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Evaluation of circular welds strength capacity with corrosive defects

Oleg Tarayevs'kyy

Ivano-Frankivsk national technical university of oil and gas,
15 Karpatska Str, Ivano-Frankivsk 76019, Ukraine

Abstract
The results of experimental studies and analyzed the impact of long-term operation of gas pipelines, as well as natural stress concentrators on the physico-mechanical properties of welded joints of steel 17G1S. The technique and the regularities of the destruction of the material of welded joints of gas pipelines under static and low frequency loading for long term use, as well as stress concentrators. Some aspects of the mechanism of fracture of welded zednantruboprovodiv who are in long-term operation, as well as stress concentrations.

Keywords: *fatigue, floods, stress concentrators, weld of unity, weld, gas, static load, low-frequency loads.*

Introduction

The problem of maintenance of high service reliability of main pipelines is of great importance for the Ukrainian national economy because most of them are operated for a long period of time and have already depleted their rated recourse. The stable operation of main pipelines and their high economical efficiency first of all depends on their technical condition. While evaluating of technical condition of a pipeline it is important to determine with assurance stressed-deformed state its infrastructure as one of the main factors to which the level of service reliability of the construction is related. Otherwise pipelines can be subjected to the alarm condition.

Analysis of the reasons of main pipelines accidents helped in most cases to establish that the failures during operation are connected with shatterings along the metal in its entirely or along the circular butt-jointed seams. More then 50% of constructions are ruined due to the corrosive damages, 37% of accidents are caused by the bad quality of metal (insufficient malleability, impact hardness, bad weld junctions etc.)

Detailed analysis of the reasons of accidents enabled in most cases to determine direct connection between the source of failure initiation and any, even stealthy defect of metallurgical, industrial, construction and mounting or operational nature, which is a stress riser on the interior and exterior surface of the pipe. Manufacturing defects appear as metal failures of the pipe, non-metallic impurities appear as sulphide zones, scabs, partial removal of residual stress of the weld bead, defects of mechanical damage of the interior surface of the pipe. During pipelaying and pipe handling different mechanical damages such as buckles, plough defects, bands and also the defect of cross butt joint especially incomplete penetration are prevalent.

For the development of influence of the operational corrosive medium over durability and enduring quality of pipe steel one should characterize corrosive medium. The medium and metal cooperation depends on:

- constitution and certain components
- large and anelastic deformation
- surface condition

One should distinguish three possible cases of metal behavior while hydrogenation:

metal hydrogenation with strain-free lattice
metal hydrogenation with deformed lattice (processes of cold metal deformation)
hydrogenation during the deformation process of metal

The structural condition of steel and its deformation affects essentially on the electrochemical corrosive processes as well as on diffusion processes and the greater phase instability, the higher and its sensitivity to corrosion.

Efficiency upgrading of gas pipeline network is a very important problem, which needs to be solved. Engineering and operational processes of such gas pipeline networks are characterized by a set of specific features. Nonconformity of supplied gas volume and its consumption lead to the unsteadiness of gas flow, that combined with complicated manufacturing system of pipelines and its location in the distorted surface lead to the complexity of working regime forecast and their control. Scientifically based determination of plan tasks of gas supply in conditions of unsteadiness lie in necessity to have the exact information about days, seasonal and other types of irregular gas consumption.

At the moment the two main ways of forecasting are forming: the irregular gas consumption is the task of engineering and developing (advanced forecasting) of gas supply system; forecast of consumption schedules for controlling the regimes in actual gas transport systems.

It is considered, that industrial customers consume gas uniformly during a day. This statement is not always correct as the quantity of the utilized gas as a fuel in the industry is defined by many factors, for example, irregular fuel supply, requirements of technical process to the production quality etc. That is why for the industrial gas customers there also exists irregular fuel consumption during a day, that can essentially differ from irregular fuel consumption of domestic customers, which are defined mostly by the scheme of life of the society and connected with that type of energy usage. Buffering consumers can use different types of energy materials (including natural gas), their usage in the region lead to the smoothing the ripple of gas consumption.

The running pressure disturbance in the pipeline during a day is determined by the way of consumption in this region, which have the fixed number of gas consumers. On the quantity of the consumers and the way of their daily gas consumption depends the discharge fluctuation in the gas-transport system, which in its turn lead to the pressure disturbance. The gas consumers, concerning the way of gas consumption, are divided into three groups: industrial gas consumers, domestic gas consumers and buffering consumers. But this division carries conditionality.

For the operative executive control is mostly of great importance accounting the fluctuation of daily gas consumption. For such researches it is important to find out the reason of the appearance of nonsteady process, which in its term in most cases determines the character of its course. All the reasons of nonsteady processes can be divided into regular and impulsive.

Besides, the sharp increase or fall of intake by the consumers leads to the fugitiveness of its course in the pipeline, moreover the unstable processes due to the changes of the gas density can last for hours or even days. To the similar consequences lead the decrease or increase of gas priming, sudden switching on/off of booster station, opening or closing the gate valves etc. That is why the general process of pressure fluctuation in the pipeline is characterized by the frequency spectrum.

Problem state

Underground main gas pipelines in spite of the complex protection from the corrosion, which includes the passive protection by anticorrosive coating and active pipeline electrochemical protection, are rather often subjected to corrosive damages. But still the common factors of strength behavior of corrosive damages are examined incompletely.

Table 1 Targets of research and their main characteristics

No of the pipe	$D_н \times \delta$, steel grade, mm	Run life before trim, years	The cause of a trim based on the type of defect	The size of critical defect, mm	The terminal pressure (MPa), the character of damages

1	1220 × 12, 17Г1С	13	Corrosion in accordance with fabrication document	1100 × 520 × 2,8	9,2 fluidity
2	1220 × 14,5, 17Г1С	13	Corrosion in accordance with the fabrication document	3000 × 3,5	12,0 slabby
3	1220 × 12, 17Г1С	17	Damage because of the stress-corrosion cracking	General corrosion 800 × 0,5	9,8 slabby
4	1220 × 12, 17ПСУ	6	Corrosion in accordance with fabrication document	General corrosion 800 × 4,4	11,0 slabby
5	1020 × 9; 17Г1С, thermostabilized	18	Corrosion in accordance with fabrication document	Pit corrosion 900 × 4,4	8,0 slabby
6	1020 × 9; 17Г1С, thermostabilized	18	Corrosion in accordance with fabrication document	Pit corrosion 300 × 3,0	10,5 slabby
7	1220 × 10,5; 17Г2СФ, thermostabilized	23	Damage, structural defects	Opens up to 2,5 depth	11,3 slabby
8	1220 × 12,5, 17ГС	30	Gas main, surfaced on the muskeg	Wrinkling, buckles 1220 × 800 × 109, corrosion pits up to 2,0	11,0 slabby

The existing normative requirements for the safe and fault-free operation of main gas pipelines provide expressly the immediate clearing of corrosive damages that are above norm. Meanwhile progressing of corrosive damage on the underground pipeline is of the latent character and appears as the emergency failure of different complexity. In this situation there are some unfinished methods allowing to estimate the working speed of the gas pipeline strength value during development of corrosive damages. Otherwise, the modern ways of pig inspection allow to indicate the vast majority of corrosive damages by direct measurement during one inspection. In this case the plurality of corrosive damages is fixed and their clearing needs scientific evidence of time priority, as single- step clearing, in accordance with normative requirements, is impossible for technical reasons.

On the research- and- industrial stand for the gap specification the full-scale hydrostatic testing of corrosive-damaged pipelines, which were rejected from working gas pipe, was performed.

In the given classification group the results of testing of eight objects (see table 1), subjected to the corrosive damages depth more than 10% of the wall thickness.

It should be marked that corrosive damages were found only on the outer surface of the pipe in places of end-to-end or closed damages of the insulation blanket. It is clear that corrosive thinning of a pipe provides the in-situ growth of stressed-deformed state and strength retrogression of a pipe. Visually it can be seen while comparing deformation of nondefective and defective zones during testing pipe seams No 12 and 13. The results of testing are shown in the table 2.

From the table 2 one can see that the actual deformation of a pipe in the nonfailed zone is correlated with rated value, calculated in accordance with Hook’s generalized law for biaxial tension, i.e. the achieved results, excluded the abnormal indications of some tensometers, monitored during the prime stages of the stress, should exactly reflect the proceeded processes.

Turning to the results achieved, one can state, that the number of tensometers (No 2, 4, 6) installed usually in zones of areal damages have monitored the deformation correlated with the deformation of nonfailed pipe, i.e. such failures have not caused the noticeable reduction of strength.

At the same time pit zones (tensometers No 1, 3, 8, 9) have deformed more than nonfailed pipe, i.e. these zones had higher voltage. Further stresses showed that disjunction # 12 arose in zone of tensometer No1, where the largest deformation was monitored. It was 2,52 times higher than deformation of nonfailed zone. Concerning the stalk No 13, some artificial flaws were applied, which turned to be the center of damages.

Along with abovementioned the real integral criterion of availability and the rate of stress reduction of damaged pipe can be determined only after its damage, that was carried out while the final stages of weld bead (No 2,3,9,13,18,19) testing.

The results of testing and calculations are shown in the table 3. From this table one can see that five weld beads tested (No 1,2,9, 12,13) have pits, that are defined by acting governing documents as out-of-tolerance.

Table 2 The results of pipe deformation in the cross sectional area from interior pressure impact.

No	Location of the tensometer	Incrementation of indication of tensometer during the pressure change, MPa						Mean normal strain during the pressure change on 1, MPa	
		0÷1	1÷2	2÷3	3÷4	4÷5	5÷6	Devisions of tensometer	Relatival deformation % × 10^2
Weld bead No12									
1	Extensive corrosion zone up to 4,4 mm depth	-1	32	29	28	22	24	27	6,75
2	Short defect up to 4,4 mm depth	13	14	13	13	10	12	12,5	3,13
3	Extensive corrosion zone up to 4,4 mm depth	56	27	20	17	15	15	18,8	4,70
4	Short defect up to 5,2 mm depth	16	14	6	8	8	11	10,5	2,63
5	Short defect up to 4,5 mm depth	34	20	16	17	13	12	14,4	3,60
6	Long defect up to 43,5 mm depth	19	12	9	10	7	9	9,4	2,35
Weld bead No 13									
7	Extensive corrosion zone up to 1 mm depth	53	17	18	14	13	10	14,4	3,60
8	Extensive corrosion zone up to 3 mm depth	80	29	26	18	17	13	20,6	5,15
9	Extensive corrosion zone up to 2,5 mm depth	63	28	22	16	5	22	18,6	4,65
10	Undamaged pipe	10	9	14	11	10	10	10,7	2,68

The availability of such damages requires their maintenance or reduce of the pressure till the safe value (4.3…30% from design pressure).

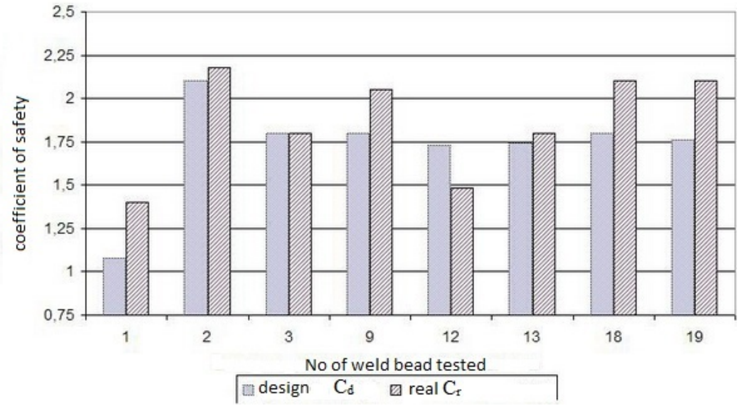

Figure 1 Comparison of the designed and real coefficient of safety of the pipes tested.

During the analysis of inspected defects in the category of damages requiring the complemental repair got the defect of pipe weld bead No18. Herein the level of reduction of working pressure (if the repair cannot be fulfilled) in all tested objects increases (about 4.3….27.1% comparing with the original scheme).

Along with this, correlation of real (C_r) and design (C_d) coefficient of safety, graphic presentation of which is shown on the fig. 1 and 2. This correlation shows that only in one instance (weld bead No 12) the necessary pipe reliability is not provided.

If it is impossible here to carry out the repair operations, it is necessary to reduce the working pressure in accordance with [5,6] 3.78 MPa, that is 70% of design pressure. On the results of hydraulic testing of this weld bead it is noticeable that the design coefficient of safety is provided when the working pressure is 8/1,71 = 4,68MPa (86,7% of the design pressure) i.e. it is 23,8 % more than extent.

Table 3 The results of testing and design of pipe weld beads corrosion damages

Parametr			No of weld bead tested							
			1	2	3	9	12	13	18	19
Diameter and nominal wall thickness, mm			1220×12,0	1220×14,5	1220×12,0	1220×12,0	1020×9,0	1020×9,0	1220×10,5	1220×12,0
Steel grade			17Г1С	17Г1С	17Г1С	17Г1СУ	17Г1С	17Г1С	17Г2СФ	17ГС
Normative mechanical data, MPa	Break point, σt		520	520	520	520	600	600	550	520
	Yield point, σ_y		360	360	360	360	420	420	380	350
Pit	Short Long		Long	Long	Long	Long	Long	Long	Short	Long
	maximum depth of the defect	mm	2,8	3,5	0,5	4,4	4,4	3,0	2,5	2,0
		%	23,3	24,1	4,2	36,7	48,9	33,3	23,8	16,0
Allowable depth of the defect [58,59] , %			21,2	21,7	21,2	21,2	28,1	28,1	70,0	22,2
Pressure of weld bead break, MPa			9,2	12,0	9,8	11,0	8,0	10,5	11,3	11,0
Design load factor coefficient, K^t_s			1,8	2,15	1,8	1,8	1,71	1,71	1,8	1,8
Design margin for liquid limit coefficient			1,05	1,26	1,05	1,05	1,0	1,0	1,05	1,05

C_d								
Real coefficient of safety, C_s	1,48	2,22	1,81	2,04	1,48	1,94	2,09	2,04
Coefficient of strength safety, C_d/C_r	1,41	1,03	1,006	1,13	0,87	1,13	1,16	1,13
Safe working pressure [58, 59]	5,17	5,15	5,4	4,27	3,78	4,94	5,4	5,4
Safe working pressure [61]	4,14	4,22	5,17	3,42	2,76	3,6	4,11	4,54

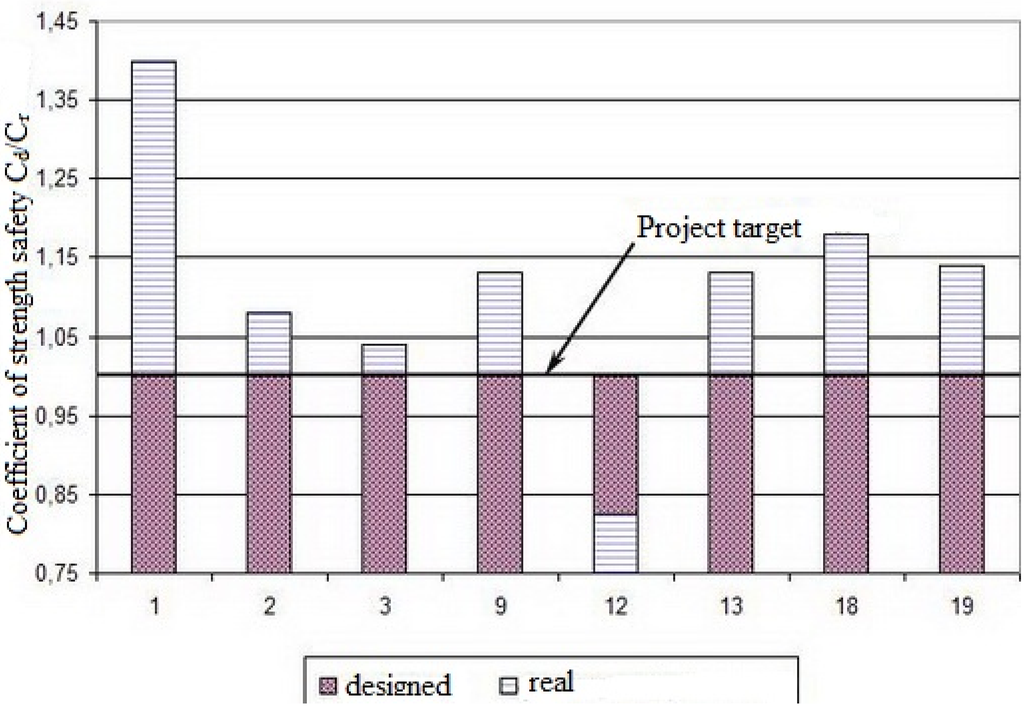

Figure 2 The coefficient of strength safety for the testing weld beads

For other pipe weld beads the real degree of safety compared with design degree of safety, excluding object No 1, where the pipe was lead to yielding of metal makes 0,6 ÷ 16 % (fig.2), i.e. the necessary pipe safety is provided if there is a need in repair operations in accordance with existing norms or technological measures reducing the working pressure (weld beads No2,9,13).

So, in result of hydraulic testing of pipe weld beads concerning interior pressure it was established that if there any corrosion damages exceeding standard values, the current level of strength recourse of gas pipeline occurs to be nonunique. It can be enough for further safe operation (weld beads No 9, 13, 18, 19), to be critical or equitable (weld beads #No 2, 3), indefinite for grading (weld bead No 1) or really dangerous (weld bead No 12). Each of these conditions requires an individual control of the use reliability level of gas transmission object. In the first case – it is just a system monitoring, in the second case - maintenance prevention, in the third case – formulation of detailed examination, in the forth case - emergency repair etc. Such control should be based on the criterial priority for evaluation of the pipeline operation capacity, which were subjected to corrosion.

Conclusions

This testing shows that the calculation of safe stress arisen inside gas pipeline as a result of uneven gas consumption in the hydrogen-charged media should be computed in respect with coefficient β_{cr}, that allows to increase it, and this will lead to the evaluation of main gas pipeline coefficient of flow due to the pressure increase. The given approach will let to determine correct and reasonable choice of the value of safe stress while operation for working medium and with small quantity cycle of loads.

Indeed the endurance processes in steel are of probabilistic nature. This together with non-destructive testing method and risking analysis with safety concept “realize and correct” and to keep the pipeline in workable condition. But negative here is that in such longtime operating condition (combined action of fluctuating loads and the medium) there accumulate defects in the pipe, which lead to its damage. Particular risk is in the hard-to-reach places (it is impossible to remove the danger in time) or in complicated operating condition (ex. the pipeline is in shift zone). Here the new concept of risking analysis should work – “foresee and keep ahead”.

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