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TECHNICAL PAPER

The coining force influence on springback in TRIP800 steel V and L-bending processes

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Abstract The metal sheet forming process is widely used in manufacturing, especially in the production of parts by bending. In recent decades, the increasing competition and growing demand for lightweight, high performance and crash worthiness structures in automotive vehicle forced steel industry, automakers and the scientific community to start focusing on more efficient production. As a result, a significant increase in the application of new materials such as Advanced High Strength Steel and Transformation Induced Plasticity (TRIP) steels has been observed in automobiles over the last decade. Thus, a better understanding of the formability of these materials is necessary to reduce costs and to optimize processes. Among the forming parameters, the springback—dimensional and geometric accuracy—has a considerable influence. In this work were formed strips of TRIP800 steels by V-bending processes to achieve a predetermined geometry with low springback. Among the forming parameters studied, the force applied to the sheet during the bending showed significant influence in springback. Therefore, different coining forces were applied on the radius region in V-bending. It was observed a reduction, elimination and even an advance in the springback for V-bending when higher forces—beyond the necessary—were applied in the process.

Keywords Springback · V-bending · TRIP steel

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1 Introduction

The question for continuous improvement should start in product development and manufacturing. In the development stages, the engineers seek to design the product with satisfactory quality to meet the needs of customers, the expected useful life and ease to manufacture it. In the production stage, the objective is to manufacture the product according to the design specifications and a competitive price. However, at this stage, some deviations that may surpass the ranges established in the project and lead to noncompliance with specifications and dimensional tolerances, surface roughness, interference gaps and assembly may occur. As a consequence of these deviations, we can have an increasing number of rejected products, thus raising the cost of production and the final price.

The automobile industry has fostered great advances in steel metallurgy development over the last years. Earlier, the first cars had thicker sheet metal, basically due to inadequate ferritic–pearlitic sheet steels formability. Environmental requirements, global market and other process led automotive industries to significantly increase the use of ultrahigh strength steels such as Advanced High Strength Steel (AHSS). Among AHSS, the TRIP steels—Transformation Induced Plasticity—go beyond with the effect of retained austenite transformation into martensite during plastic deformation. The high resistance of these new materials allows the use of sheet metal with reduced thickness in automotive components, without compromising safety. That is, without compromising the ability to absorb collision energy and also maintaining the car mechanical resistance during its use.

However, the viability of these materials depends on the knowledge of their characteristics and formability parameters, tool life and springback control. In the production of parts with dimensional and geometrical requirements, the springback has a considerable influence and, therefore, compromises the quality of the shaped product as well as its assembly.

The springback effect on sheet bending process has been the focus of many studies in recent decades. This shows that the consideration of springback is extremely important in industries that manufacture products formed by bending. For many years, experimental methods of trial and error have been used to solve problems arising from elastic recovery in bent parts. The time reduction for the development of new products and the manufacturing cycle cost reduction requirements are the reasons why the empirical approaches are virtually impossible these days. Moreover, the strong interactions of constitutive material parameters, geometrical and operational factors are those that further reinforce the need to investigate the issue. Therefore, although the literature provides a wide publication on the springback and related topics, the subject is not exhausted and there is still available space for research in this area, especially when using advanced high-strength steels such as TRIP and, furthermore, the TRIP steel large hardening capacity attracts special interest for industrial applications. However, there are still many scientific questions which require answers regarding the actual phenomena behind this material behavior such as a better understanding of the martensitic transformation phenomena.

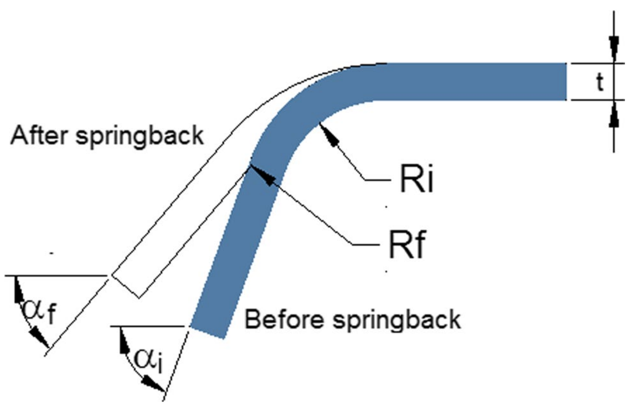


Fig. 1 Springback terminology in bending [1]

The definition of the springback factor for Kalpakjian [1] can be described by the ratio expressed in Eq. 1, where: T, α_f, α_i, R, R are illustrated in Fig. 1 and the K_s is the springback factor.

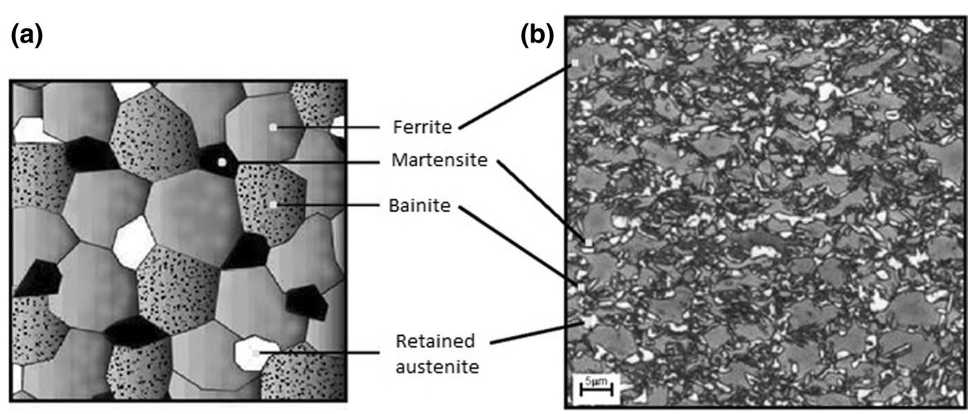
$$K_s = \frac{\alpha_f}{\alpha_i} = \frac{2R_i/T + 1}{2R_f/T + 1} \quad (1)$$

Wassermann and Burchitz [2] noted that it was possible to obtain high values of elongation during mechanical tests on Fe–50 %Ni, calling the phenomenon "*Umwandlungsplastizität*". In this work, it was noticed an increase of plasticity as a consequence of austenite–martensite transformation. Zackay et al. [3] described how the transformation of austenite to martensite promotes increased ductility in austenitic steels of high strength and thus called this phenomenon as TRIP.

According to Bleck et al. [4], the term "assisted steels by TRIP effect" is being used to describe multiphase steels consisting of a polygonal ferrite matrix, bainite, martensite and a significant amount of retained austenite—with a minimum volume of 5 % (Fig. 2).

For Benson [7], bending is a more versatile and economical forming process due to the possibility of obtaining any angle between 0° and 180°. Bended parts not only produce functional geometries such as edges, flanges, bends, splices and corrugation, but can also increase the components structural stiffness—increasing the transverse moment of inertia. Currently, laminated profiles are being replaced, where necessary and possible, by elements of bended sheets. These sections are generally made in bending machines but when the elements are relatively short the forming can be performed advantageously by means of dies and presses, Fig. 3a. To Altan et al. [8], bending is one of the simplest processes to forming a sheet steel, consisting of performing a linear bending. Plastic strain occurs only at the bended region and the remaining material does

Fig. 2 Micrograph of TRIP steel: **a** schematic [5] and **b** TRIP 780 steel with 18 % of retained austenite [6]



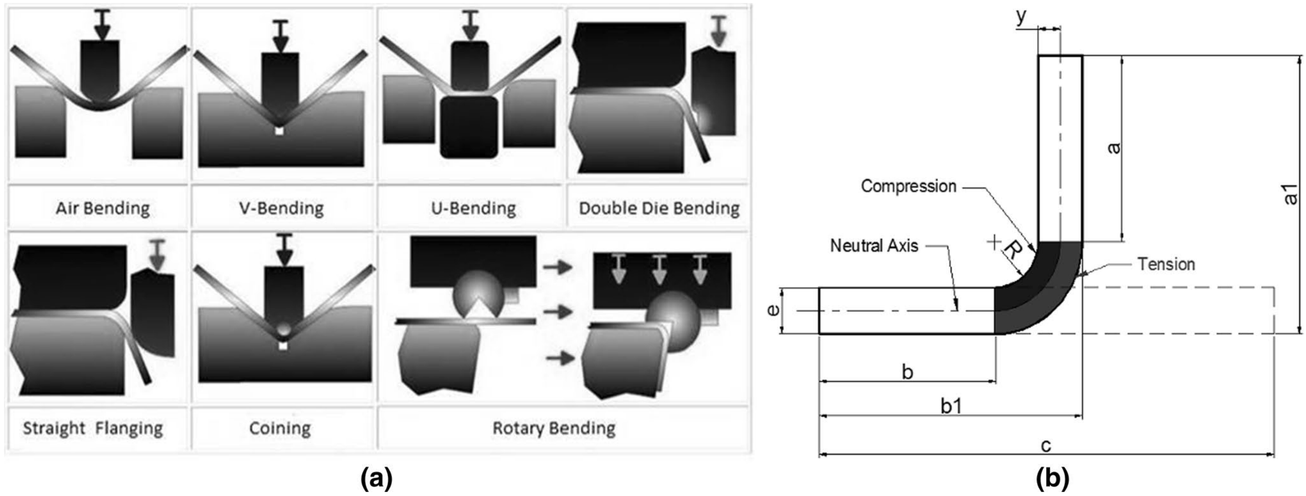


Fig. 3 Bending process: **a** types of bending [8], **b** bended part and neutral axis representation

not undergo any plastic strain. Analyzing the bended part, the outside region is tensioned and the inner part is compressed. Figure 3b shows the compressed and tensioned side and the neutral axis of a bended part. The neutral axis is the one that after the bending process remains with the same length and the tensile strain on the outer surface is equal to the compressive strain in the inner surface [9].

The process variables on V-bending steel sheet were discussed by Huang and Leu [10]. They investigated the process with a model which predicts the correct punch load for bending and the precise products final shape after unloading in relation to the material tensile properties and the tools geometry. The process variables were the punch radius, die radius, punch width, punch speed, friction coefficient, strain hardening exponent and the normal anisotropy (or Lankford *r* value).

Fei et al. [11] investigated the effect of the unloading apparent modulus variation on springback prediction during the TRIP steels V-bending. The relation between unloading apparent modulus and strain was defined by a linear equation and it was imputed to ABAQUS by USDFLD subroutine.

Tiryaki et al. [12] studied the ratio effect between the die radius and the sheet thickness on the springback angle. The main observation they have obtained from the experiments was that after a certain level of springback the effect increases as the *R*/*t* ratio increases. Thipprakmas [13] also reported an investigation by simulating the die radius effect and blank thickness on the springback angle during the flanging process. They used an identical *R*/*t* ratio proposed by Tiryaki et al. [12], i.e., ranging from 1.0 to 5.0. The main observation was almost the same and the simulations were validated using the experimental data reported by Tiryaki et al. [12].

Thipprakmas and Phanitwong [14] used Taguchi technique for the process parameter design of springback and spring-go during V-bending process. In this work, three processes parameters, namely, bending angle, material thickness and punch radius were investigated. The finite element method (FEM), in association with the Taguchi and the analysis of variance techniques (ANOVA), were also carried out to investigate the degree of influence of the parameters process in V-bending. In their work, they reported the importance of parameters process in V-bending on the springback and spring-go.

Chikalthankar et al. [15] reviewed various parameters that can affect springback such as punch angle, material grain orientation, die opening, ratio of die radius to sheet thickness, sheet thickness, punch radius, punch height, coining force and the strip pre-bend condition.

2 Experimental procedure

The TRIP800 steel has been selected. The specimens with 100 mm × 15 mm were cut by guillotine and the burrs were removed by hand files. The mechanical properties and thickness are shown in Table 1.

Table 1 Mechanical properties and thickness

Material	Thickness (mm)	Yield strength (MPa)	Ultimate tensile strength (MPa)	Total elongation (%)	Young's modulus *E* (GPa)
TRIP800 Steel	2.0	548	860	24.4	206

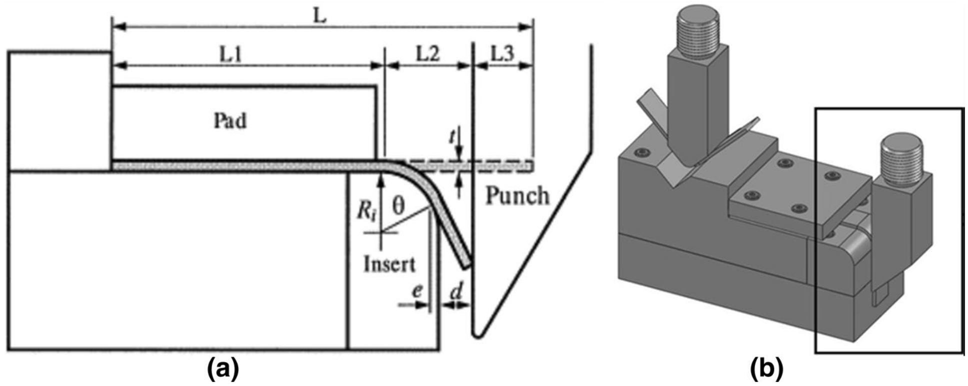


Fig. 4 L-bending setup: **a** the tooling setup [16] and **b** experimental tool

In the present study, the TRIP800 steel springback effects resulting from the V-bending and L-bending processes were evaluated. Among the forming parameters studied, the force applied to the sheet after the bending showed significant influence in springback. For the sake of clarity, all the data are discussed separately for each one of the bending processes.

The bending experiments were performed in a universal tensile testing machine—EMIC model DL10000 (10 tons). The punch was fixed on the crosshead machine on thread M24 × 2 mm. Thus, it was possible to perform the measurement of the bending force and displacement of the punch during the bending process. Figure 4a, b schematically shows both tooling and fixture proposed for the L-bending process.

The bending angle before the springback return can be determined by Eq. 1, where the values of L2 and L3 are defined in Fig. 3. The t parameter is the sheet thickness and R_i is the die radius. Subtracting this value from the angle after the springback in each test, the resultant springback can be determined.

$$L2 \times (1-\cos\theta) - L3 \times \cos\theta + (R_i + 1/2 \times T) \times \cos\theta - R_i \times \sin\theta = 0 \tag{2}$$

Specimens of TRIP800 steel, all of them 100 mm long, 12 mm width and 2 mm thick were bent. The samples were positioned between the die and the blank holder (pad). The punch with a radius of 2 mm was downwardly moved 50 mm, bending the sheet at an angle of approximately 90°—die radius (R_i). Subsequently, the punch was moved upward and the sample was released generating the springback. The used die radii were: $R_i = 5$ mm, $R_i = 10$ mm, $R_i = 15$ mm and $R_i = 20$ mm and the set of fixed parameters is shown in Table 2.

Table 2 Set parameters used in straight flanging

Temperature	~20 °C
Lubricant	EP oil
Roughness between punch/die	$R_a = 1.6$ μm
Punch speed	60 mm/min
Clearance between punch/die	1.5 × t

Figure 5 shows the steps of the L-bending process. At the beginning, the punch moves down and makes contact with the sheet (a), starting the application of force to perform the bending process (b), after unloading (c) and the obtained springback (d).

The V-bending tool is illustrated in Fig. 6. The punch is exchangeable enabling the bending radius variation and it was fixed in the place of the movable holding grips of the tensile machine allowing the forces monitoring during the process.

The fixed parameters are the same as the L-bending process (Table 2). This bending experiment was assessed using a factorial experiment, as follows: factor A being the maximum force with three levels ($F1$, $F2$, $F3$)—three different coining forces—and factor B being the punch radius with four levels (no radius, 2.5, 5 and 10 mm) as in Table 3.

After each test, the springback angle was measured with an AROTEC profile projector Model PA300-AB. The angle measured in degrees, minutes and seconds was converted into decimal degrees.

The samples for metallographic analysis were extracted from the curvature of the hinge region, as shown in Fig. 7. The samples were prepared with the aid of a metallographic cutter. The techniques used for the metallographic preparation followed the standard testing procedures, ASTM E 3-10 (2007): cutting the sample in the region to be analyzed, hot phenolic resin inlay (Bakelite) under controlled pressure and temperature conditions, grinding using abrasives papers with different particle size and polishing.

The samples were immersed for a few seconds in an appropriate reagent for revealing the microstructure (Table 4).

Le Pera [17] proposed the use of a reagent obtained by mixing two pre-prepared solutions—(sodium metabisulfite and 1 % picric acid 4 %) and (10 mL of 1 % sodium metabisulfite and 10 mL of Picral 4 %)—to reveal the martensite and bainite present in the microstructure of low carbon

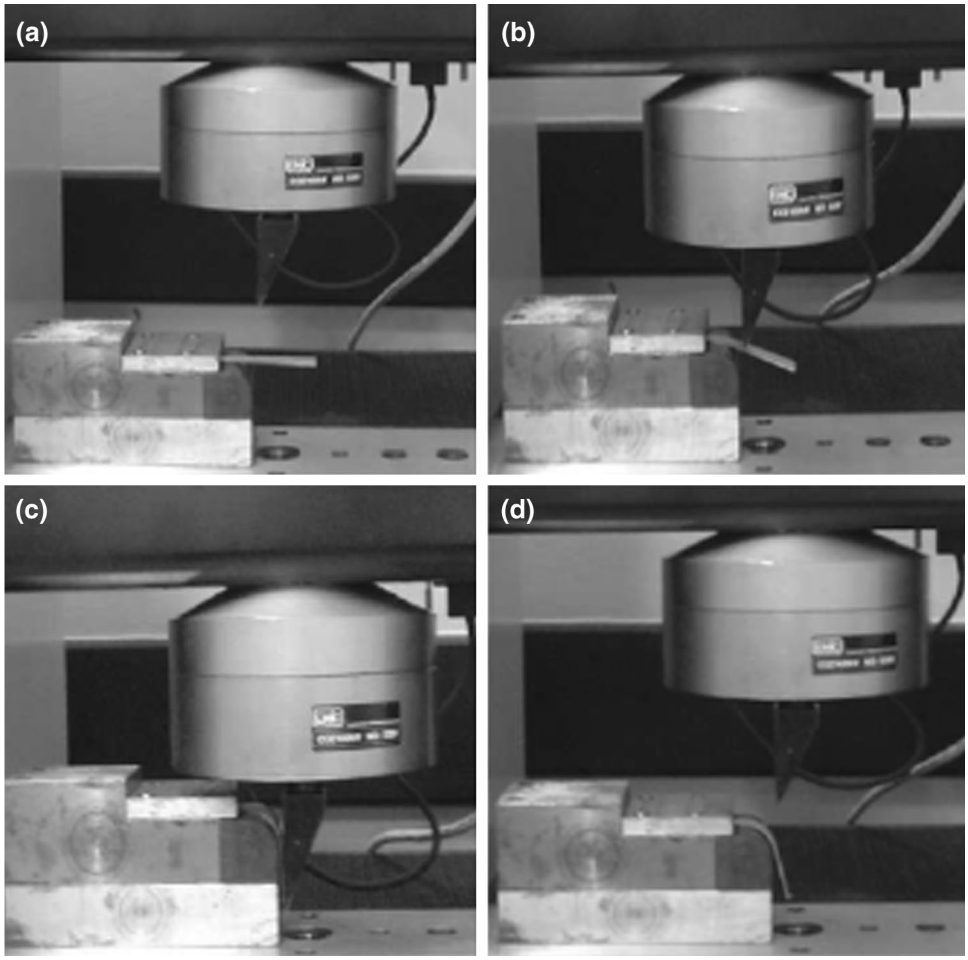


Fig. 5 The sequence on L-bending: **a** initial bending, **b** intermediate bending, **c** final bending and **d** springback

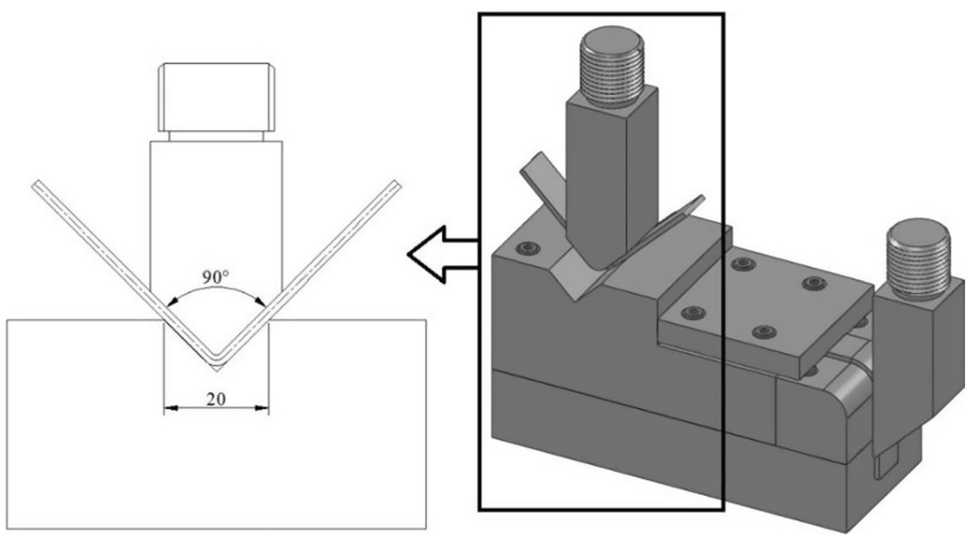


Fig. 6 Experimental V-bending setup

steel. However, Salemi and Abdollah-Zadeh [18] suggested variations of this reagent as shown in Table 4, which was used in this work and called modified LePera.

Nital reagent was also used to etch the surfaces of the samples, as reported in Table 5. The concentration used was 4 % (4 mL of concentrated 65 % nitric acid and 96 mL

Table 3 Experimental test plan (2 variables)

Test number	Processes variables			
	Replication	Punch radius (mm)	Force/width (N/mm)	
			Steel	
			Forces	TRIP800
1	(1), (2), (3)	0 (no radius)	F1	170
2	(1), (2), (3)	0 (no radius)	F2	360
3	(1), (2), (3)	0 (no radius)	F3	600
4	(1), (2), (3)	2.5	F1	170
5	(1), (2), (3)	2.5	F2	360
6	(1), (2), (3)	2.5	F3	600
7	(1), (2), (3)	5	F1	170
8	(1), (2), (3)	5	F2	360
9	(1), (2), (3)	5	F3	600
10	(1), (2), (3)	10	F1	170
11	(1), (2), (3)	10	F2	360
12	(1), (2), (3)	10	F3	600

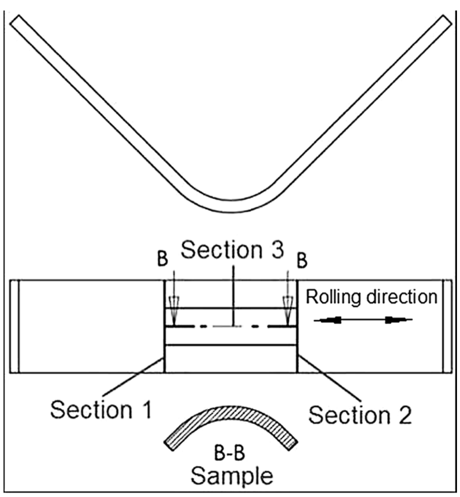


Fig. 7 Extracted section of the test samples for metallography

of ethyl alcohol 95 %). After each etching, six fields of each sample were photographed using a magnification of 1000×. However, in some situations, it was obtained images with the use of lower magnifications of 500×, 50× and 10×, to have a wider view of the material microstructure and the neutral bending line. The images were captured in regions of the neutral axis, compressed and tensioned areas of the samples.

3 Results and discussion

Initially, the results of the L-bending tests are presented. In Table 6, the measured values of springback and the calculated values of springback factor (K_s) for the average of three replications are shown.

In Fig. 8, the TRIP800 steel curve obtained during the L-bending process was shown. In this curve, there is the relationship between springback factor (K_s) and die radius. Note that the smaller the die radius was the springback factor was nearest 1, that is, less springback.

The data of the force and displacement during the L-bending process were obtained from the universal testing machine using the compression module, as in Fig. 9. It can be observed that for all the curves a peak of force appeared near the end of the curvature—lower tangent of the die radius.

In Fig. 10a is shown a graph with the results of maximum forces during the L-bending process. In this figure, trend curves were plotted and established a polynomial relation between the maximum bending strength and die radius, evidencing the strength bending reduction when the die radius was increased. In Fig. 10b, the relationship between the forces measured during bending and springback for TRIP800 is presented. In all cases, when higher bending strength was used, it was observed lower springback. It was also plotted a trend line allowing to obtain a polynomial relationship between springback and bending force.

Table 4 Etching procedure

Material	Etching	Time of etching (s)	Method of etching	Drying
TRIP800 steel	LePera (modified)	50	Immersion	Hot air
TRIP800 steel	Nital 4 %	5	Immersion	Hot air

Table 5 LePera (modified) reagent composition

Solution 1	Solution 2
Picral 4 %: 4 g of picric acid and 100 mL of alcohol	Sodium metabisulfite: 1.5 g $Na_2S_2O_5$, 100 mL of distilled water
1:1 ratio	

Table 6 Springback results: straight flanging of TRIP 800 steel

Clearance = (*t*) thickness	Average (3 replication)		*R*/*t*
Die radius (*R*)	Springback (°)	K_s	*t* = 2 mm
5	7.6	0.92	2.50
10	10.3	0.89	5.00
15	13.2	0.85	7.50
20	16.2	0.82	10.00

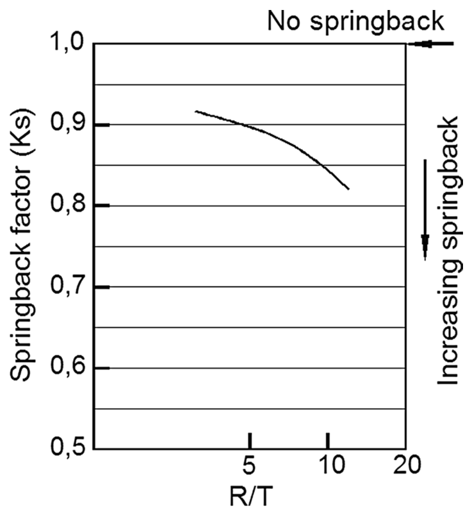


Fig. 8 Springback factor (K_s) for TRIP 800 steel by L-bending, A factor of $K_s = 1$ indicates that there is no springback

Figure 11 shows V-bended (90°) samples of TRIP 800 steel using punch radius of 2.5 mm (a, b, c) and with no punch radius (d, e, f). Just by varying the post-bending force (3 different values), it is possible to observe that the bending with no radius punch showed a greater variation of springback compared with the sample formed with the punch with radius of 2.5 mm. Figure 11g–j shows bended parts with applied post-bending force of 600 N/mm and bending radius of 10 mm (g), 5 mm (h), 2.5 mm (i) and with punch without radius (j). It is possible to notice, in sample g, that the angle after the bending is bigger than 90°, i.e., showing springback and for the sample j the angle of bending is smaller than 90°, i.e., showing spring-go.

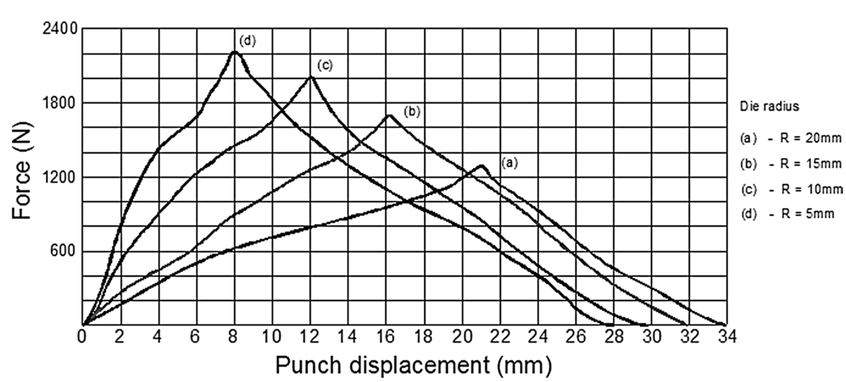
Table 7 shows the data of the V-bending (90°) samples of the TRIP800 steel. Springback values and calculated values of springback factor (K_s) were measured for each specimen and also the average of the results is also presented. The results show that the higher the coining force the lower the punch radius is, also greater the springback factor thus reducing the springback. There were situations whereby the angle becomes smaller, the springback factor was >1 which is called negative springback or spring-go.

Figure 12a shows the tensioned and the compressed area and the neutral axis region of the TRIP800 steel. This steel shows a refined microstructure with basically four phases: bainite, martensite and retained austenite in ferritic matrix. In the neutral axis region, Fig. 12b, it is possible to notice practically no presence of martensite (black color). And that is because this region is a transition zone between the compressed and tensioned zone and no stress/strain during bending was present—without strain the transformation of retained austenite to martensite cannot occur. In the compressed region, Fig. 12c, it is possible to see that part of the retained austenite was transformed into martensite (black color). Next to the bright areas, it is possible to notice this feature. In Fig. 12d, in the region that was tensioned during the bending, it was noticed an increased presence of martensite compared to the compressed region. In this area, apparently all the retained austenite was transformed into martensite.

4 Conclusion

The increase in strength during the L-bending process was obtained by reducing the die radius—promoting lower springback. During V-bending, coining forces in the punch radius region were applied. This caused strain

Fig. 9 L-bending tests results: force vs. punch displacement



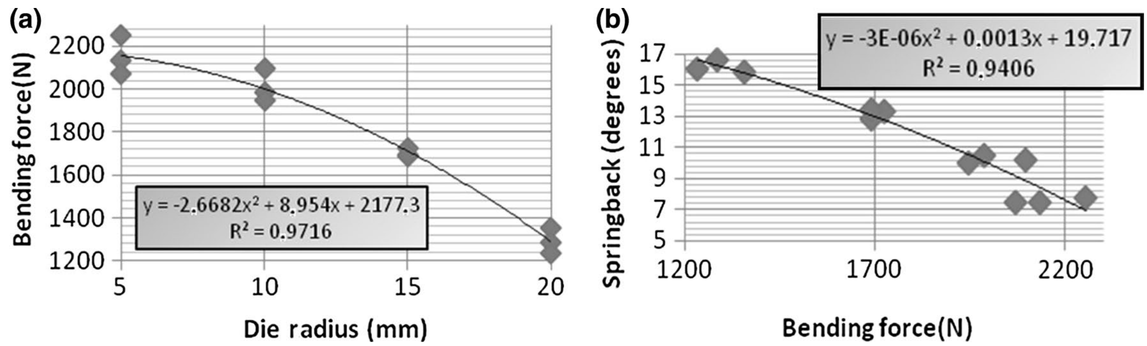


Fig. 10 L-bending tests: **a** bending force × die radius and **b** springback × bending force

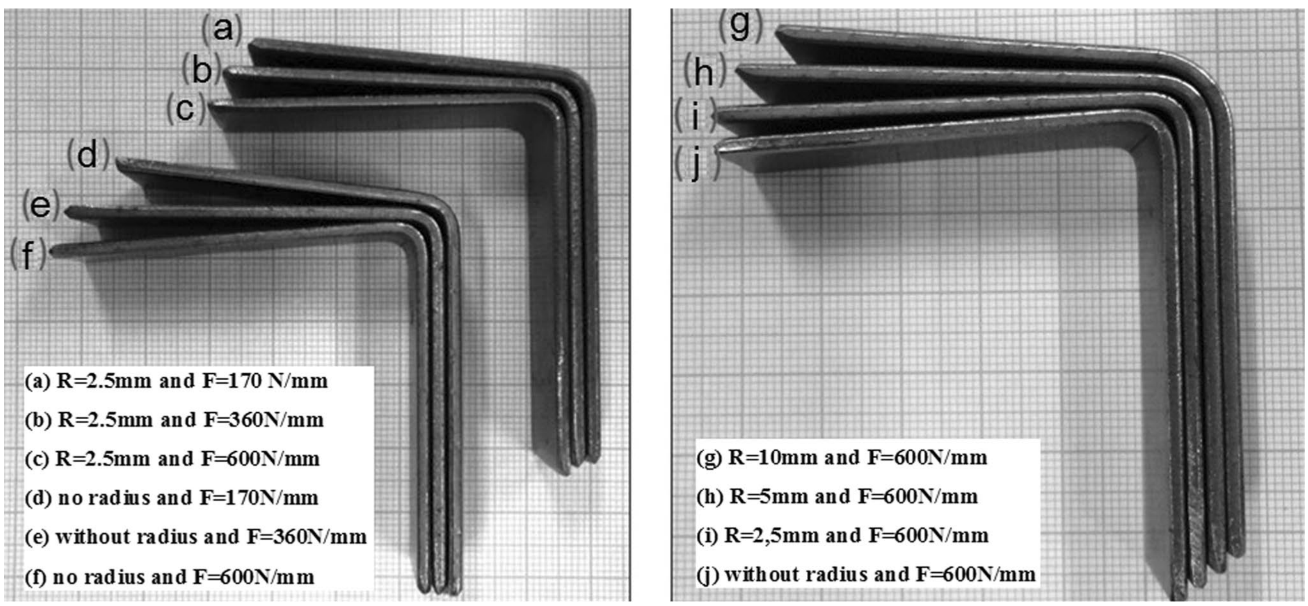


Fig. 11 TRIP800 steel V-bended samples

Table 7 V-bending data for the TRIP800 steel

V-bending		3 replications (average)		R/t
Force/width (N/mm)	Radius (mm)	Springback (°)	K_s	$t = 2$ mm
171.15	10	9.0	0.9000	5
385.09	10	6.6	0.9271	5
616.45	10	4.9	0.9461	5
170.51	5	7.1	0.9207	2.5
371.14	5	4.9	0.9458	2.5
602.72	5	2.5	0.9725	2.5
173.63	2.5	5.9	0.9344	1.25
344.71	2.5	3.2	0.9649	1.25
587.2	2.5	−1.2	1.0132	1.25
175.54	0	5.3	0.9408	0
343.65	0	2.1	0.9768	0
565.63	0	−3.7	1.0414	0

in the bend radius region, which for the tested steel was possible to control the springback without having to switch tools or to make any adjustments. The springback was controlled just by varying the post-bending strength.

The metallographic analysis of the TRIP800 steel showed greater transformation of martensite in the tensioned region when compared with the neutral axis and compressed regions in a visual observation. Due to the refined microstructure, the measurement of the phases via optical microscope was not possible. It was metallographically evident the observation of the neutral axis line.

The main contribution of this work was to demonstrate that it is possible to control the springback of the TRIP800 steel during V-bending by applying a coining force on the curvature region. In some cases, the springback was reduced, which showed a negative value and it was found spring-go.

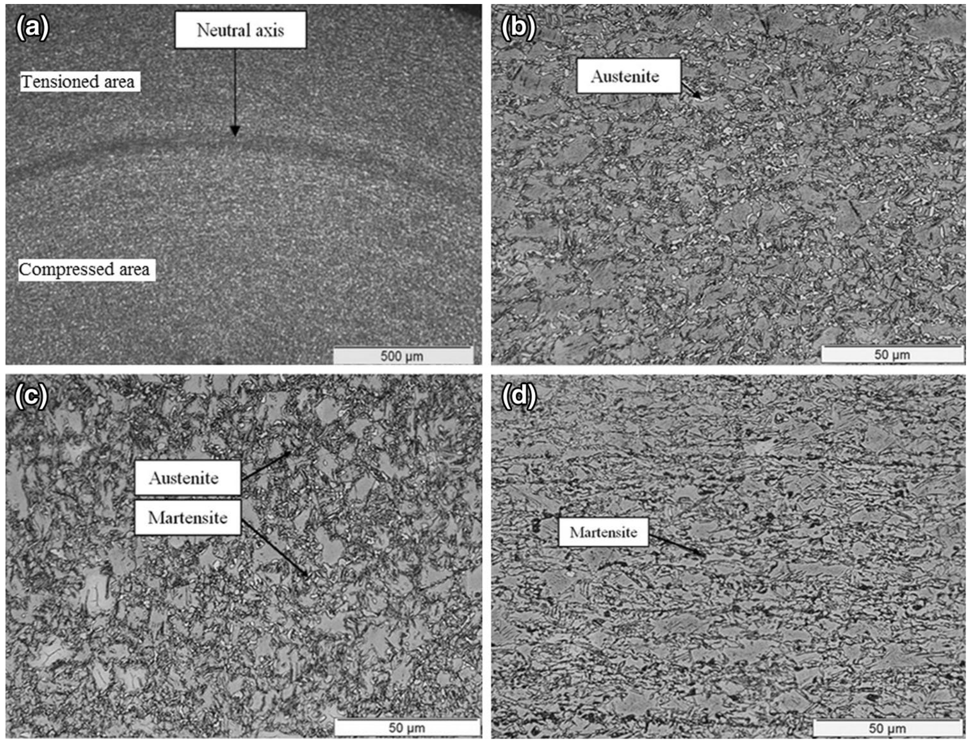


Fig. 12 Metallographic images analysis of V-bending TRIP 800 steel—using no radius punch and conning force of 8484 N: **a** neutral axis in bending, **b** neutral axis region detail; **c** compressed region and **d** tensioned region

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Compliance with ethical standards

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