Selection of Compositions in Ti-Cr-C-Steel, Ti-B, Ti-B-Me Systems and Establishing Synthesis Parameters for Obtaining Product by “SHS-Electrical Rolling”

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Abstract. For the production materials by the proposed Self-propagating High-Temperature Synthesis (SHS) - Electric Rolling method, there are no limitations in the length of the material and the width only depends on the length of rolls. The innovation method enables to carry out the process in nonstop regime, which is possible by merging energy consuming SHS method and Electrical Rolling. For realizing the process it is mandatory and sufficient, that initial components, after initiation by thermal pulse, could interact with the heat emission, which itself ensures the self-propagation of synthesis front in lieu of heat transfer in the whole sample. Just after that process, the rolls instantly start rotation with the set speed to ensure the motion of material. This speed should be equal to the speed of propagation of synthesis front. The synthesized product in hot plastic condition is delivered to the rolls in nonstop regime, simultaneously, providing the current in deformation zone in order to compensate the energy loses. As a result by using the innovation SHS –Electrical Rolling technology we obtain long dimensional metal-ceramic product.

In the presented paper optimal compositions of SHS chasms were selected in Ti-Cr-C-Steel, Ti-B and Ti-B-Me systems. For the selection of the compounds the thermodynamic analysis has been carried out which enabled to determine adiabatic temperature of synthesis theoretically and to determine balanced concentrations of synthesized product at synthesis temperature. Thermodynamic analysis also gave possibility to determine optimal compositions of chasms and define the conditions, which are important for correct realization of synthesis process. For obtaining non porous materials and product by SHS-Electrical Rolling, it is necessary to select synthesis and compacting parameters correctly. These parameters are the pressure and the time. In Ti-Cr-C-Steel, Ti-B and Ti-B-Me systems the high quality (nonporous or low porosity <2%) of materials and product is directly depended on the liquid phase content just after the passing of synthesis front in the sample. The more content of liquid phase provides the higher quality of material. The content of liquid phase itself depends on synthesis parameters: speed and temperature of synthesis. The higher the speed and temperature of synthesis we have, higher the content of liquid phase is formed. The speed and the temperature of synthesis depend on the \( \Delta \rho \) relative density of sample formed from initial chasm, this mean it depends on the pressure of formation of the sample. The paper describes the results of determination of optimal pressures in Ti-Cr-C-Steel, Ti-B and Ti-B-Me systems. Their values are defined as 50-70 MPa, 180-220 MPa and 45-70 MPa.
1. Introduction
The progress of science and technique is in direct connection with the application of specific new metal-ceramic and composite materials, which can work/resist at high temperature and aggressive media. Majority of the materials in the mentions class represent the prospective materials for application in modern machine building, airspace, chemical and metallurgical industry and nuclear fields. Although, it must be mentioned, that the wide application of application metal-ceramic materials is restricted due to the absence of effective technologies for the production of such materials. In this point it is very important to orientate industry onto development and realization of resource-saving, environmentally friendly technologies [1].

The fabrication of materials by Self-propagating High-temperature Synthesis (SHS) gave possibility to elaborate the technology for obtaining compact composite materials. The method is characterized with number of technological advantages, in particular, high productivity, low energy expanses, high quality of the product and ecological purity. The main idea of the technology involves in direct compaction of SHS products down to non-porous state just after the arrival of synthesis front. As a result of the application of the method, the instrumental and construction materials are fabricated [2].

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2. Proposed Technology and Investigations
For the production materials by the proposed SHS - Electric Rolling method, there are no limitations in the length of the material and the width only depends on the length of rolls. The innovation method enables to carry out the process in nonstop regime, which is possible by merging energy consuming SHS method and Electrical Rolling. For realizing the process, it is mandatory and sufficient, that initial components, after initiation by thermal pulse, could interaction with the heat emission, which itself ensures the self-propagation of synthesis front in lieu of heat transfer in the whole sample [3].

Electric energy is delivered in the heart of deformation area with the use of electric contact and the heat, generated in the initial section of deformation heart, initiates the SHS process. As a result the front of synthesis is created, which starts displacement with distinct speed in the sample located in container. Just after the described process, the rolls instantly start rotation with the set speed to ensure the motion of material. This speed should be equal to the speed of propagation of synthesis front. The synthesized product in hot plastic condition is delivered to the rolls in nonstop regime, simultaneously, providing the current in deformation zone in order to compensate the energy loses. As a result by using the innovation SHS – Electrical Rolling technology we obtain long dimensional metal-ceramic product.

3. Results and conclusions
The analysis of literature, as well as the experiments conducted by us before [4,5], shows, that it is very promising to elaborate materials on the base of Ti-Cr-C-steel, Ti-B and Ti-B-Me systems by using the proposed technology. For selection the optimal chasm compositions in Ti-Cr-C-steel, Ti-B and Ti-B-Me systems, the thermodynamic analysis of those systems has been carried out. It enables to determine adiabatic temperature of synthesis theoretically and to determine balanced concentrations of synthesized product at synthesis temperature. Thermodynamic analysis also gives possibility to determine optimal compositions of chasms and define the conditions, which are important for correct realization of synthesis process.

The results of thermodynamic analysis is giving chance to reduce the number of experiments, which are necessary for optimization of chasm content. The “figure 1” represents the results of thermodynamic analysis.
Figure 1. Variations of TiC, Cr3C2, Cr7C3 in the synthesized product depending on ratio of 
(Ti+C/3Cr+2C) in initial chasm; 1 – TiC; 2 - Cr3C2; 3 – Cr7C3;

The curves indicate the contents of TiC, Cr3C2 and Cr7C3 in the synthesized product, depending on 
the concentration of initial Ti, Cr, C components and TiC/Cr3C2. As shown from the figure, when the 
ratio is Ti+C/3Cr+2C < 2, it is possible to form the three-phase system. Taking into account that at 
high temperatures Cr3C2 is well solved in TiC, in order to obtain single-phase solid solution, it is 
necessary to have the following ratio: Ti+C/3Cr+2C >2.

“Figure 2” presents the theoretical and experimental temperature variations of Ti-Cr-C system, 
depending on the concentration of initial components Ti, Cr and C. It is obvious, that when there is 
condition: Ti+C/3Cr+2C >2, the experimental value of synthesis temperature is 2620K.

Based on the analysis we can conclude that form obtaining single-phase solid solution of Cr3C2 in 
TiC with high temperature, necessary compaction of product down to non-porous state, it is necessary 
to reduce 3Cr+2C in the chasm; on the other hand this leads to the reduction of microhardness and 
strength values. Therefore, the optional value of “Ti+C/3Cr+2C” must be between 2 and 9 and it can 
be written as follow: 2 < Ti+C/3Cr+2C<9.

Figure 2. Variations of theoretical and experimental temperatures of synthesis in initial chasm 
(Ti+C/3Cr+2C), depending on the ratio. 1-theoretical; 2-experimental
The curves, presented on “figure 3” shows the possible changes of phase content, number of phases and synthesis temperatures in Ti-Cr-C-X18H15 system depending on the content of X18H15 in chasm. The synthesized product may contain TiC, Cr3C2, Cr7C3, Fe3C, Steel and Nickel.

In addition, based on the analysis we can conclude, that when the content of Steel X18H15 is less than 5%, we may have the process of extrusion of Chromium carbide (Cr3C2) from solid solution. This is not desired process, as it leads to the reduction of microhardness value. Besides the second negative affect, when the Steel X18H15 is less than 5% can be the increase of porosity of compacted rolled material. As a conclusion the lowest threshold value of Steel X18H15 content is 5% in the chasm.

![Figure 3. Variation of synthesis temperature and content of TiC, Cr3C2, Cr7C3, Fe3C and Ni in initial chasm, depending on the content of steel X18H15](image)

The increase of X18H15 in the chasm over 25% leads to the reduction of synthesis temperature, which degrades compaction/consolidation conditions, which is not desired as well.

Therefore, based on thermodynamic analysis can be concluded following boundary conditions:

1) $2 < \text{Ti+C}/3\text{Cr+2C}<9$;
2) Content of steel X18H15 must be between 5% and 25%.

The curves, presented on “Figure 4” shows the possible variations of phase content and number and synthesis temperatures in Ti-B system, depending on the boron content in the chasm. The synthesized product may contain Titanium, TiB and TiB2. During the current stage of implementation of the project tasks, one of the main goal is the selection of material to be well compacted after the synthesis.

For reaching the goal is necessary and sufficient to have minimum 5% (wt) of liquid phase in the synthesized material after the arrival of synthesis front. The lifetime of the liquid phase must be no less than the necessary time for compaction (10-12 seconds). The material should be characterized with high mechanical and physical properties, in particular, high strength, hardness and resistivity against high intensity loadings. The literature analysis shows that the self-allying hard alloys are characterized with high strength values. In the system such alloy system is TiB-Ti. This can be obtained, when the content of boron in chasm is between 10% and 16% (wt). When the content of boron is less than 10% (wt) the SHS process is not realized, and when the content of boron is more than 16% (wt), the new TiB2 phase is formatted and the content of Ti is decreased. Finally, it can be concluded that in TiB-Ti system the content of boron must be between 10% and 16% (wt).
In some occasions the task can be the obtaining of materials with higher hardness than in the above described TiB-Ti material. In this point it is necessary to obtain TiB$_2$ containing material. In Ti-B system, we have no more liquid phase for obtaining TiB$_2$, it becomes urgent to add bounding metal in the system. This metal must not be able to form brittle compounds with hard components, in the mentioned case with TiB$_2$ component. Besides, this bounding metal must have wetting ability as well. Therefore, in this purpose was selected copper and steel. As it is Shown on “figure 5” and “figure 6”, their content varies from 10% to 50 % (wt). The curves presented on “figure 5” shows the possible variations of number and content of phases, as well as the synthesis temperatures in Ti-B-Cu system, which depends on the content of copper in the initial chasm. The product can contain TiB, TiB$_2$ and Cu.

**Figure 4.** Variation of number and content of phases and adiabatic temperature in the product synthesized in Ti-B system, depending on the content of boron in the initial chasm.

In some occasions the task can be the obtaining of materials with higher hardness than in the above described TiB-Ti material. In this point it is necessary to obtain TiB$_2$ containing material. In Ti-B system, we have no more liquid phase for obtaining TiB$_2$, it becomes urgent to add bounding metal in the system. This metal must not be able to form brittle compounds with hard components, in the mentioned case with TiB$_2$ component. Besides, this bounding metal must have wetting ability as well. Therefore, in this purpose was selected copper and steel. As it is Shown on “figure 5” and “figure 6”, their content varies from 10% to 50 % (wt). The curves presented on “figure 5” shows the possible variations of number and content of phases, as well as the synthesis temperatures in Ti-B-Cu system, which depends on the content of copper in the initial chasm. The product can contain TiB, TiB$_2$ and Cu.

**Figure 5.** Variations of number and content of phases and synthesis temperatures in Ti-B-Cu system, depending on the content of Cu in the initial chasm

**Figure 6.** Variations of number and content of phases and synthesis temperatures in Ti-B-X18H15 system, depending on the content of steel X18H15 in the initial chasm
The curves presented on “figure 6” shows the possible variations of number and content of phases, as well as the synthesis temperatures in Ti-B-X\textsubscript{18H15} system, which depends on the content of X\textsubscript{18H15} in the initial chasm. The product can contain TiB, TiB\textsubscript{2} and alloys on the base of CrNiFe.

It is possible to obtain practically non-porous materials and product by applying compaction technique to hot materials obtained by SHS. By for this reason it is necessary to select optimal parameters of synthesis and compacting parameters. These parameters are time and pressure. While selecting the optimal composition of chasm we take into account the results of thermodynamic analysis, which was described above. For the system Ti-Cr-C-X\textsubscript{18H15} the following dependence was established: $2<\frac{\text{Ti+C}}{3\text{Cr+2C}}<9$. Though, the experiments conducted by SHS technology (schematically shown on “Figure 7”) confirmed, that the optimal value of $\frac{\text{Ti+C}}{3\text{Cr+2C}}$ is quite close to 5 ($\frac{\text{Ti+C}}{3\text{Cr+2C}}\approx5$). The idea of the technology is following: the sample (3) is placed in inert media (4). This inert media is the river sand, which plays role for heat isolation, for uniform distribution of pressure on sample and is also excellent media for the release of adsorbed gases. For the production of high quality non-porous materials by SHS-electrical rolling (Figure 8) it is important to have more liquid phase, as the time of formation of final product is restricted and is limited with the time which is necessary for the material to pass through the rolls. Therefore it is important to have higher temperature during the rolling than during the SHS process.

![Figure 7. SHS compaction technology; 1-press form, 2- initiating spiral, 3- sample, 4- inert material (sand)](image)

![Figure 8. a) Production of composite material by SHS-electrical rolling b) Production of gradient material by SHS-electrical rolling; 1-Rolls, 2- heating electric contacts, 3- container, 4- briquette of chasm, 5- synthesis (combustion) front, 6-rolled sample, 7- metal support](image)

On the base of presented investigations, it is determined that the value of $\frac{\text{Ti+C}}{3\text{Cr+2C}}$ in the chasm must be up to 5 ($\frac{\text{Ti+C}}{3\text{Cr+2C}}=5$), for the production of materials in Ti-Cr-C-X\textsubscript{18H15} by SHS-electrical rolling technology.
The “figure 9” (a,b,c) describes the dependence of synthesis speed and temperatures on pressures of sample formation in Ti-Cr-C-X18H15, Ti-B and Ti-B-Me systems relevantly.

![Figure 9](image)

**Figure 9.** U-speed (mm/s); P-pressure (kg/cm²)

a) Curves (1-6) of synthesis temperature and curves (1₁-₆₁) of synthesis speeds in Ti-Cr-C-X18H15 system, depending on formation pressure of sample; 

b) Curves (1-3) of synthesis temperature and curves (1₁-₃₁) of synthesis speeds in Ti-B system, depending on formation pressure of sample

c) Curves (1-6) of synthesis temperature and curves (1₁-₆₁) of synthesis speeds in Ti-B-Me (Me – Cu, X18H15) system, depending on formation pressure of sample

In Ti-Cr-C-Steel, Ti-B and Ti-B-Me systems the high quality (nonporous or low porosity <2%) of materials and product is directly depended on the liquid phase content just after the passing of synthesis front in the sample. The more content of liquid phase provides the higher quality of material. The content of liquid phase itself depends on synthesis parameters: speed and temperature of synthesis. The higher the speed and temperature of synthesis we have, higher the content of liquid phase is formed. The speed and the temperature of synthesis depend on the Δρ relative density of sample formed from initial chasm, this mean it depends on the pressure of formation of the sample. Therefore, the optimal pressures in Ti-Cr-C-Steel X18H15, Ti-B and Ti-B-Me systems are established. Their values are defined as 50-70 MPa, 180-220 MPa and 45-70 MPa.

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