Investigation of Composite Materials Based on Titanium, Aluminum and Silicon Carbide-Borides

In almost all areas of modern industry, traditional materials can no longer meet the requirements placed on them, due to increased necessity to use new materials having combined properties. New generation materials must possess a number of unique properties, such as low density, high strength, heat resistance and much more… At the same time manufacturing process should be easy and cheap. Similar requirements apply to metals and non-metals materials, as well as their combinations. A material obtained by combining two or more materials with different properties is called a composite material. With combination of different combinations of constituent elements it is possible to obtain composite material tailored specific tasks and the industry. Basically, composite materials is a combination of a metal or ceramic matrix reinforced by various elements and compositions.

The present study aimed to obtain composite materials based on carbide and boride compounds of titanium and silicon, reinforced by different high-temperature and plastic materials, in order to use as armor materials. The widely used boride material is titanium diboride, as well as carbides of titanium and silicon. Consequently, TiB_2-TiC-SiC has been selected as a base and matrix of the researched composite materials. Mainly attention has been due to the fact that they are characterized by high melting temperature, high hardness and corrosion-resistance. Different additives and systems of raw materials are used to increase the hardness and strength of composite materials.

Matrix of TiB_2-TiC-SiC composite has been obtained from elements (by reaction $7Ti+3B_4C+3Si=6TiB_2+TiC+3SiC$) or using desired ratio of TiB_2, TiC, SiC compounds. Composite materials has been produced as a multi-phase matrix and with reinforcement elements. Reinforcement elements have been chosen to reduce brittleness, increase hardness and strength, considering that researched materials were to be used as armor. Mentioned materials have been reinforced by AlMgB14, $Al_8B_4C_7$, Al_8SiC_7, Al_4SiC_4, $Ti_3Al_{0.5}Si_{0.5}C_2$, FeNi materials and their combinations. In some cases titanium nitride TiN was also used. Has been developed technology of obtaining armor tiles and their assembling. Initially has been calculated ratio of composite components in order to prepare mixture of precursor element. Appropriate amount of powders of elements (Ti, Al, Si, C, B, Mg, Fe, Ni and so on…) or compounds (TiB_2, TiC, SiC, B_4C, $AlMgB_{14}$ and so on…) have been mixed and prepared for synthesis.

The sample have been sintered by spark-plasma synthesis/sintering (SPS) method. The sintering has been performed in a vacuum, in a laboratory-made device. In order to prevent the release of low-temp. elements/compounds from the system, the pressure and temperature have been adjusted accordingly. Density and porosity have been determined of samples obtained after sintering process. Hydrostatic method has been used for density measurements. Hardness tests have been conducted by Vickers micros-hardness method. Morphology and microstructure have been investigated by optical (LEITZ WETZLAR) and scanning electron (SEM-JEOL JSM-6510LM) microscopes. Phase and elemental analysis have been performed by X-ray diffractometer XZG 4A.

This research also aimed to design armor tiles from the developed composite materials and their ballistic examination. Composite materials with low density, high strength and toughness were selected for the construction of armor tiles. Mainly, armors are made by one whole plate, customized on human body or combat vehicle. While elite military corps uses armors made from the small rectangular or hexagonal shaped low-weight tiles. Armor tiles with size-50X50mm and 8-10mm thick are usually used for ballistic testing. Making a plate of this size is associated with high energy costs and technical difficulties such as uneven sintering. An anisotropic temperature distribution through the sample body leads to the insufficient density and hardness.

To solve this problem, relatively small plates were sintered and used to assemble an armor plate of appropriate size. Different three-layer armor tile has been obtained, which was assembled from 2 different size plates (8pieces-24x24x3mm and 9pieces-16x16x3 mm). The first and third layers were assembled from 4pieces of large plate, while the middle layer consisted of 9pieces of small plate. The edges of the previous layer were overlapped by each subsequent layer. Assembling the tile with this method will also allow us to construct the plates using different materials. With different layouts of materials it is possible to achieve the optimal configuration.

Ballistic testing was conducted at the GTU-based shooting range in compliance with required safety standards. The conducted ballistic testing meets the requirements of the NATO standard-NIJ standart-0101.06 typeIIIA. Five different samples were tested and two of the appeared to be bullet resistant. The sample TiB_2-TiC-Ni was found to be the most resistant to the used bullets, which could fully neutralize bullet energy and sample showed back face signature (BFS) less than 3mm. Also good results showed sample made by B_4C-TiB_2-SiC-Al_4SiC_4. In this case BFS was around 15mm. According to the NIJ standart maximum allowed BFS is 44mm.

Results of ballistic testing showed the compositions that definitely can be used for armor application.