UDC 621.762.4

Production of High Efficiency Complex Alloyed Steels and Alloys with Ceramic and Intermetallic Strengthening

Yu.F. Ternovoi, V.T. Zubkova, Yu.V. Artamonov, A.B. Kuratchenko, Yu.V. Melnikov , L.I. Zolotareva

SE "USSI"

The paper shows the fundamental possibility of production wear and heat resistant materials with ceramic and intermetallic strengthening. Developed in the SE "USSI" structures of composite materials and alloys with intermetallic strengthening, as well as their production technology provide a set of high service properties, that allows to use these materials for various types of tools and high-duty machine parts.

Keywords: METAL-CERAMIC COMPOSITES, ALLOYS WITH INTERMETALLIC STRENGTHENING, HOT GASOSTATIC PRESSING, HOT EXTRUSION, 4-DIE FORGING DEVICE, UNIFORMITY OF STRUCTURE, TOOLS AND PRODUCTS DURABILITY

Introduction

Improving the efficiency of production of science-based metal products of special steels and alloys (instrumental, corrosion resistant, heat resistant, precision, etc.) is of great importance for both metallurgical and machine-building complex of Ukraine. Necessity of creating high-performance materials with high wear resistance, heat resistance, corrosion resistance and fire resistance is caused by rapid development of special branches of machine building (aircraft building, rocket production, shipbuilding), and other industries (mining and metallurgical industry, pipe production, etc.).

In recent years, the experimental plant SE "USSI" mastered the production several dozens of steel grades and alloys with a radically new and complex scheme of alloying. Our partners from EU countries (France, Germany, Spain, Portugal) are particularly interested in the creation and manufacturing experimental batches of products from heat-resistant and wear-resistant materials with ceramic and intermetallic hardening. One of the ways to increase wear resistance of materials used for manufacturing various types of tools and machine parts of critical applications is ceramic hardening of alloyed steels and alloys by powder metallurgy methods.

Results and Discussion

"USSI" developed a technology of production of wear-resistant composite materials, which are metal-ceramic composites based on alloyed steels and alloys hardened by refractory particles in the form of carbides, nitrides, oxides, borides and other refractory compounds by mechanical alloying. The technology of composite materials production is based on finely dispersed refinement of atomized powders of special steels and alloys and refractory compounds, their mechanical mixing and compaction methods of solid-phase sintering (**Figure 1**). It was established that the most promising device for fine grinding of metal powders is air-jet mill, and for refractory compounds - vibration mill [1].

Hot isostatic pressing (HIP) and hot extrusion (HE) are considered to be the most effective methods of compaction.

Thanks to using HE a principle possibility of producing strained materials from complex alloyed steels and alloys with ceramic hardening, which have low plasticity and high resistance to deformation. The experience of "USSI" shows that such difficult-to-form materials can not be obtained by traditional methods of forging or rolling. Under the conditions of the institute approximately 50 compounds of composite materials based on powder materials of different classes of steels and alloys, hardened refractory particles TiC, TiN, TiCN, BN, Al_2O_3, Y_2O_3, ZrO_2, MoS_2, SiC and other compounds were obtained. In foreign countries similar materials under the trade name “Ferro-TiC” (USA) and “Ferro-Titanit”

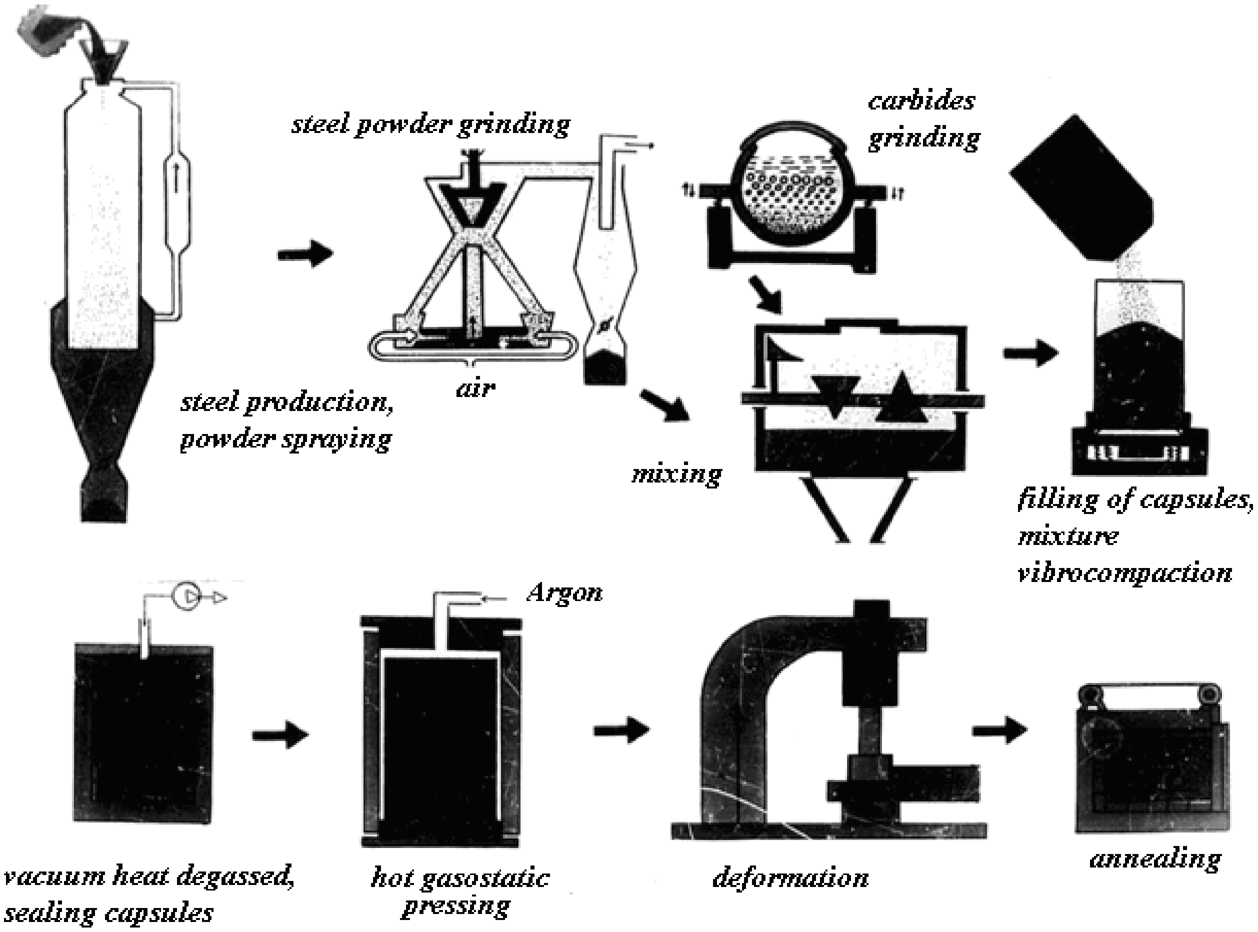


Figure 1. Flow sheet of production of composite materials with ceramic hardening in the SE "USSI"

(Germany) are produced by liquid-phase sintering at temperatures of 1380-1420°C [2].

The main advantage of the technological process using the method of liquid-phase sintering is the possibility of production billets made of composite materials maximally close in shape to the finished products. However, this method has two major drawbacks - the presence of high porosity and the interaction of the steel matrix with refractory particles because of diffusion processes, what leads to a decrease in physical and mechanical and operational properties of metal-ceramic composites [3]. The principal difference of the developed in "USSI" technology from the known method of liquid-phase sintering is compaction with sintering (HIP method) or compaction with sintering and deformation (HE method) of powdered composites mixing in the solid phase at temperatures not exceeding 1180°C.

Using the methods of solid-phase sintering (HIP or HE) is appropriate in terms of preventing the diffusion processes between the matrix and refractory compounds, as a result of which their own hardening phases remain in the form of carbides and /or intermetallides in a steel matrix of composites.

Figure 2 shows the microstructure of the most representative compounds of composite materials with complex hardening on the basis of high-speed (a), die (b), corrosion resistant (c), steels and superalloys (d). The microstructure of composite materials based on different classes of steels and alloys is characterized by a high degree of alloying of α- or γ-solid solution of the matrix and uniform distribution of the introduced phase-reinforcers in the form of refractory compounds.

The deformed material obtained by the HE is characterized by a more uniform distribution of refractory particles introduced into the steel matrix by mechanical alloying (**Figure 2a, b**), what provides a higher level of mechanical properties compared with material obtained by HIP (**Figure 2c, d**). Due to the presence of their own phase-reinforcers in the metal matrix and high uniformity of distribution of ceramic particles (refractory compounds) improvement of wear resistance, heat resistance and high temperature characteristics of powder metal composites is achieved.

Composite materials obtained by the developed technology of the "USSI" are subjected to heat treatment, different types of machining,

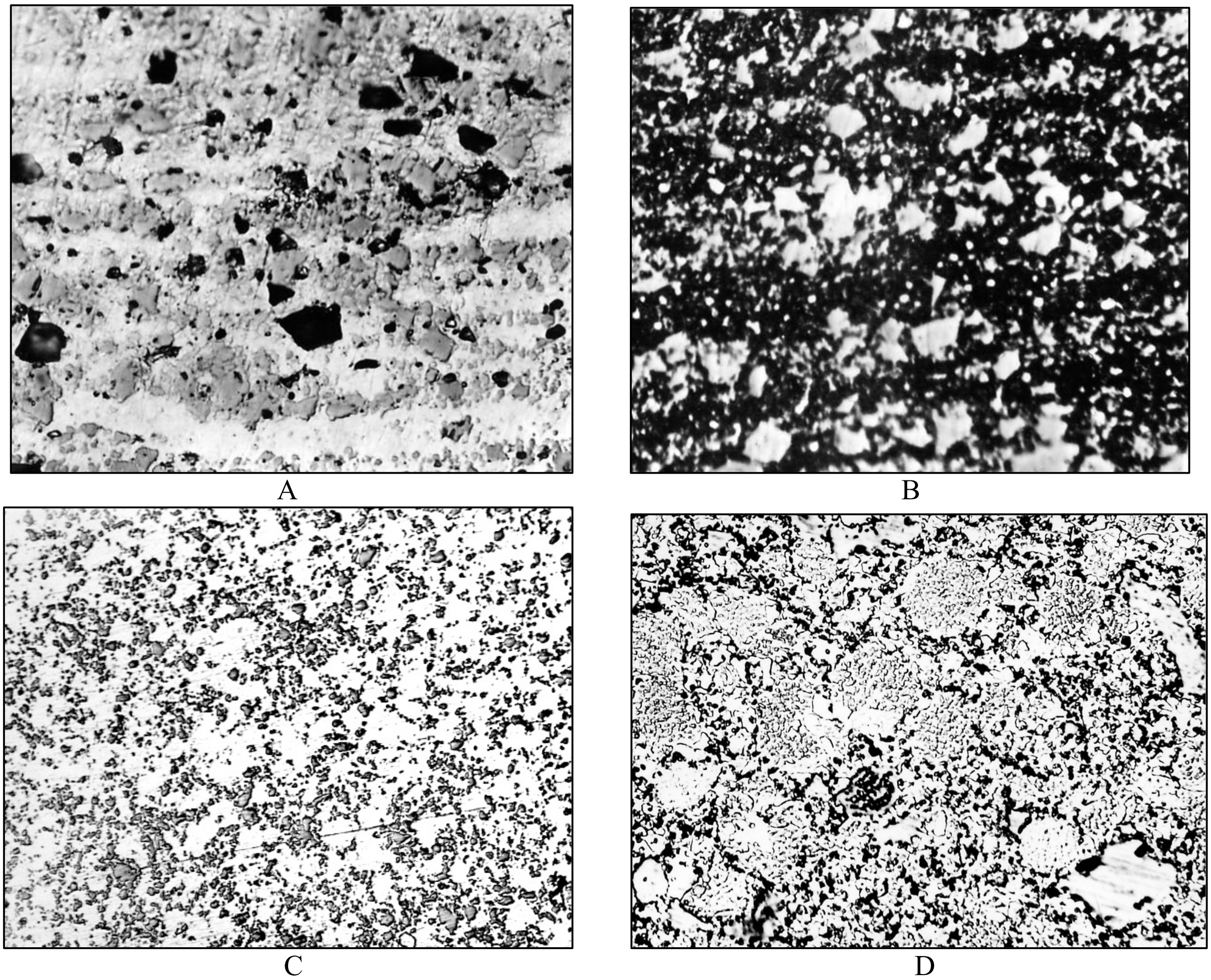


Figure 2. The microstructure of composite materials based on different classes of steels and alloys with ceramic hardening, zoom 800^x: a – Р12М3К8Ф2-МП+16%TiC+4%Al_2O_3; b– 6Х6В3МФС+19%TiC+1%MoS_2; c – Х18Н10Т+20%TiC; d – ЖС-6+16%TiN

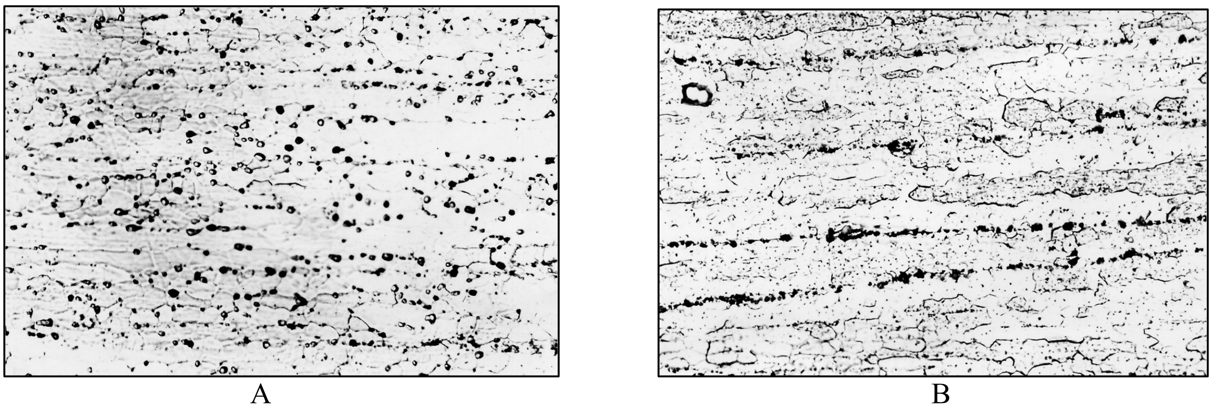


Figure 3. The microstructure of the powder aluminum alloy Al-Zn-Mg-Cu-Zr (a) and composite material system Al-Zn-Mg-Cu-Zr+2%SiC (b), zoom 800^x

welding and soldering. Heat-treated composites (after hardening followed by tempering or aging) have high resistance to wear, abrasion, corrosion and oxidation, low coefficient of friction. Composite materials are fire resistant, lighter than steels by 12-15%, and hard alloys by 50-60%.

The developed technology of powder composite materials provides a set of high service properties that allows to use these materials for various kinds of wear-resistant cutting, die and deforming tools as well as machine parts and mechanisms of high duty.

Hardness of the composites based on high-speed steels with complex hardening of type

Р12М3К8Ф2-МП+16%TiC+4%Al_2O_3, Р12МФ5К5-МП+19%TiC+1%B_4C and other compounds reaches the level of 87-89 HRA that corresponds to hardness of hard alloys of the type ВК8; heat resistance 650-670 ° C, which is 20-30 ° C higher than the level of heat resistance of heavy alloyed powdered metal high-speed steels Р9М4К8-МП, Р12М3К5Ф2-МП, Р6М7Ф6К10-МП (ASP 2060), etc. These materials also have a sufficiently high level of mechanical properties: bending strength 1500-2200 MPa, impact strength 80-150 kJ/m^2, depending on the method of compaction (HIP or HE).

Resistance of cutting tools made of composite materials based on heavy alloyed high-speed steels is 2-5 times higher than similar steels of traditional ways of production. Composites based on heavy alloyed high-speed steels with complex hardening should be used for high-performance cutting tool manufacturing, mostly of complex shape (angular and end mills, taps for coarse-feeding thread) and simple shape tools (cutters) for processing high-strength, refractory and titanium alloys. These composites can be used for deforming the tool instead of hard alloys: grooving dies, mandrels for tube drawing, rolling and grooving instrument, inserts for drilling tool, cutting coal, frozen soil.

Composite materials based on die steels should be used for cutting, drawing and cold forging dies including for the reinforcement of wearing parts in the assembled dies as well as working elements of molds (matrices, punches), circular knives.

The use of composite material of 6Х6В3МФС+19%TiC+1%MoS_2 has provided improvement of resistance of mandrels for deformation of tubes of corrosion-resistant steels in 5-6 times in comparison with the cemented and chrome-plated steel 30ХГСА with hardness 58-60 HRC. The use of composite materials based on stainless steels and fire resisting alloys based on nickel is possible under conditions of a wide range of temperatures, alternating dynamic and static loads and chemical effects, such as during cyclic friction in corrosive media, etc.

Tests for hot abrasion of the composite structure ЖС6-МП+16%TiN based on the heat-resistant nickel alloy showed that the resistance of the tested material is 1.5-2.0 times higher than the resistance of the basic casting alloy ВЖЛ-2. The data obtained indicate the prospects of using these materials as a solderable plate, reducing wear of tyre blades of aircraft engines

The institute has experience in obtaining powder of aluminum alloys on the basis of Al-Zn-Mg-Cu-Zr system, including hardened by silicon carbide particles (SiC). High alloyed powder alloy Al-Zn-Mg-Cu-Zr, produced by HE has shown the level of properties, significantly higher than that of cast alloys: σ_B = 725 MPa, B, σ_T = 705 MPa, δ = 7,5% due to improved microstructure (**Figure 3a**). Injection of hardening carbide phase SiC in amount of 2 wt% into this alloy by mechanical alloying allowed to increase wear resistance and high temperature performance as compared to non-reinforced alloys (**Figure 3b**).

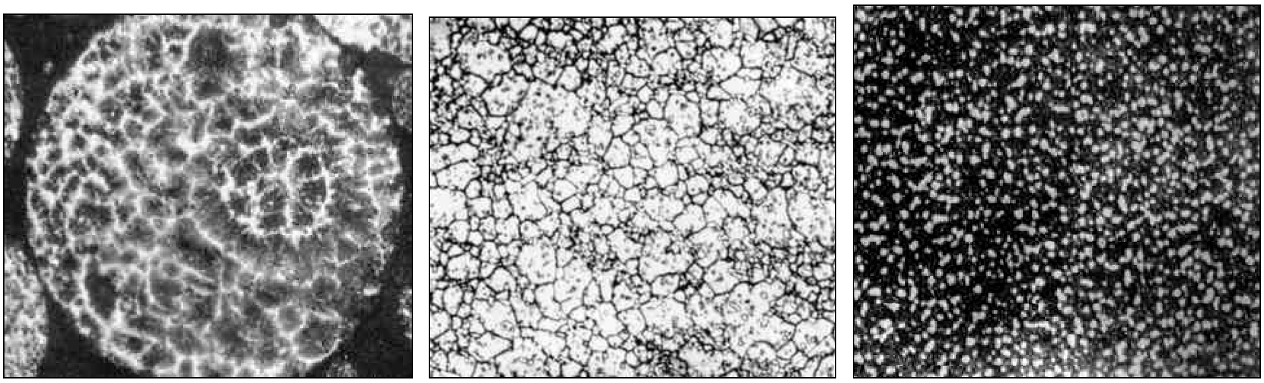
Extensive use of high strength steels and alloys based on nickel and titanium with low machinability in machine building served as a pretty powerful incentive for the creation of new tool materials with intermetallic hardening based on the of the system Fe-Co-W-Mo or Fe-W-Mo-V-Co. Development of alloys of this type was studied by many researchers, both in our state and abroad [4]. One of the major drawbacks of produced alloys with intermetallic hardening was their low technological plasticity [5].

The most focused and complete research on the development of new alloys with intermetallic hardening and methods of their production were conducted in SE "USSI". The Institute has developed new precipitation-hardening alloys with intermetallic hardening - USP18K23-MOD (В11М7К23-МП-МОД) and USP20K18-MOD (В9М10К18-МП-МОД). According to operating characteristics these alloys occupy an intermediate position between hard alloys and instrumental steels, combining hardness, heat resistance and wear resistance of hard alloys with strength and toughness of high speed steels of increased productivity.

For the first time in Ukraine on the base equipment of USSI the production of new alloys with intermetallic hardening by powder metallurgy method was implemented. Technological process of production these alloys includes vacuum-induction melting, atomizing, classification of powder, compaction by the HIP method, the strain redistribution in the 4-die forging device and heat treatment. Using a 4-die forging device installed on the press АКП-500 has increased the metal yield by 10-30% in the production of powdered alloys with intermetallic hardening of type USP18K23-MOD and USP20K18-MOD.

The developed design of a 4-die forging device and advanced technology of the quadripartite radial shear forging (**Figure 4**) provide deep study of the metal on the entire cross section of the workpiece, absence of gaps in the central zone of the billet, and also exclude development of surface defects [6]. Experimental batches of powder alloys with

Figure 4. 4-die forging device installed in a hydraulic forging press АКП-500 SE "USSI"



A B C

Figure 5. **Microstructure of the gas dispersed powder (a) and deformed alloy powder USP18K23-MOD with intermetallic hardening after tempering (b) and tempering + aging (c), zoom 800^x**

intermetallic hardening on the basis of the system Fe-Co-W-Mo obtained with the use of the quadripartite compression scheme have extremely uniform microdispersed structure and high physical-mechanical and service properties.

The microstructure of the initial gas dispersed powder represents primary dendrites of α-solid solution with the size of the dendritic cells up to 8 microns, along the boundaries of which hardening intermetallic phases are located, identified as θ-phase (Fe, Co)$_7$(W, Mo)$_6$ and Laves phase ($Fe_2W(Mo)$) (**Figure 5a**). The structure of the deformed alloy powder is characterized by high homogeneity and dispersion of intermetallic phases. During heating for hardening with optimum temperatures (1250-1260 °C) intensive dissolution of intermetallic phases, mainly θ-phase, occurs but a part of intermetallic compounds retaines up to temperatures of tempering (1260 °C), delaying the growth of the austenite grain. Structure of a powder alloy after tempering is fine-grained, the austenite grain size is 11-12 ball (**Figure 5b**).

With aging at 580-600 ° C the release of dispersed particles θ-phase and Laves phase occurs, dissolved during hardening, the so-called process of dispersion hardening. The microstructure of the deformed powder alloy after hardening and aging represents fine-needled martensite with uniformly distributed fine particles of intermetallic phases (Fe, Co)$_7$ (W, Mo)$_6$ and $Fe_2W(Mo)$ (**Figure 5c**).

Results of the study of physical and mechanical properties (Table) showed that after tempering and aging of alloys with intermetallic hardening reach the level of hardness of solid alloys of the type BK8 - 70 HRC, heat resistance of 700 °C, which is 50-60 °C higher than heat resistance of high-performance high-speed steels (with carbide hardening). The maximum values of hardness, heat resistance and mechanical properties are achieved in alloys produced by powder metallurgy.

It is established that when using the obtained materials with hardness 67.5-70 HRC, heat resistance 690-700 °C and bending strength 2300-2600 N/mm^2 increasing resistance of tools 3-7 times in comparison with high-speed steels with carbide hardening during heavy-duty processing of titanium and nickel alloys is achieved.

Table. Physical and mechanical properties of the alloy USP18K23-MOD, obtained by different technological options

Production method	Hardness after annealing, HB	Hardness after tempering, HRC	Martensite grain number	Hardness after aging, HRC	Bending strength, σ_b, N/mm^2	Impact strength, MJ/mm^2	Heat resistance, °C (HRC58)
MF	340	46-47	10-11	69	2400-2500	10-11	695
VIM	343	45-46	9-10	68.5	2300-2400	9-10	695
ESR	350	46-47	10-11	67.5	2500-2550	10-11	690
OO	350	44-45	11-12	69-70	2500-2600	11-12	700

Given the results of the process of plasticity and resistance, the production of such materials should be implemented by the most appropriate method of powder metallurgy, using effective methods of deformation (HE, radial forging at the RFM and radial-shear forging in a 4-die forging device) that eliminate the disadvantages peculiar to the traditional hard-forged materials in presses and hammers with double-sided compression scheme.

Implementation of the developed steels and alloys with intermetallic and ceramic hardening into the industry of Ukraine, Russia and other CIS countries and the EU will provide materials for different types of wear-resistant tools and details of high duty (structural elements of aircrafts, highly loaded metal-cutting tools and other products).

Conclusions

1. SE "USSI" developed the technology for production wear resistant composite materials based on complex alloyed powder steels and alloys, hardened with refractory compounds (carbides, nitrides, oxides, borides) by mechanical alloying.

2. The principal difference between the developed technology of production metal-ceramic composites from the known method of liquid-phase sintering is the compaction with sintering (HIP method) or by compaction with sintering and deformation (HE method) of the initial components of composite mixtures in the solid phase at temperatures not exceeding 1180 ° C.

3. Deformed composite material produced by HE has a more uniform distribution of refractory particles introduced into the steel matrix by mechanical alloying that provides a higher level of mechanical properties in comparison with the material obtained by HIP.

4. In Ukraine (SE "USSI") the production of wear-resistant and heat-resistant instrumental alloys with intermetallic hardening by powder metallurgy is implemented.

5. Using 4-die forging device installed on the

press АКП-500, allows to provide deep study of the entire cross section of the metal, the absence of surface defects and fractures in the central zone of he billets in the production of instrumental alloys with intermetallic hardening of type USP18K23-МОД and USP20K18-МОД.

6. Experience of SE "USSI" shows that the production of cjmplex alloyed alloys with intermetallic hardening, etc. hard-to-deform materials from high-alloy steels and alloys, it is advisable to carry out the method of powder metallurgy, using effective methods of deformation (ET, radial forging in RFM and radial-shear forging in 4-die forging device), under which the conditions of all-round compression of the billet are provided.

References

1. Antsiferov A.V., Zubkova V.T., Kameneva S.A. i dr. Otrabotka tekhnologii izmelcheniya i smesheniya komponentov karbidostali v vertikalnoi vibratsionnoi melnitse, Poroshkovaya metallurgiya, 1998, № 5/6, P. 4-8.*

2. Lekomt-Bekers J., Magni A. Svoistva poroshkovoi stali, uprochnennoi dispersnymi oksidnymi i karbidnymi fazami, Stal, 2000, № 10, P. 98-99.*

3. Zubkova V.T., Parabina G.I., Bokii Yu.F. i dr. Mikrostruktura i svoistva karbidostali v zavisimosti ot tekhnologii proizvodstva, Stal, 1990, № 8, P. 81-83.*

4. Geller Yu. A. Instrumentalnye stali, 5-e izd, M.: Metallurgiya, 1981, 526 p.*

5. Poznyak L.A. Instrumentalnye stali, K.: Naukova dumka, 1996, P. 371-374.*

6. Lazorkin V.A., Ternovoi Yu.F., Artamonov Yu.V. Chetyrekhboikovoe kovochnoe ustroistvo dlya gidravlicheskikh kovochnykh pressov, Kuznechno-shtampovochnoe proizvodstvo, 2000, № 8, P. 43-44.*

* Published in Russian

Received November 22, 2011

Производство высокоэффективных комплексно-легированных сталей и сплавов с керамическим и интерметаллидным упрочнением

Терновой Ю.Ф., Зубкова В.Т., Артамонов Ю.В., Куратченко А.Б., Мельников Ю.В., Золотарева Л.И.

В работе показана принципиальная возможность получения износостойких и теплостойких материалов с керамическим и интерметаллидным упрочнением. Разработанные в ГП «УкрНИИспецсталь» составы композиционных материалов и сплавов с интерметаллидным упрочнением, а также технологии их производства обеспечивают комплекс высоких служебных свойств, что позволяет использовать эти материалы для различных видов инструментов и деталей машин ответственного назначения.