COMPARATIVE ANALYSIS OF ISO 18841:2005 STANDARD AND RF 26389–84 STANDARD ON EVALUATION TO HOT CRACK RESISTANCE IN WELDING

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Differences between the EU standard on tests to hot crack resistance in welding and standard 26389–84 in force in the Russian Federation are considered, and specific variants for their harmonization to quantitative evaluation of the sensitivity of steels and welding consumables to hot cracking are suggested.

Keywords: *arc welding, hot cracks, brittleness temperature range, ductility margin, crack physical simulation, critical rate of deformation, technological and machine methods of testing, EU and RF standards*

The first standard of such designation GOST 26389–84 was developed at Welding Faculty of the N.E. Bauman Moscow State Technical University with the assistance of author. Monograph of Prof. N.N. Prokhorov and works of other researchers studying the problems of hot crack (HC) resistance, the results of which were widely discussed during two meetings on problem of HC formation in the welds, castings and ingots in 1958 and 1962 [1], became a theoretical basis of this standard.

As a result, a theory of production strength of metals during solidification in welding was stated. Based on this theory, the HC appear in the alloys under effect of welding stresses in a brittleness temperature range (BTR) as a result of exhausting of ductility margin δ_{BTR} in a period of solid-liquid state t_{BTR}. Possibility of HC formation is determined by ratio of three main factors: BTR, minimum ductility δ_{min} of metal in the BTR, and intensity of deformation rise in the BTR, depending on rigidity of welded structure. If accumulated deformation ε_i exceeds current value $\delta_i(T)_{min}$ (Figure 1) in the BTR limits the HC will appear.

Critical tension speed V_{cr}, equal δ / t_{BTR} ratio, was taken as an index of weld metal HC resistance for specific welding mode, and at comparison of modes [2] critical tension rate B_{cr}, equal δ_{min}/BTR, at which HC formation is possible, was considered. These indices are to be determined by means of increase of deformation rate of welded samples from studied alloys up to HC appearance.

There are two variants of determination of V_{cr} and B_{cr} in GOST 26388–84:

- technological methods, i.e. by means of welding of the samples under conditions of increase of rigidity (thickness, level of fastening, mode of welding up to HC formation);
- machine methods, i.e. by means of increase of deformation intensity of weld being solidified using testing machine.

Testing machines of three types, i.e. LTP1-4, LTP1-6 and MIS, allowing tension or bending of small-dimension samples in welding with adjusted speed up to HC appearance [1], were developed at the Bauman MSTU for practical application. This provided a wide implementation of a testing technique at the E.O. Paton Electric Welding Institute, main research institutes, at plants, as well as abroad [3–5]. Effect of standard 26389–84 on the territory of the Russian Federation was reinstated since 2000.

ISO 17641 standard, developed by European Committee for Standardization (CEN) in collaboration with Technical Committee ISO/TC44 «Welding and related processes» in 2005, consists of preface and two independent parts. The preface of ISO 17641-1:2004 describes the methods of testing to HC resistance and areas of their application.

The first part of standard ISO 17641-2:2005 describes in details a test procedure applying welding of butt and tee samples of natural rigidity, and methods for testing of the welded samples with forced loading are characterized in the third part of ISO 17641-3:2005.

Its configuration corresponds with that of the RF standard. General favorable reception of standard ISO 17641 is given in work [5].

However, insignificant selectivity in comparative testing as well as inapplicability for testing of sheet samples of not less than 10 mm thickness should be noted proceeding from proposed production tests and types of welded joints of «natural» rigidity. Therefore, formation of HC is unlikely in testing of modern quality electrodes of many grades and modes of testing do not reproduce welding conditions of more rigid structures to significant extent. Besides, limitation of dimensions on length of the tee joint with double-sided weld and gussets prevent performance of automatic welding and weld failure after welding for detection of cracks on fracture type. The process of result evaluation is extremely complicated and long due to manufacture and testing of special rod and plate samples from the welded joints. No data on thickness of metal to be welded and method of fastening, which eliminats deformation in welding, are provided by procedure of application of the sample with butt weld.

In contrast, the RF standard provides for possibility of wide variation of thickness of samples being welded, modes and methods of welding which make more effect on crack formation process in comparison with chemical composition change. The universal samples with butt and circumferential welds in sheet plane are as well represented for this in the RF standard together with rigid single-sided tee weld [6]. They allow changing a metal thickness (1–12 mm), diameter of circumferential weld, modes and methods of welding in a wide range and, thus, obtaining critical values at which formation of HC in sample welding is possible.

Change of width of plates to be welded in the sample with butt joint allows increasing high-temperature welding deformations up to the level sufficient for obtaining of quantitative result of testing from weld metal of any composition (GOST 26389–84) that is very important for consumable selection.

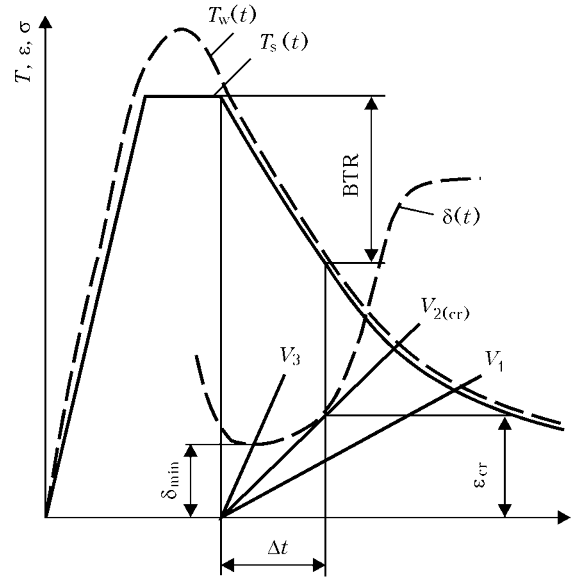

Figure 1. Scheme of weld and near-weld metal tests to HC resistance in welding by means of deformation growing developed using test machine: $T_W(t)$ — welding thermal cycle; $T_S(t)$ — simulation of thermal cycle; V_1–V_3 — growing of deformation in the BTR; V_{cr} — deformation resulting in crack formation; $\delta(t)$ — predicted character of ductility change in the BTR; $V_{cr} = \varepsilon_{cr}/\Delta t$ — critical rate of deformation

The second part of standard ISO/TR 17641-3 is represented in a form of engineering report on tests with forced «loading» in welding and can be considered as its first project. It contains description of American procedures Varestraint, TransVarestraint, Gleeble, as well as PVR procedure developed in Austria [7].

A series of notes should be made on this document.

1. High-speed deformation by bending of solidifying weld metal on Varestraint and TransVarestraint procedures violates the principles of physical simulation in sample testing and conditions promoting failure in real welded structures. This note also refers to Gleeble procedure, in accordance to which speed of high-temperature tension of investigated samples in the BTR makes 0.15–0.25 m/s (6–10 inch/s) [7].
2. Evaluation of degree of deformation in mandrel bending on formula $\varepsilon = h/2R$ is suitable for homogeneous, i.e. isotropic material. However, solidifying metal in welding has double-phase structure and defomations are accumulated along the grain boundaries which is a reason for HC formation.
3. Evaluation to HC resistance in bending testing of the welded joint from thin-sheet metal, including pass, is impossible since the critical values are not achieved in mandrel bending.
4. Proposed criterion of total length of cracks L_{tot} does not consider ductility margin of metal in it being the main factor of crack formation.
5. Diffusion processes and high-temperature creep preparing conditions for HC nucleation are limited by a dynamic deformation of weld being solidified. Elimination of these processes in the dynamic deformation develops seeming increased HC resistance that can result in unpredicted failure of the welded structures.

It should be noted that as a rough approximation HC length can only characterize the BTR value in the dynamic deformation. Another factor, i.e. ductility margin δ_{BTR}, can not be evaluated by number of cracks and their length, therefore, L_{tot} does not considered to be a qualitative criterion of tendency to HC (see Figure 1).

Inter-grain ductility of metal in the BTR according to Gleeble procedure is proposed to be evaluated on degree of its change outside the BTR, i.e. in area of high-ductility weld metal condition that violate validity of tests [8].

Tests to HC, types of cracking and designation according to ISO 17641:2005 standard

Test type	Type of cracking	Results	Designation
Method of deformation along the weld axis	Solidification	L_{tot}	Base metal (selection and confirmation) Consumable (selection and confirmation) Welding procedure
	Liquation	L_{tot}	
	Ductility reduction	L_{tot}	
Method of deformation across the weld axis	Solidification	L_{tot}	Selection of consumable. Welding procedure
Tensile test of flat sample along the weld (PRV test)	Solidification	V_{cr}	Metal selection. Multipass welded joints. Welding procedure. Metal combination
	Liquation	V_{cr}	
	Ductility reduction	V_{cr}	Selection and confirmation of material
Tensile test in hot state (Gleeble^{TM})	Solidification	BTR	
	Liquation	BTR	

The advantage of the RF standard is that $V_{cr} = \delta / t_{BTR}$ index can be evaluated using a method requiring no direct measurement of ductility of the weld metal and the BTR limits. At that, the sample is subjected to continuous, i.e. static, deformation in the temperature range from upper to lower limits of the BTR up to $0.5T_{melt}$ temperature in the investigated section with weld being solidified.

At that, intergranular shifts are not accumulated in deformation out of the BTR. They appear only in the BTR that is the main advantage of static tension or bending in HC resistance tests.

Inclusion of procedure of static deformation (programmable deformation cracking PVR) procedure in project of ISO/TR 17641-3 standard is its positive moment. However, testing of PVR sample having deposited bead of large length results in heating and increase of length of the sample between the machine grips that distort predicted linear distribution of deformations along the sample.

Besides, a local concentration of deformations under the arc, to large extent machine v_m, is inevitable as a result local arc heating of the sample and reduction of metal resistance to deformation. Its level depends on thermophysical properties of steels and alloys being compared and duration of deformation can be smaller than the BTR time.

In the RF standard the similar tests to HC resistance, oriented along the weld axis («paling»), are carried out with growing tension speed within one series of the samples. This allows determining V_{cr} index and using it in selection of alloys and consumables.

Large number of mutually exclusive indices (Table) and absence of correlation coefficients between them should be noted at general evaluation of ISO 17641 standard. This provides a necessity of purchase and operation of large number of testing machines.

One conditional index of HC resistance V_{cr} (mm/s) is regulated in RF standard. Comparison of its values is possible at equal speed w_{BTR} of metal cooling in the BTR. In other cases physical index B_{cr} (mm/°C) equal V_{cr}/w_{BTR} is determined. This index allows evaluating resistance of weld metal and near-weld zone to formation of longitudinal and transverse cracks in different welding methods [8].

New model of testing machine MIS (Figure 2) equipped with a fixture for static tension and bending of samples (Figure 3) in process of welding, welding head with possibility of movement along x, y and xy axes (circum–ferential weld) and fixture for electric contact heating and tension of the samples for evaluation of metal tendency to formation of HC in the near-weld zone

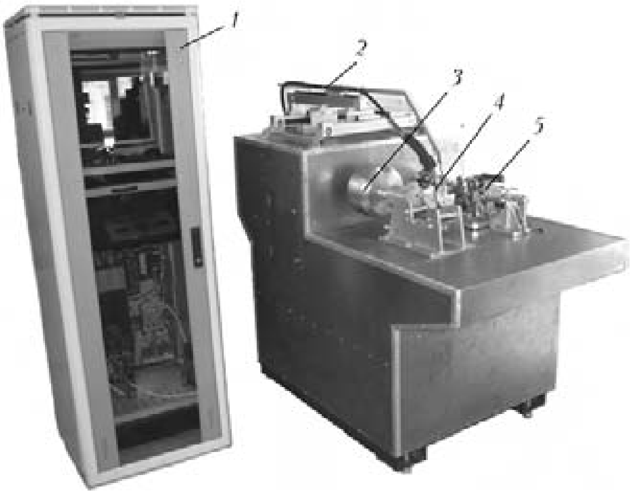

Figure 2. General view of machine MIS for HC testing on the RF standard: *1* — box for control of test parameters, their imaging and registration; *2* — manipulator of welding head for its movement along x, y and xy axes; *3* — force measure device; *4* — machine for welding of samples and their bending or tensile tests; *5* — machine for simulation of welding cycle in the samples and HC tests at cooling stage

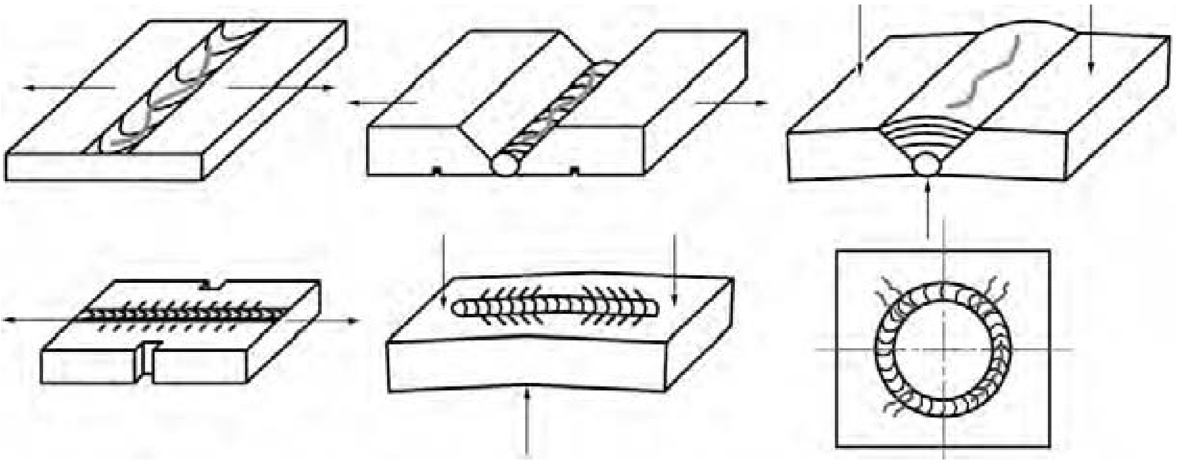

Figure 3. Types of samples applied for MIS machine testing

was designed for performance of metal tests to HC resistance. Presence of dynamometer in power mains and dilatometer allows applying MIS machines for testing of joints to cold crack resistance etc.

CONCLUSION

1. Theory of production strength is the basis of standard for quantitative evaluation of metal to HC resistance. In accordance to it the HCs are the result of exhaust of ductility margin in the BTR under effect of welding stresses and deformations.

2. Critical rate of deformation, determined based on a fact of exhaust of ductility of the samples with weld in the BTR at static machine deformation, is quantitative index of metal HC resistance.

3. Machine methods of evaluation of metal to HC resistance in testing of small dimension samples should provide the possibility of physical modelling of conditions resulting in HC formation at manufacture of real welded structures.

4. Machine tests on ISO/TR 17641-3 standard project using impact bending of the samples with weld (Varestraint and TransVarestraint) or impact rupture of the samples (Gleeble) do not have sufficient ground, since convective and diffusion processes, determining metal ductility in the BTR, are not considered in determination of L_{tot} and high-temperature ductility dip (BTR) and not suitable for qualitative evaluation.

5. Technological tests of metal to HC resistance on GOST 26389–84 provide for application of samples with butt and tee welds as well as widely used [8] samples with circumferential weld of various thickness (1–20 mm) that guarantee their suitability for comparison of consumables and technological variants of welding and, thus, widening their versatility in comparison with samples of ISO 17641–2 standard.

1. (1991) *Welding and welded materials*: Refer. Book. Vol. 1: Weldability of materials. Ed. by E.L. Makarov. Moscow: Metallurgiya.
2. Yakushin, B.F. (1969) Assessment of technological strength depending on welding conditions. *Svarochn. Proizvodstvo*, **1**, 19–21.
3. Bernasovsky, P. (2005) *Contribution to HAZ liquation cracking of austenitic stainless steels. Phenomena in welds*. Berlin: Springer.
4. Zhelev, A. (1988) *Complex thermokinetic approach in assessment of hot cracks during welding*: Syn. of Thesis for Dr. of Techn. Sci. Degree. Sofia.
5. Wilken, K. (1999) Investigation to compare hot cracking tests. *IIW Doc. IX-1945–99*.
6. Tsarkov, V.A., Chuprak, A.I. (2010) Ways of harmonisation of national and European standards for assessment of metal resistance to hot cracking. *Svarka i Diagnostika*, **6**, 58–62.
7. Yakushin, B.F. (2003) Harmonisation of RF and EU standards on weldability tests. *Svarochn. Proizvodstvo*, **1**, 39–43.
8. Steklov, O.I. (1976) *Strength of welded structures in aggressive media*. Moscow: Mashinostroenie.