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Alternative Method for Determining the Quality of Structural Steels

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Abstract

In this article the problem of quantitative estimation of the steel quality according to their ability to resist brittle fracture is considered. The research on the approbation of the alternative method showed that the results obtained using this method correlate with the results of an acceptance tests. It was offered to use the characteristics of the mechanical stability K_{ms} and measures of optimality for mechanical stability, which can be determined by means of uniaxial tensile tests, to evaluate the quality of steel used in the construction metal structures and large-diameter pipes for main oil and gas pipelines.

Key words:*steel quality, brittle fracture, mechanical stability, uniaxial tension*

The following indicators that define the uniaxial tension of cylindrical or flat samples are included in the range of mechanical properties determining the suitability of metal rolled production for use in building structures: $\sigma_{0,2}$ – constrained yield stress, MPa; σt – breaking strength (breaking point), MPa; δ_5 – tension set, %, determined at the studies of fivefold cylindrical samples ($l_0 = 5{,}65\sqrt{F_0}$); ψ_K – constriction after break, %.

To estimate the viscosity of steels used in building, such indicators as fracture energy (impact strength) – KCU or KCV, determined in tests of samples with the size of 10x10x55 mm with the cut on the impact machine. For the evaluation of ductile constituent in the breakage of constructional steel the drop-weight test (DWT) is performed.

In case when the obtained values of the mechanical properties of the metal correspond to the standard, it is supposed that the metal production is suitable for use in building structures. If the obtained characteristics do not match the values given in the standards for steel supply, it is believed that the metal is not suitable for use in these constructions. Such metal production is defective. These parameters reflect the properties of the metal only under the conditions of the tests and can not predict the possibility of steel operation in the construction. Such conventional indicators as ductility ψ_K or KCV impact strength do not always provide a reliable guarantee against the possibility of brittle fracture of the construction. The reason is that the existing methodologies for assessing the quality of steels and alloys operate not with direct mechanical characteristics reflecting the ability of a metal to resist the transition to the brittle state, but with indirect ones, determining the values of residual plastic deformation ψ_K or fracture energy (KCV, KCU) of samples of the given geometry and in the specified conditions of laboratory tests. In the conditions of complex stress-strain state indicator ψ_K loses its information value, and such an integral method of steel viscosity evaluation as DWT has rather subjective nature.

In order to eliminate the lack of existing methods of evaluation of tendency of structural steels to brittle fracture, G.V. Kurdiumov Metallophysics Institute of NASU together with State Higher Education Institution "Prydniprovs’ka State Academy of Civil Engineering and Architecture" developed and proposed a new alternative method of assessing the quality of the metal on the specified criterion.

In the proposed method of assessing the quality of structural steels the concept of "metal quality" is interpreted as the level (degree) of metal resistance to the transition into brittle state or its distance from the state of fragility.

The basis of this method is in the determination of new key features of metal: brittle fracture (R_{MC}) and mechanic stability (K_{ms}) [1], and also the "indicator" of metal quality which are the measures of optimality by the mechanical stability (μ^{σ}_{Kms}) at the given accuracy $\sigma_{0.2}$ [2]. Brittle strength R_{MC} is the strength of metal at a critical degree of deformation $\psi_C = 2\%$ in a state of transition from the plastic state into brittle in the conditions of uniaxial tension at a temperature of ductile-brittle transition. R_{MC} features directly depend on the structural state of metal and is determined by laboratory testing of cylindrical samples for uniaxial tension [1]. The characteristics of the mechanical stability K_{ms} reflects the of the feature of metal to resist the transition to the brittle state, or, in other words, the degree of its resistance to brittle fracture in conditions of uniaxial tension and, therefore, may be a quantitative measure of its utility properties. Quantitatively interpreted category of quality of structural steels ("indicator" of quality) can be a measure of optimality for mechanical stability μ^{σ}_{Kms}, which is the ratio of the mechanical stability value of the chosen steel for its value at a given strength value $\sigma_{0.2}$ [2].

The main advantages of the proposed methodology for quality assessing the quality of structural steels using the mechanical stability feature K_{ms} of the following characteristics:

– the connection of the characteristics of brittle fracture R_{MC} and mechanic stability K_{ms} with the structural state of metal;

– the use of the parameters K_{ms} and μ^{σ}_{Kms} which characterize the most important metal property to ensure the reliability of the structures and mechanisms: the resistance to the transition to fragile state;

– the applicability of the offered method for estimation of constructional steels and alloys quality which are widely used in different industries;

– economical effectiveness during the estimation of metal effectiveness, caused by the usage of only the results of tests of standard bare cylinder samples for this aim for uniaxial static tension, which is available for majority of plant laboratories;

- invariance of used dependencies in the method for different combinations of strength and ductility properties of structural steels, their types and modes of heat treatment;

– the applicability of method for testing of metal in a wide temperature range of from 293 to 77 K;

- The ability to adapt to the currently effective conventional methods of quality control of steel (the definition of the share of shear area of the sample, the toughness of KCV, KCU, etc.), as well as supplement and control of these methods by finding correlations between these parameters and the proposed characteristics in the presence of a database containing the results of the tests, and the values of the basic mechanical characteristics of the corresponding steels ($\sigma_{0.2}$ is a conditional yield stress; σ_B is tensile strength; ψ_K relative reduction after the destruction of the sample).

In order to test the technique of experimental characterization of the brittle strength R_{MC} and mechanical stability K_{ms} characteristics in the plant laboratory LPC 3000 on the basis of PJSC "Ilyich Iron and Steel Works" the tests of cylindrical samples of structural steel 10G2FB for tension in the temperature range from +20 ° C to -196 °C were performed.

The bare cylindrical samples (Fig. 1a) and cylindrical samples with a ring notch (Fig. 1b) were tested; they were made of skelp steel 10G2FB according to GOST 1497-84 and GOST 22706-77, respectively.

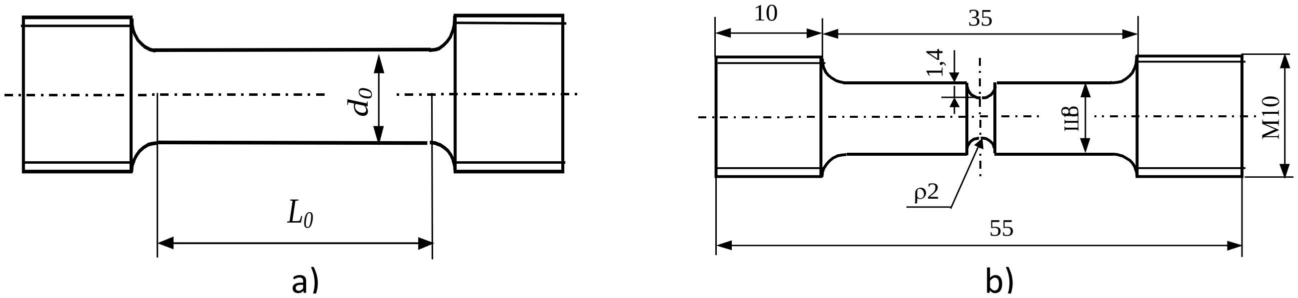

Figure 1 The scheme of: a) bare cylindrical sample; b) cylindrical sample with ring notch

For welded structural steels, in which at the boiling point of liquid nitrogen value of the residual strain of 2% $< \psi_K \leq$ 20% (welds, heat-treated rolled) the amount was determined in accordance with paragraph 1.5 and paragraphs 6.1.1 6.1.2 method [3] (hereinafter - Method) according to test results of a series of 15-bare cylindrical specimens in a temperature range of -196 ° C $\leq T_{test} \leq$ +20 ° C, and to monitor the result, the test results of a series of 5 samples with annular notch. These methods of R_{MC} determination were selected because of high plastic properties of tested steel ($\psi_K >$ 20% at T_{test}= -196 ° C), whereby brittle fracture of bare cylindrical test specimens at a temperatureT_{test} = -196 ° C (77 K) does not occur.

The chemical composition of the investigated steel 10G2FB of smelting No.318099 is shown in Table 1, and the mechanical properties of this melt are shown in Table 2.

Table 1 The chemical composition of the investigated steel 10G2FB of smelting No.318099

C	Mn	Si	S	P	Al	Mo	V	Nb	Ti	Cr	Ni	Cu	As	N_2	Ca	V+ Nb+ Ti
0.09	1.57	0.25	0.004	0.010	0.040	0.001	0.094	0.035	0.013	0.02	0.01	0.01	0.002	0.007	0.002	0.142

Table 2 The mechanical properties of the investigated steel 10G2FB of smelting No.318099

σ_T	σ_B	σ_T/σ_B	δ_5	DWT (-20 °C)	KCV (-20 °C)	KCU (-20 °C)	Hardness
MPa	MPa		%	%	J/cm^2	J/cm^2	HV
520	610	0.85	22.5	100	135	202	163

Methods for determining values R_{MC} according to the paragraphs 6.1.1 and 6.1.2. The methods are presented in Fig. 2 and 3, respectively.

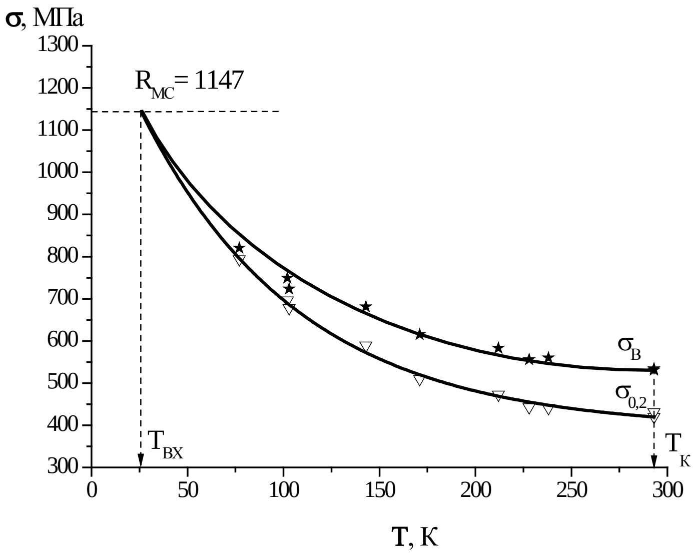

Figure 2 The definition of the values R_{MC} for a series of samples (Metallophysics Institute), in accordance with paragraphs 6.1.1 Methods

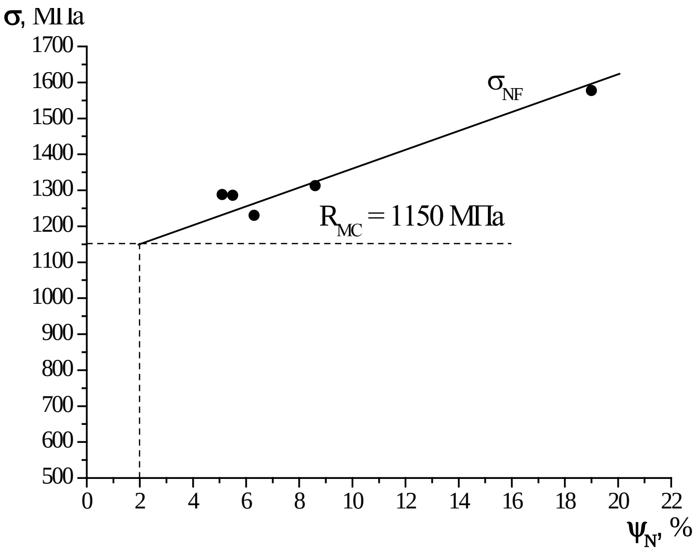

Figure 3 The definition of the values R_{MC} for a series of samples (IISW), in accordance with paragraphs 6.1.2 Methods

Table 3 and 4 represent mechanical characteristics values of investigated steel 10G2FB, and values of brittle hardness characteristics R_{MC} and mechanical stability K_{ms} obtained by the results of bare cylindrical samples testing for the temperature range -196 ° C $\leq T_{test} \leq$ +20 ° C at IMP and IISW.

Table 3 Some results of testing series, carried out at IMP

Material	T_{test}, K	ψ_K, %	$\sigma_{0,2}$, MPa	σ_B, MPa	ψ_p	δ_p	S_B, MPa	n	σ_2, MPa	R_{MC}, MPa	K_{ms}
	77	64.3	794	820	0.033	0.034	848	0.023	838		**1.369**
	102	67.3	696	749	0.067	0.072	803	0.040	764		**1.501**
10G2FB	103	66.5	678	723	0.060	0.064	769	0.037	738	**1147**	**1.554**
	212	77.9	473	583	0.141	0.165	679	0.083	573		**2.002**
	228	75.1	443	556	0.154	0.182	657	0.089	544		**2.108**

	238	74.3	441	560	0.160	0.191	667	0.093	546		**2.101**
	293	79.5	420	531	0.151	0.178	625	0.090	517		**2.219**
	293	79.4	431	534	0.142	0.165	622	0.085	524		**2.189**

Table 4 Some results of testing series, carried out at IISW

Material	T_{test}, K	ψ_K, %	$\sigma_{0,2}$, MPa	σ_B, MPa	ψ_p	δ_p	S_B, MPa	n	σ_2, MPa	R_{MC}, MPa	K_{ms}
	77	63.1	850	862	0.016	0.016	876	0.015	879		**1.308**
	112	64.9	710	762	0.065	0.070	815	0.039	777		**1.480**
	135	72.6	657	705	0.061	0.065	751	0.039	718		**1.602**
	141	74.4	646	706	0.073	0.079	761	0.045	717		**1.604**
10G2FB	161	77.5	556	640	0.105	0.117	715	0.063	642	**1150**	**1.791**
	175	73.9	544	647	0.128	0.147	742	0.074	644		**1.786**
	196	76.4	511	613	0.130	0.149	705	0.076	608		**1.891**
	293	77.4	422	528	0.150	0.176	621	0.088	517		**2.224**
	293	78.6	430	527	0.138	0.160	611	0.082	519		**2.216**

Note: value and methods of characteristics determination of ψ_p, δ_p, S_B, n and σ_2 are given in the Methods [3]

Tables 3 and 4 show that the relative error at the determination of the characteristics of the brittle fracture R_{MC} of steel 10G2FB strength at testing of two series of samples in different laboratories and by different methods does not exceed ± 1%. Thus, the proposed method is applicable in practice to determine the characteristics of brittle strength R_{MC}, mechanical stability K_{ms} and evaluation of the quality of structural steels.

In the example given below the methodic of determination of optimality measure (quality) μ^{σ}_{Kms} of the investigated steel from the series of tests carried out at IMP and at IISW (according to one sample out of each series tested at temperature -196 °C).

The value of characteristics of mechanical stability K_{ms} is determined as ratio of values of two mechanical characteristics σ_2 and R_{MC}. It is calculated by the formula [1]

$$K_{ms} = \frac{R_{MC}}{\sigma_2} = \frac{R_{MC}}{\sigma_{0,2} \cdot 10^n},$$

where σ_2 is hardness of plastic metal at the critical degree of deformation e_C=2%; R_{MC} is brittle hardness (hardness at critical temperature of brittle-plastic transition T_{bp}); n is an indicator of mechanical hardening; $\sigma_{0,2}$ is constrained yield stress.

Thus, for bare sample tested at temperature -196 °C at IMP: σ_2 = 838 MPa, R_{MC} = 1147 MPa. Thus, $K_{ms} = 1.369$.

Therefore, for bare sample tested at temperature -196 °C at IISW: σ_2 = 879 MPa, R_{MC} = 1150 MPa. Then, $K_{ms} = 1.308$.

The optimum value for the mechanical stability K_{ms}^{opt} of the desired strength $\sigma_{0,2}$ is calculated by the formula

$$K_{ms}^{opt} = 1 - \frac{a \cdot \psi_K^{opt} + b}{\psi_K^{opt} - c},$$

where $a = 0.086$; $b = 1.310$; $c = 89.478$,

$$\psi_K^{opt} = a - \frac{b}{(1 + c \cdot \sigma_{0.2})^d},$$

where $a = 84.52$; $b = 1.42$; $c = 0.0001\left[\frac{1}{MPa}\right]$; $d = -19.58$.

Therefore, for the sample tested at IMP: $\psi_K^{opt} = 78.18\%$; $K_{ms}^{opt} = 1.78$.

For the sample tested at IISW: $\psi_K^{opt} = 77.42\%$; $K_{ms}^{opt.} = 1.66$.

The optimum value for the mechanical stability μ_{Kms}^{σ} of the desired strength $\sigma_{0,2}$ is calculated by the formula

$$\mu_{Kms}^{\sigma} = \frac{K_{ms}}{K_{ms}^{opt}}$$

Therefore, for the sample tested at IMP:

$$\mu_{Kms}^{\sigma} = 0.769,$$

and for the sample tested at IISW:

$$\mu_{Kms}^{\sigma} = 0.789.$$

Thus, metal has a high level of quality [2], which corresponds to the data obtained during the acceptance test (the proportion of ductile constituent in the sample fracture at shear area of the sample at DWT is 100%).

Conclusions

1. In the IMP name after G.V. Kurdyumov of NASU the new basic mechanical properties for evaluating the mechanical properties of structural steels resistance to brittle fracture that are alternative to standard ones were suggested for the first time: ψ_K, KCV, the proportion of ductile constituent in the sample fractures at DWT, etc.: R_{MC} is brittle strength (minimum tension of metal brittle fracture at a value of residual strain ~ 2 %); K_{ms} is the mechanical stability (property of the metal to resist brittle fracture in uniaxial tension).
The characteristics for quality estimation is suggested which is the measure of optimality (quality) of metal μ_{Kms}^{σ} at the preset hardness

$\sigma_{0.2}$ and which can be used in the engineering practice for qualitative interpretation of the category of “quality” of structural metal.

2. IMP named after G.V. Kurdyumov of NASU together with SHEI "Prydniprovs’ka State Academy of Civil Engineering and Architecture" developed the method of carrying out the tension tests at temperature range within +20 °C to -196 °C for experimental determination of characteristics of brittle hardness R_{MC} and mechanical stability K_{ms} of structural steels (welding seams).

3. The value of characteristics of mechanical stability K_{ms} of skelp steel of grade 10G2FB (melting No.318099) at the temperature of testing +20°C stayed within the ranges of 2.189-2.224, and the value of optimality measure μ^{σ}_{Kms} was 0.95-0.99. It shows the high level of quality of the tested steel (the value of optimality measure is close to optimal level μ^{σ}_{Kms} =1.0).

4. The performed series of investigations according to the methods developed by IMP together with SHEI “Prydniprovs’ka State Academy of Civil Engineering and Architecture” showed that the results obtained correlate with the value of the share of ductile constituent of this steel grade obtained by the results of release testing.

5. On the basis of the results of testing of new method of determination of a set of mechanical properties of the structural steels it is suggested:

- to specify the results of the determination of K_{ms} and μ^{σ}_{Kms} in the shipment documents additionally for skelp steel (eg., 10G2FB) for each tenth smelting of one series of smelting of the definite steel grade;
- to provide the obligatory performance of tests for determining K_{ms} and μ^{σ}_{Kms} for skelp steels (eg., 10G2FB) at the negative results of DWT;
- to ship the metal to the customer for its usage in more productive climate conditions at the satisfying results of K_{ms} and μ^{σ}_{Kms} and non-satisfying results of DWT;
- provide for the mandatory inclusion of data by K_{ms} and μ^{σ}_{Kms} to the acceptance documentation for the shipment of structural steels used in the constructions of critical applications.

6. The test results can serve as a basis for filing an application to the Ministry of Regional Construction and Housing for the development of technical standards on the measurement of the quality of the metal.

References

1. C.A. S.A. Kotrechko. Yu.Ya. Meshkov Predel'naya prochnost'. Kristally, metally, konstruktsii. – Kyiv: Naukova dumka, 2008. - 295 p.
2. Yu.Ya. Meshkov, S.A. Kotrechko A.V. Shiyan et al. Novyy podkhod k otsenke kachestva konstruktsionnykh staley // Stal'. - 2012. – No. 8. - P. 66-71.*
3. Metodika provedeniya ispytaniy na rastyazheniye pri temperaturakh ot +20 °S do -196 °S dlya opredeleniya kharakteristik khrupkoy prochnosti R_{MC}, mekhanicheskoy stabil'nosti K_{ms} i otsenki kachestva konstruktsionnykh staley.*

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