The Consolidation of a Powder Material in Conditions of Combined Influence of Different Technological Factors

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Abstract: In the present paper the problems, connected with the formation of a powder material and its surface layers in conditions of chemical thermal treatment and impregnation with melt, combined with the use of mechanical loads at different process stages are examined. The new results of liquid phase influence on compaction of powder preforms, subjected to impregnation, are obtained. The presence of a liquid phase in preform surface layers can also be connected with the change of the materials chemical composition as the result of boronizing, siliconizing or other kinds of chemical thermal treatment.

Keywords: Consolidation; Diffusion saturation; Liquid phase.

Резюме: В данной работе изучены проблемы, связанные с получением порошкообразных материалов и их поверхностных слоев в условиях термохимической обработки и импрегнирования расплавом в комбинации с применением механической нагрузки в различных фазах процесса. Получены новые результаты о влиянии жидкой фазы на прессование прессовок импрегнированного порошка. Присутствие жидкой фазы в поверхностных слоях прессовок может также быть связано с изменением химического состава материала в результате боронирования, силиконирования или других способов термохимической обработки.

Ключевые слова: Уплотнение; диффузионное насыщение; жидкокая фаза.

Садрже: У овом раду проучени су проблеми везани за добицање прашкастог материјала и његових површинских слојева у условима термохемиског претпрачак и импрегнације расплавом у комбинацији са употребом механичког олтарења у различитим фазама процесса. Добијени су нови резултати о утицају течне фазе на компактирање искрскака праха подретних импрегнацији. Присуство течних фаза у површинским слојевима искрскака може се такође повезати са променом хемијског састава материјала као резултатом боронирања, силиконирања или других врста термичког претпрачака.

Кључне речи: Консолидација; дифузионо засићење; течна фаза.
1. Introduction

The sintering concept as a process of the formation of a powder material out of particle conglomeration includes, first of all, variation characteristics of pores and porosity in general. Besides that, this concept must include numerous effects on interparticle surfaces and elementary volumes of powder preforms. Simultaneously, one can observe a change of chemical composition and material modular state (diffusion saturation, interaction between mixture components and protective environment, melting, impregnation and etc.). Especially specific are the processes proceeding in conditions of intensive thermo mechanical influence on the treated material.

Earlier work [1] connected with impregnation of porous powder preforms based on iron by fusion of chromic cast iron in checked depth as performed, resulting in the formation of a practically non-porous wear resistant surface layer. The increase of density and properties of central preform areas was reached by their hot repressing.

Last time investigations were devoted to:
• the study of processes of infiltration of iron preforms with a pressed infiltrate layer and their recompacting during hot or cold forging (HF or CF);
• formation of bimetallic preforms with activation of the transitional layer on the account of its partial flashing and intensity increase of plastic deformation;
• providing minimum porosity and increase of properties of preform surface layers as the result of saturation with boron or silicon and with liquid phase formation followed by hot repressing.

2. Experimental Procedure

Porous (20 – 25 %) preforms of iron powder with the diameter of 20 mm and with a pressed layer of infiltrate out of copper, bronze or brass powders (up to 28 w/o) under pressure \( p_{CP} \) were used for the infiltration study. Sintering (1453 K, 2 h) was matched with infiltration. Cold forging was produced under pressure \( p_{CF} = 300 – 1000 \) MPa. hot forging – after heating 1453 K, 20 min at reduced (referring to the unit of preform material volume in the compact state) energy of compaction \( w = 40 – 200 \) MJ/m\(^3\).

The bimetallic material investigations were performed on cylindrical specimens 20 mm in diameter, and with the height of steel and bronze layers of 11–13 and 2.5–3 mm, correspondingly. Porosity of powder preforms made up 10 – 35 %, knurlings were applied on the end face of compact steel base. Irregular preform heating (on the side of the steel base) was carried out in an electric furnace on a steel support or in a high frequency unit for providing temperature in the area of layer contact 850–950°C.

3. Results and Discussion
3.1. The Compaction of Infiltrated Preforms

The compaction of infiltrated powder materials is possible only in the presence of residual porosity either in the whole volume of preform, or in its part. The presence of significant differences of deformability of the base material and infiltrate inclusions defines expediency of performing special analysis and experiments. The case, when infiltrate inclusions are in a liquid state, deserve special attention.
Energy, expended for the compaction of composite $w_c$, can be determined, based on the rule of additivity and considering it to be equal to the sum of energies, which are spent on the compaction of base material $w_b$ and infiltrate $w_i$. The uses of given values, that is, referring to the unit of volume in compact state, are justified for applying to all these values:

$$w_c = w_b (1 - \varepsilon_i) + w_i \varepsilon_i,$$  

(1)

where $\varepsilon_i$ - volume share of infiltrate content in the composite.

Using the energy equation of compaction in polytropic form [2], we'll obtain

$$w_c = w_m \cdot \left[ \theta_0^n - (\theta_0)_h^n \right] \left( 1 - \varepsilon_i \right) + w_m \cdot \left[ \theta_0^n - (\theta_0)_l^n \right] \varepsilon_i,$$  

(2)

where $w_m, w_m$ - maximum reduced energy of compaction that is spent during all the process from the initial density up to non-porous state for the base material and infiltrate; $\theta_0, (\theta_0)_h, \theta_0, (\theta_0)_l$ - current and initial values of relative density for the base material and infiltrate, correspondingly; $n_h, n_i$ - are degree indexes for the base material and infiltrate.

The equation (2) will be simpler, if one neglects the values $(\theta_0)_h^n$ and $(\theta_0)_l^n$. They are significantly less, than corresponding current values, if at the close of compaction process stages $\theta_0 >> (\theta_0)_h, \theta_0 >> (\theta_0)_l$. Then, on this basis (2), we obtain

$$w_c = w_m \cdot \theta_0^n \left( 1 - \varepsilon_i \right) + w_m \cdot \theta_0^n \cdot \varepsilon_i.$$  

(3)

Analysis of equation (3) shows that its use is not possible as the consequence of the uncertainty of values $\theta_0$ and $\theta_i$. It is possible to be get rid of such an uncertainty by examining the mechanism of the base material and infiltrate behaviour when compacting. These materials fill base pores, remaining after impregnation, whose volume is defined by relative density of composite $\theta_c$. Considering, that conditions of their filling with the material of both components are equal and change in dependence on the change of value $\theta_i$ it is possible to accept

$$\theta_0 = \theta_i = \theta.$$  

(4)

Values of degree indexes in equations (1) – (3) in a wide interval of temperatures turn out to be almost invariant and practically identical for iron (6.53–7.74) and copper (7.70–8.52) [2]. It is possible to accept that composite components occurred in a solid phase state,

$$n_h = n_i = n_c.$$  

(5)

Based on the considerations mentioned above it is possible to bring equation (3) to the following form

$$w_c = \theta_0^n \cdot \left[ w_m \left( 1 - \varepsilon_i \right) + w_m \cdot \varepsilon_i \right].$$  

(6)

Consumption of energy will make up for composite compaction to a non-porous state ($\theta_i = 1$)

$$w_{m_0} = w_m \left( 1 - \varepsilon_i \right) + w_m \cdot \varepsilon_i.$$  

(7)

In the case, if the infiltrate is in a liquid state during hot forging, it is possible to neglect its resistance to compaction. Adopting, that the infiltrate fusion influence on the process of composite compaction is similar to the influence of pores, increasing
(conditionally) its porosity, which approaches base porosity in limit (that is $\theta_i \to \theta_b$) we obtain ($w_m = 0$)

$$w_c = \theta_b^m_n \cdot w_m (1 - \varepsilon_i).$$

(8)

In this case in the presence of a liquid phase $\theta_c$ changes from $[\theta_0 - \varepsilon_i]$ to $(1 - \varepsilon_i)$.

Most frequently cold forging of examined materials is produced on the press equipment, whose main characteristic is the exerted force. That is why the simplest dynamic equation of polytropic function one is used for the compaction analysis of these materials. Using the designations and indexes, used above for analyzing consumption of energy for compaction, it is possible to register similar dynamic compaction equations

$$p_c = p_b (1 - \varepsilon_i) + p_i \cdot \varepsilon_i;$$

(9)

$$p_c = p_m [\theta_b^m_n - (\theta_{0b}^m_n) (1 - \varepsilon_i) + p_m [\theta_i^m_n - (\theta_{0i}^m_n) \varepsilon_i];$$

(10)

$$p_c = \theta_c^m_n [p_m (1 - \varepsilon_i) + p_m \cdot \varepsilon_i];$$

(11)

$$p_m' = p_m (1 - \varepsilon_i) + p_m \cdot \varepsilon_i.$$

(12)

where $m$ – the exponent of dynamic equations, which has corresponding indexes and is connected with the exponent of energy equations by the dependence $m = n - 1$, for composite and its components.

As a rule initial preform density cannot be neglected during compaction of a high-density composite. In this case it is possible to use equations (2) and (10) using components of infiltrated powder materials with similar properties of base and infiltrate materials

$$w_{0m} = w_m; n_b = n_i; p_{0m} = p_m; m_b = m_i.$$

Then from these equations an achievable value of relative density $\theta_i$ is defined at for predetermined consumptions of energy and compaction pressure, and also for known equation characteristics and initial conditions of the process.

As a result of statistical data handling the equation of regression (13), adequately describing the influence of technological factors on porosity $P$, was obtained

$$P,i = 41.44 - 9.87 \cdot p_{CF} - 20.75 \cdot \varepsilon_i - 5.92 - \ln w.$$

(13)

The value $P_i(\varepsilon_i)$ is defined by the influence of two groups of factors. On one hand the infiltrate mass increase increases the volume of the infiltrate filled pores, but on the other hand it brings about the reduction of resistance of plastic deformation, bettering conditions of particle deformation and metal filling of moulding pores. The fact, that during pressing not all infiltrate is in liquid state, can have a definite effect on the process of compaction, when the infiltrate does not (conditionally) exert resistance to the compaction, a part of it can crystallize until compaction ends, and the other part can dissolve in the base material. Determination of the quantity of the infiltrate, placed in liquid state at the moment of hot repressing, can be determined by means of reckoning.

Equation (2) is used as the initial one. Marking volume shares of infiltrate in liquid state $-\varepsilon_i$, and in solid state $-\varepsilon_i$, and supposing that only part of the infiltrate in the liquid state does not prevent compaction, and that the solid phase at high temperatures behaves like a base material, rising its volume share, we obtain
\[ \varepsilon_i = \varepsilon_1 + \varepsilon_2; \bar{w}_{m_1} = 0; \bar{w}_{m_2} = \bar{w}_{m_3}; \theta_c = \theta_c - \varepsilon_i; \theta_0 = \theta_0 - \varepsilon_i. \]  

(14)

For limiting composite compaction, that is in its non-porous state
\[ \theta_c = 1; \bar{w}_c = \bar{w}_{m_2}; \theta_0 = (1 - \varepsilon_i). \]  

(15)

Taking these considerations, changing (2), we get
\[ \bar{w}_{m_2} = \bar{w}_{m_2} \cdot (1 - \varepsilon_i) \cdot (1 - \varepsilon_i)^{p_{m_2}}, \]  

(16)

\[ \varepsilon_i = 1 - \left( \frac{\bar{w}_{m_2}}{\bar{w}_{m_2}} \right)^{p_{m_2}}. \]  

(17)

3.2. The Formation of Bimetallic Materials

Significant difficulties appear during bimetallic material formation especially in the case, when physicomechanical properties of the material of their layers have essential differences. The most well known examples of such materials are bimetals based on steel with a bronze working layer. As this takes place the base can be a compact or powder. Here the main task is providing high quality of joining between layers in the process of preform hot forging.

As the result of investigations the possibility of obtaining of bimetal of the type "steel-bronze" with a powder working layer by the method of irregularly heated preform hot forging in the presence of a liquid phase at interlaminar boundary was confirmed.

The analysis of mass transfer activation possibilities when obtaining hot-deformed bimetals showed, that in the area of layer contact the temperature must make up 850 – 950°C, providing an austenite state of the steel base, its satisfactory deformability, activity and wettability with bronze which is in a solid-liquid state at indicated temperatures. It is possible to prevent spreading of bronze on the surface of compact steel base (or impregnation of the porous powder base with bronze), by creating a temperature gradient in the preform.

A computer program [3] is used for calculation of the bimetal preform temperature field at the furnace and inductive heating. It is established that the necessary temperature gradient in the preform with a compact base can be created by applying a furnace as well as inductive heating, and only inductive heating is necessary when obtaining a bimetal on a powder base in connection with low thermal conductivity of the steel powder base.

The optimal form is asymmetrical form of knurlings, deposited on the surface of the compact base in the shape of concentric circles, in order to provide satisfactory technological strength of preforms with a bimetal compact base after cold pressing of the powder layer and creation of conditions of maximum activation of joining process during hot forging. The angle at the top of knurlings should be in the interval of 40–50°, step – 1.4–1.7 mm, height – 1.0–1.5 mm. In such a way, the technological possibility of performing hot forging in the presence of a liquid phase of bronze, which was formed near the boundary of layer division, is provided.

Estimation of the complex influence of technological factors on layer connection strength is performed. It is established, that the temperature-time and energy parameters of technology, determining temperature on the contact boundary, value of fusion area and also the conditions of deformation process operation, are the most significant. To provide
maximum strength of the layer connection of the bimetal specimen on the compact base it is necessary to perform cold pressing at \( p_{cp} = 360 \text{MPa} \), irregular preform heating should be realized in the furnace on the steel support, and hot forging – at \( w = 170 \text{MJ/m}^3 \).

The pressure of cold pressing is the most significant factor when obtaining bimetallic specimens on a powder base, which is connected with its influence on the relation of opened and closed pore quantity in the base material and on the depth of pore infiltration with liquid bronze. The porosity value defines physicothermal preform properties and the conditions of irregular heating performing. Optimal conditions of joining of layers of the bimetallic sample on a powder base and compaction of the whole preform volume are provided in the case of cold pressing performed at 300 MPa, hot forging – at 250 MJ/m³.

Both furnace and inductive conditions of irregular heating in the dependence on preform parameters can be calculated with the use of a defined mathematical model.

The structure of the working bimetal layer, obtained by hot forging, using irregular heating, is characterized by the presence of four areas. The structural state of these areas depends on the liquid phase quantity, which existed in them during irregular heating and hot forging. The maximum quantity of liquid phase is typical for area I of adhesion interaction of bimetal layers and melting area II, adjacent to it, and minimum quantity – for the area of mainly solid state IV. Localization of area II depends on the base type. It is mainly situated in hollows between knurlings using a compact base, and in the case of a powder base it is situated in its pores, adjacent to the contact boundary. Area III of the solid-liquid bronze state is situated between areas II and IV. The area sizes are defined by temperature dynamic parameters of the process if the thickness of the working layer is constant.

High connection strength of layers of bimetal on the compact base is provided mainly thanks to mass transfer acceleration near the division boundary on the account of joint synergistic action of the liquid phase of bronze and intensive plastic deformation of knurlings, inducing activation of the contact surface. It is established, that the indexes of mass transfer reach maximal values on those parts of knurlings, whose deformation proceeded under the action of tensile stresses. Mass transfer takes place less actively in the action area of compressive stresses.

The performance of preliminary sintering provides mass transfer relief during hot forging on the account of performance of diffusion processes and reduction of oxidized films on the contact surface of bimetal layers. Optimal conditions of bimetal preform with compact base sintering are – 870°C, 60 min, bimetal with powder base – 870°C, 80 min.

The hypothetical structure formation model was suggested to obtain bimetal by hot forging, applying irregular heating, the nature of which is in the consideration of changes of preform material structure stipulated by temperature and deformation at different technological stages of its treatment. Four main stages can be defined:

- in the first stage during irregular preform heating melting of the working layer material takes place with the formation of a liquid phase, whose quantity reduces as far as possible from the contact boundary to the outside surface and is defined by a corresponding temperature distribution in the process of irregular heating. It is accompanied by the shrinkage of the working layer material in the axis direction, besides the impregnation of the powder base takes place in the depth of 1–1.5 mm when obtaining bimetals on a powder base. In connection with the performance of irregular heating near the liquidus temperature of bronze the supposition of the fact, that impregnation takes place in the condition of self-excited
oscillations with the alternation of melting and impregnation processes in areas of bimetal layers adjacent to the contact boundary, was put forward;

• the second stage begins from the moment of preform transfer from the furnace into the die and finishes with the moment of loading application. The possibility of technological realization of transportation of preform, containing the liquid phase, is provided by the concentric knurlings of compact base and powder base pores, in the volume where it is localized;

• the third stage – hot forging of heating preform, in the process of which deformation of the working layer material, knurlings of compact base and powder base compaction take place in succession;

• in the final stage crystallization of the liquid phase in the material of the working layer finishes and phase transformations take place in the base material.

Hot forging with the use of irregular heating enables obtaining of a material, whose antifriction properties do not yield corresponding indexes of famous analogs. Good resistance against abrasion is stipulated by the presence in the structure of an eutectoid net on grain boundaries of the α-solid solution, and satisfactory indexes of the friction coefficient are stipulated by regular distribution of lead inclusions as well as by the volume of working layer as over its surface. Such bimetals can be used for work in conditions of sharp changes of temperatures and can also be put to heat treatment with the purpose of steel base strengthening. This method can be recommended for practical use considering the technological and economical effectiveness of the developed method [4] of obtaining bimetals.

3.3. Surface Layer Formation with the Presence of a Liquid Phase, Obtained as the Result of Boronizing and Siliconizing of Materials

The experience of boron use for alloying powder materials testifies to its positive influence on the process of porous preform consolidation during sintering on the account of formation of liquid eutectic areas, providing accommodation of particles and refining of their surfaces from oxide films. To our regret, great potential possibilities of boronizing on improving the quality of interparticle boundaries, and also deformability of surface preform layers on the account of liquid phase presence were not used. Meanwhile, increasing of the temperature of diffusion saturation and hot forging to eutectic is in perspective. But information on the choice of rational technological schemes and conditions of such material obtaining is absent in literature. Determination of this problem will allow widening of nomenclature of powder items, raising their wear and corrosion resistance.

As the result of investigations of regularities of kinetics of solid and liquid phase diffusion saturation of cold pressed and hot forged powder preforms on iron base with boron are established, saturation differences from compact material boronizing are defined. The presence of open and blunt knife pores in such preforms, and also increased defectiveness of the structure of powder materials stipulate active diffusion performing and larger depth of the boronized layer in comparison with cast steel. In the course of formation of a liquid phase the boron content eutectic latter is infiltrated in the limited depth of porous preforms, and its exit takes place on the surface of item significantly later, than in the case of hot-forged powder and compact cast preform boronizing.
A hypothesis, describing the mechanism of consolidation of boronized powder preform in the process of its hot repressing in the presence of a liquid phase eutectic, is proposed. At the instant of preform transfer into the die and in the die itself the processes of eutectic crystallization and deformation in the surface layer in the presence of a liquid phase follows. In the course of hot repressing the processes of forcing fusion through into interparticle pores, its diffusion hardening in pores, matrix compaction, and also pressing borides in the sublayer with insignificant exit of the latter in fin take place simultaneously.

It is established, that the reason of anomalous decrease of strength indexes of boronized powder materials with carbon content increasing is the action of residual stresses, connected with the difference of thermal expansion coefficients of borides and iron. The performance of hot forging, providing a manifestation effect of boronized preform hardening, stipulates the formation of tensile stresses, whose value rises with carbon content increase.

The structure and phase composition of boronized powder materials is determined. On the surface the continuous boride FeB and Fe₂B layer, under which a sublayer and transitional area are situated, is formed. Under the condition of solid phase saturation the sublayer presents boron ferrite with boride inclusions, and in the condition of saturation in the presence of a liquid phase it presents an eutectic (α-Fe+Fe₂B). A transitional area is formed on the account of carbon rejection with boron into the item core. The carbon content in the material determines the depth of this area, and its composition is on the eutectoid level.

The optimal conditions of boronized preform repressing, providing required precision and surface finish, are established: $t = 1200^\circ C$, $\tau = 600$ s; $w = 250$ MJ/m³.

Applications to hot-deformed powder materials on iron base siliconizing were not studied. This is connected with the fact, that siliconized layers on powder iron are characterized by high porosity, reducing their operational properties significantly. At the same time it known from the practice of diffusion siliconizing of compact steels, that it allows a significant increase of their corrosion, heat and wear resistance. In this case, contrary to chroming, siliconizing provides an increase of corrosion resistance in sulphuric and hydrochloric acids, and diffusion layers have a larger depth. The mechanical properties of siliconized material exceed siliceous cast iron.

Liquid siliconizing, siliconizing in alumino-thermical and powder mixture on the base of ferrosilicon without an activator and with an activator NaF at $t \leq 1100^\circ C$ bring about the formation of a diffusion layer, consisting of α-phase – disordered solid solution of siliceous in iron. In the course of siliconizing with activators N⁺HCl, NaCl and NaF and at $t \geq 1200^\circ C$ two-phase layers, consisting of α-phase and α₂-phase – ordered solid solution of siliceous in iron (Fe₃Si) – are formed. FeSi is formed at $t = 1150 - 1200^\circ C$ and saturation time $\tau \geq 6$ h in the external part of the diffusion layer.

The presence of a columnar structure of grains of siliconized layers after hot forging is discovered, which is stipulated by the growth of grains of siliceous ferrite into the core. It is necessary to perform hot forging at the temperature, providing the possibility of the existence of a liquid phase in the system Fe – Si, that is $\sim 1200^\circ C$, in connection with low deformability of siliconized layers. The size of layer grains rises with carbon content increase in the saturated material. The core structure of powder material practically does not undergo changes after diffusion siliconizing.

The concentration of silicon $C_{Si}$, w/o: in α-phase – 2 – 5.3; in α₂-phase – from 5.3 to 13 – 15, in the core – 0.5 – 2 – is determined. Microhardness reaches $5100 - 5500$ MPa on the
surface, smoothly decreasing to 2000 – 5000 MPa when passing to the core. Carbon and alloying elements significantly affect $C_S$ and microhardness, by raising them.

The effect of pressing carbon back out of siliconized layer is discovered. It is stipulated by the insolubility of carbon in $\alpha$-solid solution of siliceous ferrite and its significant solubility in $\gamma$-iron.

The siliconized layer formation mechanism is established. Using chloride activators ($NH_4Cl$ and $NaCl)$ a $\alpha_r$-phase ($Fe_3Si$) is formed first, and then as a consequence of silicon diffusion in depth of the $\alpha$-phase is formed. On the contrary, when using a fluoride activator first a $\alpha$-phase is formed, and then - $\alpha_r$-phase. In the first case the mass and sizes of items decrease, in the second case – increase.

It is discovered, that $\alpha_r$- and $\varepsilon$-phases, forming at $t \leq 1200^\circ$C, are characterized by high porosity. Practically non-porous siliconized layers are obtained only at temperatures higher than 1200°C, providing a possibility of liquid phase formation. The performance of siliconizing in powder backfilling of optimal composition, w/o: 50 – 80 of ferrosilicon ($Si - 45$ w/o), 18 – 47 of aluminium oxide and 2 – 3 of activators $NaF$ or $NH_4Cl$, is the condition for obtaining of non-porous siliconized layers, containing 14.5 w/o of silicon.

Increasing the saturation temperature and time brings about an increase of the depth of the siliconized layer, porosity decrease and $C_S$ growth in the layer. Alloying elements, widening $\gamma$-iron field ($C$, $Ni$ and $Cu$), provide reduction of layer depth, and elements, narrowing the field ($Mo$) – increase. Siliconized layers on specimens out of alloyed iron powders have a smaller porosity and greater silicon concentration than the layers on the specimens made out of iron powder. The preform porosity increase brings about the siliconized layer depth increase, and the silicon concentration in it decreases.

Non-porous siliconized layers, with the highest silicon content, possess the greatest resistance. The performance of siliconizing at the temperature of liquid phase formation, increasing of the content of carbon, nickel, copper, molybdenum, the decrease of initial porosity of saturated material provide this. The defence of siliconized materials from corrosion and oxidation is provided by the silicon oxide film, forming in the process of tests; in this case the silicon concentration should not be less than 14.5 w/o for the formation of continuous oxide film.

Quantity indexes of changing material properties as the result of high temperature siliconizing are determined:

- mechanical property decrease, which is stipulated by the deficient of strength of the siliconized layer, its high fragility and initiation of residual tensile stresses in it;
- wear resistance increase for dry friction 3.3 – 5.4 times because of high microhardness of siliconized layers, and their low adhesive ability as a consequence of oxide silicon film formation on the surface;
- heat and corrosion resistance increase. In this case heat resistance is on the level of stainless steel 12H18N9T;
- the materials, combining high corrosion and wear resistance possess the greatest resistance, owing to corrosion-mechanical wear. In this case the wear at friction in an aggressive environment depends on material corrosion resistance to a greater degree than on its physico-mechanical characteristics. That is why the increase of aggressiveness of corrosion environment, bringing about the significant increase of non-corrosion resistant carbon steel wear, practically does not effect the resistance of siliconized materials.
The steel 40N2M (the composition, w/o: C – 0.4; Ni – 2.0; Mo – 0.5), siliconized according to scheme HF+DS (DS – diffusion siliconizing), should be considered in the material, possessing the best combination of properties. The ultimate bending strength of this steel makes up 1285 MPa, impact strength – 670 kJ/m², its wear resistance is on the level of hardened eutectoid steel and its corrosion and heat resistant properties do not yield the same properties of stainless steel 12H18N9T. In the case when high demands of precision and surface finish are made, the production of items out of high carbon powder steels according to scheme DS+HF is preferable.

4. Conclusions

The use possibilities and perspectives of combined methods of powder item obtaining are shown. These methods foresee the liquid phase presence in the whole volume or in localized preform area during its hot forging.

Analytical dependences, allowing us to take into account liquid phase presence in dynamic and energy compaction equation, are obtained. It is possible to establish liquid phase quantity at the moment of hot deformation performance, owing to a decrease of expenditure of energy on compaction.

Method variants of effective use of liquid phase presence in localized areas of treated performs based on iron are examined. In the transition area of bimetal “iron - bronze” it is formed on the account of bronze and activates the joining process during HF. A liquid phase appears in the surface layers on the account of formation of easily melted material components. In the case of boronizing the liquid phase improves layer deformability and provides its non-defectiveness. It is advisable to perform siliconizing after hot forging, when liquid appearance provides repairing of surface defects. In both cases working material characteristics repeatedly increase.

References