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METHODS FOR DETERMINATION OF THE WELD METAL PROPERTIES IN THE CASE OF TAILOR WELDED BLANKS USED IN MANUFACTURING OF DRAW PARTS

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Abstract: *The quality of a weld in the tailor welded blank is very important for the success of the forming operation. The mechanical properties of the weld metal can be determined by applying different methods, such as: parallel test, normal test, microhardness test etc. The present paper investigates the mechanical properties of the weld metal in a tailor welded sheet made by joining similar metals. The investigation was performed by applying the microhardness and parallel tests in conjunction with the rule of mixture. The analysis of the behaviour of tailor welded blanks by examining the strain variation during tensile parallel test of tailor welded sheets applying the image analysis method is also presented in the paper.*

Key words: *weld metal properties, parallel test, rule of mixture, image analysis, strain distribution.*

1. INTRODUCTION

A tailor welded blank consists of two or more sheets that are welded together to make a single blank prior to forming (Fig. 1). These sheets can be identical, or they can be of different thickness, mechanical properties, or surface coatings. The blanks are either joined by mash seam welding or by laser beam welding, electron-beam welding, and induction welding.

Welding line can be placed transversal or longitudinal as a function of the forming direction. (Fig. 2) and it can be oriented in three ways with respect to the material rolling direction (Fig. 3), respectively: parallel with the rolling direction, inclined in comparison with the rolling direction and perpendicular on the rolling direction.

The quality of the weld in the tailor welded blank is very important for the successful of the forming operation.

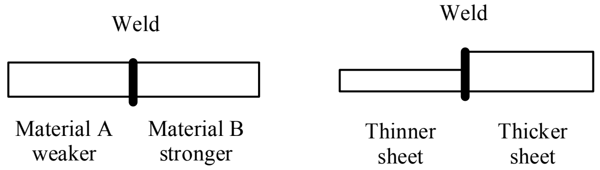


Fig. 1. Tailored blanks.

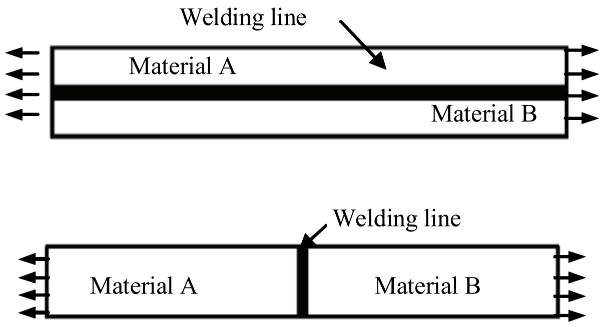


Fig. 2. Different positions of the welding lines as a function of the forming direction.

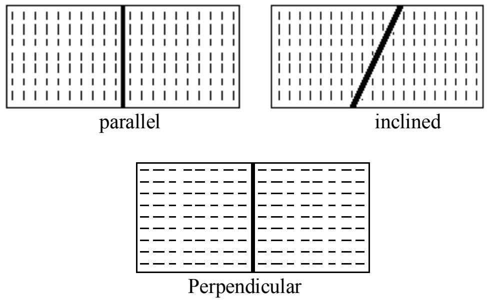


Fig. 3. Different orientations of the welding line with respect to the material rolling direction.

In comparison with homogeneous sheets, specific and many factors and phenomena that occur during forming process influence the forming quality of TWBs. These factors and phenomena are presented bellow:

1. Formability of the tailor-welded blanks depends on the type of welding, welding schedules, material and thickness combinations.

2. Because the welding process causes a hardening of the weld joint and heat – affected zone, formability will be reduced in this area. The amount of this decrease is dependent on the material type, welding process, and welding parameters; for example the limit strain can be reduced by more than 50% for a typical laser beam or resistance mash seam welded blanks. Generally, for a steel TWB the basic metal has significantly lower yield strength and tensile strength and hence higher ductility than the weld metal.

3. The variations in thickness can cause an uncontrolled metal movement of the blank with the draw die operation by the sheet with lower tolerance limit. The thinner material in the TWB may undergo more deformation than the thicker-stronger material in the forming area. This is visually evident in the movement of the weld line towards the thicker material.

4. Different strength materials can cause the concentration of deformation in the lower strength material; this will increase the probability of fractures, especially in the areas of stretch flanging. The using of tailor-welded

blanks with different strength materials, proper spring-back and/or over crown allowance must be provided for the high strength material.

Physical testing of the weld metal is very important to determine the behaviour of the TWB during forming. Generally, for a steel TWB the basic metal has significantly lower yield strength and tensile strength and hence higher ductility than the weld metal [1, 2]. The mechanical properties of the weld metal can be determined by applying different methods, such as: parallel test, normal test, microhardness test etc. The tests can be performed using standard or sub size specimens.

The present paper investigates the mechanical properties of the weld metal in a tailor welded sheet by applying the microhardness and parallel tensile tests in conjunction with the rule of mixture.

2. DETERMINATION OF WELD METAL PROPERTIES RULE OF MIXTURE

To extract the weld metal properties, a parallel test can be done in conjunction with the *rule of mixture*. According to this rule, the stress-strain tensile test must be performed using specimens cut from basic materials and from TWB. The following relation gives the total load applied on specimen:

$$F = \sigma_1 A_1 + \sigma_2 A_2 + \sigma_w A_w, \tag{1}$$

where: σ_1, σ_2 are the stresses corresponding to the areas of the basic materials; σ_w is the average stress corresponding to the weld area; A_1, $A_2$and A_w are the cross section areas of the basic and weld metal, respectively. The longitudinal strains are assumed to be constant across the TWB specimen, so that:

$$\varepsilon_1 = \varepsilon_2 = \varepsilon_w. \tag{2}$$

Based on the Ludwik-Hollomon equation, the relation (1) takes the following form:

$$F = \left(K_1 \varepsilon_1^{n_1}\right) A_1 + \left(K_2 \varepsilon_2^{n_2}\right) A_2 + \sigma_w A_w. \tag{3}$$

From relation (3) the average stress will result as follows:

$$\sigma_w = \frac{F - \left(K_1 \varepsilon_1^{n_1}\right) A_1 - \left(K_2 \varepsilon_2^{n_2}\right) A_2}{A_w}. \tag{4}$$

By taking into account the assumption (2), equation (4) can be rewritten as:

$$\sigma_w = \frac{F - \left(K_1 \varepsilon_w^{n_1}\right) A_1 - \left(K_2 \varepsilon_w^{n_2}\right) A_2}{A_w}, \tag{5}$$

equation that defines the stress-strain relation for the weld metal. In the conditions when the basic materials are the same and the sheets have the same thickness, the following parameters of the materials and sheets will have equal values:

$$K_1 = K_2 = K, \quad n_1 = n_2 = n, \quad A_1 = A_2 = A.$$

Hence, the equation (5) can be rearranged as follows:

$$\sigma_w = \frac{F - 2\left(K \varepsilon_w^n\right) A}{A_w} = \frac{F - \left(K \varepsilon_w^n\right)\left(A_t - A_w\right)}{A_w}, \tag{6}$$

where the cross section area of the basic materials was replaced by $A = \left(A_t - A_w\right)/2$. The area A_w of the weld metal cross-section can be obtained using the following methods: the direct measurement of the weld width; the measurement of a metallographic section; the determination of micro hardness profiles [3, 4]. The width of the weld was determined on a microhardness profilometer. The obtained results have been presented as follows: estimated values of A_w area in Table 1, hardness variation on the width of the specimens in Fig. 2.

True stress-strain curves for the weld metals determined by applying the rule of mixture are represented in Figs. 4 and 5.

Table 1

Estimated values of A_w area

TWBs	Sheet thickness [mm]	Width value [mm]	A_w area [mm²]
TWBs made from SPE 220 steel sheets	0.7	0.64	0.448
TWBs made from FEPO 5BM steel sheets	0.75	0.65	0.4875

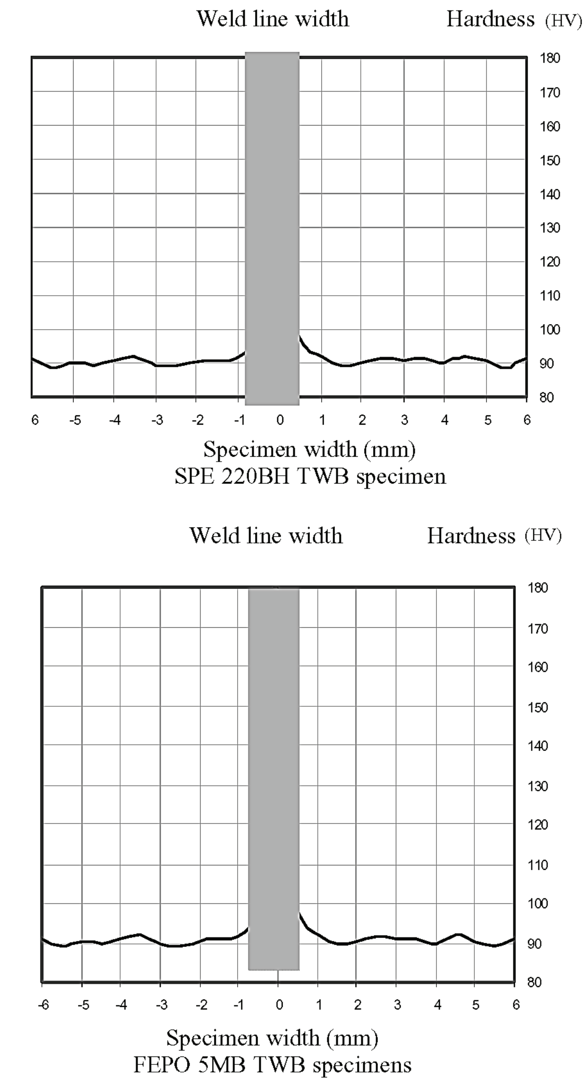


Fig. 4. Hardness variation on the width of the specimens.

3. DETERMINATION OF THE WELD METAL PROPERTIES BY TENSILE TEST

The parallel test was performed in the frame of laboratories from LMecA – ESIA Annecy, France on an INSTRON-5569 Tensile Testing Machine. Standard specimens were used in the test according to ASTM E8 standard; the geometry of the tested specimens must be as it is shown in Fig. 3. The specimens were made from TWBs and obtained by joining the same metals: SPE 220BH and FEPO 5MB. The results concerning the weld metal properties obtained from the parallel test using the strains measurement by extensometer were compared with the results obtained from the parallel test using the image analysis. The determination of strains based on the method of image analysis was made by using a Hamamatsu C4742-95 digital video camera and a SEPT-D LMECA – version 0.5.0.15 software – for the case of strains determination. The parallel tested specimens and the zones of necking and fracture are shown in Fig. 4.

Each type of test was performed using the following crosshead rates: 4.5 mm/min – its corresponding strain rate being equal to 10^{-3} s^{-1} and 45 mm/min – its corresponding strain rate being equal to 10^{-2} s^{-1}.

The obtained results have been presented as follows: True stress – strain curves for the TWB - FEPO 5MB TWB specimens in Fig. 4 and true stress – strain curves for TWB - SPE 220BH TWB specimens in Fig. 5.

From the analysis of the stress-strain curves and values obtained from the strain measurement using the extensometer, the following aspects were observed:

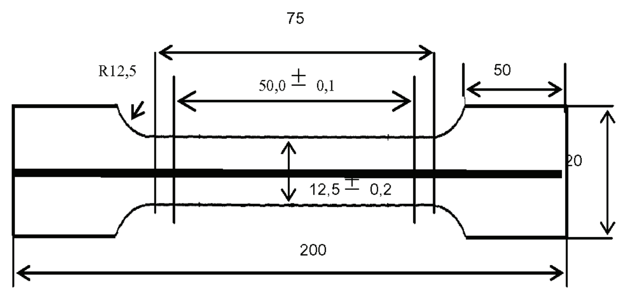
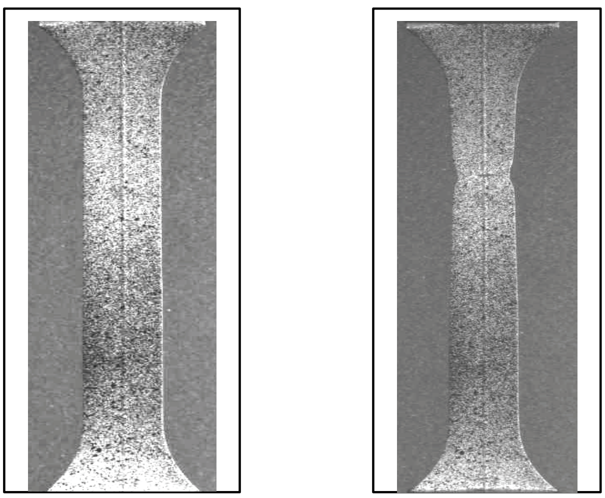


Fig. 5. Geometry of the tested specimen.



a b

Fig. 6. Parallel tested specimens: zone of necking and fracture.

1. In the case of TWB specimens made from FEPO 5 MB steel sheets tested with a strain rate of 10^{-3} s^{-1}:

- a higher position of the stress-strain curve and an increase of the limit strain have resulted for specimens cut along the rolling direction in the case of specimens having the weld line perpendicular to loading direction;

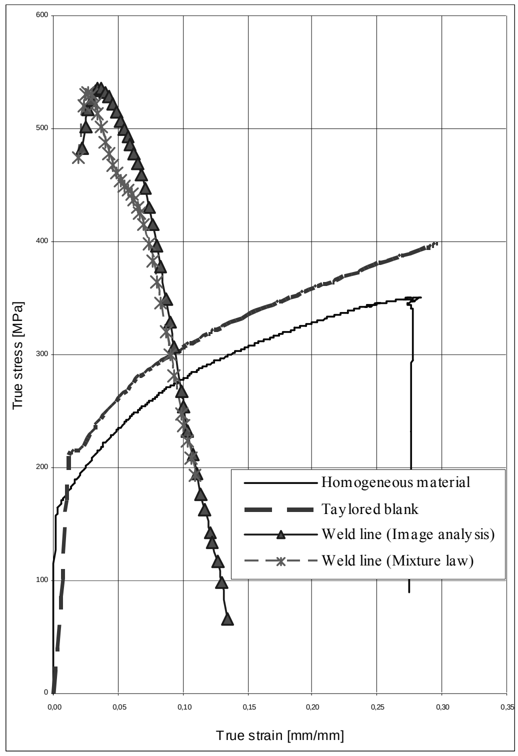


Fig. 7. True stress-strain curves for the weld metal for FEPO 5MB TWB specimens.

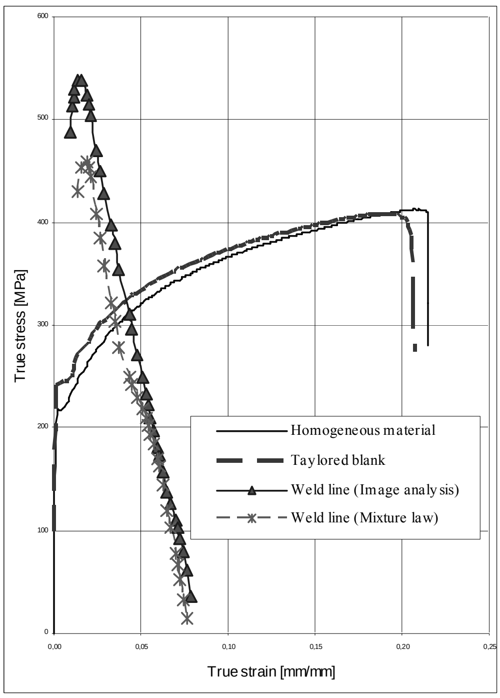


Fig. 8. True stress-strain curves for the weld metal for SPE 220BH TWB specimens.

- a higher position of the stress-strain curve resulted for specimens cut to 0° against rolling directions and an increase of the limit strain was obtained for specimens cut to 90° against the rolling direction in the case of specimens having the weld line parallel to loading direction;

2. In the case of TWB specimens made from FEPO 5 MB steel sheets tested with a strain rate of 10^{-2} s^{-1}:

- an approximate the same position of the stress-strain curve has resulted for the both rolling directions and an increase of the limit strain was obtained for specimens cut to 90° against the rolling direction in the case of specimens having the weld line perpendicular to loading direction;
- a higher position of the stress-strain curve resulted for specimens cut to 90° against rolling directions in the case of specimens having the weld line parallel to loading direction;
- the increase of the strain rate determines a higher position of the stress-strain curves in the case of specimens having the weld line parallel to loading direction and a decrease of the curves level in the case of specimens having the weld line perpendicular to loading direction.

3. In the case of TWB specimens made from SPE 220BH steel sheets tested with a strain rate of 10^{-3} s^{-1}:

- a higher position of the stress-strain curves resulted for specimens cut to 90° against the rolling direction in the case of specimens having the weld line parallel to loading direction;
- an approximate the same position of the stress-strain curves for both rolling directions resulted in the case of TWB specimens having the weld line perpendicular to loading direction.

4. In the case of TWB specimens made from SPE 220BH steel sheets tested with a strain rate of 10^{-2} s^{-1}:

- an approximate the same position of stress-strain curves and values of limit strain were obtained in the case of specimens having the weld line perpendicular to loading direction;
- a higher position of the stress-strain curves and an increased limit strain were obtained for specimens cut to 0° against rolling direction in the case of specimens having the weld line parallel to loading direction;
- the increase of the strain rate determines a higher position of the stress-strain curves for the both, perpendicular and parallel, positions of the weld line.

4. CONCLUSIONS

Concerning the mechanical properties of weld metal:

- The mechanical properties of the weld metal can be determined by applying different methods, such as: parallel test, normal test, microhardness test etc. The tests can be performed using standard or sub size specimens.
- In the case of parallel test, for both TWBs, the strains of the weld metal in elastic region could not be determined. For the plastic region both methods – low of mixture and image analysis – lead to approximately the same result.
- The tensile strength of the weld metal is 1.6 times bigger than that of the base material in the case of TWBs made in SPE 220BH and 1.3 times bigger in the case of TWBs made in FEPO 5MB.

General conclusions:

- The testing of the weld metal is very important to determine the behaviour of the TWB during forming.
- Generally, for a steel TWB the basic metal has significantly lower yield strength and tensile strength and hence higher ductility than the weld metal.
- Based on the hardness variation at the transverse section of a specimen, it can be concluded that the analysis of TWB mechanical properties should only take into account the behaviour of base materials and weld materials whereas the heat affected zone (HAZ) does not seen to have any influence.
- Hence, we can conclude that for the determination of the weld metal properties the application of the parallel test in conjunction with the "rule of mixture" is beneficial for the accuracy of results.

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