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A Numerical Modelling of V-Bending

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Abstract

In the study, a sheet metal is bent to analyze the punch force, Von Misses stresses and plastic strains on the metal for friction and non-friction cases. The 2-D v-bending forming is modelled in program. Model includes a die, a punch and a blank. Solid mechanics physics interface has been used in program. The analyze has been run with friction and non-friction cases for different strain-hardening exponents and sheet metal thicknesses. The sheet lengths and widths are 60 mm. Thickness of sheet metal is varied between 1.0 to 3.0 mm. The strain hardening exponent has been altered from 0.1 to 0.5. It is computed that the punch force has been increased as thickness of sheet metal and strain hardening exponent decreases. The achieved maximum punch force is at values of 1.12×10^5 N, 3.75×10^5 N and 4.05×10^5 N for thickness of 1.0-mm, 2.0-mm and 3.0-mm respectively when strain hardening exponent is 0.3. Also, as the strain hardening exponent increases from 0.1 to 0.5, the maximum punch force lowers from 2.03×10^5 N to 8.08×10^4 N for 1 mm thickness at friction case. Moreover, the maximum punch force reached up to 9.13×10^4 N for 1 mm thick sheet metal at non-friction case when the strain hardening exponent is 0.1. It is concluded that the maximum Von Misses stress has been calculated at the tip of sheet metal.

Keywords: Numerical, Sheet metal, Punch, Thickness, V-bending, Strain hardening exponent

V- Bükmenin Sayısal Modellenmesi

Öz

Çalışmada, sürtünmeli ve sürtünmesiz durumlar için zımba kuvvetini, Von Misses gerilmelerini ve metal üzerindeki plastik gerinimleri analiz etmek için bir metal levha bükülmüştür. 2 boyutlu v-bükme şekillendirme programda modellenmiştir. Model bir kalıp, bir zımba ve bir sac levhadan oluşmaktadır. Programda katı mekanik fiziği arayüzü kullanılmıştır. Analiz; farklı pekleşme üsteli ve sac kalınlıkları için sürtünmeli ve sürtünmesiz ortam koşullarında yürütülmüştür. Sac uzunlukları ve genişlikleri 60 mm'dir. Sac kalınlıkları 1,0 ila 3,0 mm arasında değişmektedir. Pekleşme üsteli 0,1'den 0,5'e kadar değiştirilmiştir. Sac kalınlığı ve pekleşme üsteli azaldıkça zımba kuvvetinin arttığı hesaplanmıştır. Elde edilen maksimum zımba kuvveti, pekleşme üsteli 0.3 olduğunda 1,0 mm, 2,0 mm ve 3,0 mm kalınlık için sırasıyla 1.12×10^5 N, 3.75×10^5 N and 4.05×10^5 N değerlerindedir. Ayrıca sürtünmeli durumda 1 mm kalınlık için pekleşme üsteli 0,1'den 0,5'e arttıkça maksimum zımba kuvveti 1.49×10^5 N to 8.08×10^4 N'ye düşer. Dahası, pekleşme üsteli 0.1 iken maksimum zımba kuvveti sürtünmesiz durumda 1 mm kalınlığındaki sac için 9.13×10^4 N değerine ulaşmıştır. Maksimum Von Misses gerilmesinin sacın ucunda hesaplandığı sonucuna varılmıştır.

Anahtar Kelimeler: Sayısal, Sac metal, Zımba, Kalınlık, V-bükme, Pekleşme üsteli

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1. INTRODUCTION

Bending is performed in terms of different forming processes such as v-bending [1,2], air bending [3], flanging [4], u-bending [5], rotary draw bending [6], three-point bending [7], hemming [8,9] and seaming [10]. V-bending process is dominantly used in manufacturing of automobile industry [11]. Some of the researches are focused on spring-back problem [12,13], bend radius [14], bend angle [15,16] and strain hardening [17].

Researchers studied on bending experimentally and numerically [12,18,19]. Cao et. al. [20] changed temperature and speed of bending during forming of stainless steel. It was found that as temperature increased from 600˚C to 850˚C, springback angle was reduced continuously. Bending speed has an influence on springback angle so that spring back angle is decreasingly increased as the bending speed increased from 0 mms^{-1} to 5 mms^{-1}. Dhilip et. al. [21] realized finite element analysis of 3-D model of sheet metals in ANSYS program. The maximum principal stress and elastic strain was computed for annealed 1020 carbon steel, aluminum and stainless steel. Thipprakmas and Sontamino [15] used bent hole parts to observe effect of hole and hole position on the springback character of material experimentally. It was observed that bent hole parts show higher springback character when comparing to bent non-holed parts. Özdemir [22] investigated the bending behavior of continuous glass fiber-reinforced composite sheets. Dwell time, pressure, bending angle and die radii were the studied parameters in Özdemir's work.

As a result of the work, it was found that the most suitable option to reduce springback problem is at 90˚ bending angle and 120 s dwell time under 3 MPa pressure for a die radius of 6 mm. Li et. al. [23] bent titanium tubes to focus on effect of forming temperature and bending angle on springback numerically and experimentally.

It was concluded that increase in forming temperature lowers the springback and unlike springback increases with bending angle. Pritima et al. [24] analyzed the bending of AISI 1040 sheet metal. Effect of width of sheet, velocity, holding time are some of the parameters studied in the work. It was evident that decrease in holding time, increase in width and rise in punch speed increase the springback. Krinninger et. al. [25] used stainless steel and microalloyed steel to investigate the influence of bending angle, punch velocity and bending radius on springback angle. It was concluded that as the punch velocity increases from 10 mm/s to 300 mm/s, it lowers the springback angle and as the bending angle or bending radius increases, the springback angle increases. Nakajima et. al. [26] focused on the bending of square tubes and used mandrel to get an accurate square cross section of aluminum tubes as workpiece after press bend and utilized restraint plate to decrease the deviation of thickness of square tubes. Gupta and Payal [27] bent the electrogalvanized steel to search the effect of die width and galvanized thickness. The findings showed that spring back increases with the increase of coating thickness and spring back for rolling of direction 90° orientation is more than rolling direction 0° orientation. Hotaka et. al. [28] used repeated bending to develop formability of twin roll cast Mg-Al-Zn-Sn alloy. Two methods such as repeated bending by differential speed rolling and repeated bending by using three rolls were applied. After bending processes, the solution heat treatment of the pre-strained material was performed. Thus, the microstructure of specimens was changed. Then, the specimens were bent by V-bending. It was concluded that repeated bending by using three rolls was effective to develop formability of specimens and achieved springback angles of specimens were lower after V-bending.
Örnekçi and Ekşi [29] investigated springback properties of 6061 aluminum in V-bending for different die angles and widths. It was found that springback decreased as the die width increased and as die angle increased, springback also increased. Also, the ANOVA results showed that die width was more important than die angle in terms of springback.

Sofia et. al. used [30] USS CR980XG3TM steel to analyze and clarify the dependence of springback on the tool's geometry and the V-bending tools with different bending angles of 60˚and 90˚ and punch radii of 5˚ and 10˚ were selected. It was concluded that as the punch radius increased or die angle decreased, the mean springback increased.

In the work, the model of a sheet metal has been analyzed numerically in a multiphysics program. The punch force and displacement have been examined for different strain hardening exponents and thicknesses of sheet metal at friction and non-friction conditions. The work provides to determine the effect of parameters on punch force in fields of metal bending.

2. METHODS

2.1. V-Bending Model

V-bending is preferred to be analyzed in the work. Because v-bending is commonly utilized in low manufacturing processes. V-die angles varying from obtuse to acute are able to be manufactured. The v-dies are cheap and basic compared to other bending operation equipment [31].

Model of the bending is shown in figure 1. V-Bending forming consists of a punch, a die and a sheet metal as illustrated in figure 1. Because of the symmetric process, just one half of the geometry is used. The length and the width of the sheet metal is 60 mm and die angle is 90˚. The model was run at friction and non-friction mediums.

The parameters such as strain hardening exponent and sheet metal thickness affecting the punch force have been studied on the work for different cases. For friction case, Coulomb friction coefficient was defined between punch with sheet metal and die with sheet metal as 0.2. The sheet material is selected as an aluminum alloy due to the fact that it has an advantage of lightweight because of comparatively low density and demonstrates relatively high ductility [32]. The material parameters of the blank material and the parameters that are changed for the representative blank material is given in table 1.

The material of punch and die are structural steel. The material properties have also an influence in forming is given in table 2. Strain hardening is one of the most vital effects on material to become it stronger. Hardening functions are given as;

Hollomon hardening function [33]:

$$\sigma = K\epsilon^n \quad (1)$$

Ludwing equation [34]:

$$\sigma = \sigma_y + K\epsilon^n \quad (2)$$

n is strain-hardening exponent, it gets the value of 0 for perfectly plastic solids and the value of 1.0 for perfectly elastic materials. The elasto-plastic material model is built for the work of v-bending process. K is Hollomon hardening parameter in units of N.mm^{-2}. ϵ is strain in units of mm/mm.

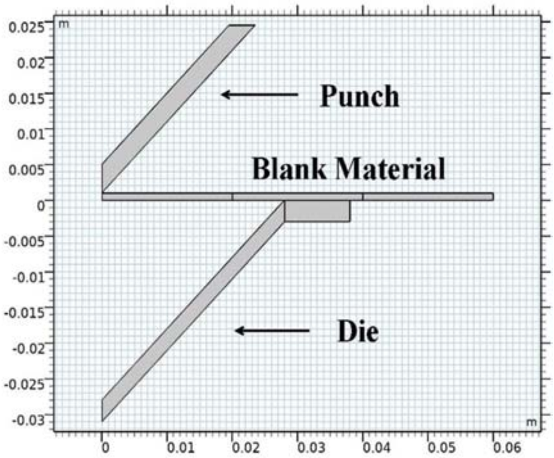

Figure 1. V-bending model

Punch and die are defined as rigid bodies. Thus, duration of simulation can be reduced when the bending metal is modelled as deformable with homogeneous solid element. The punch is adjusted as full contact with top surface of the blank. The displacement of the punch is determined as equal to the depth of die. The displacement behavior of punch is given in figure 2. Figure 2 describes how the punch movement has been changed according to time. Maximum punch displacement is 28 mm.

In the mesh, the maximum element size was 0.00402, the minimum element size was 0.00003, the maximum element growth rate was 1.3, the curvature factor was 0.3 and the resolution of narrow regions was 1.

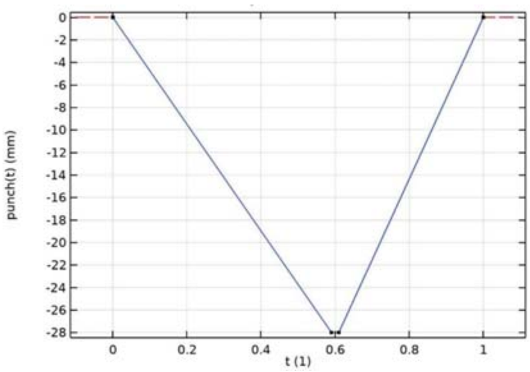

Figure 2. Displacement of punch

2.2. Numerical Modelling of Bend Forming

Method of finite element analysis is an active and an adequate choice to assist the design and analyze the bend forming.

The 2-D model contains several nonlinearities such as boundary nonlinearity (contact), material nonlinearity (elastoplastic material) and geometric nonlinearity. It is assumed that plain strain is occurred because out of plain thickness is wide. Due to the fact that the thickness of the plate is small when comparing the tool, moderate strains are occurred in spite of large displacements and rotations. The augmented Lagrangian contact technique is adopted. Solid mechanics physics interface was defined and user-controlled mesh was applied. MUMPS solver was used for the stationary solver.

Table 1. Material properties of representative blank material

Term	Representative blank material
Hollomon hardening parameter, K	550.4 MPa
Strain hardening exponent, n	0.1-0.3-0.5
Initial yield stress, σ_0	150 MPa
Young's modulus, E	70.5 GPa
Density, ρ	2700 kgm^{-3}
Thickness	1.0mm-2.0mm-3.0mm
Width	60 mm
Length	60 mm
Poisson ratio, ν	0.342

Table 2. Material properties of structural steel die and punch

Term	Steel die and punch material
Young's modulus, E	200 GPa
Density, ρ	7850 kgm^{-3}
Poisson ratio, ν	0.30

3. RESULTS AND DISCUSSIONS

3.1. Effect of Sheet Thickness in Friction Case

The effect of thickness on punch force was investigated due to being one of the parameters determining the machine capacity. So, the thickness of plate was changed. The 1.0-mm, 2.0-mm and 3.0-mm thick plates were bent under friction case. The friction coefficient was defined as 0.2. Figure 3 emphasizes variation of the punch force according to punch action in the case strain hardening exponent of 0.3 for different sheet metal thickness at friction case. The punch force is reached up to $1.12x10^5$ N, $2.38x10^5$ N and $4.05x10^5$ N for thickness of 1.0-mm, 2.0-mm and 3.0-mm respectively as illustrated in figure 3. The amount of maximum stress and the region of maximum stress on the sheet metal in friction case for the thickness of 2.0 mm are shown in figure 4. Von Mises stress distribution on blank material, punch and die are depicted in figure 4. Equivalent plastic strain on the sheet metal for the case of strain hardening exponent of 0.5 for 1 mm thick sheet metal in friction case is illustrated in figure 5.

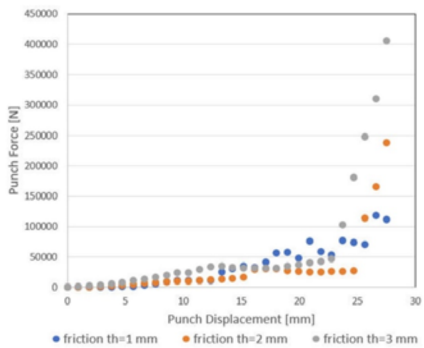

Figure 3. Punch force according to displacement for different thickness of sheet metal at friction case for strain hardening exponent of 0.3

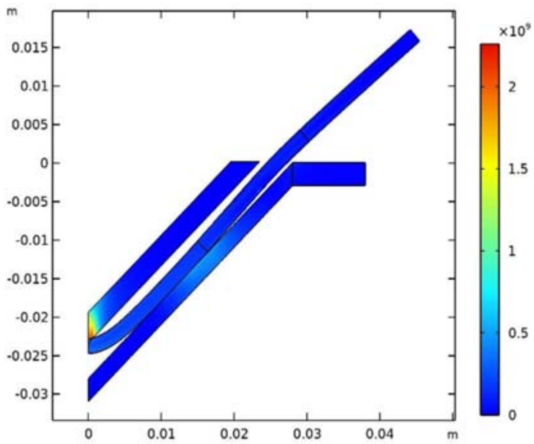

Figure 4. Stress distribution on surface of sheet metal in v-bending at friction case for thickness=2.0 mm and strain hardening exponent of 0.3

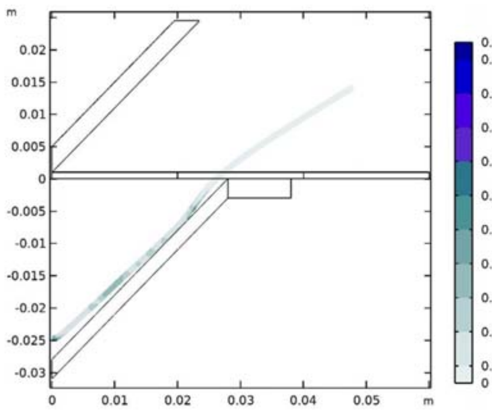

Figure 5. Equivalent plastic strain on sheet metal in v-bending for the case of strain hardening exponent=0.5 and thickness=1.0 mm in friction medium

As the thickness of blank metal is increased, the punch force raises. The punch force increases exponentially as the displacement increases. Figure 3 shows that it needs much more force and energy to form it as the cross-section area increases.

3.2. Effect of Strain Hardening Exponent in Friction Case

The effect of thickness on strain hardening exponent was investigated. Small plastic strains were defined for plasticity model. So, the strain hardening exponent was taken as 0.1, 0.3 and 0.5 at friction case. The sheet plates having different strain hardening exponents were bent under friction case. As the strain-hardening exponent increases, the punch force to bend the sheet material by an angle of 90˚ decreases. Figure 6 emphasizes variation of the punch force according to punch action for different strain hardening exponent and 1.0 mm thick sheet metal at friction case. As shown in figure 6, as the strain hardening exponent increases from 0.1 to 0.5, the punch force to deform the blank material decreases from $2.03x10^5$ N to $8.08x10^4$ N at a displacement rate depicted in figure 2.

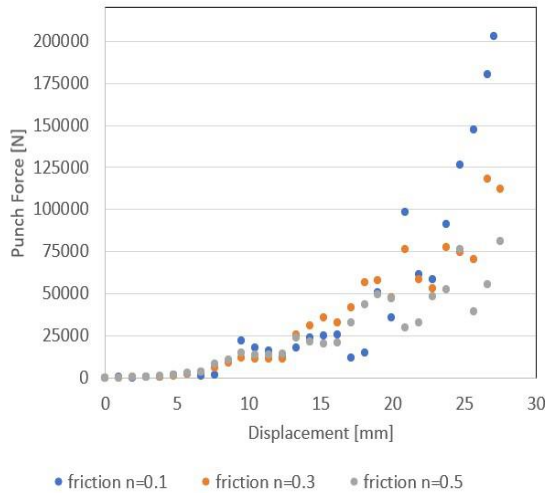

Figure 6. Punch force according to displacement for different strain hardening exponent of 1mm thick sheet metal material at friction case

The amount of maximum stress and the region of maximum stress on the sheet metal in friction case for the strain hardening exponent of 0.5- and 1.0-mm thick sheet plate are shown in figure 7. Von Mises stress distribution on blank material, punch and die for strain hardening exponent of 0.5 are depicted in figure 7. The equivalent plastic strain on sheet metal in the case of strain hardening exponent of 0.3 for 3.0 mm thick sheet metal at friction condition is illustrated in figure 8.

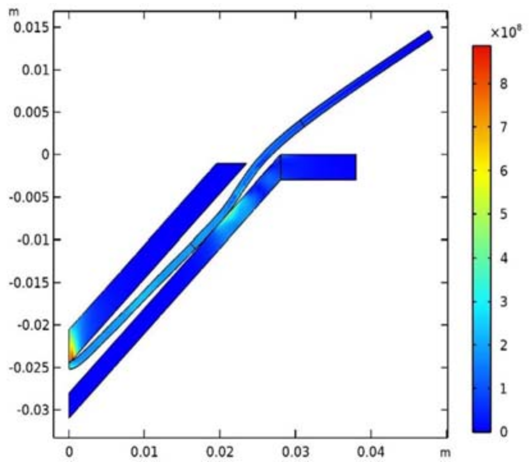

Figure 7. Stress distribution on surface of 1 mm thick sheet metal in v-bending for n=0.5

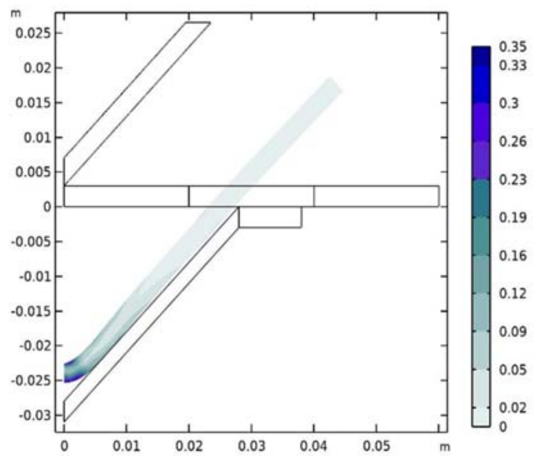

Figure 8. Equivalent plastic strain on sheet metal in v-bending for the case of strain hardening exponent =0.3 and thickness=3.0 mm in friction medium

3.3. Effect of Sheet Thickness in Non-Friction Case

The effect of thickness on punch force was investigated. So, the thickness of sheet metal was varied. The 1.0-, 2.0- and 3.0-mm thick plates were bent under non-friction condition. The punch forces keep increasing to deform the sheet metal within the die. As the blank is sufficiently deformed after a certain point, it needs a lower punch force to suppress the sheet metal into the die. Figure 9 emphasizes variation of the punch force according to punch action for different sheet metal thickness in the case of strain hardening exponent of 0.3 at non-friction case. As the punch reaches the forming shape, the sheet metal gets in contact with the bottom of the die, thus the force increases remarkably to end the bending as illustrated in figure 9. At non-friction case, the punch force raises from $5.67x10^3$ N to $14.21x10^3$ N, as the thickness of material increases from 1.0 mm to 3.0 mm as seen in figure 9.

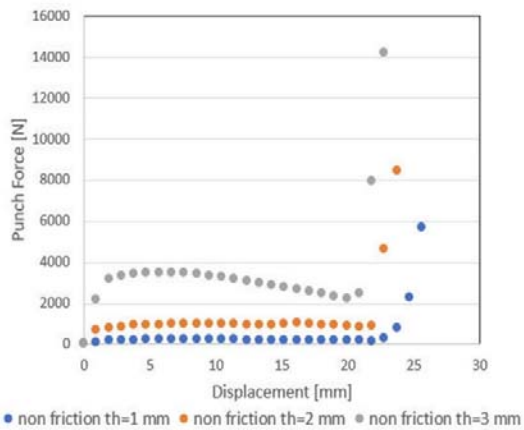

Figure 9. Punch force according to displacement for different thickness of sheet metal at non friction case for strain hardening exponent of 0.3

The amount of maximum stress and the region of maximum stress on the sheet metal for the strain hardening exponent of 0.3 are shown in figure 10. The amount of maximum stress and the region of maximum stress on the sheet metal in non-friction case for the thickness of 2.0 are shown in figure 10. As depicted in figure 10, the highest Von Misses stress was computed at tip of the V-bended sheet metal. The equivalent plastic strains on sheet metal in the case of strain hardening exponent of 0.5 for 1.0 mm thick sheet metal at non-friction condition were illustrated in figure 11.

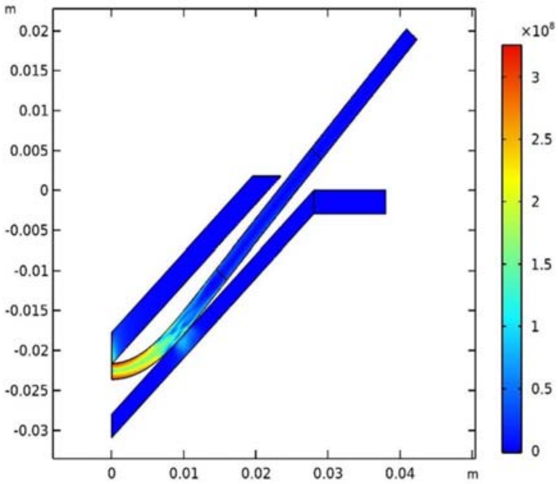

Figure 10. Stress distribution on surface of sheet metal in v-bending at non-friction case for thickness is 2.0 mm and strain hardening exponent of 0.3

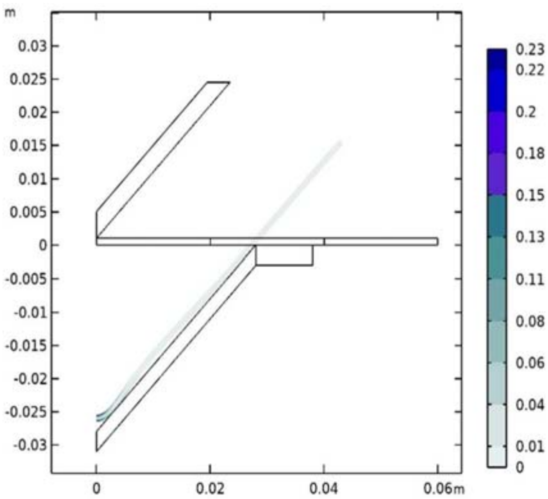

Figure 11. Equivalent plastic strain on sheet metal in v-bending for the case of strain hardening exponent =0.5 and thickness=1.0 mm in non-friction medium

3.4. Effect of Strain Hardening Exponent in Non-Friction Case

The effect of thickness on strain hardening exponent was investigated. Isotropic hardening model was chosen. Small plastic strains were specified for plasticity model. So, the strain hardening exponent was taken as 0.1, 0.3 and 0.5 at non-friction medium. The sheet plates having different strain hardening exponents were bent under non-friction condition. Figure 12 emphasizes variation of the punch force according to punch action for different strain hardening exponent and 1.0 mm thick sheet metal at non-friction case. As the strain hardening exponent increases from 0.1 to 0.5, the punch force to deform the blank material decreases from 9.13×10^4 N to 191 N at non-friction case as shown in figure 12. The amount of maximum stress and the region of maximum stress on the sheet metal in non-friction case for the strain hardening exponent of 0.5 and 1.0 mm thick sheet metal are shown in figure 13. As illustrated in figure 13, the highest Von Misses stress was calculated at tip of the V-bended sheet metal. In non-friction case, equivalent plastic strain on 3 mm thick sheet metal in the case of strain hardening exponent of 0.3 are depicted in figure 14.

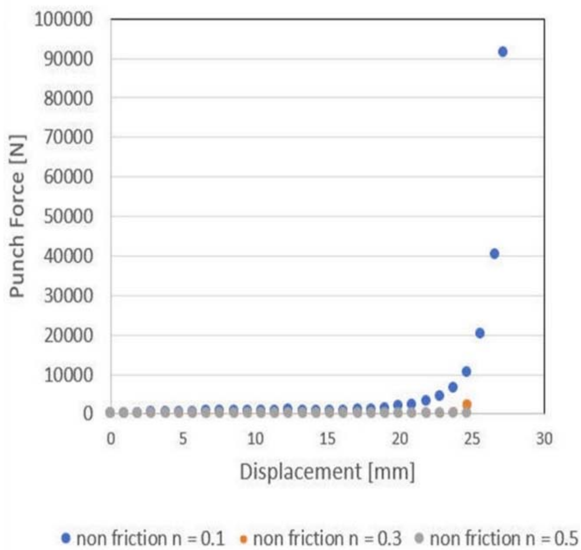

Figure 12. Punch force according to displacement for different strain hardening exponent of 1mm thick sheet metal material at non-friction case

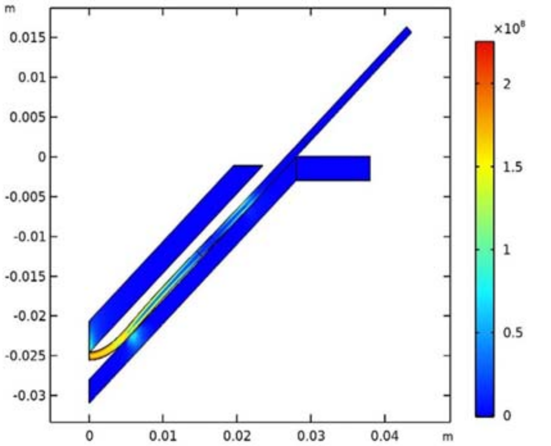

Figure 13. Stress distribution on surface of 1.0 mm thick sheet metal in v-bending for strain hardening exponent of 0.5

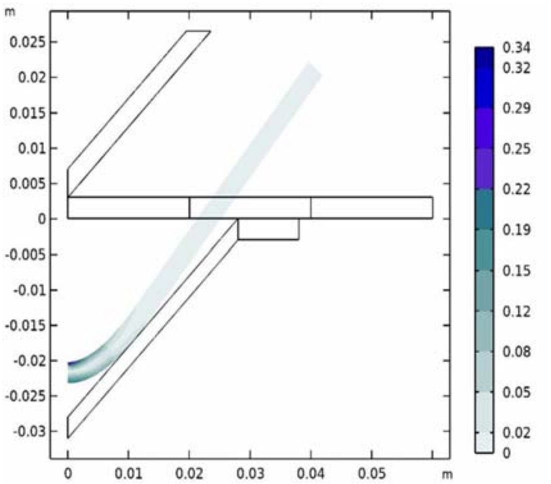

Figure 14. Equivalent plastic strain on sheet metal in v-bending for the case of strain hardening exponent =0.3 and thickness=3.0 mm in non-friction medium

4. CONCLUSION

The change in punch force was investigated in the work of v-bending analysis. The punch force increased exponentially as the deflection increases in v-bending analyzes for the blank metal thickness value of 1.0, 2.0 and 3.0 mm. The results show that as thickness of the blank metal increases, there must be higher force to bend it by an angle of 90˚. If the non-friction case and friction case are compared in terms of punch force capacity, at friction case it requires higher punch force to form the sheet metal due to Coulomb friction between the punch-sheet metal and sheet metal-die. Practically, the surfaces are able to be lubricated to lower the friction.

Although the strain hardening exponent indicates the how much the metal can be strengthened, for the small plastic strains, lower the value of n, greater is the punch force.

Also, the blank material starts to be bent, it will need more punch force. Results demonstrate that as the sheet metal deforms, it becomes stronger and harder. The strain hardening exponent was lowered from 0.5 to 0.1, the punch force reached the highest value of 2.03×10^5 N for the 1 mm thick sheet metal at friction case and 9.13×10^4 N for the 1 mm thick sheet metal at non-friction case.

The findings provide a comprehensible approach at the bending region and can help to understand the effect of parameters on forming to improve the design of the forming actions for different sheet metal bending applications.

5. NOMENCLATURE

σ	stress [$N.m^{-2}$]
σ_y	yield strength [$N.m^{-2}$]
K	hardening parameter
$\in$	strain [$mm.mm^{-1}$]
n	strain hardening exponent

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