MINERALOGIA POLONICA
Vol. 9, No 2 — 1978

Cezary WIEJA *, *Krystyna WIEJA* **

ALITE PHASE IN FUSED PORTLAND CLINKERS

UKD 666.94.014:549.623.02 alit

A b s t r a c t. A raw mixture from the Kujawy cement plants was fused at 1810°C in an induction generator. The resulting fused portland clinker was investigated by chemical, X-ray and microscopic methods. It was found that the mineralogical composition of fused clinker does not differ essentially from that of clinker sintered under ordinary conditions, i.e. at about 1500°C. Microscopic studies revealed that the habit of alite crystals changes in fused clinkers. Instead of pseudohexagonal alite crystals, typical of sintered clinker, crystals, exhibiting a rodlike habit crystallize in fused clinker. The attack of the liquid phase on alite crystals was also noted.

INTRODUCTION

Portland clinker is an intermediate material from which a product referred to as portland cement is obtained upon the addition of gypsum (5%) and grinding to a specific surface area of 3000—3500 cm^2/g. The principal raw materials used in the manufacture of cement are limestone, chalk, marl and clay. From these material a raw mixture is stoichiometrically set up and burned at 1500—1550°C using wet or dry method.

The ever increasing demand for portland cement requires constant intensification of the process of manufacture of portland clinker. This can be accomplished by introducing new designs or by developing new technologies. It is also possible to expedite certain stages of clinkering in heterogeneous systems by highly intensive burning of raw flour.

This paper presents a laboratory experiment involving fusion of the raw mixture used in the manufacture of portland clinker. Its aims were to reduce the clinkering time of the raw mixture, and to determine the mineralogical composition and microstructure of the resulting portland clinker.

* Institute of Binding Building Materials, Cracow (Kraków-Nowa Huta).
** Institute of Building Materials and Refractories, Academy of Mining and Metallurgy, Cracow (Kraków, al. Mickiewicza 30).

ALITE PHASE IN PORTLAND CLINKER SINTERED AT 1500—1550°C

The principal mineral constituents of sintered portland clinker are two calcium silicates, alite and belite. They form in the solid phase, with the liquid phase containing tricalcium aluminate and tetracalcium aluminoferrite present in an insignificant amount. In sintered portland clinker there is, as rule, a small amount of free calcium oxide, which failed to react with the other constituents of the raw mixture due to the shortcomings of the technological process. The average microstructure of sintered portland clinker is shown on Phot. 1, and its X-ray powder pattern is presented in Figure 1.

The principal mineral constituent of portland clinker is tricalcium silicate, referred to as alite. Its content averages 55 to 65%. Owing to its

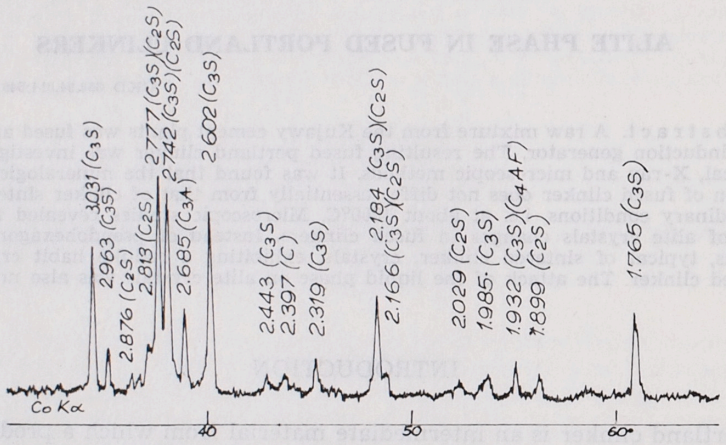


Fig. 1. X-ray diffractogram of portland clinker sintered at about 1500°C
Crystalline phases are marked by symbols used in the chemistry of cement: C_3S — alite, C_2S — belite, C_3A — tricalcium aluminate, C_4AF — tetracalcium aluminoferrite, C — free calcium oxide. X-ray diffractogram made by E. Skomorowski

hydraulic properties, alite plays a significant role in the process of setting and hardening of portland cement after it has been kneaded with water, imparting binding properties to the product.

The structural formula for tricalcium silicate (Jeffery 1952) is $Ca_3[SiO_4]O$. In the cement technology and chemistry, the oxide formula $3CaO \cdot SiO_2$ is commonly used, frequently abbreviated to C_3S. Tricalcium silicate forms several polymorphic modifications. Initially, on the basis of X-ray and thermal studies (Trümel, Möller 1952; Nurse 1960; Yamaguchi, Miyabe 1960), tricalcium silicate was assumed to form three polymorphs, two of which were stable only at high temperatures:

$$\text{triclinic} \overset{920°C}{\rightleftharpoons} \text{monoclinic} \overset{970—980°C}{\rightleftharpoons} \text{trigonal}$$

Recent studies (Guinier, Regourd 1969) provided evidence that tricalcium silicate has six polymorphic forms: one polymorph of trigonal symmetry

— R, two monoclinic polymorphs — J_I and J_{II}, and three modifications showing triclinic symmetry — T_I, T_{II} and T_{III}:

$$T_I \overset{600°C}{\rightleftharpoons} T_{II} \overset{920°C}{\rightleftharpoons} T_{III} \overset{980°C}{\rightleftharpoons} J_I \overset{990°C}{\rightleftharpoons} J_{II} \overset{1050°C}{\rightleftharpoons} R$$

The tricalcium silicate phase occurring in portland clinker (alite) contains small amounts of some oxides in the form of isomorphous admixtures. As shown by Jander and Wuchrer (1938), Koyanagi (1938) and Jeffery (1952), isomorphous admixtures of MgO and Al_2O_3 are present in alite. According to Jeffery, who investigated alite monocrystals by X-ray method, Al^{3+} and Mg^{2+} substitute for Si^{4+} ions in the crystal lattice of alite according to the pattern:

$$2Si^{4+} \rightarrow 2Al^{3+} + Mg^{2+}$$

Moreover, Jeffery's hypothesis assumes that the above substitution is regular, taking place once for 18 molecules of $3CaO \cdot SiO_2$, so it has, in a way, the character of a compound with the formula $54CaO \cdot 16SiO_2 \cdot Al_2O_3 \cdot MgO$.

Ordway (1960) arrived at the conclusion that not only isomorphous admixtures of MgO and Al_2O_3 but of Fe_2O_3 and FeO as well can occur in alite. In his opinion, the solid solution in tricalcium silicate can be defined by the following formula:

$$108CaO \cdot 32SiO_2 \cdot 2[(Al_2O_3)_x (Fe_2O_3)_{1-x}] \cdot 2[(MgO_3)_y, (FeO)_{1-y}]$$

In alite, solid solutions can also be formed by the following oxides: ZnO, Mn_2O_3, Cr_2O_3, K_2O, and Na_2O (Guinier, Regourd 1969; Gorshkov, Timashev 1963). Limit contents of respective oxides in solid solution in alite are not well known yet. Recent studies of Guinier and Regourd (1969) con-

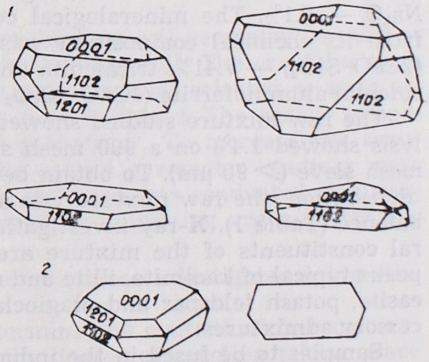


Fig. 2. Alite crystals after:
1 — Guttman and Gille (1933), 2 — Andersen and Lea (*vide* Kühl 1951)

cerning the solubility limit of individual oxides in tricalcium silicate show that alite is not compound of constant and defined composition, as suggested by the stoichiometric formula of Jeffery (1952).

Thermal curves (Yamaguchi, Miyabe 1960) and high-temperature X-ray investigations provide evidence that alite forms two polymorphic modifications. The monoclinic modification is stable at low temperatures and at about 830°C it converts into the trigonal form.

In portland clinkers sintered at 1500—1550°C alite phase occurs commonly in the form of crystals with a pseudohexagonal habit, which are pseudomorphous after the high-temperature trigonal modification (Fig. 2). The habit of alite crystals in sintered portland clinkers is affected by several factors, the major ones being: burning temperature, amount of liquid phase, cooling rate, and the character (reducing or oxidizing) of the gas atmosphere in the kiln.

Under the conditions close to equilibrium (e.g. slow cooling of blast furnace slags), crystallization of alite gives rise to platy and tabular crystals with well-developed *0001*, *1102* and *1201* faces. In sintered portland clinkers diversified forms of alite crystals can be found. Due to a relatively low content of the liquid phase, the growth of alite crystals is limited and the crystallization conditions are varying. In spite of this, the most common form of occurrence of alite crystals in sintered portland clinkers is well-developed hexagonal crystals (Phots 2, 3). It is interesting to note, however, that in industrial clinkers the typical pseudohexagonal habit of alite crystals is, as a rule, partly obliterated due to the formation of random, polygonal crystal intergrowths (Phot. 1). Upon etching of the surface of alite crystals with 1% HNO_3 alcohol solution, a characteristic zonal structure can be observed (Phot. 4). This phenomenon is most likely due to the varying content of isomorphous admixtures in alite.

EXPERIMENTAL

Investigations were carried out on a raw mixture from the Kujawy cement plant, consisting of Jurassic limestones and marls, of the following chemical composition: heating loss — 35.8%, SiO_2 — 13.5%, Fe_2O_3 — 2.3%, Al_2O_3 — 3.5%, CaO — 43.0%, MgO — 1.0%, SO_3 — 0.3%, K_2O — 0.4%, Na_2O — 0.1%. The mineralogical composition of the mixture calculated from its chemical composition was: alite ($3CaO \cdot SiO_2$) — 70.07%, belite ($2CaO \cdot SiO_2$) — 7.41%, tricalcium aluminate ($3CaO \cdot Al_2O_3$) — 7.86%, tetracalcium aluminoferrite ($4CaO \cdot Al_2O_3 \cdot Fe_2O_3$) — 11.79%.

The raw mixture studied showed good fineness. Standard screen analysis showed 1.4% on a 900 mesh sieve (> 200 μm) and 7.2% on a 4900 mesh sieve (> 90 μm). To obtain better characterization of the grain size distribution, the raw mixture was analyzed on a Sartorius sedimentation balance (Table 1). X-ray investigations revealed that the dominant mineral constituents of the mixture are calcite and quartz. Also diffraction peaks typical of kaolinite, illite and muscovite were noted. Dolomite, marcasite, potash feldspar and plagioclases were found to be present as accessory admixtures.

Samples to be fused in the induction generator were prepared in pellets adopting the following procedure: The raw mixture containing 38.5% water was dried in a laboratory dryer at 105°C until the water was completely evaporated. Then it was dry-homogenized in a laboratory porcelain mill, and pellets were formed from the flour obtained in this way. To ensure uniform contraction of samples, the pellets were formed under identical conditions. Weighed portions of 2.5 g each were prepared from the raw flour, and after adding ca 5 drops of absolute ethyl alcohol, they were pressed at a pressure of 720 kg/cm² for 15 s. The resulting pellets

were dried in a laboratory dryer to evaporate ethyl alcohol. Then the pellets were subjected to decarbonization in a sillite furnace, where they were kept at 950°C for 11 min.

Samples in the form of pellets were fused in a Warel T12 GIS-50B induction generator. The high-frequency GIS — 50B generator is designed for induction heating of samples placed in the heating coil field. In the present experiment, samples were set in the heating coil field in graphite crucibles lined with sheet tungsten. The charge temperature in the gene-

Table 1

Granulometric composition of the mixture from cement plant Kujawy estimated with sedimentation analysis

Grain size, μm	Content, %	Grain size, μm	Content, %
200	1.4	20—15	5.6
200—90	5.8	15—10	6.3
90—60	6.2	10— 5	12.7
60—40	4.4	5— 3	8.6
40—30	5.4	3— 2	5.2
30—25	3.3	2	30.8
25—20	4.3		

rator depends on the crucible geometry, heating coil geometry, as well as on controlled current parameters of the heating coil. The crucibles were made of graphite electrodes, and their geometry was selected so as to attain the present temperature within a period of 10 s. The charge temperature was measured with an optical pyrometer. To increase the accuracy of temperature measurements, the optical pyrometer readings were graduated with pyrocones. The process of fusion was conducted in a neutral atmosphere, which was accomplished by supplying argon to the reaction chamber.

Samples fused in the induction generator were investigated using chemical, microscopic and X-ray methods.

Chemical analysis was used to determine the content of free calcium oxides in the samples, which defines the degree of reaction taking place between the raw mixture constituents. To this end, glycol method, commonly used in the chemistry of cement, was adopted.

Microscopic observations in reflected light were made on polished sections prepared in the following way: Samples were placed in Vinidur rings and impregnated with Epidian V epoxy resin. After induration of the resin, polished sections were made. Rough and intermediate grinding was done with electrocorundum powders whereas diamond paste was used for final grinding and polishing. Anhydrous ethyl alcohol was used to wet

the abrasives and rinse the polished sections. Mineral components present on the surface of polished sections were etched with 1% HNO_3 alcohol solutions and HF vapours.

X-ray powder patterns were recorded with a Philips PW 1040 diffractometer, using Co-K_α radiation. Basing on the *d* values and the intensities *I*, the mineral constituents were identified using Taylor's catalogue (1964).

RESULTS

Observation of samples set in crucibles in the induction generator revealed that over a temperature range up to 1710°C, the pellets preserve their original form, showing only cracks and fractures on the surface. Samples fired at 1710°C for 5 min. and longer, as well as all samples burned at 1760°C, became softened. Samples burned at 1810°C were fused within a period of 1 minute.

Chemical analysis made on clinker samples fused at 1810°C and heated at the same temperature for 1.2 and 3 min. revealed that the content of free calcium oxide was 1.99% after 1 min., 1.79% after 2 min., and 1.23% after 3 min. This shows that the reactions taking place in the raw mixture fused at 1810°C and heated at this temperature for 3 minutes have proceeded virtually to completion, and that the content of free calcium oxide does not exceed the amount limited by the specifications.

Both X-ray and microscopic studies provided evidence that the mineralogical composition of fused clinker does not differ from that of sintered clinker. The X-ray diffraction pattern of clinker fused in the induction generator (Fig. 3) displays diffraction peaks attributed to all the

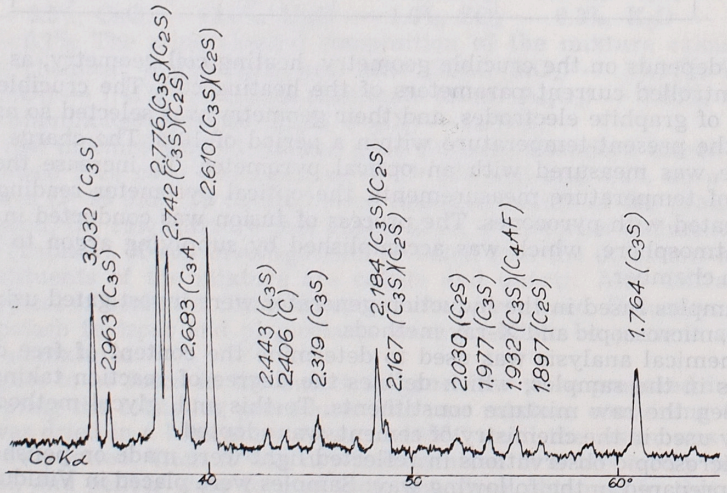


Fig. 3. X-ray diffractogram of portland clinker fused at about 1810°C
Crystalline phases are marked by symbols used in the chemistry of cement: C_3S — alite, C_2S — belite, C_3A — tricalcium aluminate, C_4AF — tetracalcium aluminoferrite, C — free calcium oxide. X-ray diffractogram made by E. Skomorowski

basic mineral constituents typical of portland clinker, i.e. to alite, belite, tricalcium aluminate, and tetracalcium aluminoferrite. The intensity of reflections of the individual minerals phases indicates that both sintered and fused clinkers have similiar contents of alite, belite, tricalcium aluminate and tetracalcium aluminoferrite.

Microscopic observation in reflected light showed that, compared with clinkers sintered at 1500—1550°C, the habit of alite crystals changed in fused clinkers. In clinkers fused in the induction generator at 1810°C, pseudohexagonal alite crystals typical of sintered clinkers do not appear at all. As a result of rapid cooling, elongate crystals with a rodlike habit crystallize most commonly from the melt (Phot. 5).

Rapid cooling of the melt at 1810°C results in the formation of numerous cracks on the surface of alite crystals (Phot. 6). A similar phenomenon can be observed, e.g. in melilite crystals crystallizing from blast furnace slag. In fused portland clinkers, the attack of the liquid phase composed of fused aluminates and aluminoferrites on alite crystals often takes place. This attack is usually attended by the rise of very fine-crystalline secondary belite, which forms characteristic occlusions on the corroded alite crystals (Phot. 7). Fused portland clinkers also show microareas in which alite crystals surficially corroded by the liquid phase concentrate. Such microareas contain numerous inclusions of free calcium oxide and metallic iron (Phot. 8). The presence of the latter suggests that in fused clinkers, despite a neutral atmosphere in the reaction chamber (fusion in an atmosphere of argon), ferric iron oxide is partially reduced to metallic iron.

Microscopic studies showed that the size of alite crystals depends largely on the burning temperature. In clinkers fired at about 1500°C, the size of alite crystals averages 20—80 μm, while in fused clinkers rapid growth of alite crystals was noted, which at 1800°C attain a size of 700 μm.

DISCUSSION

Raw mixture samples from the Kujawy cement plant prepared in pellets were fused under laboratory conditions in an induction generator at 1810°C. The resulting fused portland clinker was subjected to chemical, X-ray and microscopic investigations which showed that its mineralogical composition was very similar to that of clinker sintered at about 1500°C. Both in fused and sintered clinkers the principal constituents are two calcium silicates, alite and belite, tricalcium aluminate and tetracalcium aluminoferrite. Microscopic observation in reflected light provided evidence that there are marked differences in the habit of alite crystals. It has been found that fused clinkers do not contain alite crystals with a pseudohexagonal habit, which are typical of portland clinker sintered under normal conditions. In fused clinkers alite crystallizes as a rule in the form of elongate crystals exhibiting a rodlike habit. The length of alite crystals averages 500—700 μm, being fifteen times greater than in sintered clinker. It has also been found that the liquid phase of aluminate and aluminoferrite composition attacks the alite crystals. This attack is attended by partial decomposition of alite to belite and free calcium

oxide. The resulting secondary belite forms microcrystalline occlusions on the alite crystals. Moreover, microscopic studies revealed that in fused portland clinkers there occur alite crystals containing inclusions of free calcium oxide and metallic iron. This fact suggests that during fusion of the clinker in the induction generator in a neutral atmosphere of argon, ferric iron oxide is partially reduced to metallic iron. This problem, however, requires more detailed studies that are beyond the scope of the present paper.

From the technological point of view, it would be advisable to investigate the hydraulic properties of fused clinkers. Such studies would solve the question whether the change of the habit of alite crystals and the increase in their size affect the binding properties of portland cement.

REFERENCES

[GORSHKOV V. S., TIMASHEV V. V.] ГОРШКОВ В. С., ТИМАШЕВ В. В., 1963 — Методы физикохимического анализа вяжущих веществ, 28—30.

GUINIER A., REGOURD M., 1969 — Principal paper structure of portland cement minerals. *Proc. of the 5th Intern. Symp. on the Chemistry of Cement*, I, 1—31.

GUTTMAN A., GILLE F., 1933 — Zementtechn. Bedeutung und Feinbau des Tricalciumsilikates. Mitt. Forsch. Instit. Verein. Dtsch. Zem. Werke.

JANDER W., WUCHRER J., 1938 — Röntgenographische Untersuchungen am Tricalciumsilikat. *Zement* 27, 73—86.

JEFFERY J. W., 1952 — The tricalcium silicate phase. *Proc. of the 3rd Intern. Symp. on the Chemistry of Cement*, 30—49.

KOYANAGI K., 1938 — Beitrag zur Konstitutionsfrage von Portlandzement. *Zement* 24, 363.

KÜHL H., 1951 — Zement Chemie, II, 67—68.

NURSE R. W., 1960 — Phase equilibria and constitution of portland cement clinker. *Proc. of the 4th Intern. Symp. on the Chemistry of Cement*, I, 9—21.

ORDWAY F., 1960 — Crystal structures of clinker constituents. *Proc. of the 4th Intern. Symp. on the Chemistry of Cement*, I, 39.

TAYLOR H. F., 1964 — The Chemistry of Cements, II, 347—409.

TRÜMEL G., MÖLLER H., 1952 — Hochtemperatur-Röntgenaufnahmen von Kalziumsilikaten und Zementklinkern. *Zement, Kalk, Gips* 8, 235—241.

YAMAGUSCHI G., MIYABE H., 1960 — Precise determination of the $3CaO \cdot SiO$ cells and interpretation of their X-ray diffraction patterns. *Journ. Am. Ceram. Soc.* 43, 219.

Cezary WIEJA, Krystyna WIEJA

FAZA ALITU W TOPIONYCH KLINKIERACH PORTLANDZKICH

Streszczenie

W generatorze indukcyjnym stopiono w temperaturze 1810°C szlam surowcowy z Cementowni Kujawy. Otrzymany topiony klinkier portlandzki badano chemicznie, mikroskopowo i rentgenograficznie. Stwierdzono, że skład fazowy klinkieru topionego nie różni się w sposób zasadniczy od klinkieru spiekanego w temperaturze około 1500°C. W klinkierze spiekanym faza alitu wykształcona jest w postaci pseudoheksagonalnych kryształów o wymiarach od 20 do 80 μm. Obserwacje mikroskopowe wykazały, że w klinkierze topionym krystalizują wydłużone kryształy alitu o pokroju pręcikowatym o wymiarach podłużnych zawartych przeciętnie w granicach od 500 do 700 μm.

Często obserwuje się agresywne działanie fazy ciekłej o składzie glinianowo-żelazianowym na kryształy alitu. Z agresją fazy ciekłej związany jest powierzchniowy rozkład kryształów alitu połączony z krystalizacją bardzo drobnokrystalicznego wtórnego belitu. W kryształach alitu występujących w klinkierach topionych stwierdzono występowanie wrostków niezwiązanego tlenku wapniowego oraz inkluzje metalicznego żelaza.

OBJAŚNIENIA FIGUR

Fig. 1. Dyfraktogram rentgenowski klinkieru portlandzkiego spiekanego w temperaturze około 1500°C
Fazy krystaliczne zaznaczono symbolami stosowanymi w chemii cementu C_3S — alit, C_2S — belit, C_3A — glinian trójwapniowy, C_4AF — glinożelazian czterowapniowy, C — niezwiązany tlenek wapniowy. Dyfraktogram wykonany przez E. Skomorowskiego

Fig. 2. Kryształy alitu według:
1 — Guttmana i Gille (1933), *2* — Andersena i Lea (*vide* Kühl 1951)

Fig. 3. Dyfraktogram rentgenowski klinkieru portlandzkiego topionego w temperaturze około 1810°C
Fazy krystaliczne zaznaczono symbolami stosowanymi w chemii cementu C_3S — alit, C_2S — belit, C_3A — glinian trójwapniowy, C_4AF — glinożelazian czterowapniowy, C — niezwiązany tlenek wapniowy. Dyfraktogram wykonany przez E. Skomorowskiego

OBJAŚNIENIA FOTOGRAFII

Fot. 1. Przeciętna mikrostruktura spiekanego klinkieru portlandzkiego
Alit — kryształy poligonalne i pseudoheksagonalne, belit — zbliźniaczone kryształy izometryczne, glinożelazian czterowapniowy — biała substancja wypełniająca, glinian trójwapniowy — szara substancja wypełniająca. Światło odbite, zgład trawiony 1% HNO_3. Pow. × 500

Fot. 2. Spiekany klinkier portlandzki
Typowy pseudoheksagonalny kryształ alitu. Światło odbite, zgład trawiony 1% HNO_3. Pow. × 800

Fot. 3. Spiekany klinkier portlandzki
Typowy pseudoheksagonalny kryształ alitu. Światło odbite, zgład trawiony 1% HNO_3. Pow. × 800

Fot. 4. Spiekany klinkier portlandzki
Kryształ alitu charakteryzujący się budową zonalną. Światło odbite, zgład trawiony 1% HNO_3. Pow. × 800

Fot. 5. Topiony klinkier portlandzki
Wydłużone kryształy alitu o pokroju pręcikowatym. Światło odbite, zgład trawiony 1% HNO_3. Pow. × 800

Fot. 6. Topiony klinkier portlandzki
Wydłużone kryształy alitu o pokroju pręcikowatym z widocznymi na powierzchni spękaniami. Światło odbite, zgład trawiony 1% HNO_3. Pow. × 300

Fot. 7. Topiony klinkier portlandzki
Kryształy alitu skorodowane przez fazę ciekłą. Światło odbite, zgład trawiony 1% HNO_3. Pow. × 300

Fot. 8. Topiony klinkier portlandzki
Kryształy alitu o pokroju nieregularnym zawierające wrostki niezwiązanego tlenku wapniowego oraz inkluzje metalicznego żelaza. Światło odbite, zgład trawiony 1% HNO_3. Pow. × 300

Цезары ВЕЯ, Крыстына ВЕЯ

ФАЗА АЛИТА В ПЛАВЛЕНЫХ ПОРТЛАНДЦЕМЕНТНЫХ КЛИНКЕРАХ

Резюме

В индуктивном генераторе сплавляли в температуре 1810°C сырьевой шлам Цементного завода Куявы. Полученный плавленый портландцементный клинкер исследовался химически, микроскопически и рентгенографически. Установлено, что фазовой состав плавленого клинкера — в принципе — не отличается от клинкера спекаемого в температуре около 1500°C. В спекаемом клинкере алитовая фаза принимает вид псевдогексагональных кристаллов размерами от 20 до 80 μм. Микроскопическими исследованиями доказано, что в плавленом клинкере кристаллизируются вытянутые кристаллы алита палочкового габитуса средними продольными размерами от 500 до 700 μм.

Очень часто наблюдается агрессивное действие жидкой фазы алюминатно-ферритового состава на кристаллы алита. С агрессией жидкой фазы связано поверхностное разложение кристаллов алита, которому сопутствует кристаллизация очень мелкокристаллического белита. В алитовых кристаллах, находящихся в плавленых клинкерах, наблюдались инклюзии несвязанной окиси кальция и металлического железа.

ОБЪЯСНЕНИЯ К ФИГУРАМ

Фиг. 1. Рентгеновская дифрактограмма портландского клинкера агломерированного при температуре около 1500°C
Кристаллические фазы обозначены символами применяемыми в химии цемента: C_3S — алит, C_2S — белит, C_3A — трёхкальциевый алюминат, C_4AF — четырёхкальциевый алюмоферрит, C — свободный окисел кальцита. Дифрактограмма выполнена Е. Скоморовским

Фиг. 2. Кристаллы алита по
1 — Гутману и Гилле (1933), *2* — Андерсену и Леа (смотри Кюль 1951)

Фиг. 3. Рентгеновская дифрактограмма портландского клинкера плавленного при температуре около 1810°C
Кристаллические фазы обозначены символами применяемыми в химии цемента: C_3S — алит, C_2S — белит, C_3A — трёхкальциевый алюминат, C_4AF — четырёхкальциевый алюмоферрит, C — свободный окисел кальцита. Дифрактограмма выполнена Е. Скоморовским

ОБЪЯСНЕНИЯ К СНИМКАМ

Фото 1. Посредственная микроструктура агломерированного портландского клинкера
Алит — полигональные и псевдогексагональные кристаллы, белит — двойниковые изометрические кристаллы, четырёхакальциевый алюмоферрит — заполняющее белое вещество. Отражённый свет, шлиф травленный в 1% HNO_3 Увеличение × 500

Фото 2. Агломерированный портландский клинкер
Типичный псевдогексагональный кристалл алита. Отражённый свет, шлиф травленный в 1% HNO_3. Увеличение × 800

Фото 3. Агломерированный портландский клинкер
Типичный псевдогексагональный кристалл алита. Отражённый свет, шлиф травленный в 1% HNO_3. Увеличение × 800

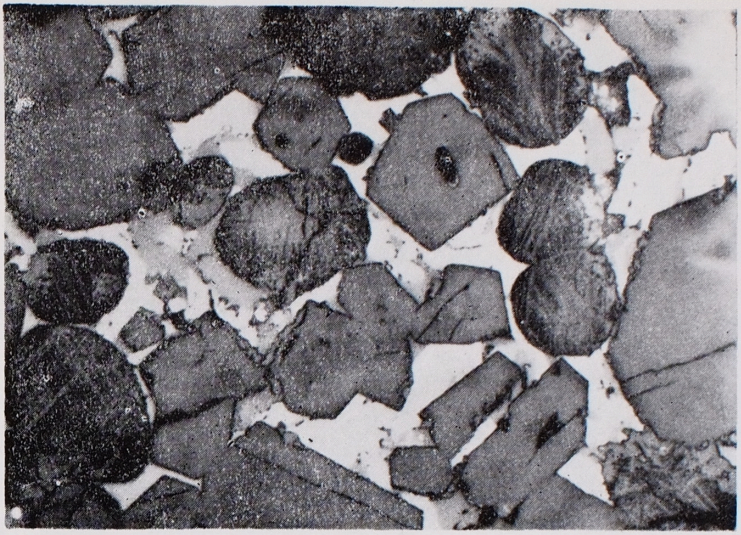
Фото 4. Агломерированный портландский клинкер
Кристалл алита, характеризующийся зональным строением. Отражённый свет, шлиф травленный в 1% HNO_3. Увеличение × 800

Фото 5. Плавленный портландский клинкер
Удлинённые кристаллы алита с палочным габитусом. Отражённый свет, шлиф травленный в 1% HNO_3. Увеличение × 300

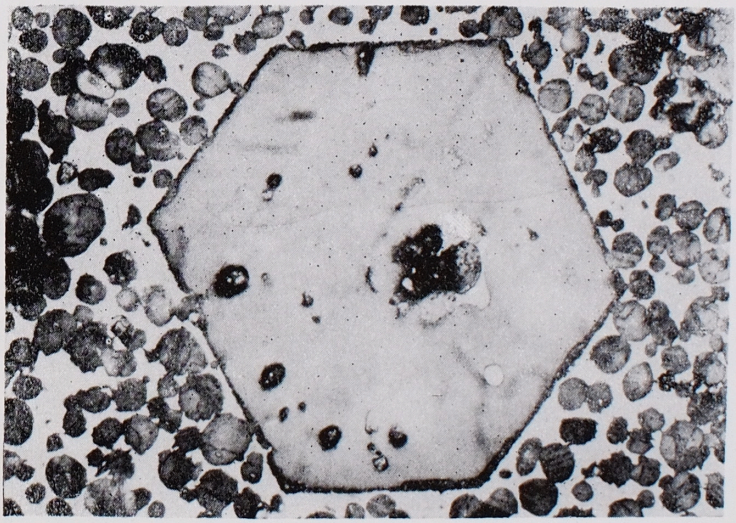
Фото 6. Плавленный портландский клинкер
Удлинённые кристаллы алита с палочным габитусом и трещинами на поверхности. Отражённый свет, шлиф травленный в 1% HNO_3. Увеличение × 300

Фото 7. Плавленный портландский клинкер
Кристаллы алита корродированные текучей фазой. Отражённый свет, шлиф травленный в 1% HNO_3. Увеличение × 300

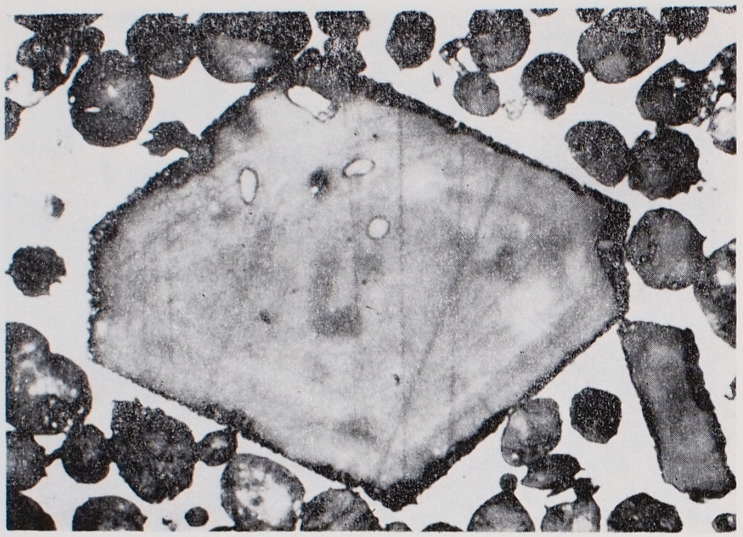
Фото 8. Плавленный портландский клинкер
Кристаллы алита с нерегулярным габитусом, содержание включения свободного окисла кальция и металлического железа. Отражённый свет, шлиф травления в 1% HNO_3. Увеличение × 300



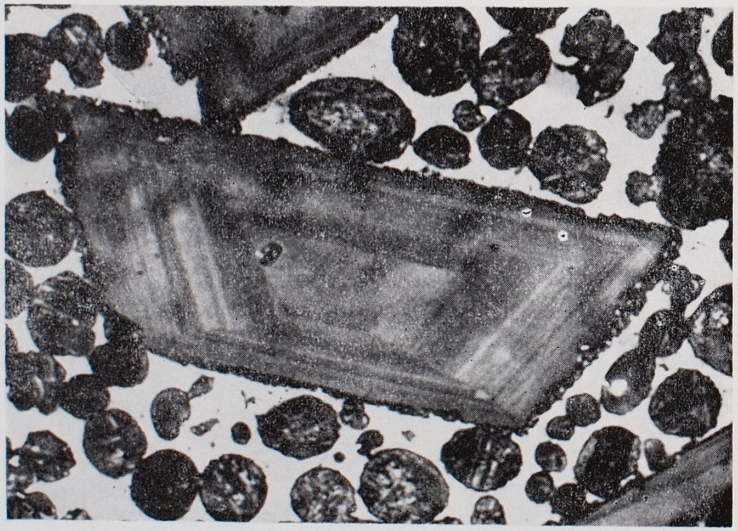
Phot. 1. Average microstructure of sintered portland clinker
Alite — polygonal and pseudohexagonal crystals; belite — twin isometric crystals; tetracalcium aluminoferrite — white filling substance; triacalcium aluminate — grey filling substance. Reflected light, polished section etched with 1% HNO_3. Magn. × 500



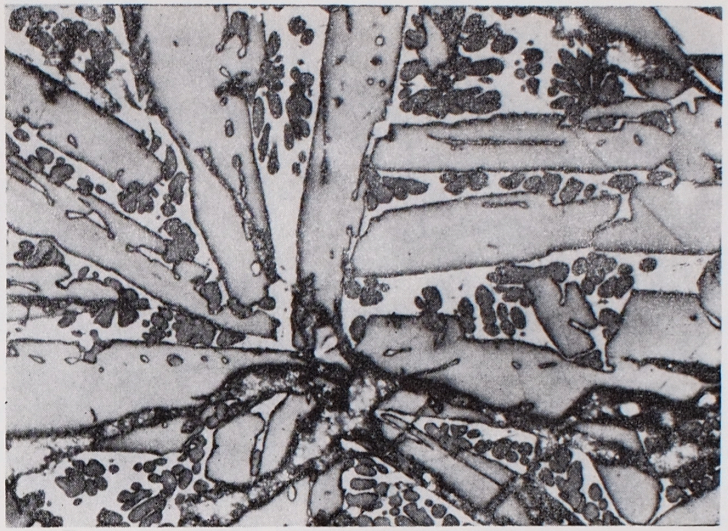
Phot. 2. Sintered portland clinker
A typical pseudohexagonal alite crystals. Reflected light, polished section etched with 1% HNO_3. Magn. × 800



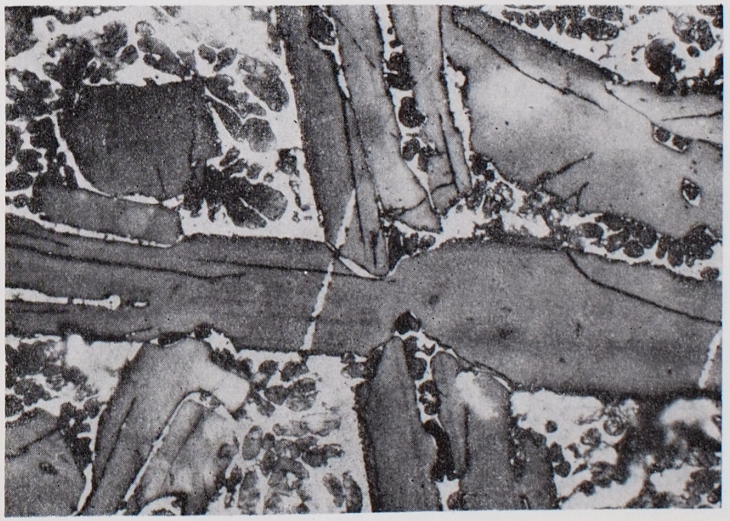
Phot. 3. Sintered portland clinker
A typical pseudohexagonal alite crystal. Reflected light, polished section etched with 1% HNO_3. Magn. × 800



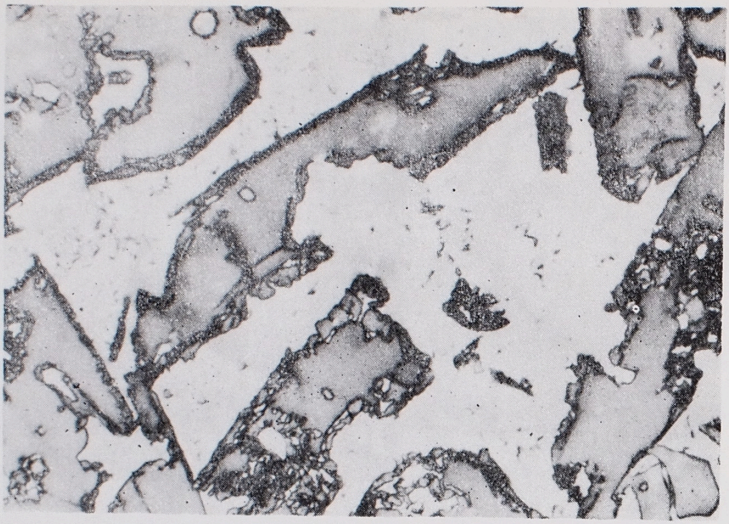
Phot. 4. Sintered portland clinker
An alite crystal exhibiting zonal structure. Reflected light, polished section etched with 1% HNO_3. Magn. × 800



Phot. 5. Fused portland clinker
Elongate alite crystals with a rodlike habit. Reflected light, polished etched with 1% HNO_3. Magn. × 300



Phot. 6. Fused portland clinker
Elongate alite crystals showing a rodlike habit, with cracks visible on the surface. Reflected light, polished section etched with 1% HNO_3. Magn. × 300



Phot. 7. Fused portland clinker
Alite crystals corroded by the liquid phase. Reflected light, polished section etched with 1% HNO_3. Magn. × 300

Phot. 8. Fused portland clinker
Alite crystals with a irregular habit, containing inclusions of free calcium oxide and metallic iron. Reflected light, polished section etched with 1% HNO_3. Magn. × 300