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Reliability estimation of the ferritic steels welded joints

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1. Introduction

The reliability of construction is its property to preserve the specific quality the predetermined time. High strength of materials can be realized in the constructions, only when it is combined with a sufficient reserve of other properties and, first of all, by the fracture toughness. Depending on metal deformation degree, which precedes destruction there are distinguished brittle (intragranular and intergranular), quasi-brittle and ductile fractures [1-9].

Brittle failure is characterized by the presence of chipping facets on the surface of the fracture. Destruction of metal structure, which contains more than 40 percents of martensite, is usually brittle.

Ductile fracture is characterized as multistage process which involves the creation of pores in the second stage, the formation of a dent as a result of growth and merging of micro spaces around the pores, plastic deformation of the material around the micro spaces and its break.

Reduction of the temperature, change from the state of plane stress to that plane-deformed contributes to the replacement of the viscous mechanism of destruction by brittle. The destruction of welded constructions or articles occurs more often on the seams; therefore reliability estimation of welded joints is very important [1-4, 8-9].

Structural failure occurs usually, when several unfavorable phenomena's appear simultaneously. For example, in the seam and the zone near the weld brittle tempering structure was formed also there are microscopic cracks and at high load on such structure usually destruction occurs. The destruction can be rapid or slow. Rapid destruction usually leads to emergencies. Slow destruction can be noted and construction usage can be stopped without the emergency. For slow destruction to occur it is necessary to have the high plasticity of the weld material and lack of defects.

Basic difficulty when welding high-alloy ferritic steels is its tendency toward the formation of hot and cooling cracks in the seam and the zone near the weld. Hot cracks usually have inter crystal nature. Hot cracks can be microscopic or visible. The formation of hot cracks is usually related to formation of coarse-grained microstructure of the seam during welding and the presence of the stresses of shrinkage [1-8].

Cooling cracks are usually caused by the mechanism of cold-shortness and appear along or across the seam. Their appearance is connected with the disturbances of welding technology and is caused by three reasons: by the presence of tempering structure in the zone near the weld; by saturation of the weld material by hydrogen (as a result of the use of the uncalcined welding materials), by the presence of stress concentrators of technological and construction types (welding defects of the type of slag inclusions, non fussion, undercuts and so on, and also the zones of sharp passage in the welding structure). The probability of cooling cracks appearance increases with an increase in thickness of the details to be welded [2-5, 9].

2. Experimental

Grade 08X25T steel GOST 5632-72 (X8CrTi25 EN10028-2) relates to partly welded steel. In the case of manual welding a good plasticity of the seam must be ensured by austenitic electrodes with the grade Sv-07X25H12Γ2T steel (brand OZL-4) wire or with the grade Sv-07X25H13 wire (brand OZL-6). Before the welding a 100-120°C preheating and later subsequent heat treatment of 600°C is necessary.

Materials for realization of complex researches in a metal science field were templets, which were cut out from the seams of welded plates. A comparative metalographic research of the seam metal and the metal of a zone near to the seem, obtained by manual arc welding (111 EN 24063) of plates (200 x 100 x 6 mm) from grade 08X25T steel GOST 5632-72 (X8CrTi25 according to the standard EN10028-2 and CR 10260), were carried out. Pearlitic electrodes UONI -13/45 (EN 499 − E46 3 B4H10), austenitic electrodes OZL-6 (ISO 3581: E 25.13B), austenitic-ferritic electrodes UTP-65D (EN1600: E29 9 R/2), nickel electrodes UTP-068HH (EN 1736: EL-NiCr19Nb) and copper electrodes UTP 34N (EN 1733: EL- CuMn14Al) were applied. The welding was conducted on a constant current of return polarity in one pass by electrodes of a diameter 3.0 and 3.25 mm. The current of welding was 110 A, the voltage of an arch was 22-24 V. Welding was done without preheating and the subsequent heat working. A hydraulic jack type device was used for the destruction of welded plates. The fracture was taking the place all time through the welded seam.

The places for stress concentration in the welded joint, which can contribute to crack formation in the seam are represented in Fig. 1.

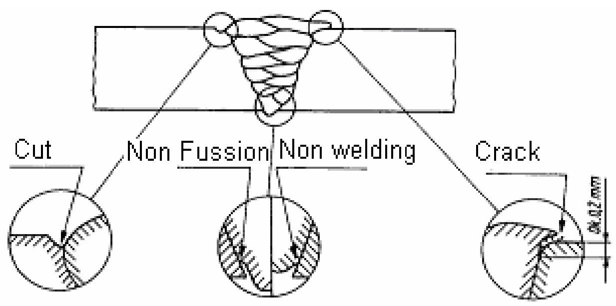


Fig. 1 The places for stress concentration in the welded joint, which can contribute to crack formation in the seam

Structure of the seam was investigated using microscope LEICA MEF 4M and scanning microscope XL 30 ESEM, PHILIPS. Chemical composition was determined by microscope Spectro LAB 05 3/N 45/263.

3. Results and analysis

Chemical structure of the base and welding materials is presented in the Table 1, and chemical structure of welded seams – in the Table 2.

Comparative studies of weld material, microstructure and the zone near the weld were done. The mechanism of interface destruction was determined also.

The destruction of the connection which was obtained by welding grade 08X25T steel by tungsten electrodes in the medium of argon and also with pearlitic UONI-13/45 and copper UTP-34N electrodes has quasi-brittle nature. Also when welding by copper electrodes the large number of intermetallic starts are formed. Therefore in the dilution zone structural heterogeneity and large internal stresses are formed. Crack formation is the consequence of this.

Table 1

Chemical composition of the base and welding materials, %

Material	C	Mn	Si	Cr	Ni	Fe	The note
08X25T	0.08	0.63	0.41	26.71	-	71.34	Ti - 0.83
UONI-13/45	0.10	0.35-0.60	0.03	0.15	0.30	98.7-99.0	
OZL-6	0.09	1.0-2.0	0.5-1.0	23.0-26.0	12.0-14.0	57.0-63.0	
UTP-65D	0.10	1.0	1.0	30	9.5	57-58.5	
UTP-068HH	0.03	5.0	0.4	19	69	3	Mo- 1.5; Nb- 2.2
UTP-34N	0.03	13	-	-	2.5	2.5	Al-7; Cu-75

Table 2

Chemical composition of welded seams, %

Material	Electrode	C	Cr	Ni	Mn	Si	Fe
08X25T	UONI-13/45	0.115	14.11	0.32	0.62	0.46	84.38
08X25T	UTP-068HH	0.056	22.85	34.76	2.92	0.40	39.01
08X25T	UTP-034N	0.062	13.82	1.53	8.54	Al-4.47	Cu-54.28
08X25T	UTP-65D	0.112	28.35	4.86	0.83	1.68	64.17
08X25T	OZL-6	0.092	25.93	10.02	1.56	1.16	61.24

When welding using copper electrodes microscopic cracks in the base metal are observed, and when welding using tungsten and pearlitic electrodes microscopic cracks are observed in the weld material (Fig. 3). Connection breaking obtained by welding grade 08X25T steel by austenitic OZL-6 and austenite-ferrite UTP-65D electrodes usually is viscous (with the separate starts of brittle). With the use of austenite-ferrite electrodes flat, tight seam with a sufficient smelting is obtained. When welding using nickel UTP-068HH electrodes ductile fracture is observed. Seam is large-flaked, less smelting than when welding using UTP-65D electrodes.

The comparative study of metal seam microstructure and the zone near to the seam were done during welding of heat-resistant steels.

For reliability estimating of a the welded connection it is very important to know its strength and the character of a possible destruction. Martensite has high hardness and durability, also low plasticity. In the case of a martensitic structure of a welded joint, and when upper limit of loading takes place, there can be fast fragile destruction It is especially dangerous during shock or variable loading. In this case the reliability of a construction will be low and it can be used only at static loading. An austenite has lower durability and higher plasticity. At presence of an austenitic structure in a welded joint and when loading upper limit is used, a slow (viscous) destruction takes place more often. . The reliability of the construction in this case is much higher, as the beginning of destruction can be noticed in time and the operation of a design can be stopped without accident. It was considered, that the longer destruction time of the structure is, the reliability of it is higher.

Fusion zone microstructures and surface fracturegrams of the destroyed seam received during grade 08X25T steel GOST 5632-72 (X8CrTi25 under the standard EN100028-2 and CR 10260) welding using various electrodes are presented in Fig. 2-6.

The structure of weld metal can be determined using Sheffler diagram and Table 3 taking average values of Ni and Cr.

Table 3

Structure weld metal

Cr_{eq}/Ni_{eq}	$Cr_{eq} + Ni_{eq}$	Weld structure
< 2.5	< 30 %	martensitic structure
> 2.5	< 30 %	martensitic - ferritic structure
< 2.5	> 30 %	ferritic structure
1.25-2.5	> 30 %	austenitic - ferritic structure
< 1.25	> 30 %	austenitic structure

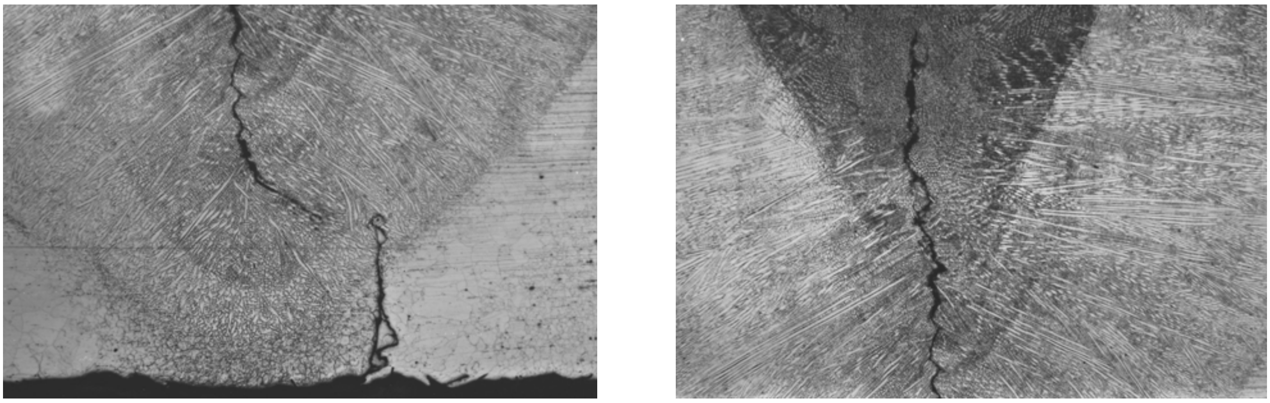
$$Ni_{eq} = \%\,Ni + 30 \times \%C + 0.5 \times \%Mn \quad (1)$$

$$Cr_{eq} = \%\,Cr + \%\,Mo + 1.5 \times \%\,Si + 0.5 \times \%Nb \quad (2)$$

During grade 08X25T steel welding by electrodes OZL-6 we have received Cr_{eq} = 27.67 %; Ni_{eq} = 13.50 %; Cr_{eq} / Ni_{eq} = 1.83; Cr_{eq} + Ni_{eq} = 41.17 % > 30 %. The received data shows, that the seam structure should be ferritic (under the Sheffler diagram – austenitic-ferritic). Fusion zone structure and the fracturegram of destroyed surface of the seam are presented in Fig. 5. There can be seen that the seam structure is close to martensitic-ferritic and the seam can be used in the case of static loading.

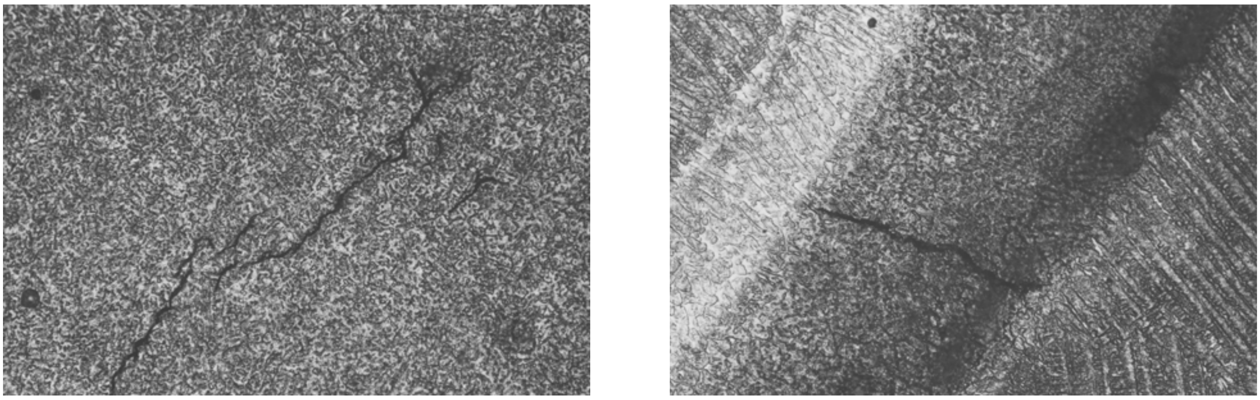
During grade 08X25T steel welding by electrodes UTP-65D we have received Cr_{eq} = 30.59 %; Ni_{eq} = 8.20 %; Cr_{eq} / Ni_{eq} = 3.73; Cr_{eq} + Ni_{eq} = 38.79 % > 30 %.

The received data shows, that the seam structure should be ferritic (under the diagram Sheffler - ferrite with 10% austenite). Fusion zone structure and the fracturegram of destroyed surface of the seam are presented in Fig. 6. There can be seen that the seam structure is more ferritic-martensitic, destruction of the seam is fragile and occurs in



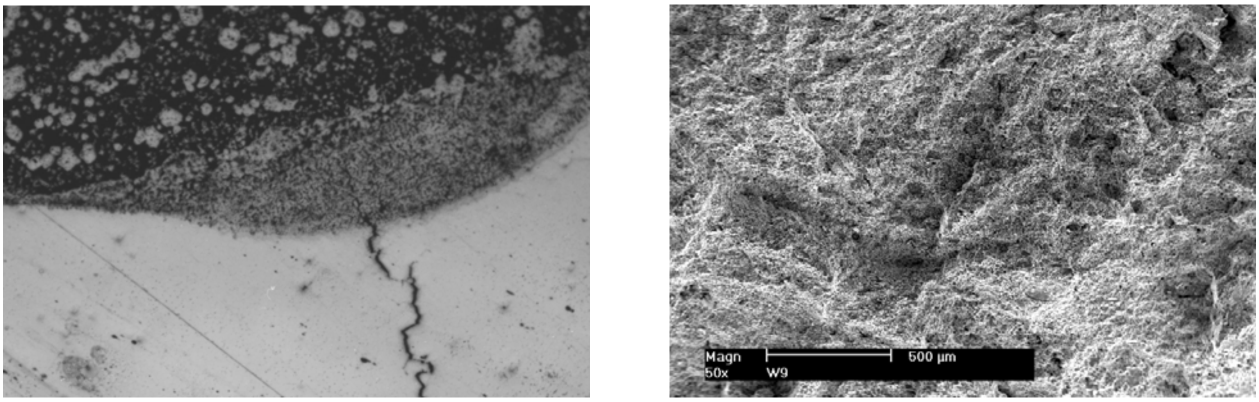
a b

Fig. 2 Cracks formed welding became grade 08X25T steel by nonfusible electrode (x200): a – crack was formed when welded using 2 passages; b – crack was formed when welded using single passage



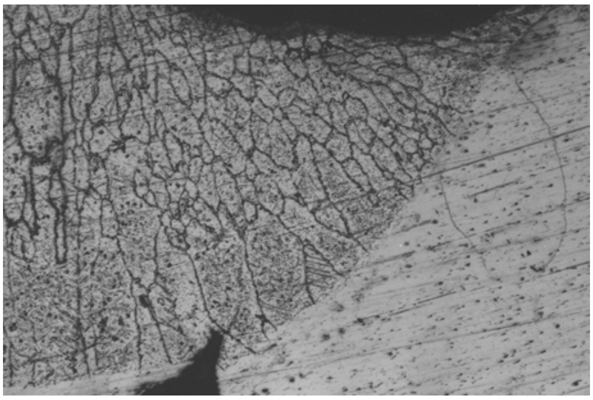
a b

Fig. 3 Microscopic cracks in the weld metal and the heat-affected zone with the welding became grade 08X25T steel by the pearlitic UONI-13/45 electrodes (x200) : a –hydrogen cracks; b – quenching crack



a b

Fig. 4 Structure of a fusion zone (a, x200) and a fracturegram (b) of a welded seam received at welding grade 08X25T steel by copper electrodes UTP-34N



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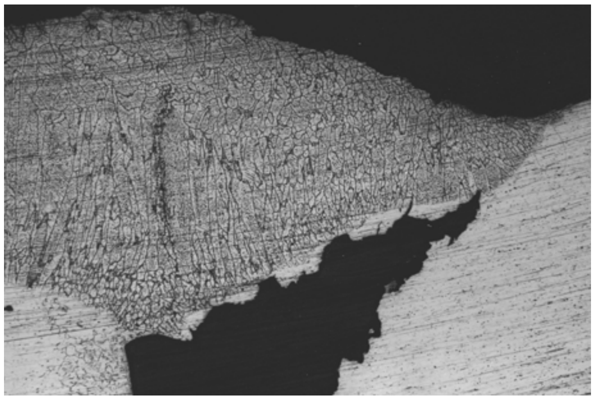
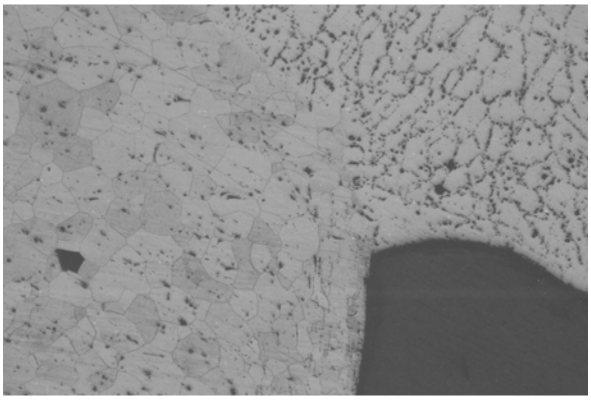


b

Fig. 5 Initial (a, x100) and final (b, x20) stages of the destruction of a welded seam received at welding grade 08X25T steel by austenitic electrodes OZL-6



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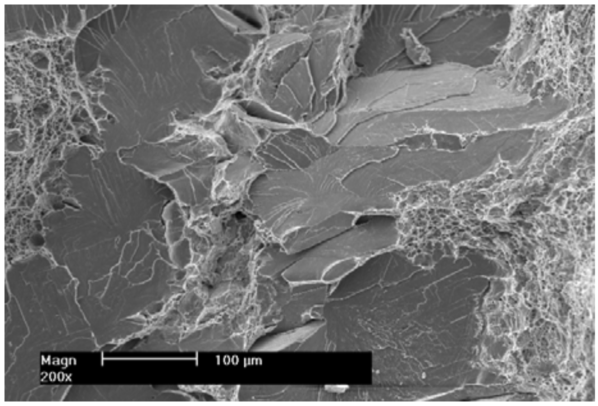

b

Fig. 6 Structure of a fusion zone (a, x200, left – basic metal, right – welded joints) and a fracturegram (b) of a welded seam received at welding grade 08X25T steel by austenitic-ferritic electrodes UTP-65D

the fusion zone. Such seams can be used during static loading and under operation at high temperature.

In the dilution zone, and also in the zone of overlap of rollers, microscopic cracks sometimes are observed with the presence of flux contaminations. When there are no welding defects, microscopic cracks are not observed.

With the use of different welding materials it is possible to obtain different structure of the weld and to consequently change the reliability of the welded joint. Authors propose to estimate the reliability of a welded joint by hardness and plasticity of the metal. In this case it can be

$$K = HV \times A \tag{3}$$

where HV is hardness of the metal according to Vickers, A is plasticity of the metal, %.

Structural plasticity was estimated as follows: austenite - 40%, ferrite - 30%, pearlite - 15%, sorbite - 10%, troostite - 5%, martensite - 1%.

During grade 08X25T steel welding by austenitic ОЗЛ-6 electrodes the weld has hardness of 190-195 HV, dilution zone – 165-170 HV, base metal – 200-210 HV. During grade 08X25T steel welding using austenite-ferrite electrodes there is observed approximately the identical hardness of the weld material and the zone near the weld - 180-185 HV, while during welding using nickel electrodes weld material has hardness 160-170 HV, dilution zone – 180-190 HV. During grade 08X25T steel welding using pearlitic UONI-13/45 electrodes the weld has hardness

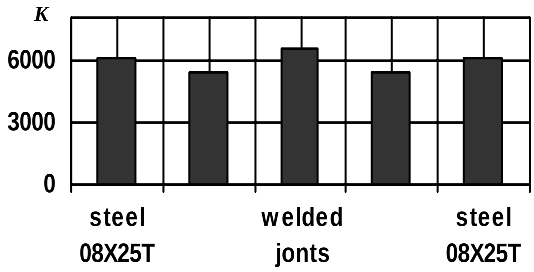

Fig. 7 Distribution of reliability in the welded joint welding grade 08X25T steels by austenitic-ferritic UTP-65D electrodes

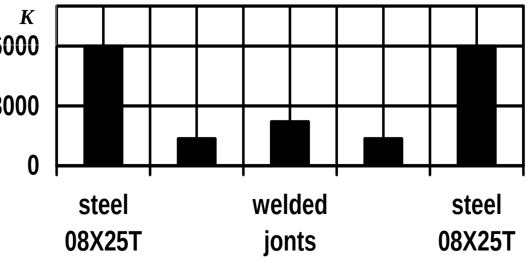

Fig. 8 Distribution of reliability in the welded joint with welding of grade 08X25T steels by the pearlitic UONI -13/45 electrodes

195-220 HV, dilution zone – 240-270 HV, base metal – 200-210 HV. During welding using copper electrodes the weld material has hardness 170-200 HV, dilution zone - 180-200 HV. Fig. 7 and 8 depict the diagrams of reliability distribution with grade 08X25T steel welded by nickel and pearlitic electrodes. As can be seen from figures the lowest reliability is observed in the dilution zone.

4. Conclusions

1. Destruction of the welds that are welded by austenitic electrodes has viscous nature with the individual sections of quasi-brittle destruction in essence, and the welds that are welded by pearlitic electrodes – intermediate nature.

2. The presence of increased hardness zones in the dilution zone is not the condition for the possible appearance of hot cracks.

3. It is recommended to estimate the reliability of welded joints using maximum hardness of the weld and plasticity. The lowest reliability (without taking into account welding stresses) is observed in the dilution zone from the side of base metal (grade 08X25T steel).

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I. Višniakas

FERITINIŲ PLIENŲ SUVIRINTŲJŲ JUNGČIŲ PATIKIMUMO NUSTATYMAS

R e z i u m ė

Įvertintas kaitrai atsparaus (iki 1100°C) feritinės klasės plieno 08X25T GOST 5632-72 (X8CrTi25, EN 10028-2) jungčių, suvirintų rankiniu lankiniu būdu (111 LST EN 24063) skirtingų klasių glaistytaisiais elektrodais, patikimumas. Siūloma suvirintųjų jungčių patikimumą vertinti pagal maksimalų siūlės ir terminio poveikio srities metalo kietumą ir struktūros plastiškumą. Nustatyta, kad tiriamuose sujungimuose mažiausiai patikimumas yra jungtys, suvirintos nelydžiuoju elektrodu, bei variniais (UTP-34N) ir perlitiniais elektrodais (UONI-13/45), o patikimiausios – suvirintos nikeliniais (UTP-068HH) ir austenitiniais-feritiniais (UTP-65D) elektrodais.

I. Vishniakas

RELIABILITY ESTIMATION OF THE FERRTIC STEELS WELDED JOINTS

S u m m a r y

It was evaluated the reliability of the welded joints of high-temperature oxidation-resistant (up to 1100°C) grade 08X25T steel of ferrite class GOST 5632-72 (X8CrTi25, EN 10028-2) by the manual arc welding (111 LST EN 24063) with the coated electrodes of different classes. Is proposed the method of evaluating the reliability of the welded joints of using maximum hardness of weld material and near-weld zone and the plasticity of structure. It is established that in the connections being investigated the smallest reliability have joints that are welded by the nonfusible electrode, copper (UTP-34N) and pearlitic (UONI-13/45) electrodes, and greatest − by austenitic (UTP-068HH) and austenite-ferrite (UTP-65D) electrodes.

И. Вишнякас

ОЦЕНКА НАДЕЖНОСТИ СВАРНЫХ СОЕДИНЕНИЙ ФЕРРИТНЫХ СТАЛЕЙ

Р е з ю м е

Оценивалась надежность сварных соединений жаростойкой (до 1100°C) стали ферритного класса 08X25T ГОСТ 5632-72 (X8CrTi25, EN 10028-2), выполненных ручной дуговой сваркой (111 LST EN 24063) покрытыми электродами различных классов. Предложен метод оценки надежности сварных соединений использующий максимальную твердость металла шва и зоны термического влияния, а также пластичность структуры. Установлено, что в исследуемых соединениях наименьшую надежность имеют соединения, сваренные неплавящимся электродом, а также медными (UTP-34N) и перлитными (UONI-13/45) электродами, а наибольшую – аустенитными (UTP-068HH) и аустенитно-ферритными (UTP-65D) электродами.

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