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UNIONS FOR REPAIR OF DAMAGED SECTIONS OF A MAIN PIPELINE

Vitaliy Fedorovich Lukyanov, Anton Alekseevich Lukyanov and Vadim Genadievich Osadchiy
Don State Technical University, Rostov-on-Don, Russian Federation
E-Mail: vflukyanov@hotmail.com

ABSTRACT

The presented study discusses repair structures, which are applied for restoration of load bearing capacity of sections of main pipelines having corrosion damage on surface of a tube. It is demonstrated that the most widely used in repair weld union can effectively decreases stresses in walls of tubes only in the case it is mounted without a gap. In order to increases efficiency of the repair structure it is proposed to place an elastic layer between a tube and a union, which can fill space and transfer a part of load from a tube to a sleeve. The material of elastic layer must be "soft" enough to tightly fill the gap between a tube and a union taking into account roughness of a tube's surface and have quite big modulus of elasticity, which allows transferring load from a tube to a union. The study contains analysis of influence of modulus of elasticity of the elastic layer's material on efficiency of the repair structure. It is demonstrated that in order to satisfy the conditions, mentioned above, the material must have modulus of elasticity in the range 1,000 MPa < E < 3,000 MPa. Optimum conditions are met in the case of elastic layer made from polymer materials, such as low-pressure polyethylene, polypropylene and polyvinylchloride.

Keywords: repair of main pipelines, upset welded union, corrosion damage, finite-element method.

1. INTRODUCTION

Pipelines play a very important role as a method of long-distance transportation of gases and liquids from their sources to final consumers.

In particular, in Russia there is a developed network of pipeline transport of natural gas, oil and petrochemicals: total length of main pipelines exceeds 200 thousands km and length of field pipelines reaches 400 thousands km.

Length of gas pipelines in the USA in 2013 reached 1,984,321 km and length of pipelines transporting oil and petrochemicals – 240,711 km (Pipeline transport, n.d.).

Total length of pipelines of various purposes in 120 world countries is, approximately, 3.5 mln. km [19].

The pipeline system is one of the biggest engineering structures of XX century. Main and field pipelines are potentially dangerous engineering objects, which require special attention during their installation, repair and reconstruction, as well as during their operation, because their destruction can cause ecological disasters and danger to lives of people.

Deffects taking place during construction of a pipeline, generally, lie in limits, which are acceptable according to corresponding standards.

However, a pipeline, which is in operation, will inevitably experience large defects at some part of its service life.

In spite of the fact that rated service life of main pipelines exceeds 30 years, technological heredity and complicated conditions of operation of pipelines (influence of corrosion media, displacement of soils etc.) cause accumulation of damage in walls of tubes well before of end of the rated service life (Table-1).

Table-1. Relationship of ratio of tubes with defects and service life.

Service life	less than 10 years	10-20 years	20-30 years
Ratio of tube with defects, %	11.9	25.6	35.3
Including dangerous defects, %	0.05	0.34	0.44

According to the data of "Transneft" JSC, main causes of leaks of oil from pipelines are as follows: mechanical damage of oil pipelines - 33% of all accidents; corrosion (internal and external) - 53%; defects of tubes - 4%; defects of welding - 3%; errors in operation - 6%; others - 1% [2]. Significant role of corrosion in premature destruction of pipelines is marked out by the majority of studies and analytical reports [15]. For southern regions of Russia the most characteristic mechanism is corrosion of a wall's metal, and for northern regions – stress-induced corrosion cracking (Figure-1).

The data presented in Table 1 shows that volume of repair works increases with increase of age of the network of main pipelines. For example, welders of affiliate companies of "Gazprom" JSC annually produce more than 200 thousands welding joints during repair works [20].

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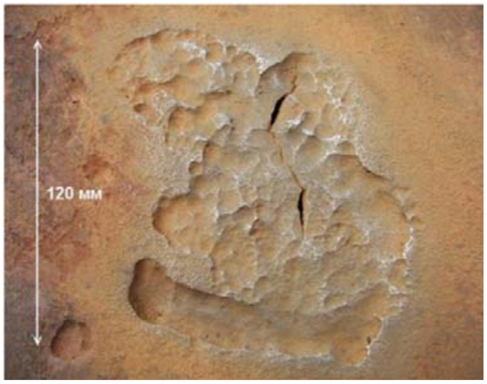

a)

b)

Figure-1. Corrosion damage of a tube's wall.

Nowadays in Russia, approximately, 50 thousands km of pipelines are operated for more than 20 years, 40 thousands km for more than 30 years (i.e. their rated service life is over), 3.7 thousand km - more than 40 years. Aging of pipeline transport is a global phenomenon. In the USA only 15% of pipelines are operated for less than 10 years, 18% of pipelines are operated for 10 to 20 years, and 67% of pipelines length corresponds to pipelines operated for more than 21% years [10]. For oil and gas industry problem of pipelines' corrosion becomes increasingly serious. Untimely diagnostics and repair of pipelines taking into account their aging will lead to the situation, in which the problems of accidents become delayed.

All of it speaks about topicality of search of ways to improve technologies of repair and restoration of load bearing capacity of pipelines with damage of walls, including corrosion damage.

Corrosion damage leads to decrease of thickness of a tube's wall.

Damaged zones of length and width of 100 mm and more are classified as defects, which must be repaired independently of depth.

The most widely used method of increase of service life of a main pipeline is repair with implementation of the repair structures (unions) [14].

The technology of repair of main pipelines with implementation of steel unions was developed by Battelle institute (USA) in the beginning of 1970 [1, 11]. Two halves of the union (semicylinders) were installed onto a damaged zone of a pipeline and welded between each other by means of longitudinal welds (Figure-2). Two methods of repair were proposed: with welding of the union to the body of the pipeline (Type B) and without the welding (Type A). The gap between a wall of a pipeline and a union in the structure Type A was filled by epoxy-based sealants [1]. In further these technology were significantly developed in terms of design; they are widely applied all over the world, including USSR and Russia.

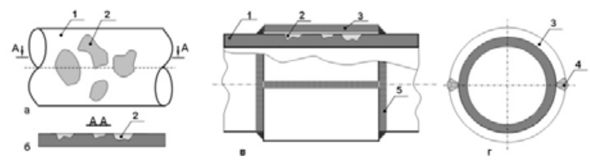

Figure-2. Repair of a damaged zone of a pipeline using sleeves. 1-pipeline; 2-corrosion damage; 3- semicylinders of sleeve; 4- welding joints connecting semicylinders with each other; 5- welding joints connecting ends of the sleeve to the pipeline.

In Russian normative documentation methods of repair of main pipelines are divided into methods of temporary repair, which restore load bearing capacity of a section of oil pipeline with defects for a limited period of time, and methods of permanent repair, which restore load bearing capacity of a section of oil pipeline with defects to a level without defects for the whole term of its further operation [3].

One of the most widely used methods of permanent repair is installation of a composite union P1 [3] and a welded union with auxiliary rings P2 [3]. Similar design of a union is used in "Gazprom" JSC [5]. The application technology of welded unions imply that there is no gap between a wall of a tube and a union, in other words, a tube is in direct contact with a union.

In this regard a problem of role of a welded union during further operation appears. The question is whether it only protects damaged site from further corrosion or in addition to corrosion protection it decreases level of stresses in a wall of a tube. In order to answer these questions it is necessary to analyze development of stresses, deformations and displacements of independent elements of the repair structure during loading of a pipeline by internal pressure.

It can presumed that internal pressure leads to increase of diameter of a tube and a wall of tube contacts with a union and transfers a part of load to a union.

The aim of the presented study is to identify mechanisms of development of elastic deformation of various sections of a pipeline, evaluate, how a union can unload a wall of a tube, and discuss ways to increase efficiency of repair of pipelines by means of unions.

2. MATERIALS AND METHODS

As the working hypothesis we presumed the following mechanism of interaction between a pipeline and a union. In the course of loading of a pipeline by internal pressure diameter of a tube increase due to appearance of elastic deformation in a wall of a tube. If a tube and a union are connected without the gap, than the union will limit development of deformations of the wall of the tube by taking a part of load from pressure in the tube, thus, decreasing stresses in the tube.

In order to evaluate possible value of effect of unloading of the pipeline by the union we carried out numerical simulation of mode of deformation of the repair structure P2 depending on value of the gap between the tube and the union. For simulation we used finite-element method. The following parameters of the model are accepted: external diameter of the tube D_0=1000 mm, thickness of the wall of the tube t_{tube}=12 mm; thickness of the union's wall t_{union}=12 mm; material of the tube and the union is K65 steel ([sigma]$_{0.2}$=550 MPa). Maximum pressure in the tube is 10.8 MPa. The value of the gap was varied in the range 0 ≤ [delta] ≤ 3 mm. Results of the calculations is presented in Figure-3. The stresses were analyzed in the point 1, which is situated on the pipeline far away from the union, in the point 2, which is situated on the pipeline under the union, and in the point 3, which is situated on the union.

Position of the points was selected considering distance from the edge of the union, which would allow to avoid influence of edge effect.

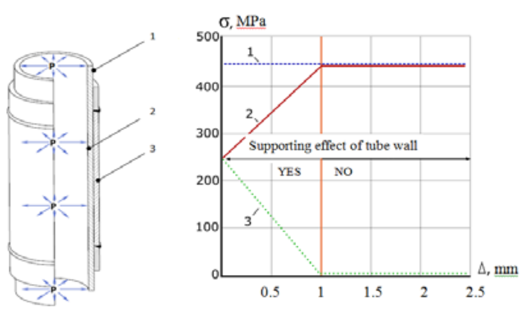

Figure-3. Influence of the value of the gap between the tube and the sleeve on decrease of stress in the repaired wall of the tube. 1- measurement of stress outside the zone of the repair structure, 2- measurement of stress in the unloaded zone under the sleeve, 3- measurement of stress in the sleeve.

It can be seen that in the case of installation without the gap in the point 2 and the point 3 the stresses are, approximately, the same, in other words, the union decreases stresses in the repaired zone of the tube to ~225 MPa. The role of the union as the supporting element is decreasing with increase of the gap. For example, for the value of the gap [delta] = 0.5 mm the stress in the point 2 [sigma] $_{point2}$ ~340 MPa, and in the point 3 [sigma]$_{point3}$ ~110 MPa. It should be mentioned that in that case the supporting influence of the union starts to appear only after contact of the wall of the tube and the union, and maximum effect is achieved only with maximum pressure in the tube. In the case of increase of the gap for more than 1.0 mm, the union stops having effect of the supporting element even for maximum pressure in the pipeline.

It is related with the fact that elastic deformations caused by internal pressure lead to increase of the tube's diameter for the value, which is equal or smaller than the value of the gap; thus, the wall of the tube doesn't contact with the union.

Simplified calculation show that, if the tube deforms freely, without restrictions caused by the union, increase of its diameter under load can be evaluated using the following expression:

$$\frac{D_1}{D_0} = \frac{\sigma_1}{E}, \quad (1)$$

where: D_0 - initial value of diameter of a tube without load; D_1 - diameter of a tube under load; [sigma]$_1$ - stresses in a wall of a tube in circular direction under load; E – modulus of elasticity of a tube's material.

Substitution in the equation (1) of values of stresses [sigma]$_1$ = 450 MPa and modulus of elasticity of steel E = $2.1 \cdot 10^5$ MPa shows that for the specified value of stress diameter of the tube D_1 must increase for 2.14 mm, i.e. for the gap of, approximately, 1.0 mm the tube losses contact with the union.

In the conditions of repair in a field it is impossible to install P2 union with the gap of less than 1 mm, even with implementation of special mounting accessories [13, 12]; moreover, in some normative documentation it is allowed to install the union on a pipeline with the gap of 3 mm [4].

In the presented study it is proposed to install an elastic layer between the union and the pipe in order to provide tight contact; the elastic layer, which is, for example, made from the polymer material, is aimed to eliminate the gap and transfer pressure of the wall of the tube to the union in the radial direction.

3. RESULTS

Application of polymer materials for repair of damaged section of main pipelines is known from end of 1980 – beginning of 1990. Examples are the technology of "Clock spring" company [6,18], technology of repair of pipelines by polymer composites [17], strengthening composite union of pipeline – UKMT [21], etc.; however, in all case used polymers had high modulus of elasticity, which values were reaching those of steel.

It can be presumed that material of elastic layer must have the following properties:

- significantly soft, in order to tightly fill the gap between a tube and a union;

- large modulus of elasticity, in order to transfer load from a wall of a tube to a union.

For simulation of stressed state of three-layer repair structure we selected polymer materials with various values of modulus of elasticity: high-pressure polyethylene (HPP), low-pressure polyethylene (LPP), polyvinylchloride (PVC), flexible anisotropic rolled fiberglass reinforced plastic (FARFRP) and unidirectional fiberglass reinforced plastic produced by "Argus limited" company and used for Clock spring unions.

For polyethylene HPP of grades15003-002 and 15503-004 modulus of elasticity E = (88.2-127.4) MPa [7]; for polyethylene LPP of grades 273-79, 20108-001 and 20308-005 modulus of elasticity E = (637.0-880.0) MPa [8]; for polyvinylchloride (PVC) E = 2,200 MPa [9], for the material FARFRP technical requirements TU 2296-152-05786904-99 E = 52,000 MPa, for unidirectional fiberglass reinforced plastic E = 34,500-45,000 MPa.

Simulation was carried out using the finite-element in ANSYS software with the following initial data: external diameter of the tube 1,020 mm, wall thickness 12 mm, length of tube L= 4,000 mm; material of the tube - steel K60 ([sigma]$_u$ = 590 MPa; [sigma]$_y$, = 460 MPa; elasticity modulus E = $2.08 \cdot 10^5$ MPa; [delta]$_5$= 20%). Material of the union - steel K60, length of the union - 1,500 mm, thickness of wall - 12 mm. Thickness of elastic layer - 12 mm. As material of elastic layer we used HPP, LPP, PVC, FARFRP and unidirectional fiberglass reinforced plastic. Pressure inside the pipeline P = 8.3 MPa.

Figure-4 demonstrates segment of the three-layer repair structure.

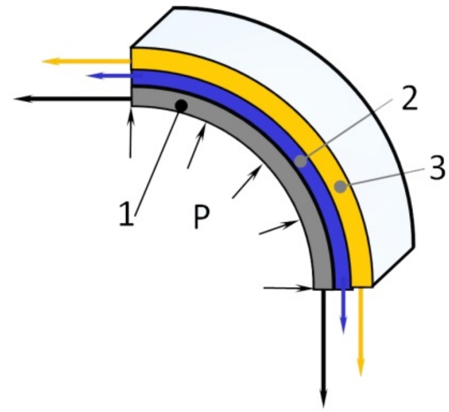

Figure-4. Scheme of three-layer repair structure. 1- pipeline; 2- elastic layer; 3- sleeve.

For calculation we assumed the condition of contact between layers – sliding with friction coefficient of 0.2. Taking into account possibility of appearance of complex stressed state in certain layers of the union, we characterized stressed state of independent layer by value of equivalent stress of von Mises [sigma]$_i$:

$$\sigma_i = \frac{1}{\sqrt{2}}\sqrt{(\sigma_1-\sigma_2)^2+(\sigma_1-\sigma_3)^2+(\sigma_2-\sigma_3)^2} \qquad (2)$$

where: [sigma]$_1$; [sigma]$_2$; [sigma]$_3$ – components of main stresses.

Table-2 presented the results of calculations of stresses in various layers of the repair structure (Figure-4), which correspond to pressure in the tube of 8.3 MPa. At that pressure in the wall of the tube far away from the union (point 1 in Figure-3) equivalent stresses were [sigma]$_i$ = 353 MPa. In brackets there is relative ration of load, which is transferred to various layers of the repair structure in percent from the value of equivalent stress in the point 1.

Table-2. Influence of elasticity modulus of the elastic layer's material on redistribution of stresses between the tube and the union.

Stresses in layers of the repair structure MPa	Material of the elastic layer (Modulus of elasticity)				
	HPP, $E = 0.15 \cdot 10^3$ MPa	LPP, $E = 1.0 \cdot 10^3$ MPa	PVC, $E = 2.2 \cdot 10^3$ MPa	Clock Spring FRP $E = 38 \cdot 10^3$ MPa	FARFRP $E = 52 \cdot 10^3$ MPa
Wall of tube	264 (74.7%)	201 (58%)	180.5 (51%)	168 (48.4%)	164 (46%)
Elastic layer	0.98 (0.3%)	2.13 (0.6%)	3.8 (1%)	30.5 (8.6%)	40 (11%)
Wall of union	88.5 (25%)	147.5 (41.4%)	167 (48%)	157.5 (43%)	153 (43%)
Coefficient [beta]$_u$	1.34	1.76	1.96	2.10	2.15

4. DISCUSSIONS

It can be seen that increase of modulus of elasticity of the elastic layer leads to decrease of stresses in the wall of the tube, which is accompanied by increase of stresses in the wall of the union, in other words, efficiency of work of the union as the supporting element is increasing.

Supporting effect of the union can be numerically characterized by ratio of stresses in the wall of the tube far away from the union (point 1 in Figure 3) to stress in the wall of the tube under the union (point 2 in Figure 3). We specified that ratio as coefficient of efficiency the repair structures $[beta]_u$. If thickness of the wall of the tube and the union is the same, then, in the case of installation of the union without the gap and the elastic layer $[beta]_u = 2$; with increase of the gap $[beta]_u$ tends to 1. In the repair structures with polymer layer (see Table-2) $[beta]_u > 1$, at that, the value $[beta]_u$ generally, doesn't depend on level of pressure in the tube, i.e., in contract to the repair structure without the elastic layer, the union takes load both for low and high pressure in the pipeline.

It worth mentioning that in the zone of low value of modulus of elasticity (for HPP, LPP, PVC) values of stress in the elastic layer are, approximately, 1% from stresses in the tube, at that, coefficient of efficiency of the repair structure $[beta]_u$ is quite large - 1.34…1.96, i.e. reaching the value of $[beta]_u \approx 2$, which is characteristic for installation of the union without the gap. Thus, for low values of modulus of elasticity of the elastic layer (E < 3,000 MPa) efficiency of the repair structure increases mainly due to elimination of the gap between the tube and the union and more complete transfer of load from the union in radial direction. It should be mentioned that due to low modulus of elasticity the elastic layer can fill roughness of the surface of the tube and provide more complete contact between the union and the tube.

Further increase of the modulus of elasticity of the elastic layer's material lead to significant increase of stress transferred to the elastic layer. Their ratio to stresses in wall of tube increases from 11% for the case of application of FARFRP, at that, ratio of load, which is taken by the union, is decreasing. Thus, for large values of modulus of elasticity of material of the elastic layer increase of coefficient of efficiency of the repair structure is related with the fat that a part of load is taken by the elastic layer, and, therefore, level of increase of $[beta]_u$ depends on thickness of the interlayer. The disadvantage of application of polymer materials with large modulus of elasticity is the fact that due to high rigidity of that kind of interlayer it is hard to provide tight contact between the surfaces of the tube in places, where the surface is rough.

The carried out analysis show that application of the interlayer of materials with modulus of elasticity of 1,000 MPa < E < 3,000 MPa allows to increase efficiency of application of the repair structures of main pipelines due to provision of tight contact of the union and the tube.

5. CONCLUSIONS

a) In the case of repair of the linear part of main pipelines by the repair structure "welded union" the supporting effect can be obtained only if the technology of installation allows to provide the gap between the union and the tube less than 0.5 mm.

b) Influence of the modulus of elasticity of a polymer interlayer in the three layer repair structure on level of supporting effect of a damaged part of a min pipelines is theoretically established; at that the role of the interlayer is ambiguous.

c)For increase of efficiency of operation of the repair structures "Welded joint" between the union and the tube it is reasonable to place elastic interlayer from material with elasticity modulus 1,000 MPa < E < 3,000 MPa.

d) For large values of modulus of elasticity of material of the elastic layer increase of coefficient of efficiency of the repair structure is related with the fat that a part of load is taken by the elastic layer, and, therefore, level of increase of $[beta]_u$ depends on thickness of the interlayer.

e) The disadvantage of application of polymer materials with large modulus of elasticity is the fact that due to high rigidity of that kind of interlayer it is hard to provide tight contact between the surfaces of the tube in places, where the surface is rough.

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