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Some Methods of Increasing Hot-Pressing Process Efficiency in Production of Diamond Composite Materials

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The work is directed to increase the technological efficiency of hot-pressing process. The paper describes the solution of the problems of hot-pressing technology, which is still relevant today and is related to the profitability of technology. Based on the analysis of the kinetic equations of hot-pressing processes, the authors identified and experimentally confirmed basic parameters that determine efficiency of the process and quality of the obtained product. Experimental data presented in the paper confirm that the use of specially designed thermal and electrical resistance materials in hot pressure schemes allows significantly to improve sintering conditions. Consequently, the isotropy degree of the composite materials properties is improved throughout its volume. At the same time, the use of the developed thermal insulation materials leads to 70-80% reduction of energy capacity.

Hot pressing, diamond composite

Fabrication and application of new materials and composites make it necessary to develop new effective technologies of production. Due to a wide range of properties, composite materials are widely used in various fields of engineering.

The most applied classes of composites include metal-ceramic and diamond composite materials (DCMs). The quality and operational properties of DCMs depend on both the composition of a diamond-metal (the binder) and the technology of its production.

The existing technologies of diamond-containing composite materials production differ from each other by the time and temperature of the sintering process and, by the pressure value.

Among various technological ways of DCM sintering the most popular ones are vacuum sintering, electro discharge sintering and hot-pressing.

The fabricating structured material, isotropic throughout its volume, requires a definite time interval at optimal sintering temperatures. Experimental data and the practice of DCM production with metal and ceramic-metal binders show that the optimal sintering duration at T_{sint} is 5-15 min in the conditions of vacuum or protective environment.

During pressure sintering (hot pressing), T_{sint}, may decrease up to 0.5-2 min depending on P, but no more.

Products fabricated by the method of hot pressing are distinguished by their fine-grain size, which is induced by relatively low sintering temperature and short processing times. The lack of hot pressing technology causes low productivity and, consequently, high energy consumption, limited size and geometrical shape of the product.

Some technical ideas about how to eliminate the above-mentioned difficulties and thereby to improve the technological effectiveness and quality of the hot-pressing process are given in the present paper with the aim of producing DCMs based on metal and ceramic-metal binders. The paper presents the results obtained during hot-pressing of the composition – TiC–Cu–Ti–Ni, which is used as a binder in the DCM. The content of TiC is not less than 50% by weight, content of Ti is 22% by weight; T_{sint} is 890^{0}C and the working pressure P = 400 kg/cm^2.

As is well known, diamond particles are retained in the matrix as a result of mechanical and/or chemical bonding [1]. Mechanical bonding is achieved through cooling that follows the process of hot pressing. Unlike metals, diamonds have a very low coefficient of thermal expansion [2]. Diamond particles are squeezed by the scribing matrix. The mechanical bonding depends on the elastic and plastic properties of the matrix material.

Hot pressing is an effective method to fabricate the segments of diamond tools. Metal-bond powder can be densified at a lower temperature and a shorter cycle of time by hot pressing required by conventional sintering. Several mechanisms were suggested to model the densification during hot pressing [3,4]. An important factor is the density since hardness and even more pronounced impact strength of the binder decrease with the increase of porosity [5].

Among the attempts to quantitatively describe the density changes during hot pressing, we can note the work of Murray, Roger and Williams, who relied on the Mackenzie and Shagtleworth's theory of sintering. They propose an equation describing the densification during hot pressing.

$$dQ/d\tau = \left[dQ/d\tau\right]_{p+s} + 3/4\ P/\tau\ \left(1\text{-}Q\right) \rightarrow$$

$$\rightarrow \ln 1\text{-}Q_0/1\text{-}q \sim \tau\ 0.75P/\eta \qquad (1)$$

$\left[dQ/d\tau\right]_{p+s}$ – is the densification speed in conventional process "pressing + sintering", P – hot pressing pressure, η – material viscosity at process temperature, Q_0 – initial relative density of powder, Q – the relative density after hot pressing.

In work [6] a mechanism of viscous flow during sintering and an expression for viscosity was suggested.

$$\eta = k\cdot T/D\cdot a = k\cdot T/D_0\cdot a\ \exp Q/\left(k\cdot T\right), \qquad (2)$$

where D – is the self-diffusion coefficient; a – the distance between atoms; k – Boltzmann constant; T – temperature; D_0 – pre-exponential factor; Q – activation energy of self-diffusion.

Analysis of expressions (1) and (2) show that the degree of densification in the process of hot pressing of diamond-composite materials and thus their properties mainly depend on the applied pressure (P), process temperatures (T) and, therefore, on the viscosity η of the material under sintering conditions. When obtaining a composition containing diamond crystals, as is known, there is a limitation on the pressure (hot-pressing tooling) and temperature (degradation and graphitization of diamond) of the process. Therefore, it is very important that the maximum possible and permitted P–T parameters are implemented in the entire working volume of hot pressing. In other words, the urgent task of hot pressing technology is to conduct the sintering process in a gradient-free field as much as possible. As is known, the effectiveness of power consumed for the uniform and fast initial heating of the sintered mass volume depends on a number of characteristics and values. In our case, when specimens and equipment are initially heated up by the current flow through them (direct-resistant sintering), the power consumption of the process depends on the electro-physical and thermo-physical properties of materials used in the electric heating circuit, on an electric circuit type, and on the intensity of heat dissipation from the heating zone. In other words, the pressing volume is provided with maximum thermal insulation. This formulation of the problem required the use of heat-insulating materials of a given regulated electric conductivity and a certain set of physical and mechanical properties.

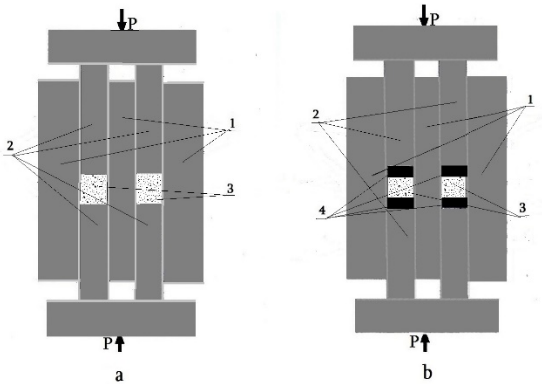

Fig. 1. Schematic diagram of a hot-pressing mold for high-hardness composite materials.
a) standard scheme; b) the proposed scheme
1 – matrix, 2 – punches, 3 – sintered sample, 4 – heat-insulating elements of electrical resistance.

We realized this circuit by using the so-called thermo- and electro-insulating caps which were placed between the punches and the specimen (Fig. 1.b). This method is borrowed from high-pressure technique and is characterized by high efficiency [6].

The developed material for thermal insulation is a graphite-mulita $2Al_2O_3 \cdot SiO_2$ composition compressed and subsequently sintered in a protective atmosphere at 1300^0C according to a specially developed technology. After selecting R opt. for heat-insulating materials, it was possible to substantially equalize the temperature field in the sintered volume in all directions. Fig. 2 shows the data of changing the value of absolute temperatures along the height of the sintered sample. When hot pressing is carried out according to the scheme given in Fig. (1.a) the temperature changing corresponds to curve 1 in Fig. 2. On the other hand, the temperature changing significantly differ (curve 2, Fig. 2) when using the heat-insulating gaskets Fig. (1.b). The thermal gradient in the first case is no less than $35\text{-}40^0C$ with a sample height of 14 mm that means the gradient is $\Delta T/h \approx 2.5\text{–}3^0C/mm$.

The use of developed heat-insulating products reduces the value of thermal gradients to $5\text{-}10^0C$ by 14 mm that means $\Delta T/h \approx 0.5\text{–}0.7^0C/mm$. Equalizing of the temperature field helps to reduce the anisotropy of the physical and mechanical proper-

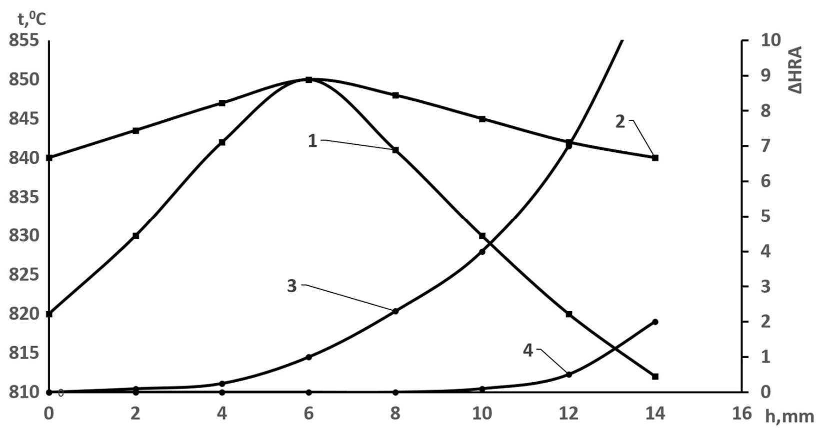

Fig. 2. Curves of the change in the temperature value (curve 1.2) along the height in the process of hot pressing and the change in the hardness of sintered specimens of the TiC – Ti – Cu – Ni composition along the height (curve 3.4).

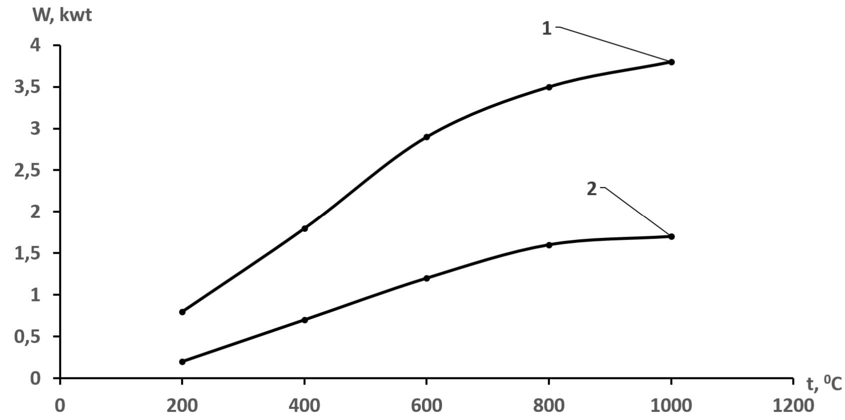

Fig. 3. Change in the consumed electric power for heating the working volume depending on the set temperature for different schemes of assembly of hot pressing molds. 1 – curve according to Fig. 1a); 2 – curve according to Fig. 1b).

ties of the sintered composition (Fig. 2, cr. 3.4). The developed scheme of the working cell makes it possible to obtain samples with practically the same hardness values (HRA) in the entire volume of sintering (Fig. 2, cr. 4). It is very important that hot pressing compounds produce relatively high (compression axis) products with isotropic properties, which is problematic to this day.

The use of heat-insulating heating elements in hot-pressing schemes made it possible to achieve ~~a~~ certain energy efficiency at specific temperatures (Fig. 3). The data indicate that using the described developments, it is possible to reduce the electrical consumption of hot pressing by 70-80%, which, in our opinion, is a significant step towards increasing the efficiency and profitability of the hot-pressing process, especially of diamond-composite materials.

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მასალათმცოდნეობა

ალმასკომპოზიციური მასალის ცხელი წნეხვით მიღებისას პროცესის ეფექტურობის ამაღლების გზა

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**საქართველოს ტექნიკური უნივერსიტეტი, „ალმასებისა და კომპოზიციური მასალების“ სამეცნიერო ცენტრი, თბილისი, საქართველო*
***აკადემიის წევრი, საქართველოს ტექნიკური უნივერსიტეტი, თბილისი, საქართველო*

სამუშაოს მიზანია ცხელი წნეხვის ტექნოლოგიური პროცესების ეფექტურობის ამაღლება. აღწერილია ცხელი წნეხვის ტექნოლოგიაში არსებული პრობლემები, რომელთა გადაწყვეტა დღესაც აქტუალურია და ტექნოლოგიის რენტაბელობის მაჩვენებელთანაა დაკავშირებული. ცხელი წნეხვის პროცესების კინეტიკური განტოლებების ანალიზის საფუძველზე ავტორების მიერ გამოკვეთილია და ექსპერიმენტულად დადასტურებულია ის ძირითადი პარამეტრები, რომელნიც განაპირობებენ პროცესის ეფექტურობასა და მიღებული პროდუქტის ხარისხს. სამუშაოში წარმოდგენილი ექსპერიმენტული მონაცემები ადასტურებენ, რომ სპეციალურად შექმნილი თბო- და ელექტროწინაღობის მქონე მასალების გამოყენება ცხელი წნეხვის სქემებში იძლევა საშუალებას მნიშვნელოვნად გაუმჯობესდეს შეცხობის პირობები. შესაბამისად, მთელს მოცულობაში უმჯობესდება კომპოზიციური მასალების თვისებების იზოტროპულობის ხარისხი. ამავე დროს, შემუშავებული თბოსაიზოლაციო მასალების გამოყენება იძლევა საშუალებას 70-80%-ით შემცირდეს პროცესის ენერგოტევადობა.

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