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Universal model for predicting the phase composition of multicomponent brasses based on chemical analysis data

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Abstract: When developing technical requirements for alloys, it is important to apply an integrated approach. Combining analytical and simulation modelling, it is possible to reduce technological risks at the stage of creating or modifying requirements. The implementation of this approach directly depends on the degree of consideration of all factors included in the models, as well as on their influence on the variability of characteristics. However, known models do not provide satisfactory convergence with real industrial alloys. Using the example of a complex-alloyed CuZn13Mn8Al5Si2Fe1Pb brass, an approach is proposed that allows describing the variability in the structural state of multicomponent brasses. The analysis of statistical data on the chemical composition and microstructure of industrial batches, made it possible to establish that the alloy matrix solution is a (α+β)-brass, and corresponds to the phase ratio at 700 °C on the polythermal pseudo-binary cross-section of the Cu–Zn–Mn_5Si_3 diagram. The distribution of alloying elements in the main phases was studied using X-ray spectral analysis. The complete binding of iron in silicides and uniform distribution of manganese in the hot-pressed state were confirmed. A calculation of the silicon proportion in the solid solution was proposed. The measured density of the alloy is 7650 kg/m³, while the calculated density of the matrix solution is 8100 kg/m³. Based on the updated parameters of the universal model, the authors used the Monte Carlo method to assess the variability of the microstructure in relation to the requirements for the chemical composition. The instability of technological properties is attributed to significant variability in the ratio of the α- and β-phases. The content of the α-phase in the alloy ranges from 37.5 % to 66.5 %, while the β-phase varies from 17.5 % to 55.2 %. The simulation model developed in this study enables both to analyse the existing alloys and to predict the behaviour of new alloys. This is critically important for optimising technological processes, and improving the operational properties of materials.

Keywords: multicomponent brass; CuZn13Mn8Al5Si2Fe1Pb; stability of technological processes; chemical composition of special brasses; statistical simulation modelling of phase composition; brass microstructure; brass density; zinc equivalent; silicides.

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INTRODUCTION

Modern mass production places strict requirements for the manufacturability of metal products. The development of domestic brands of special multicomponent brasses comparing favourably in manufacturability, and performance characteristics with brands of foreign manufacturers is an urgent task. Increasing the stability of the manufacturability of processes in mass production is considered within the theory of variability [1; 2] and statistical thinking (Six Sigma concept) [3]. Managing the phase composition variability is the main factor determining manufacturability. It is possible to reduce the time for designing requirements for alloys by introducing modern methods of statistical modelling. One of such methods is the Monte Carlo method, based on the reproduction of a large number of executions of a random process, specially created for the conditions of the problem being solved. The random process is formed in such a way that its probabilistic characteristics are equal to the observed ones, or it would be possible to calculate through them the desired values of the problem under consideration.

The LMtsAZhKS 70-7-5-2-2-1 alloy (European analogues: CuZn13Mn8Al5Si2Fe1Pb – EN, Diel470HT by Diehl) is used in the domestic automotive industry, has high wear resistance, but unstable technological and operational characteristics [4; 5]. Alloying elements such as aluminium, manganese, iron, silicon, on the one hand, contribute to the improvement of mechanical properties [6; 7]. On the other hand, they have conflicting effects on the manufacturability of casting processes and plasticity in hot and cold states, slowing down diffusion processes [8; 9]. Lead, filling the pores, allows increasing machinability by cutting due to the formation of small intermittent chips [10], but also contributes to crack formation during stamping [10;

11]. Therefore, for the engineering of brass multicomponent alloys, it is important to understand how changes in the content of alloying elements will affect the variability of the phase composition.

The works [12; 13] proposed methods for assessing the phase composition of multicomponent brasses, based on the calculation of the zinc equivalent, taking into account the Guillet coefficients proposed more than 100 years ago [14], but still actively used in technical literature. The main provisions of the forecasting methods [12; 13] are the following.

1. The calculation of the zinc equivalent (Zn_e) according to the Cu–Zn diagram is performed using the formula

$$Zn_e = \frac{Zn + \sum K_i \cdot C_i}{Cu + Zn + \sum K_i \cdot C_i}, \quad (1)$$

where Cu, Zn are the actual content of copper and zinc in the alloy, %;

C_i is the content of the i-th element in the alloy, %;

K_i is the corresponding Guillet equivalence coefficient (Table 1).

2. It is taken into account that lead is in a free state, silicon is completely bound in silicides, and manganese and iron are partially bound.

3. The predicted content of silicides is estimated by the formula

$$Me_5Si_3 = \left(1 + \alpha_{Fe} + \alpha_{Mn} + \alpha_{Ni}\right) \cdot Si \cdot \frac{\rho_{brass}}{\rho_{Me_5Si_3}}, \text{ \% vol.}, \quad (2)$$

where α_{Fe}, α_{Mn}, α_{Ni} are the coefficients of connectivity for silicon [12; 13];

$\rho_{Me_5Si_3} \approx 6.0$ kg/dm^3 is the average density of Fe and Mn silicides.

4. Moreover, it is noted that after pressing, the phase composition corresponding to the Cu–Zn diagram at 500 °C [12] or 400 °C [13] is fixed.

However, the indicated works do not contain information on checking the quality of the models. When testing the methods on industrial batches of CuZn13Mn8Al5Si2Fe1Pb brass, low quality indices of the models were obtained[1]. The described approach seems to be justified, but the model does not take into account a number of factors that can introduce significant errors. The brass density corresponds to the reference data for less alloyed brasses. The mechanism of nucleation and growth of silicides during crystallisation is diffusion, therefore, in case of a decrease in the crystallisation rate, the number and size of silicides should increase to the maximum possible value, specified by the chemical composition [15]. With an increase in the crystallisation rate, diffusion does not have time to occur, and part of Si, Mn, Fe remains in the solid solution. The solid solution will change depending on the interaction of the above elements. Therefore, the volume of silicides in alloys depends on the cooling conditions of the blanks after casting. Considering the variable solubility of silicides in brass in the range of 200...800 °C, the statement about the complete binding of silicon in silicides requires rechecking. At the same time, it is known that iron barely dissolves in brass, forming γ-Fe [16]. To describe the equilibrium state of special brass alloys doped with Mn and Si, it is logical to use the pseudo-binary polythermal cross-section of the Cu–Zn_e–Mn_5Si_3 diagram (Fig. 1). Note that in [17], the calculation of alternative equivalence coefficients is given, based on electron concentrations calculated as the sum of the products of the atomic concentration of each component, and the number of its collective electrons.

The aim of this work is to update the universal forecasting model based on information on the chemical composition of the phases of a multicomponent brass.

METHODS

The objects of the work were industrial batches of CuZn13Mn8Al5Si2Fe1Pb brass tubes in a hot-pressed state (heating temperature is 750 °C).

A batch of samples was formed from 20 real industrial melts of CuZn13Mn8Al5Si2Fe1Pb brass in a hot-pressed state. Technical requirements for the chemical composition are given in Table 2, which shows as well the average values for chemical elements, and the standard deviation for the analysed batch of samples. For each element, the nature of the distribution of the population was assessed. As a rule, the main elements of the alloy from batch to batch have a normal distribution; impurities have a uniform (rectangular) distribution. The hypothesis of the normal distribution was tested using the Pearson criterion.

Further, metallographic analysis was carried out to identify actual structural relationships. The results were compared with the Cu–Zn_e–Mn_5Si_3 phase diagram (Fig. 1). Quantitative metallographic analysis was performed using an Olympus GX51 microscope (Japan), with a SIAMS 800 panoramic microscopy system (Russia). The proportion of silicides ($(Fe, Mn)_5Si_3$) was determined on unetched sections in longitudinal and cross sections. The amount of α- and β-phases was recorded after etching ($FeCl_3$ – 5 g; HCl – 30 ml; H_2O – 100 ml).

To refine the chemical composition of the phases, X-ray spectral analysis was performed on an EVO18 Carl Zeiss scanning electron microscope (SEM) (Germany), with EDX from Bruker (Germany). Measurements were carried out after studying the fields at a magnification in the range of ×2000...7000 to exclude the influence of highly dispersed silicides, using the Point Analysis function.

For project activities when developing and adjusting technical requirements, the main indicator in mass production is the statistical convergence of the mathematical expectation and standard deviation of models and direct observations.

The solution density was refined based on the following considerations:

[1] *Kostin G.V., Svyatkin A.V. Evaluation of the adequacy of models for predicting the phase composition of silicon-manganese brass. Fizicheskoe materialovedenie: sbornik materialov XI mezhdunarodnoy shkoly. Togliatti, Togliatti State University Publ., 2023, pp. 163–164. EDN: ONACBO.*

Table 1. *Equivalence coefficients of zinc in brasses*
Таблица 1. *Коэффициенты эквивалентности цинка в латунях*

Element	Si	Al	Mn	Fe	Ni	Sn	Pb	Mg
According to Guillet [14]	10.0	5.0	0.5	0.9	−1.3	2.0	1.0	2.0
According to Efremov [17]	6.0	4.0	−0.2	–	−0.6…1.5	1.7	–	1.7

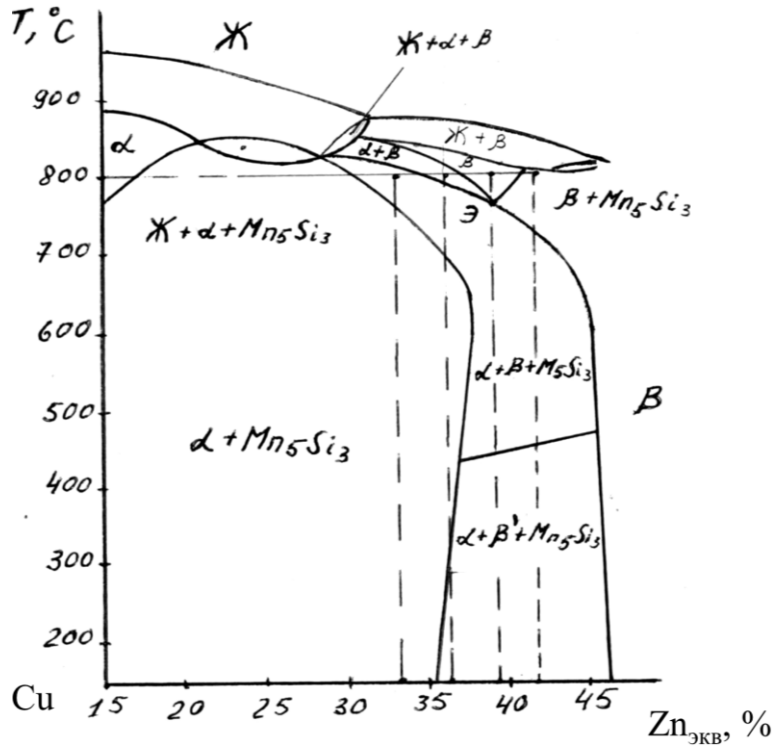

Fig. 1. *Pseudo-binary polythermal section of the Cu–Zn_e–Mn_5Si_3 diagram with a constant content of silicides.*
Source: Kotlyarov I.V., Kopyl M.D., Tropotov A.V. Special brass alloys for synchronizer rings: optimization of compositions and technological processes. Problemy razvitiya avtomobilestroeniya v Rossii: sbornik izbrannykh dokladov II–IV mezhdunarodnykh nauchno-prakticheskikh konferentsiy. Tolyatti, TGU Publ., 1996, pp. 130–134, p. 131.
Рис. 1. *Псевдобинарный политермический разрез диаграммы Cu–Zn_e–Mn_5Si_3, с постоянным содержанием силицидов.*
Источник: Котляров И.В., Копыл М.Д., Тропотов А.В. Специальные латунные сплавы для колец синхронизаторов: оптимизация составов и технологических процессов // Проблемы развития автомобилестроения в России: сборник избранных докладов II–IV международных научно-практических конференций. Тольятти: ТГУ, 1996. С. 130–134. С. 131.

$$M = M_{mat} + M_{MeSi}, \quad (3)$$

where M is the sample mass;
M_{mat} is the mass of the matrix solution;
M_{MeSi} is the mass of silicides.

Having expanded the formula for finding the sample mass, we obtain

$$\rho \cdot V = \rho_{mat} \cdot V_{mat} + \rho_{MeSi} \cdot V_{MeSi}, \quad (4)$$

where ρ is the sample total density measured according to GOST 20018-74;
V is the sample volume taken equal to 1;
ρ_{MeSi}=5990 kg/m^3;
according to the law of stereometric metallography on the correspondence of phase volumes and areas:
$V_{mat} \approx S_{mat}$, $V_{MeSi} \approx S_{MeSi}$ are the volumes occupied by the matrix and silicides, respectively, calculated according to the data of metallographic analysis;
S_{mat} и S_{MeSi} are the ratio of the surface area measured by metallographic analysis of the matrix solid solution and silicides, respectively.

To determine the actual density of brass, samples from 20 batches of the CuZn13Mn8Al5Si2Fe1Pb alloy were measured.

After refining the method of phase composition forecasting, the authors simulated its variability using the Monte

Table 2. *Chemical composition of the CuZn13Mn8Al5Si2Fe1Pb alloy components, wt. %*
Таблица 2. *Химический состав компонентов сплава ЛМцАЖКС, мас. %*

Element	Al	Cu	Fe	Mn	Ni	Pb	Si	Sn	Zn	Impurities
Norm	5.0–6.0	69.5–71.5	1.4–2.4	6.5–7.5	≤0.1	0.6–1.2	1.7–2.5	≤0.1	res.	≤0.5
Average	5.35	70.06	1.61	7.10	0.07	0.88	1.87	0.03	12.98	0.13
Standard deviation	0.16	0.41	0.12	0.17	0.02	0.04	0.06	0.02	0.43	0.02
Distribution	+	+	+	+	–	+	+	–	+	–

Note. "+" corresponds to normal distribution, "–" corresponds to rectangular distribution, the α-phase amount is not less than 50 %.
Примечание. «+» соответствует нормальному распределению, «–» – прямоугольному, количество α-фазы не менее 50 %.

Carlo method for 500 iterations. The average value corresponded to the middle of the tolerance field; the standard deviation was calculated using the Six Sigma rule:

$$6_\sigma = \frac{UTL - LTL}{6}, \quad (5)$$

where *UTL* and *LTL* are the upper and lower tolerance limits.

The element value for each iteration:

$$E_1 = \overline{E} \pm K_e \cdot \sigma, \quad (6)$$

where E is the corresponding element of the chemical composition;
K_e is a random coefficient from 0 to 1 generated for the corresponding distribution.

A set of random numbers was obtained and regression models were built using the Analysis Package of Microsoft Excel.

RESULTS

Table 3 presents the results of the metallographic study of 20 batches of the CuZn13Mn8Al5Si2Fe1Pb alloy as the average and standard deviation. The α- and β′-phases change in a fairly wide range: α=43.1…63.2 %, β′=26.0…53.6 %. The proportion of silicides $(Fe, Mn)_5Si_3$ in the alloy is stable between batches of the alloy and is 9.2…12.5 % with a standard deviation of 0.4 %.

As a result of the density analysis of the sample, it was found that the CuZn13Mn8Al5Si2Fe1Pb alloy has a density of 7650±20 kg/m^3. Then, from formula (4), it follows that the density of the CuZn13Mn8Al5Si2Fe1Pb brass matrix is ≈8100 kg/m^3.

When studying the microstructure, it was found that the CuZn13Mn8Al5Si2Fe1Pb alloy is a 4-component system, and consists mainly of equiaxed grains of the (α+β′) solid solution, silicides and structurally free lead inclusions. Subsequent examination using an electron microscope confirmed the almost complete absence of signs of eutectoid decomposition. The β′-phase consists of dispersed plates oriented transversely to the pressing direction (Fig. 2). Intermetallides are represented by two main types – large primary $(Fe, Mn)_5Si_3$ silicides, and secondary dispersed rod-shaped Mn_5Si_3 inclusions.

Statistics on the chemical composition of the α- and β′-phases are given in Table 4. The chemical composition of the α- and β′-phases is rather stable from batch to batch. It was found that iron is completely bound in silicides – $(Fe, Mn)_5Si_3$, silicon is unevenly distributed in the solid solution, and is part of the α-phase with a content of 0.14±0.09 % by weight, and of the β′-phase with a content

Table 3. *Results of metallographic study of the CuZn13Mn8Al5Si2Fe1Pb alloy microstructure*
Таблица 3. *Результаты металлографического исследования микроструктуры сплава ЛМцАЖКС*

Indicator	α-phase, vol. %	β-phase, vol. %	α/β	$(Fe,Mn)_5Si_3$, vol. %
Average	52.2	36.3	1.5	11.5
Standard deviation	4.8	6.3	0.4	0.9
Minimum	43.1	26.0	0.9	9.2
Maximum	63.2	53.6	2.4	12.5

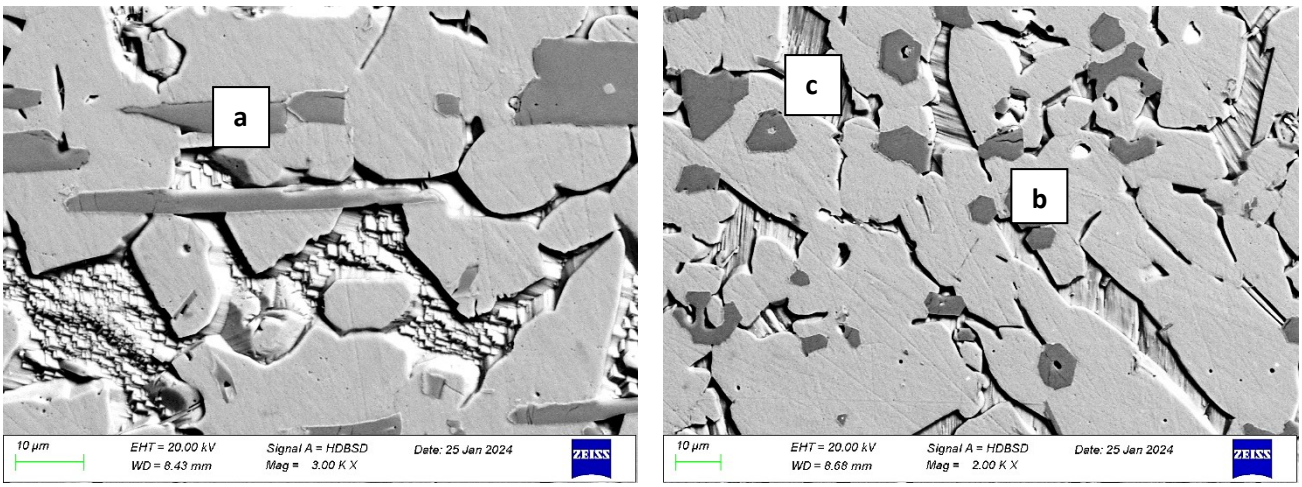

Fig. 2. *Microstructure of the CuZn13Mn8Al5Si2Fe1Pb alloy:*
a *– section in the pressing direction;* ***b*** *– radial section;* ***c*** *– view of the β-phase plates with the radial section*
Рис. 2. *Микроструктура сплава ЛМцАЖКС:*
а *– сечение в направлении прессования;* ***b*** *– радиальное сечение;* ***с*** *– вид пластин β-фазы с радиальным сечением*

Table 4. *Statistics of chemical composition of α- and β-phases*
Таблица 4. *Статистика химического состава α- и β-фаз*

Element	α-phase						β-phase					
	Al	Si	Mn	Cu	Fe	Zn	Al	Si	Mn	Cu	Fe	Zn
$\bar{X}$	4.78	0.14	2.72	78.80	0	13.63	7.72	0.05	2.75	74.83	0	14.69
σ	0.29	0.09	0.12	0.26	0	0.20	0.44	0.06	0.14	0.55	0	0.29

of 0.06±0.05 % by weight. Manganese is uniformly distributed between the α- and β′-phases with a concentration of 2.72…2.75 %. Aluminium is detected in both phases, despite the fact that it belongs to the β-forming elements. In the α-phase, the aluminium concentration is 4.78±0.29 %, in the β′-phase – 7.72±0.44 %.

Linear scanning showed that the manganese concentration peaks are caused only by the transition from the matrix solution to silicides. Manganese is distributed uniformly between the α- and β-phases. The amount of α-phase in the alloy determined by the Six Sigma rule varies from 37.5 to 66.5 %, and the amount of β′-phase varies from 17.5 to 55.2 %.

Based on the results obtained, a different approach was used: the calculation for silicon was performed taking into account the provision that in CuZn13Mn8Al5Si2Fe1Pb brass, silicon forms a stable (Fe, Mn)$_5$Si$_3$ silicide with iron and manganese, and iron is completely bound in silicides. Since the centre of the intermetallic compound is enriched with iron, and the periphery is enriched with manganese [18], the amount of silicon bound by iron is

$$\mathrm{Si_{Fe}} = \frac{3}{5} \cdot \frac{\mathrm{Fe} \cdot Ar(\mathrm{Si})}{Ar(\mathrm{Fe})}, \quad (7)$$

where Fe is the concentration of iron in the alloy;
Ar(Fe) is the atomic mass of iron, equal to 55.845 amu;
Ar(Si) is the atomic mass of silicon, equal to 28.086 amu.

The proportion of silicon bound with manganese:

$$\mathrm{Si_{Mn}} = \frac{3}{5} \cdot \frac{\mathrm{Mn} \cdot Ar(\mathrm{Si})}{Ar(\mathrm{Mn})}, \quad (8)$$

where Mn is the concentration of manganese in the alloy;
Ar(Mn) is the atomic mass of manganese, equal to 54.938 amu.

The amount of silicon in the matrix:

$$\mathrm{Si}_{mat} = \mathrm{Si} - \mathrm{Si_{Fe}} - \mathrm{Si_{Mn}}. \quad (9)$$

By comparing the result of determining the amount of total silicon in the alloy with the amount of silicon dissolved in the matrix, it was found that it is possible to use the regression equation

$$\mathrm{Si}_{mat} = 0.07 \cdot \mathrm{Si} + 0.03. \quad (10)$$

By analysing Table 2, and comparing it with the Cu–Zn–((Fe,Mn)$_5$Si$_3$) diagram (Fig. 1), the authors found that the obtained results correspond to the phase ratio at a temperature of 700 °C, which is somewhat different from

the works [12; 13]. In this case, the formulas for the prediction methods take the form:

$$\alpha_{press} = \frac{41.6 - Zn_e}{41.6 - 34.4}, \quad (11)$$

$$\alpha_{anneal} = \frac{45.6 - Zn_e}{45.6 - 36.5}. \quad (12)$$

Similarly to [12], we multiply the obtained result by the *K* coefficient, which takes into account the weight fraction of lead and silicides, adjusting the amount of silicon in accordance with calculation (7)–(10):

$$K = \frac{100 - Pb_{(volume)} - (Fe,Mn)_5Si_{3(volume)}}{100}. \quad (13)$$

The volume fraction of lead and silicides is determined in accordance with the formula [12]:

$$W_{volume} = W_{mas} \cdot \frac{\rho_{brass}}{\rho_c}, \quad (14)$$

where W_{mas} is the mass fraction of the corresponding substance; ρ_{brass} and ρ_c are the densities of brass and the corresponding substance.

Next, the R^2 determination coefficient was calculated for the methods [12; 13] and according to formulas (9)–(12), using the Guillet [14] and Efremov [17] coefficients. When calculating according to [14; 17], in all cases we obtain single-phase α-brass. The calculation indicators according to (11)–(14) are given in Table 5.

The calculation of the zinc equivalent, according to Table 4, showed that Zn_e=33.0 % is for the α-phase, Zn_e=41.8 % is for the β-phase, which corresponds to the α-phase at 750 °C and to the β-phase at 700 °C in the diagram (Fig. 1). The result corresponds to the data obtained in the metallographic analysis.

Based on the current requirements (Table 2), the authors determined the minimum and maximum amounts of α- and β-phases in the alloy: α-phase=39…70 % (α≥50 % in 88 % of cases), β-phase=18…50 %. In 99 % of cases, the α-phase predominates in the microstructure.

DISCUSSION

It is known [18], that the silicides in the alloy are the $(Fe,Mn)_5Si_3$ compound. However, no signs of the β→α+β eutectoid decomposition identified earlier in [18] were revealed. The microstructure of the CuZn13Mn8Al5Si2Fe1Pb alloy in the cited work was investigated in the annealed state, which is the reason for the difference in the results. Thus, in the industrially produced CuZn13Mn8Al5Si2Fe1Pb alloy, after pressing, the eutectoid decomposition of the high-temperature β-phase, is almost completely suppressed, and the alloy is in a nonequilibrium state. High variability of the microstructure α/β=0.9…2.4 is a factor determining the instability of the technological properties.

The alloy microstructure is not optimal in terms of manufacturability, since the main operations of the technological process are associated with hot deformation. In [19], it is shown that the correction of aluminium by 0.4 % wt. allows stabilising significantly the process, without qualitatively changing the requirements of the standards. In our case, with an aluminium content of 5.3...6.0 %, the α-phase will be 40...65 % (α≥50 % in 67 % of cases), the β′-phase will be 23.5...50 %. From the point of view of a qualitative increase in manufacturability, it is advisable, to ensure a ratio of α- and β-phases of 50/50 [17]. This can be achieved by limiting the content of copper to 68.45...70.40 %, of aluminium – 5.3...6.0 %. Then the amount of α-phase is 28.5...58.3 % (α≥50 % in 18 % of cases), β-phase – 30...61 %. It is known that maximum wear resistance is ensured with the amount of β′-phase of 45...50 %, α-phase – 30...45 % [20; 21]. This ratio corresponds to a content of copper of 68.8...70.7 %, of aluminium – 5.5...6.1 %. To prevent the formation of silicides of unfavourable form, it is recommended to limit the concentration of silicon in the alloy to no more than 2.2 % [18].

Testing the prediction technique demonstrated that the resulting model has a determination coefficient (R^2) equal to 0.62, which indicates an acceptable quality of the model, in contrast to previously known models [12; 13], which can be explained by changed production conditions of the alloy. The provision on the complete connectivity of silicon, and the use of the coefficients of connectivity of manganese and iron with silicon, in our opinion, is one of the main sources of error in the models [12; 13]. As a result, it was found that the predicted values, according to [12; 13], give significantly overestimated results (by 20...30 %) and R^2<0. Therefore, based on the proposed simulation model, it is possible both to analyse technological risks and to predict the behaviour of new alloys with a corrected or fundamentally new chemical composition. This is critically important for optimising technological processes, and improving the performance properties of materials. It is expected that the results of this study will contribute to the development of technologies for the production and processing of multicomponent brasses, and will increase their competitiveness in the modern market.

Table 5. *Calculation model indicators*
Таблица 5. *Показатели расчетной модели*

Average for the sample group, %			Standard deviation, %			Coefficient of determination R^2
α	β	$(Fe,Mn)_5Si_3$	α	β	$(Fe,Mn)_5Si_3$	
53.1	35.5	11.5	4.4	4.0	0.4	0.62

CONCLUSIONS

Statistical analysis of industrial batches of CuZn13Mn8Al5Si2Fe1Pb brass showed, that the variability of the alloy microstructure ensuring the stability of technological and operational characteristics, can be described by an analytical and simulation model, based on the Guillet coefficients and the Cu–Zn–($(Fe,Mn)_5Si_3$) diagram.

The formula for predicting the α-phase of the alloy after pressing was refined. At the same time, it was found that the observed microstructure corresponds to the ratio of the α- and β-phases in the pseudo-binary polythermal section of the Cu–Zn_e–Mn_5Si_3 diagram at 700 °C. For the hot-pressed state, complete binding of Fe in silicides, the presence of residual Si content in the α- and β-phases, and uniform distribution of Mn in the α- and β-phases were found.

To improve manufacturability, it is recommended to change the copper and aluminium content to 68.45…70.40 % and 5.3…6.0 %, respectively. It is assumed that maximum wear resistance is ensured by a copper content of 68.8…70.7 %, aluminium content of 5.5…6.1 %.

The proposed simulation model will reduce the risks of deviations in technological processes, when adjusting the requirements for chemical composition, and developing new brass grades co-doped with aluminium, manganese, iron and silicon.

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Универсальная модель прогнозирования фазового состава многокомпонентных латуней на основе данных химического анализа

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Аннотация: При разработке технических требований к сплавам важно применять комплексный подход. Сочетая аналитическое и имитационное моделирование, можно уменьшить технологические риски на этапе создания или изменения требований. Реализация данного подхода напрямую зависит от степени учета всех факторов, включенных в модели, а также от их влияния на изменчивость характеристик. Однако известные модели не дают удовлетворительной сходимости с реальными промышленными сплавами. На примере сложнолегированной латуни ЛМцАЖКС (CuZn13Mn8Al5Si2Fe1Pb) предложен подход, позволяющий описать изменчивость структурного состояния многокомпонентных латуней. Анализ статистических данных химического состава и микроструктуры промышленных партий позволил установить, что матричный раствор сплава представляет собой (α+β)-латунь и соответствует соотношению фаз при 700 °С на политермическом псевдобинарном разрезе диаграммы Cu–Zn–Mn_5Si_3. Методами рентгеноспектрального анализа исследовано распределение легирующих элементов в основных фазах. Подтверждена полная связанность железа в силицидах и равномерное распределение марганца в горячепрессованном состоянии. Предложен расчет доли кремния, входящего в твердый раствор. Измеренная плотность сплава составляет 7650 кг/м^3, расчетная плотность матричного раствора – 8100 кг/м^3. На основании уточненных параметров универсальной модели методом Монте-Карло оценили изменчивость микроструктуры в зависимости от требований к химическому составу. Причиной нестабильноости технологических свойств является значительная изменчивость соотношения α- и β-фаз. Содержание α-фазы в сплаве изменяется от 37,5 до 66,5 %, β-фазы – от 17,5 до 55,2 %. Имитационная модель, разработанная в рамках исследования, предоставляет возможность не только анализировать существующие сплавы, но и предсказывать поведение новых сплавов, что является критически важным для оптимизации технологических процессов и улучшения эксплуатационных свойств материалов.

Ключевые слова: многокомпонентная латунь; ЛМцАЖКС 70-7-5-2-2-1; стабильность технологических процессов; химический состав специальных латуней; статистическое имитационное моделирование фазового состава; микроструктура латуней; плотность латуни; цинковый эквивалент; силициды.

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