Influence of Water Cement Ratios on the Optimum use of Steel Slag in Concrete

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Abstract. In Nigeria and numerous nations of the world, steel is mainly created from purifying of metal scrap and hundreds of tonnes of steel slag are manufactured each year. This study investigated the effect of water-cement ratios (w/c) on the optimum replacement of crushed stone with Prism Nigeria Slag (PNS) in concrete production. PNS were used to substitute crushed stone by 0, 40, 50 and 60%. A mix ratio of 1:2:4 was adopted with w/c of 0.4, 0.5, 0.6 and 0.7. Concrete cubes and cylindrical concrete specimens were cast and cured in water for 7 and 28 days. The behaviour of the hardened concrete shows consistent decreased in compressive and split tensile strengths with increase in w/c. The optimum replacement at 28th days curing for compressive strength was observed at 60% PNS for all w/c. However, the optimum replacement of split tensile strength for w/c of 0.4, 0.6 and 0.7 was found to be 60% PNS while 0.5 w/c had optimum replacement of 40% PNS. The study concluded that 60% PNS with w/c of 0.4 would produce a concrete of high compressive and split tensile strengths than traditional concrete for mix ratio 1:2:4.

1. Introduction
Concrete is a construction material that is mostly used in the universe. It is formed by cement, fine aggregate, coarse aggregate, admixtures (if required) and water [1, 2, 3]. The aggregates account for large volume of the concrete and play important function in concrete properties. This calls for interest in the use of waste materials as aggregate replacements and efforts has been made on the use of waste as aggregate substitutes [4]. Utilization of environmental friendly materials in construction industry is of major importance. Steel slag are already being used as aggregates due to their stiffness, mechanical energy, wear resistance, porosity and water absorption potential [5]. It has been reported as a better substitute for coarse aggregate in concrete production.

Steel slag is a by-product of steel manufacturing which is categorized in line with the steelmaking technique [6]. In Nigeria and numerous nations of the world, steel is mainly created from purifying of metal scrap and hundreds of tonnes of steel slag are manufactured each year. Steel slag are disposed around the steel producing centres leading to ecological dangers [7].
In the study by Ravikumar et al., [4], Gokul et al., [8], Subramani and Ravi [9], and Thangaselvi [10], it was observed that the optimum use of steel slag in concrete by weight of granite is 60%. However, 40% was reported by Kothai and Malathy [11], and Qurishee et al., [12] as the optimum use of steel slag in concrete.

Water-cement ratios (w/c) is a significant factor for production of concrete. Strict control on the use of w/c on site could be a better approach required to get best concrete. Increase in w/c affect concrete by minimizing strength of concrete [13, 14]. Utilization of high water content for production of concrete mix has been a common practice to foreman and some supervisor/engineer in Nigeria construction industry.

This study investigated the effect of water-cement ratios (w/c) on the optimum replacements of coarse aggregate with steel slag (reported by previous researchers) in concrete production.

2. Materials and Methods

2.1 Materials
Ordinary Portland cement (OPC) of 32.5R and potable water were used for concrete production. The aggregates used are fine aggregate (natural sand) that pass through sieve 5.0 mm and coarse aggregate (crushed stone) of 12.5 mm maximum size conforming to BS 882 [15]. Steel slags were collected from Prism Nig. Ltd., Ikirun, Nigeria and were identified as Prism Nigeria Slag (PNS). The PNS were broken manually with hammer into required sizes and allow to pass through British sieve 13.2 mm.

2.2 Methods
This study investigated the effect of w/c on the optimum replacements of coarse aggregate with PNS in concrete. The replacements of crushed stone (granite) with PNS were 0, 40, 50 and 60% (in line with optimum reported by previous study). A mix ratio of 1:2:4 was adopted and batching was conducted by weight with w/c of 0.4, 0.5, 0.6 and 0.7 using cement content of 300 kg/m$^3$. Workability of fresh concrete was measured using slump and compacting factor test. A total number of Sixty-Four (64) concrete cubes of sizes 150 by 150 by 150mm (48 cubes for PNS-concrete and 16 cubes for conventional concrete) and 64 cylindrical concrete specimens of sizes 150 by 300 mm (48 for PNS-concrete and 16 for conventional concrete) were produced. The concrete specimens were cured by immersion in water for 7 and 28 days. At the end of the curing ages, density and Compressive Strength (CS) test were determined on concrete cubes, and Split Tensile Strength (STS) test were determined on cylindrical concrete specimens.

Density test was carried out in compliance with BS EN 12390-7 [16]. The concrete cubes were taken from curing tank and water was allowed to wipe off and measured using equation 1.

$$\text{Density} = \frac{M}{V} \left( \frac{\text{kg}}{\text{m}^3} \right) \quad (1)$$

Where: $M$ = Mass of cube
$V$ = Volume of cube

The CS was done in accordance with BS EN 12390-3 [17] using a compression machine of 2000 kN capacity at Soil and Concrete Laboratory, Department of Civil Engineering, Federal Polytechnic Offa, Offa, Nigeria. The cubes were placed appropriately in the compression testing machine. The machine was turned on and the gear of the machine was rotated clockwise. The dial gauge of the machine stopped at failure and maximum load at failure was taken as CS using equation 2.

$$\text{CS} = \frac{F}{A} \left( \frac{\text{N}}{\text{mm}^2} \right) \quad (2)$$

Where: $F$ = Failure load
$A$ = Cross sectional area of cube

STS was done in accordance with BS EN 12390-6 [18] using Haida Universal Testing Machine (UTM) of 2000 kN capacity at Materials and Structures Laboratory, Osun State University, Osogbo,
Nigeria. The concrete specimens were dried and placed in the testing machine. The specimens were subjected to load by turning on the UTM. The load at failure was obtained from the UTM and the STS was obtained using equation 3.

\[
f_{ct} = \frac{2F}{\pi Ld} \left( \text{N/mm}^2 \right)
\]

Where: 
- \( f_{ct} \) = STS, in Newton per square millimetre (N/mm²);
- \( F \) = maximum load, in Newton (N);
- \( L \) = distance of the line of contact of the specimen, in millimetres;
- \( d \) = designated cross-sectional dimension, in millimetres.

3. Results and Discussion

3.1 Physical properties of aggregates

The physical properties of the aggregate used are as presented in Table 1. The results of the Specific Gravity (SG) of aggregates shows that PNS value was higher than fine aggregate and crushed stone; the Water Absorption Capacity (WAC) indicated that PNS absorb water than crushed stone; Aggregate Impact Value (AIV) results indicated that PNS gives better relative degree of resistance to a sudden shock (impact) than crushed stone; the Aggregate Crushing Value (ACV) shows that PNS can withstand applied compression load than crushed stone and the Los Angeles Abrasion Value (LAAV) results indicated that PNS possesses better resistance to degradation than crushed stone.

| Test | Aggregates | Conformity |
|------|------------|------------|
|      | Fine sand  | Granite    | PNS        |
| SG   | 2.67       | 2.69       | 2.71       |
| WAC (%) | 0.5       | 1.7        | BS 1377:2 [19] |
| AIV (%) | 12.5      | 7.14       | BS EN 1097:6 [20] |
| ACV (%) | 24.6      | 19.67      | BS 812-110 [22] |
| LAAV (%) | 19.7      | 15         | ASTM C131 [23] |

3.2 Slump of PNS-concrete

The slump was done in accordance with BS EN 12350-2 [24]. The result of the PNS-Fresh-Concrete is as presented in Figure 1. As the water contents in the fresh concrete mix increases, the PNS-Fresh-Concrete-Mix becomes more workable. The PNS-Fresh-Concrete witnessed reduction in slump height as the crushed stone substitute with PNS increased for w/c of 0.4, 0.5, 0.6 and 0.7.

![Figure 1. PNS-slump height against w/c](image_url)
3.3 Compaction factor of PNS-concrete
The Compaction Factor (CF) was carried out in accordance with BS 1881:103 [25] and the result is as presented in Figure 2. The trend of the CF corresponds to the slump test result. The higher the w/c, the higher the CF value, and the higher the crushed stone substitute with PNS, the lower the CF value. The PNS-Fresh-Concrete observed reduction in CF value as the crushed stone substitute with PNS increased for w/c of 0.4, 0.5, 0.6 and 0.7. The results obtained (Figure 2) is within the range (0.70 to 0.98) of CF recommended by BS 1881:103 [25].

![Figure 2. PNS-compacting factor against w/c](image)

3.4 Density of PNS-hardened-concrete
The density of the PNS-Hardened-Concrete cubes are presented in Figures 3 to 4. As the w/c increased, the density of the concrete reduced. At 7 days, as the PNS contents increased, the density values also increased but reduced at 50% PNS and further increased at 60% PNS in all w/c (0.4, 0.5, 0.6 and 0.7). The twenty-eight days PNS result also indicate similar trend to that of 7 days curing. Hence, the density values at 28 days curing were higher than the 7 days curing.

![Figure 3. Seven days PNS-density against w/c](image)  ![Figure 4. Twenty eighth days PNS-density against w/c](image)

The density of the PNS-Concrete falls within the recommended range of 2000 kg/m³ to 2600 kg/m³ specified by BS EN 206 [26] for normal weight concrete.

3.5 Compressive strength of PNS-hardened-concrete-cube
The PNS-CS results (Figures 5 to 6) indicate that the CS reduced as the w/c increased. At 7 days, the CS increased up to 40% PNS and reduced at 50% PNS substitutes of crushed stone but later increased at 60% PNS replacements for w/c of 0.4, 0.5, 0.6 and 0.7. The 28 days CS shows similar trend to 7 days CS.
The optimum replacement for CS of PNS-concrete cubes at 28 days curing was found to be 60% for w/c of 0.4, 0.5, 0.6 and 0.7. The maximum CS of PNS-Hardened-Concrete-Cube obtained at 60% PNS correspond to 60% of steel slag (by weight of granite) reported by Ravikumar et al., [4], Gokul et al., [8], Subramani and Ravi [9], and Thangaselvi [10].

![Figure 5. Seven days PNS-CS against w/c](image)

![Figure 6. Twenty eighth days PNS-CS against w/c](image)

### 3.6 Split Tensile Strength of PNS-hardened-cylindrical-concrete

The PNS-STS (Figures 7 to 8) reduced as the w/c increased. The 7 days PNS-STS increased up to 40% PNS and reduced at 50% PNS substitutes of crushed stone but later increased at 60% PNS replacements for w/c of 0.4, 0.5, 0.6 and 0.7. At 28 days, the PNS-STS increased up to 40% PNS and reduced at 50% PNS substitutes of crushed stone but later increased at 60% PNS replacements for w/c of 0.4, 0.5 and 0.6. However, for w/c of 0.7, the STS increased as the crushed stone substitute with PNS increases.

The optimum replacement with the highest STS for w/c of 0.4, 0.6 and 0.7 at 28 days curing age was found to be 60% PNS while 0.5 w/c had optimum replacement of 40% PNS. The maximum STS of PNS-Cylinder obtained at 60% PNS is in agreement with the optimum replacement of granite with steel slag reported by Subramani and Ravi [9], Ravikumar et al., [4] and Thangaselvi [10], while 40% PNS (at 0.5 w/c) correspond to the study by Kothai and Malathy [11], and Qurishee et al., [12].

![Figure 7. 7 days PNS-STS against w/c](image)

![Figure 8. 28 days PNS-STS against w/c](image)

### 4. Conclusion

The following conclusions were drawn from the study:

- The results of the SG of aggregates shows that PNS values is higher than fine aggregate and crushed stone; the WAC indicated that PNS absorb water than the crushed stone; AIV results indicated that PNS gives better relative degree of resistance to a sudden shock (impact) than crushed stone; the ACV indicated that PNS can withstand applied compression load than crushed stone while the LAAV results indicated that PNS possesses better resistance to degradation than crushed stone.
• The PNS-Fresh-Concrete-Mix of the slump test became workable as the w/c in the fresh concrete mix increased. While the CF values of the PNS-Fresh-Concrete-Mix shows similar trend to the slump result.
• The behaviour of the PNS-Hardened-Concrete shows consistent decreased in CS and STS as the w/c increased.
• The optimum replacement at 28 days curing for PNS CS was found at 60% for w/c of 0.4, 0.5, 0.6 and 0.7. However, the optimum replacement of STS for w/c of 0.4, 0.6 and 0.7 was found to be 60% PNS while 0.5 w/c had optimum replacement of 40% PNS.
• 60% PNS with w/c of 0.4 would produce a concrete of better CS and STS than traditional concrete for mix ratio 1:2:4.

References
[1] Ige J A, Anifowose M A, Odeyemi S O, Adebara S A and Oyeleke M O 2018 Int. J. Eng. Res. Africa 40 22-9
[2] Anifowose M A, Ige J A, Yusuf A L, Adebara S A and Abdulkarim A A 2018 ANNALS Faculty Eng. Hunedoara-Int. J. Eng. 16 111-4
[3] Anifowose M A, Adeyemi A O, Odeyemi S O, Abdulwahab R and Mudashiru R B 2019 Nigerian J. Tech. 38 283-8
[4] Ravikumar H, Dattatreya J K and Shivananda K P 2015 J. Civ. Eng. Enivir. Tech. 2 58-63
[5] Padmapriya R, Bupesh Raja, V K, Kumar, V G and Baalamurugan J 2015 Int. J. ChemTech. Res. 8 1721-29
[6] Yi H, Xu G, Cheng H, Wang J, Wan, Y and Chen H 2012 Proc. 7th Int. Conf. Waste Manag. Tech. vol 16 (Procedia Environmental Sciences) p 791
[7] Olonade K A, Kadiri M B and Aderemi P O 2015 Nig. J. Tech. 34 452-58
[8] Gokul J, Suganthan S, Venkatram R and Karthikeyan K 2012 Int. J. Current Res. 4 106-9
[9] Subramani T and Ravi G 2015 IOSR J. Eng. 5 64-73
[10] Thangaselvi K 2015 Int. J. Adv. Res. Trends Eng. Tech. 2 1-6
[11] Kothai P S and Malathy R 2013 Australian J. Basic App. Sci. 7 278-285
[12] Qurishee M A, Iqbal I T, Islam M S and Islam M M 2016 Proc. 3rd Int. Conf. Adv. Civ. Eng. (Bangladesh: CUET, Chittagong) p 475
[13] Rahmani K, Shamsai A, Saghaifian B and Peroti S 2012 Middle-East J. Sci. Res. 12 1056-61
[14] Varma M B 2015 J. Modern Eng. Res. 5 43-59
[15] BS 882 1992 Specification for Aggregates from Natural Sources for Concrete (London: British Standard) p 1
[16] BS EN 12390:2009 Testing Hardened Concrete, Density of Hardened Concrete (London: British Standard) part 7 pp 4-8
[17] BS EN 12390:2009 Testing Hardened Concrete: Compressive Strength of Test Specimens (London: British Standard) part 3 pp 5-7
[18] BS EN 12390:2000 Testing Hardened Concrete: Tensile Splitting Strength of Test Specimens (London: British Standard) part 6 pp 5-8
[19] BS 1377:1990 Methods of Test for Soil for Civil Engineering Purposes (London: British Standard) part 2 pp 28-30
[20] BS EN 1097:6 2013 Tests for Mechanical and Physical Properties of Aggregates: Determination of Particle Density and Water Absorption (London: British Standard) part 6 pp 13-15
[21] BS 812:112 1990 Testing Aggregate: Methods for Determination of Aggregate Impact Value (London: British Standard) p 3
[22] BS 812:110 1990 Testing Aggregate: Methods for Determination of Aggregate Crushing Value (London: British Standard) p 1
[23] ASTM C131 2014 Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine (Philadelphia: ASTM
[24] BS EN 12350 2009 Testing Fresh Concrete: Slump Test (London: British Standard) part 2 pp 5-8
[25] BS 1881:103 1983 Testing Concrete: Method for Determination of Compacting Factor (London: British Standard) p 2
[26] BS EN 206 2013 Concrete: Specification, Performance, Production and Conformity (London: British Standard) p 16