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Effect of Waste Steel Shavings on Bond Strength between Concrete and Steel Reinforcement

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Abstract: The investigation was carried out to know the effect of waste steel shavings on the bond resistance between concrete and steel reinforcement using 16mm and 20mm diameter high-yield reinforcing bars. Eighty (80) RILEM specimens, made up of forty (40) cubes each of 160mm x 160mm x 160mm and 200mm x 200mm x 200mm were cast and tested with varying percentages of waste steel shavings, (0%, 1%, 1.5%, and 2%, by weight of concrete) using pull out arrangement. The normal concrete (with no steel shavings) which are ten (10) in number were used as reference. Also, twelve (12) 150mm concrete cubes were cast to monitor the compressive strength of concrete. The results showed that bond strength increased with the addition of 2%, (by weight of concrete), of waste steel shavings.

1. Introduction

The population of Nigeria is about 170 million people; the amount of waste generated in all spheres of life is enormous. Of interest, in this work is the quantity of Waste Steel generated. A reasonable quantity of waste steel is now being melted and reprocessed as steel reinforcing rods. Disposing steel waste is already an environmental issue in Nigeria. Attempt to find a gainful use for waste steel is desirable and worthwhile.

Corrosion of reinforcement is a major problem in reinforced concrete, as water molecules would always find its way into the concrete and attack the reinforcement, corroding it, especially in those structures that are in the coastal environment. To prevent early corrosion reinforcements are coated. Coating is known to reduce bond strength. There is therefore a need to continue to research into possible ways of finding efficient and effective methods of improving bond strength of coated bars and other materials that are known to have a reduced bond strength e.g. Laterised concrete.

Bond is the interactive mechanism that enables force to be transferred between reinforcing bars and the surrounding concrete. Bond influences the behaviour of concrete structures in many ways, no matter whether the reinforcing material is steel, an FRP composite, fibers forming a constituent of the concrete mix, or whether it is embedded or external to the concrete section [1].

An investigation on the improvement of bond strength of epoxy coated bars using stirrups was carried out in [2]. Three beam sizes (300mm x 230mm, 300mm x 200mm, and 300mm x 180mm) were used with 28mm, 20mm, 16mm diameter high yield bars respectively, the stirrups used were 8mm and 10mm diameter high yield bars. It was found that stirrups improved the bond efficiency of epoxy coated bars. The application of coating materials, epoxy and tyrolin in sequence and as a mixture on coated bars to improve the bond strength was also reported. Epoxy was applied first and then tyrolin. The two materials were also mixed together and applied; the results gave higher bond efficiency. Simple lap spliced beams were used in a four point loading system. The two methods improved bond but application in sequence gave higher bond strength.

The effect of increased cover on bond efficiency of coated reinforcing bars with 30 full size beams of varying length and sectional dimensions with lap-spliced beam in constant moment region. The ultimate moment from the tests were used to determine the stress develop in the steel rods. Bond efficiency was studied for the parameter under investigation. Increased concrete cover was found to increase bond efficiency of coated reinforcing bars, but the increase was not proportional to the additional cover thickness [3].

The effects of fibre surface area on the bond properties of fibre were studied in [4]. It was shown that significant increases in surface area can be achieved by changing the cross- sectional shape, which in turn leads to an increase in bond strength. Fibre crimping further increases the bond strength. More importantly, it was also found out that crimped macro- synthetic fibres with modified cross sections (cross, star, etc.) can attain a bond stress versus bond slip relationship similar to that of steel fibres, characterized by a steep and linear elastic frictional bond component, followed by a “bend-over point” and a subsequent parabolic increase to the maximum bond stress.

This work investigates the bond strength between concrete and steel reinforcement when waste steel shavings are incorporated. If found to improve the interaction between steel reinforcement and concrete, the waste steel shavings disposed indiscriminately will be used profitably subsequently saves landfill space for other beneficial use. The environmental hazard of indiscriminate disposal of the waste steel shavings will be reduced. Very many attempts have been made in the past to improve the bond strength between concrete and steel reinforcement, to date, not much has been done using waste products. Attempt to do so is worthwhile.

2. Materials and Methodology

2.1. Materials & Samples Preparation

The waste steel shavings were collected from Lathe machines that are used to turn steel rods at the Steel Scrap Market, Lagos, Nigeria. Figure 1. The shavings were fairly corroded and were cut into 25mm – 50mm lengths. The coarse and fine aggregates were air dried to obtain a surface dry condition and to ensure that water cement ratio was not affected. 12mm coarse aggregate was used for the investigation. Ordinary Portland cement, Clean and drinkable water were used in producing the concrete mixture. The reinforcement used were obtained from the open market and tested for strength. Table 4.

Figure 1. Waste Steel Shavings.

Forty (40) RILEM specimens for 160mm cube were cast with 16mm diameter bars centrally and horizontally placed in the cubes. In the preliminary investigation five (5) cubes were cast each with the addition of steel shavings at varying percentages (0%, 1%, 1.5% and 2%, by weight of concrete). Confirmatory tests were later carried out in which ten (10) cubes each for the percentages that showed good promise (1.5% and 2%). Similarly, forty (40) RILEM specimens for 200mm cube were cast with 20mm diameter high yield bars. The concrete investigated was of mix ratio1:2:4 (cement: sand: granite), with water /cement ratio of 0.55. The addition of the waste steel shavings was in varying percentages of 1%, 1.5% and 2% the weight of concrete and the batching was by weight. The mixing was carried out in three (3) batches; each batch contained the varying percentage (1%, 1.5% and 2%). Also, three (3) samples of 150mm cubes were cast per batch to check for the compressive strength of each batch. A total of twelve (12) cubes were cast for monitoring the compressive strength. The RILEM samples and the compressive strength cubes were cured by immersion in water for 28 days.

2.2. Testing Procedures
Before the commencement of the pull-out test, the RILEM samples were kept under room temperature after the completion of the 28 days curing in water. Thereafter, each of the RILEM specimens and the strength cubes were weighed on the electronic weighing balance, before they were finally taken to the Tensile testing machine for the pull out test and the strength cubes to the compression testing machine.

The samples were placed in the machine, carefully centralised between the upper and lower plates and properly adjusted in order to ensure proper contact, after which the Compression machine was loaded. The failure load was recorded for each specimen.

3. Results and Discussion

3.1. Compressive Strength of Concrete
The compressive strengths of the 150mm cubes with different % of steel shavings are shown in Table 1. The results show that the steel shaving did not improve the compressive strength of normal concrete. However, the reduction in the compressive strength with incorporation of steel shavings was negligible. For example, for 1.5% steel shaving, the average compressive strength at 28 days was 27.77N/mm^2 which was even higher than the normal concrete (without steel shaving) of 27.48N/mm^2. However, for 1% inclusion, the compressive strength was 25.26N/mm^2. The variation may not be unconnected with the fineness of the steel shavings.

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Table 1. Compressive Strength (f_{cu}) of Concrete at 28days with different percentages of Steel shavings.

Specimen ID	% of Steel Shavings	Cube Strength (N/mm^2)	Average Cube Strength (N/mm^2)
R01		30.00	
R02	**0**	23.11	27.48
R03		29.33	
X01		26.89	
X02	**1.0**	26.67	25.26
X03		22.22	
Y01		26.44	
Y02	**1.5**	30.00	27.77
Y03		26.88	
Z01		21.55	
Z02	**2.0**	23.11	22.37
Z03		22.44	

4. Crack Patterns

Different crack patterns were found with different sizes of reinforcement and percentages of waste steel shavings in the RILEM specimens. The reinforced concrete with 16mm diameter steel reinforcing bars with 160mm cube specimens gave the values of most specimens failing by splitting and few by slipping while all 200mm cube specimen failed by slipping. The results of the various crack patterns in the 160mm and 200mm cubes are summarized in Tables 2 and 3 and shown in Figures 2 and 3.

Figure 2. RILEM specimen that failed by splitting.

Figure 3. RILEM Specimen that failed by slipping.

The variations in crack pattern formation on the specimens may be as a result of insufficient cover for the transfer of the force from the reinforcement bar to the concrete; this would exert high pressure on the concrete. For instance, the concrete cover for 20mm diameter bar samples was 90mm while the cover for 16mm diameter bar samples was 72mm. Slipping occurred when the cover was more, this was observed in samples with 20mm diameter bars. The level of compaction could also result in different crack patterns.

Table 2. Bond Resistance and Crack Pattern of RILEM Concrete Specimens with Steel Shavings and 16mm Diameter bars.

Specimen ID	% Steel Shavings	Bond Failure (kN)	Bond Resistance (N/mm^2)	Average Bond Resistance (N/mm^2)	Slip (mm)	Crack Pattern
			160mm x 160mm x 160mm			
R01		80.442	1.82		10	Split
R02		86.328	1.95		8	Split
R03	0	77.499	1.75	1.61	7	Split
R04		51.012	1.15		3	Slip
R05		60.822	1.38		5	Slip
X01		73.212	1.64		10	Split
X02		65.623	1.47		8	Split
X03	1.0	66.515	1.49	1.49	7	Split
X04		60.712	1.36		3	Split
X05		66.515	1.49		5	Slip
Y01		58.860	1.45		10	Split
Y02		62.784	1.55		8	Split
Y03		58.860	1.45		7	Split
Y04		64.1	1.58		3	Slip
Y05		71.613	1.76		5	Slip
Y06	1.5	60.822	1.52	1.6	9	Split
Y07		68.67	1.71		4	Split
Y08		65.727	1.64		8	Slip
Y09		69.651	1.74		5	Slip
Y10		62.784	1.57		10	Split
Y11		67.689	1.69		2	Slip
Y12		68.67	1.71		9	Slip
Y13		60.822	1.52		10	Split
Y14		64.746	1.61		8	Slip
Y15		62.784	1.57		7	Split
Z01		52.479	1.46		10	Split
Z02		57.511	1.60		8	Split
Z03		56.433	1.57		7	Slip
Z04		66.497	1.85		3	Split
Z05		63.262	1.76		5	Split
Z06	2.0	64.746	1.74	1.69	3	Slip
Z07		62.784	1.67		5	Slip
Z08		62.784	1.67		9	Split
Z09		58.86	1.57		4	Split
Z10		66.708	1.78		7	Split
Z11		70.632	1.88		4	Slip
Z12		60.822	1.61		8	Slip
Z13		58.86	1.57		5	Split
Z14		66.708	1.78		10	Split
Y15		68.67	1.83		2	Split

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Table 3. Bond Strength and Crack Pattern of RILEM Concrete Specimens with Steel Shavings and 20mm Diameter bars.

Specimen ID	% Steel Shavings	Bond Failure (kN)	Bond Resistance (N/mm^2)	Average Bond Resistance (N/mm^2)	Slip (mm)	Crack Pattern
200mm x 200mm x 200mm						
P01		98.141	1.42		10	Slip
P02		108.71	1.57		8	Slip
P03	0	128.51	1.86	1.58	7	Slip
P04		110.50	1.60		3	Slip
P05		98.716	1.43		5	Slip
Q01		97.119	1.39		10	Slip
Q02		102.04	1.46		8	Slip
Q03	1.0	88.290	1.27	1.43	7	Slip
Q04		106.99	1.53		3	Slip
Q05		103.05	1.48		5	Slip
R01		100.50	1.58		10	Slip
R02		100.41	1.58		8	Slip
R03		100.02	1.58		7	Slip
R04		95.171	1.50		3	Slip
R05		92.637	1.46		5	Slip
R06		100.02	1.50		9	Slip
R07		102.04	1.62		2	Slip
R08	1.5	108.81	1.74	1.58	6	Slip
R09		105.98	1.69		10	Slip
R10		94.176	1.50		7	Slip
R11		102.04	1.62		8	Slip
R12		99.081	1.66		9	Slip
R13		98.100	1.65		3	Slip
R14		100.02	1.50		5	Slip
R15		90.252	1.52		2	Slip
S01		87.309	1.55		10	Slip
S02		92.731	1.65		8	Slip
S03		93.429	1.66		7	Slip
S04		94.413	1.68		3	Slip
S05		90.102	1.60		5	Slip
S06		102.04	1.76		9	Slip
S07		94.176	1.62		2	Slip
S08	2.0	100.02	1.72	1.65	4	Slip
S09		98.100	1.69		10	Slip
S10		89.271	1.54		8	Slip
S11		99.081	1.71		7	Slip
S12		98.100	1.69		3	Slip
S13		92.214	1.59		5	Slip
S14		105.98	1.80		4	Slip
S15		88.29	1.52		9	Slip

5. Effect of Waste Steel Shavings on bond

In general, the bond stress corresponding to the maximum pull out load can be regarded as the ultimate bond resistance. With the failure load, the bond stress was determined using the following relationship in [5]

$$\tau_{\Sigma} = (0.00637F \times 25)\, 10^3/\emptyset^2 \times f_c \quad (1)$$

Where:
τ_{Σ} = bond strength; (N/mm^2); F = Failure load (kN)
$\emptyset^2$ = Bar diameter (mm); f_{cu} = Compressive strength of concrete (N/mm²).

The results obtained, using equation (1) for 160mm RILEM specimens with 16mm diameter steel reinforcing bar gave the value of average bond resistance of 1.49N/mm^2 at 1% with one specimen failing by slipping, while the rest failed by splitting, average bond resistance of 1.60N/mm^2 was recorded at 1.5%, with two samples failing by slipping and the rest failed by splitting and average bond resistance of 1.69N/mm^2 at 2% with majority failing by splitting and the last one failed by slipping while the reference specimens has a average bond resistance of 1.61N/mm^2 in which few specimens failed by slipping and the others by splitting.

The results of specimens cast with 20mm diameter bars gave the value of average bond resistance of 1.43N/mm^2 at 1% and all of the specimens failed by slipping. An average bond resistance of 1.58N/mm^2 was recorded at 1.5% with all of the specimens failing by slipping, and average bond resistance of 1.65N/mm^2 at 2% in which all the specimens in this category failed by slipping while the reference specimens has average bond resistance of 1.58N/mm^2 and all the samples also failed by slipping. The results are shown in Figure 4.

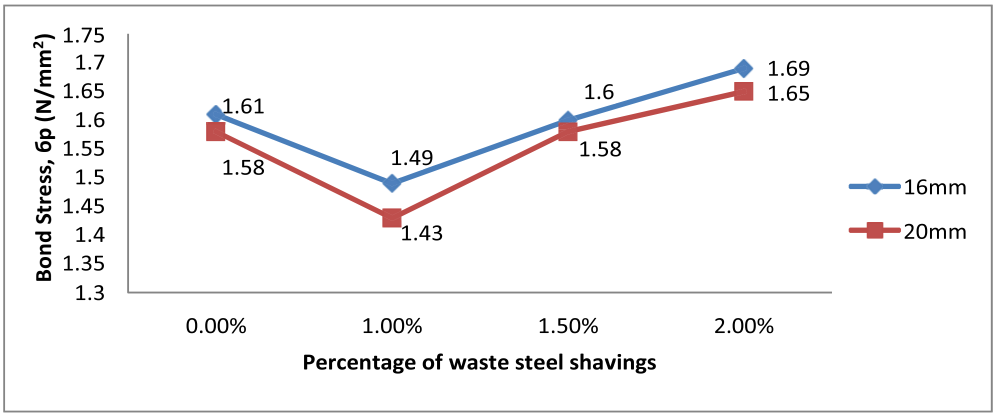

Figure 4. Bond Strength of RILEM Specimens with Waste Steel Shavings.

It was observed that with 2% steel shavings for 16mm reinforcement bar, bond resistance increased up to 4.7% while incorporation of 1.5% and 1% steel shavings caused a decrease of 0.6% and 8.1% respectively. For 20mm diameter reinforcing bar, in the 200mm RILEM specimens there was an increase of 0% and 4.20% and decrease of 10.5% for 1.5%, 2% and 1% addition of waste steel shaving content respectively. The low bond resistance obtained for 1% may not be unconnected with the possible inadequacy of the steel shavings to spread out and this may have effect on the composite.

It was also observed from the test results that the bigger the size of the specimens and the reinforcement therein, the lesser the bond resistance. 200mm RILEM specimens gave a bond resistance lesser than 160mm specimens. This effect may be due to air pockets below the steel bar which were more in bigger diameter bars because of the larger surface area.

However, the bond resistance of RILEM specimen with 16mm steel reinforcing bars containing 1%, 1.5% and 2% of the waste steel shavings was greater than RILEM specimens with 20mm reinforcing bar respectively, due to the concrete cover which was more in specimen with 16mm diameter bars.

The waste steel shavings was also compared with other waste materials like wood and plastic in [6] and [7] to confirm the most effective material that can enhance the improvement of bond resistance using both 16mm and 20mm steel reinforcing bars and the results are shown in Figures 5 and 6 respectively. The results showed that with 1% addition of any of the waste the value of the bond was lower when compared to 1.5% or 2%. That is, there was a similar behaviour of the composite to bond resistance.

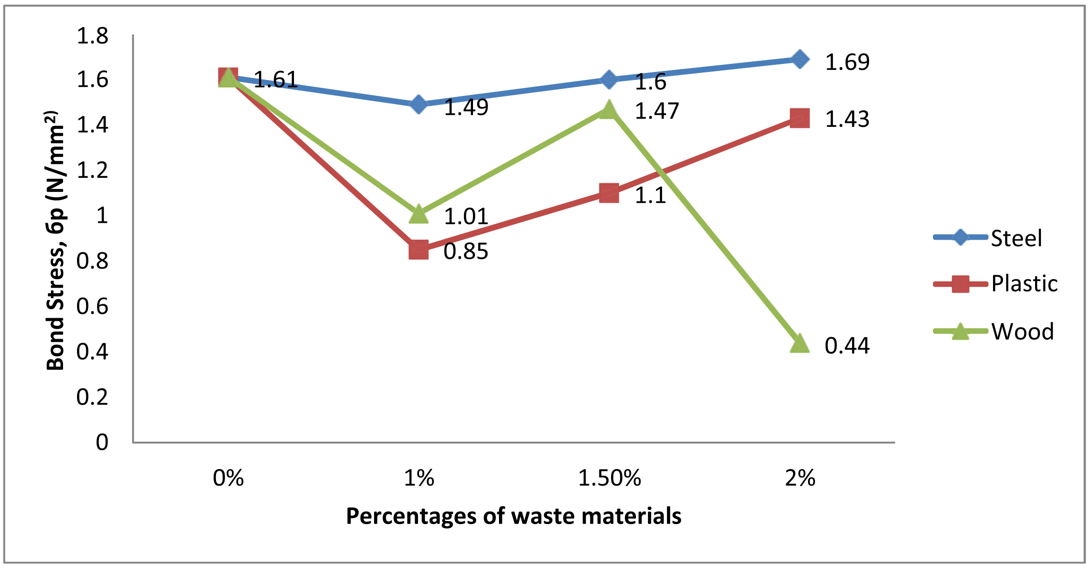

Figure 5. Comparison of Bond Strength of Various Waste Materials using 16mm Bar.

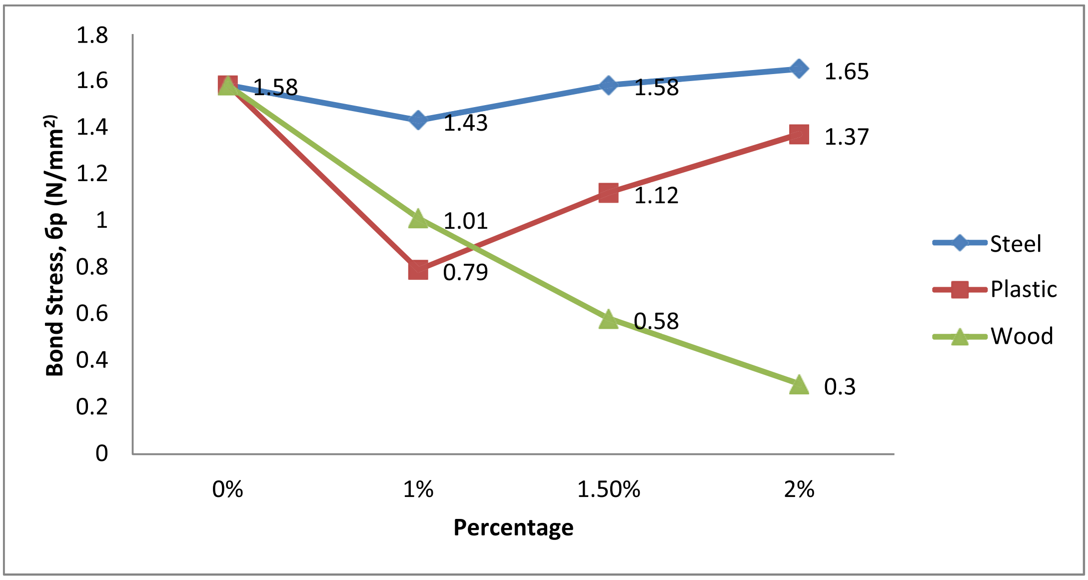

Figure 6. Comparison of Bond Strength of Various Waste Materials using 20mm Bar.

During the compaction it was also observed that addition of waste steel shavings to reinforced concrete enhance greater bond between the concrete and the steel bars compared to conventional reinforced concrete because the addition of steel shavings to concrete necessitated an alteration to the mix design to compensate for the loss of workability due to the extra paste required to cover the surface of the added steel shavings. This may aid improvement in resistance to cracking and durability of conventional reinforced concrete.

6. Conclusions and Recommendation

Based on the eighty RILEM pull out test specimens tested, and the analysis of the test results, the following conclusions can be drawn:

- The steel shavings did not improve the 28-day compressive strength of concrete.
- The mode of failure of the 160mmx160mmx160mm specimens are majorly by splitting while majority of 200mm x 200mm x 200mm specimens failed by slipping. (see Figures 2 and 3)
- Bond resistance improved with the addition of 2% steel shavings by 4.7% and 4.2% on16 mm and 20 mm diameter bars tested respectively.
- The bond resistance of 16mm diameter bars was higher than that of 20mm diameter high yield bars.

Further work is recommended on bond resistance of higher percentages of waste steel fibre-like addition to concrete so as to establish the optimum percentage inclusion of this waste steel fibre-like material for increased bond strength. Bond beam test is also desirable to corroborate the findings from RILEM tests.

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