Górnictwo i Geoinżynieria • Rok 30 • Zeszyt 3/1 • 2006

Saad M. Fouzi, M.G. Kahlifa**, Y.M.Z. Ahmed***,*
*F.M. Mohamed***, M.E.H. Shalabi****

SINTERING OF EGYPTIAN IRON ORE

1. Introduction

Iron and Steel Company at Helwan is the lonely company in Egypt which produces iron and steel from local raw materials using the sintering process for processing of the raw materials to be suitable for charging in the blast furnaces. The iron ore used in the production process is delivered from the Baharia Oasis at El-Gedida Region. The chemical composition of the ore is changing periodically as a result of its exploration from different mine locations. Accordingly, it is necessary to optimize the different operating conditions controlling the technological parameters of the sintering process. Amount of added water during the preparation of the raw mix, amount of sinter returns, amount of coke breeze, basicity of the sinter charge as well as the time of ignition was considered as the main parameters controlling the sintering process.

The total amount of water already present in the sinter charge must be accurately controlled to give the best sinter charge permeability before and through out the sintering process [1].

Shalabi *et al.* [2] found that the sintering time for particular sinter charge depends on the amount of water added, and any variation in such optimum quantity of water added even in small amount will lead to a significant drop in the productivity of sintering machine.

Ball *et al*. [3] indicated that for each raw mix, there is definite relationship between the water content and the pre-ignition permeability. The later increase with increasing water content and then goes down after reaching a maximum.

Returns including the mineralogical constituents with low melting temperature accelerate the fusion of the sinter mix, promotes the amount of melt on the combustion zone, increase the amount of the blinder matter after crystallization [4].

* Omar El-Mukhtar university, Libya
** El-Tabbin Institute for Metallurgical Studies (TIMS)
*** Central Metallurgical Research and Development Institute (CMRDI)

Rasuh *et al.* [5] found that as a return content in raw mix is increased, strength of sinter produced is increased.

Shalabi *et al.* [4] indicated that the optimum ignition time of Baharia iron ore sinter is =3 min at which the productivity at blast furnace yard is higher.

Lysenko *et al.* [6] found that the vertical sintering speed varied extremely with increasing the heat time from 1.3 to 3.8 min and maximum sintering rate and specific productivity were achieved with heating time = 2.8 min.

Many authors indicated that the increase of basicity up to a certain limit leads to an increase the amount of ready made sinter. The further increase in the basicity decrease the amount of ready made sinter then it increase a gain. It was also revealed that with the increase of sinter basicity, the strength is decreased where it reaches a minimum in the basicity range 1.2-1.5 and then it increase a gain. [7-10].

Some authors [11, 12] have found that the optimum fuel content for sintering of hematite, proceeding with high efficiency is acquired only together with 4–5% coke.

El-Tawil *et al.* [13] indicated that the sintering rate was decreased with increase of the fuel in the mix. El-Hussiny [14] showed that increasing the amount of coke breeze in the raw mix improves the amount of ready made sinter and its strength, also it decreases the vertical velocity. The productivity of sintering machine and productivity at blast furnace yard reached to maximum value at 7% coke breeze.

Karabasof [15] found that the increase of fuel in the raw mix leads to an increase of the percentage of ready made sinter and decrease in the productivity of sintering machine.

El- Afifi *et al.* [16] concluded that the addition of iron oxide wastes from 2.5 to 5% can be increase the technical parameters of the sintering process, such as amount of ready sinter, strength of produced sinter and productivity of the sintering machine.

Elimenko *et al*. [17] indicated that the addition of 10% mill scale into the sinter mix leads to a 3.5-3.9% increase in productivity of the sintering machine, and 11% rise in sinter strength.

Gamayurov *et al*. [18] indicated that the preheating of the charge leads to an increase the productivity and improve quality the sinter.

Shalabi *et al*. [19] indicated that the addition of hot water to the charge leads to an increase the productivity of sintering machine and the productivity at blast furnace yard.

The present investigation is devoted to study some factors affecting on the sinter process of El-Baharia iron ore now days.

2. Materials and experimental

2.1. Materials

The raw materials used in this work were El-Baharia Oasis (El-Gedida iron ore deposits), limestone, recycled sinter (sinter return), and coke breeze. The chemical compositions of the raw materials used are given in Table 1.

TABLE 1
Chemical composition of the sintering raw materials

Component, %	Iron ore	Mill scale	Limestone	Coke breeze
Fe total	52.76	68	–	2.24
FeO	–	10.14	–	–
Fe_2O_3	75.37	85.7	0.35	3.203
SiO_2	7.58	1.0	1.4	4.55
Al_2O_3	1.97	0.5	0.76	2.2
CaO	0.51	–	55.6	0.732
MgO	1.46	0.1	3.52	0.082
MnO_2	3.42	2.0	–	–
P_2O_5	0.39	0.45	0.07	0.022
Na_2O	0.327	–	0.18	0.04
K_2O	0.154	–	0.070	0.106
Cl	0.4	–	0.1	–
BaO	1.3	–	–	–
Zn	0.08	–	–	–
S	0.65	–	0.04	1.08
CO_2	–	–	37.56	–
L.O.I	6.57	–	37.90	4.86
F.C	–	–	–	84.76

2.2. Apparatus and Technique

Sintering experiment was conducted in a laboratory down draft sinter pot, (5 kg). Airflow was provided by two fans in series, which were capable of producing suction pressure in excess of 11.76 Kpa. Pt-Pt. Rh. Thermocouple measured the temperature of the waste gas, which gives an indication of the end of the sintering process. The raw materials with the required basicity (CaO/SiO_2) were blended together. A sinter bed of 0.5 kg sinter (+10 mm) was placed over the grate of the pot to protect it against the high temperature during the sintering operation. The green mix was loaded over the sinter bed layer in the sinter pot.

The green mix was ignited with a gas flame. The ignition was done under suction pressure of 5.88 KPa, while the sintering process was done under suction pressure of 11.76 KPa. The sintering time was determined by time elapsed from start of ignition until the exhaust gas temperature reached a maximum value [1, 20]. At the end of the sintering experiment the sinter cake was dropped from the sinter pot on to a steel plate laid on concrete. The technological parameters ready made sinter, vertical velocity, shatter test (sinter strength), productivity of sintering machine and productivity at blast furnace yard were evaluated. The sinter strength, productivity of the sintering machine and the productivity at blast furnace yard was determined according to the following equation [20, 21]:

$$P = 14.4\, V \cdot K \cdot \rho \quad \text{t/m}^2\text{.day} \tag{1}$$

$$P_{B.F} = P\,(W/100)\ \text{t/m}^2\text{.day} \tag{2}$$

$$(W)\% = M_1 \cdot 100/M_2 \tag{3}$$

where:

P — productivity of sintering machine +7 mm, ton/m^2.day,
V — vertical velocity of sintering machine, $V = (H/T)$ m/min,
H — height of the charge, m,
K — percentage of ready made sinter from the charge, +7 mm,
T — time of sintering process, min,
ρ — bulk density of the charge, ton/m^3,
W — is the sinter strength +7 mm, %,
$P_{B.F}$ — productivity at blast furnace yard, ton/m^2.day,
M_1 — weight of sinter +7 mm before shatter test, kg,
M_2 — weight of sinter +7 mm after shatter test, kg.

3. Results and discussions

3.1. Effect of the amount of water added

The amount of water was changed while the other conditions of sintering process, (basicity of the raw mix CaO/SiO_2 =1, amount of coke breeze = 6% of charge weight, bed height = 340 mm, time of ignition = 1.5 min) were kept constant. The results of these experiments are shown in Figures 1–3.

From these figures it is evident that the increase of amount of water from 6% to 12%, the vertical velocity, amount of ready made sinter +7 mm, shatter index (+7 mm), productivity of sintering process and productivity at blast furnace yard increased. Behind the 12% water added all the pervious technical parameters decreased. The increase of these parameter before 12% water added is due to the improve of sinter charge permeability subsequently the heat utilization during the sintering process improved [22, 23].

With higher amount of water than 12% the more condensed water in the lower part of sintering layer is formed, thus the permeability decreased, [2] subsequently the heat utilization during the sintering process decreased, thus the technical parameter of sintering process in this range decreased.

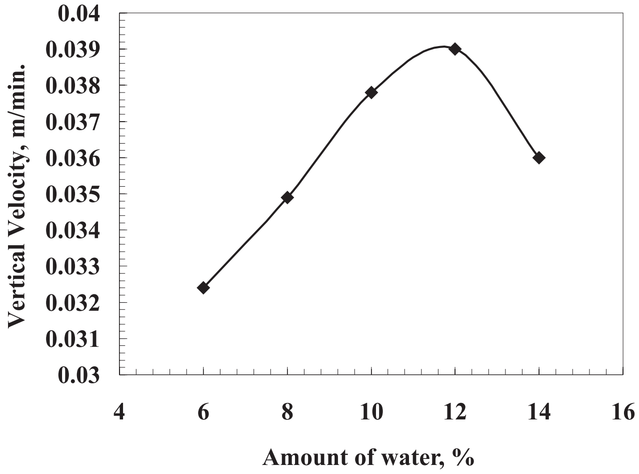

Fig. 1. Relationship between amount of water added and vertical velocity of the sintering process

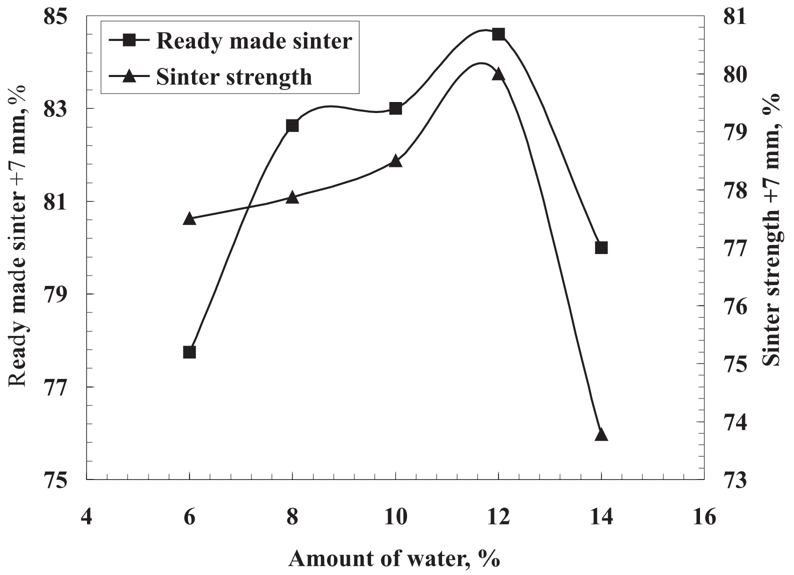

Fig. 2. Relationship between amounts of water added and amount of ready made sinter and its strength

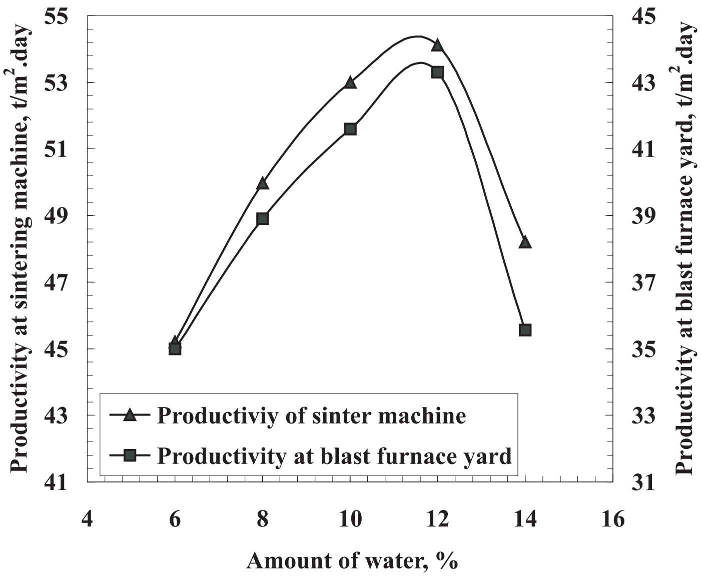

Fig. 3. Relationship between amount of water added
and the productivity of sintering machine and productivity at blast furnace yard

3.2. Effect of amount of sinter return on the technical parameters of the sintering process

The effect of amount of sinter return was studied under the following constant condition (the amount of water added = 12%, coke breeze weight of charge = 6%, basicity of the raw mix = CaO/SiO_2 = 1, bed height = 340 mm, time of ignition = 1.5 min), the percent of sinter return was taken as percent of total of charge i.e.

$$\frac{\text{amount of sinter return}}{\text{amount of (iron ore + limestone + sinter return + coke breeze)}} \cdot 100,\ \%$$

The results of these experimental are illustrated in Figures 4–6.

From these figures, it is clear that the maximum vertical velocity, maximum productivity of sintering machine and productivity at blast furnace yard are present at 30% sinter return.

Due to the improvement of sinter permeability followed by improvement of heat utilization. But when sinter return increased more than 30% the heat formed leads to more melt which decreases the permeability [4, 24].

Figure 5 shows that as sinter return increased the amount of ready made sinter and its strength increased too, this is due to return sinter did not consume coke as iron ore and consequently the temperature in zones of bed increased which leads to the increase the amount of melt in the sintering process [4, 25, 26].

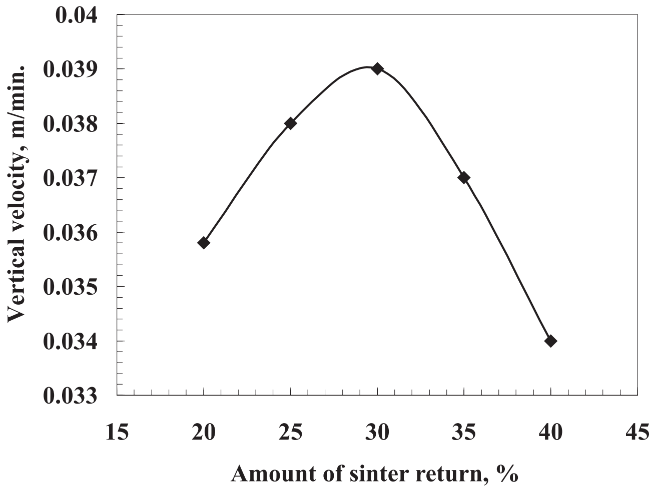

Fig. 4. Relationship between amount of sinter return and vertical velocity of sintering process

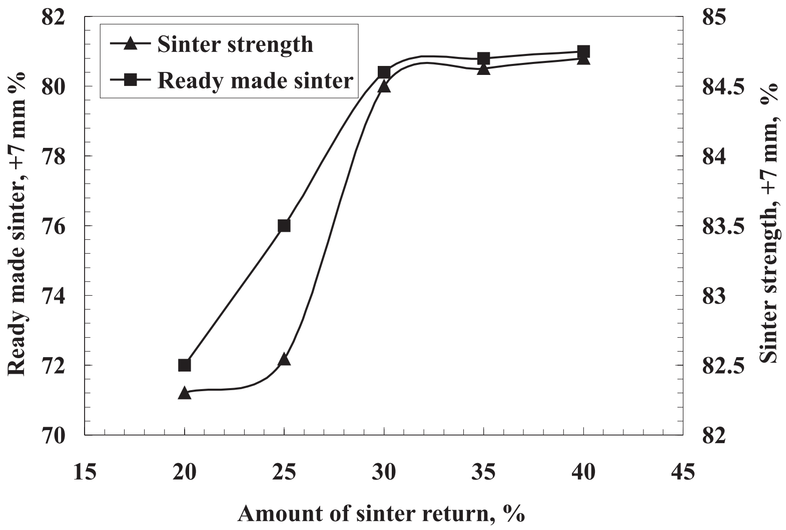

Fig. 5. Relationship between amount of sinter return and amount of ready made sinter and its strength

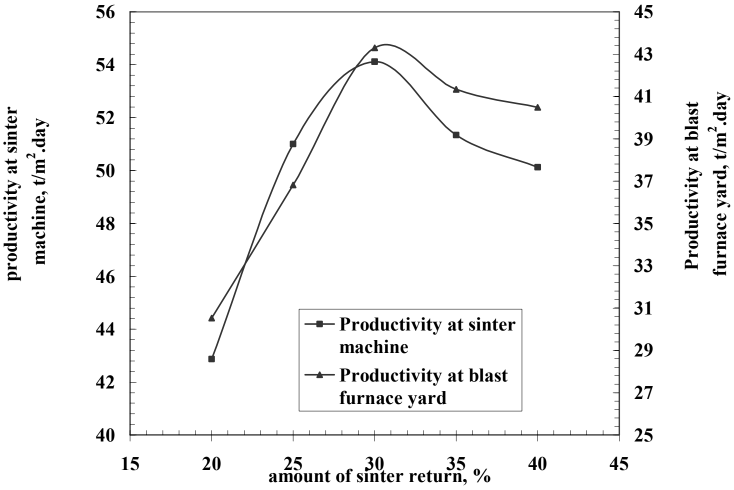

Fig. 6. Relationship between amount of sinter return and productivity at sinter machine and productivity at blast furnace yard

3.3. Effect of ignition time on the technical properties of sinter

The effect of ignition time on the technical properties of the sinter were studied under the constant following conditions (basicity of the raw mix $CaO/SiO_2 = 1$, amount of water added = 12%, sinter return = 30%, amount of coke breeze = 6%). The ignition time were varied from 1 to 2.5 min. The results are shown in Figures 7–9.

Figure 7 shows as the time of ignition increased the vertical velocity decreased. This may be due to the formation of more melt of the sintering charge [6].

Figure 8 illustrates as the time of ignition increased the ready made sinter and its strength increased.

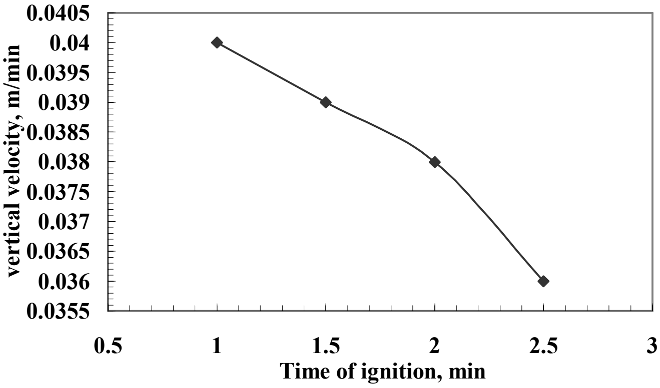

Fig. 7. Relationship between time of ignition and vertical velocity of sintering

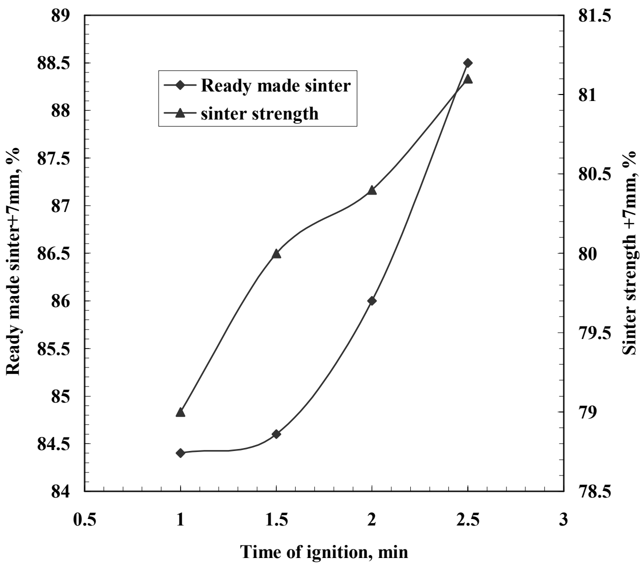

Fig. 8. Relationship between time of ignition and ready made sinter and its strength

Figure 9 shows as the time of ignition increased up to 2 min, the productivity at blast furnace reached to maximum value. Beyond this time of ignition the productivity and productivity at blast furnace yard decreased this attributed to a decrease in vertical velocity of the sintering process.

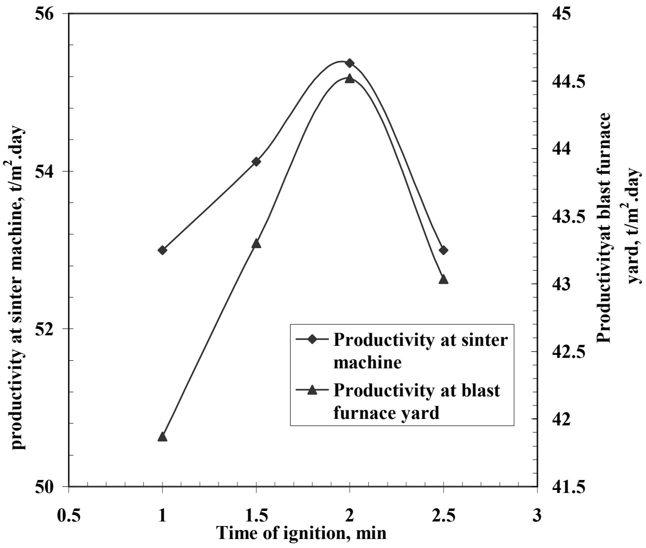

Fig. 9. Relationship between time of ignition
and productivity at sinter machine and productivity at blast furnace yard

From results of studying the effect of time of ignition, it is clear that the difference between the productivity and productivity at blast furnace yard at 1.5 min and 2 min ignition is about 2.3% and 2.8% respectively. Therefore we chose 1.5 min ignition is optimum from economic point of view.

3.4. Effect of basicity on the technical parameter of the sintering process

The effect of basicity (CaO/SiO_2) from 0.5 to 2 on the vertical velocity was studied under the following constant condition (amount of water added = 12%, sinter return = 30%, time of ignition = 1.5 min and the bed height = 340 mm and the amount of coke breeze = 6%).

Figure 10 illustrates the relationship between basicity and vertical velocity. From which it is clear that increasing basicity from 0.5 to 1.5, the sintering velocity decreases and then it is slowly increases in the basicity rang 1.5 to 2.This may be due to the increases of basicity from 0.5 to 1.5 the leads to a considerable amount of micro crystals in the formed sinter which decreases the permeability of the sinter charge. While the increase of the basicity from 1.5 to 2 leads to increased permeability [27–29].

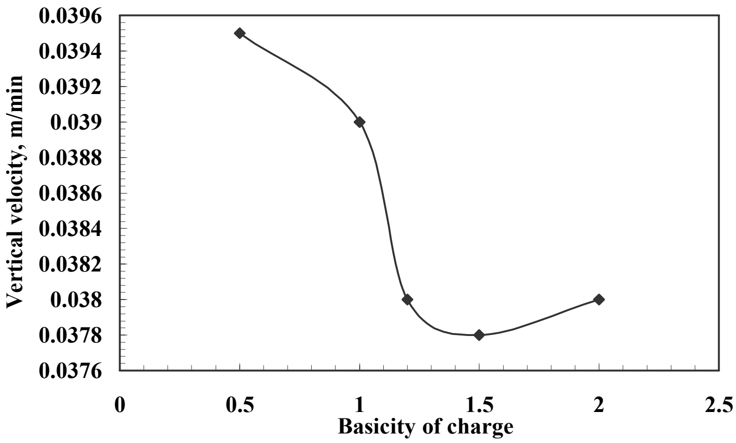

Fig. 10. Relationship between amount of basicity and vertical velocity of sintering process

Figure 11 shows that as the increase of basicity from 0.5 to 1.5 the ready made sinter and its strength decreased, while as the basicity increase from 1.5 to 2 the amount of ready made sinter and its strength increased.

The decrease of ready made sinter and its strength at while changed basicity from 0.5 to 1.5 may be due to the increase of calcium silicate, this calcium silicate β Ca_2 SiO_4 transfer to γ Ca_2 SiO_4, which leads to form the internal strength which badly effect on the strength and ready made sinter. While the increase of ready made sinter and its strength when the basicity increased from 1.5 to 2 may be due to the increase of calcium ferrite and $3CaO.SiO_2$ [27, 28].

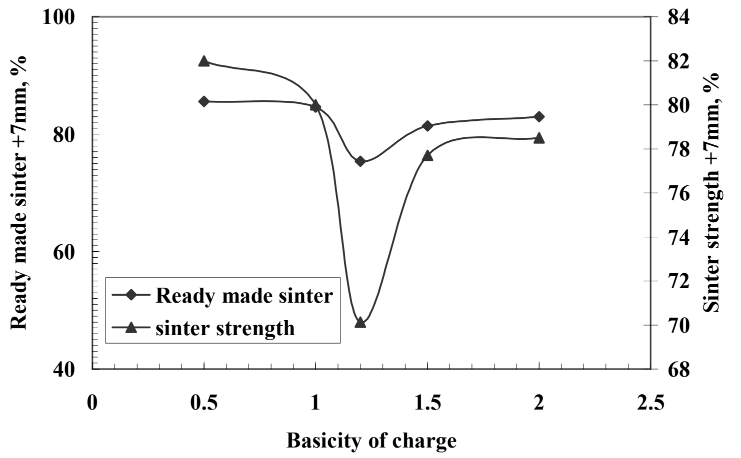

Fig. 11. Relationship between basicity and amount of ready made sinter and its strength

Figure 12 shows that the productivity and productivity at blast furnace reached to minimum value at basicity 1.2. This is due to the combination of ready made sinter and its strength and vertical velocity.

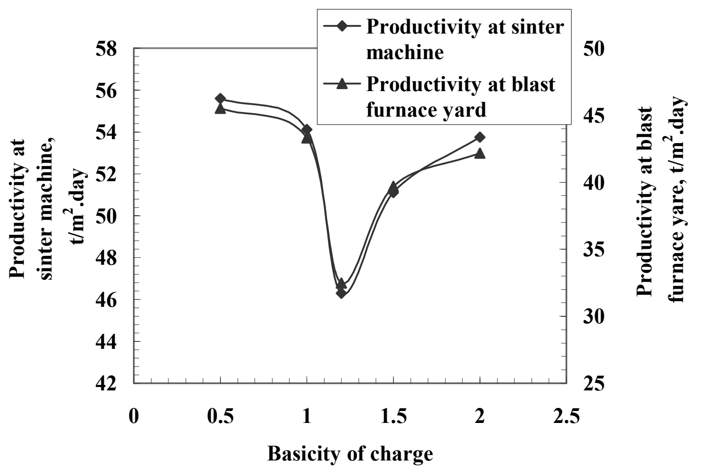

Fig. 12. Relationship between basicity and productivity at sinter machine and productivity at blast furnace yard

From the above results the basicity are chosen 1 this is due to at this value the "Na" and "K" are present in the form Na_2SiO_2 and K_2SiO_3 which leads to decrease the change of scaffold formation in blast furnace.

3.5. Effect of the amount of coke breeze on the technical properties of the sinter

The effect of the amount of coke breeze on the technical properties of the sinter is conducted keeping the following parameters constant (basicity of raw mix $CaO/SiO_2 = 1$, amount of moisture = 12%, amount of sinter return = 30% and time of ignition = 1.5 min). The results are illustrates in Figures 13–15.

Figure 13. shows that as the amount of coke breeze increased from 4% to 10%, the vertical velocity decreased. This may be due to the increase of melt which, subsequently, leads to decrease the permeability of sinter cake [14, 30].

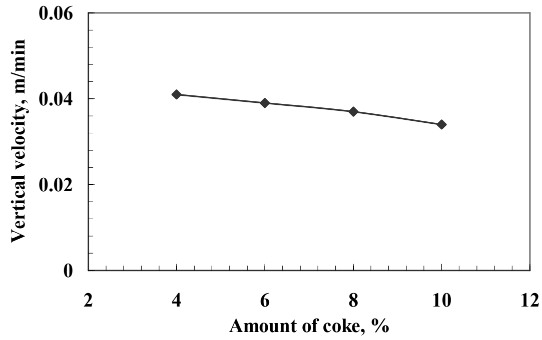

Fig. 13. Relationship between amount of coke breeze and vertical velocity of sintering process

Figure 14 illustrates that as the coke consumption increased from 4 to 10% the amount of ready made sinter and its strength increased from 76.65% to 85.6% and from 67.9% to 83% respectively. This fact is due to the increase in the amount of heat evolved as the amount of coke increase subsequently more melt formed [8, 14, 30].

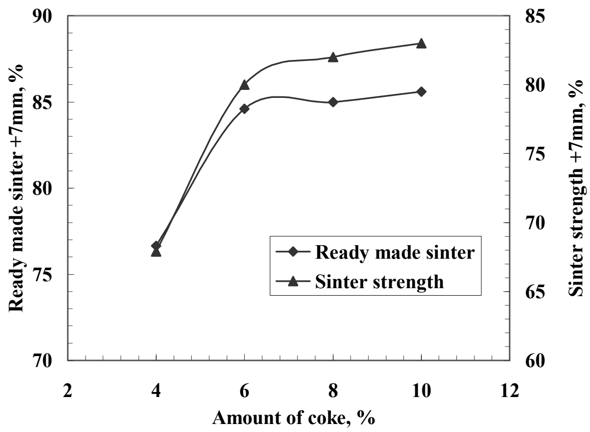

Fig. 14. Relationship between amount of coke breeze and vertical velocity of sintering process

Figure 15 illustrates that the productivity of sintering machine and productivity at blast furnace yard reached to maximum value (54.12 and 43.3 ton/m^2.day respectively) at 6% coke breeze, beyond which, the productivity of sintering machine and productivity at blast furnace yard were decreased. This may be due to the effect of vertical velocity of the sintering process. From the above mentioned results it is clear that the optimum amount of coke breeze is 6%.

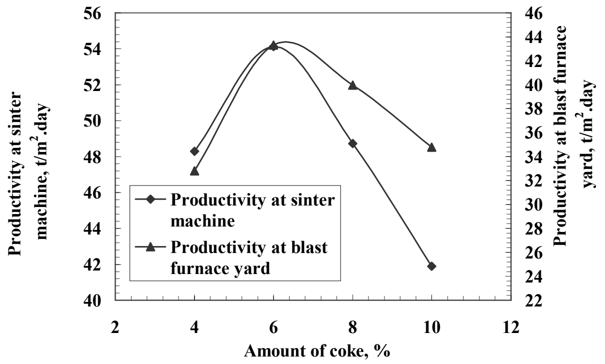

Fig. 15. Relationship between amount of coke and productivity at sinter machine and productivity at blast furnace yard

3.6. Effect of replacement part of iron ore by mill scale

In this work the following conditions (sinter mix basicity $CaO/SiO_2 = 1$, sinter return = 30%, amount of coke breeze = 6%) were kept constant, while the replacement of iron ore by mill scale were changed from zero percentage to 5%. The results of these experiments are as follow.

Figure 16 shows that as amount of mill scale replacement increases from 0 to 5% the vertical velocity of sintering process slightly increased by ≈ 5.9%.

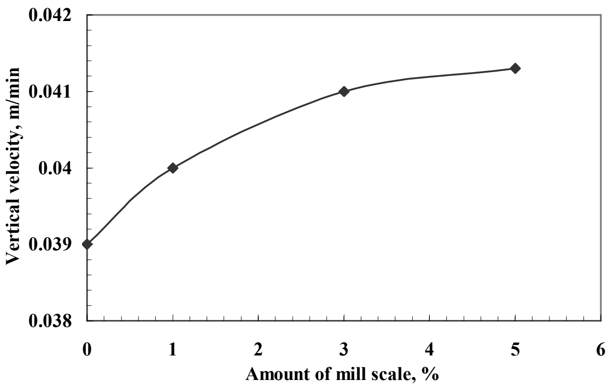

Fig. 16. Relationship between amount of mill scale and vertical velocity of sintering process

Figure 17 shows that as the amount of mill scale replacement increased from 0 to 5% the amount of ready made sinter and its strength increased by about 11.68% and 1% respectively. This may be due to the excess of heat produced during the sintering process leads to more melt and improvement the reaction between the different mineral [13, 16].

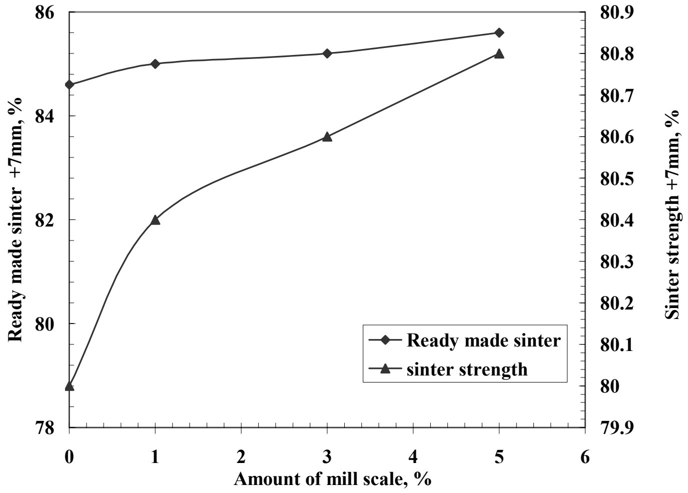

Fig. 17. Relationship between amount of mill scale and amount of ready made sinter and its strength

Figure 18 shows that as amount of mill scale replacement increases, the productivity of sintering machine and productivity at blast furnace yard increased by about 11.25% and 12.36% respectively. This may be due to increasing of the amount of ready made sinter, increasing sinter strength and increasing vertical velocity [16].

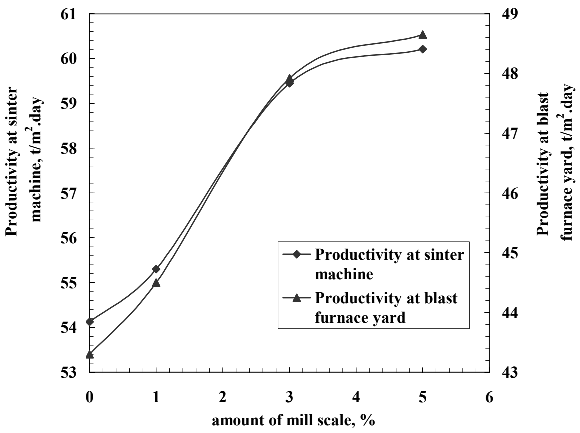

Fig. 18. Relationship between amount of mill scale and productivity at sinter machine and productivity at blast furnace yard

3.7. Effect of hot water addition on the technical parameter of the sintering process

The effect of hot water addition on the technical parameter of the sinter were studied under the constant conditions such as (the amount of water added = 12%, basicity of the charge CaO/SiO_2 = 1, amount of coke breeze = 6%, time of ignition = 1.5 min and sinter return = 30%) the temperature of hot water were 60°C and 100°C, this lead to heated the charge to 34°C and 45°C respectively.

The results of these experiments are shown in Figures 19–21.

Figure 19 shows that the increase of temperature of the charge leads to an increase the vertical velocity, this may be due to the increase of sinter charge permeability and decrease the over moisture of the lower layer of the sintering charge [31].

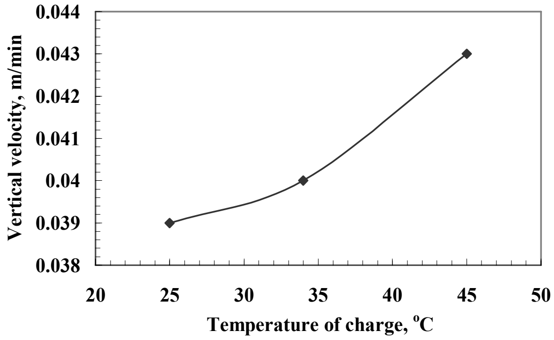

Fig. 19. Relationship between temperature of charge and vertical velocity of sintering process

Figure 20 illustrate that as the temperature of the charge increase the amount of ready made sinter and its strength increased. This may be due to the improvement of heat transfer in the sintering layer [20, 31, 32, 33].

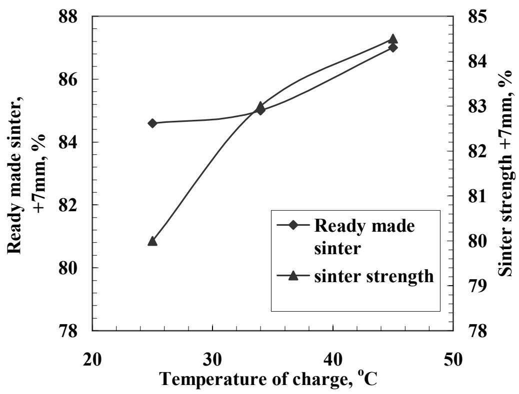

Fig. 20. Relationship between temperature of charge and ready made sinter and its strength

Figure 21 shows that as the temperature of the charge increases the productivity and productivity at blast furnace yard were increased .This fact due to the combination of vertical velocity, ready made sinter and its strength.

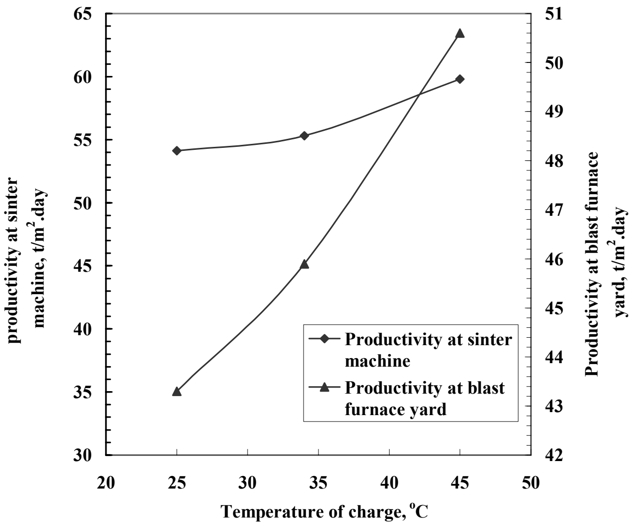

Fig. 18. Relationship between temperature of charge and productivity at sinter machine and productivity at blast furnace yard

4. Conclusions

There are many parameters affecting the sintering process such as; amount of water added to the charge, basicity of sintering, amount of sinter return, amount of coke breeze, any addition of iron bearing material and time of ignition. These factor depend upon the composition of the raw mix.

The results of experiments showed that:

1) The optimum amount of water added is ≈ 13% of the total charge at which the productivity of the sintering machine and productivity at blast furnace yard is reached to maximum value.
2) The optimum amount of ready made sinter is equal to 30% at which both productivity of sintering machine and productivity at blast furnace yard is maximum value.
3) The optimum time of ignition = 2 min at which the maximum value of productivity at sinter machine and productivity at blast furnace yard is obtained. While the time chosen in these experiments was 1.5 min because the productivity of sintering machine and productivity at blast furnace yard is closely to 2 min.
4) The productivity of the sinter machine and productivity at blast furnace yard is reached to the minimum value at basicity CaO/SiO_2 = 1.2.

5) The maximum value of productivity of the sintering machine and productivity at blast furnace yare is achieved at 6% coke breeze.
6) The productivity of sintering machine and productivity at blast furnace yard increased as the amount of mill scale increased.
7) Increasing the temperature of added water to sinter charge leads to increase in both productivity of sintering machine and productivity at blast furnace yard.

REFERENCES

[1] *EL-Hussiny N.A., Abdel-Khalek N.A., Morsi M.B., Mohamed O.A., Shalabi M.E.H., Baraka A.M.*: Górnictwo, 1996, vol. 231, 93–115.
[2] *Shalabi M.E.H., Boulis S.N., Mustasa S.I.*: Second International Ain Shams University Conference on Production Engineering and Design for Development, PEDD, vol. 2, pp. 401–409, Cairo, 1987
[3] *Ball D.F., Dertnell J.*: Agglomeration of iron ores. Heineman Eductional Books Limated London, 1973
[4] *Shalabi M.E.H., Kalifa M.G., El-Hussiny N.A.*: Górnictwo, vol. 231, pp. 485–498, 1996
[5] *Raush H., Cappel F.*: Stahl, and Eisen V, No. 2, pp. 18-102, 1961
[6] *Lysenko I.S., Shurkhal V.A., Sigov A.A.*: Steel in USSR, vol. 3, No.4, pp. 262-263, 1973
[7] *Shalabi M.E.H., Selim M.H., Abed El-Kerim O.I., Shahin M.I.*: Bulletin of TIMS, No. 43, Jan. 1982, pp. 3–13
[8] *Vegman E.F.*: Theory and Technology of agglomeration. Moscow, 1974
[9] *Danloy G., Vidal R.*: J S.R.M, 1976, No. 48, pp. 33–40
[10] *Efimenko G., Gimmelfart I.A., Levtchenko*: Manufacture of pig iron. Kiev, 1974
[11] *Conti M., Collida L., Paola A.*: Met. Ital., No. 61, pp. 39, 1969
[12] *Mekrasov Z.I., Chekin V.V., Gladkov N.A.*: Nauk Ukr. USSR, No. 12, pp. 89, 1960
[13] *EL-Tawil Z.S., Mohamed A.O., Ali H.F.*: J. Iron and Steel International, October, 1980, pp. 259–269
[14] *EL-Hussiny N.A.*: PhD Thesis, Faculty of Science, Cairo University, Cairo, Egypt, 1995
[15] *Karabasof Ya.S., Valavin V.S., Voropaev E.M.*: Izv. Vuz chernga Metallurg, No.9, pp. 25–30, 1973
[16] *El-Afifi S., Shalabi M.E.H., Ibrahim A.A., Hawash S.I., EL-Ibiary N.N.*: Steel Times International, Marsh, 1988, pp. 58–60
[17] *Efimenko Y.G.*: Etal, Steel in USSR, vol. 16, April, 1986
[18] *Gamayurov A.I., Dolgopolov V.M., and others*: Metallurgical, vol. 26, No. 1, pp. 10–12, 1982
[19] *Shalabi M.E.H., Mohamed O.A., N. Abed EL-Khalik M.H., Khalifa M.G., EL-Hussiny N.A.*: Międzynarodowa Konferencja Przerobki Kopalin, Zakopane, pp. 17–32, sep. 1995
[20] *Shalabi M.E.H., Mohamed O.A., EL-Hussany N.A.*: Górnictwo, z. 238, pp. 289–303, 1998
[21] *Vegman E.F.*: Okockovaneia rode Concentratov, Moscow, Metallurgia, 1984
[22] *Seshadri V.*: International Symposium on Beneficiation and Agglomeration, Bhubaneswar, proceedings (India) IV- pp. 159–166, 17–19 Dec. 1986
[23] *Korotch V.I., Puzanov V.P.*: Izv. Vuz Chernya Metallurgy, No.10, pp. 28-33, 1964
[24] *Wendebonn H.B., Cappel F.*: proc. Of Inter. SympIII, Agglomeration philadwiphia Pa, V, XIV, W.A, Knepper Ed., Metal. Conf. Ser. AIME and Inter Sci. Press NY. pp. 1040, 1962
[25] *Gledhill P.K., Long C.*: JISI, No. 184, pp. 434, 1956
[26] *Onodera M., Saeki M., Yosunaga M.*: Instrum metals Ind., No. 22, pp. 321, 1972
[27] *Shalabi M.E.H., Selim M.H., Abd El-Kerim O.A., Shain M.A.*: Bulletin of TIMS, No. 43, Jan 1982, pp. 3–13
[28] *Vegman E.F., Bazilevich S.V.*: Agglomeration Metallurgy, Moscow, 1967, pp. 212
[29] *Vegman E.F.*: Theory and Technology of agglomeration, Moscow, 1974
[30] *Shalabi M.E.H., Mustafa S.I., Boulis S.N., Youssef M.A.*: AMSE. Transaction. AMSE press, vol. 8, No. 1, pp. 37–55, 1991
[31] *Shalabi M.E.H.*: PhD Thesis, 1980, Mscow
[32] *Shalabi M.E.H., Abd- El-Khalek M.H., Baraka A.M.*: Neue Hutte, vol. 35, No. 7, pp. 246–248, 1990
[33] *Shalabi M.E.H., Mohamed O.A.*: etal, Neue Hutte, vol. 37, No. 2, pp. 52–54, 1992