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# Reliability Estimation of the Austenitic Steels Welded Joints

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The reliability of the welded joints of high-temperature (oxidation-resistant) and heat resistant (to 1100 °C) austenitic steel 20X23H18 (X20CrNi23-18, EN 10028-7 ) by the executed manual arc welding (111 EN 24063) by the coated electrodes of different classes was evaluated. It is proposed the method of evaluating the reliability of the welded joints by using maximum hardness of the weld material and near-weld zone and the plasticity of structure. It is known that when the connections are being investigated, the smallest reliability have connections that were welded by copper (UTP-34N) electrodes, and greatest – by austenitic (UTP-068HH) and austenite-ferrite (UTP-65D) electrodes.

*Keywords*: welded joints, austenitic steels.

## INTRODUCTION

The fundamental characteristics of high-temperature (strength) alloys and steels are: stress-rupture strength, prolonged creep, prolonged plasticity, reliability [1].

The high strength of materials only can be realized in the constructions, when it is combined with the fracture toughness and sufficient reserve of other properties. Depending on metal deformation degree, that precedes the destruction, there is distinguished brittle (intragranular and intergranular), the quasi-brittle and ductile fracture [2 – 10].

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

Ductile fracture is characterized as a multistage process which involves the creation of pores in the second stage – the formation of dent as a result of growth and merging of micro spaces around the pores, the plastic deformation of 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 the estimation of the reliability of welded joints is very important [1 – 7].

Structural failure occurs usually, when several unfavorable phenomena appear simultaneously. For example, in the seam and zone near the weld brittle tempering structure was formed, there are microscopic cracks. During high load on such structure destruction occurs usually. Destruction can be rapid or slow. Rapid destruction usually leads to the 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 in the seam and the zone of hot and cooling cracks near the weld. Hot cracks can be microscopic or visible. The formation of hot cracks is usually related to the formation of the coarse-grained microstructure of seam during welding and the presence of the stresses of shrinkage [1 – 7, 10 – 16].

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 weld material by hydrogen (as a result of use with welding of the uncalcined welding materials), by the presence of the stress concentrators of technological and construction types (welding defects of the type of slag inclusions, non fusion, undercuts and so on, and also the zones of sharp passage in the welding construction). Cooling cracks appearance probability increases with an increase in the thickness of the details [4 – 10] to be welded.

The aim of this work is to determinate the reliability of the welded joints of austenitic steel 20X23H18 (X20CrNi23-18, EN 10028-7) that were obtained during manual welding with different electrodes.

## EXPERIMENTAL

Steel 20X23H18 (GOST 5632-72) refers to partly welded steel type. In the case of manual welding a good plasticity of seam got to be ensured by austenitic electrodes with the wire made of steel Св-13X25H18 (brand ОЗЛ-9) or with the wire made of steel Св-07X25H13 (brand ОЗЛ-6). Before the welding a 100 °C – 120 °C preheating and later subsequent heat treatment is necessary.

Materials for complex research were templates, which were cut out from the seams of welded plates. A comparative metallographic research of a seam metal and a metal of a zone near to the seam, obtained by manual arc welding (111 EN 24063) of plates (200×100×6) mm from steel 20X23H18 GOST 5632-72 (X20CrNi23-18 according to the standard EN10028-7 and CR ISO 15608-8.2), 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 (EN 1600: 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 at a constant current of return polarity in one pass by

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**Table 1.** Chemical composition of the basic and welding materials, %

| Material | C | Mn | Si | Cr | Ni | Fe | The note |
|---|---|---|---|---|---|---|---|
| 20X23H18 | 0.09 | 1.61 | 0.36 | 23.68 | 17.41 | 56.30 | |
| 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 | Cr | Ni | Mn | Si | Fe |
|---|---|---|---|---|---|---|
| 20X23H18 | UONI-13/45 | 12.51 | 8.17 | 1.32 | 0.44 | 77.56 |
| 20X23H18 | UTP-068HH | 21.49 | 45.01 | 3.50 | 0.88 | 29.12 |
| 20X23H18 | UTP-034N | 6.82 | 8.53 | 8.54 | Al = 4.47 | Cu = 54.39 |

electrodes of a diameter 3.0 mm and 3.2 mm. The current of welding was 110 A – 120 A, voltage of a arc was 22 V – 24 V. Welding was done without the preheating and the subsequent heat working.

The structure of a seam was investigated using a microscope LEICA MEF 4M and scanning microscope XL 30 ESEM, PHILIPS. Chemical composition was determined by a spectroscope Spectro LAB 05 3/N 45/263. The chemical structure of the basic and welding materials is presented in the Table 1 and Table 2.

## RESULTS AND ANALYSIS

Comparative studies of the welded material micro-structure and zone near the weld were done. The mechanism of destruction of interface also was determined. The destruction of the connection which was obtained by welding steel 20X23H18 by tungsten electrodes in the medium of argon and also with pearlitic UONI-13/45 and copper UTP-34N electrodes has quasi-brittle nature according to Fig. 1, a. When copper, tungsten or UTP-65D electrodes are used for welding, microscopic cracks in the base metal can appear. When nickel electrodes UTP-068HH are used for welding ductile fracture is observed according to Fig. 1, b. The seam is large-flaked, less smelting than when welding using electrodes UTP-65D.

The comparative study of microstructure of metal of the seam and of the zone near to the seam was carried out during welding of the heat-resistant steels.

For estimating of a reliability of a welded connection it is very important to know its strength and character of possible destruction. Martensite has high hardness and durability, also small plasticity. In the case of martensitic structure of a welded joint, and when upper limit of loading takes place, there can be fast fragile destruction. It is especially dangerous at 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 an upper limit of loading 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 more time of destruction of a design, the reliability of it is higher.

Microstructures of a fusion zone and fracture of a surface of the destroyed seam received at welding steels 20X23H18 GOST 5632-72 (X20CrNi23-18 under the standard EN10028-7) using various electrodes are presented in Figs. 2 – 6.

The structure of the metal weld can be determined using the Sheffler diagram taken average values Ni and Cr, using (5) and (6):

$$Ni_{eq} = \text{of } \% \, Ni + 30 \, \% \, C + 0.5 \, \% \, Mn; \quad (5)$$

$$Cr_{eq} = \text{of } \% \, Cr + \% \, Mo + 1.5 \, \% \, Si + 0.5 \, \% \, Nb. \quad (6)$$

The reliability of the construction in this case depends on the phase composition of the weld. Using the Sheffler diagram for the determination of welding carbon steel with an austenitic one, we can see that the structure contains 90 % of an austenite and 10 % of ferrite. The martensite in his case is entirely excluded.

Therefore it may be expected that the formation of cracks in the weld metal is nearly impossible when the weld is formed by welding different metals using austenitic electrodes. By the way, in practice during the welding of austenitic steel with carbon steel in the weld metal also in the fusion zone cracks can appear sometimes in the weld metal of carbon steel and also in the fusion zone.

During steel 20X23H18 welding by the nonfusible electrode we have received: $Cr_{eq} = 24.5$ %; $Ni_{eq} = 25$ %; $Cr_{eq} / Ni_{eq} = 0.98$ %; $Cr_{eq} + Ni_{eq} = 49.50$ % > 30 %.

In this case the structure of the seam should be austenitic (Table 3), according to Sheffler diagram – austenitic; dilution zone – austenitic-beinitic structure.

During welding of steel 20X23H18 by electrodes UTP-068HH we have received: $Cr_{eq} = 22.81$ %; $Ni_{eq} = 49.46$ %; $Cr_{eq} / Ni_{eq} = 0.46$; $Cr_{eq} + Ni_{eq} = 72.27$ % > 30 %.

The received data show, that the seam has an austenitic structure only (Table 3). Such seams can be exploited

**Table 3**. The structure of a welded on 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 |

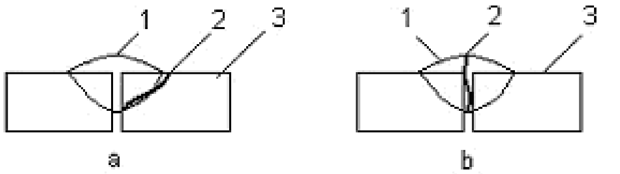
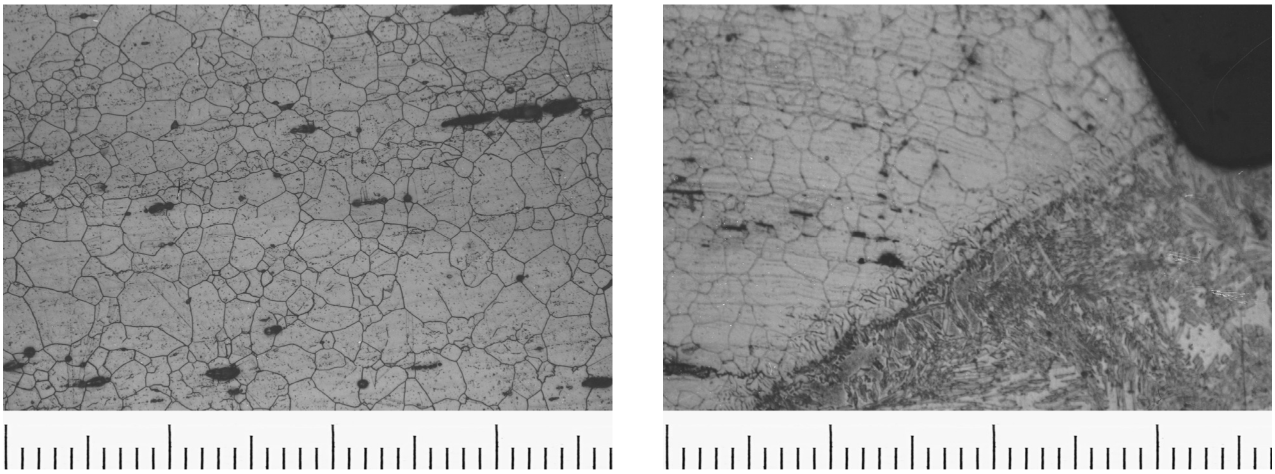
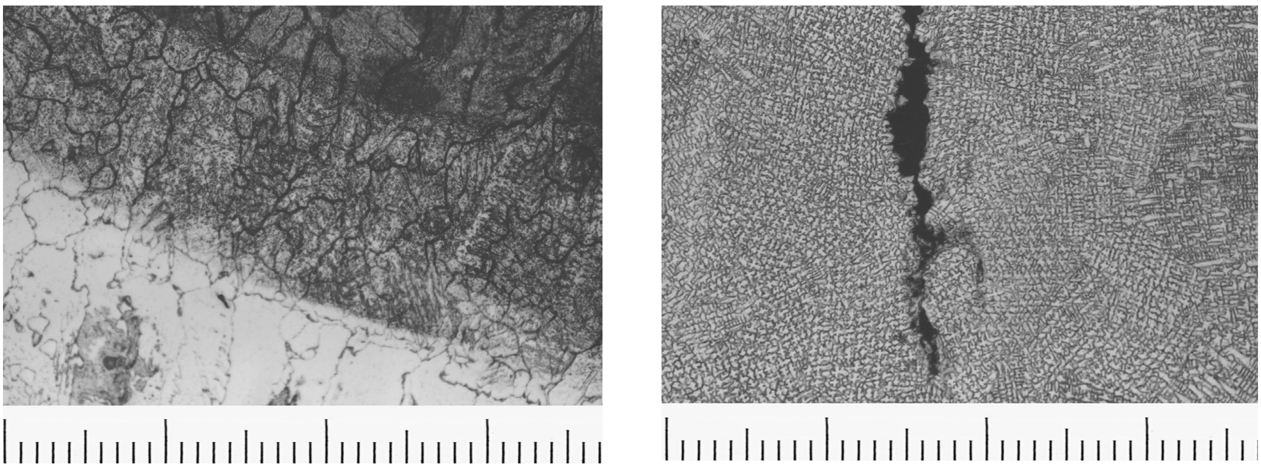



**Fig. 1.** Diagram of breaking the welded connection obtained by welding steel 20X23H18 by different electrodes: a – the destruction of a seam in the dilution zone; b – destruction in the zone of close one to center seam. 1 – the weld, 2 – the place of crack formation, 3 – the base metal



a b

**Fig. 2.** Structure of steel 20X23H18 (a) and fusion zone (b) with the welding by the austenitic OZL-6 electrodes (mark size – 1 mm)



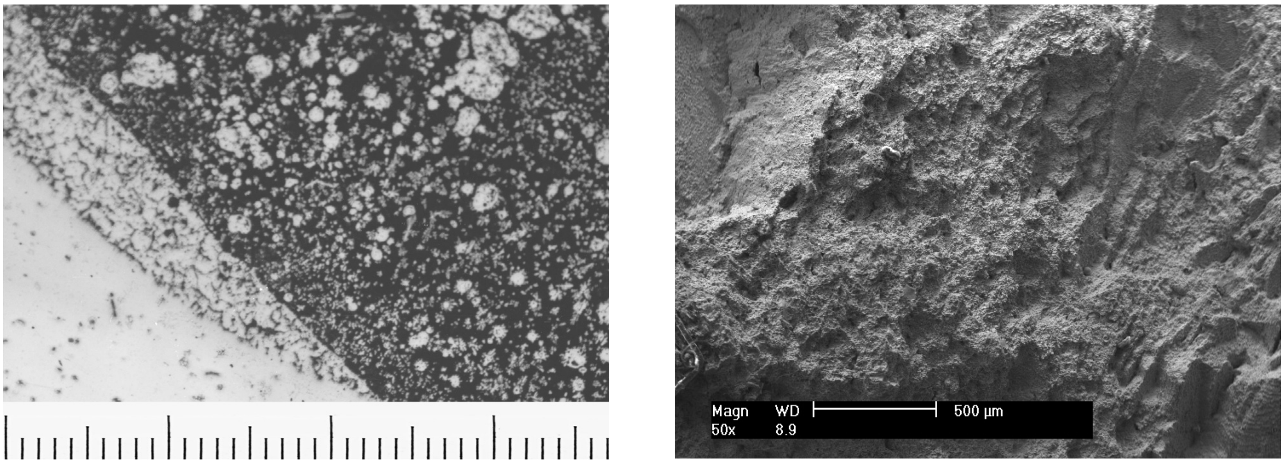
a b

**Fig. 3.** Structure of a fusion zone (a) and microscopic crack (b) in the weld metal during welding of 20X23H18 by the pearlitic UONI-13/45 electrodes (mark size – 1 mm)

under any conditions. Structure of a fusion zone and a fracturegram of a destructions surface shown in Fig. 6, confirms it. The destruction of a seam occurs on its middle and it has a viscous character. It is also necessary to note, that electrodes UTP-068HH are the most expensive of the studied electrodes.

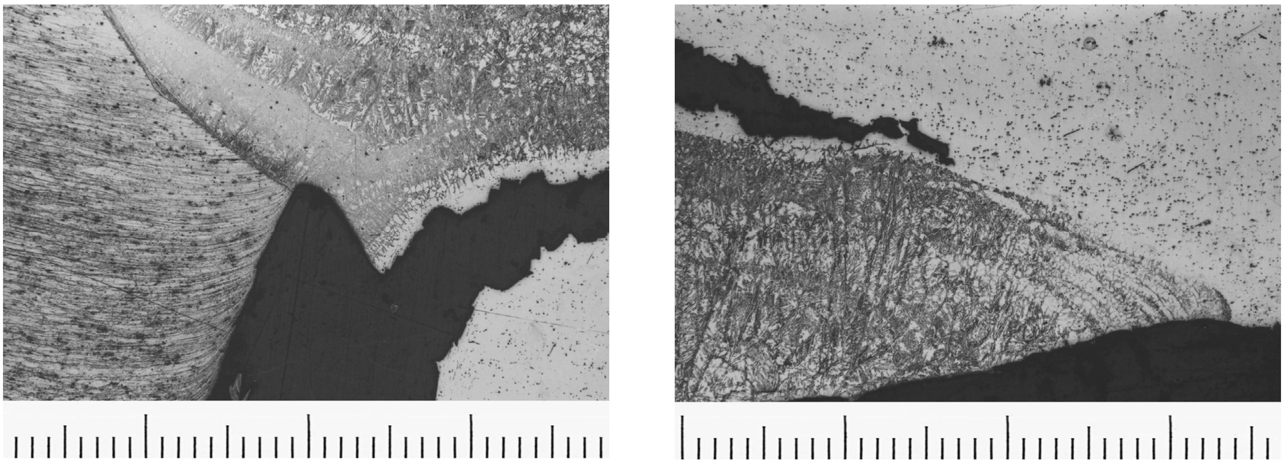
During steel 20X23H18 welding by electrodes UONI-13/45 we have received: $Cr_{eq} = 13.17$ %; $Ni_{eq} = 11.53$ %; $Cr_{eq} / Ni_{eq} = 1.14$ %; $Cr_{eq} + Ni_{eq} = 24.70 \% < 30 \%$. In this case the structure of the seam should be martensitic (Table 3), or according to the Sheffler diagram – austenitic-martensitic (Fig. 7). Structure of a fusion zone and fracturegram of a surface of the seam destruction, presented in Fig. 4 show, that the seam has a complex austenitic-martensitic structure. The destruction of a seam occurs in a zone close to a fusion zone. Such seams can be used in products, the operation temperature of which does not exceed 400 ºC.

During welding of steel 20X23H18 by electrodes UTP-034N we have received: $Cr_{eq} = 6.82$ %; $Ni_{eq} = 15.50$ %; $Cr_{eq} / Ni_{eq} = 0.44$; $Cr_{eq} + Ni_{eq} = 22.32 \% < 30 \%$. The received data show, that the seam has only the martensitic structure (under the Sheffler diagram – martensitic-ferritic; Fig. 7). The presence of plenty of



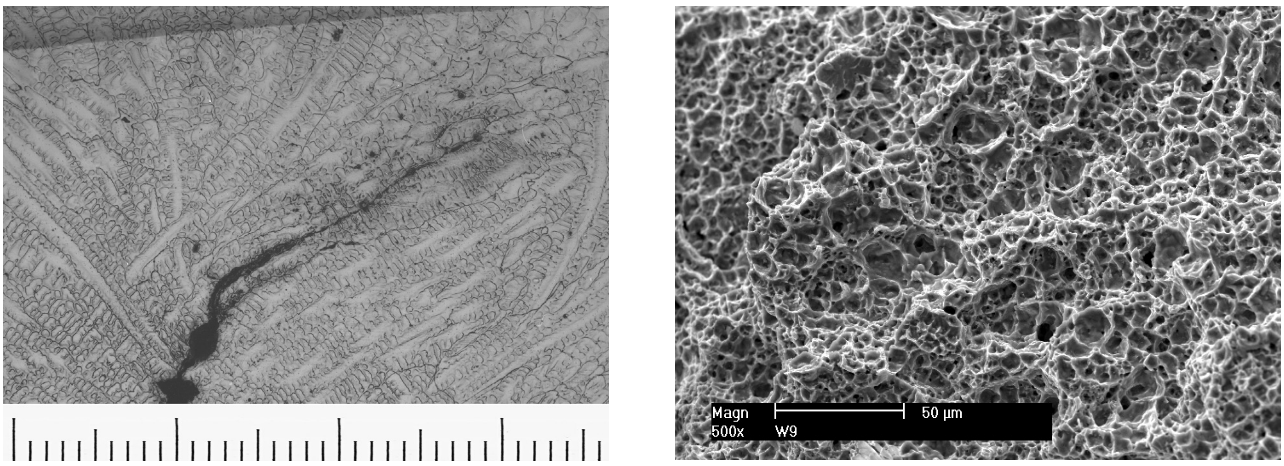

a b

**Fig. 4.** Structure of a fusion zone (a, mark size – 1 mm) and a fracturegram (b) of a welded seam received at welding steel 20X23H18 by copper electrodes UTP-34N



a b

**Fig. 5.** Initial (a) and final (b) stages of destruction of a welded seam received during welding of steel 20X23H18 by austenitic electrodes OZL-6 (mark size – 1 mm)




a b

**Fig. 6.** Destruction (a, mark size – 1 mm) and the fracture of weld face obtained with the welding by nickel electrodes UTP-068HH

copper and also aluminium produces various layers in a seam. During crystallization process the martensitic transformation of a seam occurs. As the martensitic structure is bigger in volume, than austenitic one, increasing of already hardened seam takes place. Possibly it promotes higher occurrence of cracks not only in a seam but also in a zone of the basic metal close to the seam. It is well visible in Fig. 3. The destruction of a seam occurs closer to a fusion zone. Therefore such electrodes for welding of austenitic steel could not be used.

Initial (a) and final (b) stages of destruction of a welded seam received at welding steel 20X23H18 by austenitic electrodes OZL-6 presented in Fig. 5.

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

A limited number of slag inclusions were found in the weld, mainly close to the root pass. Slag inclusions are very harmful in welds because they can promote cracks that easily originate on such discontinues. Putting more attention to the edges preparation, cleaning the face of the welded passes and following the welding procedures can improve the strength and reliability of the joints.

Applications of various welding consumables allow obtaining different structures in the weld and consequently changing the reliability of welded joint.

The method for assessing the reliability of welded joints can be used. It is based on maximum hardness and structural plasticity, using (7).

$$Kr = HV \cdot A\,, \qquad (7)$$

where: $Kr$ is the reliability factor; $HV$ is the the Vickers hardness of specified zone of the weld; $A$ is the structural plasticity of metal, %; HV $\cdot$ % = $q$ .

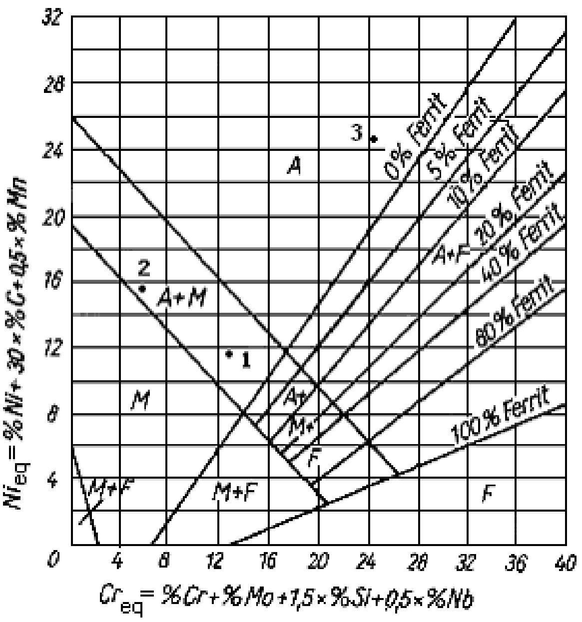



**Fig. 7.** Structures of welded seams on the Sheffler diagram [5]. 1 – structure of a seam at welding steel 20X23H18 by electrodes UONI-13/45; 2 – structure of a seam at welding steel 20X23H18 by electrodes UTP-34N; 3 – structure of a seam at welding steel 20X23H18 by the nonfusible electrode

In our evaluation the structural plasticity was assumed as: austenite – 40 %, ferrite – 30 %, pearlite – 15 %, sorbite – 10 %, troostite – 5 %, martensite – 1 %.

During steel 20X23H18 welding by nonfusible electrodes the weld has a hardness 190 HV – 195 HV, dilution zone – 195 HV – 200 HV, base metal – 190 HV – 210 HV. During steel 20X23H18 welding by austenitic ОЗЛ-6 by electrodes the weld has a hardness 190 HV – 195 HV, dilution zone – 165 HV – 170 HV, base metal – 190 HV – 210 HV. During welding steel 0X23H18 by austenite-ferrite electrodes is observed approximately the identical hardness of the weld material and zone – 180 HV – 185 HV near the weld, while with the welding by nickel electrodes weld material has hardness 160 HV – 170 HV, dilution zone – 180 HV – 190 HV.

During steel 20X23H18 welding by pearlitic UONI-13/45 electrodes the weld has hardness 195 HV – 220 HV, dilution zone – 240 HV – 270 HV, base metal – 190 HV – 210 HV. During welding by copper electrodes weld material has hardness 170 HV – 200 HV, dilution zone – 180 HV – 200 HV.

Figs. 8, 9 and 10 depict the diagrams of the distribution of the reliability with steel 20X23H18 by nickel and pearlitic electrodes. As can be seen from the figures the smallest reliability is observed in the dilution zone.

It is necessary to note that when welding using the nonfusible electrode, in the center of seam there is large stretching tension formed due to overheating molten metal and specific character of its subsequent cooling.

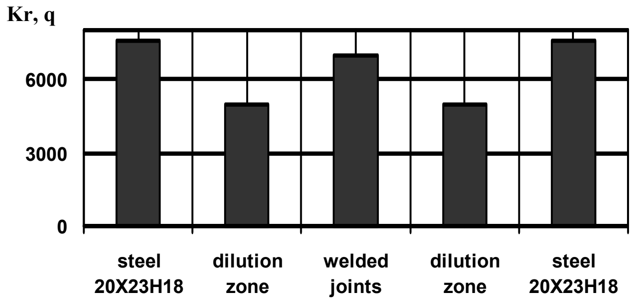



**Fig. 8.** Distribution of reliability in the welded joint during welding of steels 20X23H18 by non fusible electrodes, calculated using (7)

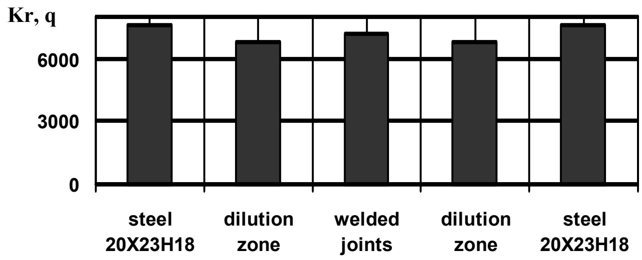



**Fig. 9.** Distribution of reliability in the welded joint during welding of steels 20X23H18 by the austenitic UTP-068HH electrodes, calculated using (7)

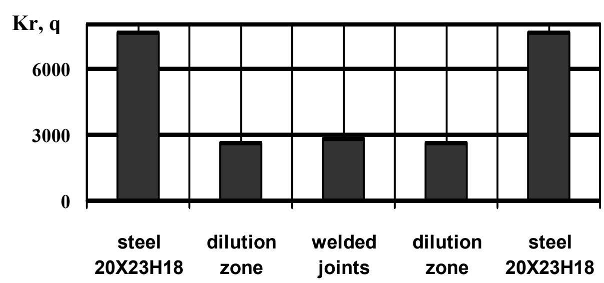



**Fig. 10.** Distribution of reliability in the welded joint during with welding of steels 20X23H18 by the pearlitic UONI-13/45 electrodes, calculated using (7)

## CONCLUSIONS

1. By welding steel 20X23H18 the best results (highest reliability) are obtained when using austenitic electrodes UTP-068HH, the worst – using pearlitic UONI-13/45 electrodes. The lowest reliability is found to be in fusion area.

2. The lowestt reliability (without taking into account welding stresses) is observed in the dilution zone from the side of steel 20X23H18.

3. The destruction of the seams welded by copper and pearlitic electrodes occurs most frequently in the dilution zone, welded by austenitic and austenite-ferrite electrodes – at the center section of the seam.

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