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DETERMINATION OF TAILOR WELDED BLANKS FORMABILITY CHARACTERISTICS

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ABSTRACT

The paper shows the experimental results of researches of tailor welded blanks formability obtained by laser welding of sheet metals of different thicknesses (0,8 mm and 1,5 mm) of the same material (high strength steel with BH effect) and of the same surface condition (galvanic zinc coated). Investigation by tension of series of specimens with laser weld placed transverse in relation to longitudinal specimen axis was applied. The following formability properties were defined: main mechanical properties, flow curves, r-value and n-value. Analysis of forming process of each sheet metal separately and welded assembley was performed. The conclusions indicate the specific influence of non-homogeneity caused by different thicknesses and welded zone and indicate the subsequent investigations with longitudinal and angled positions of welded line in relation to the direction of force action.

Key words: *Tailor welded blanks, Sheet metals, Deep drawing, formability*

1. INTRODUCTION

The term „tailored" sheet metals or „tailor welded blanks" (TWB) implies previously cut („tailored") and then laser welded pieces of sheet metal, by which a unique entity is obtained which represents a blank for plastic forming operations, most often deep drawing. The components (pieces) in formed welded assembley can be with various: thicknesses (most often), material types and surface and coatings quality (Fig. 1). By application of TWB (usually of steel and Al sheet metals) significant effects are achieved (in car industry most of all, Fig. 2): mass reduction, stiffness increase, reduction of total production costs (less number of tools, reduced designing time, less working positions number etc.), [1, 2, 3]. During the last decade, a sudden increase of TWB was registered, especially in car industry. It has been estimated that, globally speaking, around 120 millions of TWB assemblies were produced in 2001. That figure increased in 2005 up to around 250 millions of pieces (web sites [1]).

Plastic forming of TWB is carried out in difficult conditions due to prominent non-homogeneity of the material (different thicknesses, materials, surface conditions). Estimation of formability can be made by using different experimental tests or computer simulations. Uniaxial tensile test represents the main and the most significant source of information on formability of TWB. Different authors apply longitudinal position of weld (matches the axis of the standard specimen) [4, 5, 6], or crosswise position (normal against specimen axis) [6]. In the researches carried out at the Faculties of Mechanical Engineering in Kragujevac and Banja Luka both positions of welded zone were applied, and experiments with angled positions of weld in relation to test specimen longitudinal axis are ongoing. This paper presents the results for transverse position of weld, which is normal to longitudinal axis of specimen and is located halfway along the measuring length of 80 mm.

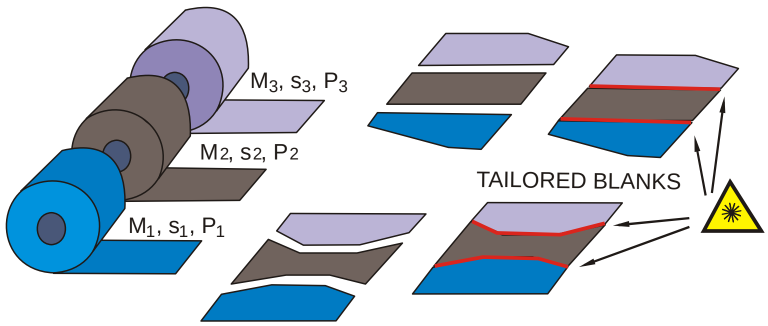

Figure1 – Principal scheme of TWB manufacturing

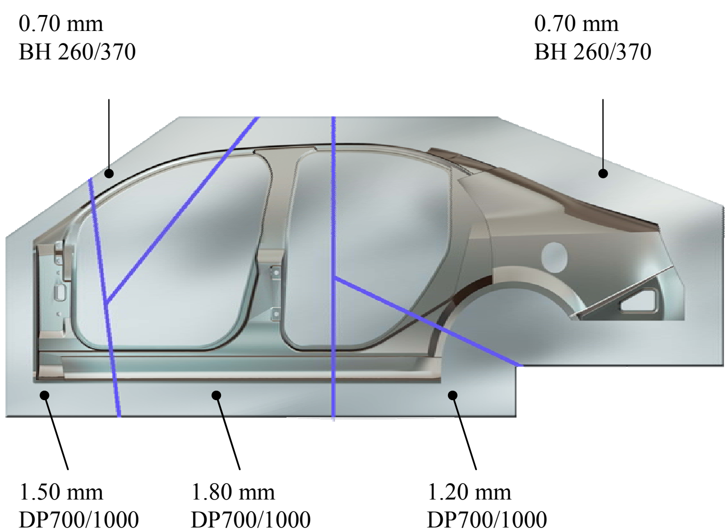

Figure 2 – Lateral side of car body made of TWB

2. EXPERIMENTAL RESEARCHES

2.1 Basic data on the material and the experiment

Investigation is performed according to standard EN 10002 in part related to investigation of sheet metals. There are no special standards for investigation of TWB. In the actual experiment, investigation of three series of specimens is performed. The first one is related to standard investigation of thinner (0,8 mm) material, the second one to the investigation of the thicker (1,5 mm) material and the third one to the investigation of TWB with crosswise position of weld halfway along the measuring length of 80 mm. Test specimen width is 20 mm (Fig. 3). Sheet metals are made out of the same material which, according to DIN, is marked ZStE 180 BH03ZE (is equivalent to numeral mark 1.0395). It is low-carbon steel sheet metal which has so called „bake hardening" effect (BH) of strength increase during the process of paint baking on car body. On both sides of sheet metal, zinc-coating was applied galvanically. Chemical composition is given in table 1. Somewhat larger content of manganese is prominent. The analysis of chemical content was made in the Laboratory of company „Čajavec" – Banja Luka, RS, BiH.
Uniaxial tensile tests were performed on fully computer controled measuring system Zwick/Roell Z 100 (measuring range of force 100 kN, force reading accuracy 1 N, initial measuring length of extensometer 80 mm, elongation reading accuracy 0,001 mm, software-TestXpert ver. 10).

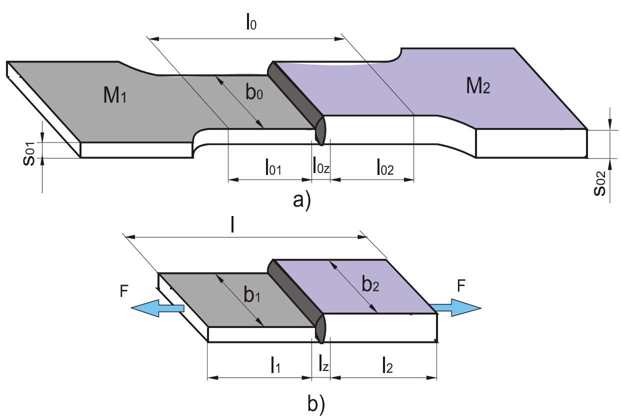

Figure 3 – Specimen before (a) and after tensile test (b)

2.2 Results of the experiment

Tables 2 and 3 present, in addition to main mechanical properties, normal anisotropy coefficient (r-value), strengthening exponent (n-value) and factor $\Delta r = \frac{r - 2 \cdot r + r}{2}$. All values are defined in relation to plane anisotropy as well. The referent direction is the direction of rolling (0^o).

Table 1 - Chemical composition of tested materials

Material	Chemical elements								
	C [%]	Mn [%]	Si [%]	P [%]	S [%]	Cu [%]	Cr [%]	Ni [%]	Al [%]
ZStE180 BH 0,8 mm	0,02	0,15	<0,05	0,010	0,014	0,028	0,03	0,03	0,07
ZStE180 BH 1,5 mm	0,03	0,15	<0,05	0,017	0,015	0,028	0,04	0,03	0,061

Table 2 - Properties of thinner sheet

Material: ZStE180 BH **s=0,8 mm**				
Properties	Angle			Average value
	0^0	45^0	90^0	
Yield strength R_p [MPa]	202,1	211,5	197,4	205,64
Tensile strength R_m [MPa]	294,8	309,6	294,7	302,20
R_p/R_m	0,69	0,68	0,67	0,68
Elongation at break A_{80}[%]	29,03	26,95	29,05	27,99
n-value	0.192	0.192	0.166	0.185
r-value	1,73	1,16	1,87	1,48
Δr-value				0,64

Table 3 - Properties of thicker sheet

Material: ZStE180 BH **s=1,5 mm**				
Properties	Angle			Averag e value
	0^0	45^0	90^0	
Yield strength R_p [MPa]	174,3	183,8	182,4	181,05
Tensile strength R_m [MPa]	262,2	263,7	263,8	263,36
R_p/R_m	0,67	0,70	0,69	0,69
Elongation at break A_{80}[%]	36,69	35,05	35,43	35,56
n-value	0,217	0,193	0,214	0,204
r-value	1,79	1,35	2,07	1,64
Δr-value				0,58

On the basis of data given in tables 2 and 3 it can be concluded that both sheet metals have good plasticity and formability properties. High value of r-value guarantees resistance to thinning which is crucial for deep drawing. Thicker sheet metal has somewhat higher values of r-value, while the values of yield and tensile strength are generally lower, so their proportion practically does not change.

Table 4 - Strengthening curve functions

Material	Angle	Strengthening curve - analytical
s=0,8 mm	0^0	$K=490{,}72\ \varphi^{0{,}192}$ $K=202{,}10+322{,}20\ \varphi^{0{,}443}$
	45^0	$K=514{,}91\ \varphi^{0{,}192}$ $K=211{,}49+338{,}25\ \varphi^{0{,}440}$
	90^0	$K=470{,}58\ \varphi^{0{,}166}$ $K=197{,}45+303{,}10\ \varphi^{0{,}395}$
	Xsr	$K=497{,}78\ \varphi^{0{,}185}$ $K=205{,}63+325{,}45\ \varphi^{0{,}429}$
s=1,5 mm	0^0	$K=485{,}54\ \varphi^{0{,}217}$ $K=174{,}35+325{,}45\ \varphi^{0{,}540}$
	45^0	$K=500{,}02\ \varphi^{0{,}193}$ $K=183{,}80+353{,}38\ \varphi^{0{,}595}$
	90^0	$K=486{,}44\ \varphi^{0{,}214}$ $K=182{,}26+339{,}10\ \varphi^{0{,}557}$
	Xsr	$K=493{,}01\ \varphi^{0{,}204}$ $K=181{,}05+347{,}21\ \varphi^{0{,}572}$

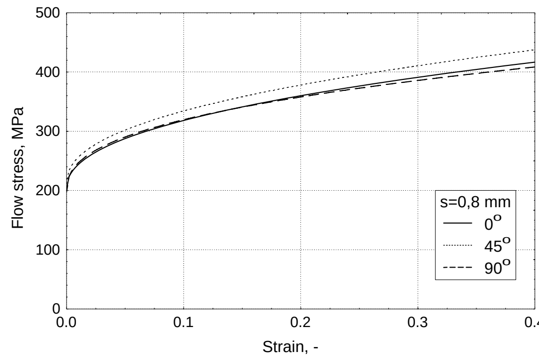

Figure 4 - Strengthening curves

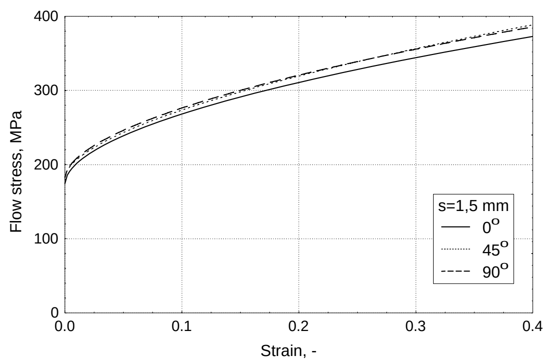

Figure 5 – Strengthening curves

Table 4 gives the survey of approximate functions of strengthening curves in relation to plane anisotropy. Graphic display of strengthening curves is given in figures 4 and 5. It should be emphasized that both sheet metals have very good plastic properties and relatively small strength. However, strength indicators given in tables 2, 3 and 4 are not final due to BH effect which is activated by plastic strain and paint baking process and can result with strength increase for about 20% [7].

During tension of specimen made of TWB with crosswise position of weld, the total strain of initial measuring length l_0 (fig. 3) can be divided into three zones: thinner material strain, thicker material strain and welded zone strain. Welded zone has significantly bigger strength, small plasticity and small length (size 1 mm) so its involvement is neglected. Strain values depend on mechanical properties of sheet metals, strengthening intensity and thicknesses ratio.

If we consider the general case of forming TWB out of different materials, in fig. 6, three process phases can be observed. In order to achieve plastic strain of both thinner and thicker sheet metal, maximal force which thinner material can endure must cause stress larger than yield strength in thicker sheet metal.

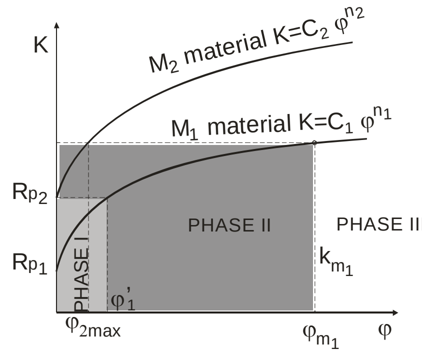

Figure – 6 Phase of TWB tension

Previous condition can be expresses in the following way:

$$R\ s\ b > R\ s\ b \tag{1}$$

Inequality (1) in the actual case can be used for defining the necessary sheet metal thicknesses in order to achieve plastic forming of both sides of TWB. If thickness s_{01}=0,8 mm is fixed, then:

$$s < s\ \frac{R}{R} = 0,8 \cdot \frac{294,74}{183,36} = 1,29\,mm \tag{2}$$

Obviously, in the observed example the condition (2) was not fulfilled, which means that only the thinner part of TWB is elongated. If s_{02}=1,5 mm is fixed, then:

$$s > s\ \frac{R}{R} = 1,5 \cdot \frac{183,36}{294,74} = 0,93\,mm \tag{3}$$

Condition (3) means that if the thicker sheet metal has 1,5 mm, the thinner sheet metal must have the minimal thickness of 0,93 mm in order to achieve permanent forming of both TWB sides.

Since the conditions (2) and (3) were not fulfilled, only the thinner zone of TWB is formed, which can be seen in Fig. 7. Maximal realised tension force for TWB is approximately equal to the maximal force for the thinner sheet metal. Elongation is significantly smaller.

It should be emphasised that at forming of complex geometry pieces by deep drawing, both sheet metals are plastically formed due to different stress-strain conditions (different material, geometry, tribological conditions.) [8]. Incorrect interpretation of results of investigation by tension can lead to an error.

If mechanical properties of unwelded main materials are known, it is not possible to determine properties of TWB. In case when only the thinner material undergoes plastic forming, stress properties (e.g. tensile strength and yield strength) are valid with a minor difference for TWB as well. If both sheets metals undergo forming, that is not the case. Strain properties (such as uniform elongation at maximal force A_g and maximal elongation at break A_{80}) differ significantly in any case. That is the reason why we cannot talk about elongations defined in standards regarding TWB. That is why the corresponding values in Table 5 and in Fig. 8 are marked with asterisk.

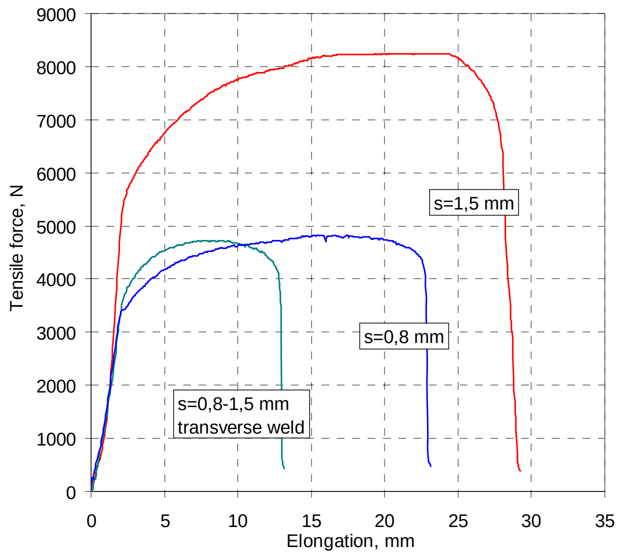

Figure 7 – Tensile force dependence on elongation

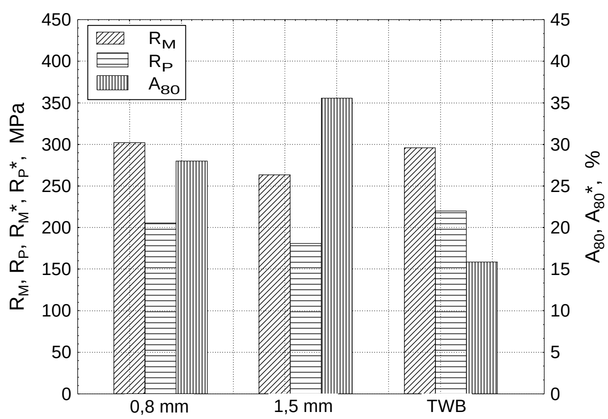

Figure 8 – Basic mechanical properties

In the actual investigation, fracture (specimen breaking) occurred approximately halfway along the distance between welding seam and beginning of widening of the thinner part of specimen.

In dependence on ratio which characterizes material quality and sheet metal thicknesses ratio, different cases of plastic forming of test-tubes parts of TWB sheet metals at tension are possible. In case that both test-tube parts are made of the same material and have the same thickness, uniform elongation of both test-tube parts would occur because the welded joint would be slightly formed due to bigger strength and small dimensions. When there is a difference in material properties or sheet metal thickness (or both) the situation is more complex and results of investigation by tension should be analysed carefully.

Table 5 Basic mechanical properties

	R_M, MPa	R_P, MPa	A_{80}, %
Sheet 0,8 mm	302,2	205,64	27,99
Sheet 1,5 mm	263,36	181,05	35,56
TWB	295,93	220	15,86

3. CONCLUSION

Tailor Welded Blanks (TWB) represent an anisotropic and non-homogenous material. In the procedure of defining the formability of such sheet metals by plastic forming (most often by deep drawing) the first and very significant experiment is investigation by uniaxial tension. It usually consists of three parts. The first one is the investigation of the thinner material, the second one – investigation of the thicker materials and the third one – investigation of TWB sheet metal. Instead of variable thickness, differences can exist in material properties and surface conditions.

In this paper, the results of investigating TWB of sheet metals of different thicknesses with analysis of forming conditions are presented briefly. Within the results, the following was determined: main mechanical properties (tensile strength R_M, yield strength R_P and maximal elongation A_{80}), forming strengthening exponent (n-value), normal anisotropy coefficient (r-value) and strengthening curves (two types of analytic exponential approximations). All properties were determined bearing in mind plane anisotropy, so that the test specimens were cut in three directions in relation to referent direction of rolling (0^o, 45^o, 90^o). Mean values and Δr – value (plane anisotropy coefficient) were also defined.

It was shown that the uniaxial tension test is irreplaceable in this case as well. Plastic forming conditions of both halves of TWB specimens are given and limitations were emphasised, mainly related to impossibility for defining TWB properties on the basis of well-known properties of sheet metals. Defining of TWB properties is not possible in the sense of existing standards. The welded zone is extremely small due to well-known properties of laser-welding procedure and its strength is considerably higher than the strength of main materials, so it almost does not participate in the forming process. In the end, it should be emphasised that the properties of uniaxial defining process should not be generalised onto the more common case of plastic forming at deep drawing and bending which are dominant in complex car body pressed parts. The properties have universal value, but forming particularities do not. The example of this is given in this paper as well – when only the thinner part of specimen undergoes plastic forming. This does not mean that at complex pressed parts only thinner sheet metal is formed, but instead it emphasizes the need for careful analysis and correct application of obtained data.

Within the more comprehensive research, a part of which is presented in this paper, uniaxial tension of TWB with longitudinal position of welding seam in relation to longitudinal specimen axis, that is, force action direction, was analysed as well. The following research (which is ongoing) will include uniaxial tension of TWB with angled positions of weld line in relation to longitudinal specimen axis, that is direction of tensile force action.

4. LITERATURE

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ODREĐIVANJE KARAKTERISTIKA OBRADIVOSTI „TAILORED" LIMOVA

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REZIME

U radu su prikazani rezultati eksperimentalnih istraživanja obradivosti plastičnim oblikovanjem „tailored" lima dobijenog laserskim zavarivanjem limova različitih debljina (0,8 mm i 1,5 mm) od istog materijala (čelik povišene čvrstoće sa BH efektom) i istog stanja površine (galvanski pocinkovano). Primenjeno je ispitivanje jednoosnim zatezanjem serije epruveta sa poprečno postavljenim laserskim zavarom u odnosu na uzdužnu osu epruvete. Definisani su sledeći pokazatelji obradivosti: osnovne mehaničke karakteristike, krive tečenja, r-faktor i n-faktor. Izvršena je analiza deformisanja svakog lima pojedinačno i zavarenog sklopa. Zaključci ukazuju na specifičan uticaj nehomogenosti koju čine različite debljine limova i zona zavara i upućuju na naredna ispitivanja sa uzdužnim i kosim položajima zavara u odnosu na pravac delovanja sile.

Ključne reči: *„Tailor welded blanks" limovi, Duboko izvlačenje, Obradivost*