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Effect on the Pull Out and The Bond Strength Of Concrete by Different Surface Treatment of Steel Reinforcement Bars

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Abstract

In present research, it is aimed to study the effect of different interface of steel reinforcement bars on the pull out and bond strength of the concrete. The concrete possess a good compressional strength but relatively low pull out strength. So to enhance its pull out strength different reinforcements like steel bars, wires etc. are introduced in the concrete. The introduced steel bars give good pull out properties to concrete but also affected in corrosive environment. Different interface is made to protect these bars from corrosion by applying different treatment on the interface between surrounding concrete and steel bars which affects the bond strength between concrete and the re-bar. Reinforced bars are surface treated with emulsion paint, polyester resin, alkali and lubricating oil. Ravi and Chenab sand are used to produce two different concrete, having the compressional strength of 24.37 MPa and 19.25 MPa respectively. Pull out testing to find out the pullout strength which is further used to calculate the bond strengths. The results shows that both types of concrete specimens possess the maximum pull out and bond strength for untreated reinforcement bars The specimens with painted reinforcement bars has the minimum pull out and bond strength among all the specimens. The ravi sand has pull out strength of 5kN and 3kN for untreated and paint surface treated respectively while chenab sand has pull out strength of 7.5kN and 2.5kN for untreated and paint surface treated respectively.

***Keywords**: Concrete, Pull out strength, Bond strength, Reinforcement*

1. Introduction:

Concrete is a material of inhomogeneous nature and of comparatively low tensile strength. Therefore steel is reinforced to make it more resistant after cracking. High strength and stability of concrete depends upon these factors optimized packing density, low water to cement ratio and usage of super-plasticizers. The load bearing capacity and serviceability performance of reinforced concrete structures depends on the interface between reinforced bars and the concrete [1]. Deterioration of the reinforced bars and the surrounding concrete causes bond degradation. When the surrounding concrete begins to crack, it affects stress transformation between the steel-concrete bonds which lead to the bond failure [2].

The transfer of stress occurs at the bond between concrete and reinforcing bars through axial stresses. The stresses acting parallel to the concrete-bar interface are known as bond stresses [3-4]. Composite behavior of concrete is due to this strong bond among matrix (concrete) and filler

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(reinforcing steel) [5-6].This bond shows resistance in the acting stress due to chemical bonding, friction and mechanical locking between the bars and surrounding concrete. High strength concrete or concrete with low water to cement ratio possess an improved steel-concrete boundary due to the decreased concentration of Ca $(OH)_2$ crystals and secondary silicate hydrates [7-9]. This phenomenon results in the production of very dense concrete structure, it possesses bond stress at the interface of concrete and reinforced material thus, increases the composite action of reinforced concrete [10].

The performance of concrete adjacent to the rib defines the characteristics of bond [11]. Concrete with higher compressive strength gives the higher bond strength because adhesion and frictional forces between concrete and reinforced material increases with the increased compact structure of concrete [12]. In practice steel reinforcing bars are surface treated with different materials for getting high corrosion and weather resistance applications. The main purpose of surface treating the reinforcing bars is to hinder corrosion process but in this process pull out and bond strength of concrete may becompromised [13].

The relationship between pullout and compressive strength is affected due to embedded length of the reinforcement rebar, bearing ring dimensions of the reinforcement rebar, depth of embedded of the reinforcement rebar and the type of aggregate. For reliability, the specimens of pullout and compressive testing should be of same dimensions, density and cured under similar conditions [14]. It has been observed that the pull out samples failed in two modes of failure splitting and slip failure. Pull out failure occur when the bond between the concrete and the groves of steel bars is not strong enough. The slip failure occurs when grove angle is greater than 70°, very little damage occurs to the concrete cover surrounding reinforcement steel bars while splitting type failure occurs when large compressive stresses come from outer surface towards the groove on the contact point in front of the groove. In the result of splitting failure the concrete specimen breaks into two or more pieces [15].

Many authors have studied the bond strength of concrete reinforced with steel bars. Moetaz et. al (1999) studied bond strength of concrete reinforced with epoxy-coated steel [16]. In Cao et. al (2001) studied the degradation of bond strength in concrete and steel bars under the cyclic loading [17]. K. Ahmed et. Al (2008) studied the effect of rebar cover and development length on bond and slip in high strength concrete. They reported direct relation between cover to diameter ratio and bond strength, and indirect relation between cover to diameter ratio and slip for steel bars of different diameters. Fang et al (2004) studied bond strength of concrete under different degree of corrosion for embedded steel bars [18]. Abdelbaky et. al (2004) studied the bond strength of reinforcing steel bars under effect of rust removal agent. He concluded 7.6% reduction in the bond strength of the concrete by using steel bars coated with this product **[19]**. Hadi et. al (2008) investigated the high strength steel as a reinforcement in high strength concrete to find the bond strength. He concluded higher bond strength in bars with smaller diameter as compared with the bars of large diameter [20]. Foroughi et. al (2008) used the self-compacting concrete to investigate the bond strength of the reinforced bars. He showed higher bond strength in self-compacting concrete specimens than the normal concrete specimens and comparatively a more consistent relation in normal concrete of bond strength and compressive strength [21]. Valcuende et. al (2009) used self-compacting concrete and steel bars with different parameters to study the bond strength [22]. Selvarag et. al applied different coatings on the steel reinforcement bar to hinder the corrosion in concrete. They used four types of coatings epoxy silicon-polyamide with two different pigments, acrylic polyol-aromatic isocyanate, and polyester poly-aromatic iso-cyanate. Good mechanical and corrosion barrier properties in very corrosive environment were reported for epoxy silicon polyamide resin based coating formulation **[23]**. Verma et. al (2011) proved the similar results with respect to the corrosion of steel reinforcement in concrete. They suggested that the use of epoxy coated steel bars can be very beneficial in those structures which are exposed to corrosive environment [24].

Alengaram et al. (2010) used oil palm based concrete, then compare it's their mechanical properties with normal concrete. They concluded that 86% higher bond strength with no slip failure with oil palm based concrete as compared with normal concrete [25]. Johnson et. al (2010) discussed type of reinforcement corrosion as well as measured the mechanical bond. They concluded that the by increasing the relative area of the steel bar ribs improved bond strength [26]. Assaad et. al (2012) study the bond strength of epoxy coated steel bars in underwater concrete. They concluded that bond strength decreases due to influence of washout loss. [27]. Yalciner et al. (2012) investigated the bond strength of steel bars and concrete with the accelerated corrosion testing. According to the results, concrete cracked during test, the higher degradation was seen in the specimens with high strength and corroded reinforcements [28].

In the present research different interfaces between concrete and reinforcing steel bars are made to study the pull out and the bond strength of the concrete specimens. The different interfaces are made by applying different surface treatments on the steel bars like emulsion paint, lubricating oil, alkylanation and polyester resin.

2. Method and Materials:

The concrete specimens for the experiment were prepared according to *ASTM C192.* The schematic diagram is show in the Figure 1.

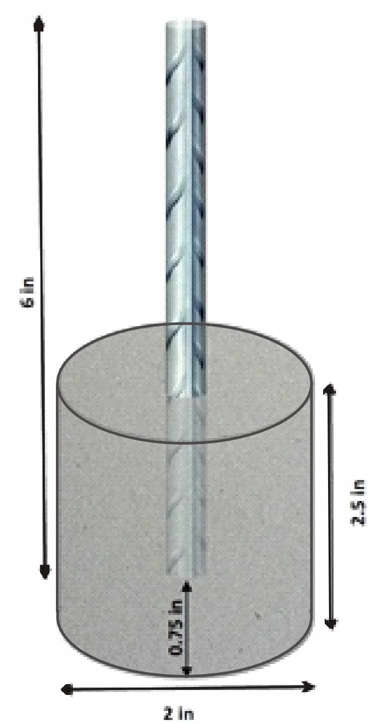

Figure 1: Schematic diagram of rebar in concrete

The steel reinforcement used having Ultimate Tensile Strength of 485 MPa and hardness of 93.7 Hv, scale F. Reinforcement having dimensions of 0.5 inch diameter and 6 inch length was used and 1.75 inch of the reinforcement bar was embedded in the concrete. The reinforcement is kept 0.75 inch above the base of concrete mold, to maintain the maximum grip of concrete on the reinforcement. Then reinforcement was surface treated with emulsion paint, alkalization by 20 % NaOH solution, epoxy resin and lubricating oil. The treated re-bars were compared with un-treated re-bars as well. Two types of concrete compositions were made from Ravi and Chenab sand. The treated bars are shown in Figure 2.

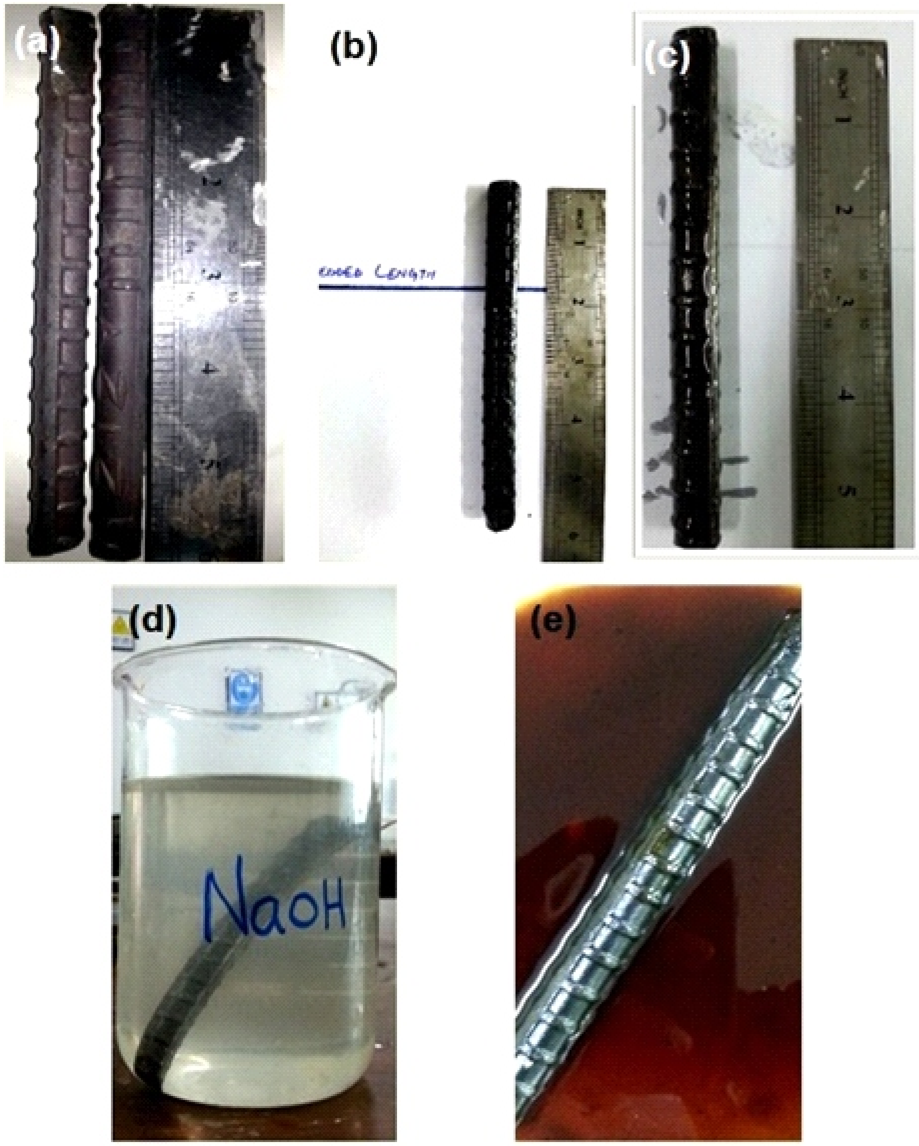

Figure 2: Photograph of treated re-bars (a) un-treated (b) emulsion painted (c) polyester resin (d) Alkalized (e) lubricated oil

The composition of the concrete mixture is illustrated in given Table 1.

Table 1: Proportion of concrete mixture

Cement	*1*
Aggregate	*0.84*
**** Sand***	*1.10*
Water/Cement ratio	*0.5*

Double ended mixer was used for the mixing of contents of the concrete and mixing was done in batches. After proper mixing, mixture was poured manually into the cylinder plastic mold having 2 inches diameter and 2.5 inches height dimension. The molds were properly filled with the mixture and curing time was 48 hours. All the samples were labeled according to the Table 2. The cured samples are shown in Figure 3.

Table 2: Scheme for the Identification of concrete samples

Surface Treatment	**Sample ID**
Un-treated	U-R
Lubricating Oil	O-R
Emulsion Paint	P-R
Epoxy Resin	E-R
Alkalization (20% NaOH solution)	A-R

**Two different sands are used (Ravi sand and Chenab sand) for the sake of comparison*

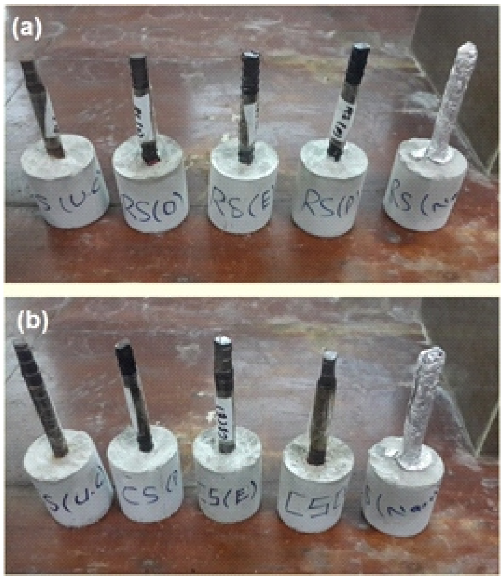

Figure 3: Photograph of hardened concrete sample (a) Ravi sand (b) Chenab sand

The compression strength of both concrete was measured by following ASTM C39M. According to which cylindrical concrete specimens are placed between the horizontal plates and hydraulic pressure is applied till the fracture of specimen as shown in Figure 4. Fracture type was also determined from the ASTM C39M standard. The measured compression strength and fracture type of Ravi and Chenab sand concrete are 24.37 MPa (*Type 3 Fracture*) and 19.25MPa (*Type 1 Fracture*) respectively.

Figure 4: Concrete specimen during compressional test

The pull out test was conducted on all the samples according to ASTM C900. This test method was conducted on a Universal tensile testing machine having a maximum load capacity of 100 kN. A pull out insert was used to pull out an embedded metal insert in hardened concrete shown in Figure 5. The maximum force required to pull the insert from the concrete was noted to measure the pullout strength.

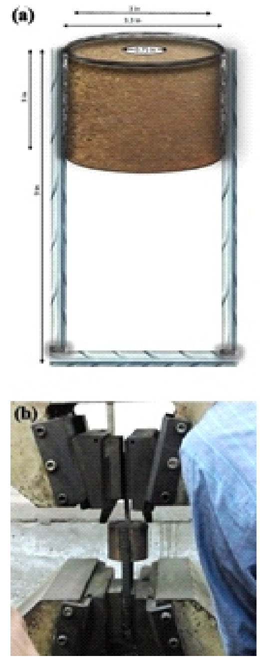

Figure 5: (a) Schematic diagram of pull out insert (b) steel reinforced concrete specimen during pull out test

The strength corresponding to the maximum pull out load is known as the bond strength or the ultimate bond. The bond strength ( ) was calculated as the pull out load developed over an equivalent surface area using the formula [2]:

$$\tau = \frac{P}{\pi d_b l_b} \qquad (1)$$

Where **P** = pull out load in newton (N); l_b = embedment length in millimeter (mm) and d_b = diameter of the rebar in millimeter (mm)

3. Results and Discussion:

Chemical analysis of each constituent of concrete was performed to find their compositions. Chenab and Ravi sand both contains lime (CaO), insoluble incombustible or nonvolatile materials and combustible materials. Although, Chenab sand contain 95.77% insoluble incombustible materials as compare with the Ravi sand which contain 93.83% . Ravi sand contains finer particles as compared with the Chenab sand particles.

Similarly for cement the main constituents are lime (CaO), silica, nonvolatile insoluble materials and volatile materials. The chemical analysis of each is given below in the Table 3.

Table 3: Chemical analysis of constituents concrete (a) Chenab Sand (b) Ravi Sand (c) Cement

(A)

Constituents	Percentage
Lime (CaO) ***(wt. %)***	3.07
Insoluble Material (in HCl) ***(wt. %)***	95.77
Loss on Ignition ***(wt. %)***	0.13

(B)

Constituents	Percentage
Lime (CaO) ***(wt. %)***	2.40
Insoluble Material (in HCl) ***(wt. %)***	93.83
Loss on Ignition ***(wt. %)***	0.17

(C)

Constituents	Percentage
Lime ***(wt. %)***	65.15
Silica ***(wt. %)***	21.53
Loss on Ignition ***(wt. %)***	1.73
Insoluble Residue ***(wt. %)***	2.15

Pullout and bond strength of concrete varies with varying composition of concrete and also depends upon the interface between concrete and reinforced material i.e. as a change occurs in the composition of concrete or at the steel-concrete, it also affects the pullout and bond strength of reinforced concrete. Pullout strength and bond strength of each type of specimen is provided in **Table 4**, whereas **Table 5** is providing the comparative bond strengths of both concrete. Graphical representation of pullout and bond strength is given in the **Figure 6** and **Figure 7**.

Table 4: Results of Pull out and Bond Strength of different surface treated steel

Sample ID	Pull out strength kN)	Bond strength (MPa)	Bond strength (%)	Differential bond strength (%)
Ravi Sand (RS)				
U-R	5	6.58	100.00	0.00
O-R	4	5.26	80.00	20.00
P-R	3	3.95	60.00	40.00
E-R	4	5.26	80.00	20.00
A-R	4	5.26	80.00	20.00
Chenab Sand (CS)				
U-R	7.5	9.87	100	0.00
O-R	5.5	7.24	73.33	26.67
P-R	2.5	3.29	33.33	66.67
E-R	3	3.95	40.00	60.00
A-R	4	5.26	53.33	46.67

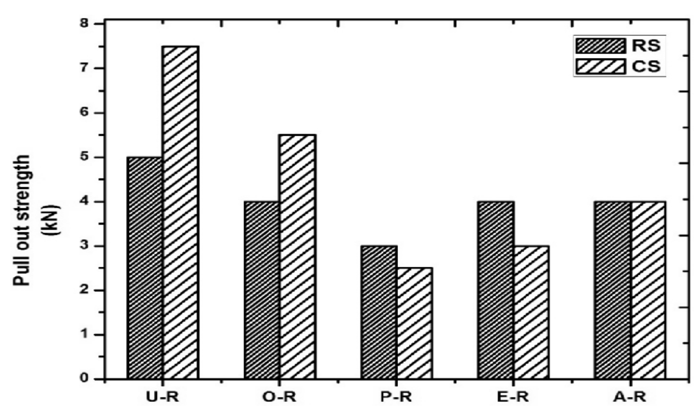

Figure 6:
Comparison of Pull out strength of different surface treated steel in different concrete

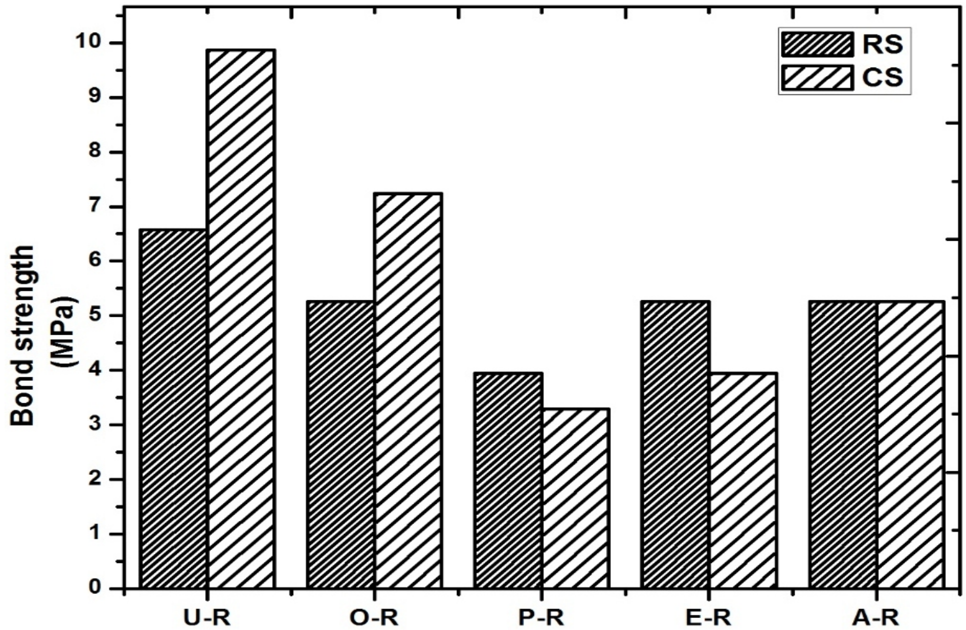

Figure 7: Comparison of Bond strength of different surface treated steel in different concrete

Table 5: Results of Comparative bond strength of different surface treated steel in different concrete

Sample ID	Bond Stress (MPa)		Comparative bond strength (%)	
	RS	CS	RS	CS
U-R	6.58	9.87	66.67	100.00
O-R	5.26	7.24	53.33	73.33
P-R	3.95	3.29	40.00	33.33
E-R	5.26	3.95	53.33	40.00
A-R	5.26	5.26	53.33	53.33

Figure 6 shows that RS concrete specimens lubricating oil, epoxy resin and alkanation treated specimens showed 20% less strength than the untreated specimens whereas emulsion painted samples showed 40% less bond strength than the untreated specimens.

As Figure 7 is illustrating CS concrete specimens oil treated, epoxy resin, emulsion painted and alkanized treated specimens showed 26.67%, 66.67%, 60% and 46.67% respectively less strength than the untreated specimens. Although due to surface treatment of steel bars hinder the corrosion by stopping the corrosive agents to penetrate but lack in significant amount of pullout strength.

This happened because un treated steel surface allows more strong adhesion to the concrete, as there is only one interface bond between the concrete and steel bar which is steel-concrete bond. This bond is very strong due to the interlocking between the rough steel surface and the hardened concrete ingredients. Interlocking also occurs at the grooves of steel bars. Thus, this interlocking at the surface and grooves of the steel bars gives good bond strength to the steel-concrete bond.

In case of coated or treated steel bars an intermediate layer exists between the steel-concrete bonds. This intermediate layer plays main role in reduction of the bond strength. There are two bonds responsible for the pullout strength: first the bond between steel rebar to coated surface bond and secondly the coated to concrete bond.

Failure at one of these two bonds cause the failure of other bond as well thus, pullout failure (slip failure or split failure) occurs earlier as compared with the case in which no treatment is present on the steel bar. Low bond strength is observed in this case because application of coating on the surface on steel bar effects its roughness thus interlocking reduces similar effect of coating is seen at the grooves of steel bar.

In case of oil treated bar specimens of both concrete very thin layer of oil remained on the steel surface remaining penetrated into the surrounding concrete, repelled some of its water content and here plays a role of solvent for concrete ingredients just in a very thin layer next to the steel bar. This presence of oil helps in the development of relatively strong bond as compared with other treatments, as shown in Figure 8. Also, oil treatment does not affected extend of the interlocking but as oil also caused lubrication thus in oil treated samples slip failure is observed, shown in Figure 9.

Epoxy coating was relatively thin and of low hardness did not affected the roughness too much and for alkalized treated bars therefore, pullout strength as well as bond strength of these specimens matches the value of oil treated specimen. The bond strength of painted bar specimens was lowest among all specimens of both compositions as shown in Figure 8 because of the thickness of paint applied on the surface of the bars, which affected the interlocking between concrete and steel.

In CS concrete NaOH treated bar specimens showed bond strength of 5.26 MPa (73% of the untreated specimen's bond strength), which is less than the oil treated specimen of CS concrete. This happened due to the high absorption ability of Chenab Sand which did not allowed NaOH to participate in the steel-concrete bond. Epoxy coated bar specimen of CS concrete exhibited the second lowest value of bond strength among all specimens of CS concrete. Because epoxy was coated on the steel bars, as Chenab sand contains larger particles as compared with Ravi sand so did not maintained strong grip as illustrated in Figure 8 and Table 5.

When we discuss the same type of bars in both types of compositions it is clear in the Table 5 and in the Figure 8 for untreated and oil treated bar specimens pullout strength of CS concrete is greater than the RS concrete specimens because of the more rough surface of the CS concrete. For painted and epoxy coated bar specimens pullout strength of RS concrete specimens is greater than the CS concrete specimens because of the high penetration power and fine size of Ravi sand. When under the compression load particles of Ravi sand come in contact with the coating surface, they penetrate into it and form a strong grip with it. But CS particles are of greater size than the RS particles thus less penetration occurs in the result less strong grip is formed. For NaOH treated bar specimens both concretes have the same value of pullout strength.

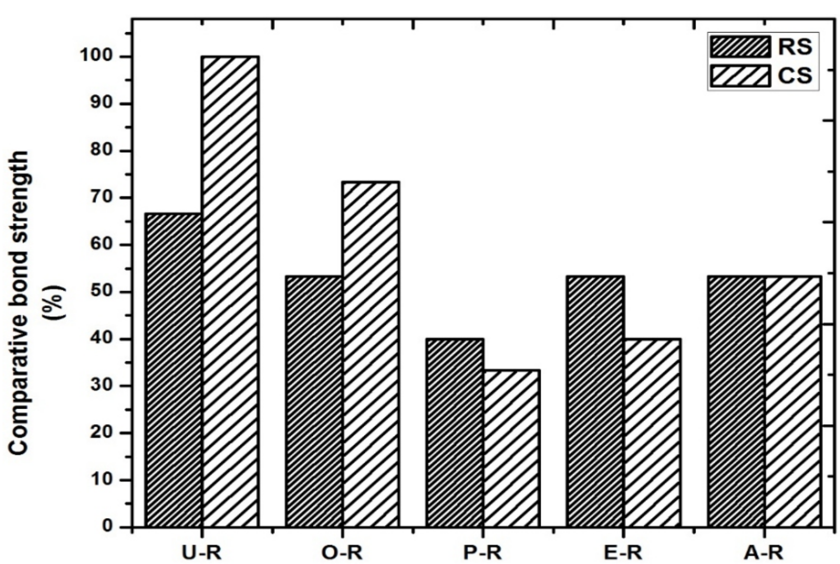

Figure 8: Percentage comparative bond strength of RS and CS based on different treatment

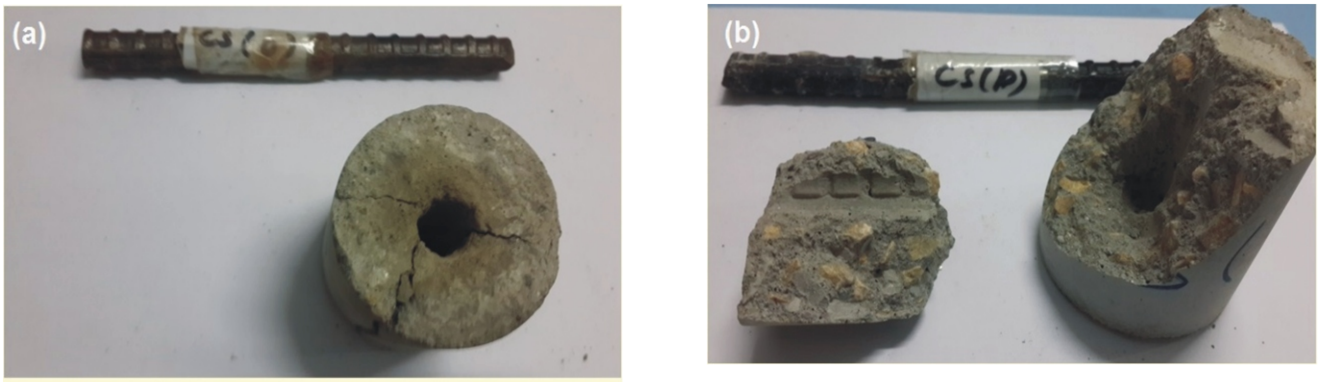

Figure 9: Failure of concrete specimen after pull out test

4. Conclusions:

The Chenab sand has less compression strength due to coarser particle size but show high pull out strength and bond strength as compared to Ravi sand. In both concrete, good pullout strength is obtained with untreated bar specimens as well as bond strength. While intermediate pullout strength and as bond strength was obtained with oil treated and alkalized treated specimens. The painted specimens showed very small pullout strength as compared with others surface treatment. It is due the fact that high degree of roughness in case of untreated reinforcement bars provided the high pull out and bond strengths due to the interlocking between concrete surface and reinforcement bar grooves. But the roughness in case of painted reinforcement bars the interlocking decreases thus the pull out and bond strengths also reduced.

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