საქართველოს მეცნიერებათა ეროვნული აკადემიის მოამბე, ტ. 18, №2, 2024
BULLETIN OF THE GEORGIAN NATIONAL ACADEMY OF SCIENCES, vol. 18, no. 2, 2024

Metallurgy

The Process of Forming Outer Layers of a Composite Product Using the Non-Ingot Rolling Method

Giorgi Kevkhishvili[*], Teimuraz Namicheishvili[*], Julieta Loria[*], Ramaz Kharati[*], Giorgi Parunashvili[*], Giorgi Basilaya[*], Malkhaz Rusadze[*], Vazha Ramishvili[*]

[*] *LEPL Ferdinand Tavadze Institute of Metallurgy and Materials Science, Tbilisi, Georgia*

(Presented by Academy Member Tamaz Natriashvili)

The paper discusses the process of product formation in clay crystallizers during the production of composite slabs based on iron aluminum and titanium aluminum using the non-ingot rolling method. Technological parameters of molding in the production of composite materials using the liquid-phase molding method (related to the non-ingot rolling process) are determined by the thickness of the outer layers and solidification conditions. At first glance, the parameters for casting an aluminum alloy sheet of a certain thickness using the non-ingot rolling method should not differ in any way from the parameters for casting a composite material with the same thickness of the outer layer, since in both cases the product is formed in clay crystallizers. Experimental studies on a test casting-rolling device showed that there is a difference caused by asymmetrical cooling conditions during the production of layered materials. The paper examines the movement of the crystallization front during the formation of a composite product, both from the side in clay crystallizers and from the side of the steel sheet used as the middle layer. Theoretical calculations show that the movement of the crystallization front from the side in clay crystallizers occurs 65-70% faster than from the side of the steel sheet used as the middle layer. In this case, the total solidification time of the outer layer of the composite will be 20-25% lower than the total solidification time of an aluminum alloy sheet of the same thickness when using the non-ingot rolling method. This fact made some adjustments to all the main casting parameters, namely: time of filling with crystallization metal before starting the process; pouring speed; values of angles α and γ; forces arising on clay crystallizers. *© 2024 Bull. Georg. Natl. Acad. Sci.*

aluminum sheet, continuous casting, rolled products, composite, riveted Joint

Since the 1940s, special attention has been paid to the processing and creation of special aluminum alloys (based on aluminum, which are used under conditions of pulsed large dynamic loads of high intensity). Although very successful results have been achieved in this direction and third-generation alloys have already been obtained, the strength of which is equal to the mechanical properties of low-alloy steel, each of them is intended for specific purposes. Thus, their scope of use is very limited.

The classical methods of metallurgy and materials science existing today do not allow the production of homogeneous aluminum alloys with high viscosity and ductility, the ability to heat treat, and at the same time anti-corrosion and resistance to welding. In this regard, the question arose about creating layered composite materials based on aluminum alloys that meet the requirements listed above.

There are several known methods for producing composite materials, namely: blast furnace pressing, hot rolling and casting. Although all of them are currently quite common and make it possible to obtain high-quality layered materials, they have a drawback. Firstly, they require quite complex and expensive equipment, and secondly, as the size of the product increases, it becomes much more difficult to obtain high-quality laminated material.

Against this background we consider it quite justified to produce layered composite materials using the non-ingot rolling method. The essence of the non-ingot rolling method is quite simple.

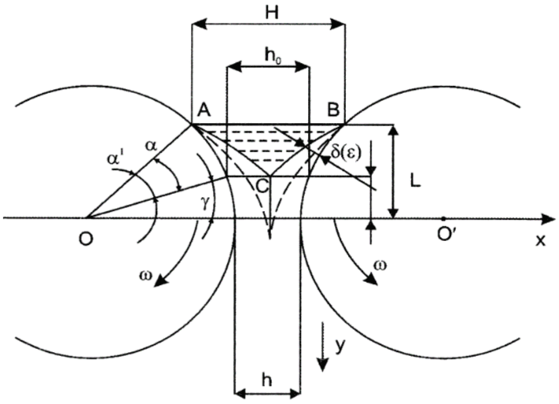

Fig. 1. Schematic representation of the formation of a product in the process of non-ingot rolling.

The product is formed in the space between clays equipped with water cooling, located in a horizontal plane, and tiles of refractory material, tightly laid on both sides (Fig. 1). Due to its specificity, this method fully satisfies the requirements for all the main technological parameters (pressure, temperature, time) necessary to obtain high-quality layered (composite) materials. If we consider that when laminates are manufactured using the "non-ingot rolling" method regardless the thickness and type of metal sheet used as the middle layer, the process actually forms two sheets of the same thickness (composite side layers). It is obvious that in the production of layered materials using the non-ingot rolling method, the technological parameters for the formation of layers will differ from those of producing sheets of the same thickness using the same method, but according to preliminary theoretical calculations, determination of their optimal value using a previously developed method is quite acceptable [1].

Tables 1 and 2 also show the interdependence of the main technological parameters specified by theoretical calculations for both cases.

Table 1. Technological parameters for manufacturing a 10 mm thick sheet of aluminum alloy using the non-ingot rolling method

№	L mm	δ mm	ε%	τ sec.	V m/min
1	112	10.0	0	2.63	2.55
2	107	11.7	14	3.07	2.09
3	106	12.5	20	3.28	1.94
4	105	13.3	24	3.5	1.80
5	104	14.2	29	3.73	1.67
6	103	15.4	35	4.0	1.54

The epiure clearly shows that the crystallization process of the monolithic plate develops symmetrically on the clay surface. The picture is different in the case of the formation of a composite plate, since the crystallization of aluminum alloys occurs on one side from the surface of a water-cooled glass crystallizer, and on the other side - from steel or titanium. the sheet is used as a middle layer whose ability to dissipate heat is limited. Obviously, the meeting of these two spreading fronts will not occur at the midpoint, but will move towards the material used as the middle layer.

Let us consider the process of product formation in a mold when casting a composite material

Table 2. The relationship between the main technological parameters of casting a layered composite plate using the "non-ingot rolling" method

№	L mm	L mm 2(δ+δ)	ε%	H mm	h mm	δ mm	δ^1 mm	τ sec.	V m/min
1	112.8	20.0	0	82.4	26.0	2.4	7.6	2	3.38
2	107	23.4	14.5	„	„	3.3	8.4	2.3	2.75
3	106	25.0	20.0	„	„	3.53	8.93	2.5	2.55
4	105.6	26.6	24.8	„	„	3.75	9.55	2.7	2.38
5	104.7	28.4	29.5	„	„	4.0	10.2	2.8	2.21
6	103.3	30,9	35	„	„	4.35	11.05	3.0	2.07

using the non-ingot rolling method. According to [2], it is capable of absorbing (per unit length) the maximum amount of heat when inserting a steel or titanium sheet into a molten aluminum alloy.

$$\theta = c\gamma\delta^2\left(t^{11}-t^1\right), \qquad (1)$$

where c is heat capacity of iron; γ-iron – specific gravity; t^{11} – melting temperature of the material; t^1 – the initial temperature of the material; δ – thickness of the middle sheet.

On the other hand, when the corresponding maximum amount of heat is removed from the molten aluminum alloy, an alloy of a certain thickness will crystallize on the middle sheet (unit of equal length).

$$\Theta^1 = c^1 y^1 \delta\left(\delta^1-\delta\right)\left(t-t^0\right)+py\left(\delta^1-\delta\right), \qquad (2)$$

where δ is initial thickness of the middle sheet; δ^1 – the total thickness of the middle sheet and the aluminum alloy crystallized for it.

Let us compare the heat amounts to each other and estimate the maximum thickness that the average sheet will achieve with the aluminum alloy hardened on top.

$$\delta^1 = \delta\sqrt{1+\frac{c\gamma\left(t''-t'\right)}{\gamma^1\left[c^1\left(t-t_0\right)+\rho\right]+\rho}}, \qquad (3)$$

where: t is melting temperature of aluminum alloy; t^0 – melting temperature of aluminum alloy; t^{11} – melting temperature of the middle sheet; t^1 is the initial temperature of the middle sheet; c – heat capacity of the middle sheet; γ – weight of the middle sheet; ρ – specific heat of melting of aluminum; c^1 – the heat capacity of aluminum; γ^1 – the specific gravity of aluminum.

When cold body is introduced into the molten metal, a certain part of the dew begins to crystallize. The pattern of crust formation over time is well illustrated by the following image (4) [3]:

$$\delta^1-\delta = \sqrt{\frac{\mu\left(t_0-t_{m0}\right)}{\rho\gamma}\left[1-\frac{2\mu^1\left(t_m-t_0\right)}{\mu\left(t_0-t_{m0}\right)}\right]\tau}, \qquad (4)$$

where μ is the heat transfer coefficient of solid aluminum; μ^1 is the heat transfer coefficient of molten aluminum.

Let us take into account the specific casting data of a layered material 26 mm thick (10+6+10) and estimate the time during which an aluminum alloy 10 mm thick will crystallize on the surface of both the clay mold and the steel sheets used as the middle layer. We get this from the crystallizer side $\delta = \sqrt{2K\tau}$ [3]. To form a crust of this thickness it will take 2.63 c, on the side of the steel sheet (4) – 8.3 s. In the first case, the average speed of the crust formation process is $V^1 = 3.8$ mm/s, and in the second case, $V^2 = 1.89$ mm/s. Therefore, these two crystallization fronts will meet each other $10/(V^1+V^2)=1.76$ s. During this time, a layer of 6.68 mm thick will harden on the clay side, and the remaining 3.32 mm on the steel sheet side. As mentioned above, the purpose of the work was to study the possibilities of obtaining high-quality composite materials based on iron-aluminum and titanium-aluminum. In addition, these metal pairs are known to be less compatible in terms of adhesion. The reason is the formation in the zone of

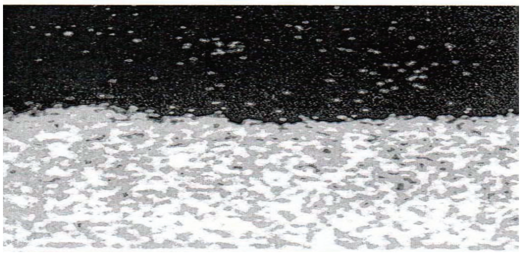

Fig. 2. Distribution of iron over the surface of the sample FeKα (1).

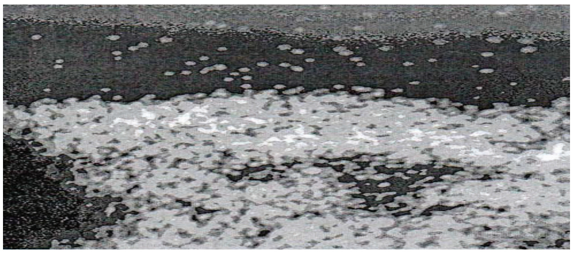

Fig. 3. Distribution of aluminum over the surface of the sample AlKα (2).

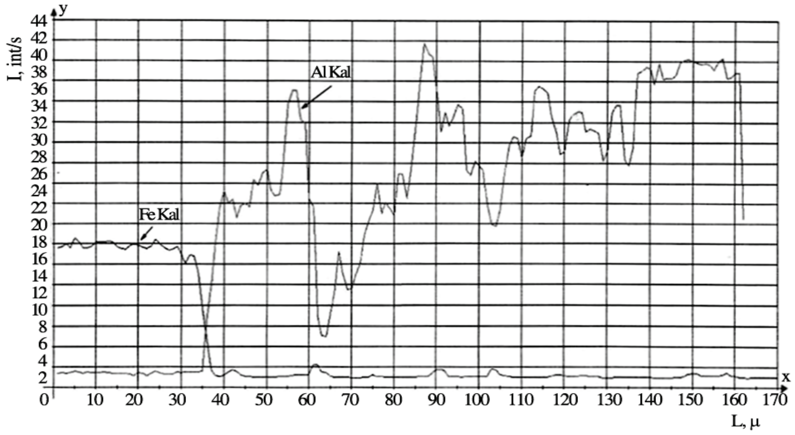

Fig. 4. Scheme of concentration curves.

their contact of intermetallic compounds, which by their nature are quite fragile structures and, under increased dynamic loads, represent the center of vibration of the composite material [4-12].

A metallographic and structural study of the transition zone was carried out in order to study the distribution of elements on the surface of the composite material and at the iron-aluminum interface. The purpose of the study was to study the distribution of these elements on the surface of the composite material and at the iron-aluminum interface. The study of the Fe-Al-composite material was carried out on a French-made Cameca-ms-46 X-ray microanalyzer. The conducted studies have shown that: iron is evenly distributed over the surface of the sample. Concentration curves are obtained using Redgen radiation FeKα_(1) and AlKα_(2).

The diagram shows the intersection point of the curves of iron and aluminum, iron and aluminum are fixed at the intersection (Al ≅ 65%, Fe ≅ 4-10%); as for the border, its width is 3-5 microns. At the point of intersection of the iron (FeK) and aluminum (AlKα_(1) curves, iron and aluminum are fixed, Al ≅ 65%, Fe ≅ 4-10%, which indicates the presence of diffusion at this point.

C.A.P. and the radiation of other elements (Mg, P, S. Co, Mn, Cr, V, T, Ca) is not detected by PET molds. To obtain information about the presence of possible intermetallic compounds, it is preferable to carry out X-ray phase analysis what will be done before the end of the project.

This work was supported by the Shota Rustaveli National Science Foundation of Georgia (SRNSFG), grant number AR-22-1411.

მეტალურგია

უსხმულო გლინვის მეთოდით მიღებული კომპოზიციური ნამზადის გარეთა ფენების ფორმირების პროცესი

**გ. ქევხიშვილი*, თ. ნამიჩეიშვილი*, ჯ.ლორია*, რ. ხარატი*,
გ. პარუნაშვილი*, გ. ბასილაია*, ვ. რამიშვილი*, მ. რუსაძე***

** ფერდინანდ თავაძის მეტალურგიისა და მასალათმცოდნეობის ინსტიტუტი, თბილისი, საქართველო*

(წარმოდგენილია აკადემიის წევრის თ. ნატრიაშვილის მიერ)

ნაშრომში განხილულია უსხმულო გლინვის მეთოდით რკინა – ალუმინისა და ტიტან-ალუმინის ბაზაზე კომპოზიციური (ფენოვანი) ფილების წარმოებისას ნამზადის ფორმირების პროცესი გლინკრისტალიზატორებში. თხიერ-ფაზური მეთოდით (რომელსაც განეკუთვნება უსხმულო გლინვის პროცესი) კომპოზიციური მასალების წარმოებისას ჩამოსხმის ტექნოლოგიურ პარამეტრებს განსაზღვრავს გარეთა ფენების სისქე და გამყარების პირობები. ერთი შეხედვით, უსხმულო გლინვის მეთოდით გარკვეული სისქის ალუმინის შენადნობის ფურცლის ჩამოსხმის პარამეტრები არაფრით უნდა განსხვავდებოდეს გარეთა ფენის სისქის მქონე კომპოზიციური მასალის ჩამოსხმის პარამეტრებისაგან, ვინაიდან ორივე შემთხვევაში ნამზადის ფორმირება გლინკრისტალიზატორებში წარმოებს საცდელ საჩამოსხმო-საგლინავ დანადგარზე. ჩატარებულმა ექსპერიმენტულმა კვლევებმა ცხადყო, რომ განსხვავება არსებობს და ფენოვანი მასალების წარმოებისას არასიმეტრიული გაციების პირობებით არის გამოწვეული. ნაშრომში დეტალურად არის განხილული კომპოზიციური ნამზადის ფორმირების პროცესში კრისტალიზაციის ფრონტის გადაადგილება როგორც გლინკრისტალიზატორების, ასევე შუა ფენად გამოყენებული ფოლადის ფურცლის მხრიდან. თეორიული გათვლებით ირკვევა, რომ კრისტალიზაციის ფრონტის გადაადგილება 65-70 % უფრო ჩქარა მიმდინარეობს გლინკრისტალიზატორების მხრიდან ვიდრე შუა ფენად გამოყენებული ფოლადის ფურცლის მხრიდან. ასევე კომპოზიტის გარეთა ფენის მთლიანი გამყარების დრო გაიზრდება 20-25% უსხმულო გლინვის მეთოდით იმავე სისქის ალუმინის შენადნის ფურცლის მთლიანი გამყარების დროს. ამ ფაქტმა გარკვეული კორექტივები შეიტანა ჩამოსხმის ყველა ძირითად პარამეტრში, კერძოდ, შეცვალა: კრისტალიზაციის პროცესის დაწყებამდე შევსების დრო; ჩამოსხმის სიჩქარე; α და γ კუთხის მნიშვნელობები; გლინკრისტალიზატორებზე წარმოქმნილი ძალები.

REFERENCES

1. Kevkhishvili G., Namicheishvili T., Zhordania I.,† Tavadze G.,† Loria J., Ramishvili V. (2018) Perspectives of non- ingot-rolling in production of composite armor materials. *Bull. Georg. Natl. Acad. Sci.,* **12,** 3: 76-84 .
2. Ramishvili Sh., Kevkhishvili G., Brovman M. (1979) Teoreticheski raschet osnovnyx parametrov kristalizacii pri ispol’zovanii vnutrennykh xolodil’nikov, sb. statiei „Processy litia i nepreryvnaia razlivka metallov“, 96-103. Tbilisi.
3. Brovman M.A., Rimen Sh., Ramishvili Sh. (1976) Analiz izmenenia temperaturi slitkov MNLZ pod kristallizatorom, 36-40. Izd.-vo „Metsniereba“, Tbilisi.
4. Brovman M.A. (2007) Neprerivnaia razlivka metallov. 24-28, Izd.-vo „Ekomet“ (in Russian).
5. Kovtunov A.I., Miamin C.V., Chermashentseva T.V. (2011) Vlianie medi na formirovanie sloistikh kompozitsionnykh materialov stal’-aliuminii. *Voprosy Materialovedenia,* 2(66): 30-36 (in Russian).
6. Kovtunov A.I., Miamin C.V., Chermashentseva T.V. (2010) Isledovanie vliania kremnia na svoistva SKM stal’-aliuminii. 12: 35-40 (in Russian).
7. Zatulovski S.S., Kezik V.IA., Ivanova P.K. (1990) Litie kompozitsionnye materialy, 240. Kiyev: Tekhnika.
8. Gavrilin I.V. (1996) CAM-protsess-metod kompozitsionnogo litia. *Liteinnoe proizvodstva,* 2: 120-121 (in Russian).
9. Shumikhin V.S., Biletski A.K., Shcheretski A.A. (1992) Kompozitsionnye splavy na osnove aliuminia. *Liteinnoe proizvodstva,* 9: 13-14 (in Russian).
10. Brovman M.A. (2004) Eksperimental’noe issledovanie protsessa prokatki s “miagkim” obzhatiem. *Proizvodctvo prokata,* 5: 3-10 (in Russian).
11. Minaev A.A. (2008) Sovmeshennye metalurgicheskikh protsessov. 549 Donetsk. UNITYEKHIK. Ukraine.
12. Riabov V.P. (1983) Svarka aliuminia i ego splavov s drugimi metallami. 264-Kiyev: Naukova Dumka.

Received April, 2024