AE322- Aerospace Structures

A Report submitted

For internal assessment for Coarse

Manufacturing Processes Lab

in

Aerospace Engineering

by

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April 10, 2024

Contents

Abstract

In this current investigation, the focus lies on sheet metal forming employing a V-bending die, with particular emphasis on the manipulation of surface friction, punch and die fillet radius, and plate thickness across copper alloy, aluminum alloy, and steel alloy materials. Employing three-dimensional models constructed through finite element analysis utilizing the ABAQUS/Standard commercial software, the simulation aims to replicate the process of sheet metal bending accurately. Validation of the finite element analysis model is conducted against experimental data gleaned from prior studies.

The investigation delves into the effects of varying parameters such as surface friction, punch and die fillet radius, and plate thickness on tension and compression stress distributions. Preliminary findings suggest that alterations in plate thickness exert a significant influence on tension and compression stresses, while the impact of surface friction and punch and die fillet radius adjustments appears to be relatively minor in comparison.

By systematically varying these parameters and meticulously analyzing their influence on stress distributions, this study endeavors to provide deeper insights into the intricate mechanics of V-bending sheet metal forming processes, thereby contributing to the optimization and enhancement of such manufacturing operations.

Chapter 1

SHEET METAL FORMING PROCESSES

1.1 Introduction

The V-bending process is pivotal in metal sheet forming, offering precise bending crucial for diverse manufacturing industries. This study aims to comprehend the mechanical intricacies of V-bending, focusing on material behavior during deformation, including factors such as material properties, tool geometry, and process parameters. Utilizing three-dimensional finite element analysis via ABAQUS/Standard software, we model sheet metal V-bending, considering die and punch as rigid bodies and the sheet plate as a deformable body. The investigation delves into the effects of punch radius, sheet plate thickness, and friction coefficient on internal stresses at upper and lower contact surfaces. By unraveling these dynamics, we seek to optimize the bending process, minimizing defects, and enhancing efficiency in metal bending operations.

1.2 Problem Statment

The V-bending process involves the deformation of metal sheets to create precise bends, crucial in various manufacturing industries. This study seeks to understand the mechanical behavior of materials during V-bending, focusing on factors such as material properties, tool geometry, and process parameters. By analyzing these factors, the aim is to optimize the V-bending process to minimize defects and enhance bending accuracy, thus improving the efficiency and reliability of metal bending operations.

In this study, sheet metal V-bending was modeled using three-dimensional finite element analysis based on ABAQUS/Standard software. The modeling contains three parts: die and punch were considered as rigid bodies, and the sheet plate was defined as a deformable body. Fig. 1 reveals the schematic of sheet metal bending type V die before and after bending. The die geometry includes: bend angle ($\alpha = 90°$), opening die ($w_d = 50$ mm), length L_d i am not using, and thickness H_d i am not using as well as die radius that is similar to punch radius. The dimensions of the punch are depth of the bending ($w_p = 50$ mm), width ($L_p = 49$ mm), and height H_p i am not using. Different punch radii ($R = 10$, 12.5, and 15 mm) were applied in the modeling. The sheet plate was simulated with 130×50 mm cross-section at various sheet plate thicknesses (t = 1, 1.5, 2 mm).

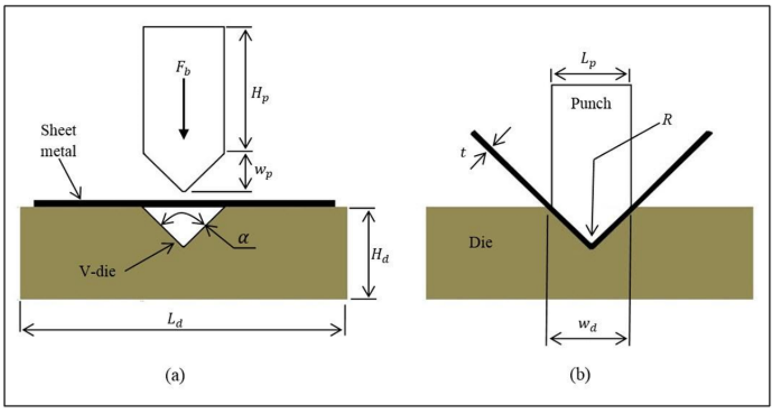


Figure 1.1: Schematic sheet metal V bending process (a) before bending (b) after bending[2]

1.3 MODELLING OF THE FINITE ELEMENT ANALYSIS

Assumptions:

1. **Plain Strain Assumption:** The sheet metal is assumed to have a thickness much smaller compared to its length, allowing us to simplify the problem into a 2D plane strain analysis.
2. **Implicit Solver Selection:** An implicit solver is chosen over an explicit solver due to the quasi-static nature of the simulation, and the negligible inertia effects.
3. **Element Selection:** The CPE4R element type (A 4-node bilinear plane strain quadrilateral with reduced integration and hourglass control) is chosen for meshing the sheet metal.
4. **Degrees of Freedom (DOF):** The degrees of freedom considered for the analysis include translation along the X and Y axes and rotation about the Z axis.
5. **Symmetry Utilization:** Symmetry boundary conditions are employed to reduce computational cost and model size while still capturing the essential behavior of the system.
6. **Contact Damping:** Contact damping is utilized to control numerical oscillations and ensure stability during contact interactions between the die, punch, and sheet metal.
7. **Automatic Stabilization:** Automatic stabilization techniques are employed to prevent numerical instabilities that may arise during the simulation.

Three types of alloys viz Cu, AA6061 T6 alloy, and Steel 360X alloy were used to simulate sheet plate bending models using three-dimensional finite element analysis. The mechanical properties needed in simulation for used alloys and the materials are assumed to be isotropic elastic-plastic behavior. These magnitudes of mechanical properties as well as the true stress and true plastic strain were determined by Refs. Cu [4], AA6061 T6 [3] and Steel 360X [1].

The die, punch, and sheet plate were assembled using the "assembly option" then these parts are mated together by "translate instance option" to obtain a correct position for the parts.

The sheet bending process involves a non-linear static analysis coupled with structural low-speed dynamic considerations. ABAQUS/Standard is chosen as the simulation software, utilizing the static/general analysis option to model sheet metal bending scenarios. Surface-to-surface contact types are essential for accurately capturing the bending process dynamics. Two main contact interfaces are established: firstly, between the V-die surface and the lower surface of the sheet plate, and secondly, between the V-punch surface and the upper surface of the sheet plate.

To ensure proper contact interaction, master and slave regions are defined within the contact interfaces using surface-to-surface discretization. Tangential behavior, incorporating frictional effects, is modeled with varying friction coefficients of 0.1, 0.15, 0.2.

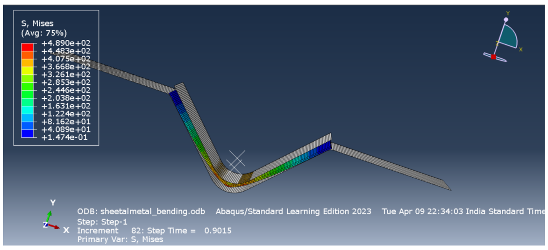
Boundary conditions for both the die and punch were set as follows: The die was fixed in the directions of U_1, U_2, U_3, U_{R1}, U_{R2}, and U_{R3}. The punch was allowed to move only in the direction $U_2 \neq 0$.

1.4 RESULTS OF FINITE ELEMENT SIMULATION

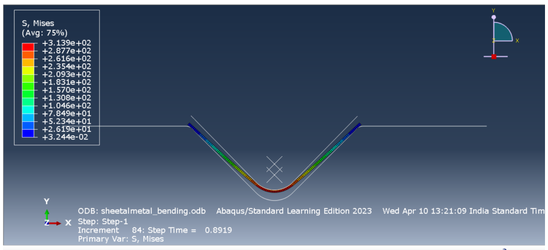
Different materials (Cu, AA6061 T6, and Steel 360X) were used in finite element modeling based on ABAQUS/Standard to study the effect of punch radius, sheet plate thickness, and friction coefficient.

1.4.1 Stress Distribution

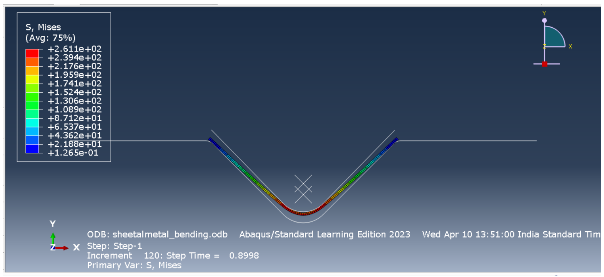
Figure 1.2 illustrates the distribution of stresses within the bend zone, encompassing the entire intersection of the sheet plate. In this depiction, key parameters include the punch radius (R) of 15 mm, a sheet plate thickness (t) of 1.5 mm, and a friction coefficient (f) set at 0.1. A discernible observation is the contrast in stress distribution across the surfaces of the sheet plate. Specifically, the upper surface, formed by the punch's surface (i.e., the apex of the V peak), exhibits compression stress, denoted by negative values. Conversely, the lower surface, calibrated by the die's surface (i.e., the base of the V peak), experiences tension stress, characterized by positive values. Of notable significance is the comparative analysis among different alloys. It is evident that the Steel 360X alloy manifests higher stress levels compared to both the Cu and AA6061 T6 alloy.



(a) Steel



(b) Aluminum



(c) Copper

Figure 1.2: Stress distribution in the bend zone for different materials at t=0.9 s.

1.4.2 Stress vs Time

The illustration in Fig. 1.4 portrays the correlation between internal stresses, observed at the lower surfaces of the V peak, and time. The depicted scenario maintains a constant punch radius ($R = 15\,\text{mm}$), sheet plate thickness ($t = 1.5\,\text{mm}$), and friction coefficient ($f = 0.1$). It is discernible from the figure that tension stresses exhibit a gradual increase with the augmentation of punch displacement, eventually reaching a state of relative constancy. The intricate nature of internal stresses stems from the multifaceted interactions occurring between the tool surfaces and the surfaces of the sheet plate. These interactions subject the material to a combination of elastic and plastic deformation phenomena during the bending process, owing to the applied bending forces. Notably, the aluminum alloy (AA6061 T6) demonstrates lower stress levels compared to both the copper (Cu) and the steel alloy (Steel 360X). This observation suggests a dependence of the maximum internal stresses, encompassing and tension, on the magnitude of punch displacement .

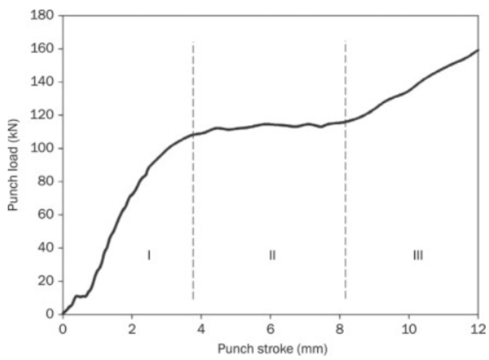
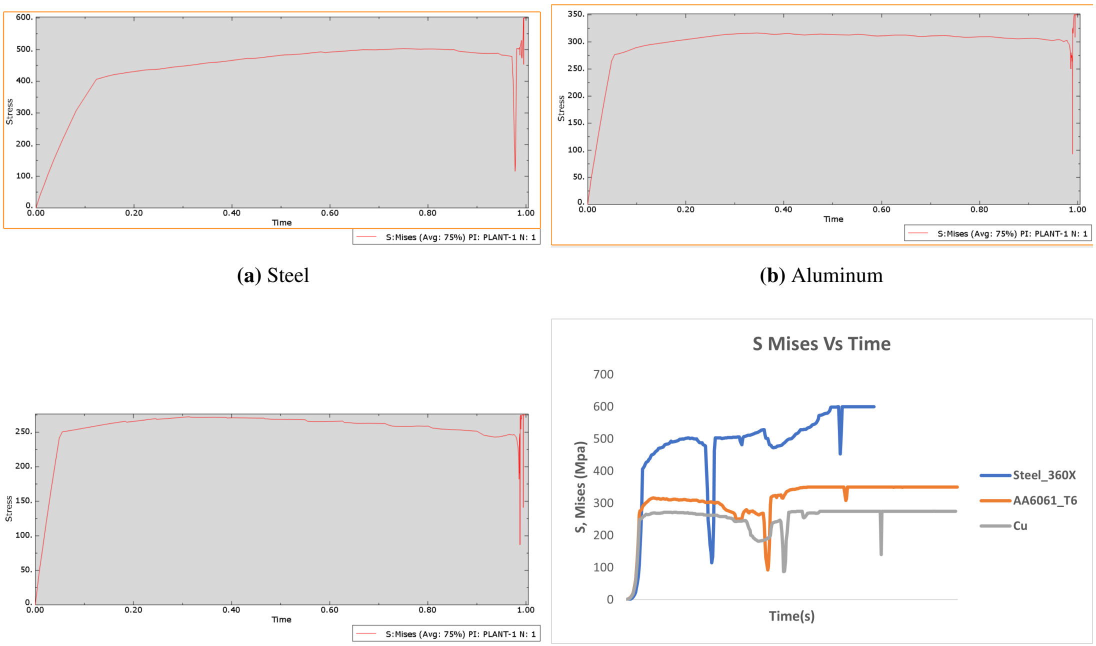


Figure 1.3: Stress vs Time Theoretical [5]



(a) Steel

(b) Aluminum

(c) Copper

(d) Combine

Figure 1.4: Stress vs Time From Abaqus

As per the theory graph should be follow Fig. 1.3 Where In zone (I), the force experiences a rapid ascent from zero to max. over a elastic limit punch displacement. This steep increase primarily stems from the elastic behavior exhibited by material and the resistance posed by the workpiece against deformation. Throughout this zone, the load demonstrates nearly linear growth concerning the punch stroke, until the initiation of plastic deformation.

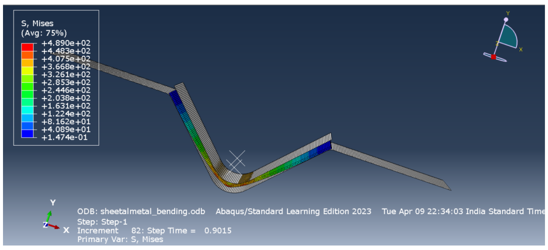
Zone (II) witnesses a marginal augmentation in bending force as the punch stroke progresses from elastic limit to plastic limit. This slight increase can be attributed to the propagation and expansion of the plastic zone within the workpiece.

Transitioning into zone (III), the force exhibits another upsurge with the advancement of the punch. This phase marks the concluding stage of the V-bending operation, wherein the workpiece achieves full contact with the metallic punch.

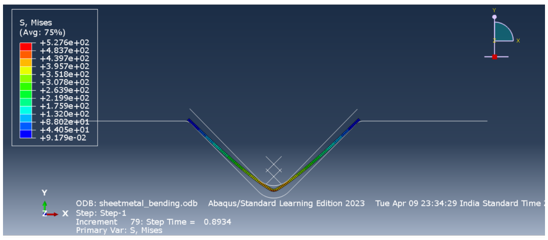
Same we can see in Stress vs Time From Abaqus in Fig. 1.4.

1.4.3 Effect of Punch Radius

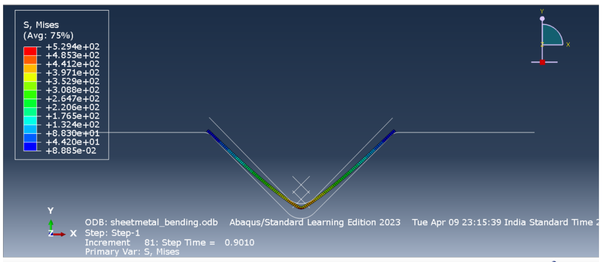
The relationship between internal stress (at upper and lower of V peak) and punch radius is exhibited in Fig. 1.6 and Fig. 1.5 with constant values of sheet metal thickness at ($t = 1.5$ mm), friction coefficient at ($f = 0.1$), and punch displacement at ($S = 43.8$ mm). The figure shows that the punch radius has a strong effect on the tension stress. It can be observed that at the punch radii of 10 mm and 12.5 mm, the stresses are almost constant, while the stresses decrease at the punch radii of 15 mm.



(a) Steel R=15

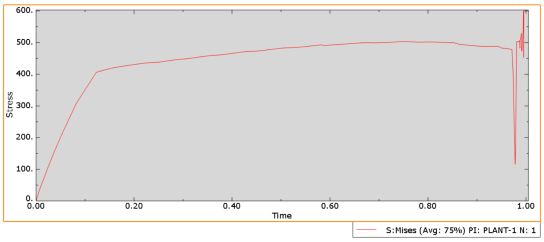


(b) Steel R=12.5

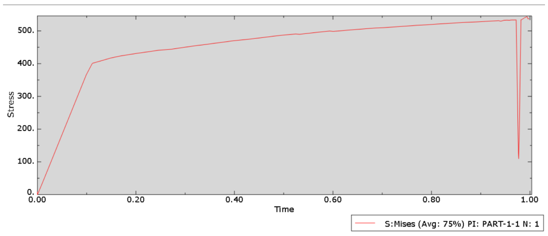


(c) Steel R=10

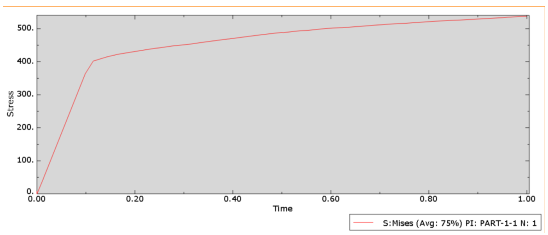
Figure 1.5: Effect of Punch Radius at t=0.9 s.



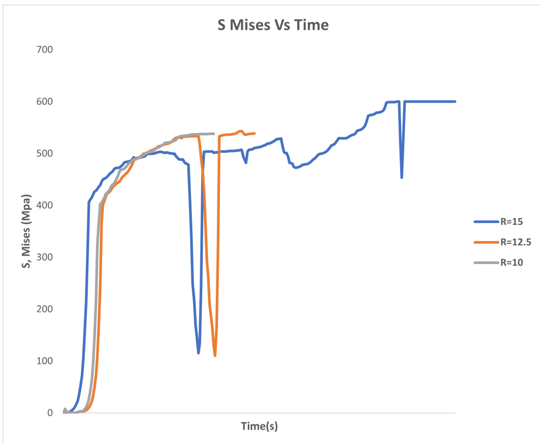
(a) Steel



(b) Steel R=12.5



(c) Steel t = 1.5mm

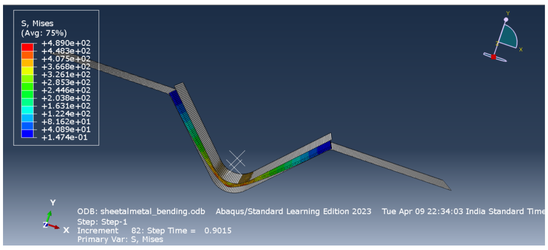


(d) Combine

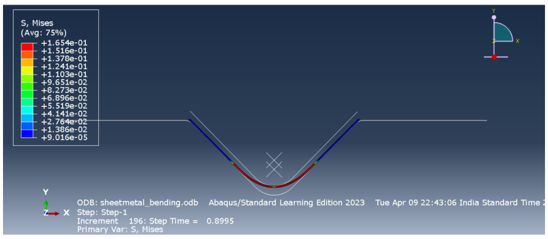
Figure 1.6: Effect of Punch Radius

1.4.4 Effect of Sheet Plate Thickness

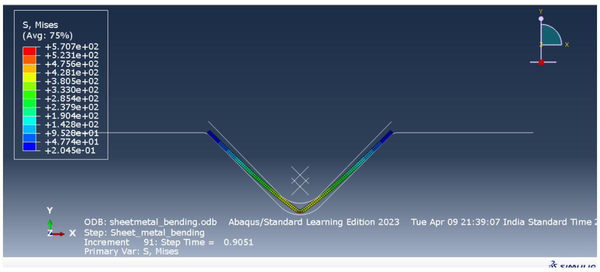
Fig. 1.8 and Fig. 1.7 indicates the relationship between internal stress (at upper and lower of V peak) and sheet plate thickness at punch radius ($R = 15$ mm), friction coefficient ($f = 0.1$), and punch displacement ($S = 43.8$ mm). Due to increasing the bending force with an increase in the sheet plate thickness, there is an increase in the internal stress. Therefore, the internal stresses mainly depend on the bending force.



(a) Steel t = 1.5mm

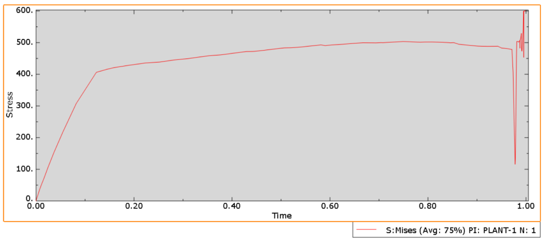


(b) Steel t = 1 mm

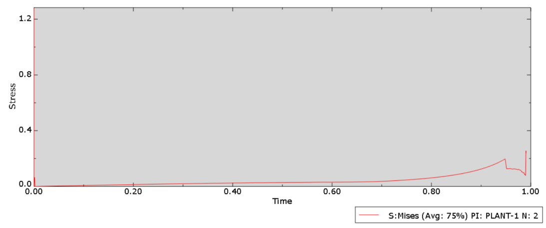


(c) Steel R = 2 mm

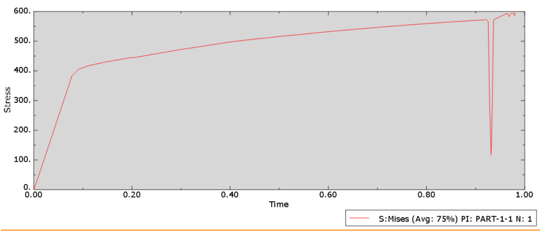
Figure 1.7: Effect of Plate Thickness at t=0.9 s.



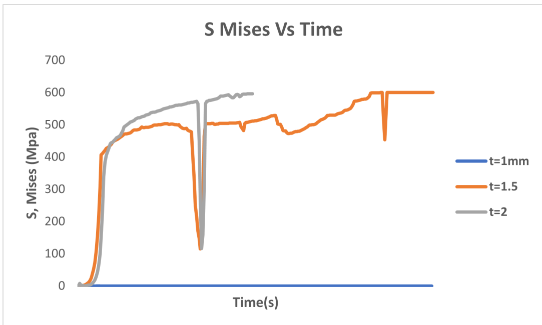
(a) Steel t = 1.5 mm



(b) Steel t=1 mm



(c) Steel t=2 mm

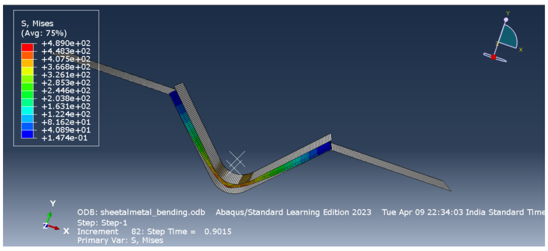


(d) Combine

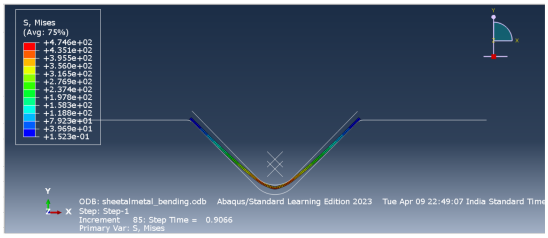
Figure 1.8: Effect of Plate Thickness

1.4.5 Effect of Friction Coefficient

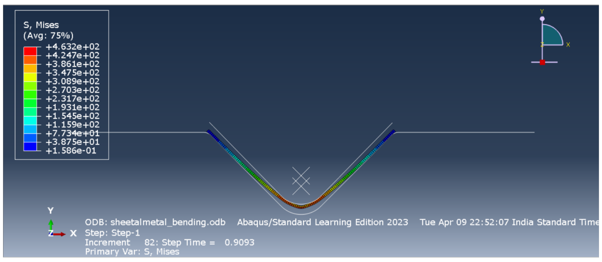
Fig. 1.10 and Fig. 1.9 refers to the relationship between internal stress (at upper and lower of V peak) and friction coefficient at punch radius ($R = 15$ mm), sheet plate thickness ($t = 1.5$ mm), and punch displacement ($S = 43.8$ mm). The figure demonstrates that there is a very little effect of the friction coefficient value on the tension stress.



(**a**) Steel f= 0.1

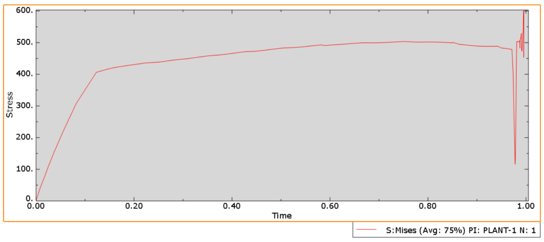


(**b**) Steel f = 0.15

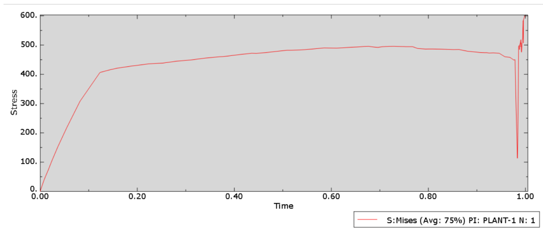


(**c**) Steel f = 0.2

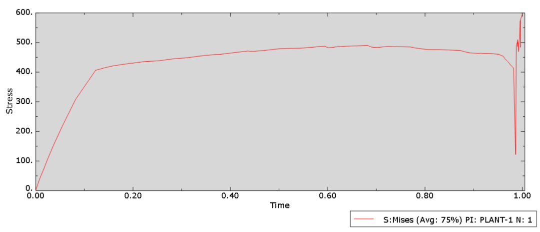
Figure 1.9: Effect of Friction at t=0.9 s.



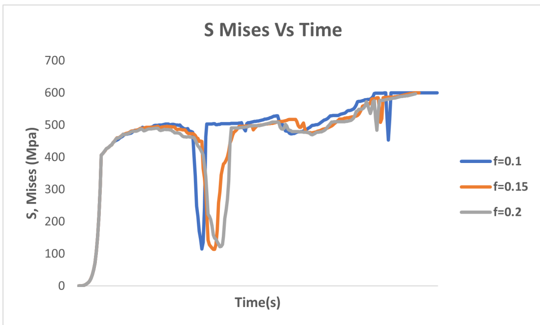
(**a**) Steel f = 0.1



(**b**) Steel f=0.15



(**c**) Steel f=0.2



(**d**) Combine

Figure 1.10: Effect of Friction

1.5 Conclusions

The present study delved into the intricate dynamics of sheet metal forming processes, specifically focusing on V-bending dies, utilizing copper, AA6061 T6, and steel 360X. Through comprehensive three-dimensional finite element analysis, the impact of various factors such as punch radius, sheet plate thickness, and friction coefficient on internal stresses at both upper and lower contact surfaces was meticulously investigated. The key findings derived from the simulation results can be succinctly summarized as follows:

1. **Gradual Increase in Bending Force**: It was observed that the bending force exhibits a gradual rise with an increase in punch displacement, followed by a sharp surge once the sheet plate reaches complete formation.

2. **Dependence of Stress on Punch Displacement**: The tension and compression stresses experienced during the sheet bending process were found to be contingent upon punch displacement and the resultant bending force.

3. **Significant Influence of Sheet Plate Thickness**: Sheet plate thickness emerged as a pivotal factor significantly impacting the pattern of tension stress. Notably, these stresses exhibited a proportional increase with the augmentation of sheet plate thickness, necessitating a corresponding rise in bending force.

4. **Effect of Punch Radius**: The investigation revealed that tension stresses experienced at punch radii of 15 mm were comparatively lower than those observed at punch radii of 10 mm and 12.5 mm.

5. **Limited Impact of Friction Coefficient**: The friction coefficient was found to exert a negligible influence on the state of tension and compression stress, highlighting its relatively minor role in shaping the bending process dynamics.

Bibliography

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[3] https://www.researchgate.net/figure/Effective-plastic-strain-and-corre tbl1_344505330

[4] https://www.researchgate.net/figure/A-typical-stress-strain-plot-from- fig2_311554234

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