A comprehensive study of steel properties in trunk oil and petroleum product pipelines with various service lives

by Dr Y.V. Lisin[1], D.A. Neganov[1], E.P. Studyonov[1], S.V. Skorodumov[1]*, and G.E. Antipov[2]
1 Pipeline Transpoirt Institute, Moscow, Russian Federation
2 Transneft PJSC, Moscow, Russian Federation

THE ARTICLE EXAMINES the approaches of a number of scientific institutions to the degradation of mechanical properties in pipe steels which may occur over long-term service life. It also presents the results of research into the actual mechanical properties and chemical composition characteristics of pipe steels with various service lives. The classification (ranking) of pipe steels of various grades used by PJSC Transneft is presented according to the criteria of length, service life, manufacturer, regulatory documents for supply, etc.

The pipe steels are grouped according to their actual mechanical properties: ultimate strength, elongation, impact toughness, and chemical composition characteristics.

Key words: pipe steels, mechanical properties, pipe steel grouping, standard and special tests

The development of approaches to assessing changes in pipe steel characteristics while in operation

At the present, there are several approaches to assessing changes in pipeline steel characteristics over long-term operation have been developed; the best-known scientific institutions specializing in this field are:

- Nizhny Novgorod University (Research Institute for Physics and Technology at Lobachevsky State University of Nizhnyi Novgorod) analyses the physical mechanisms of ageing processes in low-carbon low-alloyed pipe steels used in trunk pipelines. Ageing is attributed to the diffusion-controlled movement of carbon atoms towards lattice defects and the formation of carbide particles at the grain boundaries [1].

  The methodology of relaxation tests is suggested with an evaluation of the macro-elasticity limit, as the most sensitive parameter to ageing processes in pipe steels. The university is known for organizing the 2010 conference on 'The problems of steel ageing and resources in trunk pipelines'.

- The I.P.Bardin Central Research Institute for Ferrous Metallurgy [2-8] studies the impact of long-term operation and hydraulic tests on the mechanical properties and fracture resistance characteristics of pipe steels. As such, the fracture

*Corresponding author's contact details:
email: SkorodumovSV@niitnn.transneft.ru

resistance characteristics of metal are shown to decrease. Pipe steel properties degrade due to local micro-stresses in the structure of the metal, deformational ageing processes and the build-up of defects such as micro-cracks. Here, authors employ the internal friction method to assess the concentration and mobility of point defects, dislocation structure, and the kinetics of initial stages of ageing.

- The research team at Togliatti State University [9-12] specializes in using acoustic emission methods to inspect materials and structures, and to evaluate material resources.

- Representatives of Belgorod National Research University are conducting studies into the assessment of resource and the durability of pipeline materials with various functions, including those for nuclear industry.

- The team at the quality and reliability laboratory for gas pipeline and gas field equipment materials at the Baikov Institute of Metallurgy and Material Science, Russian Academy of Sciences [19] has shown that the mechanical properties of trunk oil pipeline steels observed on standard samples in pipes after both long-term operation and from emergency reserves are practically the same. Over long-term operation under design conditions, the efficiency of microscopic mechanisms of hardening and embrittlement in pipe steel remains practically unchanged. Substructural heterogeneity in pipe metal, acquired during production causes significant dispersion of impact toughness values at different stages of operation.

  However, impact toughness characteristics are crucial when dealing with the laws of pipe metal degradation over long-term operation in trunk oil pipelines.

- ZAO Melnikov Central Research and Design Institute of Steel Structures [14-15] has also been working on assessing the tendency for deformational ageing.

- The scientific Institute of Energy Supply Transport has formulated recommendations [16-18] according to which operating pressure should be reduced in comparison to design pressure as the pipeline ages (up to 29% when operating life exceeds 30 years).

Overall, the extensive and diverse studies carried out nationally and abroad cannot offer a clear-cut answer as to how long-term operation affects the performance of trunk oil pipelines and petroleum-product pipelines.

Systematic studies into the properties of structural low-alloyed steels

Since 2000, Transneft PJSC and the Pipeline Transport Institute, in co-operation with Baikov Institute of Metallurgy and Material Science, and IMASH RAN (the Mechanical Engineering Research Institute of the Russian Academy of Sciences), have been conducting research into the actual properties of pipe steels, including durability and resources for pipelines in long-term operation [21].

The basic results of this research are:

- there was no evidence of significant change to structural parameters and basic mechanical properties, characterising the reduction in static deformation resistance and damage resistance in pipe metal;

- structural indications of low-cyclic fatigue only appear in natural and artificial defect zones and are purely local;

- pipeline leakage or failure occur in zones of operational defects;

- strength characteristics (yield strength and ultimate strength) in steels of pipes that have been operated, before and after bench tests, and those from emergency reserve, are higher than the values stipulated in the technical specifications which were in force when the pipes were manufactured;

- ductility characteristics (relative elongation of pipe steels) after operation are significantly dispersed in relation to the value given in technical specifications, but reduction of cross-sectional area decreases insignificantly over the service life.

These studies showed that the least reliable steel grades were 19G, 14KhGS, and Ts. The growth of defects to critical size is possible in these steels at the design pressure and as the operating period increases.

Forming and implementing the program of testing and studying properties of pipe steels in long-term operation

The above-mentioned works were developed at Transneft PJSC's facilities into the concept of studying the mechanical and chemical properties of pipe steels used in operational pipelines and those under construction. Subsequently, recommendations for improving the general regulatory framework and methods were developed, along with calculations of strength and durability.

The concept comprises the following main stages:

- grouping and ranking of pipe steels;
- systematising design indicators for long-term operational, modern, and prospective pipe steels;
- substantiating a list of testing methods, as well as ways of evaluating strength, durability, and reliability;
- developing a methodology for a calculating and experimentally assessing strength, durability, and reliability.

At the first stage, the aims were:

- to group pipe sections according to steel grade (criteria: composition, alloying elements, impurities), industry standards, technical specifications, manufacturer, technologies, and production year;
- to rank, according to use, intended function (linear pipelines, industrial pipelines, and berthing facilities), years of operation, scope of replacement;
- to analyse the presence, reliability, and completeness of mechanical and chemical properties.

Transneft PJSC uses a total of over 70 steel grades in the linear sections of oil and petroleum-product pipelines. Some of them are represented only by the strength class (for instance K52) corresponding to the steel grade.

In the Transneft system, two main groups of steel are used: carbon steels (carbon content of up to 0.24% without the introduction of special alloying elements) and low-alloyed structural steel grades (total content of alloying elements is no more than 2.5%).

The content of carbon and alloying elements determines the weldability of pipe steels, which is evaluated according to the of carbon equivalent criterion value C_{eq}.

Low-alloyed steel grades with silicon and manganese of type 17GS and its modifications 17G1S and 17G1S-U are used most frequently (Fig.1) (in all, 56% of the total length), followed by steel grades Ts (7%). Modern steel grades of strength class K52, K56, and K60

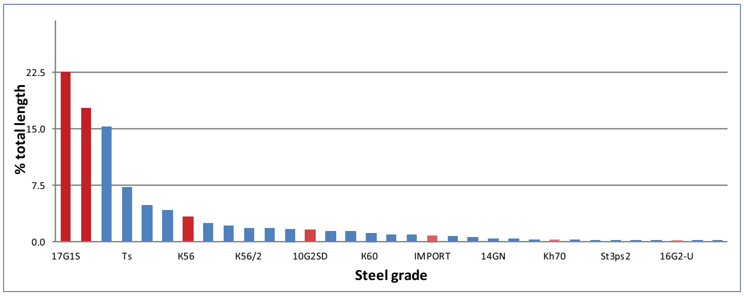

Fig.1. Classification of steel grades according to their use in Transneft PJSC's pipelines.

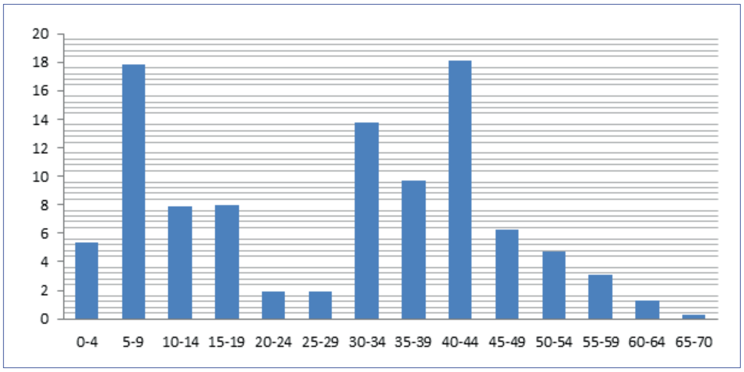

Fig.2. Ranking the length of the pipelines according to service life.

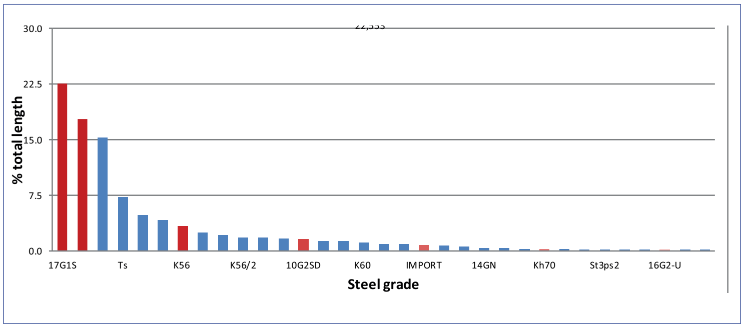

Fig.3. Volume of steel supplies from manufacturing plants.

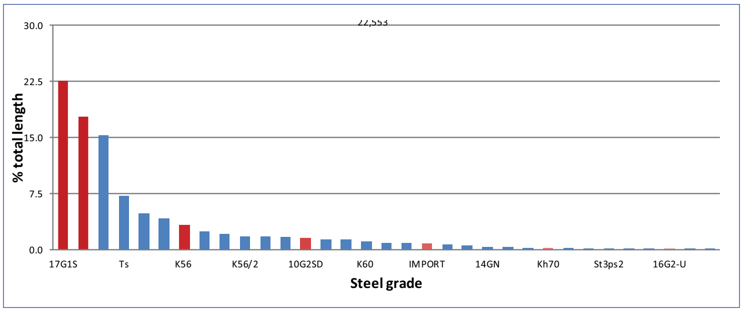

Fig.4. Relation between pipeline length and technical specification for manufacture of steels of various grades.

(10G2FBYu) comprise14% in total, while St20 makes up 3%, 14KhGS is 2.5%, and 19G is 2.1%.

The relationship between standard sizes of pipe sections and the steel grade used is an important factor when constructing and operating pipelines. Grades of steel such as steel 10, steel 20, steel 4, steel 3, and their equivalents (modifications) were used to produce pipes with small diameters, from 159 to 530 mm. Some steel grades (17G1S and 09G2S) were used for practically all standard pipe sizes.

For large-diameter pipes (from 530 to 1120 mm), the following grades were used: 10G2FBYu and steels of modern strength classes K56-R60.

The greatest range of pipe sections have service lives of between 5 to 10 years and 35 to 45 years. The percentage of pipe sections which have service life of over 30 years is no less than 57%, and a life of over 50 years it is less than 10% (Fig.2).

Of approximately 55 Russian and foreign producers (Fig.3), Russian manufacturers account for the greatest length of pipe products (73%). A significant proportion of pipes is manufactured by Chelyabinsk Pipe-Rolling Plant (49%), Vyksa Steel Works (14%), and Volzhsky Pipe Plant (8%).

Ukraine's share in production amounts to 12.5% from the Novomoskovsk Pipe Plant and the Khartsyzsk Pipe Plant products, combined).

The first six producers (Chelyabinsk Pipe-Rolling Plant, Vyksa Steel Works, Volzhsky Pipe Plant, Chomutov Tube Rolling Mill, (Czech Republic), Novomoskovsk Pipe Plant and Khartsyzsk Pipe Plant) make up the principal share (over 90%) used in Transneft system's pipelines.

There are over 200 technical specifications in total from various manufacturers and state standards which determine the supply of pipe sections to Transneft system pipelines (Fig.4). They include technical specifications from both Russian and foreign manufacturers. Moreover, pipe products may be manufactured by a number of rolling mills according to the same technical specifications and standards.

The greatest length of pipe sections was

No.	Parameter	Value
1	2	3
1	Length, km	13,600 (22.6% of the total length)
2	Number of technical specifications - manufacturer	89
3	Ultimate strength, in MPa	from 500 to 630
4	Yyield strength, in MPa	from 348 to 580
5	Impact toughness, J/cm^2	from 5.7 to 85

Table 1. Values for mechanical properties of steel grade 17G1S.

constructed in compliance with the following technical specifications: TS 14-3-109-73 and TS 14-3-602-77, ChMTS 3-225-69, TS 1381-007-05757848-2005, TS 14-3-1138-82, TS 14-3-1270-84, TS 14-3-1573-96, and TS 14-3-1973-98 and to the GOST 20295-74 and GOST 20295-85 standards. There is a significant length of pipeline (14% of the total amount) for which data regarding technical specifications and standards is not available.

The values for the mechanical properties of steel grade 17G1S, manufactured to comply with various technical specifications, have significant scatter (Table 1, Fig.5). The values for ultimate strength range from 500 to 630 MPa, for yield strength from 348 to 580 MPa, and for impact toughness from 5.7 to 85 J/cm^2. The average values used in calculations for this steel grade were 578 MPa for the ultimate strength, and 410 MPa for the yield strength.

The same is true for other steel grades produced by various manufacturers.

These data indicate the possibility of reducing the actual mechanical properties in comparison to the requirements of the technical specifications, which can vary by as much as 10-20%. As such, in order to improve the accuracy of strength and longevity calculations based on actual characteristics, it is necessary to additionally take into account the year of manufacture and technology used to produce each steel grade. This is especially true when design characteristics for mechanical properties are found to be lower than those stipulated in technical specifications.

Each steel grade used in Transneft's facilities can be classified according to various criteria: the year of development and production (service life), the alloy level (the content of carbon and alloying elements), the content and distribution of detrimental impurities, the production technology, and other parameters (Fig.6).

Up until the mid-1950s, carbon ferritic-pearlitic steels St.3, St.4, St.10, and St.20 were used to construct oil pipelines, with strength classes K30-K38. Subsequently hot-rolled steels of grades 19G, 16GN, 14KhGS began to be used with the aim of decreasing the steel's liability to brittle

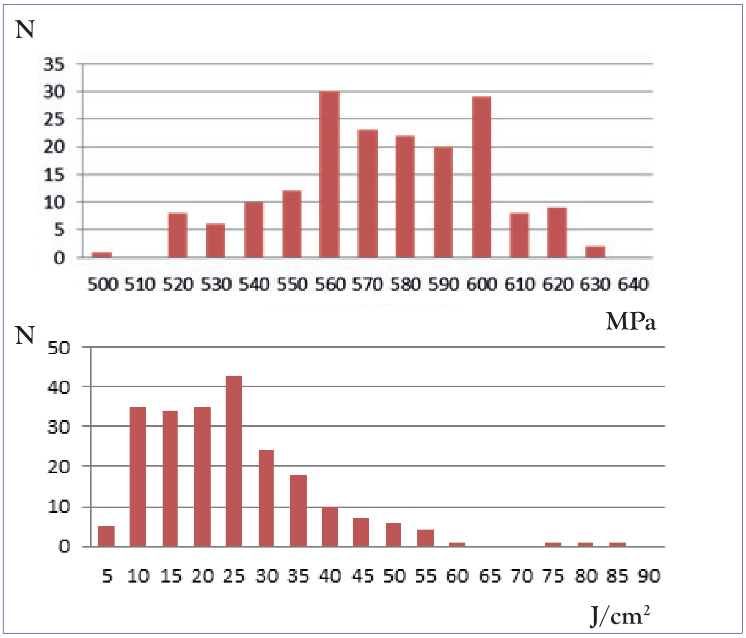

Fig.5. The scatter of actual basic characteristics for steel grade 17G1S, manufactured in accordance with various technical specifications.

1940s-50s: Carbon Steels	VSt3sp, VSt3sp2, VSt3sp4, St3 (St3sp), St3sp4, St3ps2, St4 (St4sp), Steel 10, Steel 20, St10PS, St20L
1950s-60s: Low-alloyed steels with solid-solution strengthening	09G2S, 10G2S1, 13GS, 13G1S-U, 13GS-U, 17G1S, 17G1S-U, 17GS, 19G, 14GN, 16GN, 14KhGS
1960s-70s: Low-alloyed steels with carbide strengthening	09GSF, 17G2SF
1970s-80s: Low-alloyed steels with carbo-nitride strengthening	13G2AF, 14G2SAF, 15GSTYu, 16G2SAF
1980s-90s: Low-alloyed perlite-reduced steels	08G1NFB, 08G2FB, 09G2FB, 10G2FB, 10G2FBYu, 10G2B□Yu2, 12GSB,12G2SB
2000s: Bainitic steels	06GFBAA

Fig.6. Grouping of steel grades according to development year and production technology.

fracture and strengthening it by adding carbon, manganese, and chrome. These grades were, however, still subject to brittle fracture, in particular avalanche-type and extended-ve fractures.

In the 1960s and later, low-alloyed steels based on hot-rolled 17GS (normalized 17G1S, including 17G1S-U after synthetic slag treatment, with strength level up to K52) came into widespread use. This was made possible by reducing the content of detrimental impurities (sulphur and phosphorus) and carbon, and strengthening the steel using manganese and silicon, as well as grain refinement by heat treatment in normalization.

Steels of types 14G2SAF, 14G2AF, 16G2SAF, and 17G2A are characterized by carbonitride strengthening, smelting in oxygen steel-making converters and subsequent continuous casting, steel treatment in the ladle, control of the shape of non-metallic inclusions and further reduction of the sulphur and carbon content. These steels have K55-K60 strength classes, and significantly exceed silicon-manganese steels by their properties.

In micro-alloyed low-perlitic and ferritic steels of 10G2FBYu, 09G2FB and other types, grain boundary, substructural and dispersion strengthening are used. These steels undergo thermos-mechanical rolling and subsequent accelerated cooling. Controlled rolling modes allow strength and toughness to be increased while maintaining sufficient weldability.

Steel quality was further improved with the development of low-alloyed steels, for instance 08G2MFB and 08G2FBT, which have a lower carbon content and other types of structures (acicular ferrite, ferrite-bainite) which undergo thermos-mechanical rolling, and which have ultimate strength of up to 640 MPa.

Data on the chemical composition of steel grades (intervals for the content of alloying elements) are selected from reference books and scientific and technical literature on pipe steels. In the vast majority of cases, there are no actual results for determining the chemical composition of the steel in pipe sections.

Steel grades were grouped according to standard values for carbon, phosphorus, and sulphur content (Tables 2-3).

As a rule, the lower is the content of detrimental impurities, the higher are the ductility and toughness indicators.

In Figs 7-9, pipe steels are ranked based on the actual mechanical properties of steel grade, taking into account technical specification data for ultimate strength values (group interval of 50 MPa), relative elongation (group interval of 3%), and impact toughness (group interval of 20 J/cm^2).

Assigning points to each of the groups was proposed as a way to make a generalised ranking by chemical composition parameters and actual mechanical properties. The higher is the group that

No.	Maximum allowable content of detrimental impurities (S, P), %	Steels
1	2	3
1	over 0.045	St3, St3ps2, St3sp4, VSt3sp, VSt3sp2, VSt3sp4, VSt3ps5, St4
2	0.035 < S,P ≤ 0.045	Steel 10, Steel 10ps, 10G2S1, 10G2SD (MK), 14GN, 14KhGS, 15GSTYu, 15G2S, 16GN, 17GS, 17G1S, 17G2SF, 19G
3	0.025 < S,P ≤ 0.035	13G2AF, 14G2SAF, 17G1S-U Steel 20
4	0.015 < S,P ≤ 0.025	08G1NFB, 08G2FB, 09GSF, 09G2FB, 10G2FB 10G2FBYu, 10G2B-TYu2, 12GSB, 12G2SB, 13GS, 13GS-U, 13G1S-U, 16G2SAF
5	0.015 or less	06GFBAA

Table 2. Grouping of steel grades according to content of detrimental impurities.

No.	Maximum allowable carbon content, 0.01%	Steel grade
1	2	3
1	22 and over	St3, St3ps2, St3sp4, VSt3sp, VSt3sp2, VSt3sp4, VSt3ps5, St4, 19G, Steel 20
2	16 ≤ C < 22	14GN, 14KhGS, 14G2SAF, 15G2S, 15GSTYu, 16GN, 16G2SAF, 17GS, 17G1S, 17G1S-U, 17G2SF
3	10 ≤ C < 16	08G2FB, 08G1NFB, 09GSF, 09G2S 09G2FB, Steel 10, Steel 10ps, 10G2S1, 10G2SD (MK) 10G2FB 10G2FBYu, 10G2BTYu2, 12GSB, 12G2SB, 13GS, 13GS-U, 13G1S-U, 13G2AF
4	Less than 10	06GFBAA

Table 3. Grouping of steel grades according to carbon content.

No	VS, MPa	Steel grade
1	650 MPa and higher	17G2SF, 16G2SAF, 17G1S(K60), 15GSTYu
2	600 – 650 MPa	13G1S-U, 17G1S-U, 10G2FBYu, 06GFBAA, 14KhGS, 17GS, 17G1S
3	550 – 600 MPa	14KhGS, 17GS, 14KhGS, 13G1S-U, 17G1S, 16G2-U, 09G2S, 10G2SD, 19G, Z
4	500 – 550 MPa	17GS, 16G2-U, Z,17G1S, 14GN, 14KhGS, 19G, Steel 20
5	Lower than 500 MPa	Ts, St4, vSt3sp4, vSt3sp2, vSt4, Steel 20

Fig.7. Grouping of steel grades by strength.

No	Ductility	Steel grade
1	30% and higher	10G2SD, 14KhGS, Ts, vSt3cp4, Steel 20, VSt4
2	27-30%	09G2S, 17GS, 17G1S-U, Ts, vSt3sp2, 13G1S-U, 14GN, 14KhGS, 16G2-U, 17G1S, Steel 20
3	24-27%	St4, 17G1S, 14KhGS, 17GS, 19G, 17G1S-U, 06GFBAA, 10G2FBYu, 16G2-U
4	21-24%	14KhGS, 17G1S(K60), Ts, 17GS, 15GSTYu, 19G
5	18-21%	16G2SAF, 14KhGS, 17G2SF, 17G1S, 17GS
6	18% and lower	13G1S-U, 19G

Fig.8. Grouping of steel grades by ductility.

No	Impact toughness	Steel grade
1	100 J/cm^2 and higher	17G1S-U, 13G1S-U, 10G2FBYu, 09GSF, 17G1S(K60)
2	80 – 100 J/cm^2	06GFBAA, 13GS
3	60 – 80 J/cm^2	-
4	40 – 60 J/cm^2	14KhGS, 09G2S, 17GS, 12G2SB, 10G2SD
5	20 – 40 J/cm^2	17GS, 14GN, 17G2SF, 17G1S, 16G2-U, 14KhGS, 16G2SAF, vSt4, 16G2-U, Steel 20, 17G1S-U, Ts, 19G
6	20 J/cm^2 and lower	13G2AF, 10G2SD, 17G1S-U, 17GS, Steel 20, St4, 19G, Ts, vSt3sp4, 14KhGS, 15GSTYu, Steel 20, Steel 10, 16GN, vSt3sp2, 15G2S

Fig.9. Grouping of steel grades by toughness.

the steel grade falls into, the higher is the score, and the final values were obtained by combining scores for each characteristic. The modern steel of the ferritic - bainitic class 06GFBAA (Fig.10) was found to be the best steel grade.

Transneft R&D, LLC together with Transneft Diascan, JSC, and the organizations of the Transneft system, has developed and continue to enlarge a database based on the results of actual mechanical properties of pipe steels from various manufacturers, using technical documents and he time of manufacture. At present, it contains the results of more than 19,000 different tests.

Combined data on the mechanical properties of pipe steels

In summarizing the results of the tests and studies that have been carried out, the following statistics can be formulated.

The largest guaranteed impact toughness values were found in modern steel grades of strength class K56-K60, 10G2FBYu, 09G2SF, 13G1S-U, and 17G1S-U; these results were taken from Mesnager sample tests. The lowest values were found in 14KhGS, Ts, 19G and carbon steels (Fig.11).

No.	Grade	Manufacturer	Technical specifications (TU)	Scores for rating properties based on ranking results					Total score
1	2	3	4	5	6	7	8	9	10
1	06GFBAA	Chelyabinsk Pipe-Rolling Plant	TS 14-3R-28-99	4	4	5	5	4	22
2	13G1S-U	Volzhsky Pipe Plant	TS 14-3-1973-98	4	5	6	4	2	21
3	10G2FBYu	Vyksa Steel Works	TS 14-4-1573-96	4	4	6	4	2	20
4	13G1S-U	Vyksa Steel Works	TS 14-4-1573-96	3	5	6	4	2	20
5	17G1S-U	Volzhsky Pipe Plant	TS 14-3-1973-98	4	5	6	3	1	19
6	17G1S (K60)	Volzhsky Pipe Plant	TS 14-3-721-78	5	3	6	2	1	17
7	10G2SD	Mariupol Steel and Iron Works n.a.Ilyich	TS 5/VII 1949	3	6	3	2	2	16
8	13G1S-U	Khartsyzk Pipe Plant	TS Ukraine 322-8-10-95	3	1	6	4	2	16
9	14KhGS	Khartsyzk Pipe Plant	TS 14-3-109-73	3	5	3	2	2	15
10	17G1S-U	Chelyabinsk Pipe-Rolling Plant	TS 14-3-1698-90	4	5	2	3	1	15
11	10G2SD	Mariupol Steel and Iron Works n.a. Ilyich	PTS (Provisional Technical Specifica-tions) 06-OS-58	3	6	1	2	2	14
12	16G2SAF	Novomoskovsk Pipe Plant	TS 14-3-602-77	5	2	2	4	1	14
13	17G1S	Chelyabinsk Pipe-Rolling Plant	TS 3-225-69	4	5	2	2	1	14
14	17G1S-U	Novomoskovsk Pipe Plant	TS 14-3-602-77	3	5	2	3	1	14
15	17G1S-U	Khartsyzk Pipe Plant	TS 14-3-602-77	4	4	2	3	1	14
16	17GS	Novomoskovsk Pipe Plant	MRTU (Inter-Republic Technical Specifications) 14-4-13-65	3	5	3	2	1	14

Fig.10. Element of grouping steel grades by property:

column 5 -strength
column 6 – ductility
column 7 – toughness
column 8 - detrimental impurities
column 9 - carbon content

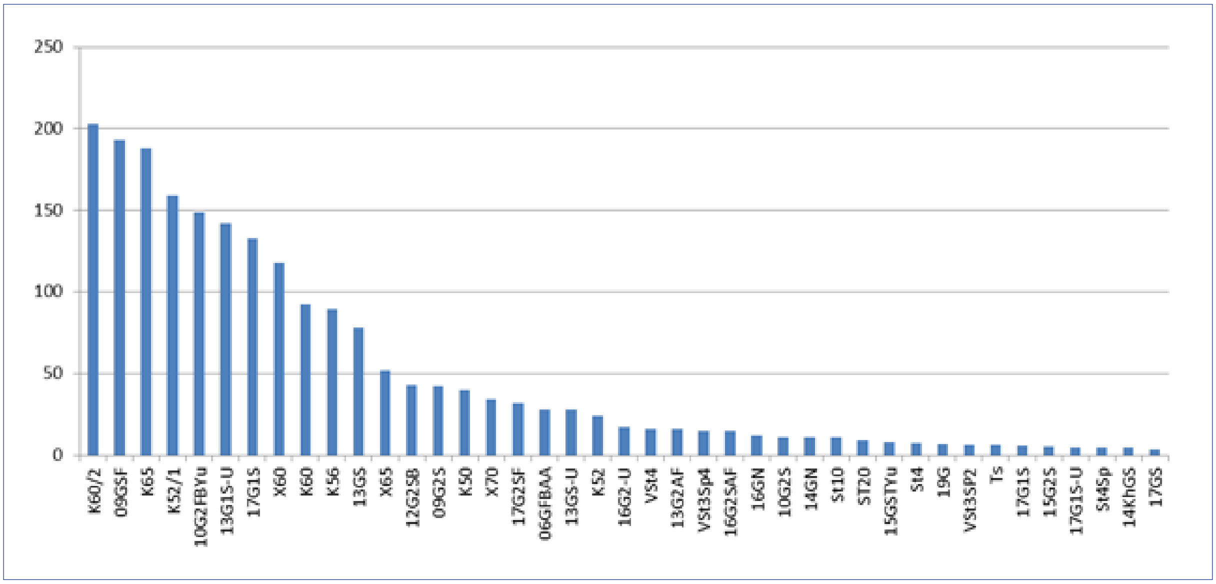

Fig11. Minimum actual values for impact toughness KCV (-40) for various steel grades, J/cm².

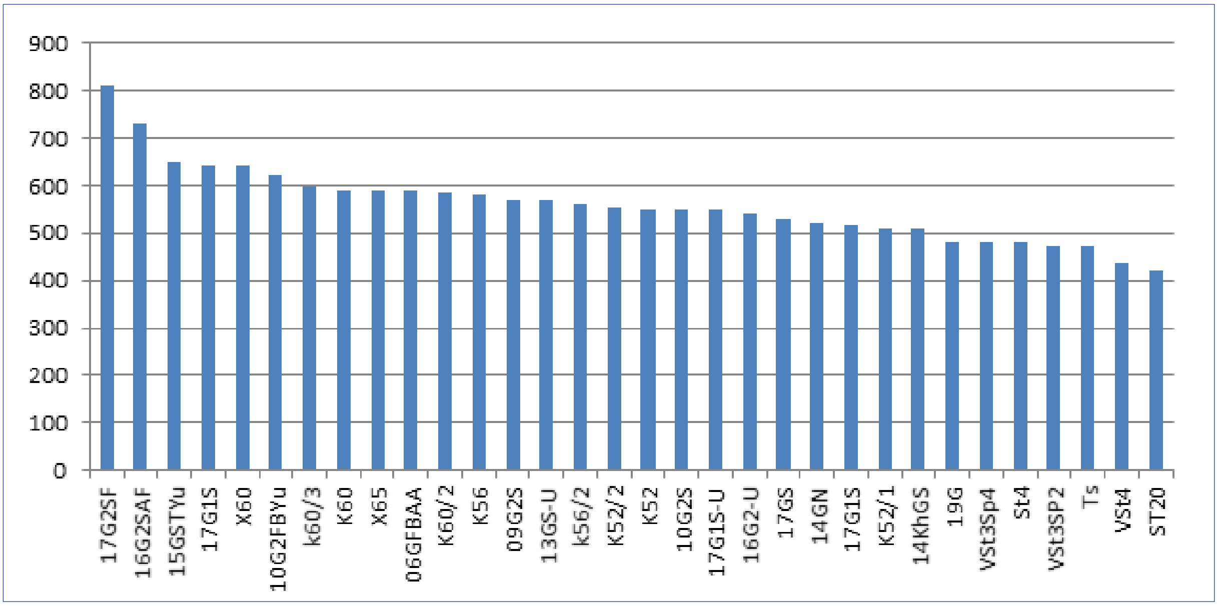

Fig.12. Minimum actual values for elongation in different steel grades, %.

A significant safe margin of ductility can be seen in carbon steel grades 09G2S and 10G2S, while the lowest margin of ductility was found in 19G and 14KhGS (Fig.12).

The lowest values for strength are observed in carbon steel grades. The greatest are found in steel grades 17G1S-U, its derivatives, and steel grades manufactured using controlled-rolling technology (Fig.13).

To assess the effect of alloying element content and impurities on the mechanical properties of various steel grades, and the relationship of the normative content of carbon and sulphur vs the actual values of mechanical properties, are plotted in Fig.14.

By analysing the above relationships, it can be concluded that impact toughness values for pipe steels increase when sulphur content is reduced. The influence of carbon was less noticeable.

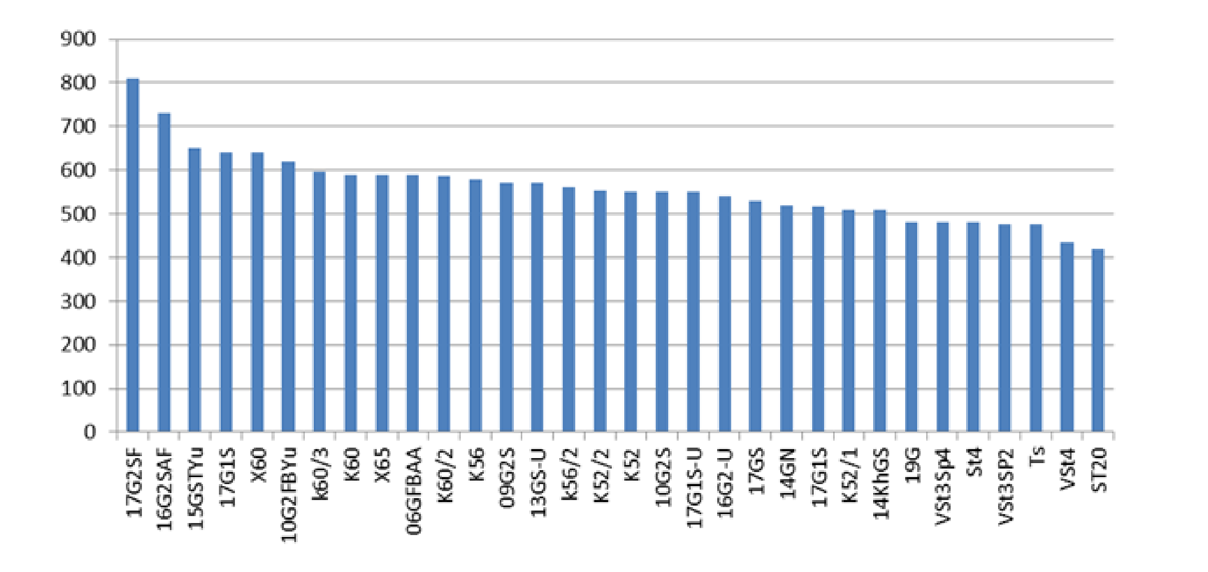

Fig.13. Minimum actual strength values for different steel grades according to the database of mechanical test results, MPa.

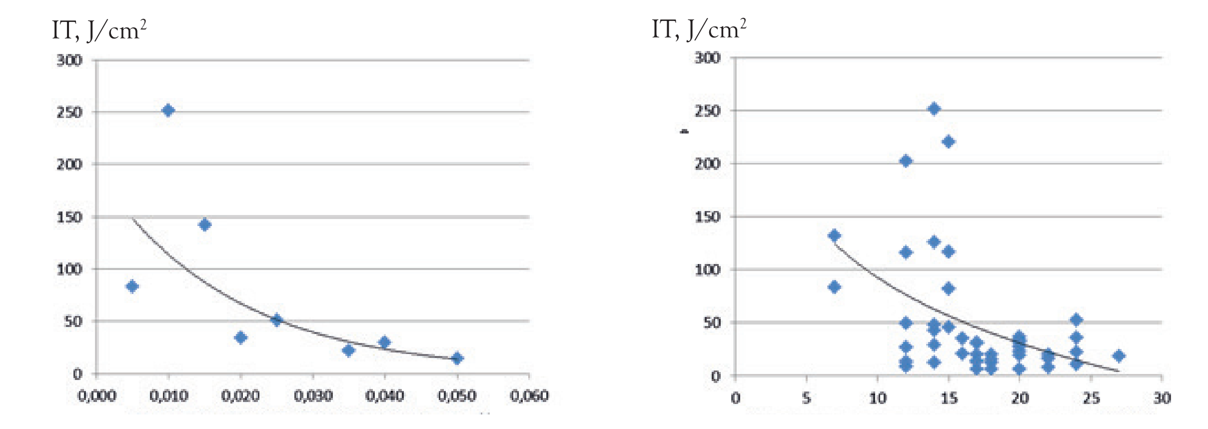

Fig.14. Effect of composition on the mechanical properties of pipe steels: (left) maximum allowable sulphur content, %; (right) maximum allowable carbon content, 0.01%.

Rather complex relationships were found for a certain drop in ductility when pipe steel strength increased, together with a simultaneous increase in the magnitude of reduction in area when elongation grew and in yield strength when ultimate strength grew for various steel grades. These are shown in Fig.15.

It is important that the pipe metal characteristics used to calculate strength and durability were in fact the closest to the average values from the test results. The relative scatter in the characteristics studied within a series of tests is characterised by the value of the variation coefficient.

Analysis of the actual test results revealed a range of technical specifications from a number of manufacturers. For some characteristics, the value of the variation coefficient was significant (over 10%), which indicates a great heterogeneity of metal properties when transferred from sheet to sheet, and from pipe to pipe.

There are various combinations of manufacturer - technical specifications - steel grade for which test results are currently not available.

Conclusions and the way forward for future research

As opportunities for testing increase (given the availability of grades in pipe

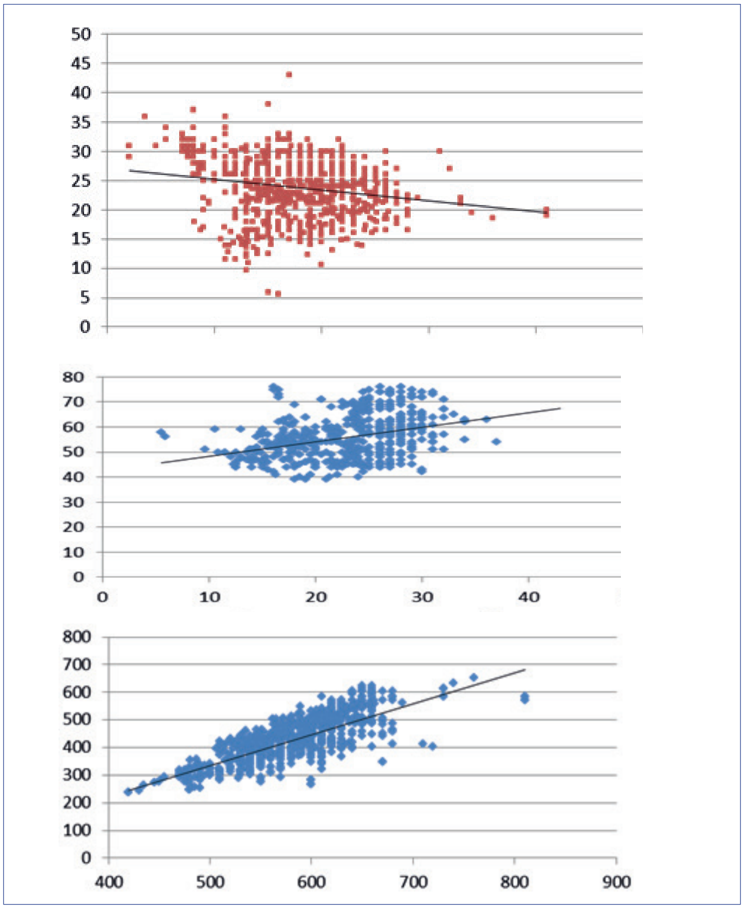

Fig.15. Relationship between strength and ductility for pipe steels:

top: ultimate strength vs elongation;

centre: elongation vs reduction in area;

bottom: ultimate strength vs yield strength.

sections for cutting during stoppages or replacements), and taking into account total length, it is necessary to select the templates and conduct tests and studies for specific combinations. These templates should be tested with both standard and specialized methods, including those developed by our partners in leading scientific institutions.

We plan to expand the area in which the mechanical properties obtained, based on the methods that can be applied when evaluating the strength and durability of pipe sections. This will be supported by performing verification bench tests using Transneft-Diascan JSC's current and planned testing facilities [20]. The objectives for further research are:

- To expand knowledge of the problem of degradation in the characteristics of pipe steel metal during operation.
- To conduct tests of selected templates using existing methods of mechanical testing:
  - standard tests (tensile tests, impact bending, hardness measurement, etc.);
  - unified tests (calculation from deformation diagrams of work-hardening index, uniform reduction in area, fatigue strength, stress intensity factor, etc.);
  - special tests (ductility in Z-direction, indentation diagrams, anisotropy of properties in various directions).
- To develop new methods of assessing mechanical properties, and testing model samples:
  - taking into account surface layers;
  - research into the local properties of welded joints and damaged zones, micro-structural studies;
  - estimation of local strain-stress state;
  - study of natural, artificial, dynamic and deformational ageing.
- To analyse the methods used for evaluating the destruction of pipe steels within a critical temperature interval.
- To verify existing methods through computational experiments.
- To develop new bench and full-scale test methods (with the involvement of leading scientific institutions).

References

1. V.N.Chuvildeev 2006. Effect of ageing on steel performance characteristics of main gas pipelines. Collection of Works of the Scientific and Practical Seminar, Nizhny Novgorod, pp 18-67.

2. G.A.Philippov, O.V.Livanova, and V.F.Dmitriev, 2003. Steel properties degradation over long-term operation of pipelines. *Steel* 2 pp 84 -87.
3. V.G.Pleshivtsev, Y.A.Pak, G.A.Filippov, O.N.Chevskaya, and O.V.Livanova, 2007. Factors affecting operating reliability of pipelines. *Deformation and Destruction of Materials*, 1. Pp 6-11.
4. O.V.Livanova. Degradation of mechanical properties and parameters of resistance to destruction of ferrite-pearlitic and pearlitic steels over long-term operation. Dissertation presented for PhD in Technical Science.
5. O.V.Livanova, 2007. Degradation of mechanical properties and parameters of resistance to destruction of ferrite-pearlitic and pearlitic steels over long-term operation. Collection of Research and Development, Design and Experimental reports. Series 16: 29 Physics; 30 Mechanics; 41 Astronomy; 89 Space research. 4 p 142.
6. G.A.Philopov, 2006. Degradation processes and their influence on crack resistance of steel pipes after long-term operation / ageing problems of main gas pipelines. Collection of works of a scientific-practical seminar (N. Novgorod, 23 -25 January 2006) N.Novgorod: University Book, pp 196 -209.
7. V.N.Zikeev, G.A.Filippov, I.P.Shabalov, D.M.Solov'ev, and O.V.Livanova, 2014. Regularities (patterns) of changes in the mechanical properties of constructional steels during long-term operation and modelling of the ageing processes. *Problems of Ferrous Metallurgy and Materials Science* 4 pp 74-82.
8. I.P.Shabalov, D.M.Solov'ev, G.A.Filippov, and O.V.Livanova, 2015. Influence of U-O-shaped forming scheme on the mechanical properties of large-diameter electrowelded pipe. *Steel* 45 4 pp 56-61.
9. E.D.Merson, M.M.Krishtal, D.L.Merson, A.A.Eremichev, and A.Y.Vinogradov, 2012. Study into the stages of high-carbon hydrogen-embrittled steel destruction process = using acoustic emission method. *Deformation and Destruction of Materials* 9 pp 41-48.
10. E.V. Chernyaeva, D.I.Galkin, G.A.Bigus, and D.L.Merson, 2010. Application of acoustic emission method for nondestructive testing of the base metal and welded joints of pipelines operating under conditions of low cycle fatigue. *Welding and Diagnostics* 2 pp 50-56.
11. D.L.Merson and E.V.Chernyaeva, 2007. Application of acoustic emission method for evaluation of the mechanical properties of pipe steels. *Metallurgy and Heat Treatment of Metals* 5 pp 60-64.
12. D.L.Merson and E.V.Chernyaeva, 2005. Spectral response characteristics for acoustic emission method and the mechanical properties of steel pipes in relation to tempering temperature. *Deformation and Metal Fracture* 5 pp 24-27
13. R.V.Mishnev, N.R.Dudova, and R.O.Kaibyshev, 2014. Low-cycle fatigue life of heat-resistant martensitic steel 10Kh10K3V2MFBR. In: Electric Engineering, Power Engineering, Machinery Manufacturing Collection of Scientific Works I International Science conference of Young Scientists pp 309-313.
14. L.A.Efimenko, Y . I l y u k h i n , V.M.Goritskii, G.R.Sheiderov, and A.M.Kylyomin, 2008. Tendency to stress ageing and hydrogen embrittlement of high-strength steel X80 for main pipelines. *Chemical and oil machinery manufacturing* 9 pp 43-45.
15. V.M. Goritskii and O.M.Goritskii, 2014. Metallurgical factors as a cause of premature failure of technical equipment and pipelines. *Workplace safety in industry* 3 pp 56-60.
16. Recommendations for taking into account steel pipes ageing when designing and operating oil pipelines. Ufa: VNIISPTneft, 1988 p 29.
17. I.K.Gumerov, V.A.Shmakov, A.A.Galyautdinov, and I.A.Ryabov, 2006 Challenges of evaluating remaining operation life and safety of main pipelines. Challenges of collection, preparation and transport of oil and oil-products. Ufa.
18. A.G.Gumerov, R.S.Zainullin, K.M.Yamaleev, and A.V.Roslyakov, 1995. Ageing of oil pipelines. M.Nedra, p 218.
19. N.P.Lyakishev, M.M.Kantor, A.A.Belkin, and V.N.Timofeev, 2007. On evaluation of effects of long-term service life on mechanical properties and metal structure of main pipelines. *Factory Laboratory. Diagnostics of Materials* 1. Vol. 73.
20. D.A.Neganov, E.. Studyonov, S. Skorodumov, and V.A.Solov'ov, 2017. Study of the construction of hydraulic stands for testing of tubular products. *Science and Technology of Pipe Transport of Oil and Oil Products* 2.
21. Y.V.Lisin, 2017. Research of physical and chemical properties of steel for long-operated pipelines and assessment of safe operational life. *Science and Technology of Pipe Transport of Oil and Petroleum Products* 4.