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# Performance of Bricks and Brick Masonry in Aggressive Chemical Environment

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***Abstract***
*In India, the use of burnt clay bricks in dwellings is common since the ancient Indus civilization. In buildings, bricks are used in brick masonry, reinforced brick work and in some cases as coarse aggregate in the construction of foundation base. The performance of brick masonry depends upon the quality of bricks, quality of masonry work and the prevalent environmental conditions which have to be faced by the structure. As bricks are more porous than concrete, they are more susceptible to deterioration in aggressive chemical environments. Considerable experimental input is required to establish durability of brick masonry structures with reasonable confidence in aggressive environment. Presently compared to concrete very limited data is available on the durability of brick masonry in aggressive chemical environments. Hence, in the present investigation it is proposed to study the influence of aggressive chemical environments on bricks in both sulfate bearing soils and ground waters. It is also proposed to conduct experiments on scaled models of brick masonry wall to study the effect of aggressive chemical environment.*

**Keywords:** brick masonry, durability

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## INTRODUCTION

Brick is considered as a basic building block in masonry structure. It is one of the oldest building materials which is popular even now because of economy and ease in construction. Several researchers have investigated behavior of Brick Masonry under different condition. Dhansekar *et al*.[1] have reported the results of an experimental investigation in which they suggested biaxial stress strain relationship for brick masonry. Basbare *et al*.[2] discussed the role of sea salts in decay of brick masonry, they also reported different decay patterns observed during investigation. Dhansekar[4] reported results of an experimental investigation in which effect of grout confinement on the compressive strength of masonry is reported. Bortolotti *et al*.[4] discussed the behavior of brick masonry under biaxial stress state and reported that in biaxial compressive state masonry is found to behave as an isotropic material. Sarangpati *et al*.[5] discussed some issues pertaining to brick mortar bond and masonry compressive strength. The review indicates that although lot of work has been done to access the strength of brick masonry under normal environmental conditions but not much work has been done to study the strength under aggressive environmental condition. The brick masonry foundations in aggressive chemical environments are subjected to continuous attack of chemical environment throughout the life of structure. The performance of brick masonry is primarily dependent on the quality of bricks. In the present study the effect of aggressive chemical like magnesium sulfate, sulfuric acid, contaminated ground water and contaminated soil environments on bricks is observed.

In the construction of foundation in most of the buildings, brick masonry is buried into the soil without plastering it from outside. Due to fluctuation in water table, the salts existing in the soil are leach out and on reacting with the bricks causes its continuous deterioration. The durability of brick masonry is mainly dependent upon quality of bricks and mortar used arrangement of bond in between bricks and concentration of attacking chemicals. To observe a long term effect on brick masonry, scaled model of brick pedestals were soaked into different type of chemicals tanks with various concentration of chemicals. In scaled model of brick masonry, a pair of two bricks are arranged in three layers such that alternate layer shows stretcher and header. Therefore in one scaled model six bricks were used. The effect of chemical bond concentration and period of chemical exposure on the scaled models of brick masonry was observed.

The brick masonry used in super structure is plastered for aesthetics. But plastering of walls may be beneficial for providing protection against aggressive environment. These weathering agents may cause the deterioration of plastered brick masonry through cracks and fissures in masonry work. The problem of saltpeter, blistering of plasters, etc. are the several examples related to it. In order to find the effect of aggressive environment on plastered brick models they were immersed in the water tanks of various chemical concentrations.

The strength of brick masonry depends upon several factors viz.

1. The strength of individual bricks
2. The strength of mortars
3. Curing time
4. Thickness of mortar joint
5. Orientation of bricks
6. Attack of aggressive chemical environment
7. Degree of protection due to plastering
8. Workmanship

Since most of the factors are variable in nature therefore it is difficult to find the overall strength of brick masonry. In this investigation some of these important factors are isolated and a relationship amongst the strength of brick masonry, bricks and mortar under different aggressive chemical environment is developed. On the basis of results obtained a predictive model has been developed.

## EXPERIMENTAL PROGRAMME

The deep cherry red color bricks with smooth surfaces, rectangular and approximately sharp and straight edges were procured from a brick kiln situated at Bhognipur, Kanpur. The water absorption of bricks was 13.5%. The average compressive strength of bricks was 10.62 N/mm$^2$. The frogs of the bricks were filled with 1:3 cement mortar to study the chemical attack on bricks following eight curing conditions were created-ordinary water, magnesium sulfate solution with sulfate concentrations 4200 and 10,000 ppm, 0.1 N $H_2SO_4$ solution, 0.2 $H_2SO_4$ solution, contaminated water with sulfate concentration 4200 and 10,000 ppm, and contaminated soil slurry with sulfate concentration 10,000 ppm.

The physical properties of bricks were obtained as per the method recommended in IS: 3495-1976. Fifteen bricks with frogs filled up with mortar were completely soaked in each tank. Five samples from each tank were taken out at the end of 28, 90, and 180 days, respectively, and kept for air drying for 24 hours and then subjected to the testing for the evaluation of weight and compressive strength. The bricks were also visually assessed.

Scaled model of brick masonry were also prepared. The joints were filled with 1:6 cement mortars. Fifteen sets of unplastered and plastered brick models each were immersed in each type of solution tanks for studying the effect of aggressive chemical environment. Five sets of brick models were taken out after 28, 90, and 180 days of contact period. Prior to testing for compressive strength they were kept for one day for air drying.

## EXPERIMENTAL RESULTS AND DISCUSSION

The results obtained are presented in Tables 1, 2 and Figures 1–4. Table 1 and Figures 1, 2 show the weight and loss in weight of bricks kept in water and different aggressive chemical environments of various concentrations for different curing periods. It is observed that the loss increases with the increase in time of exposure and concentration of chemicals in solution. After 28 days maximum loss of 1.93% was observed in specimens immersed in 0.2 $H_2SO_4$ and this loss increases to 3.42% after 180 days. Table 2 and Figures 3, 4 show the variation of compressive strength of bricks and loss in strength due to aggressive chemical environments of various concentrations for different curing periods. It is noticed that the loss increases with the increase in time of exposure and concentration of chemicals in solution. The variation was similar to that observed for weights of brick.

***Table 1.*** *Effect of Aggressive Chemical Environment on Weight of the Bricks.*

| Age (days) | Weight (kg) and % weight loss | Water | $MgSO_4$ with sulfate conc. | | $H_2SO_4$ with conc. | | Contaminated water with sulfate conc. | | Contaminated soil with sulfate conc. |
|---|---|---|---|---|---|---|---|---|---|
| | | | 4200 ppm | 10,000 ppm | 0.1 N | 0.2 N | 4200 ppm | 10,000 ppm | 10,000 ppm |
| 28 | Weight | 3.783 | 3.762 | 3.738 | 3.713 | 3.709 | 3.765 | 3.761 | 3.768 |
| | % Weight loss | – | 0.56 | 1.20 | 1.86 | 1.93 | 0.46 | 0.58 | 0.40 |
| 90 | Weight | 3.864 | 3.826 | 3.790 | 3.783 | 3.775 | 3.828 | 3.824 | 3.839 |
| | % Weight loss | – | 0.98 | 1.90 | 2.10 | 2.31 | 0.92 | 1.02 | 0.64 |
| 180 | Weight | 3.958 | 3.895 | 3.863 | 3.847 | 3.823 | 3.901 | 3.895 | 3.921 |
| | % Weight loss | – | 1.60 | 2.40 | 2.80 | 3.42 | 1.43 | 1.58 | 0.94 |

***Table 2.*** *Effect of Aggressive Chemical Environment on Compressive Strength of the Bricks.*

| Age (days) | Compressive strength ($N/mm^2$) and % loss | Water | $MgSO_4$ with sulfate conc. | | $H_2SO_4$ with conc. | | Contaminated water with sulfate conc. | | Contaminated soil with sulfate conc. |
|---|---|---|---|---|---|---|---|---|---|
| | | | 4200 ppm | 10000 ppm | 0.1N | 0.2N | 4200 ppm | 10,000 ppm | 10,000 ppm |
| 28 | Compressive strength ($N/mm^2$) | 14.48 | 14.21 | 14.27 | 14.13 | 13.98 | 14.29 | 14.23 | 14.32 |
| | % loss | – | 1.86 | 2.12 | 2.83 | 3.42 | 1.30 | 1.69 | 1.1 |
| 90 | Compressive strength ($N/mm^2$) | 15.20 | 14.54 | 14.32 | 14.31 | 14.18 | 14.71 | 14.45 | 14.77 |
| | % loss | – | 4.32 | 5.78 | 5.80 | 6.7 | 3.2 | 4.9 | 2.8 |
| 180 | Compressive strength ($N/mm^2$) | 16.65 | 15.16 | 14.97 | 15.05 | 14.63 | 15.28 | 14.93 | 15.62 |
| | % Loss | – | 8.92 | 10.10 | 9.6 | 12.1 | 8.2 | 10.3 | 6.2 |

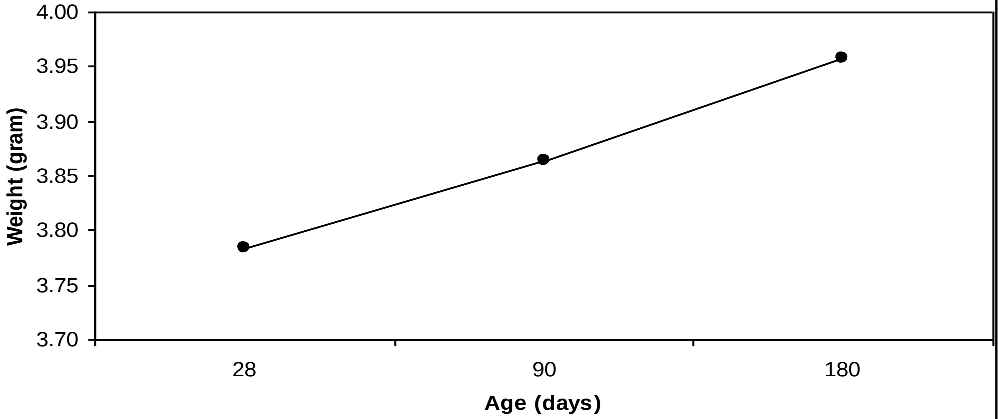


**Fig - 1 Variation of weight of bricks cured in fresh water**

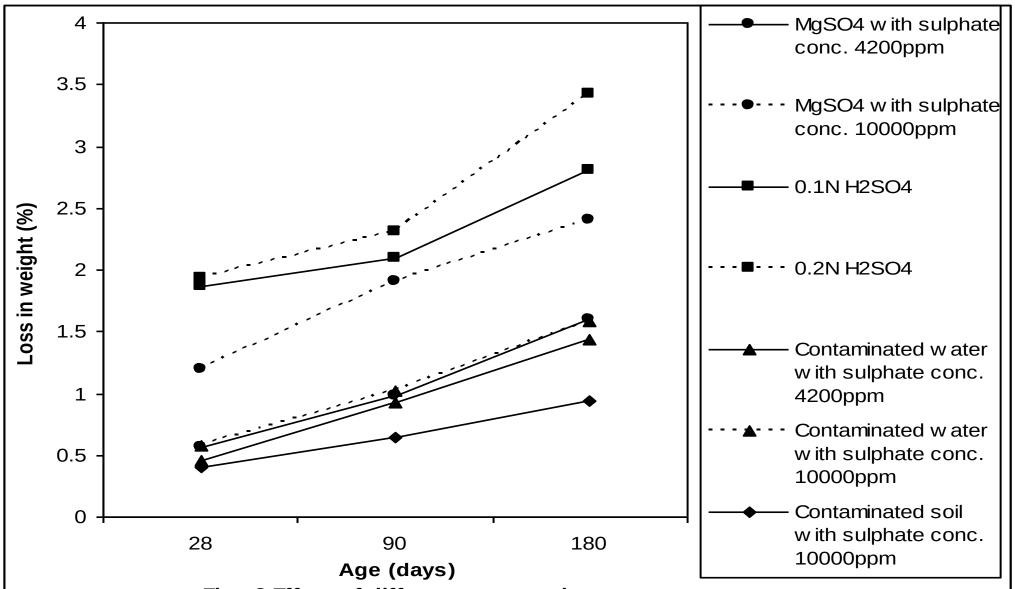


**Fig - 2 Effect of different aggressive chemical environment on weight of bricks**

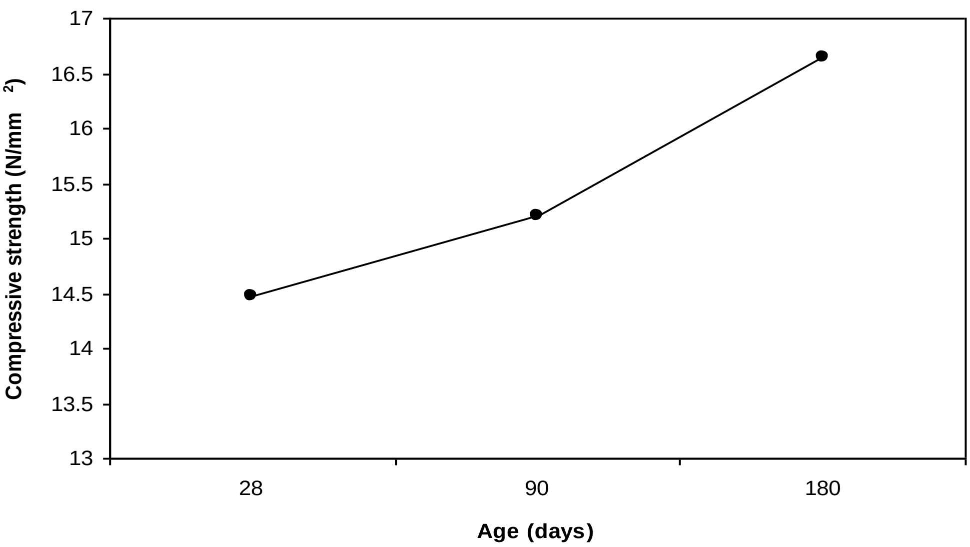


**Fig - 3 Variation of compressive strength of bricks cured in fresh water**

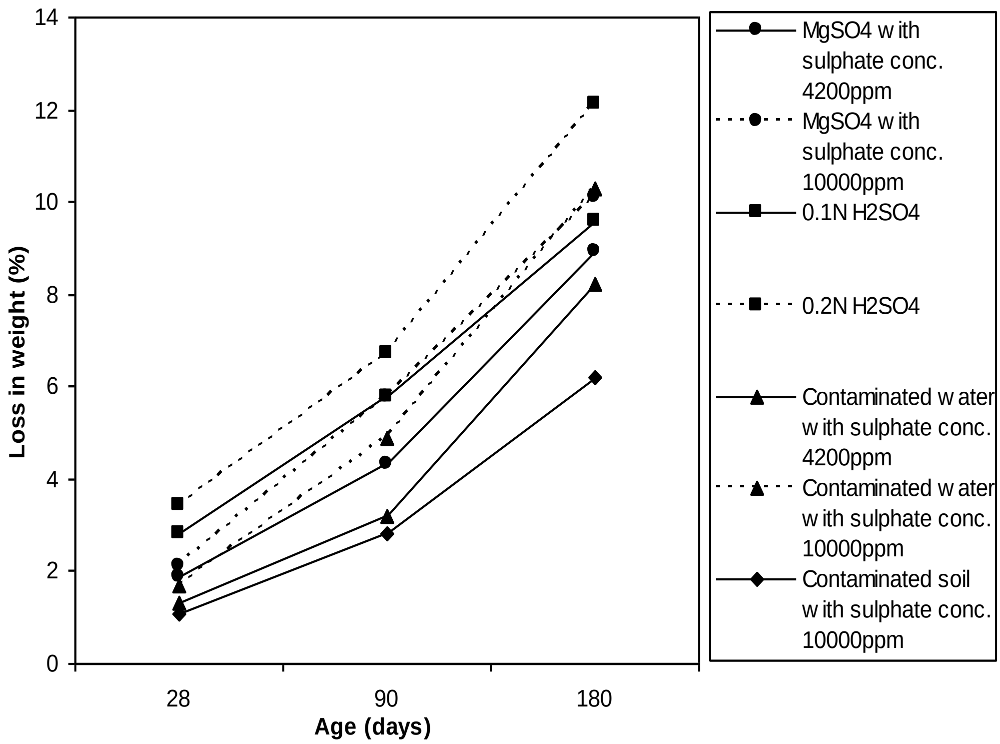


**Fig - 4 Effect of different aggressive chemical environment on compressive strength of bricks**

To study the durability aspects of brick structures, their compressive strength development characteristics were studied in $MgSO_4$ solution, $H_2SO_4$ solution, contaminated water and contaminated soil slurry. It is observed that the losses in compressive strength increases with increase in the concentration of chemicals. It was also observed that the bricks suffered more losses if exposed to chemical environment for a longer time. On comparing the results of chemical attack on bricks in sulfate solution, contaminated water and contaminated soil slurry solution, it is noticed that for the same concentration of sulfates in all three types of solution, the brick cured in sulfate solution alone had suffered maximum loss in compressive strength. It is also noticed that the bricks cured in contaminated soil slurry has shown the least loss in compressive strength. It is evident from the results that the effect of sulfate reduces considerably in the presence of other chemicals. This may be due to the reason that sulfate ion available freely in solution causes more damage in bricks as compared to the sulfate present in soil slurry.

The experimental results presented in Figure 3, 5 and 6 shows the variation of compressive strength of brick masonry models cured in fresh water. It can be observed from Figure 5, that 90 and 180 days compressive strength of brick masonry models are 1.08 and 1.17 times more than that of 28 days compressive strength.

The compressive strength of brick models increases with curing time. Figure 6 presents the percentage loss in compressive strength of brick models with exposure duration and chemical concentration of different solutions. The percentage loss in strength is defined as below:

Percentage loss = $(\sigma_w - \sigma_s) \times 100/\sigma_w$

where $\sigma_w$ is the strength of brick models cured in water for various time durations and $\sigma_s$ is the strength of brick models exposed to various chemical solutions for the same period.

***Table 3.*** *Effect of Aggressive Chemical Environment on Compressive Strength of the Unplastered Brick Wall Model.*

| **Age (days)** | **Compressive strength ($N/mm^2$) and % loss** | **Water** | **$MgSO_4$ with sulfate conc.** | | **$H_2SO_4$ with conc.** | | **Contaminated water with sulfate conc.** | | **Contaminated soil with sulfate conc.** |
|---|---|---|---|---|---|---|---|---|---|
| | | | **4200 ppm** | **10000 ppm** | **0.1N** | **0.2N** | **4200 ppm** | **10,000 ppm** | **10,000ppm** |
| 28 | Compressive strength ($N/mm^2$) | 7.75 | 7.60 | 7.55 | 7.52 | 7.46 | 7.61 | 7.59 | 7.61 |
| | % Loss | – | 1.94 | 2.5 | 3.0 | 3.8 | 1.8 | 2.1 | 1.8 |
| 90 | Compressive strength ($N/mm^2$) | 8.32 | 7.90 | 7.82 | 7.84 | 7.77 | 7.99 | 7.89 | 8.05 |
| | % Loss | – | 5.0 | 6.0 | 5.8 | 6.6 | 4.0 | 5.2 | 3.2 |
| 180 | Compressive strength ($N/mm^2$) | 9.20 | 8.17 | 8.04 | 8.11 | 8.00 | 8.32 | 8.14 | 8.39 |
| | % Loss | – | 11.2 | 12.6 | 11.8 | 13.0 | 9.6 | 11.5 | 8.8 |

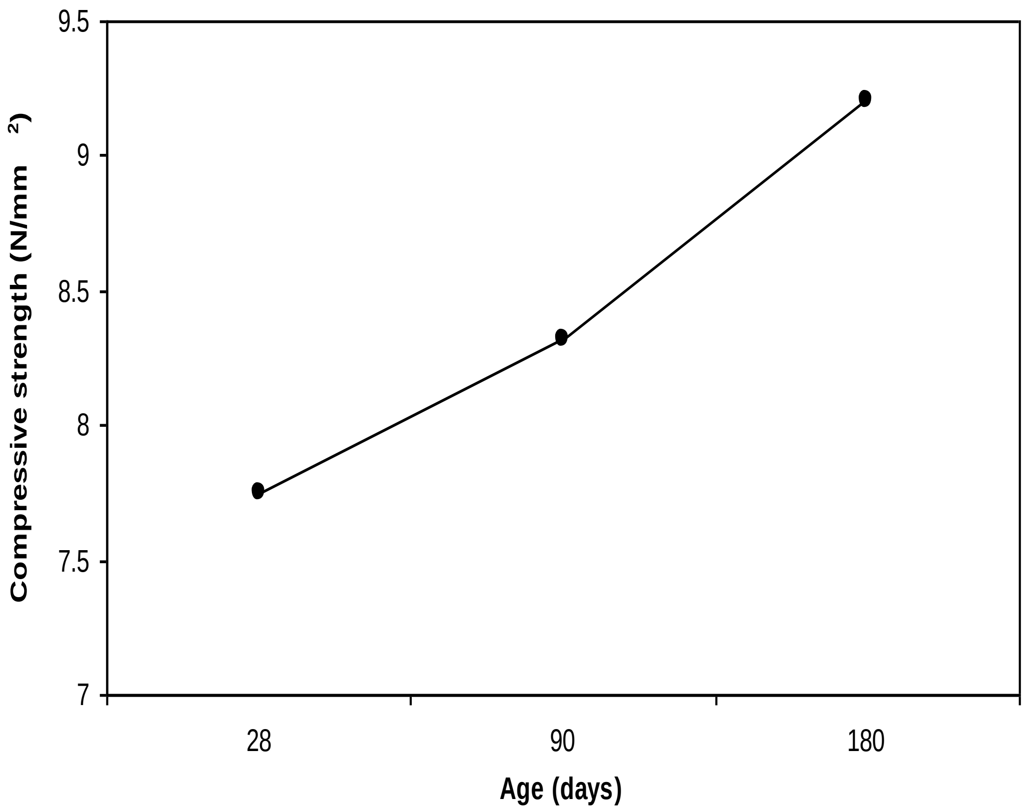


**Fig - 5 Variation of compressive strength of unplastered brick masonry cured in fresh water**

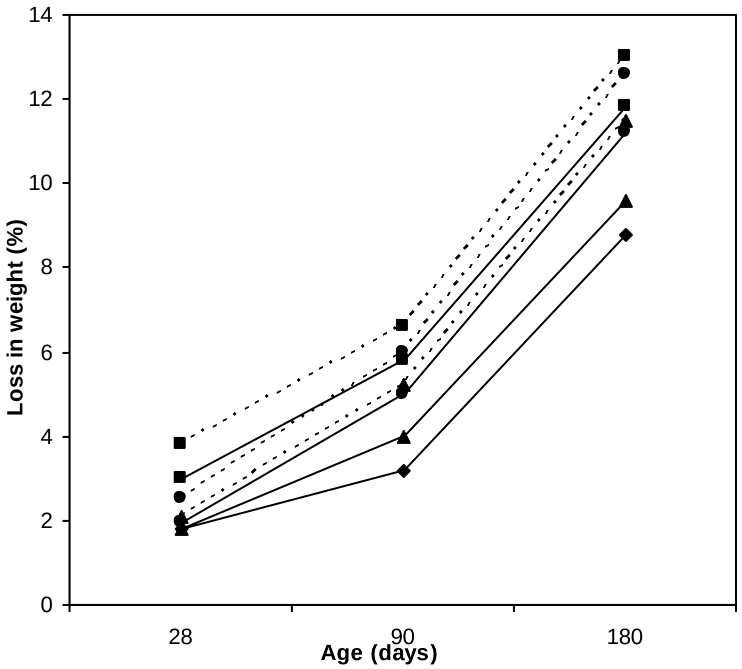


**Fig - 6 Effect of different aggressive chemical environment on compressive strength of unplastered brick masonry**

The maximum loss in compressive strength of brick masonry model was observed in case of sulfuric acid. The magnesia and silica present in bricks reacts with chemicals present in magnesium sulfate solution, sulfuric acid solution, contaminated water and soil slurry and causes loss in strength and renders bricks less durable. It was also observed that white patches were marked on the surfaces due to leaching of gypsum from the bricks after the exposure to various chemical solutions. For the brick masonry models, both bricks and mortar are losing strength, therefore overall strength of the brick models was also reduced and the same was evident from the experimental study results.

The experimental results are presented in Table 4 and Figures 7, 8. The variation of compressive strength of plastered brick wall models cured in fresh water is as shown in Figure 7. It is noticed from figure that 90 and 180 days compressive strength of plastered bricks wall models are 1.09 and 1.2 times more than that of 28 days compressive strength of wall models. It is also noticed that compressive strength of plastered brick models increases with curing time. Figure 8 shows the percentage loss in compressive strength of brick models with age and concentration of different solution. It can be observed that the losses are less as compared to that of unplastered bricks wall models, this may be due to the fact that rate of ingress of chemicals in plastered bricks models was slow as compared to unplastered bricks models. Like unplastered bricks models, in case of plastered brick models the percentage loss in strength is highest in case of sulfuric acid solution as compared to other contaminants and this loss increases on increasing the concentration of sulfuric acid. The losses are least in case of contaminated soil slurry. This may be due to the fact that the chemicals present in soil slurry are not as free as in water solution.

***Table 4.*** *Effect of Aggressive Chemical Environment on Compressive Strength of the Plastered Brick Wall Model.*

| Age (days) | Compressive strength ($N/mm^2$) and % loss | Water | $MgSO_4$ with sulfate conc. | | $H_2SO_4$ with conc. | | Contaminated water with sulfate conc. | | Contaminated soil with sulfate conc. |
|---|---|---|---|---|---|---|---|---|---|
| | | | 4200 ppm | 10,000 ppm | 0.1N | 0.2N | 4200 ppm | 10000 ppm | 10,000ppm |
| 28 | Compressive strength ($N/mm^2$) | 10.92 | 10.76 | 10.70 | 10.66 | 10.61 | 10.77 | 10.73 | 10.81 |
| | % Loss | – | 1.5 | 2.0 | 2.4 | 2.8 | 1.4 | 1.7 | 1.0 |
| 90 | Compressive strength ($N/mm^2$) | 11.36 | 11.00 | 10.84 | 10.81 | 10.76 | 11.04 | 10.95 | 11.06 |
| | % Loss | – | 3.2 | 4.5 | 4.8 | 5.3 | 2.8 | 3.6 | 2.6 |
| 180 | Compressive strength ($N/mm^2$) | 12.48 | 11.68 | 11.51 | 11.45 | 11.30 | 11.73 | 11.70 | 11.86 |
| | % Loss | – | 6.4 | 7.8 | 8.2 | 8.8 | 6.0 | 6.2 | 5.0 |

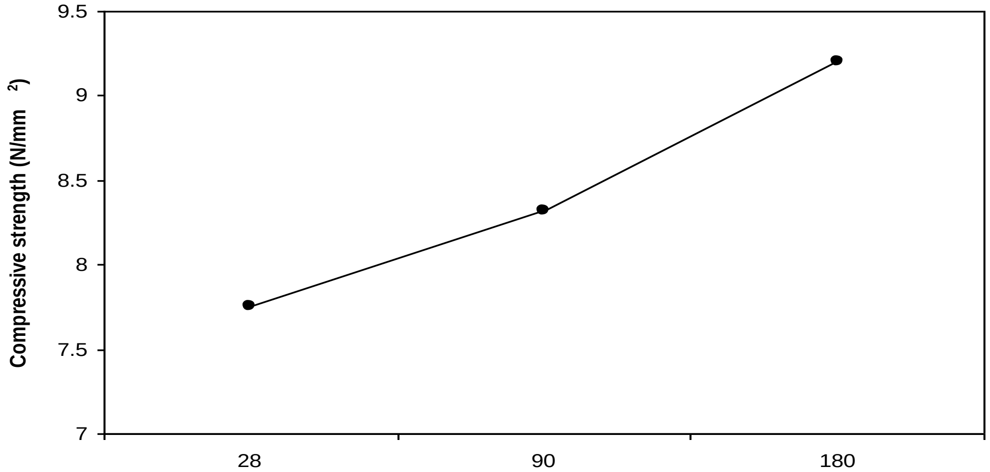


Fig - 7 Variation of compressive strength of plastered brick masonry cured in fresh water

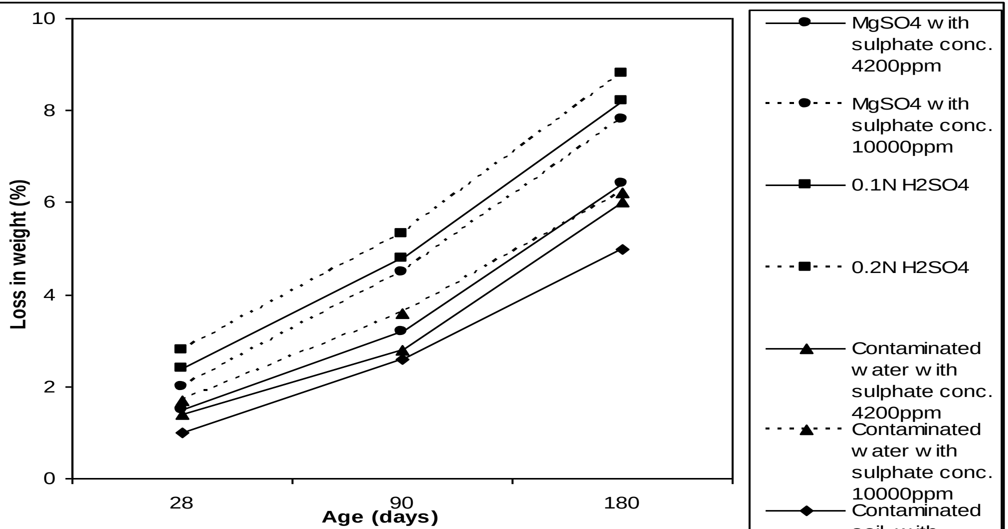


Fig - 8 Effect of different aggressive chemical environment on compressive strength of plastered brick masonry

## Prediction of Compressive Strength of Unplastered and Plastered Brick Masonry

On the basis of experimental results obtained a relation to access the compressive strength of unplastered and plastered brick masonry has been developed. The general relation for the compressive strength of brick masonry ($f_w$) is given by

$$f_w = K\,(f_m f_b)^{0.5}$$

where $f_m$ is the compressive strength of mortar, $f_b$ the compressive strength of brick, and K is a constant which depends upon the period of curing and protection of masonry. The value of K is shown in Table 5.

***Table 5.*** *Constant K for Different Condition of Masonry and Curing Time.*

| Curing period (days) | K value (unplastered masonry) | K value (plastered masonry) |
|---|---|---|
| 28 | 0.455 | 0.642 |
| 90 | 0.435 | 0.595 |
| 180 | 0.428 | 0.600 |

The value of K in case of plastered masonry is 1.35–1.40 times more than that of unplastered masonry under different environmental conditions. This shows that the compressive strength of plastered brick masonry is 35–40% more than that of unplastered brick masonry. On the basis of predictive relation given the results of experimental values and predicted values of compressive strength of unplastered and plastered bricks masonry under different environmental conditions are shown in Tables 6 and 7 and Figures 9 and 10, respectively. The difference in the experimental and predicted compressive strength of brick masonry increases with the concentration of aggressive chemical environment and contact period. In case of sulfuric acid with concentration 0.2 N highest error recorded was 8.78% at 28 days exposure and which increases to 11.27% at 180 days of exposure for unplastered. But in most of the cases the error was less than 7%. The least error was obtained when the masonry was subjected to contaminated soil with sulfate concentration 10,000 ppm.

***Table 6.*** *Prediction of Compressive Strength ($N/mm^2$) of Unplastered Brick Masonry.*

| Age (days) | 28 | | | | | 90 | | | | | 180 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $f_m$ | $f_b$ | $f_w$ | $f_w''$ | %Error | $f_m$ | $f_b$ | $f_w$ | $f_w''$ | %Error | $f_m$ | $f_b$ | $f_w$ | $f_w''$ | %Error |
| Water | 20 | 14.48 | 7.75 | 7.74 | 0.13 | 24 | 15.20 | 0.32 | 8.31 | 0.14 | 26 | 16.65 | 9.20 | 8.90 | 3.2 |
| $MgSO_4$ with $SO_4$ – conc. 4200 ppm | 19 | 14.21 | 7.60 | 7.48 | 1.63 | 22 | 14.54 | 7.90 | 7.70 | 1.52 | 24 | 15.16 | 8.17 | 8.16 | 0.07 |
| $MgSO_4$ with $SO_4$ – conc. 10,000 ppm | 18 | 14.17 | 7.55 | 7.26 | 3.75 | 21 | 14.32 | 7.82 | 7.54 | 3.54 | 21 | 14.97 | 8.04 | 7.59 | 5.61 |
| 0.1 N $H_2SO_4$ | 17.5 | 14.13 | 7.52 | 7.15 | 4.85 | 19.6 | 14.31 | 7.84 | 7.28 | 7.08 | 20.8 | 15.05 | 8.11 | 7.57 | 6.60 |
| 0.2 N $H_2SO_4$ | 16.0 | 13.90 | 7.46 | 6.80 | 8.78 | 18.0 | 14.18 | 7.77 | 6.95 | 10.6 | 18.0 | 14.63 | 8.00 | 7.10 | 11.27 |
| Contaminated water with $SO_4$ – conc. 4200 ppm | 19.4 | 14.29 | 7.61 | 7.58 | 0.449 | 22.4 | 14.71 | 7.99 | 7.90 | 1.17 | 24.4 | 15.28 | 8.32 | 8.26 | 0.67 |
| Contaminated water with $SO_4$ – conc. 10,000 ppm | 18.0 | 14.23 | 7.59 | 7.28 | 4.05 | 19.0 | 14.45 | 7.89 | 7.21 | 8.64 | 21.6 | 14.93 | 8.14 | 7.69 | 5.58 |
| Contaminated soil with $SO_4$ – conc. 10,000 ppm | 19.0 | 14.32 | 7.61 | 7.50 | 1.38 | 23.0 | 14.77 | 8.05 | 8.01 | 0.403 | 25.0 | 15.62 | 8.49 | 8.46 | 0.353 |

$f_m$ – compressive strength (N/mm$^2$) of cement mortar cubes. $f_b$ – compressive strength (N/mm$^2$) of bricks. $f_w$ and $f_w''$ – observed and predicted value of compressive strength (N/mm$^2$) of unplastered brick masonry.

***Table 7.*** *Prediction of Compressive Strength (N/mm$^2$) of Plastered Brick Masonry.*

| Age (days) | 28 | | | | | 90 | | | | | 180 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $f_m$ | $f_b$ | $f_w$ | $f_w''$ | %Error | $f_m$ | $f_b$ | $f_w$ | $f_w''$ | %Error | $f_m$ | $f_b$ | $f_w$ | $f_w''$ | %Error |
| Water | 20 | 14.48 | 10.92 | – | 24 | 15.2 | 11.36 | 11.36 | 11.36 | – | 26 | 16.65 | 12.48 | 12.48 | – |
| $MgSO_4$ with $SO_4$ – conc. 4200 ppm | 19 | 14.21 | 10.76 | 10.55 | 1.96 | 22 | 14.54 | 11.00 | 10.64 | 3.25 | 24 | 15.16 | 11.60 | 11.45 | 2.01 |
| $MgSO_4$ with $SO_4$ – conc. 10,000 ppm | 18 | 14.17 | 10.70 | 10.25 | 4.17 | 21 | 14.32 | 10.84 | 10.32 | 4.81 | 21 | 14.97 | 11.51 | 10.64 | 7.57 |
| 0.1 N $H_2SO_4$ | 17.5 | 14.13 | 10.66 | 10.09 | 5.92 | 19.6 | 14.31 | 10.81 | 9.96 | 7.82 | 20.8 | 15.05 | 11.45 | 10.62 | 7.28 |
| 0.2 N $H_2SO_4$ | 16.0 | 13.98 | 10.61 | 9.60 | 9.50 | 18.0 | 14.18 | 10.76 | 9.51 | 11.65 | 18.8 | 14.63 | 11.38 | 9.95 | 12.56 |
| Contaminated water with $SO_4$ – conc. 4200 ppm | 19.4 | 14.29 | 10.77 | 10.69 | 0.749 | 22.4 | 14.71 | 11.04 | 10.80 | 2.16 | 24.4 | 15.28 | 11.73 | 11.50 | 1.23 |
| Contaminated water with $SO_4$ – conc. 10,000 ppm | 18.0 | 14.23 | 10.73 | 10.28 | 4.24 | 19.0 | 14.45 | 10.95 | 9.86 | 9.96 | 21.6 | 14.23 | 11.70 | 10.77 | 7.90 |
| Contaminated soil with $SO_4$ – conc. 10,000 ppm | 19.0 | 14.32 | 10.81 | 10.59 | 2.04 | 23 | 14.77 | 11.06 | 10.96 | 0.90 | 25.0 | 15.62 | 11.86 | 11.06 | – |

$f_m$ – compressive strength (N/mm$^2$) of cement mortar cubes. $f_b$ – compressive strength (N/mm$^2$) of bricks. $f_w$ and $f_w''$ – observed and predicted value of compressive strength (N/mm$^2$) of plastered brick masonry.

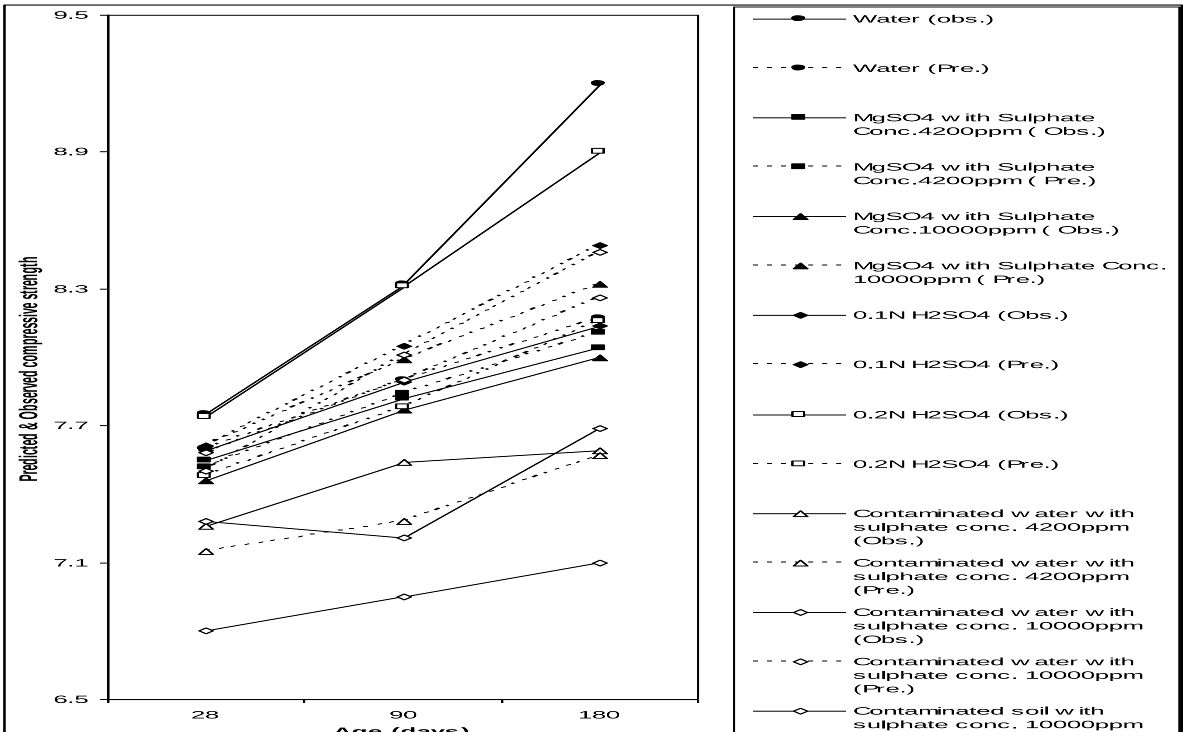

Fig - 9 Predicted and observed compressive strength of unplastered brick masonary in aggressive chemical environment

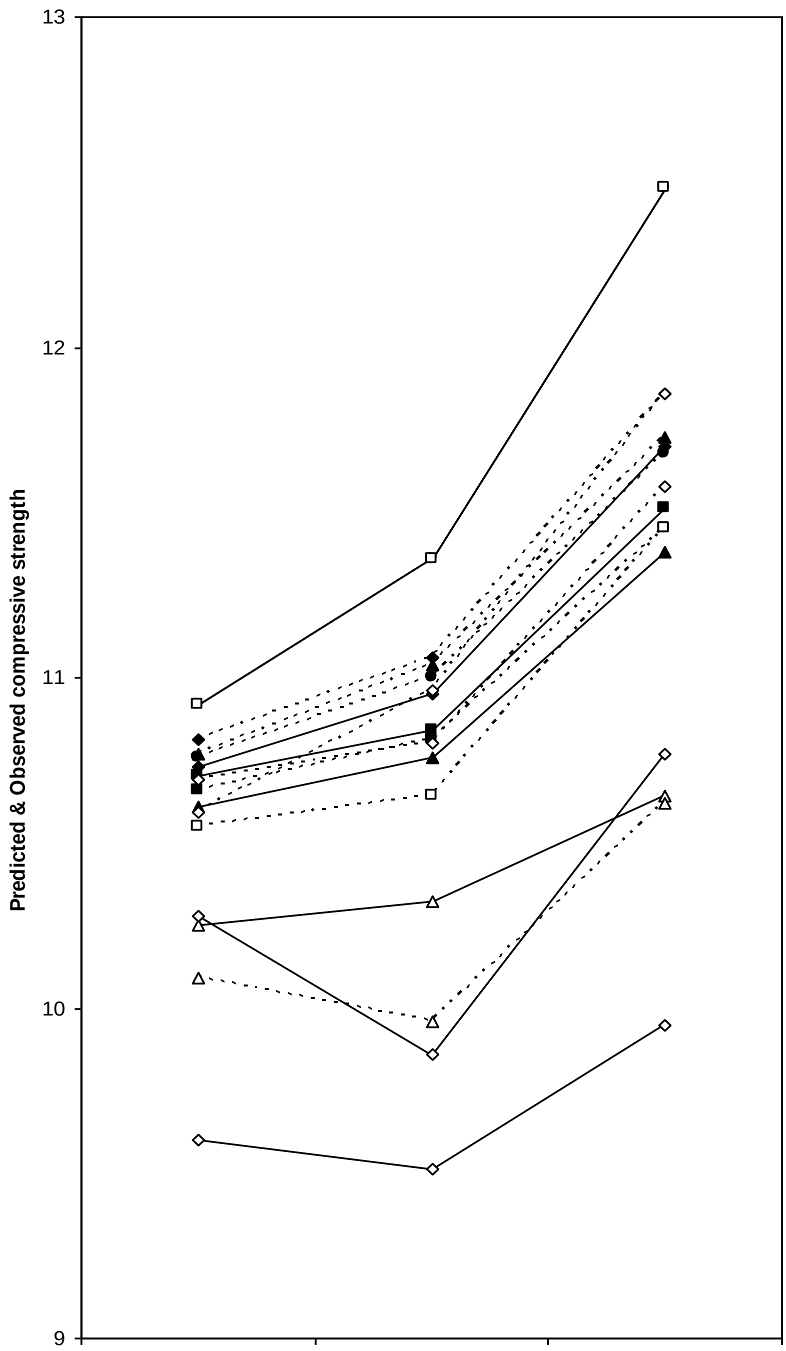


**Fig - 10 Predicted and observed compressive strength of plastered brick masonary in aggressive chemical environment**

## CONCLUSIONS

On the basis of experimental results obtained with respect to effect of aggressive chemical environment on the strength and weight of bricks and plastered and unplastered brick wall models, following conclusions can be drawn.

1. The compressive strength of bricks, unplastered brick wall models and plastered brick models increases with

curing time when cured in ordinary water.

2. The 90 and 180 days compressive strength of unplastered as well as plastered brick models were 1.08 and 1.09 and 1.17 and 1.20 times more than 28 days compressive strength.
3. The loss in compressive strength of unplastered brick wall models as well as plastered brick wall models increases with concentration and exposure time of aggressive chemical environments. But loss in strength is less in plastered brick wall models as compared to that of unplastered brick wall models.
4. The l0ss in 180 days compressive strength of unplastered brick models was maximum (13.0%) when exposed to 0.2 N sulfuric acid and minimum (8.8%) when exposed to contaminated soil slurry. For plastered brick wall models it was maximum (8.8%) when exposed to 0.2 N sulfuric acid and minimum (5%) when exposed to contaminated soil slurry.
5. The difference in the experimental and predicted compressive strength of brick masonry increases with the concentration of aggressive chemical environment and contamination period. In most of the cases the error was less than 7%. However, in case of sulfuric acid with concentration 0.2 N highest error recorded was 8.78% at 28 days exposure and which increased to 11.27% at 180 days of exposure for unplastered masonry.

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