nogo uprochneniya metalla pri avtomatizirovannom proektirovanii rezhimov kholodnoy prokatki. (Comparison of methods of forecast of deformation hardening of metal supported by automated design of cold-rolling modes). *Vestnik Magnitigorskogo gosudarstvennogo teknicheskogo universiteta* = Bulletin of Nosov Magnitogorsk State Technical University. 2012, No. 2. P. 55–58.

9. Rumyantsev M. I, Shubin I. G., Mitasov V. S. et al. Specification of methods of determining friction coefficient at cold-rolling at the mill combined with the pickling unit. Simulation and development of metal forming processes. International Collection of Research Papers. Magnitogorsk. Nosov Magnitogorsk State Technical Unviversity. 2012, P. 64–74.
10. Salganik V. M., Medvedev G. A., Rumyantsev M. I. et al. Sposoby vybora rezhimov i raschety pri avtomatizirovannom proektirovanii prokatki tonkikh listov (Methods of mode selection and specification calculation at automated design engineering of thin sheets). Gauge Rolling. *Trudy 3-go kongressa prokatchikov* = Materials of the Third Congress of Rollers. Moscow. Chermetinformatsiya. 2000. P. 180–188.

***S. Yu. Sarancha*[1], *S. A. Levandovskiy*[1], *J. S. Statsenko*[1], *A. B. Moller*[1], *D. I. Kinzin*[1]**

[1] Nosov Magnitogorsk State Technical University (Magnitogorsk, Russia)

E-mail: science.mgn@gmail.com; levandovskiy@mail.ru; kinzin@mail.ru

Optimization of long products rolling and cuttung technology based on modern it

In modern industry information technology and electronic system design, simulation, control systems, production flows, systems of control and accounting of production resources are playing a growing role. Metallurgical production isn't an exception too. There is a task in the section and long product rolling companies associated with the shipment of finishing product by gage lengths. The application of mathematical modeling based on the use of modern information technologies contributes to the efficiency of solving such problems. After the completion of implementation of such APCS the off-gauge length management at the rolling mill will be automated — optimal rolling schedules will be chosen based on the weight of the billet and wear of the rolls. The use of APCS will reduce the number of defects in production and will increase the automation level of the mill increasing the efficiency of the personnel, reducing the influence of human factor and reducing production costs. The economic effect from implementation of the system is more than 50 million rubles per year on heavy-medium section mill with production capacity of about 500 000 tons per year [1]. A promising development of APCS is not only increasing the level of automation, but also the extension of the supported range, for example, the section profiles.

Key words: *off-gage length, not custom length, off-gage balance, measuring length, cut, varying cross-sectional area of the finished product, reducing metal losses, increasing efficiency of the rolling production, variation of the roll gap, information technologies, optimization technology of the cutting, long products rolling.*

In modern industry information technologies (IT) are playing a growing role and metallurgical industry isn't exception. Electronic system design, control systems, production flows, systems of control and accounting of production resources, and automated control systems (management information system) and automated control systems of technological processes (APCS) — all of that is the norm for modern industry. For example, all of the modern continuous rolling mills are equipped with APCS that controls the speed of the mill at each stand to provide the desired tension in the stock, there are also cases where you can meet APCS that control roll gaps online.

IT spreads due to the high efficiency, automatic operation without human's intervention and a high speed of response to the changing process conditions. On the basis of the conducted researches [1], we can conclude that a promising direction in the long product rolling is the development of such an APCS, which automatically selects the optimal roll gap in the last rolling stands of the mill based on the weight of the billet and on the rolls wear to reduce defects and to improve profitability of the long product rolling production, requiring a minimal human intervention.

According to the research results we conclude [1, 2] that there is a task of the correct material cutting in front of modern bar rolling production, and the solution depends not only the volume of the finished product and yield, but also profitability. The main task of cutting is to reduce the number and length of the bars that are shorter than customers need (hereinafter off-gage length). Those bars are generated in the production process at the stage of the gage length formation.

Analysis of the production defect types during long product rolling and its percentage distribution shows that most of them were caused by the wrong cutting, i.e. off-gage length (**Fig. 1**) [2].

On the whole, the full solution of the problem of correct cutting can reduce the number of defects for more than 40 %.

Reducing the metal loss in the off-gage length, and hence, increasing the yield ratio is an effective way to improve profitability.

The task of cutting has at least six solutions:

– The endless rolling: *a* — the technology of the continuous casting [3], *b* — billet welding before rolling [3–5];

– Varying lengths: *a* — of billet, *b* — the technological trimmings within acceptable ranges;

– The variation of cross-section: *a* — of billet, *b* — finished products within the tolerance range.

Endless rolling of continuously cast billets fixes the problem of the off-gage length. The positive side is continuous production without “off-gage length” defect. Negative — complexity and high cost. This technology is used since 2000 [3] in the framework of pilot production.

Endless rolling with the welded billets at the junction interface is a popular method of production. The positive side of this approach is the possibility of obtaining much longer billet. Negative — high cost, the need for purchasing expensive and complex welding units.

Installation of billet welding equipment requires almost complete reorganization of the rolling mill and has a high cost. The main technological problem of billet-welding is the difference between the quality of the welded joint, which limits the product range of the rolling mill, as the joint in the rolling process is rolled out at great length, and reduces uniformity of chemical composition, and the mechanical stability of the finished product.

Varying the length of the billet does not require any changes in the production technology, but requires the reorganization of production management and strategy of the enterprise as a whole, because in this approach the production of continuously cast billets must come from existing orders, adjusting the parameters of the casting under a specific profile. The billet length has to be chosen correctly to obtain shortest off-gage bars. The reverse side of this technology is a mandatory requirement of high production culture: maintenance work, strict adherence to technology, total control. In Russia the solution of this problem is extremely expensive and inefficient.

The method of varying the off-gage length is interesting because it actually does not require the purchase of new equipment. It needs the implementation of online trimmings control. But because the acceptable range of trimming is quite small, it is possible only to reduce the off-gage length and not eliminate it. It should also be noted that a significant complexity creates the current rolls wear, and the effectiveness of this method would be low without this.

The method of varying the cross-sectional area of the billet is quite interesting, but to change the cross-section on CCM we need to change the mold, which is costly and time-consuming. The technology of varying cross-section of the finished product within the tolerance range does not require any deep intervention in the production technology. Variation of the area goes on inside the tolerances. Varying the roll gap, and the cross-section the finished product, it is possible to minimize the off-gage bar length. Increasing cross-section of the finished product is beneficial when company ships bundles at actual weight, and reducing it can increase the number of bars, which is beneficial when bundles are shipped by the theoretical mass and the bar quantity.

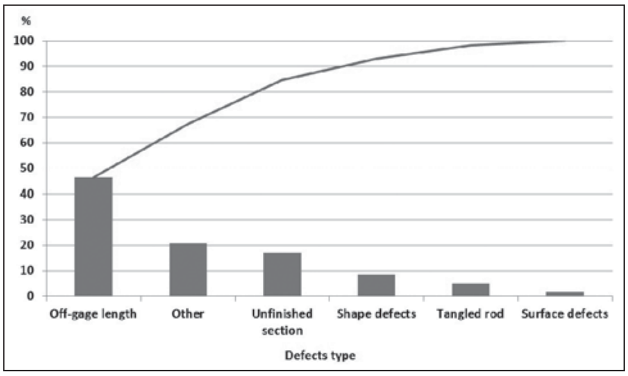

Fig. 1. Manufacturing defects

Analyzing these methods, comes to the conclusion that without IT the methods implementation impossible or difficult. Moreover, IT often allows to find a solution to a particular problem, opening a hidden reserve of modern production (an example is the technology of varying cross-section of the finished product within the tolerances). It’s not only difficult, but it’s waste of time to find the optimal solution without using IT.

Thus, there are at least 6 ways to solve this problem, but as shown by research and practice is most beneficial for long product rolling mill is the method of varying the cross-sectional area of the finished product within tolerances (hereinafter Method) as the most affordable, versatile and quickly implemented method [2].

Positive and negative tolerances, regulated by state standards (for example, GOST 2590–88 regulates hot-rolled round steel, and GOST 5781–82 — hot-rolled steel for reinforcement of concrete structures), allow to vary the cross-sectional area of the finished products in a wide range, while satisfying customer requirements (**Fig. 2**).

The weight of the billet and finished product are closely connected. In practice, it is necessary to consider head and tail cutting, scale, dividing when the stock enters the cooling bed and at the cold shear cutting into bars. By changing the cross-sectional area of the finished product we can change the total length of the stock, which in turn changes the off-gage length because the total mass must remain relatively constant.

Thus, the goal of cutting is to find such a cross-section areas of the finished products, which gives the min-

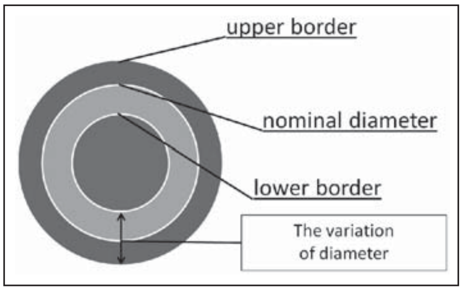

Fig. 2. The interval variation of diameter

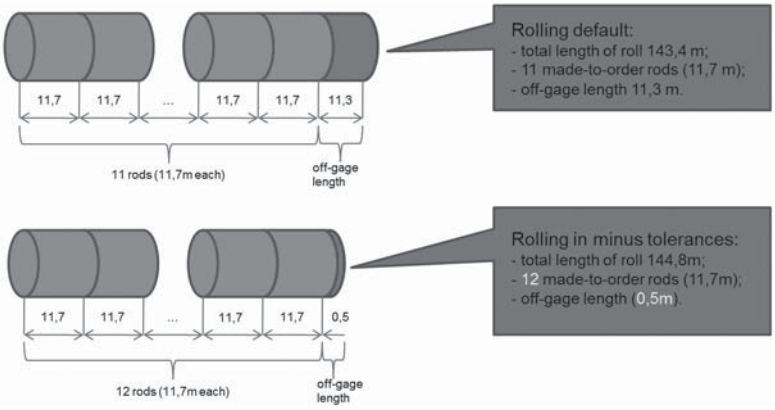

Fig. 4. Rolling

imum off-gage length. The Method offers to change the cross-section of the finished product in the last stands of the rolling mill.

It is important to note that most manufacturers ship finished products by weight and not by the number of bars, so it's better to vary the cross-section of the finished product towards positive tolerance, transferring metal from off-gage length to the finished products, increasing its mass. It will be most profitable to vary the cross-section of the finished product in negative tolerance, which should increase the number of bars for companies that ship long products by the theoretical mass.

Within R&D [1] we developed software that allows quick finding the optimal cross-sectional area of the finished product in the workplace [6]. A simplified algorithm of the program is presented in the diagram (**Fig. 3**).

On the basis of the conducted research it can be concluded that the Method allows to reduce the off-gage length at the bar mill by 80–90% [4].

As shown by practice [1] and model [7] of rolling large bar, for example, the round 48, the off-gage length can be reduced from 11,3 m up to half, thereby increasing the yield from 90,09% to 97,3% (billet weight 2000 kg; mill 370 OJSC MMK). Analyzing the research, it becomes clear that the greatest benefit from the application of the Method can be obtained in large profiles — for example, by rolling the round 30 mm at nominal size off-gage length is 8 meters, while using the Method, off-gage length was reduced to 0,5 m.

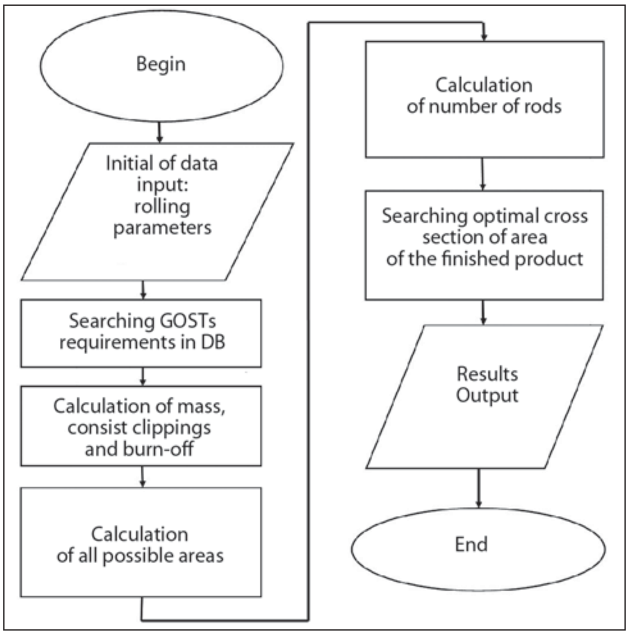

Fig. 3. Simplified algorithm of the program

During the rolling the nominal size, the total length of the rolled stock is 143,4 m or 11 separate bars. Off-gage length in this case is 11,3 m, which cannot be shipped to the customer and is scrapped. Rolling in negative tolerance allows you to get the length of the stock to 144,8 m or 12 separate bars, off-gage length in this case is half a meter. It is worth noting that the Method calculated off-gage length will usually be smaller less than in reality, because the software calculates optimal roll gaps and optimal bar length on the cooling bed, but in reality – without using the Method – dividing bars before the cooling bed is not optimal, which increases the output of crop and off-gage length (**Fig. 4**).

Let's take a closer look at the results: the weight of off-gage bar reduced from 158,02 kg to 7,19 kg and yield increases from 90,09% to 97,3 %; money loss for one billet drops from 2918 to 132 Rub. This effect is achieved by reducing the roll gap from 2,00 to 1,63 mm. The method of varying the cross-sectional area of the finished product is one of the reserves for increasing the efficiency and profitability of production, while not requiring significant investment and time.

The attention should be payed to the accuracy of placing a gap — as shown by studies to ensure maximum efficiency of the Method and the required accuracy of changing the roll gaps in the last stands of the rolling mill at the level of 0,01 mm. Let's have a look at situation at the long product rolling mills OJSC MMK.

In the early 2000ies OJSC MMK has installed three Danieli rolling mills 170, 370, and 450 [8]. The minimum step of placing a gap on the mill 370 is 0,05 mm, which according to R&D "Cutting the rolling mills bars" [1] is not enough to obtain the maximum effect from the Method to reduce off-gage length. The reduction of the minimum step of placing a gap in the last stand from 0,05 mm to 0,01 not only reduces off-gage length at the bar mill, but it's often the only way to do it for heavy section products. Let's compare the minimum gap steps — 0,05 and 0,01 mm (see tables 1–3).

For round 48 mm step of 0,05 mm doesn't allow to reduce the off-gage length using the method of varying the cross-sectional area of the finished product within tolerances. At the same time, improving the accuracy of setting the roll gap of up to 0,01 mm will significantly reduce off-gage bar length of the round 48 mm (by 95%). Thus, for large profiles, improving the accuracy of setting the roll gap reduces the crop, whereas conventional precision placing of the gap is not enough.

Despite the fact that the number of bars remains generally the same, with variable balance is reduced, and this means that less metal goes into scrap — and, consequently, the weight of the finished product increases. Since delivery of the metal occurs, as a rule, by weight, not by number of bars, the reduction of off-gauge length — in other words, the transfer of metal from scrap into finished products — allows you to increase the profitability of the mill.

Generally, improving the accuracy of operation of the metallurgical equipment of the mills together with varying the cross-sectional area of the finished product in the tolerance range is one of the reserves for increasing the efficiency and profitability of long product rolling.

As has been written previously, the further development of the Method is the creation of APCS, which will automatically select the optimal parameters of the rolling mill based not only on the mass of the billet, but also the wear of the rolls. Detailed information on the wear of the rolls depending on the amount of rolled steel and profile shape can be obtained from the following sources: [8-11]. The principle of APCS: the operator of the rolling mill selects the desired profile and custom length. Software reads the mass of the billet, and then calculates the optimum parameters of rolling considering the wear of the rolls. After rolling on the quality control post the measurements of the off-gauge length are made and the system adjusts the coefficients (**Fig. 5**).

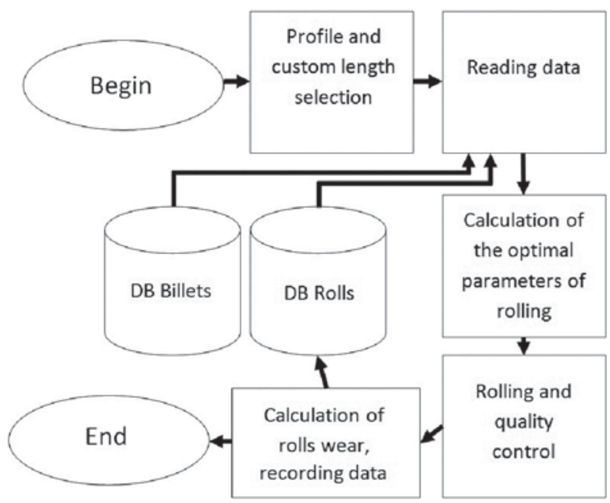

Fig. 5. Automated control system of technological process (APCS)

Table 1. Round 48 mm rolling results (the mill 370 of OJSC MMK)

	Rolling		
	Default	Optimum with step 0,05 mm	Optimum with step 0,01 mm
Weight of billet, kg	2000		
Profile	Circle		
Diameter, mm	48		
Gap in the last stand, mm	No solutions	2	1,63
Off-gage length, m	No solutions	11,33	0,52
Number of rods	No solutivons	11	12

Table 2. Round 20 mm rolling results (the mill 370 of OJSC MMK)

	Rolling		
	Default	Optimum with step 0,05 mm	Optimum with step 0,01 mm
Weight of billet, kg	2000		
Profile	Circle		
Diameter, mm	20		
Gap in the last stand, mm	0,8	1	0,82
Off-gage length, m	1,6	2,6	0,5
Number of rods	70	69	70

Table 3. Round 30 mm rolling results (the mill 370 of OJSC MMK")

	Rolling		
	Default	Optimum with step 0,05 mm	Optimum with step 0,01 mm
Weight of billet, kg	2000		
Profile	Circle		
Diameter, mm	30		
Gap in the last stand, mm	1,5	1,2	1,23
Off-gage length, m	8	1,1	0,6
Number of rods	30	31	31

It is proposed to insert the APCS in the process into several stages according to [12] to ensure the commissioning without stopping the production cycle for a long period. The first step is the implementation of a software system. All measurements and recordings in the database are made manually by the employees of the mill —

in fact, we are talking about semi-automated system, but researches have shown [1] that this system allows to reduce off-gage length in production by more than 50%, requiring regular data input into the database by mill personnel. The main disadvantage of this system is the necessity of correction the burning coefficients in furnaces, thermal shrinkage and tolerances of shears based on empirical data to increase the accuracy of the Model. In the second stage of implementation proposes installation of automated weighing station before and after the reheating furnace, and automatic weighing of the off-gauge bar. Re-weighting of the billet after reheating furnace will let correct burn in scale factor in the database, and the off-gage bar weighing will correct internal index of the model describing the correspondence of theory with practice. The installation of this equipment will transfer the task of correction coefficients from employees to the APCS.

After the completion of implementation of such APCS the off-gauge length management at the rolling mill will be automated — optimal rolling schedules will be chosen based on the weight of the billet and wear of the rolls. The use of APCS will reduce the number of defects in production and will increase the automation level of the mill increasing the efficiency of the personnel, reducing the influence of human factor and reducing production costs.

The economic effect from implementation of the system is more than 50 mln. Rub per year on heavy-medium section mill with production capacity of about 500 000 tons per year [1]. A promising development of APCS is not only increasing the level of automation, but also the extension of the supported range, for example, the section profiles.

REFERENCES

1. Moller A. B., Tulupov O. N., Levandovskiy S. A., Kinzin D. I., Ruchinskaya N. A., Sarancha S. Yu., Guschina M. S., Naydenova A. V., Elesina V. V., Kulakova A. E. Otchet o NIR/NIOKR (Report about scientific-research and pilot-engineering works). Nosov Magnitogorsk State Technical University. Financed by OJC MMK. Registered No. 01201366941.
2. Sarancha S. Yu., Moller A. B., Novickiy R. V. Nemernaya dlina v sortoprokatnom proizvodstve i sposoby ee ustraneniya (Non-measured length in section rolling and ways of its elimination). *Kalibrovochnoe byuro* = Roll pass design bureau. 2013. № 2. P. 48-55.
3. Zhuchkov S. M., Lohmatov A. P., Kulakov L. V. et al. Tendencii razvitiya tehnologii i oborudovaniya dlya realizacii processa beskonechnoy sortovoy prokatki (Development tendencies for technology and equipment for realization of the process of endless section rolling). *Fundamental'nye i prikladnye problemy chernoy metallurgii* = Fundamental and applied problems of iron and steel industry. Collection of scientific works, 2003. Issue 6. P. 152–161.
4. Austen T. X.. EBROS – sistema beskonechnoy prokatki sortovyh profiley (EBROS: the system for endless section rolling). *Novosti chernoy metallurgii za rubezhom* = News of the foreign iron and steel industry. 2004. Issue 2. P. 40–42.
5. Zinovyev A. V. (ref.). Potochnoe soedinenie zagotovok – glavnyy tehnicheskiy priem pri beskonechnoy goryachey prokatke (Online connection of billets as the main technical method in endless hot rolling). *Novosti chernoy metallurgii za rubezhom* = News of the foreign iron and steel industry. 2004. Issue 1. P. 52–53.
6. Sarancha S. Yu., Moller A. B., Kinzin D. I., Novickiy R. V. Svidetel'stvo o gosudarstvennoy registracii programmy dlya EVM «Raskroy produkcii sortoprokatnyh stanov» (Certificate of the state registration of the software program "Pattern cutting of products from section mills"). *Ofitsialnyi byulleten "Programmy dlya EVM. Bazy dannykh. Topologii integralnykh mikroskhem" (OBPBT)* = Official bulletin "Software programs. Data bases. Topology of integrated schemes" ((OBPBT). 2013. № 4. P. 470. № 2013619897.
7. Sarancha S. Yu., Moller A. B..Modernizaciya sortoprokatnogo proizvodstva putem vnedreniya informacionnyh tehnologiy: reshenie problemy kratnosti raskroya (Modernization of section rolling via putting information technologies into practice: solving the problem of pattern cutting rate). *Modelirovanie i razvitie processov obrabotki metallov davleniem* = Simulation and development of metal forming processes). International collection of scientific works. Issue 20. Nosov Magnitogorsk State Technical University. Magnitogorsk. 2014. P. 61–70.
8. Tulupov O. N, Moller A. B., Nigris D., Chukin M. V, Kinzin D. I. Gibkie resheniya v tehnologii i podgotovke kadrov: pozitivnyi opyt sotrudnichestva s kompaniey DANIELI (Flexible solutions in the technology and personnel training: a positive experience of collaboration with DANIELI company). *Vestnik Magnitogorskogo gosudarstvennogo tehnicheskogo universiteta im. G.I. Nosova* = Bulletin of Nosov Magnitogorsk State Technical University. 2014. № 1 (45). P. 81–85.
9. Moller A. B., Zaytsev A. A., Tulupov O. N. Model' nastroyki sortoprokatnogo stana pri matrichnom opisanii formoizmeneniya v kalibrakh prostoy formy (Adjusting model for a section rolling mill with matrix description of forming in simple-shaped passes). *Izvestiya vysshikh uchebnykh zavedeniy. Chernaya metallurgiya* = News of high schools. Iron and steel industry. 1999. № 10. P. 15–18.
10. Moller A. B., Zaytsev A. A., Tulupov O. N., Rashnikov S. F Metody primeneniya matematicheskoy modeli nastroyki nepreryvnykh sortovykh stanov

(Methods of usage of mathematical model for adjusting of continuous section rolling mills. *Proizvodstvo prokata* = Rolling production. 1999. № 5. P. 7—12.
11. Moller A.B. Adaptiruemaya matrichnaya model dlya povysheniya tochnosti nepreryvnoy sortovoy prokatki (Adaptive matrix model for increase of precision of continuous section rolling). The thesis for degree of candidate of technical sciences. Nosov Magnitogorsk state technical university. Magnitogorsk. 1996
12. Fedorov Yu. N.. Poryadok sozdaniya, modernizacii i soprovozhdeniya ASU TP (Order of creation, modernization and accompanying of automatic control system for technological processes). Moscow. *Infra-Inzheneriya* = Infra-Engineering. 2011. 576 p.

***V. E. Roshchin*[1], *N. V. Malkov*[1], *A. V. Roshchin*[1]**
[1] *South Ural State University, (Chelyabinsk, Russia)*
E-mail: Roshchinve@susu.ac.ru

Usage of worked-out metallurgical slag In electroslag remelting processes

There are economically and technically effective technologies of steel producing with low level of sulfur, phosphorous, oxygen and hydrogen in metal. As a consequence, there is no special need of refining metal from impurities in electroslag remelting. Remelting primary objective is to obtain a favorable structure while maintaining of low hydrogen content and increasing the technical and economic evidence of the remelting process itself. The new generation flux of low base-to-acid ratio based on worked-out metallurgical slag was developed. The physical, physico-chemical, technological properties of this flux, structure and properties of the investigated weld metal have been studied in laboratory and industrial conditions. The technical parameters of the process of ESR have been evaluated. It was shown that proposed flux is workable and its application provides consistently ESR process with a high speed, reduces electricity consumption up to 1,5 times and provides welding of metals with a good surface quality. Proposed flux protects the weld metal better from hydrogen saturation than widely used $CaF_2 - Al_2O_3$ *flux ANF-6. The mechanical properties of cast metal, welded under this flux are close to forged steel after remelting under* $CaF_2 - Al_2O_3$ *flux.*

Key words: *flux, slag recycling, electroslag remelting, metal refining, metal welding, hydrogen saturation, mechanical properties, sulfur, phosphorus, oxygen, hydrogen.*

1. Introduction

It's well-known that metallurgical enterprises, in addition to metal production, produce a lot of various slags (blast furnace slag, steelmaking slag, secondary metallurgy slags etc.). Pyrometallurgical companies engaged for a long time the challenge of the slag usage and solve it rather successfully. Nowadays, such slag is used for manufacture of building materials, roadway backfills, in the cement industry, in agriculture for liming the soil etc. [1], because it brings significant economic benefits (lower consumption of lime, alumina and the other additives, saving coke, recovering heat etc). Thus in Europe about 87% of worked-out pyrometallurgical slags nowadays are used at present time in building industry [2]. It must be noted, that blast furnace slag is the most suitable for recycling — it's recycled up to 100%, steelmaking slags are used less — about 79%, and the least used slag is slag of ferroalloy production industry. However, it's possible that the further requirements would be more environmentally concerned, taking into account targets like preservation and protection of the environment and humans. From that positions, using of metallurgical slags, especially from ferroalloys (because of self-disintegrate property, possibility of heavy / toxic compounds like Cr^{6+} forming and so on) in building could be restricted or even forbidden, so another usage of such materials should be find.

The chemical and granulometric composition and low price of ferroalloy slags make them challenging to reuse in the metallurgical industry, particularly as a starting materials for the production of low base-to-acid ratio and low-fluorine fluxes for electroslag remelting process (ESR).

ESR is used in the steel industry mainly for deep desulfurizaing, refining of metal from non-metallic inclusions and obtaining a dense cast structure of metal. To achieve these goals, a series of fluxes has been developed, which is based on the systems of calcium fluoride with thermodynamically strong oxides (calcium, aluminum and magnesium). These fluxes are characterized by high refining capability and they have a set of physical and physico-chemical properties. It allows to provide stable melting conditions. Wide circulation of flux from 70% mass. CaF_2 and 30% mass. Al_2O_3 (named ANF-6) was obtained in Russia.