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SIMULATION OF SHEET-TITANIUM FORMING OF WELDED BLANKS

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Abstract. The increase in demand for the light and tough drawn-parts causes the growing interest in sheet metal forming of Tailor-Welded Blanks (TWB). Application of such blanks allows for achieving in one operation the drawn-parts characterized by diverse strength and functional properties. It also allows for reduction of material waste and decrease in number of parts needed to produce component. Weight reduction is especially important for the car and aircraft industry. Forming welded blanks requires solving many problems such as different plasticity of the joined materials, presence of the weld and its dislocation. In order to evaluate suitability of welded blanks for the forming processes, it is necessary to carry out several studies, including numerical simulations of the process, that will allow for prediction of sheet behaviour in consecutive forming stages. Although to date aluminium and steel TWBs are mainly used, the aircraft industry is also interested in application of titanium TWBs. Generally sheet-titanium forming is more difficult than steel or aluminium sheets. The weld presence complicates the forming process additionally.

In the paper some numerical simulation results of sheet-titanium forming of welded blanks will be presented. Forming the spherical caps from the uniform and welded blanks will be analysed. Grade 2 and Grade 5 (Ti6Al4V) titanium sheets with thickness of 0.8 mm will be examined. A three-dimensional model of the forming process and numerical simulation will be performed using the ADINA System v.8.6, based on the finite element method (FEM). An analysis of the mechanical properties and geometrical parameters of the weld and heat affected zone (HAZ) are based on the experimental studies. Drawability and possibilities of plastic deformation will be assessed basing on the comparative analysis of the determined plastic strain distributions in the drawn-parts material and thickness changes of the drawn-part wall. The results obtained in the numerical simulations will provide important information about the process course. They will be useful in design and optimization of the forming process.

1 INTRODUCTION

Tailor-Welded Blanks (TWB) come to be very widespread in industry sectors for which weight and manufacturing cost reduction is vital. The automotive and aerospace industries are particularly interested in this issue. It is observed a growing demand for the drawn-parts which provide both lightness and high strength [1-5].

Reduction of production costs, in the case of TWB's technology, results from a limitation to material consumption (waste reduction) and number of the required forming operations so decrease in need for costly dies. It is estimated that application of TWB blanks can reduce the number of required parts to 66% and reduce the weight by half [6-8]. And more importantly, TWB's technology allows for achieving in one operation the drawn-parts having regions with different strength i.e. parts with tailored mechanical properties. By tailoring the material across the entire component, it may be possible to obtain different functional properties and improved crashworthiness so the parts made of TWBs are often used in energy absorbing structures. TWBs improve the energy absorption characteristics by introducing local regions with increased ductility while maintaining the high strength material in locations where resistance to impact loading is required.

Generally, forming the welded blanks requires solving many problems. Both presence of the weld usually having lower plasticity than the base material, and TWB heterogeneity cause change in the deformation scheme in comparison to the deformation scheme of homogeneous material. This is due to the weld dislocation, which direction and magnitude depend on the difference in mechanical properties and thickness of welded materials [6,9-12]. The numerical simulations are a very useful tool in assessing TWB suitability for forming. They allow for prediction of the sheet behaviour in the forming process and assessment of the strain and stress distribution [13,14]. TWB forming is even more difficult when hard-to-deform sheets, such as alpha - beta titanium alloys have to be formed [15-17].

The increase in demand, including aircraft industry, for structural parts with specific functional properties leads to a growth of interest in forming titanium sheets. Generally, commercially pure titanium sheets (e.g. Grade 2 sheets) have good drawability but the drawn-parts produced from such sheets have low strength. On the other hand titanium alloy sheets (e.g. Grade 5) have higher strength than Grade 2 ones but simultaneously much lower propensity to plastic deformation and this limits their application in the sheet-metal forming processes [18-22].

2 GOAL AND SCOPE OF THE WORK

Evaluation of changes in deformation and scheme of the displacement during forming TWB blanks using numerical simulations was the main goal of the work. Experimental studies were carried out to confirm validity of the assumptions made in the numerical model of the forming process. Experimental measurements of the drawn-part wall thickness were compared to these predicted in the calculations.

A spherical drawn-part made of welded titanium sheets was analysed. The initial blank with a diameter d_k=60 mm was made of commercially pure titanium Grade 2 and titanium alloy Grade 5 (Ti6Al4V). Both sheets had thickness g=0.8 mm. The sheets were joined by electron beam welding (EBW) technology as it was described in [23-25]. EBW causes some changes in material microstructure (see Fig. 1). Analysis of the joint microstructure shows occurrence of 5 zones: from the left base material – Grade 5, heat affected zone (HAZ) in Grade 5, fusion zone, heat affected zone in Grade 2 and base material – Grade 2.

For comparison, the calculations were also carried out for the uniform Grade 2 and Grade 5 sheets.

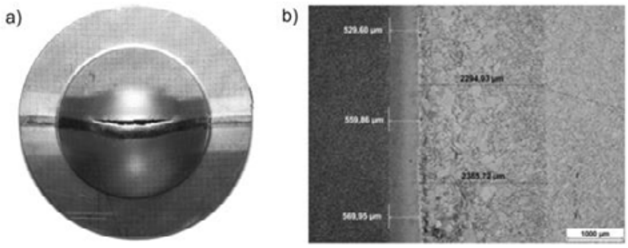

Figure 1: Drawn-part after Erichsen cupping test (a), microstructure of electron beam welded joint (b)

The heat affected zone in Grade 2 is wider than this in Grade 5. Its width is of about 2300 μm, while the width of HAZ in Grade 5 together with fusion zone is of about 550 μm.

3 NUMERICAL MODEL

A three-dimensional model of the stamping process was developed. The model consists of the welded blank materials and stamping tool: a die, a punch and a blank-holder. FEM geometry model is shown in figure 2.

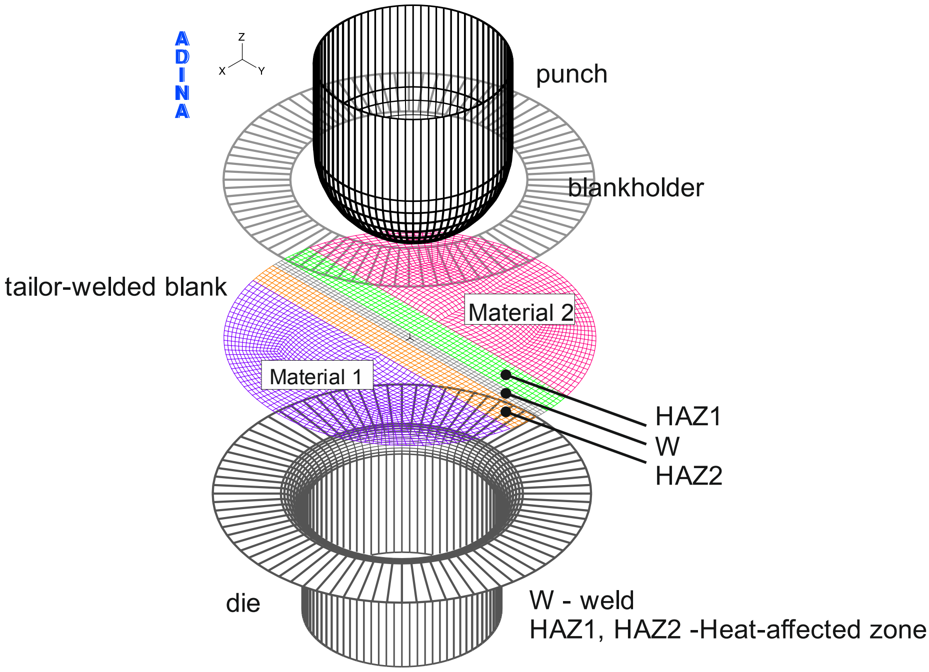

Figure 2: A discrete model of forming the spherical drawn-part made of TWB blank with 5 different material zones

In the calculations all individual tool parts were modelled as perfectly rigid while the welded blank as an isotropic elastic-plastic materialwith kinematic hardening.

All degrees of freedom were taken off the die. The displacement in Z direction was applied to the punch. A progressive motion of the blank-holder was limited to a blank-holder force F_d.

A proper selection of the blank-holder force prevents the deformed material from wrinkling and fracture. The blank-holder force effectively affects the strain distribution. An optimal value of the blank-holder force was determined based on the preliminary numerical simulations of the stamping process.

Discretization of the blank material was done using four-node shell elements. During modelling the following 5 zones were distinguished: weld (W), two heat affected zones located symmetrically on both sides of the weld : HAZ1 and HAZ2, and two zones representing base materials: M1and M2 (Fig. 2). Different material properties were taking into account for each zone. The individual zone width was measured on the basies of the microstructure of the joint cross-section. In the calculations a constant thickness of the weld and heat-affected zones, which equals to thickness of the welded sheets i.e. 0.8 mm was assumed. Some important geometric parameters of the model are presented in table 1. In the analysed case the weld was located in a centre of the blank.

Table 1: Parameters assumed in FEM model for the stamping process of TWB blanks

Parameter	value
blank diameter d_k	60 mm
clearance between punch and die $l=d_m-d_s$	2 mm
punch radius r_s	16 mm
die fillet radius r_m	4 mm
blank thickness g	0.8 mm
weld width W	1.9 mm
heat-affected zone width *HAZ1*	1.7 mm
heat-affected zone width *HAZ2*	1.0 mm
blank-holder force F_d	3000 N
punch path h_s	20 mm

A contact interaction between the tool and the deformed material plays an important role during forming [1,26]. In the numerical calculations a friction coefficient $\mu = 0.3$ was assumed for dry condition i.e. for the contact surface “punch – deformed material (blank)” and $\mu = 0.1$ for lubricated surfaces i.e. for the contact surfaces between the die, blank and blank-holder.

Calculations were carried out using the ADINA System v. 8.6 [27], which is based on FEM. The ADINA System allows for non-linear description of material hardening and the contact between the tool and the deformed material.

The mechanical properties, which are required for the calculations were determined based on the uniaxial tensile test (for the base materials) as well as on the basis of scratch test (for the weld and heat affected zones) assuming that mechanical properties i.e. yield point is in direct proportion to material hardness. The assumed mechanical properties are summarized in table 2.

Table 2: Experimentally determined material properties for Grade 2 and Grade 5 titanium, the weld and the heat affected zones

Material	Tensile strength Rm [MPa]	Yield strength $R_{0,2}$ [MPa]	Young's modulus E [GPa]	Poisson's ratio ν
M1-GRADE 2	316.6	236.8	110	0.37
M2-GRADE 5	1002.4	964.3	110	0.37
HAZ1	442.8	368.3	110	0.37
HAZ2	798.5	747.7	110	0.37
W	518.5	375.0	110	0.37

4 RESULTS

Figure 3 shows the shape of the drawn-part obtained during the numerical simulation of the stamping process of the TWB blank.

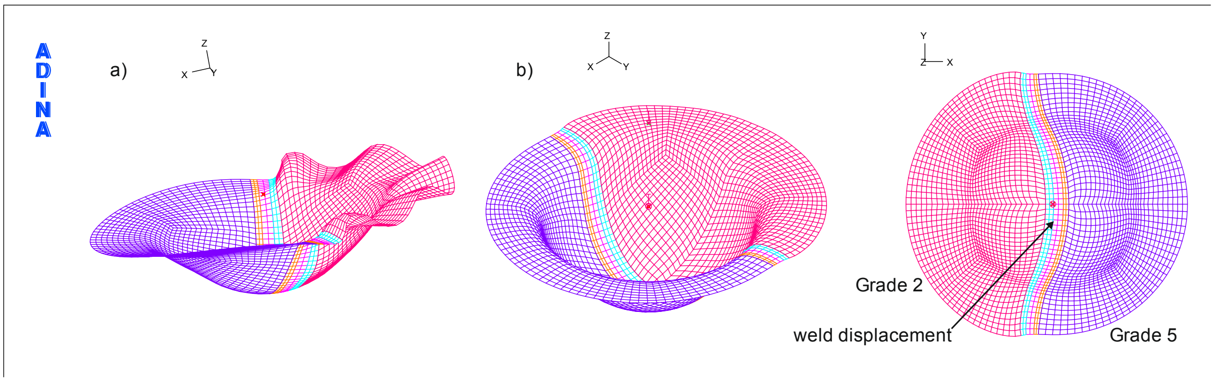

Figure 3: The drawn-part shape obtained in the numerical simulation of welded blank forming : a) blank-holder force 1000N, b) blank-holder force 3000N

The calculatiing results of plastic strain ε [-] and thinning of the drawn-part wall are shown in figures 4-6. In the case of forming the uniform Grade 2 blank it can be observed that the plastic strain distribution is uniform and circular (Fig. 4a), and it is accompanied by the uniform thinning of the drawn-part wall (Fig. 4b). In the case of forming the uniform Grade 5 blank concentration of plastic strains in a pole of the drawn-part is visible. A considerable material thinning is seen in this area (Fig. 5a and 5b).

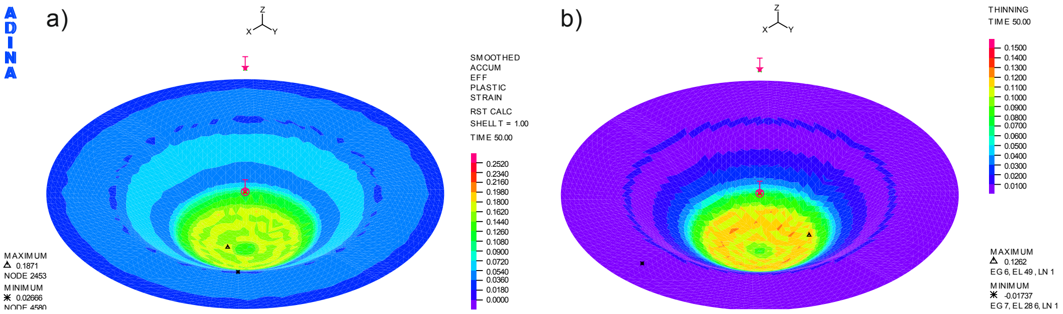

Figure 4: Numerical simulation results of forming the spherical drawn-part made of Grade 2 blank at the punch penetration of 10 mm: a) plastic strain distribution ε [-], b) material thinning [mm]

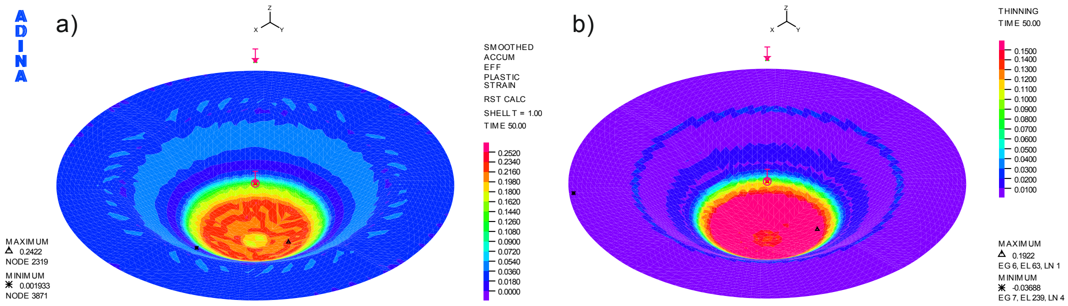

Figure 5: Numerical simulation results of forming the spherical drawn-part made of Grade 5 blank at the punch penetration of 10 mm: a) plastic strain distribution ε [-], b) material thinning [mm]

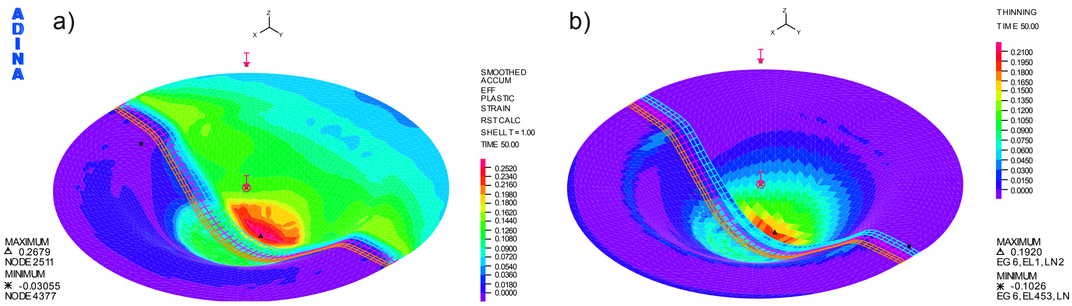

Figure 6: Numerical simulation results of forming the spherical drawn-part made of welded blank Grade2||Grade5 at the punch penetration of 10 mm: a) plastic strain distribution ε [-], b) material thinning [mm]

The numerical simulation of TWB forming shows that the weld moves in direction of Grade 5 material as punch hollows into the deformed blank (Fig. 6). As a result of weld displacement plastic strains increase in more deformable material and decrease in less deformable material (Fig. 6a). It should also be noted that at the pole of the drawn-part (on the border between more deformable material and the heat affected zone) there is a local increase in strains and significant thinning of the drawn-part material (Fig. 6a and 6b). This might indicate that there is a possibility of drawn-part weakening and possible loss of material continuity in this area.

5 CONCLUSIONS

The main goal of the study was to develop a numerical model of TWB forming. The carried out numerical simulations (FEM) allow for analysis of material deformation and assessment of welded blank drawability. In future the studies will be focused on a more accurate description of material mechanical characteristics, especially in the weld and heat affected zone, which will allow for further improvements.

The calculations confirmed experimental results that forming titanium welded blanks having different mechanical properties, using rigid tools, is much more difficult than forming the uniform blanks. Comparison of strain distribution shows that the weld presence introduces irregularity in the strain scheme. It can be observed that there is limited formability in the weld zone and that there is a displacement of the weld in direction of less deformable material.

The simulation results show the efficiency of applying numerical calculations to study of TWB forming. The results provide important information on the process and may be useful for the design and optimization of the process parameters such as (blank-holder force, lubrication conditions etc.).

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