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Study of Bond Strength of Plain Surface Wave Type Configuration Rebars with Concrete: A Comparative Study

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ABSTRACT

This study investigates the bond strength behaviour of plain surface wave type configuration (PSWC) rebars in comparison to mild steel (MS) and high yield strength deformed (HYSD) rebars of varied rib configuration as per BIS and ASTM standards. The variables in the rebar include plain surface, curved surface, parallel rib, diamond rib and Nano modified cement polymer anticorrosive coating (CPAC). Total of 30 pull-out specimens and 12 beam-end specimens were put to a pull-out test following BIS and ASTM standard respectively. The load corresponding to 0.025mm free end (FE) slip and 0.25mm loaded end (LE) slip were carefully observed. The load-deflection behaviour, appearance of the first crack in the specimens and ultimate failure load was recorded. The experimental results showed that as compared to MS rebars, HYSD rebars offer an approximately threefold increase in ultimate bond strength and 1.5 times increase in usable bond strength irrespective of varied rib configuration. PSWC rebars with 4mm offset and 80mm pitch offered 2.4 times increase in ultimate strength and 76.2% increase in usable bond strength as compared to MS rebars. The ultimate pull-out load of PSWC rebars was around 25% and the usable bond strength was only 8.6% lesser than HYSD rebars with parallel ribs. The adopted coating enhanced the corrosion resistance and the reduction in bond strength with any surface configuration was less than the permissible maximum reduction of 20% as specified in IS 13620-1993. Hence it can be concluded that PSWC rebars offered promising bond strength results and upon further optimization and study in other aspects, PSWC rebars can be a way to replace HYSD rebars in future for enhancing concrete durability at zero added cost.

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1. INTRODUCTION

The durability problem of concrete structures reinforced with HYSD rebars is worldwide resulting in early age failures and renovation costs add a large amount in annual expenditures [1, 2]. Neville [3] suggests reasons as "poor understanding of deterioration processes, inadequate acceptance criteria of concrete at site, and changes in cement properties and construction practices". The major prominent threat unquestionably is corrosion of reinforcing steel, causing cracking, staining, and spalling of the cover of RC elements [4, 5]. This can result in unserviceable structures which can be unsafe for the occupants. Alekseev, et al. [6] commented on the above scenario as "the durability of reinforcement specimens with a stepped (deformed) profile may be roughly an order less than that of smooth specimens since the former have stress concentrators on the surface at the bases of projections, which represent sites of preferential formation of cracks".

Anil [7] reported the yield strength as well as the bond strength of HYSD rebars is higher in comparisons to plain round MS rebars and concluded that there are certain durability issues concerning HYSD rebars in reinforced concrete structures like problems of early distress and associated failures of reinforced concrete structures built using HYSD rebars due to early corrosion. The observations by CPWD [8], Swamy [9], and Papadakis, et al. [10] are evidence of old concrete structures which were reinforced with MS rebars, performing much better than more recent structures reinforced with ribbed CTD and TMT rebars when such structures were subjected to the same environment.

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To attain a substitute and economical solution for overcoming the early corrosion problem in using HYSD rebars in reinforced concrete structures, an innovative type of reinforcing steel rebar named as PSWC rebar with a normal plain round surface having slightly curved axis has been proposed [7]. The offset (excursion from the original straight axis) is merely 4-8 millimetres as shown in Figure 1.

The PSWC rebar having offset-length of 4mm was selected for the study. The selection of the parameters was done based on the literature study [11-14].

In plain rebars, the ultimate pull-out force is not unlike as the load at which initial noticeable slip occurs, but in ribbed rebars, the ultimate pull-out load may resemble a greater slip which may not be obtained practically before other major failures occur. Thus in the study, the ultimate pull-out/failure load and complete load-slip behaviour of the selected rebars was observed and compared.

2. SCOPE AND OBJECTIVE OF THE STUDY

The strength aspect of PSWC rebar has to be tested to prove its viability of replacing the conventional rebars in concrete structures. Hence the bond strength of PSWC rebars in comparison with MS and HYSD rebar with varied rib configuration was presented in the study. Also, the influence of Nano modified CPAC on bond strength development has been included and compared following BIS guidelines.

3. MATERIAL PROPERTIES & MIX DESIGN

3. 1. Concrete Mix Proportioning

The M30 concrete mix was formulated as per IS 10262-2009 [15]. “Ordinary Portland Cement, 53-grade approved by IS 12269-1987” [16], fine aggregate (FA) of zone II as specified in IS 383-1970 [17] and 20 mm downgraded blue granite coarse aggregate (CA) was used. The proportioning of ingredients per m^3 of concrete are presented in Table 1 with w/c ratio obtained as 0.45.

3. 2. Reinforcing Rebars

To maintain quality throughout the study samples of selected 16mm diameter of MS of Fe250 grade, HYSD parallel ribs and HYSD diamond ribs rebars of Fe500 grade conforming to IS 1786-2008 [18] were tested to study the mechanical properties and chemical composition. The tension test outcomes as per IS 1608:2005 [19] are stated in Table 2.

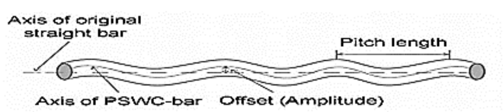


Figure 1. Representation of PSWC rebar

TABLE 1. Mix proportion

Cement (kg/m^3)		FA (kg/m^3)	CA (kg/m^3)
438		588.74	1044.22
Mix ratio:	1:	1.344:	2.384

Table 3 includes the chemical composition of rebars used in pullout tests. The tests were conducted in ‘Chennai Mettex Laboratory’. The test results were compared with standard values set by major steel-producing industries and other premier research centres. The outcomes were found in the optimum range confirming the use of quality steel in the study.

3. 3. Development of Cement Polymer Anticorrosive Coating System

The Nano modified CPAC on the rebars was applied following IS 13620-1993 [20] guidelines. The “site oriented CPAC (passivating type) was composed of nitrite, styrene-butadiene polymer and other additives” [21]. The polymer solution was milky white, basic pH of 12.5 and a density of $1.035 g/cm^3$. This anticorrosive polymer solution was compatible with concrete or cement paste

TABLE 2. Tension test results

Category of Rebar	Yield Strength (MPa)	Ultimate Strength (MPa)	Percentage Elongation in Length (mm)	Percentage Reduction in Area (mm^2)
MS R	466.72	583.40	27.5	54.23
HYSD PR R	498.36	622.96	22.5	55.45
HYSD DR R	547.77	684.72	26.2	54.90

R: Rebar, PR: Parallel Ribs, DR: Diamond Ribs

TABLE 3. Chemical composition of steel

Chemical Component (%)	MS R	HYSD PR R	HYSD DR R
Carbon	0.284	0.203	0.222
Manganese	0.553	0.696	0.567
Silicon	0.157	0.208	0.104
Sulphur	0.028	0.024	0.024
Phosphorous	0.036	0.033	0.032
Chromium	0.190	0.092	0.186
Nickel	0.099	0.068	0.069
Molybdenum	0.017	0.013	0.016

R: Rebar, PR: Parallel Ribs, DR: Diamond Ribs when uniformly mixed with fresh OPC. The procedure involved the removal of loose rust and scales from the steel rebars by hard wire brush before brush coating [21]. The Nano modification in the CPAC was done by incorporating 5gram of Nano Titanium Dioxide (Nano TiO_2) in 1litre of CPAC. The thickness of the coating ranges from 150±25μm for 1 coat and 225±25μm for 2 coat measured by pull-off type thickness gauge. The treatment duration was 12hours.

4. EXPERIMENTAL PROGRAM

The Universal Testing Machine (UTM) of capacity 1000 kN and capable of load increment at the rate of 2250kg/minute was used for testing. The load cell of 500kN (Model: ELC-30S) was used in the test setup. Dial micrometres were used at both FE and LE of the rebars to measure corresponding slip. A 20mm rebar length from the rear face of the concrete specimen was provided with proper facing done to measure the FE slip and also the sufficient rebar from the front face was provided to safeguard the rebar in the UTM. "Polyvinyl Chloride (PVC) pipes were used as a bond breaker to restrict the bonded length of the rebars and to avoid a localized cone-type of failure of concrete at the LE of the specimen" [22, 23]. The standard procedure followed was as per IS 2770 (Part I)–1967 [23] and ASTM A944-10 [24]. The minimum load corresponding to 0.025mm FE and 0.25 mm LE slip was considered for calculating the usable bond strength throughout the study. Equation (1) is recommended to calculate bond stresses.

$$u = F/\pi\, d_r\, l_r \qquad (1)$$

where F is the force in rebar, dr is the diameter and lr is the bond length of the rebar.

4. 1. BIS Pull-out Specimens

Pullout specimens of dimensions '150×150×150mm' were cast with centrally embedded test rebar. At the FE, dial micrometre with least count of 2.5×10^{-3} mm with a range of 2·5mm was used. At the LE, dial micrometre with least count of 2.5×10^{-2} mm and a range of 12.5mm was used. The bonded length was restricted to 80mm in all the test rebars. The mould, mixing and curing of specimens conform to the requirements as specified in IS 516-1959 [25]. In the LE, the concrete cube was placed on a bearing arrangement of similar dimensions with 18mm hole in the centre to accommodate the test rebar. A helical of 6mm diameter, MS rebar conforming to Grade I of IS 432 (Part 1)-1982 at 25 mm pitch [23] was provided as reinforcement.

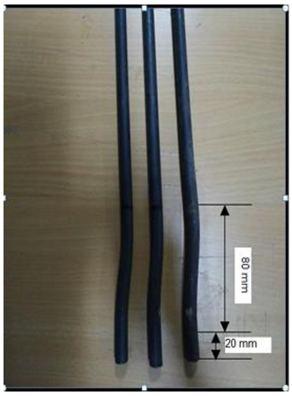
Totally 30 BIS pull-out specimens were cast and tested. Figure 2 shows the different types of rebars that were tested for bond strength as per the procedure.

Figure 3 shows the reinforcement and arrangement of mould for casting pull-out specimens.

After 28 days of curing a thin and neat layer of good strength, gypsum plaster was applied on the specimens before 2 hours of testing to assure proper seating of the specimens in the test setup. Figure 4 shows the view of casted BIS pull-out specimens and Figure 5 illustrates the pull-out test setup.

(a) Uncoated rebars

(b) Coated rebars



(c) PSWC rebars

Figure 2. (a), (b) and (c) Type of rebars

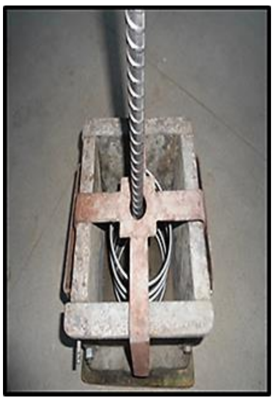


Figure 3. Arrangement of mould for casting pull-out specimen

4. 2. ASTM Beam End Specimens As per ASTM A944-10 [24], the specimen shall consist of the test rebar cast in a block of RC with dimensions as follows:

i. [600 + 25mm] length
ii. [db+200+13mm] width
iii. Minimum [db+cb+le+60mm] height

Notations:

cb = concrete cover in mm
db = nominal diameter of test rebar in mm
le = embedment length in mm

Four stirrups were provided on the two flexural reinforcing rebars on either side of the test rebar and placed inline to the length of a specimen. Figure 6 shows the reinforcement and arrangement of mould for casting beam-end specimens.

4. 2. 1. Modifications Done in Beam End Specimens The specimen was scaled down to suit the testing facility. The beam–end specimens were scaled down to 75% of the recommended size that is 25% of the length was reduced. To the scaled-down length of the specimen, the reinforcement was also scaled down.

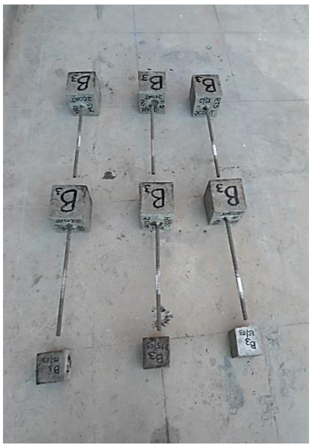


Figure 4. Casted BIS pull-out specimens

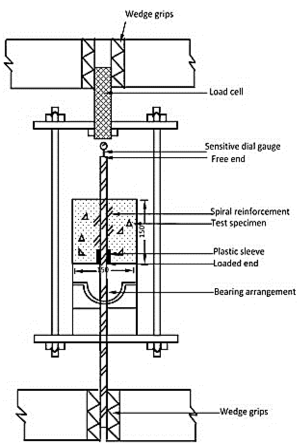


Figure 5. Schematic diagram of pull-out test setup

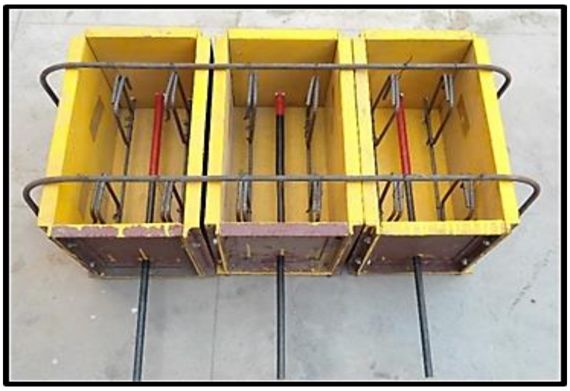


Figure 6. Arrangement of mould for casting beam-end specimens

Table 4 shows the details of the original and scaled-down specimen.

The bonded length was restricted to 200mm in all the test rebars. PSWC rebar of 4mm offset and 200mm pitch length was used to compare with conventional rebars. The flexural reinforcement having 0.5 times the cross-sectional area of the test rebar was provided with 4 rings of size '200mm×110mm' as side face reinforcement in which each flexural rebar was provided with 2 rings. Figure 7 shows the PSWC rebar of 4mm offset and 200mm pitch length.

Subsequent 28days of curing, the specimens were tested in the UTM with fabricated testing apparatus. Two dial gauges of accuracy 0.001 mm and 0.01 mm were used to measure the slip of the rebars at the FE and LE. Figure 8 shows the casted beam-end specimens and Figure 9 shows the test setup.

5. RESULTS AND DISCUSSION

5. 1. Summary of BIS Pull-out Test Results Table 5 shows the test observation in BIS pull-out specimens. The variation in the usable bond strength has

TABLE 4. Original and scaled-down test specimens

Description	Original Dimensions	Scaled Down Dimensions
Length	600 mm	450 mm
Breadth	230 mm	230 mm
Height	300 mm	300 mm

Figure 7. PSWC rebar with bonded and un-bonded regions

been calculated with respect to MS uncoated rebar. The coating thickness mention was a mean of a minimum of five readings that were taken throughout the length of rebar.

Figure 10 shows the modes of failure in BIS pull-out specimens. From left to right it represents yielding of steel, pullout failure and pullout associated with splitting of concrete.

Figure 8. Casted beam-end specimens

Figure 9. Pull-out test in progress

TABLE 5. Observations on pullout test

No.	Type of Rebar	Load (kN) 0.025 mm FE slip	Load (kN) 0.25 mm LE slip	Usable Bond Strength (MPa)	Mean Variation (%)	Coating Thickness (µm)	Mean cube compressive strength of concrete (MPa)	Inclination of Ribs (Degrees)	Ultimate Pullout Load (kN)	Average Ultimate Pullout Load (MPa)	Variation (%)	Type of Failure
1	S1MS UR	17.91	16.89	4.20		-			32			Pullout
2	S2MS UR	20.71	18.72	4.65	-	-	32.91	0	34	32	-	Pullout
3	S3MS UR	15.11	15.06	3.75		-			30			Pullout
4	S1HYSD PR UR	37.80	32.60	8.10		-			102			Splitting
5	S2HYSD PR UR	42.67	33.46	8.32	+92.86%	-	31.47	78	105.7	102	+218.75%	Splitting
6	S3HYSD PR UR	32.93	31.74	7.89		-			98.3			Splitting
7	S1HYSD DR UR	39.00	35.37	8.80		-			112.61			Yield
8	S2HYSD DR UR	44.87	38.07	9.47	+109.52%	-	29.66	83	115.77	112.61	+251.90%	Yield
9	S3HYSD DR UR	33.13	32.67	8.12		-			109.45			Yield
10	S1HYSD PR 1C	40.06	25	6.21		150.5			97.60			Splitting
11	S2HYSD PR IC	34.96	23	5.71	+47.86%	151	30.98	78	101.6	97.60	+205%	Splitting
12	S3HYSD PR 1C	45.16	27	6.71		150			93.6			Splitting
13	S1HYSD PR 2C	24.2	25	6.01	+39.52%	250	31.65	78	90.20	90.20	+181.88%	Splitting
14	S2HYSD PR 2C	23.7	21.91	5.45		253			84.78			Splitting

15	S3HYSD PR 2C	24.7	28.09	6.14		247			95.62			Splitting
16	S1HYSD DR 1C	37.22	26.74	6.65		150			105.32			Yield
17	S2HYSD DR 1C	36.56	27.62	6.87	+60.95%	148	31.09	83	101.99	105.32	+229.125	Splitting
18	S3HYSD DR 1C	37.88	27.18	6.76		152			108.65			Yield
19	S1HYSD DR 2C	34	25.70	6.40		250.5			100			Yield
20	S2HYSD DR 2C	33	23.12	5.75	+47.61%	246	29.21	83	100.76	100.66	+214.56	Splitting
21	S3 HYSD DR 2C	35	25.90	6.44		255			101.24			Splitting
22	S1MS R 1C	23.5	17.50	4.35		150			26			Pullout
23	S2MS R 1C	25	16.57	4.12	-4.76%	147	32.43	0	23	26	-18.75%	Pullout
24	S2MS R 1C	22	14.07	3.50		153			29			Pullout
25	S1MS R 2C	19	16.20	4.03		250			25			Pullout
26	S2MS R 2C	17	12.62	3.14	-11.90%	260	31.17	0	27.72	25	-21.88%	Pullout
27	S3MS R 2C	21	15.80	3.92		240			22.28			Pullout
28	S1PSWC UR	33.5	29.75	7.40		-			76.40			Pullout
29	S2PSWC UR	34.67	30.37	7.55	+76.20%	-	30.91	0	72.96	76.40	+138.75%	Pullout
30	S3PSWC UR	32.33	29.13	7.24		-			79.84			Pullout

S: Specimen, R: Rebar, UR: Uncoated Rebar, C: Coat

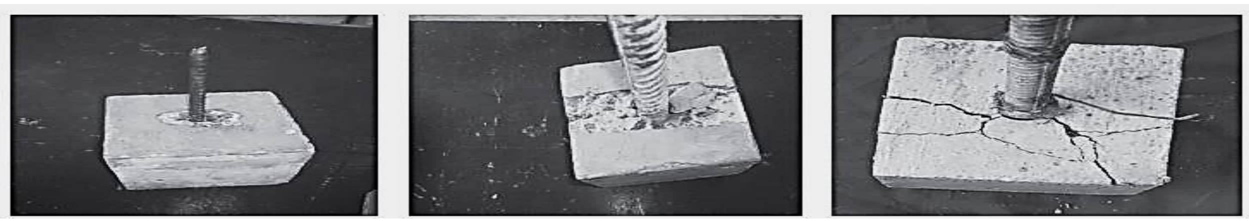


Figure 10. Modes of failure

The following observations were noted in the load-slip behaviour of rebars in BIS pull-out specimens:

(a) From the load-slip behaviour of MS UR, HYSD PR UR and HYSD DR UR revealed that at 0.025mm FE slip value, the load values observed for HYSD PR were in line with HYSD DR configuration. However, the MS R shows some initial resistance to slip with load increment but once the initial slip in the rebar occurs there was further huge slip observed on an increment of load in both FE and LE. The average ultimate load in MS UR was observed as 32kN with a usable bond strength of 4.20MPa. Similarly, the ultimate load for HYSD PR UR and HYSD DR UR was observed as 102kN and 112.61kN respectively. The usable bond strength value of HYSD PR UR and HYSD DR UR was observed as 8.10MPa and 8.80MPa respectively.

(b) From the load-slip behaviour of HYSD PR UR, HYSD PR 1C and HYSD PR 2C revealed that the peak load sustained by one and two coated rebars was 97.60kN and 90.20kN respectively. However, for uncoated rebar the ultimate pull-out load was 102kN. The single coated rebars carried 4.31% and two coated rebars carried 11.57% lesser load than uncoated rebars. Usable bond strength of single coated rebars was 23.33% and for double-coated rebars was 27.65% lesser than uncoated rebars.

(c) From the load-slip behaviour of HYSD DR UR, HYSD DR 1C and HYSD DR 2C.It was observed that single and double coated rebar withstands 6.47% and 10.61% lesser ultimate load respectively than uncoated rebar. Usable bond strength of single coated rebars was 23.18% and for double-coated rebar was 29.55% lesser than uncoated rebars.

(d) From the load-slip behaviour of MS UR, MS R 1C and MS R 2C. The ultimate load-carrying capacity of single and double-coated rebars was less by 18.75% and 21.88% respectively when compared to uncoated rebars. The usable bond strength for single coated rebars was 4.76% and for double-coated rebars was 11.90% lesser when compared to uncoated rebars.

(e) From the load-slip behaviour of MS UR, HYSD PR UR and PSWC UR with 4 mm deformation and 80 mm pitch length. It was observed that MS rebar carries 138.75% lesser load than PSWC rebar. HYSD PR UR showed 33.50% greater ultimate load carrying capacity and usable bond strength of just 9.46% greater than PSWC rebars.

5. 1. 1. Evaluation of Initial Crack and Ultimate Load of MS Rebars, HYSD Rebars and PSWC Rebars Figure 11 shows the evaluation of loads at which the first crack was visible and the ultimate load at which specimens failed in the pull-out test. PSWC rebars perform better than MS rebars. In HYSD rebar with parallel and diamond rib configuration, there was an appreciable difference between the first visible crack load and ultimate load. The corresponding difference between load at which first visible crack in HYSD PR UR and PSWC rebar was comparatively low.

5. 2. Summary of ASTM Beam-end Specimens Table 6 shows the observation of the pull-out test in beam-end specimens. The variation in usable bond strength has been calculated with respect to MS uncoated rebar. Figure 12 shows the crack pattern observed in the specimens during the test.

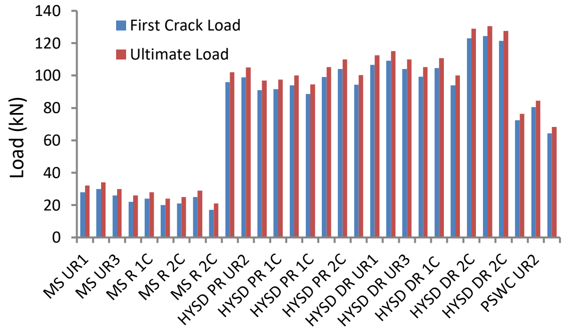


Figure 11. Evaluation of initial crack load and ultimate load

Figure 12. Crack pattern in beam-end specimens

TABLE 6. Observations on pull-out test

No.	Type of Rebar	Load (kN) 0.025 mm FE slip	Load (kN) 0.25 mm LE slip	Usable Bond Strength (MPa)	Mean Variation (%)	Mean cube compressive strength of concrete (MPa)	Inclination of Ribs	Ultimate Pullout Load (kN)	Mean Ultimate Pullout Load (MPa)	Variation (%)	Crack Pattern	Type of Failure
1	S1 MS UR	25.19	24.89	2.48				35.7			Linear	Pullout
2	S2 MS UR	24.47	22.64	2.25	-	32.91	0	32	35.70	-	Linear	Pullout
3	S3 MS UR	25.91	27.14	2.58				39.4			Linear	Pullout
4	S1 PSWC UR	37.52	36.75	3.66	+48.36%	31.77	0	78.40	78.40	+119.60%	Linear	Pullout

5	S2 PSWC UR	38.44	35.76	3.56				84			Linear	Pullout
6	S3 PSWC UR	36.6	37.74	3.64				72.8			Linear	Pullout
7	S1 HYSD PR UR	39.81	38.61	3.84				114			Y shape	Splitting
8	S2 HYSD PR UR	38.42	37.90	3.77	+57.38%	29.89	78	118	114	+219.33%	Y shape	Pullout
9	S3 HYSD PR UR	41.20	39.31	3.91				110			Y shape	Splitting
10	S1 HYSD DR UR	43.86	41.5	4.12				120			Y shape	Splitting / Yield
11	S2 HYSD DR UR	41.78	39.53	3.93	+68.85%	32.43	83	126.7	120	+236.13%	Y shape	Splitting
12	S3 HYSD DR UR	45.94	43.47	4.32				113.3			Y shape	Pullout

S: Specimen, UR: Uncoated Rebar

The following observations were noted in the load-slip behaviour of beam-end specimens:

(a) From the load-slip behaviour of MS UR, HYSD PR UR and HYSD DR UR. The average ultimate load-carrying capacity of HYSD PR UR and HYSD DR UR was 219.32 and 236.13% greater than MS UR respectively. The usable bond strength of HYSD PR UR and HYSD DR UR was 57.37 and 68.85% greater than MS UR respectively.

(b) From the load-slip behaviour of MS rebar and PSWC rebar with 4mm profile deformation and 200mm pitch length, the PSWC rebar offered significantly improved resistance against slip in the initial stage as compared to MS rebar. PSWC rebar offered appreciably higher ultimate bond strength, 119.60% greater than MS rebar due to the presence of offset (ridge) and pitch (valley) of the steel-concrete interface. PSWC rebar showed significantly higher usable bond strength of the order of 48.0% greater as compared to MS rebar.

5. 2. 1. Evaluation of Initial Crack Load and Ultimate Load of MS Rebars, HYSD Rebars and PSWC Rebars Figure 13 shows the evaluation of loads at which the first crack was visible in the specimen and the ultimate load at which the specimen fails in the pull-out test. It was evident that PSWC rebars perform better than MS rebar in the pull-out test. In HYSD rebar with parallel and diamond ribs, there is an appreciable difference between first crack load and ultimate load. The corresponding difference between the load at which the first crack is visible in HYSD PR UR and PSWC rebar was less.

Figure 14 shows the embedded coated rebars and the concrete at the end of the test. It was observed that the

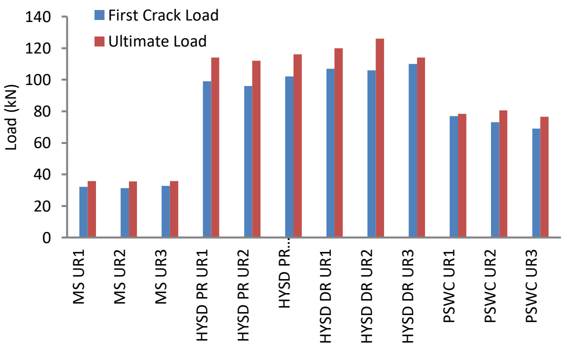


Figure 13. Evaluation of first crack and ultimate load

Figure 14. Condition of concrete and coated rebar at the end of the test

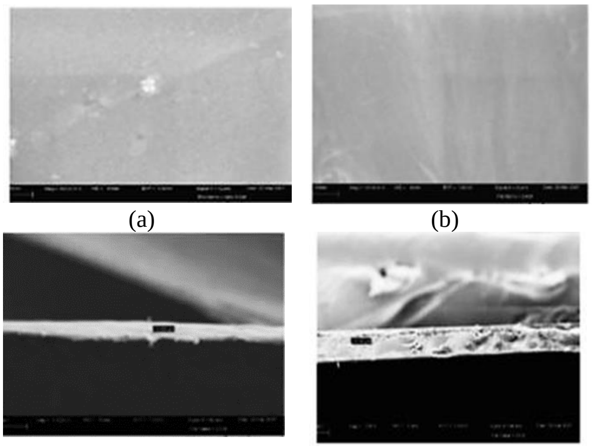


Figure 15. SEM Images of a) Plain CPAC b) TiO_2 Modified CPAC c) Cross-sectional View of 1coat Coating d) Cross-sectional View of 2-coat Coating; All images have a magnification level of approximately 100,000 times

uncoated rebars were corroded more and the coating is more adhesive to the concrete than rebar. Figure 15 shows the scanning electron microscope (SEM) images of Nano modified CPAC adopted in the study.

6. CONCLUSIONS

The experimental and comparative study on bond strength of plain surface wave type configuration rebars (PSWC) with concrete was carried out as per BIS and ASTM procedure. In addition to this, a Nano TiO_2 altered cement polymer anti-corrosive coating (CPAC) was included in the study to access its mechanical and durability properties. The following conclusions were noted.

(a) Irrespective of surface configuration, the bond strength of uncoated rebars was found more than that of coated rebars.

(b) There is a marginal rise in usable bond strength and the peak pull-out load of HYSD DR rebars as compared to HYSD PR rebars by 5-11%.

(c) As compared to MS rebars, HYSD rebars offered an approximately threefold increase in ultimate bond strength and 1.5 times increase in usable bond strength irrespective of rib configuration. The ultimate load-carrying capacity of coated HYSD diamond rib rebars surpassed mild steel rebars by four times in few cases.

(d) In BIS pull out test, PSWC rebars with 4mm offset and 80mm pitch offered ultimate load-carrying capacity of 76.40kN that is 2.4 times more than MS rebars. Also, there was a rise in usable bond strength by 76.20% compared to MS rebars.

(e) In ASTM beam-end specimens, PSWC rebars with 4mm offset and 200mm pitch offered ultimate load-carrying capacity of 78.4kN that is 2.2 times more than MS rebars. Also, there was a rise in usable bond strength by 48.36% compared to MS rebars.

(f) PSWC rebars exhibit an improved slip resistance and well-established load-slip behaviour as compared to MS rebars.

(g) In BIS pull-out test the ultimate bond strength of PSWC rebars was around 33.5% less as compared to uncoated HYSD rebars and the usable bond strength was about 9.5% less than for HYSD rebars with parallel ribs.

(h) The reduction in bond strength of coated rebars with any rib configuration was less than the maximum reduction of 20% specified by IS 13620-1993. Both 1coat and 2coated rebars satisfied IS code provisions.

(i) PSWC rebars with 4mm offset and 80 mm pitch offered promising bond strength. Upon further optimization and testing of the rebar in other aspects, PSWC rebar can be future rebar to replace HYSD rebars for durable concrete construction at zero additional cost.

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Persian Abstract

چکیده

این مطالعه رفتار استحکام پیوند میلگردهای پیکربندی نوع موج سطح ساده (PSWC) را در مقایسه با میلگردهای فولاد خفیف (MS) و تغییر شکل مقاومت عملکرد عملکرد بالا (HYSD) با پیکربندی دنده متنوع مطابق با استاندارد BIS و ASTM بررسی می کند. متغیرهای موجود در میلگرد شامل سطح ساده ، سطح منحنی ، دنده موازی ، دنده الماس و پوشش ضد خوردگی پلیمر سیمان اصلاح شده نانو (CPAC) است. در مجموع ۳۰ نمونه کششی و ۱۲ نمونه انتهای پرتو به ترتیب با استاندارد BIS و ASTM در آزمون کشش قرار گرفتند. بار مربوط به لغزش انتهای آزاد ۰.۰۲۵ میلی متر (FE) و لغزش انتهای بارگذاری شده ۰.۲۵ میلی متر (LE) با دقت مشاهده شد. رفتار انحراف بار ، ظاهر اولین ترک در نمونه ها و بار شکست نهایی ثبت شد. نتایج تجربی نشان داد که در مقایسه با میلگردهای MS ، میلگردهای HYSD تقریباً سه برابر در افزایش مقاومت پیوند نهایی و ۱.۵ برابر در مقاومت پیوند قابل استفاده بدون توجه به پیکربندی دنده متنوع ، افزایش می یابد. میلگردهای PSWC با افست ۴ میلی متر و گام ۸۰ میلی متر در مقایسه با میلگردهای MS 2.4 برابر افزایش مقاومت نهایی و ۷۶.۲۰٪ افزایش مقاومت باند قابل استفاده دارند. بار نهایی کششی میلگردهای PSWC حدود ۲۵٪ است و مقاومت باند قابل استفاده تنها ۸.۶٪ کمتر از میلگردهای HYSD با دنده های موازی است. پوشش پذیرفته شده مقاومت در برابر خوردگی را افزایش داده و کاهش مقاومت پیوند با هر نوع پیکربندی سطحی کمتر از حداکثر کاهش مجاز ۲۰٪ است که در ۱۳۶۲۰: ۱۹۹۳ مشخص شده است. از این رو می توان نتیجه گرفت که میلگردهای PSWC نتایج امیدوار کننده استحکام باند را ارائه می دهند و با بهینه سازی و مطالعه بیشتر در سایر جنبه ها ، میلگردهای PSWC می توانند راهی برای جایگزینی میلگردهای HYSD در آینده برای افزایش دوام بتن با هزینه اضافه شده صفر باشند.