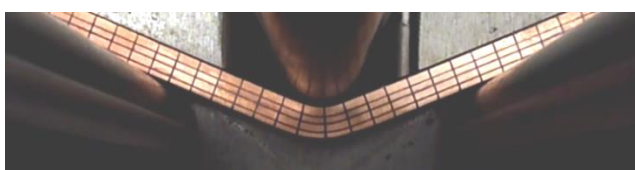
The bending forming experiment is carried out under the condition of the finite element discretization of the real sample surface. At present, there are many methods for finite element discretization of metal surface, but the simplest and most feasible method is still manual description method. However, the accuracy of this method is all guaranteed by hand, so it should not be used under sufficient experimental conditions.

The T2 copper studied in this paper with a large ratio of length to width. The grid of surface divided manually, so it is not suitable to use smallest sized. After comprehensive consideration, it is considered that the $5 \times 2 \text{ mm}^2$ grids is the most suitable, and the most middle horizontal line is the middle line of the bending part, so the deformation of the middle line can be observed. The sample picture after gridded is shown in Fig. 4.

The current work is motivated by a lack of system-



a) Original sample



b) Bent sample

Fig. 4 The photo of the special marking-off sample

atic spring-back measurements for deformation under a range of carefully controlled laboratory conditions but applicable to industrial practice. In particular, the role of friction coefficient and R/t in spring-back has been equivocal, and data is needed to evaluate the accuracy of simulation techniques. A variety of manufacturing techniques have been developed for dealing with spring-back. The simplest involves designing tools to over-bend the sheet to compensate for spring-back. However, this is not applicable to thick curved parts and, without additional control, this approach can lead to large variations in practice as material properties and thickness varies. The grouping method is suggested to deal with the bending problem of thick circular plates. The scaled-down test parameters were listed in Table 2.

Table 2

Mechanical property of pure T2 copper

Group	R, mm	R/t	Pressure	Same parameters
1	8	1	Y	Expected angle: 90° Fixed value B:100 mm Size: $150 \times 20 \times 8, \text{mm}^3$
2	8	1	N	
3	15	≈ 2	Y	
4	15	≈ 2	N	

3. Image processing

Based on the bending FEM simulation model, the bending spring-back rule under the different craft parameters and the material parameters were studied in literature. However, all the methods presented have some limitations, simulation or measurement.

Digital image processing technology has been widely used in engineering, computer science, information science, statistics, physics and other disciplines. There are broad prospects for development. And advanced image processing algorithms assist operators with change detection, image classification, identifying anomalies and tracking patterns of activity over time. In order to facilitate analysis, the collected images need to be processed. Due to the actual shooting, the obtained photos will inevitably have various defects such as tilt, local reflection and uneven focus.

Due to the difference in sharpness and exposure of each photo, the actual processing process is different. But there are basically three steps: preprocessing, marginalization and image gridding. Among them, the pretreatment process and image gridding process are the same, and only the marginalization process needs to observe whether the image has reached the required clarity. In order to obtain the contour map of the bending process, the photo taken needs to be processed. The specific image processing process is as follows.

Table 3

Mechanical property of pure T2 copper

Step	Items	Details
1	Bitmap	For subsequent processing
2	Grey	Convert into grey-scale map
3	Edge	Remove the influence of background
4	Brightness	The intensity component of image
5	Laplace	Enhance the details and contours
6	Gaussian	Restrain noises and improve qualities
7	Binaryzation	Obtain the proper binarized signals
8	Refinement	Find the center line

There are two main tasks while processing the pictures - to drag the maximum details from the usually dim objects and noise removing. After studying and mastering some basic principles of the digital image processing and pattern recognition, the task of image meshing was programmed with VC++ 6.0 using above principles. And the software was programmed by VC++ 6.0 was used to process all the collected photos by programming with the image processing algorithms adopted in Table 3. Compared to the original image, the processed image could be more easily distinguished as shown in Fig. 5.

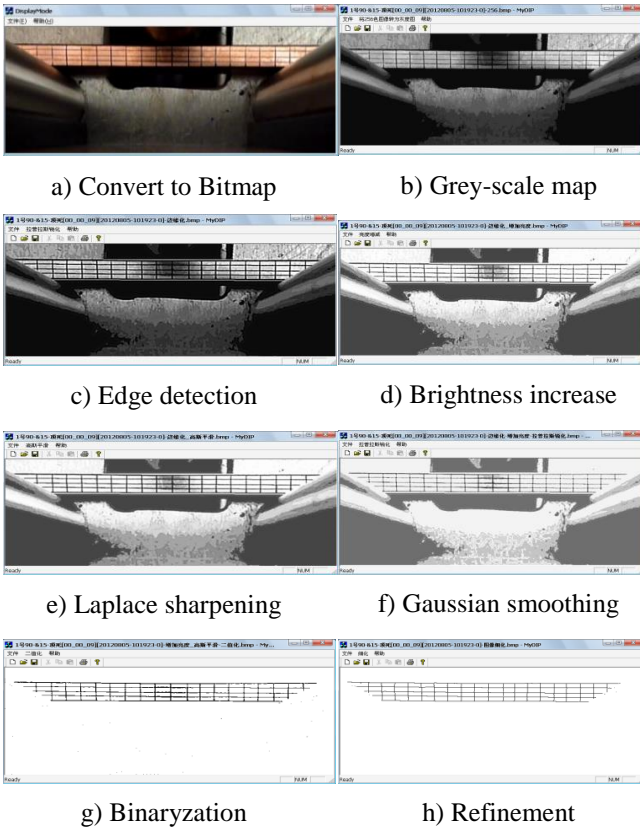


Fig. 5 Image processing

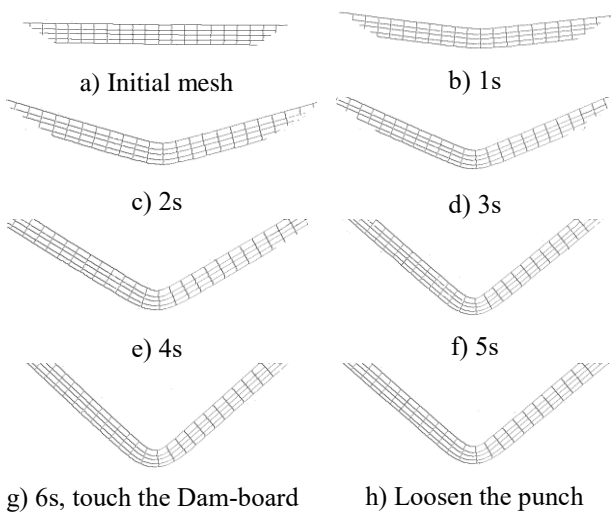


Fig. 6 Mesh plots of the sample at different period

As showed in Fig. 5, through the surface topography magnified by the stereomicroscope, the characteristic of the scorings become more clearly. But the tester must have rich experience to distinguish the subtle distinction from the

topography which was just being critical scratched.

Mesh plots as shown in Fig. 6 can reflect the many detail change in each phase of the bending processing.

On the basis of the surface measurement results of the sample as showed in the Fig. 6 above, the characteristic of the bending deformation appears to more clearly, which is not only reflected in qualitative measurement, but also in quantify.

4. Results and discussion

Bending forming is an important processing method in plastic forming. Copper, aluminum and other non-ferrous metal bending parts are being more and more widely adopted. But the present study is mostly concentrated in the sheet steel, so it is necessary to research the non-ferrous metal thick sheet's bending forming. Studies have shown that the outside of bending part is in tension, and the inside is in compression in the forming process. There are elastic deformation and plastic deformation in the processing of forming at the same time [20]. The internal forming mechanism and its quality influence are not clear, although the stress and deformation of the produce seems so easy. And this paper mainly studied the non-ferrous metal T2 copper plate material forming mechanism analysis and its quality influence. The experiment accomplished in this paper not only confirmed many previous summarize theories, also found some laws that were neglected because of various factors.

Profile is the most basic requirement for bending precision and quality of bending parts. It not only requires bending specimens to the required angle, but also requires proper bending angles and straightness of bending arms. At present, there are many researches on bending radius at home and abroad. However, as modern machines require more and more precision and quality of parts, we also need to consider the straightness of the elbow. Because the force of the bending part is not uniform when freely bending, the strain will also be produced when the bending arm is under stress. The analysis of contour change in bending process is helpful to obtain the strain change rule.

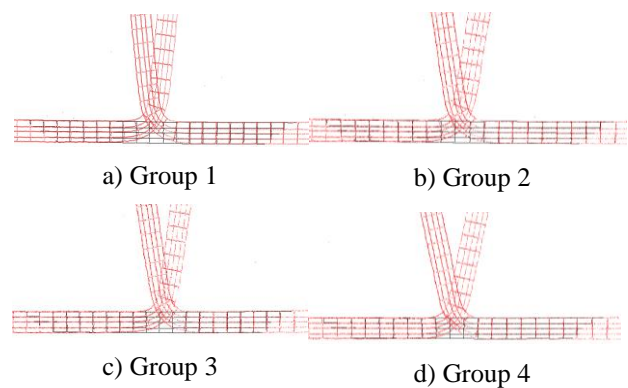
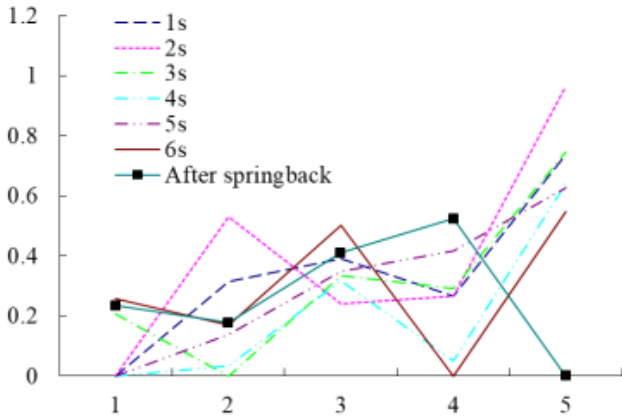


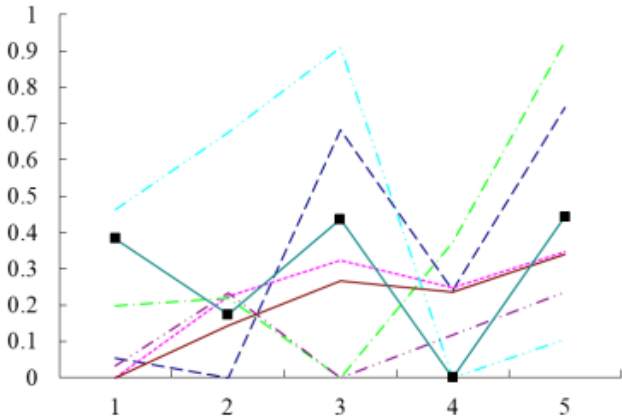
Fig. 7 Stacking mesh plots of beginning and after bend

Observation of Fig. 7, a and b, experiments of 6 s and initial grid overlay chart can be found that when the straight arm part inside and initial medial overlap, 6 s of the outer edge of the grid and the initial figure there is a tiny angle. By observing the above four graphs, it can be seen clearly that the resilience of group 1 is greater than that of group 2. Then compare rates inside and outside the spring-back, first observed bent left arm of a grid graph is shown

in Fig. 7, to note here is that we want to compare the thickness on the spring-back amount on the dash, rather than to be looking at the same level, you can clearly find that the outside of the spring-back amount is slightly less than the inside.



a) Group 1



b) Group 2

Fig. 8 Line graph of the sample at different period

The line chart of angular change rule is obtained by the following calculation steps: 1. Calculated the average of three measurements. 2. Looked for the same time the minimum average angle in five layer, average minus the minimum angle respectively used five angle, get a new set of sequence, this group of sequence shows the specimen sometime changes in the angle of each layer. 3. Take the new sequence value obtained in step 2 as the ordinate value, and draw the incremental broken line graph of five layers of angles.

The analysis of mechanism of forming completed based on the grid profiles gotten by the experiment shown in Fig. 8. Firstly, the profile changes of the specimen were analyzed. The straight arm of the sheet also had elastic deformation and plastic deformation by analysis of the grid maps superposition. And the deformation in a correction force was greater than when under no correction force. Then studied the fillet radius of curvature change of bending parts, obtained the conclusion that the radius had the tendency of been gradually reduce in the bending process, even been less than punch radius in the end. Finally the bending forming angle was analyzed at length. The inside and outside of the bending part weren't strict equaled in the forming process by the analysis of the experimental results and numerical simulation. There was a trend that the angle would

increase gradually from inside to outside. The experimental statistical average should be the range within 0.4° and 0.8° in this test. And the difference would be smaller after spring-back. But the size still was more than experimental measurement error whose size was about 0.2° . Every layer's spring-back rate was researched on the basis of angle data table. It is concluded that the spring-back rates of the bending parts in a correction force would be less than no correction force, and there was a trend that the size of the resilient rate would decrease gradually from inside to outside.

First transverse comparison R/t is 2 to 1 and resilient rate, and the rate of group 1 rebound slightly less than group 3, but the although resilient rate in the medial and second layer of group 2 higher than that of group 4. But the third and lateral layer are almost the same of group 4, the overall difference calculation are small and within 0.2% (except group 1 experimental measurements, the outside of the spring rate differ with other results too big, should give up). Therefore, it can be considered that in the sheet metal bending experiment of the pure copper of the non-ferrous metal T2, when R/t is 2 and 1, there is no obvious law of the rebound rate, whether free bending or correction bending. Then group 1 and group 3 experimental spring rate of each layer was compared under the condition of $R/t = 1$, and result of group 3 shown significantly greater than group 1 in free bending. Which is also clear in group 2 and 4 with the $R/t = 2$, obviously is relatively, and could be verified in the subsequent analysis. In the end, it is easy to find that there is a tendency from inside to outside. And the rate of resilience decreases gradually. This is due to the inside of the grid by the compression deformation, and metal compression ability is weak, but by stress is the same, as shown in Fig. 9. Both inside and outside of the lateral deformation is greater than the stress of the inside. The medial part of the energy will be saved by compressing grid after the bending forces to eliminate. Bending under the effect of internal stress began to rebound, due to compression be able to release the energy stored by the grid, so the grid by the original state of flattening, extend the straight arm part makes the bending parts to twice, cause the spring-back. While the outer part is more deformed than the inner part before the rebound, and the energy after the rebound is less than the inner part, the outer resilience rate after the rebound is naturally lower than the inner part.

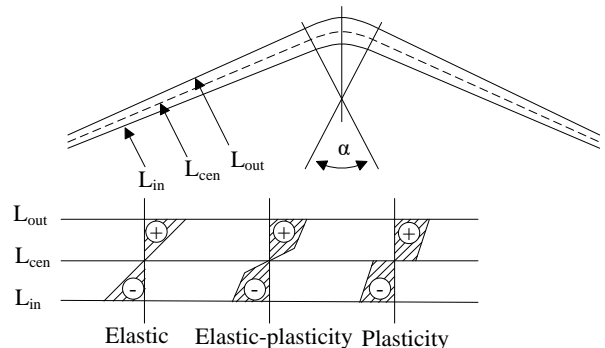


Fig. 9 Distribution of tangent stress on bending area

The compressive stress on the inside of the bending part is less than that on the outside, so the inner deformation of the bending part is also less than that on the outside. Therefore, bending deformation will be larger than the inside part of the straight arm of the lateral, and medial angle

decreases its value Δ_1 will be less than the angle of the lateral Δ_2 reduced values, so the inside of the angle of $\alpha - \Delta_1$ is greater than the lateral angle of $\alpha - \Delta_2$. As shown in Fig. 10.

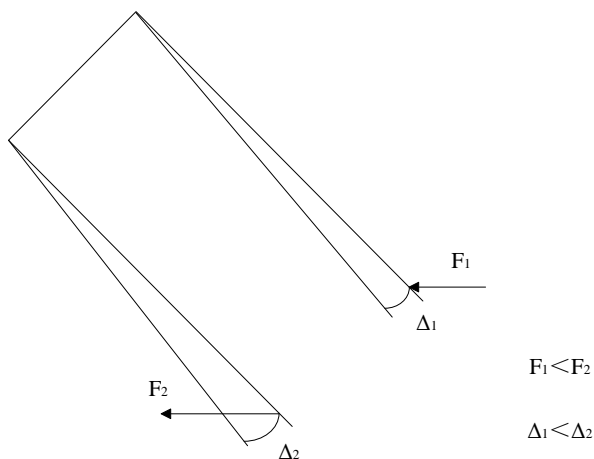


Fig. 10 Deformation schematic diagram of bending round

Bending parts inside and outside of the different point of view, using the theory can be easily explained, but because of its small differences. As well as the limit of the measurements, that has not yet found the forming mechanism. This paper hope to be able to do this work as a result, the author makes the peer has a chance to review the mechanism of forming problem, get more precise forming application results.

5. Conclusions

Dynamic photos of the bending parts were obtained by gridding the surface of the sample and taking real-time video photos. After image processing, photos from any time point can be transformed into clear mesh images of samples. T2 copper thick plate was chosen as the subject for the experiment, and the ratio of punch radius to sheet thickness was $R/t = 1$ and 2. The important observations are summarized as follows:

1. There was a trend that the angle would increase gradually from inside to outside. The experimental statistical average of the angle difference measured between 0.4° and 0.8° in this paper. The difference would be decreased after springback.

2. The angle difference would be decreased under the effect of the correction force after spring-back.

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THICK PLATE BENDING AND IMAGE PROCESSING ALGORITHMS ASSISTANT FOR DE-FORMATION PROCESS DISCRETIZATION ANALYSES

S u m m a r y

The mechanism of three-point thick plate bending finished via the specially designed experiment device in this paper. The deformation process discretization analysis completed via gridding method. T2 copper thick plate was chosen as the subject for the experiment, and the ratio of punch radius to sheet thickness was $R/t = 1$ and 2. The surface of the specimen was meshed by use of fine ink pen. The forming process was accomplished on the experimental facility of three-point free of sheet metal bending. And photos of the specimen in the forming process were recorded on every moment by use of digital camera. The grid pictures of specimen were gotten by image processing, and the accuracy is comparable with finite element analysis. Compared with the grid pictures, the inside and outside of the thick plate bending angle wasn't strict equaled in the forming process, and there was a trend that the angle would increase gradually from inside to outside. The angle difference would be decreased under the effect of the correction force after spring-back.

Keywords: fracture toughness, welded joints materials.

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