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BLANK HOLDER FORCE INFLUENCE ON THE SPRINGBACK OF ADVANCED HIGH STRENGTH STEELS

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Abstract. *Advanced High Strength Steels (AHSS) appear as a good alternative to common steels for reduce vehicle weight and decrease the fuel consumption. Despite the excellent mechanical behavior compared to their lower weight, such materials suffer limitations of manufacturing. The literature shows the springback as the problem that most compromises the mass production of structural components with the use of AHSS. The present study aims to explore computationally the influence of blank holder force on the phenomenon of springback. A computational model has been constructed with the objective of simulate a stamping process in a U-shape form. Different blank holder force configurations and conditions of clearance between the sheet and the blank holder were evaluated. The same tendencies were observed during the experiments for all the analyzed materials, whereas steels with higher mechanical strengths within the same microstructural group showed larger springback. Moreover, it was evident that the microstructure is an important parameter on the problem. It was concluded that the use of higher blank holder force on the final half of process is essential for reduce the problem.*

Keywords: *Springback. Blank-holder force, Advanced high strength steel, Simulation.*

1. INTRODUCTION

The metal forming is an important manufacturing process used in several industrial areas, such as appliances, automotive and packaging. In the vehicle manufacturing, the main application is on the forming of sheet metal components. Due to high competition in the sector and the search for safer vehicles, more comfortable, and innovative design, the mechanical industry was encouraged to develop new materials. Moreover, the growing environmental concern forced the market to produce lighter automotive components with the objective of reducing emission of pollutant gases generated from fuel burning. In this context, appear the AHSS (Advanced High Strength Steel). These steels have higher mechanical strength combined with a good ductility. However, they suffer manufacturing limitations, particularly with regard to springback after stamping.

The formability challenges in industrial applications are the mainly concerns - the joining of the sheets, the tool life and the springback. The latter case, it is pointed out in the literature as the problem that most compromises the mass production of structural components with the use of AHSS. Limitation in predicting the springback in AHSS is mainly due to the difficulty of computationally describes the mechanical behavior of these steels during and after the plastic strain. The justification, which is a consensus among some authors, is that various nonlinear phenomena resulting from microstructural changes that occur during the strain are not well described by approximations and conventional constitutive equations.

In the manufacturing process, the numeric simulation is an important tool to be used during the development of processing strategies - the sizing of the tools and process optimization - offering process time reduction and predictions of results very close the reality. Lajarin *et al.* (2012) performed computational and practical tests in order to verify the approximation of the results from the mathematical model constructed for simulation. In their work, they analyzed the influence of some parameters on the prediction of the experimental results of the springback. One of the most important conclusions of their study, during the practical tests, is that the blank holder force (BHF) shows very significantly influence on the springback effect. The BHF has the capability to restrict more or less slippage of the sheet over the radius of the die - decreasing the stress over the wall specimen.

The main aim of this study is to explore by FE analysis the BHF effect in the springback. Furthermore, the search demands, from the observation of the computational model when compared with the actual process, approximate the predictions of reality by making changes in the structure of the problem. The results obtained in the different configurations are compared in order to verify the magnitude of each influence.

The deep drawing tool used is common in automotive structural components and the model conventionally adopted in the literature was proposed by Makinouchi *et al.* (1993). This tool allows the forming of channels conducting to the occurrence of different forms of springback.

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2. EXPERIMENTAL PROCEDURE AND MATERIAL

It was analyzed by finite element methods the blank holder force variation on the magnitude of springback in samples stamped with the channel profile. The materials tested and the test configurations are shown below.

2.1 Materials

The materials used for the springback simulation was five advanced high strength steel (AHSS) of different grades with thickness of 1.5 mm. These materials are of great interest in automotive industry for body structural parts. The materials constants are summarized in Table 1. The true stress–strain curve was described with the Power Law. The material elasticity properties were assumed to be isotropic and von Mises yield function was used to describe the sheet metal strain. The elastic behavior was defined by the modulus of elasticity and Poisson's ratio.

Table 1. Mechanical properties of tested materials.

	Yield strength (MPa)	Maximum resistance limit (MPa)	Uniform elongation (%)	Total Elongation (%)	Modulus of elasticity (Gpa)
DP350/600-A(1)	395	620	14.9	20.0	206
DP350/600-U(2)	387	605	15.8	23.0	207
DP450/780	488	741	12.7	17.0	205
DP750/980	828	934	7.0	10.4	208
TRIP450/78	548	860	22.6	24.4	206

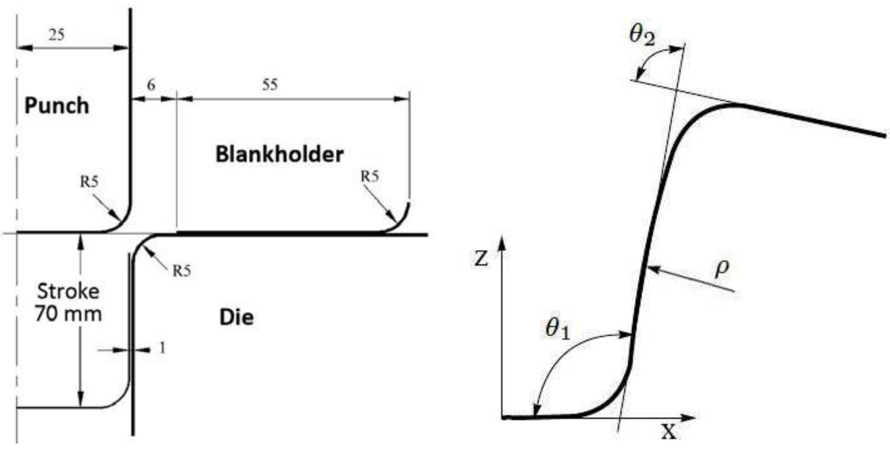
(1) Supplier A; (2) Supplier U.

2.2 FE model

The FE analyses of Numisheet'93 U-channel forming process has been performed in the Abaqus software. The channel geometry and the forming process investigated in this paper were proposed by Makinouchi et al., (1993) (Fig. 1a). This model was used because it can simulate similar forming conditions that occur in the industry. The blank geometry is a metal strip of size 300 x 35 x 1.5 mm. Due to the symmetry conditions, only the half of the tooling and blank were included in the simulations with appropriate boundary conditions, see Fig. 2.

In order to reduce the processing time, shell elements (S4R) with four nodes and six degrees of freedom were used to describe the blank (ABAQUS, 2009). The choice was based on the research of Li *et al.* (2002); Wang *et al.* (2005); Burchitz (2008) e Lajarin *et al.* (2012) and, also, in theories for bending of sheets which are applicable to situations where the material thickness is significantly smaller than other dimensions. The punch, die and blank holder were considered as rigid elements. The computational and process parameters default setting was: punch velocity of 1 m/s, 18 elements in contact with tool radio, friction coefficient of 0.144, 9 integration points through thickness and clearance between punch and die of 1.5t.

Three measurements, namely the springback of wall opening angle, the springback of flange angle and sidewall curl radius - shown in Fig. 1b - has been used to characterize the total springback. It was considered only the cross-sectional shapes of formed parts. The results were recorded in digital imaging with extension BMP (bitmap) and analyzed in the AutoCAD® software - measurements of θ_1, θ_2 and ρ. The measurement of each of these types of springback follows the procedure reported by Makinouchi et al. (1993).



(a) (b)

Figure 1. Numisheet'93 U-channel tool: (a) tool design and (b) springback measured parameters.

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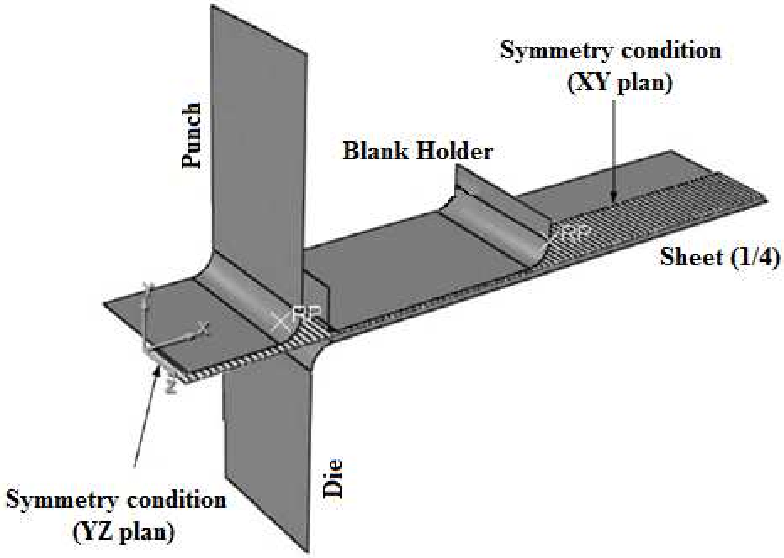
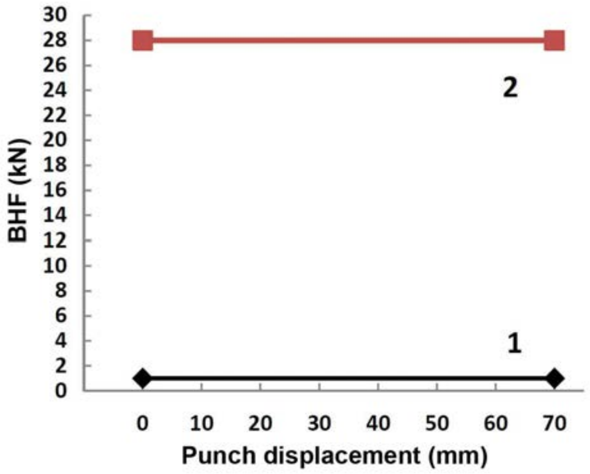


Figure 2. FE model with ¼ of sheet.

Each simulation was divided into two parts: loading (initial forming with dynamic explicit model) and unloading (springback with implicit static model). Regarding the step of unloading, two methods are commonly used, one with the gradual unloading of the tool and the other instantaneous. Studies suggest that the first method is the most realistic but the implementation is impracticable because the computational cost. In the method of instantaneous release of the tool - selected for the present model - a change of the form of the sheet is calculated as an increment. All contact forces were instantly removed, turning into residual internal forces that are induced to zero.

2.3 Load settings

In order to evaluate the influence of the BHF in the magnitude of springback were tested six load amplitudes during the forming process (Fig. 3). In the ranges 1 and 2, (Fig. 3(a)) the BHF is applied constantly during the deep drawing process, 1 to 28 kN, respectively. On the amplitude 3, the BHF is increased linearly from 1 kN, at the beginning of the forming process, until 28 kN, at the end. On the amplitude 4, the BHF is decreased of 28 kN during the beginning of the process until 1 kN at the end (Fig. 3(b)). On the amplitude 5, the BHF is remained as 1 kN until 30 mm of displacement of the punch and increases rapidly until 28 kN, then is kept constant until the end of the forming process. On the amplitude 6, the BHF behaves inversely to case 5, see Fig. 3 (c).



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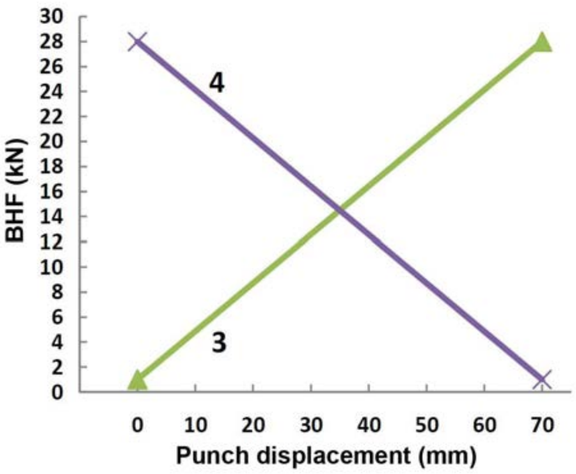

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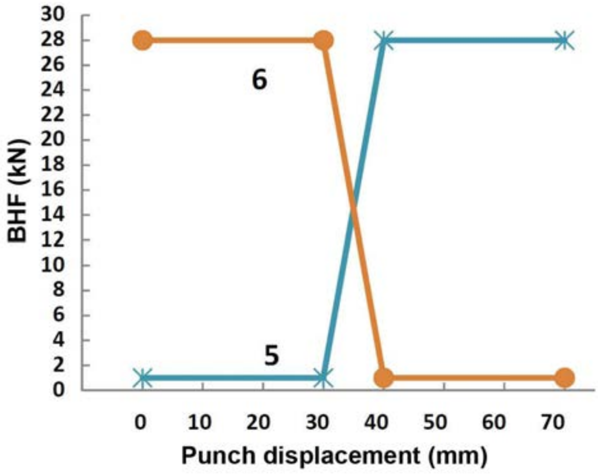


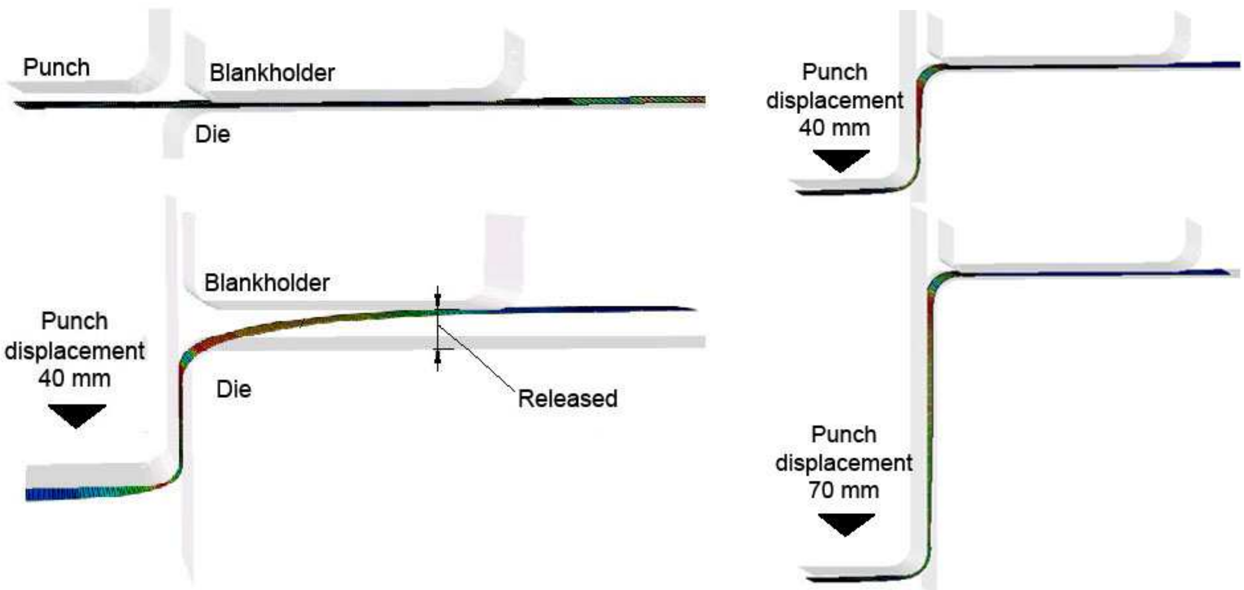
(c)

Figure 3. Six blank holder force amplitudes.

2.4 Blank holder settings

In this work, two blank holder configurations were tested (Fig. 4). At first, the blank holder did not move in the opposite direction of force application. Thus, when the lower BHF was applied (1 kN), the sheet is not pushing the blank holder in the opposite direction. In the second configuration, the motion of blank holder was released in the opposite direction of the force. Thus, when the smaller force is applied, the sheet moves up and pushes the blank holder up, releasing the performance - due to the displacement of the punch. This proposed configuration is based on studies of Yagami *et al.*, 2007 that explored the effect of the clearance between the blank holder and the sheet.

In the setting of blank holder released were tested only the amplitudes 3 and 5 (referred 3#2 and 5#2 in this condition). Only those amplitudes have been chosen because they are the only ones which apply less force at the beginning of the process thereby releasing the blank holder so that the sheet can slid free on the radius of the die. These amplitudes can be seen in Fig. 5.



(a) (b)

Figure 4. Blank holder configurations: (a) released and (b) restricted.

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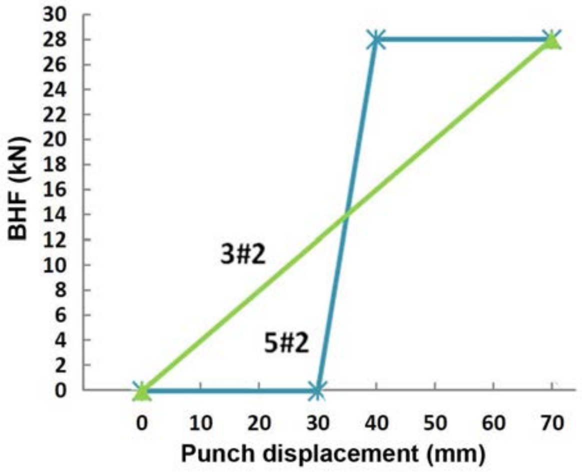


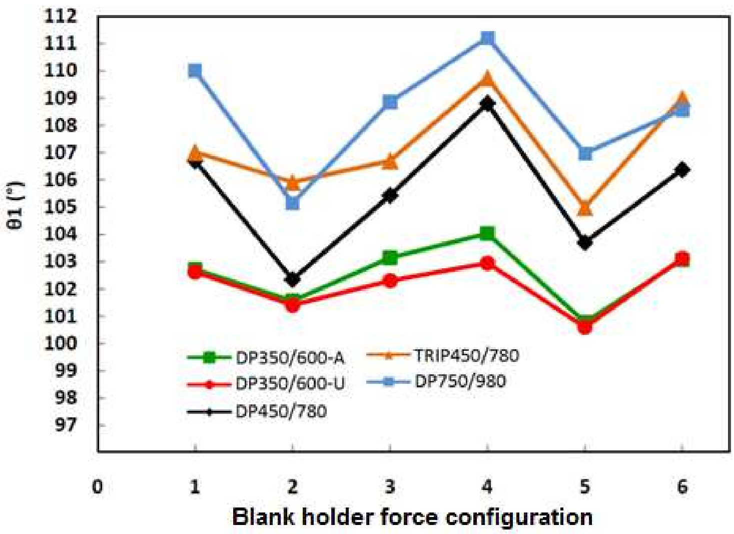
Figure 5. Blank holder force amplitudes with the BH releasing at the beginning of the process.

3. RESULTS

3.1 Restricted blank holder

The springback results obtained with the configuration of blank holder restricted by applying six amplitudes of BHF is illustrated in Fig. 6. In general, the best results were observed for curves 2, 3 and 5 and in such cases the larger BHF was applied at the end of the process.

In relation to angular change on the wall (θ_1), in three of the five materials tested the lowest springback was observed for configuration 5. For steels DP 750/980 and DP 450/780 the most favorable case occurred in curve 2. Configuration 3 is the third best result in all cases. For the angular changes on flange (θ_2) and sidewall curl (ρ), the same tendency regarding the best curves can be observed and in such cases the measured differences are very small, so that these values fall on the range of the error of measurement.



(a)

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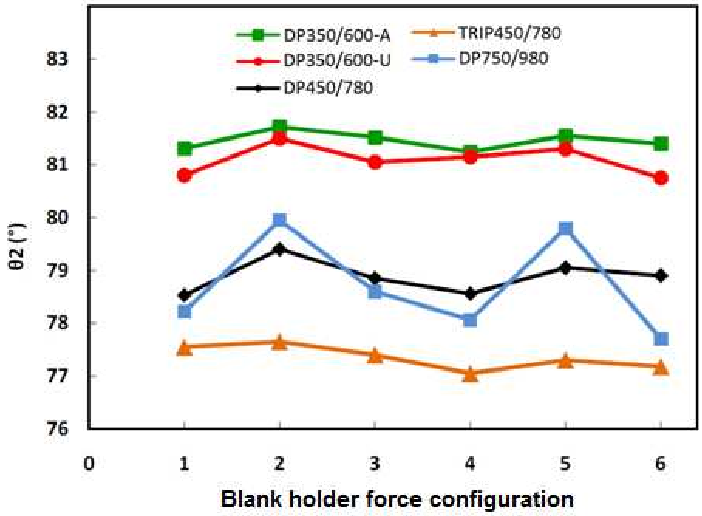

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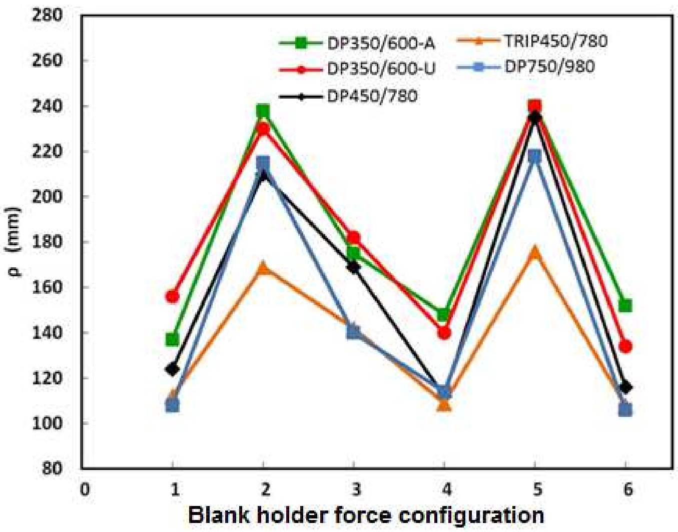

(c)

Figure 6. Springback after deep drawing with five Advanced High Strength Steels under six levels of BHF: (a) θ1, (b) θ2 and (c) ρ.

The behavior of the five materials tested showed similar variation with respect to three types of springback, compared to six levels of BHF studied.

Another behavior that can be observed is the tendency of steels with higher mechanical resistance suffer major damage in springback - by a comparison within the same microstructure group. The DP steel which showed higher levels of springback was DP750/980, followed by DP450/780, and then the steels DP350/600 from different supleiers which have significantly lower levels of springback - mainly for θ1 and θ2.

The TRIP450/780 steel presented mechanical strength smaller than the DP750/980 but showed angular change in the flange (θ_2) significantly larger than the dual phase steel of higher mechanical strength. This fact can indicates an influence of the microstructure effects of the TRIP steel in the springback.

The best results in springback were achieved with the options of BHF curves with higher restriction of the sheet occurring in the final of the process. This behavior shows that the constraint of the corners of the sheet during forming - obtained by the increase of the level of strain imposed in the region of the spokes - induces a biaxial deformation (stretching) in the wall of the specimen and decreases the springback.

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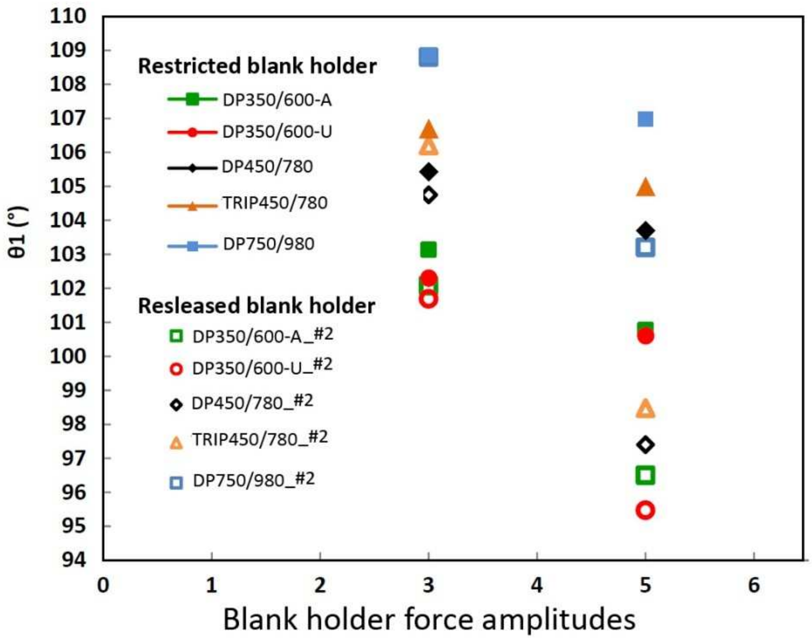
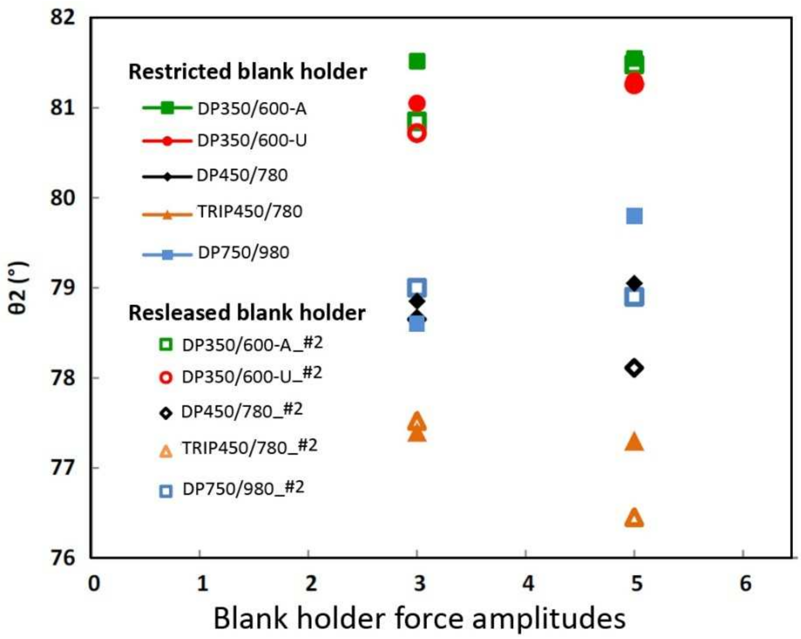
3.2 Released blank holder

The springback results obtained with the configuration of blank holder released are shown in Fig. 7, compared with the results obtained with the condition of restricted blank holder. It can be seen that the results with the amplitude 5 decreased the springback significantly, mainly in θ_1, between 3.78° and 6.43º. The amplitude 3 difference was within the range of measurement error.

In the case of amplitude 5, the force at the beginning of the process is low and remains so until 42% of the process. Because the action of the punch against the sheet the blank holder is pushed in the opposite direction of the force, i.e., getting loose. The release of the blank holder in the initial stage causes the free sliding of the sheet on the radius of the die. After moving the punch 30 mm, the strength of the blank holder increases rapidly to 28 kN, applying large restriction to the sliding of the sheet. This strong restriction induces a stretching of the wall of the specimen and an additional deformation in the bending region - reducing the springback.



(a)



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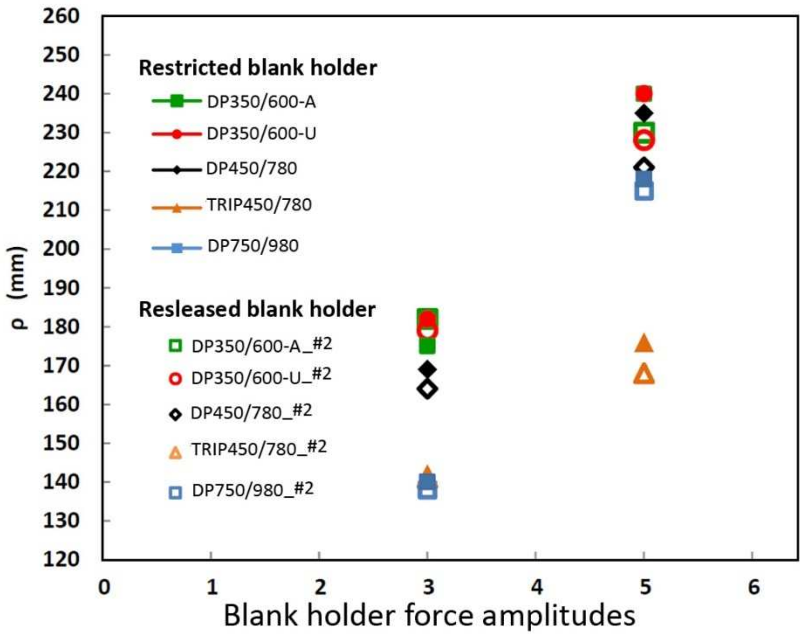
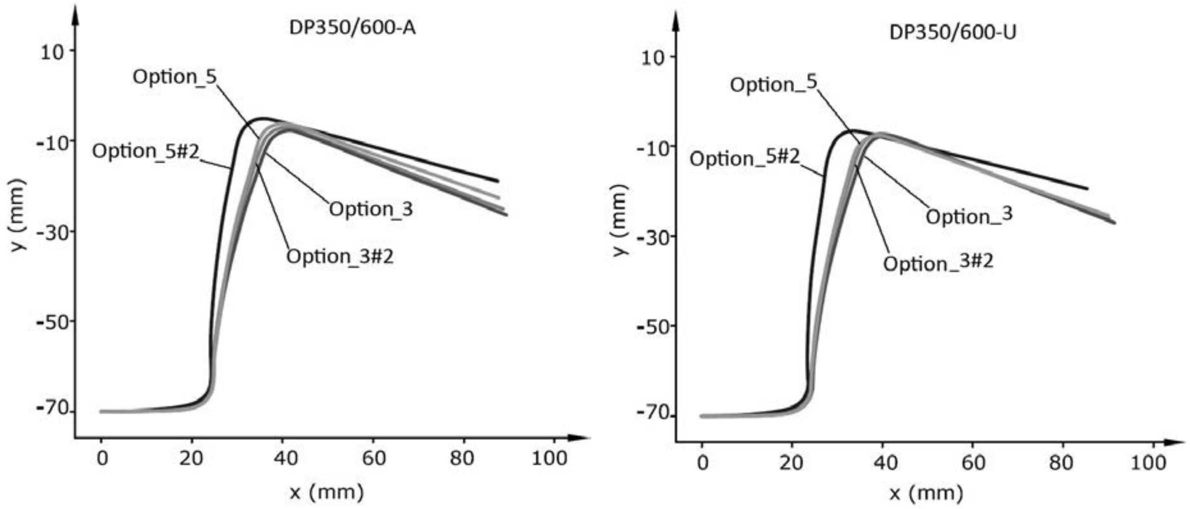


(c)

Figure 7. Springback after deep drawing with the blank holder released and restricted: (a) θ1, (b) θ2 and (c) ρ.

In Fig. 8 it is possible to visually compare the effect of different configurations in the profiles of the sheet tested for each material. In all steels is evident the great improvement of option 5#2.



(a) (b)

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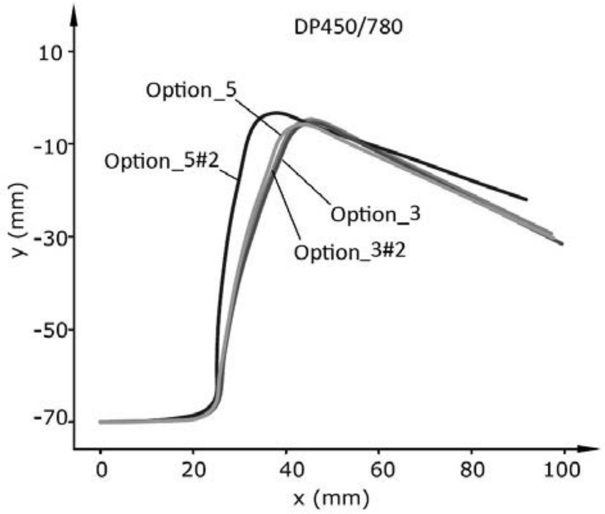

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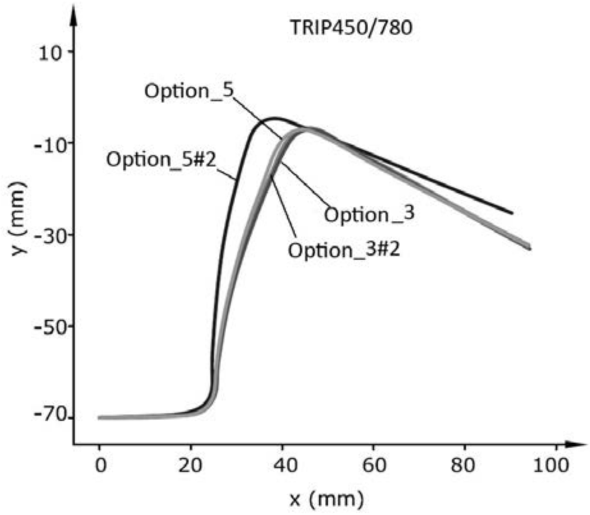

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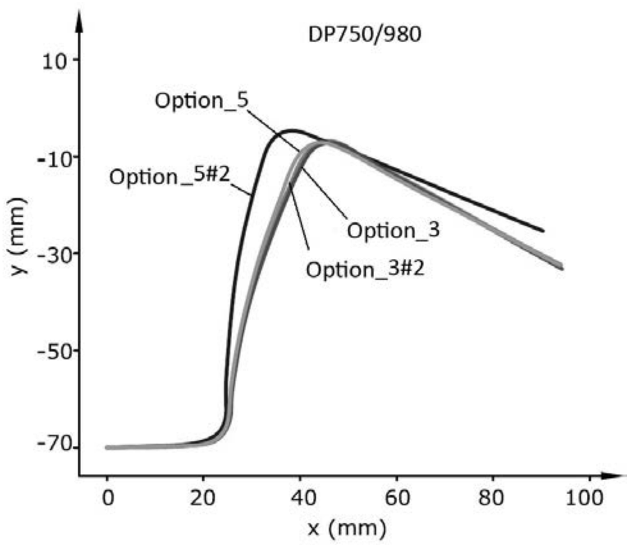

(e)

Figure 8. Springback after deep drawing with the configurations 3 and 5 (with restricted blank holder) and with the blank holder free (3#2 and 3#5).

4. CONCLUSIONS

It was observed that the springback can be substantially reduced by freeing the sheet to slide on the die with the null action of blank holder in the early stages - with high BHF application at the end of the process. This optimal configuration was simulated by setting the course of blank holder - upper limit - for a distance of five times the sheet thickness.

It was concluded that is essential to apply high levels of BHF to around 58% of the displacement of the punch. The similarities between the results of curves 2, 3 and 5 (restricted blank holder) demonstrate the above cited, being considerably better than the others from the viewpoint of improving the three types of springback.

The five AHSS tested materials showed similar trends when subjected to load configurations of tooling of level 1 (restricted blank holder) and 2 (blank holder free). The changes become more sensitive to materials with higher strength when a comparison within the same group of microstructure was made. By other hand, it was observed that in addition to mechanical strength the microstructure significantly influences the springback phenomenon - when it was compared two steels with different microstructures.

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6. RESPONSIBILITY NOTICE

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