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Brick Masonry Components Exposed to Aggressive Environment: Mechanical Behavior and Properties - An Experimental Investigation

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ABSTRACT

Deterioration of porous materials lead to severe damage in buildings. Salt weathering being the most common deterioration mechanism in porous materials which is related with the growth of crystal and pressure inside the pores of the materials associated with masonry. However the study on effect of salts on behavior of masonry as a whole unit and their individual components have not been elucidated for Indian conditions and only limited knowledge is available on deterioration of mortars which is the binder of brick masonry. This paper presents primary investigational study on components of masonry made of burnt clay bricks and cement mortar at joints in order to assess the damage induced by salts (sulphate and chloride). With this as aim, specimens were prepared in laboratory and were subjected to accelerated weathering conditions of different durations in sodium chloride and magnesium sulphate solutions which are the most common salts of attack in brick masonries when the environmental ambiance is strongly aggressive, either acidic or alkaline or in presence of sulphate and chloride produces physicochemical external attack and alterations in their integrity. Relevant studies have also been performed in the field by other authors, but in the study, conventional mortar mixes are manufactured and their behavior in aggressive environments. Certain mortar properties related to their behavior such as density, compressive strength, water absorption and porosity are analyzed for their disruptive effects. The paper presents the results obtained by the exposure of brick masonry and its components for a total duration of 14 weeks exposed to aggressive environment. Variation in mechanical properties of brick and its components were observed as the concentration of salts increased in the simulated environment created artificially in laboratory.

***Keywords*—** Brick, Masonry, Construction

I. INTRODUCTION

Brick masonry buildings undergo several disruptive processes when exposed to aggressive environment which threatens its durability and preservation. Aggressive environment is characterized by the presence of chemicals which may harm the integrity of a structural component. For example, the brick masonry of a sewage treatment plant, brick masonry of a manhole, brick masonry of a chemical factory etc., the environment may contain acid fumes, chemical effluents etc., The masonry is required to resist the attack by such deteriorating substances. Presence of salts (sodium chloride and magnesium sulphate) in soluble state plays a vital role in degradation of masonry materials as they are porous. Crystallization of salts needs special attention as they may induce rupture of pore walls, leading to crumbling, pulverization and flaking etc. Research efforts have been made to investigate the damage caused due to salt attack in stones, concrete and masonry, but less effort has been made for the studies under aggressive environment in Indian context. (Bakar et.al., 2011)

The nomenclature "Indian context" is used to denote a wide variation in methods of masonry construction, wide variation in material properties due to different mineral combinations in different areas, large variation in quality of construction, non engineered constructions, improper adherence to standards of construction practices and improper sequence of construction. The specific difference arises in wide variations in method of construction especially the type of bond used and non availability of good quality bricks. In this work, an experimental investigation is made to determine certain mechanical properties of bricks (sample1 and sample2) and masonry mortar (M_N and M 1, 2, 3 etc.,) such as density, water absorption and compressive strength under both normal and aggressive environmental conditions i.e., exposure to magnesium sulphate and sodium chloride solutions of varying compositions. The effect on durability is evaluated on the basis of reduction in the strength and changes in external appearance. The effect of aggressive environment on existing brick masonry structures becomes visible after many years. There is no codal provision to handle this problem. The design specifications to deal with this are not readily available. In the absence of studies on effect of deterioration of brick masonry, there is no legitimate solution to achieve

problem free design life. The study aims to generate such data which can be readily incorporated in design process to satisfy the limit state of durability.

II. MATERIALS AND METHOD

2.1 Materials Used

Brick masonry units which are commonly made of bricks and masonry mortar comprises of ordinary Portland cement, fine aggregate (manufactured sand) and water from regular water supply system.

In the present investigation two different brands of bricks named as (Source 1& Source 2) are taken into consideration, which are brunt clay bricks. Burnt clay bricks used in the present study are procured from different part of Mysuru district. The clay bricks used are of good quality and falls under the class designation of 7.5 as per Indian Standard IS 1077:1992 classification. Bricks with uniform color, smooth faces and with sharp corners were selected for the study. The results of water absorption of these samples are represented in Table 1 which obeys the IS standards. Binding material used is ordinary Portland cement with density 3106 kg/m^3. Various tests are performed on cement to determine the physical properties of cement and they are represented in Table 2 below which is as per IS standards.Fine aggregate [manufactured sand (M-sand)] with its physical characteristics and grading is represented in Table 3 which satisfies IS standards.

Figure 1: Water absorption test for brick source 1 and 2

Table 1: Results of water absorption test of brick samples

Particulars	Results	BIS Requirements
Water Absorption		
Source 1	14.60%	IS:3945-2-1992
Source 2	11.16%	

The difference in mean value of water absorption of brick samples is not much; perhaps this may be due to some similar properties of brick making materials from two different sources.

Table 2: Properties of Ordinary Portland cement in conformation with BIS specifications

Tests on cement (opc 43 grade,brand: coromandel)	**Results**	**BIS requirements**
Standard consistency	28.5%	IS 4031 -4 (1988)
Specific gravity	3.106	IS 4031-5 (1988)
Fineness	2%	IS4031-5 (1988)
Initial setting time	180 min	IS 4031 -11 (1988)
Final setting time	240 min	IS 4031 -1 (1988)

Table 3: Fine aggregate (manufactured sand) with physical characteristics and grading as per IS standards

Tests on fine aggregate	Results	BIS requirements
Specific gravity	2.67	IS 2386-3 (1963)
Water absorption	0.8%	IS 2386-3 (1963)
Silt content	2.24%	IS 2386-2 (1963)
Sieve analysis	zone - ii	IS 383 (1970)
Finess modulus	2.498	IS 2386-3 (1963)

III. EXPERIMENTAL INVESTIGATIONS

3.1 Mechanical Properties

Variation in density of brick samples and masonry mortar were tested according to IS 3495 (Part-1& part-2):1992 standards for a total duration of 13 weeks under exposed salt conditions of varying concentrations. Test specimens under fully immersed condition for different concentrations of sodium chloride (NaCl) and magnesium sulphate (MgSO4) i.e, 5%, 10% and 15% of Nacl and 1%, 2% and 3% of MgSO4 salt solution by volume was created artificially in the laboratory and the brick samples and mortar cubes were tested for mechanical properties such as compressive strength and reduction in weight.

Each test specimen was triplets and a mean of three numbers of specimens for each concentration of salt are considered for experimental investigations.

Figure 2: Weight of brick samples obtained from source1 and source2

3.1.1 Durability Study

To assess the performance of brick samples and masonry mortar for their durability various tests carried may be grouped under two divisions. At first exposure of these under aggressive environment: simulated magnesium sulphate and chloride salt environment which was artificially created in the laboratory. Secondly durability performance of these under the exposed conditions. Durability test of bricks selected from two different sources and mortar mix in presence of aggressive environment which was artificially created in the laboratory using sodium chloride and magnesium sulphate salts. Initially brick samples were visually examined to observe changes in size and shape and in turn to study the changes in density of brick samples. Finally, brick samples and mortar mix were studied under fully immersed condition to determine reduction in compressive strength to evaluate the durability parameters.

3.1.1.1 Aggressive Environment Test

Aggressive environment was artificially created in laboratory by preparing NaCl and MgSO4 salt solutions of different concentrations to evaluate the resistance of bricks and mortar exposed to salt attack in sewage treatment plants, sewer appurtenances or industrial environment by immersing the samples fully in the solution prepared for different concentration. The test involves placing the samples in the tanks of standardized solutions of 5%, 10% and 15% of NaCl for 10 weeks and 1%, 2% and 3% of MgSO4 solution for same duration. Effects of chloride and sulphate salts play vital role in producing detrimental effects of durability of brick masonry. Mean of three samples are taken. Care is taken to avoid errors in procedure.

IV. RESULTS AND DISCUSSION

Fig (a) 1% magnesium sulphate solution

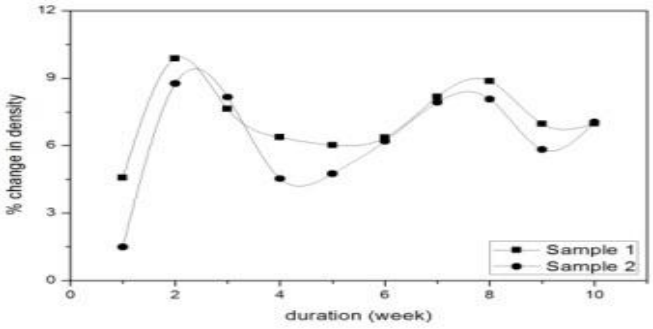

Fig (b) 2% magnesium sulphate solution

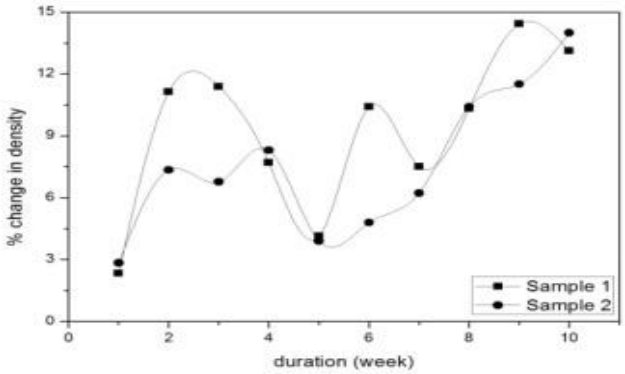

Fig (c) 3% magnesium sulphate solution

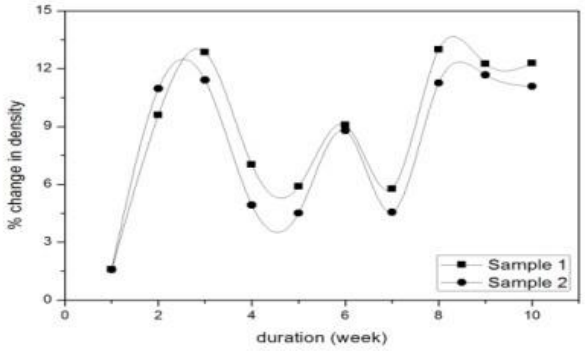

Figure 3: Percentage variation in density of different brick samples immersed in 1% , 2% and 3% magnesium sulphate solution

Fig (a) 5% sodium chloride solution

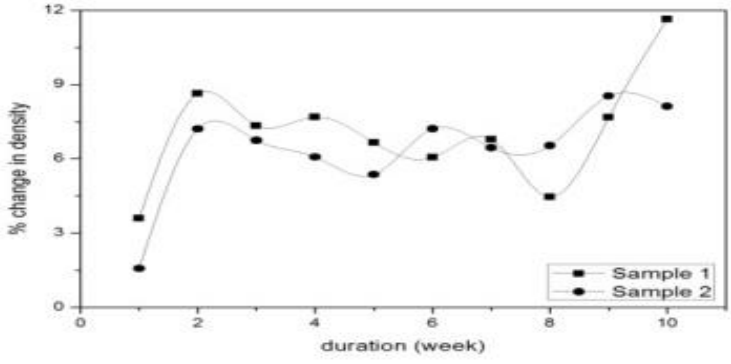

Fig (b) 10% sodium chloride solution

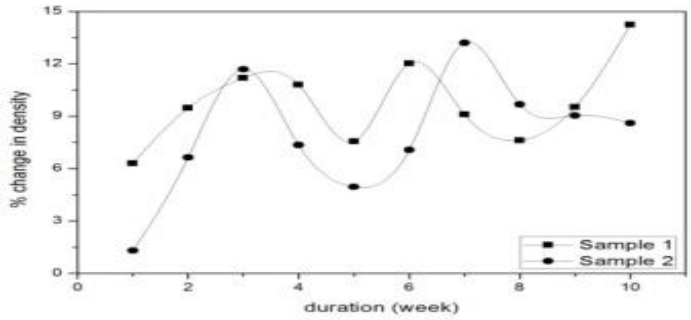

Fig (c) 15% sodium chloride solution

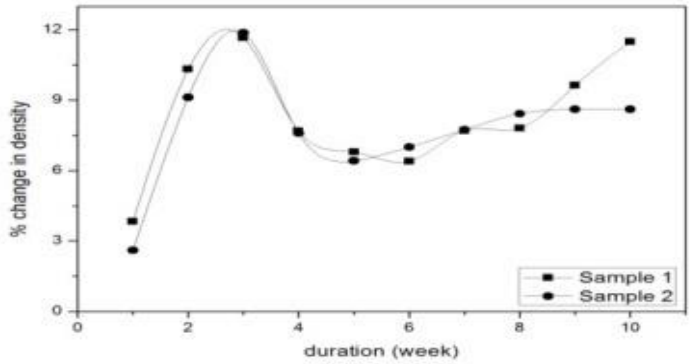

Figure 4: Percentage variation in density of brick samples immersed in 5% , 10% and 15% (sodium chloride solution

Loss in weight after every week of exposure to severe environmental condition for both magnesium sulphate and sodium chloride solution of varying concentrations was compared for the brick samples obtained from source1 and source2. The results obtained were very similar and there was no significant variation in density between source1 and source2. The graphical representation of percentage change in density is shown in Fig.3, and Fig.4.Though the change in dimensions of burnt clay bricks are independent of its composition the bimodal distribution of pores make the samples porous and the deposition of salts in these areas results in loss in weight of the brick samples thereby showing variation in their densities. The probable reason for little difference between properties of source 1 and source 2 is that the brick making earth may have some similar properties in composition.

Fig (a) 1% magnesium sulphate solution

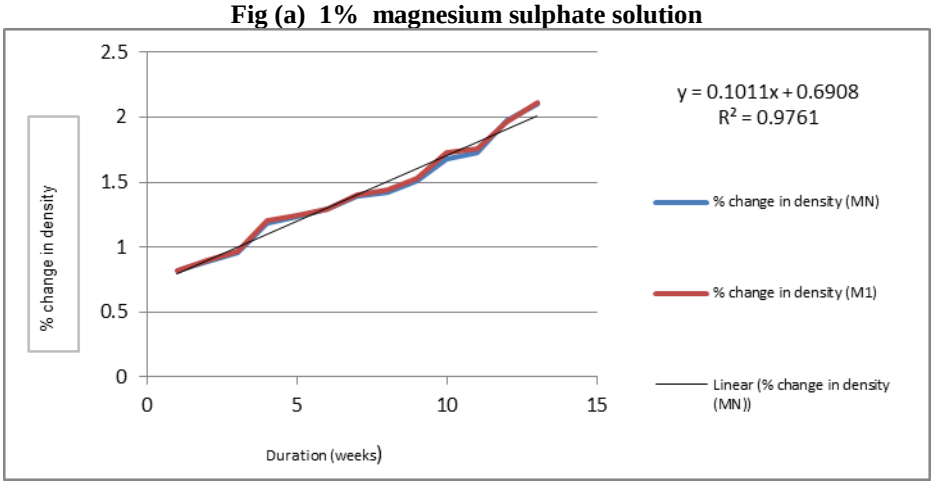

Fig (b) 2% magnesium sulphate solution

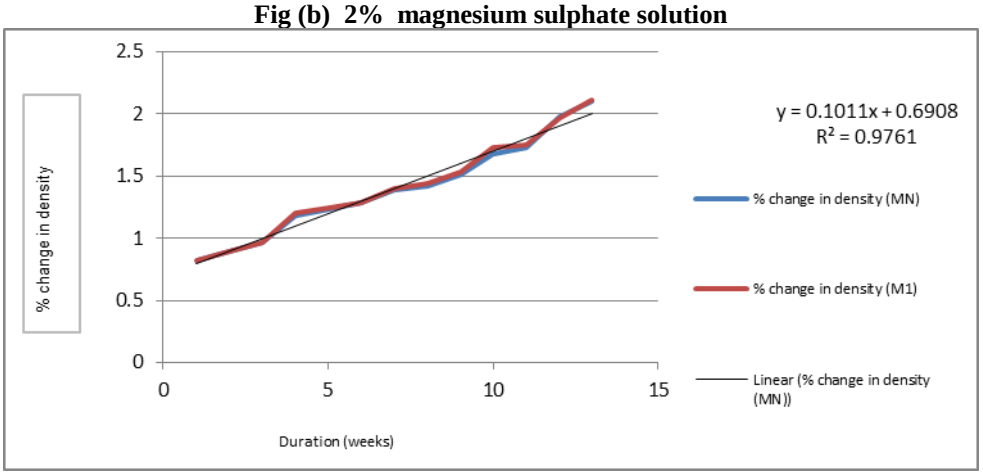

Fig (c) 3% Magnesium sulphate solution

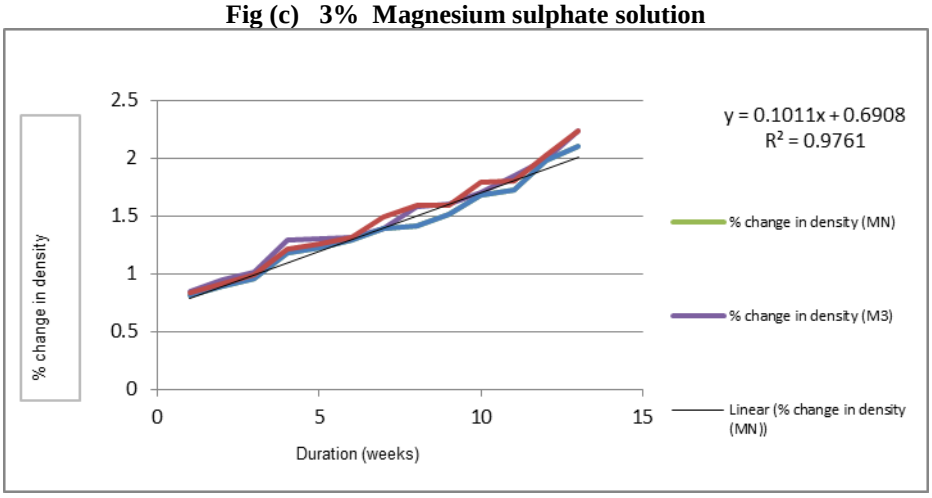

Figure 5: Percentage change in density of masonry mortar cubes immersed in 1% , 2% and 3% magnesium sulphate solution as compared with normal mortar cubes

Fig (a) 5% sodium chloride solution.

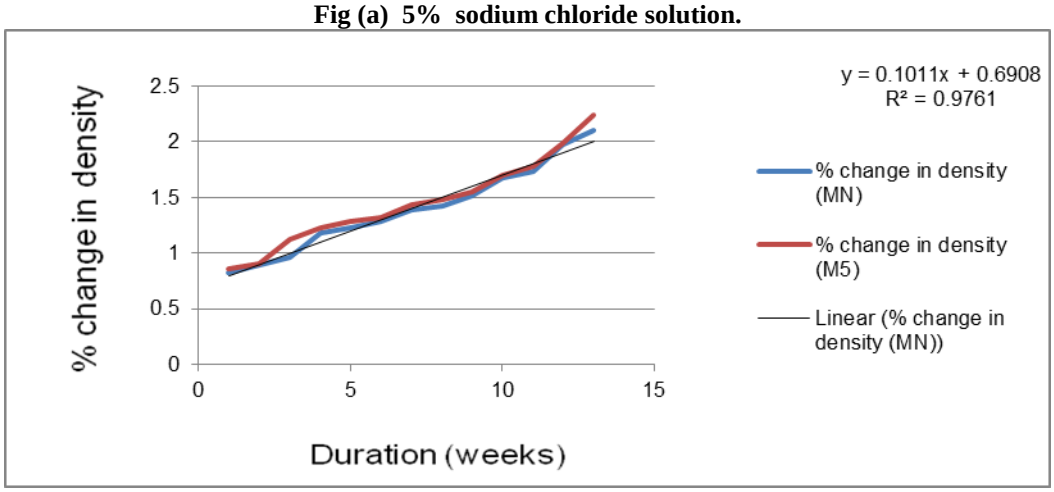

Fig (b) 10% sodium chloride solution

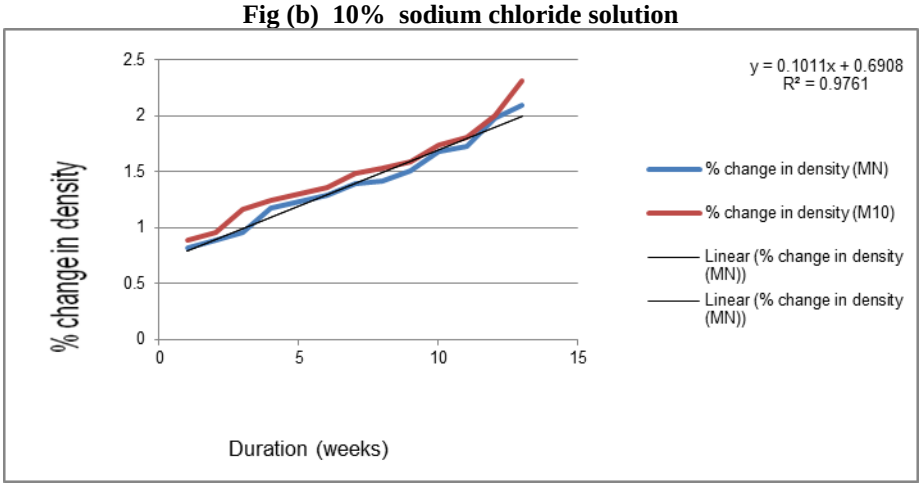

Fig (c) 15% Sodium chloride solution

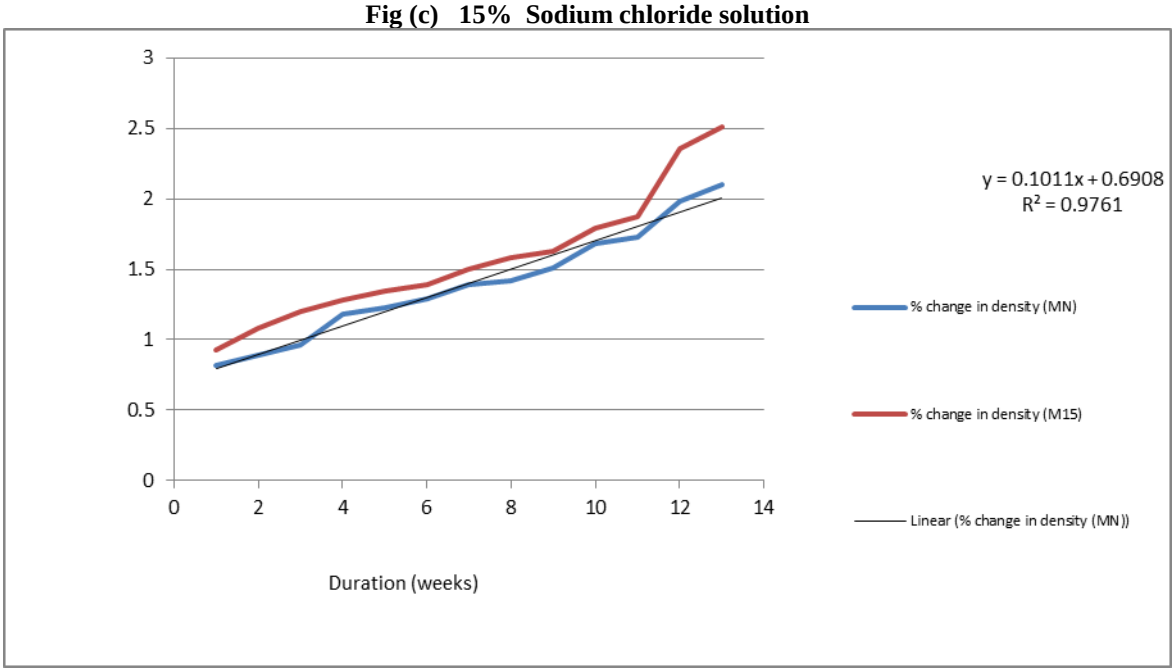

Figure 6: Percentage change in density of masonry mortar cubes immersed in 5% , 10% and 15% sodium chloride solution as compared with normal mortar cubes

The property (density) of masonry mortars immersed under simulated aggressive environment i.e, sulphate solution and normal potable water for duration of 14 weeks are represented in Fig.5. The test results show a considerable variation as the concentration of salt increases. This may be attributed due to the entry of salt into the mortar cubes through pores and absorption capacity of mortar from the environment. Similar tests were carried under chloride medium with varying concentration of salt and normal potable water which are as represented in Fig.6. Effect of chloride salt on density was predominant as the number of weeks increased compared to sulphate salt; this may be due to reason that the intrusive nature of chloride ions and crystallization of salts in pores.

Fluctuation in density is observed due to randomness in water absorption observed in brick samples collected from sourec1 and source2 and since both the sources exhibit similar earth properties, a minor variation in density for different concentration of salt exposure was observed.

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Fig (a) 1% (M_1) magnesium sulphate solution

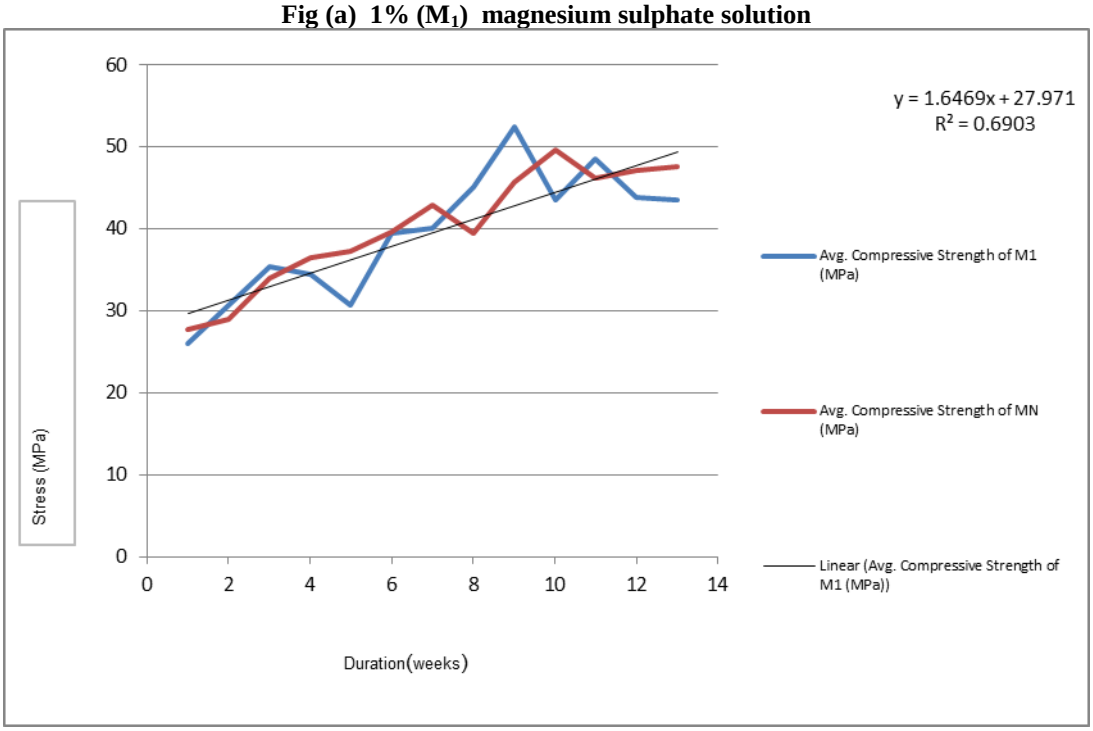

Fig (b) 2% (M_2) magnesium sulphate solution

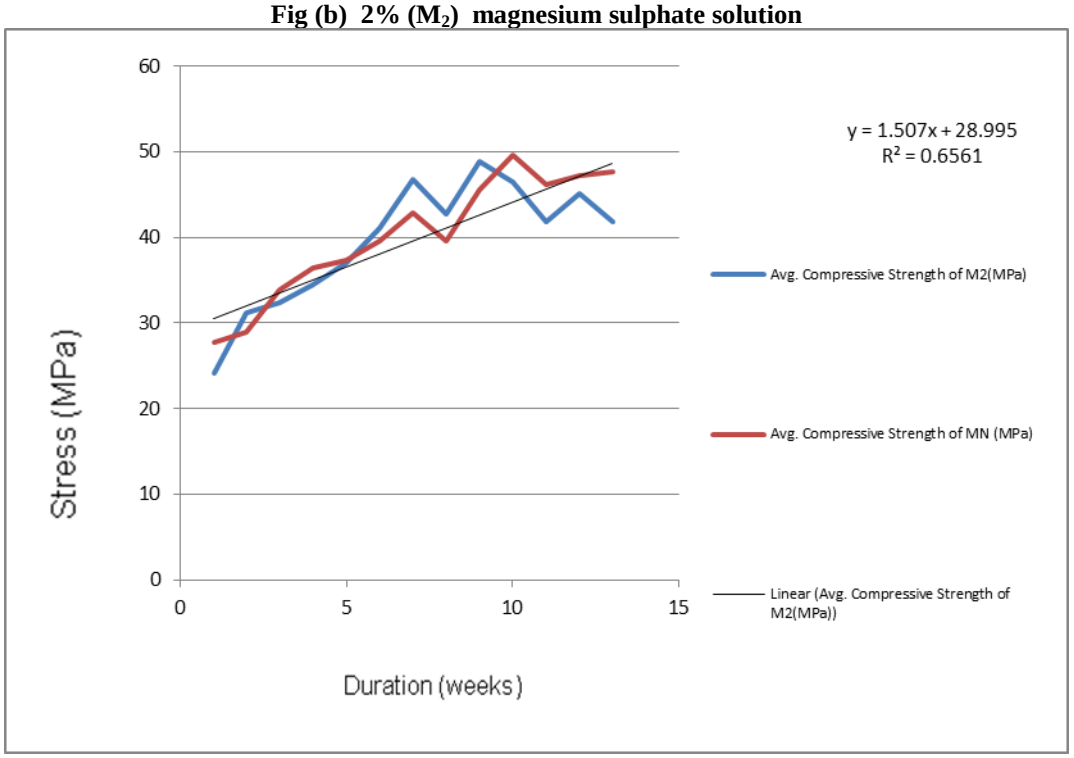

Fig (c) 3% (M_3) Magnesium sulphate solution

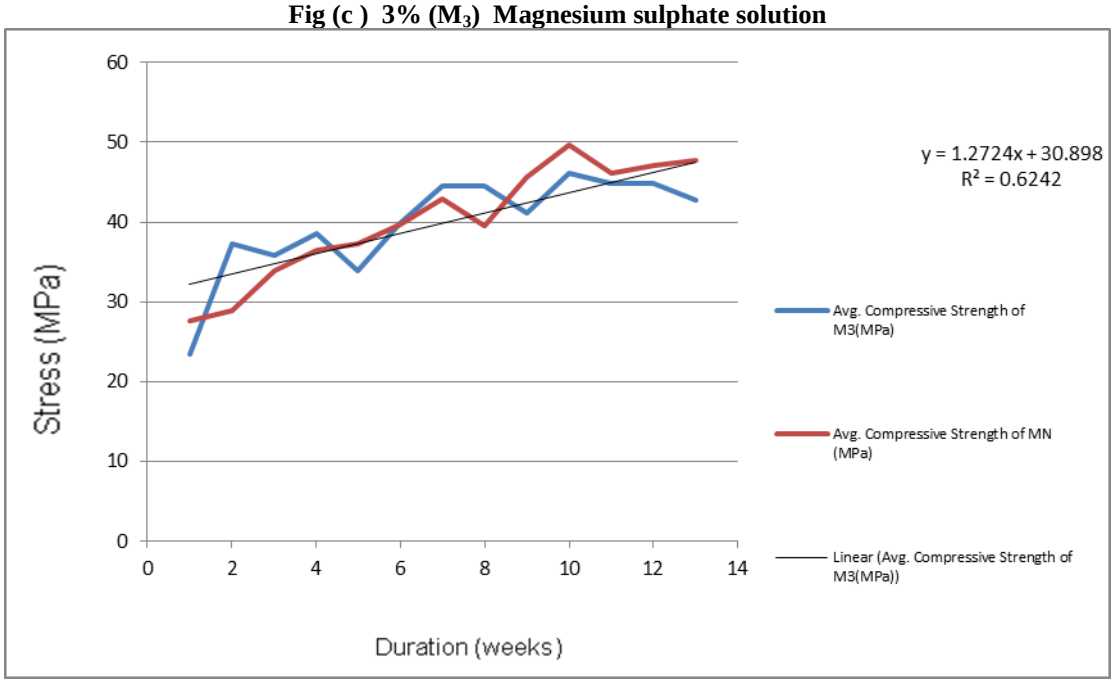

Figure 7: Comparison of compressive strength between normal mortar cubes (M_N) and mortar cubes immersed in 1%(M_1), 2%(M_2) and 3% (M_3) magnesium sulphate solution

Fig (a) 5% (M_5) sodium chloride solution

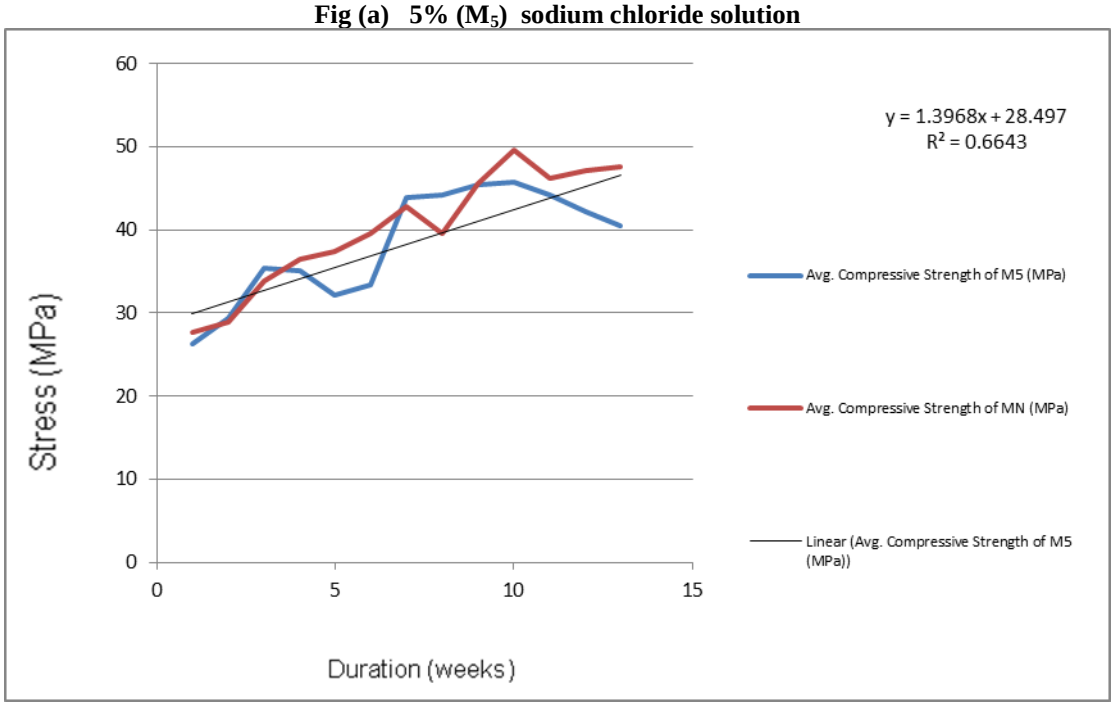

Fig (b) 10% (M_{10}) sodium chloride solution

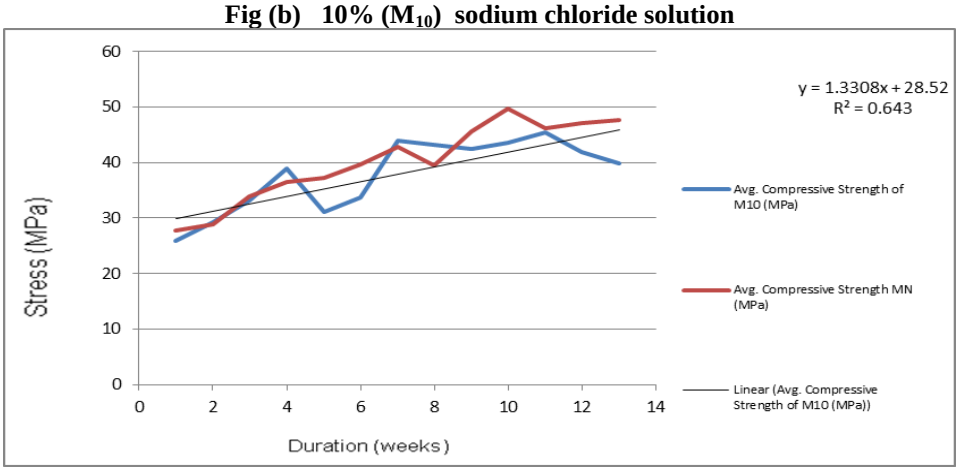

Fig (c) 15% (M_{15}) sodium chloride solution

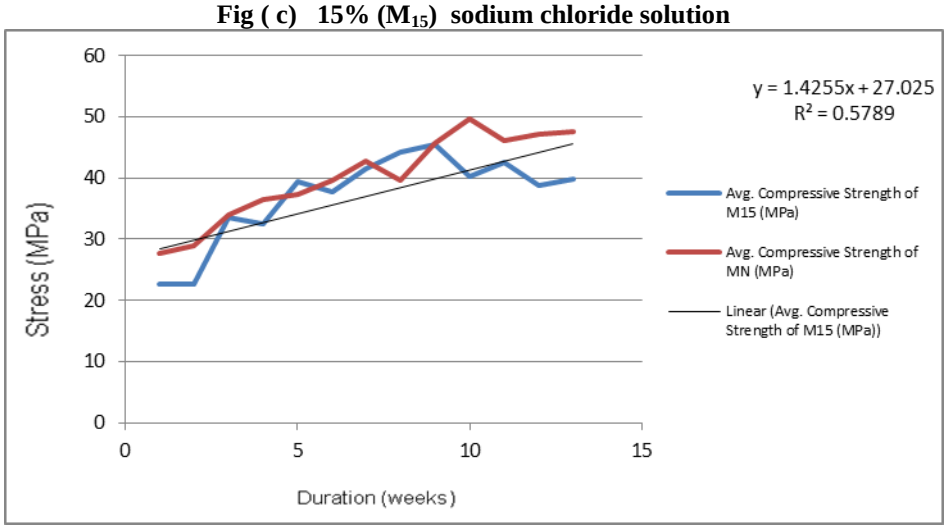

Figure 8: Comparision of compressive strength between normal mortar cubes (M_N) and mortar cubes immersed in 5% (M_5) , 10% (M_{10}) and 15% (M_{15}) sodium chloride solution

Masonry mortars exposed to severe environmental conditions were compared with mortars subjected to normal environment as represented in Fig. 7 and Fig. 8. Initially the result shows no significant variations in compressive strength between mortars under severe environment and mortars subjected to normal environment. But a wide range in decrease of compressive strengths was observed as the days of exposure increased especially in case of chloride medium. This was due to continuous exposure of mortars in salt medium and the intrusion of salts from external environment into pores and fissures of mortars which resulted in loss in strength of mortars as duration of exposure increased.

Fig(a) 5% Sodium chloride solution

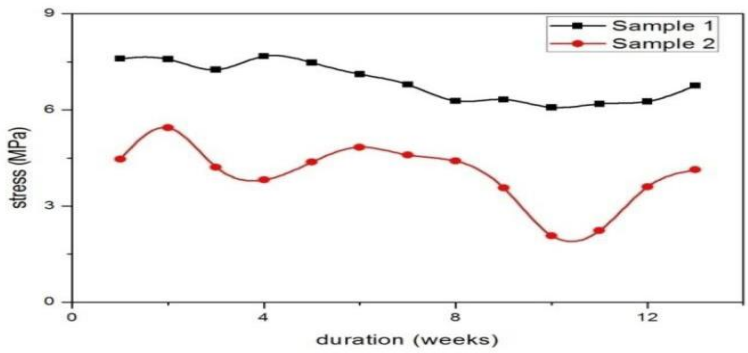

Fig (b) 10% Sodium chloride solution

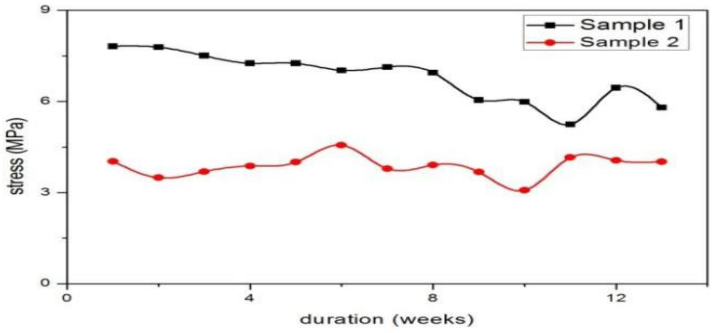

Fig (c) 15% Sodium chloride solution

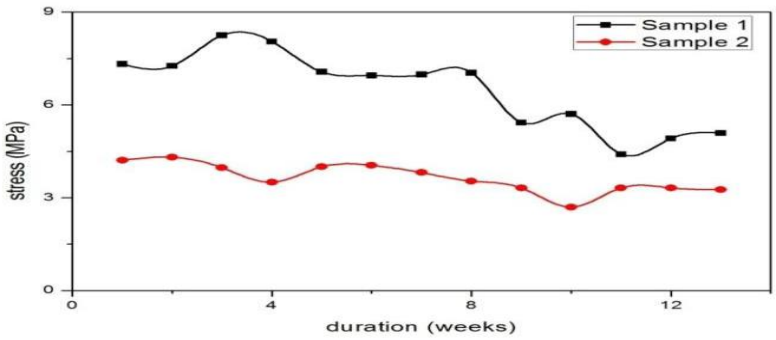

Figure 9: Comparision of compressive strength of bricks of two different sources immersed in 5%, 10% and 15% sodium chloride solution

The load displacement curves Y –axis being stress, shows the compressive strength of brick samples in MPa for brick samples exposed to chloride solution which exhibit larger displacement at the peak load with respect to each other. Conversely after 14 weeks exposed in the stimulated environment brick samples show a significant decrease in peak load. The results may be attributed due to the absorption capacity of brick samples from the simulated aggressive environment. Variation in mechanical strength of brick samples observed between the sources is primarily due to the procedural practice followed during the manufacturing of brick samples which differs from place to place as a result leading to non uniform distribution of pores which make the building material more porous and affinity towards reduction in service life of material. Experimental investigations in the present study are carried out by considering burnt clay brick samples made of different earth composition and different manufacturing process.

Fig (a) 1% Magnesium sulphate solution

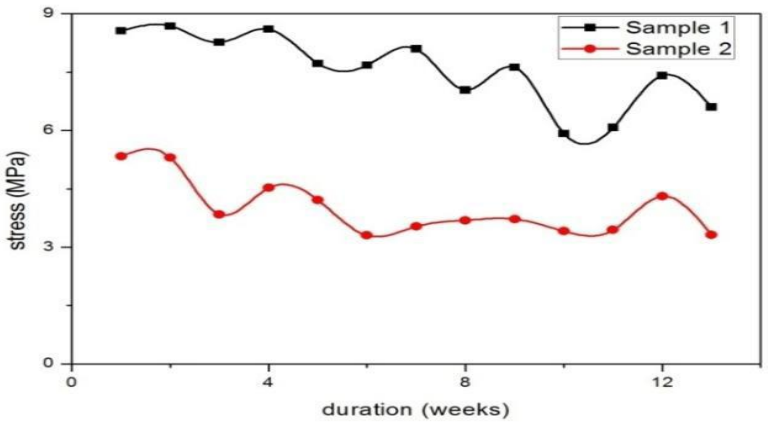

Fig (b) 2% Magnesium sulphate solution

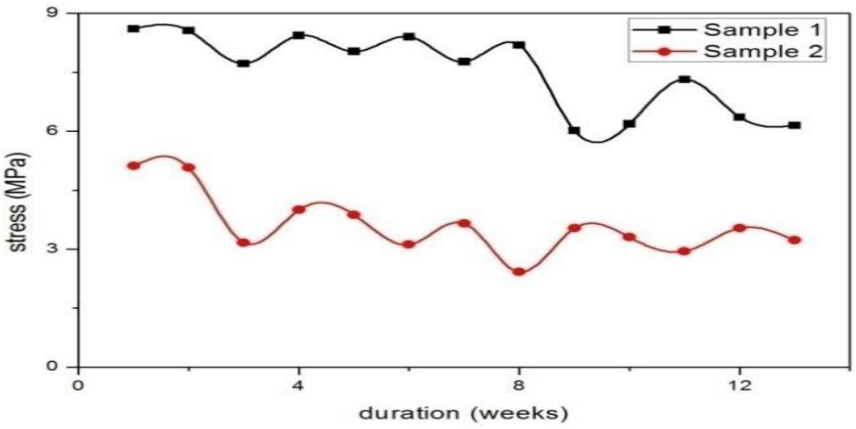

Fig (c) 3% Magnesium sulphate solution

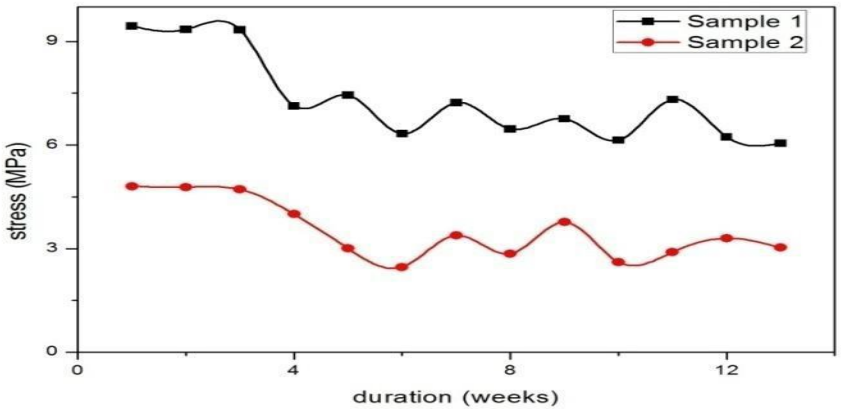

Figure 10: Comparision of compressive strength of bricks from two different sources immersed in 1%, 2% and 3% magnesium sulphate solution

The mechanical strength of brick samples under compression was compared after every week of testing. Change in strength after every week of exposure to severe environmental condition under Chloride solution and magnesium sulphate solution of varying percentage in concentration shows significant variations between the brick samples. As an example the graphical representation of change in compressive strength is shown in Fig.9 and Fig.10. This may be due to the reason that the penetration of sulphate ions through water into the building material (brick) and due to the crystallization of sulphate salt inside the pores of the sample resulting in loss of mechanical strength as the duration of exposure increased.

Reduction in strength, as the exposure duration changes can be attributed from the equations connecting strength and weeks of exposure to salty environment of different concentrations as referred in Fig. 7 and Fig.8. Decrease in R value implies strength reduction. The inherent randomness in the system causes the fluctuations in the results.

V. CONCLUSION

In the present study, experimentation is conducted to study the change in density and compressive strength performance of brick samples collected from two different sources and masonry mortar subjected to sulphate and chloride simulated aggressive environment. Such environment was created to study the effect of salt damage on durability aspect of bricks and masonry mortar (components of brick masonry) through pores under adverse environmental condition. Mechanically the samples were tested after every week for a total duration of 13 weeks and the results of the present work can be concluded as follows:

- Percentage variation in density of brick samples shows decrease in density as the concentration of the sulphate and chloride salt increases. Variation in density between the sources has been observed which is attributed due to the inherent randomness in water absorption of bricks.
- It is possible that Pollutants have entered into the brick structure through water which may seep in due to defective plastering or defective damp proof

course leading to reduction in compressive strength.

- Loss in compressive strength for brick samples and masonry mortar is attributed to salt crystallization inside the brick structure. Considerable loss in mechanical strength of brick samples as compared with masonry mortars under stimulated aggressive environment may be due to the bimodal distribution of pores in brick samples as compared with masonry mortars. Hence the durability of brick masonry is more influenced by the type and characteristics of bricks than the mortar joint.
- Failure of brick masonries exposed to aggressive environment is due to the failure of bricks rather than at its joints.

Presently, the research is in progress and further aspects are under investigation, such as the durability effects of brick masonry prisms in presence of simulated aggressive environment. A proper understanding of role of salts in the durability performance of porous masonry units is of fundamental importance where less effort has been made in Indian context.

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