ANÁLISE E SÍNTESE DA LITERATURA SOBRE OS ASPECTOS DA FUSÃO COM ELETRODO DE TIRA DURANTE A SOLDAGEM DE SUPERFÍCIES DE VEDAÇÃO DE ACESSÓRIOS DE TUBULAÇÕES

ANALYSIS AND SYNTHESIS OF LITERATURE ON THE ASPECTS OF STRIP ELECTRODE FUSION DURING OVERLAY WELDING OF THE SEALING SURFACES OF PIPELINE ACCESSORIES

АНАЛИЗ И ОБОБЩЕНИЕ ЛИТЕРАТУРНЫХ ДАННЫХ ОБ ОСОБЕННОСТЯХ ПЛАВЛЕНИЯ ЛЕНТОЧНОГО ЭЛЕКТРОДА ПРИ НАПЛАВКЕ УПЛОТНИТЕЛЬНЫХ ПОВЕРХНОСТЕЙ ТРУБОПРОВОДНОЙ АРМАТУРЫ

GALINSKY, Andrey A.[1*]; RYABKOV, Anton V.[2]; OGUDOVA, Evgeniya V.[3]

[1] Tyumen Industrial University, Department of Mechanical Engineering, 72 Melnikayte Str., zip code 625000, Tyumen – Russian Federation
(phone: +89199486170)

[2,3] Tyumen Industrial University, Transport of Hydrocarbon Resources Department, 72 Melnikayte Str., zip code 625000, Tyumen – Russian Federation
(phone: +89088745503; +89222694401)

** Corresponding author*
e-mail: Don-Andre-1990@yandex.ru

Received 21 June 2017; received in revised form 15 November 2018; accepted 20 November 2018

RESUMO

O artigo trata das peculiaridades da soldagem de sobreposição com eletrodos de tira nas superfícies de vedação de instalações dos tubos industriais para usinas nucleares (UNs). É realizada uma análise dos dados da literatura, publicações científicas e resultados de pesquisas sobre problemas relacionados à soldagem de sobreposição automática de um eletrodo de tira e escolhido o tipo mais favorável de superfície para a solda sobre superfícies de vedação dos encaixes de tubulações. O principal componente de qualquer tipo de instalação é uma superfície hermética que pode ser obtida usando solda a arco elétrico. Sobreposição de solda hermética é usada quando o material de encaixe impede que a superfície do obturador da válvula tenha uma qualidade de vedação satisfatória. As superfícies consideradas estão sujeitas a desgaste como resultado de atrito mútuo, efeitos dinâmicos e químicos do ambiente. A confiabilidade operacional e a durabilidade de uma instalação de tubulação para uma UN dependem da hermeticidade do obturador da válvula, determinada não apenas pelas propriedades da liga, mas também pela qualidade da hermeticidade da superfície. Soldagem de sobreposição pode ser uma das principais causas de defeitos; portanto, uma abordagem qualitativa e racional do processo tecnológico de soldagem é necessária, bem como os materiais para solda e a boa condição técnica de equipamentos e acessórios.

Palavras-chave: *soldagem de sobreposição automática, eletrodo de tira, aspectos da fusão, superfície de vedação.*

ABSTRACT

The paper considers questions about the features of strip electrode overlay welding of the sealing surfaces of industrial pipeline fittings for nuclear power plants (NPPs). The analysis of literature data, scientific publications and research results on problems associated with automatic overlay welding with strip electrodes are performed, and the most perspective type of a surfacing strip for overlay welding of the sealing surfaces of pipeline fittings is selected. The main component of any type of fittings is the sealing surface which can be obtained by electric arc overlay welding. Sealing overlay welding is used when the fitting material prevents

DOI: 10.52571/PTQ.SI1.2018.23_PeriodicoES.pdf

obtaining a satisfactory quality of the sealing seat surface. The surfaces considered are subject to wear as a result of mutual friction, dynamic and chemical impact of the medium. Operational reliability and durability of pipeline fittings for NPPs depend on the valve gate tightness determined not only by the properties of the alloy but also by the quality of the sealing surface. Overlay welding can be one of the main causes of defects; therefore, a qualitative and rational approach to the technological process of overlay welding, the availability of surfacing materials, and the technical condition of equipment and accessories are needed.

Keywords: *automatic overlay welding, strip electrode, aspects of fusion, sealing surface.*

АННОТАЦИЯ

В статье рассмотрены вопросы об особенностях наплавки полоскового электрода на герметичных поверхностях фитингов промышленных трубопроводов для атомных электростанций (АЭС). Проводится анализ литературных данных, научных публикаций и результатов исследований по проблемам, связанным с автоматической наплавкой полоскового электрода, и выбран наиболее перспективный тип наплавочной поверхности для наплавки на герметичные поверхности фитингов трубопроводов. Основным компонентом любого типа фитингов является герметичная поверхность, которая может быть получена с помощью электродуговой наплавки. Герметичное наложение сварки используется, когда материал фитинга препятствует получению удовлетворительного качества герметичности поверхности затвора клапана. Рассматриваемые поверхности подлежат износу в результате взаимного трения, динамического и химического воздействия среды. Эксплуатационная надежность и долговечность фитингов трубопроводов для АЭС зависят от герметичности затвора клапана, определяемого не только свойствами сплава, но и качеством герметичности поверхности. Наплавка может быть одной из основных причин дефектов; поэтому необходим качественный и рациональный подход к технологическому процессу наплавки, наличие наплавочных материалов и техническое состояние оборудования и принадлежностей.

Ключевые слова: *автоматическая наплавка, полосковый электрод, аспекты плавки, поверхность герметизации.*

INTRODUCTION

At present, three main types of electrode strips are the most widely used: cold-rolled, powder-coated and sintered. Let us note the identified features of their fusion. The nature of fusion of a cold-rolled electrode strip depends on the arc behavior at its end, which determines the productivity of fusion of the electrode material, the nature of the transfer of droplets to the weld pool, the depth and uniformity of penetration of the base metal, the physicochemical processes occurring when electrode metal droplets contact with the gas medium, slag, etc.

In contrast to the electrode wire, when welding with a cold-rolled strip, the arc moves irregularly along the end of the electrode. Due to the constant movement of liquid metal droplets along the edge of the strip, the position and number of discharges vary. Their behavior is determined by the complex effect of electrical, magnetic, chemical, and gas-dynamic factors. The arc tends to burn at the point of the smallest distance between the electrode and the product with minimal resistance and voltage drop (Matvienko *et al.*, 2013).

A large number of studies discuss the quality of overlay welding of the sealing surfaces of pipeline fittings for nuclear power plants (NPPs). The main requirements for sealing surfaces are high resistance to intergranular corrosion and hardness of 41.5-49.5 HRC. The weld metal of type 09Kh31N8AM2 meets these requirements. The following surfacing materials became common: electrodes for manual arc overlay welding UONI 13/N1-BK and ELZ-NV1; welding wire Sv-04Kh19N11M3 for submerged automatic overlay welding with flux ELZ-FKN-Kh32N8, as well as submerged or argon overlay welding with powder-coated wires PP-AN177A and PP-AN177P (Eremeev and Strelyaniy, 1990).

However, all the above-mentioned methods of overlay welding are advisable to use in the manufacture of the elements of pipeline fittings of complex shape and small diameters. The main problem of manufacturing parts with the nominal diameter DN> 50 mm is the low productivity of overlay welding of the sealing surfaces. To solve the problem, it is proposed to develop a new technology for automatic overlay welding of the sealing surface using a strip electrode. Automatic submerged overlay welding is the most effective and high-performance method of depositing a layer of metal of specified properties.

The purpose of the article is to analyze the results of strip electrode fusion in order to determine the most promising type of the surfacing strip for the development of a new technology for overlay welding of the sealing surfaces of pipeline fittings.

Objectives of this study are an improvement of the productivity of overlay welding of the sealing surfaces of pipeline fittings and the determination of the most promising type of surfacing materials.

MATERIALS AND METHODS

The rate of the electric stable discharge movement has a significant effect on productivity, depth of penetration and uniformity of fusion of the base metal. With the increasing mobility of the arc, the productivity increases and the depth of penetration decreases, the base metal fuses more evenly. The rate of discharge movement is determined by the values of the welding current, arc voltage, width and thickness of the electrode, deposition rate, composition of the shielding medium, and other factors (Gulakov *et al.*, 2006; Yakubovskaya *et al.*, 2018).

When depositing a strip, one or more arcs may burn on its end. The number of electrical discharges depends on the current, voltage and size of the electrode. At high voltage, only one arc burns. If the voltage between the strip and the product decreases, then several stable discharges arise, which move in a narrow area. The duration of existence of the arcs varies with the variation of the voltage and the current load. During submerged arc welding, the rate of the heating source movement can vary within 0.4-4.2 cm/s, and the burning time of several arcs is 0.001-0.015 s (Patskevich and Deev, 1974).

When welding with narrow strips (15-20 mm wide), the rate of the arc movement along the end of the electrode increases; with a further increase in the width of the strip, several arcs are formed on the end, the rate of movement of which decreases (Patskevich and Deev, 1974). With increasing thickness of the electrode, the mobility of the electric discharge decreases. With increasing deposition rate, the cycle of the arc movement becomes longer, and at high voltage, it becomes longer and has a greater mobility (Gulakov *et al.*, 2010).

As the welding current increases, the arc oscillation frequency increases, the mass, and diameter of the droplets decrease, and the number of droplets increases. However, for each strip size, there is a critical current at which the discharge movement rate does not change anymore, and a further increase in current leads only to the appearance of several simultaneously burning arcs (Oparin, 1981).

The fusion of the strip is characterized by the simultaneous transfer of metal, both in the sections of the column of the arc and in other places at the end of the electrode. In the arc burning region, the metal transfer has a small-droplet nature, while in other parts of the strip metal transfers as large droplets closing the interelectrode gap (Serenko *et al.*, 2012).

The time for the droplet formation varies from 0.03 to 0.7 seconds. It increases with direct polarity with an increase in the arc voltage and the width of the strip. With an increase in the welding current, droplets form faster, their number increases per unit of time, and the size decreases (Muratov, 2010).

As the arc voltage increases, fewer droplets but larger in size fall into the pool. Droplets come off the edge of the electrode under the action of gravity, as well as under the influence of electromagnetic forces and surface tension and fall into the weld pool. Droplets of the electrode metal float on the pool surface in the slag coating for a while and then pass into the deposited metal (Nosovskiy and Lavrova, 2011).

According to (Leshchinskiy *et al.*, 1985), the average droplet temperature at the electrode during overlay welding with the direct polarity is 1650 °C, with the reverse one – 1800 °C. These temperatures are a little lower than during welding with the electrode wire.

A larger contact surface of the strip and molten slag leads to an increase in the bridging current, which reaches 30-35% of the welding current. This causes electroslag fusion of the electrode and increased the productivity of its fusion. As the voltage increases and the width of the strip increases, the bridging current increases and the stability of the process of the strip fusion decreases (Nosovskiy and Lavrikova, 2009). Stability is largely dependent on the electrical conductivity of the slag (Matvienko *et al.*, 1985).

The process of fusing the powder-coated strip differs significantly from that of the cold-rolled strip. Due to the low electrical conductivity of the charge, the arc burns mainly on the shell of the strip and occupies only a part of the electrode end. Flashing-off of the powder-coated strip along its width due to the arc wander occurs unevenly (Starchenko *et al.*, 2011). In most cases, its movement has a certain regularity: the electric discharge quickly moves from one edge of the strip to the other and for a comparatively long time burns in extreme positions (Malikin and Oparin, 1981). The average duration of the movement cycle depends on the model parameters. With increasing current for overlay welding with the direct and reverse polarity, the cycle time decreases, and with increasing arc voltage, it increases. For most of the cycle, the heat source is located on the side walls of the stripped shell, and in the case of a powder-coated strip, this time is longer compared to a cold-rolled one.

With increasing current and voltage, the arc burning stability increases with the direct polarity greater than with the reverse (Paton, 1974). This feature of the behavior of the electric discharge at the end of the powder-coated strip significantly affects the nature of the electrode metal transfer, the chemical composition and the quality of overlay welding (Potskevich *et al.*, 1971).

During forced overlay welding with a powder-coated strip, 75-80% of the electrode metal is transferred to the weld pool as droplets, and the rest – through the charge, bypassing the droplet phase. The electrode metal transfer is carried out by large droplets with a diameter of 4-6 mm or more (Nikolaenko *et al.*, 1976).

As the current increases, the fusion rate of the electrode strip increases, the quantity and mass of droplets of all sizes increase, the speed of arc displacement across the end of the electrode increases, which melts more evenly, contributing to the homogeneity of the composition and the uniformity of the hardness distribution of the weld metal. Alignment of the chemical composition and properties of the weld metal is also facilitated by an increase in the intensity of convective flows in the weld pool.

Sintered strips differ from cold-rolled and powdered strips in electrical resistances and capillary structures (Matvienko, 2011; Oparin, 1970).

The fusion rate of the sintered strip, as well as the cold-rolled strip, is affected by heating of the stick-out strip by the heat of the welding arc, heating with the molten slag and passing current. However, the process of the strip fusion is characterized by a higher rate. Due to the porosity of the sintered tape, droplets of liquid metal actively wet the strip, spreading along its end and intensively impregnating the flashed-off portion of the strip end. In this regard, the heat of the arc is transferred to the porous electrode much more intensively than in the case of its usual transmission through a droplet during the fusing of the cold-rolled strip.

Resistivity (ρ) plays an important role in this process. As the electrode heating temperature (T) increases, it increases more sharply (Fig. 1) than in cold-rolled strips, and intensifies the process of fusing the strip. As a result of the increase in electrical resistivity, the amount of Joule heat released in the strip during the passage of the current increases (Formalev *et al.*, 2015; Formalev *et al.*, 2016). The latter contributes to a more intense fusing of the electrode and an increase in the productivity of the process (Razmyshlyaev *et al.*, 2009).

RESULTS AND DISCUSSION:

Based on the above data obtained and generalized in the course of the analysis of many research works in the field of fusion of various types of strip electrodes, it can be concluded that the most promising surfacing material for overlay welding of the sealing surfaces of pipe fittings with DN>50 mm is the surfacing strip produced by the sintering method. The main criterion for choosing a sintered strip is its high porosity which contributes to an increase in electrical resistivity, hence, its higher heating and increase in productivity. The advantage in comparison with powder-coated strips is the uniform distribution over the section and the length of alloying elements in the sintered strip, so the weld metal has a more uniform structure.

Based on the analytical review of the technical literature and scientific papers, the development of a new technology for overlay welding of 09Kh31N8AM2-type metal was initiated. An experimental batch of sintered strip LS-09Kh31N8AM2 was ordered at AO Vyksa Steel Works as the material for overlay welding.

CONCLUSIONS:

The authors have made an analysis and synthesis of literature data, scientific publications and research results on problems associated with automatic overlay welding with strip electrodes are performed, and the most perspective type of a surfacing strip for overlay welding of the sealing surfaces of pipeline fittings was found. The most promising surfacing material for overlay welding of the sealing surfaces of pipe fittings with DN>50 mm is the surfacing strip produced by the sintering method.

On the basis of theoretical review of the technical literature and scientific papers, an experimental surfacing material of grade LS-09Kh31N8AM2 was developed for automatic electric arc overlay welding under a flux that was manufactured at AO Vyksa Steel Works. Currently, the welding and overlay welding laboratory of the Tyumen Industrial University is working on the development of an automatic overlay welding technology under a layer of flux with a sintered ceramic strip.

REFERENCES:

1. Matvienko, V.N., Leschinskiy, L.K., Mazur, V.A. *Herald of PSTU. Series: Engineering*, **2013**, *26*, 144-150.
2. Gulakov, S.V., Matvienko, V.N., Nosovskiy, B.I. *Surfacing with a flux strip electrode*, Mariupol: PSTU, **2006**.
3. Patskevich, I.R., Deev, G.F. Surface phenomena in welding processes, Moscow: Metallurgiya, **1974**.
4. Gulakov, S.V., Burlaka, V.V., Psareva, I.S. *Herald of PSTU*, **2010**, *20*, 176-180.
5. Oparin, L.I. *Automatic Welding*, **1981**, *8*, 61-64.
6. Serenko, A.N., Lavrova, E.V., Ivanov, V.P. *Herald of PSTU. Series: Engineering*, **2012**, *25*, 124-131.
7. Muratov, V.A. *Herald of PSTU*, **2010**, *20*, 187-193.
8. Nosovskiy, B.I., Lavrova, E.V. *Herald of PSTU. Series: Engineering*, **2011**, *22*, 166-169.
9. Leshchinskiy, L.K., Matvienko, V.N., Lavrik, V.P. *Automatic Welding*, **1985**, *9*, 60-62.
10. Nosovskiy, B.I., Lavrikova, E.V. *Herald of PSTU. Series: Engineering*, **2009**, *19*, 192-195.
11. Matvienko, V.N., Leshchinskiy, L.K., Belousov, Yu.V. *Welding*, **1985**, *5*, 32-33.
12. Starchenko, E.G., Mastenko, V.Yu., Volobuev, Yu.S., Khodakov, V.D. *Welding*, **2011**, *10*, 22-27.
13. Paton, B.E. *Technology of electrical welding of metals and alloys by fusion*, Moscow: Mashinostroenie, 1974.
14. Nikolaenko, M.R., Kuznetsov, L.D., Kortelev, G.A. *Welding*, **1976**, *6*, 33-35.
15. Formalev, V.F., Kuznetsova, E.L., Rabinskiy, L.N. *High Temperature*, **2015**, *53(4)*, 548-553.
16. Formalev, V.F., Kolesnik, S.A., Kuznetsova, E.L., Rabinskiy, L.N. *International Journal of Pure and Applied Mathematics*, **2016**, *111(2)*, 303-318.
17. Yakubovskaya, S.V., Krasovskaya, N.I., Silnitskaia, N.Y. Simulation of the stress-strain state for longlength flexible pipes. *Periódico Tchê Química*, **2018**, *15(30)*, 670-678.
18. Oparin, L.I. *Automatic Welding*, **1970**, *3*, 19-23.
19. Potskevich, I.R., Rykov, A.M., Sokolovskiy, V.M. *Welding*, **1971**, *4*, 27-28.
20. Razmyshlyaev, A.D., Mironova, M.V., Deli, A.A. *Welding*, **2009**, *1*: 4-7.
21. Eremeev, V.B., Strelyaniy, Yu.V. *Automatic Welding*, **1990**, *5*, 49-52.
22. Malikin, V.L., Oparin, L.I. *Automatic Welding*, **1981**, *6*, 45-47.
23. Matvienko, V.N. *Herald of PSTU. Series: Engineering*, **2011**, *22*, 169-176.

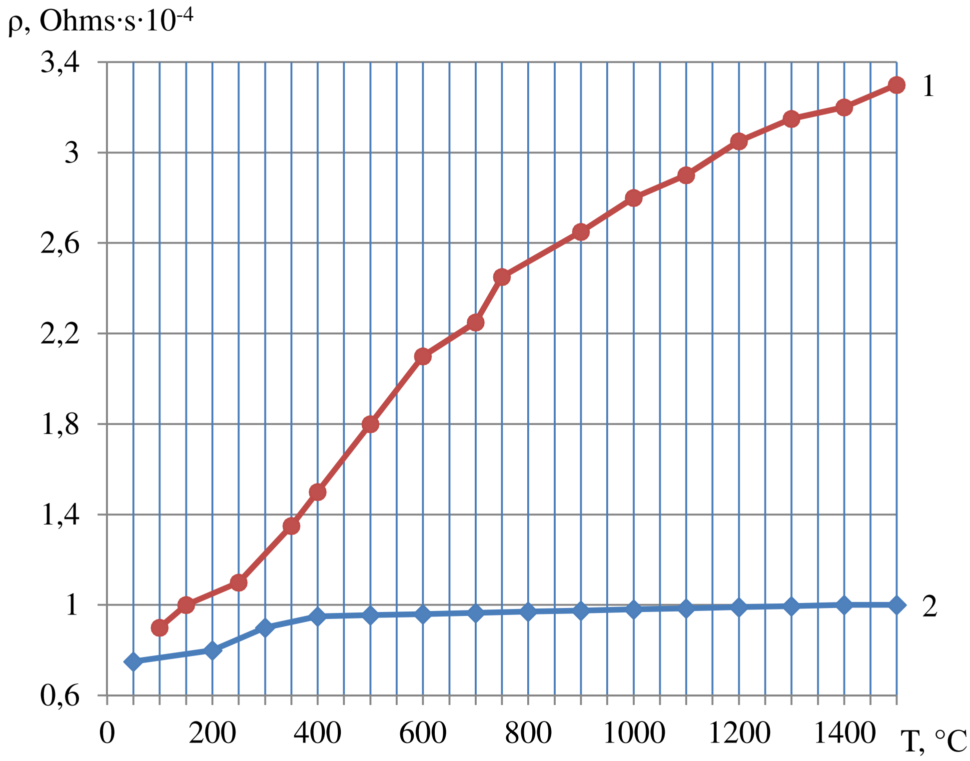

Figure 1. *Dependence of the electrode strip resistivity ρ on temperature: 1 – sintered strip LS-70Kh3M, 2 – cold-rolled strip 70Kh3M*