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Metallurgy

Investigation of Speed Regimes in SHS-Electric Rolling Based on the Ti-B System

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(Presented by Academy Member Tamaz Natriashvili)

To obtain metal-ceramic plates of uniform longitudinal dimensions with SHS-electric rolling, it is necessary to comply with the conditions for the coincidence of the values of the velocities of the synthesis front and the container with the synthesized charge, i.e. finding the cross section of the synthesis front at a constant distance from the deformation zone. The parameters that violate these conditions are shown - the change in charge density and relative deformation. It is shown that the difference between the virtually delivered and compacted masses (excess mass) shifts towards the less stable, more porous back of the workpiece. As a result, the length of the synthesized product from the inlet section of the deformation zone increases, which violates the condition of constancy of the distance between the combustion front and the deformation zone. Therefore, it is necessary to increase the billet speed to such a value that the synthesized mass is continuously fed to the deformation zone in a homogeneous viscoplastic state. In this paper, the method for determining the change in speeds and the dependence of the increase in the speed of movement of the container during the electric rolling of TiB_{06} plates on the change in charge density and relative deformation are presented. *© 2023 Bull. Georg. Natl. Acad. Sci.*

metal-ceramic plates, SHS-electro rolling, charge and material density, relative deformation, synthesis and rolling speed

It is known that one of the main ways to obtain metal-ceramic and ceramic tiles of unlimited length by the method of SHS-force compaction is a combined process of SHS and electric rolling [1]. In this method, the initiation, synthesis, and production of non-porous products is carried out on a SHS-electric rolling unit. When a high-density current is passed through the sample in the deformation zone, the process of synthesis and compensation of heat losses is initiated, which ensures an isothermal process and rolling at large deformations by limiting the free broadening in the roll caliber. In this case, it is necessary to synchronize the speed of the combustion front with the speed of rolling in the process, so that any end section of the billet enters the deformation zone in a heated viscoplastic state [2-6]. Experiments have shown us that during SHS-electric rolling, the back

part of the product (about 10% of the total length) breaks or detaches from the main part. This is explained by the fact that the "negative" flow in the deformation zone changes the temperature and technological regime of the electric rolling of the product with a change in the density of the rolled mass. In the deformation zone, the difference between the virtually delivered and compacted masses (excess mass) moves to the rear regions of lower density (less resistance), the so-called "negative" drawing, which causes the outflow of a viscous hot mass from the deformation zone into the synthesis zone and increases the length of the synthesized material. The length from the combustion section to the section of the entrance to the deformation zone increases, and, accordingly, the time of advancement of this section to the deformation zone increases, i.e. the deformation of the synthesized material is delayed. This effect is maximum at the end of the rolling process. The rear section of the product no longer receives additional thermal energy, it begins to cool down intensively, and in the capture section, the cooled mass below the phase formation temperature is fed to the rolls. The material becomes non-deformable, brittle, and subsequent deformation causes the appearance of cracks in it and even breakage of products [7-9].

Considering the above-mentioned, the main reason for the breakage of the last section of the workpiece is a violation of the synchronization of the rolling speed and the speed of the combustion front, in particular, the lag in the rolling speed.

Thus, in order to maintain the temperature balance in the process of electric rolling of the synthesized mass, it is necessary to control the rolling speed taking into account technological parameters (geometric, speed and power).

In SHS electric rolling, a necessary condition for obtaining a material with a homogeneous structure is an equal distance from the combustion front section to the deformation center while maintaining a certain ratio of the speeds of the SHS and the container with the charge throughout the entire process, which ensures the constant delivery of the synthesized mass in a viscoplastic state to the deformation zone (Fig.).

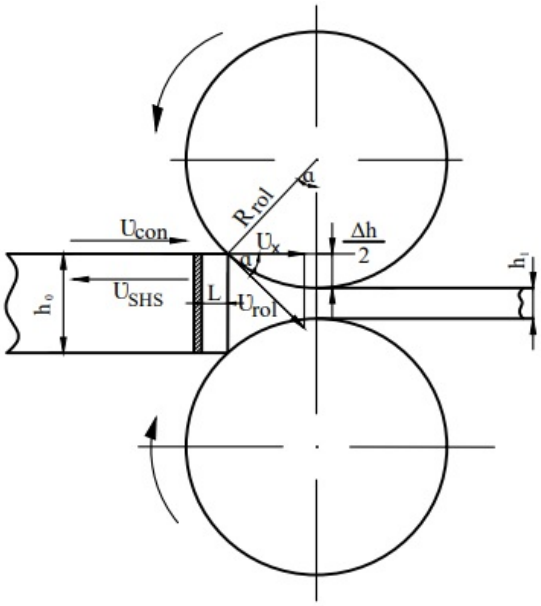

Fig. Diagram of SHS-electric rolling.

Based on the scheme of SHS-electric rolling (Fig.), taking into account the law of mass constancy during rolling of porous materials and mathematical transformations, an image is obtained, with the help of which the speed of movement of the container with the charge is determined:

$$v_{con} = 0{,}95\rho_0 v_{shs} / \rho_{mat}\left(1-\varepsilon\right), \qquad (1)$$

where: ρ_0, ρ_{mat} are charge and material densities; g/sm^3, ε – relative strain, %; v^{shs} – synthesis rate, mm/s; 0.95 is a coefficient that takes into account the expansion of the product in the roll caliber.

The density of the material depends on the degree of deformation. At various relative deformations, the density of the material can be expressed empirically [2]:

$$\rho_x = \rho_0 + \left(\rho_{mat} - \rho_0\right)\left(\varepsilon_x / \varepsilon_{\max}\right)^{0,5}, \qquad (2)$$

where: ρ_x is the density of the material at the value of the degree of deformation ε_x; ρ_{mat} is the density

of the non-porous material at the maximum degree of deformation εmax (in our case, when rolling TiB_{06} $\rho_{mat} = 5.07$ g/cm^3, and $\varepsilon_{\max} = 65\%$).

To control the process of SHS-electric rolling, it is expedient to express the speed of the container corresponding to the speed of synthesis by the technological setting parameter of the mill, namely, the number of revolutions of the rolls.

From Fig.:

$$v_{con} = \pi D_{rol} n_{rol} \cos\alpha / 60 \qquad (3)$$

$$n_{rol} = 30 v_{con} / \pi \left(R_{rol} - \Delta h / 2 \right), \qquad (4)$$

where: n_{rol} is the number of revolutions of the rolls, rpm; D_{rol}, R_{rol} – clay diameter and radius, mm; Δh – absolute reduction, mm; α – capture angle, deg.

Taking into account (1) and (4), we obtain

$$n_{rol} = 9,08 p_0 v_{shs} / \rho_{mat} \left(1 - \varepsilon\right)\left(R - \Delta h / 2\right). \qquad (5)$$

Thus, depending on the condition of speed synchronization, one should choose the number of revolutions of the rolls according to the image (5).

The experimental part is presented with specific examples. Amorphous brown boron powder with a dispersion of not more than 5 μm and titanium powder with a dispersion of 45 μm, in a ratio of Ti – 75%, B – 25% (stoichiometric composition) are mechanically mixed for 8-10 hours. Then, the resulting mixture is subjected to cold briquetting in a mold with a section of 70 x 70 mm by pressing P = 200 kH (average specific pressure p= 408 kg/cm^2) to a density $\rho_0 = 2.0$ g/cm^3 (specific density 38.5%). The briquettes are placed in a container 24x210x350 mm^3 in size, and then a high-density current (I~0.7A/mm^2, U~12V) is applied to the sample through the rolls in the deformation zone under its influence. The synthesis process is initiated and heat losses are compensated throughout the process. SHS-electric rolling takes place in a box caliber of rolls, 220 mm wide, with four different relative deformations of 50-55-60-65% for individual samples. In addition, the speed of the synthesis front in a given Ti-B briquette is $v_{\sin} = 20$ mm/s. Rolling is obtained: ε=50-55-60-65% at strain values – ρ_{mat}=4.69-4.82-4.95-5.07 g/cm^3 (corresponding porosity ~9.8-7.3-4.8-2.5%) density, rolled TiB_{06} dimensions: 1 – 12x220x350 mm^3; 2 – 10.8x220x350 mm^3; 3 – 9.6x220x350 mm^3; 4 – 8.4x220x374.5 mm^3. For cases 1-2-3, there was no increase in length, and for case 4 it is 24.5 mm. Thus, for the first three cases, with a low density of the briquette (ρ_0=2.0 g/cm^3), the values of the degree of deformation of 50-55-60% cannot provide a high-density non-porous material. For the 4th case (ε=65%), with an increase in length (+24.5 mm), the porosity is minimal (П=2.5%). For the first three cases, the speed of the container movement corresponds to the speed of synthesis and is equal to $v_{con} = 20$ mm/s, and in the fourth case $v_{con} = 21.4$ mm/s (the number of revolutions of the rolls corresponding to this speed $n_{rol} = 1.67$ rev/min).

In the second case, the powder of the same composition in the same mold is briquetted by pressing P = 10000 kH (average specific pressure p = 2041 kg/cm^2) to a density of ρ_0=2.6 g/cm^3 (rel. density 50%). The briquettes are placed in a 24x210x350 mm^3 container. SHS-electric rolling takes place in a 220 mm wide caliper with four different relative strain ratios of 50-55-60-65% for individual samples. In addition, the speed of the self-propagating high-temperature synthesis front in a given Ti-B briquette is $v_{shs} = 16$ mm/s. Rolling yields: ε=50-55-60-65% at reduction values – ρ_1=4.77-4.87-4.97-5.07 g/cm^3 (corresponding porosity 8.3-6.4-4, 6-2.5%) density of rolled TiB_{06} plates with dimensions: 1 – 12x220x363 mm^3; 2 – 10.8x220x394 mm^3; 3 – 9.6x220x435 mm^3; 4 – 8.4x220x488 mm^3. Accordingly, the increase in length is 13-44-85-138 mm. Thus, for all four cases, with a high density of the briquette (ρ_0=2.6 g/cm^3) and values of the degree of deformation ε = 50–55–60–65%, the length of the rolled material increases, which requires a change in the speed of the container. The increase in the speed of the container with the speed of synthesis

Table. Change in the speed of movement of the container depending on the charge density and the degree of deformation during SHS-electric rolling of the TiB_{06} material

ρ_0, g/см^3	ε,%	ρ_{mat}, g/см^3	υ con , mm/s (υ_{shs}=16mm/s)	Δυ, mm/s	υ con, mm/s (υ_{shs}=18 mm/s)	Δυ, mm/s	υ_{con}, mm/s (υ_{shs}=20 mm/s)	Δυ, mm/s
2.0	50	4.69	13.0	-3.0	14.6	-3.6	16.3	-3.7
2.0	55	4.82	14.0	-2.0	15.8	-2.2	17.5	-2.5
2.0	60	4.95	15.4	-0.6	17.3	-0.7	19.3	-0.7
2.0	65	5.07	17.1	1.1	19.2	1.2	21.4	1.4
2.2	50	4.72	14.2	-1.8	16.0	-2.0	17.8	-2.2
2.2	55	4.84	15.4	-0.6	17.3	-0.7	19.3	-0.7
2.2	60	4.96	16.9	0.9	19.0	1.0	21.1	1.1
2.2	65	5.07	18.8	2.8	21.2	3.2	23.5	3.5
2.4	50	4.74	15.4	-0.6	17.3	-0.7	19.3	-0.7
2.4	55	4.86	16.7	0.7	18.8	0.2	20.9	0.9
2.4	60	4.97	18.4	2.4	20.7	2.7	23.0	3.0
2.4	65	5.07	20.6	4.6	23.2	5.2	25.8	5.8
2.6	50	4.77	16.6	0.4	18.7	0.7	20.8	0.8
2.6	55	4.87	18.0	2.0	20.3	2.3	22.5	2.5
2.6	60	4.97	19.9	3.9	22.4	4.4	24.9	4.9
2.6	65	5.07	22.3	6.3	25.1	7.1	27.9	7.9

was v_{con} = 0.6-2.0-3.9-6.3 mm/s. The results are shown in Table. Based on the data given in the examples, the container movement speeds were experimentally and theoretically determined at various values of the increased density of the charge, relative deformation and synthesis, the values of which are given in Table. Whence it can be seen that with a relative deformation of 50-60% and the initial density of the material $\rho_0 = 2.0/\text{cm}^3$; ε=50-55% - $\rho_0 = 2.2\,\text{g/cm}^3$ and ε=50% $\rho_0 = 2.4\,\text{g/cm}^3$ the container displacement rate coincides with the synthesis rate. This is explained by the fact that in the deformation zone the supplied mass is virtually smaller than the mass to be compacted. There is not enough mass, therefore the actual density of rolled products is lower than the density indicated in Table, and the material is highly porous (П=5-10%). Therefore, it is not recommended to use such modes. The higher the relative deformation (60-65%) and the higher the initial density of the material (2.4-2.6 g/cm^3), the lower the porosity, the higher the density of the rolled material and, accordingly, the higher the difference in the speed of the container and synthesis (in our case, when rolling TiB_{06} ρ_{mat} = 5.07 g/cm^3, П =2-2.5%, ε=65%, Δυ=6.3-7.9 mm/s). In the case when the lengths of the product and material are equal, the speeds of movement of the container and synthesis are the same.

მეტალურგია

Ti-B სისტემის ფუძეზე თმს-ელექტროგლინვის ჩქაროსნული რეჟიმების კვლევა

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ნაშრომში განხილულია სინთეზის ფრონტისა და კაზმიანი კონტეინერის გადაადგილების სიჩქარეთა მნიშვნელობების თანხვედრის, ანუ სინთეზის ფრონტის კვეთის, დეფორმაციის კერიდან წინასწარ დადგენილი მანძილით დაშორების პირობები თმს-ელექტროგლინვით გრძივი გაბარიტების ერთგვაროვანი სტრუქტურის ლითონკერამიკული ფილების მისაღებად და ნაჩვენებია ამ პირობების დამრღვევი პარამეტრები – კაზმის სიმკვრივისა და ფარდობითი დეფორმაციის ცვლილება. ნაჩვენებია, რომ წარმოსახვით მიწოდებულ და კომპაქტირებულ მასათა სხვაობა (ჭარბი მასა) გადაადგილდება ნაკლები წინააღმდეგობის, მეტად ფორიანი უკანა უბნებისაკენ. შედეგად იზრდება სინთეზირებული ნამზადის სიგრძე დეფორმაციის კერის შესვლის კვეთიდან, რაც არღვევს წვის ფრონტის დეფორმაციის კერამდე მანძილის მუდმივობის პირობას. ამიტომ საჭიროა ნამზადის სიჩქარის ისეთ მნიშვნელობამდე გაზრდა, რომ გაზრდილი ნამზადის სინთეზირებული მასა დეფორმაციის კერას მუდმივად მიეწოდოს ერთგვაროვან ბლანტ პლასტიკურ მდგომარეობაში. ნაშრომში მოყვანილია გლინვის სიჩქარის განსაზღვრის მეთოდიკა და TiB_{06} სინთეზირებული კაზმის ელექტროგლინვისას კონტეინერის გადაადგილების სიჩქარის ნაზრდი კაზმის სიმკვრივისა და ფარდობითი დეფორმაციის ცვლილებისას.

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