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Distortion of Circumferential Welds of Cylindrical Shells with Respect to Tacking and Welding Sequence

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"The term "weld shrinkage" conjures up a mental image of a molten bead solidification and cooling, and pulling in the adjacent plate edges as it contracts. Deeper consideration reveals that this is not the case." This citation in respect of transverse shrinkage from Leggatt [1] refers to the area next to the weld. Its elongation and contraction during the heating and cooling cycle are mainly responsible for welding distortions. This will be demonstrated on thin circumferential welded cylindrical shells. The investigation was performed with cylinders with wall thicknesses from 1 mm to 4 mm and R/t-ratio between radius R and wall thickness t from 100 to 1600.

Tacking leads to welding distortions which remain until the final welding. The influence of several tacking distances will be discussed and it will be shown that tacking determinates the circumferential wave frequency of distortion.

Start and end points of circumferential welds lead to maximal distortions. Therefore, it has an impact whether two welds start, two welds end or one weld starts and one weld ends in the considered start point. The influence of these weld sequences on the welding distortion will be explained.

1 Introduction

Strains in flat sheets lead at first to distortions in plane. This behavior differs to the one of cylindrical shells where in plane strains create distortions in radial direction orthogonal to the shell surface. Rethmeier et. al. [2,3] investigated distortions and distortion minimization of a laser beam welded injection valve. The considered valve has a small R/t-ratio. Rethmeier worked out, that radial distortion is minimized, when the volume of the welding bead is reduced and the welding sequence becomes rotationally symmetrical.

In contrast to Rethmeiers investigation the influence of weld-distortion in respect to taking and welding sequences can be visualised more evidently at thin walled cylinders. For the investigation dealed in this paper all decisive effects for welding simulation are taken into account: a changing of the microstructure with transformation effects, adding filler-material, strain hardening and the removal of the material history near by the melting temperature. Loose [4] pointed out, that especially phase transformation strains, realistic consideration of the filler material and the consideration of a transient heat source has a significant influence on the calculated distortion.

The authors used the finite element program Sysweld, which allows a realistic simulation. Numerical calculations were performed on scientific supercomputing HP XC4000 at computing center der Universität Karlsruhe.

2 Development of distortion circumferential welded cylindrical shells

Generally, shrinking of the weld bead is considered as the main cause for distortion [1]. But this behavior alone does not explain the complex distortion envelopment of welded cylindrical shells. This is shown for a welded cylinder of the steel grade S355 with a radius R = 400 mm, the wall thickness t = 4 mm, the height L = 800 mm, four tacks and one circumferential weld at the equator.

A real welding procedure starts with fixing tack welds. At the first tack the radial distortion is inwards and between the tacks, the radial distortions are outwards. This is caused by the mechanical behavior of cylindrical shells. Radial distortion inwards at one point occurs and radial distortion outwards next to it. Additionally, in this part occurs a sharp bend between the upper and lower cylinder half, caused by the gap.

The welding bead is the hottest area with the lowest stiffness. During heating the weld area is elongated radially outwards. In the boundary between the two halves of the cylinder in the not yet welded area and the area of welding pool there is no bending stiffness tangential in meridian direction. The tangential rotation r_x is free, so in the middle of weld a sharp bend occurs. **Figure 2** and **figure 4** show this situation.

The ongoing procedure is meanly determinated by elongation and contraction of the areas beside the weld and the continuous varying stiffness of the system during the welding process. After solidifying of the meltpool the sharp bend between the upper and lower cylinder halves remains. The radial distortion inwards beside the weld is larger than in the middle of the weld (**figure 3** and 4).

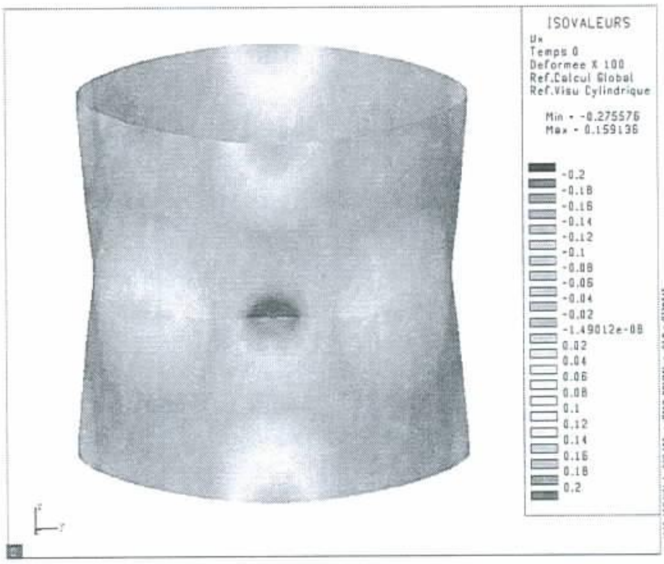

Figure 1: Cylinder R = 400, t = 4, Distortion after tacking

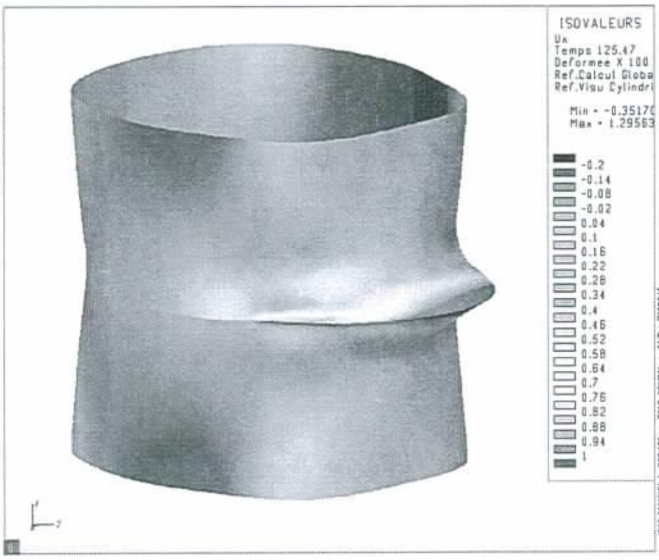

Figure 2: Cylinder R = 400, t = 4, Distortion after 125 s welding

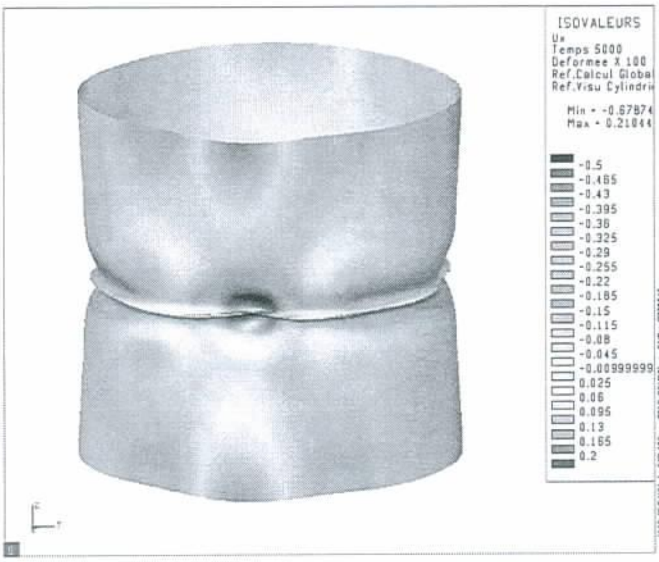

Figure 3: Cylinder R = 400, t = 4, Distortion after welding and cooling

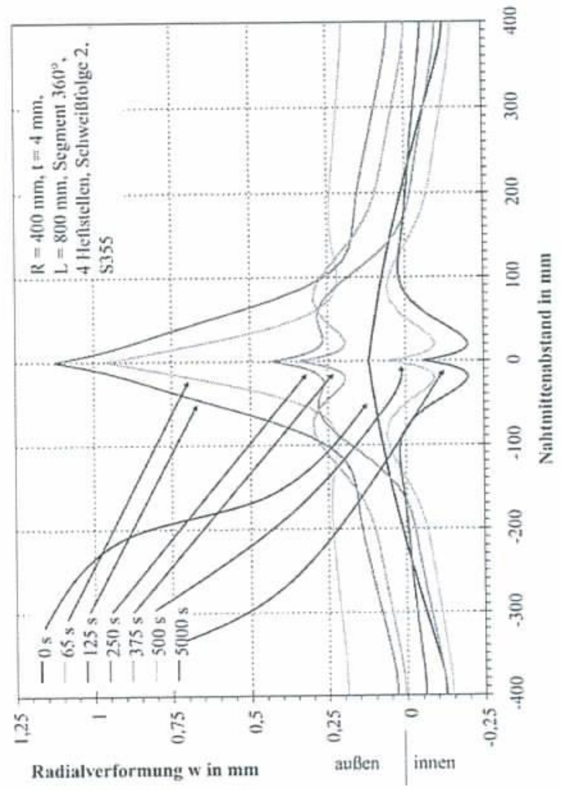

Figure 4: Cylinder R = 400 mm, t = 4, Distortion at meridian after several time-steps

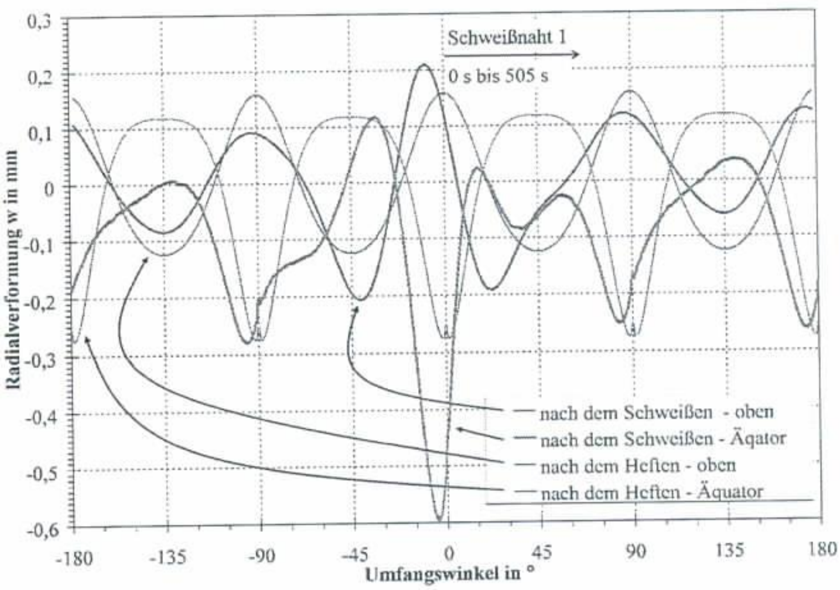

Figure 5: Distortion at equator after tacking and after welding

In **figure** 4 the radial distortion at meridian 45° after start of weld is visualized for several time steps. After 65 s the heat source reached this meridian. The maximum of distortion outwards is reached, when the heat source has passed the meridian. The period of cooling follows. Finally, the procedure ends at time step 5000 s with a typical distortion curve. The characteristic of the curve is validated by Banke [5] who measured radial distortions of circumferential welded cylinder. Figure 6 shows the comparison between the measured distortion by Banke [5] and calculated distortion by Loose [4].

The characteristic of distortion differs at the start and end points of weld. At the start point of weld the distortion is outwards. Without a connecting weld the stiffness of cylinders is low and therefore, the radial distortions outwards during heating are larger than in the following seam (**figure** 3 and 5).

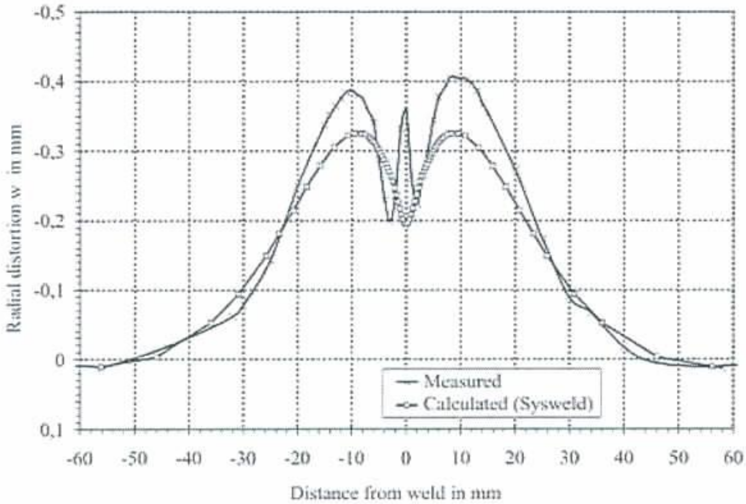

Figure 6: Measured [5] and calculated [4] distortion of circumferential weld of cylinder

At the end of weld the heat source hits the start of weld meanwhile it has cooled down. This leads to additional constraints which have not existed before. The weld pool is cooling down without moving. Therefore, the maximum inwards distortions increase. At the same time the areas next to the seam were pushed outwards (**figure** 3 and **figure** 5).

The distortion outwards is intensified by transformation strains resulting from an expanding volume. These strains are counteracting to the shrinking strains resulting from cooling.

Figure 5 shows the correlation between the distortions after tacking and distortions after welding. Tacking determine the final distorted shape after welding.

3 Tacking

It could be shown that the number of tacks determines the circumferential wave frequency of distortion. In **figure 7** the distortions at the equator are visualized for the following described cylinders made of S355 and for following tack distances:

- R = 400 mm, t = 4 mm tack distance 314 mm = 45° and 628 mm = 90°
- R = 800 mm, t = 1 mm, tack distance 157 mm = 11,25° and 314 mm = 22,5°

With an increasing number of tacks the radial distortions decrease. This behavior can be clearly seen in a comparison of different tack distances of the two cylinders (**figure** 7). The scaled distortion w/t depends on the R/t-ratio and it is larger for cylinder with greater slendernesses.

To estimate the influence of tacks simulations with and without taking are performed. In **figure 8** the results for a cylinder segment of 45°, R = 400 mm and t = 4 mm are shown.

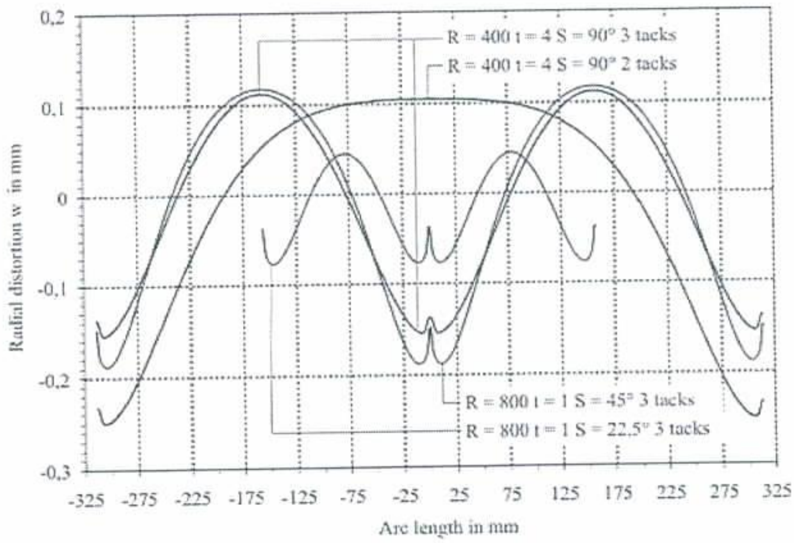

Figure 7: Radial distortion at equator after tacking, several tack distances

The comparison of the distortion at the equator after tacking, after welding with tacking and after welding without tacking indicates that tacking leads to an greater distortion amplitude. With respect to the fact, that the distortions after tacking decrease if the number of tacks increases, the case as much tacks as possible is the border case to no tacks.

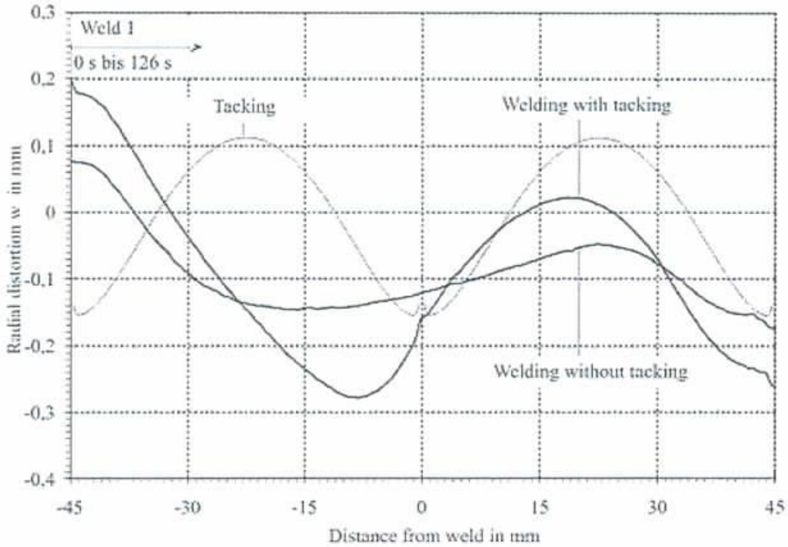

Figure 8: Radial distortion at equator after tacking, after welding with and without tacking

4 Welding sequences

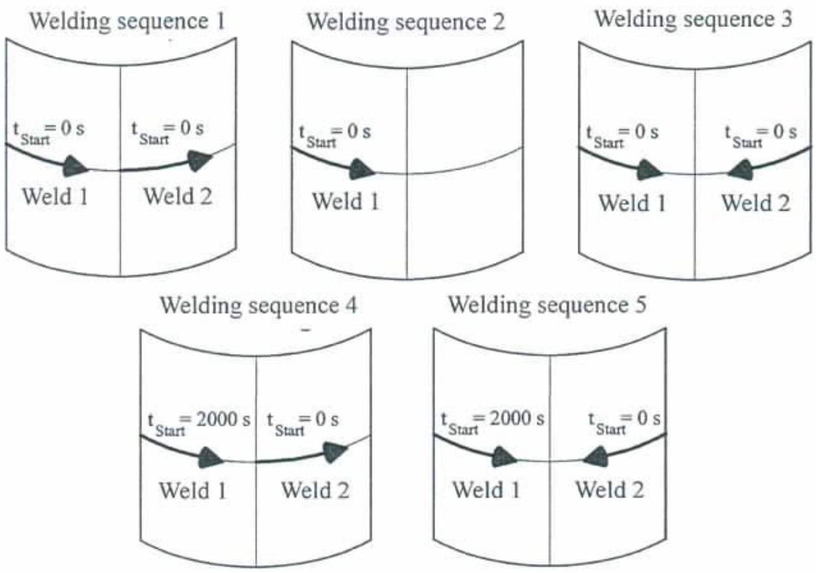

Figure 9: Investigated welding sequences for cylinder segments

Figure 9 shows the welding sequences which are taken into account for investigation. The analyses are performed on segments with symmetrical boundary conditions. These boundary conditions are used for thermal and structural analysis. A heat source starting at the boundary edge means two heat sources are starting and disperse. In the same manner, a heat source ending at boundary means two heat sources are converging and end in one point. These effects are caused by symmetry.

Radial distortions at the equator are shown in figure 9 and at meridian -6,8° in **figure 10** for a cylinder segment of 90° with R = 800 mm, t = 4 mm. All five welding sequences indicate that the start of weld is associated with radial distortions outwards and the end of weld is associated with radial distortions inwards. The considered welding sequences contain the cases start - start, end - end (sequence 2, 3, 5) and start - end (sequence 1, 4). Further the two cases that the heat sources hit at same time (sequence 2, 3) and that the heat sources hit with time delay (sequence 1, 4, 5) exist.

Weld sequence 2 and 3 are similar, but the number of welds in circumferential direction is double for sequence 3 while the number of tacks is the same. For weld sequence 3 the weld starts at the tack and ends at the next tack, which increases the distortion of tacking. The circumferential wave at weld sequence 2 is caused by the distortion of tacking.

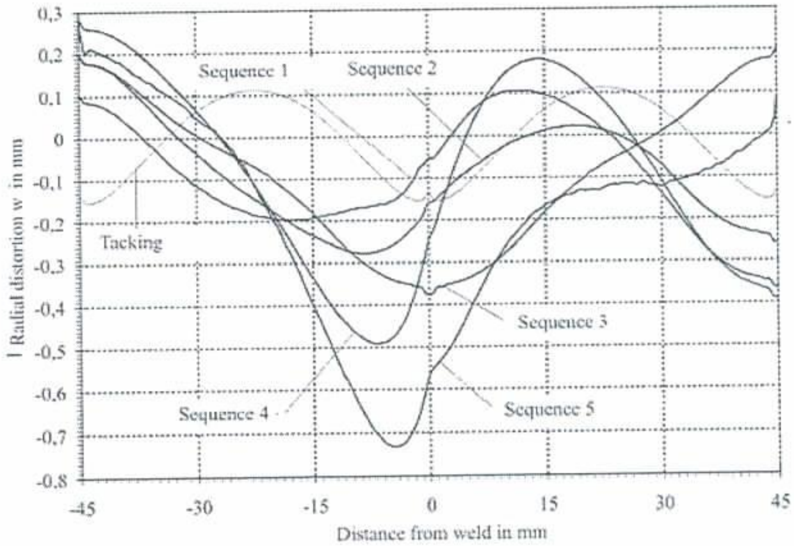

Figure 10: Radial distortion at equator for cylinder R = 400 mm t = 4 mm and different welding sequences

If two heat sources hit not at same time but with time delay, the radial distortion increases. This is observable in comparison between weld sequence 3 (same time) and 5 (time delay). The time delay between solidifying start of the weld and the arriving of the heat source in middle of the cylinder segment is for weld sequence 1 shorter than for weld sequence 4. This means, temperature at the end of the first weld is higher in sequence 4 then in sequence 1. Hence, radial distortions inwards are greater in weld sequence 4.

Weld sequence 4 compared with weld sequence 5 indicates, that radial distortion inwards increases if the end of the weld hits the end of the cooled weld (5) instead of the start of the cooled weld (4) (**figure 11**).

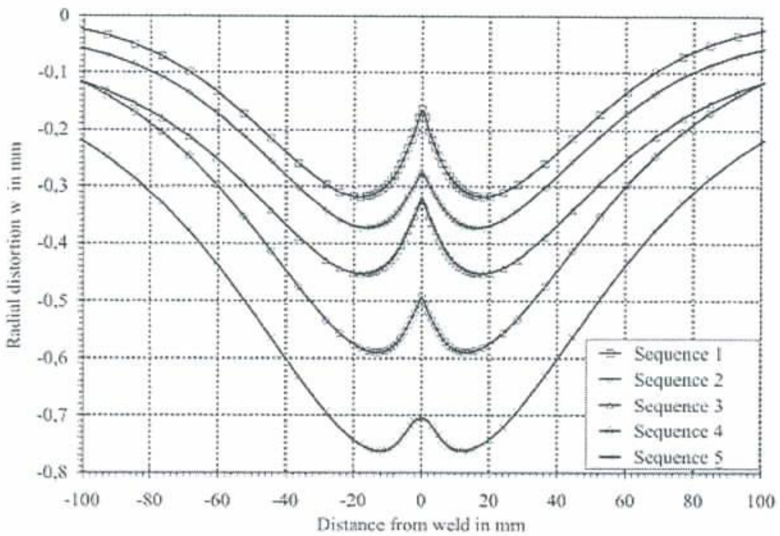

Figure 11: Radial distortion at meridian -6,8° for cylinder R = 400 mm t = 4 mm and different welding sequences

5 Conclusion

This paper refers to investigations in single layered circumferential welds of cylindrical shells. To describe the evolution of the envelopment of the weld distortion the whole process - tacking, heating, cooling and the transient heat source - has to be considered to predict a realistic shape.

Taking determine the first distortions and by this the qualitative shape of the remaining distortions after welding. So, the higher the number of tacks is, the less is the radial distortion.

At the start of a weld the radial distortions are always outwards. In contrast to that, the distortions at the end of the weld are inwards and increase in the following order:

- The weld ends at the heated start of a second weld -> -> (lowest distortion)
- The weld ends at a hot end of second weld, ending at same time -> <-
- The weld ends at a cold start of a second weld -> ->
- The weld ends at a cold end of a second weld with a time delay -> <-(highest distortion)

6 References

[1] Leggatt, H. L.: Distortion in Welded Steel Plates, University of Cambridge, Diss., 1980

[2] Rethmeier, M.; Voß, O.; Decker, I.; Wohlfahrt, H.; Kocik, R.: Minimierung der Temperaturbelastung und des Verzugs an Einspritzventilen mit Hilfe der Methode der finiten Elemente. In: Schweißen und Schneiden, 52 (2000) Nr 8, pp 446-471

[3] Rethmeier, M.; Stadtaus, M.; Michailov, V.; Wohlfahrt, H.: Numerical calculation of temperature load and distortion during welding of circumferential weld seams. In: Cerjak, H. (ed.): Mathematical modelling of weld phenomena 6, Maney, pp 685-701

[4] Loose, T.: Einfluß des transienten Schweißvorganges auf Verzug, Eigenspannungen und Stabilitätsverhalten axial gedrückter Kreiszylinderschalen aus Stahl, Universität Karlsruhe, Diss. 2007.- Online-Resource

[5] Banke, F.; Schmied, J.; Schulz, U.: Der Einfluss von Schweißeigenspannungen und Schweißverformungen auf das Beulverhalten von axialgedrückten Zylinderschalen. In: Stahlbau 72 (2003), Nr. 2, pp 91-101