FORMABILITY OF TAILORED HYBRID BLANKS

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Abstract. Tailor Welded Blanks (TWB) characterized by the fact that sheets with different material qualities and/or thicknesses welded together before forming process. The application of TWBs in the automobile industry brings several advantages, for instance, reduction of car body weight, reduction of manufacturing costs and integration of several drawing parts into one part. Despite several established tailor welded blanks types, a new version has emerged the Tailored Hybrid Blanks (THB). Unlike steel TWBs, the challenges in connecting steel and aluminum by a conventional welding method are, on the one hand, the different physical characteristics such as density, melting temperature, electrical conductivity and thermal expansion. On the other hand, due to high heat input a thick, very hard and brittle intermetallic phase seam (IMP) develops in the weld seam. This strongly distinctive phase seam reduces the formability of the welding line. Therefore this limits the realization in technical applications. The current investigation focuses on tailored hybrid blanks joined by the CMT-welding technology. The main aim of this study is to specify the forming ability of Aluminum Steel tailored blanks. Steel (HC340LA, 0.8 mm) blank sheets combined with an Aluminum alloy (AA6014-T4, 1.2 mm). Nakajima tests with online deformation analyses shows that the main formation takes place on the Aluminum side. All specimens in the tensile test failed beyond the HAZ in the Aluminum. In particular, the weld line has the tendency to move during the forming operation toward the direction of the steel. In the cup test, the deep-drawing ability improved by introducing recesses on the tool.

Key words: Aluminum steel tailored hybrid blanks, cold metal transfer welding.

1. INTRODUCTION

In the last years, Cold Metal Transfer (CMT) welding considered for joining aluminum and steel. The characteristic of the Al / St CMT seam is a weld braze. The aluminum edge melted while creating a solder joint on the steel surface. A prerequisite for the joining of aluminum and steel with the CMT process is according to Jank et al. [1] the use of a galvanized steel sheet. In order to ensure adequate wetting of the aluminum on the steel sheet, a zinc layer thickness of about 10 μm recommended. Bruckner et al. mention in [2] that through numerous trials, compared to electro galvanized steel sheets (+ ZE), pure hot-dip galvanized coil-

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coated zinc coatings (+ Z) are by far the most suitable for an Al / St compound. In contrast, galvanic coated (+ ZA) steels are not suitable for use. In the further course of the work, a continuing development of the company Voest Alpine presented. By a special geometrical adaptation of the joining edges such as the rolling of the steel edge and the notch of the aluminum edge, it is possible to produce a quasi-butt seam. This arrangement showed a massive reduction in surface corrosion in corrosion studies compared to an overlap joint. In [3] on CMT welded blanks, it is proved that the residual stresses in the top and bottom of the seam are due to a symmetrical weld geometry. In general, the measurement shows a typical residual stress state at welds without phase transformation.

Singar and Banabic [4] determined in first fundamental experiments the mechanical properties by means of a tensile test, microhardness measurements and a prototype for an application of THB welded by the CMT Technique. Due to the material and thickness ratio between steel or CMT seam and aluminum, no significant plasticization recorded in the steel sheet and in the area of the CMT seam. All specimens failed beyond the HAZ in the aluminium, which leads to the result of no impact of quality irregularities inside of the CMT to the stress behaviour. The hardness of this zone varies between the hardness of the aluminum base material and the hardness of the welding zone, which is under 100 HV. Optical micrographs present a weld width of approx. 2.4 mm and a total length of approx.7 mm. The determination of the HEZ of the weld seam shows that the thermally influenced zone lies within the weld seam and shows no significant expansion in the direction of the aluminum base material. The results of microhardness testing across the weld seam show that constant mechanical properties in the seam thickness direction can used with regard to the modelling of the CMT seam.

Further work from Singar and Banabic concentrate to the numerical simulation of the tailor hybrid blanks. A compression test used to define the exact flow parameters of the flow curve. By comparing the experimental data, it shown that the consideration of the plastic weld properties in the simulation model leads to an increase in the calculation accuracy. However, with the increase in accuracy, it should taken into account that modeling with volume elements including a complex failure description of the weld seam, results in an increase in the calculation time [5].

While tailored blanks of steel are used in many different components of the body shell, Tailored Hybrid Blanks (THB) are still in the development phase. In order to introduce the THB in car structures, careful examinations regarding forming characteristics and mechanical properties of hybrid blanks should carried out. In this paper, results taken from forming analysis of joined aluminium-steel THB presented.

2. EXPERIMENTAL SET UP

2.1. NAKAJIMA TEST

The experiment according to Nakajima used to determine the limit shape changes of materials. For this purpose, the blanks with different geometries shaped by a hemispherical punch until failure occurs. Different stress states realized by varying the width of the sample geometries. The schematic experimental setup shown in Fig. 1a). In principle, the blank placed on the holder, and the drawing ring pressed by hydraulics with a specific hold-down force F_N on the hold-down device. The stamp moves against the hold-down force at a constant feed rate and reshapes the sample until it fails. The ARAMIS optical measuring system record the three-dimensional changes in shape.

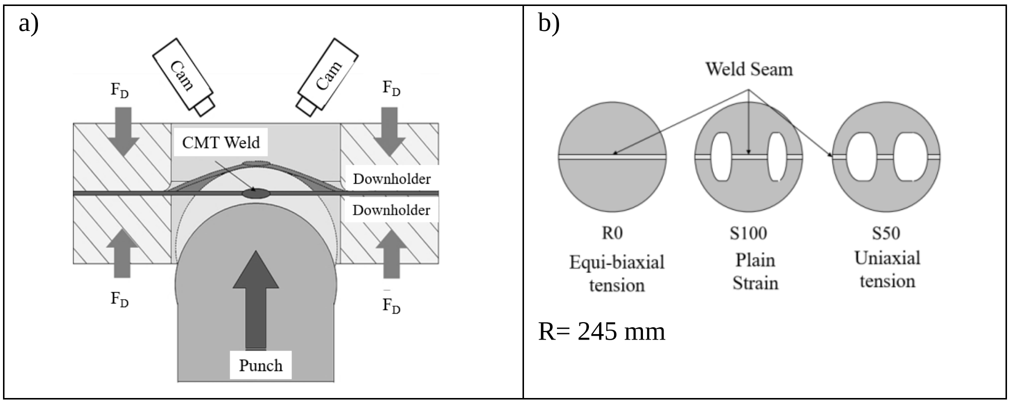

Fig. 1 – Nakajima Test.

Within the scope of the work, using the Nakajima test, the formability of the THB with an initial diameter of 245 mm and a sample geometry, the stress state, the biaxial stretching R0 $(\varphi_1 = \varphi_2)$, the flat elongation S100 $(\varphi_1 = 0)$ and simulates the uniaxial tensile test S50 $(\varphi_1 = -2\varphi_2)$, determined, see Fig. 1b). In order to compensate for the sheet thickness jump and to ensure an even hold-down pressure, compensating sheets with recesses for the weld seam were inserted above between the board / hold-down and below between the board / counter-hold. Other parameters, such as lubrication or process-specific settings on the test system, such as forming speed or hold-down force, remained unchanged compared to the standard settings for base materials.

2.2. CUP TEST

The deep drawing test is suitable to characterize the formability of the THB. The experiments are carried out at with a hydraulic press from Lasco Umformtechnik GmbH, type 100So, which is equipped with a pressing force of

1000 kN, a drawing force of 250 kN and an ejector force of 250 kN.

The measuring system of the test records the distance formed by the press, the pulling force applied the time and the hold-down force. The connection to the press takes place via a separate control, with which the hold-down force, feed, drawing depth and drawing force can set, Fig. 2a).

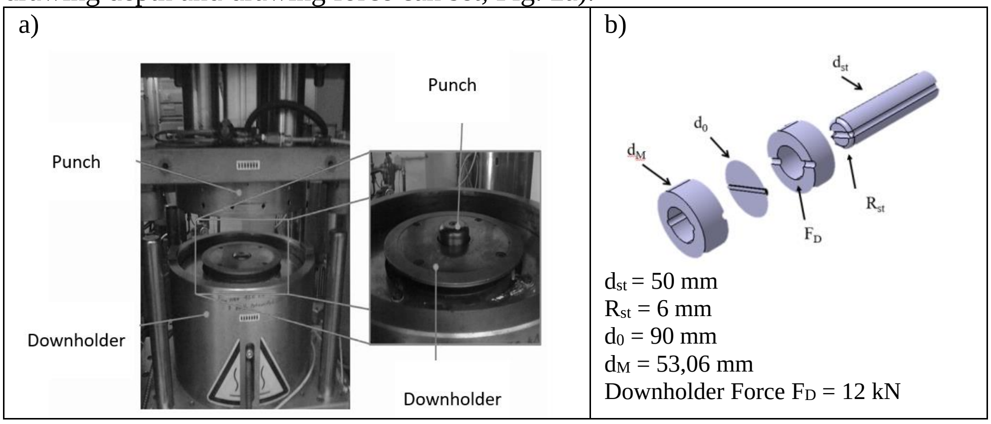

Fig. 2 – Cup Test Equipment.

In order to be able to use the existing test setup, which intended for cup tensile tests with the use of sheet metal without a weld seam, tool adjustments carried out for the weld seam and the existing sheet thickness jump. The existing cup pulling tool with a punch diameter of 50 mm optimized with recesses for the weld seam of the THB on the punch, on the hold-down device and on the die. The recess made semi-circular with a width of 10 mm and a depth of 5 mm. As part of an inexpensive tool production, a drawing gap is set over the entire circumference of the punch. The sheet thicknesses equalized by grinding on the tools without a tangential transition from the drawing radius to the area of the drawing ring. Furthermore, a drawing gap of 2 mm, a punch radius of 6 mm and a die inlet radius of 5 mm specified, see Fig. 2b). The possibility of measuring the force-displacement curves for hold-down devices and punches retained due to the modified design.

Adjustable test parameters such as the pulling speed, the maximum press force and the lubrication of the blanks kept the same according to the standard cup pull test. Furthermore, the hold-down force should remain constant at the same round diameters and determined by preliminary tests. To select a suitable blank diameter, before the actual deep-drawing test with a modified tool, with the help of compensating / centering rings, this is first done with three different blank diameters ($d_{0.1}$ = 90 mm, $d_{0.2}$ = 95 mm and $d_{0.2}$ = 110 mm) limit drawing ratio $ß_{max} = d_{0, max} / d_{St}$ determined.

In addition to the determination of the drawing ratio, an assessment of the drawn cups carried out after completion of the deep-drawing test with an adapted tool. The measurements of the occurring strains during the forming in the area outside the weld seam carried out by taking pictures with the optical strain measuring system ARGUS. The evaluation carried out by means of image processing on the formed component by analyzing the distortions of the pattern. Finally, the sheet thickness distribution on the formed cup including the weld seam determined by the ATOS surface measurement system using a strip light projection method.

3. RESULTS

3.1. NAKAJIMA TEST

The Nakajima test is a known method to identify the maximum formability performance of sheets. The test based on the principle of deforming sheet blanks of different geometries until fracture occurs by using a hemispherical punch. Depending on the strength of the base material, the weld line shifts across the THB during the deformation process, Fig. 3. Due to a greater material flow in aluminium, the weld bead moves toward the steel side. Because of higher material deformation, a large shift of the weld line observed in the Equi-biaxial tension state, Fig. 3c). This observation has to consider in the construction of a special manufacturing forming tool for THBs. If no enough gap planned in the forming die for welding movement, additional stresses introduce into the material, which can lead to earlier failures.

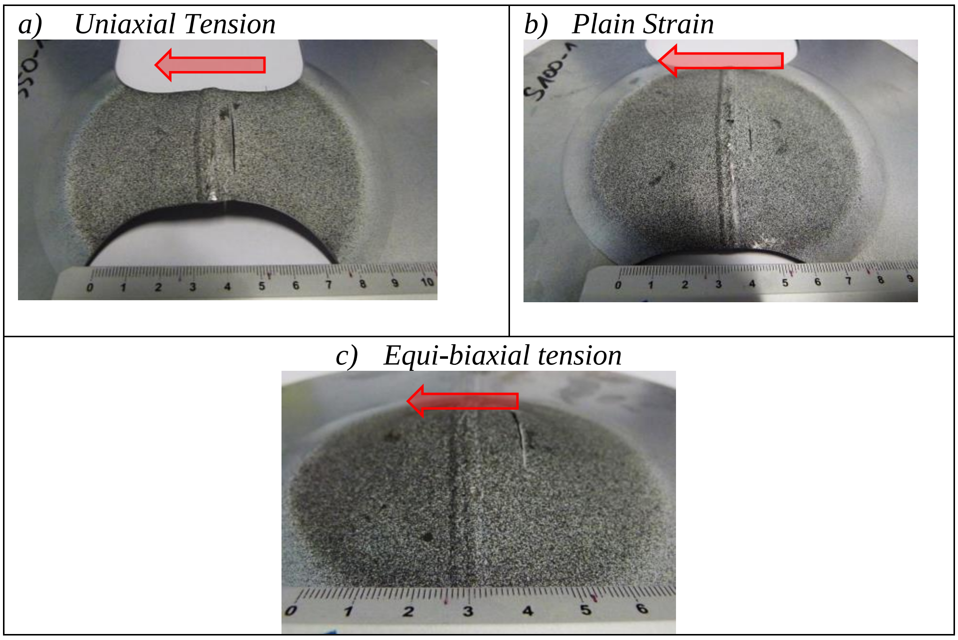

Fig. 3 – Movement of the weld line.

The major and minor strain distributions for deformation state measured from the specimen formed to failure given as an example for Equi-biaxial tension in Fig.4. As can be seen main strain localization and the failure occurred on the aluminum side. All of the welded specimens failed on the aluminum, and none of them in the weld. The higher mechanical properties of the steel compared to aluminum prevent the plastic deformation on the steel side.

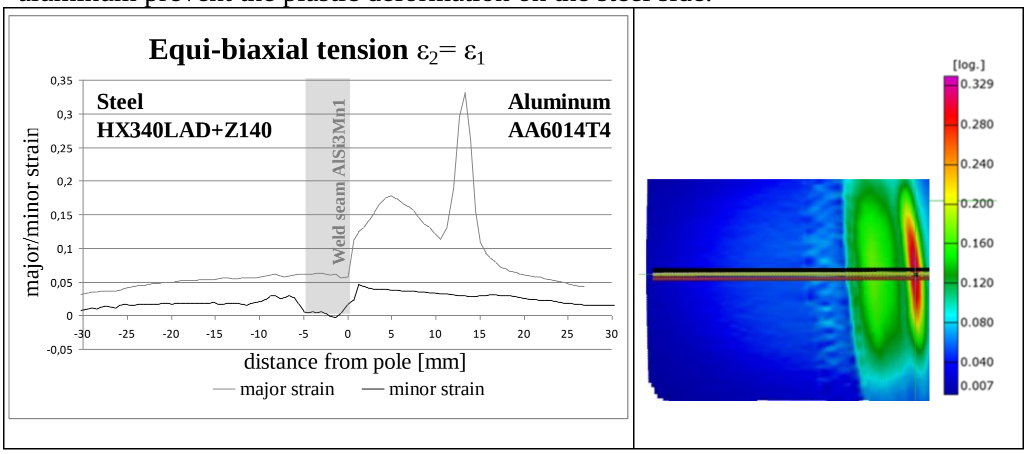

Fig. 4 – Equi-biaxial tension.

Fig. 5 represents the influence of the THB to the forming limit curve. It is obvious, that the deformation limit of THB is significant lower compared to the base materials. The decrease in forming limits arises mainly based on non-uniform deformation in the blank due to the difference in thickness, material properties and the presence of the weld bead.

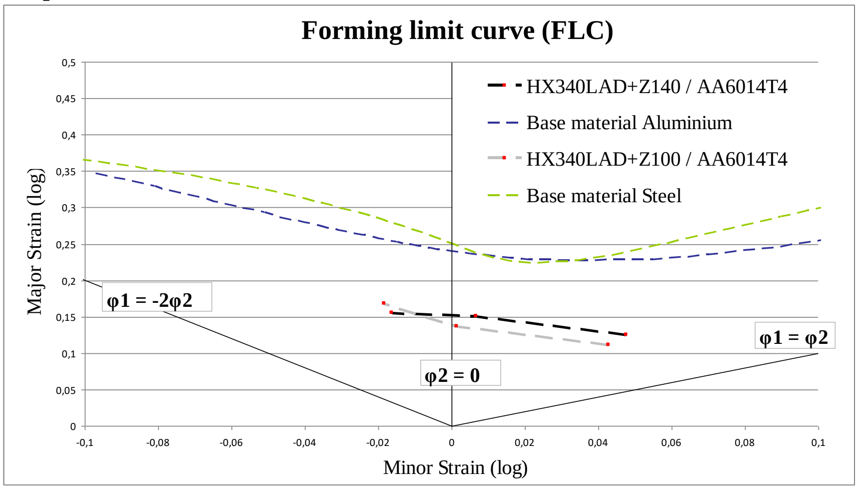

Fig. 5 – Forming limit curve for THB.

3.2. CUP TEST

To characterize the formability, cup tensile tests carried out on CMT-joined steel-aluminum THB. The processing of the test tool with the creation of recesses for the weld seam is relatively complex and costly. For this reason, before the actual deep-drawing test, the maximum formability is determined with the help of compensating / centering rings with three different round diameter ($d_{0.1}$ = 90 mm, $d_{0.2}$ = 95 mm and $d_{0.2}$ = 110 mm). In order to eliminate the influence of the required drawing gap for the weld seam on the overall formability, the forming process ultimately carried out with an adapted tool. Fig. 6a) shows the mean punch paths achieved. The weld-soldered blanks show no cracks with round diameters of 90 mm and 95 mm, i.e. cups drawn without seam failure. However, the shaped blanks present a different deep-drawing behavior. Although the highest drawing depths achieved with a blank diameter of 95 mm without seam failure, the base material buckled in the direction of the punch due to the required drawing gap. The kink is always in the steel material and in the immediate vicinity in the weld seam in the flange transition. This was not always the case for samples with a circular blank diameter of 90 mm. Here, samples with an average punch path of 32.5 mm and an average punch force of 16.27 kN could be drawn without failure.

Limit drawing ratios with a blank diameter of 110 mm (ß = 2.2) could not be realized. The main type of failure is floor cracks. In all samples, the beginning of crack initiation on the aluminum base material shown with continuous breakage perpendicular to the weld seam and first-order folds when the hold-down force was set.

From the results, it can be summarize that a maximum formability with a round diameter of 90 mm can be achieve without failure. However, due to the unavoidable drawing gap, no shaped cups can be created, which makes it difficult to specify whether the maximum drawing ratio limit $\beta_{max} = d_{0, max} / d_{St} = 1.8$ has been reached. For this reason, the next step is to improve the formability to check $\beta max = 1.8$ with a modified tool.

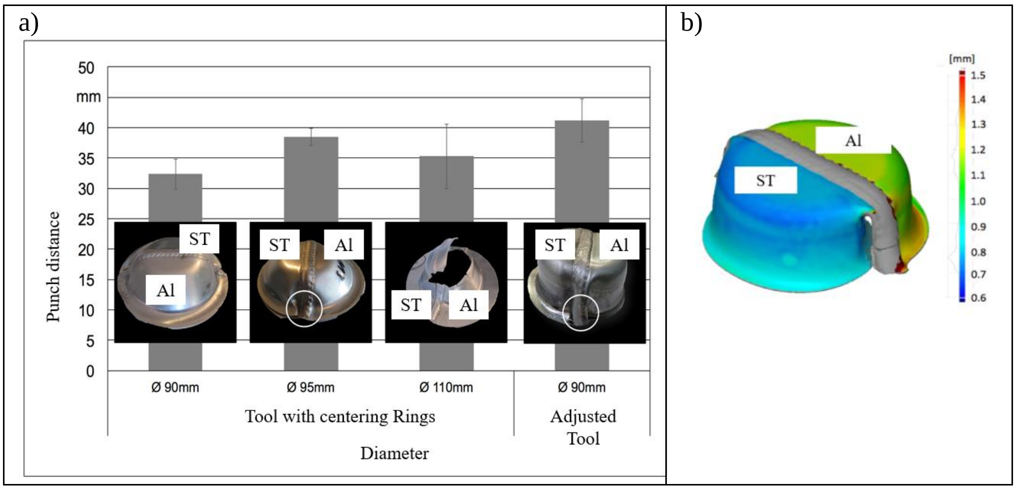

Fig. 6 – Cup test.

As already mentioned before, the existing cup test tool with a punch diameter of 50 mm was expanded with cutouts for the weld seam on the punch, the hold-down device and the die. Based on the results of the bending test, THB with rolling direction along the weld seam used. In comparison to the preliminary tests, Fig. 6a) shows the cup pull result from the modified tool as well. Analogous to the preliminary tests with a circular diameter of 90 mm, samples without seam failure could be produced with an average punch force of 31.5 kN and an average punch travel of 41.2 mm. The cup shape contour show that the formability of the THB can be improve by making recesses for the weld seam on the tool under the same test conditions. However, due to the different sheet thicknesses and strength ratios of the base materials, it was still not possible to prevent the steel edge from buckling. The measurement of the remaining sheet thickness after forming shows that with an adequate load on the blank, due to the material properties of aluminum, the sheet thickness reduced. In contrast, the sheet steel shows an almost constant residual sheet thickness, Fig. 6b). In summary, it can be state that the deep-drawing ability of the cups could be improve by making recesses for the weld seam on the tool. Due to the different forming properties of the base materials steel and aluminum, the area of the weld seam design must critically examined before the respective component application.

4. CONCLUSION

The forming limit of the tailored hybrid blank sheets is significantly reduce when compared to the base materials. The Nakajima test showed that the reduction effect is mainly due to the presence of different material combinations (steel-aluminum) and geometric discontinuity rather than the weld itself. All specimens failed in the ductile material aluminum. Last, another conclusion of this study is that the weld line has the tendency to move during the forming operation toward the direction of the steel. In this regard, weld-line displacement is an important indicator of deformation and caution should take for designing THBs- forming operations. In the cup pull test, the deep-drawing ability could be improve by introducing recesses on the tool, but the buckling of the steel edge could not be prevented by using a common hold-down with sole sheet thickness compensation. The different forming properties of the base materials continue to influence the deep drawing ability. Therefore, the steel-aluminum material separation of the component should be design so that the formability affected as little as possible by the base materials.

Received on November 24, 2020

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