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Določanje razmerja kovinskih komponent šarže v kupolki

Determining the Ratio of the Metal Components of the Charge at the Cupola Furnace

Povzetek

Talilna peč je najpomembnejša oprema v livarni. Za taljenje litega železa se uporabljajo različne vrste peči. Pri pripravi taline za visoko stopnjo proizvodnje se v obratih za litje železa uporabljajo predvsem kupolke ali električne talilne peči. Glavne prednosti kupolk v primerjavi z električnimi so: enostavna in gospodarna naprava, manj škodljiva za okolje, manjša občutljivost na nizkokakovostne materiale šarže in onesnaževalce, oksidacijske in redukcijske reakcije med taljenjem v kupolki potekajo znotraj talilne cone in nad njo, kar omogoča uporabo visoko oksidiranega in nizkokakovostnega odpadnega materiala, cenejših zlitin in nekovinskih dodatkov. Ena osnovnih tehnoloških težav pri delovanju kupolke je določitev razmerij med komponentami šarže, ki jo sestavljajo koks, topilo in kovinska šarža, da bi ustvarili talino z želeno kemijsko sestavo. V praksi je masno razmerje kovinske šarže in koksa v določenih vrednostih, prav tako tudi skupna masa topila glede na maso koksa. Izkazalo se je, da je glavna težava določitev sestavin kovinskega dela šarže, ki je običajno sestavljena iz odpadkov iz lastne proizvodnje, jeklenega odpada, kupljene sive litine, nodularne litine, silicijevega mangana, ferosilicija itd. V tem prispevku smo z metodo izbire iz razpoložljivega razpona izračunali deleže kovinskih komponent kovinskega dela šarže za izdelavo taline iz sive litine, standardizirane pod oznako EN-GJL-250:
Ključne besede: kupolka, šarža, kovina, komponente

Summary

The most important equipment in a foundry is the melting furnace. Various types of furnaces have been used for cast iron melting. In cases of melt preparation for production at high capacities, the primary melting methods used in iron casting plants are cupola furnaces or electric melt furnaces. The main advantages of cupola furnaces compared to electric ones are: simple and economical device, less harmful to the environment, less sensitive to low-quality charge materials and contaminants, oxidation and reduction reactions take place within and above the melt zone during cupola melting, which allows the use of highly oxidized and low-quality scrap material, lower prices of alloys and non-metallic additions. One of the basic technological problems in the work of the cupola furnace is to determine the relationships between the charge components consisting of coke, flux, and metal charge to obtain a melt of a given chemical composition. In practice, the mass ratio of metal charge and coke is in certain mass relations as well as the total mass of flux in relation to the mass of coke. It turns out that the main problem is to determine the components of the metal part of the charge, which usually consists of waste of own production, steel scrap, purchased cast iron, nodular cast iron, silicon manganese, ferrosilicon, etc. In this paper, using the method of selection from the available range, the proportions of metal components of the

metal part of the charge were calculated to produce a gray cast iron melt standardized with the code EN-GJL-250.
Key-words: cupola furnace, charge, metal, components

1 Uvod

Kupolka je visoka jaškasta peč z jeklenim obodom, obloženim z ognjevzdržnim materialom, uporablja pa se predvsem za proizvodnjo različnih vrst litega železa in brona za livne postopke. Nadaljuje se proces taljenja v peči, ki je primerna za predelavo grodlja, odpadkov lastne proizvodnje (odrezani konci, zavrnjeni izdelki), dodajajo se železove zlitine za zagotovitev kemijske sestave v primeru primanjkljajev v postopku taljenja [1]. Glavni vir energije za postopek taljenja je metalurški koks. Zaradi enostavnih delovnih postopkov ta vrsta peči pri optimalnih tehnoloških parametrih porabi majhno količino goriva [2]. Razdelki so razporejeni vertikalno, zato so primerni za tri ali štiri stojala [3]. V primerjavi s šaržnimi talilnimi napravami ima ta peč z navpičnim jaškom s protitokom veliko verjetnost dobrega talilnega učinka [4]. Sodobne kupolke so običajno opremljene z gorilniki za obogatitev s kisikom ali s plazemskimi gorilniki. S povečanjem stopnje segrevanja lahko kupolko upravljamo bolj fleksibilno, kar je pogosto potrebno pri proizvodnji ulitkov [5].

Procesni prostor kupolke je sestavljen iz naslednjih con, ki so razporejene navpično: zbiralnik, območje zgorevanja, območje redukcije, območje taljenja in območje predgretja (Slika 1). Staljeni material se zbira v zbiralniku. V zgorevalni ali oksidacijski coni poteka hitro zgorevanje koksa, pri čemer nastajata toplota in CO_2. Temperatura se giblje med 1550 in 1850 °C. Oksidacija silicija in mangana ustvarja dodatno toploto. Redukcija iz CO_2 v CO poteka v redukcijski coni. Zaradi te

1 Introduction

The cupola furnace is a vertical shaft furnace with a steel shell, lined with refractory material, which is mainly used for the production of various types of cast iron and bronze in casting processes. The melting processes in the furnace continue which is capable of processing pig iron, waste of own production (crop ends, foundry returns), and the addition of ferroalloys to make the chemical compositions in a case where there is a shortfall in the melting processes [1]. Metallurgical coke is the principal energy source for the melting process. Due to the simple operational processes, this type of furnace consumes a low amount of fuel at optimal technological parameters [2]. The sections are arranged in a vertical position to withstand the three or four stands [3]. Compared to batch-type melters, this counterflow vertical shaft furnace has a high likelihood of good melting performance [4]. Modern cupola installations are usually equipped with either oxygen enrichment or plasma torches. By increasing the heating rate, the cupola can be operated more flexibly, which is often necessary in casting production [5].

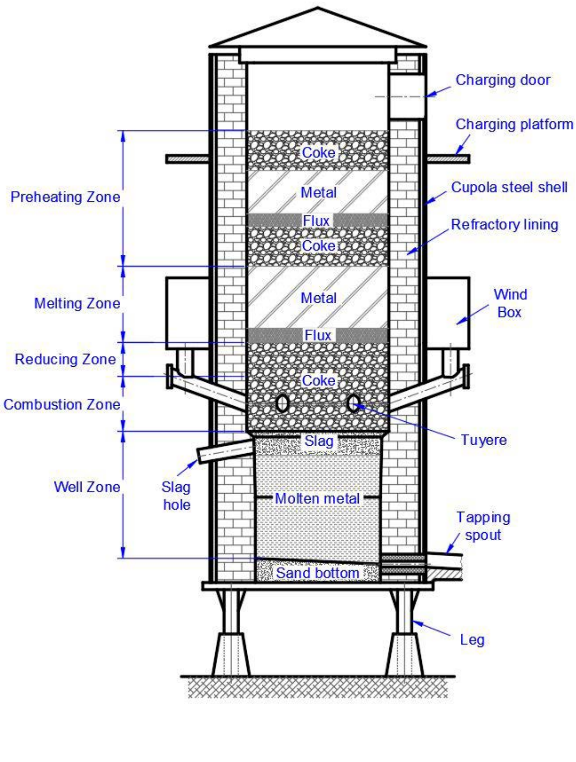
The process space of the cupola furnace consists of the following zones arranged in a vertical position: well zone, combustion zone, reducing zone, melting zone, and preheating zone (Figure 1). The molten material is collected in the well zone. In the combustion or oxidizing zone, rapid combustion of coke takes place generating heat and CO_2. The temperature varies from 1550 to 1850°C. Oxidation of silicon and manganese generates additional heat.

endotermne reakcije se temperatura v tej coni zniža na približno 1200 °C. Posebnost te cone je, da ustvarjena redukcijska atmosfera šaržo varuje pred oksidacijo. V talilni coni se kovinska šarža začne topiti in še naprej uhaja proti zbiralniku. Pri prehodu skozi redukcijsko cono staljeno železo pobere ogljik, ki tvori Fe_3C. V zbiralniku se topilo prav tako tali in reagira z nečistočami v staljeni kovini; posledično nastaja žlindra, ki plava na površini staljene kovine in jo varuje pred oksidacijo.

Ta prispevek obravnava težavo določanja razmerja med komponentami šarže, da bi ustvarili talino z želeno kemijsko sestavo. V praksi je masno razmerje med šaržo kovin in koksom od 1:10 do 1:8. Apnenec je pogosto topilo. Skupna masa apnenca je običajno enaka 20 % mase koksa [6]. Zato je glavna težava določitev komponent kovinskega dela šarže. Za določanje sestavin kovinskega dela šarže

Reduction of CO_2 to CO occurs in the reduction zone. Due to this endothermic reaction, the temperature in this zone decreases to approximately 1200°C. A special feature of this zone is that the created reducing atmosphere protects the charge from oxidation. In the melting zone, the metal charge starts melting and continues to leak toward the well zone. Passing down through the reduction zone the molten iron picks up carbon forming Fe_3C. In the well zone, the flux also melts and reacts with the impurities of the molten metal forming a slag, which floats on the surface of the molten metal protecting it from oxidation.

This article discusses the problem of determining the relationship between the components of the charge to obtain a melt of a given chemical composition. In practice, the mass ratio of metal charge and coke is in the range of 1:10 to 1:8. Limestone is a common flux. The total mass of limestone is usually 20% of the mass of coke [6]. For that reason, the main problem is to determine the components of the metal part of the charge. When determining the components of the metal part of the charge, three methods are usually used: The analytical method, the graphic method, the so-called Triangle method, and the method of selection from the available range [7]. In this paper, using the latter method, the proportions of metal components of the metal part of the charge were calculated to produce a gray cast iron melt standardized with the code EN-GJL-250.



Slika 1. Shematski prerez kupolke

Figure 1. Schematic cross-sectional view of the cupola furnace

se običajno uporabljajo tri metode: analitična metoda, grafična metoda, t. i. metoda trikotnika ena metoda preveč in metoda izbire iz razpoložljivega območja [7]. V tem prispevku smo z uporabo slednje metode izračunali deleže kovinskih komponent kovinskega dela šarže za izdelavo taline iz sive litine, standardizirane pod oznako EN-GJL-250.

2 Izračun kovinskih komponent šarže na 100 kg taline

Kemijska sestava sive litine (EN-GJL-250) je podana v Preglednici 1, vrstica 1, komponente kovinske šarže pa v isti preglednici v naslednjem vrstnem redu: odpadki iz lastne proizvodnje (vrstica 4), kupljena siva litina (vrstica 5), odpadno jeklo (vrstica 6), nodularna litina (vrstica 9), beli grodelj (vrstica 10), silicijev mangan (vrstica 13), ferosilicij (vrstica 14).

Med prehajanjem skozi redukcijsko cono staljeno železo pobere ogljik z naslednjo reakcijo:

$$3Fe + 2CO \rightarrow Fe_3C + CO_2$$

Po drugi strani pa potekajo reakcije oksidacije mangana in silicija v območju zgorevanja z reakcijami:

$$2Mn + O_2 \rightarrow 2MnO + \text{toplota}$$

$$Si + O_2 \rightarrow SiO_2 + \text{toplota}$$

Iz tega razloga se glede na dejanske proizvodne podatke [7] ogljik poveča za 12,5 %, silicij zmanjša za 22,5 % in mangan za 27,5 % v primerjavi z začetnim stanjem šarže. Med postopkom taljenja se količina žvepla poveča za 62,5 %, količina fosforja pa se bistveno ne spremeni, zato sprememba količine fosforja med postopkom taljenja ni upoštevana (Preglednica 2, vrstica 2).

Zahtevana povprečna vsebnost elementa E_{ch} v šarži ob upoštevanju njegove

2. Calculation of Charge Metal Components Per 100 kg of the Melt

The chemical composition of the gray cast iron (EN-GJL-250) is given in Table 1, row 1, and the metal charge components in the same table in the following order: Waste of own production (row 4), Purchased gray cast iron scrap (row 5), Steel scrap (row 6), Nodular cast iron (row 9), White pig iron (row 10), Silicomanganese (row 13), and Ferrosilicon (row 14).

While passing down through the reduction zone the molten iron picks up carbon by reaction:

$$3Fe + 2CO \rightarrow Fe_3C + CO_2$$

On the other side, the reactions of oxidation of manganese and silicon take place in the combustion zone by reactions:

$$2Mn + O_2 \rightarrow 2MnO + \text{heat}$$

$$Si + O_2 \rightarrow SiO_2 + \text{heat}$$

For this reason, according to actual production data [7], carbon has an increase of 12.5%, silicon has a decrease of 22.5%, and manganese of 27.5% compared to the initial state of the charge. During the melting process, the amount of sulfur has an increase of 62.5%, and phosphorus does not change significantly, so the change in the amount of phosphorus during the melting process is not taken into account (Table 2, row 2).

The required mean content of the element E_{ch} in the charge, taking into account its change in the melting process, is calculated according to the expression:

$$E_{ch} = E_m \cdot (100 – X) / 100, \% \quad (1),$$

where E_m is the content of the element in the molten metal, and X is the amount of increase or decrease of the element during the melting process (in the expression sign - in case of an increase, i.e., sign + in case

Preglednica 1. Kemijska sestava sive litine (EN-GJL-250) in sestavine kovinske šarže

Table 1. The chemical composition of the gray cast iron (EN-GJL-250) and the components of metal charge

	Materiali šarže / Charge materials	Masni delež / Mass fraction % (kg)	Kemijska sestava / Chemical composition									
			C		Si		Mn		P		S	
			%	kg	%	kg	%	kg	%	kg	%	kg
1.	Zahtevana sestava taline / Required melt composition	100	3	3	1,8	1,8	0,7	0,7	0,15	0,15	0,1	0,1
2.	Povečanje/zmanjšanje mase elementov / Increase / Decrease of the mass of the elements		12,5	0,43	-22,5	-0,41	-27,5	-0,23	0	0	62,5	0,062
3.	Potrebna povprečna vsebinska sestava šarže / Required mean content composition of the charge		2,63	2,63	2,21	2,21	0,9	0,9	0,15	0,15	0,04	0,038
4.	Odpadki iz lastne proizvodnje / Waste of own production	20	3	0,6	1,8	0,36	0,7	0,14	0,15	0,03	0,1	0,02
5.	Kupljena odpadna siva litina / Purchased cast iron scrap	15	3,2	0,48	2	0,3	0,7	0,105	0,2	0,03	0,1	0,02
6.	Odpadno jeklo (v skladu z izračunom) / Steel scrap (according to the calculation)	14	0,3	0,042	0,4	0,056	0,7	0,098	0,05	0,01	0,05	0,007
7.	Skupni vnos / Total entered	49		1,122		0,716		0,336		0,04		0,047
8.	Potreba po vnosu / Need to enter	51		1,503		1,489		0,556		0,11		0,009
9.	Nodularna litina, (A) / Nodular cast iron, (A)	21	3,4	0,714	2,2	0,462	0,4	0,084	0,12	0,03	0,02	0,0042
10.	Beli grodelj, (B) / White pig iron, (B)	30	3,6	1,08	1	0,3	0,3	0,09	0,08	0,03	0,02	0,006
11.	Skupaj / Total	100		2,916		1,478		0,51		0,16		0,058
12.	Primanjkljaj/presežek po elementih / Deficit/surplus by elements			0,286		-0,732		-0,379		0,01		0,02
13.	Silicijev mangan $MnSi_{20}$ / Silicomanganese $MnSi_{20}$	0,748	1,5	0,01	20	0,150	65	0,486	0,1	0,0007	0,02	0,0001
14.	Ferosilicij $FeSi_{20}$ / Ferrosilicon $FeSi_{20}$	3	1	0,03	20	0,6	1	0,03	0,2	0,006	0,02	0,0006
15.	Skupaj / Total	103,748		2,956		2,228		1,026		0,17		0,058
16.	Razlika glede na sestavo taline / Difference in relation to the given melt composition	3,748		+0,04		+0,018		+0,126		+0,02		+0,02

spremembe v postopku taljenja se izračuna s formulo:

$$E_{ch} = E_m \cdot (100 – X) / 100, \%\quad (1)$$

kjer je E_m vsebnost elementa v staljeni kovini, X pa je količina povečanja ali zmanjšanja elementa med postopkom taljenja (v of a decrease). Example of calculating the required carbon content in the charge:

$$C_{ch} = 3 \cdot (100 – 12,5) / 100 = 2,625 \%.$$

The calculation for Si, Mn and S is performed in an analogous way. The results are shown in Table 1, row 3.

formuli znak – v primeru povečanja in znak + v primeru zmanjšanja). Primer izračuna zahtevane vsebnosti ogljika v šarži:

$$C_{ch} = 3 \cdot (100 - 12{,}5) / 100 = 2{,}625\ \%.$$

Izračun za Si, Mn in S se izvede na enak način. Rezultati so prikazani v Preglednici 1, vrstica 3.

Da bi zagotovili želeno sestavo taline, je treba zmanjšati vsebnost ogljika. To je mogoče doseči z zahtevanim deležem jeklenih odpadkov v šarži. To količino je mogoče določiti na podlagi ravnotežne enačbe ogljika v šarži:

$$C_{ch.st} \cdot m_{st} + (100 - m_{st}) \cdot C_{ch.m} = C_{ch} \cdot 100 \quad (2)$$

kjer so $C_{ch.st}$ vsebnost ogljika v jeklenih odpadkih (%), m_{st} masa jeklenih odpadkov (kg), $C_{ch.m}$ želena vsebnost ogljika v talini (%), C_{ch} predizračun vsebnosti ogljika v šarži (%).

Z vnosom podatkov v enačbo (2) dobimo:

$$0{,}3_t \cdot m_{st} + (100 - m_{st})_t \cdot 3{,}0 = 2{,}625_t \cdot 100$$
$$= 13{,}88\ \text{kg}$$

Za nadaljnji izračun se privzame vrednost 14 kg jeklenega odpadka na 100 kg šarže. Masa ogljika, vnesenega v šaržo z jeklenimi odpadki, se izračuna, kot sledi: $C_{st} = 0{,}3 \cdot 14/100 = 0{,}042$ kg. Izračun za Si, Mn in S se izvede na enak način. Rezultati so prikazani v Preglednici 2, vrstica 6.

Običajno se v sestavo kovinske šarže doda 15 % lastnih odpadkov in 15 % kupljene sive litine. Sestava in deleži posameznih komponent so prikazani v Preglednici 1, vrstici 4 in 5. Vsota vseh komponent je prikazana v 7. vrstici. Na podlagi razlike med 3. in 7. vrstico (vrstica 8) dobimo mase posameznih elementov, ki jih dodamo šarži.

Za primer vzemimo livarno, ki ima na razpolago nodularno litino (vrstica 9) in belo litino (vrstica 10). Za določitev njihovega deleža v kovinski šarži glede na zahtevano

In order to obtain the desired melt composition, it is necessary to lower the carbon content. This can be achieved by the required proportion of steel scrap in the charge. This amount can be determined from the carbon balance equation in the charge:

$$C_{ch.st} \cdot m_{st} + (100 - m_{st}) \cdot C_{ch.m} = C_{ch} \cdot 100 \quad (2)$$

where are $C_{ch.st}$ the content of the carbon in steel scrap (%), m_{st} the mass of steel scrap (kg), $C_{ch.m}$ the desired content of carbon in the melt (%), C_{ch} pre-calculate the carbon content in the charge (%).

Entering data into the equation (2) is obtained:

$$0{,}3_t \cdot m_{st} + (100 - m_{st})_t \cdot 3{,}0 = 2{,}625_t \cdot 100$$
$$= 13{,}88\ \text{kg}$$

For further calculation, a value of 14 kg of steel scrap per 100 kg of charge is adopted. The mass of carbon introduced into the charge with steel scrap is calculated as follows: $C_{st} = 0.3 \cdot 14/100 = 0.042$ kg. The calculation for Si, Mn, and S is performed analogously. The results are shown in Table 2, row 6.

Usually, 15% of own waste and 15% of purchased gray cast iron are added to the composition of the metal charge. The composition and proportions of individual components are shown in Table 1, rows 4 and 5. The sum of all components is shown in row 7. The masses of the individual elements to be added to the charge were obtained on the difference between the 3rd and 7th rows (row 8).

Take, for example, the foundry has at its disposal Nodular Cast Iron (row 9) and White Cast Iron (row 10). In order to determine their share in the metal charge concerning the required melt composition, it is necessary to set up a balance equation in which the letter A denotes Nodular Cast Iron and B White Cast Iron. The calculation is sestavo taline je treba sestaviti ravnotežno enačbo, v kateri je s črko A označena nodularna litina, z B pa bela litina. Izračun se glede na vsebnost silicija izvede, kot sledi:

A + B + 49 = 100

2,2 · A + 1,0 · B = (A + B) · 1,489

A = 20 % B = 31 %

V 9. in 10. vrstico je treba vnesti izračunane deleže in izračunati masne deleže posameznih elementov z naslednjo formulo:

$$E_i = E_i' \cdot A / 100 \quad (3)$$

kjer so A masa komponente šarže (kg), E_i' delež elementa i v komponenti šarže.

Potrebno je primerjati povprečno sestavo začetne sestave šarže po elementih (vrstica 3) z izračunanimi vrednostmi (vrstica 11) in rezultate vpisati v vrstico 12. Znak (+) označuje presežek, (-) pa primanjkljaj posameznega elementa. Izkazalo se je, da je treba dodati 0,732 kg silicija in 0,379 kg mangana. Ta primanjkljaj je mogoče nadomestiti s silicijevim manganom MnSi20 (65 % Mn, 20 % Si) in ferosilicijem FeSi20 (20 % Si, 1,0 % Mn) (vrstici 13 in 14). Izračun potrebne mase silicijevega mangana za nadomestitev primanjkljaja mangana s stopnjo uporabnosti 0,95:

$$m_{MnSi} = 0{,}462 \cdot 100 / (65 \cdot 0{,}95) = 0{,}748 \text{ kg}$$

Masa silicija, dodanega s silicijevim manganom, je:

$$m_{MnSi} = X_{Si} \cdot 100 / (20 \cdot 0{,}95)$$

$$X_{Si} = m_{MnS} \cdot 20 \cdot 0.95 / 100 = 0.142 \text{ kg}$$

Primanjkljaj silicija (0,732 - 0,142) = 0,59 kg je mogoče nadomestiti z dodatkom ferosilicija:

m_{FeSi} = 0,59 · 100 / (20 · 0,95) = 3,1 kg (zaokroženo na vrednost 3,0)

performed according to the silicon content, in the following way:

A + B + 49 = 100

2,2 · A + 1,0 · B = (A + B) · 1,489

A = 20 % B = 31 %

It is necessary to enter the calculated proportions in rows 9 and 10 and to calculate the mass fractions of individual elements using the expression:

$$E_i = E_i' \cdot A / 100 \quad (3)$$

where are A mass of charge component (kg), E_i' the proportion of the *i*-th element in the charge component.

It is necessary to compare the mean composition of the initial composition of the charge by elements (row 3) with the calculated values (row 11), and enter the results in row 12. The sign (+) indicates the surplus, and (-) the deficit of an individual element. It turns out that it is necessary to add 0.732 kg of silicon and 0.379 kg of manganese. This deficit can be compensated by silicon manganese $MnSi_{20}$ (65%Mn, 20% Si) and ferrosilicon $FeSi_{20}$ (20% Si, 1.0%Mn) (rows 13 and 14). Calculation of the required mass of silicon manganese to compensate for the manganese deficit with a degree of usability of 0.95:

$$m_{MnSi} = 0{,}462 \cdot 100 / (65 \cdot 0{,}95) = 0{,}748 \text{ kg}$$

The mass of silicon introduced with silicon manganese is:

$$m_{MnSi} = X_{Si} \cdot 100 / (20 \cdot 0{,}95)$$

$$X_{Si} = m_{MnS} \cdot 20 \cdot 0.95 / 100 = 0.142 \text{ kg}$$

Silicon deficit of (0.732 - 0.142) = 0.59 kg can be compensated by adding ferrosilicon:

m_{FeSi} = 0,59 · 100 / (20 · 0,95) = 3,1 kg (Rounded to the value of 3.0)

Vrstica 16 prikazuje razliko med izračunano sestavo šarže glede na zahtevano sestavo taline. Razlike so praktično zanemarljive. V praksi se v primeru majhnih razlik v količinah C, P in C korekcija sestave komponent šarže ne izvaja.

3 Sklepi

Za izdelavo taline sive litine, standardizirane pod kodo EN-GJL-250, v kupolki, naj bi na podlagi rezultatov izračuna 100 kg kovinske šarže sestavljalo naslednje: odpadki iz lastne proizvodnje 20 kg, kupljena siva litina 15 kg, odpadno jeklo 14 kg, nodularna litina 21 kg, beli grodelj 30 kg, silicijev mangan 0,748 kg, ferosilicij 3 kg. Razlika dodanih 3,748 kg kovinskega dela šarže ne vpliva bistveno na zahtevano sestavo taline.

Predstavljeni primer izračuna sestave kovinskega dela šarže pri taljenju v kupolki se je v praksi izkazal za izredno učinkovitega. Vendar pa je enak način izbire iz razpoložljivega obsega mogoče uporabiti tudi v primeru drugih vrst talilnih peči za proizvodnjo ulitkov ob upoštevanju posebnosti dela vsake od teh peči.

Kot primer izračuna sestave kovinskega dela šarže smo zaradi zahtevnejših procesnih reakcij v primerjavi z drugimi, na primer električnimi pečmi, izbrali kupolko. Očitno je, da je pri ostalih naštetih pečeh izračun šarže manj zahteven.

Row 16 shows the difference between the calculated charge composition with respect to the required melt composition. The differences are practically negligible. In practice, in the case of small differences in the amounts of C, P and C, the correction of the composition of the charge components is not performed.

3 Conclusion

In order to produce the cast iron melt standardized with the code EN-GJL-250 in the cupola furnace, according to the results of the calculation, 100 kg of metal charge should consist of: Waste of own production 20 kg, purchased gray cast iron 15 kg, Steel scrap 14 kg, Nodular cast iron 21 kg, White pig iron 30 kg, Silicomanganese 0.748 kg, Ferrosilicon 3 kg. The difference of the added 3.748 kg of metal part of the charge does not significantly affect the required melt composition.

The presented example of the calculation of the composition of the metal part of the charge for the case of melting in a cupola furnace, proves to be very effective in practice. However, the same method of selection from the available range can be applied in the case of other types of melting furnaces in casting production, taking into account the specifics of the work of each of them.

As an example of the calculation of the composition of the metal part of the charge, the cupola furnace was chosen because of more complex process reactions compared to others, for example, electric furnaces. Clearly, in the other listed furnaces, the charge calculation is less demanding.

Viri / References

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