THE RESEARCH THERMOPLASTIC DEFORMATION MODES OF DUAL-PHASE SPECIAL ALLOYS FOR OBTAINING RATIONAL INTERMETALLIC STRUCTURE

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Abstract

The purpose of this work is to investigate the structure formation in intermetallic γ-TiAl alloys by using a complex plastic deformation technology under non-stationary temperature conditions with niobium doping. Also in given work, the using of Hall-Patch model, the interrelation of the nanostructured quantities with strength characteristics is considered. It allows to obtain materials with increased plasticity by an optimal combination of mechanical properties over a wide range of temperatures. The paper considers the influence of the stress-strain state of the formation structure and properties of γ-TiAl alloys obtained under thermochemical pressing, with the help of computer modeling program Deform. The process of extrusion rods is characterized by uniform compression stress, which provides γ-TiAl alloys best in these conditions' plastic properties. It was shown that high-temperature synthesis intermetallic γ-TiAl compounds in the powder mixture in a pure elements SHS intermetallic compression allows to obtain an alloy having an average grain size of about 30 microns. An increase in the degree of plastic deformation of the intermetallic product synthesized under pressure in the conditions of the thermochemical pressing allows to reduce the size of the grain in the final product by an order of magnitude and even to form a sub-microcrystalline granular structure in the intermetallic alloy.

Keywords: Metal forming, intermetallic alloy, thermochemical pressing, grain size, properties, structure

1. INTRODUCTION

The introduction should provide a clear statement of the study, the relevant literature of the study, subject and the proposed approach or solution. Light alloys, based on titanium aluminide with TiAl phase, are currently considered as potential construction materials to use at temperature range 600 - 900 °C and they, as supposed, will find wide application in the near future. It has a unique complex of mechanical properties in comparison with traditional construction materials. It includes high specific strength and elasticity, which persist to high temperatures, high heat and oxidation resistance. These properties are due to the highly directional covalent component in the interatomic bond and the ordered atomic structure. At the same time, TiAl alloys are predominant in comparison with ceramic materials, owing to definite ductility and fracture toughness. The most promising application of TiAl alloys is in aircraft and space vehicles. The lightweight exterior panels with cellular filler and rigid thin-walled integral structures can be manufactured from these materials [1]. The main attention of the intermetallic γ-TiAl alloys developers in the last two decades was concentrated on achieving the optimal combination of mechanical properties by varying the microstructure from fully lamellar to duplex with varying grain size and plate thickness [2]. Depending on the alumina content alloys, based on γ-TiAl are divided into two groups: single-phase γ-alloys (50 - 52% Al) and two-phase $\gamma + \alpha_2$ alloys (44 - 49 % Al). Through the obtaining technology with hot-deformation modes and heat treatment of biphasic alloys, three basic types of intermetallic structure are distinguished: lamellar, recrystallized (globular) and bimodal (duplex). Nowadays, three generations of industrial intermetallic alloys, based on γ-TiAl with different types of structure, are developed [3]. In our opinion, to give the TiAl alloy product the final properties, it is necessary to subject plastic deformation in the high-temperature phase region to obtain a plate structure. It provides the best combination of high-temperature properties - strength, creep resistance, with room ones - plasticity and fracture toughness. Apparently, plastic deformation can be effective not only for the production of fine-grained semi-finished products but also for controlling the parameters of the plate structure in TiAl alloys. In particular, it can be used for obtaining plate-like microstructures with a small colony size and nanocrystalline interplanar spacing, which are of great interest [4]. The purpose of this work is to investigate the structure formation in intermetallic γ-TiAl alloys by using a complex plastic deformation technology under non-stationary temperature conditions with niobium doping. Also in given work, the using of Hall-Patch model, the interrelation of the nanostructured quantities with strength characteristics is considered. It allows to obtain materials with increased plasticity by an optimal combination of mechanical properties over a wide range of temperatures.

2. RESEARCH METHODOLOGY

On the basis of the results of the above papers [5-15] and the earlier self-study results of the thermochemical pressing process [5, 6, 14], an attempt was made to determine the basic patterns of deformation and structure formation, to determine the ways and methods of controlling the processes of forming the structure and properties of compressed articles under conditions SHS In order to solve the problem, the method of mathematical modeling is used, in the implementation of which can be conditionally distinguished the following main stages: the idealization of internal properties of the given process (object) and external influences (construction of the physical model); mathematical formulation of the behavior of a physical model (construction of a mathematical model); choice of method for studying a mathematical model and conducting this research; analysis of the obtained mathematical result.

In the mathematical description of thermochemical pressing it is necessary to take into account the thermokinetic characteristics of the process, the velocity of the reactant and its macroscopic density. Therefore, in addition to the kinetic equations for the formation of the intermetallic structure, the activation energy and chemical transformation, it is necessary to use the rheological equations used in describing the rhodynamic models, which allows us to carry out numerical calculations of the kinetic dependences of the basic parameters of the process of compressing the product of high-temperature synthesis - the temperature of synthesis, the completeness of chemical transformation, macroscopic the density of the product of synthesis, the level of elastic stresses in the product, the velocity of its melting point deformation and grain size finite product. The starting material for SHS synthesis of the intermetallic compound TiAl is a powder mixture of nickel with aluminum, placed in the form of a molding in a closed mold. The powder compactor is warmed up to a given temperature and ignites in the mode of thermal explosion when the external pressure is applied, under the action of which the compression deforms. The plastic deformation ceases when the synthesis product is cooled to a temperature T_k, at which it loses ductility. For a mathematical description of the process of extrusion of a high-temperature synthesis product, it is necessary to determine a system of equations that takes into account the distribution of the thermo-kinetic and rheological properties of the synthesis product in a mold and caliber. For the final grain size of the intermetallic product under the SHS compression, we can write [6,9]:

$$D_k = \sqrt{D_\varepsilon^2 + \frac{c\rho_0\rho_c r_2 R T_{a\partial}^2}{\chi_2 E_a \left(T_{a\partial} - T_0\right)} k_0 exx\left(-\frac{E}{RT_{a\partial}}\right)} \tag{1}$$

where D_ε – the initial size parameter of the grain,
c – heat capacity of the initial mixture,
ρ_0 – relative density,
k_0 - pre-exponential factor,
E - activation energy of a chemical reaction,
E_a - energy of activation of grain growth,
$T_{a\delta}$ – the material temperature in the matrix,
T_0 - initial temperature.

Computer simulation of the hot-deformation processes of intermetallic γ-TiAl alloys is made using the software package Deform. The Deform program is a powerful system for modeling technological processes designed to analyze the three-dimensional behavior of the metal under various pressure processing processes. The program is based on the finite element method, one of the most well-known, reliable and currently used calculation methods. An automatic grid generator allows you to build an optimized finite element grid, thickening it in the most critical areas. In addition, the program provides important information on material flow and temperature distribution during the deformation process, which allows modeling a complete list of pressure processing processes and solving deformation and heat transfer problems. In solving the thermal deformation problem of compressing γ-TiAl alloys into the Deform program, the following output data were integrated: $H_0 = 50$ mm, $r_1 = 25$ mm, $r_2 = 15$ mm, $T_{ad}(TiAl) = 1654$ K, $T_0 = 300$ K, $p_0 = 0{,}6$, $\rho_{TiAl} = 3800$ kg/m^3, $c_{TiAl}= 600$ J/kg·K, $E_a(TiAl) = 79$ kJ/mol, $D_{Ti} = 100$ μm. In work [8], based on experimental research's methods of kinetic interaction in intermetallic alloys in SHS conditions, it was established that for obtaining γ-TiAl alloy the activation energy was nearly 79 kJ/mole and pre-exponential coefficient $k_0 = 7.2 \cdot 10^8$ s^{-1}. In solving the thermoforming problem of compressing γ-TiAl alloys into the Deform program, the following data were integrated:

- the rheological properties of the γ-TiAl alloys $\sigma = f(\varepsilon, u, T)$, obtained experimentally on the Gleeble-3800 complex [6, 7], which makes it possible to carry out numerical calculations of the kinetic dependences of the basic parameters of the process of compression of the product of high-temperature synthesis - the temperature of the system, the completeness of the chemical transformation, the macroscopic density of the synthesis product, the level of elastic stresses in the product, the speed of its plastic deformation and the grain size of the final product.

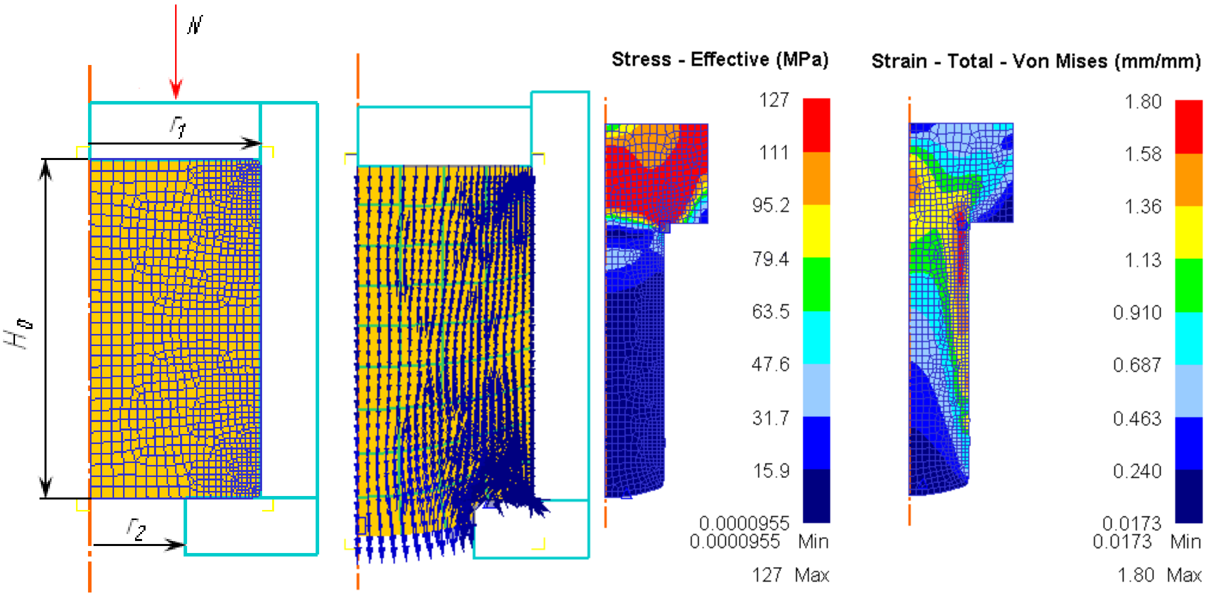
- parameters of the hydraulic press, according to the passport and the layout of the equipment;
- deformation and velocity (degree of deformation, displacement of the punch, etc.);
- temperature and temporal (thermophysical characteristics of the deformable and material of the technological instrument, coefficients of heat transfer, radiation, duration of pause, etc.).

To simulate the compression of the γ-TiAl alloy, the original finite element grid consisted of 100 elements grouped in a rectangle of 10 elements on one side. The sample in question was a cylinder 60 mm in diameter and 90 mm high.

3. RESULTS OF THE STUDY

The simulation results of the stress-strain state of TiAl alloys are presented in **Figure 1.** The process of extrusion is characterized by a stress of comprehensive compression, which provides the material the best in these conditions' plastic properties. Under the influence of compressive stresses, the material flows in the direction of the largest gradient of stresses - from the surface of the punch, where they have the maximum value, to the caliber of the matrix (**Figure 1, b**), where the normal stresses on the free surface of the tangent material are zero.

Comprehensive uneven compression provides the material with the highest ductility compared to other processes of metal treatment, but this feature of the process is manifested in extremely uneven deformations. In this case, only the compressive voltages acting continuously in the direction of extrusion from the maximum values to zero are not always in full volume of the deformed material. The presence of the difference between the intersections of the container and the caliber of the matrix, the forces of contact friction and other factors leads to the fact that the particles of the material begin to move not only in the directions of the greatest deformation, but also in transverse directions. The latter contributes to the emergence of local (additional) stresses, the magnitude of different, direction and sign, and the emergence of tensile stresses. This is facilitated by the movement of material particles along trajectories of different lengths with velocity, change in the process of passage through different zones. The results of modeling the stress-strain state of TiAl alloys are shown in **Figure 2.**



a b c d

Figure 1 Simulation of the process of SHS pressing of the intermetallic TiAl alloy in the program Deform: a - the initial workpiece for calculation, b - the direction of the tensile metal in the workpiece, c - the pattern of the intensity distribution of stresses, d - the intensity of deformation

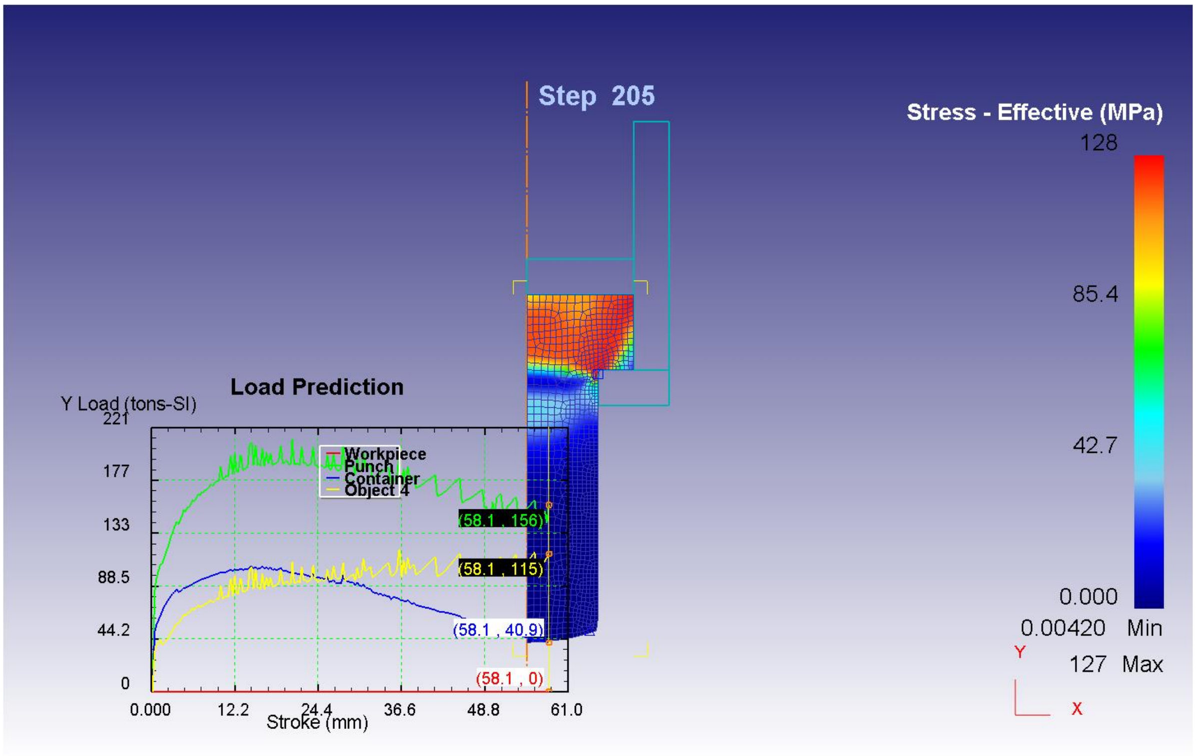


Figure 2 Modeling of pressing processes of TiAl alloys

In the conditions of the synchronization of thermal processes of the SHS and the dynamic compactation of the synthesis product, it is possible to obtain a compact intermetallic alloy with a highly dispersed structure, the size of which is much smaller than that of the alloys obtained by the methods of casting, sintering or shockwave action on the synthesized product. Grinding of grain of intermetallic alloy in the process of its synthesis under pressure occurs as a result of plastic deformation of the product of synthesis and high cooling rates (**Figure 3**). High-temperature synthesis of the intermetallic compound γ-TiAl in a powder mixture of pure elements in the conditions of thermochemical pressing at a thermal explosion at a minimum external pressure on the mixture allows obtaining an intermetallic synthesis product with an average grain size of ~ 30 µm. An increase in the degree of plastic deformation of the intermetallic product synthesized under pressure in the conditions of the thermochemical pressing allows to reduce the size of the grain in the final product by an order of magnitude and even to form a sub-microcrystalline granular structure in the intermetallic alloy [12,15]. The graphical interpretation of calculated results is shown on **Figure 3**.

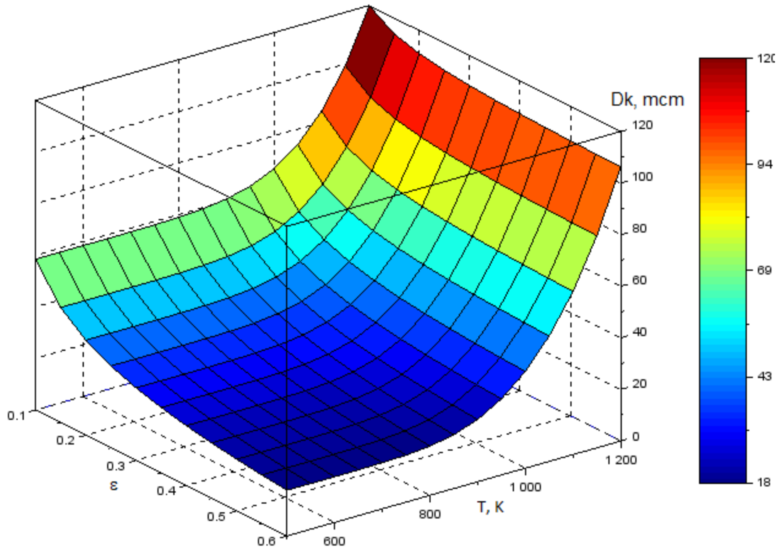


Figure 3 The dependence of grain size of TiAl intermetallic on deformation and temperature degree

4. CONCLUSION

Thus, a mathematical model aimed at obtaining γ-TiAl alloys with a given structure and properties is proposed and implemented, based on the use of data on the features of the physical modeling of the thermochemical pressing process and the DEFORM software complex. High-temperature synthesis of intermetallic compound γ-TiAl in a powder mixture of pure elements in the conditions of thermochemical pressing allows to obtain an intermetallic alloy with an average grain size of ~ 30 microns.

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