Experimental and Numerical Prediction of Spring back in U-bending Process

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Abstract-- **One of the most sensitive features of sheet metal forming processes is the elastic recovery during unloading, called spring back, which leads to some geometric changes in the product. In this paper spring back dependence on the mechanical properties of different materials and tools geometry has been examined numerically and experimentally in sheet metal U-bending test. The computer code MARC was used to simulate the U- bending process under plane strain condition. A Comparison between the experimental and the finite element simulation results also performed. A complete knowledge of the spring back phenomenon and its dependence on material and process variables is strongly required in order to develop effective real time process control systems.**

Index Term-- **U-bending, spring back, FEM, numerical simulation.**

1. INTRRODUCTION

As a fundamental and traditional process in metallic forming technologies, sheet metal forming is widely being employed in almost all industrial fields. Needless to say, it is because a final sheet product of desired shape and appearance can be quickly and easily produced with relatively simple tool set. However, sheet metal forming may frequently produce the unacceptable products with wrinkle, tear, poor dimension precision, and so on, unless tool and process parameters are appropriately chosen. After the sheet metal forming process, residual stress remains at the final product due to the plastic deformation. The residual stress leads to elastic recovery of the formed part which called spring back that causes shape error in final product [1]. Spring back can be defined as an elastically-driven change of shape of a deformed product which takes place during removal of external loads. It is a complex physical phenomenon which is mainly governed by the stress state obtained at the end of a deformation [2]. Hence, the tool design, for given specific sheet material and final product dimension, should be based upon the accurate prediction of amount elastic recovery. Nevertheless, the determination of process parameters had been traditionally made according to a trial and error procedure, by invoking the designer’s empirical are know-how or expensive and time-consuming experiments [3, 4]. The main reasons are as follows: First, the elastic recovery phenomenon is influenced by a combination of various process parameters, such as the tool shape and dimensions, the temperature change and frictional contact condition, the material properties, and so on. Second, the prediction accuracy by analytical approach is quite low because of the limitation in mathematical modeling of process and solving methods. Of course, such a limitation is resulted from the problem nonlinearity and other process complexities [5].

Fortunately, the advances in numerical simulation techniques, such as the finite element method and the numerical optimization, have been relaxing such a limitation, so that the accurate elastic recovery prediction and the systematic tool design are in a rapid development growth [6, 7]. During the past two decades, number of researchers have investigated and attempted to obtain a basic understanding of spring back behavior [8-17]. In this paper, we intend to investigate the parametric dependence of spring back amount on the major process parameters through the spring back simulation of a plane-strain sheet metal U-bending. For this goal, experimental and numerical studies of the effects of tool geometry and material properties of U-die bending processes have been conducted. Results of the experiments were also compared with those of the finite element simulations.

2. NUMERICAL

Analysis of bending process based on consideration of the plane strain condition is conducted using FE mesh for the axisymmetric continued flat samples. The finite-element computer code (Marc Mentat 2010.1.0 FEM software) was used to simulate strain distribution across the sheet thickness and spring back parameters calculation. Plane-strain quadrilateral four-noded isoperimetric elements with bilinear interpolation were used for this simulation. Fig.1 shows a two-dimensional symmetric finite element model for the numerical simulation, the profile of the die, punch, the initial shape and FE mesh are applied. Four rigid surfaces were used to simulate the punch, die, blank holder, and ejector. The detailed dimensions of tools and material properties are listed in Tables 1 and 2. A finer mesh is generated between the punch and die for increasing the simulation results accuracy.

3. EXPERIMENTAL

The U-shaping stage is carried out with the experimental set-up shown in Fig. 2. This type of set-up was selected for this work so that spring back effects could be obtained simultaneously. Three different materials strips were tested: aluminum alloy, mild steel, and stainless steel sheets of 1.0

mm gauge thickness with die profile radius Rd = 5mm, 7mm and 9mm. Moreover, different values for each of the punch profile radius, Rp, and coefficient of friction between tools and strip with 1.1 ho clearance were used for these experiments. Table 1, shows the mechanical properties of tested materials, and Table 2 shows the tool geometries and forming conditions used in the experiments. The samples were prepared by cutting sheets into strips (rolling direction lengthwise). The final dimensions of the strips were 200 mm^{x}60 mm. Punch travel was stopped automatically after 20 mm to produce samples of the same wall height.

A universal testing machine with a capacity of 300 kN was used for experiments. The tests were performed at a constant velocity. After placing the blank on the die (under the blank holder), the punch holder which was attached to the ram of the machine is moved against the die holder. The bending process was divided into two stages; in the first stage, called loading, the punch moved down until its stroke reached a specific value, 20 mm. In the second stage, named unloading (spring-back), the punch moved up. In U-die bending, the effect of punch profile radius on spring-back was studied for the sheet thickness 1 mm at different values of die profile radius. Also, the effect of materials properties was examined for die profile radius 5, 7 and 9 mm at various punch profile radius; thus 27 tests were totally performed for this die set.

4. SPRING BACK MEASURMENT

The amount of spring back of each blank was measured using spring back parameters of spring back angles $\boldsymbol{\theta_x}$ and $\boldsymbol{\theta_y}$ as shown in Fig.3. The method with which these angles were measured also illustrated in Fig.4.

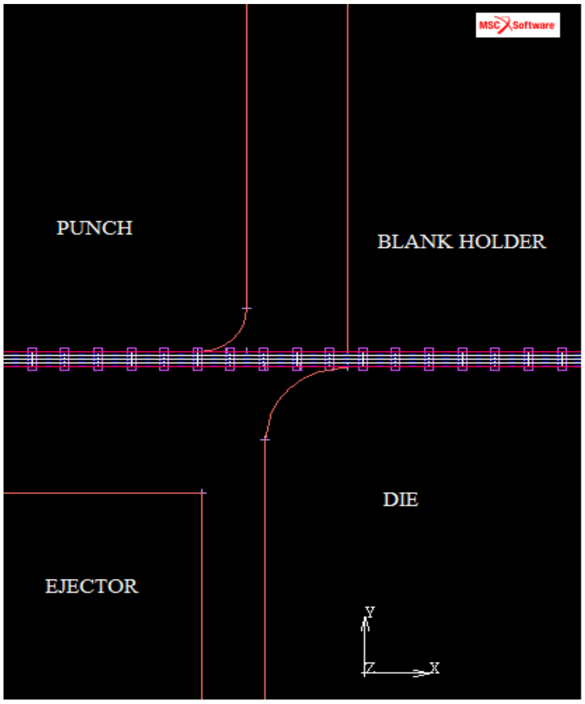

Fig. 1. The initial shape and FE mesh

Nomenclature

FEM	finite element method
BHF	blank holder force
$\mathbf{R_p}$	punch profile radius
$\mathbf{R_d}$	die profile radius
$\mathbf{h_\circ}$	original thickness of strip
C	clearance between punch and die
E	modulus of elasticity
n	strain hardening exponent
r	normal anisotropic parameter
μ	Coulomb friction coefficient
υ	Poisson's ratio
$\epsilon_\circ$	initial strain
$\boldsymbol{\sigma_y}$	yield stress
$\boldsymbol{\theta_x}$	spring back parameter developed in the flange
$\boldsymbol{\theta_Y}$	spring back parameter developed in the wall

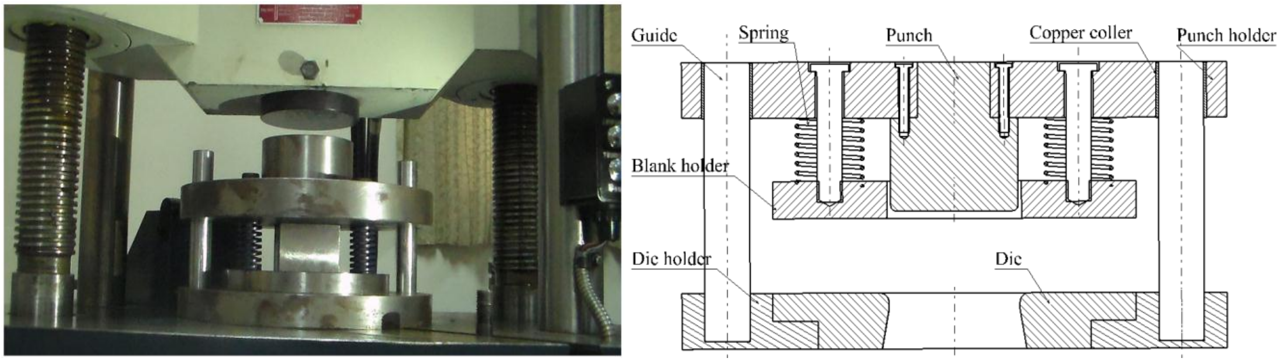

Fig. 2. Schematic and photograph for experimental set-up.

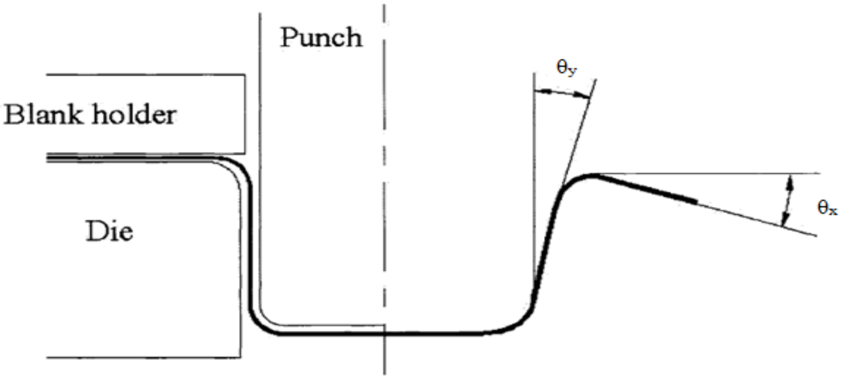

Fig. 3. Illustration of the u-bending process and the spring back angles after unloading.

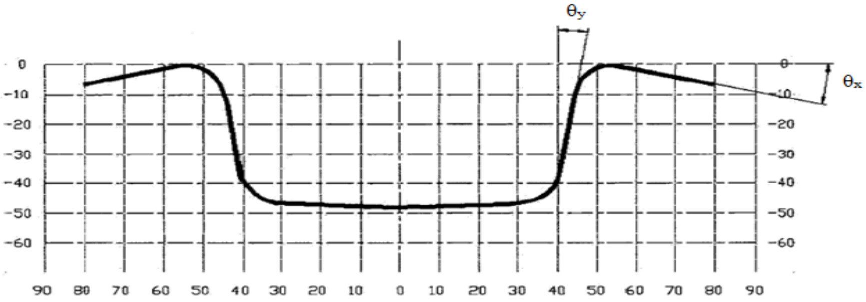

Fig. 4. Schematic illustration of the way used to measure the specimens' spring back angles

Table I
Material properties from experimental tests and used in the simulations model.

Material	Aluminum alloy (SAE 5754)	Mild steel (SAE1008)	Stainless steel (AISI 304)
$h_\circ$(mm)	1	1	1
E (GPa)	71	206	206
σ_y(MPa)	136	178.1	278.2
r	0.65	1.78	1.66
υ	0.34	0.3	0.3
$\epsilon_\circ$	0.017	0.0072	0.0128
n	0.359	0.259	0.218
μ	0.162	0.143	0.128

Table II
Tooling geometries used for the experiments

Punch size (mm)	70x70
Die opening (mm)	72.2
Rp (mm)	3,6, and 9
Rd (mm)	5, 7 and 9
C/ one side (mm)	1.1
Blank holder load(kN)	5.5
Punch travel, YP (mm)	20
μ	0.17

5. RESULTS AND DISCUSSION

5.1. Effect of process variables on the equivalent Von Mises stress and total plastic strain

Figs.5-7 show the effect of the die profile radius and punch profile radius on the equivalent Von Mises stress and total plastic strain for the tested materials. In Figs.5 and 6, the equivalent stress and total plastic strain decreased as the die profile radius increased with punch profile radius =3mm.InFig.7 the equivalent stress and total plastic strain for mild steel increased as the punch profile radius increased with die profile radius =5mm due to the increasing of sheet stretching at punch profile radius.

5.2. Effect of die profile radius on the spring back angle

Fig.8 shows the effect of die profile radius on the spring back angle θ_X at three different values of R_P. It was noted that θ_X inversely preoperational with R_d for the three materials used. Since the amount of the spring back developed in the flange of the deformed part decreased as the R_d increased because of the decreasing of the bent ratio.

5.3. Effect of punch profile radius on the spring back angle

Fig.9 shows the effect of punch profile radius on the spring back angle θ_Y at two different values of R_d. It was noted that θ_Y directly preoperational with R_P for the three materials used. Since the spring back value developed in the wall of the U- bent part increased as the R_P increased.

5.4. Effect of the material properties upon the spring back angle

Fig.10 shows the experimental and numerical effect of material properties on the spring back parameters of the three different materials used. It can be seen that the spring back for stainless steel are higher than those for mild steel. It is noted also that the aluminum alloy shows the highest values of spring back than the stainless and mild steels. This is due to the fact that the yield stress-to-modulus of elasticity ratios for mild steel is greater than stainless steel, and for stainless steel greater than aluminum alloy. Note also that the greater the magnitude of this ratio, the greater the effect on the spring back. In addition, the spring back parameters increase as the strain hardening exponent (n) increase or as the normal anisotropic value(r) decrease. A summary of the above results are tabulated in Tables III and IV for both numerical and experimental models.

6. CONCLUSION

An attempt, based on the experiment and the simulation, was made to explore the effects of material variables and tool geometry on spring back phenomenon in U- bending process. A numerical model based on the updated Lagrangian formulation has been proposed in this paper to calculate spring back in a plane-strain draw sheet forming problem. The model took into consideration the material properties tool geometry. The model implemented using the MARC FE package. For comparison purposes, various results regarding the unloaded shape of the spring back predictions were calculated using the FE computer program .These results were then compared with experimental measurements. The comparison indicated that the numerical model is capable of predicting spring back in 2D draw bending very accurately. Based on this study, the following remarks are drawn.

1. Spring back in the wall of U-drawn section increased with the punch profile radius.
2. Spring back in the flange of U-drawn part decreased as the die profile radius increased.
3. Spring back parameters increased as the strain hardening exponent increased.
4. Spring back parameters increased as the normal anisotropic value decreased.

5. Results from the experimental set-up agree very well with those from the theoretical model.

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Table III
Results from simulation for the investigated materials

	R_p	Mild steel		Stainless steel		Aluminum alloy	
		θ_x°	θ_y°	θ_x°	θ_y°	θ_x°	θ_y°
μ= 0.17 BHF=5550N , $R_{d=}$ 5. Y_p=20	3	2.2	3.4	4.5	4.3	4.9	6.3
	6	2.3	3.5	2.6	5.8	6.4	6.6
	9	2.6	5.2	4.9	8.9	5.1	11.4
μ= 0.17 BHF=5550N , $R_{d=}$ 7. Y_p=20	3	1.9	1.5	2.7	2.3	3.15	2.9
	6	1.8	1.5	2.03	4.3	2.5	4.8
	9	2.1	8.3	3.9	11.7	5.8	15.02
μ=0.17 , BHF=5550N , $R_{d=}$ 9, Y_p=20	3	1.48	2.05	1.5	4.05	1.7	6.2
	6	0.7	4.8	1.17	5.8	1.7	7.5
	9	1.8	6.1	2.8	9	6.4	12.5

Table IV
Experimental results for the investigated materials.

	R_p	**Mild steel**		**Stainless steel**		**Aluminum alloy**	
		θ°_x	θ°_y	θ°_x	θ°_y	θ°_x	θ°_y
μ= 0.17, BHF=5550N, $R_{d=}$ 5, Y_p=20	3	3	3	4	4	4.5	5
	6	3	4	5	6	6	7
	9	2	6	3	7	4	12
μ= 0.17 BHF=5550N , $R_{d=}$ 7, Y_p=20	3	2.5	1.9	3.2	2.8	3.8	4
	6	1.5	2.7	3	3.8	3.1	5.3
	9	2	7.8	2.6	9.8	5	13
μ=0.17, BHF=5550N, $R_{d=}$ 9, Y_p=20	3	1	2.5	1	4.5	2	7
	6	1	3	1	5	1	8
	9	2	6	2	7	6	10

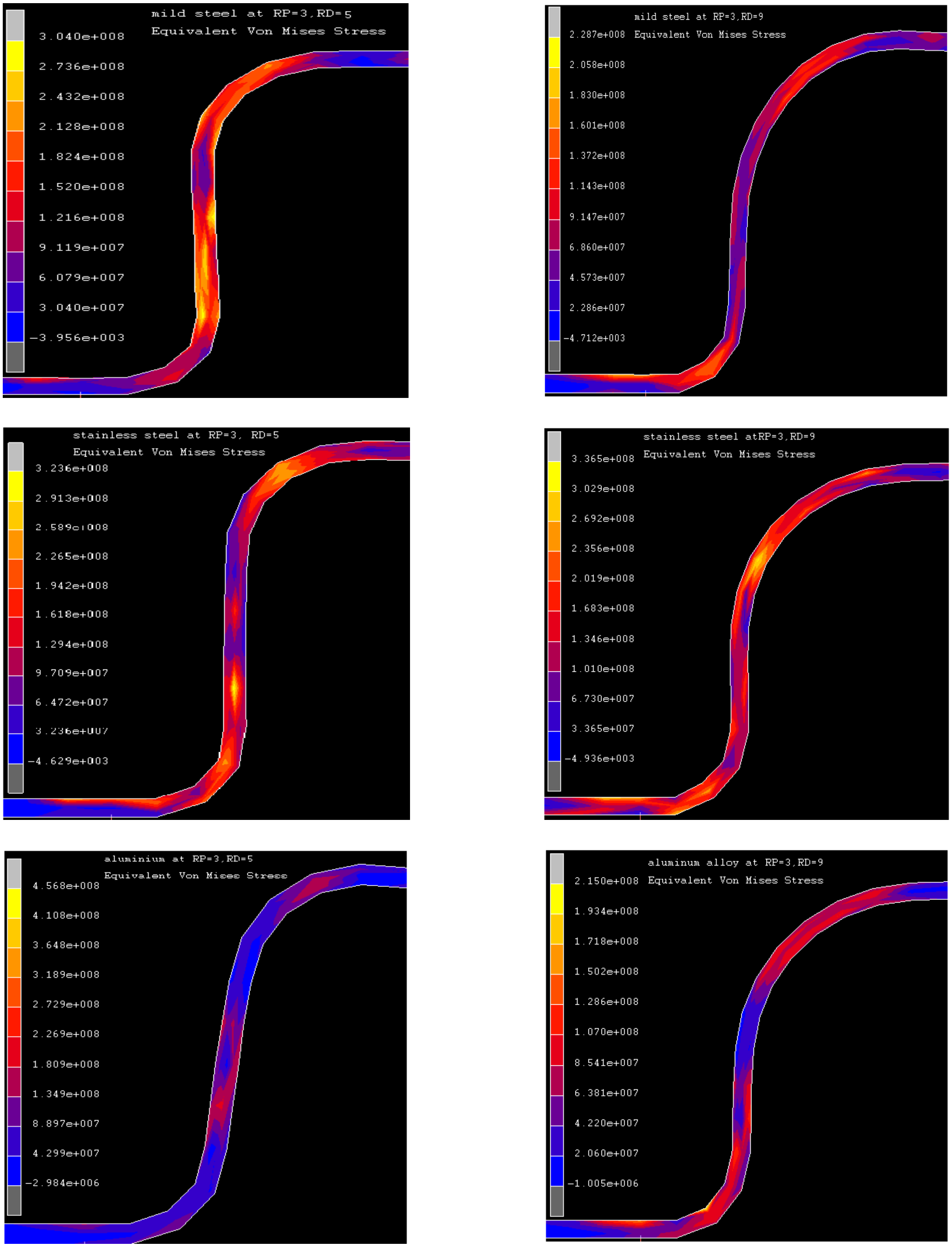


Fig. 5. Influence of die profile radius on the equivalent Von Mises stress, (on left) R_d=5mm, (on right) R_d=9mm, for mild steel, stainless steel and aluminum alloy respectively, at R_p = 3mm.

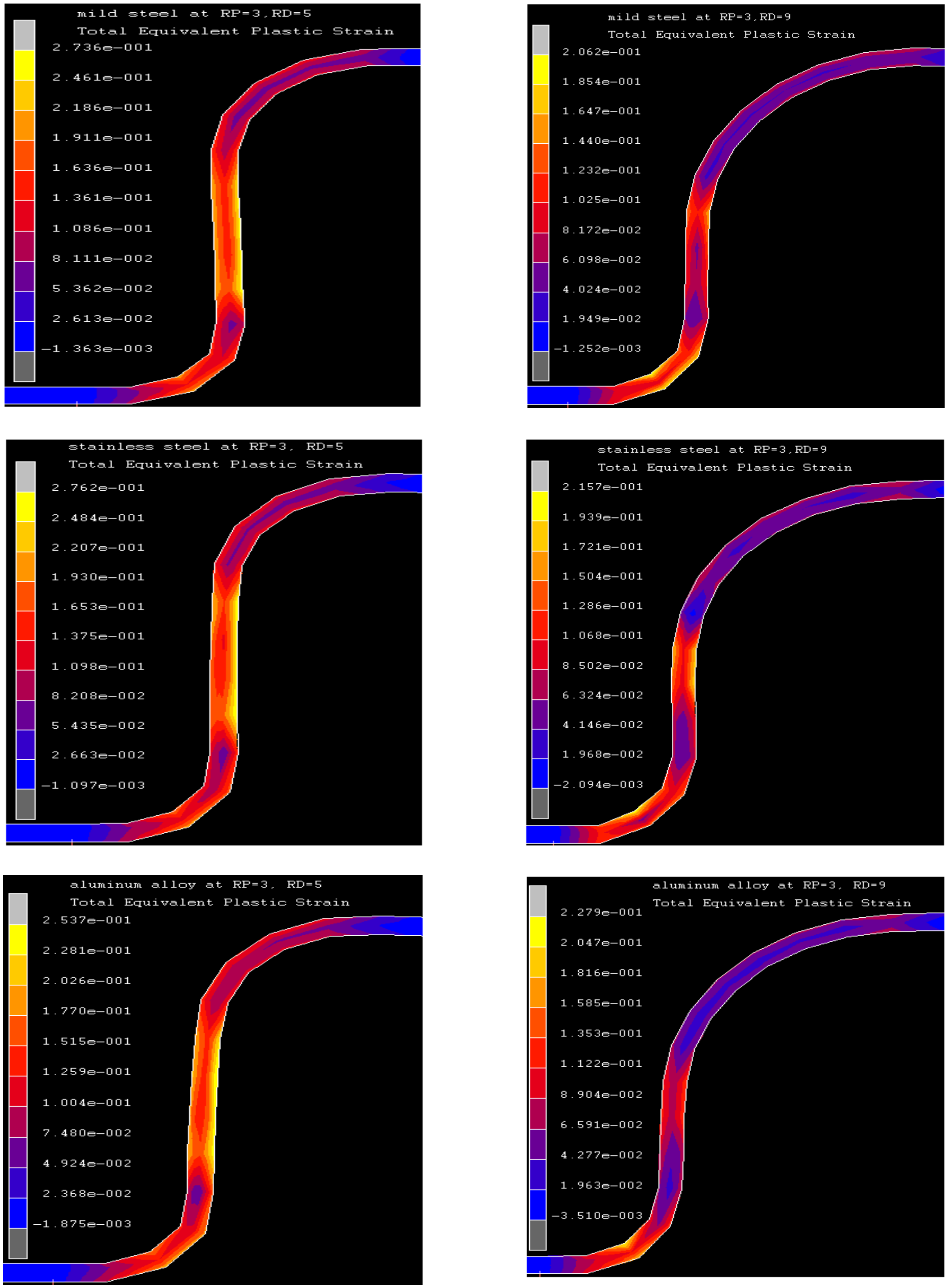


Fig. 6. Influence of die profile radius on the total plastic strain, (on left) R_d=5mm, (on right) R_d=9mm, for mild steel, stainless steel and aluminum alloy respectively, at R_p = 3mm.

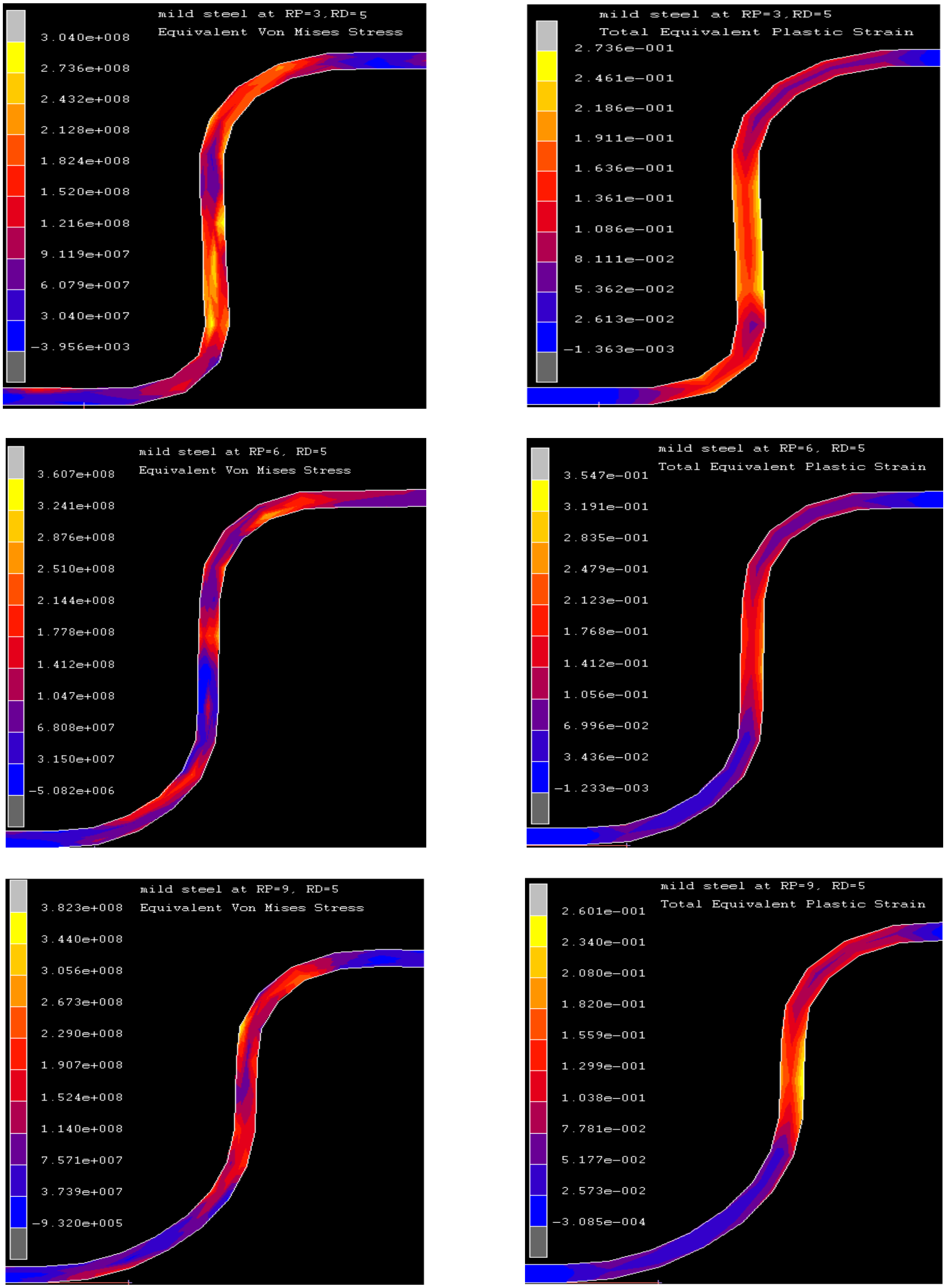
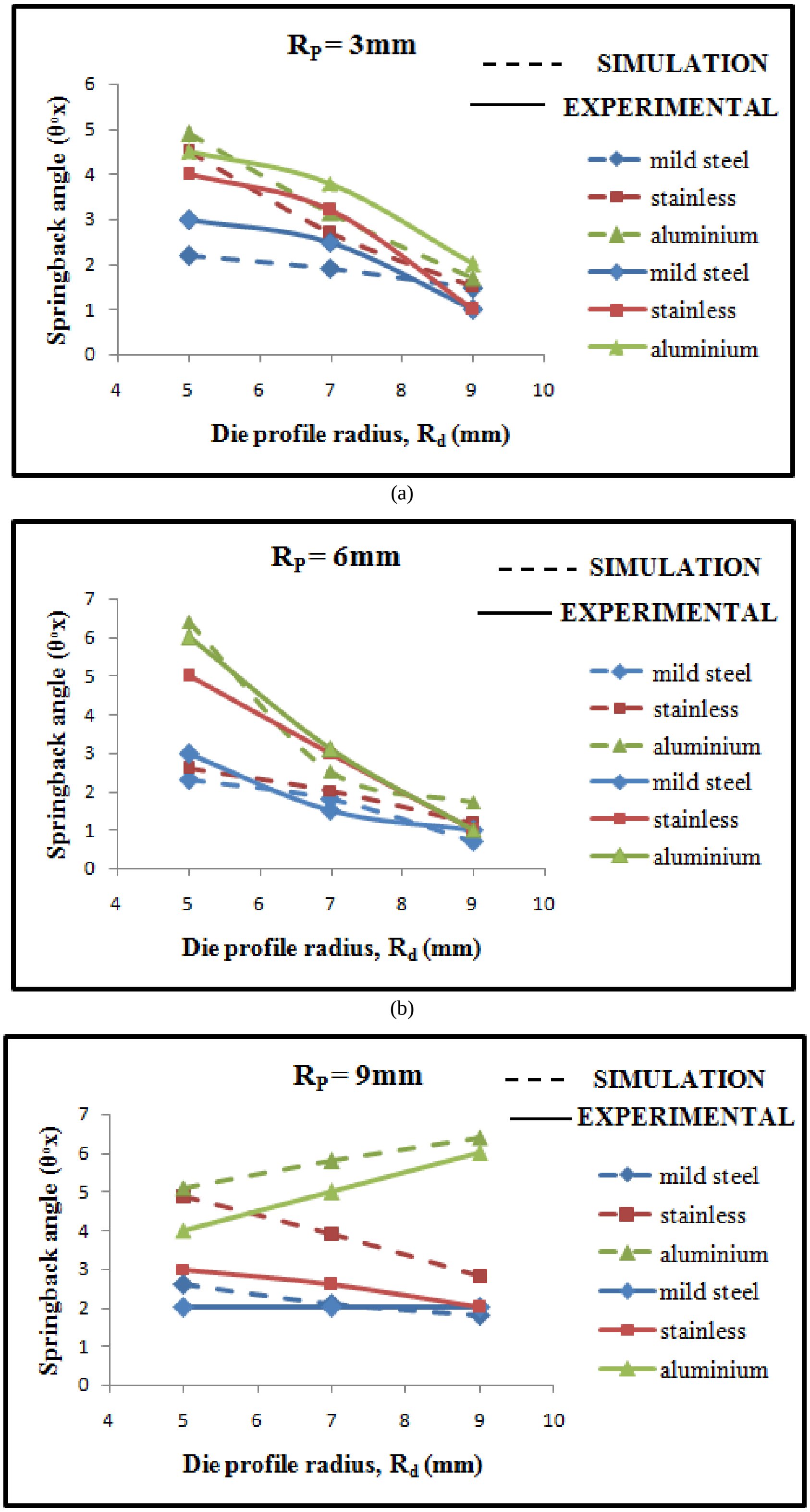


Fig. 7. Influence of punch profile radius on the equivalent Von Mises stress and total plastic strain with R_d = 5mm at BHF= 5.5 KN and µ =0.17 for mild steel.

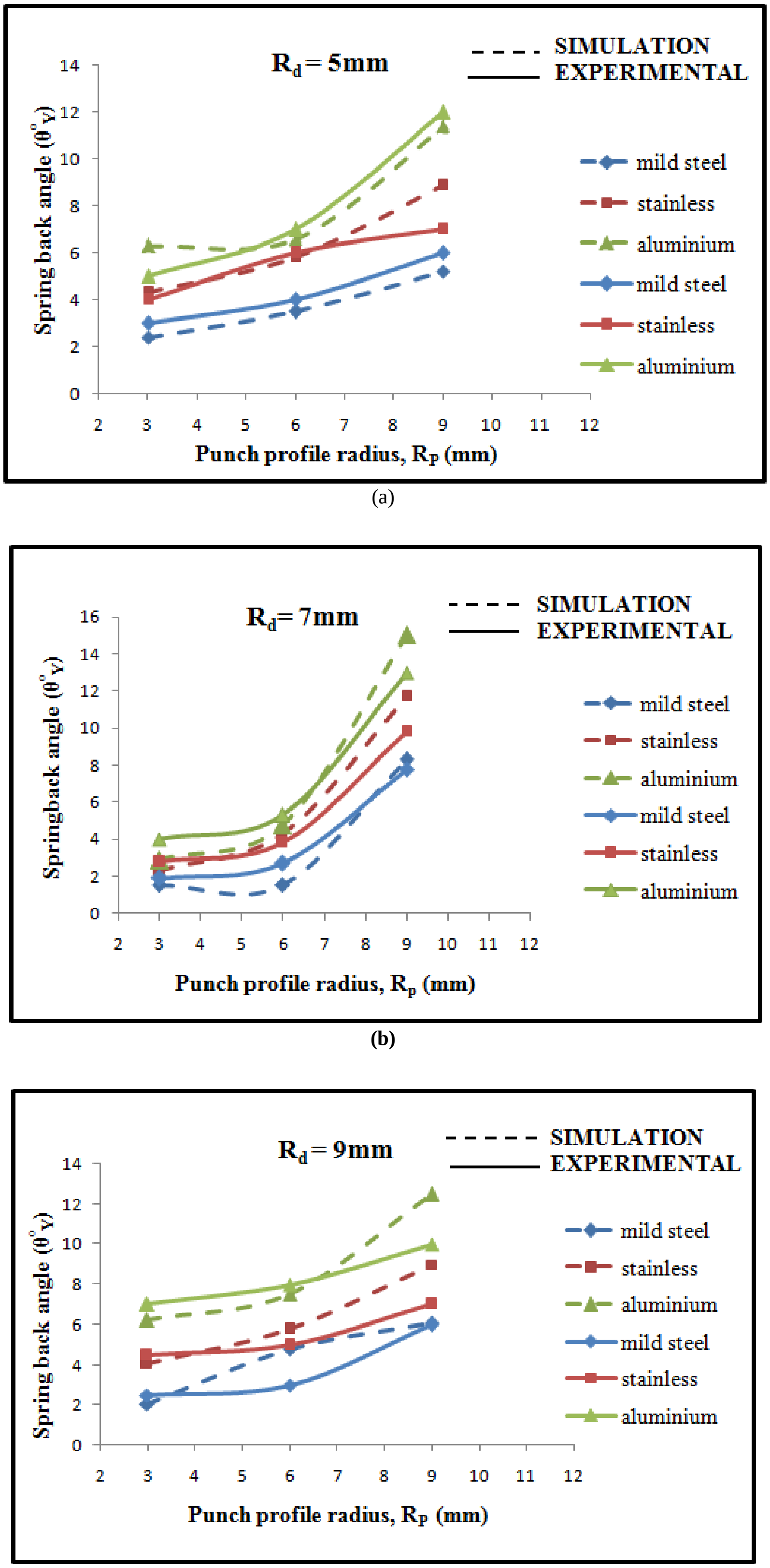


(a)

(b)

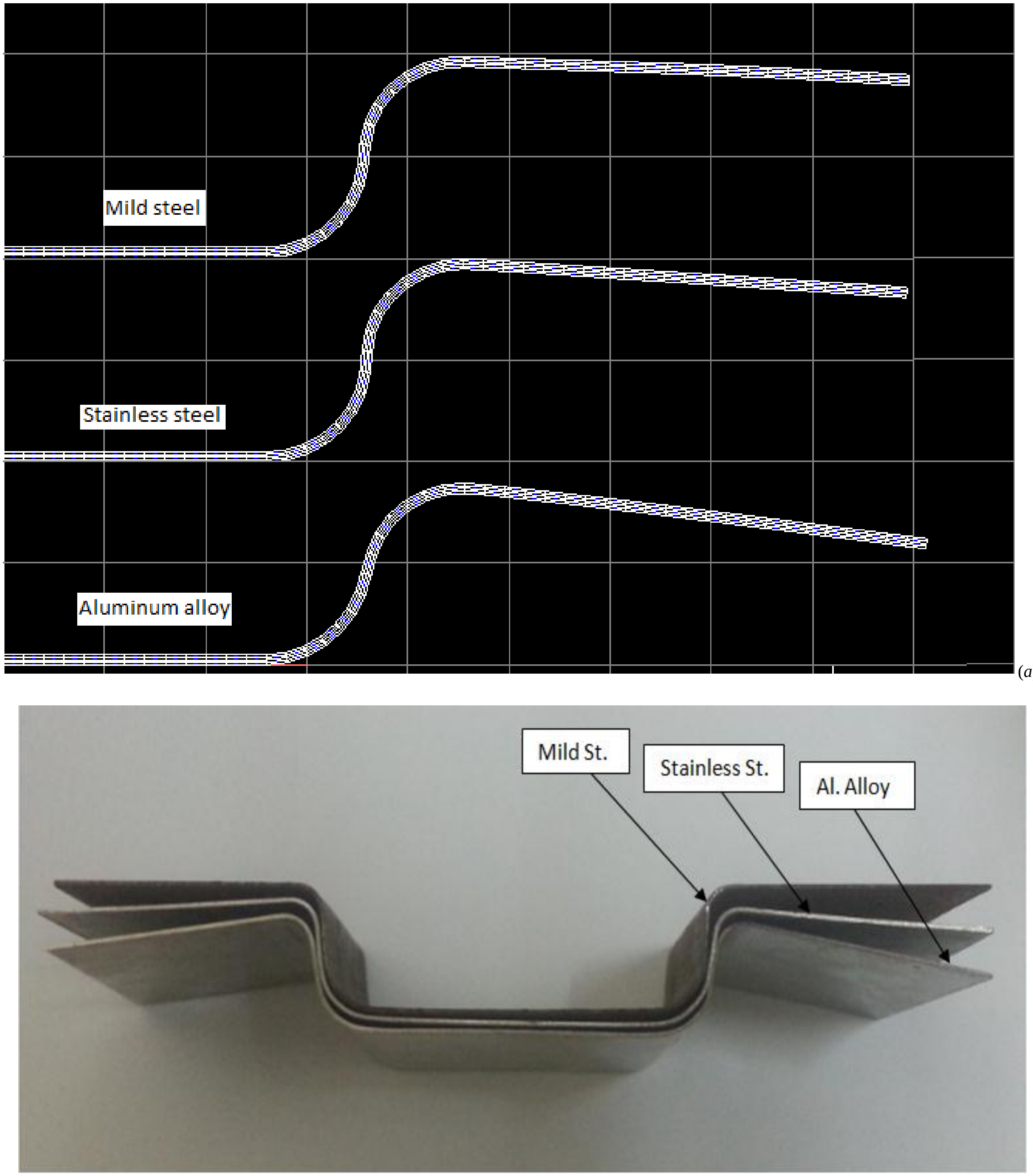
(c)

Fig.8. Effect of die profile radius on the springback angle (θ_X) at different punch profile radii (a) R_P=3mm, (b) R_P=6mm, and (c) R_P=9mm.



(c)

Fig. 9. Effect of punch profile radius on the spring back angle (θ_Y) at different die profile radii (a) R_d= 5mm, 7mm and (b) 9mm.



(*a*)

(b)

Fig. 10. Predicted geometry for the U-shape (a) from the FE in MARC package, and (b) from the experimental results.