**CHAPTER 4**

**PRESENTATION AND ANALYSIS OF RESULTS**

**4.1 Presentation of Results**

The results for the Practicals conducted are presented below

**4.1.1 Physical Property test results**

The physical test results on river sand, laterite and GPKS are presented in Tables 4.1through Table 4.8 and the summary of the results presented in Table 4.9. The gradation curve is presented in Fig 4.1 and the flow curve for the liquid limit is presented in Table 4.2

**Table 4.1: Specific gravity of river sand**

|  |  |  |  |
| --- | --- | --- | --- |
| **Descriptions** | **Trial Run** | | |
| **Trial I** | **Trial 2** | **Trial 3** |
| Mass of empty pyncnometer bottle [W1], (g) | 149.74 | 149.74 | 149.74 |
| Mass of bottle + dry sample [W2], (g) | 210.50 | 213.00 | 214.50 |
| Mass of bottle + dry sample + water [W3], (g) | 684.64 | 686.70 | 687.20 |
| Mass of bottle filled with water only [W4], (g) | 646.80 | 646.80 | 646.80 |
| Mass of dry sample [W5] = [W1]-[W2], (g) | 60.76 | 63.26 | 64.76 |
| Mass of water occupying same volume as the sample, [W6] = [W4]-[W3-W5], (g) | 22.92 | 23.36 | 24.36 |
|
| Specific gravity = W5/W6 | 2.65 | 2.71 | 2.66 |
| Average Specific Gravity | 2.67 | | |

**Table 4.2: Specific gravity of laterite**

|  |  |  |  |
| --- | --- | --- | --- |
| **Descriptions** | **Trial Run** | | |
| **Trial I** | **Trial 2** | **Trial 3** |
| Mass of empty pyncnometer bottle [W1], (g) | 149.74 | 149.74 | 149.74 |
| Mass of bottle + dry sample [W2], (g) | 214.45 | 214.65 | 214.50 |
| Mass of bottle + dry sample + water [W3], (g) | 686.94 | 686.70 | 687.20 |
| Mass of bottle filled with water only [W4], (g) | 646.80 | 646.80 | 646.80 |
| Mass of dry sample [W5] = [W1]-[W2], (g) | 64.71 | 64.91 | 64.76 |
| Mass of water occupying same volume as the sample, [W6] = [W4]-[W3-W5], (g) | 24.57 | 25.01 | 24.36 |
|
| Specific gravity = W5/W6 | 2.63 | 2.60 | 2.66 |
| Average Specific Gravity | 2.63 | | |

**Table 4.3: Specific gravity of ground palm kernel shell(GPKS)**

|  |  |  |  |
| --- | --- | --- | --- |
| **Descriptions** | **Trial Run** | | |
| **Trial I** | **Trial 2** | **Trial 3** |
| Mass of empty pyncnometer bottle [W1], (g) | 149.74 | 149.74 | 149.74 |
| Mass of bottle + dry sample [W2], (g) | 206.00 | 217.00 | 203.00 |
| Mass of bottle + dry sample + water [W3], (g) | 679.50 | 685.00 | 678.20 |
| Mass of bottle filled with water only [W4], (g) | 646.80 | 646.80 | 646.80 |
| Mass of dry sample [W5] = [W1]-[W2], (g) | 56.26 | 67.26 | 53.26 |
| Mass of water occupying same volume as the sample, [W6] = [W4]-[W3-W5], (g) | 23.56 | 29.06 | 21.86 |
|
| Specific gravity = W5/W6 | 2.39 | 2.31 | 2.44 |
| Average Specific Gravity | 2.38 | | |

**Table 4.4: Grain Size distribution of Sand**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Sieve Sizes  (mm) | Mass of sample Retained(g) | Percent retained(g) | Cumulative mass retained(g) | Cumulative percent retained(%) | Cumulative percent passing(%) |
| 4.75 | 9.33 | 1.87 | 9.33 | 1.87 | 98.13 |
| 2.36 | 24.97 | 5.00 | 34.30 | 6.87 | 93.13 |
| 1.18 | 71.46 | 14.31 | 105.76 | 21.19 | 78.81 |
| 0.60 | 178.42 | 35.74 | 284.18 | 56.92 | 43.08 |
| 0.45 | 120.07 | 24.05 | 404.25 | 80.97 | 19.03 |
| 0.30 | 51.73 | 10.36 | 455.98 | 91.34 | 8.66 |
| 0.15 | 36.85 | 7.38 | 492.83 | 98.72 | 1.28 |
| Pan | 6.41 | 1.28 | 499.24 | **∑=357.88** |  |
| Fineness modulus= 357.88/100 = 3.60 | | | | | |

**Table 4.5: Grain Size distribution of Laterite**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Sieve Sizes  (mm) | Mass of sample Retained(g) | Percent retained(g) | Cumulative mass retained(g) | Cumulative percent retained(%) | Cumulative percent passing(%) |
| 4.75 | 0.80 | 0.16 | 0.80 | 0.16 | 99.84 |
| 2.36 | 10.65 | 2.15 | 11.45 | 2.31 | 97.69 |
| 1.18 | 52.76 | 10.65 | 64.21 | 12.96 | 87.04 |
| 0.6 | 284.13 | 57.35 | 348.34 | 70.31 | 29.69 |
| 0.43 | 80.94 | 16.34 | 429.28 | 86.65 | 13.35 |
| 0.30 | 33.43 | 6.75 | 462.71 | 93.39 | 6.61 |
| 0.15 | 23.31 | 4.71 | 486.02 | 98.10 | 1.90 |
| Pan | 9.41 | 1.90 | 495.43 | **∑=363.88** |  |
| Fineness modulus= 363.88/100 = 3.64 | | | | | |

**Table 4.6: Grain Size distribution of GPKS**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Sieve Sizes  (mm) | Mass of sample Retained(g) | Percent retained(g) | Cumulative mass retained(g) | Cumulative percent retained(%) | Cumulative percent passing(%) |
| 4.75 | 1.12 | 0.22 | 1.12 | 0.22 | 99.78 |
| 2.36 | 160.54 | 32.17 | 161.66 | 32.39 | 67.61 |
| 1.18 | 228.74 | 45.83 | 390.40 | 78.21 | 21.79 |
| 0.60 | 70.53 | 14.13 | 460.93 | 92.35 | 7.65 |
| 0.45 | 12.81 | 2.57 | 473.74 | 94.91 | 5.09 |
| 0.30 | 8.20 | 1.64 | 481.94 | 96.56 | 3.44 |
| 0.15 | 7.23 | 1.45 | 489.17 | 98.00 | 2.00 |
| Pan | 9.94 | 1.99 | 499.11 | **∑=492.64** |  |
| Fineness modulus= 492.64/100 = 4.92 | | | | | |

**Fig 4.1: Grading Curves of Sand, Laterite and GPKS**

From Fig 4.1, the grading coefficients are determined from equations 2.1 and 2.2 as follows:

For Sand: D10= 0.32 D30=0.5 D60=0.8

For Laterite: D10=0.37 D30=0.61 D60=0.81

For GPKS: D10=0.7 D30=1.5 D60=2.1

**Table 4.7: Plastic limit test for Laterite**

|  |  |  |
| --- | --- | --- |
| **Description** | **Trial No.** | |
| **I** | **II** |
| Empty Weight of Container (W1) in g | 21.21 | 19.73 |
| Weight of Container (W2)+ Wet Soil in g | 34.23 | 32.18 |
| Weight of Container (W3) + Dry Soil in g | 31.91 | 29.96 |
| Calculation |  | |
| Weight of Moisture = W2-W3 | 2.32 | 2.22 |
| Weight of Dry Soil = W3-W1 | 10.70 | 10.23 |
| Water Content = ((W2-W3)/(W3-W1)\*100) | 21.68 | 21.70 |
| Average PL | 21.69 | |

**Table 4.8: Liquid limit test for laterite**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Description** | **Trial No.** | | | | | | | | | |
| **I** | | **II** | | **III** | | **IV** | | **V** | |
| Empty Weight of Container (W1) in g | 10.30 | 9.99 | 10.07 | 6.53 | 10.12 | 9.83 | 22.35 | 6.69 | 18.05 | 18.15 |
| Weight of Container (W2)+ Wet Soil in g | 19.24 | 17.96 | 21.23 | 18.53 | 23.20 | 20.72 | 33.01 | 20.61 | 25.49 | 28.35 |
| Weight of Container (W3) + Dry Soil in g | 16.97 | 16.02 | 18.51 | 15.62 | 19.94 | 17.95 | 30.43 | 17.23 | 23.73 | 25.92 |
| No. of Blows | 12.00 | | 17.00 | | 22.00 | | 28.00 | | 34.00 | |
| **Calculation** |  | | | | | | | | | |
| Weight of Moisture = W2-W3 | 2.27 | 1.94 | 2.72 | 2.91 | 3.26 | 2.77 | 2.58 | 3.38 | 1.76 | 2.43 |
| Weight of Dry Soil = W3-W1 | 6.67 | 6.03 | 8.44 | 9.09 | 9.82 | 8.12 | 8.08 | 10.54 | 5.68 | 7.77 |
| Water Content = ((W2-W3)/(W3-W1)\*100) | 34.03 | 32.17 | 32.23 | 32.01 | 33.20 | 34.11 | 31.93 | 32.07 | 30.99 | 31.27 |
| Average Moisture Content for Each Trial (%) | 33.10 | | 32.12 | | 33.66 | | 32.00 | | 31.13 | |
| Average Moisture Content (%) | 32.402 | | | | | | | | | |

**Fig 4.2: Flow curve for liquid limit**

The Plasticity Index of the laterite is given by equation 2.6 as:

P.I = 32.20%-21.69% = 10.51%

**Table 4.9: Summary of Physical properties test result of fine aggregates.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Property** | **River sand** | **Laterite** | **GPKS** |
| Specific gravity | 2.67 | 2.63 | 2.38 |
| Fineness Modulus | 3.6 | 3.64 | 4.92 |
| Coefficient of uniformity, Cu | 2.5 | 2.19 | 3 |
| Coefficient of curvature, Cc | 0.98 | 1.24 | 1.53 |
| Plastic limit | **-** | 21.69 | **-** |
| Liquid limit | **-** | 32.20 | **-** |
| Plasticity Index | **-** | 10.51 | **-** |

**4.1.2 Chemical Property test results of cement and laterite**

The chemical composition of cement, laterite and GPKS is shown in Table 4.9.

**Table 4.10: Chemical composition of Cement, Laterite and GPKS**

|  |  |  |  |
| --- | --- | --- | --- |
| **Oxide compounds** | **Cement** | **Laterite** | **GPKS** |
| Calcium oxide (CaO) | 64.30 | - | 8.79 |
| Silica (SiO2) | 21.25 | 29.10 | 54.80 |
| Alumina (Al2O3) | 4.33 | 20.30 | 11.4 |
| Iron oxide (Fe2O3) | 1.85 | 33.50 | 0.362 |
| Tin oxide (TiO2) | 0.13 | 1.30 | - |
| Sodium oxide (Na2O) | 0.17 | 0.02 | - |
| Potassium oxide (K2O) | 0.71 | 0.14 | 6.25 |
| Magnesium (MgO) | 1.81 | - | 6.11 |
| SO3 | 3.70 | - | - |
| Loss of Ignition | 1.5 | - | - |

The silica-sequioxides ratio of laterite is calculated as:

S-S ratio =

**4.1.3 Characteristics test results of blocks**

The 7th, 14th and 28th day density, compressive strength and static modulus of the blocks are presented for laterite-sand blocks, GPKS-sand blocks and GPKS-laterite-sand blocks in Tables 4.11 through Table 4.19. The relationship of this replacement with density and static modulus of elasticity of the blocks are presented in Fig 4.3 to Fig 4.8 at the different curing age.

**Table 4.11: Static modulus of elasticity for laterite-sand blocks at 7 days**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Mix No.** | **Sample** | **Mass (kg)** | **Density (Kg/m3)** | **Average Density (Kg/m3)** | **Compressive Force(KN)** | **Compressive Strength (N/mm2)** | **Average Compressive Strength (N/mm2)** | **Static Modulus of Elasticity (N/mm2)** | **Average Static Modulus of Elasticity(N/mm2)** |
|
|
| 1 | A | 24.30 | 1699 | 1706 | 113 | 1.78 | 1.76 | 5.94 | 5.96 |
| B | 24.50 | 1713 | 109 | 1.70 | 5.95 |
| C | 24.40 | 1706 | 115 | 1.80 | 6.01 |
| 7 | A | 23.20 | 1622 | 1622 | 105 | 1.65 | 1.66 | 5.28 | 5.29 |
| B | 23.00 | 1608 | 107 | 1.67 | 5.21 |
| C | 23.40 | 1636 | 105 | 1.65 | 5.37 |
| 8 | A | 22.80 | 1594 | 1620 | 101 | 1.59 | 1.60 | 5.04 | 5.21 |
| B | 24.00 | 1678 | 103 | 1.61 | 5.60 |
| C | 22.70 | 1587 | 102 | 1.60 | 5.00 |
| 9 | A | 22.30 | 1559 | 1558 | 93 | 1.45 | 1.44 | 4.68 | 4.66 |
| B | 22.40 | 1566 | 92 | 1.44 | 4.71 |
| C | 22.15 | 1548 | 91 | 1.43 | 4.59 |
| 10 | A | 22.00 | 1538 | 1540 | 86 | 1.35 | 1.35 | 4.44 | 4.45 |
| B | 22.15 | 1548 | 85 | 1.34 | 4.49 |
| C | 21.93 | 1533 | 87 | 1.36 | 4.42 |
| 11 | A | 21.70 | 1517 | 1520 | 65 | 1.02 | 1.04 | 3.95 | 3.97 |
| B | 21.60 | 1510 | 67 | 1.05 | 3.94 |
| C | 21.90 | 1531 | 66 | 1.04 | 4.03 |

**Table 4.12: Static modulus of elasticity for laterite-sand blocks at 14 days**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Mix No** | **Sample** | **Mass (kg)** | **Density (Kg/m3)** | **Average Density (Kg/m3)** | **Compressive Force(KN)** | **Compressive Strength (N/mm2)** | **Average Compressive Strength (N/mm2)** | **Static Modulus of Elasticity (N/mm2)** | **Average Static Modulus of Elasticity(N/mm2)** |
|
|
| 1 | A | 23.70 | 1657 | 1655 | 153 | 2.40 | 2.38 | 6.23 | 6.20 |
| B | 23.90 | 1671 | 147 | 2.30 | 6.25 |
| C | 23.40 | 1636 | 155 | 2.43 | 6.10 |
| 7 | A | 22.90 | 1601 | 1601 | 142 | 2.23 | 2.24 | 5.68 | 5.69 |
| B | 22.70 | 1587 | 144 | 2.26 | 5.61 |
| C | 23.10 | 1615 | 142 | 2.23 | 5.78 |
| 8 | A | 22.50 | 1573 | 1599 | 137 | 2.15 | 2.16 | 5.41 | 5.61 |
| B | 23.70 | 1657 | 139 | 2.17 | 6.03 |
| C | 22.40 | 1566 | 138 | 2.16 | 5.38 |
| 9 | A | 22.00 | 1538 | 1537 | 125 | 1.96 | 1.95 | 5.03 | 5.01 |
| B | 22.10 | 1545 | 124 | 1.95 | 5.06 |
| C | 21.85 | 1528 | 123 | 1.93 | 4.93 |
| 10 | A | 21.70 | 1518 | 1520 | 116 | 1.82 | 1.82 | 4.77 | 4.78 |
| B | 21.85 | 1528 | 115 | 1.81 | 4.82 |
| C | 21.63 | 1513 | 117 | 1.84 | 4.75 |
| 11 | A | 21.40 | 1497 | 1499 | 88 | 1.38 | 1.40 | 4.24 | 4.27 |
| B | 21.30 | 1490 | 90 | 1.41 | 4.23 |
| C | 21.60 | 1511 | 89 | 1.40 | 4.33 |

**Table 4.13: Static modulus of elasticity for laterite-sand blocks at 28 days**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Mix No** | **Sample** | **Mass (kg)** | **Density (Kg/m3)** | **Average Density (Kg/m3)** | **Compressive Force(KN)** | **Compressive Strength (N/mm2)** | **Average Compressive Strength (N/mm2)** | **Static Modulus of Elasticity (Gpa)** | **Average Static Modulus of Elasticity(Gpa)** |
|
|
| 1 | A | 23.50 | 1643 | 1641 | 170.00 | 2.67 | 2.64 | 6.35 | 6.31 |
| B | 23.70 | 1657 | 163.00 | 2.56 | 6.37 |
| C | 23.20 | 1622 | 172.00 | 2.70 | 6.21 |
| 7 | A | 22.70 | 1587 | 1587 | 158.00 | 2.48 | 2.49 | 5.78 | 5.79 |
| B | 22.50 | 1573 | 160.00 | 2.51 | 5.70 |
| C | 22.90 | 1601 | 158.00 | 2.48 | 5.88 |
| 8 | A | 22.30 | 1559 | 1585 | 152.00 | 2.38 | 2.40 | 5.51 | 5.71 |
| B | 23.50 | 1643 | 154.00 | 2.42 | 6.14 |
| C | 22.20 | 1553 | 153.00 | 2.40 | 5.47 |
| 9 | A | 21.80 | 1525 | 1523 | 139.00 | 2.18 | 2.16 | 5.11 | 5.09 |
| B | 21.90 | 1532 | 138.00 | 2.16 | 5.14 |
| C | 21.65 | 1514 | 137.00 | 2.15 | 5.02 |
| 10 | A | 21.50 | 1504 | 1505 | 129.00 | 2.02 | 2.02 | 4.85 | 4.86 |
| B | 21.65 | 1514 | 128.00 | 2.01 | 4.90 |
| C | 21.43 | 1499 | 130.00 | 2.04 | 4.83 |
| 11 | A | 21.20 | 1483 | 1485 | 98.00 | 1.54 | 1.55 | 4.31 | 4.33 |
| B | 21.10 | 1476 | 100.00 | 1.57 | 4.29 |
| C | 21.40 | 1497 | 99.00 | 1.55 | 4.40 |

**Fig 4.3: Relationship between laterite replacement and block average density.**

**Fig 4.4: Relationship between Laterite replacement and block average static modulus.**

**Table 4.14: Static modulus of elasticity for GPKS-sand blocks at 7 days**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Mix No** | **Sample** | **Mass (kg)** | **Density (Kg/m3)** | **Average Density (Kg/m3)** | **Compressive Force(KN)** | **Compressive Strength (N/mm2)** | **Average Compressive Strength (N/mm2)** | **Static Modulus of Elasticity (N/mm2)** | **Average Static Modulus of Elasticity(N/mm2)** |
|
|
| 1 | A | 24.30 | 1699 | 1706 | 113 | 1.78 | 1.76 | 5.94 | 5.96 |
| B | 24.50 | 1713 | 109 | 1.70 | 5.95 |
| C | 24.40 | 1706 | 115 | 1.80 | 6.01 |
| 2 | A | 21.50 | 1504 | 1508 | 52 | 0.82 | 0.76 | 3.60 | 3.54 |
| B | 21.80 | 1525 | 51 | 0.80 | 3.68 |
| C | 21.40 | 1497 | 43 | 0.67 | 3.34 |
| 3 | A | 19.20 | 1343 | 1342 | 43 | 0.67 | 0.67 | 2.69 | 2.68 |
| B | 19.40 | 1357 | 38 | 0.60 | 2.65 |
| C | 19.00 | 1329 | 47 | 0.74 | 2.71 |
| 4 | A | 18.10 | 1266 | 1268 | 32 | 0.50 | 0.68 | 2.16 | 2.40 |
| B | 18.30 | 1280 | 48 | 0.76 | 2.54 |
| C | 18.00 | 1259 | 50 | 0.78 | 2.48 |
| 5 | A | 16.70 | 1168 | 1167 | 32 | 0.50 | 0.50 | 1.84 | 1.82 |
| B | 16.75 | 1171 | 45 | 0.70 | 2.07 |
| C | 16.60 | 1161 | 19 | 0.30 | 1.54 |
| 6 | A | 16.10 | 1126 | 1123 | 21 | 0.33 | 0.33 | 1.49 | 1.49 |
| B | 15.90 | 1112 | 22 | 0.35 | 1.49 |
| C | 16.20 | 1133 | 20 | 0.31 | 1.48 |

**Table 4.15: Static modulus of elasticity for GPKS-sand blocks at 14 days**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Mix No** | **Sample** | **Mass (kg)** | **Density (Kg/m3)** | **Average Density (Kg/m3)** | **Compressive Force(KN)** | **Compressive Strength (N/mm2)** | **Average Compressive Strength (N/mm2)** | **Static Modulus of Elasticity (N/mm2)** | **Average Static Modulus of Elasticity(N/mm2)** |
|
|
| 1 | A | 23.70 | 1657 | 1655 | 153 | 2.40 | 2.38 | 6.23 | 6.20 |
| B | 23.90 | 1671 | 147 | 2.30 | 6.25 |
| C | 23.40 | 1636 | 155 | 2.43 | 6.10 |
| 2 | A | 21.20 | 1483 | 1487 | 70 | 1.10 | 1.03 | 3.85 | 3.79 |
| B | 21.50 | 1504 | 69 | 1.08 | 3.94 |
| C | 21.10 | 1476 | 57 | 0.90 | 3.57 |
| 3 | A | 18.90 | 1322 | 1322 | 57 | 0.90 | 0.90 | 2.87 | 2.86 |
| B | 19.10 | 1336 | 52 | 0.81 | 2.83 |
| C | 18.70 | 1308 | 63 | 0.99 | 2.90 |
| 4 | A | 17.80 | 1245 | 1247 | 42 | 0.67 | 0.68 | 2.30 | 2.33 |
| B | 18.00 | 1259 | 44 | 0.68 | 2.38 |
| C | 17.70 | 1238 | 45 | 0.70 | 2.32 |
| 5 | A | 16.40 | 1147 | 1146 | 29 | 0.45 | 0.45 | 1.72 | 1.69 |
| B | 16.45 | 1150 | 40 | 0.63 | 1.93 |
| C | 16.30 | 1140 | 17 | 0.27 | 1.43 |
| 6 | A | 15.80 | 1105 | 1103 | 19 | 0.30 | 0.29 | 1.39 | 1.37 |
| B | 15.60 | 1091 | 20 | 0.31 | 1.37 |
| C | 15.90 | 1112 | 17 | 0.27 | 1.36 |

**Table 4.16: Static modulus of elasticity for GPKS-sand blocks at 28 days**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Mix No** | **Sample** | **Mass (kg)** | **Density (Kg/m3)** | **Average Density (Kg/m3)** | **Compressive Force(KN)** | **Compressive Strength (N/mm2)** | **Average Compressive Strength (N/mm2)** | **Static Modulus of Elasticity (N/mm2)** | **Average Static Modulus of Elasticity(N/mm2)** |
|
|
| 1 | A | 23.50 | 1643 | 1641 | 170 | 2.67 | 2.64 | 6.35 | 6.31 |
| B | 23.70 | 1657 | 163 | 2.56 | 6.37 |
| C | 23.20 | 1622 | 172 | 2.70 | 6.21 |
| 2 | A | 21.00 | 1469 | 1473 | 78 | 1.22 | 1.14 | 3.91 | 3.85 |
| B | 21.30 | 1490 | 77 | 1.20 | 4.01 |
| C | 20.90 | 1462 | 64 | 1.00 | 3.63 |
| 3 | A | 18.70 | 1308 | 1308 | 64 | 1.00 | 1.00 | 2.91 | 2.90 |
| B | 18.90 | 1322 | 57 | 0.90 | 2.87 |
| C | 18.50 | 1294 | 70 | 1.10 | 2.94 |
| 4 | A | 17.60 | 1231 | 1233 | 47 | 0.74 | 0.76 | 2.33 | 2.36 |
| B | 17.80 | 1245 | 48 | 0.76 | 2.41 |
| C | 17.50 | 1224 | 50 | 0.78 | 2.35 |
| 5 | A | 16.20 | 1133 | 1132 | 32 | 0.50 | 0.50 | 1.74 | 1.71 |
| B | 16.25 | 1136 | 45 | 0.70 | 1.95 |
| C | 16.10 | 1126 | 19 | 0.30 | 1.45 |
| 6 | A | 15.60 | 1091 | 1089 | 21 | 0.33 | 0.32 | 1.40 | 1.39 |
| B | 15.40 | 1077 | 22 | 0.34 | 1.38 |
| C | 15.70 | 1098 | 19 | 0.30 | 1.38 |

**Fig 4.5: Relationship between GPKS replacement and block average density**

**Fig 4.6: Relationship between GPKS replacement and block static modulus**

**Table 4.17: Static modulus of elasticity for GPKS-laterite-sand blocks at 7 days**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Mix No** | **Sample** | **Mass (kg)** | **Density (Kg/m3)** | **Average Density (Kg/m3)** | **Compressive Force(KN)** | **Compressive Strength (N/mm2)** | **Average Compressive Strength (N/mm2)** | **Static Modulus of Elasticity (N/mm2)** | **Average Static Modulus of Elasticity(N/mm2)** |
|
|
| 1 | A | 24.30 | 1699 | 1706 | 113 | 1.78 | 1.76 | 5.94 | 5.96 |
| B | 24.50 | 1713 | 109 | 1.70 | 5.95 |
| C | 24.40 | 1706 | 115 | 1.80 | 6.01 |
| 12 | A | 20.70 | 1448 | 1434 | 50 | 0.78 | 0.79 | 3.29 | 3.24 |
| B | 20.50 | 1434 | 51 | 0.80 | 3.25 |
| C | 20.30 | 1420 | 50 | 0.79 | 3.17 |
| 13 | A | 19.90 | 1392 | 1392 | 47 | 0.74 | 0.72 | 2.99 | 2.96 |
| B | 20.10 | 1406 | 48 | 0.75 | 3.06 |
| C | 19.70 | 1378 | 43 | 0.67 | 2.83 |
| 14 | A | 21.10 | 1476 | 1473 | 50 | 0.78 | 0.77 | 3.41 | 3.39 |
| B | 21.20 | 1483 | 49 | 0.77 | 3.43 |
| C | 20.90 | 1462 | 49 | 0.76 | 3.32 |
| 15 | A | 19.00 | 1329 | 1338 | 37 | 0.58 | 0.59 | 2.51 | 2.55 |
| B | 19.60 | 1371 | 38 | 0.60 | 2.70 |
| C | 18.80 | 1315 | 36 | 0.57 | 2.44 |
| 16 | A | 17.80 | 1245 | 1247 | 31 | 0.48 | 0.48 | 2.07 | 2.08 |
| B | 18.00 | 1259 | 29 | 0.46 | 2.09 |
| C | 17.70 | 1238 | 32 | 0.50 | 2.07 |
| 17 | A | 20.10 | 1406 | 1402 | 49 | 0.77 | 0.77 | 3.08 | 3.07 |
| B | 20.15 | 1409 | 50 | 0.79 | 3.12 |
| C | 19.90 | 1392 | 48 | 0.76 | 3.00 |
| 18 | A | 16.90 | 1182 | 1186 | 28 | 0.44 | 0.44 | 1.80 | 1.82 |
| B | 17.20 | 1203 | 26 | 0.40 | 1.82 |
| C | 16.80 | 1175 | 30 | 0.47 | 1.83 |
| 19 | A | 19.20 | 1343 | 1340 | 39 | 0.61 | 0.62 | 2.60 | 2.61 |
| B | 19.00 | 1329 | 43 | 0.67 | 2.63 |
| C | 19.30 | 1350 | 37 | 0.58 | 2.59 |

**Table 4.18: Static modulus of elasticity for GPKS-laterite-sand blocks at 14 days**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Mix No** | **Sample** | **Mass (kg)** | **Density (Kg/m3)** | **Average Density (Kg/m3)** | **Compressive Force(KN)** | **Compressive Strength (N/mm2)** | **Average Compressive Strength (N/mm2)** | **Static Modulus of Elasticity (N/mm2)** | **Average Static Modulus of Elasticity(N/mm2)** |
|
|
| 1 | A | 23.70 | 1657 | 1655 | 153 | 2.40 | 2.38 | 6.24 | 6.20 |
| B | 23.90 | 1671 | 147 | 2.30 | 6.25 |
| C | 23.40 | 1636 | 155 | 2.43 | 6.10 |
| 12 | A | 20.40 | 1427 | 1413 | 67 | 1.05 | 1.07 | 3.52 | 3.46 |
| B | 20.20 | 1413 | 69 | 1.08 | 3.48 |
| C | 20.00 | 1399 | 68 | 1.06 | 3.39 |
| 13 | A | 19.60 | 1371 | 1371 | 64 | 1.00 | 0.97 | 3.19 | 3.16 |
| B | 19.80 | 1385 | 64 | 1.01 | 3.27 |
| C | 19.40 | 1357 | 57 | 0.90 | 3.02 |
| 14 | A | 20.80 | 1455 | 1452 | 67 | 1.04 | 1.04 | 3.65 | 3.63 |
| B | 20.90 | 1462 | 66 | 1.04 | 3.67 |
| C | 20.60 | 1441 | 65 | 1.03 | 3.56 |
| 15 | A | 18.70 | 1308 | 1317 | 50 | 0.78 | 0.79 | 2.68 | 2.72 |
| B | 19.30 | 1350 | 52 | 0.81 | 2.89 |
| C | 18.50 | 1294 | 49 | 0.77 | 2.60 |
| 16 | A | 17.50 | 1224 | 1226 | 41 | 0.65 | 0.65 | 2.21 | 2.21 |
| B | 17.70 | 1238 | 40 | 0.62 | 2.23 |
| C | 17.40 | 1217 | 42 | 0.67 | 2.20 |
| 17 | A | 19.80 | 1385 | 1381 | 66 | 1.04 | 1.04 | 3.30 | 3.28 |
| B | 19.85 | 1388 | 68 | 1.06 | 3.34 |
| C | 19.60 | 1371 | 65 | 1.02 | 3.21 |
| 18 | A | 16.60 | 1161 | 1166 | 37 | 0.59 | 0.59 | 1.92 | 1.93 |
| B | 16.90 | 1182 | 34 | 0.54 | 1.94 |
| C | 16.50 | 1154 | 40 | 0.63 | 1.94 |
| 19 | A | 18.90 | 1322 | 1319 | 52 | 0.82 | 0.83 | 2.78 | 2.79 |
| B | 18.70 | 1308 | 57 | 0.90 | 2.81 |
| C | 19.00 | 1329 | 50 | 0.78 | 2.77 |

**Table 4.19: Static modulus of elasticity for GPKS-laterite-sand blocks at 28 days**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Mix No** | **Sample** | **Mass (kg)** | **Density (Kg/m3)** | **Average Density (Kg/m3)** | **Compressive Force(KN)** | **Compressive Strength (N/mm2)** | **Average Compressive Strength (N/mm2)** | **Static Modulus of Elasticity (N/mm2)** | **Average Static Modulus of Elasticity(N/mm2)** |
|
|
| 1 | A | 23.50 | 1643 | 1641 | 170 | 2.67 | 2.64 | 6.35 | 6.31 |
| B | 23.70 | 1657 | 163 | 2.56 | 6.37 |
| C | 23.20 | 1622 | 172 | 2.70 | 6.21 |
| 12 | A | 20.20 | 1413 | 1399 | 75 | 1.17 | 1.18 | 3.57 | 3.52 |
| B | 20.00 | 1399 | 77 | 1.20 | 3.53 |
| C | 19.80 | 1385 | 75 | 1.18 | 3.44 |
| 13 | A | 19.40 | 1357 | 1357 | 71 | 1.11 | 1.08 | 3.24 | 3.21 |
| B | 19.60 | 1371 | 71 | 1.12 | 3.32 |
| C | 19.20 | 1343 | 64 | 1.00 | 3.06 |
| 14 | A | 20.60 | 1441 | 1438 | 74 | 1.16 | 1.15 | 3.70 | 3.68 |
| B | 20.70 | 1448 | 73 | 1.15 | 3.73 |
| C | 20.40 | 1427 | 73 | 1.14 | 3.61 |
| 15 | A | 18.50 | 1294 | 1303 | 55 | 0.87 | 0.87 | 2.72 | 2.76 |
| B | 19.10 | 1336 | 57 | 0.90 | 2.93 |
| C | 18.30 | 1280 | 54 | 0.85 | 2.64 |
| 16 | A | 17.30 | 1210 | 1212 | 46 | 0.72 | 0.72 | 2.23 | 2.24 |
| B | 17.50 | 1224 | 44 | 0.69 | 2.25 |
| C | 17.20 | 1203 | 47 | 0.74 | 2.23 |
| 17 | A | 19.6 | 1371 | 1367 | 73 | 1.15 | 1.15 | 3.34 | 3.33 |
| B | 19.65 | 1374 | 75 | 1.18 | 3.39 |
| C | 19.4 | 1357 | 72 | 1.13 | 3.26 |
| 18 | A | 16.4 | 1147 | 1152 | 41 | 0.65 | 0.65 | 1.94 | 1.95 |
| B | 16.7 | 1168 | 38 | 0.6 | 1.96 |
| C | 16.3 | 1140 | 45 | 0.7 | 1.96 |
| 19 | A | 18.7 | 1308 | 1305 | 58 | 0.91 | 0.93 | 2.82 | 2.82 |
| B | 18.5 | 1294 | 64 | 1 | 2.85 |
| C | 18.8 | 1315 | 55 | 0.87 | 2.81 |

**Fig 4.7: Relationship between GPKS-laterite replacement and average block density.**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 0% S | 90%S | 85%S | 85%S | 75%S | 75%S | 75%S | 75%S | 80%S |
| 0% L | 5% L | 5%L | 10%L | 15%L | 10%L | 20%L | 5%L | 10%L |
| 0%G | 5% G | 10%G | 5%G | 10%G | 15%G | 5%G | 20%G | 10%G |

**Fig 4.8: Relationship between GPKS-laterite replacement and average block static modulus**

**4.2 Discussion of results**

**4.2.1 Physical properties of sand, laterite and GPKS**

The major materials employed in this work are river sand, ground palm kernel shell(GPKS), laterite and water and their physical properties have been presented in Table 4.1 through Table 4.9

**4.2.1.1 Specific gravity of sand, GPKS and laterite**

The specific gravity of the river sand, GPKS and laterite were found to be 2.67, 2.38 and 2.63 respectively. These values are within the normal ranges for the respective materials. The specific gravity for GPKS depends on the specie of the parent palm fruit. Olutoge et al (2012) obtained 2.3 as specific gravity for GPKS in his work. The specific value obtained for laterite is 2.63. Fromme(1994) gave a range of 2.55-4.6 as specific gravity for laterite suitable for concrete works and the value obtained falls within this range.

**4.2.1.2 Gradation of sand, laterite and GPKS.**

The gradation curve for sand, laterite and GPKS is shown in Fig 1.The sieve analysis result for sand classifies the sand into Zone II for NIS 87(2004) and class C for BS882(1992). The fineness modulus of 3.6 was gotten for sand which shows that the mean aggregate size in sand falls within the third and fourth sieve (0.45mm-0.6mm). The Cu and Cc values obtained for sand were 2.5 and 0.98 respectively. This value shows that the sand has a small range of particle size since Cu is less than the value provided in Table 2.3 in the literature although it is well graded since the Cc value is approximately 1. The gradation result for laterite meets with the British standard for class M as specified by BS882(1992) and it is therefore suitable for concrete/sandcrete works. The Cu and Cc values are 2.19 and 1.24. The Cu value doesn’t fall within the range but Cc value falls within the range provided in Table 2.3 in the literature for well graded soils. The fineness modulus obtained is 3.64. This indicates the average size of particle falls within the third and fourth sieve(0.45mm-0.6mm). The sieve analysis result for GPKS indicates the range of sizes of the aggregate falls within 2.36mm-0.15mm. The fineness modulus gave a value of 4.92 and the gradation falls with the overall limits and in particular to class C as provided by BS882(1992).

**4.2.1.3 Atterberg’s limit for laterite**

The consistency limit test carried out on laterite gives the plastic limit, liquid limit and plasticity Index of 21.69%,32.20% and 10.51%. Plotting the liquid limit and the plasticity index value on the cassagrandre’s plasticity chart positions the soil over the Activity line. This classifies the laterite as a clay of low plasticity(compressibility).

**4.2.2 Chemical analysis of cement, laterite and GPKS**

The chemical composition of cement, laterite and GPKS are given in Table 4.10. The percentage composition of the major compounds namely: CaO, SiO2, Al2O3 and Fe2O3 are 64.03%,21.35%,4.33% and 1.85% respectively. These values are within the range provided in Table 2.2 in the literature for ordinary Portland cement. The other percentage constituents- SO3 and loss of ignition are 3.7% and 1.5% respectively. They also fall within the limits given in Table 2.2 and by BS EN 197-2(2000). The chemical composition of laterite shows the percentage composition for the major constituents namely: SiO2(29.10%), Al2O3(20.3%), Fe2O3(33.05%). This constituent compounds evident from the chemical analysis confirms the constituent compounds of a typical laterite as explained in the literature. The silica content of the laterite indicates that it can be used for sand replacement in sandcrete works. The degree of laterization as indicated by the silica-Sesquioxides(S-S) ratio and its value is 0.54(<1.33) which indicates that it is a laterite. The constituent compound from the chemical analysis of GPKS shows the major compounds of GPKS as silica(SiO2) and Alumina(Al2O3). The total percentage of silica present is 54.81% which represents more than half of the constituent compounds and this high percentage of silica content is indicative that the material can be used for sand replacement. The alumina(Al2O3) content is 11.4%

**4.2.3 Effect of laterite and GPKS replacement on the properties of sandcrete blocks**

The effect of laterite, GPKS and their combined (laterite and GPKS) replacement on the mass, density, compressive strength and static modulus of blocks are examined.

**4.2.3.1 Effect of laterite replacement on the mass and density of blocks**

The mass and density values of the blocks for laterite replacement are presented in Table 4.11through Table 4.13 and the relationship presented in Fig. 4.3.

Blocks produced with 0% replacement (control specimen) up to 20% replacement gave density above 1500kg/m3 as specified by BS 2028 (1968) for type A (dense blocks while the 25% replacement of sand with laterite gave 1484kg/m3 and 1498kg/m3 for 28 days and 14days respectively which is below 1500kg/m3 hence can be classified under type B (lightweight blocks).

Generally, there was a gradual decrease in the densities of the blocks produced as the lateritic content increases. The highest density recorded was 1706kg/m3 for control specimen (0% replacement) while blocks with 5%,10%,15%,20% and 25% recorded average densities of 1587kg/m3,1585kg/m3,1523kg/m3,1505kg/m3 and 1484kg/m3 respectively. It is also observed that the density for a particular mix decreases with increase in curing age.

Obviously, this signifies that blocks with laterite content are less dense with blocks with only sand as fine aggregate. This behavior can be attributed to the lower specific gravity possessed by laterite relative to sand as presented in Tables 4.1 and 4.2.

**4.2.3.2 Effect of laterite replacement on the static modulus of elasticity of the block.**

The values recorded for static modulus of elasticity of the blocks are presented in Table 4.11 through Table 4.13 and the relationship illustrated in Fig. 4.4.

The static modulus of elasticity of the bocks reduces with increasing laterite content and increases with curing age. This property of the block was calculated using equation 2.4 as presented in the literature. The compressive strength and density of the blocks are the terms contained in the equation. As these terms decreases as shown in fig4.3 with increasing lateritic content, the static modulus decreases. The maximum value of static modulus obtained was on the 28-day curing age as 6.31GPa for the control specimen and the 5%, 10%, 15%, 20% and 25% replacements gave 5.79GPa, 5.71GPa, 5.09GPa, 4.86GPa and 4.33GPa respectively. This trend conforms to earlier studies by Asiedu et al (2014) on the sand-laterite blend.

**4.2.3.3 Effect of GPKS replacement on mass and density of blocks**

The value obtained for the mass and density of the blocks are presented in Table 4.14 through Table 4.16 and their relationship illustrated in Fig.4.5. Block produced at 0% replacement recorded the highest density value of 1706kg/m3 which classifies them into dense blocks as specified by BS 2028(1968). 5% to 25% replacement gave densities below 1500kg/m3 and are hence classified as lightweight blocks.

In general, the block density decreases with increase in GPKS replacement and curing age. The drastic drop in the density of the block produced with 5% GPKS compared to the controlled specimen validates the lower value of 2.38 as specific gravity of GPKS as presented in Table 4.3. Hence, GPKS-Sand blend are suitable for lightweight blocks.

**4.2.3.4: Effect of GPKS replacement on the static modulus of the block.**

The value obtained for the static modulus of the blocks are presented in Table 4.14 through Table 4.16 and their relationship illustrated in Fig. 4.6. It is observed from the graph that the static modulus of elasticity of the blocks produced for 0% replacement recorded highest value of 6.31GPa at 28-day curing age and at 5% replacement reducing to 3.85GPa (40% reduction). The reduction continued to 25% replacement which is the maximum replacement. Meanwhile, the static modulus increases with curing age for each mix recording the maximum value at 28-day and the minimum value at 7-day curing age. This behavior conforms to the fact that the static modulus of the blocks is a function of the compressive strength and density of the block and it reduces as the block compressive strength and density reduces.

**4.2.3.5 Effect of combined replacement of laterite and GPKS on the block density and mass**

The density of the blocks with combined replacement of GPKS and laterite are presented in Table 4.17 through Table 4.19 and their relationship presented in Fig 4.7. It is observed from the relationship that the highest value of density/mass is recorded for the control specimen as 1706kg/m3 which is above 1500kg/m3 as specified by BS 2028(1968) for dense blocks. Subsequent replacement recorded densities below this value and are hence classified as lightweight blocks.

**4.2.3.6 Effect of combined replacement of laterite and GPKS on the block static modulus**

The static modulus of elasticity of the blocks for the combined replacement are presented in Table 4.17 through Table 4.19 and their relationship presented in Fig 4.8. From the chart, it is observed that the highest recorded static modulus of elasticity is 6.31GPa which was attained by the control specimen. As the combine replacement is made, the static modulus of elasticity reduces. The highest recorded value is 3.68GPa which was made for Mix No. 14 (85%Sand,10%Laterite and 5%GPKS) and the lowest value recorded is 1.95GPa for Mix No. 18(75%Sand,5%Laterite and 20%GPKS) at 28 day curing age.

For this combined replacement, it can be deducted that the Static modulus of elasticity is poor for blocks with GPKS content above 5%. However, the reduced static modulus of elasticity is expected to occur for replacement as the average compressive strength and bulk densities which are factors that affect this property reduces.