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Influence of Different Surface Preparations on the Capacity of Composite Steel-Concrete Beams

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Abstract

External bonding of steel plates to structural concrete members has widely gained popularity in recent years, particularly for repairing and strengthening reinforced concrete beams. The success of this bonding technique depends on the effectiveness of the surface preparation of the steel and concrete beams. Studies have shown that most of the beams strengthened using this technique usually fail prematurely by debonding. In this study, concrete beams with different types of surface preparations were investigated, such as no surface preparation (NSP), wire brushing (WB), scabbling (SC) and hand chipping (HC). The quality of the surface preparation established was measured based on the flexural performance of the externally strengthened steel-concrete beams. Eight (8), 250x450x3600 mm reinforced concrete beams were prepared and strengthened with glued steel plates on their soffits. All the specimens were tested under two-point static loading and failure modes were observed. The results showed that beams with rougher surface preparation have a high bond strength as compared to smoother surface preparations. The increase in the average capacity of strengthened beams with the surface prepared by hand-chipping, scabbling, wire brushing was found to be 75.3%, 67.5% and 46.9% respectively, compared to the capacity of the beam strengthened without surface preparation.

Keywords: Concrete, Steel plate, Surface roughness, Strengthened, Adhesive, Debonding, Flexural capacity.

1. INTRODUCTION

Steel plates have been widely used to repair/strengthen many bridges and concrete structures in the United Kingdom, United States of America, South Africa, Japan, Poland, Belgium, France and Switzerland, because they are cheap and readily available, have uniform material properties (isotropic), have high ductility and high fatigue strength, can be secured easily whilst the structure is in use (Raithby, 1982), do not change the overall dimensions of the structure and can be secured without causing any damage to the structure (Swamy, Jones & Bloxham, 1987, Jumaat et al, 2011). The epoxy-bonded st;el plate (EBSP) technique has been reported by many eminent researchers to be the most effective and convenient method of enhancing the flexural performance under serviceability and ultimate limit states (Swamy, Jones & Bloxham, 1987, Jumaat et al, 2011). Despite these benefits, tests have shown that epoxy-bonded steel plates are prone to premature debonding, due to high interfacial shear stress concentration at the plate's ends (MacDonald, 1978; Jones, Swamy & Charif, 1988; Oehlers & Moran, 1990; Oh et al, 2003b). The interfacial bond failure takes place owing to the poor surface preparation of the steel plate and the concrete beams.

The bond strength in the steel plate-to-concrete interface is influenced by various factors such as the material properties of the epoxy, concrete substrate and steel plate, and surface preparation of the concrete and steel plate. (Lovinella et al., 2012, Ariyachandra and Gamage, 2013). For better results, the surfaces of the steel plate and concrete beams should be prepared so that it is clean, sound and suitable for the application of the adhesive and strengthening material (Lovinella et al., 2013). Some of the most common surface preparation methods are wire brushing, grinding, scarifying, bush-hammering, shot-blasting and sand-blasting, each with its own associated advantages and disadvantages, related to the desired roughness profile of the prepared surface, cost and processing time (Lovinella et al., 2013). Chajes et al. (1996) presented an experimental investigation on the study of the bond and force transfer of composite material plates bonded to concrete. The test results in this study suggested that an increased interfacial bond is achieved when the concrete surface is mechanically abraded using grinding wheel, creating porous concrete surface.

A strong bond is necessary between the steel plate and the concrete so that the concrete and the steel plate work monolithically when loaded, and shear forces are transferred from the concrete to the steel plate. Although the adhesive provides the bond, it is critical that the steel plate and the concrete are prepared sufficiently in order to maximise the bonding capabilities of the adhesive. A poorly prepared surface is a weak link, no matter how good the adhesive material might be. Adequate surface preparation produce a sound, clean, and suitably roughened surface on the bonded elements, and includes the removal of laitance (weak layer of cement and fines at the concrete surface), dirt, oil, films, paint, coatings, sound and unsound concrete, and other materials that will interfere with the adhesion or penetration of the adhesive.

A comprehensive roughness profile of the concrete surfaces is given in Technical Guidelines provided by the International Concrete Repair Institute (ICRI, 2013). Each concrete profile carries a CSP number ranging from CSP 1 (nearly flat) through CSP 10 (very rough). Grinding produces an abrasive force, which wears away the cement paste, fines, and coarse aggregate at a uniform rate to produce a nearly flat surface having little or no profile. In preparation for an investigation on strengthening and repairing of concrete beams, a decision was taken to re-visit the work on surface roughness profiles. Guided by the roughness profile of the concrete surfaces provided by the International Concrete Repair Institute (ICRI, 2013), eight (8) reinforced concrete beams were cast and their surface were roughened using four different mechanical surface preparation methods. The aim of this study is to determine the flexural performance of plated concrete beams with four (4) different types of surface preparations, namely; no surface preparation (NSP), wire brushing (WB), scabbling (SC) and hand chipping (HC).

2.0 Material properties

Two groups (Group A and Group B) of reinforced concrete beams of 3600x250x450 mm in size and four (4) concrete cubes were cast, using concrete of different strengths. The average 28-day compressive strength of the four cubes in Group A and Group B was 30 MPa and 27 MPa, respectively. Two, 10 mm diameter high yield strength bars with corresponding yield strength of 450MPa were used as both tension and compression reinforcement. All concrete beams were strengthened with mild steel plates of 6 mm thickness, 250 mm width and 3300 mm length, and of 351.73 MPa yield strength and 483.44 MPa ultimate strength. To ensure that the strengthened beams fails in flexure, 10 mm diameter bars were used as the shear links placed at 250 mm from centre-to-centre.

2.1 Experimental results and analysis

The experimental results regarding the flexural performance of strengthened beams, with different concrete surfaces, are given in Table 1. In this Table, P_{NSP} refers to the maximum load applied to the beams with no surface preparation (control beam), P_{NSP} refers to the maximum load applied to the beams with concrete surface preparation, P_t is the code-predicted yield load, P_{CSP}/P_{NSP} compares the maximum load of the beams that are roughened to that of the beams with no surface preparation and $P_{NSP/CSP}/P_t$ compares the maximum load of the beams to the code-predicted yield load. A code-predicted yield loads of 404.10kN and was calculated using the guidelines from SANS10162-1 (2011).

Tables 1: Experimental results.

Group	Specimen	Surface profile	$P_{NSP/CSP}$ (kN)	P_{CSP}/P_{NSP}	$P_{NSP/CSP}/P_t$	Failure mode
A	A-B1-27	NSP	199.21	-	0.49	De-bonding
	A-B2-27	WB	234.36	1.18	0.58	De-bonding
	A-B3-27	SC	252.47	1.27	0.63	Shear peeling
	A-B4-27	HC	264.10	1.32	0.65	Shear peeling
B	B-B1-30	NSP	221.34	-	0.55	De-bonding
	B-B2-30	WB	265.22	1.20	0.66	De-bonding
	B-B3-30	SC	294.13	1.33	0.73	Shear peeling
	B-B4-30	HC	314.31	1.42	0.78	Shear peeling

As indicated in Table 1, all the specimens in both Group A and Group B show an increase in flexural capacity as compared to the strengthened beam with no surface preparation. In Group A, an increase in flexural capacity of the prepared beams ranges from 18% to 32% as compared to the control beam whilst in Group B an increase in flexural capacity of the prepared beams ranges from 20% to 42%. The latter differences in the increase in flexural capacities of beams in Group A and Group B is due to the difference in the average 28-day compressive strength.

The comparison of increase in percentages of the flexural capacity of beams with roughened surface (WB, SC and HC) as compared to the control beams is well represented by Figure 1. Based on the results in Table 1 and Figure 1, it is clear that there is a correlation between the level of roughness, adhesion bond strength and the flexural capacity. In addition to that, beams that were prepared using hand chipping achieved higher load carrying capacity as compared to beams that were prepared using scabbling.

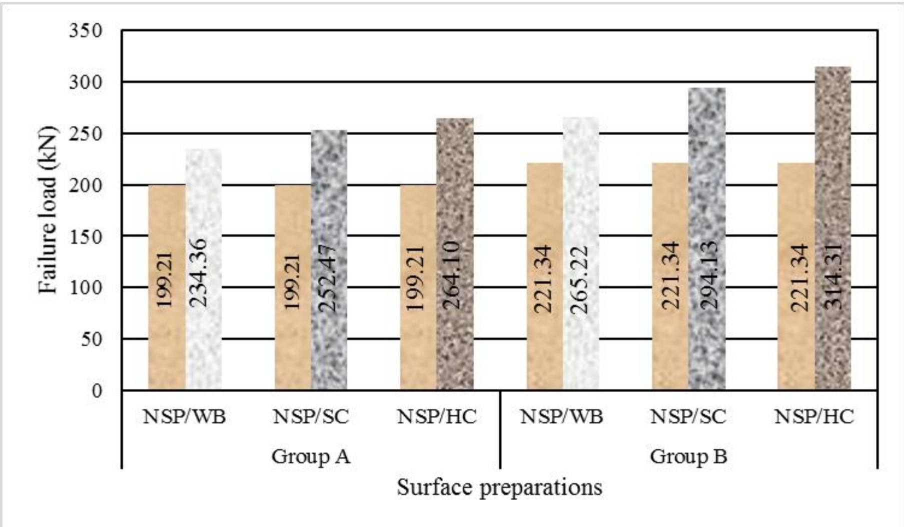


Figure 1: Comparison between the surface preparation methods

2.2 Moment-deflection curves

The moment-deflection response for each specimen is given in Figures 2 and 3. As illustrated both figures, the flexural strength of the concrete beams with improved surface roughness is significantly larger than the beam with no surface preparation (NSP). Beams with the concrete surface roughened before bonding the steel plate increased the overall stiffness of the strengthened sections, which results in high cracking load and maximum capacity as shown by various researchers.

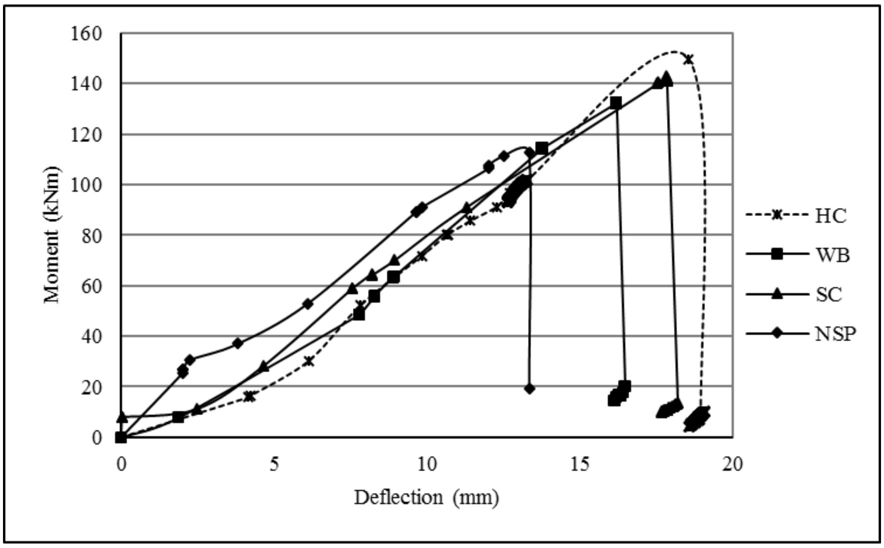


Figure 2: Moment-deflection response of the beams in Group A

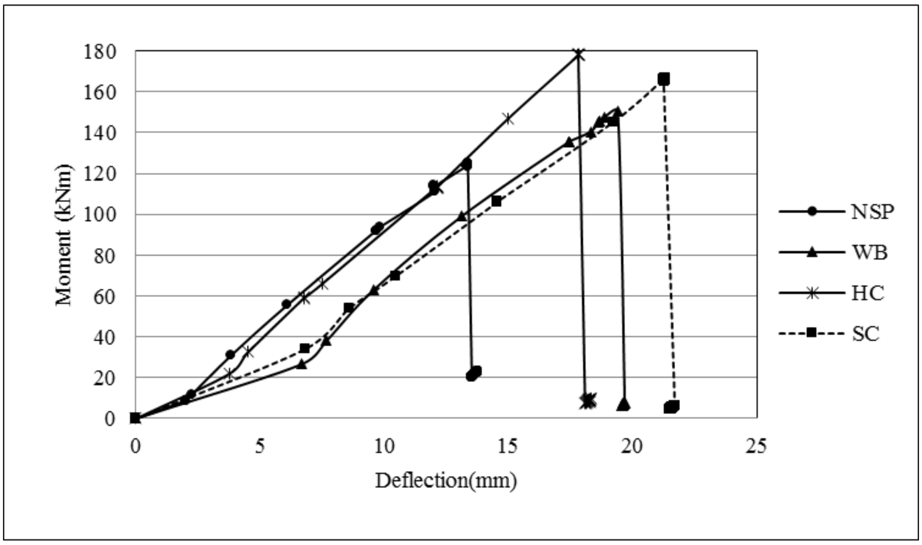


Figure 3: Moment-deflection response of the beams in Group B

2.3 Moment-steel strains curves

The moment-strain curves of beams with different concrete surface preparation are shown in Figure 4 and 5. Figure 4 and 5 shows that the steel plate of beams with concrete surface prepared by scabbling and hand chipping strained significantly as compared to beams that are prepared by wire brushing and not prepared. The latter is due to the high interfacial adhesion bond manifested between the epoxy-bonded steel and the prepared concrete surface, the two materials tend to act compositely for a longer time while being loaded, as compared to the specimens that are prepared using wire brushing and non-surface preparation which acted compositely for a shorter period of time. None of the steel plates shows any sign of yielding. From the tensile test, the yield strain of the 6 mm bonded steel plate was 0.0039, which is 64% and 59% higher than the maximum strains achieved by strengthened beams in both Group A(0.0014) and B(0.0016).

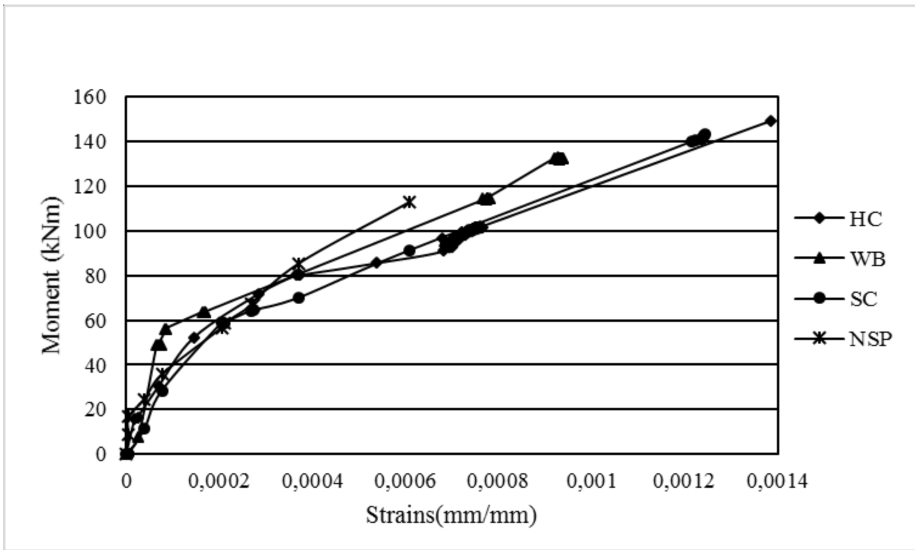


Figure 4: Moment-strain response of the beams in Group A

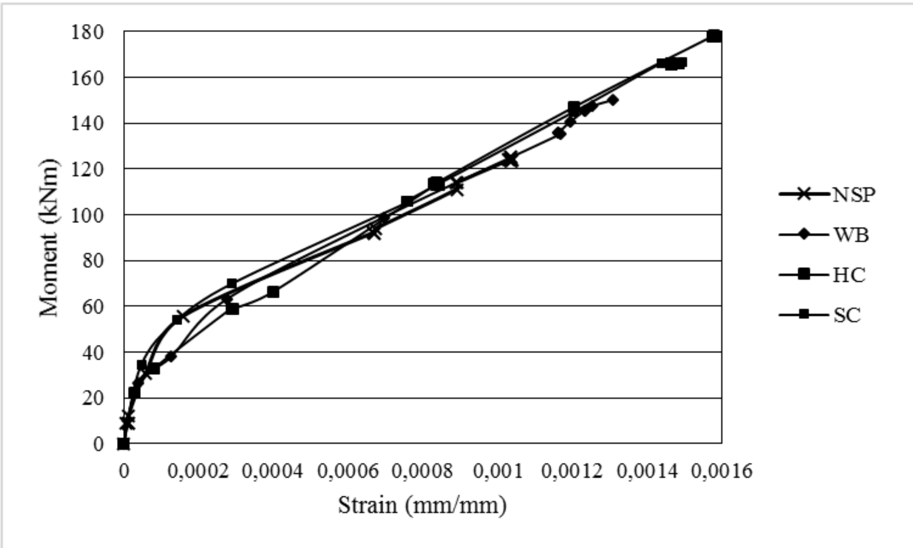
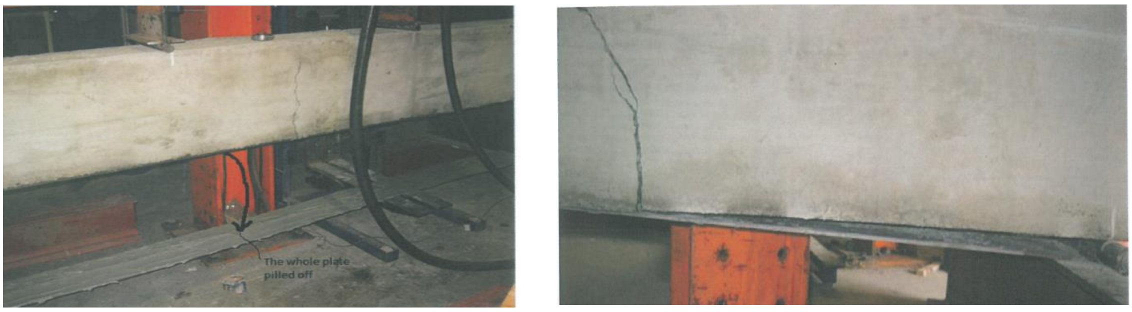


Figure 5: Moment-strain response of the beams in Group B

2.4 Failure modes

During testing of the strengthened specimen, different failure modes were observed. In both groups, the control specimens (NSP) failed prematurely, by peeling-off of the steel plate, due to lack of adhesion bond between the epoxy resin and the concrete. In addition to the latter, the control beam failed after exceeding the code predicted maximum capacity of the unplated beam of 50.28 kN. Figure 6(a) shows a debonded steel plate. The hardened epoxy resin on the steel plate clearly shows that there was no enough bond between the epoxy resin and the unprepared concrete surface. For concrete beams with wire brushed concrete surface, the premature failure of the strengthened beam was caused by the steel plate debonding in the shear zone, this is due to high shear stresses concentrated at the plate end.

For beams with scabbled and hand chipped concrete surface substrates, the mode of failure shifted from full flexural yielding to premature failure by plate-end debonding. This type of failure is common in strengthened beams, and is caused by diagonal shear cracks, in the zone of high interfacial normal and shear stresses, at the end of the plate (Oh et al., 2003; Olajumoke & Dundu., 2014). As evidence that shear stresses were dominant, as the plate separation propagated towards the mid-span, it changed into a diagonal crack, which extended towards the loading point at about 45°. The latter failure mechanism is called the critical diagonal crack (CDC) debonding and usually occurs after the formation of a large crack, which may be due to insufficient shear reinforcement (Olajumoke & Dundu., 2014, and Oehlers et al., 2003)



(a) No surface preparation (NSP) (b) Wire brushing (WB)

Figure 6: Typical failure modes of the strengthened beams

3.0 CONCLUSION

Different surface roughening produces different interfacial bond strength, as reflected by different load capacities of the specimen. Bonding steel plates to the soffit of concrete beams increased their flexural strength and stiffness, particularly when the concrete surface is prepared by hand chipping and scabbling. Irrespective of the type of concrete surface treatment, roughening of the concrete surface increases the flexural performance, with hand chipping and scabbling being identified as the most effective surface preparation method. All the strengthened specimens achieved a flexural capacity higher than the code predicted maximum load of the unplated beam. One of the disadvantages of hand chipping is that, it is time consuming and difficult to create a uniform surface roughness throughout the length of one specimen, and on different specimens that require exactly the same roughness level. In most situations, the human skill and experience, required to achieve this might not be available. To create a balance between optimum roughness and practicality, scabbling, which achieves almost the same load capacity as hand chipping, should be adopted over hand chipping.

4.0 REFERENCES

Al-Tamimi, A.K., Ozkul, T.,Azzam, M.M., Sabetnia,M.R., Abdullah, M.B. and Hossieni, S.H. (2011) Investigation of the effect of surface preparation method and the degree of surface roughness on CFRP-concrete bonding and substrate strength, *The built & human Environment Review, Volume 4, no.1,pp. 33-44*

Barnes R.A, Baglin P.S., Mays C.G and Subedi N.K., (2001). The effects of plate system for the shear strengthening of reinforced concrete beams, *Engineering structures, vol. 23, no 2001, pp. 1162-1176*

De Lorenzis, L., Miller, B and Nanni, A. (2001). Bond of FRP Laminates to Concrete, *ACI Materials Journal, Vol 98, No.3, pp. 256-264*