DOI: 10.20535/kpisn.2022.1-2.287886
UDC 621.643.03

Grigoriy S. Tymchik, Oleksandr O. Podolian, Kateryna S. Serhiienko
Igor Sikorsky Kyiv Polytechnic Institute, Kyiv, Ukraine

TECHNOLOGY OF REPAIRING THE ACTIVE MAIN PIPELINE USING BRAZE-WELDED COUPLINGS

Background. During operation, the main pipeline needs to be repaired. During periodic diagnostics of the pipeline state defects are detected, some of which are unacceptable. The classic repairing method, that involves the shutdown of the pipeline with subsequent replacement of its defective spots, requires significant financial costs and is associated with a forced pipeline outage and environmental violation.
Objective. The purpose of this article is to improve the technology of reinforcing sections of main high-pressure pipeline with welded couplings, which are filled with molten metal by allowing obtaining high efficiency of pipe strengthening of medium and small diameters.
Methods. Strength improvement of the active pipeline spots is realized by installing brazed-welded couplings on an active main pipeline. Strengthening the pipeline with the coupling consists in the redistribution of the load part from the pipe to the wall of the coupling, which leads to a decrease of the stress level in the pipe wall. The reinforcement efficiency of the pipeline could be evaluated by the degree of reduction of circumferential stresses in the fixed pipe wall.
Results. The article suggests a technique for strength improvement of pipeline spots using couplings filled with a molten metal that has a high elasticity modulus. The operations of formation of under-coupling layer with the parameters that provide achievement of the maximum value of the stresses reduction degree in the reinforced pipe are proposed, while ensuring an even load distribution between the wall of the pipeline spot being repaired and the coupling shell. An improved technology for fixing defective spots of the active pipeline has been proposed, designs for front seals have been proposed that facilitate the formation of under-coupling layer with optimal parameters. The proposed technique makes it possible to increase the efficiency of the pipe strengthening of small and medium diameters.
Conclusions. The article proposes an improved technology of the defective spots reinforcing of the active main pipeline using braze-welded coupling. The focus is on the design of mechanical seals that ensure the tightness of the under-coupling space during the formation of the coupling layer.
Further research would be performed in the direction of developing a mathematical model of the pipeline reinforced with braze-welded coupling, taking into account temperature changes during heating and cooling of the coupling structures during the formation of the under-coupling layer. Some research will be also performed to improve the coupling structures and methods of quality control of their mounting on the pipe.
Keywords: coupling; non-destructive; control; diagnostics; repair; gas pipeline; pipeline; pressure; gas; refinable crude; transit.

Introduction

During repairing of linear and curved sections of active *high pressure* main *pipelines as well as* their transfer to a higher category a method of increasing the of the pipe strength is widely used. It's related with the installation of the amplified plot of pipe couplings of various designs [1]. The most wide distribution have received couplings with an under-coupling space that is filled during the time renovations of the self-hardening substance, which allows for the pipeline section reinforcement without changing modes of the product transportation [2,3]. Commonly, the couplings compiled of multiple technological elements, most important of which are two half-shells that are centered on the pipe and fastened to each other by known methods, for example, welded longitudinal seams. Thereafter, the ends of the sheath are sealed and the space between the pipe and shell is filling up with self-hardening substance. The availability of the under-coupling layer allows reducing Hoop stresses in the pipe by referring a portion of

Пропозиція для цитування цієї статті: Г.С. Тимчик, О.О. Подолян, К.С. Сергієнко , «Технологія ремонту діючого магістрального трубопроводу з використанням паяно-зварних муфт», *Наукові вісті КПІ*, № 1–2, с. 95–101, 2022. doi: 10.20535/kpisn.2022.1-2.287886

Offer a citation for this article: Grigoriy S. Tymchik, Oleksandr O. Podolian, Kateryna S. Serhiienko, “Technology of Repairing the Active Main Pipeline Using Braze-Welded Couplings”, *KPI Science News*, no. 1–2, pp. 95–101, 2022 doi: 10.20535/kpisn.2022.1-2.287886

the load on the outer shell. In General, the efficiency of the repair depends on its strength parameters. For repairing pipes of small and medium diameters there is a developed technology [5,6] based on using the formation of an under-coupling layer of molten metal that has a high elasticity modulus. However, due to the complexity of creating the required pressure in the under-coupling space the technology requires some improvements.

Problem statement

The purpose of the article is to improve the technology of reinforcing sections of main high-pressure pipeline with welded couplings filled with molten metal by allowing obtaining high efficiency of strengthening pipes of medium and small diameters.

Strengthening the spots using braze-welded coupling

Strengthening the pipeline with the coupling is to redistribute part of the load from the pipe to the wall of the coupling, which leads to a decrease of the stress level in the pipe wall. The reinforcement efficiency of the pipeline could be evaluated by the degree of reduction of circumferential stresses in the wall of the repaired pipe $\left(\frac{\sigma_{Tp}}{\sigma_{To}}\right)$,where σ_{To}, σ_{Tp} – hoop tensile stress in the pipe wall without coupling and with mounted coupling at the working pressure in the pipeline P_p [3].

After the installation of couplings on pipe with internal pressure P_U and after filling the under-coupling space with self-hardening composition injected under pressure P_{MU}, hoop tensile stress in the pipe wall decreases to a certain value σ_{TU}. Further, in a case of pressure changes inside the pipeline P_p, a hoop tensile stress in the pipe wall is going to take the values σ_{Tp} and the reinforcement efficiency of the pipelines is described by expression [9]:

$$\frac{\sigma_{Tp}}{\sigma_{To}} = 1 - k^{-1}\left(1 + \frac{P_U - k \cdot P_{MU}}{P_p}\right).$$

Where k is the coefficient that links pressure changes in under-coupling space with pressure changes inside the pipeline (the coupling coefficient). A detailed derivation of an expression for the coefficient k, that takes into account the geometric parameters of the repaired pipe and couplings, as well as strength properties of the material of the under-coupling layer, is given in [9].

$$k = 1 + \frac{4 \cdot \delta_T \cdot \frac{E_M}{E_{PP}}\left(\delta_{ППУ} + \frac{P_{MU}}{4 \cdot E_T}\left(\frac{D_T^2}{\delta_T} + \frac{\left(D_T + 2 \cdot \left(\delta_T + \delta_{PPU}\right)\right)^2}{\delta_M}\right)\right)}{\frac{1-\mu^2}{1-3\mu^2} \cdot D_T^{\,2}} + \frac{D_M^{\,2} \cdot \delta_T}{D_T^{\,2} \cdot \delta_M}.$$

Where D_T is the internal diameter of the pipeline; $E_M \approx E_T$-is the elasticity modulus of the material of the coupling and pipe; E_{pp}, μ_{pp}-is the elasticity modulus and Poisson's ratio of the material of the under-coupling layer; δ_T is the wall thickness of the pipe; δ_M- is the wall thickness of the brace; δ_{PPU} is the mounting depth of the under-coupling space.

To ensure uniform load distribution between the reinforcing pipe and coupling, self-hardening substance should be pressed into the under-coupling space below the optimum pressure P_{MUopt}, which is defined by the expression [3]:

$$P_{MUopt} = \frac{P_U}{k} + \Delta P.$$

Where: ΔP- is the pressure reduction due to the shrinkage of under-coupling layer substance in the process of hardening.

In the case of pressing the self-hardening substance into the under-coupling space under pressure P_{MUopt}, reinforced coupling, without taking into account end effects would similarly work like a solid pipe with greater wall thickness.

The optimal filling pressure of the under-coupling space is firstly defined with the pressure inside the pipeline at the time of installation and the magnitude of the coupling coefficient k. However, the magnitude of the coupling coefficient depends on the depth of under-coupling space, which depends on the pressing pressure of the self-hardening substance into the under-coupling space.

The efficiency of the discharge pipe coupling with internal filling increases with increasing diameter of the pipeline, and with decreasing in the depth of coupling space. And also it rises with increasing the wall thickness of the coupler of the elasticity modulus and Poisson's ratio of the material of the coupling layer. The graph illustrating the change in the degree of reduction of hoop stresses in the wall of the repaired pipe for different diameters of the strengthen pipeline by using different materials for the formation of the under-coupling space shown in

Fig. 1. The graph is constructed for $P_U = 5{,}5$ *MPa*, $\delta_T = 9$ *mm*, $\delta_M = 9$ *mm*, $P_{MU} = P_{MUopt}$.

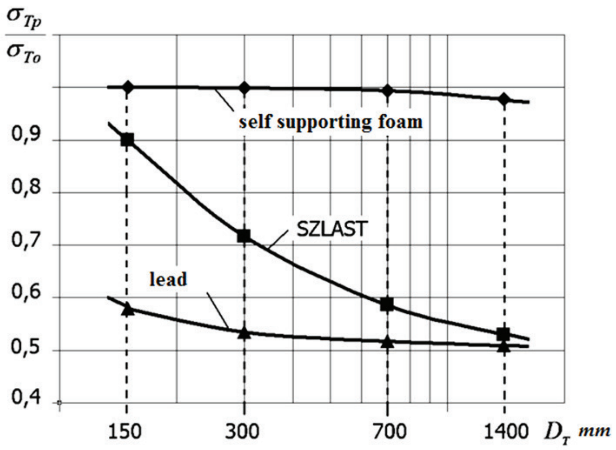

Fig. 1 The dependence of the reduction degree of hoop stresses in the wall of the reinforced pipe from its diameter

The graph shows that the use of molten metal for forming the under-coupling layer enables reinforcement of pipeline sections with small diameters, for which using of the known compounds is ineffective.

The technology of strength improvement of spots of an active pipeline using couplings with the formation of an under-coupling layer of melted metal (brazed-welded couplings)

One way to increase the efficiency of strengthening pipes with small and medium diameters is to use molten metal that has a relatively low melting point, for example, lead, tin or their alloys, to form an under-coupling layer [5].

Calculations show that the use of lead pressed into the under-coupling space under optimal pressure will hardly improve the efficiency of the pipeline's strengthening by increasing the degree of reduction of ring stresses in the pipe that is being repaired with a diameter $D_T = 150$ *mm* with $\left(\frac{\sigma_{Tp}}{\sigma_{To}} = 0{,}9\right)$ (when using self-hardening mass SZLAST, that has elasticity modulus $E_{pp} = 55$ *MPa* and Poisson ratio $\mu_{PP} = 0{,}48$) to $\left(\frac{\sigma_{Tp}}{\sigma_{To}} = 0{,}58\right)$ (when using lead that has the elasticity modulus $E_{pp} = 0{,}18 \cdot 10^5$ and Poisson ratio $\mu_{PP} = 0{,}42$).

The heating of the of the pipeline defective spot with the coupling installed on it can be carried out with the help of inductors widely used for the preparation of pipes during welding (Fig. 2)

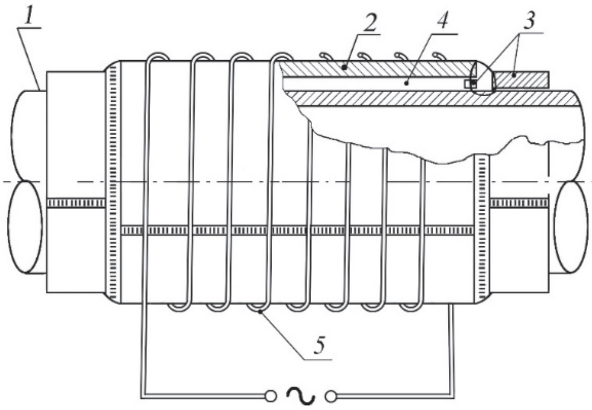

Fig. 2. The usage an inductor to warm up the coupling *1* – pipeline, *2* – coupling, *3* – technological rings, *4* – under-coupling space with molten metal, *5* – inductor

To achieve the maximum value of the mechanical ring stresses reduction degree in the pipe wall that is being strengthened and to ensure an equal distribution between the pipe that is being repaired and the coupling shell, the value of the pressure of pressing the molten metal into the under-coupling space should be selected from the expression [10].

The main difficulty in fulfilling this condition is to ensure correct recordkeeping ΔP and the coupling factor k, because in actual practice, the shrink of the same metal or alloy can be very different from the batch and the conditions of use, which will lead to a non-optimal distribution of the force between the pipe and the coupling after changing the material state of the under-coupling layer.

In addition, alloy can be used to fill under-coupling space, with an unknown value of the modulus of elasticity and shrink. Such an example can be applied during emergency operations and when using of an alloy of random lead and tin products.

In this case, the quality control of the installation can be carried out in the following sequence. After installation and assembly of the coupling metal parts (shell and face seals), the welded joints quality can be checked by traditional, well-established methods of non-destructive testing.

The heat-resistant strain gage transducers are mounted on the coupling shell. Further hydraulic tests of the under-coupling space that are combined with the treatment of internal surfaces with an adhesive (flux), which provides elevated adhesion of the molten metal to the pipe and coupling shell.

The construction of a diagram of the strain gage transducers is made during the hydraulic tests, with the usage of information from the pressure detectors installed in the coupling shell joint $R_{TD}(P_M)$, the value of the signal that comes from the strain gage transducer R_{TD} to the value of the pressure in the under-coupling space $R_{TD}(P_M)$. During the usage of the strain gage transducer with a linear characteristic (for example, strain gages with temperature compensation circuits), the calibration dependence can be represented as: $R_{TD} = K_{TD} \cdot P_M + R_{TD0}$.

Where: R_{TD} - signal at the strain gage transducer output, K_{TD}- the coefficient connecting the signal change at the transducer output with the change in pressure in the under-coupling space, R_{TD0}- the signal at the strain gage transducer output in the absence of pressure in the under-coupling space.

After heating the pipe and coupling by using of special means, for example, an inductor, molten metal is pressed into the under-coupling space, controlling the pressing process according to the information coming from the strain gage transducer. After this, molten metal injection and preheating are continued until the following conditions are fulfilled:

$$R_{MU1} = K_{DT} \cdot \left(\frac{P_U}{k_i} + \Delta P_i \right) + R_{TD0}.$$

After determining the actual values k and ΔP, the coupling, the pipe and the under-coupling space layer are heated again, so that the metal in the under-coupling layer melts. Than molten metal is additionally injected into the under-coupling space, creating a pressure that is monitored by the signal from the strain gage transducer:

$$R_{MU} = K_{DT} \cdot \left(\frac{P_U}{k} + \Delta P \right) + R_{TD0}.$$

To implement the method, the pressure in the pipeline can be changed not immediately after finishing the work, but much later, during the planned change in the modes of transport of the product. Unlike couplings with compound filling, couplings filled with molten metal make it possible to correct the stress distribution in the pipe and coupling during operation.

The proposed method is explained by the diagram shown in Fig. 3.

Giving the fact that the under-coupling space is filled with liquid molten metal, control over its distribution over the entire capacity size can be carried out by an acoustic method. At the same time, taking into account the high temperature of the coupling, which limits the use of traditional piezoelectric excitation sensors for an acoustic wave, the use of the EMA method is preferable [14-17].

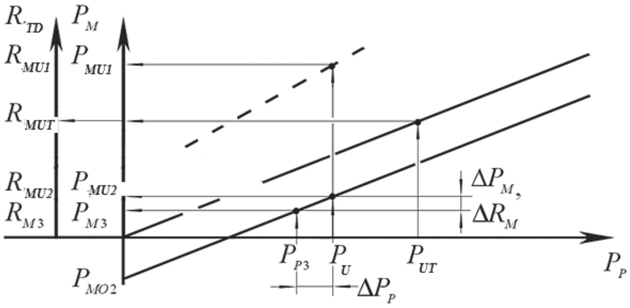

Fig. 3 A diagram explaining how to fix a pipeline using brazed-welded coupling

The relatively large shrink of lead during pouring (up to 4%) can be effectively reduced by the introduction of additional additives.

The issues of reducing lead shrink are considered in the specialized literature on the production of bullets for firearms and in the scope of application for filling under-coupling space have been studied.

The technology of the existing trunk pipeline section reinforcement using a coupling filled with molten metal

Proceedings [5,11] propose technology of strengthening of the pipeline with using braze-welded coupling that is heated by the inductor. The focus is on the quality control of repairing, ensuring proper accounting ΔP, and coupling coefficient k that are necessary for the condition (3). However, to achieving conditions (3) during the works only while ensuring the tightness of under-coupling space, which pursues high demands on the quality of the end seal.

The proposed technology that increases the strength of the pipeline is as follows [12,13]. On the amplified section of the pipeline technological elements of the coupling are installed, which, after binding with known methods, form a closed shell around the pipe with hoop cavities for forming end seals.

Then the ends of the coupling are sealed using the alloy (metal) that has a higher melting temperature (optional alloy) than the alloy (metal) used to form the under-coupling layer (core alloy). To seal the ends of the coupling pre-heating of the coupling in the area of the hoop cavity to a temperature above the melting point of the alloy is conducted (but not exceeding its boiling point). Then cavity is filled with additional molten alloy supplied under pressure. After filling the annular cavity, the temperature of the coupling is reduced, resulting in the formation of hermetic end seals. Then the whole coupling is heated to a temperature higher than the melting temperature of the basic alloy, but lower than the melting temperature of the additional alloy, and then under-coupling space is filled with the main molten alloy, fed at the specified pressure.

The process of forming the under-coupling layer is illustrated in Fig. 4, and the construction of annular cavities is shown in Fig. 5. Fig. 12, where 1 is the pipeline; 2 is the coupling shell, 3 is under-coupling space, 4 is the annular cavity, 5 – the coupling technological elements, 6 – inductors, 7 – syringes, 8 – heater, 9 – additional alloy (metal), 10 is the main alloy (metal), 11 – backing hoop, 12 – sleeve, 13 – technological hoop, 14 – weld seam, 15 – sealer, 16 – part flange, 17 – flange connection fastening.

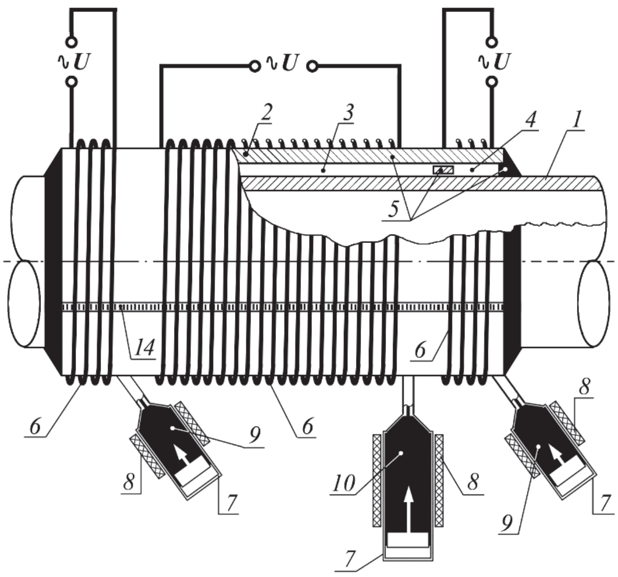

Fig. 4 Organization of the formation of the end seals and filling the under-coupling space with molten metal

Further, the coupling is cooled naturally or forcibly. With a relatively small length of coupling and a limited time of works, it is possible to heat the entire coupling to a temperature above the temperature of the additional alloy. It is also possible to form end seals with further lowering of the coupling temperature and filling the under-coupling space with the main alloy, which is supplied with a predetermined pressure.

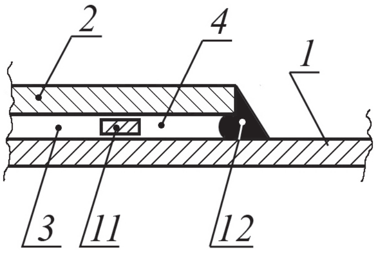

Fig.5 design version of the annular cavities

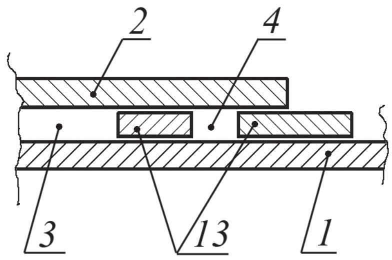

Fig.6 design version of the annular cavities

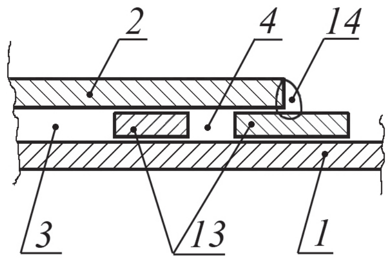

Fig.7 design version of the annular cavities

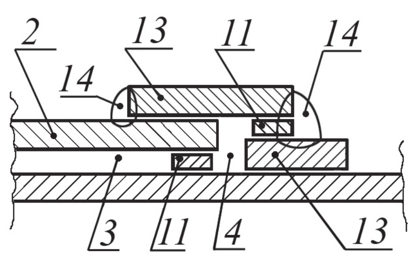

Fig.8 design version of the annular cavities

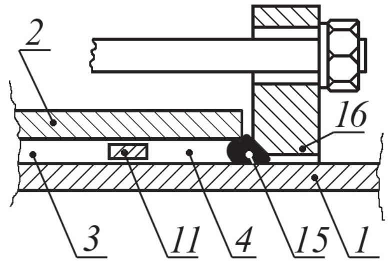

Fig.9 design version of the annular cavities

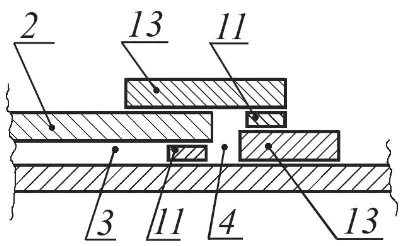

Fig.10 design version of the annular cavities

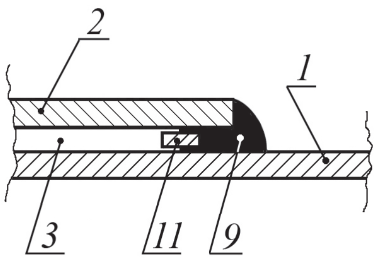

Fig.11 design version of the annular cavities

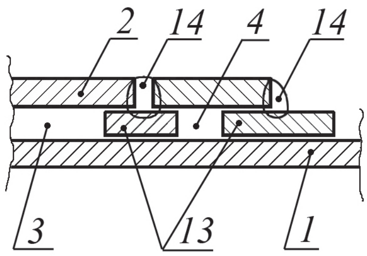

Fig.12 design version of the annular cavities

To ensure the required values of the pipe circumferential stresses reduction degree, with a uniform distribution of the load between the pipe walls and the coupling, the pressure in the under-coupling space should be changed in proportion to the pipeline pressure

$$P_M = P_p \cdot k^{-1}.$$

It is provided if selection pressure of filling the under-coupling space with the main alloy would be based on the conditions (3). However, in practice it is difficult to predict finite values of the coupling coefficient using the condition (3), provided a complicated temperature dependence. Proceeding [9] proposes an approach to select the optimum pressing pressure of the molten alloy in under-coupling space, has limited using. It involves the formation of a coupling layer in two stages with intermediate cooling of the structure. In this regard, practical and scientific interest is the dependency establishment, in order to form the under-coupling layer with optimal parameters in one-step.

Conclusions

The article proposes an improved technology of the defective spots reinforcing of the active main pipeline using braze-welded coupling. The focus is on the design of mechanical seals that ensure the tightness of the under-coupling space during the formation of the coupling layer.

Further research would be performed in the direction of developing a mathematical model of the pipeline reinforced with braze-welded coupling, taking into account temperature changes during heating and cooling of the coupling structures during the formation of the under-coupling layer. Some research will be also performed to improve the coupling structures and methods of quality control of their mounting on the pipe.

References

[1] Bekker M. V. “Repair of gas-main pipelines under pressure”, Kyiv. Ukraine, 2008. – 240p.

[2] Gas-main pipelines, arc welding repair in operating conditions, Ukrainian Standard GBN V.3.1-00013741-12:2011, 2011.

[3] Technological instruction for the repair of pressure gas mains pipelines with the use of arc welding, DK “Ukrtransgas”, 2000. – 96 p.

[4] Otegui J.L. et al. “Local collapse of gas pipelines under repairs”, Int. J. Pressure Vessels and Piping. 2000. 77. P. 555–566.

[5] O.Podolian et al., “Method of reinforcing the pipeline with the help of clutches with internal filling with work quality control (variants)”, UA patent98601, May. 25, 2012.

[6] William Pallan, “Method of repairing a pipe “, GB Patent 2210134, June 01, 1989.

[7] V.But et al., “Method for repair of defect section of pipeline without change of mode of transportation of product“, UA patent 81894, February 11, 2008

[8] V.But et al., “Method for repair of pipeline under conditions of operation “, UA patent 81895, February 11, 2008

[9] O. Podolian et al., “Quality control system of well-bonded coupling fitting onto high pressure gas-main pipelines”, Proc. SPIE 10808, Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments 2018, 108085A (1 October 2018); https://doi.org/10.1117/12.2501594

[9] I.Oryniak et al., „Method of repairing the operating pipeline with a clutch with internal filling”, UA patent 98440, May 10, 2012.

[10] O. Podolian and G. Tymchyk, , Quality control of couplings installation on the main pipeline. Kyiv. Ukraine: Igor Sikorsky KyivPolytechnic Institute, 2020. – 180 p.
[11] O.Podolian, “Method of pipeline strengthening using soldered-welded coupling”, RU patent 2563945, September 27, 2015.
[12] O.Podolian, “Method of strengthening the pipeline with the help of a braze-weld coupling”, UA patent 110155, Novemder 25, 2015.
[13] K. Whittington, “Ultrasonic testing at higt temperatures”, Phys. Techn. 1978. N 2. P. 62–67.
[14] K. Serhiienko et al., “Theoretical Investigations of the Ultrasonic Wave Generation by an Electromagnetic Acoustic Transducer“, Kyiv. Ukraine: KPI Science News, 2018, Vol.3(119), pp. 84–92.
[15] Cole P. “The generation and reception of ultrasonic surface waves in mild steel, at high temperatures”, Ultrasonic. 1978. № 4 (16) P. 151 – 155.
[16] V. Tsapenko and Yu. Kuts, “The Basis of Ultrasonic Non-Destructive Testing”, Kyiv. Ukraine: NTUU KPI, 2010. – 448 p.

Григорій С. Тимчик, Олександр О. Подолян, Катерина С. Сергієнко

ТЕХНОЛОГІЯ РЕМОНТУ ДІЮЧОГО МАГІСТРАЛЬНОГО ТРУБОПРОВОДУ З ВИКОРИСТАННЯМ ПАЯНО-ЗВАРНИХ МУФТ

Проблематика. Під час експлуатації магістральний трубопровід потребує ремонту. При періодичній діагностиці стану трубопроводів виявляються дефекти, частина з яких є неприпустимими. Класичний метод ремонту, що передбачає зупинку трубопроводу з подальшою заміною його дефектної ділянки, вимагає значних фінансових витрат і пов›язаний з вимушеним простоєм трубопроводом і порушеннями екології.

Мета дослідження. Вдосконалення технології ремонту ділянок магістрального трубопроводу високого тиску зварними муфтами, які заливаються розплавленим металом, що дозволяє отримати високу ефективність зміцнення труб середнього та малого діаметрів.

Методика реалізації. Підвищення міцності ділянок діючого трубопроводу реалізується за допомогою монтажу на діючий магістральний трубопровід паяно-зварних муфт. Посилення трубопроводу муфтою полягає в перерозподілі частини навантаження від труби на стінку муфти, що призводить до зниження рівня напруги в стінці труби. Ефективність посилення трубопроводу при цьому прийнято оцінювати ступінь зниження кольцевих напружень в стінці ремонтованої труби.

Результати дослідження. Запропонована методика підвищення міцності ділянок трубопроводів за допомогою муфт, що заповнюються розплавленим металом, що володіє високим модулем пружності. Запропоновані операції формування підмуфтового шару з параметрами, що забезпечують досягнення максимального значення ступеня зниження напружень в посилюваної трубі при забезпеченні рівномірного розподілу навантаження між стінкою ремонтованої ділянки трубопроводу і оболонкою муфти. Запропоновано вдосконалену технологію ремонту дефектних ділянок діючого трубопроводу, запропоновані конструкції торцевих ущільнювачів, що полегшують формування підмуфтового шару з оптимальними параметрами. Запропонована методика дозволяє підвищити ефективність посилення труб малих і середніх діаметрів.

Висновки. Запропоновано вдосконалену технологію підвищення міцності ділянок діючого трубопроводу за допомогою паяно-зварних муфт. Основну увагу приділено розробці конструкцій торцевих ущільнювачів, що забезпечують герметичність підмуфтового простору під час формування шару підмуфти.

Подальші дослідження передбачається проводити у напрямку розробки математичної моделі ділянки трубопроводу, посиленого паяно-зварною муфтою з урахуванням температурних змін у процесі нагрівання та охолодження муфтової конструкції при формуванні підмуфтового шару, а також у напрямку вдосконалення муфтових конструкцій та методів контролю якості їх монтажу на трубі.

Ключові слова: муфта; неруйнівний; контроль; діагностика; ремонт; газопровід; трубопровід; тиск; газ; переробна нафта; транзит.

Рекомендована Радою
Приладобудівного факультету
КПІ ім. Ігоря Сікорського

Надійшла до редакції
6 грудня 2021 року

Прийнята до публікації
27 червня 2022 року