BULETINUL Universităţii Petrol – Gaze din Ploieşti	Vol. LXII No. 2/2010	103 – 112	Seria Tehnică

Researches on the Feasibility of Convex Corner Welding

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Abstract

Feasibility of welded structures has always been of great concern for the specialists in this field. The shape of the welding bead, in the case of corner welds, is of great importance, especially for those fatigue non-resistant welded structures, considering stress concentrators of the welding line. Our research aims at highlighting the danger for convex corner welded structures to fail when fatigued as well as at underlining the need to rehabilitate such structures. Thus, concave corner welds easily applied onto pipes are recommended, as well as the elimination of irregularities resulted from repairs, measures meant to increase fatigue resistance of welded structures. The main benefits will be an enhanced feasibility of welded structures as well as a reduction in the number of check-ups regarding the repair or replacement of cracked welded structures.

Key words: *feasibility, convex corner welds, concave corner welds, irregularities, fatigue*

Generalities

Background

The present paper is based on previous researches and articles published by Prof. Ph.D Eng. Mircea D. Ratiu together with other researchers who are of the opinion that dynamically exposed convex corner welds contain cracks of different sizes and that is why rehabilitation is required (1). By factors influencing the feasibility of welding beads we actually mean fatigue resistant factors. There are numerous welded structures likely to be exposed to stress in the course of time (bridges, power installations, etc.). Research has proved that such structures crack under stress concentrations lower than the tear resistance of the static materials they are made up of; the higher the stress concentration the sooner the fracture. The functioning time, that is the number of stress variation cycles a component is resistant to depend on its maximum stress level. This is graphically shown by an experimentally fixed curve (Wohler's curve) - figure 1**.**

Such a curve in N-σ (N-τ) system shows that the higher the number of cycles N any component is resistant to, the lower the stress σ. For a certain value σ_0 of overall stress, the component resists to numerous, countless reinitializing cycles. This value σ_0 stands for fatigue resistance. Research has shown that ferrous metals resistant to 10^7 variation cycles of the overall stress never crack. Hence, for such materials, fatigue resistance is defined according to $N_B=10^7$.

Fatigue resistance of welded joints is much lower than that of the material due to the overall welding stress concentration. Internal and external concentrators differ from the structure itself. Unlike the material, that may display lamination defects, the weld displays defects typical of molded materials. Internal concentrators are the result of pores of gases, the roots of the welds and joints of electrodes change, in the case of manual welding. External concentrators can be seen at the ends of the welding line as well as in the junction point of the welding and base material. The concentrators impact can be lowered or even eliminated by appropriate welding of the respective junctions. The concentration coefficient value is influenced by various factors typical of welded joints: the base material, additional material, the welding procedure used, internal and external welding defects, the junction form, the welding bead form, recurring stress concentrations, etc. The weld may bring about the lower fatigue resistance of the component even if the welding is of high quality and does not modify the strength lines flow of the respective component.

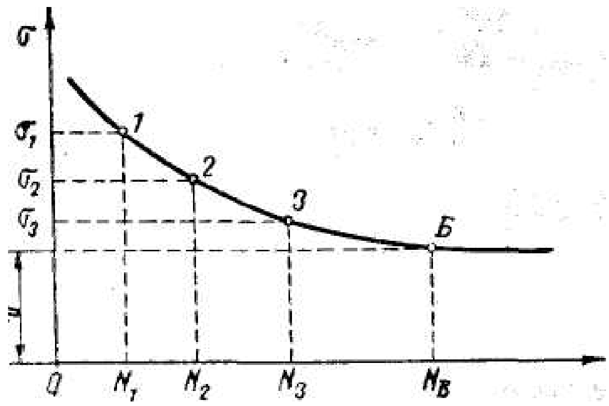
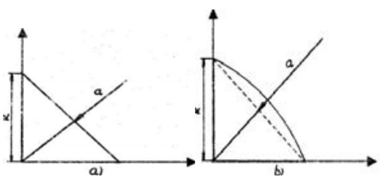


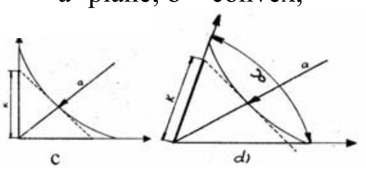
Fig. 1. Wohler's curve

The influence of the weld bead form upon corner welds feasibility

The stress, applied upon corner joint welds are complex due to: eccentricity of the charge applied, weld bead form and fracture impact comes in the form of shear and compressive stress. There is no continuous uniform stress distribution along the throat and leg of a corner welding, moreover, it varies in weld length too. The bead thickness is considered equal to the height of the isosceles triangle inscribed in the transversal section of the weld bead – figure 2 (2).



a- plane; b – convex,



c – concave, d- sharp concave

Fig. 2. Various bead forms of corner joint welding

As shown in figure 2, according to k/a ratio, corner weld beads can be:

- plane, if k/a ≈2 (figure 2.a),
- convex, if k/a > 2 (figure 2.b),
- concave, if k/a < 2 (figure 2 c and d).

The convex form of the weld beads triggers the concentration of strength lines within the material, hence, the use of concave weld beads is recommended, mainly for shock-fatigue exposed structures. It is worth mentioning that, in the case of concave weld beads, there must be an optimum, since an increase in concavity brings about an increase in residual stress.

According to some Italian norms, the conditions for the realization of a quality weld bead worsen provided the angle α falls under 70. Research, carried out by Professor Ph.D Eng.

Mircea D. Ratiu, has shown that fractures in corner welds occur more frequently during service procedures within power plants (3). This is due to fatigue stress resulting from giga cyclic stress (over 10^7 reloading cycles). There was no lifelong fatigue duration for such structures (according to Wohler's curve). The crack occurred after 1-3 years of continuous vibrations with a 1 cycle/minute frequency. Corner welds are exposed to critical stress of the welding root and finger, corresponding to possible geometric discontinuities: incomplete root, convex form of the weld bead, strength flow concentration in the welding finger. Dissemination of dynamic tests onto unilateral corner welds [4] (category E indicated in AWS D1.1 and ASME Boiler and Pressure Vessel Code)- have shown a continuous decrease in fatigue resistance by 3 ksi per 100 mega cycles. The use capacity of corner welds under vibrations has led to the control and rehabilitation of root completion, convex surface into concave and smooth pass of the welding finger between the additional and base material. Consequently, Wohler's curve is no longer valid in case of fatigue giga cyclic stress of convex corner welds. After 10^7 cycles, corner welds yield. In conclusion, corner convex welds must be rehabilitated. Existent corner welds must be reinforced by means of concave corner welds starting from the fingers to the existent welding.

Exprimental Research

Generalities

In order to prove the need to rehabilitate convex corner welds, there must be examined the influence of the weld bead form (convex and concave, respectively) upon stress and irregularities occurred in the bead and surrounding areas that frequently lead to fractures worsening the feasibility of the welded structure. In this sense, we shall determine the stress difference and irregularities, respectively, occurring during two T-type welding samples, one with a convex bead and the other with a concave one, both welded by means of an SE procedure with a 6018 (Supertit Fin) 3.25 -type electrode, under the same welding conditions and with equal linear current.

MB presentation

The T-type welding sample is based on a S235JR base material. The chemical composition for the steel used is shown in table 1, and the mechanical characteristics are indicated in table 2. This steel frame is used for tanks and recipients under pressure, and for high temperature it is in conformity with NF EN 10028-2, quality class 2b.

Table 1. Chemical composition for steel S235JR (liquid steel test)

Standardized symbol	Standard no.	Chemical composition					
		C [%]	Mn [%]	Şi [%]	S [%]	P [%]	Other elements [%]
S235JR	NF EN 10028-2	Max. 0.17	1,40	max. 0.30	max. 0.045	max. 0.045	N=0.09

Table 2. Mechanical and technological characteristics - S235JR steel

Material	Mechanical Characteristics						Technological properties	
	$R_{P\,0,2}$ [N/mm²]		R_m [N/mm²]	A_5 [%]	KCU [daJ/cm²]	KV (J)	weldability	deformability
	$s \leq 16$	$16 \leq s \leq 40$						
S235JR	235	225	340-510	20	7	27	FB	B

where: - S = satisfactory; B = good; FB = very good; $R_{p0,2}$ – passing limit; R_m – tearing limit; KCU – resilience; KV - tenacity

MA presentation

The additional material chosen was E 6013, a double rutile coated electrode that can be used both in continuous (CC) and alternative current (CA), a material whose chemical composition is shown in table 3 and mechanical properties in table 4.

Table 3. Chemical composition of material with E 6013

C %	Mn %	Si %	P %	S %
0.06-0.10	0.30-0.60	0.20-0.50	max. 0.03	max. 0.03

Table 4. Mechanical characteristics of material provided

Yield strength [N/mm²]	Mechanical resistance [N/mm²]	Stretching A 5d [%]	Kv 0°C [J]
430-470	490-600	min. 24	min. 47

Research stand

The experiment was conducted using the stand shown in figure 7.

The test tubes used to carry out the T test are shown in figure 3. The material utilized to manufacture the test tubes is S235JR, in the form of a 15 mm thickness plate. The test tubes (plates) were adjusted to 125X150 dimensions and assembled by means of welding joints, representing the two T welding samples – figure 3.

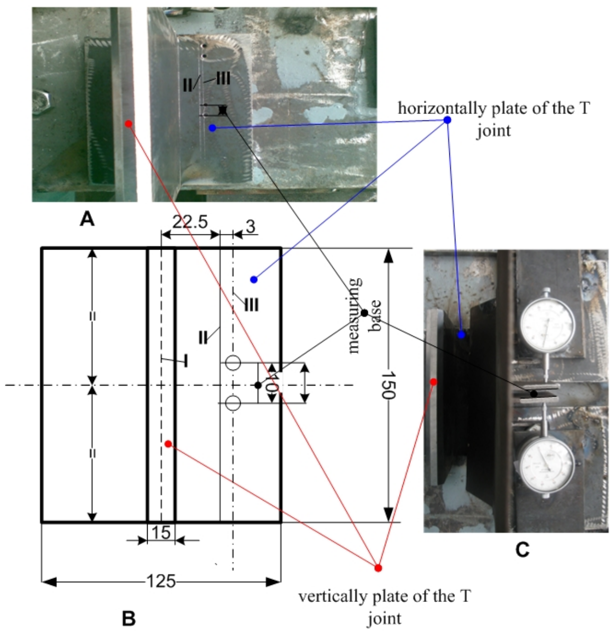


Fig. 3. T- welding sample

For the realization of the experiment, we used the test stand, shown in figure number 7. The dimensions of plates used for the realization of T joints, with dimension: 125X150X15 mm. Before the beginning of the experiment, were necessary to settle and respect some stages, such as:

- the preparation of the samples: cutting at the established dimensions;
- marking on the horizontally plate , of some axes for delimitation of the maximum size of the welding cathetus, the positioning of the measuring plates, such as: I-the axis of the vertically

plate of the T- joint, shown in figure number 3B; II- the axis for the delimitation the maximum size of the welding cathetus, on the horizontally plate, shown in figure 3 A and B; III- the axis for delimitation the positioning of the measuring plates, between has settled the measuring base,- see figure number 3 A and B. The measuring base is about 10 mm- see figure number 3 A, B, C.
- fixing with welding points of for the plates of the T- joint.

In figure number 3 C, it is shown a top view, of the necessary elements for the experiment.
The T sample was fixed to the stand with 4 clamp screws – figure 4. They blocked the rotation of the T sample and allowed movement along the stand only, due to dilatation and contraction occurred during the welding process.

A video and thermographic camera were installed as shown in figure 5 in order to monitor and record the research outcomes. The thermographic camera proved useful in the light of welding time setting and realization of some future correlations among deformations, time and temperature.

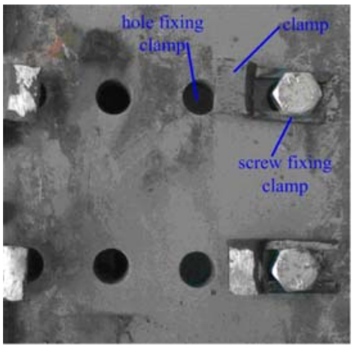


Fig. 4. Elements of sample fixing

Fig. 5. Video and thermographic cameras location

A supplementary protection device shown in fig.6 was used to protect the video and thermographic cameras as well as the mechanical comparators.

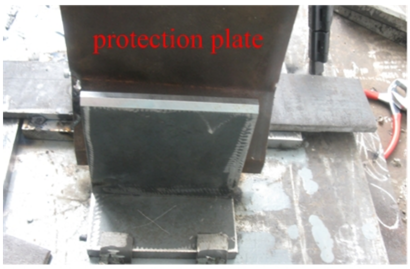


Fig. 6. Video, thermographic cameras and comparators protection

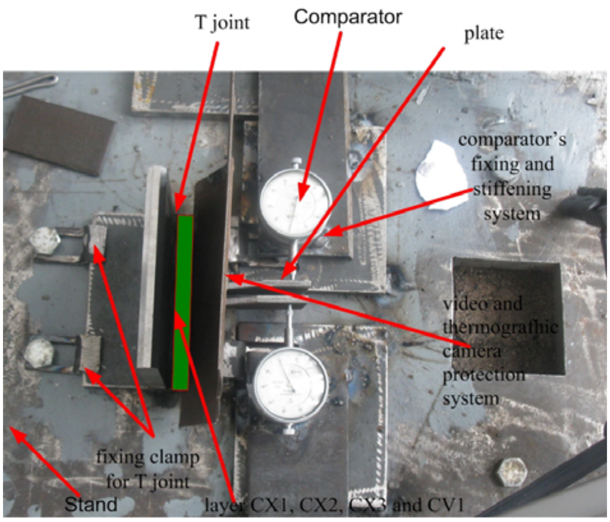


Fig. 7. Research stand for deformation and stress measurement

Two comparators were used to record movement: left comparator, right comparator, respectively, tightly fixed, totally blocked, allowing the palpator guide to move only when in contact with the mobile plates. The green marked area represents the point of convex weld beads (CX1, CX2, CX3) on a T sample and concave weld bead CV1 on the second T sample, respectively.

Before the initiation of each weld bead, both left and right comparators were set at 0.

There were conducted:
- 3 passes to obtain the convex weld bead (codes CX1; CX2; CX3);
- one pass to obtain the concave weld bead (codes CV1);
- one pass to the opposite side – convex weld bead (code CX4);
- one pass to the opposite side - convex weld bead (code CX4).

The present paper only reveals the data and results regarding the CX1 and CV1 passes in order to compare stresses and deformations corresponding to the two forms of weld beads.

Welding regime parameters

The parameters of the welding regime used in the research are shown in tables 5 and 6.

Table 5. Regime parameters for concave/convex welding

Concave/convex joint		**Value**
No.crt.	Parameter	Layer 1
1	Is [A]	120
2	Ua [V]	12…14

Considerations and Outcomes

Results

The measurement scheme is indicated in figure 8.

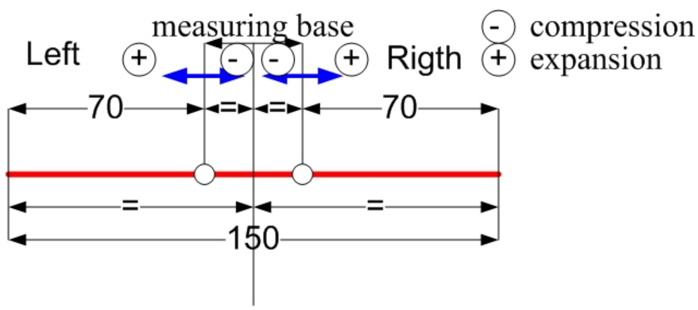


Fig. 8. Measurement scheme

The results obtained are shown in tables 7 and 8.

Table 6. Welding regime parameters

Value			
No.crt.	Parameter	Layer CX1	Layer CV1
1	Is [A]	120	120
2	Ua [V]	12…14	12…14
3	ts [s]	75	73
4	Lc [cm]	15	15
5	vs [cm/s]	0.20	0.21
6	El [kJ/cm]	6.24	6.07

Video recordings conducted have been processed by means of a specialized software, thus, obtaining the frames (shots) during the experiment, as shown in figures 9 and 10, corresponding to each welding sequence.

Passes and deformations recorded are shown in table 7 for CV1 and table 8 for CX1, respectively.

Table 7 (extract). Pass and deformation recorded for the concave weld bead layer 1 - CV1

Time [s]	Shifting L [mm]	Shifting R [mm]	Deformation [mm]
1	0	0	0
35	-0.01	0.00	-0.01
38	-0.03	0.03	-0.005
39	-0.04	0.03	-0.005
40	-0.04	0.03	-0.01
43	-0.05	0.04	-0.01
44	-0.05	0.04	-0.01
66	-0.05	0.04	-0.01
67	-0.05	0.04	-0.01
68	-0.04	0.03	-0.01
69	-0.04	0.03	-0.01
70	-0.04	0.03	-0.01
71	-0.01	0.04	0.03
72	-0.02	0.04	0.02
73	-0.02	0.05	0.03
74	-0.02	0.05	0.03
77	0.00	0.04	0.04
78	0.01	0.05	0.05
79	0.01	0.04	0.05
80	0.02	0.03	0.05
84	0.04	0.01	0.04
85	0.04	0.01	0.04
86	0.04	-0.02	0.02
87	0.04	-0.02	0.02
88	0.04	-0.02	0.02
98	0.08	-0.08	0
99	0.08	-0.08	0
100	0.08	-0.08	0
106	0.06	-0.08	-0.02
107	0.05	-0.07	-0.02
108	0.05	-0.07	-0.02
109	0.05	-0.07	-0.02
117	0.06	-0.09	-0.03
118	0.06	-0.09	-0.03
119	0.06	-0.09	-0.03
120	0.06	-0.09	-0.03
121	0.06	-0.09	-0.03
122	0.06	-0.09	-0.03

Table 8 (extract). Pass and deformation recorded for the convex weld bead layer 1 - CX1

Time [s]	Shifting L [mm]	Shifting R [mm]	Deformation [mm]
1	0	0	0
6	0	0	0
25	-0.03	0.02	-0.01
26	-0.03	0.02	-0.01
36	-0.03	0.02	-0.01
37	-0.03	0.03	0
51	0.03	0	0.03
81	0.06	-0.02	0.04
82	0.06	-0.02	0.04
115	0.06	0	0.06
116	0.06	0	0.06
122	0.06	0	0.06
123	0.07	-0.01	0.06
124	0.07	-0.01	0.06
125	0.07	-0.01	0.06
139	0.08	-0.02	0.06
140	0.08	-0.01	0.07
141	0.08	-0.01	0.07
142	0.08	-0.01	0.07
143	0.08	-0.02	0.06
144	0.08	-0.02	0.06
145	0.08	-0.02	0.06
146	0.08	-0.02	0.06
147	0.08	-0.02	0.06
148	0.08	-0.02	0.06
149	0.08	-0.02	0.06
150	0.08	-0.03	0.05
151	0.08	-0.03	0.05
152	0.08	-0.03	0.05
156	0.09	-0.04	0.05
157	0.09	-0.04	0.05
158	0.1	-0.05	0.05
159	0.1	-0.05	0.05
160	0.1	-0.05	0.05
161	0.1	-0.05	0.05
162	0.1	-0.06	0.04
180	0.1	-0.06	0.04
196	0.12	-0.08	0.04

CV1- 43 s CV1 – 68s CV1 – 109s

Fig. 9. Frame for CV1

CX1- 6s CX1-26s CX1- 82s

Fig. 10. Frame for CX1

Passing and deformation variations have been marked based on the values obtained and indicated in the above tables, fig. 11, 12, 13.

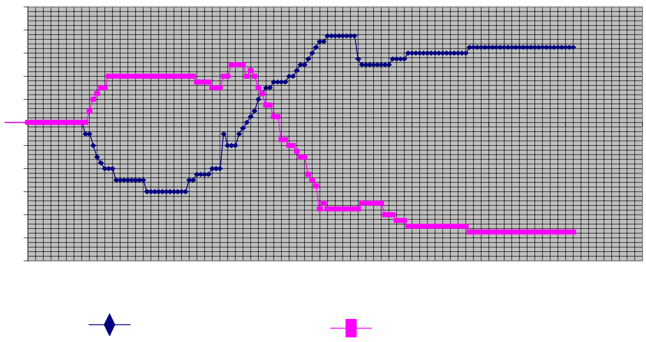


Fig. 11. Displacement variation for CV1

Interpretation

- Until second 17 (the length of the weld bead lc is at 34 mm from the plate head) – deformation approximately equal in both cases, with little variations in the case of concave welding;
- In the interval 17-28 seconds (l_c=34-56 mm), in the case of concave welding, the deformation value is low;
- In the interval 28- 36 seconds (l_c=56-72 mm), deformation values are approximately equal;
- In the interval 36-52 seconds (l_c=72-104 mm), deformation value is higher for the concave welding;
- From second 48 (l_c=96 mm), that is exceeding the measurement base by 33.5 mm., deformation value for weld bead CV1 lowers until the end of the welding process, which is not the case for weld bead CX1, where deformation increases;
- From second 52 (l_c=104 mm ,) a higher deformation value was recorded for the weld bead CX1.

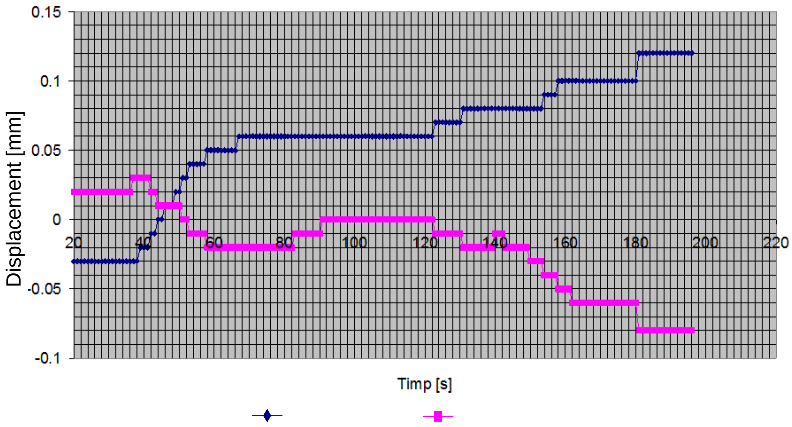


Fig. 12. Displacement variation for CX1

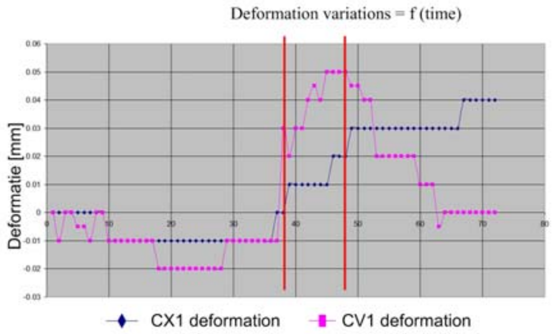


Fig. 13. Deformation variation for the measurement base

Conclusions

By way of conclusion, the results obtained in the case of the concave weld bead CV1, at the end of the welding process, have shown that the deformation value (stress, respectively) is lower than in the case of the convex weld bead, proving the pre-established hypothesis.

It is worth mentioning the fact that the deformations and stresses of the measurement base are higher with the concave weld bead and the recurring ones, sustaining the importance of welding, are higher with the convex weld bead. Moreover, the measurement base is extremely big, thus, real stress and deformation variations require new measurement methods for smaller bases.

The need to rehabilitate/replace convex corner welds, smoothly applied to the base material, may reduce possible critical defects likely to trigger low feasibility and construction life cycle.

All in all, in-depth ongoing research becomes a "must" regarding how stress may influence convex weld beads subject to fatigue as well as the rehabilitation technologies used to turn convex weld beads into concave ones.

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Câteva considerații privind fiabilitatea sudurilor de colț convexe

Rezumat

Forma cordonului de sudura in general si in special in cazul sudurilor de colt, are o importanta deosebita, mai ales in cazul structurilor solicitate la oboseala, avind in vedere concentratorii de tensiune ce apar la trecerea cusatura- material de baza.

Lucrarea de fata isi propune evidentierea pericolului cedarii in timp sub influenta solicitarii la oboseala a structurilor sudate cu imbinari de colt convexe si demonstrarea necesitatii reabilitarii acestor structuri. In acest sens este recomandat sa se utilizeze sudurile de colt concave, usor racordate la peretele tevii si indepartarea tuturor neregularitatilor , executate in timpul reparatiilor, masuri care vor determina cresterea duratei de viata la oboseala a structurilor sudate.

Principalele beneficii ale acestei lucrari, vor fi obtinerea unui nivel mai ridicat de fiabilitate al structurilor sudate si reducerea numarului de interventii pentru repararea sau inlocuirea unor structuri sudate cedate.