Stress Analysis of Non-Ferrous Metals Welds by Numerical Simulation

Helena Kravarikova

Faculty of Materials Science and Technology in Trnava, Paulinska 16, 917 24 Trnava, Slovakia, Institute of Applied Informatics, Automation and Mechatronics

Abstract. Thermal energy welded material unevenly heated and thus supports the creation of tension. During the fusing process welding transient tensions generated in the welded material. Generation of the transient tensions depends on the thermal expansion and fixed permanently welded parts. Tensions are the result of the interaction of material particles. For welded parts and constructions it is necessary to know the size and direction of application of tensions. The emerging tensions can cause local change or a total deformation of welded materials. Deformations and residual stresses impair the performance of a welded construction, reduces the stability of the parts. To reduce or eliminate of action or a screening direction stresses and strains it is necessary to know the mechanism of their emergence. It is now possible to examine the emergence of tensions numerical experiments on any model using numerical simulation using FEM. Results of numerical experiment is the analysis of stress and deformation course. In the plane the tension it divided into normal σ and τ tangential folders. Decomposition stress on components simplifies the stress analysis. The results obtained from numerical analysis are correct to predict the stress distribution and size. The paper presents the results of numerical experiments stress analysis solutions fillet welds using FEM numerical simulation of welding of non-ferrous metals.

1 Introduction

Internal forces cause stress on the parts of the construction. Internal forces are reaction external load or temperature changes. When welding the material is uneven heating and thermal energy causes the formation tensions. Local or total deformations arise when the size of generated tension is greater than the yield strength or rigidity of the material. Stress and deformation are not separable phenomena in the welding process. Stress and deformations are integral, which dominate tension or deformation. Deformations and residual stresses impair the properties of welded construction, reduces the stability of the parts. Therefore, it is necessary to know the mechanism of their formation and of action. Deformation and stress fields generated during welding due to the introduced thermal energy into the material at the point of weld. It is therefore necessary to examine the progress of the welding temperature cycles.

2 The simulation model of experimental samples fillet welds

For examining the stresses in welding non-ferrous metals was chosen fillet weld. For the numerical experiment was used aluminum welded material having a purity of 99.5%. On the accuracy of the results have affect thermo-physical properties of materials depending on the temperature changes.

Material models include the following thermo - physical properties of materials [1]-[3]:

- Coefficient of thermal conductivity λ [$Wm^{-1}.K^{-1}$]
- Specific heat capacity c [$J.kg^{-1}.K^{-1}$]
- Density ρ [$kg.m^{-3}$]
- Modulus of elasticity E [MPa]
- Linear coefficient of linear expansion α_l [K^{-1}]
- Yield strength Re [MPa]
- Tangent modulus E_t [MPa].

When crossing the yield strength of the material is often used model with linear hardening. When analyzing stress-deformation tasks in ANSYS was used model with kinematic hardening.

Stress, individual parts of the structure, causes the formation of internal forces in response to an external load or temperature change.

Deformation and stress fields are produced by action of thermal cycles of welding. The total of strains in the examined body, the non-uniform temperature field, can be expressed with as the sum of the elastic deformation, depending on stress, the temperature and plastic deformation is [1], [4]-[6]:

$$\varepsilon_x = \varepsilon_{\sigma x} + \varepsilon_T + \varepsilon_x^P = \frac{1}{E}\left[\sigma_x - \mu\left(\sigma_y + \sigma_z\right)\right] + \alpha_T \Delta T + \varepsilon_x^P \qquad (1)$$

$$\varepsilon_y = \varepsilon_{\sigma y} + \varepsilon_T + \varepsilon_y^P = \frac{1}{E}\left[\sigma_y - \mu\left(\sigma_x + \sigma_z\right)\right] + \alpha_T \Delta T + \varepsilon_y^P \qquad (2)$$

$$\varepsilon_z = \varepsilon_{\sigma z} + \varepsilon_T + \varepsilon_z^P = \frac{1}{E}\left[\sigma_z - \mu\left(\sigma_x + \sigma_y\right)\right] + \alpha_T \Delta T + \varepsilon_z^P \qquad (3)$$

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$$\gamma_x = \frac{1}{G}\tau_x, \quad \gamma_y = \frac{1}{G}\tau_y, \quad \gamma_z = \frac{1}{G}\tau_z. \qquad (4)$$

where:
ε_σ – an elongation by stress in the direction of coordinate axis x, y, z,
ε_T – an elongation of the temperature in the direction of coordinate axis x, y, z,
ε^P – the plastic an elongation in the direction of coordinate axis x, y, z,
γ – shear strain.

Equations 1 to 4 are expressions of Hook's law for linear 3D solid isotropic material in Cartesian coordinates.

Differential equations, in vector notation, for thermo elasticity has the form [1], [4]-[6]:

$$\Delta \mathbf{u} + \frac{1}{1-2\mu}\,\text{grad div}\,\mathbf{u} - \frac{2(1+\mu)}{1-2\mu}\alpha_V\,\text{grad}T = 0 \qquad (5)$$

where:
u [m] – displacement vector,
μ [-] – Poisson´s Ratio,
T [K] – thermodynamic temperature,
α_v [K^{-1}] – coefficient of thermal volumetric expansion.

Cancyho tensor of the mechanical elastic deformation $\varepsilon_{ij}^{m,E}$ and the thermo-elastic deformation tensor $\varepsilon_{ij}^{T,E}$ are defined by the relation [1], [4]-[6]:

$$\varepsilon_{ij}^{m,E} = \frac{1}{2}(u_{i,j} + u_{j,i}) \qquad (6)$$

$$\varepsilon_{ij}^{T,E} = \alpha_{i,j}\Delta T \qquad (7)$$

Hooke's law generally reflects the dependence of strain and stress in the form [1], [3], [4]:

$$\sigma_{ij} = C_{ijkl}\varepsilon_{kl}^{E} = C_{ijkl}(\varepsilon_{kl}^{m,E} + \varepsilon_{kl}^{T,E}) \qquad (8)$$

where:
$\sigma_{i,j}$ [Pa] – tensor elements of stress,
C_{ijkl} [Pa] – elements of the tensor of elasticity.

The overall relative deformation can be expressed as the sum of elastic deformation ε_{ij}^{E} and plastic deformation ε_{ij}^{P} [1], [4]-[6]:

$$\varepsilon_{ij} = \varepsilon_{ij}^{E} + \varepsilon_{ij}^{P} \qquad (9)$$

Geometric model shape and size was the same with real experimental sample. The weld was made GMAW method. The stress - strain analysis was solved by numerical simulation using FEM in ANSYS. The solution stress - strain problems of numerical simulation is the thermal analysis. For the calculation of residual stresses and deformation during welding are used the results of the thermal analysis as a load of the model. The task is solved in ANSYS as transient and nonlinear.

3 The results of numerical simulation of structural tasks

Fig. 1 shows the course of the equivalent Mises stress at the time of welding 50 s. At this time, the residual stress is minimum value 0.626 MPa. A small tensions value is in the area of the weld, there is metal in liquid phase. At time 50 s is the maximum value of residual stress 83.3 MPa.

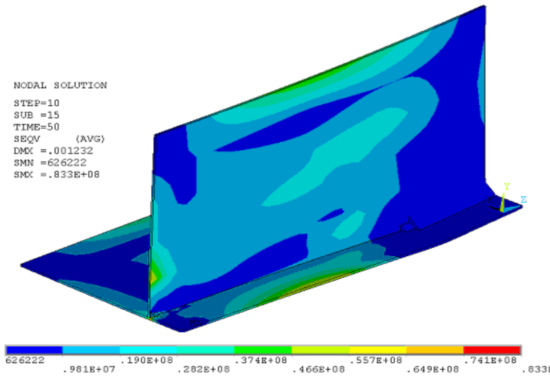

Figure 1. Stress field at the time of welding 50 s

Fig. 2 shows the equivalent Mises stress at the time of welding 130 s. At this time, the minimum stress value is 0.195 MPa and the maximum stress is 24.1 MPa.

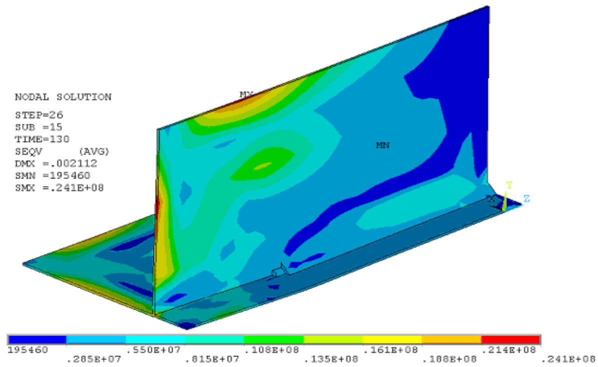

Figure 2. Stress field at the time of welding 130 s

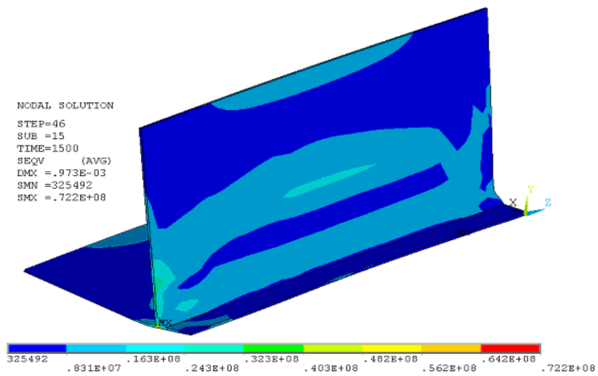

Figure 3. Stress field at the time of welding of 900 s

In Fig. 3 is shown the course of the equivalent Mises stress after cooling to room temperature 22.281 °C at the time of 900 s. At this time, the temperature field in the sample throughout the volume of the balanced and minimum residual stress is 0.325 MPa. The values of residual stress are in the weld between 8.31 MPa and

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24.3 MPa. The maximum value of the residual stress is 72.2 MPa. The maximum stress is acted simultaneously at the point where the sample has been firmly fixed, and it harvested all degrees of freedom.

Fig. 4 graphically show the results of angular deformation of the sample of numerical experiments.

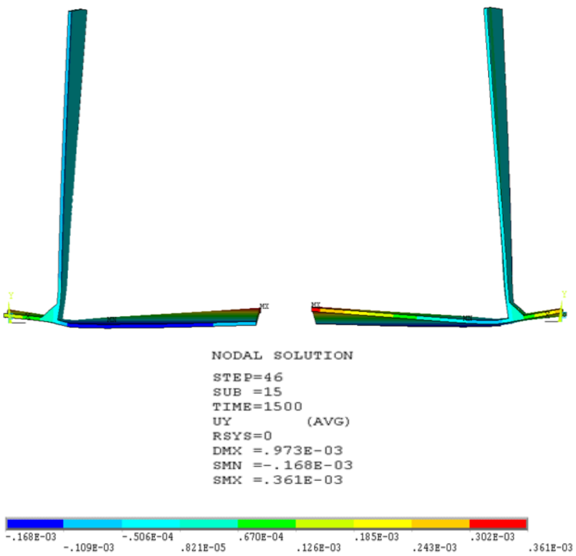
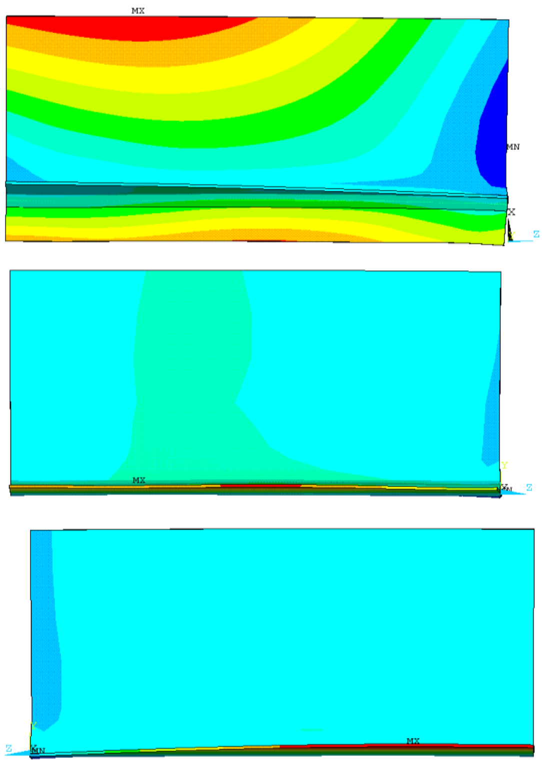


Figure 4. Graphical representation of angular deformation of numerical experiments

In Fig. 5 is graphically show the results of longitudinal deformation of the sample of numerical experiments.

The angular and longitudinal deformations produced as a result of supply of heat energy in the process of welding experimental samples.



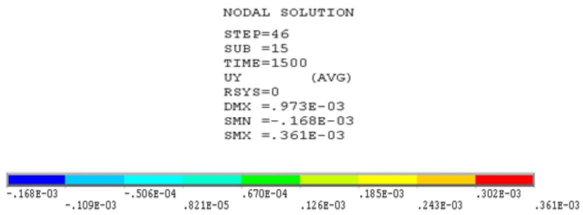


Figure 5. Graphical representation of longitudinal deformations of numerical experiments

4 Evaluation of the results

Angular weld is deformation of numerical experiments with shape deformation identical to the real experimental samples.

In Fig. 6 is graphically show the angular deformation of the sample of real experiments. Fig. 7 graphically show the longitudinal deformation of the sample of real experiments.

Figure 6. Graphical representation of angular deformation of real experiments

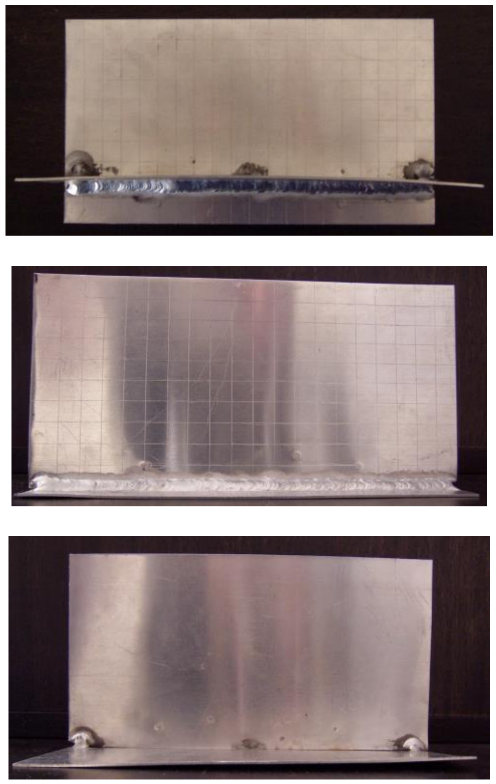


Figure 7. Graphical representation of longitudinal deformation of real experiments

In the Fig. 4 to Fig. 7 it is seen that the deformed shape of the experimental sample in the real experiment is identical to the shape of the sample graphical display of the numerical simulation of the all of the above views.

On the basis of the results obtained deformations of numerical and real experiments it can be concluded that the results of deformation for mating. Therefore, it is possible to replace the real experiment numerical simulation.

The accuracy of results obtained numerical experiments depend on many factors. The most important factors affecting the accuracy of the results are thermo-physical properties of welded materials depending on temperature change, method of simulating the heat flow in the welding site and its surroundings, initial and boundary conditions and welding method. Subject investigation the accuracy of the results of the numerical experiment might be the chemical composition of the welded materials and their dependency, temperature changes. Deviations that can arise are caused by inaccurate by subtracting thermo-physical properties of materials from the chart. The simulation is always contemplated welding speed uniformly. It is also contemplated steady movement of volumetric heat source. In manual welding it is not possible to meet uniformly speed and also moving volumetric heat source. On the accuracy of the results of numerical simulation has also implications welding parameters, the depth of fusion penetration and the size of the heat affected zone. The accuracy of the results achieved in part affects the human factor.

5 Summary

Experimental problem solving in different areas of engineering technology is very often replaced by computer simulation and numerical solution. Substitution of experimental solutions using numerical simulation has significant scientific and economic benefits. Further examination might be those of other advanced techniques such as welding special welding technology, as well as examination of the impact of the welding parameters on the accuracy of the numerical simulation. Numerical experiment is a flexible solution of stress and thermal deformation process produced during welding.

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