دراسة لأنواع الفشل في الطابوق الحراري المبطن لأفران الاسمنت

الخلاصة:

إن فشل الطابوق الحراري المبطن لأفران الاسمنت هو عملية مكلفة ولا يعود ذلك إلى كلفة استبدال الطابوق فقط بل يعود أيضا إلى خسائر توقف الإنتاج طيلة فترة الاستبدال. والبحث الحالي يهدف إلى دراسة أنواع وأسباب الفشل في الطابوق الحراري لأحد أفران معمل سمنت الكوفة باستخدام طريقتي التحليل الكيمياوي و حيود الأشعة السينية.

وقد بينت النتائج وجود عناصر ضارة في المواد الأولية و كلنكر الاسمنت تتفاعل مع الطابوق في درجات الحرارة العالية . كما أظهرت النتائج تغلغل الكلنكر على وجه الطابوق المغنيسي مما يؤدي إلى نشوء طبقة تغطي الطابوق وتمنعه من التقشر عند الظروف الطبيعية لتشغيل الفرن ، أما عند تغير درجات الحرارة (1400-550) فيبدأ الغطاء بالتقشر مسببا تآكل الطابوق. كما ظهر ان كافة أنواع الطابوق الالوميني المستخدم قد تغلغلت فيها القلويات وبنسب تزداد مع زيادة محتوى الالومينات في الطابوق.ومن نتائج انحراف الأشعة السينية فقد ظهر تكون مواد ضارة بسبب تفاعل القلويات والكبريتات مع الطابوق الالوميني مصحوبة بزيادة الحجم وكون الطابوق أكثر هشاشية مما أدى إلى تلف الطابوق بواسطة الاجهادات الحرارية- الميكانيكية.

1. Introduction:

Total refractory production in United States in 1998 was 3.66 million metric tons with a value of \$2.329 billion. Refractory sales are expected to reach \$3.2 by year 2010. About 20% of products are consumed in cement industry [Semler 2000] . In Iraq, Kufa cement new factory, for example, consumes about 250000 bricks for each kiln yearly with a replacement annual cost of about 750000 \$. The failure of refractory bricks lining cement kilns is a costly process not only due to the cost of replacing bricks but also due to the lost in production time during the replacement period. Failure of bricks, beside other factors, may results in corrosion of the kiln steel shell [Potgieter 2004] .so, it is important to study types and causes of failure in refractory bricks in order to select the suitable type for each kiln zone as well as controlling operation conditions to minimize brick failure. Fig. 1 shows the different zones of the kiln under study and types of bricks used for each zone .Fig. 2 shows the replacement of kiln bricks.

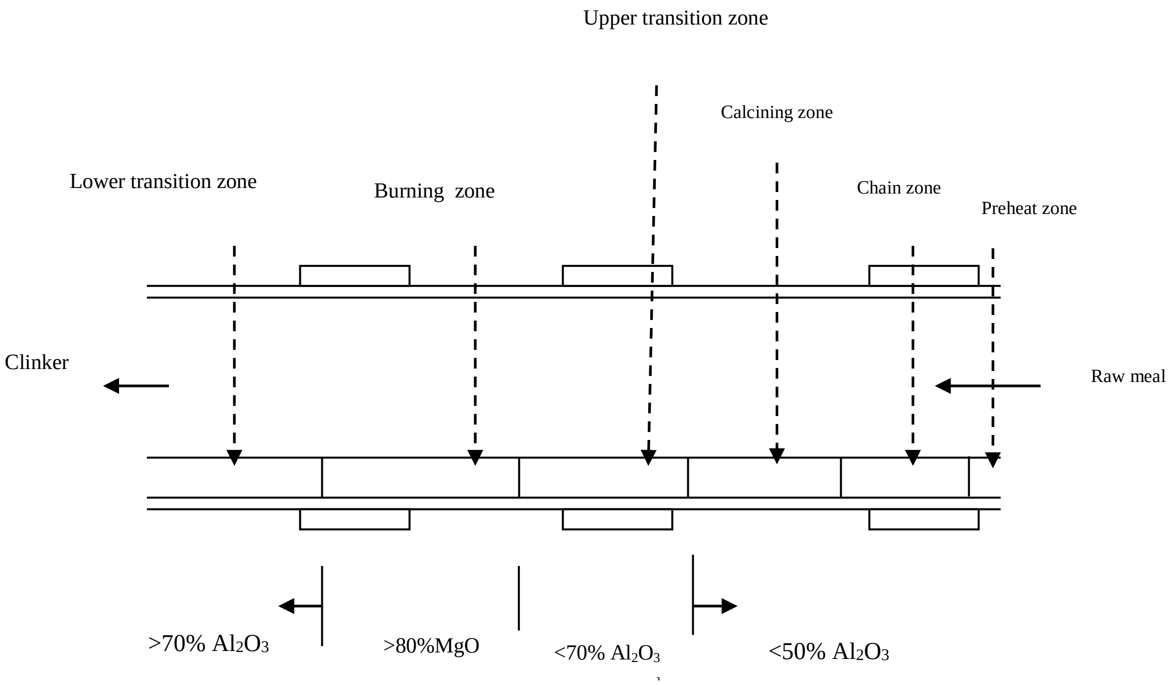

Fig. 1 : The cement kiln zones and temperature distribution (Operational Parameters:(Kufa Cement Factory) , Wet Production Method , Six Stages ,Radius (5.25-5.75)m , Length (175)m, (1.5-2.25) rpm.).[Kufa Cement Plant/Kilns Department)

The kiln's axial temperature profile can be mainly divided by three zones where all the reactions occur either independently or simultaneously. These zones include [Akwasi 2008]:

- the calcining zone 600-900 ^oC
- the transition zone 900–1300 ^oC
- the Burning zone 1300–1400 ^oC.

Fig 2 :Refractory Brick Re-building at Kufa Cement Factory (Kiln No.2).

The main types of refractory bricks included in the present work are:

High Alumina:

Bricks containing more than 45% alumina are generally termed as high alumina materials. The alumina concentration ranges from 45 to 100%. The refractoriness of high alumina refractory increases with increase in alumina percentage. The applications of high alumina refractory includes most regions of cement kilns.

Magnesite:

Magnesite bricks are chemically basic materials, containing at least 80% magnesium oxide. They are used especially in the burning zone.

Magnesia-Chrome:

Magnesia-chrome bricks are used in cement kilns because they displayed properties that met the demands of the refractory environment. Magnesia-chrome bricks exhibited long wear, high melting temperatures, low thermal conductivity, good hot strength and good thermal shock resistance [Bartha 1994]. Despite these many advantages, magnesia-chrome based refractory linings also suffered a serious disadvantage. The chrome within the magnesia-chrome brick reacted with the lime and alkali in the refractory environment to form complex chrome-component. This component was categorized as a toxic material requiring special disposal measures. Thus, the use of refractory linings fabricated from magnesia-chrome resulted in costly disposal and remediation procedures at the end of their use.

Failure of refractory bricks may occur during bad storage or due to mechanical,, chemical ,or thermal effects during the kiln operation**.** Bakker [Bakker 1993] indicated spalling as a refractory wear mechanism , and demonstrated how the repeated occurrence of it during operation would led to an incremental and rapid shortening of refractory service life versus the predictable and gradual linear wear caused by corrosion. Taber [Taber 2003] discussed general factors to take into account when choosing refractory, including chemical compatibility, thermal and mechanical concerns, and design issues.

Serena and others [Serena 2004] studied the corrosion behavior of $MgO/ CaZrO_3$ refractory by clinker of Portland cement. The attack mechanism of 80% MgO – 20% $CaZrO_3$ (wt %) was established. The results are discussed in term of the phase equilibrium diagram $MgO–CaZrO_3–(CaO)_2.SiO_2–(CaO)_3SiO_2$.They found that the dissolution of the $CaZrO_3$ refractory phase produces the enrichment with zirconium of the liquid phase increasing its viscosity and hindering the liquid phase diffusion.

Bartha [Barth 2005] developed a theoretical model for penetration and dissolution mechanism by liquid silicate slag for two types of refractory. They conducted an experimental test to estimate the reaction rate between the slag and the refractory .They found that corrosion rate is depending on the type of refractory material and temperature.

Raymond and others [Remond 2005] studied the corrosion rate of magnesite, alumina and the spinel magnesium Aluminates $MgAl_2O_4$ by slag. They found that operational changes such as increasing in temperature and service time play important role in refractory life.

Rodriguez and others [Rodriguez 2007] investigated the mechanism of corrosion of magnesia – calcium silicate by cement clinker. They found that the diffusion of the liquid clinker phase into the refractory substrate is the main cause of corrosion, and also the dissolution of $CaZrO_3$ produces the enrichment with zirconium of the liquid phase increasing its viscosity and hindering the liquid phase diffusion.

Philips [Philips 1998] studied the effect of kiln shell deformations on the lining brick, he concerned on the alignment of the kiln and he found that an ideal hot kiln alignment involves not only the horizontal and vertical axes of the shell, but the balance of the axial thrust of the kiln as well.

Walter [Walter 2008] studied Ovality of the kiln shell during rotation, he found that this deformation have a considerable effect on the mechanical stability of the refractory bricks.

2. Experimental Work

A- Physical Properties:

Physical properties of bricks were taken from Hasle company manuals according to the following specifications [Hasle 2007]:

1- Apparent porosity (ASTM C-830)

2- Thermal Conductivity (ASTM E 1225-04)

3- Modulus of elasticity (ASTM C-133)

4- Modulus of rupture (ASTM C-133)

5- Hot modulus of rupture (ASTM C-583)

Table -1: Physical properties of refractory bricks [Hasle 2007]

Physical Properties	Coelex 80-R	MTC1	Alumax 75 A	Alumax 50 A	Hasle D59A	Hasle D52A	Hasle D39A	Spinel 30-70
Density (kg/m^3)	3100	3000	2700	2300	2500	2350	2200	2900
Apparent Porosity %	13.2	12	19	17	18	16	14	15
Thermal Conductivity (W/m.K) at 400ºC	4.12	5.11	1.66	1.13	1.4	1.28	1.16	2.9
Modulus of Elasticity (GPa)	109.4	128.3	25.7	34.9	32.3	41.4	45.2	35.4
Modulus of Rupture (MPa)	17.5	17	12	14	18	16.5	16	19
Hot Modulus of Rupture (MPa)	16.7	16.2	10.2	11.3	15.6	14.2	14.1	18.4

B-Chemical Analysis and X-ray diffraction

Chemical Analysis and X-ray diffraction was done on 3 sample of Magnesite and 5 sample of Alumina bricks in order to know the amount of clinker and alkalis infiltration as well as the phases that formed in brick before and after using in several zones of cement kiln and in a known period of working. In order to investigate the clinker and alkali infiltration in the refractory bricks, chemical analysis were conducted on bricks before and after using for different periods of kiln operation. Chemical analysis was also conducted on the raw meal and clinker after burning to investigate the detrimental compounds which may react with the lining bricks.

Note: (Chemical Analysis and X-Ray diffraction were done in laboratories of Kufa Cement Factory)

XRD were done by (Cubix PANalytical X-RAY test device-Holland**,** the wave length of radiation λ=17902 nm, powder method as shown in Figure 3).sample were grinded to particles (0.002-0.005 mm) and pressed into a disk sample (r=25mm, t=5mm,weight=10g) with smooth flat surface. Data can be gotten from computer by using software (Super Q Manager).

Fig.3: X-Ray Device (Kufa Cement Plant)

Chemical analysis procedure (wet method) was done on 1 g sample foe oxide, for example the following steps will be done to get the ratio of silica in 1gram sample:

- drying the sample in oven (100-110 ^{o}C) for half hour.
- Adding 0.5g NH_4CL and mix well.
- Adding 6ml HCL gradually and mix till the sample disappear and then put on water path for half hour and mix every 5 minute.
- Adding 50 ml boiled water.
- Burning the mix in electric furnace for half hour (950-960 ^{o}C) and then calculate the percentage of SiO_2 as follow:

  SiO_2%= (weight after burning/sample weight) x 100%

C- Alkali Reaction Test (DIN 51069,page 2):

This test was carried out to study the ability of Alumina brick to withstand alkalis (K_2O, K_2SO_4) in raw materials and cement clinker. According to the above specification, the alkali attacks are evaluated as slight, medium, heavy; this evaluation is supplemented by the 0-10 points scale according to the depth of the attack (penetration in mm)as in table-2.

Table-2: The 0-10 points scale according to DIN 51069,Page 2 [Abhijit 2010].

Degree of attack	symbol	Penetration depth (mm)	Notes
Slight Attack	0	0	Absolutely unaffected. Seldom achieved
	1	1	Ideal properties
	2	2	Ideal properties
	3	3	Slight attack.
Medium Attack	4	4	Attacks that penetrate a few millimeters.
	5	5	Bricks are often unaffected in practice.
	6	6	Bricks are beginning affected in practice.
Heavy Attack	7	7	Heavy attack, possibly some cracks
	8	8	Heavy attack, possibly some cracks
	9	9	Heavy attack with deep cracks.
	10	10	Crucible quite destroyed and dissolved.

D- Materials:

7 types of refractory bricks used in Kufa new cement factory are tested before and after using in the kiln :

1- Coelex 80R (Magnesia-Chrome) used in the burning zone

2- MTC1 (Magnesite) used in the burning zone

3- Alumax 75A (Alumina) used in the upper transition zone

4- Alumax 50A (Alumina) used in the chain zone

5-Hasle D59A (Alumina) used in the lower transition zone

6-Hasle D52A (Alumina) used in the calcining zone

7- Hasle 39A (Alumina) used in the preheat zone

Spinel 30-70 refractory brick is not used yet in Kufa cement factory but it is studied here just for comparison. Physical properties of these types are shown in Table-1.

Samples of raw meal and cement clinker after burning are also tested to determine the detrimental components that may affect lining bricks.

3.Results and Discussions:

3.1 Failure during storage:

The X-Ray diffraction results for magnesia bricks (MTC1) which were not used but damaged during storage showed a formation of Brucite phase ($Mg(OH)_2$). This means that MgO reacted with water found in air or direct water during storage period according to the following hydration equation:

$MgO + H_2O \rightarrow Mg(OH)_2$

This reaction accompanied with a volume expansion leading to the spider cracks (Fig.4). To avoid hydration problem in Magnesite bricks, a dry storage or using double plastic cover may be useful, the recommended time of storage must not exceeds 4 months.

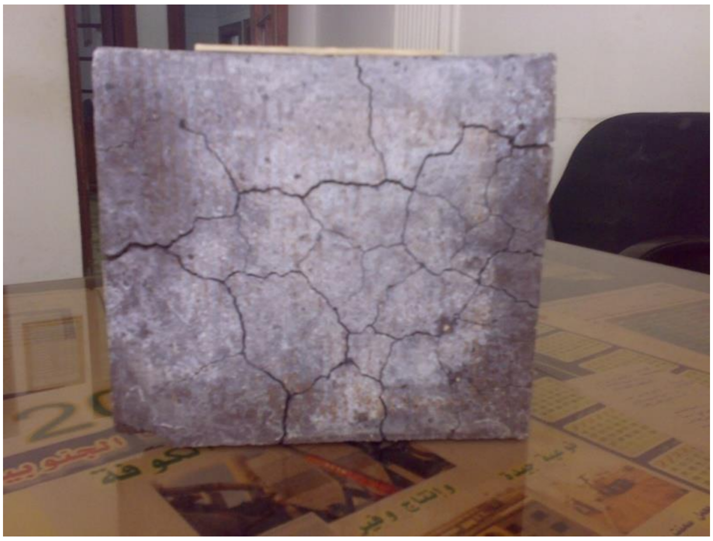

Fig 4: Spider cracks due to bad storage

3.2 Chemical analysis of raw meal and cement clinker :

Table-3 shows the results of chemical analysis of raw meal and cement clinker after burning. It can be seen that there are detrimental components like alkalis (K_2O, Na_2O) and SO_3 which tend to react with lining bricks at high temperatures.

Table- 3: Chemical analysis of raw meal and cement clinker.

Chemical analysis (wt%)	Raw meal	Clinker
Weight loss (loss of ignition)	27.12	0.28
SiO_2	14.3	19.7
Al_2O_3	3.90	5.12
Fe_2O_3	2.43	3.41
CaO	46.2	62.3
MgO	4.55	7.31
SO_3	0.37	0.59
Na_2O	0.12	0.27
K_2O	0.64	0.97
TiO_2	0.07	0.12

3.3 Chemical analysis of bricks before and after using:

Table- 4 shows the results of chemical analysis of refractory bricks before using in the kiln while Table 5 shows the results of chemical analysis of the same bricks but after using in the kiln for different periods.

Table- 4 :The chemical analysis of refractory bricks before using in cement kiln

Chemical analysis (wt %)	**Coelex 80-R**	**MTC1**	**Alumax 75 A**	**Alumax 50 A**	**Hasle D39A**	**Hasle D52A**	**Hasle D59A**	**Spinel 30-70**
MgO	80.00	92.29	----					32
Al_2O_3	7.00	0.73	75	49	39	50	62	67.1
SiO_2	3.50	0.7	19	45	56	45	33	0.22
CaO	0.60	2.31	1.4	2.1	1.6	1.6	1.4	0.17
Cr_2O_3	5.00	----						----
Fe_2O_3	4.30	----	1.5	1.6	1.4	1.1	1.1	0.13
TiO_2		----	2.7	2.2	1.1	1.4	1.4	----
Na_2O		0.39						0.3
K_2O		0.01						

Table- 5: Chemical analysis results of the hot face of bricks after using

Chemical analysis (wt %)	**Coelex 80-R** 6 months	**MTC1** 8 months	**Alumax 75 A** 5 months	**Alumax 50 A** 6 months	**Hasle D39A** 8 months	**Hasle D52A** 6 months	**Hasle D59A** 6 months
MgO	71.59	86.25	----				
Al_2O_3	6.96	0.52	66.2	43	34.4	43.2	56.2
SiO_2	5.92	3.4	18.4	47	57.1	48.4	357.4
CaO	1.88	4.24	4.4	2.9	2.4	2.6	1.9
Cr_2O_3	3.84	----					
Fe_2O_3	3.78	0.9	1.9	1.8	1.7	1.7	1.4
TiO_2		0.2	2.4	2.4	1.2	1.6	1.6
Na_2O	0.22	0.5	0.75	0.4	0.1	0.3	0.37
K_2O	0.13	0.14	4.2	1.4	0.4	0.9	1.2
SO_3	5.34	3.1	0.09	1.02	1.01	1.02	1.05
Density (kg/m^3)	3170	3090	2820	2450	2370	2470	2650

The comparison between table- 4 and table- 5 leads to the following notes:

1- For Coelex 80R and MTC1 brick types there is an increase in each of CaO and SiO_2 after using. This increase may be attributed to the infiltration of cement clinker into the hot faces of bricks. The infiltrated clinker adheres on the hot face forming a layer called ((coat)) which protect the brick from spalling as shown in Fig.5.

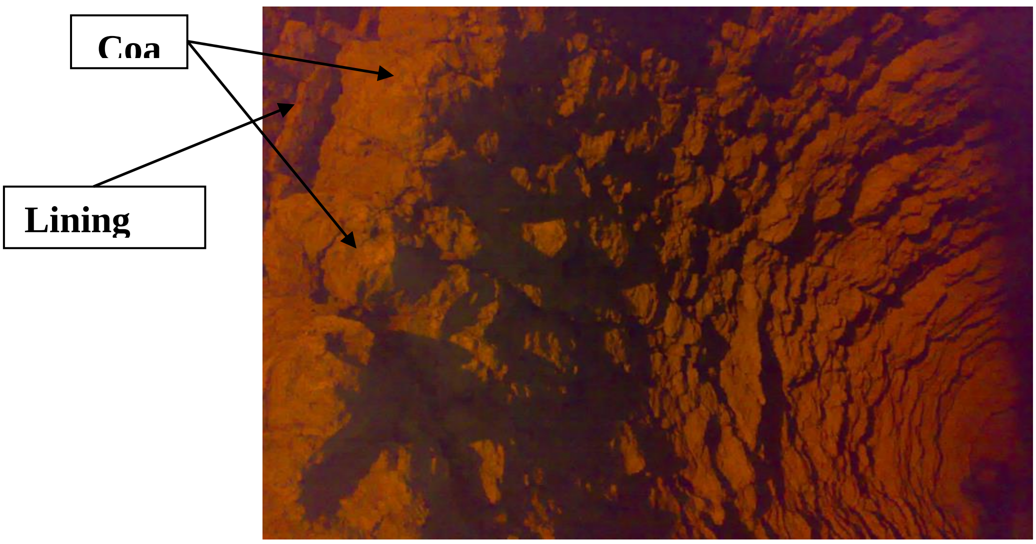

Fig. 5: Coating formation on Magnesite bricks

Coating is formed due to the high thermal conductivity of magnesite brick and its location in the burning zone. The clinker mass adhered on the Magnesite brick as clinker transforms from a liquid to a solid state in this zone. When the kiln operate under equilibrium conditions, the coating maintain itself , any change in operation temperature lead the coating to come off, when the kiln temperature is cooled the denser portion of bricks will peel off easily (Figure 6) causing brick corrosion.

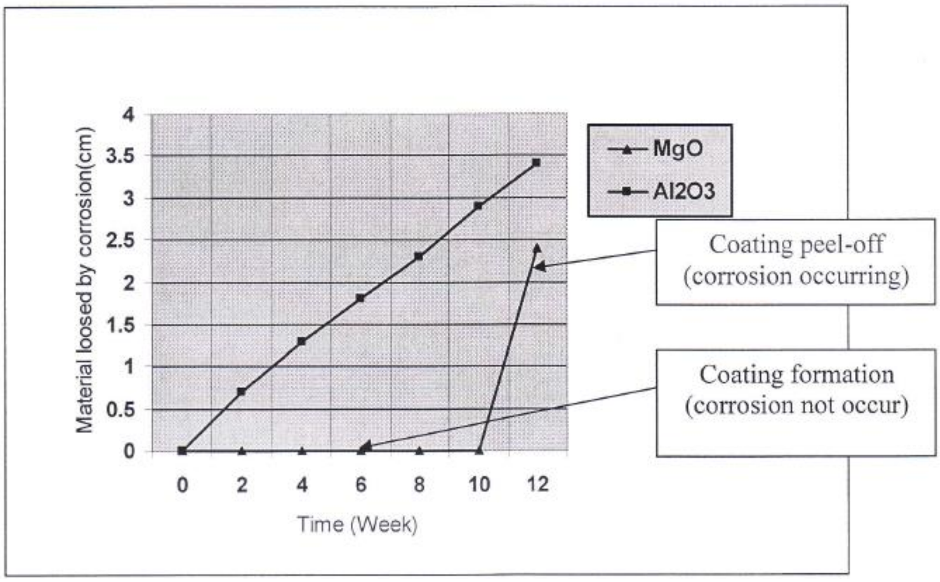

Fig. 6: Material loosed from the hot face for Magnesite and Alumina bricks.

2- It is also shown that for both **Coelex 80-R** and **MTC1** there is a very small amount of alkalis (Na_2O , K_2O) infiltrated into bricks, this may be due to the basic properties of Magnesia brick that make it unaffected by alkalis.

3- It can be seen also that for both **Coelex 80-R** and **MTC1** there is a large amount of SO_3 infiltrated into the brick after using. Infiltration of SO_3 salts weakens the bond inside the brick material resulting in another type of failure and cracking as shown in Fig. 7. To improve kiln lining against infiltration of alkali salts a reduction in alkali content of raw materials seems to be useful.

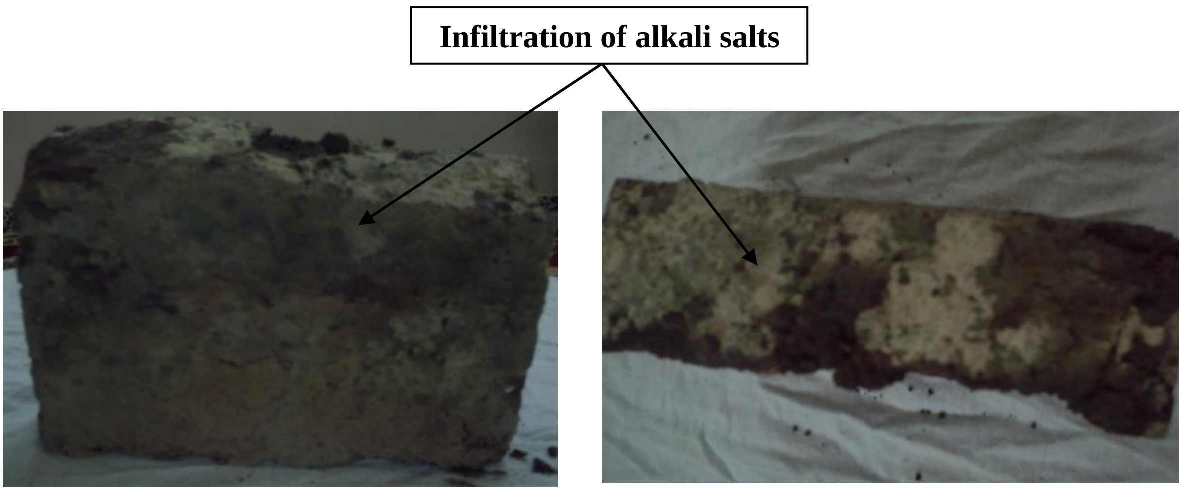

Fig. 7: Infiltration of alkali salts

4- Chemical analysis for **Coelex 80-R** brick after burning shows a decrease in chromite (Cr_2O_3) ratio at the hot face, which may refers to immigration of Cr_2O_3 from hot face to cold face by diffusion mechanism. This immigration weakens the refractory resistance because chromite is responsible for the brick toughness.

5- For all Alumina samples , significant ratios of alkalis are infiltrated into bricks during period of service, the amount of infiltration increased with the ratio of alumina content . The density of all samples increased after service resulting in a densification of hot face (e.g. density for **Alumax 75 A** increased from 2700 to 2820 kg/m^3) , this densification render the bricks more susceptible to peel off by thermo- mechanical abrasion. The clinker may diffuse through the refractory substrate by its grain boundaries and pores.

3.4 Results of X-ray diffraction:

Table-6 summarizes the results of X-ray diffraction for bricks before using while Table-7 shows results of X-ray diffraction for the same bricks after different periods of service in the kiln.

Table-6: The results of X-Ray diffraction of refractory bricks before using

Coelex 80-R	**MTC1**	**Spinel 30-70**	**Alumax 75 A**	**Alumax 50 A**	**Hasle D39A**	**Hasle D52A**	**Hasle D59A**
71% MgO	91% MgO	70% $MgAl_2O_4$	45% Al_2O_3	60% Mullite	63% Mullite	67% Mullite	62% Mullite
9% $MgCr_2O_4$	4% $CaSiO_3$	25% Al_2O_3	39% Mullite	15% Al_2O_3	12% Al_2O_3	17% Al_2O_3	17% Al_2O_3
11% $MgAl_2O_4$			2% CSSS	5% CSSS	6% CSSS	4% CSSS	4% CSSS
7%M_2S			12% Andalusite	18% Andalusite	9%SiO_2 9% Andalusite	11% Andalusite	14% Andalusite

- Mullite = Al_2O_3. $2SiO_2$
- CSSS =calcium silicate solid solution ($CaSiO_3$).
- Andalusite = Al_2SiO_5
- M_2S = $MgO.2SiO_2$

Table-7: The X-Ray diffraction results of the hot face of bricks after using

Coelex 80-R 6 months	**MTC1** 8 months	**Alumax 75 A** 5 months	**Alumax 50 A** 6 months	**Hasle D39A** 8 months	**Hasle D52A** 6 months	**Hasle D59A** 6 months
64% MgO	84% MgO	36% Al_2O_3	55% Mullite	61% Mullite	64% Mullite	58.4% Mullite
8% $MgCr_2O_4$	6% $CaSiO_3$	34% Mullite	9% Al_2O_3	10% Al_2O_3	15% Al_2O_3	14% Al_2O_3
13% $MgAl_2O_4$	8% K_2SO_4	2.5% CSSS	5.8% CSSS	6.7% CSSS	4.5% CSSS	4.7% CSSS
6.4% M_2S		9% Andalusite	13% Andalusite	8% Andalusite	10% Andalusite	11% Andalusite
3.8% K_2SO_4		4% Nepheline	3% Nepheline	7% Free SiO_2	0.7% Nepheline	1.2% Nepheline
4.1% KCr		3% Noselite	1.7% Noselite	0.3% Nepheline	0.4% Noselite	0.7% Noselite
		5% Kalsilite	4% Kalsilite	0.2% Noselite	1.7% Kalsilite	2.1% Kalsilite
		6% ß-Alumina	4% ß-Alumina	0.9% Kalsilite	2.6% ß-Alumina	2.9% ß-Alumina
				1.4% ß-Alumina		

- KCr = $KCrO_2$, Nepheline = $NaAlSiO_4$, Noselite = $Na_2O.3Al_2O_3.6SiO.2SO_3$
- Kalsilite = $KAlSiO_4$, ß-Alumina = $K_2Al_{22}O_{34}$

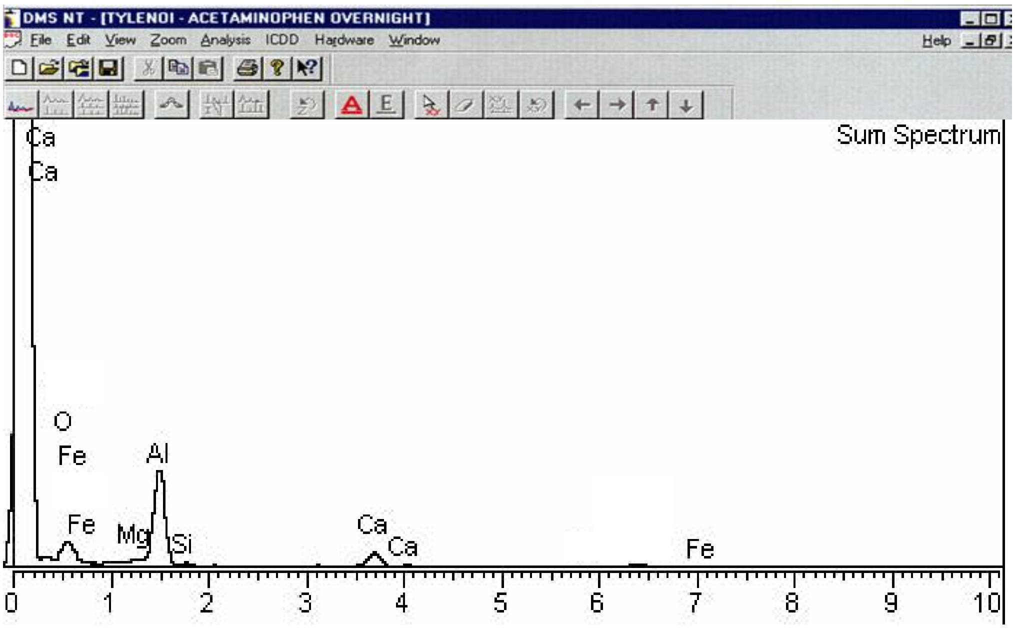

Fig. 8:X-Ray diffraction spectra for MTC1 brick before using.

A comparison between the two tables leads to the following notes:

1- The bricks were exposed to high chemical attack by alkalies and sulfur, depending on the lining area, temperature and brick type .

Chromite in **Coelex 80-R** have a tendency to react with alkalis especially (K_2O) as in the following equation:

$Cr_2O_3 + K_2O \rightarrow 2KCrO_2$

This means that Chromite works well to preventing corrosion by reaction with alkalis to form a high density phase limiting further clinker penetration.

2- In both types of magnesia bricks,there were a considerable amount of (K_2SO_4) which was formed by the following equation:

$K_2O + SO_3 \rightarrow K_2SO_4$

K_2SO_4 is a toxic detrimental compound that weakens the brick because it separates the strong inside substrate and makes the brick more brittle.

3- Many phases was formed by reaction between Alumina bricks, alkalis and sulfur as in the following equations:

$3Al_2O_3.2SiO_2 + Na_2O \rightarrow Na_2O.Al_2O_3.2SiO_2 + 2Al_2O_3$

Mullite Nepheline

$3(Na_2O.Al_2O_3.2SiO_2) + 2Na_2O + 2SO_3 \rightarrow 5Na_2O.3Al_2O_3.6SiO_2.2SO_3$

Nepheline Noselite

Mullite → Nepheline → Noselite = volume expansion → mechanical stress (which could lead to crack formation).

The formation of “ß-Alumina” takes place according to:

$11Al_2O_3 + K_2O \longrightarrow K_2Al_{22}O_{34}$

The formation of (Kalsilite) takes place according to:

$2Al_2SiO_5 + K_2O \longrightarrow 2KAlSiO_4 + Al_2O_3$

Andalusite Kalsilite

All compounds formed by reaction between alkalis ,sulfur and Alumina brick is detrimental because they are toxic and make brick more brittle so that it will easy damaged by thermo-mechanical stresses.

3.5 The Spiraling failure:

The spiraling problem (Fig. 9) occurred in **Hasle D39A** at Pre-heat zone is the result of loose installation, increased in kiln shell Ovality and the deformation in the kiln shell caused a relative movement between bricks, and in high axial stresses more than brick strength this will lead to cracks along the width of brick.

3.6 Convex spalling failure:

This Phenomenon occurs in Alumina brick type **Alumax 75 A** in upper transition zone. It occurs only in case of too fast heating up rate (overheating) which develops a compression forces near the brick hot face and when no time to expand, these pressure forces may exceed the strength of brick. As a final result the curved spalling with convex surface will appear (Fig10).

Fig. 10: Convex spalling of Alumina brick at upper transition zone.

3.7 The alkali test results:

The alkali test results for 6 alumina brick samples are shown in Table- 8.

Table- 8: The alkali test results

Alkali Test	Spinel 30-70	Alumax 75 A	Alumax 50 A	Hasle D39A	Hasle D52A	Hasle D59A
Alkali Test (Scale 0-10)	3	9	2	0	1	1
Infiltration Depth (mm)	3.4	9.2	2.4	0.5	1.2	1.4

It was shown from Table- 8 that **Alumax 75 A** sample showed very weak resistance to alkali attack so that it is recommended to replace it. Also alkali test for **Spinel 30-70** is accompanied with volume increasing so that it is not recommended for use in calcining or upper transition zones. Other Alumina types with lower alumina content showed low alkali infiltration depth.

3.8 Failure due to Ovality of kiln:

Ovality, as it applies to an operating kiln shell, is the change of curvature or flexing of the shell during the course of each revolution. This effect causes a shear stresses on the brick heads at the tire sections of the kiln (mechanical failure) as shown in Fig.11. However, Ovality is a complicated mechanical phenomenon in rotary kilns and so it may needs a special separate research.

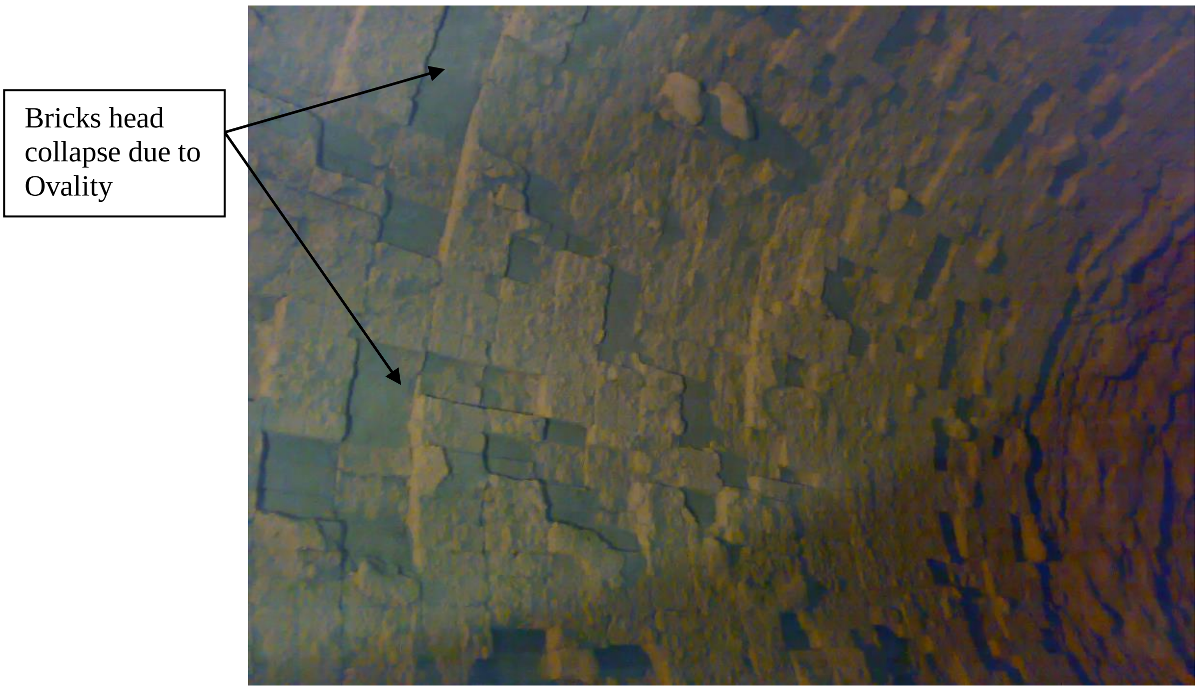

Fig. 11: Brick failure due to Ovality

4. Conclusions and Recommendations:

Within the limitations of the present work and **according to the obtained results** , the following conclusions could be reported to eliminate types and causes of failures in refractory bricks lining cement kilns:

1- Failure of Magnesia brick (**Failure during storage case Fig .4)** is occur due to presence of water which leads to formation of Brucite phase. This type of failure was accompanied with spider cracks.

2- The results of chemical analysis **(Table 3**) of raw meal and cement clinker after burning showed that there are detrimental components like alkalis (K2O, Na2O) and SO3 which tend to react with lining bricks at high temperatures.

3- It was shown that cement clinker infiltrated into the hot faces of magnesia bricks (**Coelex 80R and MTC1)** resulting in a formation of a coat layer which protect the brick from spalling. When the kiln operate under equilibrium conditions, the coating maintain itself , but with increased temperature coating will start to come off causing brick corrosion. Corrosion is the main type of failure of magnesia bricks lining cement kilns.

4- Magnesia bricks (**Coelex 80R and MTC1)** were not affected by alkalis in cement clinker but these types showed infiltration of **SO3** salts (Table 5) resulting in another type of failure and cracking.

5- Chemical analysis (Table 5) showed immigration of Cr_2O_3 from hot face to cold face (in **Coelex 80** brick) which weakened the refractory resistance because chromite is responsible for the brick toughness.

6- Chemical analysis results (Table 5) for all Alumina samples , showed that there are significant ratios of alkalis infiltrated into bricks during period of service, the amount of infiltration increased with the ratio of alumina content . The density of all samples increased after service resulting in a densification of hot face , this densification render the bricks more susceptible to failure and peeling off by thermo- mechanical abrasion.

7- X-ray diffraction showed a reaction between chromite **Coelex 80R** in magnesia chrome brick and potassium oxide (K2O) to form a high density phase limiting further clinker penetration.

8- X-ray diffraction showed formation of (K2SO4) in both types of magnesia bricks (**Coelex 80R and MTC1)** which weakens the bricks and makes them more brittle.

9- X-ray diffraction (Table 7) showed formation of detrimental compounds (mullite , nepheline , noselite,kalsilite and ß-Alumina) by reaction between alkalis ,sulfur and Alumina bricks.

Formation of these toxic compounds was associated with increased volume making the brick more brittle and easy to be damaged by thermo-mechanical stresses.

10- A spiraling failure **was noted in Hasle D39A** bricks at Pre-heat zone as a result of loose installation and kiln Ovality.

11- Because of overheating a convex spalling failure was noted in Alumina brick type **(Alumax 75 A**) in upper transition zone.

12- Alkali test results showed that **Alumax 75 A** and **spinel 30-70** bricks had very weak resistance to alkali attack accompanied with volume increasing while other types of alumina bricks showed good alkali resistance.

13- Mechanical failure due to Ovality was noted at the tire sections of the kiln. Ovality causes shear stresses at the brick heads.

5-Recommendations:

In order to minimize failure of refractory bricks , it is essential to follow the recommended standard procedures in storage , installation, kiln operation conditions , fire and temperature distribution. The following further studies may be necessary:

1- Investigating the use of Spinel type bricks in the burning zone of the kiln and evaluating its environmental and economical benefits.

2- Improve the strength of the rings of bricks inside the kiln by good installation and using suitable mortar to bond bricks.

3- It is recommended to investigate deeply the effect of Ovality of the kiln shell on the refractory brick life.

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