# PRODUCT MICROSTRUCTURE AND CHARACTERISTICS CONTROL IN THE PROCESS OF THE SHST SYNTHESIS REALIZATION

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**ABSTRACT**

In article the data about the product microstructure and characteristics control in the process of the SHST synthesis realization are presented.

**Keywords:** microstructure, control, synthesis, alloys, binary system, intermetallide compounds.

## I. INTRODUCTION

The self-distributing high temperature synthesis enables deriving various alloys of the binary system) [1].

The intermetallide compounds on the basis of the system Ti-Al are widely used in aircraft manufacturing for the gas-turbine engines and component parts production due to their small weight – to thrust ratio, high strength, to tensile, pressure, influence of aggressive matters under high temperatures. The distinctive feature of the system under study is a relatively low adiabatic combustion temperature of approximately 1300°C, which is considerably less than that of liquid solutions. Figure 1 presents the equilibrium diagram of the system under study.

It results from the diagram that α – solid Ti solution, $\alpha_2$ – $Ti_3Al$ phase, γ – TiAl phase and $TiAl_3$ phase, bordering on the Al melt are in
equilibrium under the temperature within the interval of 660-1100°C. [2]

## II. MAIN TEXT

Before the moment of reaching the adiabatic combustion temperature the following processes take place in the system: Al melting (after which phase transformations start proceeding), titanium polymorphic transformation α→β during simultaneous forming and growing of the phases, re-crystallization of $\alpha_2$ – phase into α – solid solution, the titanium resolution in the Al melt. All the processes are exothermic.

From the point of view of diffusion kinetics, the system is characterized by the essential difference of the diffusion coefficients in the phases and solutions, which enables to forecast the proceeding mechanism on the quailtative level.

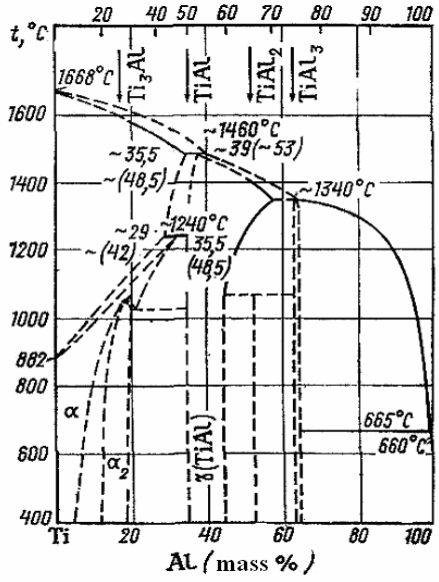


Figure 1. The diagram of the Ti - Al system state

Due to the high velocity of the diffusion in solid and liquid solutions the phase formation process is limited by the diffusion in the phases, the diffusion resistance of the layers stipulates uniform distribution in the areas of solid and liquid solutions. In the diffusion process with the formation of phases the gradients of Al (titanium) concentration in the areas of solutions are virtually absent and the components concentration changes with time in correspondence with a liquidus line and the boundary of solubility of α, β solid solutions in the equilibrium diagram. The absence of the gradient of Al concentration to the right of the area of $TiAl_3$ phase boundary with the Al melt and its presence to the left of the area leads to the phase boundary movement to the right with the simultaneous movement of the left boundary of the $TiAl_3$ homogenous phase area to the center of Ti particle (Fig.2 a). Thus, abrupt temperature increase up to the maximum extreme at the thermal explosion is stipulated by the transformation of liquid Al in the volume of heterogeneous mixture in the inter-partial space into $TiAl_3$ phase. The mentioned above is illustrated by the chart presented in Figure 2.

After intermetallide and liquid melt separation boundary reaches the boundary of the effective cell (the process of a primary structure formation is over here) the process of Al slow diffusion in phases and saturation of solid solution starts proceeding. The given process should be referred to the secondary structure formation phase. The process continues up to the titanium material exhaustion.

In case of the components initial relation corresponding to the stoichiometry of $TiAl_3$ compound (Ti -66, 3 mass %) the single phase product of synthesis should be expected.

However, the final product microstructure essentially depends on a thermal mode of the reaction proceeding, as it is shown in the research [2].

For the purpose of determination of the conditions of a single-phase product formation the experimental plant for SHS-synthesis in the thermal explosion mode was created in the SHS-synthesis laboratory of the ASTU.[3]

Figure 3 presents synthesis thermograms, made with the use of Ti particles by the sizes of 120±20 mkm.

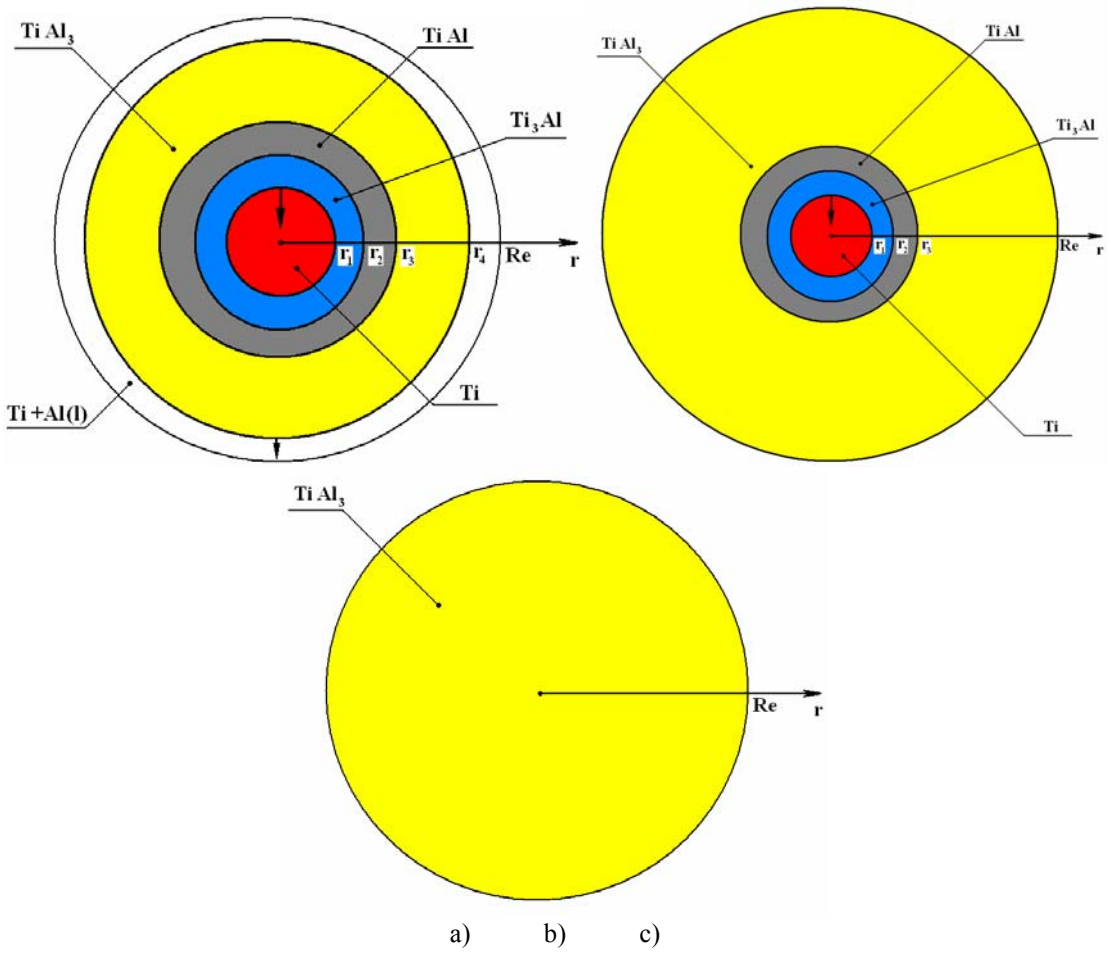


Figure 2. The dynamics of phase formation in the process of $TiAl_3$ intermetallid synthesis

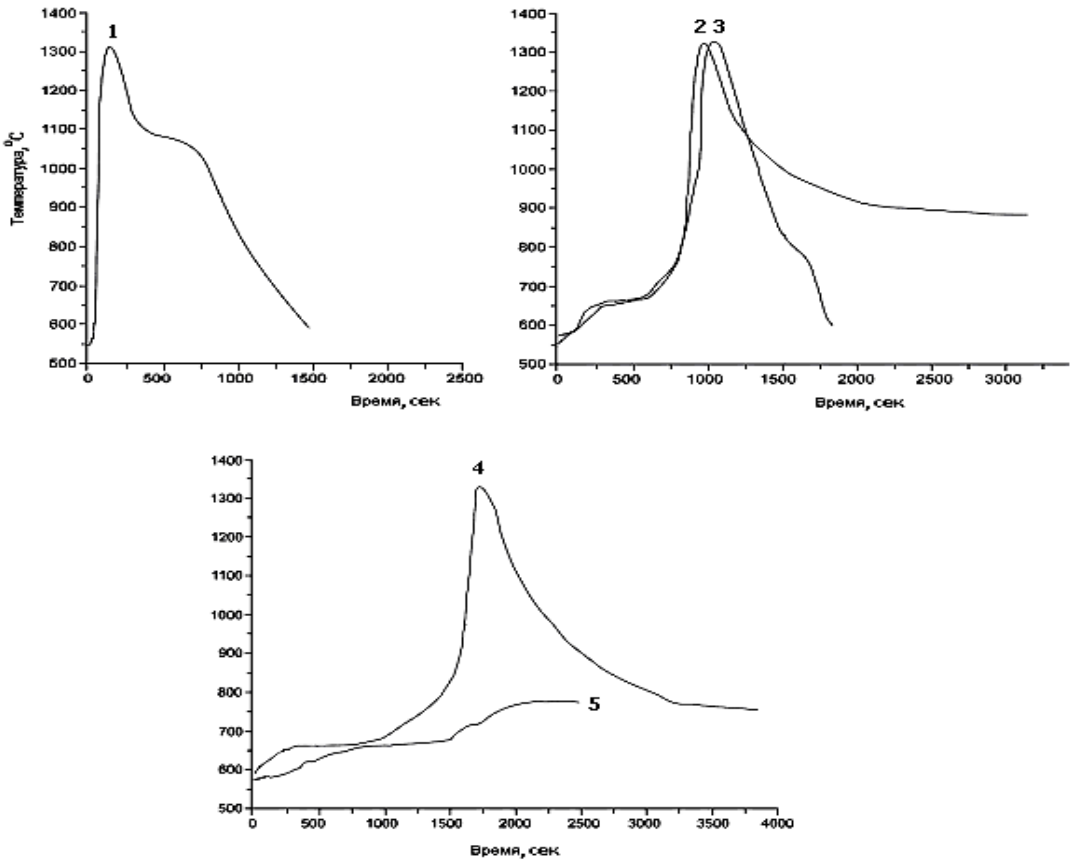


Figure 3. The synthesis thermograms at different temperature values of the reactor's wall. 1 – $T_0$ = 1050°C (the disconnection of the source was made in the moment of reaching maximum temperature by the reacting mixture). 2, 3 – $T_0$ = 850°C (Thermogram 3 – synthesis with the disconnection), 4 – $T_0$ = 750°C, 5 – $T_0$ = 730°C

Figure 4 presents the photos of the synthesis products microstructure obtained in mode 1, 3 with the source disconnection.

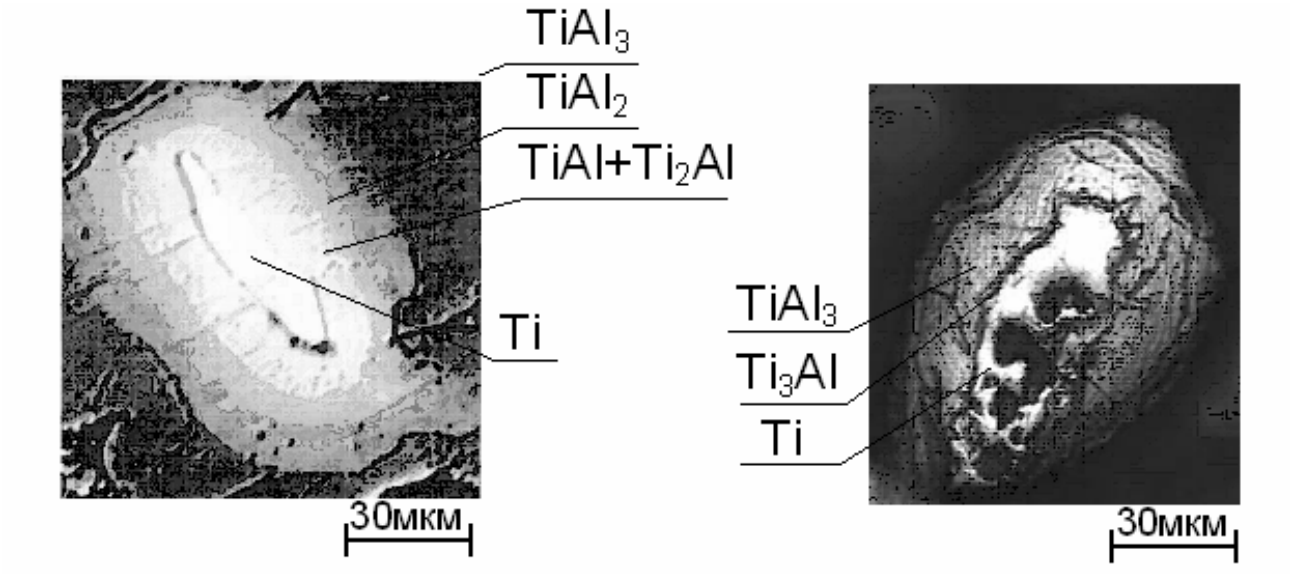


Figure 4. The photos of typical elements of the structure, corresponding to the modes 1 and 3 (Fig. 3)

The dynamics of the heating-cooling process can be explained as the following. From the point of view of structure formation process, the process of a primary structure formation consists in rapidly proceeding process of $TiAl_3$ formation in the volume of Al melt at the first stage (dark area, surrounding the structure element, Fig.4). Rapid cooling of the mixture, connected with the process of heat release in the environment through the reactor's wall takes place after the disconnection of the source at the moment of reaching of temperature maximum by the reacting mixture. The process of a secondary structure formation, occurs considerably slower than the process of a primary structure formation. It happens because the phases, formed in the process of a primary structure formation are supersaturated by Al and the diffusion velocity at phase formation in the volume of Ti particle is relatively slow. Hence, the velocity of heat release at this stage is lower than the velocity of mixture cooling in the volume, which leads to the decrease of the temperature. Further, the cooling velocity decreases to the value, equal to the velocity of heat release by law of Newton at the expense of the process of a secondary structure formation. In this connection, the plateau appears at the thermogram.

To explain inhomogeneity of phase composition of the product, it is necessary to evaluate the relation of synthesis duration and structure formation.

The time of structure formation is determined by diffusion processes in the volume of Ti particle. Hence, the scale of diffusion time for the formation of titanium $TiAl_3$ is: $t_d \sim \frac{r_0^2}{D} = \frac{\left(1{,}2 \cdot 10^{-4}\right)^2}{10^{-12}} \approx 1{,}4 \cdot 10^4 c$. In our case, the duration of synthesis up to cooling to the initial temperatures, is equal to $t_c \approx 1500c$, $t_c / t_d \sim 10^{-1}$. Thus, the slowing down of diffusion processes with the following crystallization of the product take place during the cooling of mixture at the stage of a secondary structure formation. But the reaction is not brought to completion.

Thermogram 3 also shows a bend, connected with the process of a secondary structure formation. But the temperature value in the bend point is lower than in the above considered case. It is easy explained by the fact that cooling velocity in the maximum point of thermo grams is lower in the given case than in previous one. It happens at the expense of a big difference of temperatures between the mixture and environment. Respectively, the balancing temperature is also lower.

The equilibrium plateau has less length and bend point corresponds to less temperature because the temperature of the wall is lower. The intermediate γ – phase is not found, and the layer of $Ti_3Al$ phase is very thin. Thus, the length of plateau and temperature of bend point stipulate the transformation degree and the number of phase in a final product. Temperature and length, in turn, are determined by the conditions of heat release and temperature of the reactor's wall. Hence, the process of a secondary structure formation can be controlled.

Thermogram 2, shown in the Picture 4, presents the process held without disconnection of the source at the same temperature of the wall. The delay time of the system at the given temperature is equal to 3500 sec. It is comparable with the time of a secondary structure formation in the mentioned system.

Figure 5 presents the photo of a corresponding microstructure of the product. The result of synthesis is a single-phase product of stoichiometry $TiAl_3$.

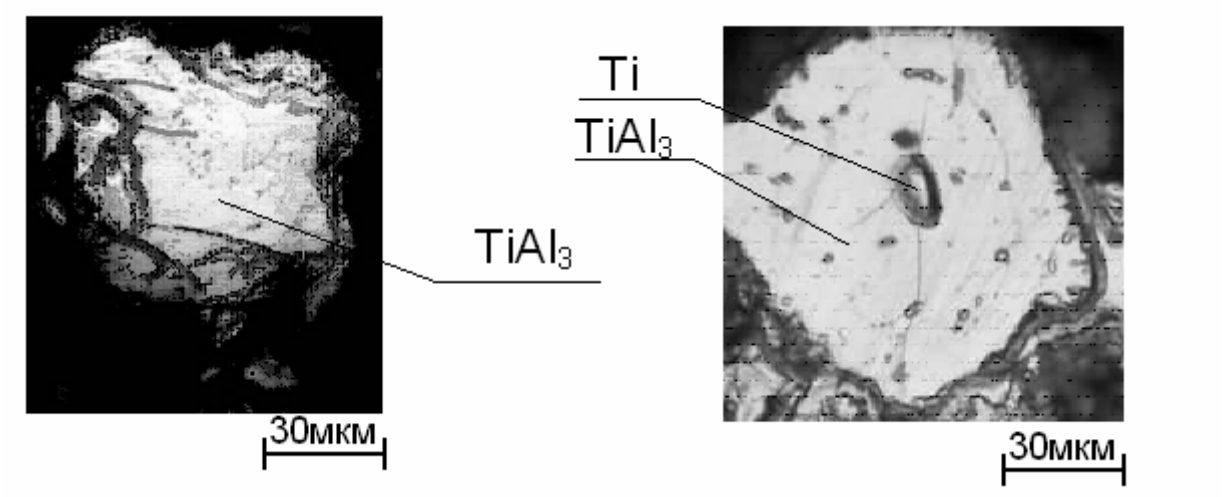


Figure. 5. a – photo of the product microstructure, corresponding to the mode 2,
b – to the mode 4

## III. CONCLUSION

The arguments presented in the section are conceptually qualitative.

To make more sound conclusions, it is necessary to have a precise theory, describing the dynamics of a structure formation development in Ti – Al system. But there does not exist at present such a systematic theory. Nevertheless, it can be considered that the introduced estimating quantitative criterion of synthesis time $t_c \geq r_0^2 / D(T_c)$, for the obtaining of multiphase product of stoichiometry $TiAl_3$ ( where $r_0$ – average size of Ti particle, $D(T_c)$ - coefficient of mutual diffusion in the phase at synthesis temperature) is in good agreement with experimental data.

It is worse to note that Ti particles, coated by intermetallid layer are obtained at an incomplete transformation (the introduced criterion is not fulfilled). It is of interest for the problem of the obtaining of foliated composites.

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