EXPERIMENTAL AND NUMERICAL ANALYSIS OF SPOT WELDED JOINTS AND CONSTRUCTIONS

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Abstract: *In this paper, experimental and numerical research of spot welded joints is presented. The most important mechanical properties of the base sheet are determined using specimens cut in different directions with reference to the rolling direction. Welding parameters are adopted with respect to the recommendations. The quality of the spot-welded joint is evaluated by experimental and numerical methods. The tensile test was used in choosing the most suitable spot welding regime. Several examples are analyzed. Force-displacement diagrams with fields of effective stress and strain show that implemented large strain theory gives good prediction of the joints behavior.*

Key words: *finite element method, spot welded joints, large strain, thin walled structure, parameters characterization*

1. Introduction

Spot welded joints are widely used in thin sheet metal welding, especially in automotive industry. Reliable behavior prediction of the spot welded joints has the significant influence on the construction integrity. Resistance spot welding is often used for such joints realization because productivity and possibility of process automation. Important factors which have influence on plastic strains occurrence are: mechanical properties of the basic material, joint geometry, properties of different welded zones, metal sheet thickness, and procedures and parameters of welding. Welding parameters are defined in respect to the recommendations given in literature. The diameter of the melted core corresponds approximately to the diameter of the electrode tip. Those parameters are: diameter of the electrode tip, welding current, welding time and electrode forces.

Mechanical properties of base sheet metal are determined in tension tests, using specimens cut in different direction with reference to rolling direction. Different hardening functions are used to describe stress – strain dependency. Chemical composition of metal sheet steel and metallographic investigation of spot welded joints gave additional information about possible behavior of welded structures. Spot welded joints are experimentally tested and analyzed in tension using universal testing machine. Different thickness of metal sheet was used and different kind of joints: overlapped joint with shear force, U profile joints with axial force and thin sheet metal shell structure. The finite element method has notable application in optimization of carrying structure of vehicle. In the car industry, i.e. in modeling of car body, gap elements are used in order to prevent progression one modeling surface through the other one. Verification of software PAK

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[1] is done on given examples modeled and analyzed by finite element method [2]. Comparing the numerical results with the force - displacement diagram of experimental results, it is verified that software gives good agreement with the experimental results. Difference between experimental results and numerical analysis is approximately 5 %.

2. Basics of spot welding

Resistance spot welding (RSW) belongs to the thermo-mechanical methods of welding because it combines influence of heat and force pressure. RSW is very common in automotive industry, truck cabs production and other products of sheet metal. Every conductor which conducts electricity produces heat because of resistance to this phenomenon. The amount of released heat:

$$Q = k \int Ri^2 dt, J \qquad (1)$$

where, i is the electric current, R is the electric resistance and t is elapsed time of welding. The utility factor k defines amount of effective energy spent during welding process.

2.1. Determination of the spot welding parameters

Basic parameters [3,4] of spot welding are chosen based on recommendations and by metallographic investigation. Diameter of the electrode is chosen with respect to the thickness and type of the welded sheet metal as: $d_e = 5\sqrt{s}$ for low carbon steels, $d_e = 4\sqrt{s}$ for highly alloyed steels or $d_e = 10\sqrt{s}$ for aluminum. The most important welding parameters are: diameter of the electrode tip d_e, welding current I_w, welding time t_w and electrode force F_w. Adopted parameters for

experimental tests are given in Table 1.

Spot welding parameters   Table 1

Thickness, s (mm)	d_e (mm)	I_w (A)	t_w (s)	F_w (N)
0.8	5.5	6600	0.28	1250
1.2	6.2	8000	0.4	1800

3. Determination of the properties of thin sheet metal

The most important mechanical properties [5] of the base metal sheet are determined. A great number of test specimens cut in different directions with reference to the rolling direction are analyzed in tension using universal testing machine Zwick&Roell.

Determined material parameters Table 2

All material properties are calculated as:
$$X = \left(X_{0°} + 2X_{45°} + X_{90°}\right)/4 \qquad (2)$$

The determined properties are: tensile strength R_p, yielding stress R_m, "n" factor,

Thickness	Angle, °	R_p, MPa	R_m, MPa	n, -	E, MPa
S=0.8mm	0°	179	305	.203	185
	45°	193	314	.195	207
	90°	187	302	.194	194
	X_{avg}	188	309	.197	198

as well as, module of elasticity E. Those material parameters with average values are presented in Table 2.

3.1. Hardening functions

Hardening functions are curves which describe dependency between deformation resistance K and strain φ [6]. According to literature, the most used hardening

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functions for soft steels and aluminium alloys are:

$$K = C\varphi^n \qquad (3)$$
$$K = C_1 + C_2\varphi^m \qquad (4)$$
$$K = C_3 + C_4\varphi \qquad (5)$$

Using the data determined as average values of measured mechanical properties, the final form of the hardening functions are:

$$K = 518.83 \cdot \varphi^{0.191716} \qquad (6)$$
$$K = 188.43 + 357.25 \cdot \varphi^{0.394} \qquad (7)$$
$$K = 302.44 + 376.65 \cdot \varphi \qquad (8)$$
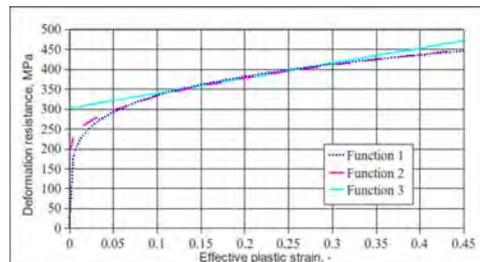
and curves which describe that dependency are given in Figure 1.

Fig. 1. *Hardening functions*

3.2. Metallographic investigations

Microstructure of the spot welded joint is determined on metallographic samples obtained from the spot welded joints. The microstructure of the heat affected zone (HAZ) was assessed as ferrite - pearlite (Figure 2). And microstructure of the weld metal as Widmanstatten microstructure (Figure 3).
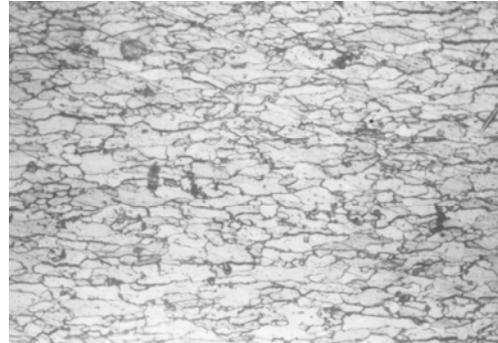
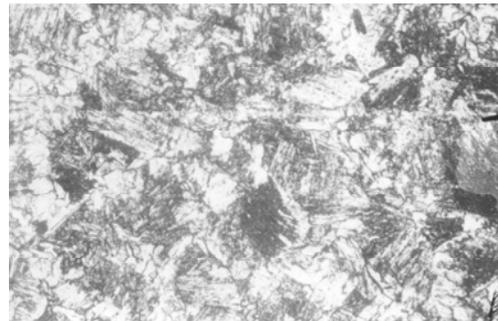Fig. 2. *Microstructure of the HAZ - ferrite-pearlite structure*

Fig. 3. *Microstructure of the weld metal - Widmanstatten*

Chemical composition of base material is given in Table 3.

Chemical composition   Table 3

Chemical composition, %			Tensile strength, MPa
C	P	S	
0.1	0.05	0.05	280-420

4. Experimental - numerical analysis of the spot - welded joint

After mechanical properties of the base material had been determined and the spot welding regime had been accepted, the welded joints were investigated to determine resistance properties and deformation ability.

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4.1. Tension tests of overlapped welded joint

Two specimens are welded (Figure 4) and geometrical and material nonlinear analysis of joint is performed. [7]
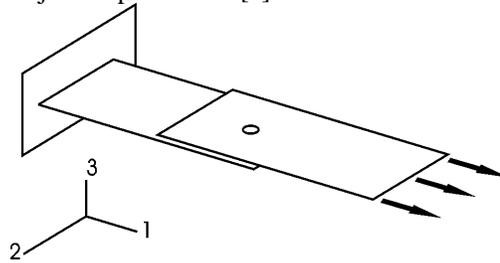

Fig. 4. *Scheme of tension test*

Diameter of weld is $d = 6mm$. Specimens are modeled with 3D solid elements with appropriate boundary conditions. Due to the plane symmetry, only half of the model was modeled with application of the corresponding boundary symmetry conditions[8-10]. Von Mises material model is used with isotropic hardening. Determined material constants for Ramberg-Osgood hardening function $\sigma_y = \sigma_{yv} + C_y \bar{e}_p^n$ are: $E = 2 \cdot 10^5 N / mm^2$, $C_y = 357.26 N / mm^2$, $\nu = 0.3$, $\sigma_{yv} = 188.44 N / mm^2$, $n = 0.3945$. Heat affected zone (HAZ) have different material constants $C_y = 520 N / mm^2$ and $n = 1$. Large strain analysis is used and logarithmic rotated Green – Lagrange strain measure.
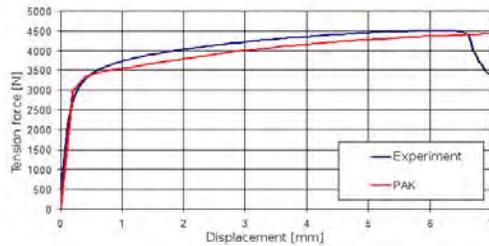

Fig. 5. *Force – displacement diagram of tension test of spot welded joint*

Diagram of force-displacement dependency is given in Figure 5. Deformed configuration of welded joint and fields of effective stress and effective strain in the 70th step are given in Figures 6-8.
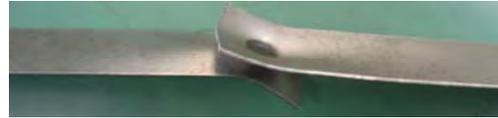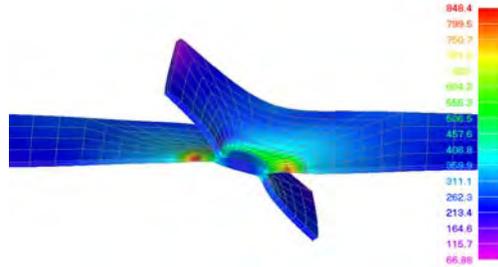

Fig. 6. *Deformed configuration of overlapped joint*
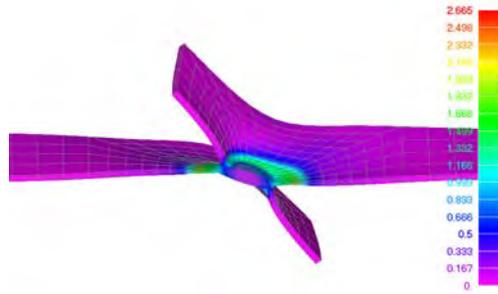

Fig. 7. *Field of effective stress of overlapped joint*

Fig. 8. *Field of effective strain of overlapped joint*

4.2. Tension tests of welded "U" profile specimens

Two "U" profile specimens are welded and geometrical and material nonlinear analysis of joint is performed. Same material parameters and modelling elements are used for FEM analysis. Force-displacement diagram is given in Figure 9. Deformed configuration of welded joint and fields of effective stress and effective strain in the 150th step are given in the Figures 10 -12.
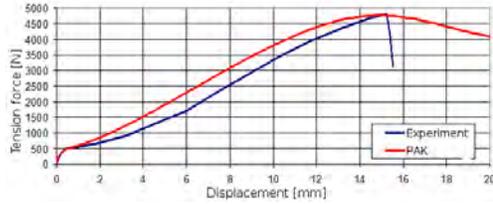
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Fig. 9. *Force – displacement diagram of tension test of "U" profile spot welded joint*

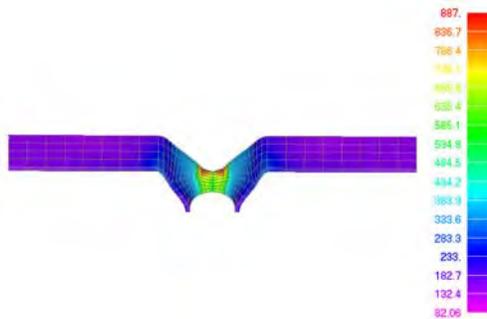Fig. 10. *Deformed configuration of "U" profile joint*

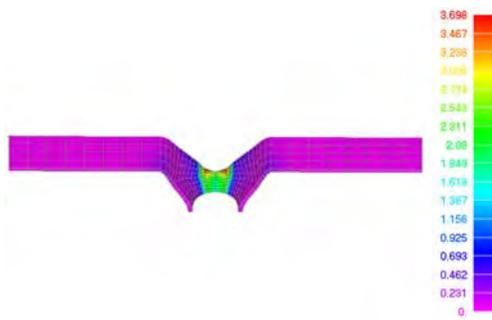Fig. 11. *Field of effective stress of "U" profile joint*

Fig. 12. *Field of effective strain of "U" profile joint*

4.3 Breakup of thin walled car shell carrier

Geometrical and material nonlinear spot welded carrier is analyzed. In modeling the carrier, due to geometric symmetry, half of the model is modeled by applying appropriate boundary conditions of symmetry. Welded joints are modeled with 20 beam elements of diameter 5mm, 7437 enhanced shell elements of thickness 0.8mm which are used for modeling sheet metal and 660 gap finite elements are used to model the joint sheet metals without initial gap [11, 12]. Isotropic Mises elasto-plastic material model is used. Material data for the Ramberg - Osgood hardening function are same as in previous examples. Since the total displacement is 120mm, 300 steps in increments of 0.4mm are performed.
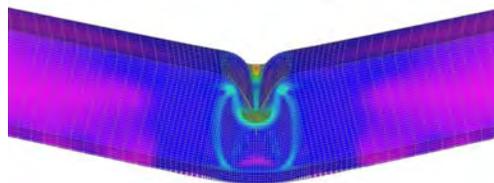

Fig. 13. *Deformed configuration of carrier*

Fig. 14. *Field of effective stress of deformed carrier*

In Figures 13-14, the model after the deformation and the deformed configuration of the numerical model are presented.

6. Conclusions

The aim of the study was verification of

numerical methods for solving spot welded joints problems using the software package PAK. Procedures for the optimal regimes of spot welding of automotive sheet metal are defined. Choice of welding parameters was influenced by the results of visual inspection, metallographic test and mechanical testing. Incompatible displacements for large strain are used, which means the correction of the deformation gradient. Identification of mechanical properties of the base material cut in different directions in reference to the rolling direction is done. Varied widths and two types of joints (overlapping, U-shaped) are analyzed. In those tests, force-displacement diagram was recorded. These results were used to compare the numerical results obtained by finite element method. Verification of analysis results proved the validity of the developed methodology and the ability to reliably developed software should be used in practice to solve the spot welded joints and structure problems.

Acknowledgements

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