Analysis of Non-Axisymmetric Stretch Flanging Process Through FEM Simulation

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Abstract*—FEM simulation of non-axisymmetric stretch flanging (NASF) process has been carried out by using commercial software package namely ABAQUS 6.14. Aluminum alloy 5052 H-32 sheets are selected as workpiece material. Blank holding force, amplitudes of forces and initial flange length are considered as process parameters for parametric study. Meshing of sheet metal is done by using four node shell type elements. It is found that peak radial strain and least circumferential strain (in negative direction) are found at punch center due to influence of blank holding force. Peak value of radial stress and von Mises stress are found at punch center while least circumferential stress found at punch center. Maximum radial strain and least circumferential strain are obtained for tabular varying amplitude at blank holding force of 600 N at punch center position as compared with other amplitudes and forces. Initial flange length has a profound influence on radial strain in contrast to circumferential strain.

***Keywords*—stretch, simulation, strain, flanging, blank holding force.**

I. INTRODUCTION

This template, Stretch flanging is major variations of flanging process. It is extensively employed in manufacturing of aircraft structures as well as in automotive industry. It has got two prominent variations namely stretch flange without also known as non-axisymmetric stretch flanging (NASF) and other one is the stretch flanging with hole, which is commonly named as hole flange forming. Both processes involve stretching phenomenon. Since past decades, these processes are readily investigated with more concentrated and focused efforts by employing both conventional forming and incremental forming technology.

In addition to this, hole flanging was explored through application of incremental forming in recent past. Donaire et al. [11] studied thoroughly about the effect of stress triaxiality on developed strain in hole flange formed by single point incremental forming. Chen et al. [12] observed a peculiar forming defect named after petal like neck formation during incremental forming of AISI 304 sheets and attributed this defect due to increment in Poisson’s ratio, friction coefficient ,sheet thickness and Modulus of Elasticity as well. Besong et al. [13] found that maximum hole expansion ratio through paddle forming is highest and after that achieved by single point incremental forming and least is obtained through conventional forming. Chen et al. [14] employed a novel concept of two point incremental forming during inclined hole flange forming. Borrego et al. [15] found strain developed around mid-height of flange is higher which results in longer and thinner flange through ingle point incremental forming as compared to conventional forming. Gandla et al. [16] investigated the influence of multistage strategies during hole flange forming through incremental approach of forming and found that surface roughness depleted with increment in stages of hole flanging and has no effect due to pre-cut hole diameter. Fernández et al. [17] applied the single point incremental forming technique in order to evaluate the formability of AA 2024- T-3 aluminum alloys sheets during stretch flanging to be applied in aircraft parts.

Stretch flanging of AA 5052 alloy which is extensively explored and investigated by Dewang et al. [18-25]. Kumar et al. [26-27] further investigated stretch flange forming of aluminum alloy and concentrated mainly on indentifying influence of punch geometries, crack formation and thinning behavior. Killi et al. [28] investigated the non-axisymmetric stretch flange forming by employing AA-6061-T6 sheets. Lin et al. [29] designated the threshold limits for angle of depression and elevation as 4.40 and 2.60 for avoiding phenomenon of crowing during stretch flanging of SUS stainless steel sheet for concave and convex punches respectively. The current work aims to investigate effect of blank holding force in conjunction with amplitudes as well as the influence of initial flange height during stretch flanging of aluminum alloy through numerical simulation.

II. MATERIALS AND METHODOLOGY

Selection of workpiece material and assignment of mechanical properties for numerical simulation is one of the significant steps. In the present work aluminum alloy AA 5052 H-32 is selected as workpiece material. Crucial important mechanical properties for numerical simulation of stretch flanging (NASF) process are given in Table 1. Material behavior of aluminum alloy 5052 H-32 is clearly depicted in Fig.1.Power law ($\sigma = K\epsilon^{n}$) is employed herein and quasi-static nature is employed for carrying out stretch flanging during numerical simulation.

Table 1	**Mechanical properties of AA 5052 H-32 [22]**		
	Mechanical property	***Magnitude***	***Unit***
1	Mass density(ρ)	2.68E-006	g/mm^3
2	Modulus of Elasticity(E)	70.3	GPa
3	Poisson’s ratio(μ)	0.33	nil
4	Strength at yield point (σ_y)	193	MPa
5	Ultimate tensile strength (σ_{ult})	289.51	MPa
6	Strength coefficient(K)	368.71	MPa
7	Strain hardening exponent (n)	0.1325	nil

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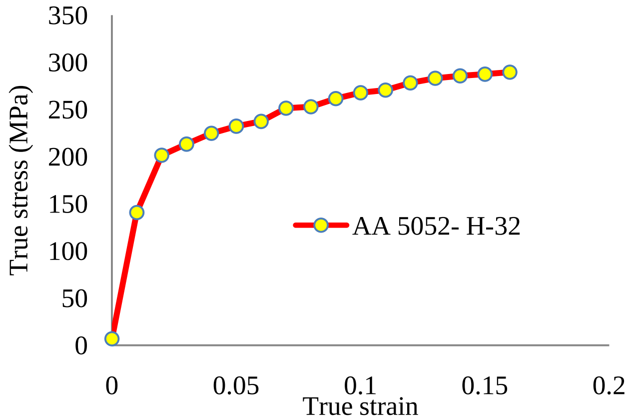

Fig. 1. Relationship of true-stress versus true strain for AA 5052 H-32[22]

III. NUMERICAL SIMULATION OF NON-AXISYMMETRIC STRETCH FLANGING (NASF) PROCESS

Numerical simulation of NASF process is performed in ABAQUS 6.14. Fig.2 gives the detailed FEM model of NASF process. Tool elements of the FEM model namely, die, punch, blank-holder are discretized through R3D4 discrete rigid elements. Sheet metal workpiece is discretized by 4 node shell type elements (S4R).FEM simulation of NASF process is conducted with ABAQUS dynamic explicit approach to model the effects of quasi-static approach which matches quite well with strain rate of 10 mm/min. Surface to surface contact interactions are assigned between the pairs of blank-holder-sheet, die- sheet- and punch-sheet.

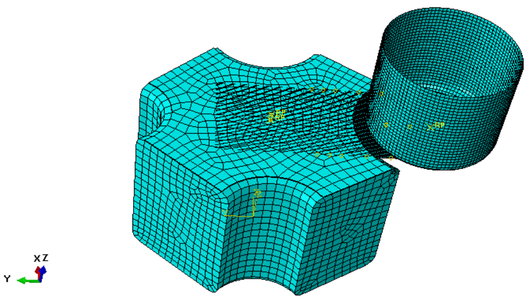

Fig.2. FEM model of NASF process [22]

In each interaction pairs master surfaces are tools surfaces and sheet is considered as slave surface. Friction coefficient is assigned as 0.1 for contacting pairs. Die is made fixed while blank holder is made free to move in vertically downward to track variation in sheet thickness. Punch is made constrained in initial step while it is given displacement in downward direction to form the stretch flanges. Free meshing technique is employed for meshing tool elements while structured mesh is selected for sheet metal blank after conducting mesh convergence analysis. Finally job is prepared and submitted for analysis and then post-processing is carried using ABAQUS plug-ins and utilities. Constant blank holding force of 600 N is applied and two other blank holding forces are applied with two different amplitudes as given in figure 3.Besides this, effect of initial flange length is also investigated through FEM simulation of NASF process.

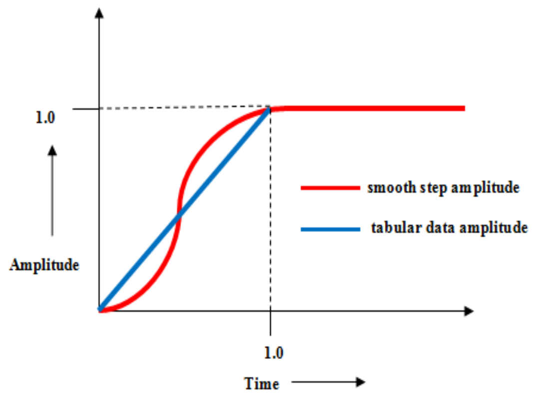

Fig.3. Definition of amplitudes of blank holding forces [30]

IV. RESULTS AND DISCUSSION

A. *Influence of constant blank holding force*

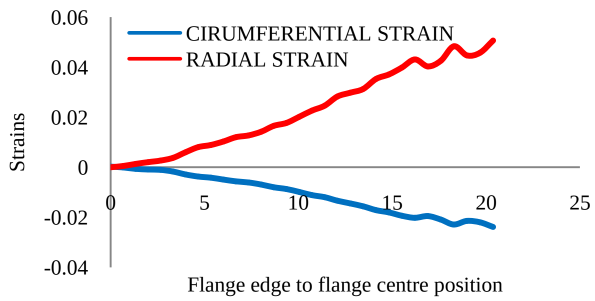

Fig. 4. Components of strain in NASF process

Figure 4 shows the distribution of circumferential strain as well as radial strain along free edge of stretch flange up to the punch centre. Circumferential and radial strain found to be varying non-linearly along free edge of sheet up to punch center. Peak radial strain and least circumferential strain (in negative direction) are found at punch center. Non-linear pattern of increment is also observed for distribution of radial stress and von-mises stress along free edge of flange up to punch center as shown in figure 5. Circumferential stresses (hoop stress) are also found to vary non-linearly along negative y-direction with least radial stress at punch center. Peak intensity of radial stress and von Mises stress are found at punch center.

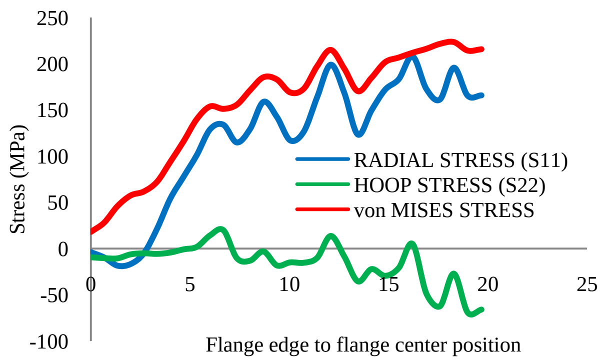

Fig. 5. Stress components distribution in NASF process

B. Combined effect of amplitude and blank holding force

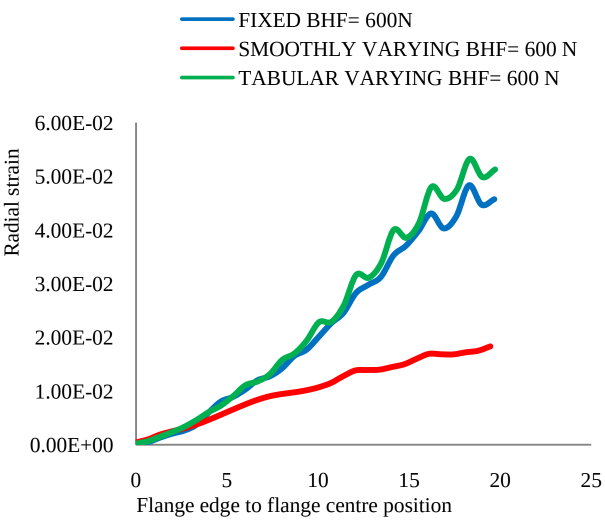

Fig. 6. Influence of blank holding force with amplitudes on radial strain

Figure 6 depicts combined influence of amplitudes with blank holding force. Constant blank holding force with smooth type and tabular type amplitudes were employed to investigate the influence on radial and circumferential strain induced in stretch flange. It is gathered from figure 6 that due to influence of blank holding force, strain in radial direction varies non-linearly along free edge upto punch centre. Peak strain in radial direction is gathered for tabular varying amplitude at blank holding force of 600 Newton at flange centre position in contrast to other blank holding forces with amplitudes.

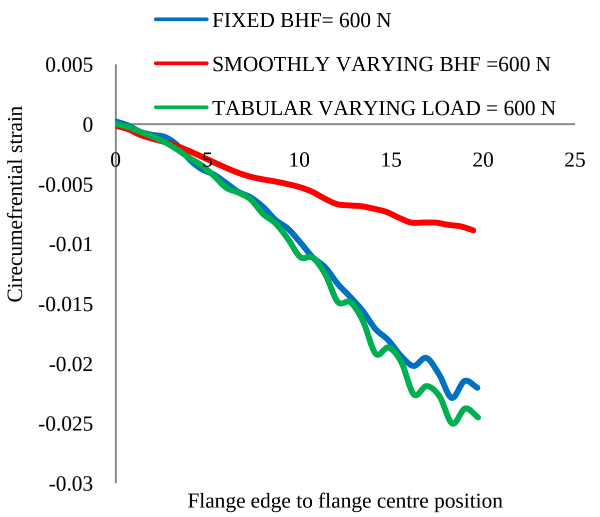

Fig. 7. Influence of blank holding force with amplitudes on circumferential strain

This is also seen from figure 7 that circumferential strain varies non-linearly along negative y-axis due to combined influence of blank holding force and amplitudes. Tabular varying amplitude with blank holding force of 600 N gives least circumferential strain with negative values at punch centre position.

C. Influence of initial flange height

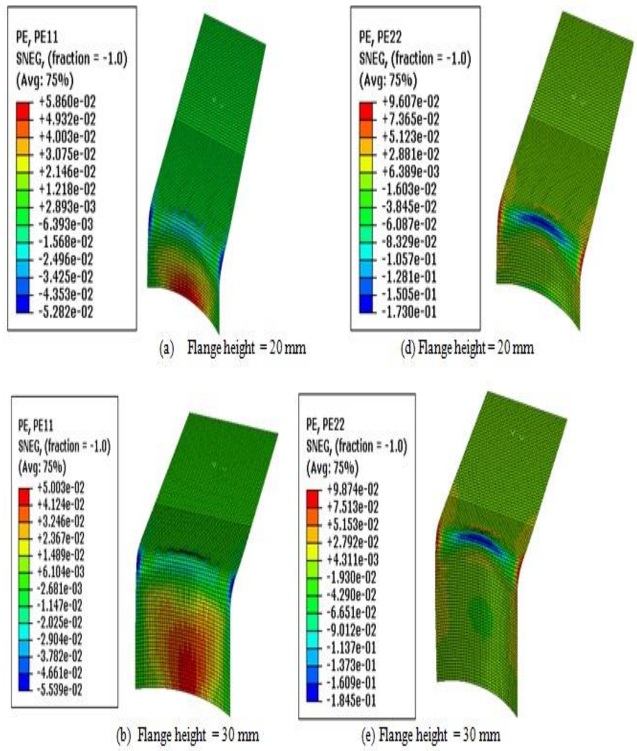

Fig. 8. Influence of flange height on radial strain (a-c)

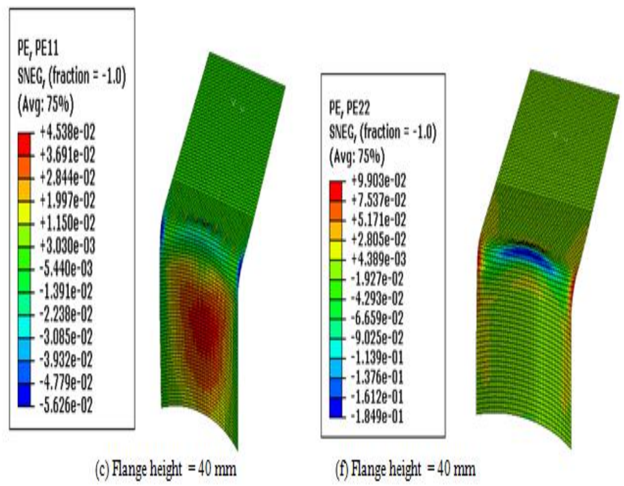

Fig.9. Influence of flange heighton circumferential strain (d-f)

Figure 8 shows the effect of initial flange height on the radial strain induced in the stretch flange. It is found that radial strain decreased by 22.5 % nearly with increment in initial flange from 20 mm to 40 mm. It is also gathered that circumferential strain increased by nearly by 3 %. This implies that initial flange height has significant effect on radial strain as compared to circumferential strain.

V. CONCLUSIONS

FEM simulation of NASF process has been conducted by using commercial software package namely ABAQUS 6.14. Influence of blank holding force, amplitudes of forces and initial flange height were investigated in the present work. The following are the important findings after FEM simulation of NASF process:

i. Peak radial strain and least circumferential strain (in negative direction) are found at punch center due to effect of constant blank holding force.
ii. Peak intensity of radial stress and von Mises stress are found at punch center while least circumferential stress found at punch center.
iii. Maximum radial strain and least circumferential strain are obtained for tabular varying amplitude at blank holding force of 600 N at punch center position in contrast to other blank holding forces with amplitudes.
iv. Flange height has a profound influence on radial strain in contrast to circumferential strain.

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