THE EFFECT OF RESIDUAL AND SERVICE STRESSES SUPERPOSITION ON THE STRESS STATE OF THE PRESSURE VESSEL CIRCULAR WELDMENT

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The investigation results on the superposition of the residual and service stresses effect on the stress state of a tank-wagon circular welded seam are presented in this paper. The results show that superposition of the residual and service stresses causes the exceeding of the allowable stress value in the circular welded seam.

It is concluded, on the base of the investigation results, that superposition may induce transversal cracks, thus reducing tank-wagon service safety.

INTRODUCTION

The occurrence of transversal cracks in circular welded joints of tank-wagon, produced of StE500 steel (nominal yield strength 500 MPa) required detailed stress analysis, including residual stress effect.

The research of the residual stresses effect is of a great significance in evaluating of the welded structure service safety. Superposition of the residual and service stresses may cause the exceeding of the allowed stress value (σ_a) and even yield strength in the critical points of the welded constructions. Those critical points are, as1 a rule, in the welded joint axis, according to Sabo (1,2,3), where the residual (tensile) stress reaches the highest value.

The objectives of the research were experimental determination of residual stresses in the circular welded seam and the defining of the residual and service stresses superposition effect on the total stress state. The circular welded seam was chosen for analyzing because of its higher level of the residual stress, compared with longitudinal welded joint.

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DETERMINATION OF RESIDUAL STRESSES IN THE CIRCULAR WELDED JOINT

The residual stress state in tank-wagon circular welded joint was defined by element cutting measurement, according to Sabo (4). Measuring bases, 25 mm long, were marked on inner wall side. Nine measuring bases transversal to the circular welded joint were marked in both, x and y - directions as it is shown in the Figure 1. Lengths of the measuring bases were measured by comparator with accuracy of 0.001 mm in as-welded structure. Indications of the comparator were marked by x_1 and y_1. In order to relax the residual stresses, plates 36x36 mm were cut after measuring the basis lengths (Fig. 1). The repeated measuring on cut plates had been performed and the indications of the comparator were signed as x_2 and y_2. Residual (unit) component strain values of the measuring elements were calculated as:

$$\varepsilon_x = \frac{x_1 - x_2}{L} \quad ; \quad \varepsilon_y = \frac{y_1 - y_2}{L} \tag{1}$$

The residual stress components in elements were calculated using relations:

$$\sigma_{rx} = \frac{E}{1-\nu^2}\left(\varepsilon_x + \nu \cdot \varepsilon_y\right) \quad ; \quad \sigma_{ry} = \frac{E}{1-\nu^2}\left(\varepsilon_y + \nu \cdot \varepsilon_x\right) \tag{2}$$

Residual stress components values in measuring elements are tabulated in Table 1 and their distribution is presented in Fig. 2.

TABLE 1 - Calculated residual stress components

Measuring element	1	2	3	4	5	6	7	8	9
σ_{rx} (MPa)	+255	-189	-34	-23	-32	-146	-22	-13	-7
σ_{ry} (MPa)	-95	-144	-28	+60	+32	-114	+10	+63	+57

SUPERPOSITION OF RESIDUAL AND SERVICE STRESSES

According to Documentation of tank-wagon 1077, capacity 95 m^3, assigned for ammonia stacking, calculated longitudinal and transversal service stresses are (5):

$$\sigma_{ex} = +234 \text{ MPa} \quad ; \quad \sigma_{ey} = +127 \text{ MPa}.$$

Total stress components obtained by superposition of residual and service stresses are:

$$\sigma_{tex} = \sigma_{rx} + \sigma_{ex} \qquad \sigma_{tey} = \sigma_{ry} + \sigma_{ey} \tag{3}$$

Table 2 shows calculated values of total stress components in the measuring elements and their distribution is presented in Fig.3.

TABLE 2 - Calculated values of total stress components in the measuring elements as results of residual and service stresses superposition

Measuring element	1	2	3	4	5	6	7	8	9
σ_{tex} (MPa)	+489	+45	+200	+211	+202	+88	+212	+221	+227
σ_{tey} (MPa)	+32	-17	+99	+189	+159	+13	+137	+190	+184

SUPERPOSITION OF RESIDUAL AND TEST STRESSES

According to Documentation of tank-wagon, (5), proof test pressure of 26 bar produces stress components:

$$\sigma_{px} = +297 \text{ MPa} \qquad \sigma_{py} = +149 \text{ MPa.}$$

Total values of acting stresses during proof test pressurizing are obtained by superposition of residual and test stresses:

$$\sigma_{tpx} = \sigma_{rx} + \sigma_{px} \qquad \sigma_{tpy} = \sigma_{ry} + \sigma_{py} \tag{4}$$

Calculated total values of stress components in the measuring elements, produced as result of residual and test stress components superposition are given in Table 3 and their distribution is presented in Fig.4.

TABLE 3 - Calculated values of total stress components during proof test pressurizing

Measuring element	1	2	3	4	5	6	7	8	9
σ_{tpx} (MPa)	+552	+108	+263	+274	+265	+151	+275	+284	+209
σ_{tpy} (MPa)	+54	+5	+121	+209	+181	+35	+159	+212	+206

SIMULTANEOUS EFFECT OF PROOF TEST PRESSURE AND RESIDUAL STRESSES

The importance of residual stresses for tank-wagon service safety and crack occurrence in welded joints can be evaluated by their distribution and values, as presented in Fig. 2 - 4. High level of residual stresses, close to the value of allowable stress σ_a, indicated that their presence can cause cracking in welded joint when service loads are applied. The critical situation was found to be during proof test pressurizing, when total stress, obtained by superposition of acting stress and residual stress, exceeded yield strength (Fig.4).

ANALYSIS OF RESULTS

The analysis of the total stress components distribution in the circular welded joint caused by the superposition of the residual and service stresses (Fig.3) proved that the allowable stress at the measuring element 1 (the welded seam axis) was exceeded (σ_{tex1} = 489 MPa > σ_a = 330 MPa).

The analysis of the total stress components distribution of the circular welded seam ensued from the residual and test stress superposition (Fig.4) approves that both the allowable stress and the nominal yield strength on the measuring element 1 (the welded seam axis) were exceeded (σ_{tpx1}=552 MPa > R_e=500 MPa > σ_a=330 MPa).

The total stress, higher than the yield strength value may induce the transversal cracks in the circular welded joint, according to Kakaš et al (6), what was approved in most cases of the tank-wagon examinations.

CONCLUSION

Based on the producers data (5), the tank-wagon was designed for service stress with safety factor K = σ_a/σ_{ex} = 330/234 = 1.41. Safety factor for the measuring element 1 (the axis of the weld) is significantly lower, even below unity (K=σ_a/σ_{tex1}=330/489=0.67).

Based on the same data (5), the tank-wagon was designed for test stress with safety factor K = σ_a/σ_{px} = 330/297 = 1.11. Safety factor for the measuring element 1 (the axis of the weld) is again significantly lower than required (K = σ_a/σ_{tpx1} = 330/552 = 0.60).

Therefore, it should be recommended to perform the heat treatment of tank-wagon in order to decrease significantly the residual stress values.

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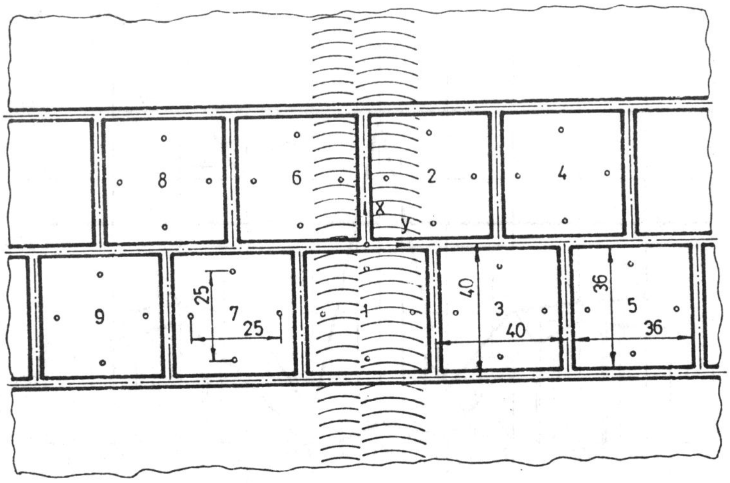

Figure 1 Disposition of the measuring bases.

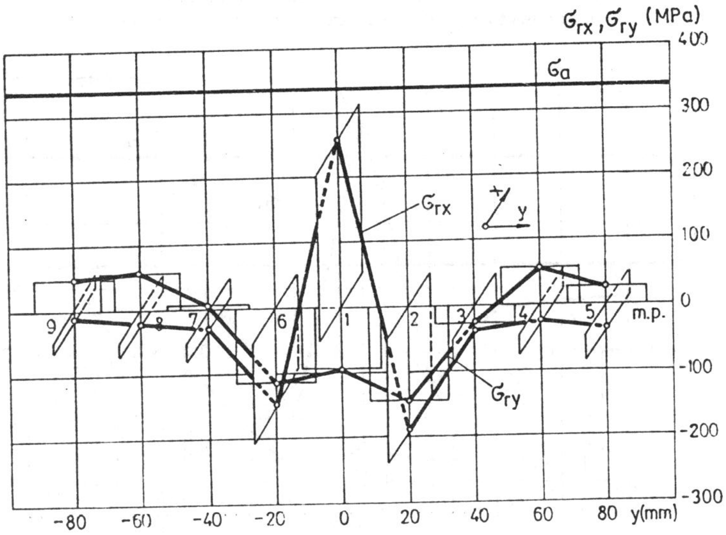

Figure 2 Distribution of residual stress components.

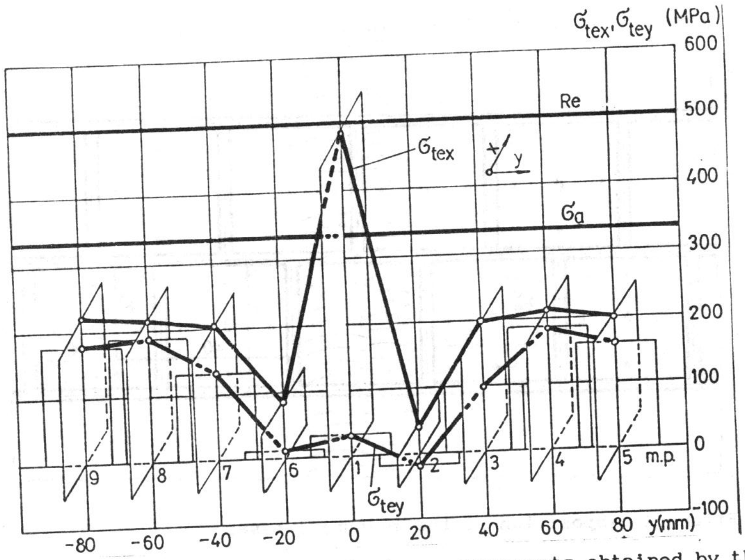

Figure 3 Distribution of total stress components obtained by the superposition of residual and service stresses.

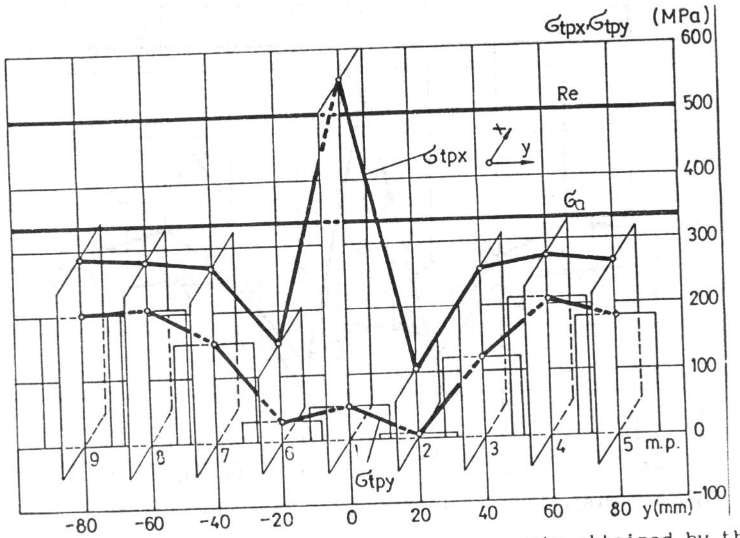

Figure 4 Distribution of total stress components obtained by the superposition of residual and test stresses.