Metallurgy

Perspectives of "Free Rolling" in Production of Composite Armor Materials

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ABSTRACT. Methods of production of the composite armor materials (on the basis of aluminium) are considered in the paper. On the basis of experimental analysis the advantage of "free rolling" method was established. The methodology of theoretical computation of the parameters in precision of 80-85% was developed for the principal technological process of "free rolling". The optimal parameters of the composite armor plates of different thickness provided in the paper were defined based on the mentioned methodology. Each of these methods has its specific character, where one of the technological parameters is greater partially compensating the two other lesser parameters. For example: in the explosion method the pressure is high and the time is very short; in pressing the time is high and the temperature is low; in casting the temperature is high and the pressure is low. But all of them have one common drawback - they require complex equipment and difficult technological processes, and most importantly, with the increase of the overall dimensions the probability of receiving high quality composite plates sharply decreases. *© 2018 Bull. Georg. Natl. Acad. Sci*

Key words: aluminium plates, free rolling, composite armor materials

Current status of material science and mechanical engineering gives ground to consider the science of aluminum armor materials as a successful independent field in the constructions of military light vehicles (10-20 t).

Aluminum is the most widely spread metal in nature, even more than iron. There are number of minerals and mountain rocks containing aluminum as a chemical compound (oxygen and salts). It is one of the main elements of soil formation.

The advantages of the efficiency of the aluminum-based alloys compared to the iron-, copper- and titanium-based alloys is worth mentioning. For example, the strength of aluminum alloys is 15-20 times higher than that of the pure aluminum. While in similar comparison the iron-iron alloys (steel) are 10- times stronger and the copper-copper alloys and titanium-titanium alloys are only 5-8-times stronger. That explains the great interest in aluminum alloys as the best construction materials in conditions of dynamic load (including armor materials)

Nowadays, considerable progress is achieved in binary and complex-alloyed systems Mg, Si, Cu, Zn. In the recent years their number was added by Li and Ag that can be explained by maximum and solubility change of these elements in aluminum. Correspondingly, high solubility in solid solutions Sв/r and the ratio of the specific elasticity and hardness are actually equal. For for determining the permissible thickness of plates for these materials in the case of equal weight the inverse

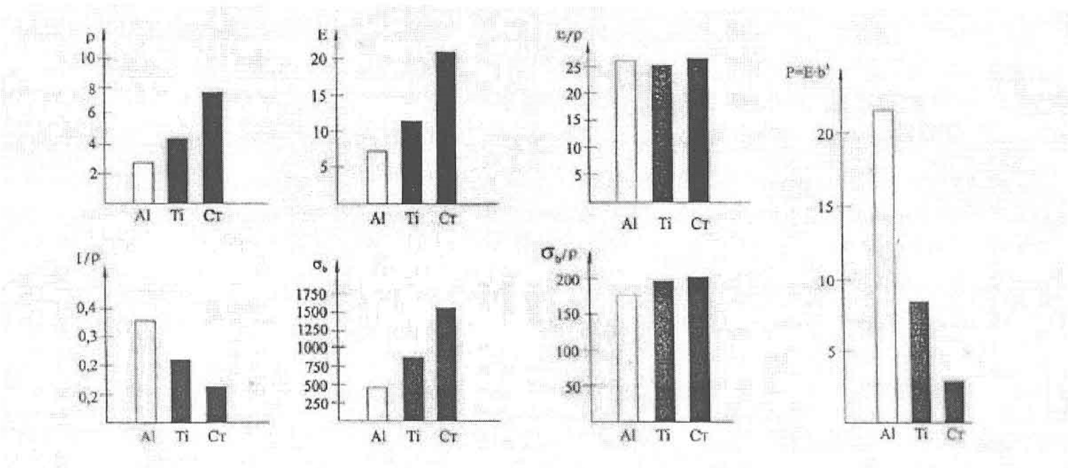

Fig. 1. The comparative data on characteristic features of different metals for the construction of the light armor vehicles.

- Mg (17.4%); (1.65%); Cu (5.7%); Zn (82%). As is known, the solubility change provides the effect of thermal hardening (quenching).

As is known, the efficiency of any construction, in particular, military vehicles, are determined by both strength and stiffness, [1] i.e. by their ability of resistance against the external loads with minimal deformation. The more so, this feature is obligatory for light class military techniques, for which the amount of weighs is strictly regulated. The hardness against bending (sustainability) is represented as a simplified relation $P = E \times b^3$, where E is the elasticity module, and b^3 is the thicknes of the armor plate. Thus, the firmness of the construction against bending is the product of multiplication of the elasticity module and the third degree of the plate thickness. For aluminum, steel, and titanium, corresponding data (breaking strength) on elasticity module and hardness in terms of equal mass are given in Fig. 1.

In terms of hardness and elasticity the steel is certainly the leader, but the ratio of the obtained results to the specific weight of each one E/r and value of specific weight should be used in the formula. In that case the aluminum will be 2.8 times thicker compared to steel and 1.6 times thicker than titan. The titanium in its turn is only 1.73 times thicker compared to steel. Thus, aluminum hardness, even in terms of its elastic module three times smaller compared to steel, is still 8 times greater than that of the steel and almost 3 times greater compared to titanium (Fig. 1). Due to that fact, aluminum, is used in the production of the military light armored vehicles, which was significantly greater in case of use of special armor alloys of aluminum (Al-Zn-Mg), when their mechanical properties are close to low-strength steel. Due to insufficient hardness, the steel armor case requires additional frame, which is not necessary in case of aluminum. Just this property of the aluminum armor cases allows to reduce the weight of the military vehicle by 25%.

Thus, we can conclude that the use of aluminum and aluminum-based materials in armor vehicles and individual protection equipment (body armours and helmets) is prospective.

Since the end of the 40s of the last century, there is an intensive work in that direction all over the world. Nowadays the third generation of armor alloys is already produced. The first generation of armor aluminum plates were produced on the basis of Al-Mg, and apart from Mg, to the alloys of the second-generation zinc was also added, while besides zinc to the alloys of the third generation cuprum was also added.

Even though each of them has armor properties, all these alloys are quite different from each other by their mechanical properties (plasticity, impact strength and hardness). Consequently, the field of application is also different. Some of them are distinguished with high protective ability against grenade splinters, and some of them against bullets. As a rule, the total number of elements in this alloy is no more than 5 ÷ 8%, while the hardness varies from 80 ÷ 100 units to 150 ÷ 180 units (Brinell).

As a rule, two groups of aluminum alloys are used for production of homogeneous aluminum armor. The first group includes the thermally non-hardening Al-Mg alloys and the low-strength and low-hard Al-Zn-Mg-based alloys (σв-300-400Па strength and hardness HV-80-120 unit (Brinell)), which are characterized by high level of protection from the fragments of shells including: 5083 and Al can D545, Al can D745, 7018.

The second group includes Al Zn Mg-based alloys of increased strength and hardness (σв-450-50Па, HV-130-150), such as 7039-T64, E745(7017), Al-Zn-Mg_3, which better protect from bullets and shells than the alloys of the first group.

The armor of the low-strength aluminum alloys of the first group is mainly used for production of the roof, bottom and lids of the light armored vehicles, protecting horizontal planes from the fragments of shells and landmines. This group of alloys are of relatively low hardness (HB 80 ÷ 120) and great impact-strength and plasticity. Therefore, they have quite limited functions.

Nowadays, it can be said that the capabilities of traditional methods of classical metallurgy and materials science are actually exhausted. Practically, it is impossible to produce a monolithic armor plate from aluminum armor alloys having all the above-mentioned properties. Development of new different approaches to production of the materials is on the agenda. We consider the composite materials to be such an approach as their constituent layers allows production of plates of universal properties.

Consequently, an aluminum-based layer composite construction of armor plates was developed, which satisfies all the requirements (high armor welding capability, anti-corrosion). The universal composite plates consists of an alloy layer of high-hardness placed between two relatively plastic aluminum alloy layers of low-hardness (HB 130÷150). The outer layers are usually made of Al-Zn-Mg -based alloys, which are good for welding and corrosion, while the middle layer is made of Al-Zn-Mg-Cu- based alloy of high strength. Besides, the thickness of the middle layer is 50% of the total thickness, while the thickness of the outer layers is 25-25%.

There are known several methods of making composite materials: pressing [2-4], explosion, hot rolling and casting. In all these cases, the process is determined by three main technological parameters: pressure, temperature and time.

Each of these methods has its specific character, where one of the technological parameters is greater partially compensating the two other lesser parameters. For example: in the explosion method the pressure is high and the time is very short; in pressing the time is high and the temperature is low; in casting the temperature is high and the pressure is low. But all of them have one common drawback - they require complex equipment and difficult technological processes, and most importantly, with the increase of the overall dimensions the probability of receiving high quality composite plates sharply decreases.

All the above considerations lead to the conclusion that if any of the methods discussed above can be combined, the probability of obtaining high quality composite will definitely increase. From this point of view, the method of “free rolling”, where the processes of continuous casting and rolling are combined, seems quite acceptable.

For several years now, the Ferdinand Tavadze Institute of Metallurgy and Materials Science has been working on determination of the main technological parameters for production of thin 8-12mm sheets from aluminum alloys by the method of “free rolling” and certain results are already achieved.

The "free rolling" is the combination of two independent processes (continuous casting and hot rolling), Fig. 2.

the main technological parameters of the process are presented. Its software was developed and the optimal combinations of these parameters were estimated for the armor alloys of aluminum [8].

The experience shows that this way allows to estimate the values of the technological parameters for casting and rolling with 80-85% accuracy, and experimental estimation of their final precision significantly reduces time and resources.

Given the current experience in production of the composite armor plates of aluminum and the specifics of the "free rolling" method the production of the composite of 30-40mm thickness seems most optimal, where the mid layer should be 15-20 mm and the outer layers 8-10 mm. The more

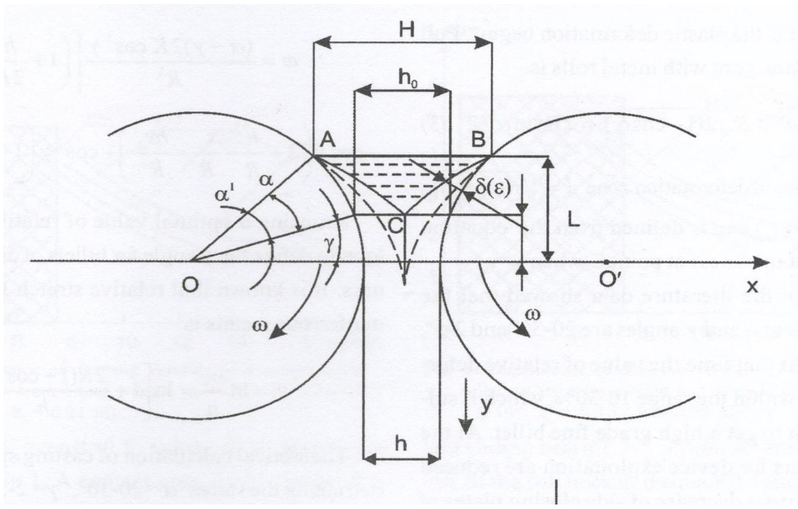

Fig. 2. Schematic representation of the process of billet formation in rolling.

Each of them has its technological parameters. Their combination requires quite laborious and expensive experimental studies, especially when it comes to the use of the technology of casting the aluminum alloys of several generations. Therefore, it is desirable to develop a mathematical model of the process and based on it to determine the optimal value of main parameters (rolling diameter, casting rate, meniscus of the melted metal against the O O1 axis, thevalue of γ and α angles, the power parameters of experimental plants, optimal stretching values) for both process. The empirical formula describing the process is created, where all

so, we have already used the method of "ingot free rolling" in the technology of production of 8-10mm plates.

Theoretical analysis of the armour aluminum alloy was carried out with the methodology developed by us to determine the main technological parameters for production of 15-20 mm plates from the armour aluminum alloy received on the basis of Al-Zn-Mg-Cu by the method of "ingot free rolling". The results of the analysis are in Tables 1, 2, 2a, 2b, and Figs. 3 - 6. The hatched zones in the diagram correspond to the probable optimal technological parameters of the

Table 1. Basic technological parameters of free rolling process (I-generation alloy based on Al- Mg)

#	α°	γ°	h_o, m	h, m	ε%	x_o m	K m^2/min	R, m	V m/min	ω rev/min
	30	3	16.6	$16·10^{-3}$	3.6	$8.9·10^{-3}$	$2.8·10^{-5}$	$210·10^{-3}$	1.19	0.90
2	30	5	17.6	$16·10^{-3}$	9.0	---”---	---”---	---”---	1.05	0.79
3	30	7	19.5	$16·10^{-3}$	16.4	---”---	---”---	---”---	0.66	0.5
4	30	10	22.4	$16·10^{-3}$	28.0	---”---	---”---	---”---	0.57	0.43
5	25	3	16.6	$16·10^{-3}$	3.6	---”---	---”---	---”---	1.18	0.90
6	25	5	17.6	$16·10^{-3}$	9.0	---”---	---”---	---”---	1.05	0.79
7	25	7	19.5	$16·10^{-3}$	16.4	---”---	---”---	---”---	0.64	0.48
8	25	10	22.4	$16·10^{-3}$	28.0	---”---	---”---	---”---	0.51	0.41
9	30	3	20.6	$16·10^{-3}$	2.9	---”---	---”---	---”---	0.93	0.70
10	30	5	21.6	$16·10^{-3}$	7.4	---”---	---”---	---”---	0.81	0.61
11	30	7	23.5	$16·10^{-3}$	14.8	---”---	---”---	---”---	0,62	0.46
12	30	10	26,4	$16·10^{-3}$	24.2	---”---	---”---	---”---	0.45	0.34
13	25	3	20.6	$9.58·10^{-3}$	2.9	---”---	---”---	---”---	0.79	0.56
14	25	5	21.6	$10.6·10^{-3}$	7.4	---”---	---”---	---”---	0.66	0.50
15	25	7	23.5	---`---	10.8	---”---	---”---	---”---	0.53	0.40
16	25	10	26.4	---`---	24.2	---”---	---”---	---”---	0.36	0.27
17	30	3	26.6	---`---	2.4	---”---	---”---	---”---	0.88	0.66
18	30	5	25.6	---`---	6.25	---”---	---”---	---”---	0.75	0.57
19	30	7	27.5	---`---	12.7	---”---	---”---	---”---	0.63	0.48
20	30	10	30.4	---`---	21.0	---”---	---”---	---”---	0.48	0.36
21	25	3	24.6	---`---	2.4	---”---	---”---	---”---	0.70	0.53
22	25	5	25.6	----`---	6.2	---”---	---”---	---”---	0.62	0.47
23	25	7	27.5	----`---	10.9	---”---	---”---	---”---	0.49	0.37
24	25	10	30.4	----`---	21.0	---”---	---”---	---”---	0.36	0.27

HH0= 39.36+h 250 α

H0=56.28+h 300α

Table 2. Basic technological parameters of free rolling process (III-generation alloy based on Al- Mg)

α°	γ°	H, mm h+39.36	h, m	h_o,mm	ε%	τ sec	X_0, m	K m^2/min	V m/min	ωrev/min	R mm
25	3	h+39.36	20X10^3	20,6	2.9	5.05	8.6X10^3	2.8X10^5	0.95	0.72	210
25	5	`	`	21.6	7.4	5.4	`	`	0.81	0.62	`
25	7	`	`	23.04	13.2	5.9	`	`	0.67	0.51	`
25	10	`	`	26.4	24.2	7.16	`	`	0.46	0.35	`
25	15	`	`	34..4	41.8	11.03	`	`	0.2	0.16	`
25	3	`	15X10^3	15.6	3.8	3.48	`	`	1.38	1.05	`
25	5	`		16.6	9.6	3.78	`	`	1.16	0.88	`
25	7	`		18.04	18.8	4.22	`	`	0.94	0.71	`
25	10	`		21.4	29.9	5.33	`	`	0.62	0.47	`
25	15	`		29.4	57	11.03	`	`	0.2	0.15	`

process. The values of these parameters will be precisely defined only in this interval experimentally, which will significantly reduce the amount of labor-intensive and expensive experimental castings.

The above said method allows to change the present complex method of multistage hot rolling in production of layered (armor) plates by “free rolling” process, which allows to produce internal plates of high hardness and outer plates of

2[a]

γ^o	α^o	H, mm h+39.36	h, m	$h_o+2\Delta$	ε%	<	τ, sec	τ, min	V m/min	ω rev/min
3	25	17.5	17.5	18.1	3.3	80.13	4.24	0.07	1.14	0.87
5	25	17.5	17.5	19.1	8.3	72.92	4.56	0.076	0.96	0.73
7	25	17.5	17.5	20.54	14.8	65.67	5.04	0.08	0.82	0.62
10	25	17.5	17.5	23.9	26,7	54.84	6.22	0.15	0.36	0.27
15	25	17.5	17.5	31.9	45.1	36.61	9.44	0.16	0.23	0.17
		h+56.28								
3	30	17.5	17.5	18.1	3.3	98.05	4.24	0.07	1.14	1.07
5	30	17.5	17.5	19.1	8.3	90.9	4.56	0.076	0.96	1.91
7	30	17.5	17.5	20.54	14.8	83.74	5.04	0.08	0.82	0.8
10	30	17.5	17.5	23.9	26,7	72.93	6.22	0.15	0.36	0.4
15	30	17.5	17.5	31.9	45.1	54.84	9.44	0.16	0.23	0.26

2[b]

30	3	h+56.28	$20X10^3$	20.6	2.9	5.05	`	`	1.17	0.89	`
30	5	`		21.6	7.4	5.4	`	`	1.01	0.77	`
30	7	`		23.04	13.2	5.9	`	`	0.85	0.65	`
30	10	`		26.4	24.2	7.16	`	`	0.6	0.46	`
30	15	`		34..4	41.8	11.03	`	`	0.3	0.23	`
30	3	`	$15X10^3$	15.6	3.8	3.48	`	`	1.69	1.29	`
30	5	`		16,6	9.6	3.78	`	`	1.44	1.11	`
30	7	`		18.04	18.8	4.22	`	`	1.19	0.91	`
30	10	`		21.4	29.9	5.33	`	`	0.82	0.62	`
30	15	`		29.4	57	11.03	`	`	0.3	0.23	`

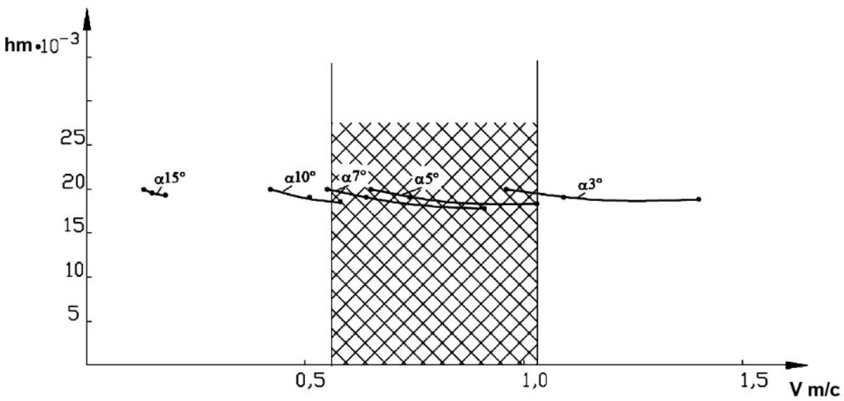

Fig. 3. Dependence of the billet casting rate on its thickness and the value of γ angle (α=25^0, third-generation alloy Al-Mg-Zn-Cu).

relativelye less hardness and a simultaneous process of their sintering.

The technological process necessary for production of the composite armor plates can be performed on the classical shaft-cutting machine of free rolling. In addition, the production costs will be reduced not only through combination of the simple actions but also by the fact that the

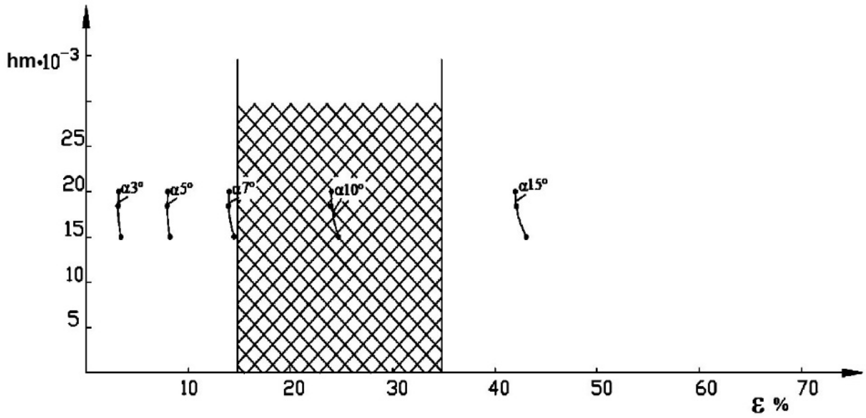

Fig. 4. Dependence of the billet casting rate on its thickness and the value of γ angle (α=30^0, third-generation alloy Al-Mg-Zn-Cu).

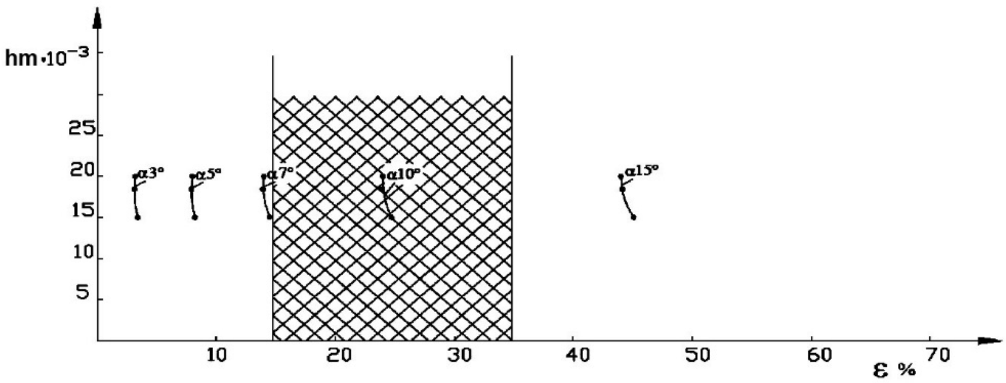

Fig. 5. Dependence of the billet reduction coeffiient on its thickness and the value of γ angle (α=25^0, third-generation alloy Al-Mg-Zn-Cu).

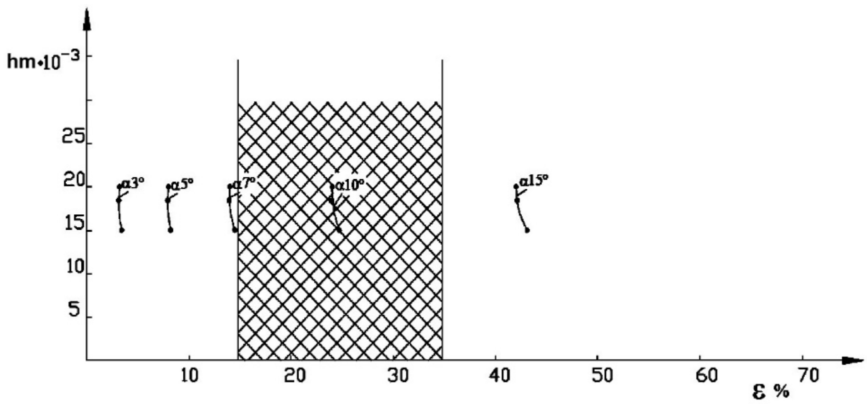

Fig. 6. Dependence of the billet reduction coeffiient on its thickness and the value of γ angle (α=300, third-

use of clean aluminum sheet for better adhesion between the layers is not required, because the process of sintering is going on practically in the melting temperature range and high pressure conditions. Besidesn, this method allows to cast and roll the inner layer of the composite plate in advance and also paired either with a vertical device of continuous casting, or with a similar device of free rolling that significantly increases (about 30-40%) the efficiency of the, process, since the middle

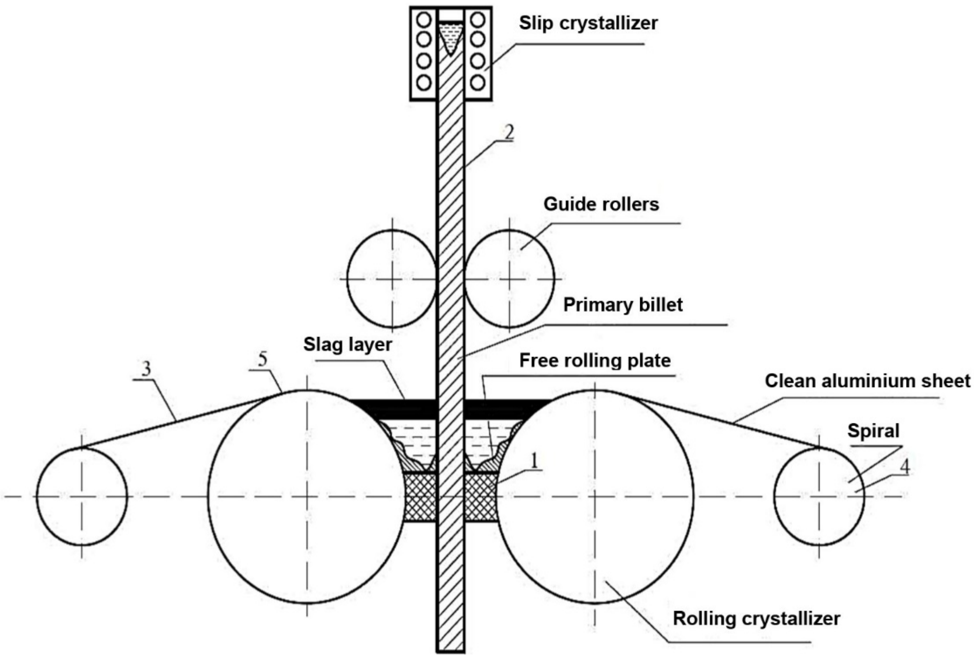

Fig 7. Schematic representation of composite materials by "free rolling".

layer of the plate is the additional site of crystallization. Use of the low-melting point slag layer of a certain thickness on the surface of the liquid metal of/in the crystallizer also improves the quality of the finished product, the composite plate, thereby the middle layer surface is deoxidized (Fig. 7).

As for the temperature of the middle layer of the composite plate before entering into a liquid metal, the size of the reduction, the composition and height of the slag it is the subject of experimental research for ensuring a high quality sintering between the layers.

მეტალურგია

კომპოზიტური საჯავშნე მასალების მიღების პერსპექტივები "უზოდო გლინვის" მეთოდის გამოყენებით

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** სსიპ. ფერდინანდ თავაძის მეტალურგიისა და მასალათმცოდნეობის ინსტიტუტი*
**აკადემიის წევრი, სსიპ. ფერდინანდ თავაძის მეტალურგიისა და მასალათმცოდნეობის ინსტიტუტი*

სტატიაში განხილულია კომპოზიტური საჯავშნე (ალუმინის ბაზაზე) ფილების წარმოების დღეისათვის არსებული მეთოდები. ექსპერიმენტული ანალიზის საფუძველზე დადგენილია „უზოდო გლინვის" მეთოდის უპირატესობა განხილულ მეთოდებთან შედარებით. დამუშავებულია „უზოდო გლინვის" პროცესის ძირითადი ტექნოლოგიური პარამეტრების 80-85% სიზუსტით თეორიული გათვლის მეთოდიკა და მოყვანილია ამ მეთოდიკის საფუძველზე განსაზღვრული სხვადასხვა სისქის საჯავშნე კომპოზიტური ფილების წარმოების ოპტიმალური პარამეტრების მნიშვნელობები.

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