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INFLUENCE OF COKE NUT INTRODUCTION IN BLAST FURNACE CHARGE ON MELTING PARAMETERS

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blast furnace, coke, coke nut, natural gas, determining area, charge resistance coefficient, productivity, gas dynamics, heat exchange, slag forming, hearth, top throat

ABSTRACT

The effect of coke nut introduction in charge material (in the amount 10.9–12.8 kg per ton of hot metal) on operation parameters of blast furnaces with volume 1370 and 2014 m^3 have been established via industrial investigations. These blast furnaces are operating in the conditions of bottom and top areas determining by their gas dynamics. Parameters of gas dynamic conditions, fuel burning, iron reduction from FeO using different reducing agents, furnace thermal operation and hearth drainage capacity are analyzed.

Introduction of coke nut in the iron ore part of charge material has increased its equivalent surface coarseness and thereby improved its gas permeability. It is shown that blast furnaces operating with the top area determining by gas dynamics are characterized by decrease of charge resistance coefficient on top throat by 7.1%. Each 10 kg of coke nut on 1 t of hot metal allowed to add 400 m^3/h of natural gas without arise of difficulties of a furnace operation. It accompanied by rise of heat exchange intensity for the temperatures below 850 °C, by increase of Fe reduction degree from FeO by hydrogen and by rise of its usage degree. The maximal increase of technical and economical melting parameters has been observed for the furnace with volume 2014 m^3. Lowering of specific coke consumption (both actual and adduced to the equal conditions) made 0,76 and 0.88 kg per 1 kg of coke nut respectively.

Usage of coke nut in the furnace operating with bottom limiting area by its gas dynamics was characterized by the negative nut effect on filtrating ability of coke packing in the furnace hearth. Introduction of 12.8 kg of nut per 1 t of hot metal has accompanied by increase of the amount of slag remaining in the furnace from 7 to 9 m^3, by enlargement of the time interval between the beginning of hot metal tapping and slag appearance from 9.5 to 8.4 min and by toughness rise from 0.40 to 0.45 Pa·s.

Challenge problem

It is known that metallurgical works try to decrease their expenses for consumption of raw materials and power sources, to optimize operation of heating furnaces and rolling mills — in order to increase competitiveness of finished rolled products. Each production stage has its own way to solve such problems. Saving of power resources is one of the main methods for cutting iron cost in blast furnace practice [1]. It seems that essential reserves exist in this direction, based on the fact that at present time about 80% of coke manufactured for blast furnaces is suitable in its coarseness. These reserves can be realized e.g. via introduction of fine coke fractions in the composition of iron ore part of charge material for blast furnaces [2–5]. Usage of non-conditional coke for blast furnace melting has both positive and negative features. From one side, its introduction in the iron ore mixture (containing sinter and pellets) can improve gas permeability of charge [6–8] and intensify the reduction processes if iron oxides [9–11], but from other side, it has negative effect on permeability of coke packing in the furnace hearth [12–14], what can be explained by its not complete consumption before the hearth. It is demonstrated especially clear in the furnaces equipped with tray-type compact bell-less top (BLT) that can't always provide uniform charge composition around the top throat [15–17]. In its turn, this fact causes excess of some components (i.e. coke nut) in its several sectors and its lack in other areas [18, 19].

In this connection, development of the procedure of nut usage in the furnaces equipped with tray-type compact bell-less top is a rather actual problem for iron making. This procedure will exclude coke nut negative effects on operation processes, including on coke packing filtrating ability in the hearth.

Methods

The paper examines variation of blast furnace operating parameters during and after introduction of coke nut in the composition of iron ore part of charge material in the blast furnaces with volume 1370 and 2014 m^3, quipped with tray-type compact bell-less top at Magnitogorsk Iron and Steel Works. For this purpose three pair periods have been investigated. It is shown that coke nut was not used during the basic periods I, III and V, while during the pilot periods II, IV and VI its consumption was varied in the range 10.9–12.8 kg per ton of got metal (see **table 1**).

Operating parameters of the blast furnaces A and C have been examined during their operation with top limiting area by its gas dynamics and it allowed to evaluate the effect of coke nut involvement in charge. Operating parameters of the blast furnace B during periods III and IV have been compared and revealed the effect of coke nut on blast furnace melting in the conditions of gas dynamics limiting in its bottom part.

Coke nut charging at the blast furnaces with volume 1370 m^3 has been conducted in a medium ore skip that is noted as P_{op} in the charging matrix (see **tables 2** and **3**). Materials have been located in the skip in the following mode: sinter on the bottom and coke nut next-to-last just before pellets. In the blast furnace these materials have

Table 1. **Main technological operating parameters of the blast furnaces A, B and C**

Parameters	Blast furnaces					
	A (*V* =1370)		B (*V* =1370)		C (*V* = 2014)	
	Periods					
	I	II	III	IV	V	VI
Period duration, days	9	9	9	9	7	5
Dry coke nut consumption, kg per ton of hot metal	0	12.2	0	12.8	0	10.9
Specific coke consumption (dry, skip), kg per ton of hot metal:						
actual	434.3	428.1	443.1	438.3	452.3	444.0
adduced	–	425.2	–	435.5	–	442.7
Productivity, t/day:						
for actual amount of charges	3654	3706	3260	3158	4542	4810
adduced	–	3760	–	3290	–	4867
Consumption, m^3/t of hot metal:						
blowing	1154	1132	1229	1247	1114	1115
natural gas	109.5	110.7	100	109.1	97.4	104.8
Specific consumption of total fuel kg/t of hot metal:						
actual (coke, natural gas, coke nut)	514.1	521.0	516.0	530.2	523.3	531.2
i.e. coke and coke nut together	434.3	440.3	443.1	451.1	452.3	454.9
adduced	434.3	437.4	443.1	447.9	452.3	453.6
O_2 content in blowing, %	28.1	27.8	27.1	26.6	28.3	28.5
Consumption, kg per ton of hot metal:						
raw materials	1693	1693	1662	1689	1660	1670
quartzite	–	–	–	–	–	0.12
Mikhailovskiy ore	–	–	–	–	43.9	31.5
Operating intensity, t/m^3 per day:						
for iron ore raw materials	3.071	3.115	3.956	3.892	3.744	3.988
for total carbon	0.701	0.699	0.870	0.835	0.867	0.922
Burden-weight ratio, t/t	3.61	3.78	3.56	3.74	3.59	3.66
Fe content in charge, %	57.2	57.2	58.2	57.3	58.3	58.0
Content in iron, %:						
Si	0.67	0.70	0.71	0.73	0.72	0.72
Mn	0.31	0.33	0.28	0.32	0.29	0.33
S	0.018	0.017	0.021	0.018	0.023	0.020
C	4.76	4.76	4.64	4.71	4.68	4.67
Content in slag, %:						
SiO_2	36.9	36.6	36.8	36.8	36.3	35.5
Al_2O_3	12.6	12.8	12.8	12.8	12.7	13.0
CaO	36.5	36.3	36.0	36.0	36.3	36.4
MgO	9.3	9.6	9.6	9.6	9.4	9.9
S	0.693	0.678	0.738	0.699	0.882	0.913

Table 2. **Charging matrix for the blast furnace A of Magnitogorsk Iron and Steel Works**

Skip content	Tray stations										
	11	10	9	8	7	6	5	4	3	2	1
K			1			1	1				
K				1			1	1			
K						1				2	
P	3										
P_{op}	1	1	1								
P		1			1		1				
K			1			1	1				
K				1			1	1			
K						1			2		
K				1				2			
P	3										
P_{op}	1	1	1								
P		1			1		1				

Table 3. **Charging matrix for the blast furnace B of Magnitogorsk Iron and Steel Works**

Skip content	Tray station										
	11	10	9	8	7	6	5	4	3	2	1
K		1	1			1					
K				1			1		1		
K									2	1	
P		1	1	1							
P_{op}				1	1	1					
P					1	1	1				

Table 4. **Charging matrix for the blast furnace C of Magnitogorsk Iron and Steel Works**

Skip content	Tray stations										
	11	10	9	8	7	6	5	4	3	2	1
3K		1		1				1	3		
$3P_{op}$		1						2	3		
3K	1	1	1			1	2				
$3P_{op}$		1	1	1		1	1	1			
3K	1								4		
$3P_{op}$	2	1	1			1		1			

Table 5. **Coarseness parameters of iron ore part of charge**

№ of Blast furnace	Periods	Coke nut consumption, kg per ton of hot metal	Coarseness parameters of skip materials, mm			
			equivalent by surface		average-weighted	
			sinter	pellets	sinter	pellets
A	I	–	11.07	11.73	19.87	13.41
	II	12.2	11.54	12.09	20.28	13.42
B	IV	–	11.41	11.73	18.42	13.41
	V	12.8	11.41	12.09	18.53	13.42
C	VI	–	11.20	12.19	19.27	13.65
	VII	10.9	11.63	12.19	19.77	13.65

been charged in inversed order. Therefore, the conditions for certain mixing of sinter and coke nut have been created.

Outloading of materials from charging hopper BLT into top throat space of the furnaces with volume 2014 m^3 has been conducted in the amount of 3 skips during 9 rounds. Coke nut has been located in the middle of this volume, what has been provided by its taking in the second ore skip noted as P_{op} in the matrix (see **table 4**).

Coarseness values of coke nut (equivalent by surface and average-weighted) made in average 21.5 and 22.0 mm respectively. Coarseness of iron ore materials is presented in the **table 5**. As a result, introduction of coke nut in sinter and pellets allowed to improve charge gas permeability in the top part of the furnace.

Table 6. **Parameters of gas dynamic conditions at the blast furnaces A, B and C for periods**

Parameters	Blast furnaces					
	A (V = 1370)		B (V =1370)		C (V = 2014)	
	Periods					
	I	II	III	IV	V	VI
Gas speed on empty furnace section in working conditions for temperature and pressure, m^3/s:						
in top throat	1.48	1.58	1.38	1.64	1.40	1.55
in belly	1.63	1.67	1.48	1.76	1.47	1.55
in hearth	2.56	2.58	2.36	2.8	2.22	2.33
Dynamic gas head on empty furnace section in working conditions for temperature and pressure, N/m^2:						
in top throat	1.93	2.11	1.64	2.29	1.83	2.17
in belly	1.01	1.07	0.84	1.18	0.84	0.95
in hearth	1.38	1.41	1.18	1.64	1.11	1.28
Charge resistance coefficient to gas movement:						
in top throat	1.45	1.32	1.56	1.07	1.53	1.45
in belly	10.58	10.02	12.31	7.97	14.20	14.22
in hearth	5.85	5.73	6.41	4.30	8.39	8.31

Table 7. **Parameters of fuel combustion in the blast furnaces A, B and C for periods**

Parameters	Blast furnaces					
	A (V = 1370)		B (V =1370)		C (V = 2014)	
	Periods					
	I	II	III	IV	V	VI
Output of tuyere gas, m^3/ton of hot metal	1527	1522	1585	1628	1604	1655
Composition of tuyere gas, %:						
CO	37.1	36.7	36.9	36.0	38.3	38.3
H_2	16.1	16.2	14.4	15.2	13.9	14.3
N_2	46.8	47.1	48.7	48.8	47.8	47.4
Kinetic power of gas-air mixture, KJ/s	131	132	201	162	111	130
Extension of the loose part of combustion zone, mm	1027	1030	1112	1069	1042	1076

Table 8. **Operating parameters of reduction in the blast furnaces A. B and C for periods**

Parameters	Blast furnaces					
	A (V = 1370)		B (V =1370)		C (V = 2014)	
	Periods					
	I	II	III	IV	V	VI
Fe reduction degree from FeO by different reducing agents. %:						
carbon	31.2	35.5	27.7	31.9	23.5	20.4
carbon momoxide	42.2	39.2	55.4	43.4	55.8	53.4
hydrogen	26.6	25.3	19.0	24.7	20.7	26.2
Application degree of reducing gas. %:						
CO	43.0	43.4	42.1	42.1	45.0	43.4
H_2	41.4	39.1	31.7	37.9	35.4	42.1

Table 9. **Thermal operating parameters of the blast furnaces A, B and C for periods**

Parameters	Blast furnaces					
	A (V =1370)		B (V =1370)		C (V = 2014)	
	Periods					
	I	II	III	IV	V	VI
Relation between thermal capacities of charge and gas:						
in the bottom part of the furnace (at the temperatures above 850 °C)	1,868	1,822	1,874	1,781	1,868	1,851
in the top part of the furnace (at the temperatures below 850 °C)	0,810	0,784	0,781	0,782	0,836	0,825

Results and discussion

The most favourable variation of technological processes has been observed at the furnaces A and C, operating with excessive tension of force interaction between charge and gas flows in the top part of the furnaces. It is explained by coke nut involvement that has decreased charge resistance coefficient in this area. This decrease made 7.1% rel. for the furnaces A and C (see **table 6**).

The most essential increase of technical and economical melting parameters has been observed at the furnace with volume 2014 m^3.Lowering of actual and adduced coke consumption made 8.3 and 9.6 kg per ton of hot metal respectively, as a result of positive effect of coke nut on melting parameters.

Lowering of gas dynamic tension in a charge layer that is removed from burden level by 2–6 m, in the blast furnace C operating with top limiting area by its gas dynamics, has allowed to increase blowing consumption by 200 m^3/min together with increase of natural gas consumption by 7.4 m^3 per ton of hot metal. At the same time intensity for iron ore raw materials rises from 3.744 to 3.988 t/m^3·day. The amount of tuyere gas also increase from 1604 to 1655 m^3 per ton of hot metal, and kinetic power of gas-air mixture increase from 111 to 130 KJ/s, what has been accompanied by rise of extension of the loose part of combustion zone by 3.3% rel. (see **table 7**).

Increase of natural gas consumption from 97.4 to 104.8 m^3 per ton of hot metal during the period VI in comparison with the period V provided rise of hydrogen content in tuyere gas from 13.9 to 14.3% at the constant CO content (see table 7). It has been also accompanied by increase of Fe reduction degree from FeO by hydrogen and by increase of its application degree (see **table 8**).

Usage of coke nut in the blast furnaces operating with top determining area by its gas dynamics has been accompanied with rise of heat exchange intensity in the area with temperatures below 850 °C and its decrease in the area with temperatures above 850 °C (see **table 9**).

Involvement of coke nut in composition of charge material for the blast furnace B, operating with bottom limiting area by force interaction between charge

Table 10. **Parameters of draining capacity of the blast furnaces A, B and C for periods**

Parameters	Blast furnaces					
	A (V = 1370)		B (V = 1370)		C (V = 2014)	
	Periods					
	I	II	III	IV	V	VI
Amount of slag being left in the furnace, m^3	11.4	10.9	7.0	9.0	9.3	5.8
Time period since tapping beginning till slag appearance, min	8.67	9.95	9.5	8.4	8.4	8.5
Calculated slag toughness, Pa·s	0.30	0.33	0.40	0.45	0.49	0.47

and gas flows, was less efficient in the period IV, in comparison with its usage in the blast furnaces A and C in the periods II and VI respectively. This tendency has been observed in spite of lowering of charge resistance coefficient and rise of heat exchange intensity in the top part of the blast furnace (in the period IV comparing with the period III). It was a result of determining effect of coke nut consumption on draining capacity of coke packing in the furnace hearth (see **table 10**). Increase of slag amount being left in the furnace from 7 m^3 after pilot melts in comparison with 9 m^3 during the basic period, as well as decrease of time period since tapping beginning till slag appearance by 1 min have testified about worsening of coke filtering ability in the furnace hearth.

Conclusions

The conditions of coke nut usage in the blast furnaces equipped with compact tray-type bell-less top are revealed; they exclude its negative effect on operation processes.

Direct and indirect influence of coke nut on operating parameters of a blast furnace is established. Charging the coke containing of 10–25 mm fractions in the blast furnace at Magnitogorsk Iron and Steel Works has created favourable conditions for lowering of coke consumption via rise of natural gas consumption. Increase of gas consumption by 400 m^3/h for each 10 kg of coke nut per ton of hot metal has been conducted without any complication of the gas dynamic operating procedure of the furnace, and thereby additional decrease of skip coke consumption by 1.7 kg per ton of hot metal has been obtained.

The effect of coke nut on operating parameters of the blast furnace has depended on location of the area determining by its gas dynamics. Involvement of 11.6 kg of coke nut per ton of hot metal in charge composition of the blast furnaces, operating with the top determining area of force interaction between charge and gas flows, was accompanied by its efficient usage and stable hearth operation. The coefficient of charge resistance to gas flow motion in the top part of the furnace has decreased during the pilot periods by 7.1 %. Specific coke consumption has decreased by 9.4 kg per ton of hot metal.

Usage of 12.8 kg of coke nut per ton of hot metal in the blast furnace at Magnitogorsk Iron and Steel Works, operating with bottom limiting area by its gas dynamics, was restricted by lowering of filtering capacity of coke packing. Amount of slag being left in the furnace after hot metal tapping increased from 7 to 8 m^3, time period since tapping beginning till slag appearance decreased from 9.5 to 8.4 min, while its toughness enlarged from 0.40 to 0.45 Pa·s. Decrease of specific coke consumption made 7.6 kg per ton of hot metal.

Improvement of gas dynamic and hydrodynamic conditions in the determining areas allows to rise efficiency of coke nut usage.

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REFERENCES

1. Druzhinin G. M., Zainullin L. A., kazyaev M. D., Spirin N. A. et al. Resursoenergeticheskie problemy chernoy metallurgii (Resource-saving problems of the iron and steel industry). *Izvestiya vuzov. Chernaya metallurgiya = Bulletin of high schools. Iron and steel industry.* 2014. No. 1. pp. 3–8.
2. Dobroskok V. A., Kurunov I. F., Lipukhin Yu. V. et al. *Sposob zagruzki v domennuyu pech tverdoy toplivnoy dobavki* (The method of charging the solid fuel additive in a blast furnace). Patent RF, № 2042714, 1993.
3. Dobroskok V. A., Lipukhin Yu. V., Kurunov I. F., Loginov V. N. Development of charging protocol and experience in using small-fraction coke in high-capacity blast furnace. *Steel in Translation.* 1998. No. 1. pp. 7–13.
4. Nikitin L. D., Maryasov M. F., Gorbachev V. P., Bugaev S. F. Blast furnace operation with coke fines. *Metallurgist.* 1999. No. 1. pp. 38–39.
5. Pishnograev S. N., Chevychelov A. V., Gostenin V. A., Shtafienko N. S., Gridasov V. P. Using coke fines in the blast furnaces at OAO MMK. *Steel in Translation.* 2009. Vol. 39. No. 10. pp. 878–881.
6. Kuzin A. V. Povedenie zhelezorudnykh materialov v zone kogezii pri zagruzke ikh v smesi s koksovym oreshkov (Behaviour of iron ore materials in a cohesion area during their charging in the mixes with coke nut). *Metallurgicheskie protsessy i oborudovanie = Metallurgical processes and equipment.* 2010. No. 3. pp. 4–7.
7. Gorin D. V., Khrapko A. V., Kuzin A. V. Issledovanie protsessa polucheniya i effektivnost primeneniya koksovogo oreshka v domennoy plavke (Study of fabrication process and usage efficiency of coke nut in the blast furnace melting). *Metallurgicheskie protsessy i oborudovanie = Metallurgical processes and equipment.* 2011. No. 3. pp. 10–16.
8. Babich A., Senk D., Gudenau H. W. Effect of coke reactivity and nut coke on blast furnace operation. *Ironmaking and Steelmaking.* 2009. Vol. 36. Issue 3. pp. 222–229.
9. Kuzin A. V. Effect of introducing different sizes of nut coke into ore layer on the degree of reduction of iron oxides. *Metallurgist.* 2014. Vol. 57 (No. 9–10). pp. 783–791.
10. Watakabe S., Takeda K., Nishimura H., Goto S., Nishimura N., Uchida T., Kiguchi M. *ISIJ International.* 2006. Issue 4. pp. 513–522.
11. Mousa E., Senk D., Babich A. Reduction of Pellets-Nut Coke Mixture under Simulating Blast Furnace Condition. *Steel Re-*

search International. 2010. Vol. 81. Issue 9. pp. 706–715.

12. Sibagatullin S. K., Kharchenko A. S., Chevychelov A. V. et al. Vliyanie koksovogo oreshka na filtratsiyu zhidkikh produktov plavki v gorne domennoy pechi (Influence of coke nut on filtration of liquid melting products in a blast furnace hearth). *Vestnik MGTU im. Nosova = Vestnik of Nosov Magnitogorsk State Technical University.* 2010. No. 4. pp. 26–28.
13. Lavrov V. V., Spirin N. A., Burylin A. A. et al. Simulation of heat transfer processes and assessment of the viscoplastic parameters of iron ore in blast furnaces. *Steel in Translation.* 2013. Vol. 43. No. 4. pp. 171–175.
14. Sibagatullin S. K., Kharchenko A. S., Beginyuk V. A. Processing solutions for optimum implementation of blast furnace operation. *Metallurgist.* 2014. Vol. 58. No. 3-4. pp. 285–293.
15. Kurunov I. F. Efficiency of using different types of charging apparatuses on blast furnaces. *Metallurgist.* 2009. Vol. 53. No. 11–12. pp. 661–671.
16. Chevychelov A. V., Pavlov A. V., Teplykh E. O. et al. Charging coke nuts in the batch bunker. *Steel in Translation.* 2013. Vol. 43. No. 7. pp. 434–435.
17. Huatao Z., Minghua Z., Ping D. et al. Uneven distribution of burden materials at blast furnace top in bell-less top with parallel bunkers. *ISIJ International.* 2012. Vol. 52. Issue 12. pp. 2177–2185.
18. Pykhteeva K. B., Zagainov S. A., Tleugabulov B. S., Filippov V. V., Nikolaev F. P., Belov V. V. Stabilizing the composition of blast furnace products from titanomagnetites with a nonconical loading trough. *Steel in Translation.* 2009. Vol. 39. No. 6. pp. 45–49.
19. Sibagatullin S. K., Kharchenko A. S., Logachev G. N. The rational mode of nut coke charging into the blast furnace by compact trough-type charging device. *International Journal of advanced manufacturing Technology.* 2016. Vol. 86. pp. 531–537.

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NITROGEN IN Fe–Mn–Al–C–BASED STEELS

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Fe–Mn–Al–C–N alloys, nitrogen solubility, Thermo-Calc program, phase diagrams, micro-alloying by nitrogen, AlN nitrides

ABSTRACT

Nitrogen and AlN solubility in Fe–Mn–Al–N, Fe–Mn–Al–C–N and Fe–Mn–Al–Ni–C–N alloys is calculated using the methods of interaction parameters and up-to-date thermodynamic data. The obtained values of balanced nitrogen solubility in these alloys are rather close to the convergence values obtained for liquid metal according to Thermo-Calc data base. Polythermic sections of the phase diagrams of these alloys are calculated and balanced residual values of dissolved nitrogen are determined for the liquidus and solidus temperatures; these temperatures are lower than nitrogen purity limited values, achieved by the modern technologies (0.0030%) for the most investigated alloys. It is possible to obtain up to 0.010% of dissolved nitrogen in the melts Fe–20%Mn–5%Al and Fe–25%Mn–5%Al at the temperatures of steel melting and alloying by nitrogen (1550–1600 °C), while in presence of carbon and with aluminium content more than 5% this value becomes lower than nitrogen purity limited value. Nitrogen content in a solid solution depends strongly on Al and C content. If Al content is 5 %, the maximal nitrogen content in a solid solution Fe–20%Mn–Al can be equal to $9.3\cdot10^{-4}$% at the solidus temperature. This value does not correspond to possibilities of the up-to-date industrial technologies. Thereby, AlN nitrides will form in liquid metal at micro-alloying of the steels of Fe–Mn–Al–Ni–C system by nitrogen, before and during crystallization. At the temperature lower 1100 °C, practically complete whole nitrogen is presented in the form of aluminium nitrides. It is displayed experimentally that complete nitrogen content in these alloys has effect on their strength (σ_{max}) at hot deformation towards its elevation. In the case of warm and cold deformation, the tendency of lowering of alloys strength with increase of nitrogen content in these alloys is observed.

1. Introduction

The new materials should have more wide complex of properties compared with the existing ones, i.e. they should have high values of strength, ductility, corrosion resistance, structural stability and workability during production process, and that will add them the universal features in applications. High-strength alloys on the base of Fe–Mn–Al–C system, presenting a new group of so-called TRIPLEX alloys with high Mn and Al content, can be considered as prospective ones [1, 2]. The alloys on the base of Fe–Mn–Al–C system, having high content of Al, C and Si, are characterized by specific strength comparable with specific strength of light metal alloys [3]. In order to increase substantially specific strength, aluminium content should not be less than 5% [1] [4]. Rise of Al content higher than 5% expands the area of δ (α)-ferrite and supports the process of γ → α transformation during cooling. Mn, Ni, C and N facilitate expanding of austenite area and austenite stabilization.

Nitrogen is an efficient element for austenite stabilization. The steels containing nitrogen are used more and more widely [5]. Alloying by nitrogen increases stability, strength and corrosion resistance, in particular the resistance to local corrosion kinds and intercrystalline corrosion of austenite steels [6].

This paper examines possibilities of nitrogen usage in steels on the base of Fe–Mn–Al–Ni–C system for hard solution and dispersion hardening.

2. AlN solubility in the alloys of Fe–Mn–Al–Ni–C–N system

AlN solubility in several liquid alloys of Fe–Mn–Al–Ni–C–N has been calculated using well-known thermodynamic parameters and Thermo-Calc data base.

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[1] Here and below in the paper — mass. % (if another does not mentioned).