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FEM CALCULATION OF RESIDUAL STRESS AFTER PULSED CURRENT ARC WELDING OF ALUMINUM ALLOY

Andrzej Skibicki

University of Technology and Life Sciences in Bydgoszcz, Faculty of Mechanical Engineering
Prof. S. Kaliskiego 7, 85-796 Bydgoszcz
e-mail: askibic@utp.edu.pl

Abstract

Construction made of aluminium alloy is lighter than of steel. The use of pulsed arc for welding is helpful, but has influence on structure and residual stresses after welding. FEM model of the welded plate made of aluminium alloy was used here. The 2D model, lying on the surface of welded sheets, was used. Because of the models symmetry only ½ of the surface was calculated. The calculations were done with ANSYS in two phases, as uncoupled thermal and mechanical calculations. The iterative calculations of deformations and stresses are non-linear with temperature dependent material properties. The mesh of 1337 finite thermal elements SHELL57 was used. Simulation has 10,3 s of welding time followed by cooling until 800 s. Different type of pulse was used. One single period of current pulse was all the time 0,5 s. This time was divided into 5 equal sub-periods. The heat source (current of welding) was switched on for some sub-periods. The power of heat source was multiplied by factor 1,2 or 3. Distributed volume heat source was moving along of weld line. Results from temperature analysis were used in stress calculation. Elements type and material properties were changed to structural PLANE42. The results show that some residual stresses after pulsed arc welding were higher as after constant. The maximums of tensile stresses were concentrated at small, perpetual areas. They are too small for experimental measuring, but together significantly sufficient for crack propagation or local stress corrosion.

Keywords: welding, stress, FEM, aluminum, pulsed arc

1. Introduction

The welding is one of the basic techniques of connecting metals. For melting metal, which make the weld, the great amount of heat is needed. The weld is heated as well as all construction. In the results of it the structural changes appear, which makes the mechanical properties of metal lower. The results in the deformation and residual stresses category are also important. They can be dangerous for the construction. If the thickness of the material is small while the plasticity high – there are also big additional loads needed to destroy the construction. The risk is higher for the fragile materials. The thick metal sheets are during and after welding in 3 dimensional (3D) stress state. For both of those cases chance of the appearance of crack is possible. The residual deformation changes the form of construction. It can unable their operating. The shrinkage and deformation make it difficult to keep the tolerances. The practical ways for reduction of deformation and stress are the results of long-term experience. The technical development and economy introduces new technologies and materials. In this case new experience can be not long-term enough.

Construction made of aluminium alloy is lighter than made of steel. The welding of aluminium is difficult however. The use of pulsed arc is helpful, but has influence on structure and residual stresses after welding [4,7]. Its important to check this influence at some cases of welding. FEM model of the welded plate made of aluminium alloy was used here. The 2D model, lying on the surface of welded sheets, was used. Because of the models symmetry only ½ of the surface was calculated.

2. The numerical research

The bases of the FEM calculations are shown in [1,6]. The calculations were done in two phases, as uncoupled thermal and mechanical calculations. The scheme is shown in Fig.1.

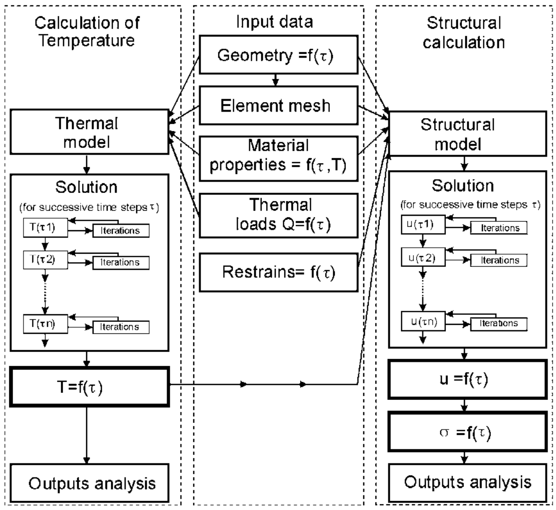
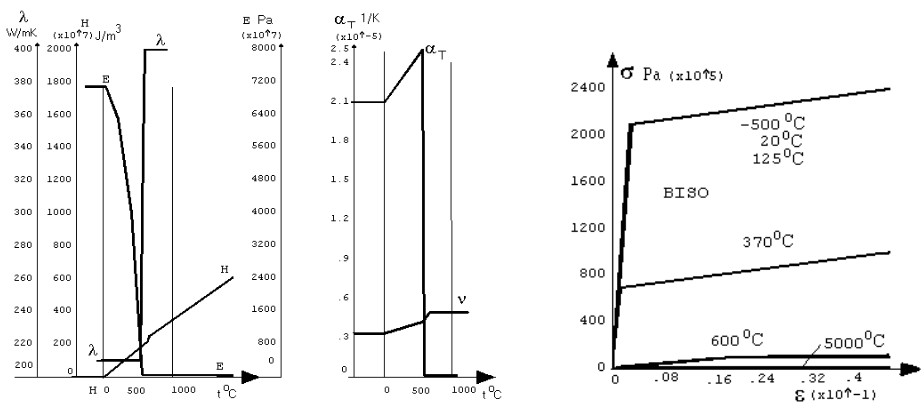


Fig. 1. Schematic diagram of uncoupled thermal-structural calculations [6]

The correct calculations are possible (especially for deformations and stresses) only with the use of non-linear, dependent on the temperature physical material properties (Fig.2)[1,2,6,8]. The material properties are dependent also on deformation. Here used properties are elastic-plastic, with isotropic hardening. The process of looking for the FEM solution is iterative (Fig. 1). The modelling welding process lasted for 10.3 s, with cooling time (until 800 s). At this time heating (loading) and cooling of models occurred. The position of the heat source was changing in following time steps. This way the “step by step” technique was used [1,6]. The results of the step (1) were necessary for the calculation of the step “2”, results of the step “2” will be necessary for the calculation of the step “3”, etc. until last step. Both of above processes strongly (factor 10^5) lengthen the process of solving the problem.



a) *b)* *c)*

Fig. 2. Properties of the aluminium alloy, as function of the temperature. a) Specific enthalpy and thermal conductivity λ, b) Elastic modul E, Poisson ratio υ, thermal dilatation α_T, c) yield stress R_e, hardening modul E_T , BISO-Bilinear ISOtropic hardening[1,2,3,6]

The full 3D calculations require very efficient computers. The 2D model was then used, lying on the surface of welded sheets. The aim of it was the best possible formulation of welding physics. For example on the 2D geometry, the higher perpendicular thickness of grain and root of weld was declared. Because of the models symmetry only ½ of the surface was calculated. The appropriate boundary conditions were used. This way the time of the calculations was shortened. Finite elements were used from the library of the program ANSYS13: SHELL57 in thermal calculations and PLANE42 in the structural calculations. 1337 elements with 1430 nodes were used. The mesh of the elements was shown in Fig.3. The size of elements is smaller near the welding lines, because of existing here high gradients (of degrees of freedom, eq. temperature or deformation).

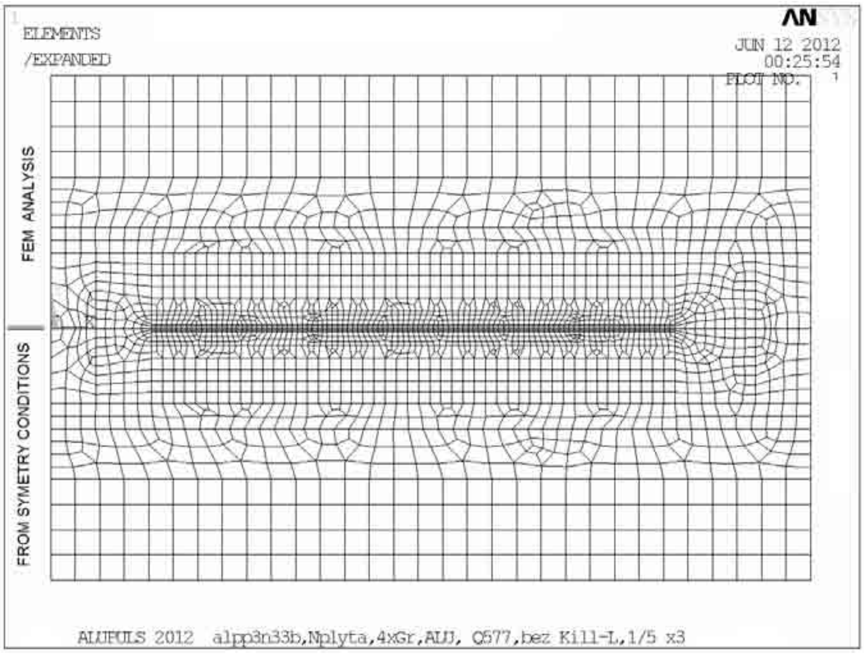


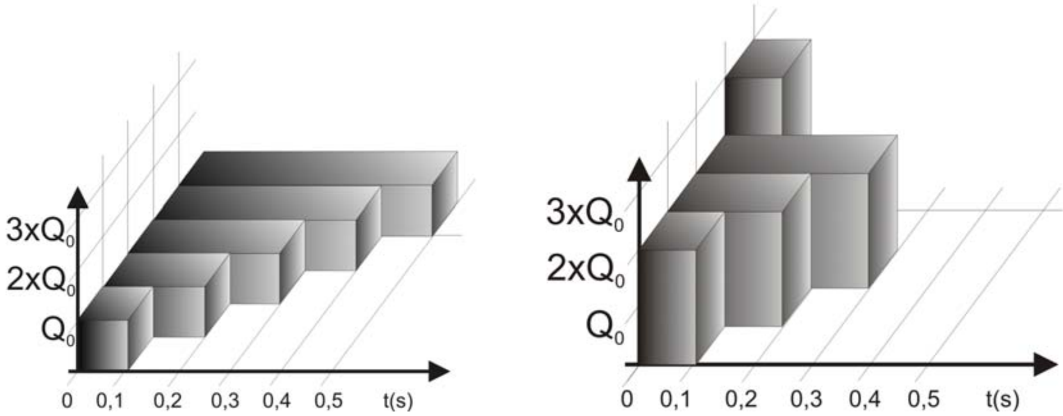
Fig. 3. Finite element mesh

Distributed, volume heat source (suggested by Goldak, [3], for MIG/MAG) was moving along the line of the weld. There were welds in the place of grooves. It happened because of completing the model by the previously removed finite elements from model (“killed”). On both surfaces (upper and bottom) the loss of heat through convection was taken into account. The convection near the weld was intensified to taken into account the heat radiation.

In the analysis different type of pulse was used. One single period of current pulse was all the time 0,5 s. This time was divided into 5 equal sub-periods. Except one, non-pulsed analysis, the heat source (corresponding to current of welding arc) was switched on for some sub-periods. The initial power of heat source (Q_o=3.4 kW) was multiplied by factor D= 1 or 2 or 3 (Table 1 and Fig.4).

Tab. 1. Calculated residual stress (maximum)

No	Power source (Q=D Q_0)	Pulsation of arc power during 0,5s period, s	Residual stress (800 s), MPa		
			Huber-Misses	longitudinal	transverse
1	2 Q_o	0,3	0 +250	-151 / +283	-198 / +158
2	Q_o	0,5	0 +245	-117 / +272	-197 / +160
3	Q_o	0,4	0 +246	-91 / +265	-187 / +164
4	2 Q_o	0,2	0 +245	-98 / +263	-193 / +175
5	Q_o	0,3	0 +246	-66 / +264	-183 / +183
6	3 Q_o	0,1	0 +252	-80 / +261	-183 / +193
7	Q_o	0,2	0 +230	-42 / +258	-146 / +195
8	2 Q_o	0,1	0 +260	-73 / +275	-186 / +203
9	Q	0,1	0 +247	-58 / +274	-173 / +214



a) *b)*

Fig. 4 Scheme of arc pulsation from tab.1 : a) for 9,7,5,3,2 , b) for 8,4,1,6.

Distributed volume heat source was moving along the line of the weld. On both surfaces the convection heat loss was set. The calculation was done in hundreds of time steps. In Fig. 5 example results, one of calculated temperature field, are shown.

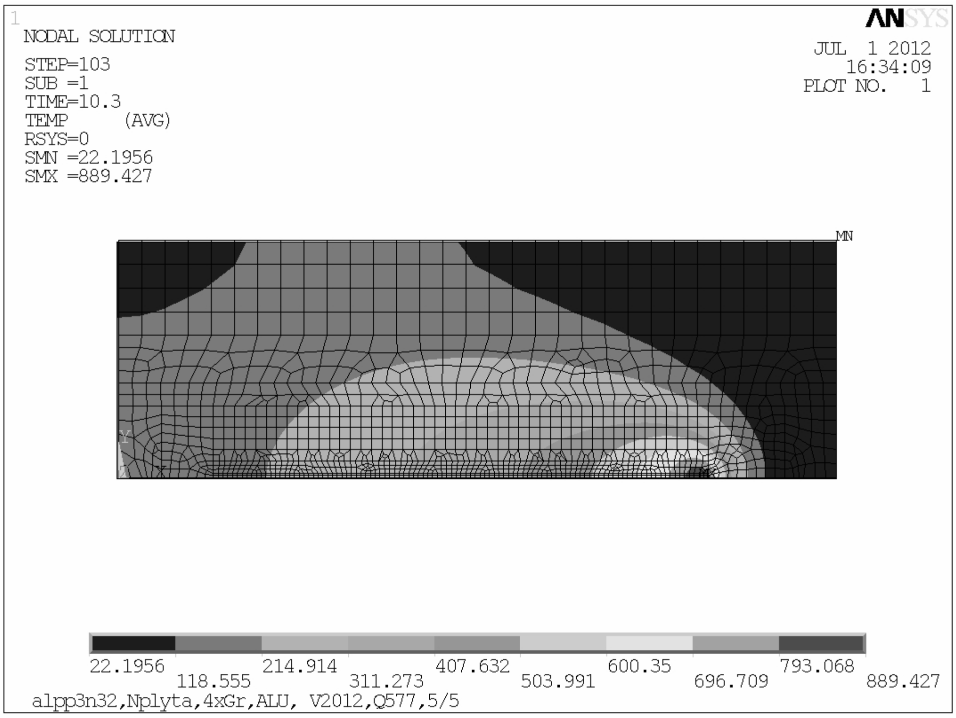


Fig. 5. Calculated temperature field, [°C], at time t=10.3 s.

Results from temperature analysis were used in stress calculation. Elements type and material properties were changed to structural. Transient and residual stresses are calculated. In Fig. 6 are shown residual stresses for constant current arc analysis and in Fig.7 for pulsed current arc analysis.

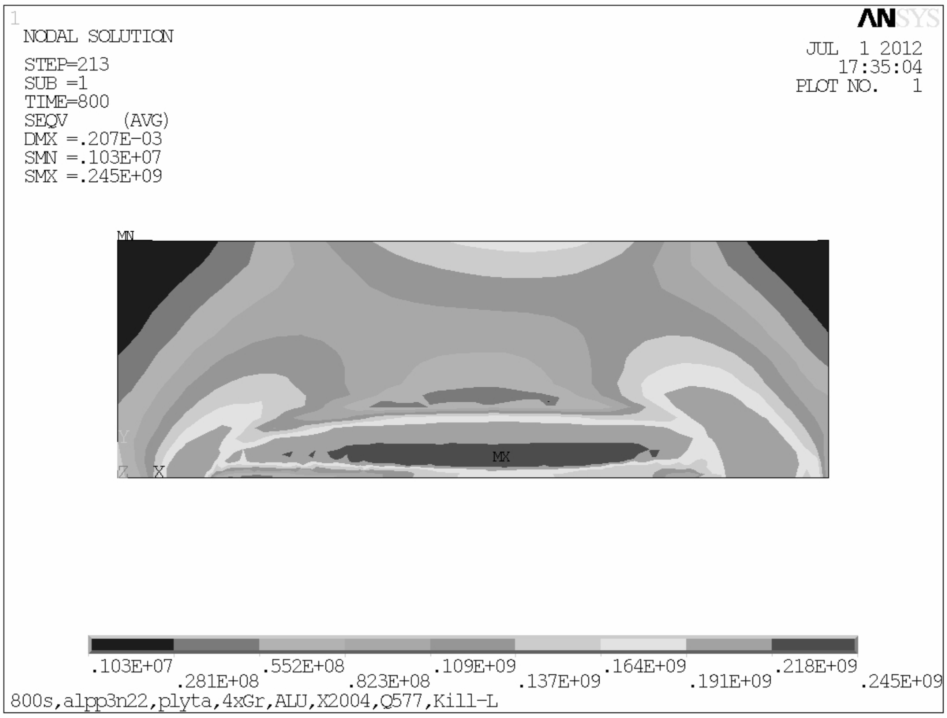


Fig. 6. Calculated residual stress (reduced von Misses) Pa, constant current arc welding (Tab.1 p.2)

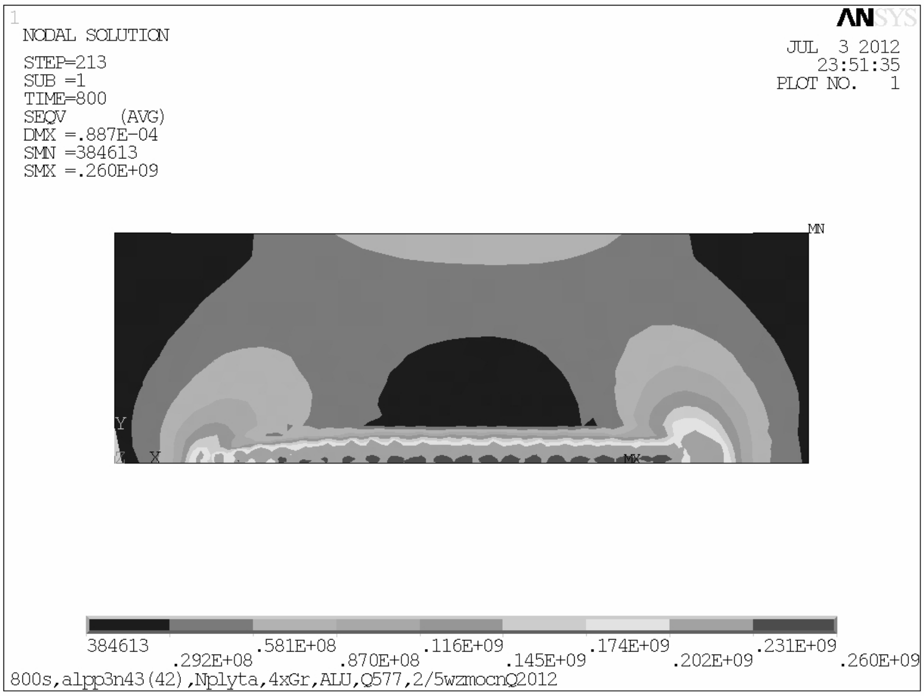


Fig. 7. Calculated residual stress (reduced Huber-Misses) Pa, pulsed current arc welding (see Tab.1 p.6)

The results are presented in Table 1. Here are show the maximum of longitudinal, transverse and reduced (Huber-Misses) residual stresses after many pulsed and constant arc welding.

The stability of solution was weak because of often, rapidly activation and deactivation of heat source [5]. The FEM program ANSYS was used.

3. Observations and conclusions

3.1 The results presented in Table 1 and in Fig.6 show that some residual stresses after pulsed arc welding were greater as after constant arc welding.
3.2 The maximum of tensile stresses were concentrated at small, perpetual areas.
3.3 These areas are too small for experimental measuring, but together significantly sufficient for crack propagation or local stress corrosion.
3.4 FEM is suitable for the calculation of the residual and transient welding stress.
3.5 The application of frequently met program ANSYS makes possible to practically use the suggested method of calculations.
3.6 Values of transient residual stresses are very difficult to obtain in experiment, and can be very useful. The use of FEM is very reasonable and effective.
3.7 Residual stresses were the greatest after spot-weld pulsed arc welding (Table 1 pos.9).

References

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