საქართველოს მეცნიერებათა ეროვნული აკადემიის მოამბე, ტ. 14, №4, 2020
BULLETIN OF THE GEORGIAN NATIONAL ACADEMY OF SCIENCES, vol. 14, no. 4, 2020

Metallurgy

Investigation of the Fluidity of the Synthesized Charge in the Deformation Site on SHS-Electrical Rolling

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The paper describes *TiB_{06}* and *TiC/CrC=5:1+X18H15* chasms for obtaining metal ceramic protective and corrosion resistant plates by new innovative SHS-electric rolling cinematic process by rolling in caliber and smooth carcass of rolls, designed and developed in F. Tavadze Metallurgy and Materials Science Institute. Proceeding from the constancy of the mass, the velocities of the work piece motion for the conditionally divided segments of deformation zone and the relative increase of the work piece velocity to the velocity of rolls are calculated. It indicates that the main part of the deformation zone is the lagging zone and a small part of the deformation zone near the cross section just before the rolls represents the advancing zone. Based on multiple experiments, an empirical formula for computing the density of the synthesized chasm, from input the cross section and leaving the deformation zone of the cross-section and the density change curve are proposed. © *2020 Bull. Georg. Natl. Acad. Sci.*

Metal-ceramic tiles, SHS-electrical rolling, deformation zone, synthesis, hardness, fluidity

One of the most promising and prominent methods of making metal-ceramic and ceramic tiles is a process of SHS (Self-Propagated High-Temperature Synthesis) – electrical rolling is worked up in F. Tavadze Institute of Metallurgy and Materials Science [1].

When receiving metal ceramic tiles from a pre-selected charge, in a number of cases the central zone of the cross-section area is characterized by a decomposition of the layers, probably due to the deformation lessening from the surface of the billet to the central zone and high temperature gradient between the center and peripheral zones (increased intensity from the surface compared to central zones due to heat loss). To prevent this it is necessary to delay the isothermal process under pressure of the billet, synthesized charge coming out of the deformation site, until its complete solidification. This process can be accomplished by a multi-pair roller system located along the horizontal axis, the first pair of which is a biting and steering pair. Steering rollers with star (chain) transmission are connected to the charge so that its

circular speed slightly exceeds (up to 5%) the speed of the billet resulted from the rollers.

For the purpose of slow cooling of the rolled product the mentioned node is placed in a heat-insulated environment.

Thus, the kinematic process in steering rollers and working rollers can be thought of as analogous to a continuous rolling mill. In order to synchronize the speeds of steering rollers and working rollers, it is necessary to determine the velocity of movement of the billet at the exit point of the deformation site, taking into account lagging and advancing zones in the deformation site.

In the process of combining HSH with electric rolling it is necessary to match the speed of movement of the combustion front to the speed of delivery to the rolls (briquetted charge placed in the container) [1]. The container dimensions at the entry cross-section of the deformation site are H_0B_0; and at the exit cross-section of the deformation site – H_1B_1, speed of delivery of the container $\upsilon_0 = \upsilon_{rolling}\cos\alpha$. At the exit cross-section of the deformation site, the velocity of the billet was calculated for the smooth barrel and for the case of rolling in the groove (increased elongation due to limited extension in the groove). Because the resistance to deformation of the container is greater than that of the hot, viscous, plastic synthesized charge, it is practically impossible to elongate the tin container (only the transverse shape of the container is changing without changing the perimeter) by rolling of the synthesized charge over the smooth barrel. Therefore, the viscous, plastic synthesized charge is predominantly flowing in the transverse direction, and this movement is artificially restricted when rolling is carried out in the groove.

The billet prepared by the SHS process is a porous material, which, after further hot-pressing (rolling), receives the intended thickness of the product. In the deformation site, the formed grains of the synthesized charge approach each other and at the exit cross section, hardening material is obtained, the porous empties are significantly reduced and the relative porosity decreases to 2-5% at certain stretches. As a result of stretching at the cross-section of the billet, there is a predominance of compression, with the grains moving in a vertical direction. Achieving some traction, the charge begins to flow in a longitudinal direction. Thus, the process of SHS-electric rolling involves intergranular and interparticle shearing deformation. The increase in the material density along the deformation site depends on the compaction of the charge [2].

In the study of the velocity of movement of the charge in the deformation site, according to the law of mass constancy:

$$\rho_0 \mathrm{H}_0 \upsilon_0 = \rho_1 \mathrm{H}_1 \upsilon_1, \qquad (1)$$

where: H_0B_0 and H_1B_1 are height and width of the charge and the rolled product, ρ_0 and ρ_1– specific density; υ_0 and υ_1 – the displacement velocities of the charge and material at the points of entry and exit sections of the deformation site.

Velocity of the rolled product in the exit section from the rolls:

$$\upsilon_1 = \pi Dn\left(1-\frac{\Delta h}{D}\right)KH_0B_0 / 60H_1B_1, \qquad (2)$$

where: $\upsilon_0 = \pi Dn\left(1-\frac{\Delta h}{D}\right)KH_0B_0 / 60$; D – diameter of the rolls; n – number of rotations of the rolls; Δh – shrinkage; $K = \rho_0 / \rho_1$ – coefficient of solidification.

(2) expression determines the velocity of the rolled product in the exit cross-section of the deformation site. The value of the density of the synthesized charge and its variation along the deformation site is determined experimentally by the weight-volume method. In general, an empirical expression of the density change curve is obtained on the basis of experimental data on rolling of the porous material in the deformation site:

$$\rho_x = \rho_0 + (\rho_1 - \rho_0)(l_x / l)^{0.5}, \qquad (3)$$

or

$$\rho_x = \rho_0 + (\rho_1 - \rho_0)(\varepsilon_x / \varepsilon)^{0.5}, \qquad (3.1)$$

where: l_x – the length of the deformation site from the initial section to the search section, mm; ε_x and ε – relative deformations matching l_x and l arcs in the deformation site, %.

Experiments were conducted on a SHS-electric rolling mill developed and manufactured at F.Tavadze Institute of Metallurgy and Materials Science. The equipment is a special rolling mill, equipped with an electrical contact heating system with a 100 kwt power transformer and a thyristor control system, providing smooth regulation of the heating current in the range of $0 \div 25kA$.

The data of the SHS-electrical rolling parameters of the selected charges for TiB_{06} $TiC/CrC = 5:1 + X18H15$ protective gradient and corrosion-resistant metal ceramic tiles are given in Table 1.

As it is seen from Table 1 in the entry section of the deformation site the velocity of the charge (container) is less than the velocity of the rolls (8.8%; 9.7%; 8.8%; 8.1%), the difference in the relative incremental gains of the velocities on rolling on a smooth barrel and a groove is varying slightly from each other (0.9%; 0.7%), which is only caused by different diameters of the roller, but in the exit section of the deformation site – is lagging on rolling on a smooth barrel (3.7%; 5.4%), on rolling in a groove – is advancing (8.1%; 5.6%), the difference in velocity gains is noticeable (11.8%; 11.0%), because on rolling in a groove, at the expense of limiting expansion, the compaction speeds up and the stretching increases. Experimentally the movement velocities of the billet at the entry and exit sections of the deformation site were measured. The error between theoretical calculations and experimental measurements is 4-7%, due to the presence of gliding between the container and the rolls.

Table 1. SHS-electrical rolling parameters of TiB_{06} and $TiC/CrC = 5:1 + X18H15$ charges

Parameters	TiB_{06}		$TiC/CrC = 5:1 + X18H15$	
Rolling	On a smooth barrel	In a groove	On a smooth barrel	In a groove
Roll diameter D_r, mm	150	144	150	144
Roll Rotation number n_r rotation/minute	2.24	2.34	2.45	2.57
Container height H_0, mm	24	24	24	24
Container width B_0, mm	71	71	71	71
Shrinkage Δh, mm	14	14	14	14
Rolled product height H_1, mm	10	10	10	10
Rolled product width B_1, mm	85	74	85	74
Density before rolling ρ_0, g/cm^3	2.59	2.59	2.80	2.80
Density after rolling ρ_1, g/cm^3	4.9	4.95	5.40	5.50
Container velocity on entering the deformation site υ_0, mm/sec	16	16	17.5	17.5
Circular velocity of the roll υ_r, mm/sec	17.54	17.71	19.18	19.37
Rolled product velocity on exit from the def. zone υ_1, mm/sec	16.97	19.27	18.21	20.51
Relative incremental gain of velocities of the container and rolls on entering the deformation site $\Delta\upsilon_0$, %	-8.8	-9.7	-8.8	-8.1
Relative incremental gain of velocities of the rolled product and the rolls on exit from the deformation site $\Delta\upsilon_1$, %	-3.7	+8.1	-5.4	+5.6

Table 2. SHS – electrical rolling parameters of TiB_{06} charge by deformation intersections

Deformation site intersection	I	II	III	IV	V
Charge container height H_1, mm	24	24	24	24	24
Charge container width B_0, mm	71	71	71	71	71
Absolute value of shrinkage Δh, mm	3	6	9	12	14
Relative deformation ε,%	12.5	25	37.5	50	58.3
Rolled product height H_1, mm	21	18	15	12	10
Rolled product width B_1, mm	74	74	74	74	74
Synthesized charge density ρ_1, g/cm^3	2.59	3.35	3,96	4,40	4,80
Rolled product density ρ_1, g/cm^3	3,35	3,96	4.40	4.80`	4.95
Relative porosity π, %	34.4	22.4	13.8	5.9	3
Container velocity on entering the deformation site υ_0, mm/sec	16	13.37	13.2	14.25	16.34
Horizontal component of the circular velocity of the roll (υ_r=17.71 mm/sec), υ_x mm/sec	16.34	16.70	17.07	17.45	17.71
Velocity of the rolled product on exiting from the deformation sit υ_1, mm/sec	13.37	13.2	14.25	16.34	19.01
Relative incremental gain of velocities of the container and rolls on entering the deformation site $\Delta\upsilon_0$, %	-9.6	-24.5	-25.5	-19.5	-7.7
Relative incremental gain of velocities of the container and rolls on exiting from the deformation site $\Delta\upsilon_1$, %	-24.5	-25.5	-19.5	-7.7	+ 6.8

It is interesting to study the variation of the billet velocity along the deformation site, from the entry section to the exit section. In the process of SHS-electric rolling along the deformation site, the change in the density of the synthesized charge depends on the compaction nature of the material. To study this effect, experiments were carried out - rolling with different stretches of the briquetted charge placed in the container of the same thickness (ΔH 3 mm, 6 mm, 9 mm, 12 mm, 14 mm). The length of the deformation site is conventionally divided into areas. The initial and final intersections of each area were considered as the entry and exit sections of the billet in the deformation site.

The values of the initial and final densities of each area were determined experimentally and calculated by (3) and (3.1) (Fig.1).

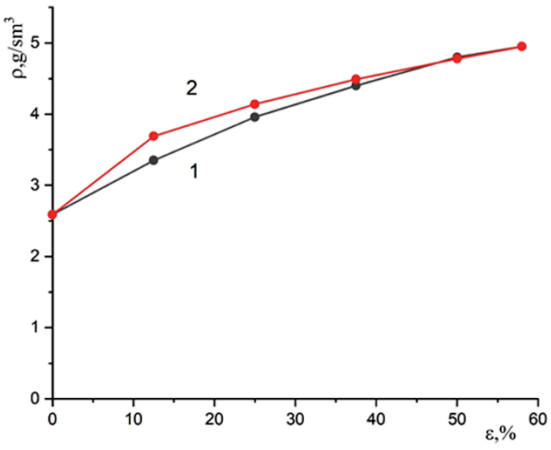

Fig. 1. Density change when relative deformation is changing: 1 – experimal data, 2 – calculated by (3.1) expression.

As can be seen from Fig. 1, in addition to the initial and final intersections of the deformation site, there is a slight difference between the calculated values of the experimental and empirical

expression along the total deformation site. The mean relative error of density change in relative deformation change is 4.4%. From the above, we can conclude that the curves obtained by expression (3.1) are more or less close to the experimental density change curve. Therefore, the empirical expressions (3.1) may be used for SHS-electrical rolling of the metal-ceramic material.

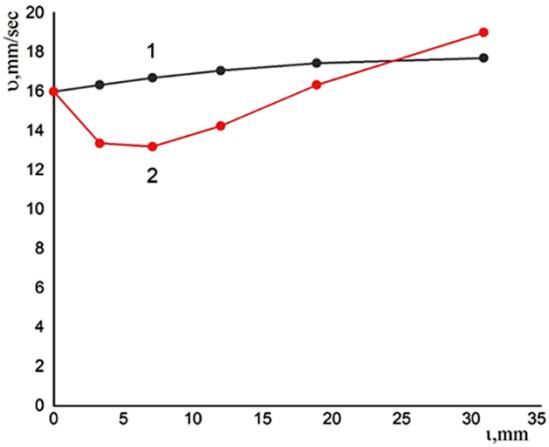

Fig. 2. The change of the horizontal component of the circular velocity of the roll (1) and the change of the velocity of the billet (2) along the deformation site.

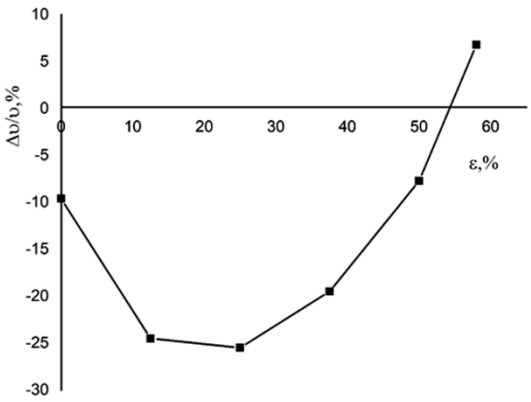

Fig. 3. Change in comparative growth of velocity of the roll and the billet in the areas of the deformation site in the entry and exit intersections, when relative deformation changes.

By theoretical calculations, in the case of rolling of a TiB_{06} charge in a box groove, the relative porosity of the initial synthesized charge is 50%, depending on the relative porosity and relative deformation of the rolled material, the velocity data at each area of the entry and exit of the deformation site are given in Table 2 and Fig. 2.

As shown in Fig. 3. on entering the deformation site the relative growth of the container velocity compared to the velocity of the rolls increases when the deformation increases (with decreasing porosity). This is due to the fact that as the shrinkage increases, the intensity of compaction decreases. The synthesized charge flows in a predominantly transverse direction, although the horizontal component of the circular velocity vector increases, but no sharp increase in friction forces is observed, which in turn ensures longitudinal displacement of the billet. From ε=25% to a certain degree of deformation (54-55%), the drop-in velocity of the billet to the velocity of the roll decreases. At this time, intensive compaction is taking place, that is, the synthesized TiB_{06} grains move predominantly in the vertical direction and the elongation is minimal. As the deformation increases ($\varepsilon = 54–55\%$), the elongation of TiB_{06} grains and titanium phase increases and the porosity decreases, thus, it can be concluded that in SHS-electrical rolling regime shown in Table 2 rolling should be conducted $\varepsilon > 54\%$ in the condition of relative shrinkage. The optimal mode is $\varepsilon = 54 - 58\%$, where the relative porosity is reduced to $2 - 3\%$. Further deformation causes worsening of the efficiency of the rolling mill (dramatically increases the power parameters), seizure conditions and hence the stability of rolling. Thus, in the process of electrical rolling of the TiB_{06} synthesized charge, as described above, to achieve optimum compacting (hence minimizing porosity), relative deformations should be selected in the range of $\varepsilon = 53 - 55\%$.

მეტალურგია

თმს-ელექტროგლინვისას დეფორმაციის კერაში სინთეზირებული კაზმის დენადობის კვლევა

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ნაშრომში განხილულია ლითონკერამიკული დამცავი და კოროზიამედეგი ფილების მისაღებად შერჩეული კაზმების TiB_{06} და $TiC/CrC=5:1+X18H15$, ფ. თავაძის მეტალურგიისა და მასალათმცოდნეობის ინსტიტუტში დამუშავებული და შექმნილი ახალი, ინოვაციური თმს ელექტროგლინვის კინემატიკური პროცესი გლინების გლუვ კასრსა და კალიბრში გლინვისას. მასების მუდმივობის პირობიდან გამომდინარე, გამოყვანილია დეფორმაციის კერის პირობითად დაყოფილი უბნებისათვის ნამზადის გადაადგილების სიჩქარეები და გლინების სიჩქარეებთან მათი ფარდობითი ნაზრდი, რომლის თანახმადაც დეფორმაციის კერის მნიშვნელოვანი ნაწილი წარმოადგენს ჩამორჩენის ზონას, ხოლო ნამზადის დეფორმაციის კერიდან გამოსვლის კვეთის სიახლოვეს მთლიანი დეფორმაციის კერის მცირე ნაწილზე – წინსწრების ზონას. მრავალჯერადი ექსპერიმენტების საფუძველზე შემოთავაზებულია სინთეზირებული კაზმის სიმკვრივის გამოსათვლელი ემპირიული ფორმულა, დეფორმაციის კერაში ნამზადის შესვლის კვეთიდან გამოსვლის კვეთამდე და სიმკვრივის ცვლილების მრუდი.

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Received June, 2020