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Art of Single Step Analytical Analysis for Springback Formation in "U" Bending Forming Process

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Abstract: ***The formation of the quality of sheet metal had been influenced through spring-back. The exact forecast and directing bouncing were significant. So that the tools are designed for the establishment of sheet metal. Numerous methods had been forecasted for bouncing recompense through alteration of the outline of the tooling. This approach was iterative FEM. In these papers, a systematic method was offered for single-step alteration of the outline of the tooling in channel establishment procedure to recompense the bouncing error. In a limited moment, the outline of the target could be attained through the optimal outline of the die. This establishment is based on these approaches. The set of rules of bouncing recompense through reverse FEM is also summarized. The consequences of the systematic method overlap through those of FEM. The exactness of the attained results was proved through the consequences of the experiment. So that there is the attainment of high exactness.***

Keyword: FEM, spring back, Bouncing error

I. INTRODUCTION

The establishment of Channel was a mutual way of establishment numerous sheet metal like an instrument, electronic equipment, and automobile design. Efficient and quick production of mass can be attained through these methods. The bouncing was mainly a distortion of elasticity. These have occurred as soon as the shaped portion was removed from the formation of the tool subsequently through the establishment of a sheet metal procedure. The geometric portion had been altered through the bouncing. Throughout the following procedure of gathering, difficulties may be caused, or the twisting may be caused in the portion which is accumulated. An exact estimation of shaped layers of bouncing is more significant. So that the tools are designed in the field of airplane and automobile. Introducing

$$D_f \;= D_l + D_{sb}. \qquad (1)$$

D_1 represents a distortion of loading which was attained usually from configuration and geometric of the equipment of die. D_{sb} represents a distortion of Unloading which was influenced through a mixture of numerous parameters of the process like outline and dimensions of the tool, condition of friction contact, the property of substances, breadth and so on.

The formation procedure of the concluding product should be enough close to the outline of the anticipated portion. If the permitted outline of portion deviation had been well-defined, then there is fulfillment through the subsequent association.

$$D_f - D_t| \leq \xi \qquad (2)$$

The over-all distortion in the procedure of the target was denoted through D_t. There is compensation for the distortion of unloading. So that equation 2 had been satisfied. During the procedure of formation, the bouncing quantity is reduced through the rise of the tensile layer. For these numerous types of research had been achieved. (Zang et al., 2013) projected a technique for reducing bouncing, during formation which employed a restrictive force of dissimilar histories. The post and pre-loading of tension could be provided over the portion of shaped through the dissimilarity of in-process of the force of binder. So that the bouncing had been reduced expressively. During the establishment, there must be tight control. So that these procedures make sense to any dissimilarities in conditions of manufacture like the quantity of friction. (Seo et al., 2014) have established and employed an algorithm that is in closed-loop for the control of the force of binder. So that the formation procedure had been made repeatable and robust supplementary. Instead of the trajectory of the force of binder, the punching force was introduced in their approach.

In this approach, no need to alter the outline of the tooling but there is a modification of force of binder for the control system. In numerous situations, the rise in force of binder results in layer tearing. Then such methods of applications were costly and limited.

The altered outline of the formation of the tools has remunerated the distortion of bouncing in another type of study. There is a forecast of bouncing and these would be corrected at the designing stage of the tool. The correction of geometric over the tools which were completed, and these are time-consuming and very expensive. The procedure of iterative had been forecasted in these types. So that the outline of the tooling had been altered. This alteration results in compensation of bouncing error.

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The incremental FEM had been employed to forecast the bouncing in this study. (Ablat & Qattawi, 2017) have projected the FDM or Force Descriptor method.
Each and every iteration, the distortion of bouncing is shaped inversely through the internal forces which are applied over the geometric of a target.
Through equation 3, the altered outline of the tooling in each and every iteration had been attained as

$$D_{1(i+1)} = D_{isb(i)} \quad (3)$$

The inverse distortion of bouncing is denoted as D_{isb}.

(Ablat & Qattawi, 2017)have projected an improved FDM through the rate of convergence which is superior. The author described a multiplier for the internal vector force. So that the number of iterations had been diminished. (Gan & Wagoner, 2004) have established the DA or displacement adjustment method. Flat sheet metal was distorted to an experimental outline of the die in the DA method. The experimental outline of the die shape was treated as the outline of a target portion for the first sequence. There is a comparison of the outline in the last iteration and target after the bouncing. The error of the outline was well-defined as the y coordinates vector of the target less the coordinates of y of the outline of bouncing for the last iteration. Then, the quantity of error of outline was added to tha e existing outline of the die. An innovative outline of tooling would be attained. A flat layer is distorted to the innovative experimental outline of the die for the subsequent iteration. Another iteration would be progressed if the outline of the target is not as unique as outline of bouncing until the quantified tolerance had been established. Fig 1 demonstrates the formation of channel of asymmetric.

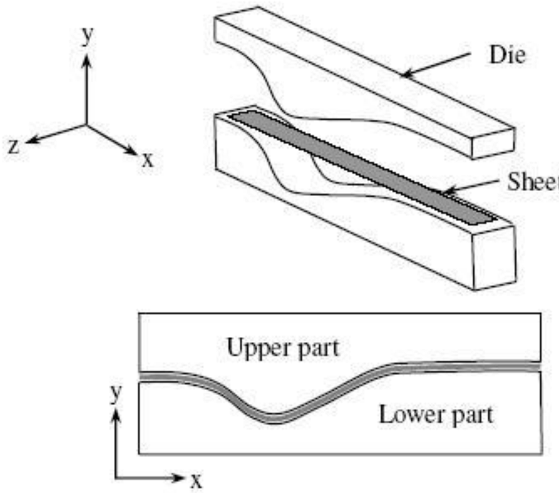

Fig 1. Asymmetric Channel Form

The outline of the tool had been altered through numerous methods. So that the error of bouncing had been balanced through FEM. This method was appropriate for a wider range of procedures. However, a huge cost and time were required for the design procedure by FEM.
Systematic procedures are employed for simple issues and for the analysis of process were timesaving. Vin et al. signified a systematic prototypical to estimate the bouncing and displacement of punch in the V-shaped Airbender. (Song et al., 2013; Zang et al., 2013) have the impact of changing Young's modulus over the bouncing had been examined. Zhang et al. developed a model of the scientific procedure to forecast the bouncing layer of the U-shaped twisting process. Numerous models of substance hardening over the bouncing layer and the impact of the force of holding blank had been examined. A model of the systematic procedure is forecasted. The bouncing in the V-shaped Airbender procedure and the allowance of bend had been computed. (Leu & Zhuang, 2016; Naceur et al., 2006) have The condition of straight-line had been assumed and employed the model of the substance of Swift. So that behavior of the stress hardening had been characterized. In this model, the shift of the axis of neutral had been well-thought-out. The impact of the force of coin is examined over the bouncing which is diminished through the systematic procedure in the V-shaped twisting procedure.
A systematic method had been forecasted in this existing work. The error of bouncing for a formation of arbitrary channel procedure had been compensated. The distortion of bouncing had been attained in reverse from the outline of the target in a single step. So, the altered outline of the tooling had been employed to develop the outline of the target which is defined through these approaches in limited seconds.
Fig 1 demonstrates the geometric of tooling for the formation of the asymmetric channel. The distortion of the bouncing of the full loaded layer had been determined systematically. This is the main purpose of these sections. The full loaded layer outline corresponds to the outline of the die. The following assumptions are applied in the analysis:

1. The layer is widespread qualified which is sufficient to its breadth. So, the state of a straight line is assumed.
2. Planes are normal to the superficial of the layer. During the formation of procedure which remains planar.
3. During the formation of the procedure, the conservation of Volume is reserved,
4. So, there is a negation of variation in the volume because of the distortion of elasticity, $er + eq = 0$.
5. Swift's model is employed to express the behavior of substance, $\sigma = K(\varepsilon_0 + \varepsilon)^n$
6. The yield condition of quadratic of Hill's 48 had been employed. So that the behavior of yielding plasticity of the normal substance of anisotropic had been described.

The outline of the middle superficial layer is employed to define the geometric of the product.The profile of the fully loaded sheet was defined by coordinates of m points:

$$X=\{x_1,x_2,\ldots,x_i,\ldots,x_m\};x_1=\{x_i,y_i\} \quad (4)$$

In each and every step, three point's xi, xi+1, xi+2 are chosen consecutively. Through this three-point, a flow of unique arc is taking place, which could be well-defined. The coordinates of arc center could be calculated as below:

$$\begin{Bmatrix} x_c \\ y_c \end{Bmatrix} = \begin{Bmatrix} (C_1.B_2 - C_2.B_1)/(A_1.B_2 - A_2.B_1) \\ (C_1.A_2 - C_2.A_1)/(B_1.A_2 - B_2.A_1) \end{Bmatrix} \quad (5)$$

$A_1 = 2\ (x_{i+1} - x_i)$; $A_2 = 2(x_{i+2} - x_i)$

$B_1 = 2\ (y_{i+1} - y_i)$; $B2 = 2(y_{i+2} - y_i)$

$$C_1 = x_{x+1}^2 + y_{i+1}^2 - x_i^2 - y_i^2$$

$$C_2 = x_{i+2}^2 + y_{i+2}^2 - x_i^2 - y_i^2$$

The angle and radius of the arc can be obtained as:

$$r_c = \sqrt{(x_i - x_c)^2 + (y_i - y_c)^2} \quad (6)$$

$$\theta = 2\ \mathrm{Arcsin}\left[\frac{\sqrt{(x_{i+2} - x_i)^2 + (y_{i+2} - y_i)^2}}{2r_c}\right] (7)$$

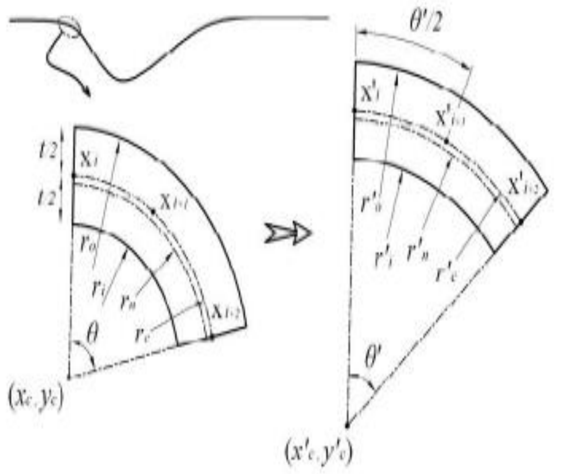

Fig: 2 Springback in a channel arc

The angle θ′ and radius of the arc of *r′c* had been computed after bouncing through the systematic method which is present in the next section. By constraining the first point (**xi**), the coordinates of the arc center after spring back can be expressed as follows:

$$\begin{Bmatrix} x'_c \\ y'_c \end{Bmatrix} = \begin{Bmatrix} r'_c / r_c(x_c - x_i) + x_i \\ r'_c / r_c(y_c - y_i) + y_i \end{Bmatrix} (8)$$

Due to the bouncing layer, the transformed position of the second and third points can be obtained as below:

$$x'_{1+1} = \begin{Bmatrix} x'_{i+1} \\ y'_{i+1} \end{Bmatrix} = \begin{Bmatrix} x'_c \\ y'_c \end{Bmatrix} + T(\theta'/2).\begin{Bmatrix} x_i - x'_c \\ y_i - y'_c \end{Bmatrix} (9)$$

$$x'_{1+2} = \begin{Bmatrix} x'_{i+2} \\ y'_{i+2} \end{Bmatrix} = \begin{Bmatrix} x'_c \\ y'_c \end{Bmatrix} + T(\theta').\begin{Bmatrix} x_i - x'_c \\ y_i - y'_c \end{Bmatrix} (10)$$

$$T(\theta) = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \quad (11)$$

The consequence of the above transformation over the residual points can be expressed as:

$$x'_k = x'_{1+2} + T(\Delta\theta).(x_k - x_{1+2} \_ \ (k = i+3,...,n) (12)$$

$$\Delta\theta = \theta - \theta'$$

The geometric of the final layer had been attained at the end of three points after the computations of bouncing.

II. SPRING-BACK CALCULATION

Fig 2 demonstrates the layer which undergoes tensile over the fibers outside and solidity over the innermost ones. The neutral fiber position of m tensile(7)free fiber, during the formation of procedure which uninterruptedly varied. The strain of tangential had been distributed through the breadth and expressed as

$$\varepsilon_\theta = \ln\frac{r}{r_n} \quad (13)$$

The following model is applied for the behavior of the substance hardening:

$$\bar{\sigma} = \begin{cases} E\bar{\varepsilon} & \text{for } \bar{\varepsilon} \le \bar{\varepsilon}_\gamma \\ K(\varepsilon_0 + \bar{\varepsilon})^n & \text{for } \bar{\varepsilon} \ge \bar{\varepsilon}\gamma \end{cases} \quad (14)$$

Where $\bar{\sigma}, \bar{\varepsilon}$ are effective stress and effective strain, respectively K, ε_0, 0, n is hardening coefficient, pre-strain and hardening exponent, respectively. $\bar{\varepsilon}_\gamma$ is the elastic limit strain, corresponding to the initial yield stress ($\bar{\sigma}_\gamma$).

The force equilibrium yields:

$$\frac{d\sigma_r}{dr} = \frac{\sigma_\theta - \sigma_r}{r} \quad (15)$$

(8)

Where σ_θ, σ_r are tangential and transverse stresses, respectively.

From Hill's yield criterion,

(9)

$$|\sigma_\theta - \sigma_r| = F\bar{\sigma} = FK(\varepsilon_0 + \bar{\varepsilon})^n \quad (16)$$

The anisotropy coefficient for plane strain condition (F) is defined as: (10)

$$F \frac{1+R}{\sqrt{1+2\bar{R}}} \quad (17)$$

(11)

Where $\bar{R}$ is the transverse anisotropy coefficient

Based on plastic work formulation, the following equation can be written:

$$\bar{\sigma}.\bar{\varepsilon} = \sigma_r.\varepsilon_r + \sigma_\theta.\varepsilon_\theta \qquad (18)$$

By applying assumption (3) in the above equation we have:

$$\bar{\sigma}.\bar{\varepsilon} = -\sigma_r.\varepsilon_\theta + \sigma_\theta.\varepsilon_\theta = (\sigma_\theta - \sigma_r).\varepsilon_\theta \qquad (19)$$

According to equation (5.16), the equivalent strain can be obtained:

$$\bar{\varepsilon} = \begin{cases} F\varepsilon_\theta & \text{for } r \geq r_n + t_y \\ -F\varepsilon_\theta & \text{for } r \geq r_n - t_y \end{cases} \qquad (20)$$

Where $t_y = \frac{F(1-v^2)\bar{\sigma}_y r_n}{E}$ is the half breadth of the elastic region.

According to assumption (5.3), the following equation can be expressed:

$$V_i = V_f \Rightarrow r_n\theta\, t_i = r_c\theta t \qquad (21)$$

Therefore

$$t = \frac{r_n}{r_c} t_i \qquad (22)$$

Where t is the initial and t_i is the final layer breadth.

By substitution of equation (5.17) in equation (5.16) and integrating from r to the outer fiber, the following equation can be obtained:

$$\begin{cases} \int_r^{r_c+t/2} d\sigma_r \quad \int_r^{r_c+t/2} FK\left(\varepsilon_0 + F\ln\left(\frac{r}{r_n}\right)\right)^n \frac{dr}{r} & r \geq r_n \\ \int_r^{r_c+t/2} d\sigma_r \quad \int_r^{r_c-t/2} -FK\left(\varepsilon_0 + F\ln\left(\frac{r}{r_n}\right)\right)^n \frac{dr}{r} & r \leq r_n \end{cases} \qquad (23)$$

σ_r at outer fiber is zero, then σ_r can be obtained as:

$$\sigma_r = \begin{cases} \frac{K}{n+1}\left[\left(\varepsilon_0 + F\ln\left(\frac{r}{r_n}\right)\right)^{n+1} - \left(\varepsilon_0 + F\ln\left(\frac{r_c + t/2}{r_n}\right)\right)^{n+1}\right] & r \geq r_n \\ \frac{K}{n+1}\left[\left(\varepsilon_0 + F\ln\left(\frac{r}{r_n}\right)\right)^{n+1} - \left(\varepsilon_0 + F\ln\left(\frac{r_c + t/2}{r_n}\right)\right)^{n+1}\right] & r \leq r_n \end{cases} \qquad (24)$$

The radius of the m of neutral fiber had been computed from the transverse stress of continuity. The moment of twisting can be attained as:

$$M = b\int_{r_c-t/2}^{r_c+t/2} \sigma_\theta r dr = b\int_{r_c-t/2}^{r_n-t_y}\left[-FK\left(\varepsilon_0 - F\ln\left(\frac{r}{r_n}\right)\right)^n + \sigma_r\right] r dr$$

$$+ b\int_{r_n-t_y}^{r_n+t_y} \frac{E}{1-v^2}\ln\left(\frac{r}{r_n}\right) r dr$$

$$+ b\int_{r_n+t_y}^{r_c+t/2}\left[FK\left(\varepsilon_0 + F\ln\left(\frac{r}{r_n}\right)\right)^n + \sigma_r\right] r dr \qquad (25)$$

where *b* is the breadth of the sheet.

The angle of twisting after bouncing (*r'c*) could be computed from:

$$\frac{1}{r_c} - \frac{1}{r_c'} = \frac{12(1-v^2)M}{Ebr^3} \qquad (26)$$

The angle of twisting θ' after bouncing could be computed easily as per the neutral fiber's fixed length.

III. SPRING-BACK COMPENSATION

The altered outline of the die had been discovered to develop the outline of the target. This is the main purpose of these sections. The points of n had been chosen over the outline of the target. So that these purposes are attained. The θti of angle and a rti of unique radius had been computed as per section 2. These were computed for every xi, xi+1, xi+2 three points successively. By assuming the angle of the arc of the modified optimal die and the radius of arc as _oi and roi, the following equation had been derived from equation (26):

$$\frac{1}{r_{oi}} - \frac{1}{r_{ti}} = \frac{12(1-v^2)M_o}{Ebt^3} \qquad (27)$$

An equation (25) evaluates, the moment of bending at the Mo of the optimal outline of the die. Therefore equation (27) becomes:

$$\frac{1}{r_{oi}}-\frac{1}{r_{ti}}=\frac{12(1-v^2)M_o}{Et^3}\int_{r\alpha-t/2}^{r_{oi}+t/2}\sigma_\theta rdr$$

$$=\frac{12(1-v^2)}{Ebt^3}\int_{r_{oi}-t/2}^{r_n-t_y}\left[-Fk\left(\varepsilon_0-F\ln\left(\frac{r}{r_n}\right)\right)^n+\sigma_r\right]rdr$$

$$+\frac{12(1-v^2)}{Et^3}\int_{r_n-t_y}^{r_n+t_y}\frac{E}{1-v^2}\ln\left(\frac{r}{r_n}\right)rdr$$

$$+\frac{12(1-v^2)}{Et^3}\int_{r_n-t_y}^{r_n+t/2}\left[FK\left(\varepsilon_0+F\ln\left(\frac{r}{r_n}\right)\right)^n+\sigma_r\right]rdr \quad (28)$$

Newton's method is employed to predict the equation of numerical solution and to evaluate the modified optimal radius of the die. The angle of the arc of the θ_{oi} of the modified optimal die had been computed easily as per the unbiased fiber's static length. The full modified optimal outline of the die had produced the outline of the target could be attained through the evaluation of the angle of modified optimal die for the N/2 portion of the framework of the target and radius of the arc.

IV. SPRING-BACK COMPENSATION BY FEM

The compensation of bouncing procedure through the inverse method of FE had been presented in these sections. An extensive variety of forms of procedures had been examined through the FEM. The method of FEA of implicit-explicit had been applied for the inverse analysis of bouncing. Some deliberations had been considered for the movement of inverse among the fully loaded and final product. The contact load which is among the layer and the die are applied over the final geometric at the loading termination. So that the above features are attained. The σres of the stress of residual at the procedure termination had been distributed over the outline of the final stage. The least rotation of the proper node had been embarrassed and elasticity of the substance had been well-defined. The method of FEA of implicit-explicit had been employed to attain the Fc of the force of contact forces and stress of residual.

The following steps encompass the compensation of bouncing procedure through the inverse method of FE.

The D_t of the geometric target was supposed as the D_l of geometry which is fully loaded. The forward analysis of FE had been established and the Fc of forces of contact at the loading termination and the σres of the stress of residual at the procedure termination are protected.

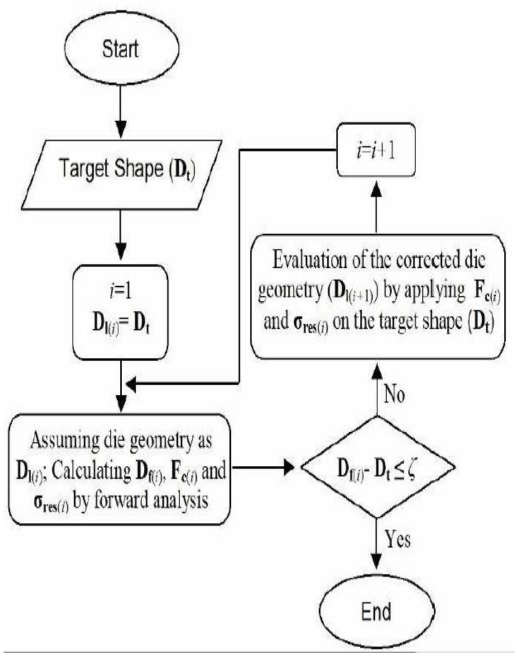

Fig 3: Algorithm of compensating the spring back error by FEM

1. The D_t of the geometric target was supposed as the D_f of geometric of the final.

The inverse analysis of FE had been progressed through step 1 which applied the protected data. So the D_{isb} of inverse distortion of bouncing had been measured and equation 4 is employed to attain the D_1 of loaded geometry.

2. The attained geometry in step 2 was supposed as the revised outline of the die.

The Forward analysis of FE had been progressed and the Fc of forces of contact at the loading termination and sres of the stress of residual at the procedure termination was protected.

3. The comparison is made among the attained final outline and the outline of the

target in the preceding step.

4. Step 3 has protected data that is applied in step 2 that should be repeated if the x-allowable tolerance is not as much of that the difference. Fig 3 demonstrates the above procedure.

V. RESULTS

In the channel formation of an asymmetric procedure, the distortion of bouncing was evaluated by applying the systematic method which is present in section 2. The distortion of bouncing was measured through the FEM. So that the systematic method results and FEM of explicit-implicit had been compared. In this case, the geometric target was treated as the geometric die in the situation of D_l equal to D_t. Fig 4 demonstrates the outline of the target. The formation of die encompasses a couple of portions with the equivalent outlines which is demonstrated in Fig 5. The gap among the portions of the die at the termination of the loading state was established to the breadth of the layer. The layer of annealed CK45 performs the channel formation of an asymmetric procedure.

The 115 mm length of dimensions of layer, 25 mm in breadth and 1mm in width.

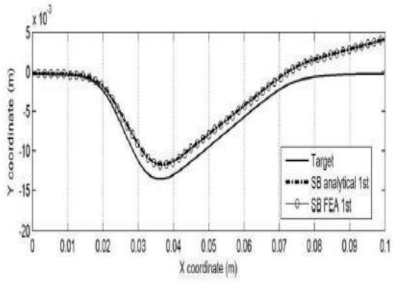

Fig 4: The target shape and the obtained optimum die shape from a one-step analytical approach

In the analysis of FE, the workpiece had meshed through the shell elements of four nodes. The analysis of FE of strain and stress curve was well-defined which was corresponds to the strain and stress curve which is attained from the tensile test performed over the applied layer. Table 1 summarizes the data of substance. The error of normalized RMS was measured for the method of FE and systematic. So that the results are compared. The error of normalized RSM was defined as:

$$R_N = \frac{\sqrt{\sum_{j=1}^{N} \Delta y_j^2 / N}}{R_0} \times 100 \qquad (29)$$

Where Δy_j represents the error of outline of the j^{th} point, N represents the number of test points and RN represents the normalized RMS is the prediction error of RMS is R_0 for the situation of D_1 equal to D_t in the systematic method.

Fig 4 shows the systematic method that produces an outline of bouncing which was associated with the method of FE. The error outline in the method of FE was evaluated for test points of 60, associated through the systematic method consequences. The error of normalized RSM for the method of FE was predictable as 2.3%. So, the forecasted bouncing results through systematic method were in unity through the results of FE with no larger than 3% of error.

The modified optimal geometric of the die is estimated through a systematic method of the compensation of bouncing. Fig 5 demonstrates the attained optimal outline of the die and the outline of the target. This outline of optimal is discovered single-step systematic calculation. The outline of the product attained from the optimal outline of die matches exactly to the outline of the target.

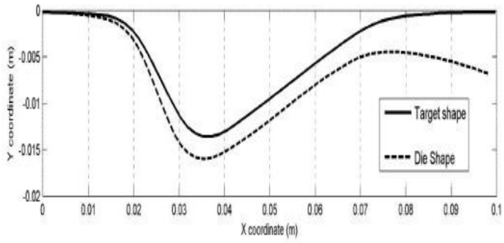

Fig 5: The target shape and the obtained optimum die shape from a one-step analytical approach

The optimal outline of the die had been discovered through the analysis of inverse FE which is applied by the procedure of compensation. For these procedures, the 5% error of normalized RSM was treated as the condition of the convergence. The outline of the bouncing and been attained through the procedure of FE and 4.6% of normalized RSM in the fifth iteration. Fig 6 demonstrates the dissimilar iterations of forecasted geometric of die. Fig 7 demonstrates the comparison of dissimilar iterations of attained outline of the bouncing and the geometric target. Fig 8 demonstrates the representation of convergence the procedure of iteration. Fig 9 demonstrates the channel formation of asymmetric test.

Table 1: The material data for annealed CK45

Material	E (GPa)	v	$\bar{\sigma}_\gamma$	K(MPa)	ε0	n	$\bar{R}$
CK45	203	0.33	344	6.59	0.0035	0.13	0.92

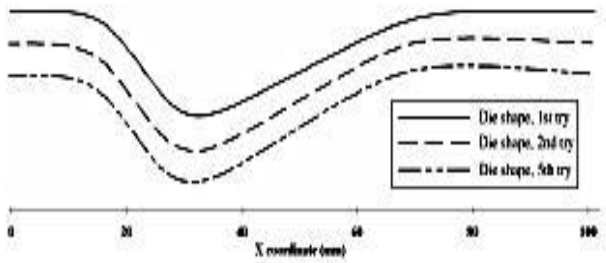

Fig 6: The proposed die shape by the FE algorithm

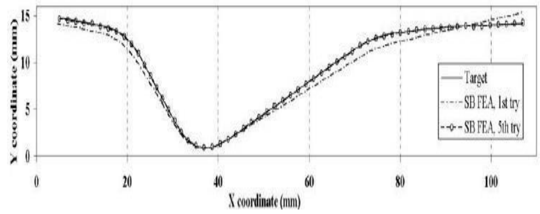

Fig 7: Comparison of the obtained product shapes from the FE compensation algorithm with the target shape

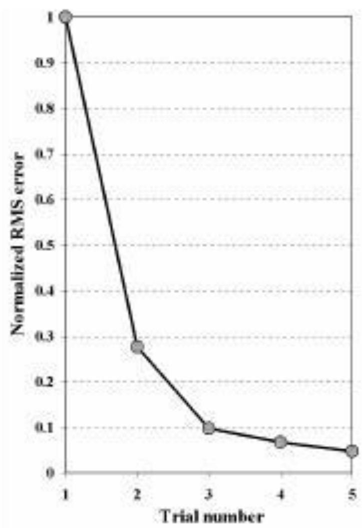

Fig 8: Convergence diagram of the FE algorithm

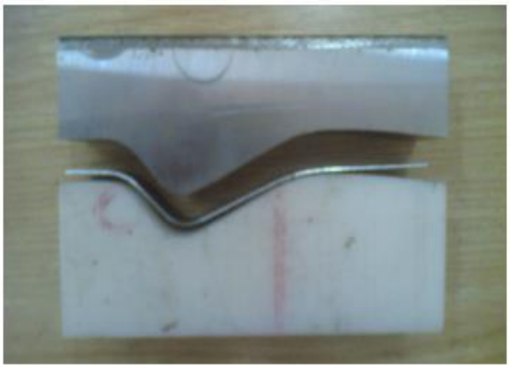

Fig 9: The asymmetric channel forming test

VI. EXPERIMENT

The applied layer must be performed through the channel formation of an asymmetric test. So that the system results are verified. The systematic method produces the attained geometric of die (Fig 5). These methods were employed to develop the desired portions of the die parts through a machine of CAM or CAD. The 1mm of the sheet breadth receives the gap among the equipment to die at the end of loading (Fig 1). The final product and the equipment of die are demonstrated in Fig 9. The comparison of attaining product and the geometric of target geometry is demonstrated in Fig 10. The error of normalized RMS is evaluated as 3.7% than the geometric of the target. The three random points of negligible outline error are also demonstrated in these representations.

VII. CONCLUSION

The quick and high precision of distortion of bouncing in the formation of the channel had been forecasted through the result of the existing scientific method. The compensation of bouncing can be applied through the modification of dying. The optimal outline of the die had been produced in the single-step calculation through these methods. There is no need to progress a procedure of iteration. FEM is employed to present the procedure of inverse for compensation of bouncing. These FEM could be applied for numerous problems of three-dimension which are highly complicated. The optimal outline of the die had been proposed through the procedure of iteration. In unique situations, the study of FEM and the scientific method's consequences had coincided. The results of systematic are authenticated through the experimentation proves the attained results accuracy was adequate for applications of industries. The test product comparison through the geometric of the target is demonstrated in fig 10.

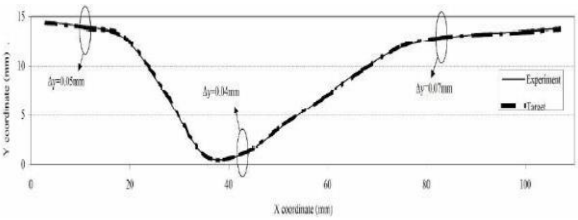

Fig 10: Comparison of the test product with the target geometry

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