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EFFECT OF BENTONITE ADDITION ON PELLET CHARACTRIZATION USED FOR FERRO-CHROME SILICON ALLOY PRODUCTION

Summary. This work is concerned basically with the investigation of the effect of Ca-bentonite addition on the pelletization process of chromite ore concentrate and the production of ferro-chrome silicon alloys.

WPŁYW DODATKU BENTONITU NA WŁASNOŚCI GRUDEK STOSOWANYCH PRZY PRODUKCJI STOPU ŻELAZOWO-CHROMOWO KRZEMOWEGO

Streszczenie. Określono wpływ dodatku różnych ilości bentonitu na przebieg grudkowania koncentratów z rud chromowych Barramyia. Ustalono optymalne parametry grudek surowych i utwardzonych przy różnych warunkach wytwarzania.

Introduction

Great attention on the production of high-quality steels is now needed for the development of many civil and military industries.

It is planed to increase considerably the output of alloy steels, whose properties are enhanced by alloying elements such as, chrome, nickel, manganese, tungsten, molybdenum, niobium, titanium, vanadium, etc...These elements are sometimes introduced into steel in pure form, form of ferroalloys. The last technique is preferable because it is less expensive. Moreover, it is considerably easier to add most of the elements to steel when they are in the form of ferroalloys. For example, metals such as tungsten and molybdenum are characterized by their high specific gravitates, high melting points and are slowly distributed through a steel bath. The iron alloys of these metals possess lower specific gravitates and lower melting points, that is why, they are more convenient to be used in the manufacture of steel.

Ferroalloys make it possible to solve another very important problem: degassing and deoxidizing processes of steel, where oxygen and other gases dissolve in steel during the smelting and cooling processes causing pipes and gas cavities in steel. These cavities in steel weaken its mechanical properties. To eliminate these gases it is necessary to introduce a technological operation called deoxidation. This is accomplished by the addition of silicon, manganese and titanium ferroalloys, which combine with oxygen to form stable oxides which do not dissolve in steel. These elements are called deoxidizers.

The suitability of Chromites ore for the production of standard grades Ferro-chrome limits the Cr/Fe ratio to be 3/1 [1,2] with minimum of 48% Cr_2O_3 ,while MgO and Al_2O_3 should not exceed 25% [2], in chromite ore while Mathur et al [3] indicated that the combined percentages of alumina and silica should not exceed 25%, sulphur and phosphorus should be less than 0.08 and 0.04% respectively in the chromite ores [3].

Ferro-chrome is classified according to its carbon content into:

a) High carbon Ferro- chrome with 2-11% carbon having a maximum 3% silicon, finds use in low alloy steels where both carbon and chromium must be present.
b) Medium carbon Ferro-chrome ranging from 0.7 to 2% carbon with maximum 2% silicon and low carbon Ferro- chrome with less than 1% carbon and a maximum 1% silicon are employed in the production of high chromium steels.
c) Ferro-chrome alloys with very low carbon contents are in great demand for the development and production of special steels and other high temperature alloys.
d) Chromium additions in different alloys are also effected on many forms such as chromium- silicides, simplex Ferro- chrome, foundry grade Ferro- chrome, manganese bearing Ferro- chrome- silicon- aluminum, exothermic Ferro-chrome, low carbon chrome, chromium metal, etc [4].

Bentonite combines with water and forms a gel at about five to six times its weight and its volume increases to approximately tenfold [5]. Bentonite envelops the ore grains together with water and can thus only becomes active in connection with water.

Neuer [6] studied the effect of bentonite on the basis of the influence of the granulometric properties and optimum water addition. He found that, the green pellet strength changes only insignificantly, while the dry strength is highly influenced. The most important bentonite property is its swelling capacity. The swelling capacity differs for various bentonite types so that its suitability as binder has to be examined before the bentonite type is selected.

Kortmann and Mai [7] indicated that the green pellet strength practically does not change, while the drop indices and dry pellet strength rise with addition of bentonite of higher swelling capacity.

Afifi, Shalabi et al. [8] started pelletizing El. Dekhaila fine oxide having -200 mesh with bentonite and indurated at 1100°C. They found that the increase in bentonite percentage lead to increasing the compressive strength.

Negm and other [9] indicated that the average drop number of pellets increased with the increase of bentonite addition, this is due to increasing the colloidal material (bentonite). Increasing bentonite addition causes an increase in pellets crushing strength and resistance breakage. This is due to the cementing action of bentonite which improves the mechanical properties of pellets [9].

Spektor [10], et al, indicated that pelletization of ore greatly improved by adding 1% bentonite to the charge. The mechanical properties of the pellets may also be improved by roasting or heat treatment.

Ganguly and others [11], found that the crushing strength of the pellets made with bentonite burden increased with increasing firing temperature from 800-1200°C.

Nasr, et al [12] indicated that:

1. Increasing amount of Ca-bentonite at the same water level retard the ball growth rate.
2. At the same level of Ca-bentonite, the ball growth rate increases with increasing the amount of water.
3. The crushing strength of indurated pellets increases with the increase of Ca – bentonite.

The aim of work is devoted to investigate the effect of Qasr El-Sagha bentonite on the quality of the chromite ore pellets.

2. Experimental work

2.1. Materials

2.1.A. Chromite ore

The chromite ore from Barramyia region, Eastern desert, Egypt having the chemical composition 38% Cr_2O_3, 10.34 SiO_2, Fe_{total} 12.29,CaO 2%,MgO 20.55%. This ore was concentrated in the Mineral Benefication pilot plant of CMRDI (13) The chromite ore concentrated product was used in this work. Its mineral constituents having the following main structure Fig.1, chromite, $FeO(CrAl_2)O_3$ Pichochromite$(Fe,Mg)O.(Cr,Al)_2O_3$and Serpentine $3MgO.2SiO_2.2H_2O$.

Table 1

Chemical analysis of raw materials

Component	Chemical compositions, %	
	Chromite ore concentrate	Ca-bentonite
Fe total	10.26	5.46
Cr_2O_3	42.25	-
Fe_2O_3	-	7.80
FeO	13.2	-
SiO_2	6.86	54.01
CaO	1.34	4.18
Al_2O_3	16.84	17.11
MgO	19.5	2.03
Na_2O	-	1.27
K_2O	-	1.25
Cl	-	0.01
S	-	1.04

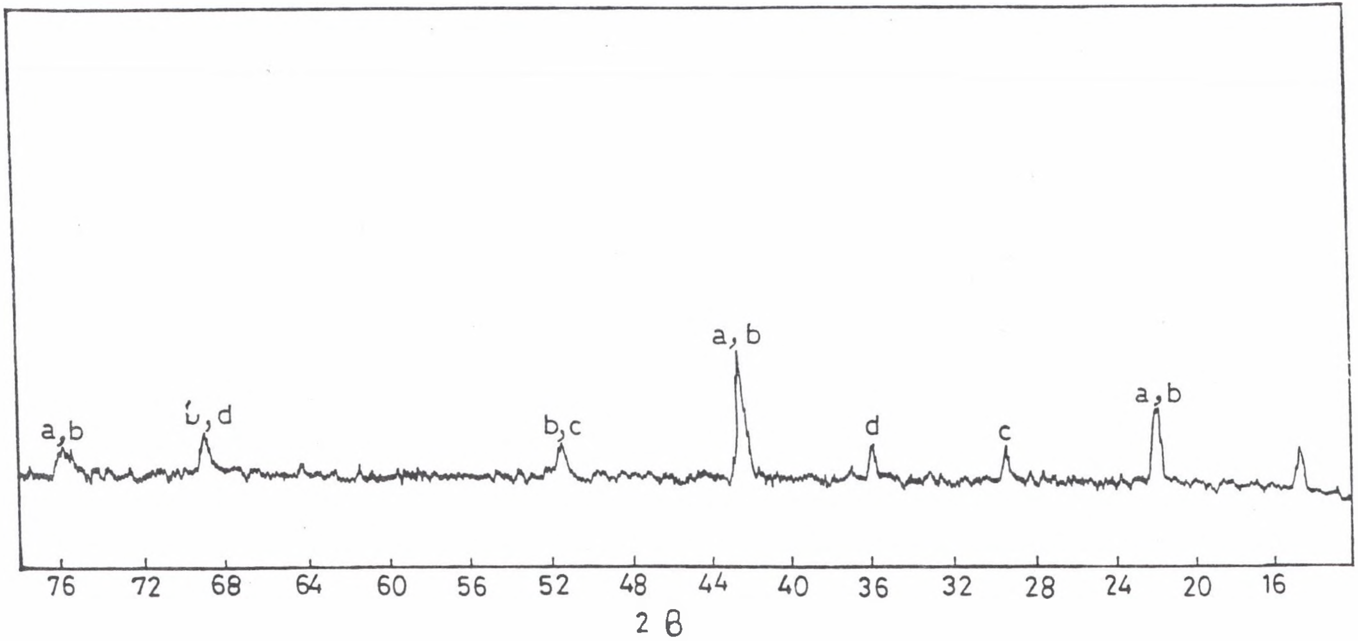

Fig. 1. X-Ray diffractogram of Barramyia chromite ore concentrate
a – $FeO(Cr_2O_3,Al_2O_3)$, b – Fe_2SiO_4, c – $FeCr_2O_4$, d – $(Mg,Fe)(Cr,Al)_2O_3$

Rys. 1. Dyfraktogram koncentratu z rud chromowych Barramyia

2.1.b. Bentonite

A sample of calcium bentonite, represents Qasr El-Sagha (Fayoum) locality, was provided by Sinai Manganese Company. The sample is mostly in lumps ~ 25 cm diameters was sun dried for prolonged periods to decrease its moisture content before its grinding.

The mineralogical composition of Qaser El-Sgha bentonite consists mainly of montmorillonite, Kaolinite and illlite [14,15]. In addition to these minerals, quartz, gypsum and calcite were also present Fig. 2. Table 1. shows the chemical analysis of chromite concentrate and calcium bentonite.

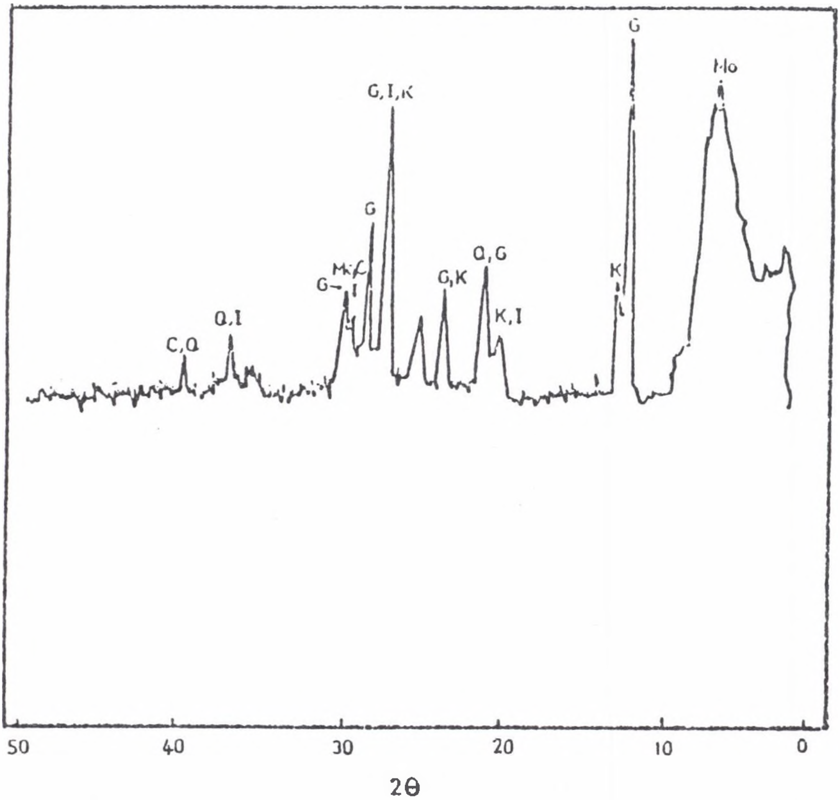

Fig.2. X-Ray diffraction pattern of Qasr El-Sagha Ca-bentonite Mo - Montmorillonite, I - Illite, K - Kaolinite, Q - Quartz, G - Gypsum, C - Calcite
Rys.2. Dyfraktogram Ca-bentonitu z Qasr El-Sagha

2.1.c. Nut coke

Local nut coke (-10 mm size) was used in the series of experiments which were carried out to investigate the high carbon ferrochromium silicon smelting process. The composition of the nut coke is given in Table.2. This coke was delivered by El-Nasr Company for coke and chemicals, Helwan, El-Tabbin.

2.1.d. Fluxes

Industrial lime, quartzite and flurospar were the main fluxes. All the fluxing materials were crushed to a grain size similar to that of the chromite concentrate. The chemical composition of these fluxes is given in Table. 2.

Table 2

Chemical composition of Nut coke And Fluxes materials, Wt, %

Charged materials %	Chemical composition							
	Fe_2O_3	SiO_2	MgO	Al_2O_3	CaO	CaF_2	C	CO_2
Nut coke	3.20	9.00	1.0	6.0	0.80	--	78	--
Quartzite	1.13	97.0	0.1	1.5	0.27	--	--	--
Lime	--	5.00	--	2.0	91.68	--	--	1.32
Flurospar	0.35	12.5	--	2.4	3.23	80.0	--	0.97

2.2.a. Pelletization

A laboratory disc pelletizer 40 cm diameter and 10 cm depth was used for granulation of the finally ground , -200 mesh chromite ore concentrate sample and bentonite. It was provided with means for adjusting the inclination angle of its disc.

The chromite ore concentrate sample mixed with bentonite then the mixture was fed to the disc pelletizer.The predetermined amount of added water was then sprayed onto the rolling bed of the material in the pelletizer. At the end of test , the sample was collected and screened to collect the -16 +10 mm pellets which was taken as a measure for the productivity which was calculated according to the following equation:

$$P = W_1/W_2 \times 100$$

where P = productivity of the green pellets (-16+10) mm diameter ,%,

W_1 = weight of the produced green pellets (-16+10)mm diameter, gm,

W_2 = weight of the starting charged materials to the disc pelletizer, gm.

The addition of Ca-bentonite as a binder materials during the pelletization of chromite ore concentrate was done under the following conditions: Tilt angle of disc bottom = 60°, residence time = 15 min , feed size = -200 mesh and feed weight = 500 gm.

2.2.b. Induration of green balls

Induratian of green balls was conducted in a computerized muffle furnace (34x15x15 cm) model Nabertherm program controller C19 .

The samples were heated , in the heat zone of furnace , using a ceramic crucible at the required temperature and time.

2.2.c. Smelting technology of ferro-chrome silicon alloys

The smelting experimental heats of ferro-chrome silicon were made in a 100 KVA laboratory submerged electric arc furnace. Electric power is supplied to the furnace through AC stepwise. Transformer, with primary electric power of 35 Volt and 380 Amperes, through 35-40 mm diameter nontilting graphite electrodes, the electrodes can be moved up and down by a normal device. The inside dimensions of the furnace with tapping hole at the bottom, are 230 mm diameter and 200 mm depth. The furnace wall and bottom were rammed with magnesite. The nominal capacity of the furnace is 1-5 Kg ore. The furnace roof is furniture with water cooled roof with three holes, tow for the electrodes and one for charging.

To carry out the heats on the furnace [16], the components of the charge; chromite ore concentrate pellets(=0.8 Kg) with particle size (-16+10mm); nut coke (0.3 Kg) of -10 mm size and quartzite (0.17 Kg) with the same particle size as chromite ore concentrate pellets were, manually, well mixed together. The roof of the furnace was then fixed and the electrodes were moved down through their holes to a place near to the bottom lining. A graphite bridge was placed between the tips of the electrodes. The electric current was, then, switched on to raise the hearth temperature due to the produced electric arc. An initial portion of the mixed charge was added gradually in the furnace manually between the electrodes through the charging hole of the roof. As soon as the molten pool has been established, the furnace was then filled with another portion of the charge. This process continued till all the charge was fed into the furnace. After complete melting of the main charge, the molten metal and slag was left for 30 minutes with the current switched on to ensure the maximum degree of reduction and the complete settling of the formed ferro-chromium silicon through the slage. The furnace was then switched off, the electrodes were raised up and the tapping hole was opened. The metal together with slag was tapping in iron laddle. The metal covered by the slag was left to cool, then detached, weighed and samples from it were taken for the determination of its chemical composition, using standard methods [16].

3. Results and discussion

3.a. Effect of Ca-bentonite Addition on the Green Pellets Formation and its Properties

Figs. 3-5 illustrate the effect of bentonite addition on the productivity of chromite ore concentrate green pellets, its drop number and its crushing strength at different amounts of water added.

From Fig. 3 it is clear that adding the same water (10-12%) the increase of Ca-bentonite to 3% leads to a decrease in the productivity of green pellets (-16+10 mm), while in case of 13% water added the productivity of green pellets increased as Ca-bentonite increased.

Also from the same Fig. 3 it is clear that at any constant Ca-bentonite added (in rang 0. 5 - 2. 5%) the productivity of the green pellets increases when the amount of water added increases from 10% to 12% , then it decreases when the amount of water added increased to 13%. While at 3% Ca-bentonite added the productivity of green pellets increased with the increase of water. This is due to the presence of bentonite layer havinghigher surface area and higher affinity to water [17]. Also due to the adsorbetion of water by which becomes immobilized within the layer [18].

The relationship between the productivity of green pellets (y,%) and the amount of bentonite added, (X,%) can be computed as follows:

for 10% water added

$$Y = 85.17 - 16.71X + 6.86X^2 - 1.56X^3$$

for 11% water

$$Y = 94.98 - 18.33X + 10.33X^2 - 2.22X^3$$

for 12% water

$$Y = 98.9 - 2.79X - 1.90X^2$$

for 13% water

$$Y = 23.7 - 20.21X + 30.44X^2 - 5.70X^3$$

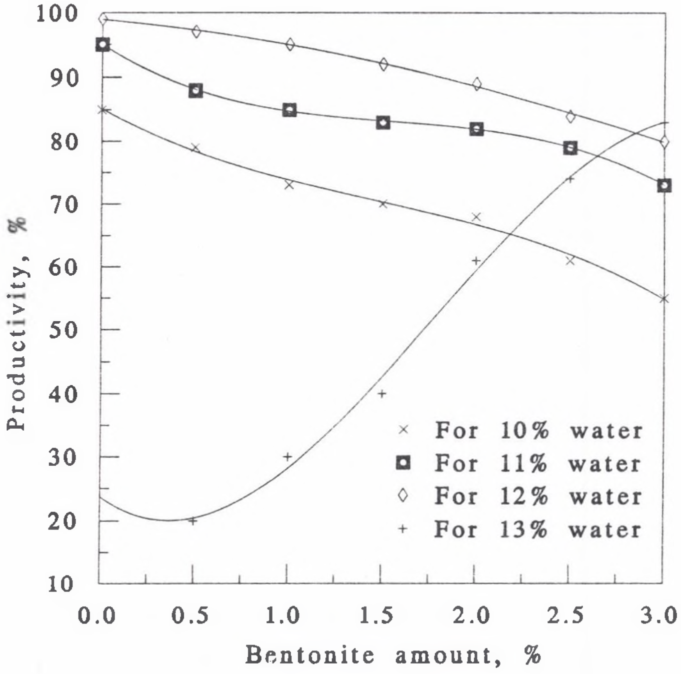

Fig.3. Effect of bentonite addition on the productivity of green pellets
Rys.3. Wpływ dodatku bentonitu na wydajność grudkowania

Fig. 4 shows that adding the same amount of water (10%) and increasing of Ca-bentonite from 0.0 to 2.5% leads to increasing the drop number from 5 to 8 respectively, then it decreased when the amount of bentonite reached to 3%. While in case of (11-13% water added) the increase of bentonite leads to an increase the average drop number.

Also at the same amount of bentonite the average drop number increased when the amount of water increased. This is due to the fact that bentonite is a colloidal material having higher surface area thus the plasticity of green pellets increased [17].

The relationship between the productivity of green pellets (D_n,%) and the amount of bentonite added, (X,%) can be computed as follows:

for 10% water

$$D_n = 5.16 - 1.74X + 2.67X^2 - 0.71X^3$$

for 11% water

$$D_n = 3.09 + 0.32X + 1.57X^2 - 0.24X^3$$

for 12% water

$$D_n = 2.11 + 2.48X + 1.52X^2 - 0.4X^3$$

for 13% water

$$D_n = 6.73 - 3.72X + 4.91X^2 - 0.92X^3$$

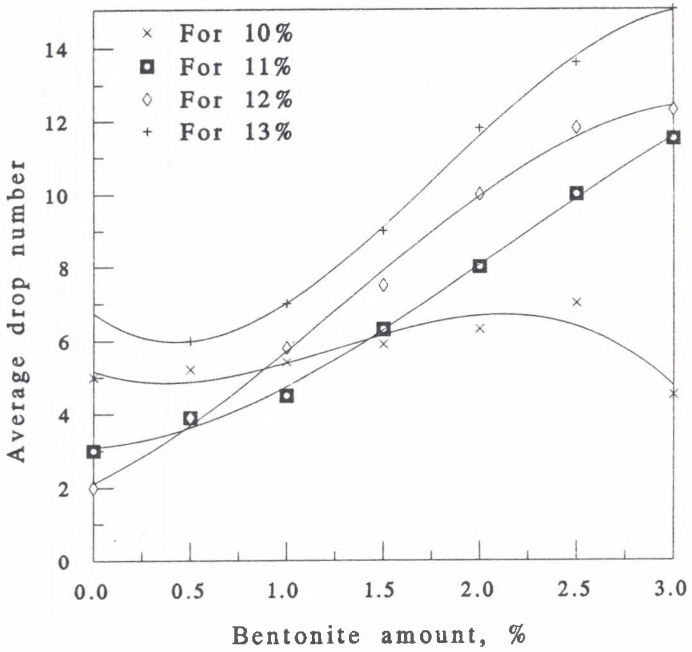

Fig.4. Effect of bentonite addition on the average drop number of green pellets
Rys.4. Wpływ dodatku bentonitu na średnią ilość zrzutów grudek surowych (odporność na zrzucanie)

Fig. 5 indicates that the addition of bentonite in case of 10% water added leads to a decrease of crushing strength of green pellets. This may be due to the insufficient amount of water which acts as a binding forces because bentonite absorbed it [19]. While at 11%, 13% water added the crushing strength increased when the bentonite increased reaching maximum value at 2% bentonite.

Its noticed that the crushing strength of the green pellets increased when the amount of water increased at the same level of bentonite added.

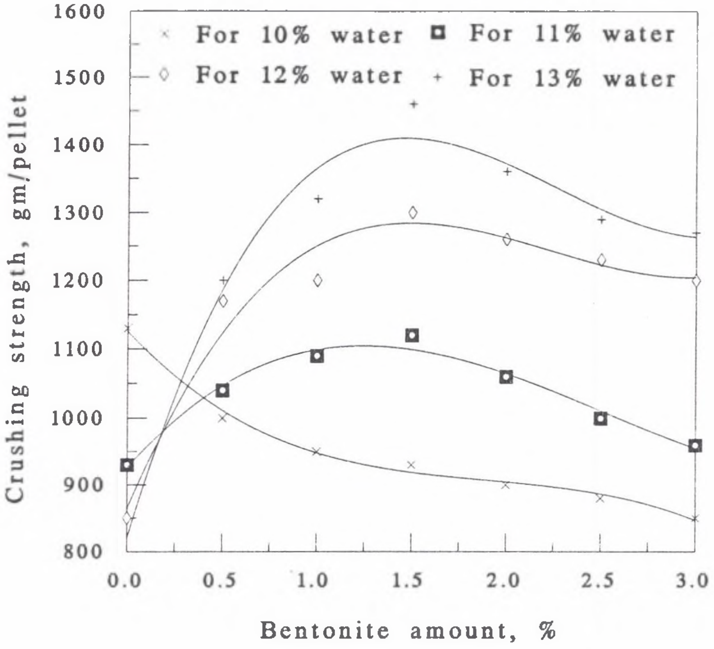

Fig.5. Effect of bentonite addition on the crushing strength of green pellets
Rys.5. Wpływ dodatku bentonitu na wytrzymałość na ściskanie grudek surowych

The relationship between the productivity of green pellets (C_s, gm/pellet) and the amount of bentonite added, (X,%) can be computed as follows:

for 10% water

$$C_s = 1125.5 - 292.94X + 140X^2 - 24.4X^3$$

for 11% water

$$C_s = 925.95 + 321.1X - 170.5X^2 + 22.2X^3$$

for 12% water

$$C_s = 864.1 + 676.27X - 340.95X^2 + 51.11X^3$$

for 13% water

$$C_s = 820 + 957.7X - 483.3X^2 + 71.1X^3$$

3.b. Effect of Ca-bentonite Addition on the Properties of the Indurated Chromite Ore Concentrate Pellets

3.b.1. Effect of Ca-betonite Addition on the Crushing Strength of Indurated Pellets

The green pellets which were produced while adding 12% water using different amounts of bentonite were indurated at 1250°C for 50 min in the muffle furnace. Fig. 6 shows the relation between the crushing strength of the indurated chromite concentrate pellets and the amount of added bentonite. From the previous figure it is clear that the maximum crushing strength of indurated pellets was at 2% Ca-bentonite added. The increase of crushing strength when the amount of bentonite was increased from 0.5 to 2% bentonite is due to the increase of slag amount which leads to an improve in the bonding between the grains and decrease the prosity [20,21] as shown in Fig. 7. Also this may be due to the crystallization process and the reactions of gangue constituents which leads to the formation of low melting eutectics compounds, as a result of which the amount of liquid phase contacts and formed a stronger bridges between the finest ore particles [19,22], while the decrease of the crushing strength at bentonite addition more than 2%

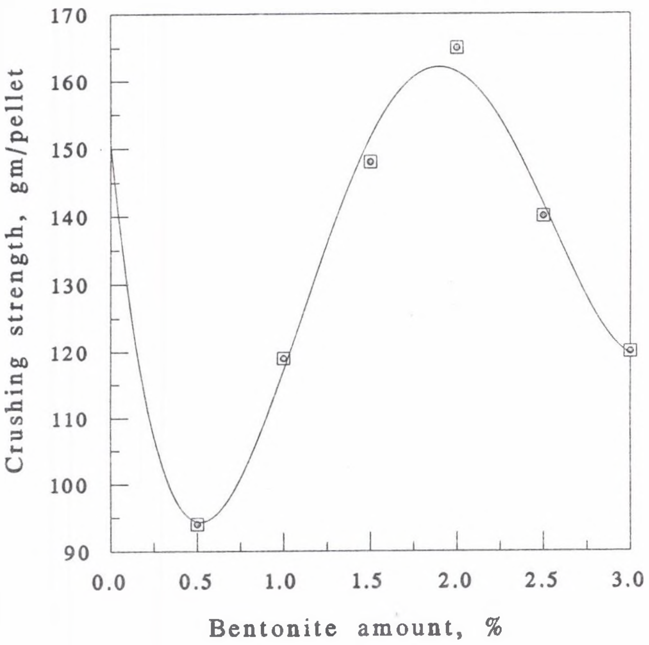

Fig.6. Effect of bentonite addition on the crushing strength of indurated pellets
Rys.6. Wpływ dodatku bentonitu na wytrzymałość na ściskanie utwardzonych grudek

may be due to the reduction in the binding force by surface fusion during the induration of pellets, because this refractory material are hard to be sinter and caused more porosity [21,23] as shown in Fig 7.

3.b.2. Effect of Ca-bentonite Addition on the Chemical Composition of the Indurated Pellets

Table 3 shows the effect of Ca-bentonite addition on the chemical composition of the indurated chromite ore concentrate pellets fired at 1250°C for 50 min. From the table 3 it obvious that the amount of Cr_2O_3, FeO & MgO decreased as the amount of bentonite increased, while the amount of SiO2 increased. This fact is due to the bentonite contains more silica and free from Cr_2O_3 and FeO.

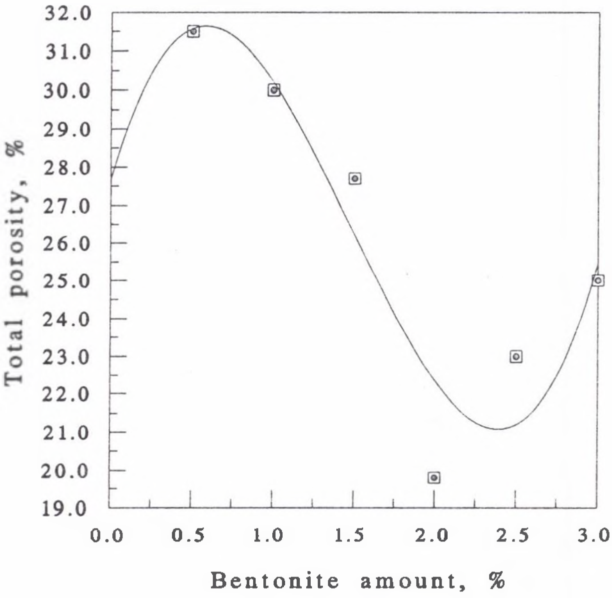

Fig.7. Effect of bentonite addition on the total porosity of indurated pellets
Rys.7. Wpływ dodatku bentonitu na ogólną porowatość utwardzonych grudek

Table 3

The chemical composition of the chromite ore concentrate pellets

Amount of bentonite, %	Chemical composition , %					
	Cr_2O_3	FeO	SiO_2	CaO	Al_2O_3	MgO
0.5	42.08	13.13	7.08	1.34	16.84	19.41
1.0	41.86	13.06	7.31	1.35	16.84	19.31
1.5	41.64	12.99	7.54	1.36	16.84	19.23
2.0	41.42	12.92	7.77	1.38	16.85	19.13
2.5	41.20	12.85	8.00	1.38	16.82	19.05
3.0	40.98	12.78	8.23	1.39	16.85	18.97

The relationship between the crushing strength of indurated pellets (C_s, Kg/pellet) and the amount of bentonite added, (X,%) can be computed as follows:

$$C_s = 150.83 - 253.15X + 351.81X^2 - 153.3X^3 + 21.0X^4$$

The relationship between the total porosity of indurated pellets (P, %) and the amount of bentonite added, (X,%) can be computed as follows:

$$P = 27.7 + 14.85X - 15.9X^2 + 3.6X^3$$

3.C. Production of Fe.Cr.Si Alloy from the Indurated Pellets Contains Ca-bentonite

The indurated pellets which produced from chromite ore concentrate with bentonite as a binder were melted in electric arc furnace to produce Fe Cr Si alloys. The results of the experiments are shown in Table 4.

Table 4

The chemical composition and yield of Fe Cr Si alloys

Bentonite %	Yield, %	Cr %	Fe %	Si %	C %	Cr/Fe
0.5	81.00	56.05	23.05	14.40	6.90	2.43
1.0	83.00	53.8	25.50	14.60	6.70	2.11
1.5	84.00	56.5	23.10	15.00	6.00	2.45
2.0	86.00	56.4	20.05	18.95	5.00	2.76
2.5	85.80	50.6	25.17	19.33	4.50	2.01
3.0	85.60	49.8	25.06	21.34	3.80	1.99

From table 4 it is clear that the yield of alloys production = 81%, when 0.5% bentonite was used and this yield increased with the increase of bentonite up to 2-3% and reached to ~ 86%. Also the amount of Si increased when the amount of bentonite increased.

Fig. 8 shows that when the silicon in the alloys increased the carbon content decreased. Also it is clear that the use of bentonite in the range of 1.5 to 3 % gave alloys similar to the Russian alloys specification [24].

The relationship between carbon content (C,%) and the amount of silicon (Si, %) in the alloy can be computed as follows:

$$C = 188.9 - 29.8S + 1.60S^2 - 0.03S^3$$

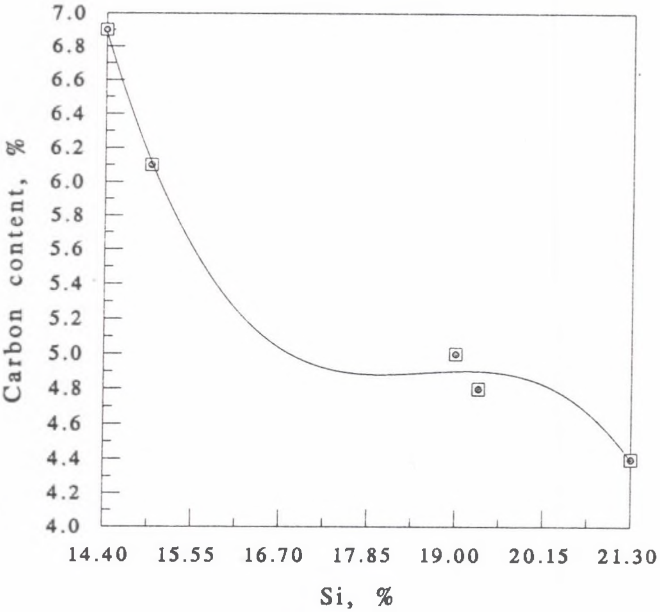

Fig.8. Effect of bentonite addition on the crushing strength of indurated pellets
Rys.8. Zależność pomiędzy zawartością węgla i krzemu w żelazostopach z grudek wytwarzanych z dodatkiem bentonitu jako środka wiążącego

Conclusion

1. At the same water amount (10-12%) added to the chromite concentrate the increasing of Ca-bentonite to 3% leads to a decrease in the productivity of green chromite concentrate pellets, while in case of 13% water added the productivity of green pellets increased when the amount of bentonite increased.
2. At any constant amount of bentonite added to the chromite concentrate in range 0.5 - 2.5% the productivity of green pellets increased when the amount of water added increased from 10% to 12%, then decreased when the amount of water increased. While at 3% bentonite added the productivity of green pellets increased when the amount of water increased.
3. At the same amount of water addition to the chromite concentrate the increase of bentonite amount from 0.0 to 2.5% leads to an increase in the average drop number of produced green pellets.
4. The average drop number of the green pellets was decreased when the amount of bentonite reached to 3% in case of 10% water added.
5. The average drop number increased as the amount of water added increased at the same amount of bentonite added to the chromite ore concentrate.
6. At (10%) water added the increase of bentonite leads to a decreasing in the crushing strength of green pellets.
7. At 11-13% water added the crushing strength of green pellets increased when the amount of bentonite increased and reached to maximum value 2% bentonite.
8. The maximum crushing strength of indurated pellets was obtained at 2% bentonite added.
9. The yield of produced FeCrSi alloys increased when the amount of bentonite increased from 0.5% to 2-3% and reached to ~ 86%.
10. The use of Ca-bentonite in the range of 1.5% to 3% gave different grades of Fe.Cr.Si alloys similar to the Russian specification of this type of alloy.

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Streszczenie

Badano efektywność dodatku różnych ilości bentonitu (0,5 – 3.0% co 0,5%) na przebieg procesu grudkowania koncentratów z rud chromowych Barramyia. W doświadczeniach stosowano koncentraty zawierające powyżej 41% Cr_2O_3 i własny bentonit o zawartości ponad 17% Al_2O_3 i 54% SiO_2 oraz koks groszek i topniki. Przy różnym dodatku bentonitu i różnej zawartości wody (10-13%) określono wydajność procesu, wielkość uzyskanych grudek surowych oraz ich wytrzymałość na ściskanie i zrzucanie. Grudki o różnej zawartości wody i bentonitu utwardzano w temperaturze 1250°C w piecu muflowym. Ustalono optymalne parametry grudek surowych i utwardzonych przy różnych warunkach wytwarzania.