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Metallurgy

Compacting Reactive Blends Based on Ta-Al-B(B_4C) by SHS-Electrorolling

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Abstract. The paper discusses the possibility of obtaining intermetallic compounds with a density close to the theoretical and high mechanical properties from Ta-Al-B(B_4C) powder reaction mixtures by combining the processes of self-propagating high-temperature synthesis (SHS) with electric rolling. The necessary parameters for the implementation of these technological modes (kinematic, force, time and geometric) are also considered. It is shown that the supply of heating current initiates the synthesis process, while in order to deform the product in an isothermal mode, thermal losses are continuously compensated by passing current in the deformation zone. At the same time, maintaining equal speeds of movement of the combustion and rolling fronts ensures a continuous supply of hot viscous plastic mass with a fixed temperature in the deformation zone. The result is a product with the required mechanical properties and dimensions. Metallographic and X-ray structural studies of samples obtained by SHS-electric rolling of a composition determined by preliminary thermodynamic analysis (Ta-19%Al-6%B, Ta-8%Al-10%B and Ta-50%Al-10%B_4C) established that their structure and properties depend on loading conditions and the phase composition of the original powders. The studies have shown that the combined SHS-electric rolling process is very promising for the consolidation-synthesis of TaxAly-TaBx composites. As a result, various Tax Aly intermetallic composite materials with a density close to theoretical, a homogeneous structure and high hardness values were obtained. © *2025 Bull. Georg. Natl. Acad. Sci.*

Keywords: intermetallic composite materials, SHS-electrorolling, charge and material density, relative deformation, synthesis and rolling speed

Introduction

The development of nuclear technologies and equipment requires new approaches and the development of innovative materials characterized by good ability to absorb neutron radiation, greater stability and relatively low cost.

Rolling of refractory and brittle materials, in contrast to plastic ones, is a very complicated problem. Such type alloys, in particular those obtained by the methods of powder metallurgy, fail under the action of static loading due to their low plasticity. However, it is known [1] that pre-heating reduces tendency to cracking even at dynamic loading, since with increasing an initial temperature of some materials such as heavy alloys and cemented carbide alloys, their hardness decreases and plasticity increases.

The application of high temperatures during the rolling of refractory alloys enables not only to prevent cracking in the obtained billets but to obtain bimetal compositions from different pairs too. During the rolling of powder materials with the increasing the temperature the plastic flow of consolidated particles under the static loading increases and at high temperatures due to mutual collision of surfaces the formation of joint boundaries occur. Proceeding from these consideration, pre-heating before rolling is highly recommended for brittle and plastic materials and promising for any other materials, since it changes their physical and mechanical properties.

The innovative technology of SHS-electric rolling is the only one among existing technologies that ensures the continuity of SHS samples and the process of hot deformation (rolling) and obtaining products with the required longitudinal dimensions. The operating principle of this method is as follows: a filled container with a charge is brought to the rolls of a special rolling mill and a small grip is made, ensuring reliable electronic contact between the rolls and the container. Through this contact, an electric current is supplied to the deformation zone, and the Joule heat released in the initial section of the specified deformation zone heats the charge and initiates the synthesis process. The combustion front of the charge moves along the container and at the moment when a certain combustion zone of the charge (an area of planned size) is created in front of the area where the material enters the deformation zone, the rolls are turned on and electric rolling begins.

From the mentioned area, the charge in a hot, viscous-plastic state is continuously supplied to the deformation site. A necessary condition for the implementation of this process is the equality of the speeds of movement of the synthesis and rolling fronts, as well as compensation of heat losses from the contact of the container with the rolls, due to the conduction of a heating current, which ensures the existence of a hot viscous-plastic mass in the deformation zone. The duration of the SHS process is determined by the length of the container loaded with the charge.

The objective of this study was to demonstrate that using of two non-standard powder metallurgy technologies of self-propagating high-temperature synthesis (SHS) and hot electric rolling technology, it's possible to obtain high density sheets based on tantalum and aluminum intermetallic compounds.

Based on the above and taking into account the data from the Ta-Al phase diagram, we can conclude that the selection of the phase composition and the use of various passive alloying elements to regulate the synthesis temperature are important technological parameters in their subsequent static or dynamic consolidation-synthesis processes.

Experimental

The SHS-electric rolling process is an innovative technology and has no analogues, created and developed at the Ferdinand Tavadze Institute of Metallurgy and Materials Science [2-7].

When studying the SHS-electric rolling process, it should be taken into account that the process of obtaining SHS charge such as composition, packaging, i.e. the density of the briquette, the temperature of the isothermal combustion process, and the speed of movement of the combustion front are directly related to the main technological parameters of electric rolling, so a theoretical study of these two completely independent processes was carried out, taking into account the joint implementation of these processes.

It is important to note that the Ta-Al system belongs to a reactive pair and in this composition self-propagating high-temperature synthesis occurs at a high temperature of ~ 2500°C. Depending on the aluminum content, the intensity of exothermic reactions changes and, accordingly, the synthesis temperature also changes

The Figure represents the set-up of rolling processing.

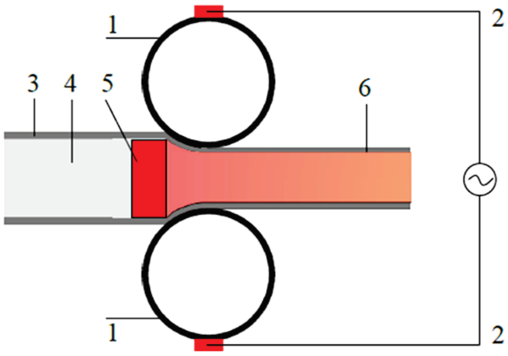

Fig. 1. SHS-electric rolling set-up. 1 – rollers; 2 – electrical contacts of the power supply; 3 – container; 4 – reactive powder blend; 5 – combustion front; 6 – rolled product.

The process of obtaining high-quality products from SHS-electric rolling is influenced by the following parameters:

- Dispersity, drying, activation and degree of mixing of the solution: what determines the volumetric homogeneity of the solution. Dry mixing of powders is carried out in a ball mixer for 24 hours at a speed of 600 rpm.
- Cold briquetting forces: determine the density of the briquette; The relative density of the briquette is selected in the range of 0.5-0.7, the pressing forces of which are 5-20 tons. The thickness of the briquette is selected within the range of 16-18 mm, the weight of one briquette is from 130 to 150 g.
- The location of the briquettes in the container that determines the degree of binding of the briquettes in the product;
- Container dimensions: determine the degree of roll deformation and gripping conditions during electric rolling. For example, to obtain the required material thickness of 6-7 mm and a width of 50-55 mm, to achieve a relative deformation of 60%, the cross-sectional dimensions of the container are 18-20 x 46-48 mm. The dimensions of the briquettes are determined by the dimensions of the mold and are 45 x 45 mm. Briquettes are placed in a container in one row. Each container contains 4 briquettes (total weight – 0.5-0.6 kg). Pre-densification of briquettes to form a sample occurs under the force of 200 tons.

Results

As it was established from view of cross section of hot rolled Ta-19%Al-6%B sample at low magnification (x30), its free from any defects of processing and no visible cracks on the surface of obtained samples not observed.

Rolled samples of composition Ta-24%Al-6%B consist of two phases. Black particles are distributed on a white background. Both phases are predominantly oriented in the rolling direction, although they occur in an unevenly distributed

Table 1. Technological parameters of synthesis and electrical rolling

Content	SHS reaction velocity, mm/sec	Pre-densification force at room temperature, kg	Velocity of roll's turning, rpm	Heating electrical current, A	Compression, %	Everage specific pressure, kg/mm^2
Ta-31%Al	6	1500	0.45	2100	60	6.8
Ta-8%Al-11% B_4C	3	1500	0.225	4300	60	12.1
Ta-8%Al-10% B	10	1500	0.76	2500	60	7.4
Ta-24%Al-6% B	5	1700	0.375	2200	60	11.0
TaB_2- 9%Al	5	7500	0.375	2300	60	10.5

deformed form the white phase – in the form of independent particles.

Rolled samples of the composition Ta-8%Al-10%B are also two-phase. Black particles are unevenly distributed on a white background. In contrast to Ta-24%Al-6%B composition, an insignificant orientation in the rolling direction is observed. The white background is a collection of round particles, although in some places there are also continuous, irregularly shaped, independent inclusions.

The microstructures of hot rolled sample with lower content of boron and higher content of aluminum have not uniform distribution of phases and unreacted inclusions of aluminum phase there observed. The reducing of amount of aluminum and increasing of boron in composition has positive influence on structure formation and after rolling it's became possible to obtain high dense samples with perfect structure and uniform distribution of phases. Unfortunately reduced fully unreacted phases (white spots) can be observed on microstructures too.

The above mentioned is confirmed by X-ray diffraction where the influence of boron content on SHS reaction and phase formation were clearly observed.

As it was established by diffraction pictures of hot rolled Ta-Al-B composites the composition with higher content of boron is more reactive in contrast to composite with higher content of aluminum as it was justified above. The increased number of new picks confirms distribution on microstructures where reduced unreacted phases in the forms of white spots were observed.

The quantitative analysis of different segments of rolled samples that there are not any unreacted phases and mainly 2 regions may be observed. In both cases the formation of tantalum aluminates takes place. The increased amount of C & B in one part may be result of formation additional tantalum carbides and borides that together with formed tantalum aluminate may be considered as a matrix phase of obtained composition.

The Table 2 represents of distribution of hardness in hot rolled Ta-Al-B composites.

Table 2. distribution of hardness in hot rolled Ta-Al-B composites

Characteristic/ composition	Ta-19%Al-6%B	Ta-8%Al-10%B
Al reach area	207 kg/mm^2	875 kg/mm^2
B reach area	250 kg/mm^2	519 kg/mm^2

Ta-Al-B(B_4C) blends were preliminary statically and dynamically densified and by combining of SHS and hot electrorolling processes were fabricated in the form of sheets near to theoretical density with definite structure and high value of hardness. It was established that the initiation of SHS reaction in compositions to fabricate high density sheets depends from content and with increase of B in powder blends provides full chemical reactions and obtaining of samples with increased value of hardness up to 900 kg/mm^2.

Conclusions

The combination of SHS processes and hot rolling electro-rolling processes makes it possible to consolidate and synthesize high dense billets in the form of sheets from Ta-Al-B(B_4C) powder compositions. The structure and hardness of the fabricated samples depends on the phase content of composition and with increase of boron percentage up to 10% gives possibility to obtain samples with fully reacted and uniformly distributed phases resulting in hardness values up to 900 kg/mm^2.

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მეტალურგია

რეაქციული ნარევების კომპაქტირება Ta-Al-B(B_4C) ფუძეზე თმს-ელექტროგლინვის მეთოდით

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ნაშრომში განხილულია თვითგავრცელებადი მაღალტემპერატურული სინთეზისა და ელექტროგლინვის შერწყმული პროცესებით Ta-Al-B(B_4C) ფხვნილოვანი რეაქციული კაზმებიდან თეორიულთან მიახლოებული სიმკვრივის და მაღალი მექანიკური თვისებების ინტერმეტალური ნაკეთობის მიღების შესაძლებლობა და ამ ტექნოლოგიური რეჟიმების რეალიზაციისათვის აუცილებელი პარამეტრები (კინემატიკური, ძალოვანი, დროითი და გეომეტრიული). ნაჩვენებია, რომ მახურებელი დენის მიწოდება იწვევს თმს პროცესის ინიცირებას, ამავე დროს, პროდუქტის იზოთერმულ რეჟიმში დეფორმაციისათვის, სითბოს დანაკარგების უწყვეტი კომპენსაცია დეფორმაციის კერაში დენის გატარებით მიმდინარეობს. ამავდროულად, გლინვისა და წვის ფრონტის გადაადგილების სიჩქარეების თანხვედრის შენარჩუნება უზრუნველყოფს დეფორმაციის ზონაში ფიქსირებული ტემპერატურის მქონე ცხელი ბლანტ პლასტიკური მასის უწყვეტად მიწოდებას. შედეგად, მიიღება საჭირო მექანიკური თვისებების და ზომების პროდუქტი. წინასწარი თერმოდინამიკური ანალიზით განსაზღვრული შემადგენლობის (Ta-19% Al-6%B, Ta-8%Al-10%B და Ta-50%Al-10%B_4C) თმს-ელექტროგლინვით მიღებული ნიმუშების მეტალოგრაფიული და რენტგენო-სტრუქტურული კვლევებით დადგენილია მათი სტრუქტურა და თვისებები, რომლებიც დამოკიდებულია დატვირთვის პირობებსა და საწყისი ფხვნილების ფაზურ შედგენილობაზე. ნაჩვენებია, რომ ალუმინის რაოდენობის შემცირება და ბორის გაზრდა დადებითად მოქმედებს სტრუქტურის ფორმირებაზე. კვლევებმა აჩვენა, რომ თმს-ელექტროგლინვის შერწყმული პროცესი საკმაოდ პერსპექტიულია TaxAly-TaBx კომპოზიტების კონსოლიდაცია-სინთეზისთვის. მოცემულ შემთხვევაში მიღებულია თეორიულთან მიახლოებული სიმკვრივის, ერთგვაროვანი სტრუქტურის და მაღალი სიმკვრივის მნიშვნელობების მქონე სხვადასხვა TaxAly ინტერმეტალური კომპოზიციური მასალები.

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