

Modeling of welding distortions and flame straightening deformations

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Abstract – This paper presents the results of numerical simulation, used for the welding technology development of a 13 m long chassis made of high strength steel. Finite element modeling aimed to describe the welding distortions, and the deformations resulted by using flame straightening of the much critical edges of the product. In FEM work SimuFact and MARC software were used. Physical simulation was also applied in order to validate the FEM results. Simulations focused mainly to the effect of the welding direction along the free displacement edges.

I. INTRODUCTION

Finite element modeling (FEM) was used to determine the welding distortions occurring during the manufacturing process. Moreover, the possibilities of flame straightening was analyzed to eliminate the distortions caused by welding. For the numerical modeling, MARC and SimuFact software with welding module were used [1]. Beside the numerical simulations we also applied physical modeling. These physical models validated the results of numerical simulations with actual welding.

The simulation was related to one of the welding technology of a welded product of Pylon-94 Ltd. The product is a fusion welded, 13 long chassis. This is a large-scale structure with high-strength low-alloy steel (HSLA), base materials: S690QL, S890QL, S960QL. In our research S355J0 type steel was used for the modeling and validation tasks.

II. FUNDAMENTALS OF FLAME STRAIGHTENING

The flame [2–4], arc [5–6] and laser beam [7] straightening are based on the same principle: if the expansion of a heated material volume is restricted, however the material can shrink freely during cooling, the

result will be a plastic deformation surrounding the shrinking material volume [8]. The mechanism of straightening can be seen in Fig. 1 and schematic samples in Figure 2. [2]

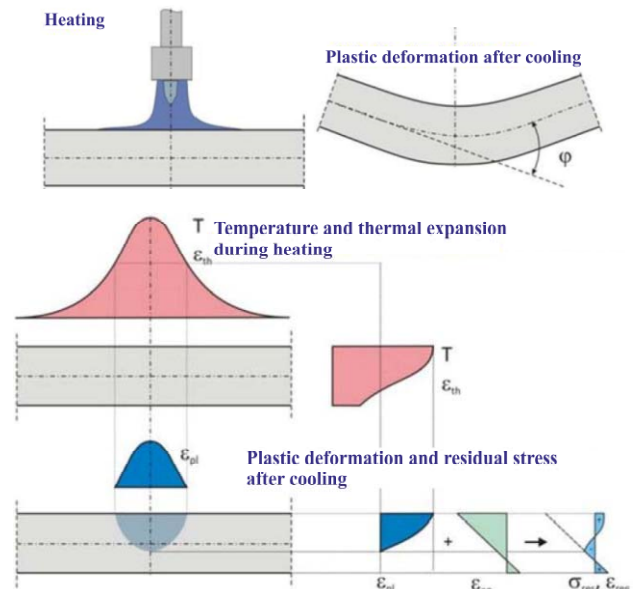


Figure 1. Thermal deformation (shrinkage) caused by a moving line-heat-source perpendicular to the plane. [2]

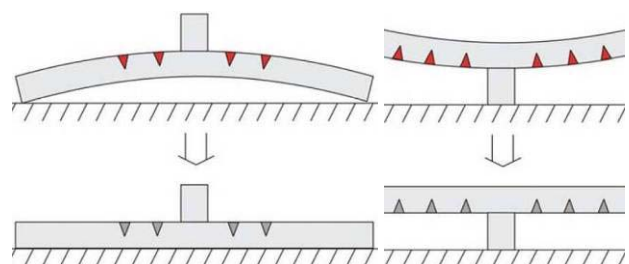


Figure 2. Schematic samples for straightening. [2]

III. MODELING OF FLAME STRAIGHTENING BY SIMUFACT WELDING SOFTWARE

The flame straightening of the chassis platform is necessary because of the distortions caused by welding. The numerical modeling attempted to show the plastic deformation in opposite direction, caused by the flame straightening. Fig 3. shows a simple example. Two edges of the plate are rigidly fixed. During welding, distortion happens on the free corner and its connected edges. The freely moving area is then heated up with a heat input similar to the flame straightening. The free corner of the plate moves in the desired direction along the axis Z, caused by the shrinkage during cooling, so the distortion from the original plane can be reduced or eliminated.

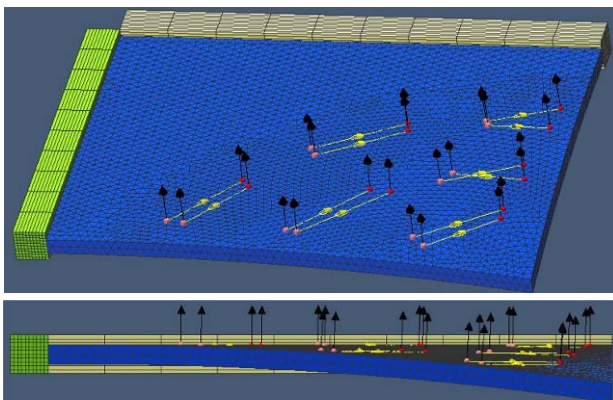


Figure 3. Model for the straightening of the distorted corner; heating is applied along the highlighted sections.

For the numerical modeling the following parameters were used: arc voltage 20 V; amperage 75 A; travel speed 120 cm/min, thermal efficiency 0,85; contact heat transfer coefficient 1000 W/(m²·K), heat transfer coefficient in air 20 W/(m²·K). The parameters of the heat source can be seen in Figure 4. The parameters for the geometrical modeling: thickness 10 mm; size 297×210 mm; previous distortion 30 mm (circular simplification).

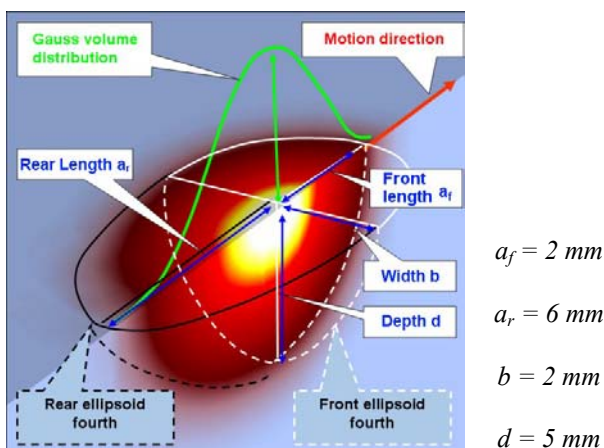


Figure 4. Parameters of the heat source in a simple thermal straightening model.

In Figure 5. the temperature gradient after 260 s and the distortion after 1000 s process times can be seen in a moment of the straightening process.

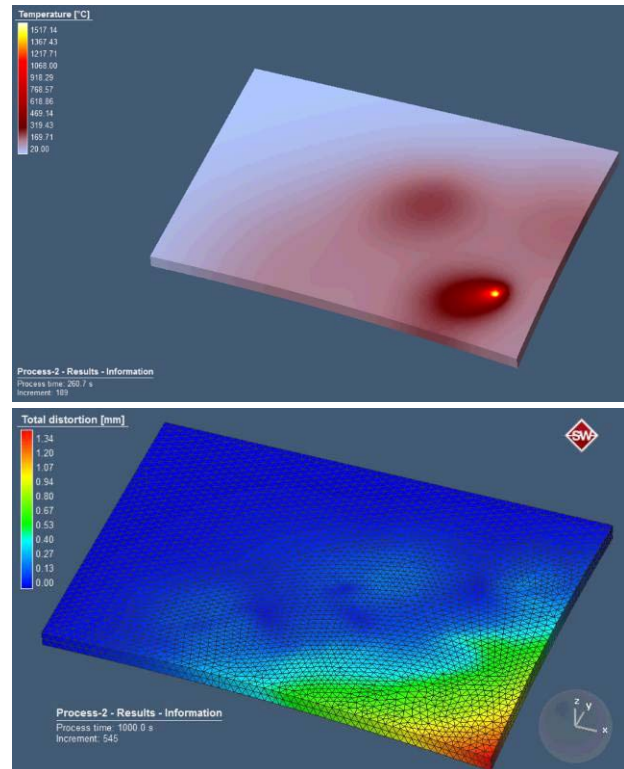


Figure 5. Simulation of straightening; temperature field after 260 s and the total distortion after 1000 s.

IV. SIMULATIONS FOR WELDING DISTORTIONS

A. Physical and numerical simulation for HSLA steel plate by using SimuFact software

For the validation of the numerical and physical simulations of welding, we used S355J0 HSLA grade plates with simplified geometry. In Fig 6 a HSLA plate can be seen, with a bead-on-plate MIG weld made with 1.0 mm diameter wire.

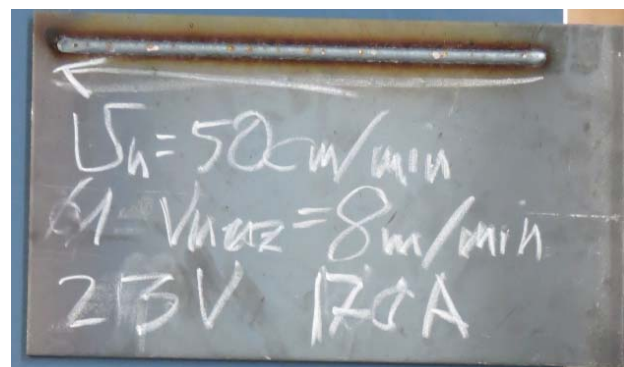
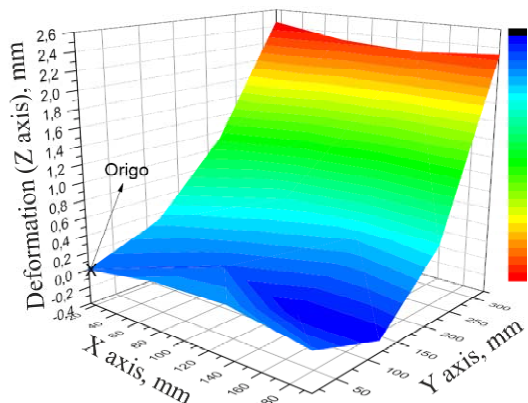


Figure 6. An example of the bead-on-plate weld on a HSLA steel.

The quantity of the welding distortion was measured by coordinate measuring machine: the values in the direction of Z axis can be seen in Figure 7, compared to the results of the simulations in Figure 8. The difference between the two methods is significant: the measured 2.9 mm total distortion was only 1.1 mm in SimuFact simulation.



Max. measured deformation is 2.908 mm

$U = 23,0 \text{ V}$; $I = 170 \text{ A}$; $v_{\text{wire}} = 8 \text{ m/min}$; $v_{\text{weld}} = 50 \text{ cm/min}$

Figure 7. Measured distortion field of the HSLA steel.

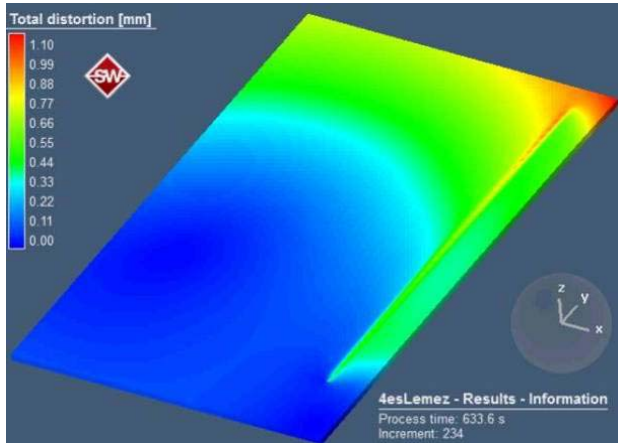
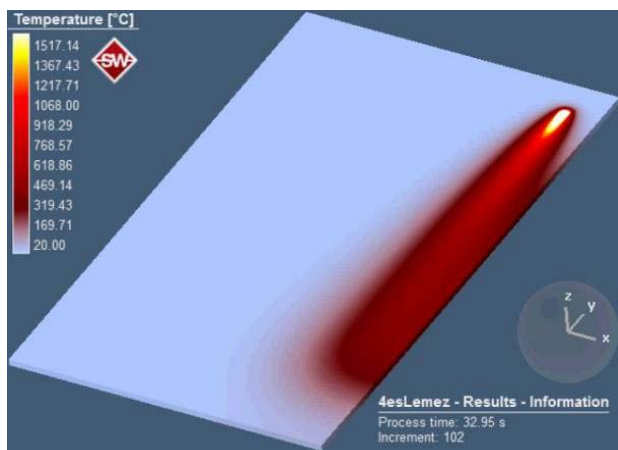


Figure 8. Distortion field of a HSLA steel plate. Temperature (top) and total distortions (bottom).

B. SimuFact and physical simulation for S960QL plate

The base material of the chassis welded by Pylon-94 Ltd. is a S960QL steel, thus the simulations were done on the same grade. One of the sample plates for physical simulations is seen in Fig. 9 that shows also the meshing and the results coming from SimuFact simulation. The shrinkage of plates resulted by welding process [9–13] was measured by coordinate measuring machine.

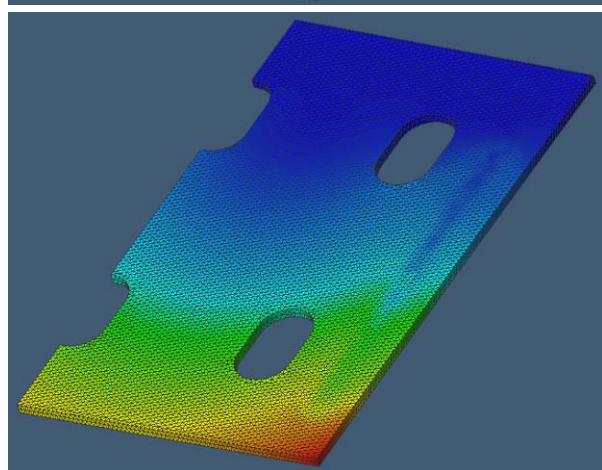
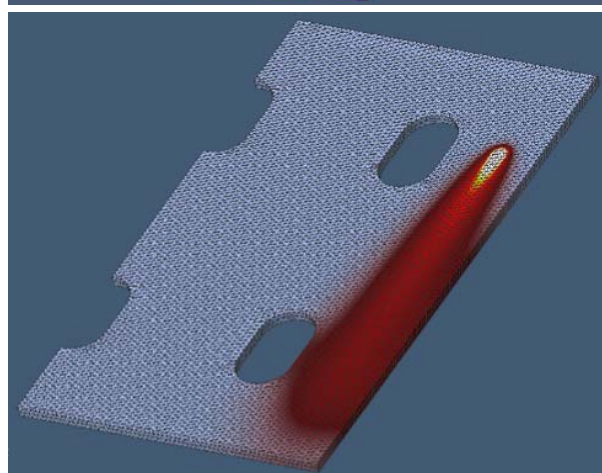
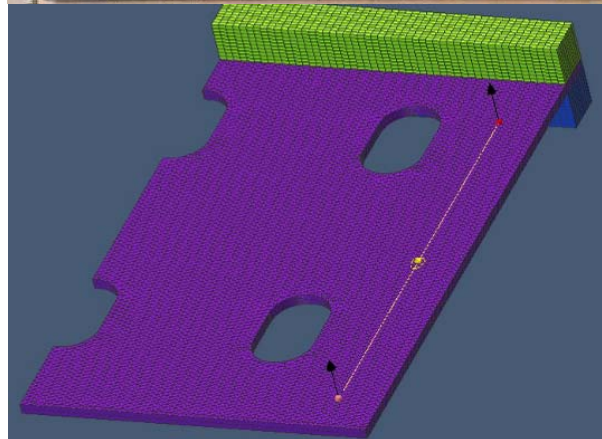


Figure 9. S960QL plate with a bead-on-plate weld; the maximal deflection after 3500 s is 1.23 mm.

The welding was done by a welding robot, the recorded technological variables are shown in Fig. 10; the welding speed was 50 cm/min.

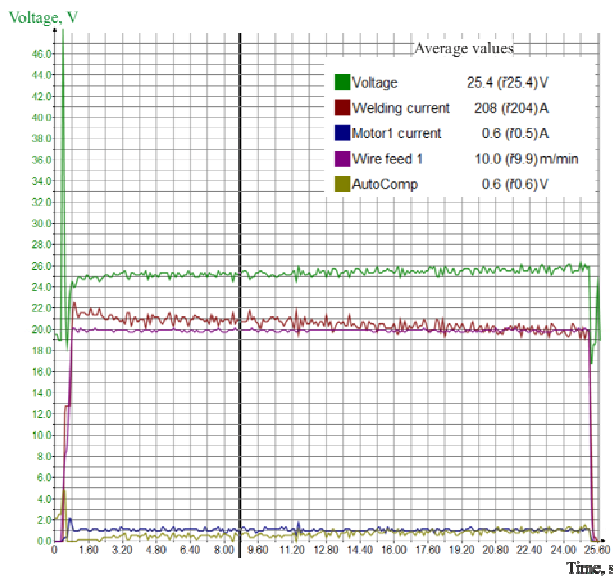


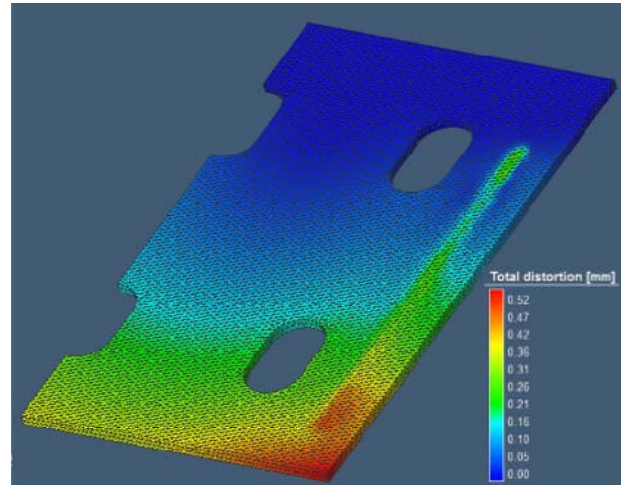
Figure 10. Recorded welding variables (plate no. 2) during welding S960QL steel plates

C. Distortions of S960QL plates calculated by SimuFact numerical simulations

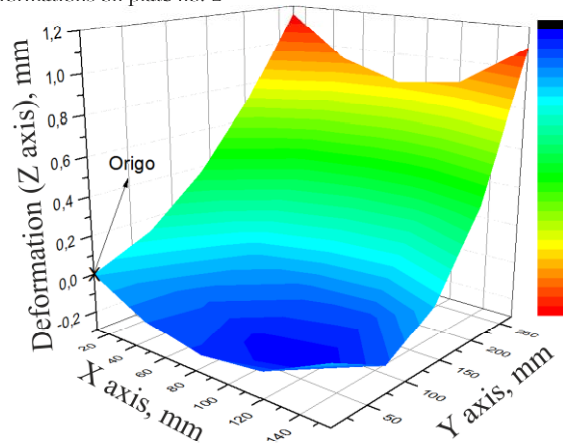
The parameters of the heat source, with the legends from Figure 2 were the following: $a_f = 2$ mm, $a_r = 4$ mm, $b = 3$ mm, $d = 3$ mm, the welding time during the welding / thermal straightening simulations was ~ 33 s and the cooling time was ~ 10 min. The runtime of the simulation was 37.5 h. The process was modeled with 1 h cooling time after welding. According to the scale, it is seen, the defined thermal conductivity of the welded plate is not right, the opposite side to the welding did not heat up. This definition of thermal conductivity in the software needed to be corrected, however because of the long runtime of the simulation (12 h 48 min in this case) the correction would consume a lot of time. These deviations caused the significant differences in the results between the coordinate measuring machine and the numerical simulations. The performed weld is seen in Fig. 11.



Figure 11. The sample plate no. 2 of S960QL steel.



Deformations on plate no. 2



Max. measured deformation is 1.428 mm

Figure 12. Distortions on plate no. 2. The total distortion is 0.520 mm in SimuFact simulation (top) and 1.428 mm measured in physical simulation (bottom).

With the modified model the results were closer to the measured, real distortions. The reason of this is probably the weld bead's shrinkage, which results in a high degree of distortion. The problem is that, the simulation software can only generate the weld bead geometry in case of corner welds, so a groove had to be inserted into the model. This modeling procedure is not feasible in case of numerous number of welds and complex geometries.

The usage of SimuFact software is even more difficult in case of meshing, because in case of using hexagonal elements the grooves simply disappear, so triangular elements had to be used. With the same average element size, more triangular elements had to be used for the same meshing, compared to hexagonal elements, which means even longer simulation runtime.

It is important to mention, the numerical simulation still not gave us the results measured during physical simulations (2.9 mm distortion), and the result only approach it in case of total distortion (1.38 mm). The error in the distortion along the Z axis is much bigger (0.62 mm).

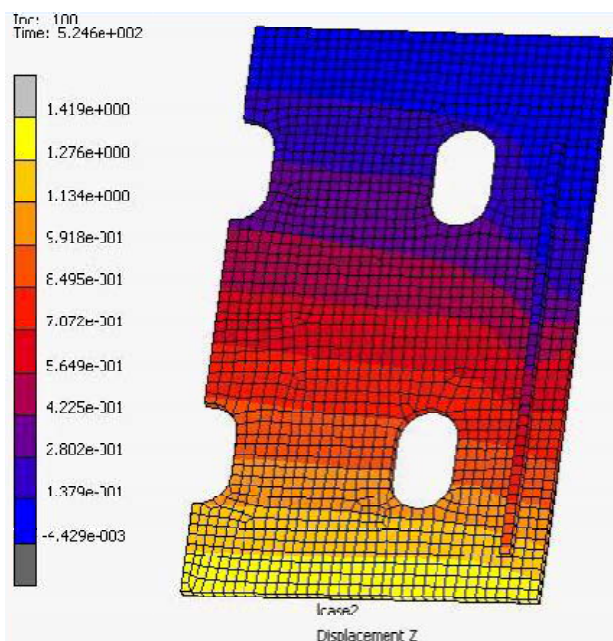
D. Distortions calculated by MARC numerical simulations for S960QL steel plates

In case of the finite element simulation by SimuFact the simulation runtime was very long and errors were found in the heat gradient calculations in case of the used heat source model. Because of these problems we continued the simulations in MARC software.

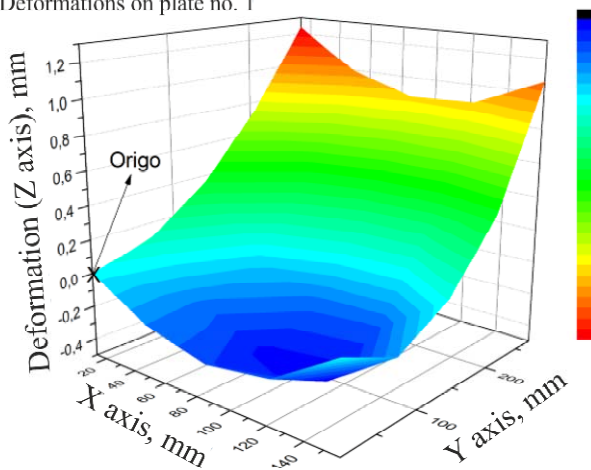
The runtime was radically shorter compared to SimuFact and the calculated distortion results were much closer to the measured after physical simulations. The distortions in the direction of axis Z calculated by the simulations can be seen on Fig. 14 and Fig. 16. Figure 15 shows the sample plate no.3 containing a two-directionally prepared bead on plate weld.



Figure 15. S960QL steel plate no. 3 containing the bead on plate weld.

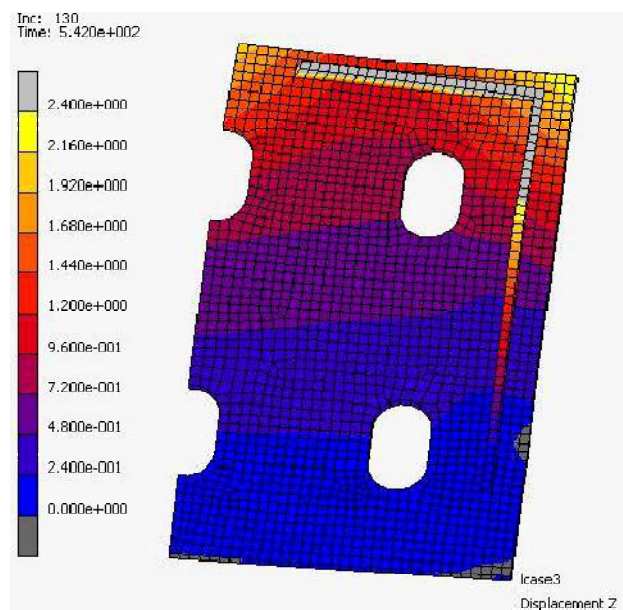


Deformations on plate no. 1

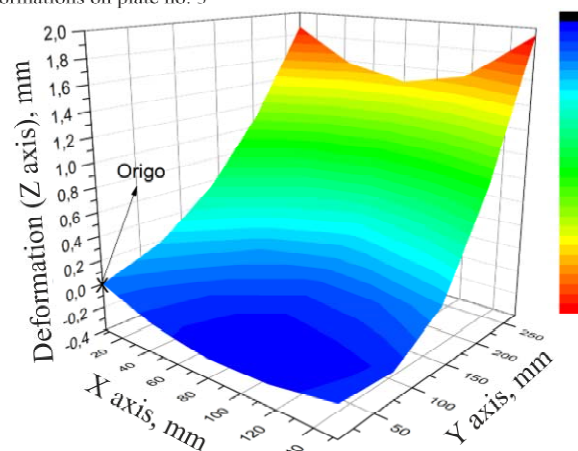


Max. measured deformation is 1.624 mm

Figure 14. Distortions on plate no. 1. The total distortion is 1.423 mm in MARC simulation (top) and 1.624 mm measured in physical simulation (bottom).



Deformations on plate no. 3



Max. measured deformation is 2.222 mm

Figure 16. Distortions on plate no. 31. The total distortion is 2.400 mm in MARC simulation (top) and 2.222 mm measured in physical simulation (bottom).

V. CONCLUSIONS OF THE SIMULATIONS

For validation a new model was created by Simufact Welding software, which gave us in more accurate results, however the simulation runtime increased to 37 h, and the accuracy is also uncertain because of the used geometry (grooves were applied to the plate in order to “compensate” weld beads). The validation in MARC software gave us more accurate results, the runtime is 30 min, after the model is prepared. In SimuFact we increased the extent of the heat source 1.5 times, however the maximum distortion in axis Z was increased by only 0.02 mm.

On the base of these experiences, it was performed the simplified numerical simulation of a large welded structure – a long truck chassis [14] – at the PYLON-94 company that product is seen in Fig. 17.

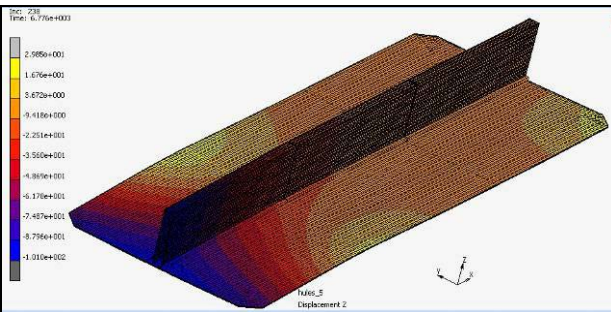
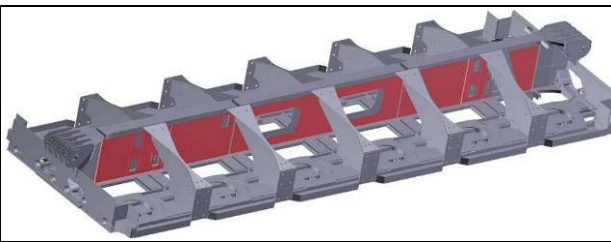


Figure 17. The GHF chassis welded at PYLON-94 Ltd., and the simplified model for shrinkages.

VI. ACKNOWLEDGEMENTS

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