XI–2 REPORT ON COMPOSITION-ANALYSIS OF BRICKS FROM BABYLON AND HAMRIN

(1) Sample

1) Babylon's ancient mud brick (A brick)
2) Babylon's newly made mud brick (B brick)
3) Babylon's ancient baked brick (C brick)
4) Babylon's newly made baked brick (D brick)
5) Hamrin's ancient mud brick (E brick)
6) Hamrin's ancient burnt brick (F brick)

(2) Analysis Methods

1) Analysis of constructive elements by fluorescent X-ray analysis.
2) Composition-analysis of crystallines by X-ray diffraction.
3) Analysis of dehydration and decomposition by thermal analysis.

(3) Period of Measurements

Dec. 11, 1979–Jan. 9, 1980

(4) Results of Analysis

Table 19 Identification of elements contained in bricks by fluorescent X-ray analysis.

Table 20 Identification of crystallines contained in bricks by X-ray diffraction.

Table 21 Weight loss by thermal analysis and ignition.

(5) Discussion

1) Identification of elements contained in bricks

There is no difference of constructive elements in each brick. Main elements are Ca, Si, Fe, Al, K, Ti and Mg, and micro impurities are Cl, S, heavy metals and rare metals.

B brick contains more rich Cl in surface layer than inner part and so it suggests that B brick was soaked in sea water.

2) Identification of crystallines contained in bricks

Main crystallines in each brick are $CaCO_3$, α-SiO_2 and anorthite, and there are alittle crystallines such as micas and clay minerals

But $CaCO_3$ and anorthite are not detected in C and D brick. It suggests two reasons:

i) Raw materials are different between mud brick and baked brick.

ii) Raw materials are same but they are changed in quality by buring.

And so we heated each brick for 1 hour at 800°C to investigate how they change in quality by burning. After that we analysed them by X-ray diffraction.

In the result, we found that $CaCO_3$ changed to CaO and anorthite was not changed substanitally. In addition we found that (Ca, Mg, Fe)SiO_3 observed in baked bricks was not newly created when mud bricks were baked. There is a possibility to create (Ca, Mg, Fe)SiO_3 when they are baked at higher temperature, but we consider that it was not able to obtain such higher temperature in ancient time. Therefore, we think raw materials are different between mud bricks and baked bricks.

Hamrin's burnt brick contains a lot of $CaSO_4 \cdot 2H_2O$, so we consider it was not burnt actually.

3) Thermal analysis

Three endothermic peaks were observed in each brick except D brick.

We understand that the broad peak at around 70°C is the dehydration of adhesive water or hygroscopic water, the sharp peak at around 120°C is the dehydration of $CaSO_4 \cdot 2H_2O$ to $CaSO_4$, and also the sharp peak at around 730°C is the decomposition of $CaCO_3$ to CaO. Therefore $CaSO_4 \cdot 2H_2O$ and $CaCO_3$ are contained in every brick except D brick.

D brick was not changed in weight when it was burnt to the tmperature of 800°C, and for this reason we consider the raw materials of D brick afe different from others or the burning temperature is more than 800°C.

F brick has the peak of dehydration ($CaSO_4 \cdot 2H_2O \rightarrow CaSO_4 + 2H_2O \uparrow$) and so it is said that it was burnt, but it was not actually.

(6) Conclusion

1) We observe that constructive elements are same in each brick and so we understand constructive elements in bricks are same in each district.

Each brick is composed of Ca, Si, Fe, Al, K, Ti and Mg as main elements and many kinds of micro elements.

2) Each brick contains $CaCO_3$, α–SiO_2 and anorthite as main crystallines, and micas, clay minerals and natural gypsum as subcrystallines except C and D brick. C and D brick do not contain $CaCO_3$ but (Ca, Mg, Fe)SiO_3 as main crystalline. And F brick contains a lot of natural gypsum.

3) We consider burning temperature of D brick was higher than that of C brick.

4) We consider F brick was not burnt actually.

Table 19 Identification of elements contained in bricks by fluorescent X-ray analysis

No.			Elements contained			Remarks
			Much	Medium	Little	
1	Babylon's ancient mud brick	Surface layer	Ca, Si, Fe	Al, K, Ti Mg, Cl, S	Ba, Zu, Y, Sr Rb, Zr, Cu, Co Cr, Ce, Ni, Mu	
		Inner part	-do-	-do-	-do-	
2	Babylon's newly made mud brick	Surface layer	-do-	-do-	-do-	Cl is richer than inner part.
		Inner part	-do-	-do-	-do-	
3	Babylon's ancient baked brick	Surface layer	-do-	-do-	-do-	
		Inner part	-do-	-do-	-do-	
4	Babylo's newly made baked brick	Surface layer	-do-	Al, K, Ti Mg	-do-	Cl and not detected substantially.
		Inner part	-do-	-do-	-do-	Cl and S are not detected substantially. Zn is richer than surface layer.
5	Hamrin's ancient mud brick	Whole	-do-	Al, K, Ti Mg, Cl, S	-do-	
6	Hamrin's ancient burnt brick	Surface laye	Ca, Si	Fe, Al, K Ti, Mg, Cl S, Sr	Ba, Zr, Y, Rb Zn, Cu, Ni, Co Mu, Cr, Ce	Fe is little and S, Cl and Sr are mcuh compared with other bricks.
		Inner part	-do-	-do-	-do-	-do-

Table 20 Identification of crystallines contained in bricks by X-ray diffraction

No.			Crystallines identified: Original	Crystallines identified: Heated for 1 hour at 800°C	Remarks
1	Babylon's ancient mud brick	Surface layer	$CaCO_3$, α–SIO_2, anorthite*[1], illite*[2] montmorillonite*[3]	—	
		Inner part	-do-	CaO, α–SiO_2, anorthite illite	Clay minerals lost by dehydration.
2	Babylon's newly made mud brick	Surface layer	-do-	—	
		Inner part	-do-	CaO, α–SiO_2, anorithite illite	
3	Babylon's ancient baked brick	Surface layer	α–SiO_2, (Ca, Mg, Fe)SiO_3 anorthite	—	
		Inner part	-do-	α–SiO_2 (Ca, Mg, Fe)SiO_3	
4	Babylon's newly made baked brick	Surface layer	-d-o	—	
		Inner part	-do-	α–SiO_2 (Ca, Mg, Fe)SiO_3	
5	Hamrin's ancient mud brick	Whole	$CaCO_3$, α–SiO_2, anorthite illite montmorillonite	CaO, α–SiO_2 anorthite illite	
6	Hamrin's ancient burnt brick	Surface layer	$CaCO_3$, α–SiO_2, $CaSO_4 \cdot 2H_2O$ anorthite montmorillonite	—	
		Inner part	-do-	α-SiO_2 $CaSO_4$, CaO	

*[1] $CaAl_2Si_2O_8$

*[2] $(K, Na, Ca)_2O \cdot 3.33(Mg, Mn)O \cdot 4.3(Al, Fe, Ti)_2O_3 \cdot 16(Si, Al)O_2 \cdot 4H_2O$

*[3] $Al_2O_3 \cdot 4SiO_2 \cdot H_2O$, nH_2O

Table 21 Weight loss by thermal analysis and ignition loss

No.			Weight loss by thermal analysis: Room perature –150°C	150–800°C	Total	Ignition loss (800°C× 1 hr)	DTA peak (Endothermic peak)*1	Note ($CaCO_3$)*2
1	Babylon's ancient mud brick	Surface layer	2.6%	11.3%	13.9%	14.56%	70°C Ⓑ 120°C Ⓢ 735°C Ⓢ	25.7%
		Inner part	2.2	12.4	14.6	15.02	70°C Ⓑ 120°C Ⓢ 740°C Ⓢ	28.2
2	Babylon's newly made mud brick	Surface layer	3.6	13.9	17.5	18.78	70°C Ⓑ 125°C Ⓢ 725°C Ⓢ	31.6
		Inner part	2.1	15.7	17.8	17.96	70°C Ⓑ 125°C Ⓢ 743°C Ⓢ	35.7
3	Babylon's ancient baked brick	Surface layer	0.22	2.7	2.9	4.31	70°C Ⓑ 115°C Ⓢ 705°C Ⓢ	6.1
		Inner part	0.54	4.6	5.1	6.53	75°C Ⓑ 120°C Ⓢ 710°C Ⓢ	10.5
4	Babylon's newly made mud brick	Surface layer	0	0	0	0.11	115°C Ⓑ	—
		Inner part	0	0	0	0.02	40°C Ⓑ	—
5	Hamrin's ancient mud brick		2.2	12.1	14.3	15.08	65°C Ⓑ 120°C Ⓢ 740°C Ⓢ	27.5
6	Hamrin's ancient burnt brick	Surface layer	5.1	17.2	22.3	22.35	80°C Ⓑ 135°C Ⓢ 745°C Ⓢ	39.1
		Inner part	2.8	17.8	20.6	22.38	70°C Ⓑ 130°C Ⓢ 745°C Ⓢ	40.5

*1 The peak at around 70°C: The dehydration of adhesive water or hygroscopic water
The peak at around 120°C: $CaSO_4 \cdot 2H_2O \rightarrow CaSO_4 + 2H_2O \uparrow$
The peak at around 730°C: $CaCO_3 \rightarrow CaO + CO_2 \uparrow$

*2 Weight % of $CaCO_3$ calculated by weight loss at around 730°C.

Ⓑ Broad peak

Ⓢ Sharp peak

PROPERTY TEST OF BRICKS IN BABYLON

1. *Samples*

(1) Babylon's ancient mud brick (A brick)
(2) Babylon's newly made mud brick (B brick)
(3) Babylon's ancient baked brick (C brick)
(4) Babylon's newly made baked brick (D brick)

2. *Measurements*

(1) Surface tensile-strength by surface tension test
(2) Permeant depth and amount of RF–100 into bricks
(3) Water-resistant test
(4) Weather-resistant test by sunshine weather meter
(5) Abrasion-resistant test

3. *Period of measurements*

Dec. 11, 1979–Jan. 9, 1980

4. *Result of test*

(1) Surface tesile-strength by surface tension test

(Unit: kg/cm^2)

kinds of brick	Side face		Laid part	
	Not treated	Treated RF–100	Not treated	Treated RF–100
A brick	0.39	0.95	0.15	0.90
B brick	2.04	—	2.08	—
C brick	3.53	13.80	8.15	10.13
D brick	11.46	—	17.40	—

The figure in the above list is the average of three times tests.

(2) Permeant depth and amount of RF–100 into bricks

kinds of brick	Permeant depth		Permeant* Amount
	Side face	Laid part	
A brick	3– 5 mm	3– 5 mm	1.9 kg/cm^2
C brick	5–24	3–10	2.7

* Dilute solution (RF–100: water = 1:1)

(3) Water-resistant test

kinds of brick	Dipped in water 10 min.		Dipped in water 48 hr	
	Not treated	Treated RF–100	Not treated	Treated RF–100
A brick	Swelling Breaking	Cracking	Breaking	Cracking
B brick	Swelling	—	Breaking	—
C brick	Unchanged	Unchanged	Unchanged	Unchanged
D brick	Unchanged	—	Unchanged	—

(4) Weather-resistant test by sunshine weather meter for 24 hours

knids of brick	Not treated	Treated RF–100
A brick	Breaking	Swelling slightly
B brick	Breaking	—
C brick	Unchanged	Unchanged
D brick	Unchanged	—

(5) Abrasion-resistant test by JIS–K–5491

kinds of brick	Not treated	Treated RF–100
A brick	2.35 g	0.70 g
B brick	0.50	—
C brick	0.25	0.05
D brick	0.30	—

The figure in the above list is the weight grams of bricks which abrased by dropping sand to the surface of bricks

5. *Conclusion*

(1) Surface strength of bricks

Both A brick and C brick have very brittle surface. But by painitng and permeating of RF–100 to bricks, the surface of bricks strengthens remarkably.

(2) Permeant depth of RF–100 into bricks

RF–100 permeated deeper in C brick than in A brick. We consider this is the reason why C brick has many micro holes which were caused by burning. And so we consider the permeant depth of RF–100 is sufficient in C brick, but not necessarily sufficient in A brick.

(3) Water-resistance

It is observed when RF–100 is painted and permeated, water-resistance is improved both in A brick and C brick. Especially that of A brick is improved remarkably.

(4) Weather-resitance and abrasion-resistance

It is also observed weather-resistance and abrasion-resistance are improved by painting and permeating of RF–100.