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INVESTIGATION OF THE STRESS-STRAIN STATE OF MARTENSITIC STEEL 15CR5MO TUBE SITE IN THE PROCESS OF DIFFUSION WELDING

ИССЛЕДОВАНИЕ НАПРЯЖЕННО-ДЕФОРМИРОВАННОГО СОСТОЯНИЯ ТРУБНОГО УЗЛА МАРТЕНСИТНОЙ СТАЛИ 15Х5М В ПРОЦЕССЕ ДИФФУЗИОННОЙ СВАРКИ

V.A. Minkevich, A.M. Fairushin, R.R. Chernyatyeva, D.V. Karetnikov
FSBEI of HPE "Ufa state petroleum technological university",
Ufa, the Russian Federation

Минкевич В.А., Файрушин А.М., Чернятьева Р.Р., Каретников Д.В.
ФГБОУ ВПО «Уфимский государственный нефтяной технический университет», г. Уфа, Российская Федерация

e-mail: minkei@mail.ru

Abstract. The important task of the engineering industry today is the use of reliable and at the same time inexpensive materials in the construction of oil and gas and refining equipment. Heat-resistant steels of martensitic class 15Cr5Mo belongs to the category of such materials, it has good strength and corrosion resistant feature – at high temperatures and simultaneous with low cost

The peculiarity fabrication of pipe spools and other basic elements of steel petrochemical equipment of 15Cr5Mo, includes accompanying pre-heating and the immediate and subsequent heat treatment of the a strict observance of temperature and time parameters of the process. These activities are carried out in order to remove residual welding stresses and to prevent cold cracking during welding and make the process of making the steel 15Cr5Mo the basic elements energy-intensive and time-consuming, and in some cases impossible to make basic elements. Therefore, one of the modern trends of technology modernization welded oil and gas processing equipment from martensite steels is an elimination from the traditional techniques of arc welding.

This paper presents the results of numerical modeling of diffusion welding of a pipe spool made of martensite steel 15Cr5Mo. The analysis of stress and strain state in a welding joint under the conditions of diffusion welding process is carried out, on the basis of which the possibility of diffusion welding of a pipe spool made of martensite steel 15Cr5Mo is shown without buckling of pipe billets**.** The calculation of temperature fields, stress and strain fields of a welding joint is made.

Аннотация. Важной задачей, на сегодняшний день, в машиностроительной отрасли является применение надежных и в тоже время недорогих материалов при конструировании нефтегазового и нефтеперерабатывающего оборудования. К разряду таких материалов можно отнести жаропрочную сталь мартенситного класса 15Х5М, которая при своей невысокой стоимости обладает хорошими прочностными и антикоррозионными свойствами при высоких температурах.

Особенность изготовления трубных узлов и других базовых элементов нефтехимической аппаратуры из стали 15Х5М, заключается в необходимости предварительного, сопутствующего подогрева и незамедлительного проведения последующей термообработки со строгим соблюдением температурно-временных параметров процесса. Данные мероприятия проводятся с целью

снятия остаточных сварочных напряжений и предотвращения образования холодных трещин в процессе сварки и делают процесс изготовления базовых элементов из стали 15Х5М энергозатратным и трудоемким, а в некоторых случаях практически невозможным. Поэтому одним из современных направлений модернизации технологии изготовления сварного нефтегазоперерабатывающего оборудования из мартенситных сталей является уход от традиционных технологий дуговой сварки.

В данной работе приводятся результаты численного моделирования диффузионной сварки трубного узла из мартенситной стали 15Х5М. Проводится анализ напряженно-деформированного состояния в зоне сварного соединения в условиях проведения процесса диффузионной сварки, на основании которого показана возможность диффузионной сварки трубного узла из мартенситной стали 15Х5М, без потери устойчивости заготовки. Проведен расчет температурных полей, полей напряжений и деформаций сварного соединения.

Key words: diffusion welding, tube billets, ring joint, stress-strain state, martensite steel.

Ключевые слова: диффузионная сварка, трубные заготовки, кольцевой стык, напряженно-деформированное состояние, мартенситная сталь.

It is known that fusion welding of heat-resistant martensite steel frequently results in cold cracking in the weld seam, in the heat-affected zone and the parent metal, it also results in stress and strain, that in some cases may adversely affect the quality of a welded construction. Welded constructions production causes changes in shapes and sizes of workpieces and a lot of efforts are made to reproduce original dimensions. This is mainly due to the peculiarity of thermal strain processes taking place by using the welding arc. Thus, the use of fusion welding for modern heat-resistant materials is limited and requires special measures [1]. In this case it is necessary to consider other welding methods which considerably improve the quality of steel weldability.

The proper technical process build-up of assembly and welding, as well as the choice of rational welding conditions usually helps to avoid excessive stress and strain [2]. Nowadays, there are many different welding methods which are carried out without material melting and irreplaceable for modern alloy compounds production, which alsoprovide the fidelity and high quality of workpieces [3]. Diffusion welding is widespread among such methods. However, this method of welding for martensite steel is slightly studied.

The possibility of diffusion welding of a pipe spool made of martensitic steel 15Cr5Mo was determined by examining stress-strain state in the process of welding under the conditions of welded units buckling absence.

The analytical methods and equations for estimating stress-strain state in welding joints are not highly accurate and only help to estimate the expected distortion of the shape and dimensions of the welding joint of a simple welded construction. They are based on the results of each weld overlaying in the form of force and displacement, which afterwards can be used for calculating the shape and size of constructions by the method of material resistance. Nowadays numerical modeling and experimental methods are the most universal and reliable ones.

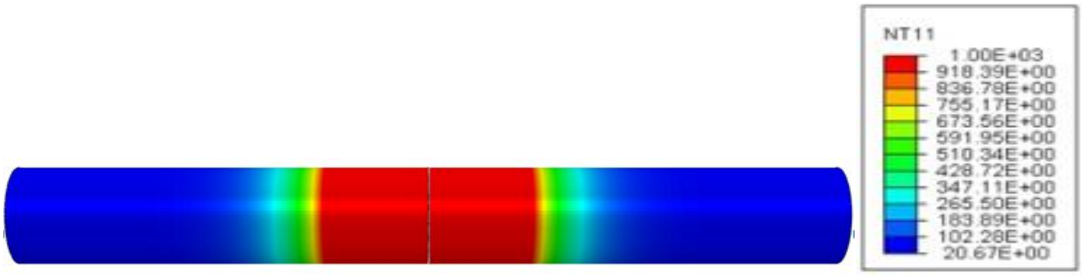
The finite element method is the most modern and accurate method of calculation which allows to estimate the stress-strain state of a workpiece on the surface and inside. The finite element method comprehensively allows to study process in terms of thermal and mechanical tasks, to consider plastic strains and creeping and hardening of a material. Therefore, the finite element method implemented in the software package ABAQUS is used in this paper to estimate temperature and stress fields and strains [4].

Picture 1 shows the model of a pipe spool and the heating section estimated by geometrical parameters of a heating pad, which is used for local thermal processing and can withstand temperature up to 1200°C. The following pipe spool parameters for this model development are used : martensite steel 15Cr5Mo with159 mm in diameter and 8 mm in wall thickness, heated metal section 300 mm wide, compressive load in the joint section equalling 20 MPa and holding time equalling 15 minutes.

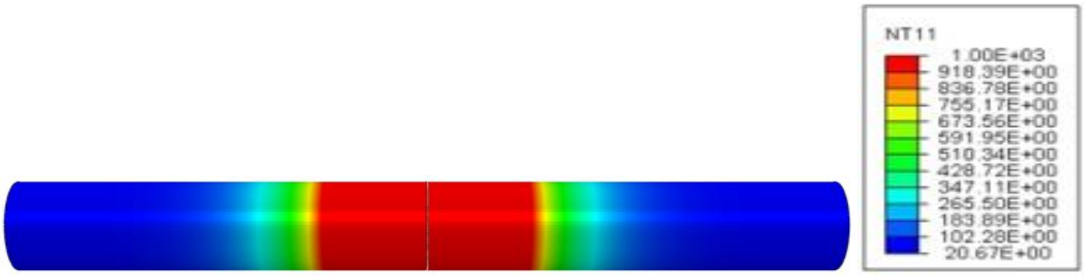
Welding conditions selection was based on available studies in this field and includes the following parameters: maximum temperature heating equals 1000°C, the pressure of a welding surface equals 20 MPa, the holding time at maximum temperature equals 15 minutes [5].

Picture 1. the model of a pipe spool

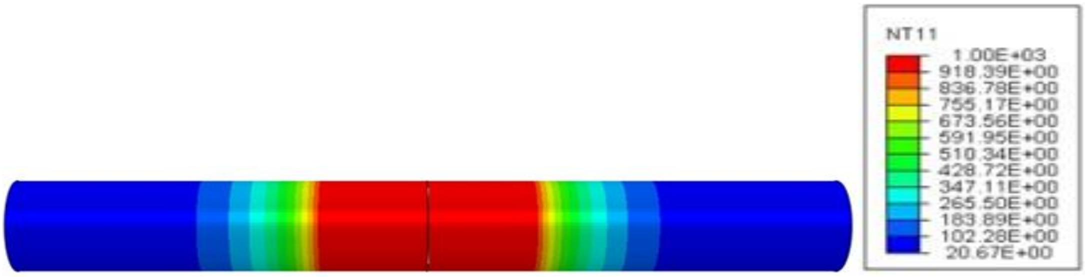
Thermal field distribution during welding process is depicted in Picture 2.



A



B



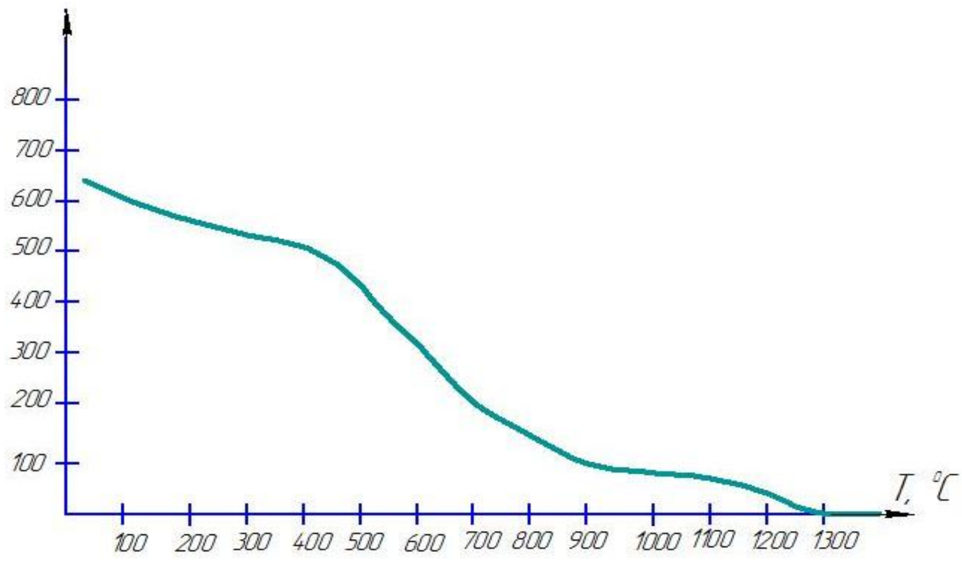
C

Picture 2. Thermal field distribution in the process of welding of pipe billets

A - at the initial time of welding, B - 10 minutes after the initial time of welding, C - at the end of welding

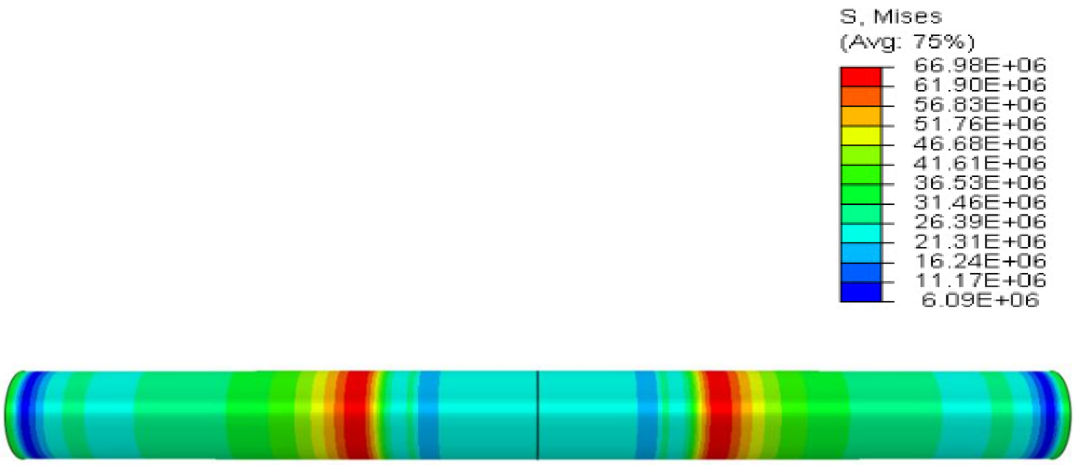
It is necessary for producing a high-quality welding joint to perform diffusion welding in the solid phase without the strain of welding billets. And it is possible if stress and strain in the weld assembly caused by welding process don't exceed the yield strength of a material at temperatures of processes. Therefore, it's necessary to take it into account while selecting a welding condition.

The graph for steel 15Cr5Mo was experimentally constructed in picture 3 which depicts the dependence of yield strength under compression on temperature. The graph shows that at the welding temperature of 1000 °C the yield strength of steel 15Cr5Mo equals 75 MPa.



Picture 3. The graph of yield strength under compressive steel 15Cr5Mo at different temperatures

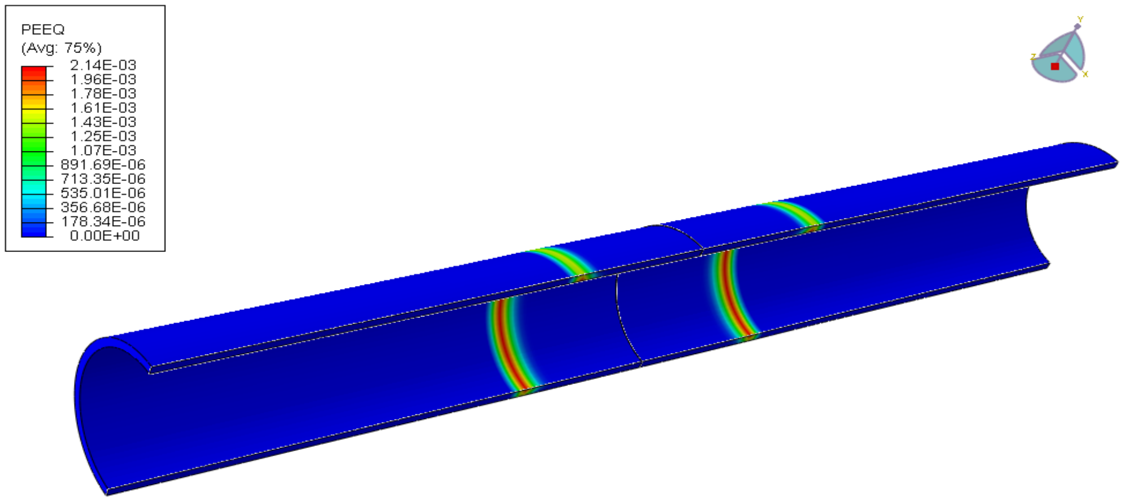
Stress distribution in welding pipe billets in the process of welding (after 15 minutes of welding at a temperature of 1000 °C under compressive load in the section of the welding joint) is depicted in picture 4.



Picture 4. Stress distribution in welding pipe billets in the process of diffusion welding, MPa

It was estimated that maximum stress is at the point of temperature drop and equals 66,98MPa. This point is the most dangerous but not critical because the yield strength at the given temperature for steel 15Cr5Mo equals 75 MPa. So, conducted studies have shown that the given pipe billet doesn't lose stability under the condition of diffusion welding and it allows to consider the method of diffusion welding for connecting pipe spools made of steel 15Cr5Mo[6, 7].

The results obtained in the temperature cycle are used in the model of the structural analysis as a load to estimate residual strains which are caused by thermal strain cycle. Equivalent strain distribution after pipe spool welding is depicted in picture 5.



Picture 5. Equivalent strain distribution after pipe spool welding

This study shows that the highest concentration of stress and strain is at the point of temperature drops while equivalent residual strains reach 0,2%.

Conclusions

1) Conducted studies have shown that maximum stress during diffusion welding occurs at the point of temperature drops and equals 66,88MPa, which is an acceptable condition for welding process. Equivalent residual strains during welding process reach 0,2%.

2) The results of these studies can be used for the development of technology of diffusion welding of basic units of oil and gas refining equipment made of heat-resistant martensite steel.

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Information about authors

Сведения об авторах

V.A. Minkevich, Postgraduate Student, "Petroleum Apparatus Building Technology" department, FSBEI HPE USPTU, Russian Federation

Минкевич В.А., аспирант кафедры «Технология нефтяного аппаратостроения», ФГБОУ ВПО УГНТУ, г.Уфа, Российская Федерация

A.M. Fairushin, Candidate of Technical Sciences, Associate Professor of the Chair "Petroleum Apparatus Building Technology" FSBEI HPE USPTU, Russian Federation

Файрушин А.М., канд. техн. наук, доцент кафедры «Технология нефтяного аппаратостроения», ФГБОУ ВПО УГНТУ, г.Уфа, Российская Федерация

R.R. Chernyatyeva, Candidate of Physical-Mathematical Sciences, Associate Professor of the Chair "Mathematics", FSBEI HPE USPTU, Russian Federation

Чернятьева Р.Р., канд. физ.-мат. наук, доцент кафедры «Математики», ФГБОУ ВПО УГНТУ, г.Уфа, Российская Федерация

D.V. Karetnikov, Candidate of Technical Sciences, Associate Professor of the Chair "Petroleum Apparatus Building Technology" FSBEI HPE USPTU, Russian Federation

Каретников Д.В., канд. техн. наук., преподаватель кафедры «Технология нефтяного аппаратостроения», ФГБОУ ВПО УГНТУ, г.Уфа, Российская Федерация

e-mail: minkei@mai.ru