

# THE INFLUENCE OF THE HEATING RATE IN THE PROCESS OF SPARK-PLASMA SINTERING ON THE KINETICS OF COMPACTION, STRUCTURE FORMATION AND PROPERTIES OF THE MATERIALS OF Fe – Ti – C – B SYSTEM

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**Abstract:** Regularities of the influence of spark plasma sintering heating rate on the structure and properties of dispersion-strengthened materials based on Fe – Ti – C – (B) system are studied. Increasing heating rate of the samples from 10 °C/s to 20 °C/s induced by increasing current rise rate leads to decrease the average grain size in the material matrix of the Fe – Ti – C – B system from 2.5 to 1.5 microns. This allows to increase hardness from 48 HRC up to 70 HRC and wear resistance 7 times compared to R6M5 (full analog of HSS M2) steel during SPS consolidation in the mode with a heating rate of 20 °C/s and isothermal exposure 1100 °C for 180 s.

**Keywords:** spark plasma sintering, high voltage electric discharge, consolidation, hardness, wear resistance, powder, carbide steel

## 1. Introduction

The contemporary industry needs the structural materials with high hardness and wear resistance which could replace the costly tungsten-containing materials. This can be achieved by creating composite materials with heterogeneous structure being a plastic metal matrix with hard inclusions. Such materials include metal-matrix composites, including carbide steels, which are obtained by powder metallurgy methods [1 – 4]. The Institute of Pulse Processes and Technologies of NAS of Ukraine (IPPT NASU) developed the technology of producing carbide steels of the Fe – Ti – C – B system with levels of hardness and wear resistance similar to tungsten-containing alloys. Improved physical and mechanical characteristics were obtained by changing the dispersion and phase composition of the initial powders using the high-voltage electric discharge (HED) treatment in the hydrocarbon liquid and their subsequent spark-plasma sintering (SPS) [5 – 7].

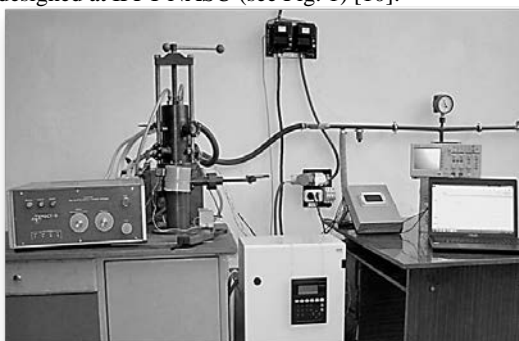
## 2. Problem discussion

It is known that physical and mechanical and functional properties of powder compacts largely depend on the porosity and grain structure [8], and that SPS provides rapid consolidation of powder materials and in many cases restricts the grain growth compared to conventional sintering [9]. Therefore, the study of the influence of the heating rate of SPS consolidation on the structure and properties of dispersion-strengthened materials based on Fe – Ti – C – (B) system is an urgent task.

**Objective of this paper** is to establish regularities of the influence of SPS heating rate on the structure and properties of dispersion-strengthened materials based on Fe – Ti – C – (B) system.

## 3. Objective and research methodologies

The SPS was carried out using experimental complex, designed at IPPT NASU (see Fig. 1) [10].



The atmosphere	Vacuum 10 <sup>-4</sup> MPa
The matrix material	Graphite MPG-3
Axial pressure	60 MPa
The amplitude of the superposition	1.1 kA

Fig. 1. SPS complex and its parameters

The mixture of powders of initial mass composition of 75% Fe – 20% Ti – 5% B<sub>4</sub>C was chosen as the charge for sintering to be treated by the HED with a specific energy of 6.25 MJ/kg, which provided the content of the strengthening phase to 25% sized from 100 nm to 600 nm and an average metal-matrix particle diameter of ~ 15 μm (see Fig. 2) [6, 7].

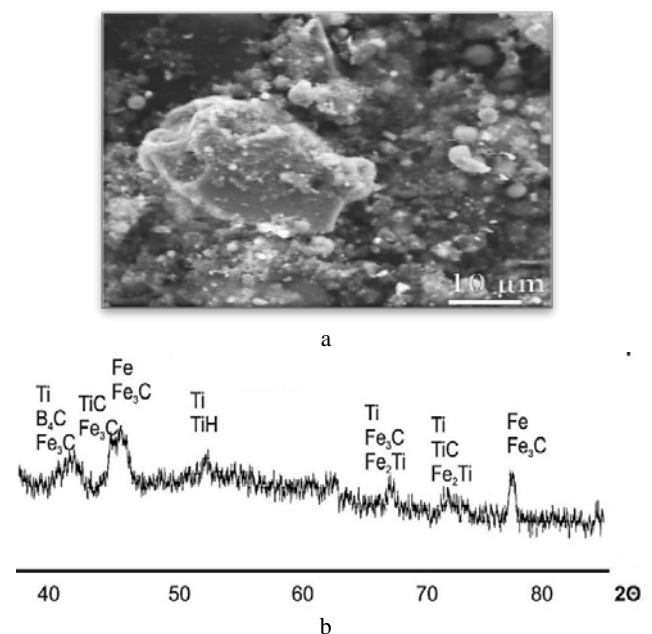


Fig. 2. Electron micrograph  $\times 1700$  (a) and the phase composition (b) of the charge of Fe – Ti – C – B system

Consolidation was carried out at a heating rate of 10 °C/s at a temperature of isothermal aging of 1100 °C, holding time  $\tau = 180$  s, cooling rate 10 °C/s. The heating rate was varied in the range of 10 °C/s to 20 °C/s by increasing the current strength amplitude rise from 14 A/s to 30 A/s.

The experimental analysis of changes in the structure of the consolidated compacts was carried out by means of computer metallography according to DSTU ISO 643:2009 using the Biolam-I optical microscope and ImageJ software. Phase analysis was carried out on DRON-3 diffractometer according to ref. [11].

Hardness of samples was measured according to ISO 6508-1:2013. Wear resistance was investigated by SMC-2 friction machine based on the “roller-pad” pattern. The counter-body was the 1A1 diamond grinding wheel with grain size of AC80/63. The results were compared with test results of the sample of steel R6M5 (GOST 19265-73, full analog of HSS M2 steel).

The average grain size of the matrix of the Fe – Ti – C – B system after HED treatment is ~ 0.5 μm. In the process of SPS at heating rate of 10 °C/s its average size increased to ~2.5 μm. Increasing the heating rate to 20 °C/s allowed to reduce the average grain size of the matrix after sintering to ~1.5 μm.



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