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Er. Pankaj Kumar TIWARI

pankajtiwari.asi@gmail.com

Archaeological Survey of India

Govind PANDEY

Madan Mohan Malaviya University of Technology

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Belgiri Fruit Paste with Lime Mortar regarding Sustainability of Heritage Structures

Er. Pankaj Kumar TIWARI [1*] and Prof. Govind PANDEY[2]

[1*]Archaeological Survey of India, Government of India, Kendriya Bhawan, Lucknow, 226024, U.P., India. [2]Department of Civil Engineering, Madan Mohan Malviya University of Technology, Gorakhpur, 273010, U.P., India.

*Corresponding author. E-mail(s): pankajtiwari.asi@gmail.com;
Contributing authors: pandey_govind@rediffmail.com;

Abstract

This paper discusses the sustainability efforts for conservation of heritage structures with the help of natural adhesive mixed in traditional lime mortar. Every object in this world has definite life-span and grows old by ageing, and the monuments are no exception to this. Environmental factors like water, air, uneven temperature, humidity etc. and roots of self-growing vegetation cause severe damage to these ancient buildings that we can't even imagine. The nature of lime mortar is alkaline and pH more than 12.5. Its alkalinity reduces due to carbonation and results are deterioration of lime mortar. The deterioration affects an expansion in volume of binding mortar course layers/joints with stone or bricks. This expansion in volume creates cracks in lime concrete or mortar. These cracks further create a situation for carbon dioxide thus the regular cycle continues and ultimately structures in a critical state. Carbonation is the result of the dissolution of carbon dioxide in the lime mortar or lime concrete pore fluid and this reacts with calcium from calcium hydroxide to form calcite ($CaCO_3$).

The structural conservation work with the help of traditional lime mortar (mix of Lime, Sand and Surkhi) used in a specific ratio with necessary and important natural adhesives like Bel fruit paste, Babool gum, Gur/molasses, Urad dal paste, chicken egg gel within a required manner and proportion may be useful to conservation, for sustainability of lime mortar to avoid the carbonation of mortar. The structural cracks should be controlled through proper grouting & stitching work, wherever required in lime mortar by addition of natural adhesives. Proper drainage system and traffic diversion are very important aspects for further sustainability.

After study, it is found that no weathering effect seems. So, it may be pointed out that carbonation effect may be reduced in lime mortar by addition of natural

adhesives and among them Bel fruit Paste as a natural adhesive is more useful. This research paper may be useful for other relevant structures for conservation with sustainability effort.

Keywords: *Lime Mortar; Sustainability; Natural Adhesive; Climate Change; Pollution; Conservation;*

1 Introduction

Archaeological survey of India, undertakes actions to maintain and conserve centrally protected monuments for the future generation by upkeep it day to day and making all efforts to restore its ancient essence, integrity and its historical values. The main principles of conservation of heritage structures is to use the traditional materials and lime mortar as per original. [2] These collective efforts are known as conservation. Recently ASI, Lucknow Circle initiated many major structural conservation works, among them the most noticeable one was the structural conservation work carried out at Rumi Gate, Lucknow, the signature building of Awadh Architectural style

Rumi Gate in Lucknow, India was built in 1784 and later became the symbol for the city of Lucknow. From top of the central Chatri to ground level, its height is 100 feet. Many major floods in the past like 1891, 1894, 1923, 1960 and the present presence of Carbon Dioxide in the atmosphere affected the sustainability of the structure.

During conservation of Rumi Gate and its adjoining structures, it was found that in the last few decades, carbonation affected the lime mortar due to presence of Carbon Dioxide in atmosphere and similarly climate change like temperature and humidity in such regions. Due to the Carbonation effect, the lime mortar gradually loses its binding strength and overall the structure gradually decreases its structural strength and after regular weathering effects, there was a big problem regarding sustainability for the structure.

2 Assessment principle

• Carbonation is a slow process. The carbonation highly depends on humidity, temperature and atmospheric carbon dioxide CO2. The attack of the atmospheric CO2 reduces the alkalinity in the lime mortar/ concrete. The lime mortar/concrete porosity allows the CO2 to react with the alkalis like calcium, hydroxides which are formed due to hydration. The reaction produces the carbonates which reduce the level of concrete pH. When carbonates ingress deeply in lime mortar / concrete, they also break the protective passive film of the steel rods used in ancient buildings. So the oxygen and moisture are easily available to steel rods, and it gets corroded and cracks in structures, due to the expansion. Hence we need to perform the carbonation test to determine the level or degree of carbonation to evaluate the rate of corrosion considering the Climatic factors. [1]

- Age of historic building
- Material of construction
- Damage area of structure
- Local atmosphere/ climate.

2.1 Lime Cycle

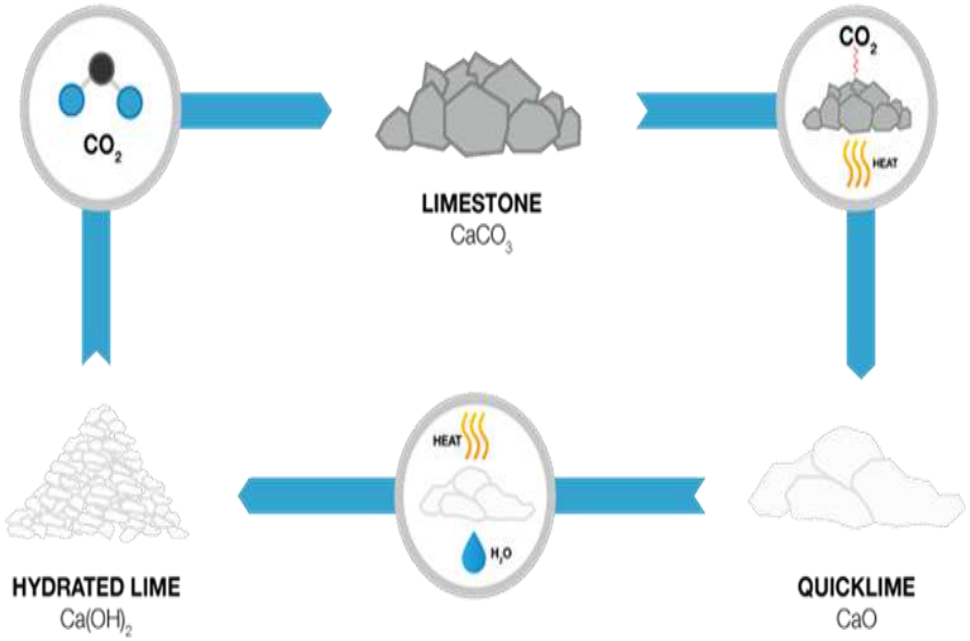


Image. 1 Lime cycle

2.1.1 Carbonation Principles

The percentage CO2 present in air varies from place to place. In the case of rural areas the concentration of CO2 in air may be about 0.03% by volume, whereas in urban areas it may vary from 0.3% to 1%. This CO2 in presence of moisture changes into dilute carbonic acid and attacks the concrete and reduces alkalinity of concrete. [3]

Due to reduction of alkalinity of concrete, the pH value of pore water in the hardened lime mortar/concrete reduces from 13 to 9. When all the Ca (OH) 2 has become carbonated, the pH value again reduces to about 8.3 and at this low pH value, the protective layer gets destroyed and the mortar/concrete may further in damaging state.

3 Mechanism of Carbonation

CO_2 (g) + H_2O = HCO_3 - (bicarbonate ion) +H+

HCO_3- = CO_3 2- (carbonate ion) + H+

The carbonate ion will react with Ca ions in the pore solution.

Ca^{2+} + CO_3 2- = $CaCO_3$

This will lead to lower concentration of Ca^{2+} which in turn will lead to dissolution of primarily calcium hydroxide (CH). The solubility of CC is much lower than that of CH.

Ca (OH) 2 = Ca^{2+} + 2 OH^-

Ca^{2+} + CO_3 2- = $CaCO_3$

3.1.1 Methodology for research work

- Collection of lime mortar preparation techniques
- Damages records of monuments
- Data of Conservation during past time
- Identifying the main causes of problems
- Study the similar work done on any other site monuments
- Carbonation depth testing after acceleration of CO_2
- Comparative study and analyzing as per natural adhesives

4 Sample Testing

• The methodology is used to determine the damages (depth of carbonation) to lime mortar/ lime mortar cubes samples of respective mix ratio of lime mortar using lab testing methods in an accelerated condition of carbonation chamber of 4% CO_2 , RH 65% and temperature at 30 degree Celsius.[4]

• Phenolphthalein Indicator to find out carbonated regions.

• The carbonation depth is approximately proportional to the square root of time. For example, if the carbonation depth is 1mm in a one-year-old lime mortar / concrete, it will be about 3mm after 9 years, 5mm after 25 years and 10mm after 100 years.

• Carbonation Depth in mm = k √ Time in years* (* Appendix)

4.1 Stages of Work Plan, Testing facilities & Preparation

• **Step 1:** The analysis of binders for lime mortar, for sample categories in 600 micron,

1.18 mm and 2.36 mm of IS sieve analysis for sand and Surkhi.

• **Step 2:** The Quick Lime/Burnt lime and Hydrated Lime/Slaked lime are mixed with binders in ratio (1 Lime: 1 Sand 1 Surkhi) for sample categories each separately in 600 micron, 1.18 mm and 2.36 mm of IS sieve for sand and Surkhi for making lime mortar 108 samples cubes of 7.5 cm x 7.5 cm x 7.5 cm. with natural adhesive and another 108 sample cubes without natural adhesive, the same mortar used during Rumi gate conservation.

• **Step 3:** The 36 nos of cubes sample after 7 days curing placed in carbonation chamber in accelerated condition of 4% CO2, RH 65% and temperature at 30 degree Celsius and also 36 nos of cubes sample of lime mortar mixed with some fine admixtures without any day curing placed in carbonation chamber in accelerated condition of 4% CO2, RH 65% and temperature at 30 degree Celsius, repeated for another 36 cubes with curing, and same for another 108 cubes with natural adhesive.

• **Step 4:** Each sample of mix ratio categories tested for carbonation depth after 7 days, 14 days, 21 days and 28 days with Phenolphthalein Indicator.

Step 5: After 28 days results of carbonation depth of cube samples, the comparative study pointed out. Carbonation is a slow process. The carbonation highly depends on humidity, temperature and atmospheric carbon dioxide CO2. The attack of the atmospheric CO2 reduces the alkalinity in the lime mortar/ concrete. The lime mortar/concrete porosity allows the CO2 to react with the alkalis like calcium, hydroxides which are formed due to hydration. The reaction produces the carbonates which reduce the level of concrete pH. When carbonates ingress deeply in lime mortar / concrete, they also break the protective passive film of the steel rods used in ancient buildings. So the oxygen and moisture are easily available to steel rods, and it gets corroded and cracks in structures, due to the expansion. Hence we need to perform the carbonation test to determine the level or degree of carbonation to evaluate the rate of corrosion considering the Climatic factors. [1]



Image. 2 Lime mortar cubes in a Carbonation chamber of 4% CO2, with adjusted RH 65% and temperature at 30 degree Celsius.

4.2 Lab Testing regarding Carbonation

•The affected depth from the cube of lime mortar /concrete surface can be readily shown by the use of phenolphthalein indicator solution. Phenolphthalein is a white or pale yellow crystalline material. For use as an indicator it is dissolved in a suitable solvent such as isopropyl alcohol (isopropanol) in a 1% solution.

•The carbonation depth is approximately proportional to the square root of time. For example, if the carbonation depth is 1mm in a one-year-old lime mortar / concrete, it will be about 3mm after 9 years, 5mm after 25 years and 10mm after 100 years.* (*Appendix)

5 Results and Analysis with Observations

5.1 Carbonation Depth of lime mortar sample cubes mix ratio (1:1:1) of lime, sand & Surkhi, curing 7 days after cube casting (Quick Lime / Burst Lime) without slaking of lime and **without natural adhesive**.

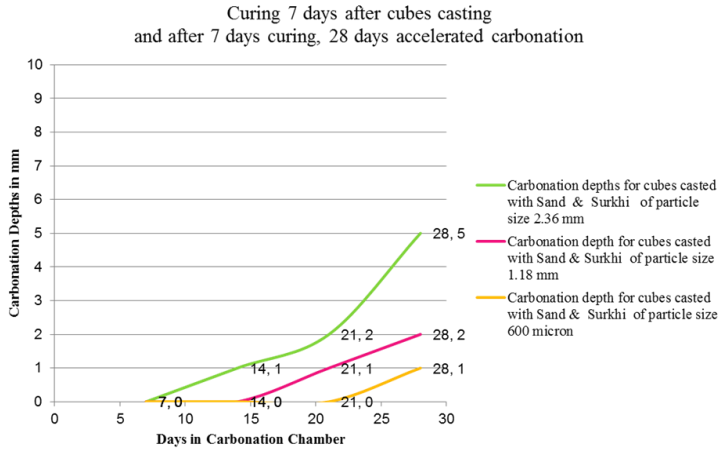


Fig. 1 Carbonation depth

5.2 Carbonation Depth of lime mortar sample cubes mix ratio (1:1:1) of lime , sand & surkhi, with 7 days curing after cube casting (Hydrated Lime/Slaked Lime) with slaking of lime and **without natural adhesive**

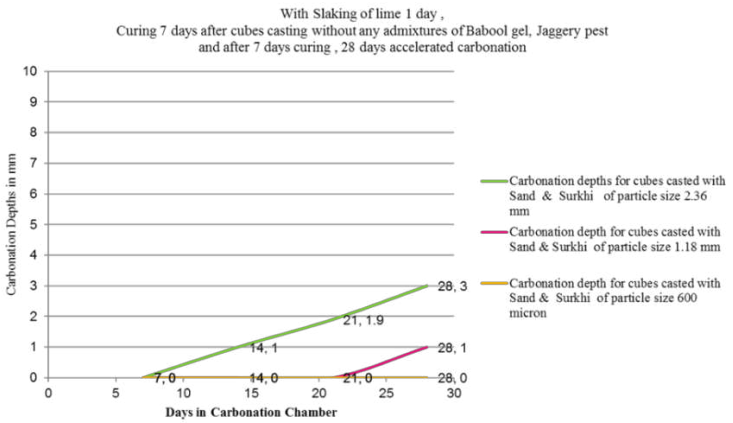


Fig. 2 Carbonation depth

5.3 Carbonation Depth of lime mortar sample cubes mix ratio (1:1:1) of lime, sand & Surkhi, with admixtures/adhesive of Babool gel, Jaggery paste, Belgiri paste with 14 days curing after cube casting (with Slaked Lime) and **with natural adhesive.**

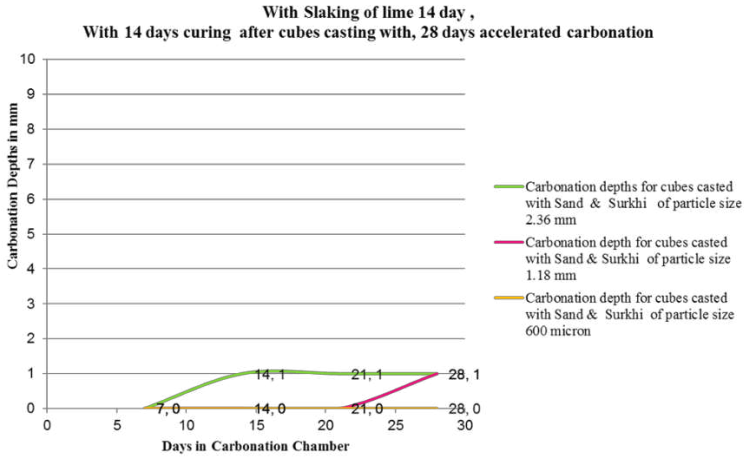


Fig. 3 Carbonation depth

5.4 Carbonation Depth of lime mortar sample cubes mix ratio (1:1:1) of lime, sand & surkhi, with admixtures/ natural adhesive of Babool gel / paste only with 14 days curing after cube casting (with SLAKED LIME).

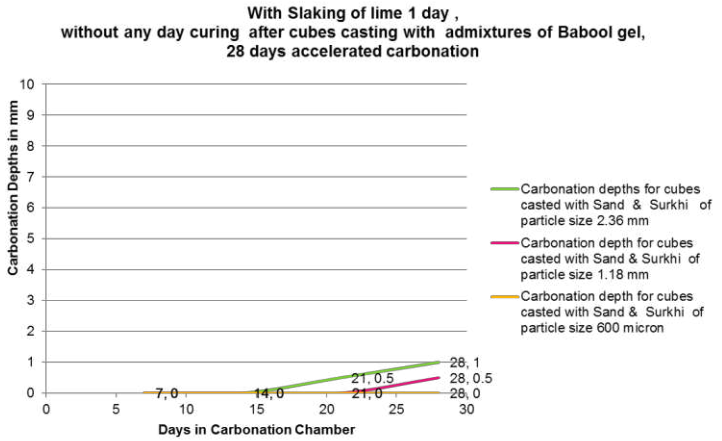


Fig. 4 Carbonation depth

5.5 Carbonation Depth of lime mortar sample cubes mix ratio (1:1:1) of lime, sand & surkhi, with admixtures/ natural adhesive of Jaggery paste only with 14 days curing after cube casting (with SLAKED LIME).

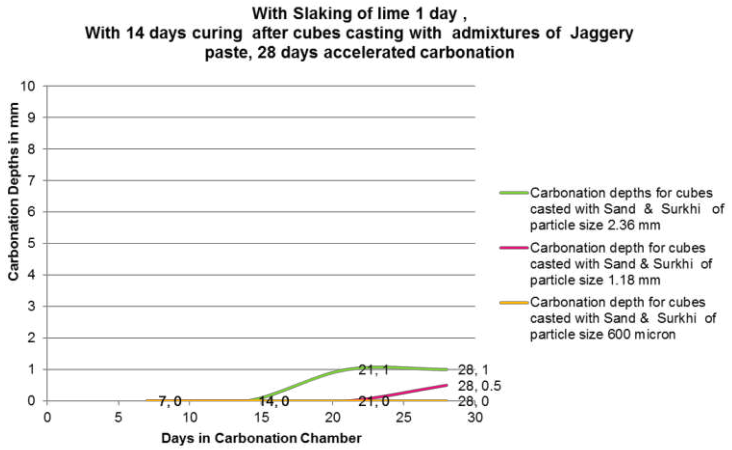


Fig. 5 Carbonation depth

5.6 Carbonation Depth of lime mortar sample cubes mix ratio (1:1:1) of lime, sand & surkhi, with admixtures/ natural adhesive of Belgiri paste only with 14 days curing after cube casting (with SLAKED LIME).

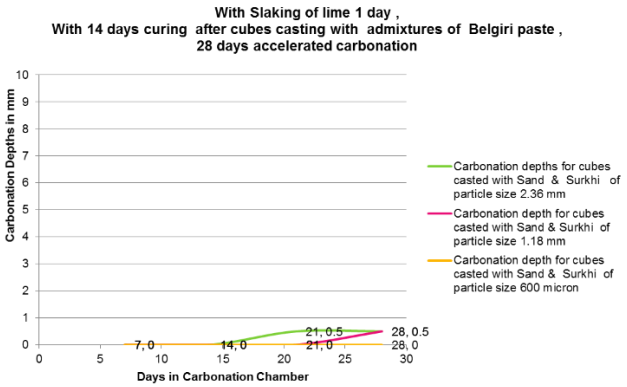


Fig. 6 Carbonation depth

5.7 Carbonation Depth of lime mortar sample cubes mix ratio (1:1:1) of lime, sand & surkhi, with admixtures/ natural adhesive of Urad dal paste only with 14 days curing after cube casting (with SLAKED LIME).

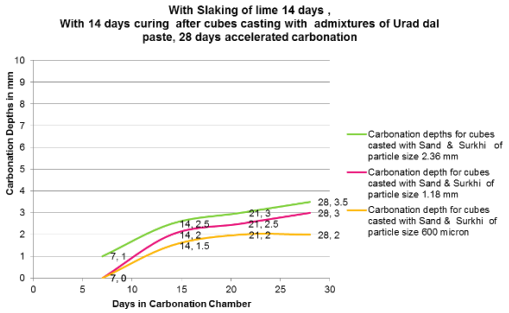


Fig. 7 Carbonation depth

5.8 Carbonation Depth of lime mortar sample cubes mix ratio (1:1:1) of lime, sand & surkhi, with admixtures/ natural adhesive of Chicken Egg gel/ egg liquid with 14 days curing after cube casting (with SLAKED LIME). (The source of the eggs, we bought from poultry in Lucknow area.)

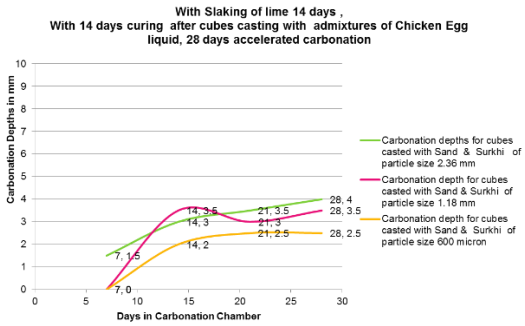


Fig. 8 Carbonation depth

6 Discussion

The higher relative humidity around and inside the monuments/structures, there are possibilities of reaction between the calcium carbonate and carbon dioxide changing into bicarbonates with time, and causing loosening of the grains and after this type of regular happenings, the weathering effect damages the monuments and their structure.

Carbonation in lime mortar depends on grain size of sand and other binding materials with presence of carbon dioxide in humid atmosphere with more than average daily temperature.

Buildings in the region suffer mostly, where temperature almost three months in every year above than varying from average daily temperature between 30 to 45 °C and humidity due to rainy season and fog in winter season.[5]

The nature of lime mortar is alkaline and pH more than 12.5. Its alkalinity reduces due to carbonation and results are deterioration of lime mortar. The deterioration affects an expansion in volume of binding mortar course layers/joints with stone or bricks. This expansion in volume creates cracks in lime concrete or mortar. These cracks further create a situation for carbon dioxide thus the regular cycle continues and ultimately structures in a critical state. Carbonation is the result of the dissolution of carbon dioxide in the lime mortar or lime concrete pore fluid and this reacts with calcium from calcium hydroxide to form calcite ($CaCO_3$).[7]

Carbonation tests may be better to know the effect of the atmospheric carbon dioxide on the lime mortar of monuments/structures. The carbonation test for in-situ lime mortar cube is associated with the deterioration often occurring on the building facades which are exposed to moisture, rainfall and shaded from sunlight.[6]

For analysis of the carbonated area of lime mortar used, the carbonation test done in INTACH lab Lucknow and found very good indication result as shown in Table 2 and Fig. 6 as per comparison with fig.1,2,3,4,5,7 & 8.

Table 1 Carbonation test result with remark

Group of samples	Test result of used mortar with natural adhesives	Test result of unused mortar without natural adhesives (only for test)	Remarks
1st group of sample	2% area carbonated	8% area carbonated	99% safe condition of lime mortar mixed with natural adhesives for sustainability indication
2nd group of sample	1% area carbonated	8% area carbonated	99% safe condition of lime mortar mixed with natural adhesives for sustainability indication
3rd group of sample	2% area carbonated	8% area carbonated	–do–

Table 2 Carbonation test result with remark

Group of sample	Lab. Test Result of used mortar with natural adhesives	Test result Indication for sustainability as per practical site observations during and after Conservation of Rumi Gate Heritage structure, Lucknow	Remarks
1st group of sample mixed with only **Babool gel / Paste**	2% area carbonated	Good	98 % Safe condition of lime mortar mixed with natural adhesives for sustainability indication
2nd group of sample mixed with only **Molasses / Jaggery**	1.5 % area carbonated	**Very good**	98.5% Safe condition of lime mortar mixed with natural adhesives for sustainability indication
3rd group of sample mixed with only **Belgiri fruit gel/ fruit liquid Paste**	1 % area carbonated	**Excellent**	99% Safe condition of lime mortar mixed with natural adhesives for sustainability indication
4th group of sample mixed with only **Urad Dal Paste**	3 % area carbonated	Satisfactory	97 % Safe condition of lime mortar mixed with natural adhesives for sustainability indication
5th group of sample mixed with only **Chicken Egg Gel/Liquid**	4 % area carbonated	Unsatisfactory	96 % Safe condition of lime mortar mixed with natural adhesives for sustainability indication

7 Conclusion

The structural conservation work with the help of traditional lime mortar (mix of Lime, Sand and Surkhi) used in a specific ratio with necessary and important natural adhesives like Bel fruit gel, Babool gum, Gur/molasses, Urad Dal Paste, chicken egg liquid within a required manner and proportion may be useful to conservation, for sustainability of lime mortar to avoid the carbonation of mortar. The structural cracks should be controlled through proper grouting & stitching work, wherever required in lime mortar of mix ratio (1:1:1) 1 lime, 1 Coarse sand, 1 Surkhi with addition of 1/8th (by volume) Bel fruit gel/ paste as a natural adhesives. Proper drainage system, seismic safety and traffic diversion are other aspects for further sustainability of heritage structures.

The individual effect of carbonation related to each natural adhesive analyzed with observation and it may be pointed out that Belgiri gel/Paste may be more useful regarding sustainability of traditional lime mortar comprising with other traditional natural adhesive.

After study, it is found that Bel fruit paste mixed with lime mortar mix ratio (1:1:1) 1 lime, 1 Coarse sand, 1 Surkhi* (*made from 1st class bricks bats) with addition of 1/8th (by volume) Bel fruit gel/ paste have no weathering effect and its compressive strength suited for load bearing structures. So, it may be pointed out that carbonation effect may be reduced in lime mortar by addition of Belgiri gel/Paste as natural adhesives.

This study may be useful for other relevant heritage structures for conservation, where lime mortar uses are very important part of conservation due to maintain the heritage significance of structure for sustainability with original mortar.

Acknowledgements.

1. Archaeological Survey of India, Lucknow Circle

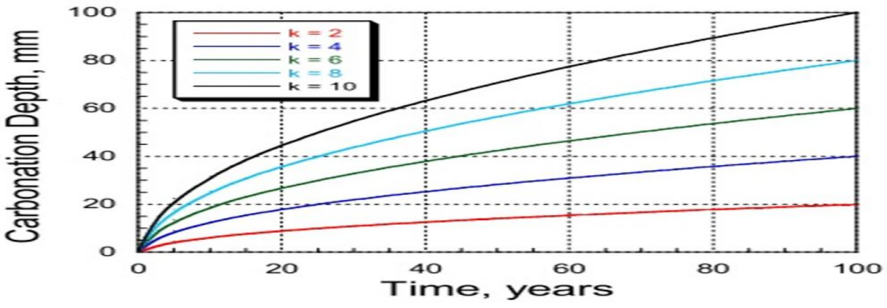
2. Carbonation concept creation of Honorable Prof. Devendra Mohan, CED, IIT-BHU, Varanasi and. Labs of Civil Engg. Dept. of IIT-BHU, India

3. Testing Lab, INTAC, Lucknow, India

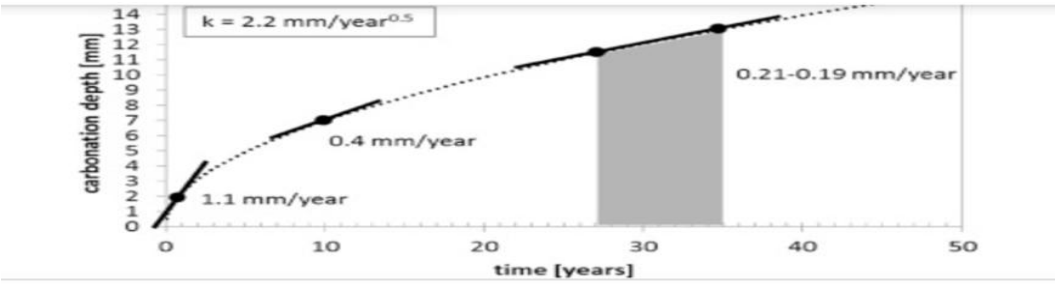
Declarations

- Funding- Authors **self-funded** for this research work.
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- Ethics approval and consent to participate-**A sentence confirming that informed consents were obtained from all participants**
- Consent for publication- **A sentence confirming that informed consents were obtained from all participants**
- Data availability statement- (**Yes) only test result of carbonation generated and analyzed. All data supporting the findings of this study are available within the paper and its Supplementary information and tables in manuscript, along with original reference describing the graph generated in this study.**
- Materials availability- **Corresponding author**
- Code availability-**'Not applicable'**
- Author contribution- Author 1(Er. Pankaj Kumar Tiwari) researched, write, and Author 2 (Prof. Govind Pandey) read, reviewed and approved the final manuscript.

Appendix A



Appendix. Fig.A Service life analysis of reinforced concrete structure under uniform corrosion through ANN model coupled to the FEM.html



Appendix. Fig.B * H. Klopfer, The carbonation of external concrete and the control of it, Bautenschutz Bausanier. 1 (3) (1978) 86–97).

- The carbonation is governed by the diffusion of carbon dioxide within concrete, the square root of time formula is commonly used for carbonation modelling. The CO2 diffusion model proposed by Klopfer [*] is based on the analytic solution of Fick's first law in the form:
- $xCO2 = k \sqrt{t}$ where: xCO2 (m) is the carbonation front depth, t (s) is the exposure time and the carbonation coefficient k (m/s1/2) is determined as: $k = \sqrt{2}.DCO2.(CO2)ext/a$
- Where: DCO2 (m2/s) is the CO2-diffusion coefficient in carbonated concrete, a (kg/m3) is the amount of CO2 absorbed. Depending on the models were developed, more or less material variables, technological and environmental factors are taken into account.
- (*H. Klopfer, The carbonation of external concrete and the control of it, Bautenschutz Bausanier. 1 (3) (1978)

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[7] I.S.O Codes regarding testing of concrete, Part 12: determination of Carbonation resistance of Concrete- Accelerated carbonation method, ISO 1920-12:(2015)

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- labtestb.jpeg
- Labtestd.jpeg