EFFECTS OF LUBRICATION ON AIR BENDING PROCESS OF INTERSTITIAL FREE STEEL SHEET USING DIFFERENT LUBRICANTS

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Abstract

In this investigation, the experiments were performed to analyze the effect of lubrication on the air bending of Interstitial Free (IF) steel sheet with two different lubricants namely SAE30 oil and white grease. The various lubricating conditions namely die only; punch only, punch and die were employed. As expected, the punch load decreases when lubricant is employed. Further, the lubrication increases the springback significantly when it is applied on die only and both punch/die. The results of the analysis highlight effectiveness of lubrication and thereby helping to enhance the process.

Key words: Bending, IF steel, Lubricants, Springback

I. INTRODUCTION

Sheet metal bending is one of the important manufacturing processes in the metal forming technology. Aircraft, Automobile Industries and Electrical Industries depend largely on sheet metal forming processes for manufacturing components. The popularity of sheet metal products is attributable to their lightweight; good surface finish and low cost. In press-brake forming, a flat sheet is placed over a die and a punch is lowered into the sheet to form the bend. In air bending, the required angle is produced on the workpiece by adjusting the depth to which the punch enters the die opening. This permits the punch to over bend the metal sufficiently to produce the required angle after springback. The main advantage of the air bending process is the variety of forming that can be done with a minimum number of punches and dies. It also requires less force for a given bend, thus preventing excessive strain on the press brake.

The sheet material used in this investigation is Indian Interstitial Free (IF) steel owing excellent formability. Vacuum degassed steels [1] containing very small amounts of titanium and niobium were 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.

In the metal forming industries, the knowledge and proper control of the springback after forming are the fundamental aspects in the achievement of near-net-shape parts. Springback refers to the change in the shape of the sheet geometry after the load has been removed. It is one of the key factors influencing the quality of sheet metal manufacture. It is encountered in all forming operation, but it is most easily recognized and studied in bending. It leads to major problems during the assembly and it complicates the die design process. Bend force analysis is another important issue for sheet metal manufacture to evaluate the desired bend of a product. The maximum external bending moment generally depends on the type of bending and the bending geometry. The bend force and springback depend on sheet material properties (thickness of the sheet, strain hardening exponent, strength coefficient, tensile strength), the tool geometry (punch radii, die radii, die opening) and process parameters (bending angle, punch travel and the lubrication).

The functions of lubrication are reducing the deformation load, increasing limit of deformation before fracture, minimizing metal pickup on tools, minimizing tool wear, thermally insulating the workpiece / tool and cooling the workpiece/tool interface. The main purposes of a lubricant are to prevent die galling, die wear and to reduce the friction over critical areas. The lubricant adhesion and type of lubricant greatly influence the co-efficient of friction, thereby the springback and punch load. The selection of lubricant depends on part geometry and the bending process. No single lubricant is optimal for all types and rates of bending and all combinations of work and die materials. Rankings of lubricants change considerably for different types of operations and material combinations, this necessitates evaluation in an individual basis. Since the lubrication is an important factor in the bending process, an analysis of the effect of lubrication on the bending process is essentially required.

Reviewing the literature, it is found that researchers have been studying the bending behavior and the phenomenon of springback for nearly four decades. Daw-Kwei presented a simple approach for calculating bendability and springback in bending (2). You-Min Hang et al. described effects of process variables such as punch radius, die radius, punch speed, friction coefficient, strain hardening exponent, normal anisotropy on V-die bending process of steel sheet(3). Aleksy et al. conducted experiment of springback for dual phase steel and conventional high strength steel for a hat channel section with varying cross sections(4). Carden et al. conducted draw bend test for various die radii, friction coefficients and tensile forces (5).Perduijn et al. derived a simple explicit bending couple curvature relation for small and larger curvatures and they verified the model with experimental results (6).Vallance et al. studied the friction behavior of zinc-based coated sheet steels and laboratory scale friction analysis techniques that involve sheet sliding over cylindrical dies are considered (7). Sanchez focused on a systematic analysis of testing equipment as a measurement system of the friction phenomena on sheet metal under plane strain (8). It provides experimental references in order to optimize the usage of lubricants and sheet metal.Wenzloff et al. introduced a new test procedure for the bending under tension friction test (9). Mary Gotzinger et al. proposed a prediction method based on the geometry and applied in both the laboratory and manufacturing environment (10). Ihab Ragai et al. discussed the effect of sheet anisotropy on the springback of stainless steel 410 draw bend specimens and lubrication(11).

Most of the earlier studies have been made to explore various parameters during air bending process. The present work is motivated by a lack of literature available on effect of lubrication on bending behavior of Indian IF steel sheet. The purpose of this paper is to report on an experimental study of the influence of lubricants and lubrication on punch load and springback of the IF sheet in an air bending process.

II. EXPERIMENTAL WORK

Several experiments were undertaken in order to determine the effects of lubricant (Dry, SAE30 and White grease) and lubrication (punch only, die only, both punch and die), on the bending behavior of IF steel sheet in the air bending process.

A. Chemical Composition and Tensile Test

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 (ppm)	35
Ti	0.04
B	0.0008
Nb	0.001
Fe	Rest

The chemical composition of the sheet metal was found out and listed in Table 1. They have excellent workability and mechanical properties due to the presence of alloying elements such as Mn and Si. The details of the mechanical properties are given in the Table 2. To determine the mechanical properties, namely the strain hardening exponent, strength coefficient , yield strength, ultimate tensile strength, plastic strain ratio ,tensile tests were conducted using an Instron testing machine. Using the equation s = K (where s is True stress, e is True strain), the strain hardening exponent and strength coefficient were determined.

Table 2. Tensile Test Data of IF Steel of Thickness 1.2 mm

Test property/ Units/ Notation	Test value
Strain Hardening Exponent (n)	0.310
Strength Coefficient MPa (K)	628.7
Yield Strength MPa (σ_y)	267
Ultimate Tensile Strength MPa (S_{ut})	322.2
Plastic Strain Ratio (r)	1.15
Young's Modulus GPa (E)	207

B. Lubricants

Effective lubrication results in controlled friction with resulting reduction in bend force and power requirements for tooling stresses (punch/die) and deflection. Proper lubricant can reduce tool wear and increase product quality through the elimination of surface damage and residual stresses. Table 3 shows technical properties of SAE30 oil.

Table 3. SAE30 oil Technical Properties

Kinematic Viscosity @ 100°C, cSt	10.6
Kinematic Viscosity @ 40°C, cSt	67.0
Viscosity Index	146
Pour Point °C	-39
Flash Point °C	236
Fire Point °C	256
Total Base Number	8.4

In general, grease is petroleum or synthetic lubricating fluid oil that has been thickened by a solid or semisolid dispersion, commonly clay or soap. The additives are used to enhance grease performance properties. The technical properties of white grease are presented in the Table 4.

Table 4. White Grease Technical Properties

Appearance and Odor	White colour Grease, Petroleum like odor
Solubility	Insoluble
Physical state	Paste
Evaporation rate	0
Boiling Point °C	315
Melting point °C	190
Specific gravity	0.9
Flash point °C	225

C. Experimental Procedure

The material selected for this study was Interstitial Free Steel sheet. The dimensions of test samples were (120mm x 40mm). For all of the experiments, the sheets were 1.2mm thick.

The experiments were performed in a Universal Testing Machine (UTM) and the experimental setup consisted of a die and punch made 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 alignment of the tool geometry under both loading and unloading conditions was verified systematically.

The sample was located in proper position over the die with extreme care. The punch travel was stopped after a total depth of 30mm was reached. For lubricated experiments, lubricant was applied on punch or die or on both and the lubricants used were SAE30 and white grease. The punch and die surfaces were deoiled or degreased after each experiment. Fresh lubricants were supplied for each experiment. Lubricated bending tests were performed at room temperature with a humidity of. The bend angle considered in this investigation is bending angle after unloading.

The tooling geometries and process parameters used in the experiments are listed in Table 5. The tooling arrangement used in the experiments is shown in Fig 1.

Table 5. Tooling Geometries and Process Parameters Used

Die radius (r_d) in mm	5
Die opening (w_d) in mm	60
Punch radius (r_p) in mm	8
Punch width (w_p) in mm	90
Sheet material	Interstitial Free Steel Sheet
Strip dimensions $(L \times w \times t)$ in mm	120 x 40 x 1.2
Orientations of the sheet	0°
Punch travel (d) in mm	0 – 30
Punch velocity (v_p) in mm/s	0.3577

The punch loads for bending and punch travel were 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 are scanned. The angles of the scanned images were measured using CAD software (5).

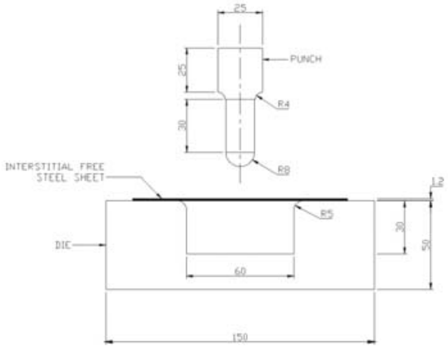

Fig. 1. Schematic Diagram of the Experimental Setup

The springback angle was calculated by the differences of the bending angles before and after unloading. The bending angles after unloading were measured at each punch travel. The above steps were repeated with different increment until the total depth was reached.

III. RESULTS AND DISCUSSION

The measured parameters were reported in graphical form for analyzing bending parameters. The intent of the analysis is to estimate the springback variation in IF steel sheets as a function of lubrication and lubricants and several experiments were performed with combination of process variables provided the punch radius and punch velocity are kept constant. The relationship between punch load and punch travel, springback and punch travel, are drawn for different conditions. The graphs have been drawn for different lubrication conditions namely on punch, on die or on both punch and die.

A. Effect of Lubrications on Punch Load

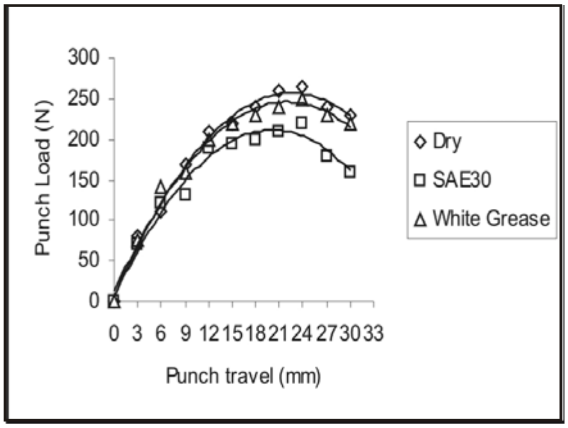

Fig. 2. Variation of Punch load with respect to punch travel for punch lubrications

The punch load as a function of punch travel for punch lubrication is given in Fig.2. It is noted that the punch load is reduced due to the application of lubricant. It is further observed that the effect of lubricant is quite dominant in the latter part than in the initial stages. The reason being, that the increase in contact area of lubricant as the punch travel increases. In this case, the white grease lubricant reduces the punch load compared to dry condition, but the grease is squeezed out during deformation. Hence the reduction in punch load is not at a significant level for white grease. As the SAE30 oil spreads over the bend surface than grease, the friction reduces to a greater extent and hence SAE30 oil is found to be better than grease.

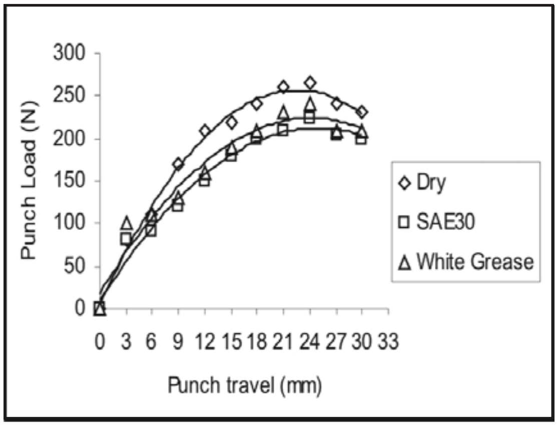

Fig. 3. Variation of Punch load with respect to punch travel for die lubrications

From Fig.3, it is observed that the behavior due to die lubrication is similar to punch lubrication. But the punch load is comparatively lower in this case. The reason is that the contact area of lubricant is larger in die lubrication than the punch lubrication. Since, the grease lubricant is not squeezed out as in punch lubrication, the lubrication effect is better for grease in die lubrication. That is the reason for significant reduction in punch load while applying grease. Due to better wetting property of SAE30 oil, the performance of SAE30 oil is still better than grease.

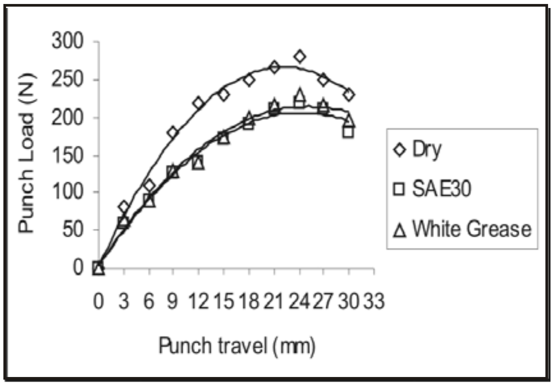

Fig. 4. Variation of Punch load with respect to punch travel for punch / die lubrications

Fig.4 depicts the variation of punch load with respect to punch travel for punch and die lubrication. The difference in the effect of lubricant (SAE30 oil and grease) on punch load for punch and die lubrication is not significant. Further, observed from the figure that the punch load is reduced to a greater extent than previous two cases. So punch and die lubrication is preferable in the air bending process. In all the cases, it can be observed that the punch load increases along with punch travel to a certain extent but after that, there is a gradual decrease in it.

B. Effect of Lubrications on Springback

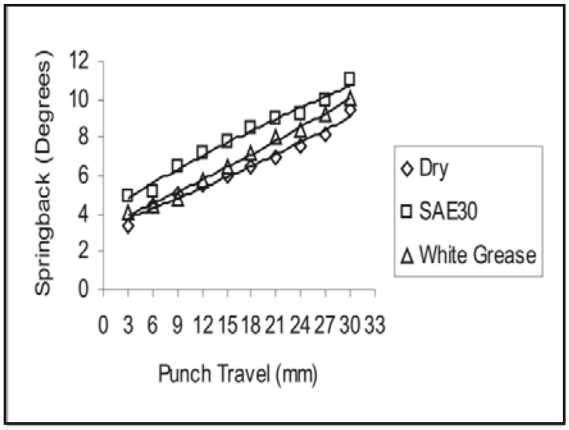

Fig. 5. Variation of spring back angles with respect to punch travel for punch lubrication

The springback results obtained under different punch travel for punch lubrication are plotted in Fig.5. It is noted that the springback increases as punch travel increases irrespective of dry or lubricating conditions**.** Furthermore, it found that springback is less for dry condition than SAE30 oil and grease lubrication conditions. The reason being, that the friction increases, the springback decreases.

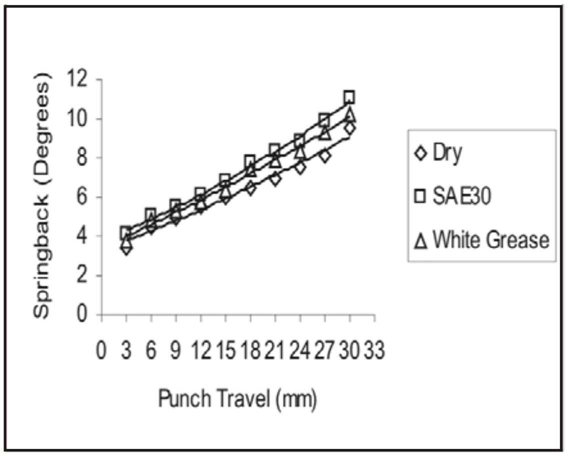

Fig. 6. Variation of spring back angles with respect to punch travel for die lubrication

According to Fig.6, it can be clearly noted that the springback increases when lubricant is applied. It is further observed that the variation of springback is quite dominant in the latter part than in the initial stages.

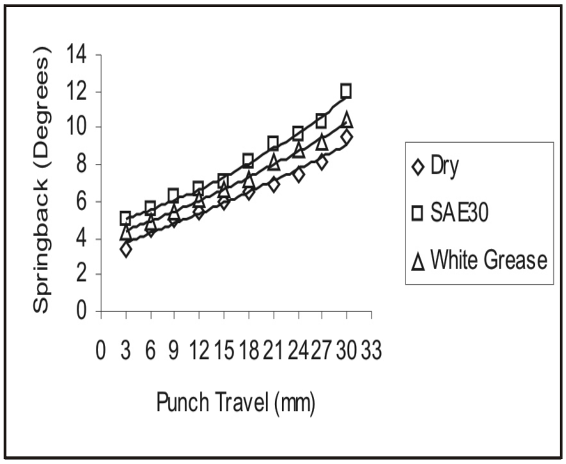

Fig. 7. Variation of spring back angles with respect to punch travel for punch / die lubrications

Fig. 7 shows that the springback and punch travel for different lubricants of punch and die lubrication. For all the cases, SAE30 oil lubricant exhibits maximum springback. For variation in punch travel from 3 to 30mm, the springback angle increases from 3.5° to 11°. This indicated that the rate at which the surface lost its ability is greater for the dry case than for the lubricated and is perhaps due to the influence of friction. It is observed that using the lubricant changes the springback angle significantly when compared to tested under dry conditions

IV. CONCLUSIONS

In this study, the springback of IF steel sheets in air bending using different lubrication and lubricants were investigated. According to the above reported results, the following conclusions were derived. The effectiveness of lubrication has been experimentally carried out using IF steel sheet of 1.2mm thickness. A greater discrepancy between oil lubricant and grease lubricant on the bending was observed. The lubricant SAE30 oil showed better results than grease in the punch load analysis. For this lubricant, load required to deform is found to be low and this shows that friction between sheet and tool is less.

- A lubricant change might introduce a different springback deformation mode. As the friction reduces due to lubrication, the springback increases.
- The experimental results show that, the effect of a lubricant in air bending process is significant and hence the selection of lubricant is an important issue in developing a successful process.
- The lubrication on punch and die effectively reduces punch load. So lubrication method is also an influencing parameter to reduce the punch load. The springback values varies significantly with respect to punch and die lubrication when compared to those tested under only punch or only die conditions and it is most considerable factor governing the magnitude of the springback.

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NOMENCLATURE

E	Young's Modulus in MPa
K	Strength Co-efficient in MPa
n	Strain Hardening Exponent
r	Plastic Strain Ratio
r_d	Die Radius in mm
r_p	Punch Radius in mm
L	Length of the sheet
d	Punch Travel in mm
t	Thickness of the Sheet in mm
v_p	Punch Velocity in mm/s
w_d	Die Opening in mm
w_p	Punch Width in mm
σ_y	Yield Strength in MPa
S_{ut}	Ultimate Tensile Strength in MPa
θ_s	Springback Angle $(\theta_1 \approx \theta_2)$ in Degrees
θ_1	Bending Angle before Springback in Degrees
θ_2	Bending Angle after Springback in Degrees

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