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Strength Prediction Model for Corroded Reinforced Concrete (RC) Elements Using MATLAB

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Abstract

Concrete structural degradation due to reinforcement corrosion is a major durability issue all over the world, particularly when exposed to a marine or harsh environment. When exposure exceeds the limit state, bond strength and compressive strength come into account. In the present work, we have considered concrete parameters like concrete cover, embedded length, steel type and diameter of the bar and temperature and relative humidity as atmospheric parameters. By making trials and errors like varying concrete parameters to minimum and maximum for constant value of atmospheric parameters values predicting the compressive strength and bond strength and plotted graph for the same to show the variation. Determined Temperature Humidity Index (THI) with respect to temperature and relative humidity to predict the heat stress in structures.

Keywords: *Corrosion, atmospheric parameters, bond strength, MATLAB.*

INTRODUCTION

Corrosion is the natural phenomenon attracts metal and corrodes in presence of air. This process may affect the stability aspects of the structure which might include bond strength between steel and concrete mainly which causes deterioration of structure resulting in decreasing serviceability and performance of structure.

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Bond strength is the adhesive force which holds concrete and steel bars together. It might depend on many other structural parameters, where corrosion is of prime importance. By knowing the bond strength, we are able to find compressive strength, tensile strength and other related stability aspects of structure. Bond strength gradually get decreases on corrosion and affects the strength. Corrosion occurs mainly due to atmospheric conditions like salinity, temperature, relative humidity and this process mainly occurs in coastal areas because of presence of salt content in water.

By considering the concrete parameters like concrete cover, embedded length, diameter of bar, steel type, corrosion rate and atmospheric parameters like temperature, relative humidity, model can be prepared and analysing the model gives the proper result of bond strength. Stability can be analysed by various software, but to get accurate and precise results, models can be prepared and analysed in software called MATLAB which helps in further studies.

In general, corrosion can be defined as declination of metal by electrochemical process. The main characteristic of corrosion is oxidation and reduction process. It occurs because metals are conductive in nature, so electrons can move through material from anodic to cathodic region. Thin film of absorbed moisture or water is essential to transport ions from different regions.

It is of two steps process.

1. When the metal is under stress or separated from the air, metal ions breakdown in the moisture film and electrons travel to another location.

2. When they are taken by oxygen which is a depolariser, resulting in the formation of hydroxide ions further reacts with Fe2+ to form the combination of hydrous iron oxides called as rust.

Corrosion is threatening and very expensive problem. Because of corrosion buildings, structures, bridges would collapse, petroleum pipelines may break, nuclear power plants may leak. Corroded electrical wires can cause fire accidents and other issues. Air pollution and blood poisoning can be caused due to corrosion damages and corroded medical implants respectively.

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There are many methods to control corrosion. Some metals have natural passivity, natural resistant to corrosion. It happens when metal corrodes in the presence of air, there is a thin oxide film is formed which resist metal to undergo future reactions. Massive structures like bridges, protection might fail due to destruction of formed thin film by structural stress. At that case, only the few parts of object get corroded, further damage can continue as it is concentrated in these sites.

There are numerous ways to control harmful corrosion. By producing passive films on metals through electrical currents that do not normally have them. In particular environments, some metals are even more stable and in order to improve the performance under different conditions, scientists have discovered alloys like stainless steel. Laser method can be used to treat some metals to make them non crystalline structure to resist corrosion. Iron or steel is covered with zinc to form galvanic cell where zinc gets corroded rather than iron which is called galvanisation. Electroplating can also be done to some metals. Non- metallic coatings like paints, plastics and oils can also reduce corrosion.

Stability Analysis

Bonding in reinforced cement concrete can be defined as “adhesion which is formed between cement concrete and steel which usually increases the strength”.

The bond ensures that there is little or no slip of steel bars relative to concrete and the means by which stress is transferred across the steel-concrete.

Bond strength depends on strength of concrete, concrete cover, diameter of steel bars, distance between steel bars, corrosion level, crack width.

When the reinforcing steel gets corroded in the structure, there will be many damages like reduction in steel reinforcement cross sectional area, reduction in concrete cover, cracking and spalling of concrete, decreasing in the bond strength and many more. These damages further decrease the load carrying capacity of the structure and affect the integrity.

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LITERATURE REVIEW

***Nolan C, et.al.,1 "Bond strength prediction model of corroded reinforcement in concrete using neural network".**

The development of cracks in reinforced concrete structures is caused by the expansion of corrosion products at the steel-concrete contact, which creates radial tensile stress. The bond reduction caused by this corrosion-induced crack involves complex non-linear interactions.

A unique bond prediction model employing artificial neural network (ANN) was created for the bond strength of corroded re-bars in concrete. 500 A/cm2 current density was used to accelerate corrosion on 108 cube samples. Using a single pull out test, the steel bond strength of concrete cube samples exposed to corrosion for 35 and 70 days was determined. The predictors in the ANN bond model included compressive strength, tensile strength, rebar diameter, embedment length, concrete cover, ultrasonic pulse velocity (UPV), fracture severity, and corrosion level.

Jaya Nepal1 et.al.,2 "Analytical Modelling of Bond Strength Degradation Due to Reinforcement Corrosion".

The cement-steel bond is a fundamental component of reinforced concrete (RC). Structures, affecting their load carrying capacity and serviceability. As a result, evaluating bond strength degradation is an important metric in predicting the residual strength of a bond.

Reinforcement corrosion affects RC constructions. The majority of existing research works in this topic are numerical and experimental in nature. Although some attempts have been made using an analytical method, there is still a need for a trustworthy model that takes into account the essential mechanical parameters impacting the bond strength of corroded RC structures. This study proposes a simple and realistic analytical model of bond strength degradation using fracture mechanics at the steel concrete interface, including the effect of adhesion, confining pressure, and corrosion pressure. The suggested model's results are compared to previously published experimental data. The research shows that the proposed analytical model coincides with current experimental data.

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Khaled. M. Osman et.al.,3 "Corrosion of Steel Bars in Concrete Mixes Designed According to different Codes Recommendations and Exposed to Variable Environmental Classes".

The purpose of this research is to investigate the influence of mix design approach and environmental exposure conditions on corrosion of steel bars experimentally. Three codes were chosen to conduct a thorough study of corrosion of steel bars in reinforced concrete and concrete behavior owing to exposure classes. R.C. Cubes and cylinders were cast and experimentally tested. Cubes with dimensions of 100*100*100 mm were chosen to investigate concrete compressive strength, cylinders with dimensions of 100*200 mm were chosen to examine concrete splitting strength, and cylinders with dimensions of 50*100 mm were chosen to study corrosion of steel bars. Curing in pure water was chosen as a reference specimen among the studied samples, while the remaining specimens were cured in salt water.

The experimental software includes several code provisions and exposure classes. The results reveal that varied mix designs and exposure classes significantly improve the performance behavior of concrete and steel bars.

Steel bar corrosion in concrete cured in pure water is less than that in concrete cured in sea water for the three design mixes ECP, ACI, and BS. Furthermore, the corrosion of steel in the ACI mix design is often less than in the other two mix designs in pure water and sea water. Furthermore, the compressive strength of concrete and splitting strength in pure water were lower in the three design combinations than in sea water.

Xiaolin Zhang et.al.,4 "An Experimental Study on Effect of Steel Corrosion on the Bond–Slip Performance of Reinforced Concrete."

The effects of reinforcement corrosion on bond performance between rebar and concrete were investigated in this research.

For varying levels of reinforcing steel corrosion, tests were performed to determine the degradation of the bond between reinforcing steel and concrete. A set of 20 specimens with varying concrete strengths and reinforcing materials.

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Steel corrosion levels were developed and produced. Each specimen was cast as a 200-mm concrete cube, with a steel rebar embedded in the centre and two stirrups surrounding it. An electrochemical accelerated corrosion approach was used to erode the steel rebar. Following the corrosion process, the width and length of the corrosion crack openings were measured. The specimens were then subjected to monolithic pull-out loading tests. The effects of reinforcement corrosion on crack opening, maximum bond stress, and energy dissipation were thoroughly explored. It was discovered that reinforcement corrosion has a significant impact on reinforcing bar bond performance.

Masoud Ahmadi et.al.,5 "Prediction models for bond strength of steel reinforcement with consideration of corrosion".

Corrosion is one of the primary deterioration reasons that has a significant impact on the behavior of structural reinforced concrete (RC) elements in seismic zones. In recent years, research on minimizing rehabilitation costs, performance assessment, and accurate modeling of corrosion-affected RC structures has grown in popularity. Corrosion reduces the binding capacity between reinforcement and surrounding concrete, resulting in a reduction in member strength and ductility. The goal of this study is to present a prediction strategy based on a large number of published research results linked to corroded reinforcement in concrete members using artificial neural networks (ANN). For evaluating the training performance of ANN models, the minimizing mean square error criterion and rising regression value of projected results are used. The proposed model's validity is investigated.

The proposed model's validity is tested using the experimental data that has been acquired. The results reveal that the estimated model has a good agreement with the experimented data.

Yi Wang et.al.,6 "Bond Strength Assessment of Concrete-Corroded Rebar Interface Using Artificial Neutral Network".

Bond strength evaluation is critical for reinforced concrete structures with rebar corrosion because bond degradation can jeopardize structural safety. One of the machine learning approaches, artificial neutral network (ANN), was used in this study to analyze the binding strength in concrete-corroded rebar interface. Data on the bond strength of concrete and corroded rebar were gathered from existing literature. The ANN model was used to investigate the factors influencing bond property degradation. The following criteria were

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examined for the relative bond strength input in the ANN model: (1) corrosion level; (2) crack width; (3) cover-to-diameter ratio; and (4) concrete strength. For cases with confinement (stirrups), (5) the diameter/stirrups spacing ratio was also taken into account. The evaluation progressed from input with a single parameter to input with many parameters. The scaled feed-forward multi- layer perception ANN model with the gradient descent error back-propagation technique and momentum was found to match the experimental and calculated results.

Hongwei Lin et.al.,7"State-of-the-art review on the bond properties of corroded reinforcing steel bar".

This paper covers the most recent scientific advances in the bond behavior of corroded reinforcing steel bar. According to the literature review, earlier investigations have primarily focused on the weakening of bond strength. The basic parameters determining bond strength have long been identified, including main bar corrosion, concrete cover, concrete type, stirrups, stirrup corrosion, and corrosion rate.

However, present bond strength models are primarily based on unique test results and are not generalizable. Although the corrosion-induced surface fracture width is a suitable measure for assessing bond strength, models in this area are currently scarce. In terms of bond-slip behavior, literature research show that corrosion has little effect on the bond-slip process. There are currently differences in the corrosion influence on the critical factors that shape the bond-slip curves. Preliminary comparisons of existing bond-slip models reveal that more accurate and generalized models must be built using a larger database. There have been few studies on the bond behavior of corroded steel bar under cyclic loading. According to the limited test results, repeated loading without changing sign has little effect on bond strength.

Simona Coccia et.al.,8"Influence of corrosion on the bond strength of steel rebars in concrete".

The problem of the durability of reinforced concrete structures has emerged rapidly in recent decades, demonstrating that one of the most serious degradation occurrences is associated with rebar corrosion. When active corrosion progresses, the oxides occupy a volume 2-4 times that of the sound bar, resulting in bond failure, cracking, and cover spalling. The corrosion effects at the steel-concrete interface are investigated in this work. Pull-out tests are

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performed with varying corrosion levels to define the bond-slip constitutive relationships of the damaged re-bars. In addition, an analytical model for evaluating internal pressure owing to corrosion products is established for concrete specimens without stirrups in order to give a technique for the defining of the corrosion percentage. Finally, the analytical data are confirmed by comparing them to the experimental results.

Lan ChungT et.al.,9 "Bond strength prediction for reinforced concrete members with highly corroded reinforcing bars."

Due to a scarcity of natural fine aggregates in many areas, sea sand has been employed as an alternative in the making of concrete. However, because sea sand contains chlorides, the potential of corrosion of steel reinforcing bars imbedded in such concrete has become a big worry. As a result, numerous research had been conducted.

Corrosion level and bond behavior tests have been carried out. Realistic corrosion levels that expose older structures to hazard are typically greater than 1% and exceed the minimum of 2%. Because safety projections of aged concrete structures based on corrosion failure are critical, research into more realistic corrosion levels would aid in the prediction process. To do this, two sorts of specimens are studied in order to comprehend the bond qualities. For pullout tests, prismatic concrete specimens with reinforcements subjected to corrosion before and after casting of concrete are employed. An equation was developed based on the experimental results. It has been created to forecast bond strength. Furthermore, the proposed equation's validity is shown through comparison with current prediction curves.

Amadou Sakhir Syll et.al.,10 "Impact of Corrosion on the Bond Strength between Concrete and Rebar: A Systematic Review".

Corrosion of the reinforcement affects more than the rebar's cross-sectional area. Steel volume expands as a result of expanding corrosion products, causing concrete cracking, delamination, and spalling. As a result, the binding capacity of concrete and rebar is compromised.

Researchers have thoroughly investigated the effect of corrosion on the bond strength of concrete and rebar in order to provide empirical, theoretical, or numerical predictive models. As a result, research initiatives on this area have grown substantially in recent years. This

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article gives a thorough literature review on this topic to investigate experimental methodologies, outcomes, and trends. Through a careful selection, the Web of Science search yielded 84 relevant research papers. Concrete cover, concrete strength, and bond strength deterioration are all important elements to consider.

However, a comprehensive model is currently lacking due to variances in testing methodologies used to assess the effect of corrosion on bond strength. Furthermore, researchers attempted to elucidate the mechanism of bond strength deterioration caused by corrosion. As a result, new approaches for developing a feasible model to analyse the bond strength deterioration of corroded structures have been offered.

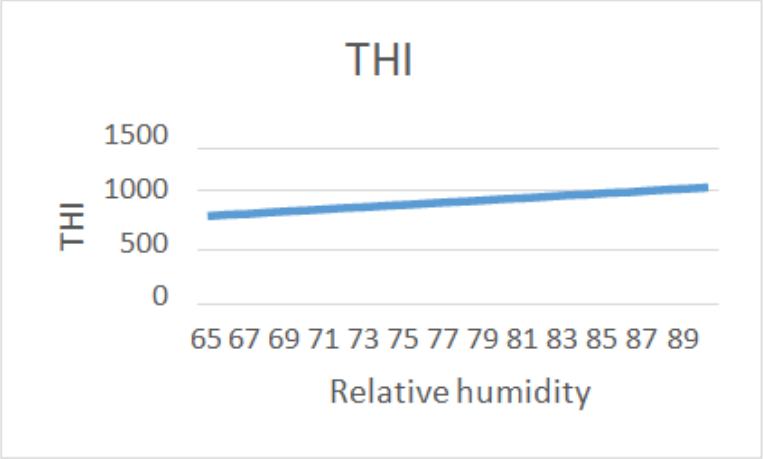


Fig 1: : THI v/s Rh for constant 'Temperature 25C'

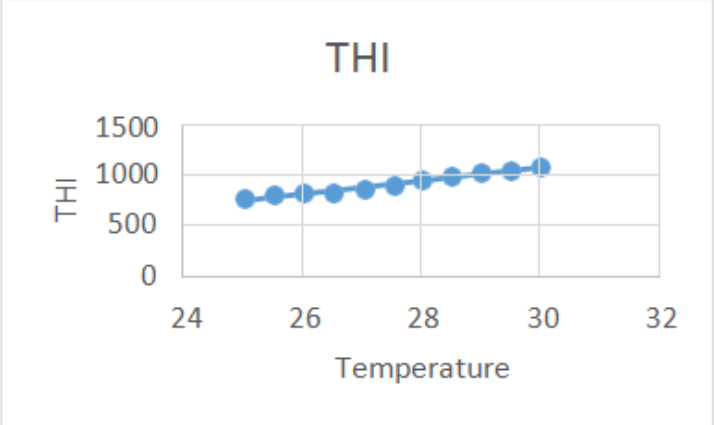


Fig 2: THI v/s Temperature for constant 'Rh of 65%

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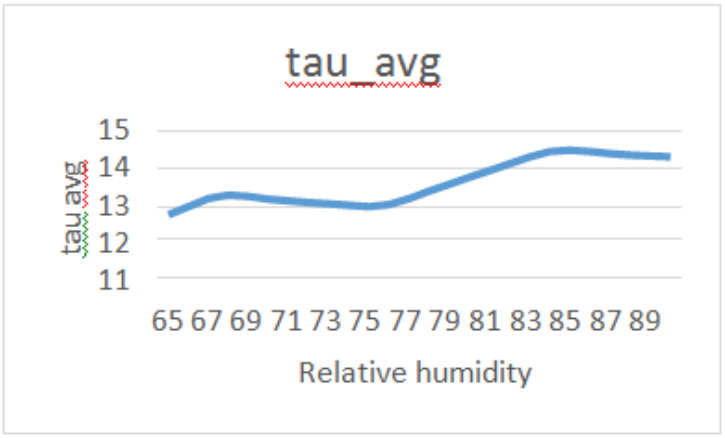


Fig 3: Rh v/s tau avg for constant 'T of 25C'

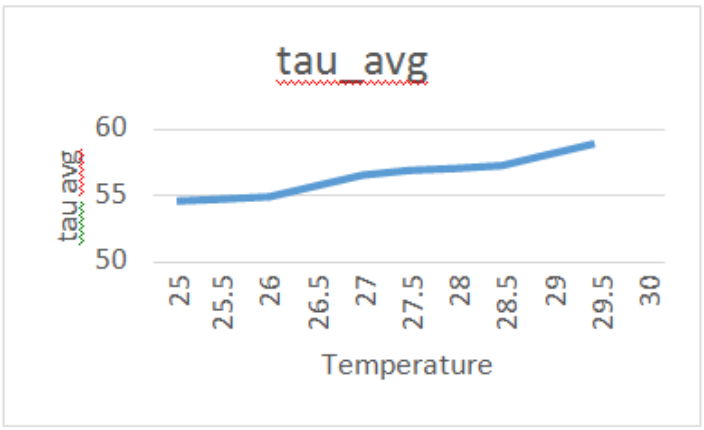


Fig 4 : Temperature v/s tau avg for constant 'Rh of 65%'

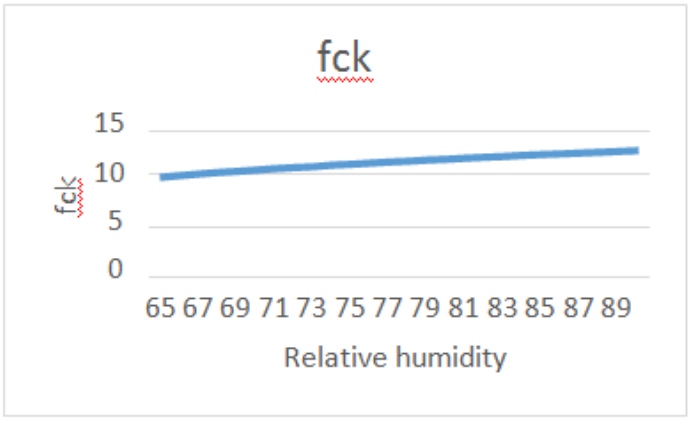


Fig 5: Rh v/s fck for constant 'Temperature of 25C'

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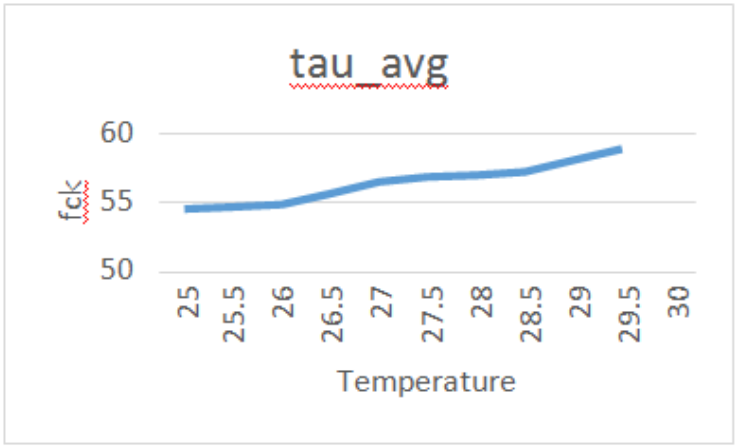


Fig 6: Temperature v/s fck for constant Rh of 65%

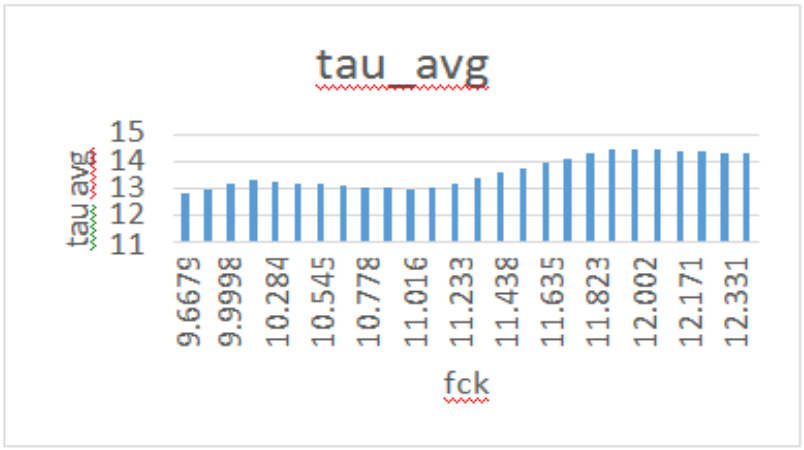


Fig 7 : tau avg v/s fck wrt 'Relative humidity'

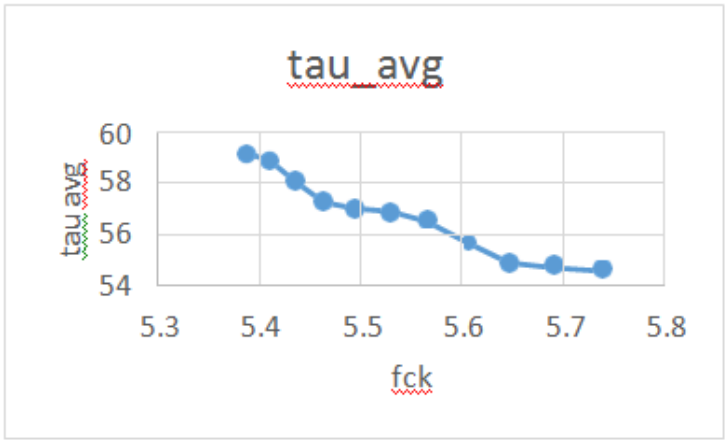


Fig 8: tau avg v/s fck wrt 'Temperature'

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CONCLUSION

1. Checked the working of model by taking the data from research paper of Nolan C et.al, where in paper, fck got is 2.4621MPa and in our model, we got 5.9884 MPa. The obtained result range is close to paper result, hence it can be concluded that model is working properly.

2. Checked the working of model by taking the data from research paper of Nolan C et.al, where in paper, τavg got is 63.44 and in our model, we got 60.3616 MPa. The obtained result range is close to paper result; hence it can be concluded that model is working properly.

3. For conditions T=25C, ST=1, c=20mm, Ø= 8mm, l=32mm, obtained τavg = 53.5190 MPa and fck = 2.091MPa and for the same temperature of 25C, ST=2, c=50mm, Ø= 12mm, l=48mm, obtained τavg = 58.0515 MPa and fck = 3.9465 MPa. By this, we can conclude that for same value of temperature with minimum values of technical parameters, τavg and fck is low when compared to given maximum values of technical parameters.

4. For conditions Rh=65%, ST=1, c=20mm, Ø= 8mm, l=32mm, obtained τavg = 12.1259MPa and fck = 6.3718 MPa and for the same Rh of 65%, ST=2, c=50mm, Ø= 12mm, l=48mm, obtained τavg = 15.1743 MPa and fck = 8.0259 MPa. By this, we can conclude that for same value of Relative humidity with minimum values of technical parameters, τavg and fck is low when compared to given maximum values of technical parameters.

5. From fig 1 and 2, we can conclude that THI increases with increase in relative humidity and temperature, hence causes heat stress within the building and causes discomfort to the occupants.

6. Fig 3 shows that there is little variation like sudden fall and raise of “tau avg” might be due to use of different water cement ratio and other environmental factors.

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7. Fig 4 shows that there is increase variation and decrease variation of tau avg due to provided different inputs of concrete parameters.

8. Fig 5 and 6 shows increase in fck with respect to both temperature and relative humidity because fck is directly proportional to tau avg so it varies according to the above graphs.

9. Fig 7 and 8 shows if there is increase in bond strength fck also increased in the same way if bond strength decreases fck also decreased.

So by making all these studies, we can conclude that bond strength decreases more in presence of relative humidity compared to temperature and compressive strength doesn't vary much in both relative humidity and temperature. Hence, while designing the structures in coastal areas, relative humidity plays a very important role as because it reduces bond strength incredibly.

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