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*Corresponding author

Dmitrik V, NTU "KhPI", Department of Welding, Ukraine

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Opinion

Features of the Structural Condition and Damageability of Long-Term Operational Welded Connections of Steam Pipes

Dmitrik V[1*], Kasianenko I[2] and Xinlei C[1]

[1]NTU "KhPI", Department of Welding, Ukraine

[2]NTU "KhPI", Department of Computer Modeling and Integrated Pressure Processing Technologies, Ukraine

Opinion

Steam pipelines and welded joints of elements of their systems of thermal power plants are one of the most responsible components of their equipment. And therefore, the reliability of welded joints of steam pipelines deserves special attention. First of all, steam pipelines operating in creep conditions at a pressure and temperature of steam P = 25.5 MPa and T = 545-565 °C. Such steam pipelines are made of heat-resistant steels 12X1MΦ, 15X1M1Φ, 20XMΦЛ, 15X1M1ΦЛ, 15X1M1ΦЛ-ЦЛ, Table 1-3.

Table 1: Chemical composition of heat-resistant steels.

Steel	Presence of Elements in Steel, %									
	C	Si	Mn	Cr	Mo	V	Ni	Cu	S	P
							no more			
12X1MΦ	0,08-0,15	0,17-0,37	0,40-0,7	0,9-1,2	0,25-0,35	0,15-0,30	0,25	0,20	0,025	0,025
15X1M1Φ	0,10-0,16	0,17-0,37	0,4-0,7	1,1-1,4	0,9-	0,2-0,35	0,25	0,25	0,025	0,025
20XMΦЛ	0,18-0,25	0,2-0,4	0,6-0,9	0,9-1,2	0,5-0,7	0,2-0,3	0,3	0,30	0,025	0,025
15X1M1ΦЛ	0,14-0,2	0,2-0,4	0,6-0,9	1,2-1,7	0,9-1,2	0,25-0,4	0,3	0,30	0,025	0,025
15X1M1ΦЛ-ЦЛ	0,1-0,15	0,17-0,37	0,4-0,7	1,1-1,4	0,9-1,1	0,2-0,35	0,3	0,30	0,025	0,025

Table 2: Heat treatment of metal pipes for steam lines and boiler headers and their initial mechanical properties (longitudinal samples).

Steel	Heat Treatment	$\sigma_в$, MPa	$\sigma_т$, MPa	δ, %	ψ, %	KCV, J/cm²
			no less			
1	2	3	4	5	6	7
12X1MΦ	Normalization 950-980 °C + Tempering 720-750 °C	450-650	280	21	55	60
15X1M1Φ	Normalization 1020-1050 °C + Tempering 730-760 °C	500-700	320	18	50	50
15X1M1ΦЛ-ЦЛ	Anti-flocculation annealing 600-630 °C, 7 h + homogenization 1000-1300 °C 10 h + normalization 970-1000 °C, 3.5 h + tempering 730-760 °C, 6 h	490-686	314	16	45	40

Table 3: Initial short-term mechanical properties of the starting metal of pipes, forgings, castings for collectors, steam pipes and elements of their systems.

Steel	$\sigma_в$, MPa	$\sigma_т$, MPa	δ, %	ψ, %	KCV, J/cm²
		no less			
12X1MΦ	450-650	280	21	55	60
15X1M1Φ	500-700	320	18	50	50
20XMΦЛ	≥ 500	320-500	15	30	30
15X1M1ΦЛ	≥ 500	320-500	15	30	30
15X1M1ΦЛ-ЦЛ	490-686	314	16	45	40

The aim of the work is to study the features of the structural-phase state and damageability of long-term welded joints of steam pipelines. X-ray structural and phase chemical analyses established that the initial structure of the metal of welded joints after high tempering (730-750 °C, 3-5 h) contains carbides of group I M_3C, M_7C_3, $M_{23}C_6$, as well as carbides of group II Mo_2C, VC. It was established that after the welded joints had been in operation for more than 270 thousand h, the total amount of M_3C carbides compared to their initial amount decreased to 3-7%, and M_7C_3 carbides to 10-15%. Accordingly, the amount of $M_{23}C_6$, Mo_2C, VC carbides increased. In $M_{23}C_6$ carbides (crystal lattice parameter a_0 = 10.64 Å), chromium atoms are gradually replaced by molybdenum atoms, which contributes to its coagulation. The presence of coagulation leads to a decrease in the adhesion forces at the interface of α-phase grains and $M_{23}C_6$ carbides. The coagulation effect causes the formation of micro discontinuities, which, by merging, turn into embryonic pores. When the temperature increases to 585-600 °C (emergency steam emissions), the coagulation of $M_{23}C_6$ carbides is noticeably activated. The study of the features of the coagulation of $M_{23}C_6$ carbides is of exceptional relevance, which is advisable for the creation of new steels, which in terms of their properties surpass similar indicators of steels P91, P92, P911 and also 10Х9К3В1М1ФБР [1-3].

Particularly finely dispersed VC carbides (a_0 = 4.16 Å) remain stable for up to 280 thousand hours. At the same time, the stability of Mo_2C carbide requires clarification. During the long-term operation of welded joints under creep conditions, structural-phase transformations occur and micropores are formed. Pores with a size of 0.03-0.2 μm are formed inside the second stage of creep. At the end of the second stage, pores with a size of 0.11-0.17 μm are observed. Their accumulation and concentration occurs, to a large extent near the coagulating carbides $M_{23}C_6$. When welded joints are operated for more than 270 thousand hours, recrystallization processes occur in the structure of the metal of welded joints, the passage of which is facilitated by overheating in the temperature range of 580-600 °C. As a result of recrystallization, the boundaries between grains are eliminated, and the grains themselves acquire an enlarged shape. At the same time, the deformation capacity of the grains increases. The mechanical properties of welded joints made of steels 15Х1М1Ф and 12Х1МФ with respect to the operating time of more than 280 thousand hours, compared to the initial mechanical properties, decrease by approximately 10-15%. Accordingly, the damageability of welded joints increases, which is realized by the mechanisms of creep and fatigue. When developing new steels, it is advisable to take into account the peculiarities of the physical and chemical processes that occur in the metal of welded joints. Such consideration will allow to prevent and slow down their progress, which is especially advisable for welded joints operating at a temperature of T = 580-600 °C and a pressure of P = 30-35 MPa.

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