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DETERMINATION OF MECHANICAL PROPERTIES OF THE WELD ZONE OF TAILOR-WELDED BLANKS

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Abstract

The present paper presents different available methods to determine mechanical properties of the weld zone of tailor-welded blanks (TWB). The presented methods are based on experimental tests as well as combine experimental procedures with numerical studies. The methods include metallographic observations, uniaxial tension tests, microhardness tests, indentation tests combined with inverse numerical analysis, numerical simulation of laser welding. Mechanical properties obtained for the weld zone are necessary to establish a constitutive model for TWB forming simulation.

Key words: tailor-welded blanks, welding, mechanical properties, indentation, simulation

1. INTRODUCTION

The basic factor influencing the formability of tailor welded blanks (TWB) is hardening of the weld zone (consisting of fusion and heat-affected zones) during welding process [1,2]. This reduces formability in the area of weld and it has been identified as the basic factor that should be taken into account in the tailored blank model.

Accurate modelling of tailor welded blanks requires knowledge of mechanical properties of material in the weld zone as well as its extension. Determination of mechanical characteristics of the weld zone in TWB is not an easy task because of small extension of this zone. The article will present different methods available to obtain data necessary for TWB forming simulation. The following methods to determine the extension and mechanical parameters of the fusion and heat affected zone will be studied:

- metallographic observations,
- microhardness tests,
- indentation tests,
- numerical simulation of laser welding.

2. PREPARATION OF THE TAILOR WELDED BLANKS

In this study, tailor welded blanks were obtained by joining steel sheets (100 mm x 300 mm) of the same grade DC04 and of the same thickness 1.0 mm. The TWBs were welded using a 2 kW Nd:YAG laser employing the following process parameters:

- power of laser beam, 1700 W,
- welding velocity, 4.5 m/min,
- diameter of laser beam, 600 μm.

3. METALLOGRAPHIC OBSERVATIONS

Metallographic observations (see figure 1) provide information about the extension of the fusion and heat-affected zones, as well as phase composi-

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tion in these zones. It has been found out that after welding a mixed microstructure is produced with about 50% of bainite, 45% of ferrite and 5% of martensite. The results of metallographic observations will be used as reference data for validation of welding simulation. Mechanical properties of the weld are related to the microstructure after welding.

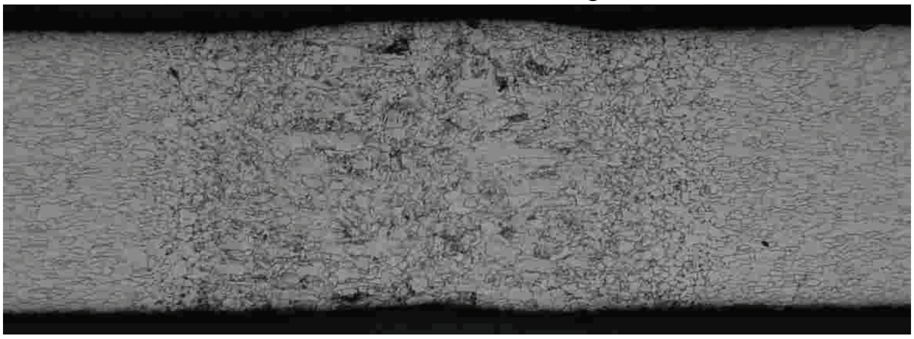
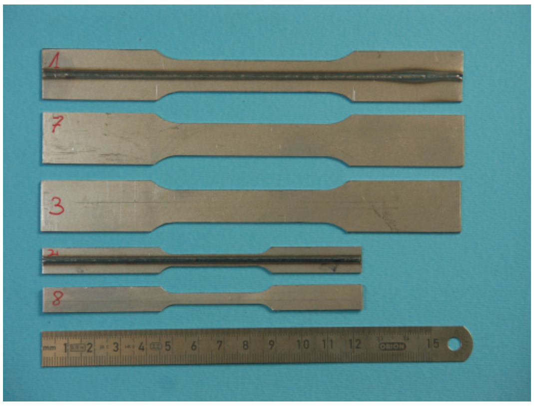


Fig. 1. *Microstructure of the investigated TWB.*

4. UNIAXIAL TENSION TESTS

Uniaxial tension tests yield stress–strain curves for the parent and weld material. Following Abdullah et al. [3] specimens of different sizes (see figure 2a) have been used for testing. The specimens have been cut out from the base material only and with the weld line parallel to the loading direction and coinciding with the axis of symmetry of the specimen.

a)



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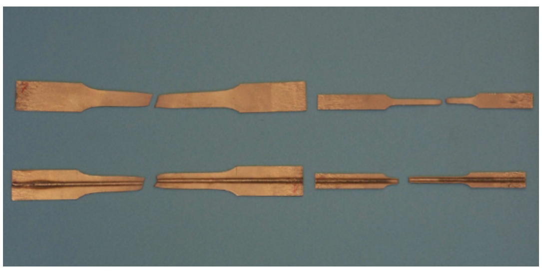


Fig. 2. *Uniaxial tension tests: a) specimens prepared for testing, b) broken specimens.*

Broken specimens after tensile tests are shown in figure 2b. Stress–strain curves obtained for different specimens are plotted in figure 3. The curves obtained for the specimens without weld characterize strength properties of the parent material. The agreement between the curves obtained with different sizes can be observed, this means that the small specimens are adequate for tensile testing. It can be seen that the strength of the specimens with weld is higher than that of the specimens without weld. The influence of the weld material strengthening can be clearly observed. The weld also decreases the maximum elongation of the tested material. The stress--strain curve obtained for the small specimen with weld, with a small error, can be considered as that corresponding to the weld zone material only.

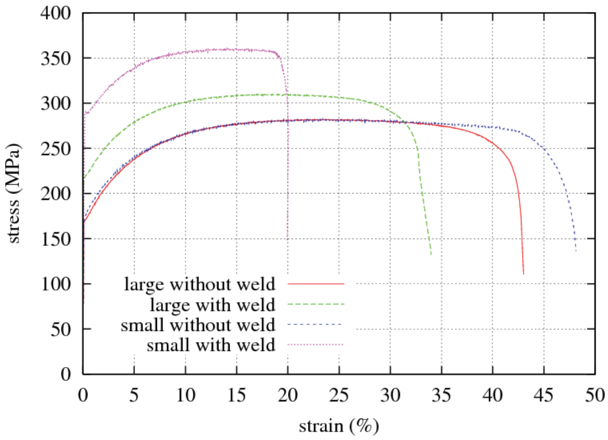


Fig. 3. *Stress-strain curves for different specimens*

5. MICROHARDNESS TEST

Microhardness tests provide information about the distribution of hardness in the tailor weld blank. This indicates the extension of the weld zone. Having obtained the hardness, the relationship between hardness and strength of the material allows us to determine strength parameters of the weld zone.

Microhardness measurements have been made for the tailor welded blank under investigation using a Vicker's microhardness tester. The scale HV 0,2 with the loading (according to the standard) of 1.961 N has been employed. Microhardness has been measured on the blank surface along the line perpendicular to the weld.

The results of microhardness measurements are plotted in figure 4. It can be observed that material in the weld zone is characterized with much higher hardness (approximately 180 kp/mm^2) than the base material (approximately 105 kp/mm^2).

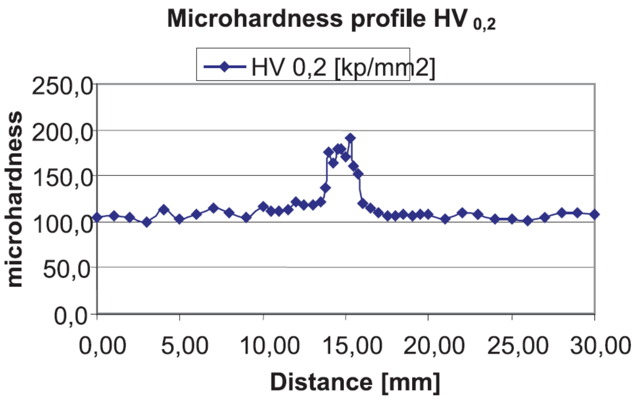


Fig. 4. Microhardness profile along the line perpendicular to the weld.

Based on the relationship between strength and hardness parameters we can determine the stress–strain curve for weld material. Knowing the stress-strain curve for the base material the stress-strain curve for the weld material can be obtained using a simplpe assumption based on the proportionality between the hardness and strength

$$\sigma_{\text{weld}} = \sigma_{\text{base}} \frac{\mu H_{\text{weld}}}{\mu H_{\text{base}}} \quad (1)$$

Stress-strain curves for weld and base material obtained from the the microhardness measurements and from relationship (1) are shown in figure 5.

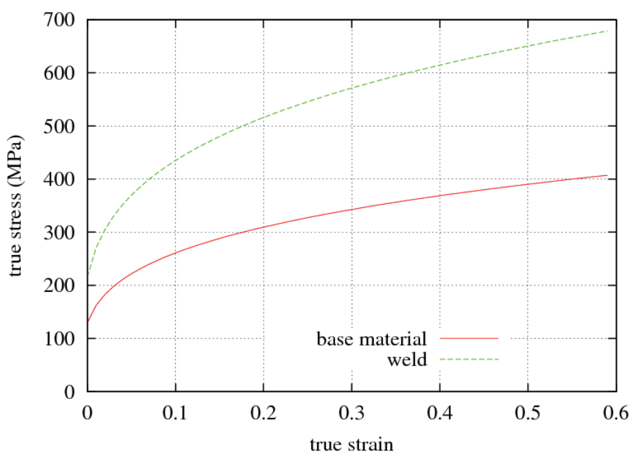


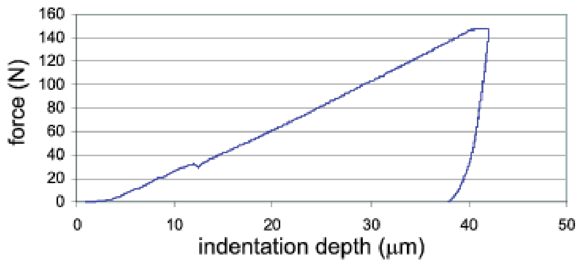
Fig. 5. Stress-strain curves for weld and parent (base) material obtained from the microhardness measurements.

6. INDENTATION TESTS

Indentation tests have been made on the studied tailor welded blank. The test points have been chosen in different places of both parent material and weld zone. The indentation tests were aimed to provide the information for macroscopic model of the weld. The results of these tests combined with an inverse numerical analysis allow us to determine mechanical properties of both parent material and weld zone.

Indentation tests have been performed using a Rockwell hardness tester and assuming the hardness scale HR15T with a steel ball indentor 1/16”. Typical results of the indentation tests are shown in figures 6 and 7. Material properties have been determined by fitting simulation and experimental force vs. indentation depth curves. As the target experimental curves we take the curves shown in figures 6a and 7b for the parent material and for weld material (this curve will be considered for loading only), respectively.

a)



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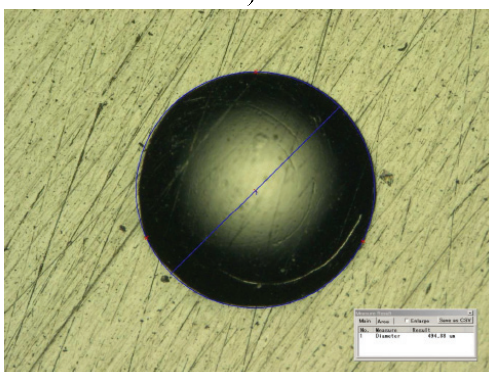
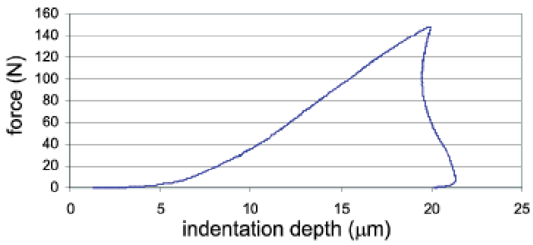


Fig. 6. Results of indentation tests for the parent material: a) force vs. indentation depth, b) indentation diameter 494.88 µm.

The inverse problem can be defined as an optimization problem. In our case we used a simple trial-and-error approach. Numerical results of simulation of indentation tests for the parent material are shown in figures 8a and 8b in the form of the deformed configuration with distribution of equivalent plastic strain and the numerical curve force vs. depth of indentation, respectively. Similar results are obtained for the weld zone. Stress-strain curves for the weld and parent (base) material obtained from the inverse analysis are shown in figure 9.

a)



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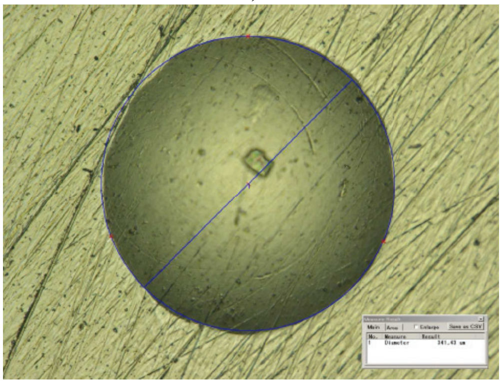
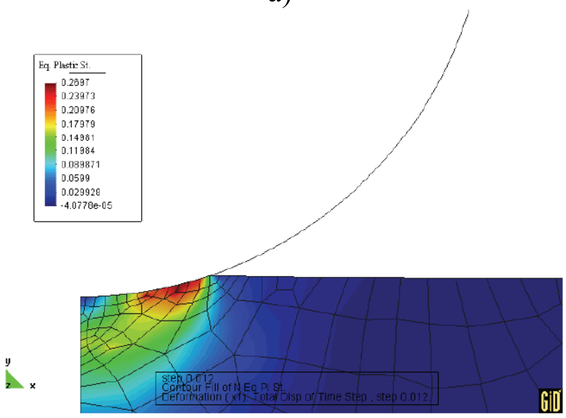


Fig. 7. Results of indentation tests for the weld zone: a) force vs. indentation depth, b) indentation diameter 341.43 μm.

a)



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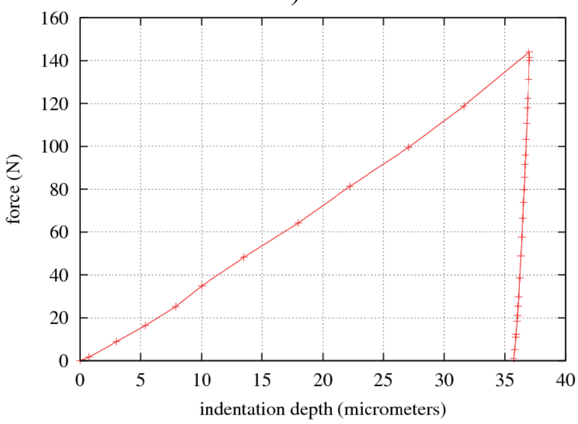

Fig. 8. Numerical results of simulation of indentation tests for the parent material: a) evolution of deformed configuration with distribution of equivalent plastic strain, b) curve force vs. indentation depth.

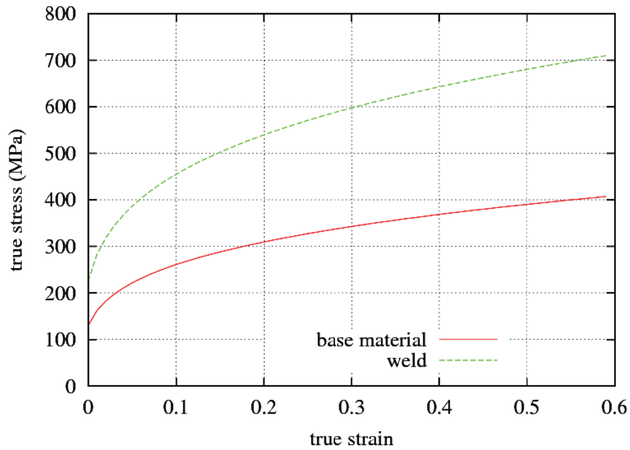

Fig. 9. Stress-strain curves for weld and parent (base) material obtained from the inverse analysis.

7. NUMERICAL SIMULATION OF LASER WELDING

Numerical simulation of laser welding is an alternative procedure to determine the geometry and mechanical properties of the weld zone. Numerical simulation has been performed using the thermo-mechano-metallurgical model developed by Bokota and Domański [4] and Piekarska [5]. Welding process parameters given in section 1 have been used. Phase fraction distributions after welding obtained in the simulation are shown in figure 10. Simulation results have been verified by superimposing the numerical contour maps upon the microstructure of the investigated TWB (see figure 11). A good agreement of the numerical results with the real microstructure can be clearly seen. Using the rule of mixtures the effective yield stress of the material in the weld zone is calculated. Yield stress distribution in the blank midsurface is plotted in figure 12. The yield stress values obtained numerically is in a good agreement with experimental results shown in figures 3, 5 or 9.

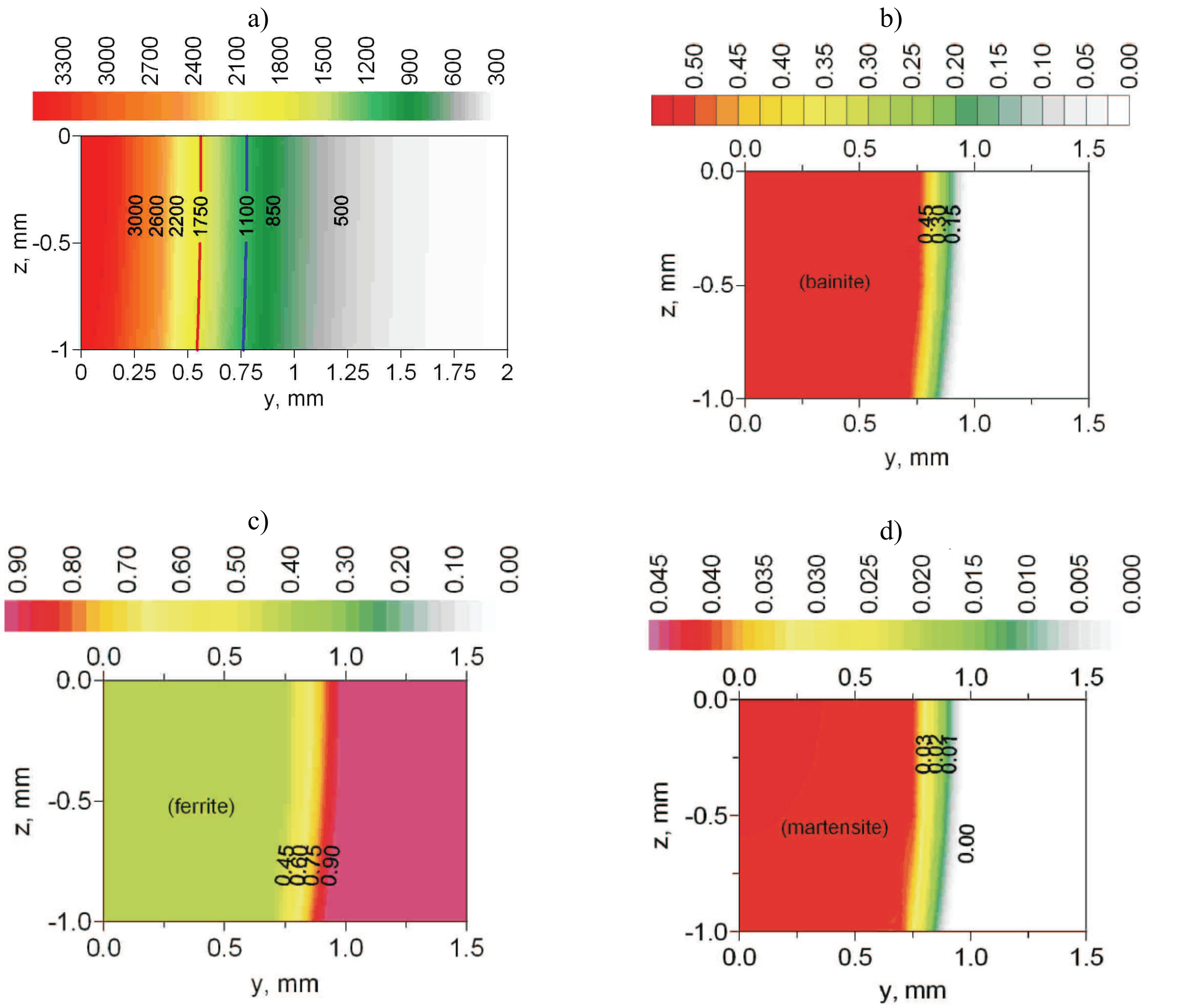

Fig. 10. Results of laser welding simulation: a) temperature distribution, b) bainite fraction distribution, c) ferrite fraction distribution, d) martensite fraction distribution.

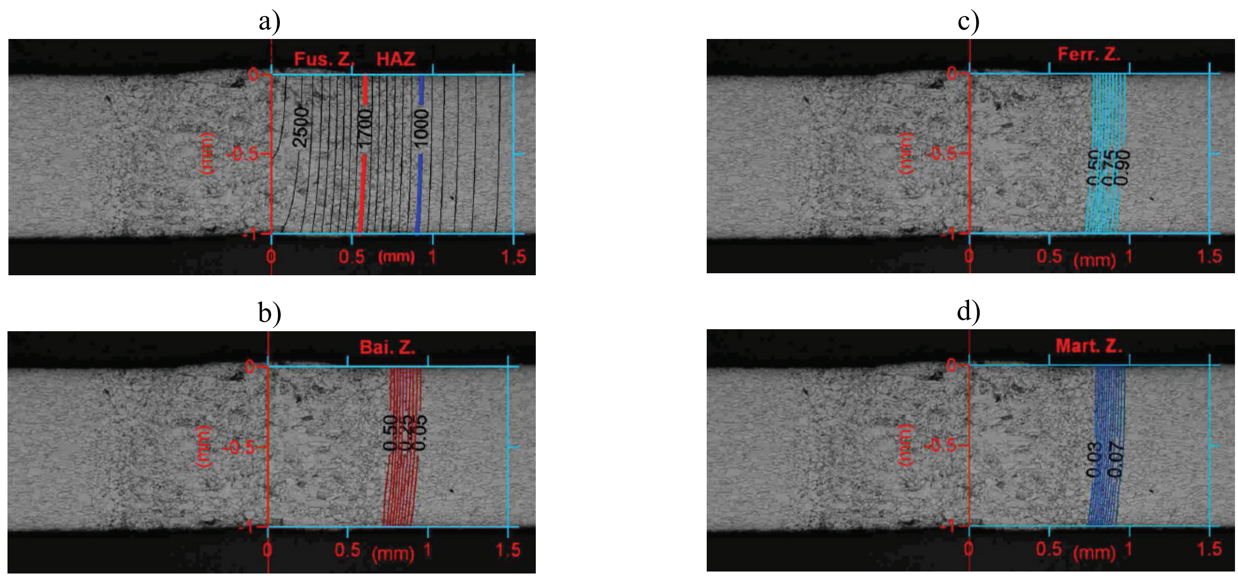

Fig. 11. Numerical contour maps overlaid on the microstructure of the investigated TWB: a) extension of the fusion and heat affected zones, b) bainite fraction distribution, c) ferrite fraction distribution, d) martensite fraction distribution.

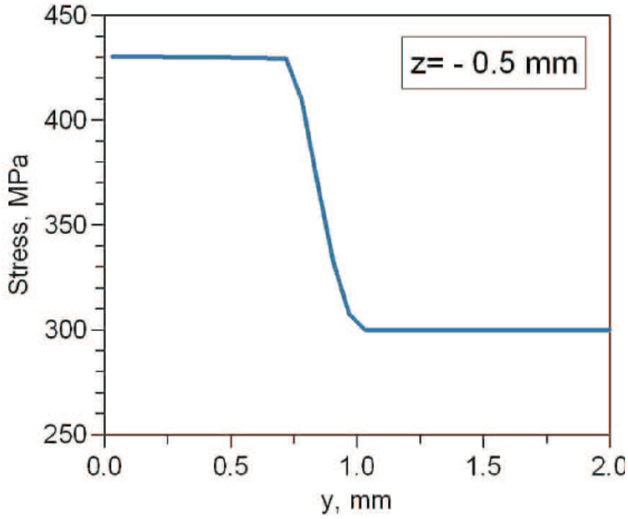

Fig. 12. *Yield stress distribution (blank midsurface).*

8. CONCLUSIONS

- Different methods (including metallographic observations, uniaxial tension tests, microhardness measurements, indentation tests and numerical simulation of laser welding) for determination of mechanical and geometrical characteristics of the weld zone in tailor welded blanks have been investigated.
- Comparisons show that different experimental methods yield similar mechanical properties.
- Mechanical properties as well as extension of the weld zone obtained numerically by simulation of welding are in a good agreement with the experimental results.
- All the experimental tests as well as numerical simulation of welding show that the material in the weld zone is characterized with higher strength and lower deformability.

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WYZNACZANIE WŁASNOŚCI MECHANICZNYCH STREFY SPOINY W BLACHACH SPAWANYCH LASEROWO

Streszczenie

Artykuł przedstawia różne dostępne metody wyznaczania własności mechanicznych strefy spoiny w blachach spawanych do tłoczenia (ang. TWB – Tailor-Welded Blanks). Przedstawione metody opierają się na badaniach eksperymentalnych jak również łączą próby doświadczalne z analizą numeryczną. Omawiane metody obejmują obserwacje metalograficzne, próby jednoosiowego rozciągania, próby wciskania (indentacji), pomiary mikrotwardości połączone z numeryczną analizą odwrotną oraz numeryczną symulację procesu spawania. Własności mechaniczne materiału w strefie spoiny są wyznaczane w celu określenia parametrów modelu konstytutywnego wykorzystywanego w symulacji kształtowania blachy spawanej laserowo.

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