# EFFECT OF PLANAR ANISOTROPY ON THE PROPERTIES OF WORKPIECES FROM TAILOR WELDED BLANKS OF DUAL-PHASE STEEL

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**Abstract**

The combination of different mechanical properties of tailor welded blanks (TWB-s) results in non-constant plastic flow and instability of the weld interface during forming. This is most marked when combining metal sheets of different thicknesses or sheets with significantly different plastic characteristics. This non-uniformity was also observed for tailor welded blanks which consisted of equally thick sheets of one material but had different texture orientations after rolling. When examining the formability of such welded blanks, simulations were performed and verified by real experiments of deep drawing of a rectangular box. Since the influence of the differently oriented texture was not very significant, it was necessary to assess the influence of the ductile characteristics of the weld metal on the overall formability. Since the influence of the differently oriented texture was not very significant, it was necessary to assess the influence of the stress-strain characteristics of the weld metal on the overall formability.

**Keywords:** Anisotropy, deep-drawing, tailor-welded blank, weld interface, simulation

## 1. INTRODUCTION

High-strength steel sheets have been developed primarily for use in the automotive industry. In addition to high strength and adequate yield strength, they are characterized by excellent formability and are able to meet the requirements for car body construction in terms of strength, rigidity and safety. A very widespread group are dual-phase (duplex) steels. Weldability and formability are among the most important properties in this case, because these properties are the most used in TWB products. These usually consist of sheets of different thicknesses or mechanical properties in order to optimize body components in terms of strength, stiffness, weight and impact deformation properties [1-3]. Laser welding is most suitable for the production of TWB products from two-phase steels, but also other material combinations. The main advantages are minimal deformations of TWB products due to the narrow heat-affected zone (HAZ), high welding speeds, process flexibility and the ability of the joint to transmit drawing force [2-4]. This meets the basic requirements for a welded joint. However, the weld itself and the change in the properties of the material in the heat-affected zone of the TWB negatively affect the formability and flow of the material during deformation [1,5,6].

## 2. EXPERIMENTS

In tailor welded blanks, the influence of planar anisotropy, the combination of the rolling direction and its orientation with respect to the shape of the workpiece can significantly affect the forming process and the final product. For the analysis of this effect, sheets made of dual-phase steel HCT600X with the same thickness of 1.2 mm but with a different orientation of the rolling direction of the individual parts with respect to the weld interface (**Figure 1**) [1] were used. The joint was formed by a solid-state fiber laser IPG type YLR 4500 with a maximum power of 4.5 kW and a wavelength of 1060 nm.

The chemical composition and mechanical properties of HCT600X steel are in **Table 1** and **Table 2**. For the experiments, the blanks with a shape optimized on the basis of default of the DYNAFORM program for deep-drawn part of rectangular shape with internal dimensions of 120 mm x 80 mm, height of 40mm and position of the welding interface according to **Figure 2**.

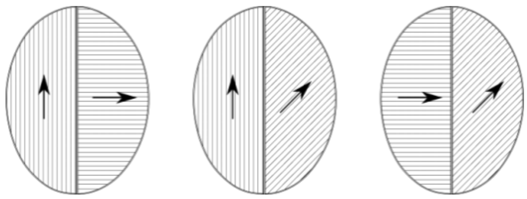


**Figure 1** Schemes of laser welded blanks with different surface orientation of the texture

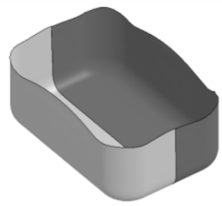


**Figure 2** Rectangular drawn part from a tailor welded blank with a weld interfac

**Table 1** Chemical composition of duplex steel HCT600X

| **Element** | **C** | **Mn** | **Si** | **Al** | **P** | **S** |
|---|---|---|---|---|---|---|
| **(wt%)** | ≤ 0.7 | ≤ 2.2 | ≤ 0.8 | ≤ 2.0 | ≤ 0.008 | ≤ 0.015 |
| **Element** | V | B | Nb+Ti | Cr+Mo | | |
| **(wt%)** | ≤ 0.2 | ≤ 0.005 | ≤ 0.,15 | ≤ 1.0 | | |

**Table 2** Mechanical properties of duplex steel HCT600X

| **$R_m$ (MPa)** | **$R_{p0,2}$ (MPa)** | **$A_{80}$ (%)** |
|---|---|---|
| 600 | 380 | 23 |

The drawing process of drawn parts from TWBs was analysed using the FEM model in the LS Dyna software. Achieving correct results depends primarily on the choice of a suitable material model. This was obtained by means of tensile tests according to STN EN ISO 6892-1 on samples of HCT600X material with orientation 0°, 45° and 90° to the sheet rolling direction. The tests were performed on universal testing machine Instron 1195 and four samples from each direction. By evaluation and extrapolation, the flow curves were obtained as a dependence of “true stress - true strain” (**Figure 3**) and values of planar anisotropy „R“ for individual directions of samples orientation. For 0° R = 0.750, for 45° R = 0.881 and for 90° R = 0.862.

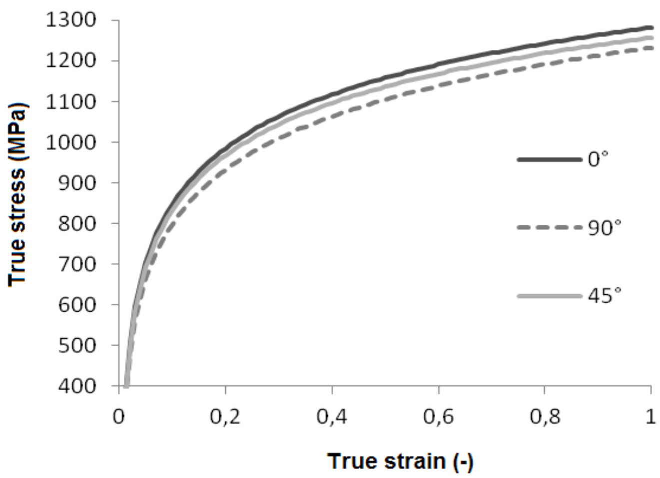



**Figure 3** Extrapolated curves of true stress used for simulations

Before welding, the surface of the samples was chemically degreased with acetone. The welds were made as butt joints without additional weld metal at a beam power of 600 W and a welding speed of 5 mm.s$^{-1}$. Metallographic analysis was performed on cut-out samples. For microstructural analysis was used Zeiss

Axiovert 40 MAT optical microscope. Mechanical tests of the welded joints were also realized, the welds being oriented transversely in the middle of the measured shank of the test specimens.

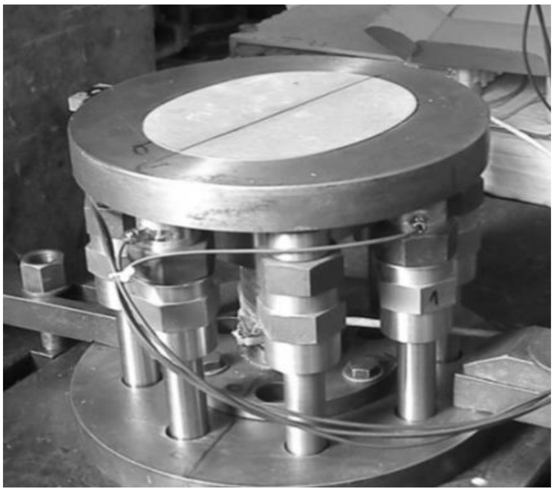


**Figure 4** Experimental tool for drawing of rectangular drawn part. The blank is on the top of the holding plate

Tensile tests were performed on Instron 1195 testing machine. The welded blanks were formed on an experimental deep-drawing tool (**Figure 4**) and a PYE160S hydraulic press with a set uniform distribution of holding force of 35 kN and a holding pressure of 2.15 MPa at the beginning of drawing. Wedolit N22-3N lubricant was used to minimize friction.

## 3. RESULTS AND DISCUSSION

### 3.1. Analysis of the welded joint

All welded joint tests ended with the sample tearing in the base material outside the joint. The measured strength parameters were the same as on the samples without welds. Due to structural changes, the welded joint had a higher strength than the base material. Microscopic analysis confirmed the two-phase structure of the base material. The dark, row-oriented formations are martensite grains deposited in a light ferrite matrix (**Figure 5**).

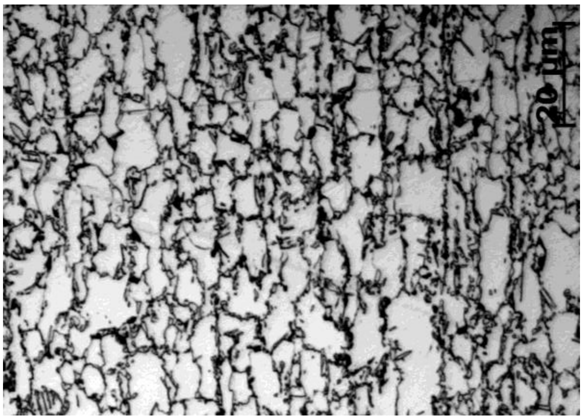
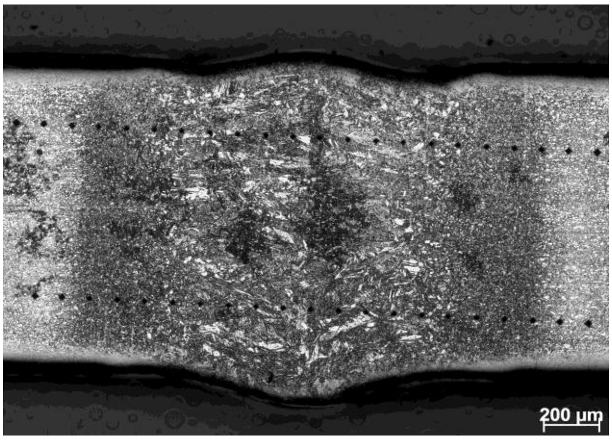



**Figure 5** Microstructure of HCT600X double-phase steel

The macrostructure of the weld and the course of microhardness in the transverse direction to TWB welded joint made of steel HCT600X 1.2 mm thick is shown in **Figure 6**. The welded joint was made at a beam power of 600 W and a welding speed of 5 mm.s$^{-1}$.



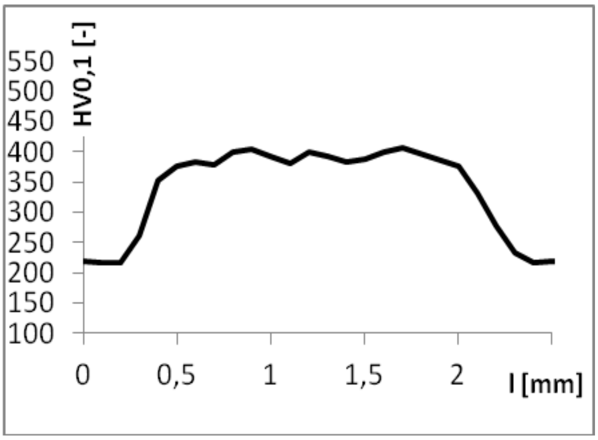




**Figure 6** Macrostructure of TWB welded joint (left), course of microhardness of welded joint (right)

In **Figure 7** on the left is the microstructure of the laser weld and on the right the heat-affected zone of the dual-phase steel HCT600X. The heat affected zone is free of pores, cavities, inclusions and microcracks. It contains a mixture of ferrite, bainite and martensite. The microstructure of the weld, formed by rapid cooling, consists of martensite with a uniform grain size. After the deep drawing experiments or in the simulations of the drawing process, the displacement of the weld interface, at the bottom of the rectangular drawn part didn´t show observable values. The displacement of the weld was visible only on the walls of the drawn part. The weld interface was tilted to the side where the texture was oriented at an angle of 0° with respect to the selected coordinate system orientation. The angle of inclination of the interface ranged from 0.5° to 1.37° with rotation according to the orientation of the texture. The magnitude of the weld interface displacement, after the experiment and during the simulation, are shown in **Figure 8**.

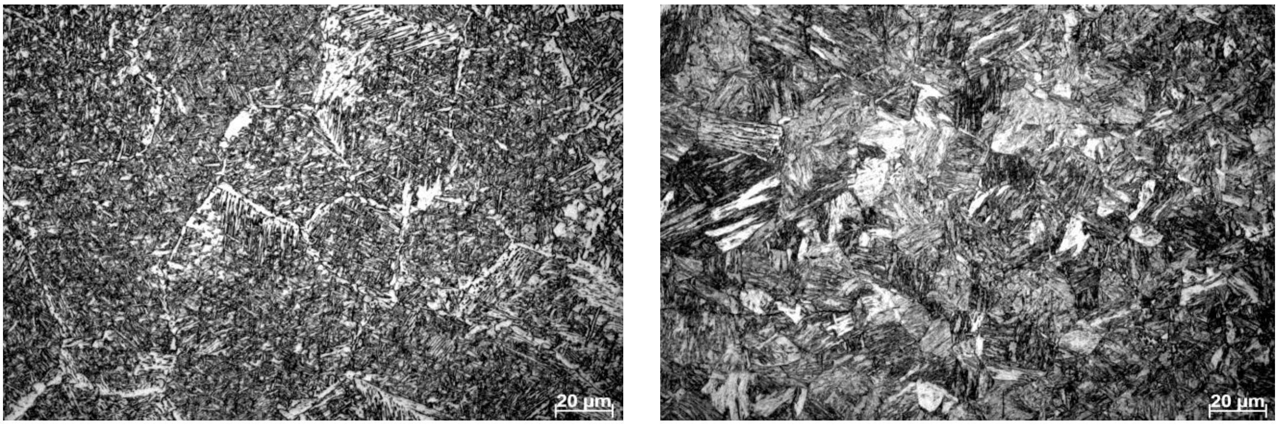



**Figure 7** Microstructure of the weld (left) and the heat-affected zone of the weld (right) of HCT600X steel

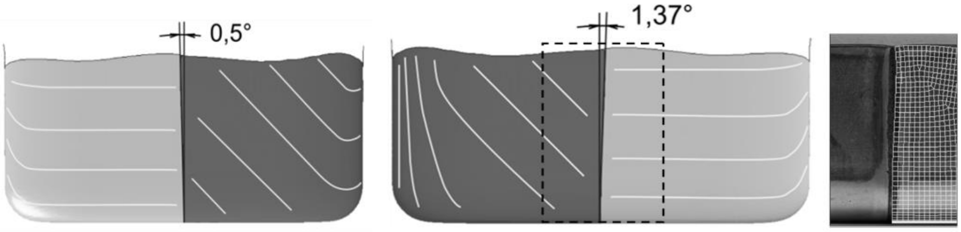



**Figure 8** Simulation of the weld interface displacement on the vertical part of the part (left, in the middle) in regard to the orientation of the texture in comparison with the displacement during the experiment (right)

### 3.2. Earing formation on drawn part

The manifestation of planar anisotropy in the deep-drawing parts is the ears formation. Simulation of the deep-drawing process of TWBs with a texture orientation of 0° and 90° showed a negligible height difference between the ears. The combination with a texture orientation of 0° and 45° has the most significant effect on the ears formation during deep-drawing of TWBs. **Figure 9** shows the waviness of edge of a rectangular drawn part from TWB. The lines in the graph represent the peripheral height positions of the drawn part circumference. Positions A and B are in the corners of the part. The schemes with texture orientation above and below the curves represent the texture orientation in the perimeter walls of the drawn part. During analysis of the side with 45° orientation on the blank, the differences in the height of the ears in the corners were revealed. In corner A, where the texture was parallel to the vertical wall, the ear was 2% higher than in corner B, where the texture was perpendicular to the vertical wall of the drawn part (**Figure 10**). The height of the perimeter walls in straight sections was comparable with a texture orientation of 0°.

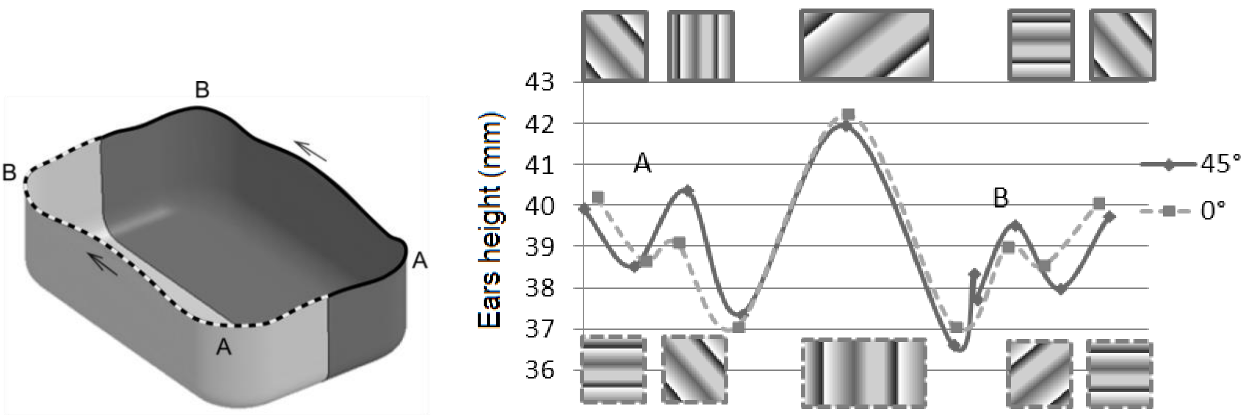



**Figure 9** Drawn part composed of blanks with 0° and 45° surface texture orientation (left), Height of the drawn part wall depending on the position around its circumference and texture orientation (right)

On the texture orientation side of 45°, the height of the ears showed variance of values according to the local orientation at the part site based on the real experiment (**Figure 11**). The height of the ears was measured by photogrammetric method and CAD software. The difference in the height of ears is about 2.5%. A comparison of the results of measurements and simulations of the height of the ears and their percentage differences is shown in **Figure 10**.

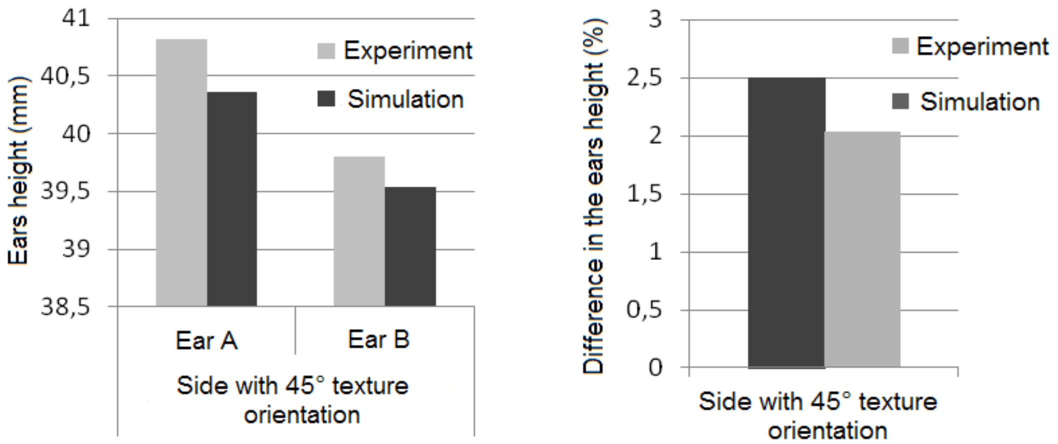



**Figure 10** Comparison of the ears height of the experimental drawn part with the simulated drawn part (left), Deviation of the ears height of the experimental drawn part with the simulated drawn part in% (right)

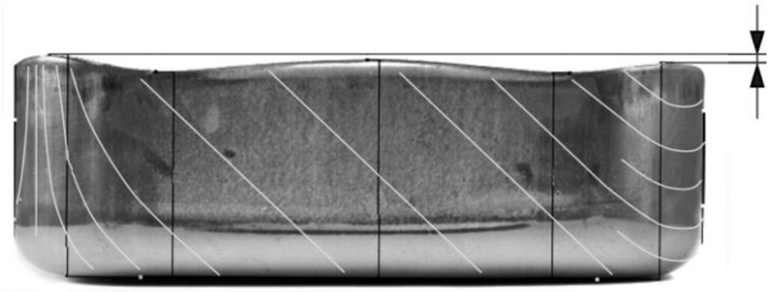


**Figure 11** Measurement of the deviation of the ear height on the drawn part with the indicated direction of texture orientation¨

## 4. CONCLUSION

The properties of tailor welded blanks (TWBs) made of dual-phase steel HCT600X were analysed with respect to weldability and formability. The following results were obtained:

1) Microscopic analysis of the welds revealed that the welds were without any defects. Welding parameters are given in the text.
2) The welding process has no effect on the strength properties of the blank. Because the test specimens broke in the base material during the tensile test, the weld has a higher strength than the base material.
3) Planar anisotropy in the tailor welded blanks can cause significant plastic flow asymmetry, which affects the final shape of the workpiece. The most critical is the use of tailor welded blanks composed of sheets with a 45 ° texture orientation. The welding interface deviates to the side with a texture orientation angle of 0° during the drawing process.
4) The height of the ears in the corners of the experimental drawn part made of TWBs is relatively constant when the welded blank includes a sheet with a 90° texture orientation angle. If the blank includes a sheet with a 45° angle of texture orientation, further asymmetry occurs and the height of the ears is non-uniform not only in the corners but also in the straight sections of the drawn part.
5) The sufficiently accurate material model of HCT600X steel used in the simulations enabled to achieve comparable results of real experiments with simulations.


## ACKNOWLEDGEMENTS

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