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Effect of buffers on gypsum particleboard properties

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Abstract The paper recounts how buffers affect the physical and mechanical properties of gypsum particleboard (GPB) and the initial curing time (IC) of gypsum. The acidic buffers were better than alkaline buffers for prolonging the IC of gypsum and affecting the properties of GPB. Weak acids were advantageous for curing gypsum. When suitable amounts of citric acid and trisodium citrate were added, high performances could be achieved and the IC of gypsum could be prolonged to about 2h. When alkaline buffers such as sodium carbonate were added, the IC of gypsum was still short but the internal bond strength (IB), modulus of elasticity (MOE), and modulus of rupture (MOR) of GPB were obviously decreased. Citric acid was the best among the four buffers used; and the GPB had a good IB, MOE, MOR, and adequate IC when citric acid of $\leq 0.1\%$ was added. Sodium carbonate was not suitable owing to low performance and short IC. Gypsum curing is an endothermic reaction.

Key words Gypsum particleboard · Citric acid · Trisodium citrate · Sodium tetraborate decahydrate · Sodium carbonate

Introduction

Semidry gypsum particleboard (GPB) manufacture was devised by Professor Kossalz at the Fraumhofer Wood Science and Technical Research Institute in Germany in 1982.[1] GPB is a good building construction material, as it has no formaldehyde emission; it also has high fire-retardant properties, good sound-insulating and absorbing abilities, and lower friability than gypsum board. During production the wood particles are not dried, and GPB is pressed in the cold condition, so there is less consumption of thermal energy. The effect of tannin on gypsum curing is low in most wood species.[2] As a consequence, GPB can be produced using most wood species.[3] Natural and chemical gypsum can be used to produce GPB.[4]

Because GPB is a new product, much research work is required to clarify its properties. Above all, the effects of adding various buffers and their quantity on the physical and mechanical properties of GPB and the initial curing time of gypsum must be investigated. During production of GPB, a buffer must be added to adjust the initial curing time (IC) of gypsum to meet the manufacturing technological demands. Moreover, it is necessary to improve the properties[5] of GPB because its properties are inferior to those of wood particleboard and cement particleboard.

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Materials and methods

Test materials

The gypsum used was building gypsum (GB9776[6] is similar to JIS R9111[7]) obtained from a gypsum manufacturer (Sichuan Province, P. R. China); the wood particles (masson pine) were obtained from a particleboard manufacturer (Chu Zhou, P. R. China). The proportions of screen analysis (S) of particles (opening) were 10.1% in $S < 0.71$ mm, 10.9% in $0.71\,mm < S < 1.00$ mm, 15.2% in $1.00\,mm < S < 1.40$ mm, 35.7% in $1.40\,mm < S < 2.00$ mm, and 28.1% in $2.00\,mm < S$, respectively. For the buffers, four chemicals (chemically pure) were applied during the test: citric acid ($C_6H_8O_7$), trisodium citrate dihydrate ($C_6H_5O_7Na_3{\cdot}2H_2O$), sodium tetraborate decahydrate ($Na_2B_4O_7{\cdot}10H_2O$), and sodium carbonate (Na_3CO_3).

Production method and conditions of GPB

Each material was weighed at a wood/gypsum ratio of 0.25 and a water/gypsum ratio of 0.35 in the laboratory.[8,9] The particles were put in a blender, and then water containing one of the buffers was added to the blender. After mixing the particles and water for about 2 min, gypsum was added. Sample boards of 10 × 400 × 400 mm were formed. The sample boards had a target density of 1.20 g/cm^3, and 15 levels of buffer content were produced in the laboratory.

All mats were pressed at 3 MPa in a cold press for 4 h. The moisture contents of GPB mats were reduced to about 2%–3% at 45°C in a dryer. After being removed from the dryer, the mats were stored at room temperature for a week. The physical and mechanical properties of GPB were measured according to Japanese Industrial Standard (JIS) A5908.[10] The data for the physical and mechanical properties are the average of eight specimens.

The initial curing time (IC), defined as the time until the gypsum started to cure after water was placed in the gypsum, was measured according to Deutsches Institute für Normung (DIN[11]) 1168. The particles, water, and gypsum were treated at constant temperature and humidity for 1 day. The materials were mixed at the same wood/gypsum and water/gypsum ratios as noted above.

The exothermic and endothermic reactions were analyzed when gypsum was cured in a thermal analysis meter adding 0.05%, 0.1%, and 0.3% citric acid. The initial and terminal temperatures for this test were 20°C and 150°C, respectively. The temperature was increased at a rate of 2°C/min.

Aging tests[12] including thickness swelling (TS), internal bond strength (IB), modulus of rupture (MOR), and modulus of elasticity (MOE) were done in citric acid contents of 0.05% and 0.1% and without citric acid. The specimens used to determine the effect of adding citric acid on the properties of GPB were divided into four groups. The IB, MOE, and MOR of the first group were measured directly. The other three groups were all treated prior to measurement of TS, IB, MOE, and MOR. The treatment methods were as follows. The specimens of the second group were soaked in water (20°C) for 24 h and then oven-dried. The specimens of the third group were soaked in water (70°C) for 24 h and then oven-dried after they had undergone the same treatment as the second group. The specimens of the fourth group were boiled in water (100°C) for 4 h and then oven-dried after they had undergone the same treatment as the third group.

The reduction ratios (K) of IB, MOR, and MOE for treated and untreated specimens were calculated using the following formula.

$$K = \left(1 - \frac{Z_x}{Z_i}\right) \times 100\,(\%)$$

where Z_i represents the IB, MOR, and MOE without treatment; and Z_x is each value of these properties after treatment under the various conditions.

Results and discussion

Effect of sodium tetraborate decahydrate on GPB properties and IC of gypsum

Adding sodium tetraborate decahydrate (borax) has an effect on the physical and mechanical properties of GPB and the IC of gypsum as shown in Figs. 1–4 and Table 1. When the sodium tetraborate decahydrate added was ≤1.0%, the IC was still short, being 26.5 min. Addition of >1.0% sodium tetraborate decahydrate brought the IC of gypsum up to manufacturing technological demands (about 2 h). The reduction of IB, MOR, and MOE, and the increase in TS of GPB were present at any concentration added.

The reduction of these properties may result from the alkalinity of sodium tetraborate decahydrate. As expected, the higher the sodium tetraborate decahydrate content, the stronger the alkalinity. The strong alkalinity influences the bonding strength because the gypsum cures under weakly acidic conditions. The results of this study clearly show that the IB, MOR, and MOE of GPB were reduced with an increase in sodium tetraborate decahydrate content. Though the addition of 1.5% sodium tetraborate decahydrate can prolong the IC to 101 min, the properties of the boards were obviously reduced. As stated above, sodium tetraborate decahydrate is considered an inferior buffer.

Effect of sodium carbonate on GPB properties and IC of gypsum

When the sodium carbonate was added, the IC of gypsum was still short, but the mechanical properties of GPB were

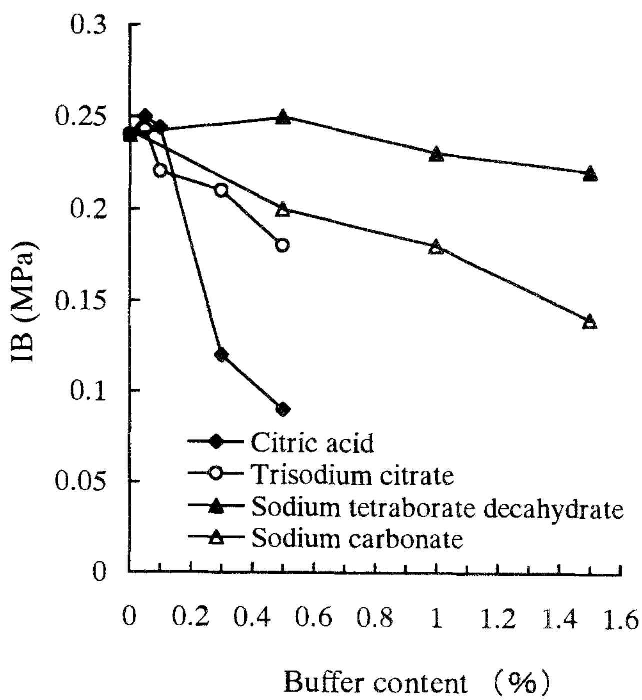

Fig. 1. Effect of buffer content on internal bond strength (*IB*)

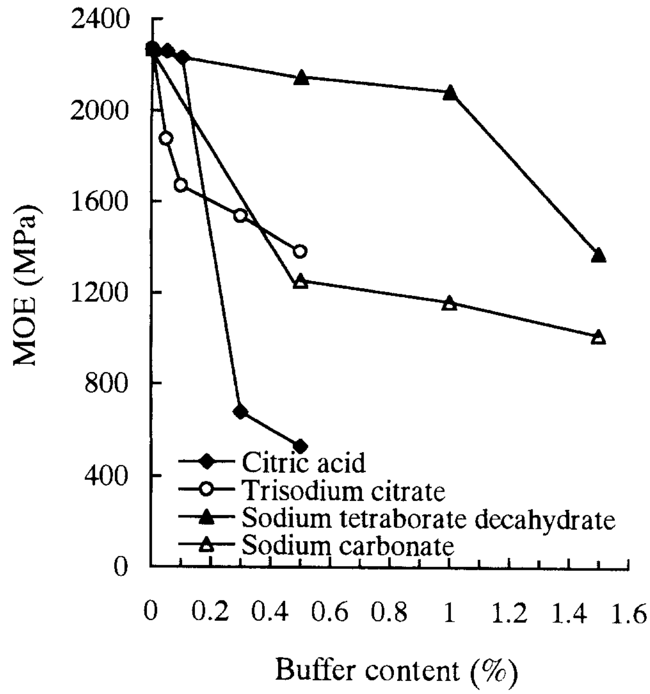

Fig. 2. Effect of buffer content on the modulus of elasticity (*MOE*)

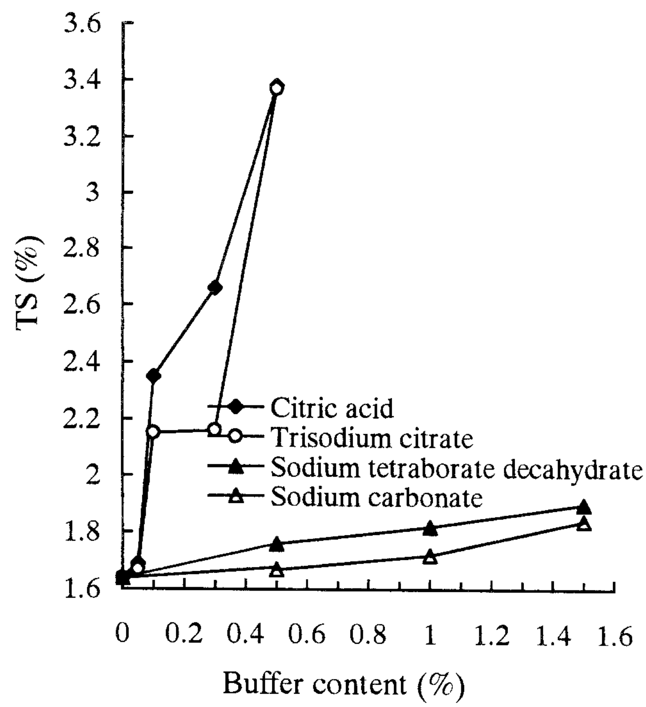

Fig. 4. Effect of buffer content on thickness swelling (*TS*)

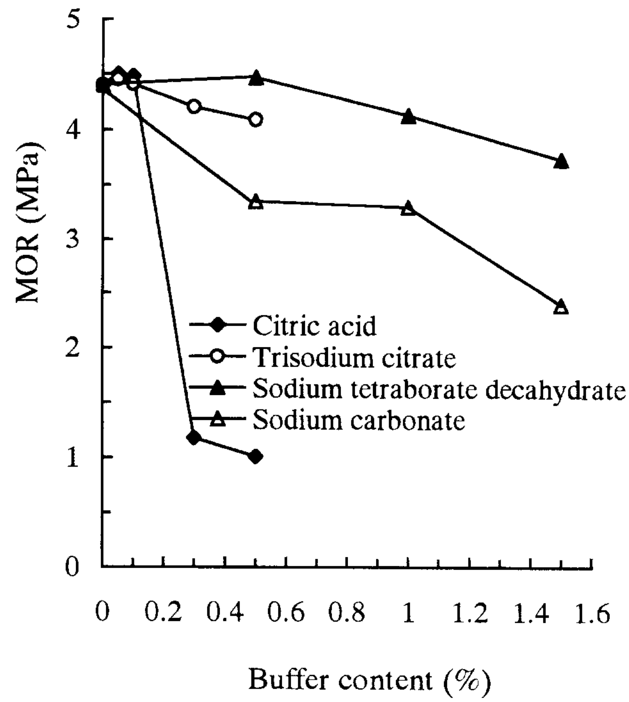

Fig. 3. Effect of buffer content on the modulus of rupture (*MOR*)

Table 1. Relations between the quantity of added buffers and the initial curing time

Condition	Initial curing time (min)
No addition	10.25
Sodium tetraborate decahydrate	
0.5%	10.5
1.0%	26.5
1.5%	101.0
Sodium carbonate	
0.5%	16.1
1.0%	17.2
1.5%	18.0
Citric acid	
0.05%	100.0
0.10%	145.0
0.30%	350.0
0.50%	>1080.0
Trisodium citrate	
0.05%	110.0
0.10%	156.0
0.30%	480.0
0.50%	>1080.0

obviously reduced (Figs. 1–3; Table 1). One possible reason for this phenomenon is that sodium carbonate has stronger alkalinity than sodium tetraborate decahydrate. The alkalinity of the solution increases with an increase in the sodium carbonate content. Strong alkalinity reduces the wood strength and bonding strength of gypsum because the gypsum cures in weakly acidic conditions.

It was shown that the sodium carbonate-treated boards taken from a cold press had a larger rebound ratio and lower density than the boards without the added sodium carbonate. The low bonding strength reduced the mechanical properties of the board. For this reason, similar trends were found for the MOE and MOR. Table 1 reveals that the IC was not prolonged by adding sodium carbonate. The IC was prolonged only about 8 min after adding 1.5% sodium carbonate compared to that with no addition. According to the test results, sodium carbonate is unsuitable as a buffer because the IC of gypsum requires about 2h for the manufacturing technology of GPB, and the mechanical properties of GPB were reduced.

Effect of citric acid on GPB properties and IC of gypsum

The effect of adding citric acid on the physical and mechanical properties of GPB and the IC of gypsum are obvious (Figs. 1–4; Table 1). The IC was prolonged from about 10min to 100min when 0.05% citric acid was added. When ≤ 0.1% citric acid is added, it causes the IC of gypsum to meet manufacturing demands (about 2h). The IC of gypsum was prolonged to 350–1080min after adding > 0.1% citric acid. It can be seen that the mixture of particles and gypsum did not bond tightly, and the rebound ratio of boards removed from a cold press became higher. Therefore, the thickness of the boards increased and their density decreased. The reduction of mechanical properties and the increase in TS are shown in Figs. 1–4.

As expected, the pH value of an aqueous solution was reduced by increasing the content of citric acid. Strong acidity influences the gypsum bonding strength, reducing the particle strength in high concentrations of citric acid. The weak acid is of benefit to the bonding strength of gypsum. This test has shown that the reduction in IB, MOE, and MOR and the increase in TS were obvious under the 0.5% citric acid condition. In contrast, the physical and mechanical properties of GPB were the greatest in the presence of 0.05% and 0.1% citric acid. The results indicated that ≤ 0.1% citric acid was suitable for use as a buffer for GPB. The IB, MOR, MOE, and TS of citric acid-treated boards were most advantageous and the IC of gypsum could be prolonged to about 2h. Therefore, citric acid is a good buffer when an appropriate amount is added.

Effect of trisodium citrate on GPB properties and IC of gypsum

Table 1 shows that trisodium citrate had almost the same effect on the IC of gypsum as did citric acid. When 0.1% and 0.5% trisodium citrate were added, the ICs were about 156min and >1080min, respectively. Similar trends were found for the effect on the properties of GPB. With the increase in trisodium citrate contents, the IB, MOE, and MOR decreased and the TS increased when the trisodium citrate concentration was more than 0.1% (Figs. 1–4). The reduction ratio of the physical and mechanical properties of trisodium citrate-treated boards was not larger than that of citric acid-treated boards when adding ≥ 0.3% trisodium citrate. The reduction ratios of IB, MOE, and MOR were 50.0%, 69.7%, and 73.7% for citric acid and 4.5%, 7.9%, and 4.8% for trisodium citrate, respectively, in concentrations of 0.1%–0.3%.

The reason for the low values for the GPB properties with high concentrations of trisodium citrate was the same as for citric acid. The small reduction ratio for GPB properties was due to the weaker acidity of trisodium citrate than citric acid when the same concentrations of buffers were added. The GPB properties after adding trisodium citrate as a buffer were worse than those seen with citric acid at lower buffer concentrations, but it was better than for sodium tetraborate decahydrate and sodium carbonate. The results of this study clearly show that trisodium citrate is a good buffer when a suitable concentration is added.

Thermal analysis

To explain the effect of citric acid on the properties of GPB, three concentrations (0.05%, 0.1%, 0.3%) of citric acid were used for the thermal analysis, the results of which are given in Fig. 5. Gypsum curing is an endothermic reaction. There were three endothermic peaks in the thermal analysis. The first peaks appeared at 67°C, 56°C, and 61°C, respectively. The highest endothermic quantity (327J/g) occurred with 0.3% citric acid. The second peaks appeared at about 115°C, generating the highest and smallest endothermic quantities (241 and 6J/g) with 0.05% and 0.3% citric acid, respectively. The third peak appeared at about 135°C, and the endothermic quantities at 0.05%, 0.1%, and 0.3% citric acid were 65, 41, and 72J/g, respectively. Based on the results of the thermal analysis and the mechanical and

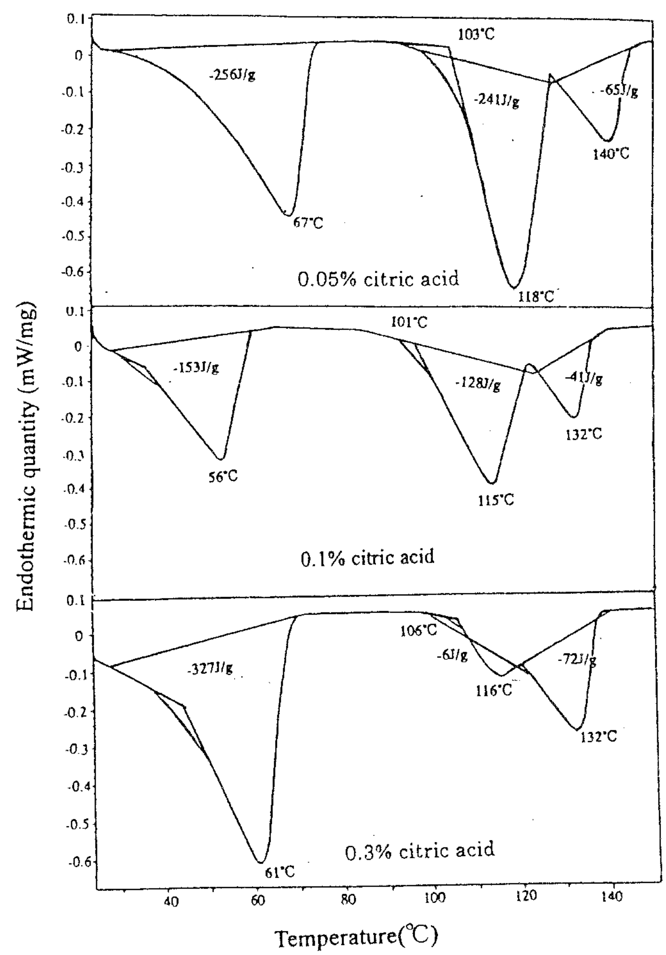

Fig. 5. Thermal analysis after addition of citric acid at concentrations of 0.05%, 0.1%, and 0.3%

physical properties of GPB treated with citric acid, it seems that the properties of boards are related to the endothermic quantity at the second peak. When this entity was high, a lot of heat was absorbed during the medium curing period of gypsum. Hence the high endothermic quantity contributed to the better curing of gypsum and produced the high bonding strength. For this reason, the properties of GPB were high (Figs. 1–4) when 0.05% citric acid was added owing to the high endothermic quantity at the second peak (Fig. 5). In contrast, when 0.3% citric acid was added, the low endothermic quantity (6J/g) at the second peak appeared and resulted in the low values for the properties of boards. The mechanical and physical properties of GPB and endothermic quantity at the second peak with the addition of 0.1% citric acid were medium among the three quantities of citric acid.

Aging test

To provide a better understanding of the effect of citric acid on the physical and mechanical performance of GPB, the specimens without and with 0.05% and 0.1% citric acid were treated with the aging test conditions. The aging test results are given in Figs. 6–8. The TS increased with an increase in treatment temperature regardless of whether citric acid was added. The increasing TS ratio after adding citric acid was slightly lower than that without citric acid after increasing the treatment temperature.

Similar trends were found for the effect on the mechanical performance. The reduction ratios of IB, MOE, and MOR without citric acid were the highest, as shown in Fig. 7. On the other hand, there are low reduction ratios of MOE and MOR with citric acid at any treatment condition.

Based on the results of the aging test, it was concluded that addition of citric acid was advantageous to the properties of GPB. The addition of 0.05% and 0.1% citric acid maintained a high physical and mechanical performance of GPB. It seems that a high bonding strength resists absorption of water when the specimens are soaked or boiled in water. For this reason, the increased TS and the reduced IB, MOR, and MOE with citric acid were less than those without any buffer when the treatment temperature was increased.

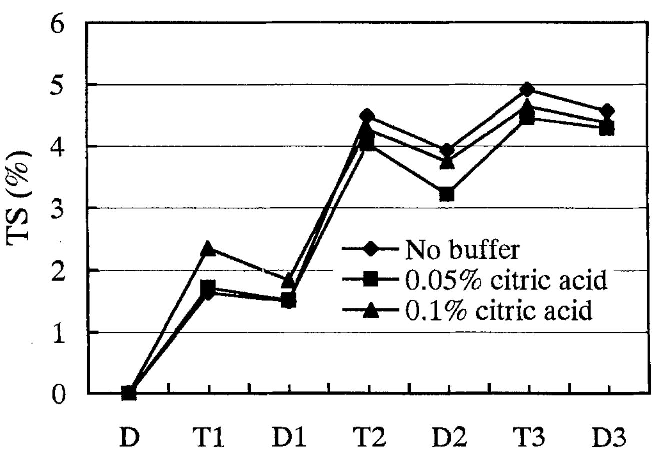

Fig. 6. Relation between the aging treatment and thickness swelling. *D*, air-dried condition; *D1*, *D2*, *D3*, oven-dried condition; *T1*, 24h of soaking in water (20°C); *T2*, 24h of soaking in water (70°C); *T3*, 4h of boiling in water (100°C)

Conclusions

The results from this study indicated that using acidic buffers such as citric acid and trisodium citrate to prolong the IC of gypsum was more significant than when alkaline buffers, such as sodium tetraborate decahydrate and sodium carbonate, were used. In addition, the effects of acidic and alkaline buffers on the physical and mechanical properties of GPB were different. High physical and mechanical

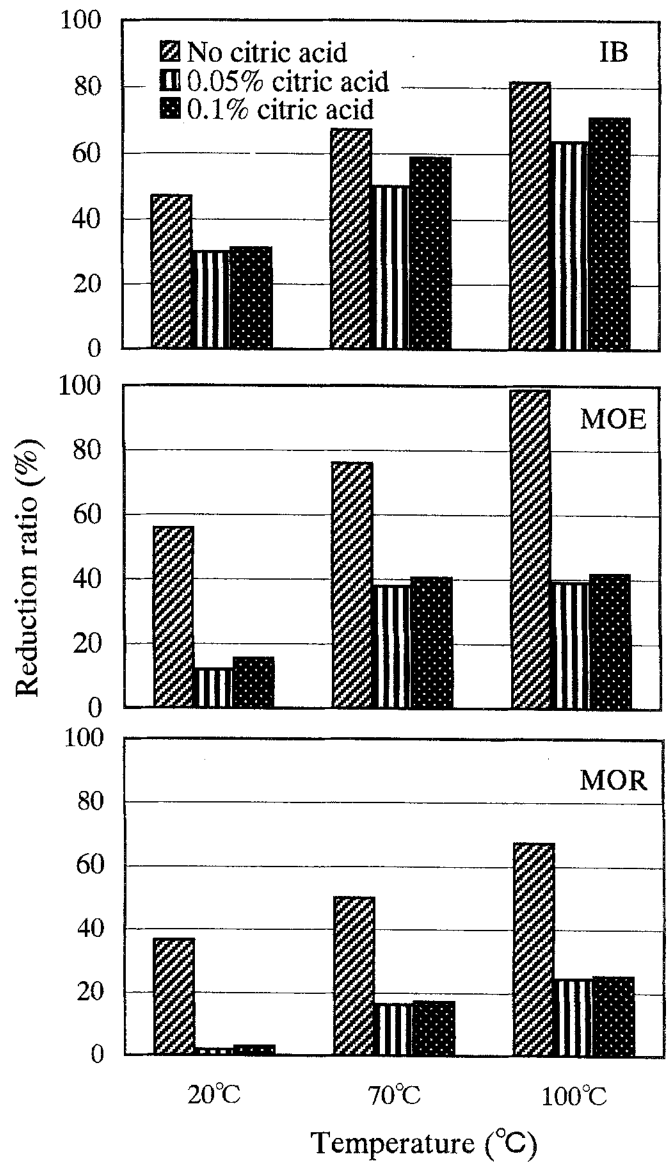

Fig. 7. Reduction ratio of IB, MOE, and MOR during the aging treatment

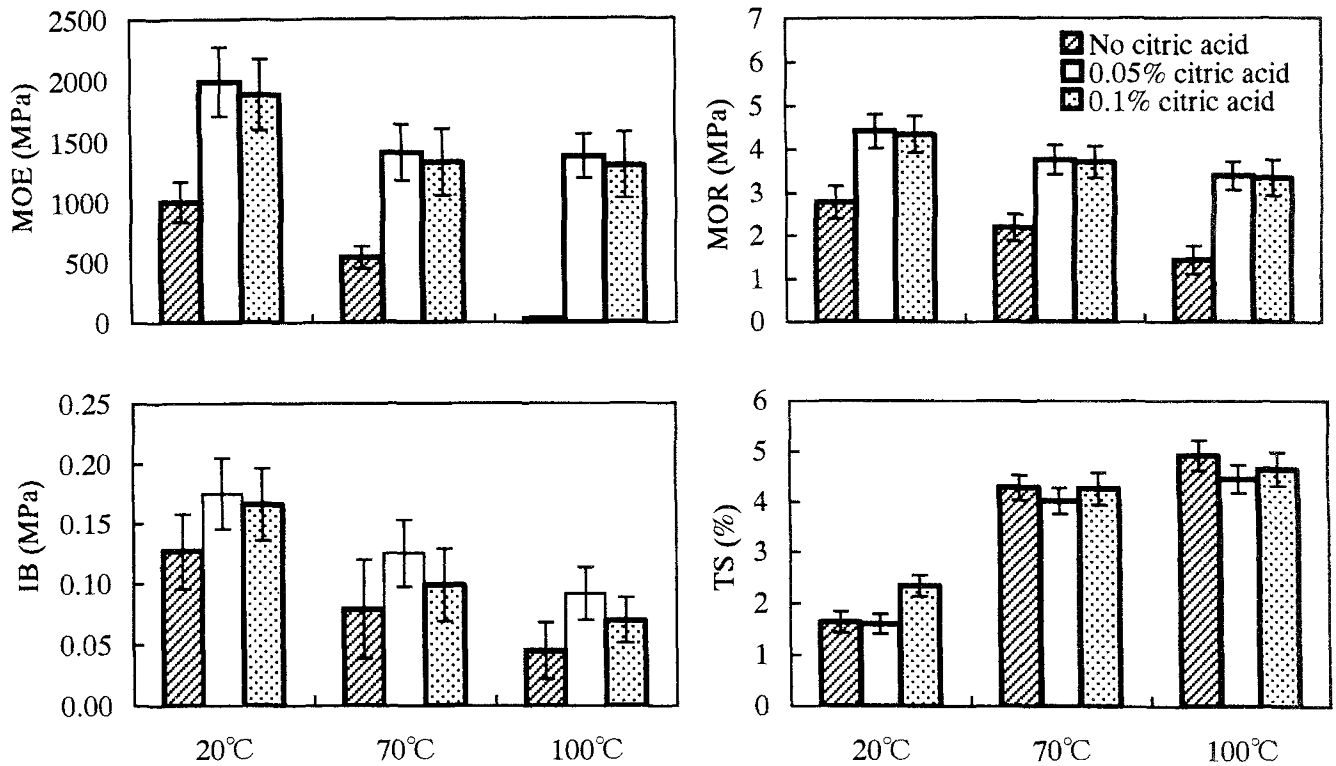

Fig. 8. Mean values and standard deviations of MOE, MOR, IB, and TS during the aging treatment

performances were achieved and the IC of gypsum was prolonged to about 2h when ≤ 0.1% citric acid or trisodium citrate was added. The addition of ≤1.0% sodium tetraborate decahydrate not only reduced the physical and mechanical properties of GPB, but it resulted in a short IC of gypsum. The low values for the mechanical properties of GPB were seen with sodium carbonate of any concentration. The thermal analysis results showed that gypsum curing was an endothermic reaction. The endothermic quantity of three endothermic peaks was related to the quantity of citric acid added. The aging test results indicated that the reduction ratio of GPB in the mechanical properties and the increase of TS when adding 0.05% and 0.1% citric acid were lower than those without citric acid. It was concluded that among the four buffers citric acid was the best and trisodium citrate was second best. Sodium carbonate was not a suitable buffer.

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