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Formability of steel and aluminium tailor welded blanks

Rodrigues, D.M., Chaparro, B.M., Leitão, C., Baptista, A.J., Loureiro, A., Vilaça, P.

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Abstract

In the industrial production of metallic components by plastic deformation processes, the introduction of the Tailor-Welded Blank (TWB) technological concept enabled, simultaneously, the production of stronger and light panels and the reduction of material waste, which is an important step in nowadays environmental concerns. However, it is well know that existing **welding** technologies can induce significant differences in mechanical properties between the welds and the base materials. An important question in current investigation on TWBs formability is whether the weld bead, that can vary from very wide to very narrow, according to the weld process in use, has a significant influence on the overall plastic behaviour of the welded blanks. In this investigation the formability behaviour of Laser steel welded blanks, with narrow weld beads, and **Friction Stir** Welded (FSW) aluminium blanks, with wide weld beads, will be compared. The base materials are two Steel Alloys (DC06 and DP600) and two Aluminium Alloys (AA 5182-H111 and AA 6016-T4) very popular in automotive industry. The TWBs were made from 1 mm thick plates by considering similar (DP600/DP600, DC06/DC06, AA 5182-H111/ AA 5182-H111 and AA 6016-T4/ AA 6016-T4) and

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dissimilar (DP600/DC06 and AA 6016-T4/ AA 5182-H111) combinations of both types of base materials. The formability behaviour of the TWBs was analysed by stamping Axissimetrical Cylindrical Cups in a Deep-Drawing laboratorial testing device specially developed to work in a classical tensile test machine. The main reported results were the punch force-displacement curves and geometrical data from the Axissimetrical Cylindrical Cups. Results from the formability tests in all type of welds are presented and compared in the paper.

Author Keywords

Formability; Laser **welding**; Taylor welded blanks; **Friction stir welding**

Matched Terms:

Index Keywords: Laser beam **welding**
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FORMABILITY OF STEEL AND ALUMINIUM TAILOR WELDED BLANKS

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Keywords: Taylor welded blanks; Friction stir welding; Laser welding, Formability

Abstract:
In the industrial production of metallic components by plastic deformation processes, the introduction of the Tailor-Welded Blank (TWB) technological concept enabled, simultaneously, the production of stronger and light panels and the reduction of material waste, which is an important step in nowadays environmental concerns. However, it is well know that existing welding technologies can induce significant differences in mechanical properties between the welds and the base materials. An important question in current investigation on TWBs formability is whether the weld bead, that can vary from very wide to very narrow, according to the weld process in use, has a significant influence on the overall plastic behaviour of the welded blanks.

In this investigation the formability behaviour of Laser steel welded blanks, with narrow weld beads, and Friction Stir Welded (FSW) aluminium blanks, with wide weld beads, will be compared. The base materials are two Steel Alloys (DC06 and DP600) and two Aluminium Alloys (AA 5182-H111 and AA 6016-T4) very popular in automotive industry. The TWBs were made from 1 mm thick plates by considering similar (DP600/DP600, DC06/DC06, AA 5182-H111/ AA 5182-H111 and AA 6016-T4/ AA 6016-T4) and dissimilar (DP600/DC06 and AA 6016-T4/ AA 5182-H111) combinations of both types of base materials.

The formability behaviour of the TWBs was analysed by stamping Axissimetrical Cylindrical Cups in a Deep-Drawing laboratorial testing device specially developed to work in a classical tensile test machine. The main reported results were the punch force-displacement curves and geometrical data from the Axissimetrical Cylindrical Cups. Results from the formability tests in all type of welds are presented and compared in the paper.

1. INTRODUCTION

Due to the worldwide extreme competitiveness and severe governmental regulations, metal forming companies suffer today increased pressures to achieve, simultaneously, high quality products, minimal costs and minimum material waste and pollutant emissions. In the particular case of the automotive industry important efforts have been made to develop new technological solutions that enabled the employment of lighter materials, such as aluminium alloys, polymers or high strength steels, and also to produce components adopting new technological processes, such as hydroforming, powder injection moulding or improved welding technologies, which allow the use of optimized blanks, such as the tailor-welded blanks (TWBs).

The TWBs technological concept consists in producing panels composed by several sheet metal blanks that may be of different material grades, strengths, gauge thickness or coatings, welded together prior to the forming process. The key advantage of using TWBs is the attained weight reduction, due to the fact that only the strictly necessary material (and implicitly only the strictly necessary mechanical resistance) is applied to each panel area, for a predefined overall resistance of the global formed part [1].

Despite of the technological process of TWBs has over 25 years of automotive applications, several difficulties continued constraining its general use in industry. Some of those difficulties have been:

- The decreased formability of the welded panel when compared with a non-welded one;
- The difficulty of welding some materials without defects or strength reduction on the weld line (aluminium alloys and high strength steels specially);
- The required high precision of the edges to align joints for laser welding (higher costs).

It is also well established that the combination of blanks with dissimilar characteristics leads to different thermal behaviour during the welding operation which, sometimes, give rise to welds with substantially different mechanical properties face the base materials. Thus, an important question is whether the weld bead has a significant influence on the overall forming behaviour of the welded blanks [2-4].

In this study, the formability behaviour of aluminium and steel TWBs and its relation with the weld bead width and mechanical properties was addressed by performing deep-drawing tests. Steel TWBs with narrow welds were produced by using the Diode Laser technology. Aluminium Friction Stir Welded TWBs were fabricated in order to obtain blanks with wide weld beads. The base materials were two Steel Alloys (DC06 and DP600) and two Aluminium Alloys (AA 5182-H111 and AA 6016-T4) very popular in automotive industry. The TWBs were made from 1 mm thick plates by considering similar (DP600/DP600, DC06/DC06, AA 5182-H111/AA 5182-H111 and AA 6016-T4/AA 6016-T4) and dissimilar (DP600/DC06 and AA 6016-T4/AA 5182-H111) combinations of both types of base materials.

2. WELDING PROCEDURE

Steel Tailor Welded Blanks: The welds were produced in steel sheets using a Rofin high power diode laser of 3 kW adapted to a Kuka robot. No filler wire was used in the welds. The weld direction was settled parallel to the rolling direction in the similar TWBs (DP600/DP600, DC06/DC06) and perpendicular to the rolling direction in the dissimilar TWBs (DP600/DC06). The welding parameters were: working distance 44 mm; rectangular focus size (0.8x1.2 mm); welding speed 18 mm/s. Inert shielding gas was used (8 lt/min) and the sheets were clamped alongside at a short distance from the weld.

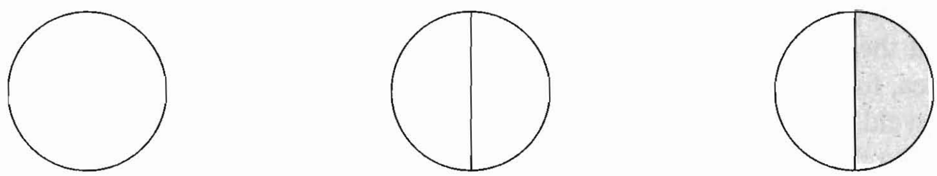
Aluminium Tailor Welded Blanks: Friction stir welded tailored blanks were made from aluminium plates by using a 10 mm shoulder diameter tool with a threaded pin of 3 mm in diameter and 1 mm in length. The welding conditions were: 1800 rpm rotation speed (ϖ), 160 mm/min travel speeds (**v**), 0.9 ~1 mm tool penetration and 2.5° tool tilt angle. Also in this case the welds were performed considering similar (AA 5182-H111/AA 5182-H111 and AA 6016-T4/AA 6016-T4) and dissimilar (AA 5182-H111/ AA 6016-T4) combinations of the base materials. The weld direction was set parallel to the rolling direction of the sheets in all types of TWBs. The sheets were clamped alongside at a short distance from the weld line.

3. TESTING PROCEDURE

Before the formability tests, the heterogeneity in mechanical properties across the different weld zones was assessed by performing hardness tests. Hardness measurements were performed transversely to the weld direction, for all the welds, using load values optimized according to the base material in study: 200 g for the two Steel base materials, 50g for the AA 5182-H111 aluminium alloy and 100 g for the AA 6016-T4 aluminium alloy. All the results were verified by performing, for each type of sample, hardness measurements in several positions along the welding directions.

The formability behaviour of the tailored blanks and homogeneous base materials was studied by stamping Axisymetrical Cylindrical Cups in a laboratorial deep drawing device specially developed to work in a classical tensile test machine. To perform the formability tests circular specimens with 200 mm diameter were extracted from the parent material sheets and from the TWBs (Figure 1).

The stamping tool, shown in Figure 2, enable to apply and maintain the force in the blank-holder, by using 10 calibrated springs. One of these springs is equipped with a 10kN force sensor in order to verify if the blank holder force remains stable during the test. The stamping operation was always performed on lubricated blanks. It was applied 1.4 g/m^2 of QUAKER N6130 oil per blank face using a pre-impregnated paper weighted before and after the application. The admissible error on lubricant weighing was less than 5 %. The base materials and the tailored blanks were tested using the following testing conditions: 100 mm/min punch speed in all tests and 16 kN clamping force for the DC06 specimens, 28 kN for the DP600 and DC-DP600 blanks, and finally, 8kN for all types of Aluminium Alloy specimens. The clamping force was previously optimized by using base material samples of both types of Steels and Aluminium alloys.



a) Base Material Sample c) Similar weld TWB e) Dissimilar weld TWB

Figure 1 – Schematic representation of the specimens used in the formability test.

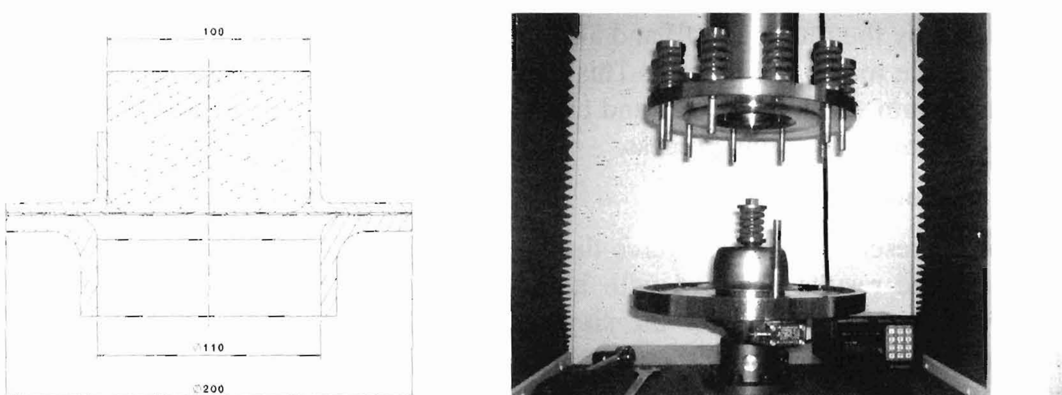


Figure 2 – Stamping tool.

4. RESULTS AND DISCUSSION

4.1 Hardness tests

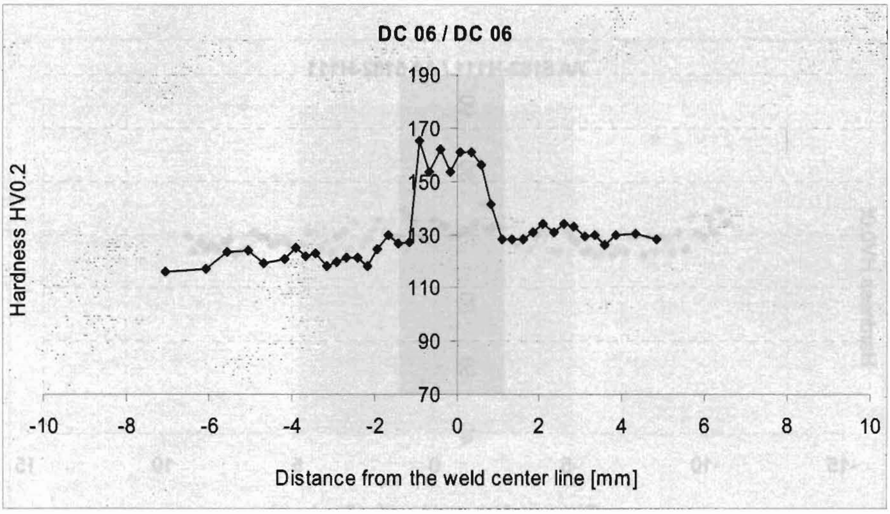
The hardness evolution across the welds is shown in Figures 3 and 4 for the Steel and Aluminium tailored blanks, respectively. The average hardness determined for each base material were: 122 HV0.2 for the DC06 steel, 223 HV0.2 for the DP600 steel, 71 HV0.05 for the AA 5182-H111 aluminium and 67 HV0.1 for the AA 6016-T4 aluminium. The weld limits, corresponding to the melted material (MM) and heat affected zone (HAZ), for the steel laser welds, and to the under tool shoulder area, for the friction stir solid state aluminium welds, are delimited in each graph by grey bars.

The hardness results for the similar DC06 welded blanks, see figure 3.a, show an increase in hardness in the melted material area (150 HV0.2) relative to the base material (122 HV0.2). The hardness increase is limited to the approximately 3 mm width melt material line. The hardness results for the DP600 welded blanks show a quite different evolution, as it is illustrated in figure 3.b. In fact, strong heterogeneity in properties was registered across de weld, being possible to observe a significant increase in hardness in the melt material area (280 HV0.2) and some softening in the heat-affected zone (208 HV0.2) relative to the base material (223 HV0.2). The mechanical heterogeneity area has approximately 7 mm width, with the hardness values falling progressively from the base material to the HAZ and rising abruptly in the melted material. Finally, the hardness profile for the DC06/DP600 dissimilar TWB is displayed in figure 3.c. The hardness evolution for this weld matches closely with those observed for the similar welds, being possible to observe a jump in hardness inside the molten metal area (300 HV0.2). After these observations an important issue is whether such a sudden change in hardness, concentrated in a narrow region, can have some influence in the plastic deformation behaviour of the similar and dissimilar TWBs.

Analysing now the results plotted in Figure 4.a and 4.b, for the similar aluminium TWBs, it is possible to conclude that there are very small differences in hardness between the welds and the base materials, for both similar welds, which indicate that the FSW process induces very small changes in mechanical properties in the weld area, for this type of materials and welding conditions. In the same way, for the dissimilar weld (Fig. 4.c) it is possible to observe a smooth hardening transition transversely to the weld line that joints together de different base materials. In fact, the hardness values in the weld fall between the average hardness values characteristic of each base material. From the hardness results it is possible to expect a relatively good homogeneity in macroscopic mechanical properties for both similar and dissimilar aluminium TWBs. However, it is important to enhance that the welding process induces locally severe changes in material microstructure and surface finishing (due to the marks left by the rotating tool) and also to a small cross section decrease in the weld, as it is possible to see in Figure 5. This material and geometrical heterogeneities extends over a 10 mm width weld area and can affect the plastic deformation behaviour of the blanks during the forming process.

4.2 Formability tests

Figure 6 presents the punch force-displacement evolution for the steel TWB samples and also the results obtained with homogeneous base material specimens. It can be observed that the curves for the similar welds (TWB_DP600 and TWB_DC06) and homogeneous base material specimens (DP600 and DC06) are very close and the maximum drawing force values are almost the same for both types of samples. The pictures of the drawn cups obtained from the monolithic DC06 material and DC06/DC06 welded blank are shown in figures 7.a and 7.b, respectively. The central hole in each sample was machined with the aim to assist the blank positioning in the deep-drawing device. From the force-displacement graph and from the pictures it is possible to conclude that despite the strong heterogeneity in mechanical properties in the welds, revealed by the measured hardness profiles, the similar TWBs can be formed with success using the same stamping parameters of the base materials.



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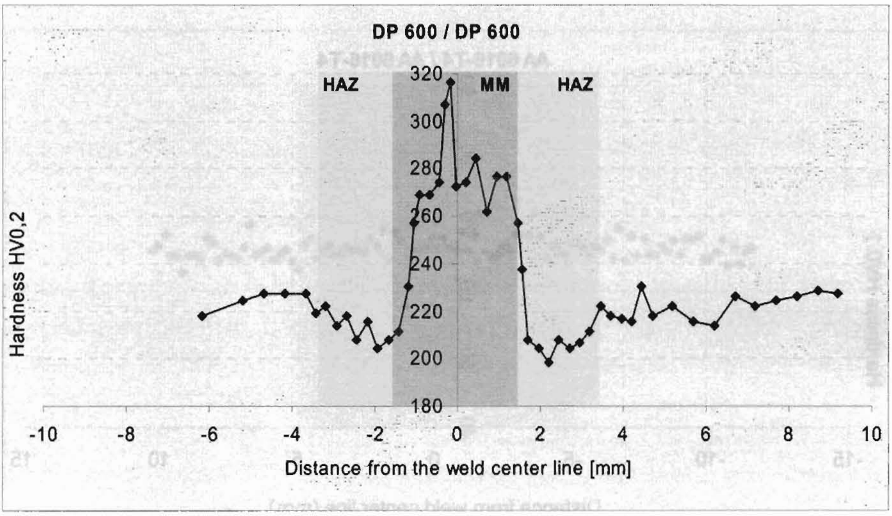

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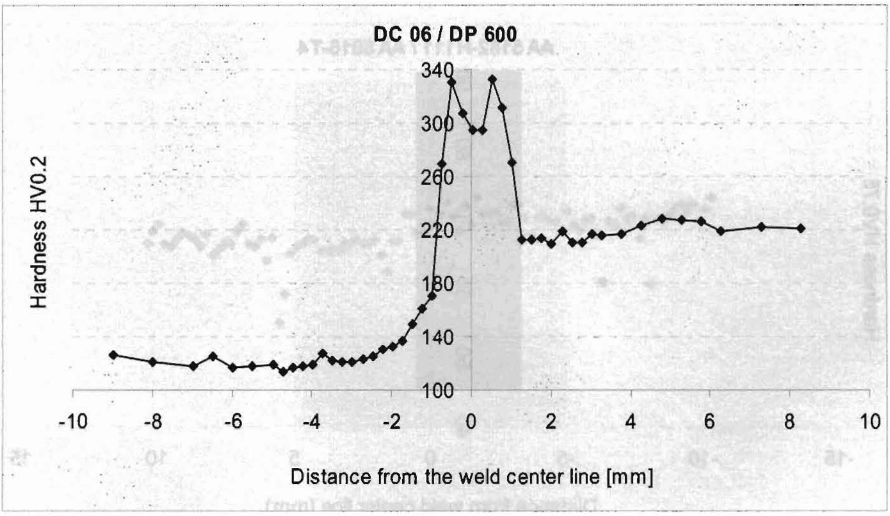
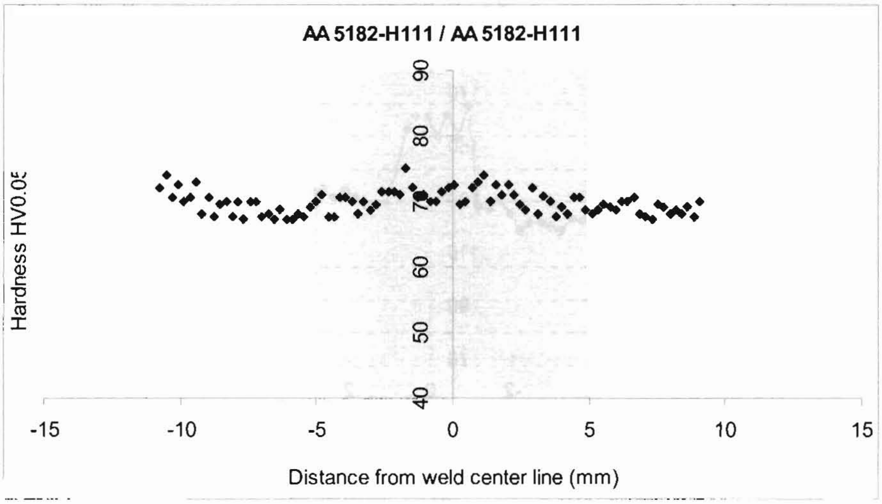


c)

Figure 3 – Hardness profile across the DC06/ DC06 (a), DP600/ DP600 (b) and DC06/ DP600 (c) welds.



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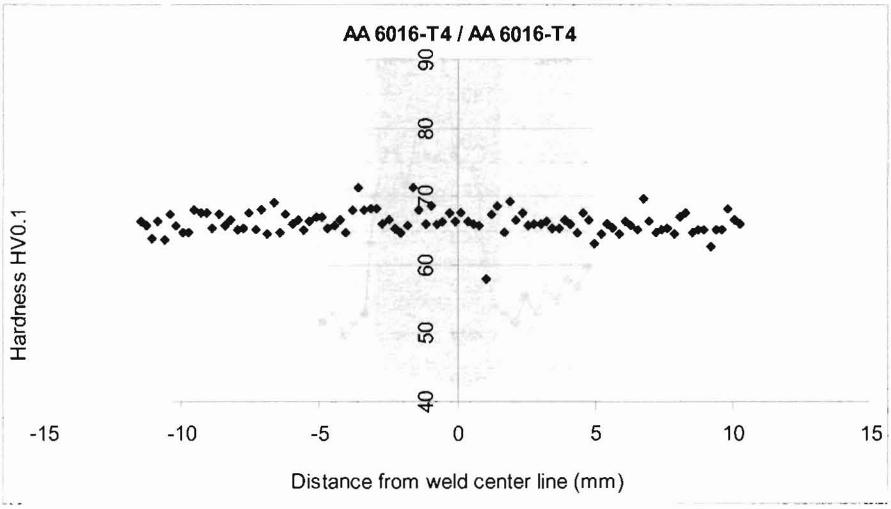

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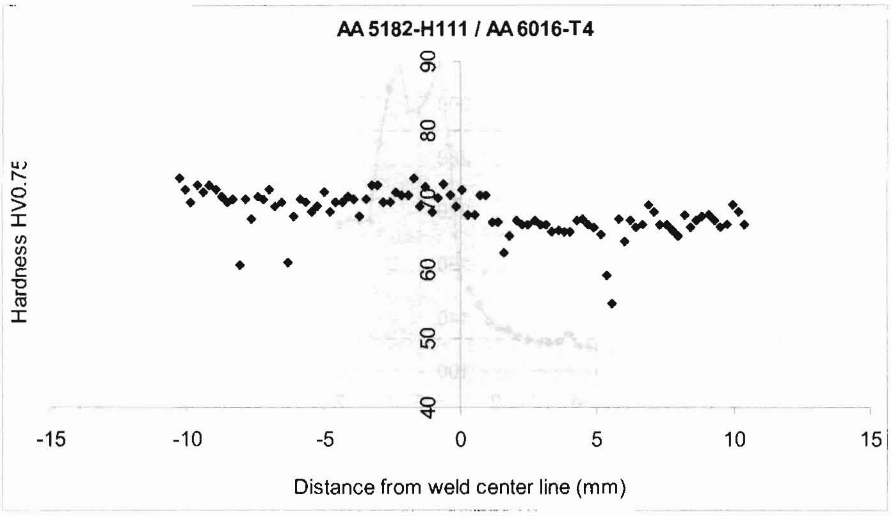


c)

Figure 4 – Hardness profile across the AA 5182-H111/ AA 5182-H111 (a), AA 6016-T4/ AA 6016-T4 (b) and AA 5182-H111/ AA 6016-T4 (c) welds.

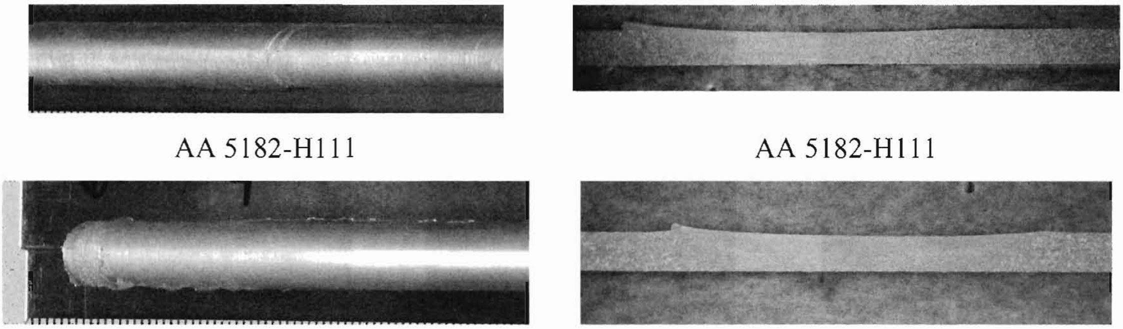


Figure 5 – Appearance of the surface and cross section of the similar aluminum welds.

In the case of the TWB composed by dissimilar materials (TWB_DC_DP600), the initial punch force-displacement curve lays, as expected, between the DC06 and DP600 curves. However, for this sample, the full punch displacement was not attained due to the rupture of the weld after 20 mm stroke, as it is possible to see in the picture of figure 7.c. In order to understand the dissimilar TWB behaviour during the stamping test a numerical simulation reproducing the experimental test was performed by using an implicit three dimensional finite element program (DD3IMP [5]). The material parameters used in the numerical simulation are those presented in Table I for both base materials and for the weld line. The material constants for the weld material zone were estimated from the hardness results by using the procedure described in [6].

According to the numerical simulation results, the rupture of the dissimilar TWB cup can be justified by different deformation behaviour of the materials, and also, by the presence of the center hole used to assist the positioning of the blank. In figure 8 is shown a picture of the equivalent plastic strain distribution in the sample in which it is possible to observe strong strain concentration near the weld line next to the hole. Numerical result shown that combining constraint induced by the hole with the smaller strength resistance of the DC06 face the DP600 material, significant thickness reduction takes place on DC06 weld side leading to failure along the weld as observed in the experimental test.

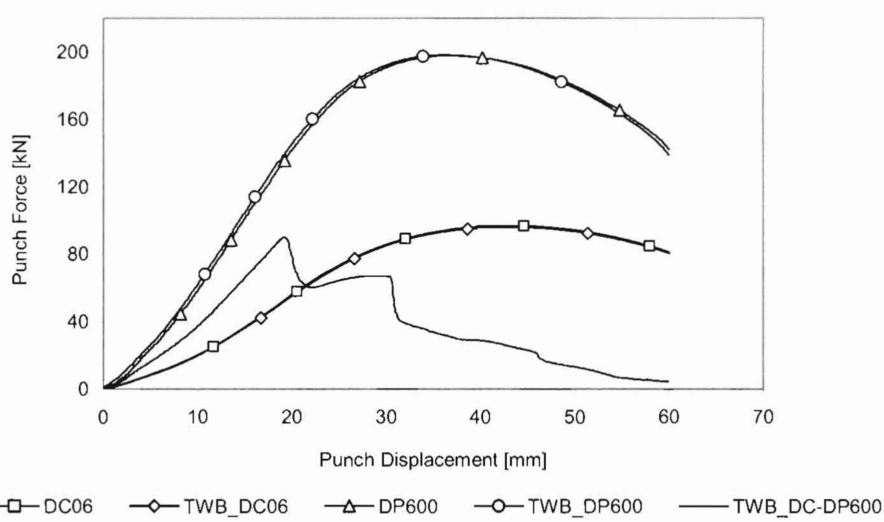
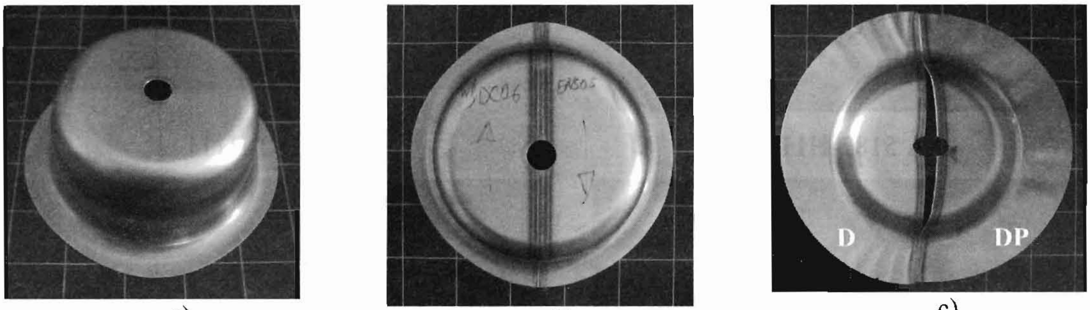


Figure 6 - Punch force versus punch displacement curves for the different sets of steel TWBs tested and for the DC 06 and DP 600 base materials.



a) b) c)

Figure 7 – Deep-drawing cups of (a) DC06 base material, (b) DC06 similar weld and (c) DP600/DC06 dissimilar weld.

Table 1 – Material parameters used in the numerical simulation.

		DC 06	DP600	DC/DP weld
Young modulus - E(GPa)		210		
Poisson coefficient - ν		0.30		
Yield stress - σ_0 (MPa)		123.6	359.38	810.9
Hardening law	K (Mpa)	529.5	1098.34	1280.1
$\sigma = K(\varepsilon_0 + \varepsilon)^n$	ε_0	0.00438	0.00145	0.0205
	n	0.268	0.171	0.117

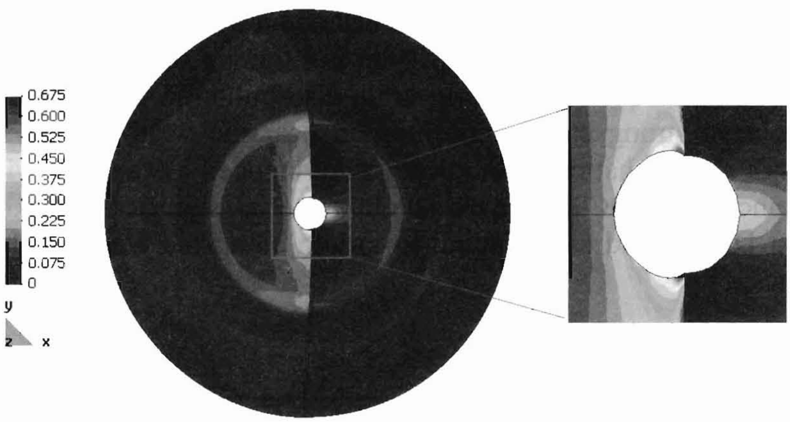


Figure 8 – Equivalent plastic strain distribution in the DC06/DP600 dissimilar TWB.

In Figure 9 are shown the punch force-displacement curves for the similar aluminium welds and for the two aluminium base materials. Analysing the graph it is possible to conclude that the punch force evolution for both similar welded blanks is very close to that of the correspondent base materials, until around 20 mm punch displacement. After 20 mm punch displacement strong wrinkling started in both TWBs, accompanied by a strong decrease in the punch force relative to the base materials. In figure 10 is possible to compare the cups obtained for the AA 5182-H11 material: Base material cup (Figure 10.a) and the inner and outer surface (Figure 10. b and c, respectively) of the similar TWB cup. As it is exemplified in this figure, no necking was observed in the weld zone for both tailored blanks, which confirms the good deformation behaviour of these solid state welds. However, the occurrence of wrinkling establishes the necessity of optimizing the stamping parameters for the tailored blanks, even when the hardness results suggest relative homogeneous behaviour between the weld line and the base materials. Since it was not possible to get the deep-drawing of the similar welds, no experiment was performed with de dissimilar weld specimens.

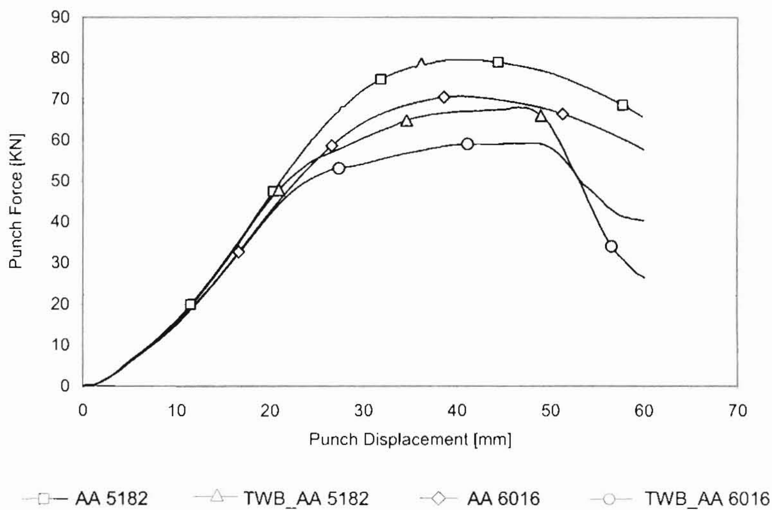


Figure 9 - Punch force versus punch displacement curves for the different sets of similar aluminium TWBs and for the AA 5182_H111 and AA 6016-T4 base materials.

a) b) c)

Figure 10 – Deep-drawing cups of AA 5182-H11 base material (a) and outer (b) and inner (c) surfaces of the similar AA 5182-H11 weld cup.

It is well known that the most frequent types of failure in the deep-drawing of metallic components are wrinkling, necking (and subsequently tearing), scratching and orange peel. All this failure mechanisms can be attributed to an incorrect design of the tools and blank shape or to an incorrect choice of material, lubrication and process parameters. The process parameters in this experimental study were previously optimized by using homogeneous base materials samples and several base material cups were formed with success. However it was not possible to obtain correctly formed parts from the TWBs, by using the same process parameter conditions. A numerical study is currently being performed in order to optimize the blank shape and blank-holder force for the stamping of the TWBs.

5. CONCLUSIONS

Based on the results presented in this paper, it is possible to conclude that the formability behaviour of the TWBs depends mainly on the mismatch in mechanical properties between the base materials joined together, on the weld width and on the macro and microstructure of the tailored blanks. In current study it was possible to perform with success several axissimetrical cups with the DC06 and DP600 base materials and its similar welds. The same process parameters were used for the stamping of the homogeneous (base material) and welded specimens. The results obtained shows that a strong mismatch in mechanical properties, if localized in a narrow weld zone (as indicated by the hardness profiles registered for these materials), doesn't have any influence on the formability behaviour of the tailored blanks. However, if the two different steels are joined together, the plastic behaviour of the dissimilar TWB is substantially different from the similar ones. In fact, rupture of the dissimilar welded blanks was observed under the same deep-drawing conditions of the similar blanks. From the results of the numerical simulation of the experimental test it is expected that changing the blank shape, more precisely, removing the central hole of the blank, it will be possible to shape with success the dissimilar TWBs.

The results obtained from the formability tests of the AA 5182-H111 and AA 6016-T4 base materials and its similar welds shown a different type of behaviour from that registered with the steel samples. In fact, despite the relative homogeneity in mechanical properties across the welds revealed by the hardness measurements, the similar TWBs suffer strong wrinkling under the same test conditions of the base materials. This behaviour can be associated with severe changes in material microstructure, surface finishing and thickness of the weld relative to the base material, which induces non-homogeneous behaviour of the blank. Optimization of the process parameters for the stamping of the aluminium TWBs is currently in progress.

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