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Use of Welding Process Numerical Analyses as Technical Support in Industry.

Part 3: Industrial Examples – Transport Industry

Abstract: At the present stage of industrial development, numerical analyses are nothing new. In developed countries, numerical analyses are present almost in every stage when designing a new part or structure or when developing repair and modernising technologies. Numerical analyses enable simulating welding processes without compromising the high compatibility of simulation results with those obtained in reality. Numerical simulations are very useful tools supporting production preparation processes and assuring the highest quality of products. However, in order to satisfy the needs of various industries, it is necessary to develop computational methods, ready-to-use modules or software applications ensuring an effective and comfortable manner of performing calculations. The article is the third part of a cycle concerned with the possibility of applying numerical techniques as tools supporting the development of technologies and structures using computer simulations of welding and heat treatment processes. Part 3 is focused on examples of the use of numerical analyses in the transport industry.

Keywords: numerical analysis, welding processes, numerical simulations

DOI: 10.17729/ebis.2015.6/5

Introduction

The numerical analyses of welding processes can be divided primarily due to types of results (analysed aimed to determine strains of elements after welding or heat treatment) and analyses, aimed to determine “the quality of a welding process”. The second type of analyses is primarily concerned with the determination of metallurgical structures, hardness, grain size, distribution and level of post-weld plastic stresses and strains [1,2]. Clearly, it is not the only manner of division as numerical analyses can also be divided in relation to the industries where it is applied, which in turn is connected with expected results. The two major industries where numerical analyses are used extensively are transport and power generation (including heavy industry) [4,5,6].

The transport industry is primarily connected with the manufacture of train, bus, lorry and ship elements. The primary problems encountered in such products are welding strains present during and after welding processes. Therefore, the most important requirements

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formulated by customers include determining the effect of strains and the optimisation of welding processes (primarily, the sequence of welding and the manner of fixing elements to be welded). A new area of applying numerical analysis in the transport industry is the integration of welding process numerical analyses with high-cycle fatigue simulations in one computational model. In order to obtain information about welding strains, analyses of this type utilise the combination of Weld Planner and Sysweld (Visual Weld) software applications. Fatigue analyses are performed using the Sysweld software package [7,8].

Welding techniques used in the power industry and heavy industry are primarily connected with the welding of pressure vessels, pipelines, heat exchangers, rotors, turbine blades and their elements repaired using welding techniques. The primary objective of analyses performed in these industrial sectors is the determination of conditions ensuring the obtainment of specific material properties and crack-free structures. Due to the fact that machinery elements are components characterised by high rigidity, problems connected with welding strains seldom occur. Therefore, the primary calculation results in this scope will be metallurgical structures, hardness, grain size, distribution of stresses and plastic strains, the determination of yield point and tensile strength as well as the prediction of potential crack areas and also, though rarely, strains. In many cases, these analyses, in a very modern manner, combine analyses of welding processes and post-weld heat treatment, and additionally include assessments of boundary states (resistance to changing loads, creep or crack mechanics – performed by means of one computational model). In these industrial sectors, actual welding tests, performed often on small specimens, do not correspond to what really happens when welding large structures. According to the authors' experience, simplifications which are frequently necessary in cases of small specimens, change welding process conditions entirely. The primary advantage resulting from the use of welding process numerical analyses in such cases is the obtainment of results related to the welding structures of actual size.

Numerical simulations in the power industry and in heavy industry are performed using the Sysweld (Visual Weld) software package. Analyses of boundary states can be conducted directly in the Sysweld package, in the Systus package (creeping, crack mechanics) or in software applications dedicated to fatigue-related analyses [1,2,3,4,8].

Numerical analyses of welding processes – transport industry

A typical example of designs analysed using numerical simulations is the welding of a vehicle frame. A welded frame, typically containing hundreds of welded joints, can be subjected to numerical analysis using a special strain-analysing software application, i.e. Weld Planner, a unique programme based on a special technique involving the calculation of local shrinkage. The "shrinkage" method enables performing calculations of very large structures in a relatively short time. However, in order to be reliable, the method requires the appropriate calibration of input data. This means that each structural welding technology requires calibration using one of the two following manners:

1. Numerical simulation analysing a welded joint as a local model (within the area of one selected joint) using calculations in the Sysweld software application (Visual Weld) involving so-called entire physics (i.e. calculations of all phenomena taking place in the welding process). The same model is prepared and calculated also in the Weld Planner software application. Values of strains calculated in Sysweld (Visual Weld) and Weld Planner are then compared. The primary objective of such an approach is finding input data for Weld Planner ensuring the obtainment of strain values comparable with those received in analyses performed

using Sysweld. The figures below present an example of such calibration. Figure 1 presents calculations performed in Sysweld (Visual Weld), whereas Figure 2 presents the same solution in Weld Planner after calibration.

2. Experimental method in which a local model is made as an actual experiment, where after welding, strains are measured at strictly specified points. Afterwards, a numerical simulation is performed in Weld Planner and required process input data are subjected to calibration.

Obviously, in some cases, where analyses target only certain fragments of a structure (components) and the computational model itself does not contain a large number of welded joints, it is possible to perform the classical analysis ("transient") involving welding process calculations in specific subsequent steps at certain predefined intervals. Therefore, the result comprises not only the final state but also individual stages of a welding process.

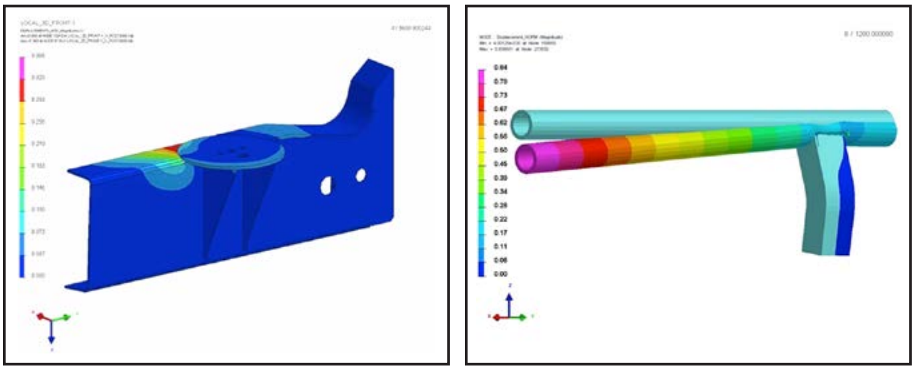


Fig. 1. Determination of welded structure strains – local model in SYSWELD (VISUAL WELD)

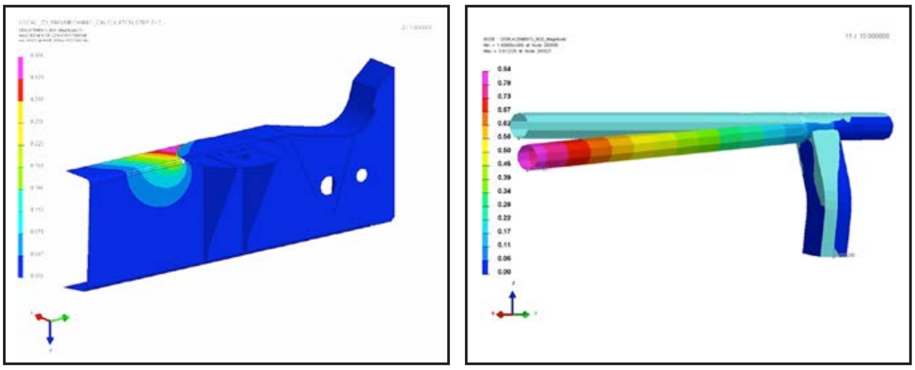


Fig. 2. Determination of welded structure strains – local model in WELD PLANNER

Welding the main beam of a vessel

The first example of analyses performed using the "shrinkage" technique was a problem encountered when welding a life raft, i.e. unexpected strains of welded elements. The primary objective of the numerical analysis was to determine the conditions in which such strains could take place, and if possible, develop a new technology preventing the formation of such strains. An element subjected to welding was a beam made of two steel grades, i.e. S355J2G3 and duplex 1.4462. The entire length of the element amounted to 7210 mm, whereas the height of profile "L" amounted to 165 mm. The elements were subjected to multi-run welding (seven layers).

Numerical analyses were performed using all the variants available, i.e. the classical "transient" analysis involving the use of Sysweld (Visual Weld), the "shrinkage" method performed using Weld Planner and the "local-global" technique using the Pam-assembly package developed by Esi Group. In the case under discussion, the "local-global" combined the "transient" type analysis with analyses typical of Weld Planner software applications, determining the effect of a local thermal cycle on the entire strain of the structure being analysed.

The analysis also involved two variants, i.e. the original and numerically optimised technology. The computational model performed in Sysweld is presented in Figure 3. The results concerning the analyses of the strains in welded elements are presented in Figures 4 and 5 (for various computational methods). For comparative purposes, Figure 5 also presents the actual welded element. After the optimisation, the calculation results were compared with those obtained for the original technology, Table 1 and 2.

Welding a carriage beam

Another example of the application of numerical analysis is connected with the welding of a railway carriage beam deformed due to heat treatment, where strains exceeded allowed tolerance values. Another problem which appeared during welding was the loss of flatness in elements subjected to welding, which in turn required the use of another post-weld technological operation, i.e. straightening. The beam was made of S355J2G3 steel using 4 welded joints, i.e. 6 runs in total. The analysis was performed as a classical "transient" type analysis using Sysweld (Visual Weld). Figures 6-8 present strains present in the welded element after each welding operation. Table 3 presents the maximum strain values after each welding operation.

The analysis also involved the distribution of individual metallurgical phases and stresses after welding. Figure 9 presents the distribution of bainite and martensite obtained as a result

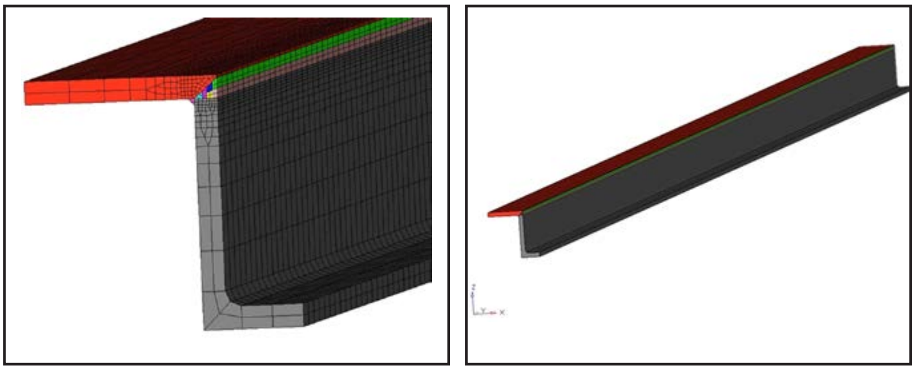


Fig. 3. Computational model – performed using SYSWELD (VISUAL WELD)

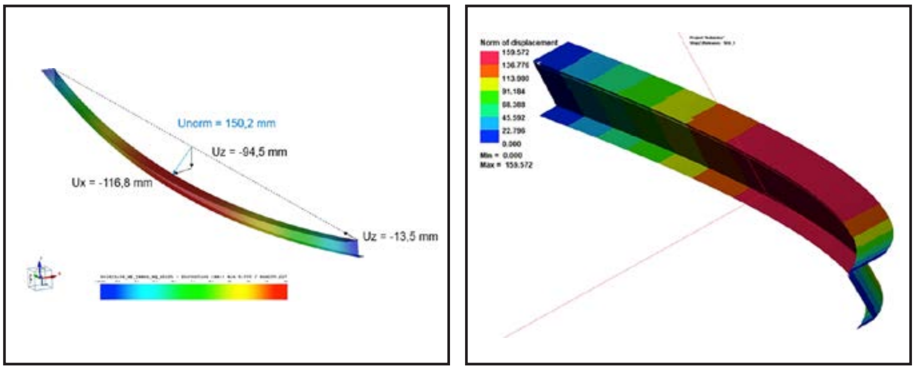


Fig. 4. Post weld strains – calculations performed in WELD PLANNER (left) and PAM-ASSEMBLY (right)

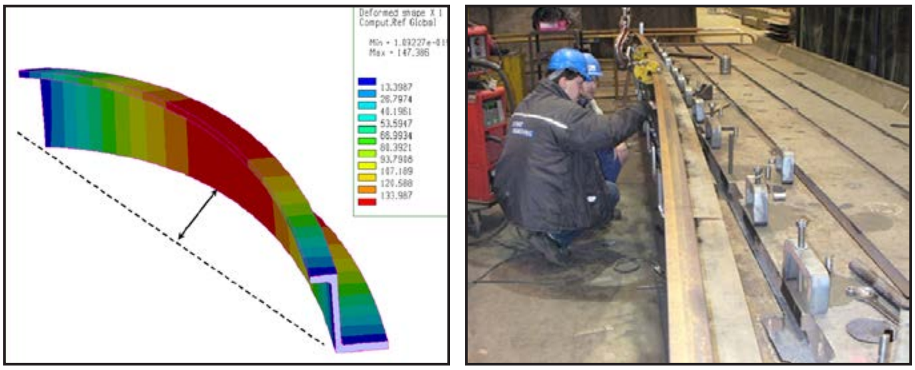


Fig. 5. Post weld strains – calculations performed in SYSWELD (left) and actual welded element (right)

Table 1. Comparison of welded beam strain analysis results for various computational techniques

	Pam Assembly	Weld Planner	Sysweld
U_{norm} [mm]	162	150.2	147
U_x [mm]	128	116.8	118
U_y [mm]	11.7	13.5	12
U_z [mm]	98	94.5	89

Note:
U_{norm} – entire strain;
$U_{x,y,z}$ – constituent strains in individual axes

Table 2. Comparison of welded beam strain analysis results for the original and optimised welding technology

	Original technology	Optimised technology
U_{norm} [mm]	150.2	106.1
U_x [mm]	116.8	83.2
U_y [mm]	13.5	9.3
U_z [mm]	94.5	65.9

Note:
U_{norm} – entire strain;
$U_{x,y,z}$ – constituent strains in individual axes

of numerical analysis. The structure is primarily bainitic with small areas of martensite present where the welding process was initiated and terminated as well as in the heat affected zone of the first and second runs.

As mentioned before, the analysis also involved the distribution of post-weld stresses (Fig. 10). As could be expected, the highest values of these stresses were characteristic of the martensitic structure.

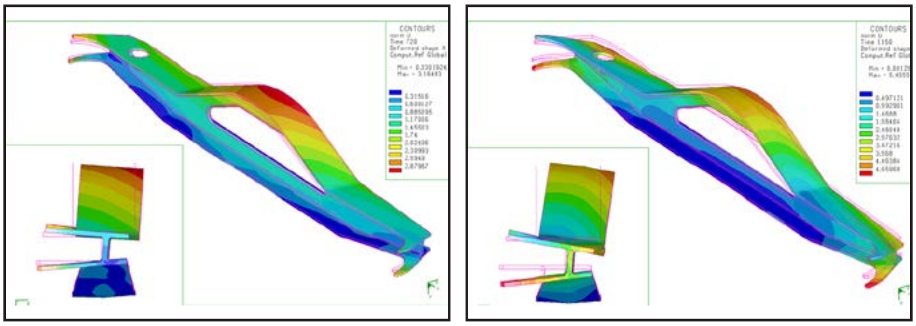


Fig. 6. Strains of the welded element – after making run 1 (left) and after making run 2 (right)

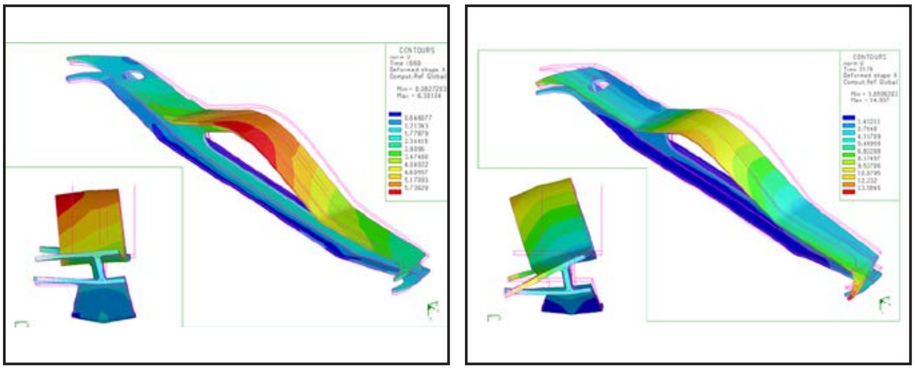


Fig. 7. Strains of the welded element – after making run 2 (left) and after making run 3 (right)

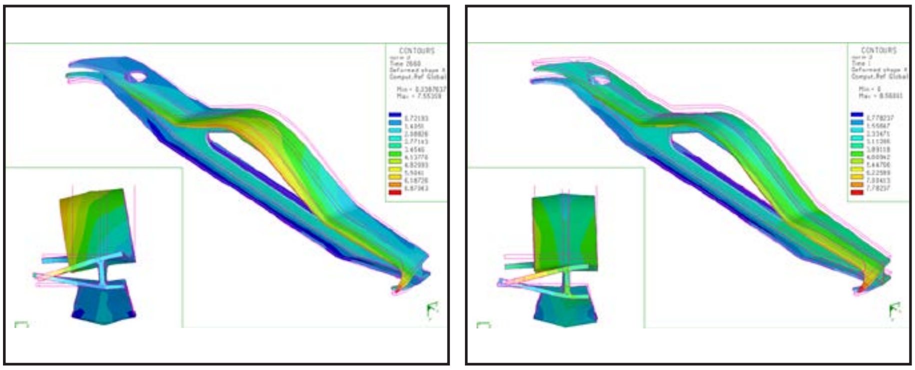


Fig. 8. Strains of the welded element – after making run 5 (left) and after making run 6 (right)

Table 3. Entire strains of the welded element (carriage beam) after making each successive run (Fig. 6-8)

	U_{norm} max [mm]
after run 1	3.16
after run 2	5.46
after run 3	6.3
after run 4	14.94
after run 5	7.55
after run 6	8.56

Welding of a suspension beam

Another example is the numerical simulation of rear suspension beam welding performed for the PSA concern. This case involved the use of a cutting-edge combination of welding process analysis with changing load resistance calculations. The solution was presented by the workers of the PSA concern during the ESI Group PUCA 2011 user forum.

The first stage of calculations involved a welding process simulation. Calculations were performed for 84 joints made using the GMAW method (the total length of joints amounted to 5 metres). Figure 11 presents the analysis results as the distribution of stresses and strains present in a welded element.

The numerical analyses of the beam welding process were followed by calculations of resistance to high-cyclic loads in accordance with the DANG VAN criterion. The calculated values of post-weld stresses, plastic strains and distribution of metallurgical phases were used when analysing the effect of high-cyclic loads. The analyses (according to the Dang Van criterion) were performed in two variants, i.e. both taking and not taking into consideration the effect of the welding process (Fig. 12). Differences between the results of the variants analysed proved significant. Higher values of the Dang Van criterion coefficient could be seen as regards the analysis of the variant taking into consideration the effect of a welding process.

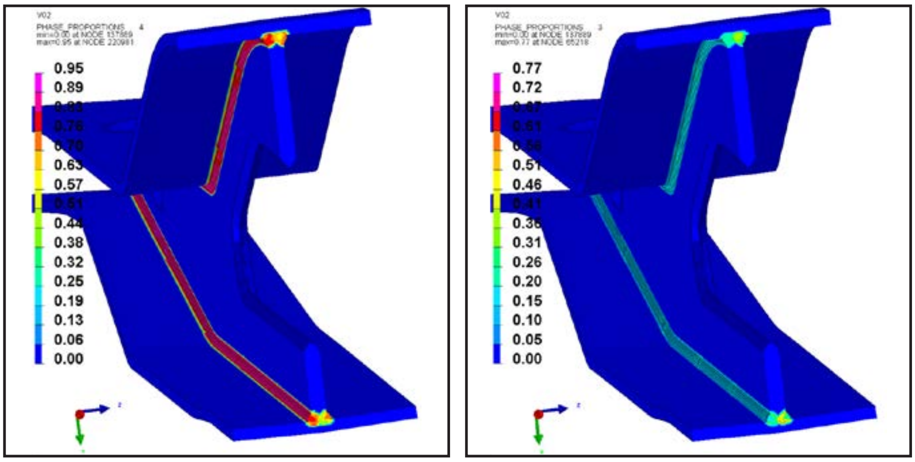


Fig. 9. Distribution of bainite (left) and martensite (right)

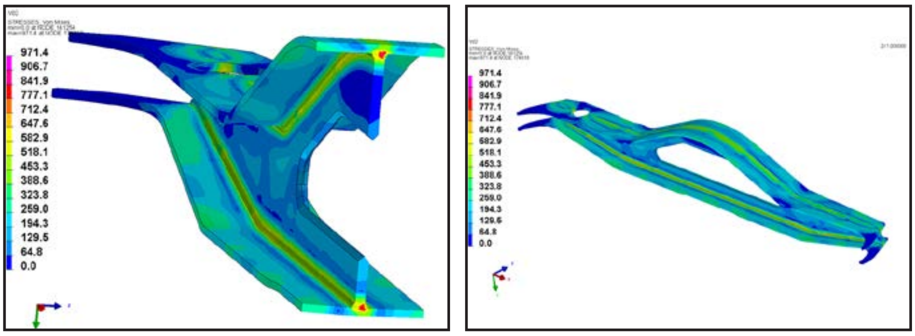
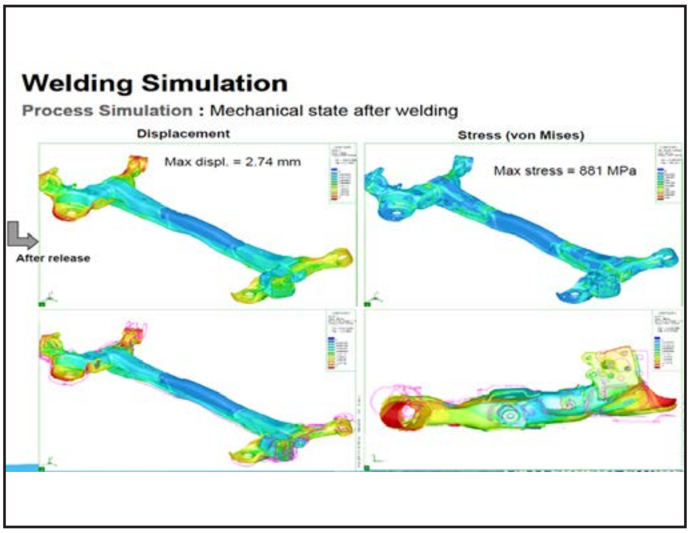


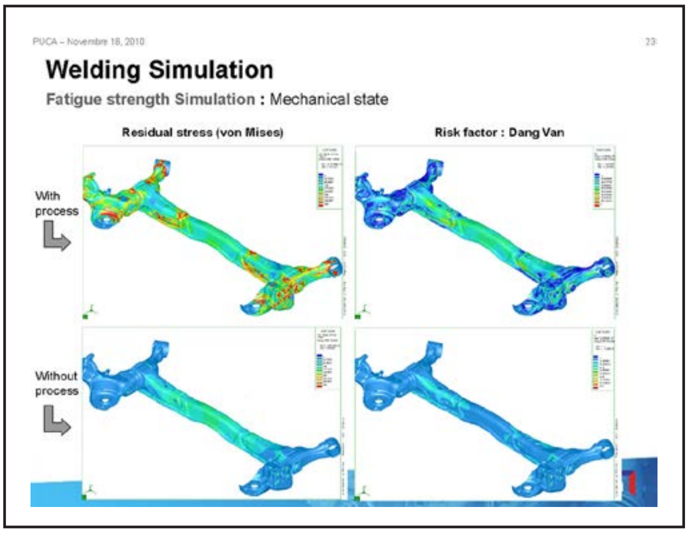
Fig. 10. Distribution of stresses in bainite (left) and martensite (right)



Welding Simulation

Process Simulation : Mechanical state after welding

Fig. 11. Calculation results – stresses and strains in the welded beam



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Welding Simulation

Fatigue strength Simulation : Mechanical state

Fig. 12. Calculation results – the DANG VAN criterion for the exemplary analysis of high-cyclic changing load

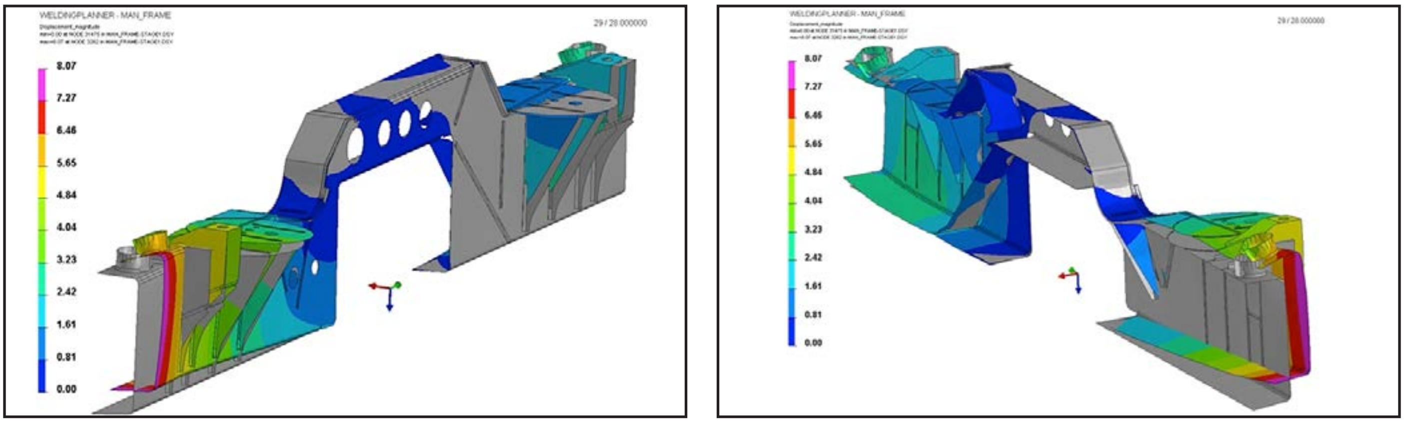

Fig. 13. Calculation results – distribution of strains in the welded element (two-sided view)

Welding of bus suspension elements

In another example, of assembly welding of bus suspension elements, the analysis again involved out-of-spec strains. In addition, this element, i.e. a bus suspension beam made of S355MC steel and containing approximately 70 welded joints, required post-weld straightening. The numerical solution combined the “shrinkage” technique performed using Weld Planner and the “transient” method in Sysweld (Visual Weld). The “shrinkage” technique was used for analysing the global model, whereas individual constituent analyses and others, e.g. calibrations of heat sources, were performed on local models. Due to the size of a welded structure, the number of individual operations and of welded joints, this example of numerical analysis is highly complex. Figure 13 presents the distribution of strains in the structure subjected to analysis.

The case under consideration also involved analyses of four different technological variants, where the primary assumption was the minimisation of post-weld strains in elements. Figures 14 and 15 present a comparison of analyses-related results. As can be seen, the solution based on results of numerical analyses significantly reduces final strains. However, due to the confidential character of data, the variants cannot be presented in more detail.

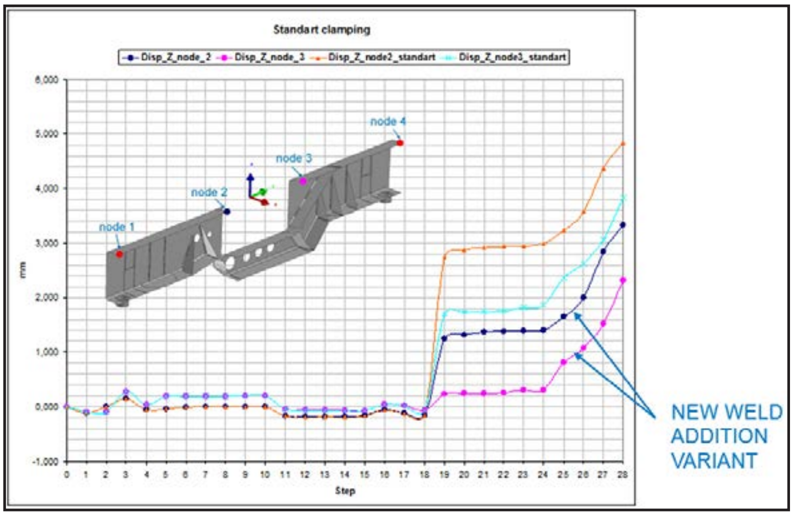

Fig. 14. Comparison of analytical results concerning strains present in the welded elements for the original and modified variants

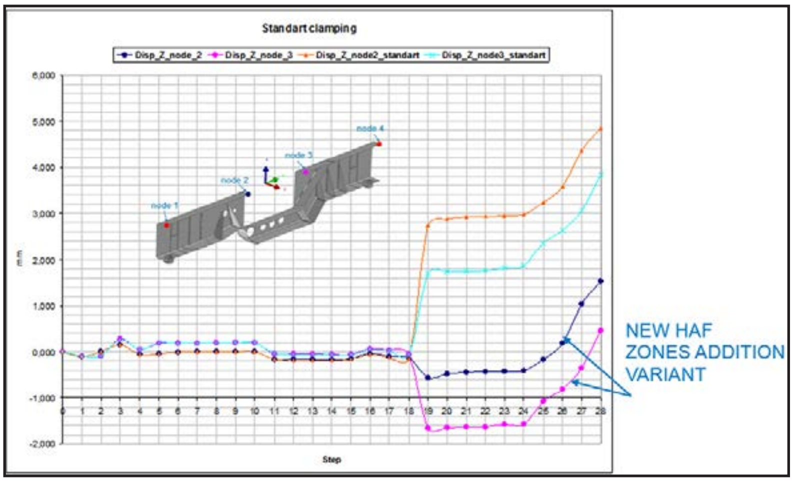

Fig. 15. Comparative results related to analysis of welded element strains for original and modified variants

Welding of car wheel rims

As regards numerical analyses of the welding of car wheel rims, the primary assumption of the analyses was to maintain the shapes of the rims (made of S355J2G3 steel). The numerical analyses were performed using a classical “transient’ type analysis in the Sysweld

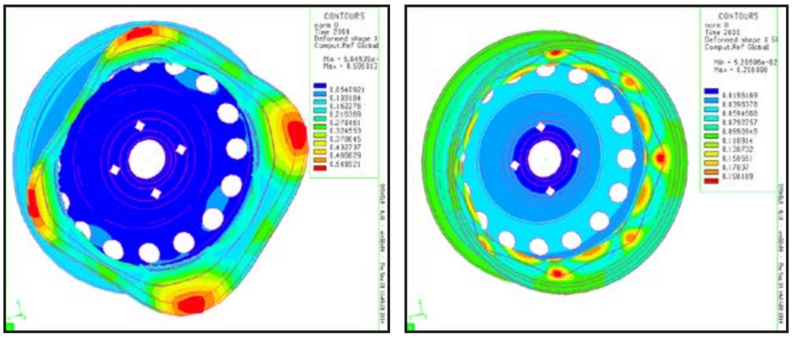

Fig. 16. Distribution of stresses in a welded wheel rim – technological variant 1 (left) and variant 5 (right)

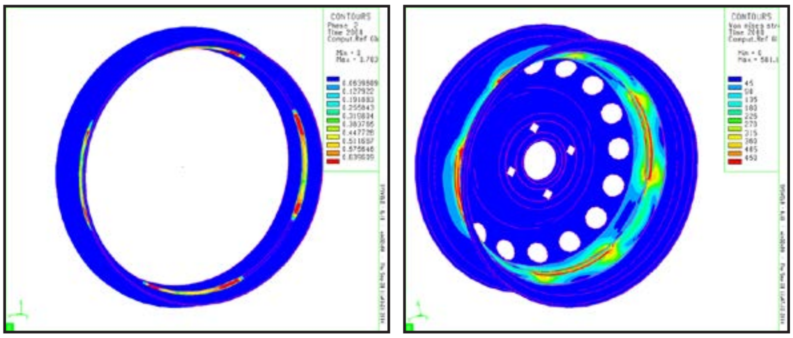

Fig. 17. Post-weld bainite distribution (left) and distribution of stresses 5 (right)

(Visual Weld) software application. The tests involved five analyses of various technological variants with various lengths and numbers of welded joints. The analyses were performed when preparing welding technologies and were treated as additional technology-related information. The results of simulations were used as the basis enabling the selection of the best technological variant, which was next tested in actual welding conditions.

Figure 16 presents examples of analysis results for two different variants. Also in this case, it is easily possible to notice the difference in strains and, primarily, in circularity between variant 1 and 5. In addition to strains of elements, the analysis also involved the distribution of metallurgical phases (distribution of bainite presented in Figure 17) and distribution of stresses after welding (Fig. 18).

Summary

Numerical analyses of welding processes are modern and effective tools enabling the control and optimisation of manufacturing processes in industrial practice as well as greatly facilitating design processes allowing flexible changes of technological processes, reducing the number of necessary experiments, decreasing costs and increasing quality, reliability and competiveness of manufactured welded structures. However, it should also be noted that the quality of performed numerical analyses is also affected by a relatively large number of input parameters (material data, description of boundary conditions etc.), which are not always easy to obtain and verify.

The primary objective of this study was to present advantages resulting from the use of welding process numerical simulations in the transport industry. Obviously, it is faster and easier to perform numerical simulations of proposed technological variants than to carry out actual welding experiments or make a finished product without testing, particularly when it comes to large welded structures.

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