

USING OF WELDING VIRTUAL NUMERICAL SIMULATION AS THE TECHNICAL SUPPORT FOR INDUSTRIAL

PRIMJENA NUMERIČKIH SIMULACIJA ZAVARIVANJA KAO TEHNIČKE POTPORE U INDUSTRiji

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Ključne riječi: Postupak zavarivanja, numerička analiza zavarivanja, SYWELD, PAM ASSEMBLY, WELD PLANNER, metalurgijske faze, tvrdoća, naprezanja, deformacije, distorzija

Key words: welding process, welding numerical analyse, SYWELD, PAM ASSEMBLY, WELD PLANNER, metallurgical phases, hardness, stresses, deformation, distortion

Sažetak: Zavarivanje kao moderna, visoko efikasna tehnologija proizvodnje ima svoje mjesto u gotovo svim vrstama industrije. U isto vrijeme zahtjevi za kvalitetu zavarenih spojeva konstantno rastu u svim proizvodnim područjima. Numeričke simulacije uz rezultate eksperimentalnih mjerjenja mogu simulirati stvarni postupak zavarivanja vrlo blizu realnog stanja. Rezultati analize su nestacionarna temperaturna polja, distribucija metalurških faza, tvrdoće, deformacije, naprezanja i distorzije na konstrukciji. Na temelju rezultata analize moguće je optimizirati postupak zavarivanja (tehnologiju) i u isto vrijeme dobiti detaljne informacije o reakcijama konstrukcije tijekom cijelog proizvodnog procesa. Numeričke simulacije su vrlo koristan alat tijekom pripreme proizvodnje u cilju očuvanja najveće kvalitete proizvoda. Cijela virtualna numerička simulacija izvedena je pomoću programa SYSWELD, PAM ASSEMBLY i WELD PLANNER koje razvija tvrtke ESI GROUP i INPRO.

Abstract: Welding as a modern, highly efficient production technology found its position in almost all industries. At the same time the demands on the quality of the welded joints have been constantly growing in all production areas. Numerical simulations supported by experimental measurements can simulate the actual welding process very close to reality. The analyses results are non-stationary temperature fields, distribution of metallurgical phases, hardness, deformation, stresses and distortion of the construction. Based on the analyses results it is possible to optimize the welding process (technology) and to receive detailed information about the construction's reactions during the whole production process at the same time. Numerical simulations are very useful tools during production preparation to keep best product quality. The whole virtual numerical simulations are done by using SYSWELD, PAM ASSEMBLY and WELD PLANNER programs, which is developing by ESI GROUP Company and INPRO Company. The programs are working based on the finite elements method.

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1. INTRODUCTION

The welding is the most prevalent metal joining process. The used heat input during welding process creates residual stresses as well as distortion in the steel components. The type and extent of distortion and residual stresses are influenced by a number of different factors as the clamping condition, mechanical and thermal property, type of the welding technology used, welding parameters, preheating temperature, weld joints design, temperature of surroundings etc. Residual tensile stresses have also got a negative influence on the construction lifetime and its brittle fracture resistance. Residual stresses create a balanced system of inner forces, which exists even under no external loading. Deformation (distortion) after and during welding process has got also negative influence for keeping construction dimension. In case that the undesirable construction deformation after welding process is carried out another repair processes as for example straightening should be used.

The numerical simulation of the welding process is one way to determine the level of the residual stresses and distortion. The calculated residual stresses are used for the prediction of the lifetime including influence of the welding process or finding possibilities of the defect initiation and defect growth under service conditions. The control of distortion is very important due to manufacturing tolerances for following-up machining and assembly process. It is clear that the compromise between fully fixed and absolutely free construction needs to be found.

The numerical simulation of the welding process can be used during the preparation of welding technology of the new products or during the innovation of the current products, for optimising welding technology and for the assessment of the lifetime of components considering the level of the residual stresses after welding process or after repairs, which have been done with welding technology. Using the welding numerical simulation can decrease number of actual experiments or prototypes during technology preparation and can also decrease the time needed for the preparation and decrease the cost, as well. The various proposals can be numerically simulated and there the first idea of the behaviour of the construction during and after welding process arises. Based on the calculated results the most suitable version is chosen. The optimization of the input welding parameters, welding sequences, clamping condition, support stiffness process is applied to obtain output parameters required.

Based on our experiences the welding numerical simulation can be divided into four following areas:

1. Comparison of several different technologies. Every technological alternative is numerically simulated and the output parameters (quality of the metallurgical structure, residual stresses, distortion etc.) are compared. The aim is to find the best alternative, which corresponds with the customer's requirements.
2. Lifetime assessment. The aim of the analysis is to predict the lifetime (welding residual stresses and plastic deformation) of the whole construction or of some components including the consideration of the influence of the welding process. The residual stresses are numerically simulated and considered in the lifetime assessment.
3. Brittle fracture prediction. The calculated level of the residual stresses can be used during the assessment of the brittle construction resistance.
4. Prediction of the distortion during welding assembly process. This type of the prediction is done with the help of the new local global approach or weld planner simulation.

The welding numerical simulations are using at heavy machinery, energetic, automotive, ship and airplane industry.

The verification projects including measurement of the material input data and welding experiments have been prepared and carried out. The numerical simulations of welding

experiments have been done and the calculated and measured parameters have been compared. The heat source models for various welding technologies have been found and validated. The main aim of these verification projects is to find the appropriate input parameters and solution methods that so the numerical simulations be corresponded as much as possible with the reality. The found parameters and experience have been used in real industrial manufacturing analysis.

2. NUMERICAL SIMULATION OF THE WELDING PROCESS

The numerical simulations of the welding process are performed with using Welding Simulation Solution with Codes SYSWELD, PAM ASSEMBLY and WELD PLANNER software (ESI Group Company). The Welding Simulation Solution schema is shown in fig. 1.

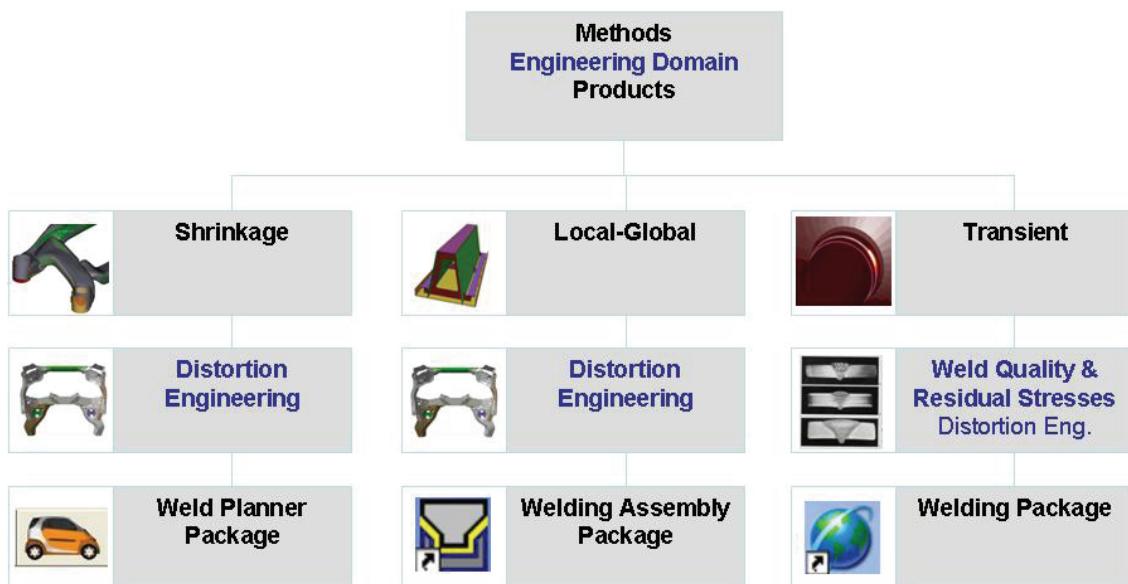


Fig.1 Welding Simulation Solution from ESI Group Company

Based on the solution method the numerical simulation of the welding process can be divided into three following groups [1]:

1. Transient welding or step by step method (TW), SYSWELD Code: The heat source model moves according to weld trajectory. The numerical calculation is done at each time increment during welding process. The real welding parameters (current, voltage, velocity and efficiency) are included as parameters of the heat source model. The results are very complete (temperature fields, hardness, metallurgical structure, residual stresses, plastic deformation, distortions). Transient method is suitable for determination of the local effect of the welding joints and optimization of the welding technology (parameters) regarding on mainly metallurgical structure, hardness and residual stresses at weld joint and close surroundings.
2. Macro bead deposit method (MBD), SYSWELD Code: The heat source is applied instantaneously in one or several macro area (element) in the same time. The real weld trajectory is divided into several macro sections. The energy per unit length of the weld joint is transferred into the structure the same as real welding process. The number of macro sections, time steps are defined based on the welding technology parameters and experience with this method. The MBD methodology is an extent of the TW method. The MBD method decreases calculation time and increases possibility calculation of the big

- construction with keeping good level of results quality.
3. Local-global method (LG), SYSWELD and PAM ASSEMBLY Codes: For very large structures with a lot of welding joints, such as maritime, automotive or heavy industry structures. Standard TW or in some cases MBD methodologies are not feasible because these methods require significant computation time and computer memory size. The idea behind the LG methodology is that welding process is a local modification of stress and strain, the total effect leads to a global state of distortion. The local welding effect is found on the refined local models calculation with using TW or MBD. The stiffness of the local models must be the same or very close the reality. The results are transferred from local models to the global model and equilibrium linear elastic simulation is performed to ascertain the global distortion. The global model represents often whole structure. The LG methodology enables simulate very huge structure with very large number of the weld joints. But the results from LG are only distortion, inner force and moments at constraint conditions. The levels of the residual stresses or metallurgical structure are determined by the local modeling, it means by TW or MBD method. The verification of the local-global method is done and published in literature [4,5].
 4. Shrinkage method (SM), WELD PLANNER Code: The Weld Planer is new programme and can be used for very fast distortion prediction on construction with high number of welding joints. The Weld Planer calculates distortion based on the shrinkage engineering. The temperature and material structure solutions are not done and only mechanical solution is using. Weld Planner is an upfront analysis tool that in minutes predicts weld-induced distortions and allows quickly and efficiently developing a weld plan, defining fixture conditions, and optimizing weld sequence to meet tolerances. The Weld Planner using is very easy and intuitive and enables the welding distortion prediction in very short time.

- The TW and MBD method can be also divided into three following stage [5]:
1. During the first stage a complete diagram of anisothermic decomposition (CCT diagram) is entered by special pre-process module. The results of this stage are coefficients describing the kinetic of transformation process depending on cooling rate at individual areas of heat-affected zone. The coefficients depend on the temperature and on the metallurgical phase of particular material and are used as direct input to the second phase.
 2. The second stage is a thermo metallurgical solution. This part needs complete thermo physical and thermo metallurgical material properties. There is applied a classical equation of the heat conduction extended with the transformation of latent heat during change of phase and during melting of material. Coupling between phase transformation and heat conductivity is used. The results of the first stage are non-stationary temperature fields, percentage distribution of individual phases, size of primary austenitic grain, hardness. The temperature analysis is transient calculation in each time interval. The all-welding passes must be simulated.
 3. The results of the second stage (mainly non stationary temperature fields) are applied as a loading condition in the third stages, the structural analysis. The complete mechanical properties are needed. The mechanical properties (thermal expansion, yield stress, hardness, Young modulus etc.) depend on the temperature and individual phases. Resulting mechanical properties in welding joint and heat-affected zone are calculated on the basis of individual material structure distribution and their mechanical properties. The results of the second stage are, total deformation (consist of elastic part, thermal part, convectional plastic part, viscoplastic part and transformation plasticity), residual stresses and distortion.

The model of the thermal source is one of the most important input parameters [5]. The computation model is loaded only with non-stationary temperature fields. Thermal load represents the thermal energy flow into the material during the welding process. The results (distortion, residual stresses) depend very much on finding the correct model of the thermal source and appropriate temperature distributions. The SYSWELD code has got a special tool "heat source fitting" which enables to find appropriate input computation parameters of heat source in order to simulate reality. The pre-defined double ellipsoidal and conical heat source models can be used by SYSWELD code. The pre-defined translation, rotation and general movement of welding heat source can be used by SYSWELD code as well.

3. INDUSTRIAL CASES

3.1 Distortion prediction of the low pressure turbine part body

The aim of the project is to predict welding induced distortion of the upper segment of the low pressure part of a turbine casing manufactured by the SKODA POWER company based in Plzen, Czech Republic. It is one of the most important European producers and suppliers of the technology equipment and customer services in the power generation industry with more than a century-old tradition of steam turbine production [2].

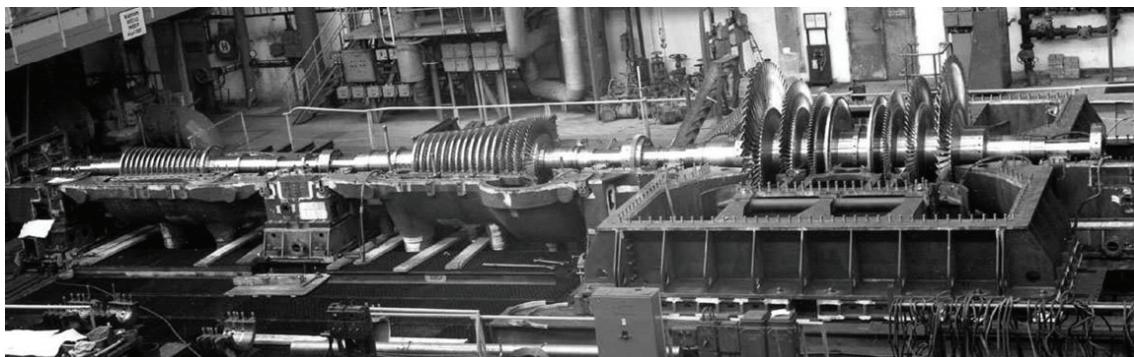


Fig. 2. Turbine casing manufactured at SKODA POWER.

As shown in Figure 2, the turbine casing acts as a cover for the turbine rotor. It also supports the stator blades and helps to distribute the steam flow to different segments of the turbine and other segment of the steam circuit. While the casing of the high-pressure and medium-pressure parts are usually produced by casting (because of much higher working pressures, a big wall thickness is required), the casing of the low-pressure part can be considerably less robust. The low pressure casing is therefore typically manufactured as a welded assembly (a frame of massive beams covered by relatively thin sheets) allowing production of such parts at a lower cost. However, the thickness of the components is still considerably high; requiring high number of multi-pass welds be applied. In the structure presented for discussion, up to 50 passes per weld joint may be required. This results in significant welding induced distortions, even though the structure is quite stiff. The manufacturing tolerances required for such parts are typically quite tight, as the casing is mounted together and sealed with surrounding/interlocking parts. Usually, some compensation of the distortion is needed to get into the nominal dimension. The repairing operations may include 581 massive machining of the distorted surfaces or in the opposite deposition of material by additional welding. In extreme cases, the part may be scrapped when the distortions exceeds the standard allowable tolerances. The financial losses from these situations are

obvious. Prediction of distortions through numerical simulation can prove to be an invaluable tool to the welding engineer.

The very progressive local-global solution method has been used due to requirement for distortion prediction of the huge welded structure. The component is shown in fig. 3. The welding joints, which have been numerically simulated, are shown in fig. 4.

The 12 different local models have been prepared and numerically analyzed. The each local model represents different welding technology during welding process. The each welding step (operation) has been numerically analyzed by using global analyses and the welding distortions have been determined after each welding step. The calculated distortions are shown in fig. 5, 6 and 7. The reference dimensions and points for measuring distortion are shown in fig. 8. The table 1 contains the comparison between calculated and measured distortion.

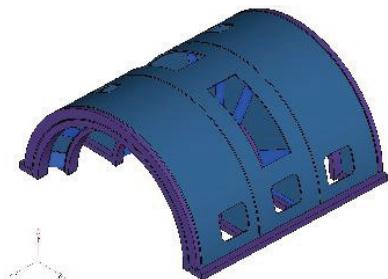


Fig. 3. Low pressure part body

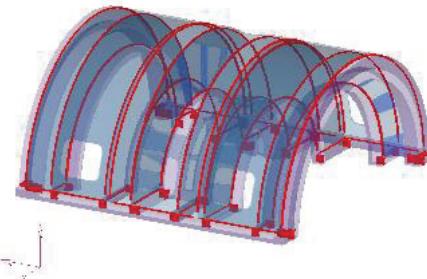


Fig. 4. Numerically simulated welded joints

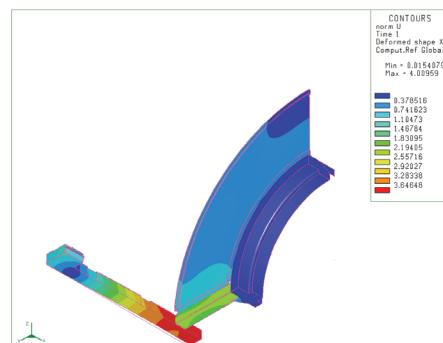


Fig. 5 Distortion after 1st step

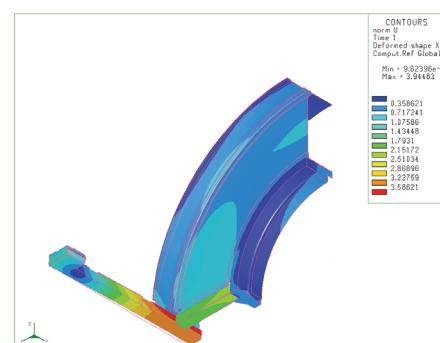


Fig. 6 Distortion after 2nd step

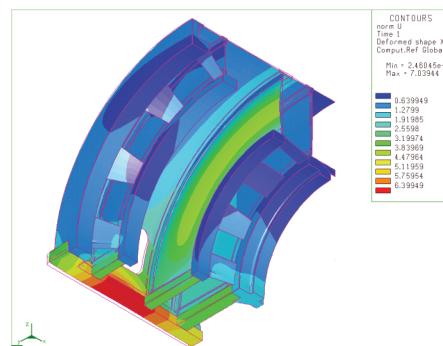


Fig. 7 Final distortion after welding

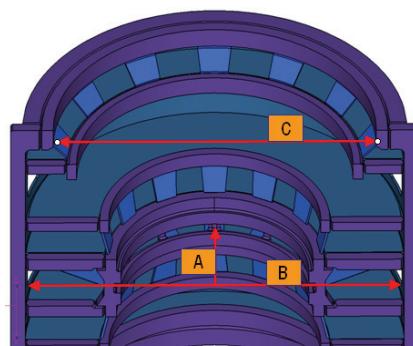


Fig. 8 Reference dimensions and points

Table 1. Comparison between calculated and measured distortion

Reference	Calculated distortion [mm]	Measured distortion [mm]
A	-0,85	-1
B	-8,8	-7
C	-1,92	-2

3.2 Distortion prediction by using WELD PLANNER

The Weld Planer is new programme. The Weld Planer uses only the SYSWELD solver and was developed by INPRO Company with VW, Daimler and Thyssen Companies cooperation and can be used for very fast distortion prediction on construction with high number of welding joints. The Weld planer calculates distortion based on the shrinkage engineering. The Weld Planner using is very easy and intuitive and enables the welding distortion prediction in very short time and can be used in wide range of industrial as automotive, ship building, civil engineering, heavy industry and others sectors.

The figure 9 presents the welding of the welded part [3]. The WELD PLANNER computation model including the constraint conditions is shown in fig. 10. Dimension of the computation model is 4800×3800×6 mm. The main aim of the simulation was predict welding distortion virtually without real prototyping and making welding technology optimization. The distortion prediction after first welding joint is shown in fig. 11. The distortion prediction after finishing welding process is shown in fig. 12 and after releasing from clamping condition is shown in fig. 13. Next step the distortion after thermal straightening is shown in fig. 14.



Fig. 9 Welded part

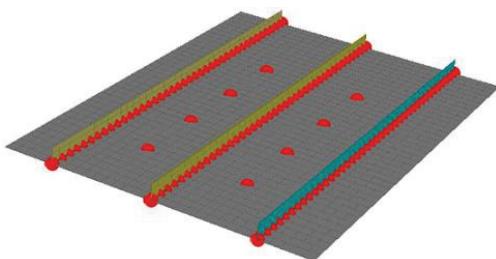


Fig. 10. Computational model

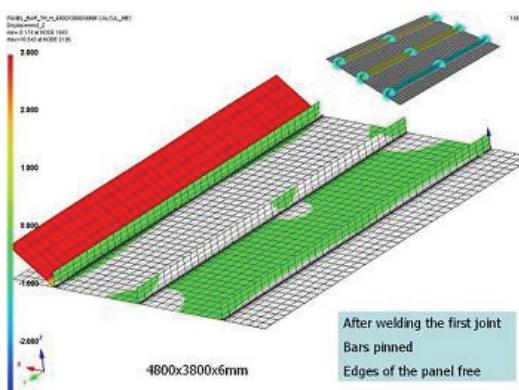


Fig. 11 Distortion after first weld joint

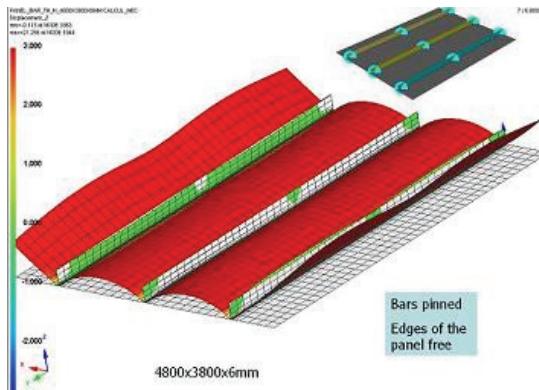


Fig. 12 Distortion prediction after welding

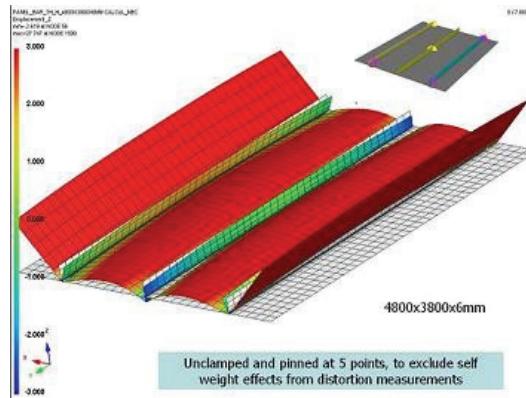


Fig. 13 Distortion after unclamping

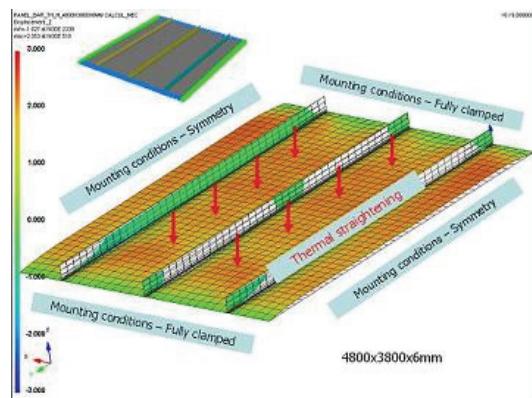


Fig. 14 Distortion after thermal straightening

5. CONCLUSION

The main aim in the industry is cost reduction with increasing product quality. The very detail knowledge about the process and product are needed to keep the customer requirements. The reduction of the cost and time for design and technology preparation can be done to decrease the experiments or repairing before the finalization of the product and technology. The numerical simulations of the welding process are very modern and productive tool. The recent rapid progress in modeling techniques provides researchers and engineers with more information to achieve a better understanding of the residual stresses and distortion in welded construction. This paper demonstrates how numerical solutions can give some very important and interesting information about welding process and behavior of the welded construction. The results can be used as one of the basis during the proposal of a new product, new technology validation or optimization of current welding technology and the lifetime prediction of the welded components.

The whole welding numerical simulations have been done by using SYSWELD, PAM ASSEMBLY and WELD PLANNER Code developed by ESI Group and INPRO Companies and distributed by ESI Group Company. The new local-global and shrinkage solution method is also introduced in this paper.

5. LITERATURE

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