ABSTRACT

of the thesis for the degree of Doctor of Philosophy (PhD)
on the specialty 6D071000 - Materials Science and Technology of New Materials

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OPTIMIZATION OF PHASE STRUCTURE AND STRUCTURE BECAME FOR PRODUCTION OF OIL AND GAS WIRE PIPES

Assessment of the current state of solved scientific and technological problems (tasks). Currently, there is a tendency to toughen the operating modes of downhole equipment, including tubular columns, and a significant increase for work requiring round trip operations in the field of oil and gas production. This is due to the development of more and more remote oil and gas fields located in areas with unfavorable, often harsh climate. Because of this, there is an urgent need to improve the requirements for the quality of metal pipes.

The most common causes of accidents black (uncoated) tubing and casing are corrosion, thread wear and fatigue damage. According to field statistics, the number of accidents with tubing in some cases reaches 80% of the total number of accidents in downhole equipment, while the vast majority of damage occurs through threaded connections. According to the results of the qualimetric analysis of the operational reliability of tubing carried out by Russian specialists at fields in Western Siberia, Orenburg and Samara regions, the failures associated with the threaded connection (destruction, loss of tightness, etc.) are dominant (about 50%). According to the American Petroleum Institute (API), due to the destruction of threaded connections, the number of accidents of tubing is 55%.

Pipe-rolling products of manufacturers from Kazakhstan (on the example of KSPSteel LLP, which produces seamless pipes for oil and gas), faced with the need to improve technology to improve the quality of pipe connections. It was revealed when testing the pipes that some pipes are able to withstand up to 20 multiple dives and lifts during operation, and certain batches of pipes do not withstand repeated immersions, since there is a failure of threaded connections. Pipe companies systematically carry out work aimed at improving the quality of production of drill, casing and tubing pipes in modern conditions. A part of oil companies (for example, Transneft JSC) set technical requirements for the quality of metal and branches at a higher level than the requirements of all known international standards when implementing projects for the construction of oil pipelines. Quality control of the metal according to the banding of the structure, grain size, metal contamination by non-metallic inclusions, and impact toughness on specimens with a sharp notch at -40^0C was introduced. Such requirements are aimed at improving the quality of metal and pipes intended for the manufacture of pipes. There is an urgent need to develop methods or programs for the automated implementation of the necessary control operations (measurement) for monitoring the parameters of the heterogeneity of the steel structure.

Pipe companies systematically carry out work aimed at improving the quality of casing and tubing production. TMK OJSC (leader in the market for the production and sale of oil and gas pipes) has created a special division of TMK-Premium Service LLC, which is developing new designs of premium-class threaded connections.

Gazprom OJSC pays great attention to the development of the production of casing pipes from high-strength corrosion-resistant steels. Rosneft OJSC uses casing pipes with threaded connections, which allow transferring increased loads during the descent of the columns with rotation (VAM TOP connections). Lukoil OJSC suppose that it is necessary to use heat-treated, resistant to carbon dioxide and sulphide types of corrosion of pipes made of steel alloyed with chromium, molybdenum, niobium and other elements for wells in difficult geological conditions.

As for the development and implementation of pipe protective coatings, here we can single out the work of such scientists and industrialists as Chizhov I.A., Pachkolina P.A., Proskurkin E.V., Bolshakov V.I., Dergach T.A., Petrov I.V., and Dmitriev V.B.

Scientists of the Ural Federal University named after B.N. Yeltsin were studied protective coatings, as one of the perspective ways to increase the service life of the threaded connection "pipe-coupling", studied the performance properties of coatings on pipe steels 45, 30G2, 37G2F and 37G2S of different strength groups.

Scientists and industrialists are engaged in the direction of improving the quality of oil and gas pipes. The leader in the production, introduction of new technologies in the production of oil and gas pipes and pipe sales are TMK OJSC, Federal State Unitary Enterprise (FSUE) I.P. Bardin, and Gazprom. Scientists as Vyboyschik M.A., Ioffe A.V., Kudrya A.V. (scientific consultant), Matrosova M.Yu., Filippova G.A., Pyshmintseva I.Yu., scientists of the Ural Federal University named after the first President of Russia and National University of Science and Technology “MISiS” can be identified among the main modern scientists who are closely involved in the issue of improving the quality of oil and gas pipes.

In this dissertation, for the first time, the task is to quantify the heterogeneity and quality of oil and gas pipe structures. A group of materials scientists under the leadership of Dr. Professor Kudrya A.V. (MISiS) engages with the problems of quality control of pipe products at all stages using information technology methods. Only the production map method is used under production conditions, which does not provide for specific measurements of structural parameters. There are also only classic GOSTs designed for individual measurement forms.

In the light of the above, there is an urgent need to develop methods or programs for the automated implementation of the necessary operations to control the heterogeneity of pipe steel: measuring the stripes of the structure, grain size, steel contamination by nonmetallic inclusions.

The base and the initial data for the development of the theme. The hardening of oil and gas pipes, improving their performance properties and

ensuring quality guarantees for oil pipe mixes in modern production conditions are mainly achieved through the use of the following methods: developing new and improving well-known pipe steel marks; using of new alloying, micro alloying and modifying elements, additives such as niobium, boron, titanium, molybdenum, vanadium, and others; development of new types of pipe connections; introduction of sections of the internal smooth and outer polyethylene coating; use of additional operations: phosphating of coupling compounds, coating of pipes with polymeric insulating, glass-enamel coating, waterproofing protective lacquer; development of such protective coatings as galvanic, thermal diffusion, hot, diffusion iron-zinc galvanizing, etc.

A significant disadvantage of all the above methods is their relatively high cost or fragility of the results. Whereas at present, the task of reducing electricity consumption and rational use of expensive and scarce alloying elements without reducing the level of technological and mechanical characteristics of the final product acquires great importance.

Therefore, in our opinion, one of the effective and promising ways to solve the problem of hardening pipe steels is the optimization of the phase composition and structure of the steel for the production of oil and gas pipes that satisfy modern quality requirements. The correct choice of the optimal phase composition and structure of the steel not only satisfies certain requirements for the quality of oil and gas pipes, but also provides for the regulation and possible elimination of blunders and deviations in structure and properties leading to sorting and marriage of individual pipe batches.

Relevance of the topic. In connection with the toughening of the working conditions of the oil and gas pipe assortment, the failure of pump-compressor and casing pipes or their connections is increasingly observed. For this reason, oil-producing enterprises are tightening technical requirements for the quality of pipes and steel and set them at a higher level than the requirements of all international standards. Control of steel in terms of the banding of the structure, grain size, steel contamination with non-metallic inclusions, impact strength is introduced. These requirements are aimed at increasing the service life and operational reliability of pipes and their connections.

It was revealed in the course of the study that there are scattered costly programs and techniques that allow to perform a number of labor-intensive metallographic tasks, for example, described in GOST 5639-82 “Steel and alloys. Methods for detection and determination of grain size: method for determining grain size by comparison with reference scales; grain counting method; methods for counting grain boundary intersections; chord length measurement method", GOST 1778-70 (Steel. Metallographic methods for the determination of nonmetallic inclusions) and GOST P 54570–2011 (Steel. Methods for assessing the degree of banding or orientation of microstructures). These methods are characterized not only by laboriousness, but also by a certain subjective component. At the same time there is a huge number of computer programs that allow you to automatically perform computational and graphical operations for processing arrays of data and images in various fields of science and technology.

Scientists in the field of mathematics and programming have developed promising theories and techniques of mathematical and binary morphology, which have found their application in limited areas that do not include the field of materials science Initially, it would be promising to use such an approach to solve quantitative materials science problems.

However, there is no single universal method for controlling the structure of steel not only by non-metallic inclusions and grain size, but also by definition of anisotropy and line structure, size and amount of a specific structural component (strengthening or softening) of its share and distribution density, which, in general, determine the mechanical characteristics of the finished product. The development of such a technique would solve the problem of optimizing the phase composition and structure of steel for the production of high-quality oil and gas pipes with a guaranteed complex of mechanical properties.

In this regard, the thesis is devoted to the development of modern efficient computer techniques aimed at determining the quality indicators and optimizing the phase composition and structure of steel for the production of oil and gas pipes with the required set of properties.

Aims of the work:

- development of new computerized procedures (programs) aimed at defining and regulating the structural heterogeneity of pipe steels;
- establishing the relationship of the quantitative parameters of the heterogeneity of the structure with a complex of mechanical properties;
- development of scientific bases for optimizing the phase composition and structure of steel for the production of oil and gas pipes with high quality indicators.

The objects of research are samples of traditional pipe steel grades and images of their structures.

The subject of research is the method of quantitative description of structures using modern computer programs.

The objectives of the study, their position in the performance of research work in general

– to develop a methodology for optimizing the phase composition and structure of steel as a tool for regulation, quality control of metal of oil and gas pipe;

– to develop a universal method for quantitative assessment of not only steel structures, as well as the determination of anisotropy and the index of stripiness and contamination of metal of pipes by non-metallic inclusions to control the quality of oil and gas pipes;

– theoretical and practical substantiation of the possibilities and prospects of the developed methodology for the quantitative assessment of structures;

– to develop domestic computer (technology) procedures - a technique of digital registration and description of image structures for the prediction of mechanical properties of steel by structure in order to increase their operational parameters and resources;

– to investigate changes in the structure of steel depending on the choice of steel grade and changes in the production technology of pipes using computerized means of observation and measurement of structures based on fundamentally sound algorithms for describing their heterogeneity;

– to determine the optimal phase composition and structure of steel for the production of casing and tubing by comparing a number of steel grades used to manufacture the above mentioned pipes;

– to determine the optimal structure of tubular steel that satisfies the requirements for the quality of the finished product;

– to explore the effect of electrolytic-plasma treatment on the structure and properties of tubular steel.

Scientific novelty of the thesis:

– digital image processing algorithm for pipe steel structures (and other materials) was proposed;

– software and methods for quantitative assessment of steel structures using computerized procedures were developed;

– a method for determining the optimal phase composition and structure of steel for the production of seamless tubing and casing pipes that meet modern requirements was proposed;

– automated methods of quantitative processing of images of pipe steel structures developed in the thesis are universal and allow replacing classical standard metallographic methods that are labor intensive;

– for the first time, electrolyte-plasma treatment was tested to harden pipe steel grade, the effect of electrolytic plasma treatment (EPT) on the structure and hardness was studied.

Provisions for the defense

Puted forward hypotheses:

– the hypothesis of a direct interrelation between heterogeneity and quantitative parameters of the structure of steel (geometry, quantity, size and volume fraction of structural components) with its mechanical properties was proposed;

– not only the chemical composition and processing of steel determine and initiate the final complex of properties and operational reliability of oil and gas pipes, but also quantitative indicators and heterogeneity of the structure;

– management of structure formation (by optimizing the phase composition and structure of steel) is a tool for regulating and controlling the quality of the metal of oil and gas pipes, eliminating blunders on the quality of the finished product.

The following provisions were developed on the basis of the proposed hypotheses:

– new information about the possibilities of computer determination of the quantitative parameters of the structure of steel for the production of high-quality oil and gas pipes;

– methodological developments (computerized procedures) on the principles of quantitative and qualitative analysis of images of pipe steel structures, using as

an example image analysis of the structures of pipe steel grades 35G2, 40G, steel 30, 32G2S, 38XNM;

– new technical solution according to the method of electrolytic-plasma hardening of samples of pipe steel grades on the example of steel 40G.

The practical significance of the thesis

The universality of computer technologies (procedures) developed and used in work and the possibility of using computerized procedures for quantitative and qualitative image processing of pipe steel structures for the purpose of optimizing the phase composition, structure and improving the quality of oil and gas pipes are shown. The effect of electrolytic-plasma treatment on the structure and properties of tubular steel has been investigated.

Research and development results described in the thesis are recommended for introduction into the pipe industry, as well as have a great perspective in order to manage, regulate and control the quality of the finished product.

Approbation of the thesis. 10 scientific articles, including 2 articles with impact factor were published on the topic of the thesis.

The main provisions and results of the research were presented and discussed at the I International Scientific and Practical Conference "Technology of Mechanical Engineering and Materials Science" (Russia, Novokuznetsk, 2017); International scientific-practical conference "Integration of science, education and production - the basis for the implementation of the Plan of the Nation" (№9 Saginov readings) KSTU (Kazakhstan, Karaganda, 2017); XI International Scientific and Practical Conference "INTERNATIONAL INNOVATION RESEARCH" ICSC (Russia, Penza); IX Eurasian Scientific and Practical Conference "Strength of heterogeneous structures" NUST "MISiS" (Russia, Moscow, 2018), report on the topic of the thesis was awarded a diploma and a gold medal.

The structure and volume of the thesis. The thesis consists of introduction, 5 chapters, conclusion, list of references. The main text of the thesis set out on 134 pages of typewritten text, contains 64 figures, 22 tables, the list of references consists of 153 titles.