STUDIES ON THE SETTING PHENOMENA OF THE PLASTER (PART V)
SETTING OF THE PLASTER WHEN MIXED WITH 0.1 N NH₄OH

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INTRODUCTION

In the authors' report of Part III¹ and Part IV², the setting of plaster when it was mixed by the acidic solutions of 0.1 N HCl and 0.1 N CH₃COOH were practiced.

In this report, the authors wish to report the case when 0.1 N NH₄OH was employed to give alkaline environment, and the experiment was practiced just as similarly as exercised in the earlier reports¹²³).

RESULTS OF EXPERIMENT

I. Setting in 21°C

1) In case of W/P=80/100

Fig. 1 shows the results of the experiment.

The peak of temperature curve appeared in 27 minutes, and the hardness curve reached each Iₕ, IIₕ and IIIₕ in 15, 33 and 39 minutes, otherwise pH curve showed a rapid descending from alkaline zone to the acidic until it represented 4.8 in 33 minutes, and then it continued almost like value up to about 45 minutes when it began ascending.

2) In case of W/P=90/100

The peak of temperature curve appeared in 30 minutes, and the hardness curve reached each Iₕ, IIₕ and IIIₕ in 18, 33 and 39 minutes, otherwise pH curve showed a rapid descending from alkaline to acidic until it reached 4.5 in 30 minutes, and it continued the like value up to about 45 minutes when it began ascending.

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3) In case of $W/P=100/100$

The peak of temperature curve appeared in 33 minutes, and the hardness curve reached each $I_a$, $II_a$ and $III_a$ in 24, 37 and 39 minutes, otherwise pH curve showed a rapid descending from alkaline to acidic until it reached 4.5 in 30 minutes, and then it continued the like value up to about 48 minutes when it began ascending.

II. Setting in 24°C

1) In case of $W/P=80/100$

The peak of temperature curve appeared in 19.5 minutes, and the hardness curve reached each $I_a$, $II_a$ and $III_a$ in 12, 21 and 24 minutes, otherwise pH curve showed a rapid descending from alkaline to acidic until it reached about 5.5 in 21 minutes, and then it continued the like value up to about 27 minutes when it began ascending.

2) In case of $W/P=90/100$

The peak of temperature appeared in 25 minutes, and the hardness curve reached each $I_a$, $II_a$ and $III_a$ in 15, 24 and 30 minutes, otherwise pH curve showed a rapid descending from alkaline to acidic until it reached 5.6 in 28 minutes, and then it continued the like value up to about 33 minutes when it began ascending.

3) In case of $W/P=100/100$

The peak of temperature curve appeared in 27 minutes, and the hardness curve reached each $I_a$, $II_a$ and $III_a$ in 21, 27 and 30 minutes, otherwise pH curve showed a rapid descending from alkaline to acidic until it reached 5.2 in 30 minutes, and then it continued the like value up to about 39 minutes when it began ascending.

III. Setting in 27°C

1) In case of $W/P=80/100$

The peak of temperature curve appeared in 25 minutes, and the hardness curve reached each $I_a$, $II_a$ and $III_a$ in 15, 21 and 27 minutes, otherwise pH curve showed about 9.6 in 3 minutes, and then it showed a little descending gradually.

2) In case of $W/P=90/100$

The peak of temperature curve appeared in 31 minutes, and the hardness curve reached each $I_a$, $II_a$ and $III_a$ in 18, 27 and 33 minutes, otherwise pH curve became about 9.4 in 3 minutes and then showed a little descending.

3) In case of $W/P=100/100$

The peak of temperature curve appeared in 34 minutes, and the hardness curve reached each $I_a$, $II_a$ and $III_a$ in 24, 30 and 33 minutes, otherwise pH curve showed about 9.3 in 3 minutes and then represented a little descending, showing more or less fluctuation.
IV. Setting in 30°C

1) In case of W/P=80/100

The peak of temperature curve appeared in 17 minutes, and the hardness curve reached each \( I_a, II_a \) and \( III_a \) in 6, 15 and 18 minutes, otherwise pH curve showed 9.8 in 3 minutes and then represented a little descending.

The peak of temperature curve appeared in 14 minutes, and the hardness curve reached each \( I_b, II_b \) and \( III_b \) in 6, 12 and 15 minutes, otherwise pH curve showed about 10 in 3 minutes and then represented a little descending to about 9.6 and kept almost constant value thereafter.

2) In case of W/P=100/100

The peak of temperature curve appeared in 21 minutes, and the hardness curve reached each \( I_a, II_a \) and \( III_a \) in 12, 21 and 24 minutes, otherwise pH curve reached about 10.2 in 3 minutes and then represented a linear descending to 9.7 from 18 to 21 minutes, and became constant thereafter.

**DISCUSSION AND SUMMARY**

I. Discussions about the effect of water powder ratio on temperature, pH and hardness curves

1) Temperature, pH and hardness curves in 21°C

Fig. 2 illustrates the change of temperature curve corresponding to the change of water powder ratio.

It was understood from the figure that the time of reaching the peak of temperature curve was delayed and the height was lowered corresponding to the increasing of water powder ratio.

Fig. 3 illustrates the change of pH curve corresponding to the change of water powder ratio.

It was understood from the figure that, in every case, pH curve showed a rapid descending from alkaline to acidic until it reached about 4.8 during about 27 minutes, and then it showed almost constant value meanwhile up to the time when it began ascending.

Fig. 4 illustrates the change of hardness curve corresponding to the change of water powder ratio.

It was understood that the larger the water powder ratio became, the later the time of reaching the peak and the lower the maximum value of the hardness appeared.

2) Temperature, pH and hardness curves in 24°C

Fig. 5 illustrates the change of temperature curve corresponding to the change of water powder ratio.
It was understood from the figure that, corresponding to the increasing of the water powder ratio, the time of reaching the peak was delayed and the peak angle being made by the coincidence between ascending and descending curves was enlarged.

Fig. 6 illustrates the change of pH curve corresponding to the change of water powder ratio.

It was understood from the figure that, in any case, the curve showed a rapid descending from alkaline to acidic during about 30 minutes, and then it changed to ascending. It was also understood that the more the water powder ratio became, the longer represented the time of descending.

Fig. 7 illustrates the change of hardness curve corresponding to the change of water powder ratio.

It was understood that the more the water powder ratio became, the slower the time of setting and the lower the maximum of hardness appeared.

3) Temperature, pH and hardness curves in 27°C

Fig. 8 illustrates the change of temperature curve corresponding to the change of water powder ratio.

It was understood from the figure that, in the beginning, a descending was observed during about 12 minutes, and then it changed to a rapid ascending until it reached the peak.

The above phenomenon was observed in the preceding cases of 21°C and 24°C, but it was not occurred in cases of the mixing solutions of water, 0.1 N HCl and 0.1 N CH₃COOH.

It was also understood that the more the water powder ratio became, the later and the lower the peak appeared.

Fig. 9 illustrates the change of pH curve corresponding to the change of water powder ratio.

It was understood that this case showed quite different curve in comparison with the cases of 21°C nad 24°C, namely it showed a little descending during about 8 minutes until it reached about 9.5 and then represented very slow descending thereafter.

As was clearly understood by the earlier reports¹⁾²⁾³⁾, setting of plaster showed a strange boundary in the temperature neighbouring 27°C. The authors found here, too, the above phenomenon by measuring the change of pH value during setting.

Fig. 10 illustrates the change of hardness curve corresponding to the change of water powder ratio.

It was understood from the figure that a quick setting and a larger hardness were observed in case of W/P=80/100 in comparison with the cases of W/P=90/100 and W/P=100/100, but in the latter cases, a definite difference was not observed in setting rate.
4) Temperature, pH and hardness curves in 30°C

Fig. 11 illustrates the change of temperature curve corresponding to the change of water powder ratio.

It was understood that a distinguished delaying effect was observed in case of W/P=100/100 in comparison with cases of W/P=80/100 and W/P=90/100.

Fig. 12 illustrates the change of pH curve corresponding to the change of water powder ratio.

It was understood from the figure that it showed almost similar curve despite of the change of water powder ratio, namely it showed a little descending until it reached about 10 in 3 minutes, and then represented a slow descending.

Fig. 13 illustrates the change of hardness curve corresponding to the change of water powder ratio.

It was understood from the figure that a distinguished delaying was observed in case of W/P=100/100 and a larger difference was not recognized in the other cases.

II. Relationship between pH and hardness curves

Fig. 14, Fig. 15 and Fig. 16 illustrate the relationship between pH and hardness curves corresponding to each water powder ratio of W/P=80/100, W/P=90/100 and W/P=100/100.

According to those figures, it was definite that pH curve represented quite different type in the higher temperature of 27°C in comparison with the case within the lower zone of the same temperature, namely in the former, the pH curve showed a little descending and then it showed almost constant value in the alkaline domain, but in the latter, the pH curve showed a rapid descending from alkaline to the acidic, showing at least neutral just in the corresponding time of Ia and completely acidic in the corresponding time of IIa, being lowered gradually, and it showed thereafter a tendency of ascending.

III. Relationship among water powder ratio, Ia, IIa, IIIa, the peak of temperature curve and the minimum of pH curve

Fig. 17, Fig. 18, Fig. 19 and Fig. 20 illustrates the relationship among water powder ratio, Ia, IIa, IIIa, the peak of temperature curve and the minimum of pH curve.

Following items of comprehension were reached from the above results.

(i) In the temperature of 21°C and 24°C, Ia, IIa, IIIa, the peak of temperature curve and the minimum of the pH curve were all delayed almost proportionally corresponding to the increasing of water powder ratio.

(ii) In the temperature of 27°C, the more the water powder ratio
became, the later represented the peak of temperature despite of the reverse tendency in the minimum of pH curve, otherwise \( \Pi_h \) and \( \Pi^*_h \) were superposed each other in cases of \( W/P=90/100 \) and \( W/P=100/100 \).

(iii) In the temperature of 30\(^\circ\)C, the setting rate was appeared quickest when water powder ratio was 90/100.

IV. Relationship among water powder ratio, surrounding temperature, \( I_h \), \( \Pi_h \), and \( \Pi^*_h \)

Fig. 21, Fig. 22 and Fig. 23 illustrate the relationship among water powder ratio, surrounding temperature, \( I_h \), \( \Pi_h \) and \( \Pi^*_h \).

Following items of comprehension were reached from the above results.

(i) The time necessitated to reach \( I_h \) was almost like in 21\(^\circ\)C and 27\(^\circ\)C, and a little quickened in 24\(^\circ\)C, and very quickened in 30\(^\circ\)C.

(ii) The time necessitated to reach \( \Pi_h \) was remarkably delayed in 27\(^\circ\)C in comparison with the cases of the higher and the lower temperature.

(iii) The tendency revealed in \( \Pi_h \) was almost brought to the case of \( \Pi^*_h \).

V. Discussions about the relationship among \( I_h \), \( \Pi_h \) and \( I,\Pi_h \)

Fig. 24, Fig. 25, Fig. 26 and Fig. 27 illustrate the relationship among \( I_h \), \( \Pi_h \) and \( \Pi^*_h \).

Following items of comprehension were reached from the above results.

(i) In the temperature of 21\(^\circ\)C and 24\(^\circ\)C, \( I_h \), \( \Pi_h \) and \( \Pi^*_h \) curves were changed almost parallely corresponding to the change of water powder ratio, but \( I_h \) was remarkably delayed corresponding to the increasing of water powder ratio, even though it was recovered in the point of \( \Pi_h \).

(ii) In the temperature of 27\(^\circ\)C, the delaying effect was distinguished in case of \( W/P=90/100 \), and this delaying was brought to the final of \( \Pi^*_h \).

(iii) In the temperature of 30\(^\circ\)C, each point of \( I_h \), \( \Pi_h \) and \( \Pi^*_h \) was remarkably quickened.

VI. Relationship between setting rate and surrounding temperature

Fig. 28, Fig. 29 and Fig. 30 illustrate the relationship between the setting rate and the surrounding temperature.

Following items of comprehension were reached from the above results.

(i) Setting rate was remarkably delayed in 27\(^\circ\)C.

(ii) In such temperature as 24\(^\circ\)C and 30\(^\circ\)C which were located near to the boundary temperature of 27\(^\circ\)C, the setting rate was rather quickened.

VII. Relationship among surrounding temperature, \( I_h \), \( \Pi_h \), \( \Pi^*_h \), peak of temperature curve and minimum of pH curve

Fig. 31, Fig. 32 and Fig. 33 illustrate the relationship existing among surrounding temperature, \( I_h \), \( \Pi_h \), \( \Pi^*_h \), peak of temperature curve and minimum of pH curve.

Following items of comprehension were reached from the above results.
(i) In the temperature of 27°C, the minimum of pH curve was remarkably delayed.

(ii) When the water powder ratio became larger, the above effect was also brought to the peak of temperature curve.

(iii) In general, the delaying effect was brought to all results of measurement.

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Fig. 1. Setting Diagram.
W/P: 80/100
Temperature: 21℃

Fig. 2. Temperature-Time Diagram
W/P: 80/100
Temperature: 21℃

Fig. 3. pH-Time Diagram.
Temperature: 21℃

Fig. 4. Hardness-Time Diagram.
Temperature: 21℃

Fig. 5. Temperature-Time Diagram.
Temperature: 24℃

Fig. 6. pH-Time Diagram.
Temperature: 24℃
Fig. 7. Hardness-Time Diagram.  
Temperature: 24°C

Fig. 8. Temperature-Time Diagram.  
Temperature: 27°C

Fig. 9. pH-Time Diagram.  
Temperature: 27°C

Fig. 10. Hardness-Time Diagram.  
Temperature: 27°C

Fig. 11. Temperature-Time Diagram.  
Temperature: 30°C

Fig. 12. pH-Time Diagram.  
Temperature: 30°C
Fig. 13. Hardness-Time Diagram. Temperature: 30°C

Fig. 14. Effect of Temperature on pH-Time and Hardness-Time Diagram. W/P: 80/100

Fig. 15. Effect of Temperature on pH-Time and Hardness-Time Diagram. W/P: 90/100

Fig. 16. Effect of Temperature of pH-Time and Hardness-Time Diagram. W/P: 100/100

Fig. 17. I₁, I₁₁, and I₁₈ corresponding to each Water-Powder Ratio. Temperature: 21°C
1: Time of maximum temperature
2: Time of minimum pH

Fig. 18. I₁, I₁₁, and I₁₈ corresponding to each Water-Powder Ratio. Temperature: 24°C
1: Time of maximum temperature
2: Time of minimum pH
Fig. 19. $I_n$, $I_b$, and $I_{III}$ corresponding to each Water-Powder Ratio.
Temperature: 27°C
1; Time of maximum temperature
2; Time of minimum pH

Fig. 20. $I_n$, $I_b$, and $I_{III}$ corresponding to each Water-Powder Ratio.
Temperature: 27°C
1; Time of maximum temperature
2; Time of minimum pH

Fig. 21. Relationship between $I_b$ and Water-Powder Ratio.

Fig. 22. Relationship between $I_b$ and Water-Powder Ratio.

Fig. 23. Relationship between $I_{III}$ and Water-Powder Ratio.

Fig. 24. Relationship among $I_n$, $I_b$, and $I_{III}$.
Temperature: 21°C
Fig. 25. Relationship among $I_h$, $I_{h1}$ and $I_{h2}$.
Temperature: 24°C

Fig. 26. Relationship among $I_h$, $I_{h1}$ and $I_{h2}$.
Temperature: 27°C

Fig. 27. Relationship among $I_h$, $I_{h1}$ and $I_{h2}$.
Temperature: 30°C

Fig. 28. Relationship between Hardness and Surrounding Temperature.
W/P: 80/100

Fig. 29. Relationship between Hardness and Surrounding Temperature.
W/P: 90/100

Fig. 30. Relationship between Hardness and Surrounding Temperature.
W/P: 100/100
Fig. 31. $I_h$, $I_{II_h}$ and $I_{III_h}$ corresponding to each surrounding temperature.

$W/P; 80/100$

1; Time of maximum temperature

2; Time of minimum pH

Fig. 32. $I_h$, $I_{II_h}$ and $I_{III_h}$ corresponding to each surrounding temperature.

$W/P; 90/100$

1; Time of maximum temperature

2; Time of minimum pH

Fig. 33. $I_h$, $I_{II_h}$ and $I_{III_h}$ corresponding to each surrounding temperature.

$W/P; 100/100$

1; Time of maximum temperature

2; Time of minimum pH