EXPERIMENTAL INVESTIGATIONS ON EFFECT OF PROCESS PARAMETERS DURING AIR BENDING OF INTERSTITIAL FREE STEEL SHEET

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ABSTRACT

This work aims at studying the effect of major parameters, namely, punch velocity (v_p), punch radius (r_p) and width of the sheet (w) with respect to material orientation to the rolling direction on air bending process of Interstitial Free (IF) steel sheets. An experimental work has been employed to analysis the sheet metals on bend force, springback and bend angle. It is observed that punch load increases as punch radius, punch velocity and width of the sheet increase. It is generally found that the springback exhibited a polynomial relationship with the punch travel. From the results, it is noted that, increase in the punch radius, punch velocity and decrease in width of the sheet increases the bend angle. The angle of springback decreases with increasing punch radius, width of the sheet and decreasing punch velocity.

Keywords: Air bending, IF steel, Springback

1. Introduction

Bending is one of the most common forming operations. The components made out of bending are innumerable and very common examples are metal cabinets of appliances and computer, steel desks automobile components. Air bending process is the most commonly used bending process because of its flexibility and reduction in punch load. The understanding of bending mechanism is crucial for controlling the process for maintaining the shape of the products made by bending. Since all materials have a finite modulus of elasticity, when the load is removed, elastic recovery follows the plastic deformation, which is called springback. It is a complex phenomenon which depends upon material properties (ultimate strength and Young's modulus), geometrical properties (width of sheet), process parameters (punch velocity, punch travel) and surface properties.

In the recent years, the trend of applying materials such as aluminum, steel, brass to automobile components has emerged due to their light weight to strength ratio. The sheet material used in this investigation is Indian Interstitial Free steel owing excellent formability. Vacuum degassed steels [1] containing very small amounts of titanium and niobium are known as interstitial free steels. Since these additions combine with interstitially dissolved atoms of carbon and nitrogen and form separate precipitates of TiC, TiN and NbCN, no carbon or nitrogen remains in ferrite solid solution. The product has very low yield stress combined with a high ductility. Considerable investigations have suggested the importance of considering the orientation in sheet metal forming. The bending angle and punch profile radius significantly effects the springback behavior [2]. The springback varies with even a small change in punch profile radius. The punch velocity and width of the sheet play a significant impact on the bend angle [3].

Various investigations of bending show that process parameters such as bend radius, die gap, punch velocity and material properties have considerable influence on springback/bend force.Some of the recent developments in this field have been depicted in this paper. A simple approach for calculating bendability and springback in bending based on the normal isotropic value, strain hardening exponent and sheet thickness has been presented as described elsewhere [4]. You-Min Hang et al. [5] described effects of process variables like punch radius, die radius, punch speed, friction coefficient, strain hardening exponent, normal anisotropy on V-die bending process of steel sheet. Aleksy. et al. [6] conducted experiments on springback for dual phase steel and conventional high strength steel for a hat channel section with varying cross sections. They described the methodology of

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experiments and discussed springback related results. Draw bend test for various die radii, friction coefficients and tensile forces was conducted by Cardeen [7]. Perduijn et al. [8] derived a simple explicit bending couple curvature relation for small and larger curvatures and they verified the model with experimental results**.** Livatyali et al. [9] presented experimental investigation to determine the influence of die corner radius, punch radius, punch – die clearance, pad force and sheet material on springback in straight flanging. The accuracy of modifications of the algorithms was verified by experimental results. Zafer Tekiner[10] examined the springback of sheet metals with various thicknesses and properties in bending dies. Carlos Gomes et al.[11] investigated the variation of springback in high strength steels based on experimental and numerical analysis. Ozgur Tekaslan et al. [12] carried out the experiment to determine springback of steel sheet with V-shaped die. Hyunok Kim et al. [13] proposed an analytical model to predict springback and bend allowance simultaneously in air bending process.

The present investigation is motivated by the lack of literature available on effect of process parameters namely, punch travel, punch radius, punch velocity and width of the sheet for larger curvature bending $\left({}^{R_c}\!/_{t} \geq 5 \right)$ behavior of Indian IF steel sheets. Most of the earlier studies have been made on smaller curvature bending $\left({}^{R_c}\!/_{t} \leq 5 \right)$ to explore various parameters on springback during air bending process.

2. An Experimental Approach

2.1 Experimental Procedure

The chemical composition of Indian IF steels used in the analysis are given in **Table 1.**

Table 1 Chemical Composition of IF Steel (in wt %)

C	0.0035
Mn	0.4
Si	0.008
S	0.007
P	0.044
Al	0.045
N	35
Ti	0.04
B	0.0008
Nb	0.001
Fe	Rest

The dimensions of test samples were (120mm x 40mm x 1.2mm and 120mm x 60mm x 1.2mm). The samples were prepared in three orientations (0^0,45^0 and 90^0) from the cold rolled and annealed sheet as per the ASTM standards. The stock from which blanks were cut must be flat enough so that the blanks could be properly inserted into the tooling and remain in position during forming. The samples were cleaned thoroughly to remove the dust and rust by wiping the samples prior to bending. The experiments were performed in a Universal Testing Machine (UTM) and the experimental setup consisted of a die and a punch of hardened steel. The die was mounted on the fixed platform provided on the UTM. The punch was mounted above the die on the movable head of the UTM. The center axis of the punch coincided with the die. The sample was located in proper position over the die with extreme care. The load was applied gradually and depth was given in incremental steps to deform the sheet. Three different punch radii of 8, 10 and 12mm were used in the bending trials. The bend angle was determined by the punch travel. Three different punch velocities of 0.3577mm/s,0.606mm/s and 0.802mm/s were selected for the experiments by adjusting the knob in the UTM. The tooling geometries and process parameters used in the experiments are listed in Table 2.

Table 2Tooling Geometries and Process Parameters

Die radius (r_d) in mm	5
Die opening (w_d) in mm	60
Punch radius (r_p) in mm	8, 10 and 12
Punch width (w_p) in mm	90
Strip dimensions $(L \times b \times t)$ in mm	120 x 40 x 1.2 120 x 60 x 1.2
Orientations of the sheet	0^o,45^o and 90^o
Punch travel (d) in mm	0 – 30
Punch velocity (v_p) in mm/s	0.3577,0.606 and 0.802

The tooling arrangement used in the experiments is shown in Fig .1.

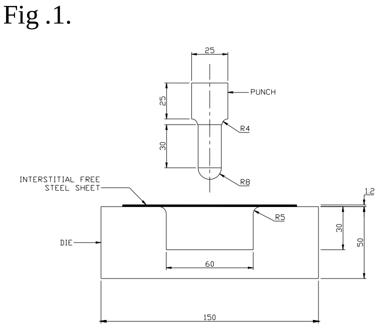


Fig1. Schematic Diagram of the Experimental Setup

The photographs of deformed samples of various widths are shown in Fig.2.

Fig.2. Photographs of Deformed Samples of Different Widths(I^{st} row-0^0,II^{nd} row-45^0,III^{rd} row-90^0)

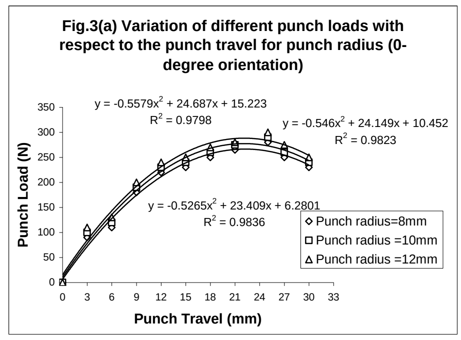
The punch load for bending and punch travel was recorded from the dial indicator and digital meter of UTM respectively. The larger edge of the bent sample was coated with black ink and the impression of the bend profile was taken on a white paper. Then the load was removed and again the impression of the profile was taken. The impression images were scanned and digitized. The angles of the digitized images were measured using CAD software [7]. The difference between bend angles $(\theta_1 \approx \theta_2)$, when the sample was subjected to load (θ_1) and after removal of load (θ_2) gives the springback angle. The above steps were repeated for each incremental punch displacement until the total depth was reached. For the springback measurement, ten values were taken for each orientation conditions.

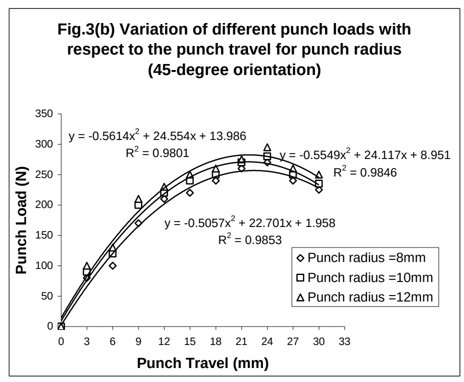
3. Experimental Results And Discussion

Several experiments were performed with combination of process variables and the results were depicted in graphs. The parameters considered for analysis are part geometry (width of the sheet), bending tool geometry (punch radius) and process parameter (punch velocity). The analysis provides an insight about the effects of process variables on punch load, bend angle and springback behavior. The curves in the graphs are least square fits with the slopes indicated appropriately. For curves in graphs second order polynomial equation was adopted. The correlation coefficient,R^2, values are so close to 1 that shows the reliability of the results.Springback values in bending is positive for all the cases.

3.1 Effect of Punch Radius

To facilitate discussions, results from the three orientations with respect to punch radius of constant punch velocity are presented here.





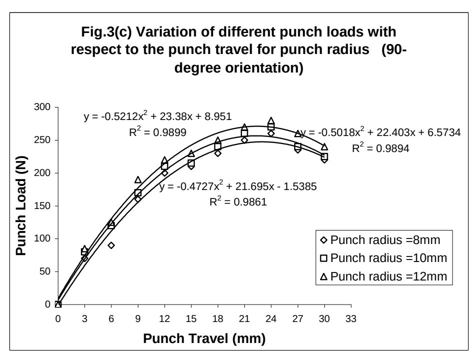
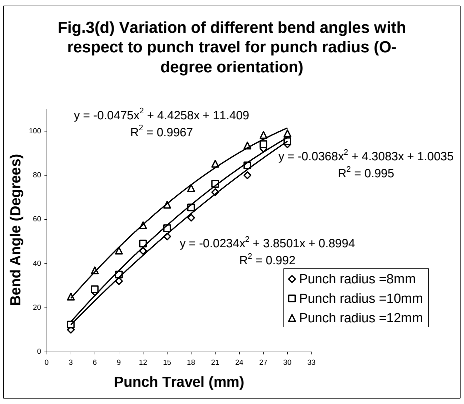
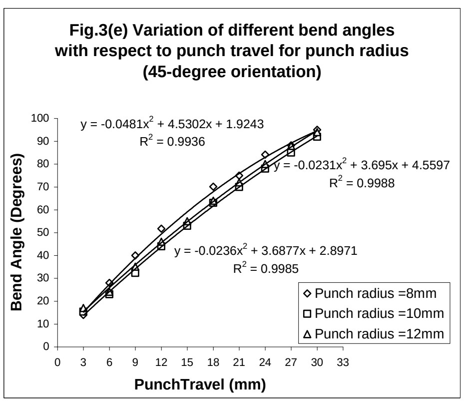
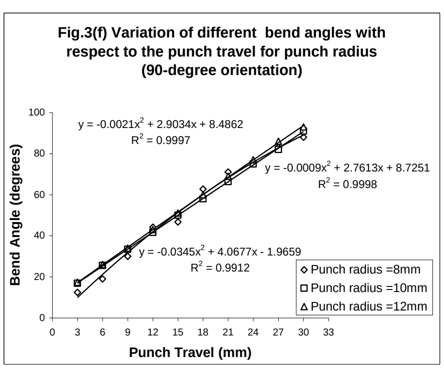


Fig. 3 (a)-(c) have been drawn for different punch radius like 8mm, 10mm and 12mm between the punch load and punch travel provided punch velocity is kept constant.

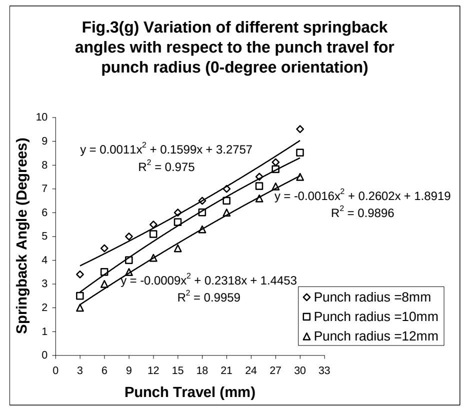
Bending load is comparatively smaller for 8mm punch profile radius. This is due to the better leverage when the radius is small. Punch load behavior is similar for all the punch radii irrespective of orientations. It is observed that the punch load increases when the punch radius increases [5].It is to be noted that the effect of punch radius is not significant on punch load for low ranges of punch travel. It is thus seen that the influence of punch radius becomes stronger only at larger punch travel. The punch load decreases after reaching a particular punch travel in the various punch radius investigated.

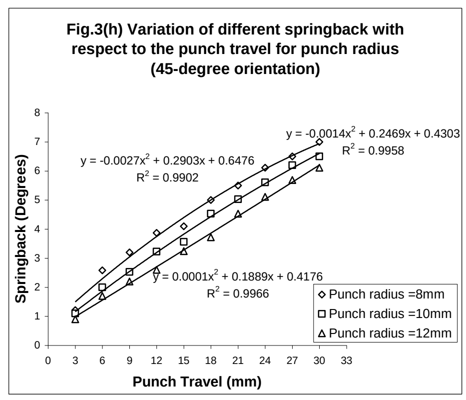






From the graphs Fig. 3 (d)-(f), it is noted that the punch travel versus bend angle under loading curves show a polynomial for different punch radii irrespective of orientations. The punch radius 12mm has make higher bend angle than 8mm punch radius. From these plots it is observed that the bend angle is dependent on punch radius.





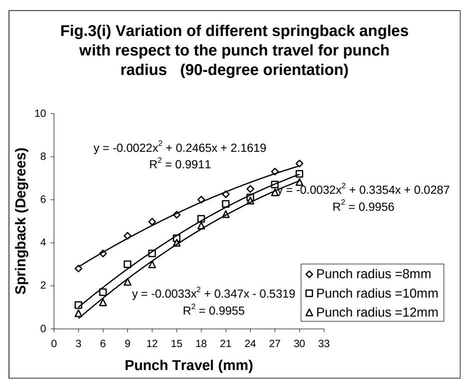


Fig. 3 (g) - (i) gives a graphical relation of the three orientations with punch radius on springback provided punch velocity is kept constant. When considering the effect of punch radius on springback, it is greater for smaller punch profile radius for all the cases studied for a constant velocity. It is due to the higher local straining level obtained when punch radius decreases [3]. The effective stress area under the punch profile is a considerable factor governing the magnitude of the springback. This is due to decrease in transverse stress gradient because of work hardening as per Ref [11]. From the discussion, it can be seen that the springback varies inversely with punch radius. The springback is reduced significantly when punch radius 12mm is used.

3.2 Effect of Punch Velocity

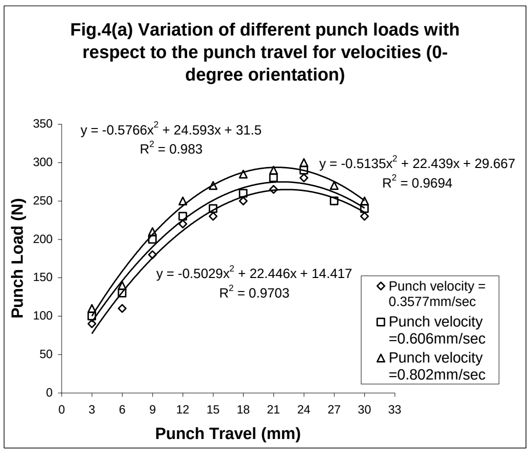


Fig.4(a) Variation of different punch loads with respect to the punch travel for velocities (0-degree orientation)

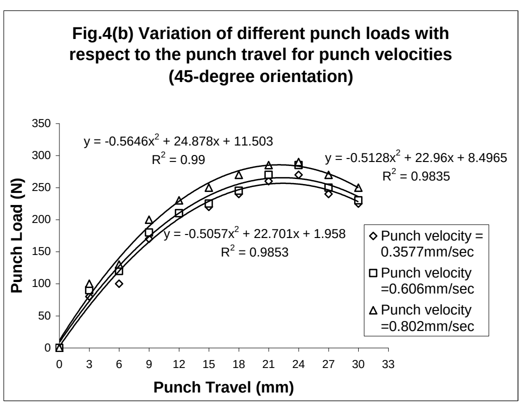


Fig.4(b) Variation of different punch loads with respect to the punch travel for punch velocities (45-degree orientation)

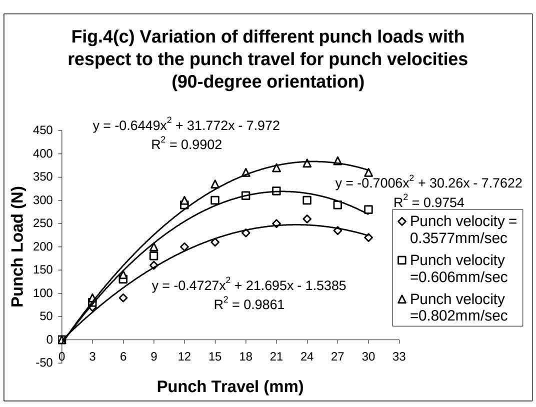


Fig.4(c) Variation of different punch loads with respect to the punch travel for punch velocities (90-degree orientation)

Fig. 4 (a)-(c) show that the punch load is higher for higher punch speeds (v=0.802mm/s). This similar behavior has been observed for all orientations tested. For a particular speed, the punch load increases with punch travel up to certain point and then decreases. The punch load increases when the punch velocity increases [5] due to the reason that the IF steel has a positive strain rate sensitivity.

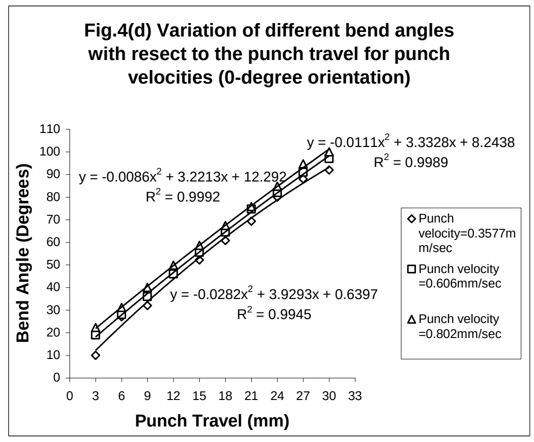


Fig.4(d) Variation of different bend angles with resect to the punch travel for punch velocities (0-degree orientation)

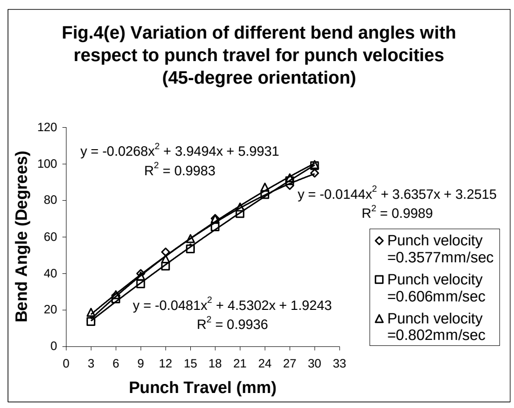


Fig.4(e) Variation of different bend angles with respect to punch travel for punch velocities (45-degree orientation)

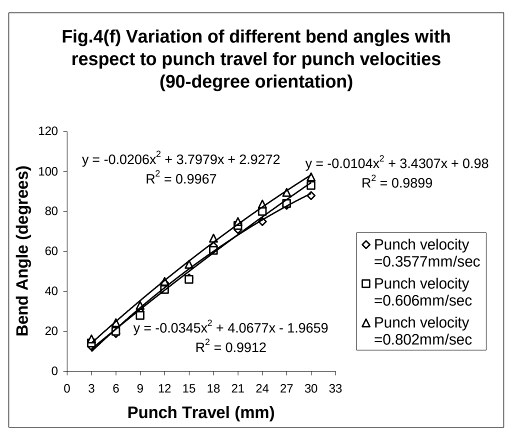


Fig.4(f) Variation of different bend angles with respect to punch travel for punch velocities (90-degree orientation)

Fig. 4 (d)-(f) show the variation of different bend angles with respect to the punch travel for three orientations provided punch radius is kept constant. The punch travel versus bend angle graphs shows a polynomial relationship for all the velocities irrespective of the orientation with the correlation coefficients greater than 0.98.

Fig.4(g) Variation of different springback angles with respect to the punch travel for punch velocities (0-degree orientation)

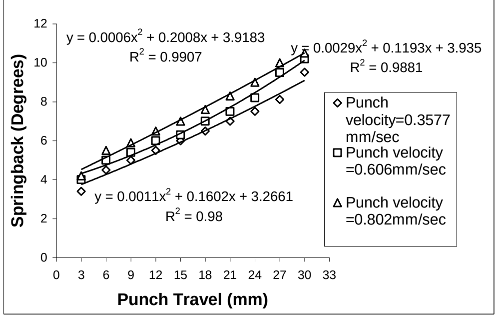


Fig.4(h) Variation of different springback angles with respect to punch travel for punch velocities (45-degree orientation)

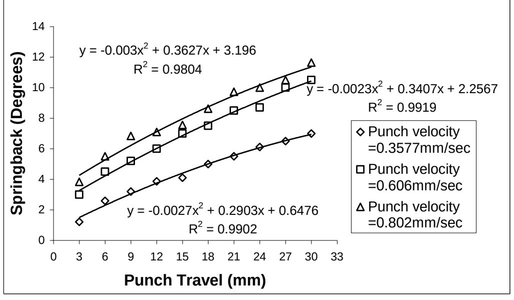
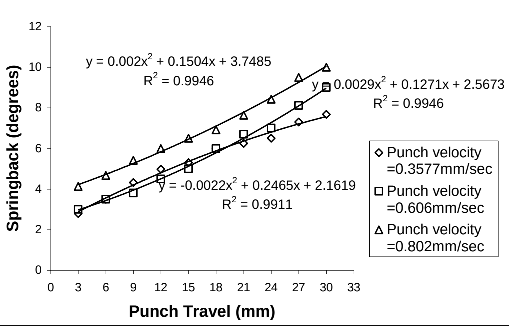


Fig.4(i) Variation of different springback angles with respect to the punch travel for punch velocities (90-degree orientation)



From the Fig. 4(g)-(i), it is clear that increase in punch velocity leads to increase in spring back. According to the data, from the graph, keeping 0.3577mm/s on the sheet provides reduction in springback angles for all three orientations. The bending with high punch velocity increases the amount of elastic recovery in IF sheet and induces larger springback.

3.3 Effect of Width of the Sheet

Fig.5(a) variation of different punch loads with respect to the punch travel for widths(0-degree orientation)

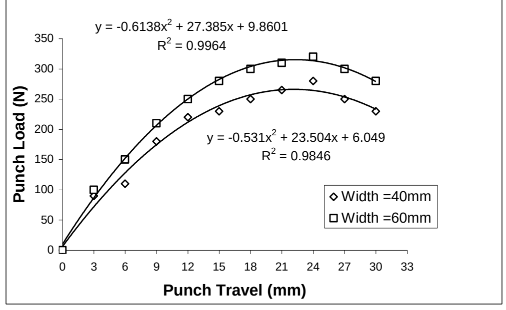


Fig.5(b) Variation of different punch loads with respect to the punch travel for widths (45-degree orientation)

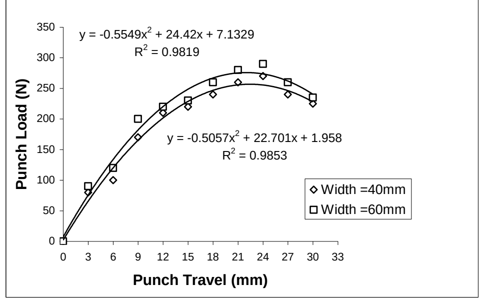
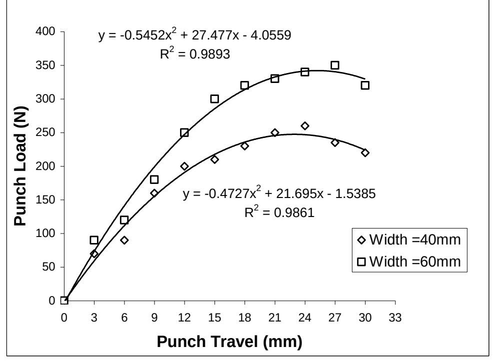


Fig.5(c) Variation of different punch loads with respect to the punch travel for widths (90-degree orientation)



It is observed from Fig. 5 (a)-(c) that the punch load increases when the sheet width increases provided punch radius and punch velocity are kept constant. The nature of curve is identical for different width. At the initial stage of punch travel, the punch load curve suddenly increases, after that gradually increases.

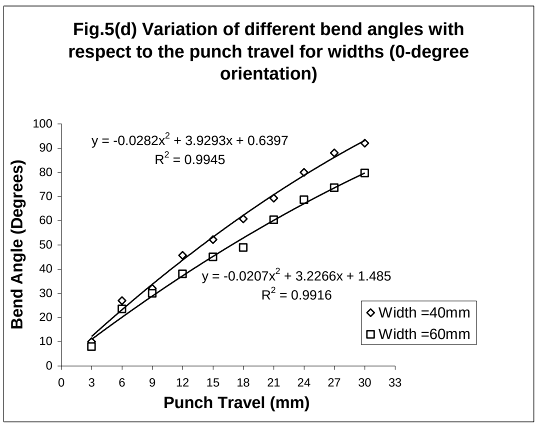


Fig.5(d) Variation of different bend angles with respect to the punch travel for widths (0-degree orientation)

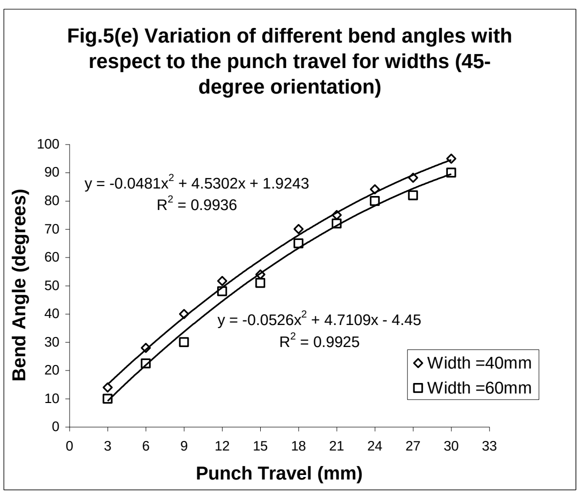


Fig.5(e) Variation of different bend angles with respect to the punch travel for widths (45-degree orientation)

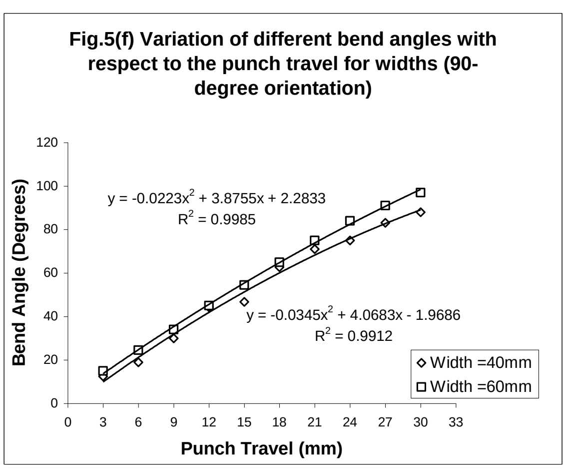


Fig.5(f) Variation of different bend angles with respect to the punch travel for widths (90-degree orientation)

Fig.5 (d) - (f) depict the bend angle as a function of the punch travel. These plots are similar in nature irrespective of the orientations. It is observed that the bend angle is larger for smaller width and bend angle varies with respect to punch travel.

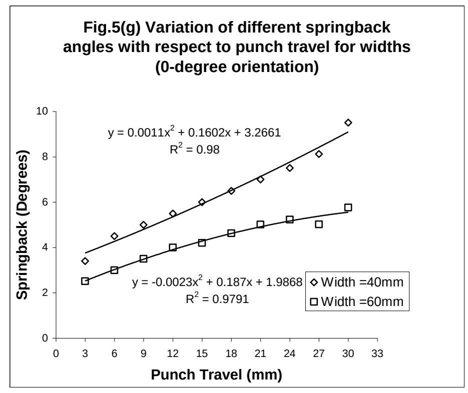


Fig.5(g) Variation of different springback angles with respect to punch travel for widths (0-degree orientation)

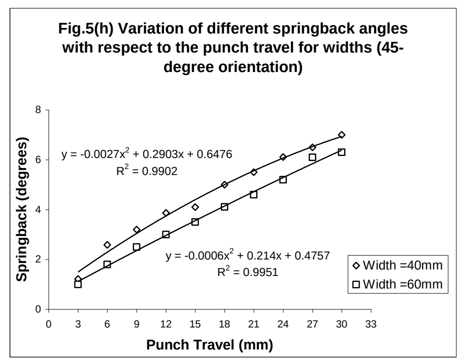


Fig.5(h) Variation of different springback angles with respect to the punch travel for widths (45-degree orientation)

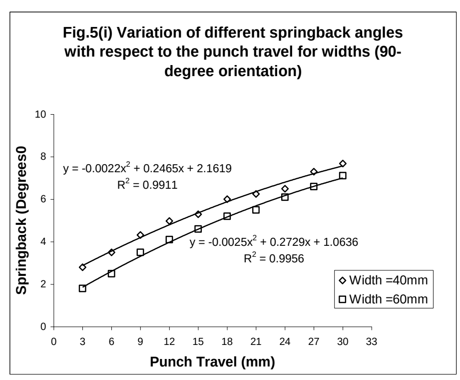


Fig.5(i) Variation of different springback angles with respect to the punch travel for widths (90-degree orientation)

The effect of punch travel on the springback can be seen in Fig. 5 (g)-(i). Irrespective of orientations, when the width increases, the springback decreases.

4. Conclusions

A large number of experiments were performed and detailed observations were carefully made in this study of air bending in the IF steel sheets. The following conclusions were drawn from the present investigation:

1. The punch radius and punch velocity effect the punch load, bend angle and springback. The punch load increases with increase in

punch radius, punch velocity and width of the sheet.

2. Increasing punch radius, punch velocity and decreasing width of the sheet increases bend angle.
3. Considering springback, it varies inversely with punch radius, width of the sheet and directly with punch velocity.
4. This study has improved the understanding of the air bending process of IF steel and provides a base for choosing appropriate press machines and designing dies.

5. References

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Nomenclature

w_p	Punch Width	mm
r_d	Die Radius	mm
r_p	Punch Radius	mm
R_c	Radius of curvature	mm
L	Length of the sheet	mm
d	Punch Travel	mm
t	Thickness of the Sheet	mm
v_p	Punch Velocity	mm/s
w	Width of the Sheet	mm
w_d	Die Opening	mm
θ_s	Springback Angle $(\theta_1 \approx \theta_2)$	Degrees
θ_1	Bending Angle before Springback	Degrees
θ_2	Desired Bending Angle after Springback	Degrees