Eng & Tech. Journal, Vol.30 , No.14, 2012

Finite Element Analysis of Sheet Metal U-Bending Using Free Form Surface

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Received on: 28/8/2011 & Accepted on:5/4/2012

ABSTRACT

This paper deals with the optimization of tools geometry in sheet metal forming U-bending in order to reduce the equivalent strain, equivalent stress, and thickness change after forming. Free form surface method (Bezier curve, B-spline curve, and NURBS curve) is used to generate the die and punch profile; this technique is accurate to describing the die and punch profile. A 3D numerical simulation using the Ansys 12.1 FEM code was conducted to understand the effect of die profile in final product. The results show that the more uniform distributions in strain, stress, and thickness when using same profile radius for die and punch (Bezier curve).

Keywords: U-bending, free form surface, FEA.

تحليل العناصر المحددة لصفيح معدني محني على شكل حرف U بأستخدام شكل السطح الحر

الخلاصة

في هذا البحث تم دراسة هندسية العدة للحصول على الشكل المثالي لعملية الحني على شكل حرف U وذلك لتقليل الانفعال والاجهاد والتغير بالسمك للمنتج النهائي. تم استخدام طريقة السطوح المعقدة لتوليد المنحنى للقالب والخرامة وهذه التقنية دقيقة لوصف شكل المنحنى للقالب والخرامة. تم تمثيل عملية الحني بأستخدام طريقة العناصر المحددة التي تم تنفيذها بأستخدام برنامج ANSYS (12.1) الخاص بتقنية العناصر المحددة. تم تمثيل عملية الحني بأستخدام موديل ثلاثي الابعاد وذلك

لدراسة تأثير منحى القالب على المنتج النهائي. ومن النتائج التي حصلنا عليها يكون الانفعال والاجهاد والتغيربالسمك اكثر انتظاماً عند استخدام نفس المنحنى للقالب والخرامة (منحنى بيزر)

INTRODUCTION

Shaping materials without removing any chips around a definite axis through or without heat is called bending. Bending is the process of placing a sheet of metal over the matrix on the press bed where the sheet is bent around the tip of the punch as it enters the die. Bending dies are the setup, proper to the required piece shape, consisting of a female die and punch, and making permanent changes on steel sheet material the terminology used in bending is shown in Figure (1.a) [1, 2]. Since all materials have limited elastic modulus, when load acting on plastic deformation is relieved from the material, it is followed by several elastic improving. In bending process, elastic limits of materials are exceeded, but flow limit thereof cannot be exceeded. Therefore, the material still keeps a portion of its original flexibility character: When the load is released, the material on forcing compress side tries to enlarge, whereas the material on tensile side tries to shrink. As a result, the material tries to springback and the bended material by flexing slightly tries to open. This is indicated in Figure (1.b). And if noticed, it can be seen that the last bending angle following springback is smaller and the last bending radius is larger than the previous ones. (Rs > Rb) [2].

Literature survey shows that considerable amount of researches are reported on modeling (including analytical, empirical and FE) and analysis of V-bending, U-bending, air V-bending etc. Few important literatures are briefly discussed here. Nowadays, with the advent of computation technology, sheet metal bending processes can be analyzed prior to experiments using the finite element method. ***W.M. Chan, H.I. Chew, H.P. Lee, and B.T. Cheok***[4]. Presents finite element simulations to study the effect of spring-back with the variation of different die–tool parameters. The type of bending process is V-die bending with one clamped end and one free end. Parameters varied are the punch radius, punch angle and die-lip radius. The analysis shows that spring-back angle of the valley region decreases with increment of punch radius and punch angle. Spring-back is dependent on punch radius, punch angle and die-lip radius. ***Rahul k.Verma and A.Halder*** [5] reported the effect of anisotropy on springback using FEA; analytical model was developed to crosscheck the trend prediction by FEA. They concluded that higher the anisotropy, higher the springback and FEA result shows the minimum springback for isotropic material. An analytical model for predicting sheet springback after U-bending is proposed by ***Zhang Dongjuan et al*** [6]. The results show that the springback can be reduced effectively by increasing the blank holding force and friction between sheet and die. And the springback increases with anisotropy and friction between sheet and punch, and decreases with the sheet thickness. A new optimization method for V and U bending processes is presented by ***L.C. Sousa et al*** [7]**.** This method integrates a genetic algorithm and a commercial finite element sheet metal simulation. The genetic algorithm is a developed FORTRAN code and the finite element analysis is carried out using the commercial code ABAQUS. The result shows that the genetic approach is efficient and gives promising results.

FREE FORM SURFACE

Bézier curves:-

Bézier curves were developed by Pierre Bézier and have its origins in the automobile industry for use in the design of Renault automobile bodies. A Bézier curve can be fitted to any number of control points, but cubic (with 4 control points) is the most common one (see figure 2). Each control point affects the curve globally, which is the main drawback. Cubic Bézier curves are defined by the positions of the curves' end points together with two more points, usually not on the curve, to indirectly define

A Bezier curve of degree n is a polynomial interpolation curve defined by $(n+1)$ points defining the Bezier control polygon. The interpolation basis functions used in Bezier interpolation are the Bernstein polynomials defined for degree n as:-

$$P_i^n(u) = \binom{n}{i} t^i (1-u)^{n-i}$$

Where the binomial coefficients are given by:-

$$\binom{n}{i} = \begin{cases} \dfrac{n!}{i!(n-i)!} & \text{if } 0 \le i \le n \\ 0 & \text{else} \end{cases}$$

The parameter t is in the range [0, 1] and there are $(n+1)$ polynomials defined for each i from 0 to n. The Bezier curve is therefore defined over the interval [0, 1] as:

$$b(u) = \sum_{i=0}^{n} biP_i^n(u) \qquad \ldots (1)$$

Where (bi) are the control points defining the Bezier polygon. A recursive algorithm defined by de-Casteljau, calculates for a given control polygon the point that lies on the Bezier curve for any value of t, and can be used to evaluate and draw the Bezier curve simply, without using the Bernstein polynomials [10].

B-spline curves

The term B-spline is short for basis spline and was coined by Isaac Jacob Schönberg from Romania in 1946. In 1973 the theory of B-spline was applied to a curve definition by Gordon and Risenfeld. A B-Spline consists of one or more polynomialv curves glued together, i.e. it is said to be piecewise polynomial curve. B-spline curves are a generalization of Bézier curves where each polynomial piece is a Bézier curve [8].

$$N_{i,k}(u)=\frac{(u-ui)}{(u_{i+k-1}-ui)}N_{i,k-1}(u)+\frac{(u_{i+k}-u)}{(u_{i+k}-u_{i+1})}N_{i+k,k-1(u)} \quad \text{.....(2)}$$

$$N_{i,1(u)} = \begin{cases} 1 \text{ if } ui \le u \le ui+1 \\ 0 \quad \text{otherwise} \end{cases}$$

$$u_{\min} \le u \le u_{\max}$$

$$2 \le k \le n+1$$

$P(u)$	Point on the curve along the control points.
$N_{i,k}$	Basis function.
B	Control polygon coordinate in Euclidean coordinates.
k	Order of the curve. The degree is $k-1$.
$n+1$	Number of control points.
U	Knot vector. $U=\{ui \le ui+1\}$, $\lvert U \rvert = n+k+1$.

NURBS Curve

NU	Non-Uniform	Knot vectors with (possibly) uneven spaces
R	Rational	Use of weights.
BS	B-Spline	Basis-functions, piecewise local curves.

Non-Uniform Rational B-Spline (NURBS) curves are a generalization of B-Spline curves.The definition and differences of non-uniform rational and non-rational B-splines. The name might indicate that there are four main combinations of B-Splines. B-Splines are usually said to be rational or non-rational and (open) uniform, or (open) non-uniform. A closed curve is less usual [8]. NURBS are represented parametrically with the following equation [9]:

$$C(u)=\frac{\sum_{i=0}^{n} N_{i,k}(u)wiPi}{\sum_{i=0}^{n} N_{i,k}(u)wi} \quad \text{.....(3)}$$

Where $N_{i,k}(u)$ is the blending function defined by the recursive formula:

$$N_{i,0(u)} = \begin{cases} 1 & ui \le u \le ui+1 \\ 0 & \text{otherwise} \end{cases}$$

$$N_{i,k}(u) = \frac{(u-ui)}{(u_{i+k-1}-ui)} N_{i,k-1}(u) + \frac{(u_{i+1}-u)}{(u_{i+k}-u_{i+1})} N_{i+1,k-1(u)}$$

Where $[ui,...,u_{i+k}]$ is the knot vector; (u) is the parameter, $C(u)$ is the vector to point defined at some value of (u), (Pi) is the control points, in 3D cases, Bi{Xi, Yi,Zi}T, (n) is the number of control points, and we is weight factors [9].

MATERIAL

The material used in all simulation is low carbon steel (1008-AISI), where this type is used for stamping applications, such as, automobile bodies, engineering application and other applications. To determine the material properties in the sheet, specimen was tested using a tensile test machine type (Winwdw electronic universal testing machine). Figure (3) shows the relationship between true stress-true strain curves for low carbon steel. Table 1 shows the mechanical properties for low carbon steel.

Table (1) the material properties.

Parameters	Units	Value
Young's modulus (E)	**GPa**	**200**
Tangent modulus (E_t)	**GPa**	**0.5**
Yield strength (σ_y)	**MPa**	**250**
Poisson's ratio (ν)	**__**	**0.3**
Thickness (t)	**mm**	**2**

U-BENDING SIMULATION.

The numerical simulation of forming processes has become a very efficient tool for the design of forming operations and it is widely used in industry. The analysis is carried out using the commercial FEA software Ansys 12.1. The 3D 8-NODE .structural solid element of solid 45 was used for workpiece (blank). The tools are modeled by analytical rigid surfaces for rigid (tool set)-flexible (blank) contact, 3D 8-node quadrilateral target elements of TARGE170 were used, to represent 3D target (tool set) surfaces which were associated with the deformable body (blank) represented by 3D 8-node contact elements of CONTA174., as the computational time spent by the contact algorithm is smaller than that spent by using rigid surfaces formed by element faces. Automatic contact procedure in Ansys 12.1 was used to model the complex interaction between the blank and tooling.

The problem is symmetric about a plane passing through the centre of the punch and only half of the cross-section is modeled. The U-bending process is essentially plane strain problems because the width of the blank is much larger than its thickness.

A schematic diagram of the U-bending process with geometric parameters is shown in Figure (4) and Figure (5) show profile punch and die by using 3D free form surface technical.

The frictions coefficients between all contact surfaces were 0.125. The punch was allowed to move into the die cavity with a uniform velocity. The finite element model is shown in Figure (6).

Successive stages of the bending sheet for varying punch stroke (displacement) are shown in Figure (7).

RESULTS AND DISCUSSION

To investigate the effect of die profile radius on FE model, Hill's48 yield criterion was used, three types of die corner radii (Bezier curve, B-spline curve, and NURBS curve), with punch profile radius (Bezier curve), μ0.1 blank size 120mm×50mm were chosen, see Figure (8)

Figure (9) shows the variation in the bending force with the punch stroke under different die corner radii. It is noted from the figure that the bending force increases with decrease in die profile radii under constant punch profile radius, due to an increase in process work by plastic bending and unbending over the smaller die profile and reach the maximum value when the die profile radius is B-spline curve .

Figure (10) shows the effect of die profile radius on thickness distribution over the wall completely bent part. It is clear from the figure that initial blank thickness (t_o=2mm) at the region of flat bottom face of the punch is small change of thickness occurs, this is because the flat face of the punch is in contact with blank, and due to the bending force, friction comes into play which prevents deformation of the metal under the punch. At the punch corner thinning will occurs, this happens because of stretching by tensile stress. It is seen obviously that the thinning increases with decreasing die corner radius, and maximum thinning (at reasonable value, more than 1.4%) occurred at smallest die profile radius (B-spline curve).

Figure (11) shows the equivalent strain distribution over the wall completely bent part. It is evident from the figure that the equivalent strain has a tensile behavior since it is the resultant of the three strains (transverse strain, thickness strain, and longitudinal strain); under punch profile the equivalent strain increases due to severe deformation in this area and reach maximum value when using small die profile radius (B-spline curve), and also It is clear that the equivalent strain increases with decreasing thickness.

Figure (12) represents the effect die profile radius on the equivalent stress over the wall completely bent part. It is noted from figure, equivalent stress has a tensile behavior and the equivalent stress reaches the maximum value at the punch corner region when using small die profile radius (B-spline curve). It is noted from the figure that the best uniformly distributed and smallest value of equivalent stress, is the when using die profile radius Bezier curve with punch profile radius Bezier curve.

CONCLUSIONS

The effect of die profile radius by using free form surface was studied from which the following conclusions can be drawn:

1. The bent part wall thickness, strains, and stresses distributions are more uniform when using same profile radius for die and punch (Bezier curve).
2. The maximum thinning (at reasonable value, more than 1.4%) occurred at smallest die profile radius (B-spline curve).
3. The graphics of thickness, strains, and stresses for die profile radius Bezier curve and NURBS curve is nearly same.
4. From the results that the highest value for stress and strian appears to be a good of success or failure of the process of bending, because the measure of the thickness, strain and stress are an important measures during the bending process.

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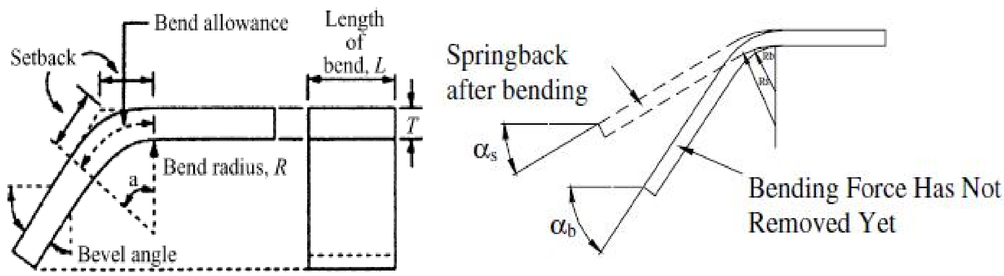

Figure (1) (a). Bending terminology, (b).Springback formed following bending [2, 3].

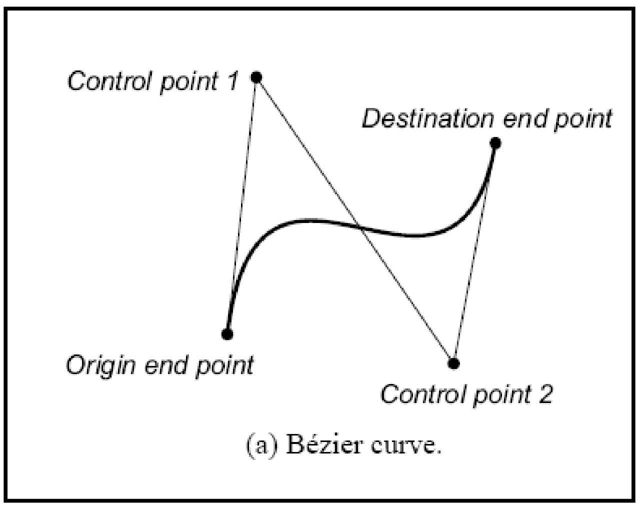

Figure (2) Smooth curve [8].

Figure (3) True stress-true

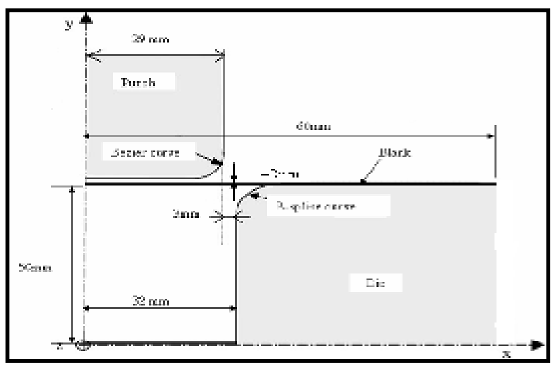

Figure (4).Schematic diagram of U-bending

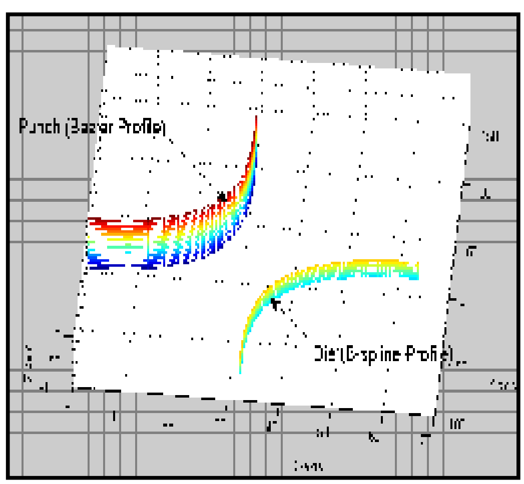

Figure (5) The model generation by free form

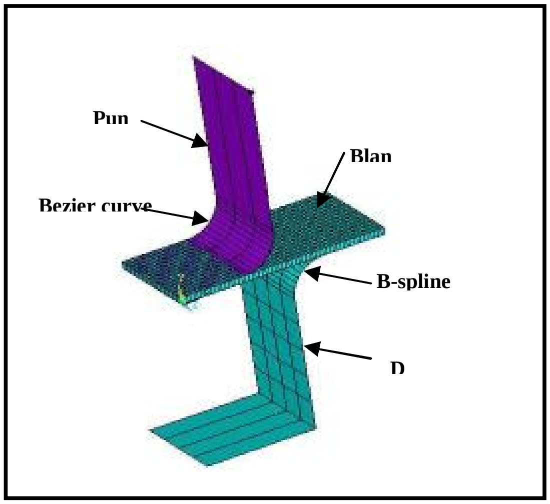

Figure (6) The finite element model of U-bending

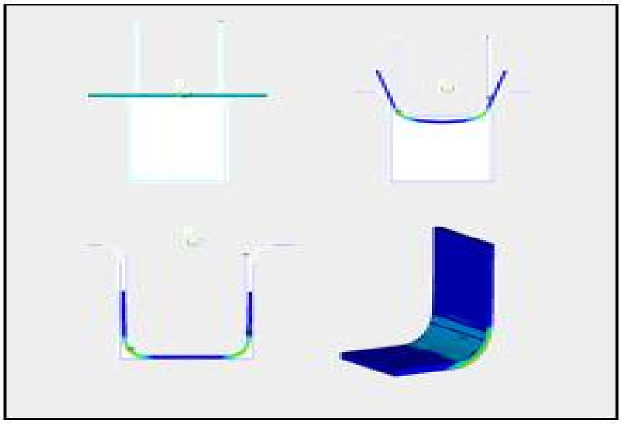

Figure (7) Sequences of U-bending

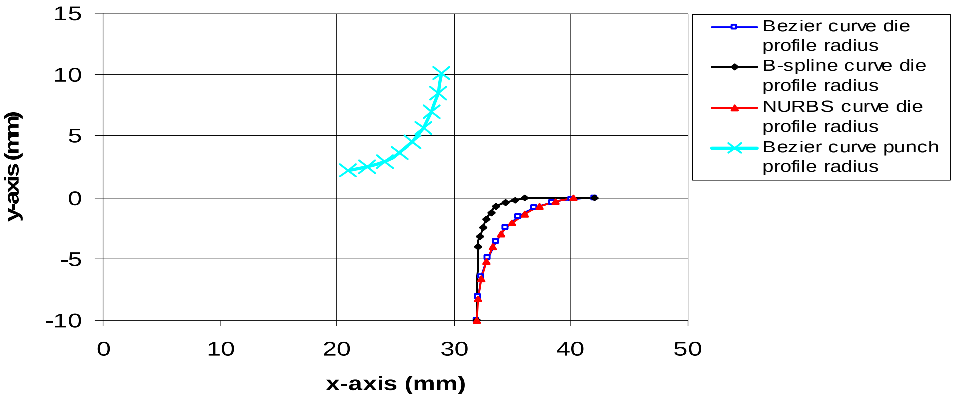

Figure (8) The die and punch profile by using free form surface.

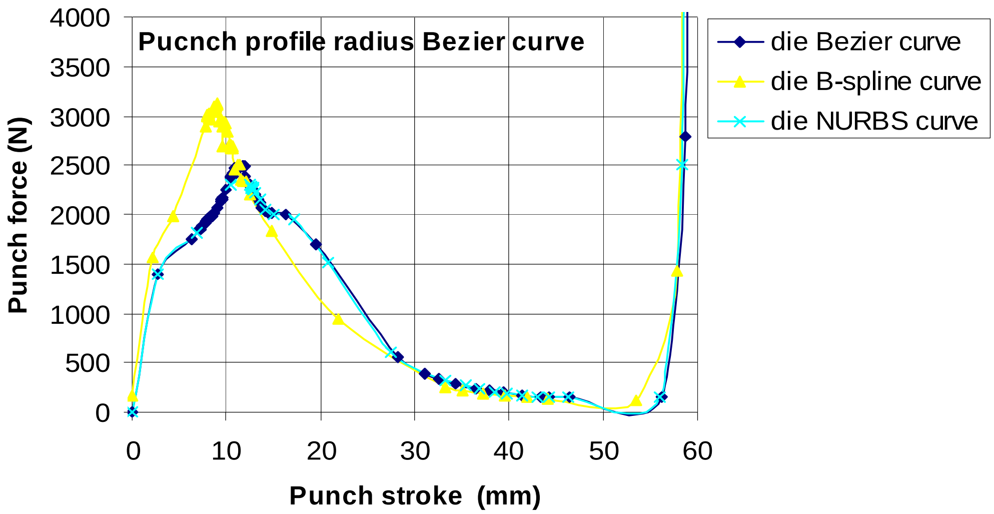

Figure (9) The effect of die profile on punch force

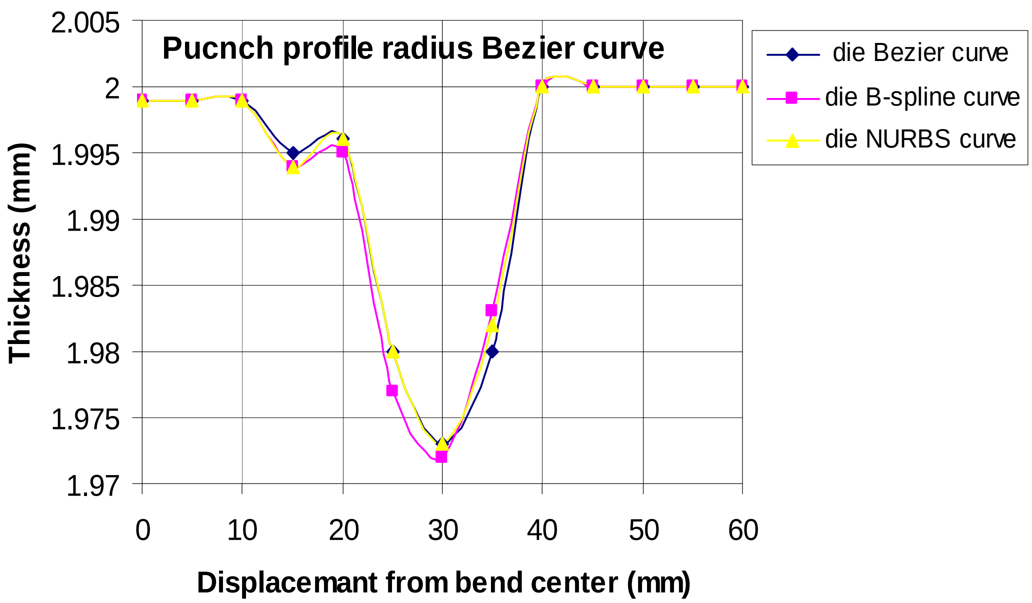

Figure (10) The effect of die profile on the wall thickness.

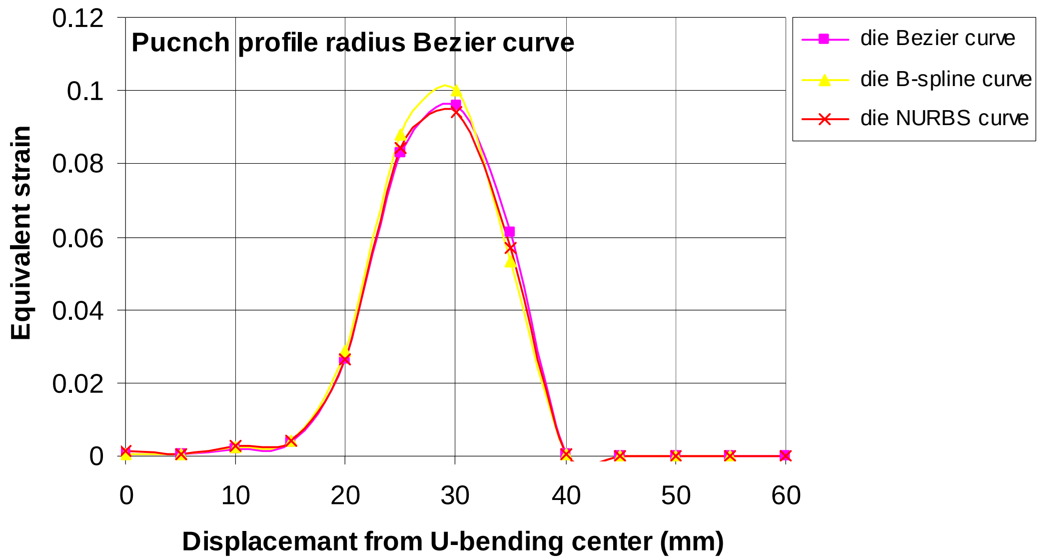

Figure (11) The effect of die profile on the equivalent strain.

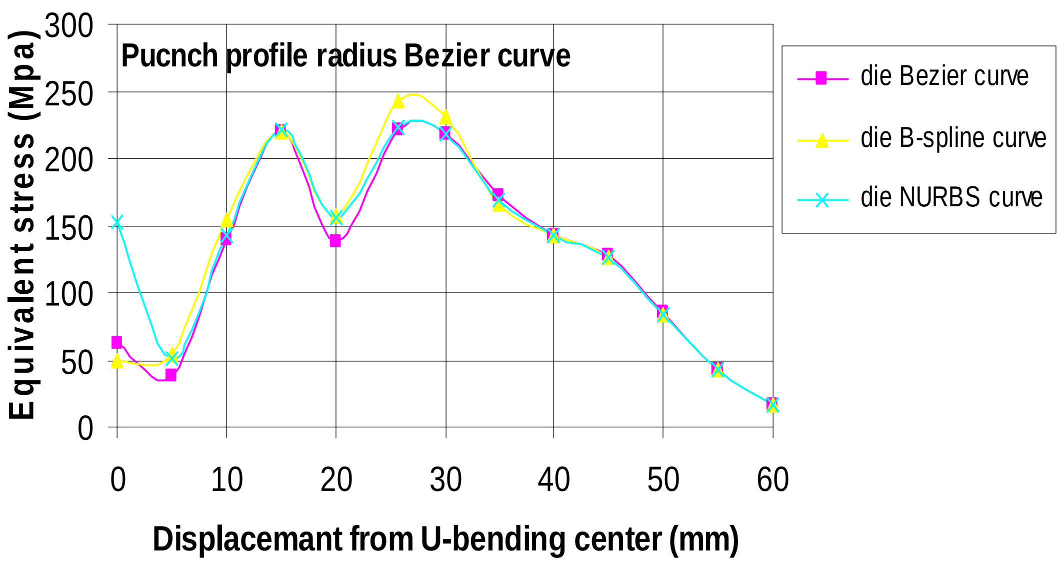

Figure (12) The effect of die profile on the equivalent stress.