https://doi.org/10.15407/scin16.01.076

PINCHUK, S.Y., VNUKOV, O.O.,
KUSHNIR, Yu.O., and ROSLYK, I.G.
National Metallurgical Academy of Ukraine,
4, Gagarin Ave., Dnipro, 49600, Ukraine,
+380 56 745 3156, nmetau@nmetau.edu.ua

IMPROVEMENT OF THE OPERATIONAL PROPERTIES OF SINTERED COPPER STEEL THROUGH THE USE OF EFFICIENT ALLOYING METHOD

Introduction. *The alloying of powder steels, unlike cast steels, has a number of characteristic features due to the specifics of their preparation. The method of introducing the alloying component into the charge has a significant effect on the compactability, compressibility, structure and properties of sintered alloy steels.*

Problem Statement. *Existing alloying methods often do not provide a uniform distribution of alloying elements over the volume of the powder mixture, which leads to uneven density and a decrease in the strength properties of sintered steel.*

Purpose. *The purpose of research is to improve the technological properties of powder mixtures by using the most effective method for alloying sintered steels with copper*

Materials and Methods. *As initial materials, we used sprayed iron powders of the ПЖР 3.200.28 grade (GOST-9849-86) and steel powder 70, which have low formability and green strength. A copper coating on iron powder particles was obtained by internal electrolysis (chemical cementation) in an acidic aqueous solution of copper sulfate with the addition of ferrous sulfate (II). Mechanosynthesis was carried out in a planetary ball mill. The technological properties of the powders were determined by standard methods: flowability ISO 4490, bulk density ISO 3923, compressibility ISO 3927, green strength ISO3995.*

Results. *The research has been done in regard to the set of technological and physical properties of powder materials, as well as the mechanical characteristics and the structure of sintered construction materials obtained through the use of various technological methods of alloying with copper and carbon: mechanical mixing, mechanosynthesis and copperizing (chemical cementation). A comparative analysis the properties of the materials obtained has been carried out and the optimal alloying method has been determined. It has been established that powder materials alloyed using the chemical cementation method have the highest level of technological and mechanical characteristics.*

Conclusion. *Chemical cementation alloying method can be recommended for the industrial production of sintered construction copper steels, since the use of it provides a high level of mechanical properties of the material and makes economic sense.*

Keywords: alloying, sintering copper steel, mechanical mixing, mechanosynthesis, copperizing.

Citation: Pinchuk, S.Y., Vnukov, O.O., Kushnir, Yu.O., and Roslyk, I.G. Improvement of the Operational Properties of Sintered Copper Steel Through the Use of an Efficient Alloying Method. *Sci. innov.* 2020. V. 16, no. 1. P. 76—82. https://doi.org/10.15407/scine16.01.076

The use of powder metallurgy methods in the creation of new materials makes it possible to provide the optimal combination of the technology for their production, structural and performance characteristics, as well as to reduce the metal and product losses. Of particular interest is the powder steel used in modern mechanical engineering; it has high-strength level combined with good ductility, toughness, low tendency to brittle fracture.

Further improvement of steel properties, including powder steel properties, is achieved by increasing the carbon content, plastic deformation, alloying, heat treatment, changing the micro- and submicrostructure.

The technological properties of powders and powder mixtures are extremely important, since they determine the technological parameters of the parts manufacture. Powders with high compactability make it possible to manufacture parts of a more complex configuration and make them more technological [1—4]. In this regard, the improvement of technological properties including the compactability of powders and powder mixtures is a relevant objective.

Alloyed powder steel, unlike cast-steel, has a number of characteristic features caused by specificity of its production. The following methods are known to fabricate powder alloyed steel: preparation of multicomponent mixtures from iron powders and alloying elements with their subsequent processing [5, 6]; the use of alloyed iron powders, to which, if necessary, carbon (usually graphite) or other alloying elements are added [1, 5, 7]; impregnation with liquid alloying metals or diffusion saturation of frameworks sintered from iron powder [8, 9]; mechano-alloying [10—17]; chemical cementation of iron-based powders [4, 18, 19]. Each of these methods has its advantages and disadvantages. In such a way, steel, obtained from the finished alloyed powders, have a homogeneous structure, and the distribution of elements in the alloy has a high degree of homogeneity. However, they have poor technological properties — compressibility and compactability; they are scarce and expensive.

Copper alloying in the amount of 1.0—10 wt.% increases the flow limit and temporary resistance of the material sintered from the material alloyed powder, but partly reduces its plasticity and toughness [1—6, 19—22]. Copper alloying significantly increases the resistance of the powder material to atmospheric corrosion. Maximum tensile strength is achieved with a mass fraction of copper of 5—7%. Moreover, copper stabilizes the shrinkage of the product during sintering, and when the copper content amount to about 2%, there is no shrinkage at all.

Copper alloying of powder sintered materials can be done in different ways. Copper can be introduced into the mixture in the form of copper powders, iron-copper ligature, copper-containing alloy (for example, bronze), in the form of copperplated graphite [1, 5, 6]. The methods of mechanical mixing of powders are most often used in the production of powder products for the preparation of the mixtures. The compactability and compressibility of the powder mixture obtained in these cases is not high enough and chipping or spilling of separate parts of the compact can occur in the manufacture of parts of complex shape or at low extrusion pressure. It is difficult enough to achieve the absolute uniformity of the components distribution by the volume of the powder mixture during mechanical mixing, especially with a low content of one of the components.

The information considered in the literature on the properties of sintered steel and methods for its alloying is disparate; this complicates the application of sintered steel in the development of new types of powder materials and their implementation into production. Research has been conducted in this regard to study the methods of alloying iron powder with copper and their influence on the properties of sintered powder steel.

The aim of the research is to improve the technological properties of powder mixtures based on the iron-copper-carbon system, which will significantly improve the set of mechanical and physicochemical characteristics of sintered steel. The authors have proposed the alloying method, which involves application of a copper plating on the particles of steel powder by chemical deposition.

The objective of this Paper is to study the influence of the copper alloying method on the technological properties of powder mixtures and mechanical characteristics of sintered copper steels.

The dispersed iron powder and powder of steel 70 with low compactability and green strength qualities have been used as the target of research. This limits their usage in the manufacture of products of complex shape.

Copper plating on the iron powder particles has been obtained using a method of internal electrolysis (chemical cementation) in an acidic aqueous solution of copper sulfate with the addition of ferrous sulfate (II). The required copper content on the iron powder has been provided by adjusting the ratio of the volume of the reacting solution of constant composition and the mass of the original steel powder. The reaction has been carried out until complete copper ions deposition. The end of the reaction has been determined visually by discoloration of the responding solution.

After copper deposition, the powder was subject to cold-water rinsing, stabilizing in a special solution to prevent oxidation, repeated washing and drying with a stream of warm air at a temperature of 55—60 °C.

The plating quality has been controlled both visually, by color, and by optical microscopy.

The set of technological properties has been determined after obtaining the finished powder; this set of properties includes the following: green strength, bulk density, compactability — by the methods established in accordance with the standards.

The mechanical properties of the sintered material Fe 5% Cu 0.5% C, which corresponds in chemical composition powder steel grade PK50D5 to that obtained from sprayed steel powder, have been investigated. Three alloying methods have been used: mechanical mixing of the initial powders, mechanosynthesis and copperizing of steel powder. Mechanical mixing has been carried out drum mixer type «umbling barrel»; mechanosynthesis has been carried out in a planetary ball mill; copperizing of steel powder 70 has been carried out in accordance with the technology developed for iron powder copperizing [18].

The iron sprayed powder brand PGR 3.200.28 (GOST 9449-89) [23], the copper electrolytic powder brand PMS-1 (GOST 4960-75) [24], the sprayed steel 70 powder and the graphite pencil grade GK-1 (GOST 4404-78) [3] have been used to develop the preproduction models.

The preproduction models have been obtained by single cold pressing followed by sintering. The pressing and sintering modes for all preproduction models under research were the same.

The following properties of preproduction models have been investigated: volumetric shrinkage; porosity; tensile strength; Brinell hardness; bending strength.

STUDY OF THE COPPER INTRODUCTION METHOD IMPACT ON THE PROPERTIES OF IRON-BASED POWDER MATERIALS

Using the developed method described above, it was possible to obtain a continuous plating on the particles of iron powder and steel 70 powder with a high level of adhesion. The plating thickness with a copper content in the mixture of 5% amounted to 1—2 μm (Fig. 1).

The alloying method proposed makes it possible to obtain a powder mixture based on iron with a copper content of from 1 to 5% by weight.

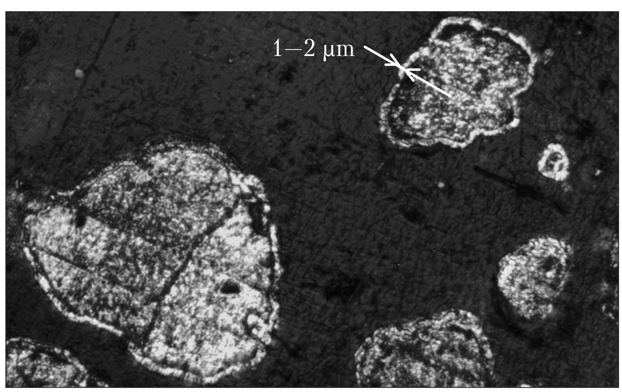


Fig. 1. Microphotograph of the copperized steel 70 particles

a *b* *c*

Fig. 2. The view of the samples after testing the raw pressing strength: *a* — mixing; *b* — mechanosynthesis; *c* — copperizing

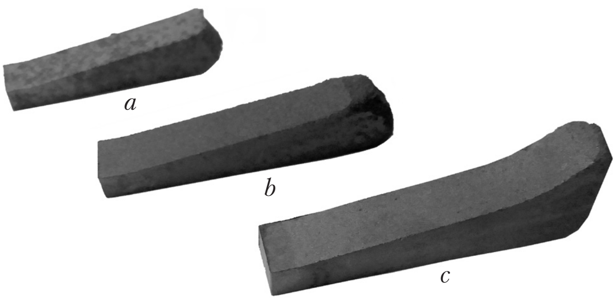


Fig. 3. The view of the samples after the test for compactability: *a* — mixing; *b* — mechanosynthesis; *c* — copperizing

Technological properties of the materials, obtained using method described, mechanosynthesis method and using a multicomponent mixture based on iron powder PGR 3.200.28 grade and copper powder of PMS-1 grade have been listed in Table 1. The copper content in all materials amounted to 5% by weight.

As shown in Table 1, briquettes of copperized powder have significantly greater green strength (15—20% higher, Fig. 2) and significantly better compactability (25—28% higher, Fig. 3), with almost equal values of the remaining technological properties of the powder mixture studied.

THE STUDY OF THE STRUCTURE AND PROPERTIES OF SINTERED MATERIALS BASED ON THE SYSTEM Fe-Cu-C, OBTAINED USING VARIOUS ALLOYING METHODS

The results of determination the physical properties of studied materials are given in Table 2.

According to the results, the material obtained alloying by mechanosynthesis has the best physical properties (the least shrinkage and low porosity).

The Figure 4 shows the microstructures of the investigated materials.

The results of determining of the studied materials mechanical properties are given in the Table 3.

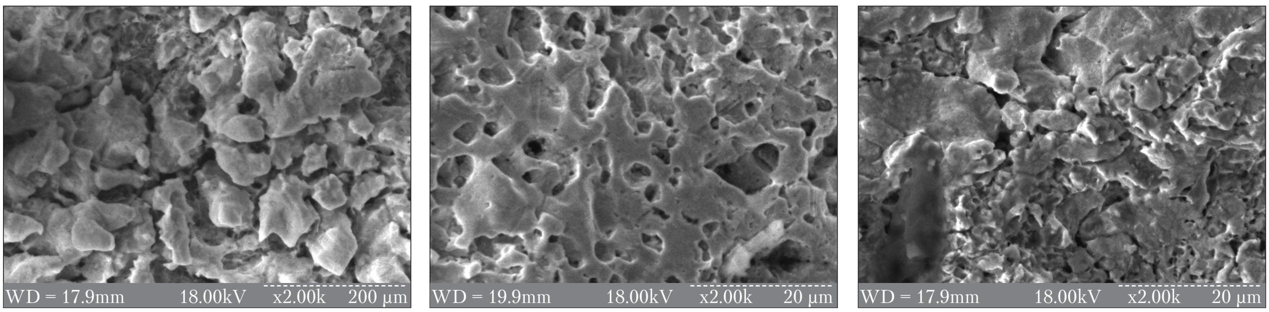
According to the results, the material obtained from copper-coated steel 70 powder possesses the best mechanical properties. The strength characteristics of sintered copperized St70 are much higher, despite the higher porosity in comparison with that obtained by means of mechanosynthesis. This is due to the structure of the materials obtained, the formation of which depends mostly on the uniform distribution of the alloying elements. Carbon has been dissolved in steel powder 70, and copperizing makes it possible to evenly distribute copper in the volume of the compact. This makes it possible to obtain after sintering the structure of alloyed ferrite with uniformly distributed inclusions of perlite, which results in a high level of mechanical properties.

Figure 5 shows microphotographs of the studied materials structures, obtained through the use of scanning microscopy.

Table 1. **Technological Properties of Powder Mixtures Obtained Using Various Alloying Methods**

Parameter	Alloying method		
	copperizing	mechano-synthesis	mixing
Bulk density, g/cm^3	2.85—2.90	2.80—2.85	2.7—2.75
Angle of repose, °	34—36	40—41	35—37
Flowability rate, s/50 g	38—40	32—35	35—37
Green strength, MPa	280—300	250—260	230—240
The green pressing porosity at a extrusion pressure 700 MPa, %	7.6—8.0	7.5—7.7	7.4—7.6
The minimum density of the briquette, at which the surfaces do not have cracks and shears, g/cm^3	2.9—3.0	3.6—3.8	3.5—3.8

Fig. 4. The microstructure of samples, obtained alloying methods (800): *a* — mixing; *b* — mechanosynthesis; *c* — copperizing



a *b* *c*

Fig. 5. The structure of the studied materials, obtained through the use of: *a* — mixing; *b* — mechanosynthesis; *c* — copperizing

Accordingly, copperizing as the means of alloying with copper can be recommended for industrial production of sintered structural copper steel. This not only provides high mechanical properties of the steel, but also makes good economic sense, since copperizing will make it possible to discontinue the use of expensive and scarce copper powder for alloying. Moreover, copperizing makes it possible to significantly increase the compactability of steel 70 powder (Fig. 3) and use a simpler, from the instrumental point of view, cold pressing instead of isostatic for its formation.

Table 2. **The Results of Determination of Physical Properties of Studied Materials**

Alloying method	Volumetric shrinkage $\Delta V/V$, %	Porosity P, %
Mixing	3.7—3.9	10—12
Mechanosynthesis	1.2—1.5	3—4
Copperizing	1.6—1.8	4—6

Table 3. **The Results of Determination of Mechanical Properties of Studied Materials**

Alloying method	Tensile strength *TS*, MPa	Bending strength *BS*, MPa	Brinell hardness *HB*, MPa
Mixing	270—275	310—320	690—710
Mechanosynthesis	310—320	460—470	790—900
Copperizing	390—400	520—530	720—730

CONCLUSIONS

1. The powder of St 70 has been obtained with a stable set of properties and the ability to control the content of copper therein.

2. The compactability of the copperized St 70 powder and its green strength are much higher as compared with powder iron-copper-carbon injection, which can be explained by a significant increase in the plasticity of each particle separately and of the mixture as a whole due to copper plating.

3. The obtained data enable concluding about the possibility of more efficient usage of mixture

alloyed by means of the developed method and having increased compactability for the manufacture of sintered materials based on the iron-copper- carbon system, with improved strength of raw briquettes, which is especially important for the manufacture of items with complex shapes.

4. The sintered materials obtained by alloying through mechanosynthesis have the lowest shrinkage and low porosity.

5. The material obtained from the copperized steel 70 powder has the highest mechanical properties: despite the higher level of porosity, the strength characteristics are much higher in sintered St70 alloyed with copper using the method of chemical cementation.

6. The proposed technology of alloying will make it possible to discontinue the mixing operation and presumably will enable obtaining sintered products with a more uniform distribution of copper and carbon in the volume of the sintered product and a more uniform structure of the material. This, in turn, will significantly improve the set of mechanical and physico-chemical properties of the sintered products.

7. The use of chemical cementation of powder for alloying with copper can be recommended for industrial production of sintered structural copper steel. This provides high mechanical properties of the material and also makes good economic sense.

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Received 12.11.18
Revised 19.06.19
Accepted 16.09.19

С.Й. Пінчук, О.О. Внуков, Ю.О. Кушнір, І.Г. Рослик
Національна металургійна академія України,
просп. Гагаріна, 4, Дніпро, 49600, Україна,
+380 56 745 3156, nmetau@nmetau.edu.ua

ПІДВИЩЕННЯ ЕКСПЛУАТАЦІЙНИХ ВЛАСТИВОСТЕЙ СПЕЧЕНИХ МІДИСТИХ СТАЛЕЙ

Вступ. Легування порошкових сталей, на відміну від литих, має ряд характерних особливостей, зумовлених специфікою їх отримання. Спосіб введення легуючого компоненту у шихту впливає суттєво на її формованість, пресованість, структуру та властивості спечених легованих сталей.

Проблематика. Методи легування, що існують, часто не забезпечують рівномірного розподілу легуючих елементів по всьому об'ємі порошкової шихти, що призводить до нерівномірної щільності та, відповідно, до зниження міцності спеченої сталі.

Мета. Підвищення технологічних властивостей спечених сталей шляхом легування залізного порошку міддю, а саме механічного синтезу, механічного змішування та оміднення.

Матеріали й методи. Вихідними матеріалами слугували розпилені порошки заліза марки ПЖР 3.200.28 (ГОСТ 9849-86) і порошок сталі 70, які мають низькі показники формованості та міцності неспеченої пресовки. Мідне покриття на частинках залізного порошку отримували методом внутрішнього електролізу (хімічної цементації) в кислому водному розчині сірчанокислої міді з додаванням сірчанокислого заліза (II). Механосинтез та механічне змішування здійснювали в планетарному кульовому млині. Технологічні властивості порошків визначали стандартними методами: текучість ІСО 4490, насипна щільність ІСО 3923, пресованість ІСО 3927, міцність неспеченої пресовки ІСО 3995.

Результати. Досліджено комплекс технологічних, фізичних властивостей порошкових матеріалів, а також механічних характеристик і структури спечених конструкційних матеріалів на основі заліза, отриманих із застосуванням різних технологічних прийомів легування міддю і вуглецем: механічного змішування, механосинтеза і оміднення (хімічної цементації). Виконано порівняльний аналіз властивостей отриманих матеріалів і визначено оптимальний спосіб легування. Встановлено, що найбільш високим рівнем технологічних і механічних характеристик володіють порошкові матеріали, леговані методом хімічної цементації.

Висновки. Зазначений метод можна рекомендувати для промислового виробництва спечених конструкційних мідистих сталей, оскільки він забезпечує високий рівень механічних властивостей матеріалу і є економічно вигідним.

Ключові слова: легування, спечені мідисті сталі, механічне змішування, механосинтез, оміднення.