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STUDY OF THE STRUCTURE AND PROPERTIES OF THE METAL OF 10Cr17Ni8Si5Mn2Ti GRADE DURING CLADDING IN A PROTECTIVE ATMOSPHERE

Abstract. The positive effect of nitrogen on the formation of the structure and service properties of chromium-nickel-silicon steel under MAG cladding in a nitrogen-containing atmosphere of 70% N_2 + 30% CO_2 is considered. It is shown that the cladded metal of 10Cr17Ni8Si5Mn2Ti grade, doped with nitrogen from the gas phase, forms a more homogeneous structure, increases the volume fraction of austenite, and reduces the tendency to form a sigma phase. During the crystallization of the weld pool, nitrogen forms fine-dispersed nitrides and titanium carbonitrides in the structure, with particle sizes of 0.1–1.5 mm. The cladded 10Cr17Ni8Si5Mn2Ti metal, doped with 0.12–0.16% of nitrogen, has a high resistance to scoring at specific pressures up to 96 MPa. The coefficient of relative erosion resistance of the nitrogen-containing alloy is 1.73 times higher than that of the same alloy cladded in argon.

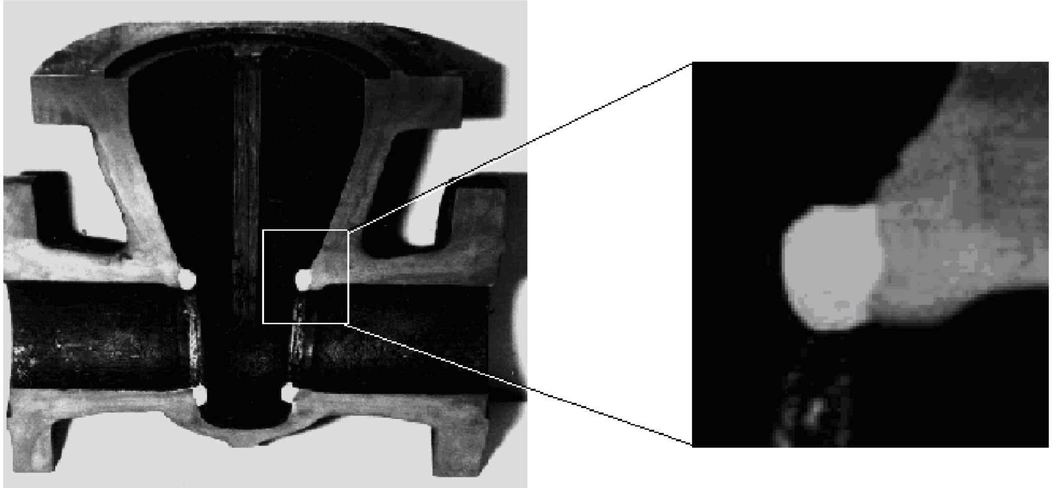
Keywords: cladded Cr–Ni–Si metal, nitrogen-containing atmosphere, sigma-phases, nitride particles, scuffing, erosion resistance.

The experience of the operation of thermal power plants and petrochemical facilities in Kazakhstan shows that for pipe fittings operating at temperatures up to 540 °C and specific pressures up to 60 MPa, a good wear resistance for metal-to-metal friction is possessed by a chromium-nickel-silicon alloy based on 08Cr17Ni8Si6Mn steel, cladded with CN-6L electrodes. For fittings operating at temperatures up to 570°C and specific pressures up to 78 MPa, the 13Cr16Ni8Mb5Si5Mn4Nb alloy cladded with CN–12M electrodes possesses such properties.

To mechanize the cladding of the sealing surfaces of the DN 50-80 fittings bodies (figure 1), respectively, powdered PP - Np-10Cr17Ni8Si5Mn2Ti and PP-Np-10Cr19Ni9Si5Mo2BMnTi wires in argon are used.

However, the use of these technologies is associated with certain difficulties due to the formation of the sigma phase in the cladded metal, which is the source of metal embrittlement and the initiation of cracks in it [1, 2]. The sigma phase can also be formed as a result of the temperature and time conditions of the cladding process and subsequent thermal treatment, the prolonged exposure to thermal loads at thermal power plants at operating temperatures of 500–600 °C, which generally reduces the service properties of the cladded metal [3-6].

At specific pressures above 60 MPa, the wear resistance of 10Cr17Ni8Si5Mn2Ti steel does not comply with its regulatory operation requirements for higher parameters. The effect of high specific pressures in combination with high temperature causes plastic deformation of the cladded sealing surfaces and the formation of scuffs on them. One of the solutions to these problems is the introduction of nitrogen into Fe-Cr-Ni-Si cladded metal as an austenizing and simultaneously reinforcing element under a suitable alloying system [5]. An economical and technological option for alloying the Cr-Ni-Si cladded metal with nitrogen is to use it as an independent protective gas or in a mixture with carbon dioxide in the process of cladding.



a b

Figure 1 – DN 80 fitting body after MAG cladding of sealing surfaces of the saddles:
a – macrospin with cladded saddles;
b – a fragment of the macrostructure of the cladded saddle; material of the fitting body of Steel 25L

The structure of the metal largely determines the strength and service properties of the alloy. In this connection, the aim of this work is to study the influence of the composition of protective Ar, CO_2, N_2 gases and mixtures of N_2 + CO_2 on the formation of the structure and service properties of Fe-Cr-Ni-Si cladded metal.

The experimental data indicate that nitrogen, being a strong austenizer, reduces the fraction of the ferrite component and reduces the width of the region in which the martensitic transformation proceeds.

X-ray structural phase quantitative analysis showed that the transition zone in samples cladded in carbon dioxide consists mainly of the ferrite component (85%). Cladding in nitrogen-containing media reduces the ferrite content to 70-60% by increasing the austenite (figure 2). Hardness decreases respectively from HRC 44 to HRC32 (figure 3). The maximum fraction of the ferrite component was observed when cladding in an argon atmosphere (89%), and the hardness increased to HRC 50.

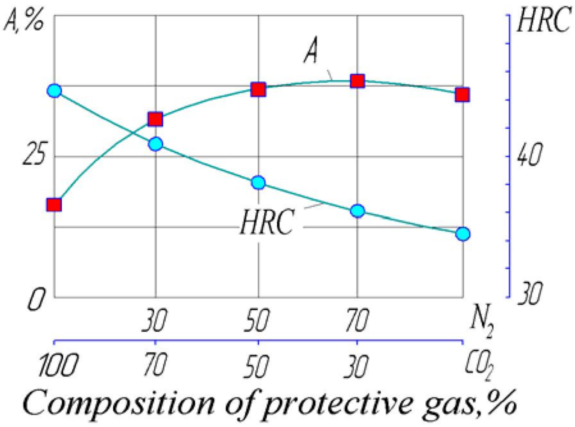


Figure 2 – Effect of the protective gas composition on the content of austenite (A) and the HRC hardness of the transition zone

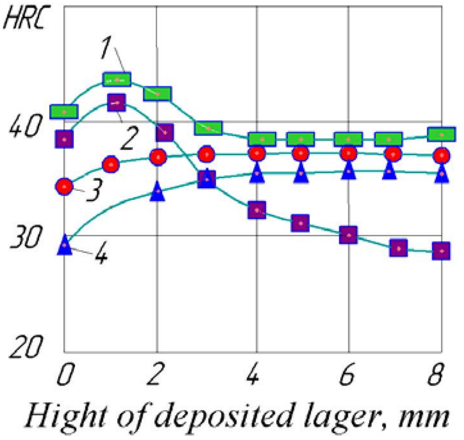


Figure 3 – Effect of the composition of the protective gas on the hardness: 1 – CO_2, 2 – 70%CO_2 + 30%N_2, 3 – 50%N_2 + 50%CO_2, 4 – 30%CO_2 + 70%N_2

The results of the studies show that a more uniform distribution of hardness over the height of the cladded layer was observed when cladding in the gas medium with compositions of 70% N_2 + 30% CO_2 and 50% N_2 + 50% CO_2 (figure 3). This increases the uniformity of the transition zone and decreases the width of the interlayer with a martensitic component.

The 10Cr17Ni8Si5Mn2Ti alloy, obtained by the multilayer MIG/MAG cladding with PP–Np–10Cr17Ni8Si5MN2Ti wire of ∅2.6 mm with different nitrogen content in the protective atmosphere of N_2 + CO_2 and in argon was investigated. Cladding was carried out in the mode: welding current 210–240 A, arc voltage 26– 27 V, cladding rate 17 m/h. The consumption of the protective atmosphere is 10–14 L/min.

The results of the phase quantitative analysis (table 1) show that with increasing nitrogen content in the CO_2 + N_2 mixture, the volume fraction of austenite increases and, accordingly, the fraction of ferrite decreases. At the same time, with an increase in the number of layers, the volume fraction of austenite in the cladded metal increases. Starting from the fusion zone, the content of austenite increases in the height of the cladding.

Table 1 – Phase composition of the cladded 10Cr17Ni8Si5Mn2Ti metal

Protective atmosphere, %	Content, %					
	First layer		Second layer		Third layer	
	Austenite	Ferrite	Austenite	Ferrite	Austenite	Ferrite
100 Ar	31	69	32	68	33	67
100 CO_2	33	67	39	61	39	61
$70CO_2 + 30N_2$	40	60	48	52	48	52
$50CO_2 + 50N_2$	40	60	54	46	55	45
$70N_2 + 30CO_2$	62	38	71	29	72	28
N_2	54	46	58	40	59	41

The presence of CO_2 in the mixture with N_2 activates the process of its absorption by liquid metal and, in the most part, the formation of nitride and carbonitride particles [7, 8].

Titanium has a strong affinity for nitrogen and during the crystallization of the metal leads to the formation of nitrides and carbonitrides. It was found that the maximum number of particles and their dispersity are observed in the alloy obtained by cladding in protective atmospheres of 50% N_2 + 50% CO_2 and 70% N_2 + 30% CO_2 (figure 4).

The results of the qualitative phase analysis are given in table 2.

Table 2 – Phase composition of cladded metal from qualitative X-ray analysis (protective atmosphere – $70N_2 + 30CO_2$)

$2\theta^0$	d, Å	(h, R, C)	Lattice parameter		Identifiable phase	Formula	Structure type
			a, Å	c, Å			
49.9	2.1213	(200)	4.242 (6)	–	titanium carbonitride	Ti (C, N)	FCC
51.7	2.0574	(111)	3.5868	–	austenite	γ-Fe	FCC
52.4	2.0313	(110)	2.8736	–	ferrite	α-Fe	VCC
53.7	1.9823	(212)	8.7719 c/a=0.516	4.531	sigma phase	MeCr	Tetragonal
54.7	1.9497	(411)			not determined		
55.5	1.9272	–	–	–	not determined		
77.4	1.4336	(220)	4.100	–	chromium nitride	CrN	FCC
89.8	1.2674	(311)	4.2034		titanium nitride	TiN	FCC
99.8	1.1706	(112)	2.8673	–	ferrite	α-Fe	VCC
111.9	1.0807	(113)	3.5843		austenite	γ-Fe	FCC

The presence of nitrogen in the protective medium increases the dispersion of carbonitride particles in the cladded metal. And the amount of fine particles in these nitrogen-containing media increases in comparison with argon and carbon dioxide.

In cladded metal alloyed with nitrogen, finely dispersed nitride and other particles with the size of 0.8– 1.5 mm are registered. The greatest number of such particles is observed in the metal cladded in nitrogen containing atmospheres with the composition of 70% N_2 + 30% CO_2 and 50% N_2 + 50% CO_2.

The resulting titanium nitrides and carbonitrides, identified by transmission electron microscopy, are the centers of crystallization in the weld pool and contribute to grain refinement.

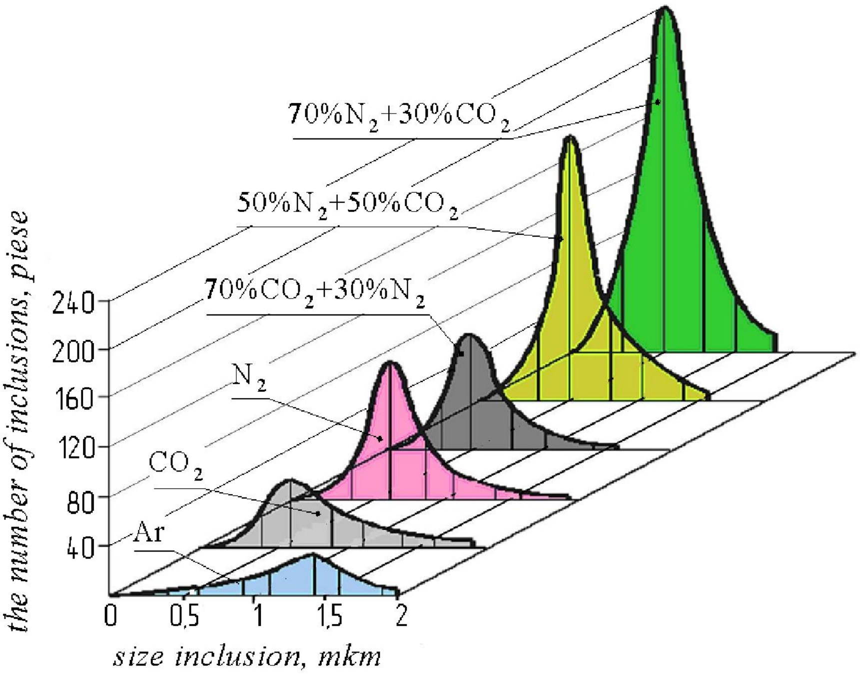
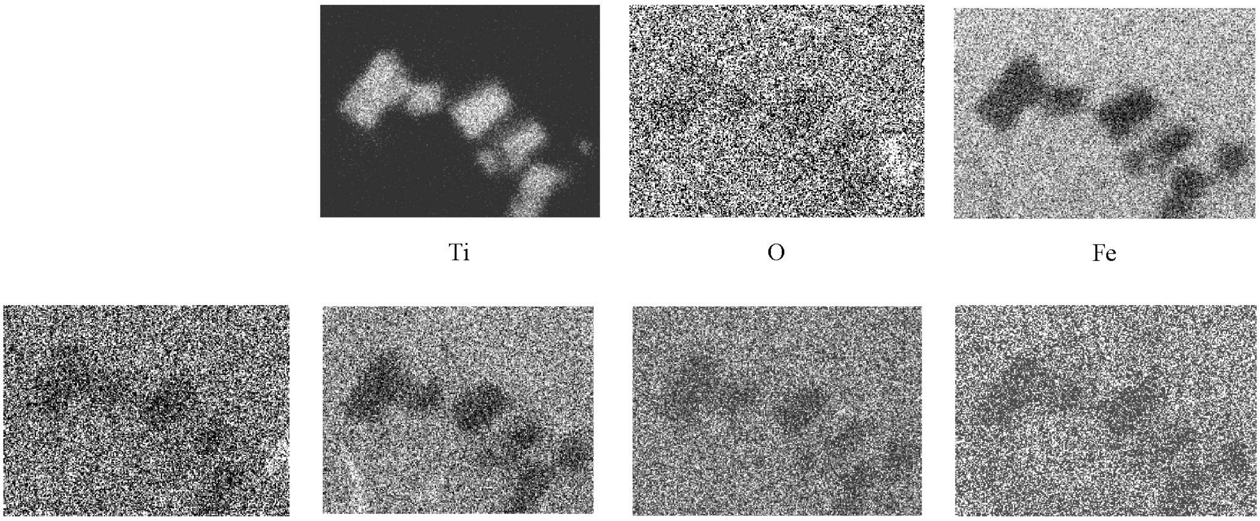


Figure 4 – Histograms of the distribution of carbonitride inclusions by size in the cladded 10Cr17Ni8Si5Mn2Ti metal as a function of the protective medium during MIG/MAG cladding

Scanning the area of the surface zone of nitrogen-containing cladded 10Cr17Ni8Si5Mn2NTi steel by electron microscopy shows the predominant presence of finely dispersed titanium nitride and oxide particles in the austenite matrix (figure 5).


Ti O Fe

Mn Cr Si Ni

Figure 5 – Charting of deposited metal surface zone

Energy dispersion analysis of point scanning (figure 6, table 3) allowed establishing that finely dispersed rhombic species mainly consist of nitrogen and titanium. Nitrogen is mainly bound to TiN nitride compounds. It is also present in the austenitic matrix of the cladded metal, but its content in the austenite matrix is significantly smaller relative to titanium nitride compounds.

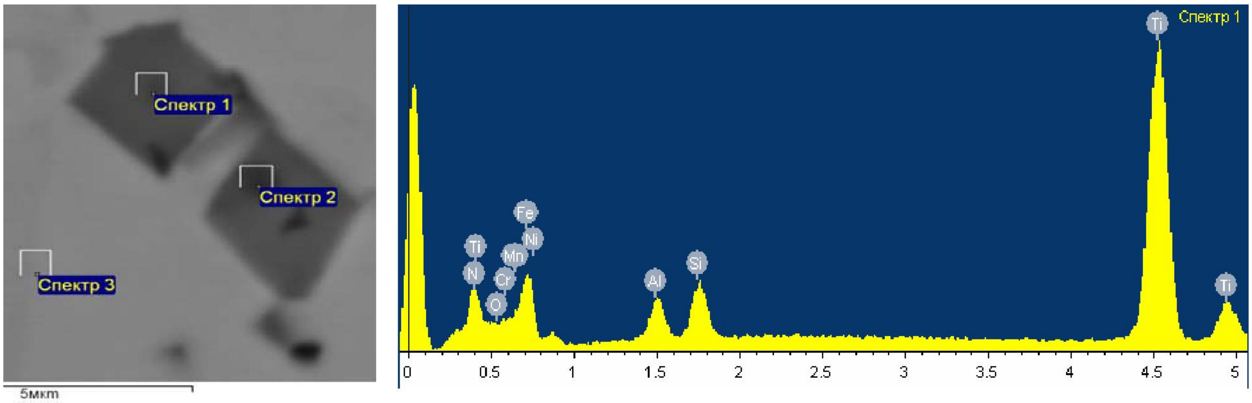


Figure 6 – Inside of rhombic inclusion rounded dark oxide particles are registered. Basic elements being present in inclusions (Table 3 spectrum 1 and 2) are titanium

Table 3 – Elemental composition of point scanning of 10Cr17Ni8Si5Mn2NTi alloy

Spectrum	N	O	Al	Si	Ti	Cr	Mn	Fe	Ni	Total
1	13.65	2.99	2.28	2.70	23.4	12.37	1.09	36.57	4.92	100
2	10.09	3.64	3.26	3.14	22.74	12.6	1.12	37.9	5.15	100
3				5.47	0.36	17.65	1.51	65.55	9.47	100

All titanium present in the cladded metal is mainly bound to nitrides, and to titanium oxides in small amounts. In inclusions, there is an insignificant amount of manganese, silicon, nickel and chromium nitrides.

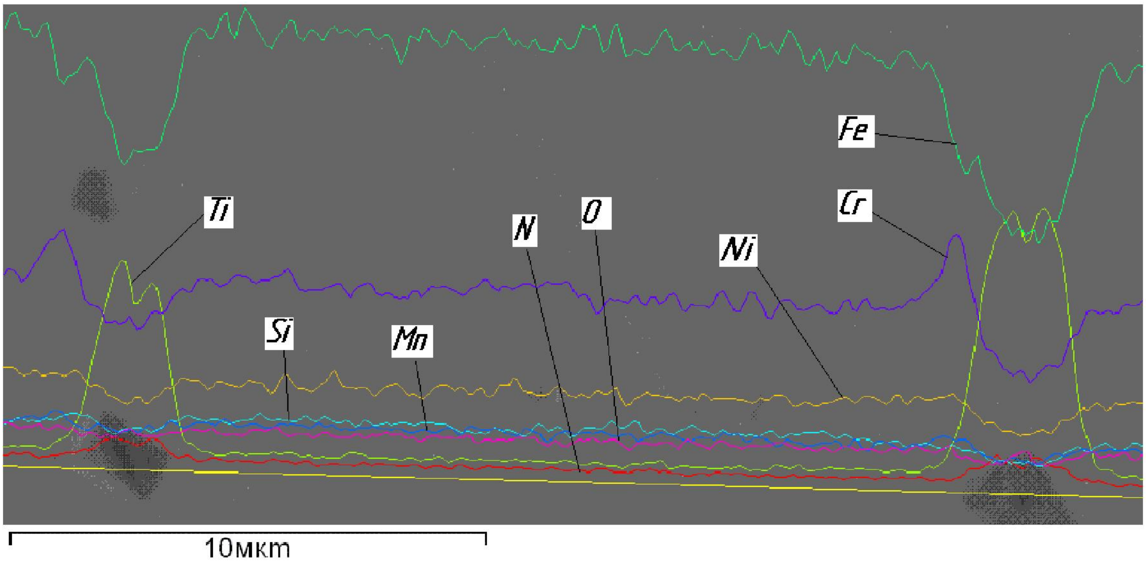
Round-shaped dark oxide particles are found inside these rhombic inclusions (figure 6). The main elements present in the inclusions (table 3 spectra 1 and 2) are titanium (23.44 and 22.74%) and respectively nitrogen (13.85 and 10.09%). The content of all other elements including oxygen decreases (figure 7).

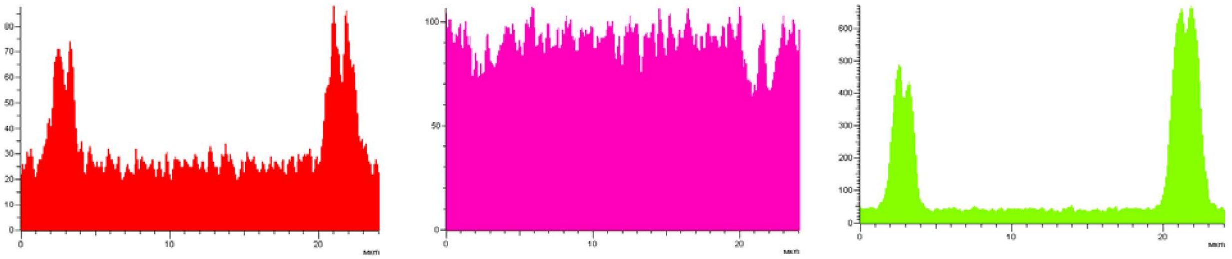
The continuous surface scanning of the cladded surface also confirms that inclusions in the austenite matrix are fine particles of titanium nitride with a size of 0.5-1.5 mm. In them, the content of Fe, Cr, Ni, Mn, Si, O decreases with respect to the austenite matrix, and the content of titanium and nitrogen increases.

The 10CrI7Ni8Si5Mn2Ti and 10Cr20Ni9Si5Mo2BMnTi alloys, obtained by cladding, respectively, with PP–Np–10Cr17Ni8Si5Mn2Ti and PP-Np–10Cr19Ni9Si5Mo2BMnTi wires in protective gases: Ar, N_2, and mixtures of $CO_2 + N_2$ were investigated.

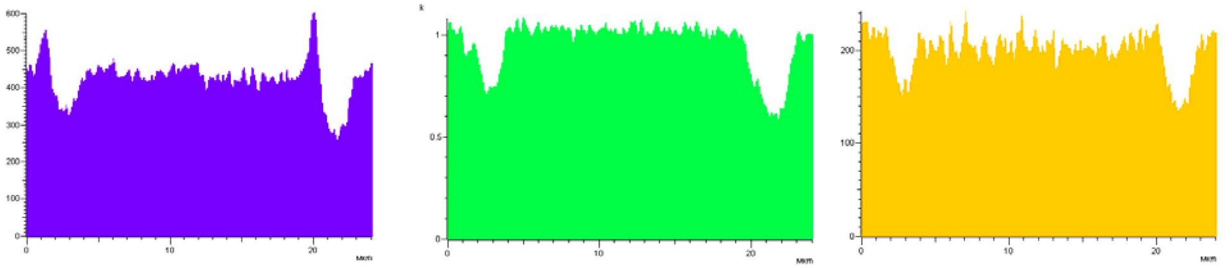
From the data presented (table 4), it follows that all pairs of samples of the 10Cr17Ni8Si5Mn2Ti alloy except for samples cladded in the atmosphere of argon have a high resistance against scuffing at specific pressures of 91.2– 96.6 MPa. However, the best properties are possessed by the metal cladded with PP-Np-10Cr17Ni8Si5Mn2Ti wire in atmospheres of 50% N_2 + 50% CO_2 (96.0 MPa) and 70% N_2 + 30% CO_2 (96.6 MPa).

When testing the unlike pairs of 10Cr17Ni8Si5Mn2Ti+ 10Cr20Ni9Si5Mo2BMnTi samples, high extreme pressure properties (93.0 MPa) are recorded in the metal cladded with the appropriate wires in the gas mixture of 50% N_2 + 50% CO_2. The anti-scuffing properties of the same-name pair from the 10Cr17Ni8Si5Mn2Ti alloy alloyed with nitrogen are not inferior to these properties when testing opposite-type pairs of 10Cr17Ni8Si5Mn2Ti+10Cr20Ni9Si5Mo2BMnTi. An increase in the anti-scuffing properties of the cladded metal is associated with the formation of a more uniform structure when cladding

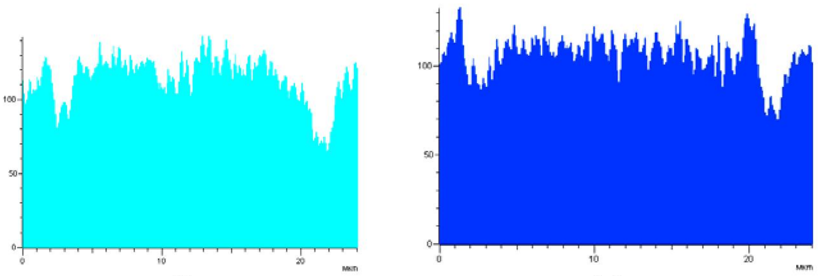




N O Ti



Cr Fe Ni



Si Mn

Figure 7 – Element composition of the working surface of the cladded metal

Table 4 – Anti-scuffing properties of alloys under study

Type of alloy of test pairs of samples	Protective gas, when cladding, %	Hardness, HRC	Specific loads that cause scuffing more than 10 μm, MPa
10Cr17Ni8Si5Mn2Ti	100 Ar	36	57.7
	100 N_2	36	93.0
	$50N_2 + 50CO_2$	35	96.0
	$70CO_2 + 30N_2$	33	93.0
	$70N_2 + 30CO_2$	35	96.6
10Cr17Ni8Si5Mn2Ti(lower)	100 N_2	32/36	70.0
10Cr20Ni9Si5Mo2BMnTi (upper)	$70N_2 + 30CO_2$	35/38	77.0

in nitrogen containing media. The 10Cr17Ni8Si5Mn2Ti alloy, alloyed with nitrogen from the gas phase, is characterized by the formation of uniformly distributed carbonitride fine particles in the austenite matrix, which causes the effect of hardening.

Investigation of erosion resistance of materials under the influence of slit flow of medium on them was carried out on a certified TPP stand. The working medium was the feed water (18MPa, 210 °C) of the boilers of the industrial TPP.

From the results (table 5) it follows that all the investigated types of alloys obtained by cladding with PP–Np–10Cr17Ni8Si5Mn2Ti wire in nitrogen and in nitrogen-containing atmospheres have a high resistance to erosion wear

Table 5 – Erosion properties of the 10Cr17Ni8Si5Mn2Ti alloy

Alloy	Protective gas for cladding	Testing parameters			Test results		
		P, MPa	T, °C	testing time, h	Depth of wear, μm	Wear rate, μm/h	Coefficient of relative erosion resistance
10Cr17Ni8Si5Mn2Ti	Ar	17.0	200	254	15.95	0.064	1.03
		18.5	180	196	15.32	0.052	0.88
		18.5	180	196	9.32	0.047	0.97
	$50N_2 + 50CO_2$	17.0	200	254	12.15	0.051	1.29
		18.5	180	196	7.21	0.033	1.39
	$70CO_2 + 30 N_2$	17.0	200	254	13.06	0.053	1.24
		18.5	180	196	7.52	0.035	1.31
	$30CO_2 + 70 N_2$	17.0	200	254	12.33	0.032	2.06
		18.5	180	196	6.15	0.051	1.40
		18.0	180	196	10.86	0.049	1.53
12Cr18Ni10Ti		17.0	200	254	16.8	0.066	1.00
		18.5	180	196	8.7	0.046	1.00

The metal that is cladded with this wire in the protective atmosphere of 70% N_2 + 30% CO_2 and 50% N_2 + 50% CO_2 has a better erosion resistance, including in comparison with the alloy obtained by cladding in argon. The phase composition of the cladded metal significantly affects the erosion properties. With an increase in the content of nitrogen austenite, the erosion resistance of steel increases.

The increase in the erosion properties of the nitrogen-containing cladded metal is also associated with the formation of finely dispersed solid nitrides with a lattice, a coherent lattice of austenite, and ensures their strong engagement in it.

Conclusions.

1. It has been experimentally proved that the transition zone of the deposited layer in the nitrogen-containing mixture is characterized by a decrease in the width and hardness of the interlayer with the martensitic component compared to the argon medium, which reduces the tendency of the cladded metal to crack in 2–2.5 times, (and, accordingly,) leads to the reduction in the labor intensity of the machining of

the fitting bodies due to premature wear of the cutting tool, and will reduce the processing costs by up to 15%.

2. As a result of the experiment, it has been proved that alloying of the cladded metal with nitrogen from the protective mixture of 50–70% N_2 + 50–30% CO_2 leads to the formation of a more homogeneous structure, an increase in the volume fraction of austenite, a decrease in the tendency of the cladded metal to form the sigma phase, the formation of finely dispersed carbonitride inclusions with particle sizes of 0.1–1.5 μm in the structure of the cladded metal, which ultimately leads to an improvement in the mechanical properties and ability of products to resist high pressures up to 60 MPa at high temperatures up to 540 °C, which will significantly increase the service life of the product.

3. It has been experimentally confirmed that the cladded 10Cr17Ni8Si5Mn2NTi metal, alloyed with 0.12–0.16% of nitrogen from the gas phase by the MAG cladding in the nitrogen-containing atmosphere of 50–70% N_2 + 50–30% CO_2, has a 1.67 times increase in scuffing resistance and a 1.73 times increase in erosion resistance relative to the similar metal without nitrogen cladded in argon, which improves the service properties of the welded seam.

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ҚОРҒАУ АТМОСФЕРАСЫНДА БЕТКІ ҚАБАТТА 10Х17Н8С5Г2Т ТҮРІНДЕГІ МЕТАЛДЫҢ ҚҰРЫЛЫМЫ МЕН ҚАСИЕТТЕРІН ЗЕРТТЕУ

Аннотация. 70% N_2 + 30% CO_2 азот қоспалы атмосферасыда MAG балқыту шартында хромды-никельді-кремнилі болаттын құрамын және қызметтік қасиеттеріне азоттын оң әсері қарастырылды. Газ фазасындағы азотпен қапталған 10Х17Н8С5Г2Т түріндегі металл біртекті құрылымды қалыптастыратындығы, аустенит көлемінің үлесін көбейтетіндігі, сигма фазасын қалыптастыру үдерісін төмендететінді көрсетілген. Дәнекерлеу аумағы кристаллданғанда азот құрамында ұсақ дисперсиялы, 1–1,5 мкм аралығындағы, титанның нитридтері мен карбонитридтері қалыптасады.

0,12–0,16% азотпен легірленген, 10Х17Н8С5Г2Т түріндегі металл 96 МПа қысымға дейін кетікке қарсы жоғары төзімділікке ие болады. Азот құрамды қорытпада эрозияға төзімділік қасиеті, аргонмен балқытылған қорытпаға қарағанда 1,73 есе жоғары болады.

Түйін сөздер: Cr-Ni-Si балқытылған металл, құрамында азот бар атмосфера, сигма фазалар, нитридтік бөлшектер, кетік, эрозияға төзімділік.

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ИЗУЧЕНИЕ СТРУКТУРЫ И СВОЙСТВ МЕТАЛЛА ТИПА 10Х17Н8С5Г2Т ПРИ НАПЛАВКЕ В ЗАЩИТНОЙ АТМОСФЕРЕ

Аннотация. Рассмотрено положительное влияние азота на формирование структуры и служебные свойства хромоникелькремнистой стали в условиях наплавки MAG в азотсодержащей атмосфере $70\%N_2+30\%CO_2$. Показано, что наплавленный металл типа 10Х17Н8С5Г2Т, легированный азотом из газовой фазы, образует более однородную структуру, повышает объёмную долю аустенита, снижает склонность к образованию сигма-фазы. В процессе кристаллизации сварочной ванны азот образует в структуре мелкодисперсные нитриды и карбонитриды титана, с размерами частиц 0,1–1,5 мкм. Наплавленный металл типа 10Х17Н8С5Г2Т, легированный 0,12–0,16% азота, обладает высокой стойкостью против задиров при удельных давлениях до 96 МПа. Коэффициент относительной эрозионной стойкости азотсодержащего сплава в 1,73 превышает стойкость такого же сплава, наплавленного в аргоне.

Ключевые слова: Cr–Ni–Si наплавленный металл, азотсодержащая атмосфера, сигма-фазы, нитридные частицы, задирание, эрозионная стойкость.

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