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# The influence of the rolling direction on the elastic characteristics of the bending samples

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**Abstract.** There are a number of factors influencing the bending process such as: the rolling direction of the blank; the minimum bend radius of the piece; the radii of the bending plate (of the mold); the play between the die and the punch, the recoverable strain of the piece after bending. The paper presents the experimental results regarding the influence of the lamination direction on the rheological behaviour of the cold bending parts, using the Lloyd LS100 Plus universal machine and the Nexygen Plus program. Thus, two categories of samples were analyzed: some being cutted off in the direction of rolling of the sheet at which the bending occurred on an axis perpendicular to the direction of rolling and others cutted on cross direction of rolling, the bending being produced along the axis parallel to the rolling direction. As an elasto-plastic process, after the loading process during experiment, the samples recorded an elastic strain recovery due to the kinetic energy stored during stresses. Thus, the recovered elastic deformation (springback) is more pronounced in the case of specimens cutted of in cross direction on the rolling fiber where the bending moment is produced in the direction parallel to the laminating fiber of materials.

## 1. Introduction

Bending is the operation of modifying the shape of a blank by flat bending around a rectilinear edge, the deformation occurring between the flow limit $\sigma_C$ and the tear strength of the material without however achieving the tensile strength value. In bending the ductility of the sheet metal plays very important role. If the ductility is lower, the minimum bend radius is larger. During bending, the metal layers located in the area from the inner radius are subjected to compression along the axis of symmetry, and those located in the area from the outer radius are subjected to stretching. Between the two areas is the neutral layer, which preserves the initial length of the blank. As the B-width of the blank gets lower, the neutral layer position moves closer to the inner radius, while in the case of the increase in width B, it moves to the outer radius of curvature [1, 2]. Bending of boards is a common and vital process in the metalworking industry. The bending of metal sheets involves the plastic deformation of the piece on an axis, thus creating a change in the geometry of the piece. But, springback of the materials after bending constitute a investigation subject. Schroeder highlights the effect of transverse stresses during forming on elastic recover, which often is neglected [1, 3].Gupta and Rajagopal, [4], present a mixed integer linear programming formulation to generate. Wang et al.[5], presents a bending methodology to achieve accurate final bend angles after springback, based

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on estimation elasto-plastic behaviour of metal piece. Stanciuet al. [6], evaluate the elasto-plastic behaviour of pipe subjected to high internal pressure. Similar to other metal forming processes, bending changes the shape of the work piece, while the material volume will remain the same. In some cases, bending may cause slight changes in the thickness of the plate. However, for most of the machining operations, the folding will essentially not cause any change in the thickness of the sheet. In addition to creating a desired geometric shape, bending is also used to confer strength and stiffness to the metal plate, to change the moment of inertia of the piece for its appearance and to eliminate sharp edges. Bending tests are performed to determine the cold deformation capacity and to check the quality of the products in terms of the absence of surface defects. During bending process, a steeply rising linear phase (purely elastic forming) is followed by a non-linear phase (elastic-plastic bending phase, plasticizing in cross section) and then by the weak linear rise of a further range (plasticizing in the longitudinal section only) up to the end. In figure 1 the bending principle is presented.

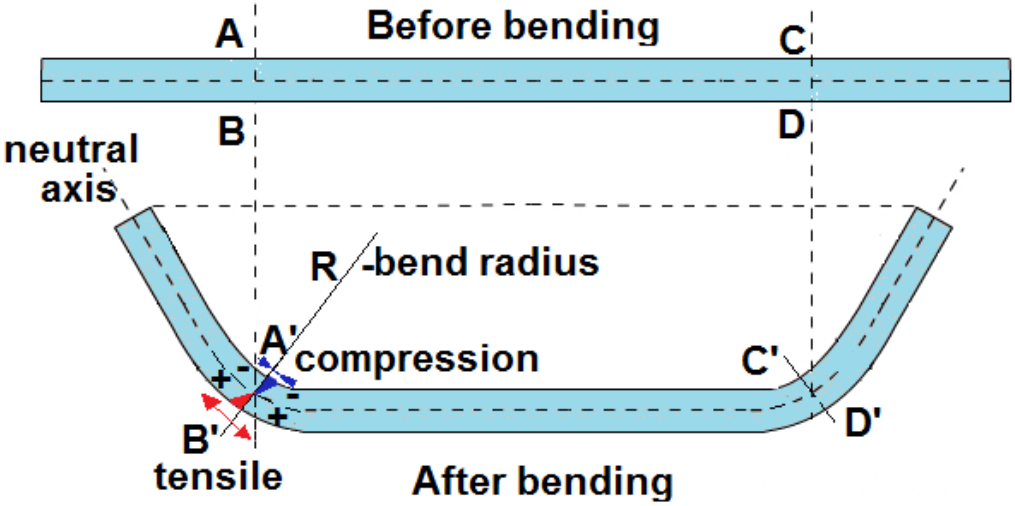


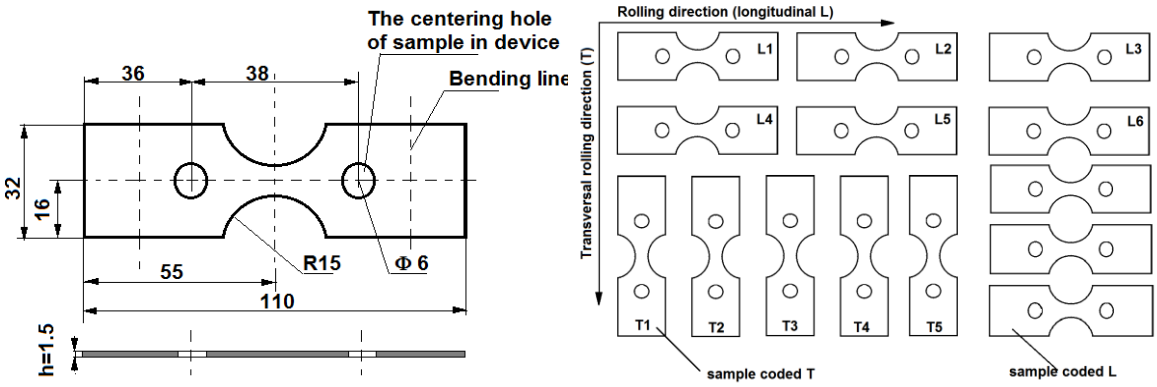

**Figure 1.** The bending principle.

## 2. Experimental set-up

In this section we discuss how the experiments were conducted and the types of samples.

### *2.1. Materials*

To perform bending tests, specimens having the shape and dimensions of figure 2 were made. Of these, 10 samples were cutted off in the direction of sheet metal and 10 samples in the direction perpendicular to the lamination. Coding of specimens consists of a number (corresponding to the sample number) and a letter (L) indicating the direction of cutting. In the case of the specimens arranged in the direction of rolling, the bending was made after an axis perpendicular to the direction of rolling (in practice it is recommended that the bending be done in this way), and in the case of the specimens placed perpendicularly, the bending was performed along an axis parallel to the direction of rolling. There are two holes on the specimen to help center the piece on the test device and two recesses of the material to allow the bolts to pass through. The dotted lines represent the bend lines.




a) b)

**Figure 2.** The shape and dimensions of the samples (a); the way of cutting the samples in the direction of rolling and transverse (b).

*2.2. Experimental method*

The test consists of bending of samples using a die and the punch devices as can be seen in figure 3. For the experiments the Lloyd LS100 Plus universal machine and the Nexygen Plus program was used. Thus, the distance traveled by the mobile test rig is 20.5 mm. It was performed a special device which is preseted in figure 3. The 3D model of the bending test device consists of the following components: 1-punch; 2-mold; 3-piece mounting plate 4 on punch 1; 5-plate for attaching the punch to the top of the test machine; 6-plate for fixing the mold to the bottom of the test machine; the pins 7 that help center the punch piece and the screws 8 that allow the piece to be fixed between the plate 4 and the punch. The material from which the device components were made is 1.2312 (40 CrMnMoS 86), which is a steel used to make small-sized molds. The loading rates were varied as shown in table 1. The applied force was approximately 8000 N. After each test, the distance of the piece at the top (dimension $l_x$, in figure 4) was measured immediately after it was removed from the mold and at a time ($t_1$) after completion of the tests. Thus, the β-angle of the piece can be deduced, the angle required to keep the parts within the permissible tolerances. Figure 4 presents the final test specimens after bending tests. Subsequently, they were reassembled with a Mitutoyo digital caliper, with an accuracy of ± 0.01mm.

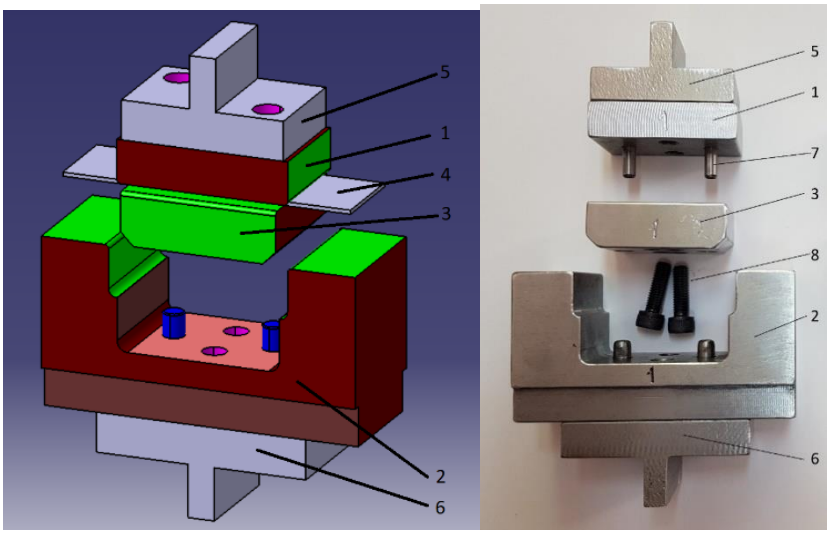



**Figure 3.** The 3D model of the bending test device.

**Table 1.** Input data.

| Samples code | | Load rates [mm/min] |
|---|---|---|
| L1-L5 | T1-T5 | 10 |
| L6 | T6 | 5 |
| L7 | T7 | 15 |
| L8 | T8 | 20 |
| L9 | T9 | 25 |
| L10 | T10 | 30 |

## 3. Results and discussion

Experimental attempts to bend cold-rolled sheet specimens yielded a series of data and through their processing resulted the force-displacement variation curves, comparative graphs on the different mechanical characteristics of the tested samples. The graphs from figures 4 and 5 highlight the dependence between the force required to achieve the bending and the relative displacement of the punch relative to the die. The maximum bending force value is reached at point A shortly before the bend reaches 900 (about 650 / figure 5), after which the punch stroke continues and the bending force decreases until point B is reached, point in which bending angle reaches 900. From point B to point C there is a slight increase in the force due to the friction between the part and the mold walls. From point C the force suddenly increases due to crushing of the bend radius. This crushing is intended to reduce the value of the elastic return angle β of the piece. Between B and C, an increase in force (a peak) due to the centering of the punch on the mold pins is recorded at one point. This part of the curve does not affect the collected data, so it can be removed from the chart.

The appearance of the curves is similar to the characteristic curves of the tested material, and according to the graphs, the values of the maximum forces are close with an average value of 8000N. In conclusion, this force is required for bending of thin sheet parts having a folded section area of approximately 96mm$^2$. The maximum force reached during the tests is about 18000N, which is due to crushing of the bending radius at the end of the punch stroke. This crushing is intended to reduce the value of the springback.

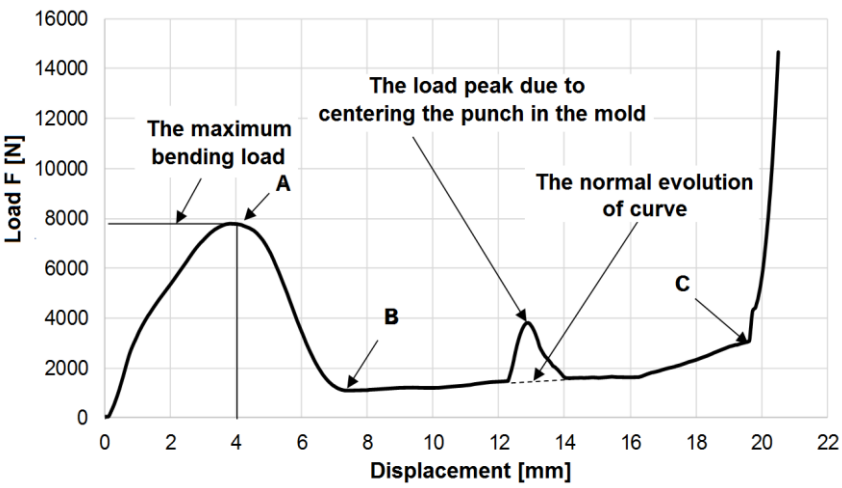
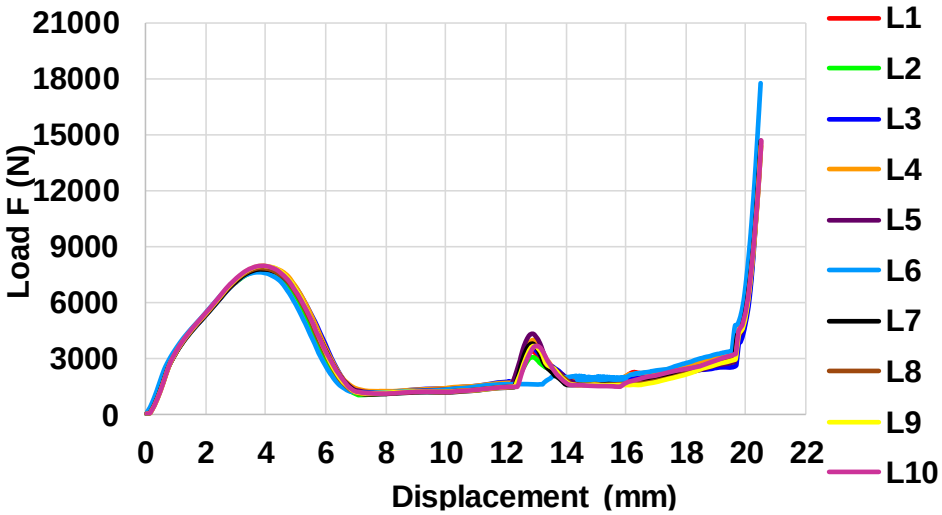
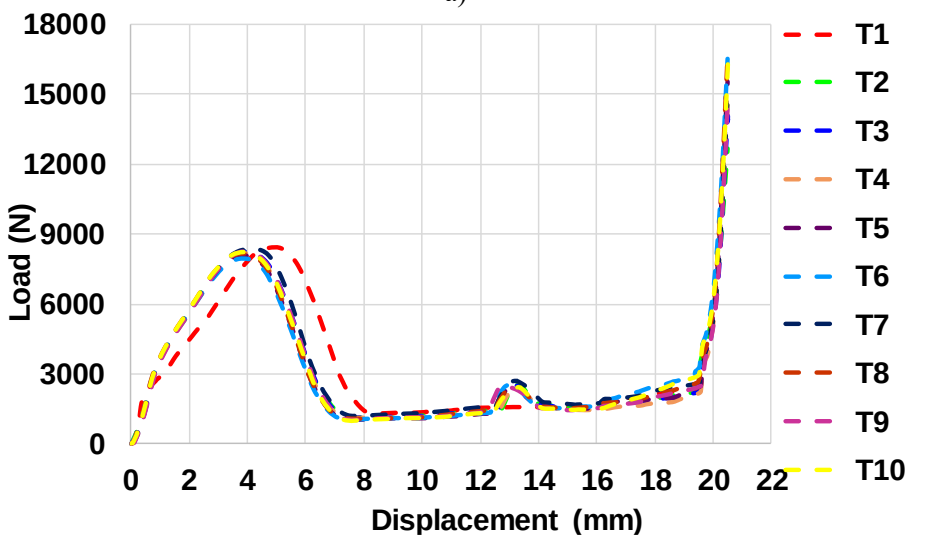



**Figure 4.** The characteristic curve during bending.



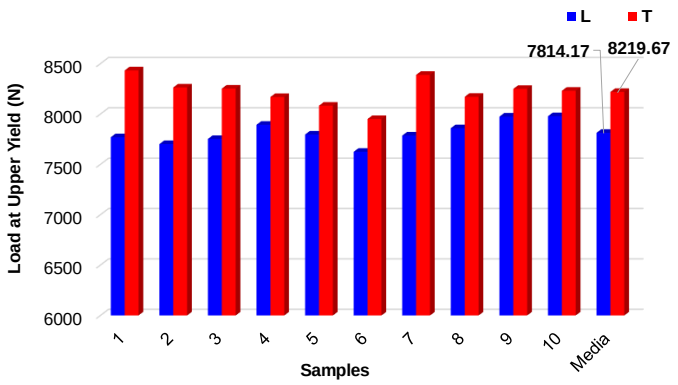

a)



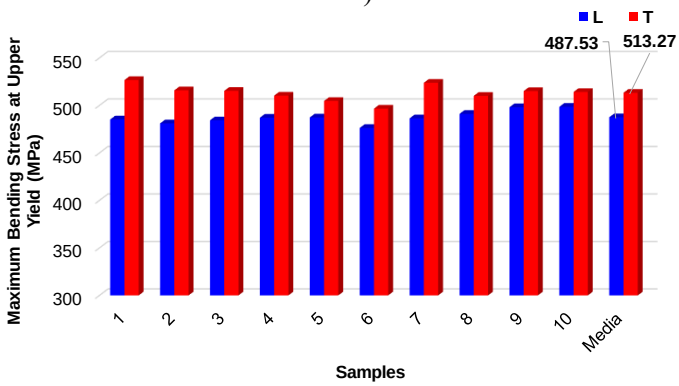

b)

**Figure 5.** The load-displacement curve for the two types of samples: (a) characteristic curve at bending in case of samples L; (b) characteristic curve at bending in case of samples T.

Figure 6 shows the variations in the maximum force required to achieve the bending and their average values. By analyzing numerically the average values, it results that the maximal bending force obtained in the case of specimens discharged in the direction of rolling of the material (the bending line is perpendicular to the direction of the laminating fiber) is about 5% lower than in the case of the specimens cut in the perpendicular direction. A higher 5% value of the average stresses of the specimens transversely to those longitudinally disposed on the rolling direction can be seen in figure 6(b), which shows both the maximum values of the recorded stresses and their mean values.




a)




b)

**Figure 6.** Comparison between maximum load (a) and normal stress (b) in case of two types of samples.

Figure 7 shows both the variations of the longitudinal elastic modulus (Young's module) and their average values. By analyzing numerically the average values, it results that the longitudinal elastic modulus obtained in the case of the specimens perpendicular to the direction of rolling of the material is about 2.9% higher than in the case of those debited in the rolling direction. In calculating the average value of the longitudinal elastic modulus for transversely arranged specimens, the value of the first measurement was removed from the calculation since it is very different from the others. After removing the samples from the die, the elastic strain is recoverd due to the elastic-plastic properties of the material.

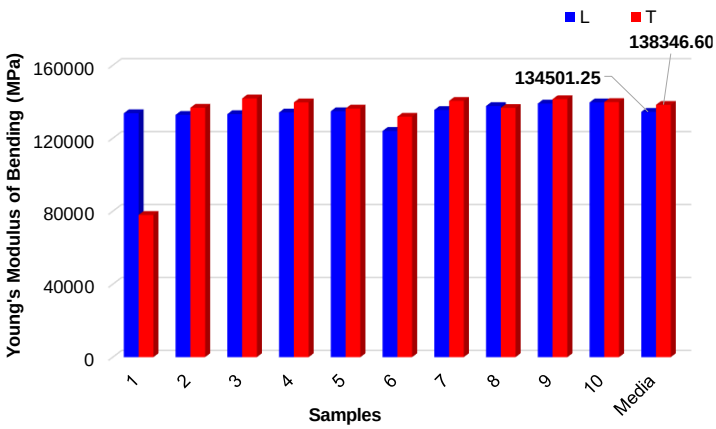



**Figure 7.** Variation of elasticity modulus in case of longitudinal and transverse samples.

In table 2 are summarized the results obtained after test for each sample in terms of the punch extension, load at upper yield, maximum bending stress at upper yield, Young's modulus of bending.

**Table 2.** Output data.

| Samples | Speed (mm/ min) | Perimeter of bending [mm] | Thickness (mm) | Area (mm²) | The punch extension [mm] | Load at Upper Yield (N) | Maximum Bending Stress (MPa) | Young's Modulus of Bending (MPa) |
|---|---|---|---|---|---|---|---|---|
| **L1** | 10.00 | 32.03 | 1.50 | 48.05 | 19.00 | 7770.2 | 485.19 | 133762.77 |
| **L2** | 10.00 | 32.02 | 1.50 | 48.03 | 20.50 | 7701.8 | 481.06 | 132865.80 |
| **L3** | 10.00 | 32.02 | 1.50 | 48.03 | 20.50 | 7753.1 | 484.27 | 133273.97 |
| **L4** | 10.00 | 32.01 | 1.50 | 48.02 | 20.50 | 7893.5 | 487.07 | 134177.62 |
| **L5** | 10.00 | 32.00 | 1.50 | 48.00 | 20.50 | 7797.2 | 487.32 | 134844.12 |
| **L6** | 5.00 | 32.02 | 1.50 | 48.03 | 20.50 | 7625.6 | 476.30 | 124070.04 |
| **L7** | 15.00 | 32.02 | 1.50 | 48.03 | 20.50 | 7786.8 | 486.37 | 135547.75 |
| **L8** | 20.00 | 32.01 | 1.50 | 48.02 | 20.50 | 7859.6 | 491.07 | 137710.57 |
| **L9** | 25.00 | 32.02 | 1.50 | 48.03 | 20.50 | 7974.9 | 498.12 | 139071.84 |
| **L10** | 30.00 | 32.01 | 1.50 | 48.02 | 20.50 | 7979 | 498.53 | 139688.03 |
| **Average** | **-** | **32.02** | **1.50** | **48.02** | **20.35** | **7814.17** | **487.53** | **134501.25** |
| **T1** | 10.00 | 32.02 | 1.50 | 48.03 | 19.00 | 8433.6 | 526.73 | 77987.98 |
| **T2** | 10.00 | 32.04 | 1.50 | 48.06 | 20.50 | 8264.2 | 515.86 | 136770.22 |
| **T3** | 10.00 | 32.03 | 1.50 | 48.05 | 20.50 | 8253.3 | 515.35 | 141867.46 |
| **T4** | 10.00 | 32.02 | 1.50 | 48.03 | 20.50 | 8169.7 | 510.29 | 139688.84 |
| **T5** | 10.00 | 32.03 | 1.50 | 48.05 | 20.50 | 8083 | 504.71 | 136321.86 |
| **T6** | 5.00 | 32.02 | 1.50 | 48.03 | 20.50 | 7951 | 496.62 | 131865.85 |
| **T7** | 15.00 | 32.03 | 1.50 | 48.05 | 20.50 | 8389.5 | 523.85 | 140552.43 |
| **T8** | 20.00 | 32.04 | 1.50 | 48.06 | 20.50 | 8171.3 | 510.07 | 136666.37 |
| **T9** | 25.00 | 32.03 | 1.50 | 48.05 | 20.50 | 8249.8 | 515.13 | 141487.33 |
| **T10** | 30.00 | 32.02 | 1.50 | 48.03 | 20.50 | 8231.3 | 514.13 | 139899.03 |
| **Average** | **-** | **32.03** | **1.50** | **48.04** | **20.35** | **8219.67** | **513.27** | **132310.74** |

The values of the return angles are highlighted in the graph in figure 8, where it can be seen that the return is more pronounced in the case of the specimens arranged in the transverse direction of the rolling fiber, so if the bending line is parallel to the material rolling fiber.

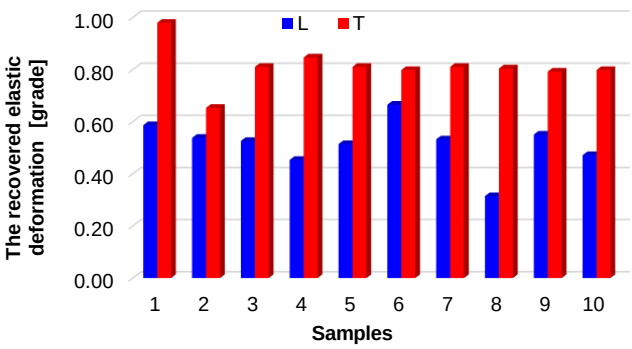



**Figure 8.** The distance between the bended parts of the samples.

In this situation we can state that the piece exhibits a higher plasticity (by 35%) in the case of bending after a line perpendicular to the rolling fiber and a higher stiffness (by 5%) in the case of bending after a bending line situated in the direction of the fiber, as demonstrated in the case of traction test specimens.

## 4. Conclusions

Two types of samples were analysed: some being cutted off in the direction of rolling of the sheet at which the bending occurred on an axis perpendicular to the direction of rolling and others cutted on cross direction of rolling, the bending being produced along the axis parallel to the rolling direction. As an elasto-plastic process, after the loading process during experiment, the samples recorded an elastic strain recovery due to the kinetic energy stored during stresses. Thus, the recovered elastic deformation (springback) is more pronounced in the case of specimens cutted of in cross direction on the rolling fiber where the bending moment is produced in the direction parallel to the laminating fiber of materials.It has been shown that the material has better plastic capacities (by 35%) in the case of specimens cut in the direction of fiber lamination, while it exhibits higher resistances (by 5%) in the case of specimens cut in the direction perpendicular to lamination.Even after plastic deformation, small elastic recovery may happen in ductile materials, after removal of load.For the most accurate results it is necessary to measure the parts on a coordinate measuring machine with an accuracy of ± 0,001mm. By processing the measured data after the tests, the elastic recovery angle of the piece was obtained. This angle is important in designing the bending molds because it is necessary to compensate it in order to keep the piece within the tolerances allowed.

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