Effects of Elevated Temperature on Splitting Tensile Strength of OPC and BLA Pozzolanic Concrete and Mortar

1*Catherine M. Ikumapayi and 2Samuel L. Akingbonmire
1Department of Civil and Environmental Engineering, Federal University of Technology, Akure, Nigeria
2Department of Civil and Environmental Engineering, Federal University of Technology, Akure, Nigeria

mayowaik@yahoo.com | sammykdg@gmail.com

Abstract — Concrete is one of the most common and widely applied construction materials in the world. It is good in compression but weak in tension. The weakness in tension is better catered for through the use of reinforcement but there is still need to ensure that its minimum tensile strength is retained during the course of production and usage to avoid cracks development at the reinforcement cover. Concrete mixes of 1:2.4 (cement: sand: granite) and mortar of 1:6 mix ratio of cement to sand were produced. The ordinary Portland cement (OPC) content was partially replaced with bamboo leaf ash (BLA) from 0% to 12% at 2% interval. They were tested under normal and elevated temperature to know the effect of elevated temperature on their splitting tensile strength. The results obtained showed OPC concrete mix to improve in splitting tensile strength (3.5 N/mm² to 3.7 N/mm² at 28 days curing) whereas there was a decrease in the splitting tensile strength obtained for BLA mixes (3.29 N/mm² to 1.75 N/mm² for 12% percentage replacement at 28 days curing). The same trend of results was obtained for mortar mix; OPC mix increases from 1.65 N/mm² to 1.86 N/mm² while BLA at 12% percentage replacement decreases from 2.02 N/mm² to 1.7 N/mm². OPC concrete and mortar under elevated temperature (100°C) will improve in splitting tensile strength while elevated temperature decreases the splitting tensile of BLA concrete and mortar mixes at 12%.

Keywords — concrete, heating, mortar, pozzolan, splitting tensile strength.

1 INTRODUCTION

Concrete as a construction material has wide application and all its constituent materials are readily available in nature except cement. Cement as an essential binding materials in the production of concrete require high temperature (1500°C) during manufacturing. It also emits harmful gases like CO₂, NO₂ and CH₂ gases into the atmosphere. Apart from these disadvantages, calcium hydroxide, one of the hydration products of cement, is a treat to construction industry. This affects the durability characteristics of Portland cement pastes, mortar and concretes. Consequently, engineering researchers are being motivated to intensify efforts in reducing the amount of cement use in concrete production without altering the properties of such concrete significantly and without causing any havoc to the environment or the society at large.

Pozzolans are siliceous and aluminous materials that possess little or no cementious value but which will in finely divided form and in the presence of water react chemically with calcium hydroxide at ordinary temperature to form compound possessing cementitious properties (Mehta, 1987). Some industrial by-products like blast furnace slag, fly ash, silica fume among others have been discovered to be practically useful when mixed with the right amount of OPC because it improves the properties of the blended cement. After due chemical and physical tests such materials are called pozzolans (ASTM, 1978). Many at times, blended cement shows properties better than OPC if proper optimization is done (Ikumapayi, 2014). Apart from industrial by-products, ashes obtained from agricultural based industries have also been discovered to have pozzolanic properties. Rise husk ash (RHA) is already in use while sugarcane bagasse ash (SBA), bamboo leave ash (BLA), locust beans pod ash (LBPA) are new emerging pozzolans which are seriously under consideration for use in form of blended cements in the construction industry (Ikumapayi, 2014).

Apart from compressive strength, tensile strength is one of the basic and important properties of concrete. The concrete is not usually expected to resist the direct tension because of its low tensile strength and brittle nature. However, the determination of tensile strength of concrete is necessary to determine the load at which the concrete members may crack. Cracking is a form of tension failure (Lee, 2007). Traditionally, there are two tests methods that can be employed in the measurement of concrete tensile strength; the splitting tensile strength of concrete cylinders and the flexural strength of beams. The splitting tensile strength known as the Brazilian or the indirect tension test is a popular method of characterizing the tensile strength of concrete. This method has been generally accepted because the cylinder is a commonly and routinely fabricated specimen. Also, the testing procedure is quite simple, and has been specified in several recommendations and standards (ASTM C496, 2002; RILEM CPC6, 1994). This research covers the determination of the splitting tensile strength of cylindrical concrete specimens for OPC concrete, BLA concrete and mortar.

Previous studies pointed out that splitting tensile strength of ordinary concrete could change with high temperature which also depends on the relative humidity (Naus, 2010). In this study, the effect of elevated temperature on the splitting tensile strength of OPC and BLA pozzolanic concrete and mortar has been investigated through experiment. The various concrete mixes were heated and their splitting tensile strengths were determined. The importance of temperature, concrete constituent and cement composition were then investigated and analysed using ANOVA at α₀.05.

2 MATERIALS

The materials used in this experiment are coarse aggregates (19mm granites chippings), fine aggregates (sand and stone dust), ordinary Portland cement, bamboo leaf ash (BLA) and portable water. The pozzolanic material used is BLA and it was obtained from burning of bamboo leaf. The bamboo leaves were sun dried to remove moisture from them. They were then subjected to...
a high temperature of about 600-700°C and allowed to cool for 12 hours. The burnt ashes collected were sieved through a BS sieve (75μ).

3 EXPERIMENTAL METHODOLOGY
Normal concrete mix of ratio 1: 2: 4 of cement to sand to granite were produced with water cement of 0.65. Pozzolanic mortar mixes obtained by replacing cement with BLA at 4%, 8% and 12% were also produced. Mortar mixes of ratio 1: 6 of cement to sand were also produced. The various mixes were cast using cylinder of size 200 mm height and 100 mm diameter. The concrete cylinders were cured by immersing in water. They were brought out at 7, 14 and 28 days for heating and for determination of their splitting tensile strengths. Those that were to be subjected to elevated temperature were placed in the oven regulated to a temperature of 100°C for a minimum of 24 hours before test. The total numbers of concrete cylinders cast were one hundred and forty four (144) i.e thirty-six (36) concrete cylinders for the different mixes at 7, 14, and 28 days.

3.1 Laboratory Tests on all Materials, Fresh and Hardened
The laboratory tests conducted on the fine aggregates were particle size distribution, specific gravity tests, determination of natural moisture content and silt clay content. Specific gravity test, aggregate impact value (AIV) and aggregates crushing values (ACV) were determined for the coarse aggregates. Consistency, soundness tests as well as the initial and final setting time were all determined for the concrete. For the fresh concrete, the slump and compacting factor tests were all carried out. The slump test was carried out using the slump apparatus which is a mould that has 200 mm bottom diameter, 100 mm top diameter and 300 mm height. The slump after pouring the concrete in layers was measured using a ruler. The difference between the height of the mould and that of the highest point of the specimen been tested. Splitting tensile strength and bulk density tests were carried out on the hardened concrete. The splitting tensile strength test shown in Fig. 1 consists of applying a diametric compressive load along the entire length of the cylinder until failure occurs. This loading induces tensile stresses on the plane containing the applied load and compressive stresses in the area around the applied load. To avoid local compressive failure, plywood strips were used between the specimen and the plate. Tensile failure occurs instead of compressive failure since the areas under the load application are in a triaxial compression state, therefore allowing them to resist higher compressive stresses than what would have been indicated by uniaxial compressive strength (ASTM C496, 2002). The splitting tensile strength test was carried out in accordance with this procedure as shown in Plate 1.

4 RESULTS AND DISCUSSION
4.1 Laboratory Test Results
Some of the laboratory tests results obtained on the properties of the research materials are presented in Table 2. The results in Table 1 fall within the range of relevant standards. The average soundness value of cement is 1.20 mm which is within the range (i.e. 10 mm maximum) specified by the IS: 4031 (1988). Also, the value of the silt clay content is 8.3% is below the maximum value (i.e. 9 % maximum) specified by the code. The particle size distribution for the sand is shown in Fig. 2. The initial setting time and final setting time obtained for the OPC were 40mins and 420mins while the consistency point was 35mm (IS: 4031, 1988).
Table 1: Properties of the research materials

| S/NO | TEST                        | RESULT                  |
|------|-----------------------------|-------------------------|
| 1    | CEMENT                      | 1.20 mm                 |
|      | Soundness                   | 0.73 kg                 |
| 2    | COARSE AGGREGATE            | Aggregate crushing value | 29.8 %                  |
|      | Aggregate impact value      | 18.2 %                  |
| 3    | SPECIFIC GRAVITY            | Sand                    | 2.24                     |
|      |                             | Stone dust              | 2.8                      |
|      |                             | Granite                 | 2.99                     |
| 4    | SILTY CLAY CONTENT OF SAND  | 8.3 %                   |
| 5    | NATURAL MOISTURE CONTENT    | 1.67                    |

4.3 Influence of Curing and BLA Pozzolans on Density of concrete and mortar

Considering the results obtained in Figs 3 to 6, it was observed that for the concrete and mixes made from BLA there is generally an increase in the density of the unheated concrete specimens made from granite chippings as the curing age increases especially at 12% percentage replacement. The reverse was the case when these specimens were heated; there was a drop in the values obtained for the densities for any of these mix components even as the curing days increases.

![Fig. 3: Result of densities for unheated BLA concrete specimens](image3.png)

![Fig. 4: Result of densities for heated BLA concrete specimens](image4.png)

![Fig. 5: Result of densities for unheated BLA mortar specimens](image5.png)
4.4 Influence of Curing and BLA Pozzolans on Splitting Tensile strength of concrete and Mortar

The results in Figs 7 and 8 show the values of splitting tensile strength of concrete made from granite aggregates and BLA pozzolans for both heated and unheated samples. The results shows that there was an increase in the splitting tensile strength of OPC concrete after heating while the BLA concrete shows a decrease in the splitting tensile strength even at 28 days curing after heating. The result implies that heating or high temperature destroys pozzolanic activity of BLA concrete while OPC concrete showed good resistance to high temperature even up to 100°C Both OPC and BLA mortar specimens show decrease in splitting tensile strength when heated and unheated (Figs 9 and 10). These results also show that the good resistance to high temperature of OPC has been aided by the granite chippings present in the concrete since mortar did not exhibit same good resistance of concrete specimens.
Table 4: LSD test for splitting tensile strength of concrete made from granite for 28 days curing. 1-OPC (control), 2-BLA (4%), 3-BLA (8%), 4-BLA (12%), 5-OPC heated, 6-BLA (4%) heated, 7-BLA (8%) heated, 8- BLA (12%) heated.

| i | j | MD (i-j) | p | Remarks |
|---|---|----------|---|---------|
| 1 | 2 | 1.0033   | .000 | *       |
| 3 | 2 | .8433    | .000 | *       |
| 4 | 2 | .2133    | .070 | NS      |
| 5 | 2 | -.2166   | .066 | NS      |
| 6 | 2 | .7366    | .000 | *       |
| 7 | 2 | 1.4266   | .000 | *       |
| 8 | 2 | 1.7466   | .000 | *       |
| 1 | 3 | -.1600   | .164 | NS      |
| 4 | 3 | -.7900   | .000 | *       |
| 5 | 3 | 1.2200   | .000 | *       |
| 6 | 3 | 2.2666   | .027 | NS      |
| 7 | 3 | 1.4233   | .001 | *       |
| 8 | 3 | .7433    | .000 | *       |
| 1 | 4 | -.4300   | .000 | *       |
| 5 | 4 | -.1060   | .000 | *       |
| 6 | 4 | 1.0600   | .346 | NS      |
| 7 | 4 | .5833    | .000 | *       |
| 8 | 4 | .9033    | .000 | *       |
| 1 | 5 | 1.4300   | .001 | *       |
| 6 | 5 | 1.5233   | .000 | *       |
| 7 | 5 | 1.2133   | .000 | *       |
| 8 | 5 | 1.5733   | .000 | *       |
| 5 | 6 | 2.9533   | .000 | *       |
| 7 | 6 | 1.6433   | .000 | *       |
| 8 | 6 | 1.9633   | .000 | *       |
| 1 | 7 | 2.6900   | .000 | *       |
| 8 | 7 | 2.6100   | .000 | *       |
| 7 | 8 | 2.6200   | .010 | NS      |
| 8 | 8 | 2.6300   | .010 | NS      |

*Mean Difference (MD) is significant at α₀.05.*
NS= Not Significant

The result of the LSD post hoc test shown in Table 3 showed that when the STS of OPC unheated was compared with OPC heated there was no significant difference in the changes that took place. This is an indication that heating does not affect the STS of OPC concrete significantly and therefore its usage under high temperature is safe in term of STS. Similarly when the STS of OPC was statistically compared with that of unheated BLA 12% there was no significant difference in the changes that took place, therefore BLA can replace cement up till 12% without significantly altering the STS. On the contrary, when heated BLA pozzolanic concrete shows significance reduction in the STS at any percentage replacement indicating that its usage under high temperature will affect the STS of such concrete which will increase the rate at which the concrete will crack at the reinforcement cover.

5 CONCLUSION

From the results, it can be concluded that heating will increase the STS of OPC concrete but not significantly. Also BLA pozzolanic concrete and mortar showed significance decrease in the STS up to 28days at various percentage replacements. Therefore, BLA pozzolanic mixes can partially replace cement without significantly affecting the STS under normal temperature but will adversely affect it when heated.

**REFERENCES**

Ad ASTM C496 / C496M-02. (2002). Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, ASTM International, West Conshohocken, PA, 2004, www.astm.org
ASTM C618-78 (1978). Specification for fly ash and air or calcined natural pozzolanas for use as mineral admixtures in Portland cement concrete. American society of testing materials, Philadelphia.
BSEN 12350-2 (2009). Testing fresh concrete; slump test. British Standard Ikumapayi, C. M. (2014). Properties of Groundnut Shell Ash Blended Portland cement. Proceedings of Nigeria Institute of Civil Engineers, Civil Engineering: the Cradle of National Economic Growth held in Lagos, Nigeria, pp:58-67
International Standard Code IS: 4031 (Part 3): 1988 – Methods of Physical Tests for Hydraulic Cement -Determination of soundness, Bureau of Indian Standards, Manak Bhavan, 9 Bhadur Shah Zafar Marg New Delhi 110002
Lee K., (2007), Behaviour of Concrete Cylinder under Elevated Temperature Focused on Surface Spalling, Internal SEMS Report, University of Colorado, Boulder.
Mehta P.K, (1987). Natural pozzolanas: suplemmentary cementitious material in concrete, CANMET special publication: 86, pp.1-33
Naus, D. J., (2010). A compilation of elevated temperature concrete material property data and information for use in assessment of nuclear power plant reinforced concrete structures, NUREG/CR-7031, US-NRC.
RILEM CPC6. (1994). RILEM Recommendations for the Testing and Use of Constructions Materials-Tension by splitting of concrete specimens, E & FN SPON, 21 – 22, e-ISBN: 2351580117, doi: 10.1617/2351580117.010
eniyi, P. A., Ishola, A. O., Laoye, B. J., Olutunji, B. P., Bankole, O. O., Shallie, P. D., & Ogundele, O. M. (2016). Neural and behavioural changes in male periadolescent mice after prolonged nicotine-MDMA treatment. Metabolic brain disease, 31(1), 93-107.
Balogun, V. A., Aramcharoen, A., Mativenga, P. T., & Chuan, S. K. (2013). Impact of Machine Tools on the Direct Energy and Associated Carbon Emissions for a Standardized NC Toolpath Re-engineering Manufacturing for Sustainability (pp. 197-202): Springer.
Balogun, V. A., Kirkwood, N. D., & Mativenga, P. T. (2014). Direct Electrical Energy Demand in Fused Deposition Modelling, Procedia CIRP, 15, 38-43.
Balogun, V. A., & Mativenga, P. T. (2013). Modelling of direct energy requirements in mechanical machining processes. Journal of Cleaner Production, 41, 179-186.
Chen, L., Hoey, J., Nugent, C. D., Cook, D. J., & Yu, Z. (2012). Sensor-based activity recognition. IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), 42(6), 790-808.
Kong, D., Choi, S., Yasui, Y., Pavanaskar, S., Dornfeld, D., & Wright, P. (2011). Software-based tool path evaluation for environmental sustainability. Journal of Manufacturing Systems, 30(4), 241-247. doi: 10.1016/j.jmsy.2011.08.005
Young, J., Roy, H. S., & Young, J. (2007). Transforming server-side processing grammars: Google Patents.

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