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Effect of waste aluminium shavings on the bond characteristics of laterized concrete

Olatokunbo M. Ofuyatan *1, Anthony A. Ivoke **2, Adeoye M. Olowofoyeku [3a], Adeyemi Adesina [4b] and Oluwafemi John [1c]

[1] *Department of Civil Engineering, Covenant University, Ota, Lagos, Nigeria*
[2] *Department of Civil Engineering, university of Lagos, Lagos State, Nigeria*
[3] *Department of Civil Engineering, Yaba College of Technology, Yaba, Lagos, Nigeria*
[4] *Department of Civil Engineering, Covenant University, Ota, Lagos, Nigeria*

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Abstract. The utilization of fibre in concrete production not only solves the problem of disposing this solid waste but helps conserve natural resources. This study investigated the effect of waste aluminum shavings on bond strength of laterized concrete. Laterized concrete spliced beams of 150×250×2150 mm and 175×275×2300 mm were prepared. Fifteen specimens with 16 mm and 20 mm were cast with the addition of aluminium shavings at varying percentages of 1vol%, 1.5vol% and 2vol%; another ten specimens with 16 mm and 20 mm diameter bars at 0% of aluminium shavings were cast as control. Concrete cubes of number were prepared, three taken for each set of various percentages of aluminium shavings were used to determine the concrete strength. It was observed from the analysis that the compressive strength decreased as the percentage of aluminium shavings increased, while the aluminium shavings increased the bond between concrete and steel. However, for normal concrete there was an increase in bond resistance with increase in aluminium shavings. The bond resistance of 16 mm was found to be higher than that of 20 mm in all the specimens tested.

Keywords: aluminum shavings; spliced beams; laterized concrete beams; reinforcing bar; bending; splice length

1. Introduction

Aluminum is produced from bauxite, a clay-like ore that is rich in aluminum compounds. The aluminum is only found as a compound called alumina, which is a hard material consisting of aluminum combined with oxygen. This alumina has to be stripped of its oxygen in order to free the aluminum. The alumina is dissolved in a molten salt at a reduction plant and a powerful electric current is run though the 5vol% of the CO_2 emissions as compared with primary production and

*Corresponding author, Ph.D., E-mail: olatokunbo.ofuyatan@covenantuniversity.edu.ng
**Corresponding author, Ph.D. Student, E-mail: ivokeanthony@gmail.com
[a] Ph.D., E-mail: adeolowoo@gmail.com
[b] Ph.D. Student, E-mail: a_adesin@encs.concordia.ca
[c] M.Sc., E-mail: John.oluwafemi@covenantuniversity.edu.ng

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reduces the waste going to landfill. Aluminum can be recycled indefinitely, as a re-processing does not damage its structure. Aluminum is also the most cost-effective material to recycle (Hosford and Duncan 1994). In cases of a deformed steel bar, the following mechanisms contribute to force transfer: (1) Chemical adhesion between the bar and the concrete, (2) Frictional forces arising from the roughness of the interface and (3) Mechanical anchorage or bearing of the ribs against the concrete surface (ASTMC 1064, ACI-318). Cracks, corrosion and low tensile strength are major weakness of cement-based construction. The only way to overcome this weakness is by incorporating high-strength and small diameter fibres into the composites. The result of fibre-reinforced concrete performance shows a significant increase in tensile strength and overall toughness is compared to plain concrete (ACI-318). Murali *et al*. (2012) investigated the use of 30 full size beams of varying lengths and sectional dimensions with lap-spliced bars in constant moment region. The beams were tested in a third-point loading system. Increased concrete cover was found to increase the bond efficiency of coated reinforcing bars, but the increase was not proportional to the additional cover thickness. For epoxy-coated reinforcement, the decrease in bond strength is proportional to the relative rib area of the bar. As the relative rib area increases, the loss in bond also increases (Cairns and Abdullah 1994). Kazım and Ahmet (2009) investigated the effect of self-compacting concrete (SCC) and the diameter of reinforcement on bond-slip characteristics of tension lap-slices. As the diameter of the steel bar increased from 16 to 20 mm the bond strength decreased regardless of concrete type; the compressive strength was almost the same and there were slight differences between the diameters of lap-spliced bars. Experimental investigation (Murali *et al*. 2012) was done using mix and tests, as recommended procedures by relevant codes. The results were compared with conventional concrete, and it was observed that concrete blocks incorporated with steel powder increased its compressive strength and tensile strength (Yoo *et al*. 2014). The effect of fibre content on the material and interfacial bond properties of ultra-high performance fibre reinforced concrete (Ofuyatan *et al*. 2018). Locally available material like cassava peel ash was used to partially replace cement at varying percentages, and curing days. It was seen that the concrete can be used for light construction works where high strength is not a major requirement. The use of typha strawbale masonry in constructing sustainable buildings, both in rural and urban settlement, not only suitable for dwellers but for keeping farm products by structures that will respond to the environmental eco-system, coupled with the fact that such structures are also affordable, durable and easy to maintain during their service period (Ofuyatan *et al*. 2017). The bond behavior between steel reinforcement and recycled concrete (Seara-Paz *et al*. 2014) was concluded that, the bond strength decreases with the increase of the percentage of recycled coarse aggregate used. This study investigates, the effect of aluminium shavings on the bonding of laterized concrete.

2. Materials and sample preparation

Waste Aluminum shavings were collected from the waste of Aluminum fillings from a dump site. It was washed, dry and cleaned before been used as fibre. The purpose of washing was to remove any oil or dirt from it to avoid contaminating the concrete. The concrete used were produced from cement, laterite and sand, granite mixed in the ratio of 1:2:4 with water-cement ratio of 0.55. The ratio of sand to laterite was 1:3 (25vol% laterite and 75vol% sand) material preparation. The percentage of waste aluminum shavings varied between 0vol%, 1vol%, 1.5vol% and 2vol% of the concrete. The waste aluminum shavings were short and of very smaller particles

Fig. 1 Tool wear and surface roughness measurement equipment

Fig. 2 Reinforcement of spliced beam

of 15-35 mm average length, mean diameter of 0.275 mm and mean aspect ratio of 75 with average density of 2700 kg/m^3. The control mix was 0vol% volume of waste aluminum shavings. Ordinary Portland Lime Cement was use BS12:(1996). Two sets of pull-out cubes with openings were prepared; 160×160×160 mm and 200×200×200 mm for 16 mm and 20 mm respectively. Two sets of spliced beam specimens were also prepared as shown in Figs. 1 and 2. The concrete mixes produced were used both for the pull-out and spliced beam tests.

2.2 Testing of the specimens

A total of 40 pull-out cubes and 12 compression test cubes specimens were prepared. In this research, four types of mixes were prepared. The control mix with 0vol% volume of waste

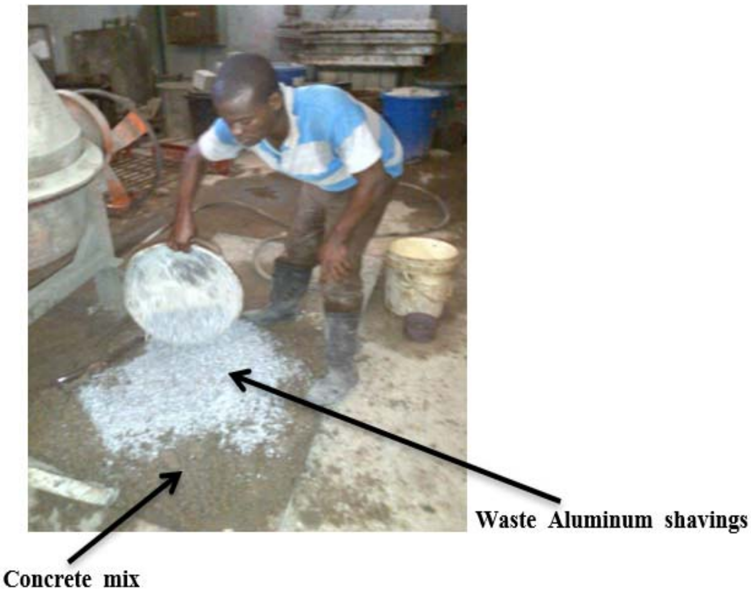

Fig. 2 Mixing of concrete with waste aluminum shavings

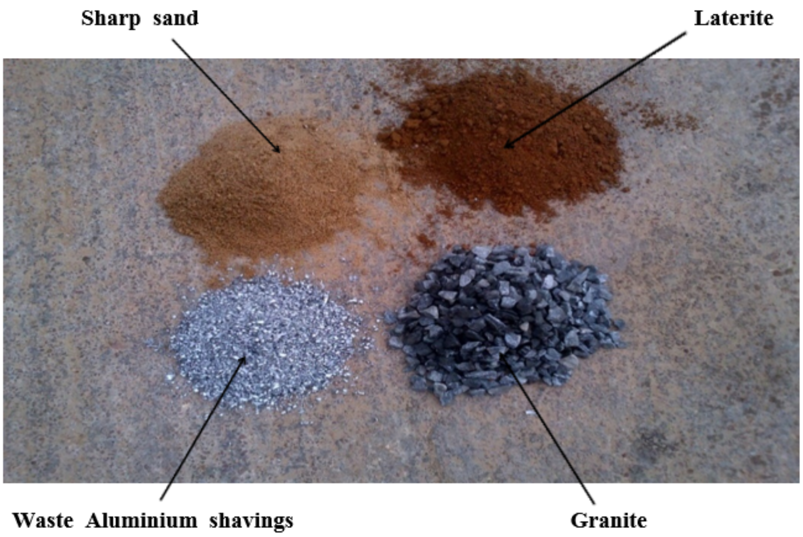

Fig. 4 Aggregates and waste aluminum shavings

aluminum shavings followed by 1, 1.5 and 2vol% volume of waste aluminum shavings were added in the mix. For bond strength test in the pull-out specimens, ten (10) samples of 160×160×160 mm and 200×200×200 mm for 16 mm and 20 mm diameter re-bars respectively were prepared in the same condition. The whole composite were mixed thoroughly before the slump test was determined. The fresh laterized concrete waste aluminum shavings were placed in the form in which the bar is kept horizontal in the axis of the mould. Compactions were carried out with internal vibrators having a maximum diameter of 25 mm. It was done by allowing the nozzle to

Fig. 5 Curing of RILEM pullout specimens

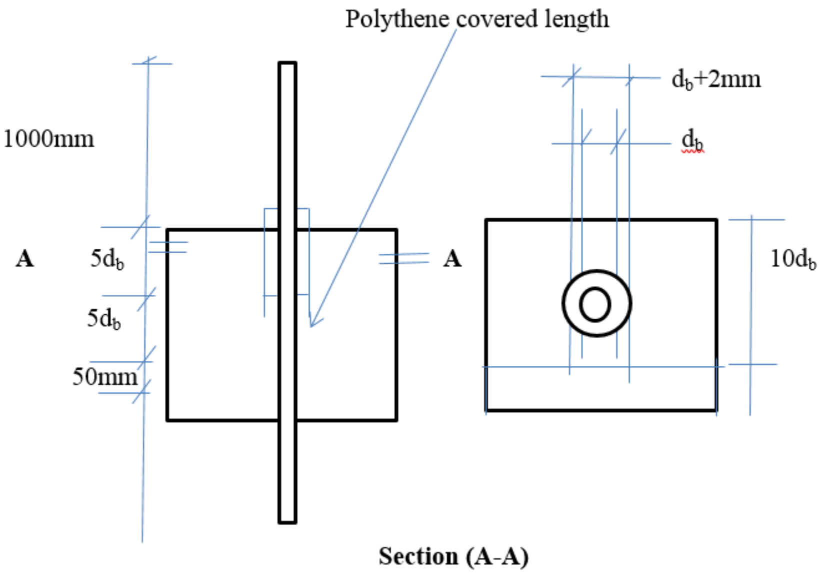

Fig. 6 RILEM Pull-out Arrangements

vibrate in the concrete for three seconds per insertion. Forms were removed 48 ± 0.5 hours after placing of the concrete, the specimens were covered with wet jute bags. The specimens were immersed in clean water until curing age as shown in Fig. 5. The concrete properties were tested for 28-day. In the pull-out test, the RILEM specimens were kept under room temperature after the 28 days curing in water.

2.3 RILEM pull-out specimen arrangements

The reinforced used were high yield steel of 16 mm and 20 mm BS8110 (1997). Figure 6 shows the RILEM pull-out arrangement. Height of the concrete specimen = $10d_b$ where d_b as the diameter of the bar. Encasement height $5d_b$, Pre-length = $5d_b$ (without adhesion) = De-bonded.

Table 1 Bond Resistance and Failure Pattern of Laterized Concrete with Waste Aluminum Shavings (16 mm Diameter bar RILEM Pullout Specimens)

Percentage Aluminum Shavings (%)	Specimens Name	Diameter of bar d_b (mm)	Bond Length (Uncovered) l_s (mm)	Pullout Force f (kg)	Bond Resistance U_t (N/mm^2)	Average Bond Resistance U_t (N/mm^2)	Failure Mode
	1A			54	1.66		Split
	2A			55	1.66		Split
	3A			57	1.72	1.71	Slip
	4A			60	1.81		Split
	5A			58	1.75		Slip
	1B			68	1.83		Split
	2B			67	1.80		Slip
	3B			70	1.88	1.82	Slip
1.0	4B			68	1.83		Slip
	5B	16	80	66	1.77		Slip
	1C			74	1.85		Slip
	2C			79	1.97		Slip
	3C			78	1.95	1.91	Slip
1.5	4C			77	1.92		Slip
	5C			75	1.87		Split
	1D			85	1.92		Split
	2D			87	1.97		Slip
	3D			92	2.08	1.97	Slip
2.0	4D			85	1.92		Split
	5D			86	1.95		Slip

Total length of the sides of the concrete specimen, Length of the bar = $10d_b$ + 1000 mm + 50 mm. Projecting parts = 50 mm shorter end and 1000 mm longer end.

The part of the reinforcing bar that was inserted into the laterized concrete cube was divided into two equal heights. The upper parts were covered with polythene material to avoid adherence to the laterized concrete while the lower part were in contact with the laterized concrete. The thickness of the polythene material was 2 mm and it was projected above the concrete height. 50 mm length of the re-bar were allowed at the bottom side while 1000 mm length of the re-bar was reserve to be used in bushing the pull-out specimen with the universal testing machine. There are also specimens that did not contain any waste Aluminum shavings which acted as control specimens.

3. Results and discussion

3.1 Bond resistance of reinforced concrete with Aluminium shavings fibre

The bond resistance decreased with increase in the diameter of reinforcement as shown in Fig. 7. At 0% waste aluminum shavings content the bond strength was 1.71 N/mm^2 and 1.27 N/mm^2 in

Table 2 Bond Resistance and Failure Pattern of Laterized Concrete with Waste Aluminum Shavings (20 mm Diameter bar RILEM Pullout Specimens)

Percentage Aluminum Shavings (%)	Specimens Name	Diameter of bar d_b (mm)	Bond Length (Uncovered) l_s (mm)	Pullout Force f (kg)	Bond Resistance U_t (N/mm^2)	Average Bond Resistance U_t (N/mm^2)	Failure Mode
	1E			66	1.28		Slip
	2E			65	1.26		Slip
0.0	3E			64	1.24	1.27	Slip
	4E			66	1.28		Slip
	5E			67	1.29		Slip
	1F			79	1.36		Split
	2F			78	1.34		Slip
1.0	3F			80	1.38	1.35	Split
	4F			79	1.36		Slip
	5F	20	100	76	1.31		Slip
	1G			91	1.46		Split
	2G			92	1.47		Split
1.5	3G			90	1.44	1.46	Split
	4G			93	1.49		Split
	5G			89	1.42		Slip
	1H			103	1.50		Split
	2H			95	1.38		Slip
2.0	3H			114	1.65	1.52	Slip
	4H			108	1.57		Slip
	5H			104	1.51		Split

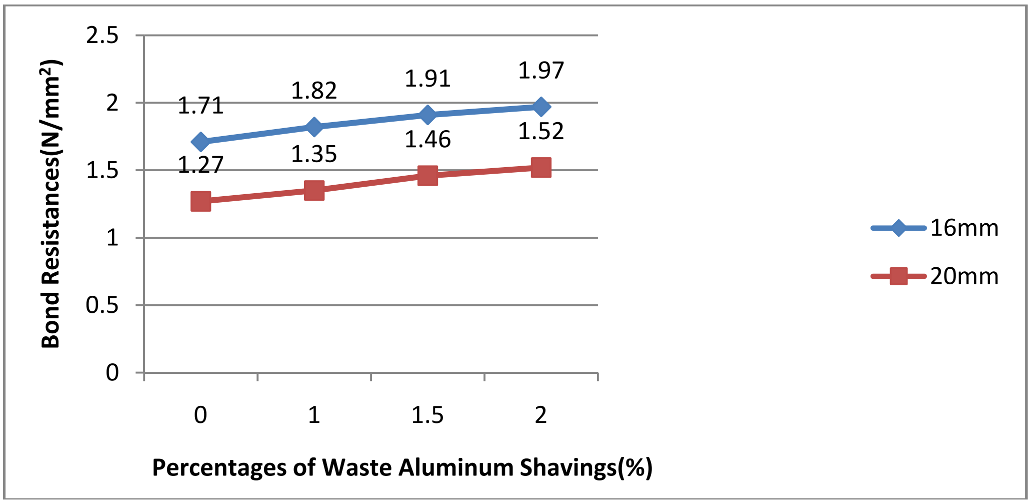

Fig. 7 Bond Resistance of Laterized Concrete with Varying Percentages of Waste Aluminum Shavings (16 mm and 20 mm Diameter bars)

Table 3 Effect of Aluminium shaving on compressive strength of concrete

Steel diameter	Constant values	Yield		Ultimate		Elongation	
d_b (mm)	k (kN/mm^2)	Load (kN)	Stress (N/mm^2)	Load (kN)	Stress (N/mm^2)	Extension (mm)	%Increase (%)
16 mm	49.55	10.6	525.23	12.7	629.3	31.00	15.50
		10.8	535.14	12.9	639.2	24.00	12.00
		10.7	530.19	12.8	634.2	30.00	15.00
Average		10.7	530.19	12.8	634.2	28.33	14.17
20 mm	31.72	18.4	583.65	21.2	672.5	28	14.0
		18.2	577.30	21.1	669.3	30	15.0
		18.5	586.81	21.3	675.6	31	15.5
Average		18.4	582.59	21.2	672.5	30	14.8

Table 4 Compressive Strength of Laterized Concrete with Waste Aluminum Shaving

Percentage of Aluminum Shavings (%)	Specimen Cube	Load P (kg)	Average Load P (kg)	Compressive Strength f_{cu} (N/mm^2)	Average Compressive Strength f_{cu} (N/mm^2)
0.0	01	470	455	20.90	20.20
	02	440		19.50	
	03	455		20.20	
1.0	01	505	511	22.43	22.68
	02	515		22.87	
	03	512		22.74	
1.5	01	541	550	24.02	24.41
	02	563		25.01	
	03	545		24.20	
2.0	01	615	607	27.30	26.93
	02	590		26.20	
	03	615		27.30	

16 and 20 mm diameter bar respectively, indicating an increase of 26.16%. This shows that larger bar diameter has smaller bond resistance compared to smaller bar diameter. The reason might be connected to the increase in perimeter of the bar size. The surface area is higher in the larger diameter bar. The reason might be what happened during the compaction of laterized concrete. The air bubbles are trapped more in the larger diameter than smaller diameter reinforcing bar. The air bubbles in the interface of laterized concrete and reinforcing bars reduced the grip effect in between them.

4.1 Effect of tensile strength

The maximum tensile stresses in reinforcement bar were 582.59 N/mm^2 and 530.19 N/mm^2 for 20 mm and 16 mm respectively. The preliminary test results of the reinforcement bars are presented in Table 3.

The results of the compressive strength of laterized concrete with waste aluminum shavings are shown in Table 4. Spliced beam and RILEM pullout compressive strength results were the same, therefore, compressive strength results of the spliced beam were adopted as shown in Table 4. Generally, there was increase in compressive strength of concrete with increase in percentage of waste aluminum shavings content. In Table 4, for 0vol%, 1vol%, 1.5vol% and 2vol% waste aluminum shavings content, the compressive strength of concrete for 28-day values were 20.2 N/mm^2, 22.68 N/mm^2, 24.41 N/mm^2 and 26.93 N/mm^2 respectively.

The coarse aggregate crushed granite was of 12.5 mm maximum diameter and density of 2760 kg/m^3 while the fine aggregate were composed of laterite and sand with densities of 2630 kg/m^3 and 2660 kg/m^3 respectively.

4.2 Mode of failure of RILEM pullout specimens

The failure pattern was generally splitting and slipping. Figs. 8(a) and (b) shows the response of laterized concrete with waste aluminum shavings to pull-out force. As the waste aluminum shavings content increased from 0.0% to 2.0% content, the pullout force increased. The pull-out is related to the bond. The higher the pull-out force, the higher the bond strength. Majority of 0% contents failed on slipping as a result low compressive strength of concrete. It was observed that in the pullout specimens without waste aluminum shavings, the appearance of cracks was not noticed before pull-out occurred. Pull-out were quite sudden and were able to pull the reinforcing bars completely out from the concrete specimen leaving the groove. It can be seen that cracks initiated at the interface of the reinforcement bar-concrete and propagated to the outside surface. It was observed that micro cracks developed in all the tested pull-out specimens but were narrow at the specimens without waste aluminum shavings, indicating the reduction in ductility of laterized concrete. It was observed that the cracks formations were similar for all tested specimens. Although in few cases, cracks occurred in zig-zag form. In pullout specimens with waste aluminum shavings, the increased cracks formations may be connected to the increase in the compressive strength of concrete due to addition of waste aluminum shavings content. Laterized concrete with waste aluminum shavings specimens failed in splitting, while control specimens pulled out, suggesting that the waste aluminum shavings may improve the bond strength of laterized concrete. This also suggests that the pull-out force was primarily determined by the mechanical bond and relative rib area of the bar. The adhesion and friction losses play little role in the ultimate bond resistance in laterized concrete.

As the fibre content increases from 0 to 2% the pull-out force increased, the higher the pull-out force, the higher the bond strength. It was also observed that in the test samples without fibres, the appearance of cracks was noticed before pull-out occurred. Pull-out was quite sudden and was able to pull the re-bars completely out from the concrete samples. In Figs. 9(a)-(d), the cracks pattern in various percentages of waste aluminum shavings can be seen. The cracks initiated at the interface of the re-bar and concrete are propagated to the outside surface. It was observed that micro cracks developed in all the tested pull-out specimens but were wider at the specimens without fibre, indicating the increase in ductility of concrete due to aluminium chips fibre. It is observed that the crack formation was similar for all tested specimens. Although in few cases, cracks occurred in zig-zag form. These reductions in cracks formation may be connected to the increase in the compressive strength of concrete due to addition of aluminium chips fibre content. Generally, fibre specimens failed in splitting, while control specimens pulled out, suggesting that the aluminium

Fig. 8 (a) Cracks Patterns; (b) Crack patterns

(a)

(b)

(c)

(d)

Fig. 9

chips fibre may increase the bond strength. This suggests that the pull-out force is primarily determined by the mechanical bond and relative rib area of the bar, and adhesion and friction losses play little role in the ultimate bond resistance.

5. Conclusion

In many developing countries, such as Nigeria, where construction materials is not only expensive but is also difficult to obtain, the use of alternative reinforcing materials such as waste aluminum shavings and laterite may be ideal for use in structural member. Waste aluminum shavings will also give a positive result when used in a coaster environment due to its reactive ability with corrosive agents. This corrosion can easily be check-mate by waste aluminum shavings in the concrete. Addition of waste aluminum shavings increases the compressive strength, tensile strength, bond strength and ductility. However, waste aluminum shavings content only increases the strength to some limit. This is due to the amount of void present and the lack of bonding in the concrete mix caused by added waste aluminum shavings.

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