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EXPERIMENTAL EXAMINATIONS ON MANUFACTURE TEMPERATURE OF BURNT CLAY MASONRY UNITS IN HISTORIC MASONRY STRUCTURES FOR ESTABLISHING JUDGMENT STANDARDS OF LONG-TERM PRESERVATIONS

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Abstract

This paper discuss a proposal on the examination methods of a manufacture temperature of burnt clay bricks, obtained from old masonry constructions, for making a judge regarding the preservation possibility. The temperature and mixing water content ratio should be definitely paid attention in making a judgement on whether they are possible to be preserved in a long run in terms of the bricks' quality. Several bricks produced in Meiji and Taisyo era, the typical modernizing periods in Japan, were examined by a series of reburning experiments. Water absorptions before and after reburning were measured, and Mullite formation was confirmed by X-ray diffraction for clarifying the temperature. As a result, this method was proved to be effective from the perspective of durability to identify the present conditions of existing heritage buildings.

Key Words

Burnt clay bricks, reburning, saturated coefficient, preservation possibility,

1 Introduction

In the middle of Meiji era, 1867-1911, the production technique of burnt clay bricks was improved, and with this as a start the full-scale production began in Japan. However, Great Kanto Earthquake on September 1, 1923 made the brick production rate

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decreased. In order to establish a method for the judgement of preservation possibility of the masonry constructions, the nine types of the burnt clay masonry bricks, which included both the existing constructions and the historic ones, such as the world heritage and important Japanese cultural assets, were examined with a reburning method. In light of the results of the water absorption and Mullite identification by using X-ray diffraction, the manufacture temperature was presumed. Furthermore, the durability of the bricks was determined based on their resistance to freeze and thaw.

2 Method

As shown in Table 1, the nine types of the burnet clay bricks, which were obtained from the cultural heritages in Meiji and Taisyo era, the typical modernizing periods in Japan, were examined in a series of reburning experiments, starting at 1000 degrees centigrade with intervals of fifty degrees centigrade. The formation of Mullite started at 1200 degrees centigrade, and it was completed at 1350 degrees centigrade.

Table 1 Specimens

Specimens	Comments
① Kiln (An establishment)	Cast moulding (1883)
② Kiln (Hunter brick)	Press moulding (1889)
③ Kiln (Upper side)	Cast moulding (1883)
④ Kiln (Repaired)	Extrusion moulding (1891)
⑤ Chimney	Extrusion moulding (Imported from German)
⑥ Former Commercial Exhibition Hall 1	Extrusion moulding (South face)
⑦ Former Commercial Exhibition Hall 2	Extrusion moulding (South face)
⑧ Brick 1 (Present commercial for comparison)	Extrusion moulding (Orange colour)
⑨ Brick 2 (Present commercial for comparison)	Extrusion moulding (Red colour)

The experimental procedure is illustrated in Figure1. First, at the stage of reburning, the specimens were burned for three hours until their temperature reached at the predetermined temperature, and then they were kept in the same condition for two hours. At this point, their absolute weights (W_1) were measured. Second, they were soaked in the stationary water of twenty degrees centigrade over 24 hours, and the weight in the water (W_2) and the surface dry weight (W_3) were measured. Third, they were boiled over three hours, and then they were taken out of the water and were cooled down until the temperature went down to the room temperature. Furthermore, the weight in the water and the surface dry weight at this time were measured, which are W_4 and W_5 respectively. Fourth, they were dried up in a chamber with a fan at 110 degrees centigrade until their weight reached back to the absolute dry weight. The weight at this point was considered as W_6. After all this series of processes, X-ray diffraction experiment was conducted.
The massive water absorptions both in the stationary water and the boiled water, the volumetric water absorption and the saturation coefficient were calculated according to the equation shown below.

$$Massive\ water\ absorption\ (stationary\ water) = \frac{W_3 - W_1}{W_1} \times 100 \quad (1)$$

$$Massive\ water\ absorption\ (boiling\ water) = \frac{W_5 - W_1}{W_1} \times 100 \quad (2)$$

$$Volumetric\ water\ absorption\ (stationary\ water) = \frac{W_3 - W_1}{W_3 - W_2} \times 100 \quad (3)$$

$$Volumetric\ water\ absorption\ (boiling\ water) = \frac{W_5 - W_1}{W_5 - W_4} \times 100 \quad (4)$$

$$Saturation\ coefficient = \frac{Volumetric\ water\ absorption\ (stationary\ water)}{Volumetric\ water\ absorption\ (boiling\ water)} \quad (5)$$

W_1: Absolute dry weight
W_2: Weight in stationary water
W_3: Surface dry weight in stationary water
W_4: Weight in boiling water
W_5: Surface dry weight in boiling water
W_6: Absolute dry weight

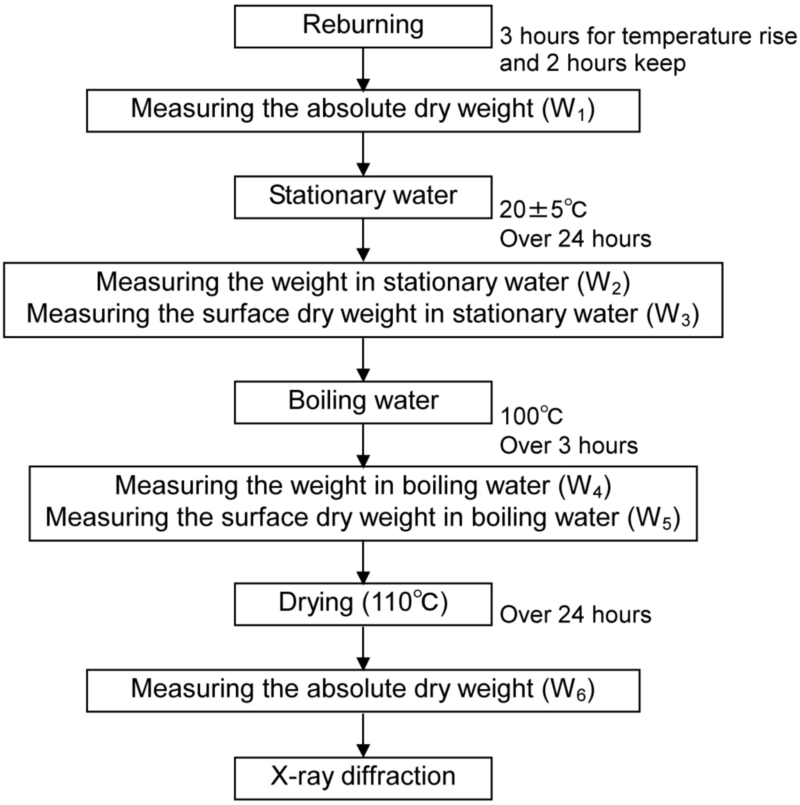

Figure 1 Experimental procedure

3 Results

3.1 Massive and volumetric water absorptions

Figure 2 shows the relationships between the massive water absorption and the individual specimen's temperature before and after reburning. The left column, (a), represents the temperature in the stationary water, and right column, (b), indicates the one in the boiling water. The difference between these two figures is not clearly apparent overall. The absorption levels of Specimen1, 3, 6, 8, and 9 decreased at about 1100 centigrade. For Specimen 2, 5, and 7, their absorption levels started decreasing at around 1000 degrees centigrade. The change of the massive water absorption rate of Specimen 4 was not observed until its temperature reached at about 1200 degrees centigrade, thereafter, its absorption rate was declined.

Figure 3 demonstrates the relationships of the volumetric water absorption. Although the tendencies of the water absorption are nearly identical to Figure2, the differences of the water absorption level of the specimens become clearer in Figure 3.

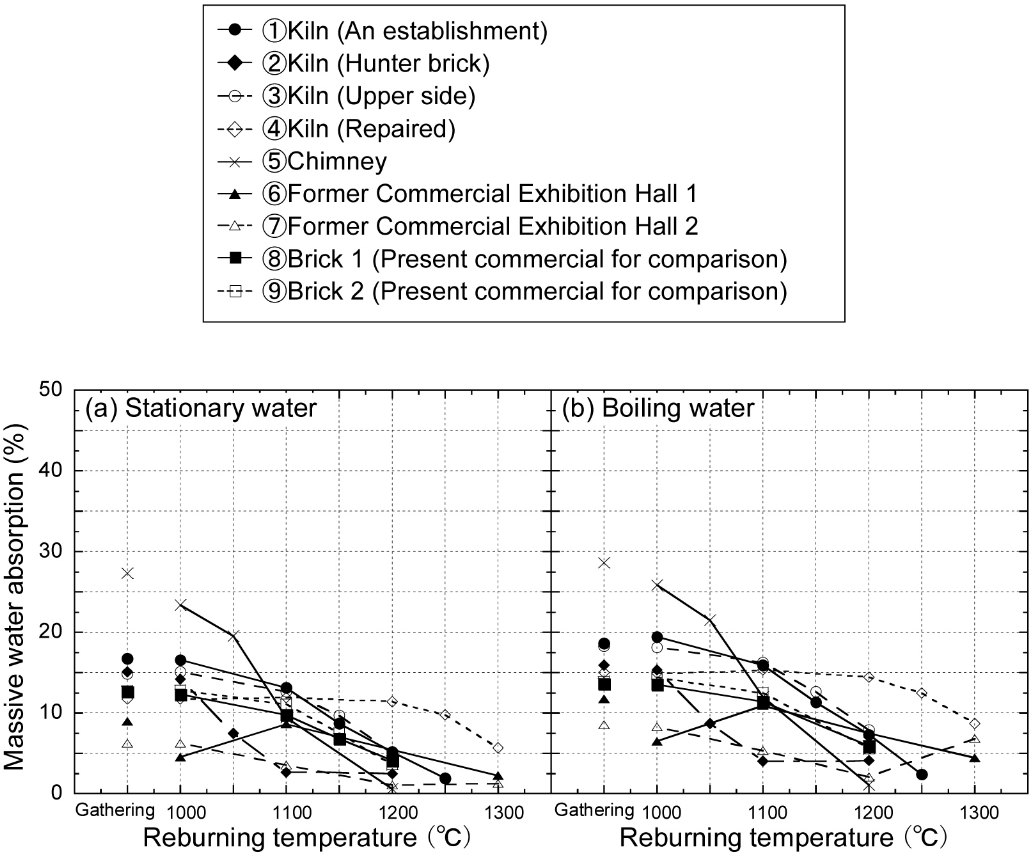

Figure 2 The relationships between reburning temperature and massive water absorption

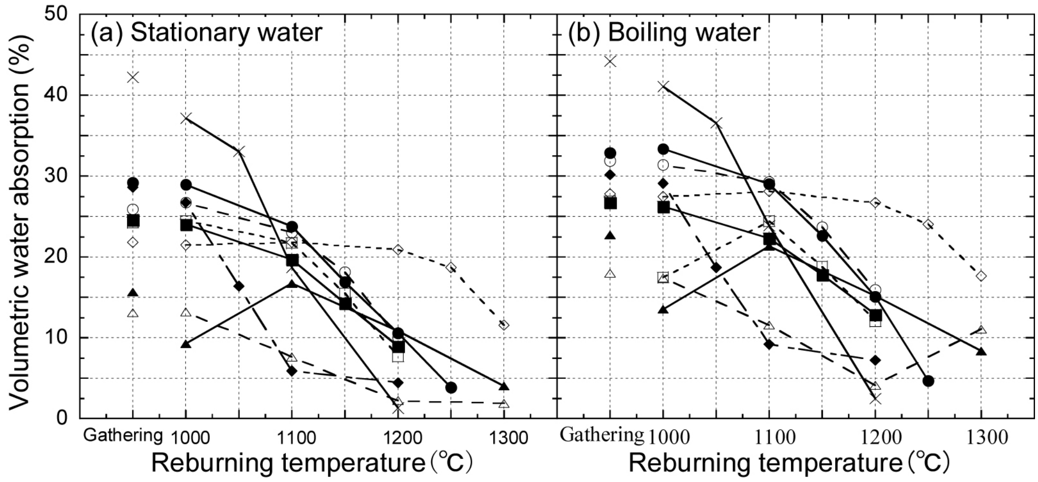

Figure 3 The relationships between reburning temperature and volumetric water absorption

3.2 X-ray diffraction

Figure 4 explains the results of X-ray diffraction for identifying Mullite formation at each reburning temperature. In this study, the diffraction angle16.4 degrees centigrade, which is the second peak of each wave, was used as the proof of Mullite existence, since the first peak of Mullite, 26.2 degrees, overlaps that of silica. Lower waves indicate the diffraction level before reburning, and the upper ones after reburning of the specimens. This figure leads to Table 2. Before burning, Mullite was identified in Specimen 2, 4, and 6, and it was also found in Specimen 1, 3, and 4 after they were burned.

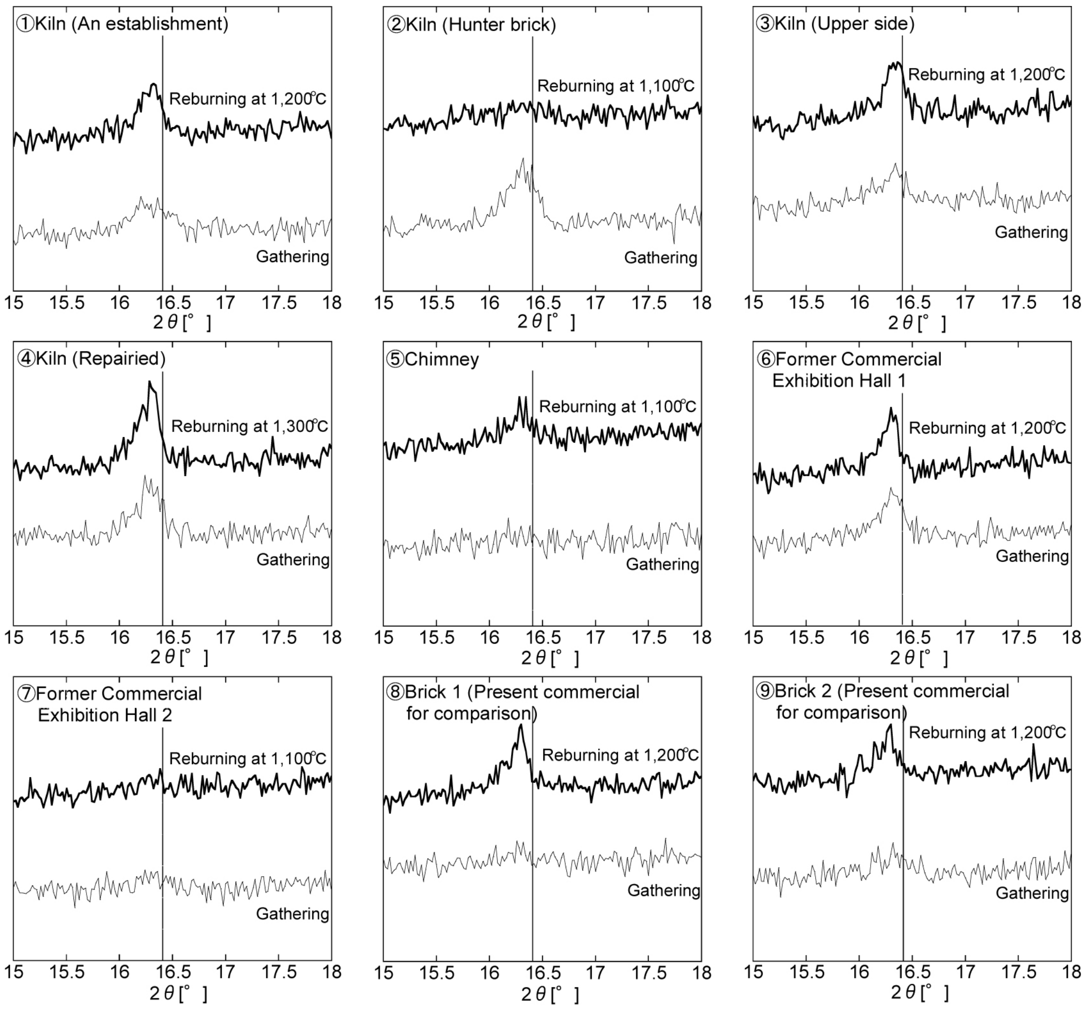

Figure 4 X-ray diffraction of specimens before and after reburning

4 Consideration

The water absorption of the bricks including the burned clay bricks never changed even though they were repeatedly burned under the manufacture temperature. Mullite formation started at about 1000 degrees centigrade, and the volumetric water absorption level became decreased at about 1200 degrees centigrade by scattering crystal water due to exothermic reaction. Based on these facts and reaction processes, the manufacture temperature was presumed.

Table 2 Existence of Mullite by using X-ray diffraction

Specimens	Mullite			
	Gathering	1,100℃	1,200℃	1,300℃
① Kiln (An establishment)	×	—	△	—
② Kiln (Hunter brick)	○	×	—	—
③ Kiln (Upper side)	×	—	△	—
④ Kiln (Repaired)	△	—	—	△
⑤ Chimney	×	×	—	—
⑥ Former Commercial Exhibition Hall 1	△	—	×	—
⑦ Former Commercial Exhibition Hall 2	×	×	—	—
⑧ Brick 1 (Present commercial for comparison)	×	—	×	—
⑨ Brick 2 (Present commercial for comparison)	×	—	×	—

× : Not identified, △: Nearly identified, ○: Identified, —: Immeasurable

4.1 Presumption of the manufacture temperature based on water absorption

Table 3 illustrates the presumption of the manufacture temperature based on the two water absorptions, namely 1) massive and 2) volumetric water absorptions. Although Specimen 1 and 3 were manufactured by a cast moulding method in 1883, the burned temperature of both bricks was about 1100 to 1150 degrees centigrade. This suggests that these specimens were burned firmly. It seems that Specimen 4, whose manufacture method was changed from cast moulding to extrusion one, was burned at around 1250 to 1300 degrees centigrade. This analysis points out the improvement of the brick manufacture technique, moulding and burning. Because Specimen 5 was imported from German so that the brick was expected to be burned at a high temperature and maintain its high quality, the study revealed the fact that the brick was actually burned at about 1000 degrees centigrade, fairly higher than the temperature of the other specimens. Specimen 6, the bricks of the World Heritage in Hiroshima, were burned completely at about 1100 to 1200 degrees centigrade, which is higher than the burned temperature of Specimen 7. Although Specimen 8 and 9 were the ones that are currently manufactured, their burned temperature were approximately the same as the burned temperature of the bricks that were manufactured in 1883. As these bricks were used not for masonry constructions but for gardening, the use of high temperature in producing bricks was presumably not required.

Table 3 Presumed manufacture temperature by two water absorptions (Massive and volumetric)

Specimens	Presumed manufacture temperature
① Kiln (An establishment)	1,100℃～1,150℃
② Kiln (Hunter brick)	1,000℃～1,050℃
③ Kiln (Upper side)	1,100℃～1,150℃
④ Kiln (Repaired)	1,250℃～1,300℃
⑤ Chimney	1,000℃ or under
⑥ Former Commercial Exhibition Hall 1	1,100℃～1,200℃
⑦ Former Commercial Exhibition Hall 2	1,000℃～1,100℃
⑧ Brick 1 (Present commercial for comparison)	1,100℃～1,150℃
⑨ Brick 2 (Present commercial for comparison)	1,100℃～1,150℃

4.2 Presumption of the manufacture temperature based on X-ray diffraction

Table 4 shows the presumption of the manufacture temperature based on the existence of Mullite by using X-ray diffraction. As presented in this table, Specimen 1 seems to have been burned at less than 1200 degrees centigrade. For Specimen 2, Mullite was identified at the gathering stage. However, it was not found at the reburning level with the temperature of 1100 degrees centigrade. The temperature, based on the water absorptions, was less than 1050 degrees centigrade as shown in Table 3 so that the manufacture temperature could not be detected because of these two contradictory facts. For Specimen 4, Mullite was found at the gathering stage as well as at 1300 degrees centigrade; thus, its manufacture temperature was presumed at over 1200 degrees centigrade. As Mullite could not be identified in Specimen 5, the brick might have been manufactured under the condition of the temperature at 1200 degrees centigrade. As for Specimen 6, the temperature could not be estimated because Mullite was identified not in the reburned brick burned at 1200 degrees centigrade, but in the brick at the gathering level. For Specimen 7, 8, and 9, the temperature might have been less than 1200 degrees centigrade because Mullite could not be identified.

Table 4 Presumed manufacture temperature by using X-ray diffraction

Specimens	Presumed manufacture temperature
① Kiln (An establishment)	1,200℃ or under
② Kiln (Hunter brick)	Unidentifiable
③ Kiln (Upper side)	1,200℃ or under
④ Kiln (Repaired)	1,200℃ or over
⑤ Chimney	1,200℃ or under
⑥ Former Commercial Exhibition Hall 1	Unidentifiable
⑦ Former Commercial Exhibition Hall 2	1,200℃ or under
⑧ Brick 1 (Present commercial for comparison)	1,200℃ or under
⑨ Brick 2 (Present commercial for comparison)	1,200℃ or under

4.3 Freezing and thawing resistance of the bricks

Table 5 shows the saturation coefficients at the gathering stage with the temperature of over fifty degrees centigrade, which is higher than the presumed manufacture one, for clarifying the coefficient status by reburning the specimens more precisely. Figure 5 also explains the characteristics of the bricks' resistance to their freeze and thaw according to the relations between the boiling water absorption and the saturation coefficient before and after reburning process; specimens under the inclined solid line in this figure are prominent for the long-term preservation of bricks. Almost all specimens but Specimen 4, 6, and 7 before reburning appeared over the line illustrated in the figure, and those after reburning turned out to stay under it. From this figure, Specimen 4, 6, and 7 were confirmed to be efficient for long-term preservation.

5 Conclusions

In order to establish judgment standards for the long-term preservations of the historic masonry structures consisted of the burnt clay masonry units, the nine types of burned clay bricks, some were manufactured in 1883 and some lately, were reburned at upper 1300 degrees centigrade. Based on the two types of water absorptions and the existence of Mullite by using X-ray diffraction, the manufacture temperature were presumed. As a result, the following findings were obtained.

1) The bricks of kiln (an establishment) manufactured in 1883, were burned at about 1150 degrees centigrade. Therefore, this empirically validates that the manufacturers then succeeded in devising to produce climbing kilns with the burning temperature as high as possible.

Table 5 Saturation coefficient before and after reburning

Specimens	Gathering	Reburning (Reburning temperature)
① Kiln (An establishment)	0.888	0.702 (1,200℃)
② Kiln (Hunter brick)	0.947	0.641 (1,100℃)
③ Kiln (Upper side)	0.812	0.629 (1,200℃)
④ Kiln (Repaired)	0.784	0.659 (1,300℃)
⑤ Chimney	0.955	0.903 (1,000℃)
⑥ Former Commercial Exhibition Hall 1	0.692	0.476 (1,300℃)
⑦ Former Commercial Exhibition Hall 2	0.728	0.537 (1,200℃)
⑧ Brick 1 (Present commercial for comparison)	0.921	0.690 (1,200℃)
⑨ Brick 2 (Present commercial for comparison)	0.903	0.636 (1,200℃)

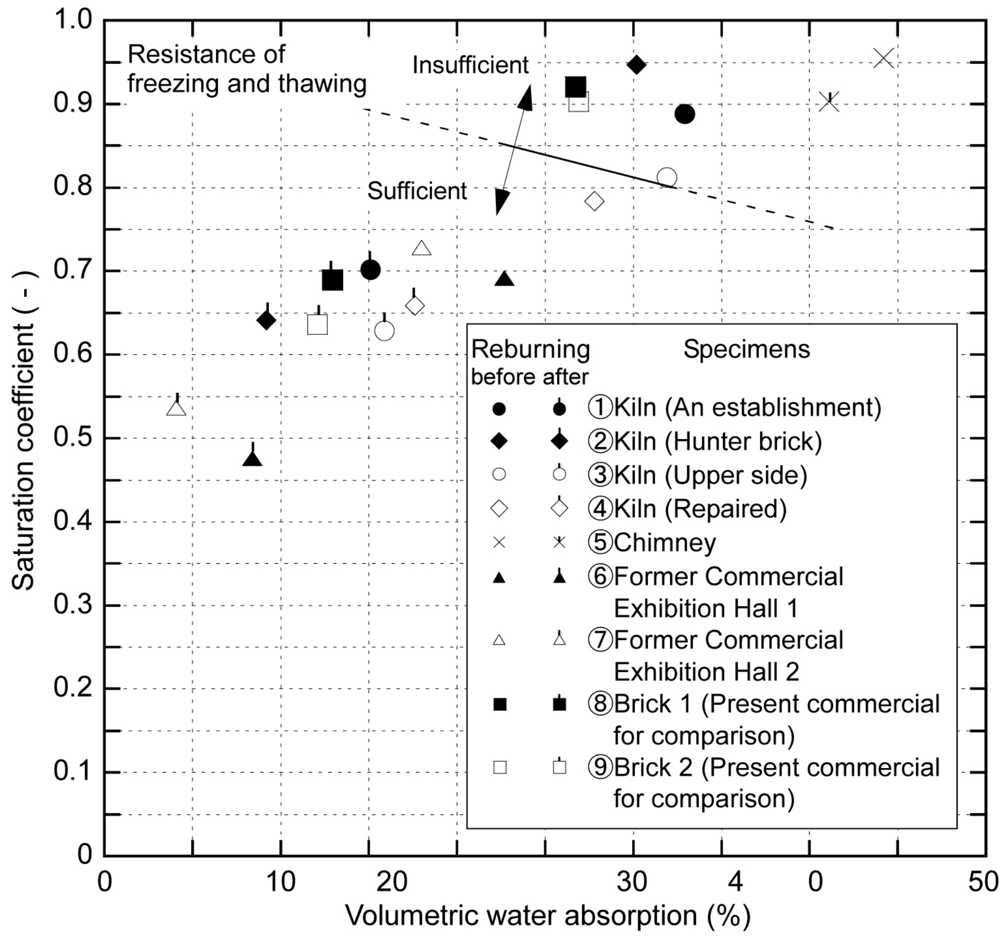

Figure 5 Characteristics against freeze and thaw before and after reburning

2) As the moulding method was changed from cast moulding into extrusion one, the burning temperature of the bricks of the kiln in 1981 (the repaired one) increased up to 1250 degrees centigrade.
3) The production temperature of the bricks of the chimney imported from German was comparatively low, and it appeared not to have much tolerance to the freeze and thaw.
4) The bricks of a former commercial exhibition Hall were burned at about 1150 degrees centigrade. It was asserted that these bricks were proficient at the resistance against freezing and thawing.

It was confirmed that the presumption of the burning temperature of the manufactures throughout the process of reburning and X-ray diffraction was evidently useful for establishing the prospect of preservation possibility and also judgment standards of the masonry constructions including historic heritages.

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