

Effects of treated corrosion reinforcement on structural behavior of concrete beams

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Paper ID - 020156

Abstract

Structural degradation phenomena like reinforcement corrosion in concrete structures imply a consequent reduction in time of the safety level. Corrosion causes a reduction of the sectional area, ductility and strength of rebars, bond strength between steel and concrete. The subsequent redistribution of internal stresses induces a reduction in ductility at ultimate limit state and a variation of the deformational behavior in serviceability conditions. In this paper, an experimental investigation was carried out to study the effect of treated corrosion reinforcement on structural behavior of concrete beams. In this investigation, phosphoric acid and vinegar solution are used to treat the corroded steel bars and compared the bending strength of concrete beams with treated and untreated corrosion reinforcement. A finite element computer software (ANSYS) has been used to compare the experimental results. From the experimental and analytical results, it was observed that performance of concrete beams with treated corrosion reinforcement is better than the concrete beams with corrosion reinforcement

Keywords: Corroded Reinforcement, Phosphoric acid, Vinegar, Concrete beams, ANSYS

1. Introduction

Concrete is one of the most versatile and widely used as construction material throughout the world. Reinforced concrete structures have to withstand the environmental conditions throughout its life-span if properly prepared and placed. It has been demonstrated by the large number of concrete structure built over the last 100 years in different part of the world. In India, the construction of reinforced concrete structures was taken up during the formative years of the 20th century. Such a durable reinforced concrete structure is in Mumbai - the Gateway of India. The steel embedded in the concrete structure whether as reinforcement or pre-stressed tendon, being ferrous material, is prone to corrosion which cannot be totally eliminated. Corrosion related distress is not confined to India but have been experienced all over the world. All developed countries have carried out necessary preventive measures including revision of the concrete codes by incorporation of suitable durability practices in seventies and eighties. However, this process has been very slow in India, even the basic concrete code IS: 456-2000, has not been fully updated for durability requirement. Corrosion of steel results in reduction of cross-section area of steel and cracks and splitting of cover concrete. Due to reduction of cross-section, the load carrying capacity is reduced, in addition to reduction of

elongation properties and fatigue strength. ASTM terminology defines corrosion as “the chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties”. Steel embedded in concrete, corrosion results in the formation of rust which has two to four times the volume of the original steel and none of its good mechanical properties. Corrosion also produces pits or holes in the surface of reinforcing steel, reducing strength capacity as a result of the reduced cross-sectional area.

Steel in concrete is usually in a non-corroding, passive condition. However, steel-reinforced concrete is often used in severe environments where sea water or salts are present. When chloride moves into the concrete, it disrupts the passive layer protecting the steel, causing it to rust and pit. Carbonation of concrete is another cause of steel corrosion. When concrete carbonates to the level of the steel rebar, the normally alkaline environment, which protects steel from corrosion, is replaced by a more neutral environment. Under these conditions the steel is not passive and rapid corrosion begins. The rate of corrosion due to carbonated concrete cover is slower than chloride-induced corrosion. Occasionally, a lack of oxygen surrounding the steel rebar

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will cause the metal to dissolve, leave in galow pH liquid. Corrosion is a destruction of material because of its reaction with the environmental conditions the most predominant among various factors of corrosion is the atmospheric corrosion which causing the rusting of steel. Appreciable corrosion only starts when the relative humidity of the air exceeds around 65%. In dry, pure air and below freezing point of water there is no danger of the corrosion. Corrosion may be defined as the involuntary destruction of substances such as metals and mineral building materials by surrounding media.

Chemical either from environmental or from within the concrete making materials are the main source of deterioration process. Due to the attack of chemicals, the concrete. Develops crack which is the first sign of deterioration. The effect of chemicals is mainly due to presence of salt, carbonation, chloride attack and reaction of sulphates with tricalcium aluminate (CsA) present in cement. Concrete is an intimate mixture of cement, aggregate and water which in the green stage is highly alkaline. The hydration of cement, develops calcium hydroxides which increases the pH values up to 12.5. In such alkaline conditions, the reinforcing steel is covered with thin film of oxide which protects the steel.

2. Corrosion Process

Both mild and high-strength steel reinforcement corrode in the presence of oxygen and water. As concrete generally has interconnected pores, air and moisture are ever present around the reinforcement. Initially, at least, the alkaline nature of the surrounding concrete naturally prevents embedded steel reinforcement from corroding. Specifically, microscopic pores within the concrete matrix with high concentrations of soluble calcium, sodium, and potassium oxide form hydroxide when water is present. This process subsequently creates this alkaline condition. The alkaline condition leads to the formation of a "passive" layer on the steel reinforcement surface. This passive layer is a dense, impenetrable film that, if fully established and maintained, prevents further corrosion of the steel reinforcement. A true passive layer is a very dense, thin layer of oxide that leads to a very slow rate of corrosion. The passive layer formed on steel reinforcement in concrete is most likely part metal oxide-hydroxide and part mineral from the cement paste. There is some discussion as to whether this layer is a true passive layer, as it is thick compared to other known passive layers and consists of more than just metal oxides. However, it behaves similarly to a passive layer and, therefore, is generally referred to as such.

Corrosion engineers try to stop the corrosion of steel by simulating the naturally occurring, yet fragile, passive layer with applied protective coatings. Metals such as zinc or polymers such as acrylics and epoxies are sometimes used to stop corrosive conditions from reaching the steel surfaces. The true passive layer is the ideal protective coating, as it will form, maintain, and repair itself as long as the alkaline environment is sustained. This is a far better situation than any artificial coating, as artificial coatings can be consumed

or damaged, allowing corrosion to proceed in damaged areas. However, in reality the passive environment is not always maintained in RC. Most notably, the chloride attack mechanism can break down the alkaline condition in concrete, resulting in a corrosion-susceptible environment

2.1 Chloride Attack Mechanism:

In structures, chloride ions can come from several sources. They can be cast into the concrete or they can come from the deliberate addition of chlorides. Calcium chloride, for example, was widely used until the mid-1970s as a concrete set accelerator. The use of sea water or sea-dredged aggregate can also contaminate the concrete mix with chloride. Chlorides can also diffuse into concrete as a result of deicing salt application, marine salt spray, and storage of salts.

The diffusion of chlorides via the application of deicing salts or marine salt spray is the primary source of chlorides in most modern RC structures. However, cast-in chloride must not be overlooked. Even a low level of cast-in chloride can lead to the rapid onset of corrosion if additional chlorides become available from the environment. This often happens in marine conditions, where seawater contaminates the original concrete mix and diffuses into the hardened concrete.⁴ Chloride ions penetrate through concrete capillaries and can act as catalysts to corrosion when ion concentration is sufficient at the reinforcement surface. This could break down the passive layer of oxide on the steel, allowing corrosion to initiate. Chloride attack is difficult to remedy, as chlorides are generally hard to eliminate once introduced into a RC structure.

2.2 Corrosion Process

Corrosion of steel reinforcement in concrete can generally be modeled as a two-stage process. The first stage is known as the initiation, diffusion, or incubation period, in which chloride ions migrate from the concrete surface to the reinforcement level. During this stage, the reinforcing steel experiences negligible corrosion. The time required for the chloride concentration to reach the aforementioned chloride threshold value at the reinforcement level can be determined by the diffusion process of the chloride ion through concrete, following Fick's Second Law of Diffusion. Once the passive layer breaks down the second stage, which is referred to as the active corrosion period of steel reinforcement, occurs and propagates. The length of the second stage depends on the speed at which the corroded steel reinforcement deteriorates and results in observable distress. Although it is not an easy task to predict the length of the second stage, eventually a RC structure will reach a condition at which some type of maintenance must be performed. When corrosion occurs, the steel reinforcement basically "dissolves" in the pore water, giving up electrons and forming cations (positively charged ions). The process of losing electrons is known as oxidation.

The surface of the iron, at which oxidation occurs, serves as an anode. The two free electrons, $2e^-$, created in the anodic reaction must be consumed elsewhere on the steel surface to preserve electrical neutrality in the system. In other words, it is not possible for a large amount of electrical charge to build up at one location. Another chemical reaction must consume the electrons. Oxidation and reduction are coupled together as

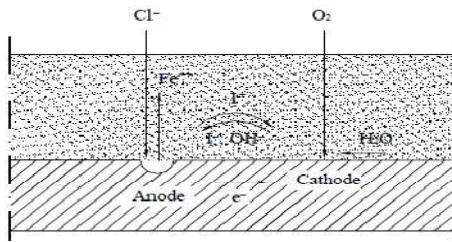


Fig. 1. Corrosion process

electrons are transferred between them. This reaction consumes both water and oxygen. If the iron were simply to dissolve in the pore water, no cracking, delaminating, and spalling of the surrounding concrete would occur.

3. Experimental Programme

Experimental program was designed to study the flexural behavior of RCC beams with treated corroded bars. Experimental program consists of five series of beams namely Plain cement concrete beams, Reinforced cement concrete beams, RCC beams with corroded steel reinforcement, RCC beams with steel reinforcement treated with Ortho-phosphoric acid and RCC beams with steel reinforcement treated with Vinegar.

3.1 Material Details:

Ordinary Portland cement (OPC) of 53 grade conforming to IS 8112:1989 with specific gravity of 3.15 was used in Concrete mix. Fine aggregate conforming to Zone II of IS 383:1970 was used. Crushed coarse aggregate passing through 20mm with specific gravity 2.7 was used. Ortho-phosphoric acid and Vinegar (acetic acid) were used to treat the corroded bars. The details of mix proportions are listed in Table 1.

3.2 Casting

Cubes of 150mm size were used to determine the compressive strength of concrete. Vinegar and Ortho phosphoric acid, these both chemicals are used for the treatment process of corroded steel bars. Before casting the beam specimens, bars immersing in Acid and vinegar solutions. After 24 hours, remove the bars from solutions and clean with cloth. Specially prepared wooden moulds were used for casting the RCC beam specimens. A needle vibrator was used for compaction. After casting the

Table-1. Details of Mix Proportions

PROPERTIES	DATA	
Grade of steel	M30	
	0.45:1:1.43:2.752	
	Ingredient	Quantity kg/m ³
	Cement	425
Mix proportion	Fine aggregate	610
	Coarse Aggregate	1170
	Water	191.5
Compressive strength	42N/mm ²	
Young's modulus	27386 N/mm ²	

specimens, demoulding was carried out with a time gap of 24 hours. All the specimens were water cured for 28 days. In this experimental investigation a total of ten concrete beams were casted.

4. Test Setup and Testing Procedure

Loading frame of 100 tone capacity was used for the testing of specimens. All the beam specimens were tested under the three point bending test (fig2). Dial gauge were placed on the centre of the beam to measure the deflection. Loading was gradually applied with the help of hand pump. For every increment of load, the dial gauge readings were noted. Loading was continued up to the failure of the beam. The crack pattern of failure is noted. For finding the Compressive strength of the cube, stress-strain curve for corroded bars and treated corroded bars were tested on the UTM. The stress-strain curves for corroded bars and treated corroded bars are shown in fig.2.

5. Test Results and Discussions

All the beam specimens were tested under the three point bending. A photograph of the test setup is shown in fig 3. To understand the flexural behavior of RCC beams with treated corroded bars, load –deflection graphs were drawn and shown in fig.5. The failure load and maximum deflection of five series of beams are reported in table 2. From the graph and Table it was observed that the performance of RCC beams with treated with OPA is close to the RCC beam with regular bars. During the test, the crack propagation of all the specimens was carefully observed. The failure pattern of beams as shown in fig.4. (A: Conventional reinforcement, B: Corroded Reinforcement, C: Treated with OPA, D: Treated with vinegar)

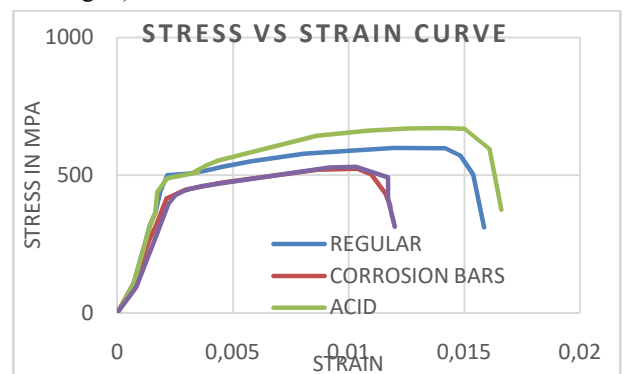


Fig.2. Strain-Strain Curve for steel bars



Fig.3. Test setup

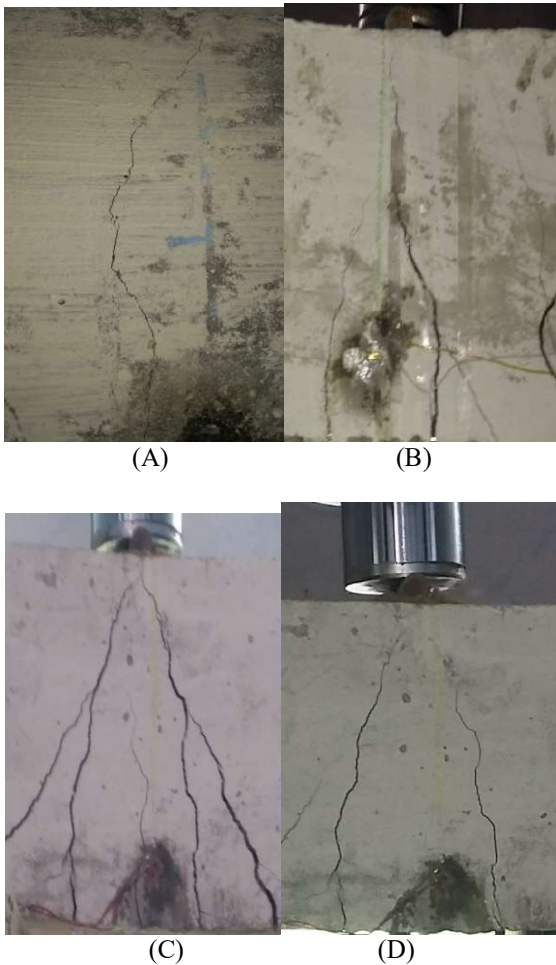


Fig.4. Failures of beams

Table-2.Experimental results of beams

Type Of Beam	Ultimate Load (kN)	Deformation (mm)
Regular	92	9.46
Corroded	76.5	5.88
Treated with acid	84.6	9.38
Treated with vinegar	77.2	7.877
PCC	17	1.68

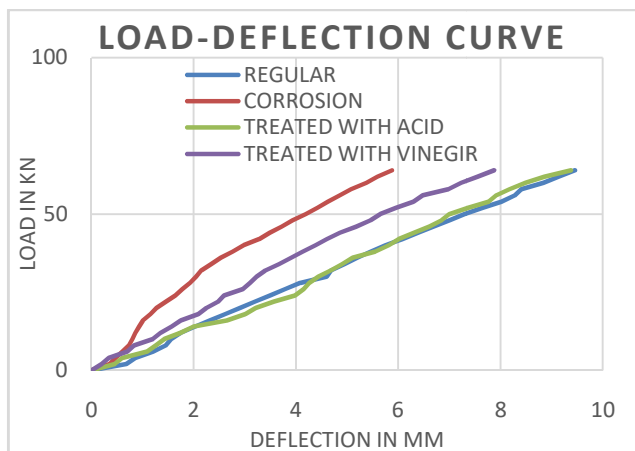


Fig.5.load deflection curve of beams

6.Analytical Model

Finite Element model of RCC beams using ANSYS was developed to compare the experimental results. The Solid65 element was used to model the concrete. This element has eight nodes with three degrees of freedom at each node – translations in the nodal x, y, and z directions. This element is capable of plastic deformation, cracking in three orthogonal directions, and crushing. A Beam188 element was used to model steel reinforcement. This element is a 3-D with six degree of freedom at each node. translations in the nodal x, y, and z directions and rotations about x, y and z directions warping of cross section is assumed to be unrestrained. This element is also capable of plastic deformation. Fig 6 illustrates the ANSYS model of RCC beam. Table 3, Table 4 and Table 5 represents the material properties of steel bars. Beam deformation and maximum displacement of five series of beams shown in fig 6 to fig 10. Table 6 represents the failure load and maximum deflection of beams observed in ANSYS. Fig 11 represents load-deflection curves of beams. Fig 12 illustrate the comparison of flexural cracks in analytical and experimental.

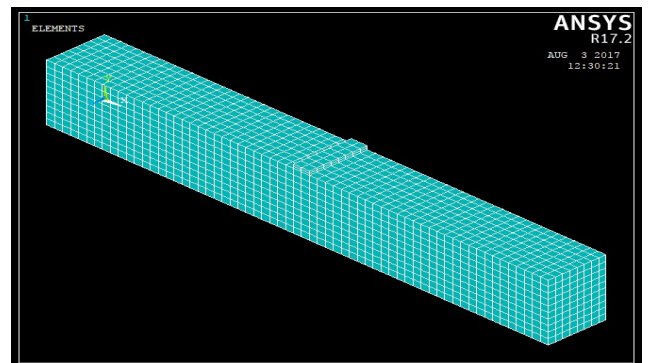


Fig.6. ANSYS model

Table-3: Element details and properties of Corroded steel reinforcement

Material no	Element type	Material properties	
2	Beam 188	Linear isotropic	
		EX(Mpa)	1.09E+05
		PRXY	0.3
		Bilinear isotropic	
		YIELD STRESS(Mpa)	437
		TANG MOD	20

Table-4:Element details and properties of steel reinforcement treated by Acid

Material no	Element type	Material properties	
2	Beam 188	Linear isotropic	
		EX(Mpa)	1.52E+05
		PRXY	0.3
		Bilinear isotropic	
		YIELD STRESS(Mpa)	530
		TANG MOD	20

Table-5:Element details and properties of steel reinforcement treated by Vinegir.

Material no	Element type	Material properties	
2	Beam 188	Linear isotropic	
		EX(Mpa)	1.365E05
		PRXY	0.3
		Bilinear isotropic	
		YIELD STRESS(Mpa)	447
		TANG MOD	20

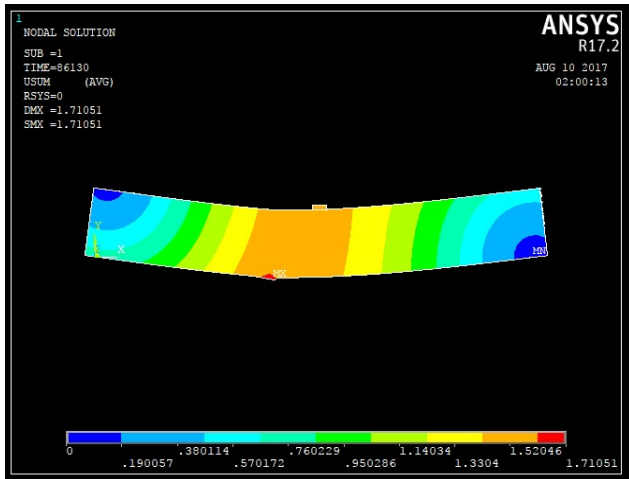


Fig.6.Beam deformation and max displacement (Conventional steel)

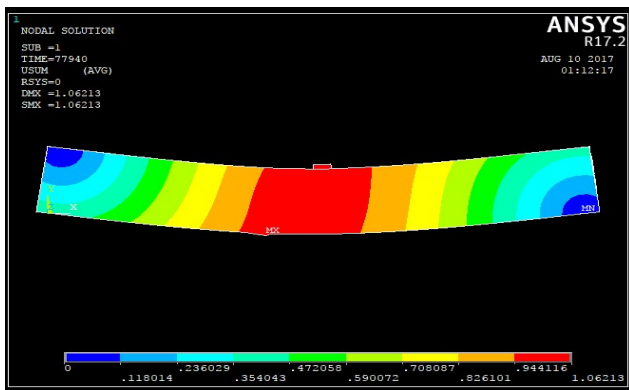


Fig.7.Beam deformation and max displacement (Corroded steel)

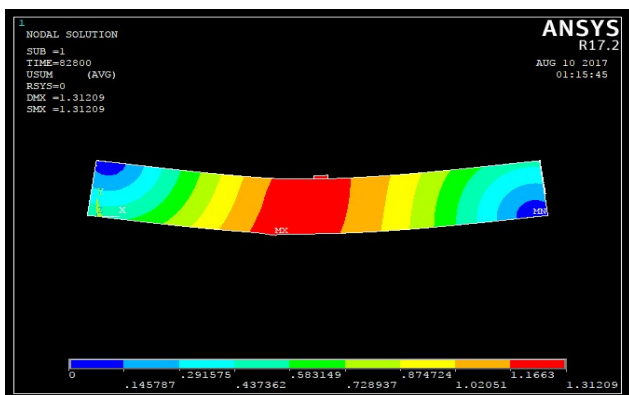


Fig.8.Beam deformation and max displacement (Treated with acid)

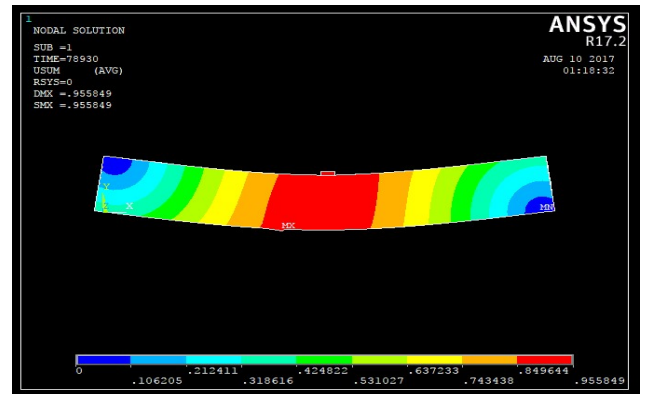


Fig.9. Beam deformation and max displacement (Treated with Vinegar)

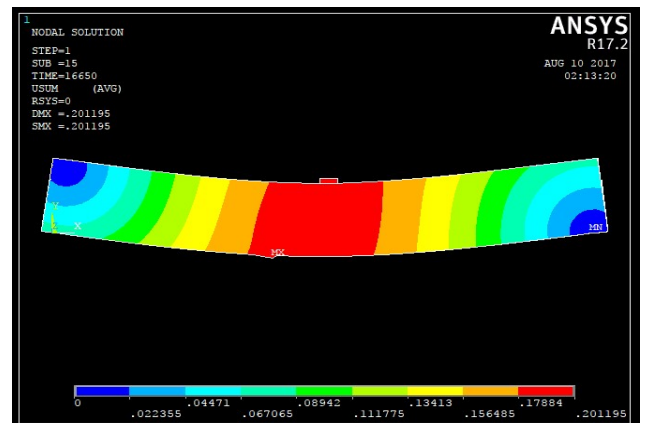


Fig.10.Beam deformation and max displacement (PCC)

Table-6: Failure load and maximum deflection of beams (ANSYS)

TYPE OF BEAM	Ultimate Load(kN)	Max Deformation (mm)
Regular	86.13	17.1
Corroded	77.94	9.5
Treated with acid	82.8	13.1
Treated with vinegar	78.93	10.6
PCC	16.65	2.011

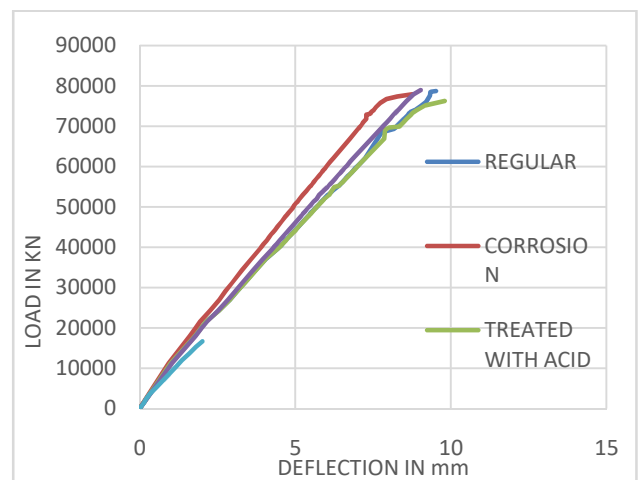


Fig.11: Load deflection curves (ANSYS)

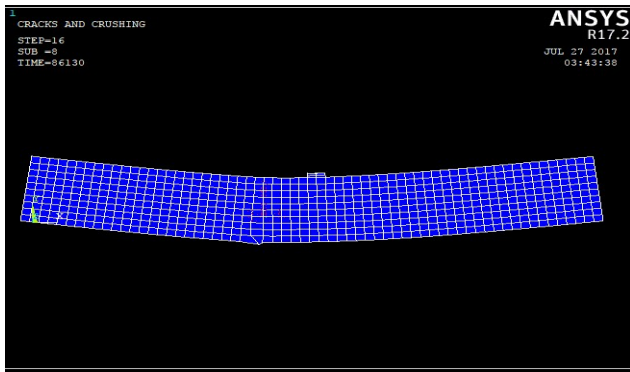


Fig.12. Comparison of flexural cracks-
Analytical and Experimental

7. Conclusions

As per analytical and experimental results, the following conclusions are obtained.

1. Yield stress and young modulus of corroded and treated with vinegar reinforcements are less than treated with acid bars. And acid bars properties are equal to the regular steel bars.
2. Beam casting with corroded reinforcement load carrying capacity and deflection of beam is less than remaining beams casting with regular, treated with acid and vinegar.
3. Corroded bars gain 5-10% of yield strength when treated with OPA and vinegar.
4. Deflections of beams are reduced when using corroded bars and bars treated with vinegar. It means that reduce the ductility than used to treated with Acid or regular bars in both Experimental and ANSYS.
5. As per experimental and analytical study results performance of RC beams with treated reinforcement is better than the corroded bars.

Acknowledgements

The authors are highly thankful to the authorities of Bapatla Engineering College, Bapatla, for providing facilities for carrying out this work.

Disclosures

Free Access to this article is sponsored by SARL ALPHA CRISTO INDUSTRIAL.

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