EFFECT OF HIGH TEMPERATURE ON THE PROPERTIES OF CONCRETE CONTAINING ITAKPE IRON ORE TAILINGS

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Abstract

The paper summarizes the experimental studies on effect of high temperature on the properties of concrete containing Itakpe Iron Ore Tailings (IOTs). Concrete cubes of target strength $25N/mm^2$ were produced with varying proportioned dosages of IOTs as a replacement of River sand in a range of 10% to 40% by weight of fine aggregate. The physical properties of constituent materials as well as the residual compressive strength test of the concrete produced was tested before and after exposure to temperature of 1000^0C for a period of 1 hour under a control furnace. From the results obtained, a substantial variation in the performance and properties of IOTs concrete before and after exposing to high temperature was shown. The unexposed IOTs concrete exhibit excellent compressive strength increment as the replacement level is being increased. All IOTs concrete after exposure to high temperature underwent a strength deterioration which developed with the high temperature.

1.0 INTRODUCTION

Historically, the fire performance of concrete has often been taken for granted considering its non-combustible nature and ability to function as a thermal barrier, preventing heat and fire spread. Design criteria have been based on the results of testing to 'standard' (i.e, ISO - 834) for fire exposures typically expressed in terms of required reinforcement cover. However, the general applicability and usefulness of this approach may be debated since the heating regimes in real-world fires may be quite different. In particular, initial heating rates can be more rapid and all real fires have a distinct 'cooling phase'; both of these conditions are recognized as imposing additional stresses on in-situ structures which may be highly restrained. (Fletcher *et al., 2017*)

According to (Kodur, 2014), The behaviour of a concrete structural member exposed to fire is dependent, in part, on thermal, mechanical, and deformation properties of concrete of which the member is composed. Similar to other materials the thermo-physical, mechanical, and deformation properties of concrete change substantially within the temperature range associated with building fires. These properties vary as a function of temperature and depend on the composition and characteristics of concrete. In fundamental terms, the fire behaviour of concrete is linked to the temperature-dependent material properties. Since then thermal diffusivity is rather low, compared to steel, strong temperature gradients are usually generated within fire-exposed concrete members. Together with the high thermal inertial, this means that the core region may take a long time to heat up. Thus, whilst the compressive strength of concrete is rapidly lost beyond a critical temperature, which is not too dissimilar to the equivalent temperature for loss of steel strength, structural effectiveness is not diminished until the bulk of the material reaches the same temperature. This requires an analysis of the thermal response of the entire structural element. (Fletcher *et al., 2017*)

The comprehensive utilization of iron ore tailings (IOTs) has received increasing attention all over the world. Utilization of mine wastes such as tailings in concrete as aggregates will help in sustainable and greener development. Iron ore tailings (IOTs) are waste material obtainable from the process of melting of iron. Iron ore tailings (IOTs) comprise fine materials, mainly containing silica, together with iron oxides, alumina and other minor minerals.

The major utilization of IOTs includes land reclamation (Maiti *et al*. 2005), re-extraction of iron or other metals using advanced technology (Li *et al*. 2010, Sirkeci *et al*. 2006), and as raw ingredients in producing infrastructure materials, backfilling materials and fertilizers (Zhang *et al*. 2006, Zhu *et al*. 2011). Wang and Wu (2000), Zheng *et al*. (2010) reported utilization of tailings in clinker and concrete respectively. Iron ore tailings used as replacement of sand in concrete (Cai *et al*. 2009), as siliceous materials in ceramics (Liu *et al*. 2009, Das *et al*. 2000) and autoclaved aerated concrete (Li *et al*. 2011). The use of IOTs in the production of infrastructure materials promotes the sustainability of the mining industry and simultaneously enhances the greenness of the construction industry by reducing the demand for raw materials like river sand.

2.0 EXPERIMENTAL STUDIES

This section aimed at discussing the materials used for the research work and the methods of various tests that was carried out to investigate the properties of concrete made with Iron Ore Tailings as partial substitute for fine aggregates.

2.1 Materials

The following materials was used in the research:

i. Ordinary Portland Cement (OPC)
ii. Iron Ore Tailings (IOTs)
iii. Aggregates (fine and coarse aggregates)
iv. Water

2.2 Mix Design/Proportioning

The experimental methodology consists of mix proportioning, which design the quantity of materials and number of specimen required for the research based on the target strength of $25N/mm^2$. The consequent design mix resulted in a mix ratio of 1:1.65:2.42 with water-cement ratio of 0.45. the final mix proportion obtain is represented in the table 1 below.

Table 1: Mix proportion for the concrete

Materials	Quantity Kg/m^3
Water	76.95
Cement	170.90
Coarse Aggregates	413.10
Fine Aggregates (River Sand)	225.52
Fine Aggregates (IOTs)	56.38

2.3 Methods

The methods and procedures adopted for achieving the research are all done in the laboratory. A total of 120 cube samples was produced, twenty-four (24) samples for replacement levels 0%, 10%, 20%, 30% and 40%, six (6) each, (three (3) samples each for exposure and non-exposure to fire), for curing ages 7, 14, 21, and 28days. The compressive strength of the specimen was determined before exposure to fire and after exposure to temperature of 1000^{0}C for a period of 1 hour in a control furnace. The method of cooling adopted was through air cooling at room temperature before testing the residual compressive strength.

Laboratory Testing

The following laboratory tests were carried out on Iron Ore Tailings and constituent materials used for the research and concrete produced with it in order to determine their properties.

i. Sieve Analysis
ii. Water Content
iii. Specific Gravity
iv. Bulk Density
v. Tests on Concrete

Sieve Analysis

The aggregates were graded in accordance to the British standard BS 812: part 2 (1995) using sieves analysis. Coarse aggregates with 19mm maximum aggregate size were retained on No.4 (4.5mm) sieve, while the Aggregate that pass a 4.75mm sieve (No. 4) and predominantly retained on a No. 200 (75µm) sieve are classified as fine aggregate.

Water Content

The amount of water content of the moist aggregate is equal to the moisture content and absorption in the aggregate. Guiding methods as prescribed in BS 812 part 109: (1990) for accuracy in determining the water content of aggregate was adopted for the research.

Specific Gravity Test

Specific gravity is defined in the (ASTM-C127, 1993), as the proportion of the mass of a unit volume of a material to the same (supreme) volume of water at the expressed temperature. This largely depends on the amount of voids and the specific gravities of the materials of which it is composed.

Bulk Density

Bulk density is the mass of material in a given volume. It is used in converting quantities by mass to quantities by volume and it is affected by several factors which include the amount of moisture present plus the amount of effort introduced in filling the measures. Bulk density depends on how densely the aggregate is packed and consequently on the size distribution and the shape of particles. BS 812 part 2: (1995) recognises two degrees: loose and compacted. The test was carried out as compacted and un-compacted on the samples.

Tests on Concrete

a) Workability Test

The American Concrete Institute defines workability as “the property of freshly mixed concrete or mortar which determines the ease homogeneity with which it can be mixed, placed, consolidated and finished.” Slump test was first standardized into ASTM in 1992, yet it remains the most widely used for measuring concrete workability.

b) Curing

Curing of concrete cubes was done with clean and colourless water with total immersion method at a normal temperature to promote the hydration of cement, and thus, the development of strength of concrete and to keep concrete saturated.

c) Fire Exposure

The specimens were exposed to fire in a control furnace at 1000^0 for a period of 1hour. The furnace temperature-time relationship followed the ISO-834 standard fire curve. After the exposure the specimens were allowed to cool. For testing the residual strength property of concrete, the method for cooling adopted was, through air cooling, by exposing the hot specimens to room temperature for a period of 24 hours just after the exposure to temperature.

d) Compressive Strength

The compressive strength test was conducted on the hardened concrete sample to determine the strength develop on the crushing effect of the crushing machine.

3.0 RESULTS AND DISCUSSION

Figure 1 and 2 shows the behaviour pattern of the curve of compressive strengths against replacement levels and the chart of the compressive strengths against curing ages respectively for all IOT replacements before exposure to temperature. While, Figure 3 and 4 shows the behaviour pattern of the curve of compressive strengths against replacement levels and the chart of the compressive strengths against curing ages respectively for all IOT replacements after exposure to temperature.

Generally, from the results obtained, the mean compressive strength test results increase gradually for non-exposed samples. At the initial strength development stage, 7days for 0% replacement was 20.13N/mm^2 which was over 80% strength development and the replacement level of 10% to 40% strength development ranges from over 85% to more than 100%. Also, the final strength development at 28 days curing ages for 0% replacement was 25.98N/mm^2 for 103.92% strength development and the replacement level of 10% to 40% strength development, which are 28.00N/mm^2, 28.63N/mm^2, 30.20N/mm^2 and 30.47N/mm^2, already reaches 112%, 114.52%, 120.8% and 121.88% respectively. These values satisfy the requirement of normal-weight concrete strength development as stipulated in the BS 8110 standard code.

For the samples exposed to high temperature, it is observed that, even though the strength developed dropped drastically due to the effect of the temperature, the strength development increases with increase in replacement level and curing ages as the initial strength development age, 7days curing ages, has a value of 4.36N/mm^2 for 0% replacement and a value of 6.81N/mm^2 for 40% replacement. Also the final strength development at age 28days curing ages, has a value of 5.86N/mm^2 for 0% replacement and a value of 9.58N/mm^2 at 40% replacement. The results show that IOT contributes a significant increment for strength development in concrete.

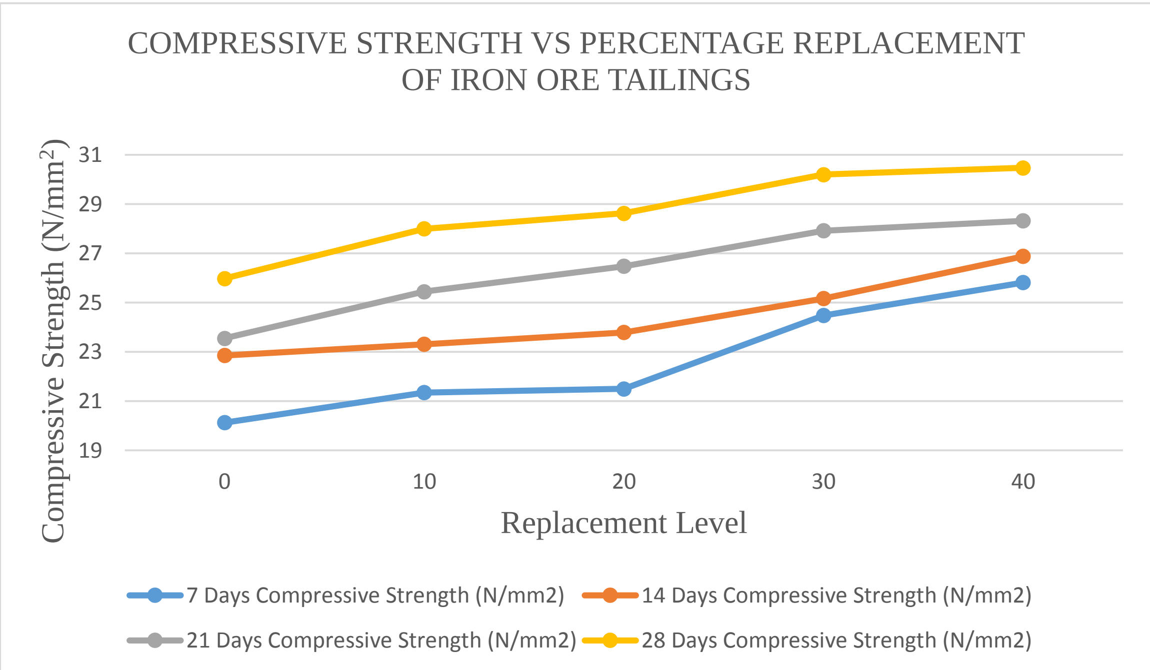

Figure 1: Compressive Strength against Replacement Level Curve for Non – Exposed sample

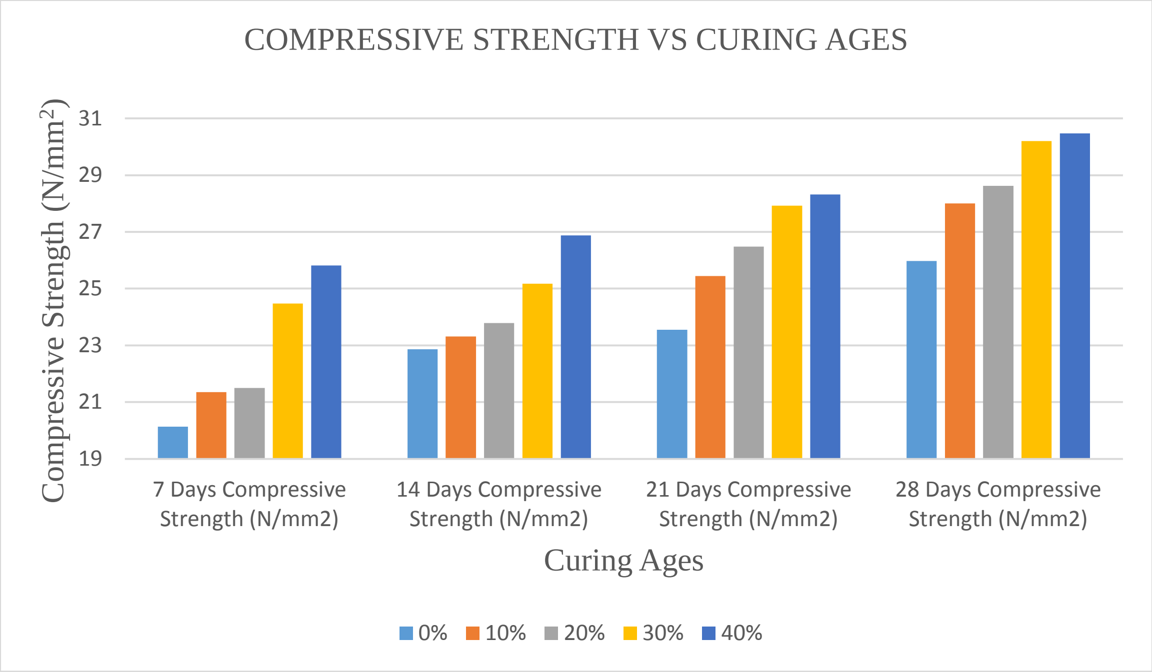

Figure 2: Compressive Strength Against Curing Age Chart for Non – Exposed sample

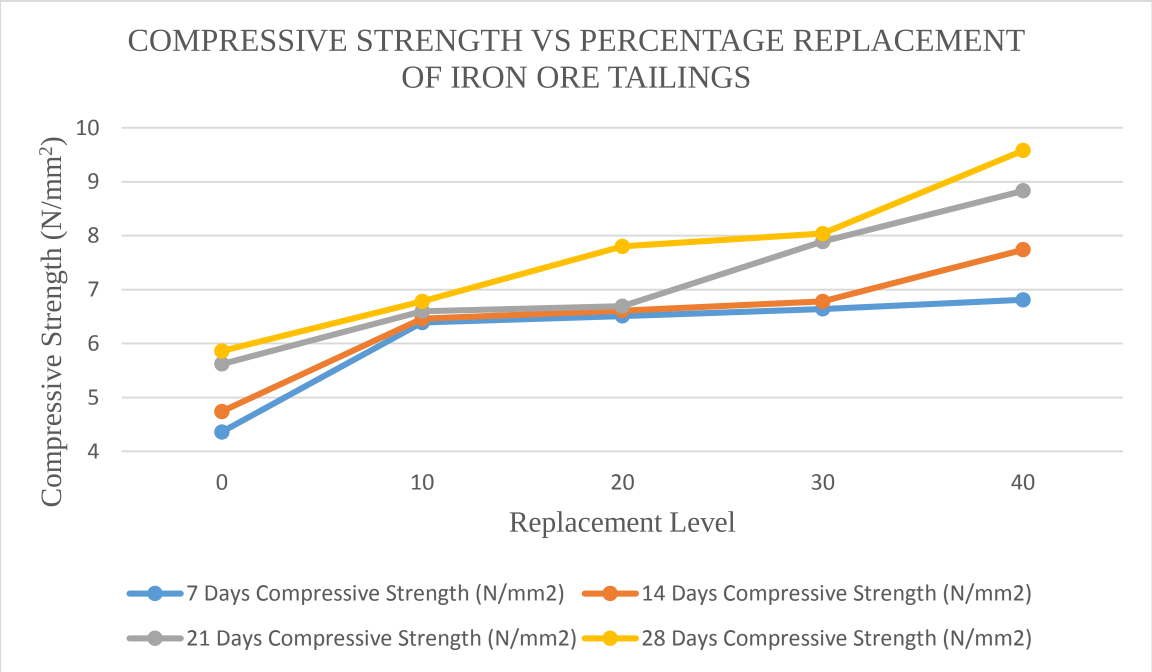

Figure 3: Compressive Strength against Replacement Level Curve for Exposed samples

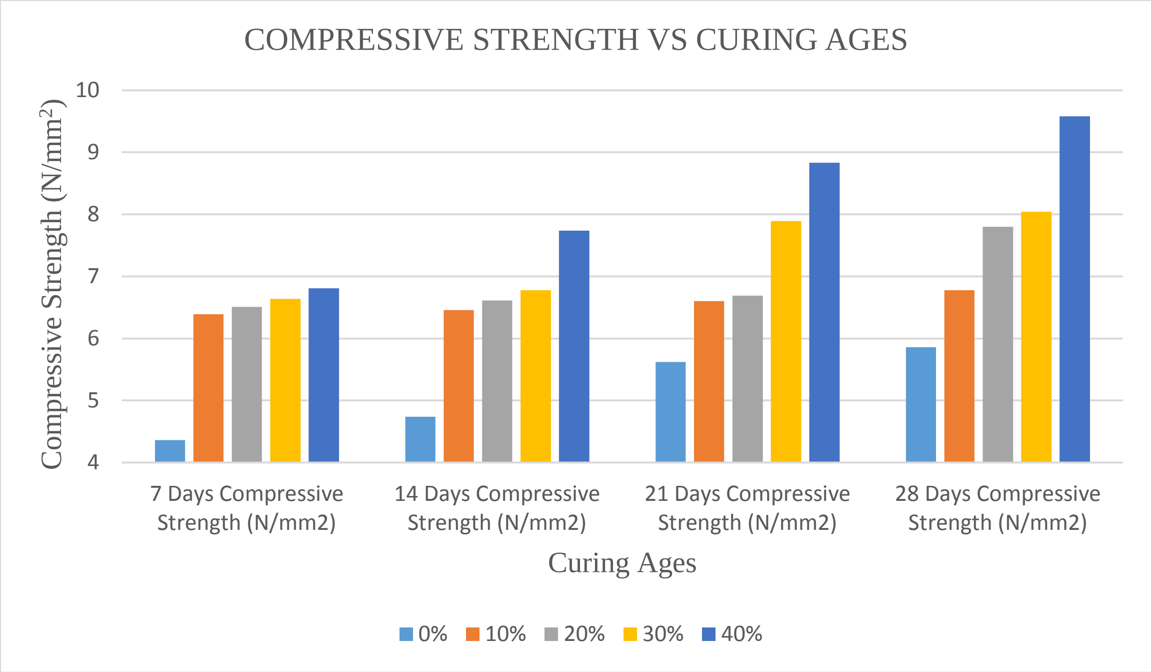

Figure 4: Compressive Strength Against Curing Age Chart for Exposed sample

4.0 CONCLUDION AND RECOMMENDATIONS

The paper presented the effect of high temperature of 1000^0C on mechanical properties of concrete containing Iron Ore Tailings gotten from Itakpe mines. From the obtained test results of IOT concretes as presented in the various sections, it showed a substantial variation in the performance and properties of the IOT concrete before and after exposing to high temperature. The unexposed IOT concrete exhibit excellent mechanical compressive strength increment as the replacement level is being increased. All IOT concrete after exposure to high temperature underwent a strength deterioration which developed with the high temperature. The physical examination of the IOT concrete after exposure to fire indicate cracks on samples. According to (Kassir, et al., 1996), He state that when conventional concrete is exposed to elevated temperatures, it begins to experience dehydration reactions in the hydrated cement paste, possible thermal incompatibilities between paste and aggregate, and eventual physiochemical deterioration of the aggregates.

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