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Research Article

Potential of Using Elevated Curing Temperature to Improve Ternary Blend of Portland Cement and Industrial By-products

Rahmon A. Suraj[1,2], Popoola O. Monsuru[2], Shittu O. Jeleel[2], Musa A. Ibrahim[3]

[1]Department of Civil Engineering, Architecture and Building, Faculty of Engineering & Computing, Sir John Laing Building, Coventry University, Coventry, CV1 5FB.
[2]Department of Civil Engineering, School of Engineering Moshood Abiola Polytechnic, Abeokuta Ogun State Nigeria.
[3]Department of Mechanical Engineering, School of Engineering Moshood Abiola Polytechnic, Abeokuta Ogun State Nigeria.

Abstract The work investigates the potential of using elevated curing at different temperature to improve the mechanical properties of mortar mixes made from ternary blend of industrial by-products and Portland cement. Mortar mixes combination comprising OPC (50%) – GGBS (45%) - BPD (5%), OPC (60%) – GGBS (25%) - SF (15%), OPC (50%) and OPC (60%) – PFA (25%)- SF (15%) was subjected to elevating curing temperature at 30 ^{o}C, 35 ^{o}C and 40 ^{o}C for 24 hours to determine the mechanical properties. The mixes were tested for both split tensile and compressive strength at 3, 7, 14 and 28 days and there is significant strength improvement at 40^{O}C for OPC (50%) – GGBS (45%) - BPD (5%) compared to the other mixes at different curing temperature. The results obtained from the study shows improvement that can translate into reducing the uses of cement in construction industry.

Keywords Ternary blend, Industrial by-product, Cement, Curing Temperature

1. Introduction

The uses waste material in replacing cement in the concrete industry has been widely researched over the past decades with success achieved in most of the research work. The construction industry has been the major user of cement and under pressure to find alternative materials to cement and reduce the carbon footprint of the product. It's important that significant efforts must be geared toward a sustainable concrete production. For instance, it has been reported that over 90 % of carbon emissions from the concrete industry are attributed to Portland cement clinker production in cement kilns, and about 1 tonne of CO_2 is generated in making 1 tonne of clinker [1]. Among the greenhouse gases, CO_2 contributes about 65 % of global warming and there is need to preserve the environment and reduce the carbon foot-print. There is also needs for new sustainable and environmentally friendly composites to replace convention cement in the construction industry [2]. Apart from the CO_2 contribution from the industrial production of cement to the depletion of ozone layer which needed to be drastically reduced, also urgent attention is required to haste the environmental degradation caused by the industrial manufacturing of cement and depletion of the natural resources as a result of continuous exploration of the raw material involved in the production of cement and provide an economical sustainable ways of utilization of the industrial waste material which its disposal has been a major problem to the stakeholder and this waste can be of benefit to the construction industry to achieve sustainability and economic stability.

The present research aimed at exploring the possibility of improving the mechanical strength of mixes containing industrial by-products and cement under elevated temperature curing regime on short term basis.

2. Experimental Work

2.1 Materials

2.1.1 Ordinary Portland Cement

Portland cement used in this research work was high strength cement grade 52.5 designed for cold weather working according to the producer Hanson Heidelberg Cement group United Kingdom.

2.1.2 Ground Granulated Blast-Furnace Slag

Granulated Ground Blast Slag (GGBS) used in the research study was obtained from Civil and Marine, a division of Hanson Heidelberg UK. The particle sizes in the range between 0.3 µm and 0.1 mm, with an average particle size around 20 µm. The material was marketed under the BS EN 15167-1-2 standard [3].

2.1.3 Silica fume

Silica fume is very fine reactive material produced as a by-product of the silicon metal ferrosilicon alloy in a smeller using electric furnace at about 2000 ^{o}C. Silica fume used in the investigation was undensified micro-silica grade 940-U sourced from Elkems Materials United Kingdom

2.1.4 Cement By-Pass Dust

By-Pass Dust is a by-product material derived from the cement manufacturing process. It is fine grained powdery material with similar appearance with cement. BPD was supplied from a local cement factory; Castle Cement (Hanson Heidelberg cement group in Rugby, UK) was used for this research work.

2.1.5 Pulverised Fly Ash (PFA)

PFA used in the investigation was supplied from the West Burton Power Station with specification in accordance with EN 450 S-Group.

2.1.6 Aggregate

Coarse aggregate were from uncrushed granite with maximum sizes of 6 mm and fine aggregate from sharp sand with maximum size of 3.35 mm supplied from local merchant in Coventry was used in the research work.

2.7 Water

Tap running water from the Coventry University concrete laboratory was used in mixing, casting and curing in phase one and two of the research work.

3. Methods

3.1 Assembly

50×50mm moulds were clean, oiled and assemble to receive the semi-dry mixes. The moulds were bolted tightly to ensure there are no leakage of material and the deformation of shape when samples are under hydraulic press. Fabricated test head with the actual size of the moulds were also prepared to aid safe transmission of the load from the hydraulic press to the sample without any loss.

Plate 1: $50\ mm \times 50\ mm moulds$

3.2 Mixing

Ternary blends mix comprising of the following combination in Table 1 were mixed in the 10 litres capacity small laboratory mixer to make paste with uniform rotating speeds. The mixing was made between 2-5 minutes to achieve the required blending of the industrial waste material with the Portland cement together to form the paste. Water was added to the mix at interval then the mixer was stopped and the mixture scrapped together using scoop for the blends to properly mixed together and achieve the required uniformly before the mixer was started to finished the mixing within the 5 minutes timeframe.

Table 1: Percentage binder combinations

Mix	OPC (%)	PFA (%)	SF (%)	GGBS (%)	BPD (%)	Water (%)
1-1	60	-	15	25	-	15
2-2	50	-	-	45	5	15
3-3	60	25	15	-	-	15

2.2.3 Placing

Blended semi - dry mix of 290 g in mass were carefully placed inside the cube moulds for the three types of mix considered in the research work and prepared to be compacted under the hydraulic press. The time between the placing of the mix in the moulds and the compaction were quickly speeds up in order to avoid the blends setting which might affect the performance of the blends.

2.2.4 Compaction

Samples from cube were subjected to compaction in a single layer under hydraulic press up to 52 kN within 1 minute. This loading was applied to all the cube specimens used in the experimental procedure at approximately the same rate within the 1 minute interval. The 52 kN were estimated as the appropriate load to apply on the 50 × 50mm specimens and was scaled down from the 400 kN load applied on the paving block based on the previous research carried out [4] on the appropriate compacting effort required to achieve the highest strength among the compacting efforts of 50 kN, 150 kN and 400 kN tested in the paving block production. Samples were scrapped to level with the surface of the mould to provide a reasonable finish after compaction [4].

2.2.5 Curing Process

The compacted samples were placed in the environmental chamber at 30 °C, 35 °C and 40 °C respectively for each mix for 24 hours while the control samples were stacked on the shelf covered with plastic bag to the reduce moisture from escaping at room temperature for 24 hours. Sample cured in environmental chamber for the elevated curing temperature and the stacked control sample were removed and de-moulded after 24 hours and placed in already prepared curing container. The containers were filled partially with water and perforated perspex plate placed over the water before samples were placed on the Perspex plate and covered with plastic lid. The containers were kept in the environmental control room at 20 ± 2 °C and 98 % relative humidity for testing at different ages as shown in plate 2 below.

Plate 2: Curing techniques employed in the research

2.2.6 Testing

Samples were subjected to both split tensile and compressive strength test after 3, 7, 14 and 28 days using the compression machine at loading rate of 2 kN/s with maximum loading of 2000 kN. The tests were carried out in accordance with specification of BS EN 1338:2003 and the results were reported in MPa. Compressive strength value were calculated

Thus: Compressive Strength = $\frac{F}{A}$ Equation 2.1

Where F = failure load in Newton's

A= Cross sectional area of the sample (mm)

The split tensile strength test were conducted on samples such that the sample were placed in the test frame packed at both bottom and top with flexible straight plywood as specified in the BS EN 1338:2003 for the split tensile strength test for paving block. The ideal was to test the samples in the same manner specified for concrete paving block in the BS standard. Adequate precautions were taken to ensure samples were placed at the centre of the frame for the split tensile strength and also new flexible straight plywood were used at every attempt during the testing period.

The split tensile strength were determined using the formula in equation 2.2

Split tensile Strength = $\frac{T}{A}$in MPa Equation 2.2

T= Splitting tensile load in kN

A= Cross-section area of the sample (mm)

Plate 3: Split Tensile and Compressive Strength Test.

4. Result and Discussion

4.1 Split Tensile and Compressive Strength

Figure 1a and 1b show the split tensile strength and compressive strength of the control sample, it can be deduced from the figure that OPC (60%)- GGBS(25%)- SF (15%) shows the highest strength in both the split tensile at 8.80MPa and compressive strength at 48.80MPa for 28 days normal curing and closely followed by OPC (50%) – GGBS (45%)- BPD (5%) at 8.2MPa, 40.12MPa in split tensile and compressive strength respectively. While the third mix OPC (60%) – PFA (25%)- SF (15%) was 7.98MPa, 38.14MPa in split tensile and compressive strength all at 28 days curing. The mix with the highest strength properties could be attributed to the cement content of 60% in the mix although the strength of the mix at control are generally low at 3 and 7 days but there was significant improvement in the strength of the sample at 14 and 28 days which correlates with [5] findings on the uses of industrial by-products and also slow hydration process of mixture contain GGBS [5]. The three ternary blends mix adopted in the first phase shows a lot of potentials in making paving blocks in the second phase.

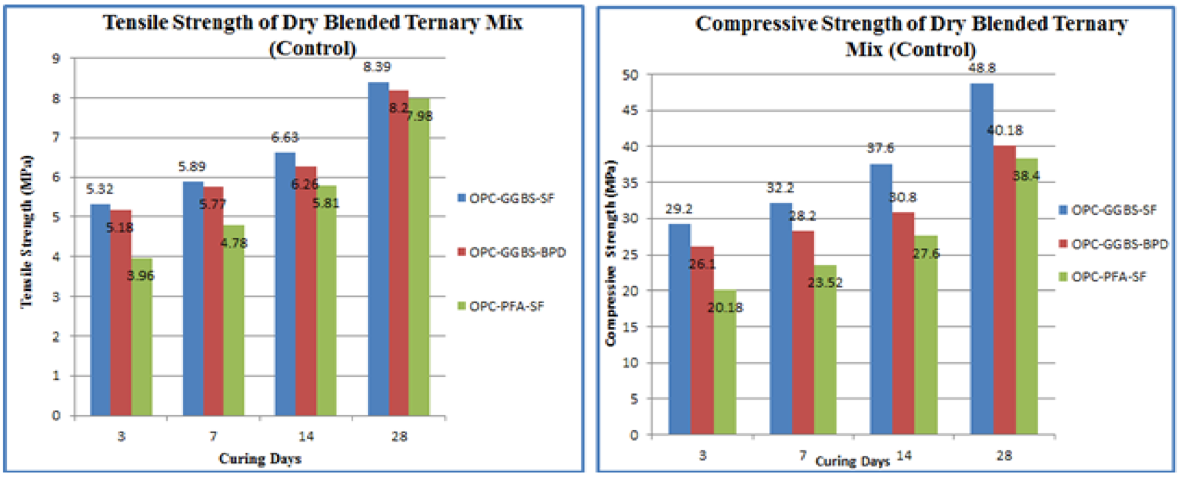

Figure 1: The summary of results of Split tensile and Compressive strength test of the Control 50 mm× 50 mm Ternary blended mix.

4.2 Effect of Elevated Curing Temperature on Ternary Blend Mix Paste

Figure 2, 3 and 4 show the result of the both split tensile strength and compressive strength of the three ternary blended mixes researched under elevated curing temperature for 24 hours at 30 °C, 35 °C and 40 °C before the normal curing described in the previous chapter. It can be deduced from the figures that samples that underwent the 40 °C elevated curing temperature in 24 hours shows the overall highest strength improvement with the OPC (60%) – GGBS (25%)- SF (15%) having the split tensile strength of 9.92 MPa and compressive strength value of 49.02 MPa for 28 days curing and this was closely followed by the OPC (50%) – GGBS (45%)- BPD (5%) with split tensile strength of 8.56 MPa and compressive strength of 41.93 MPa and the third mix OPC (60%) – PFA (25%)- SF (15%) with split tensile and compressive strength of 7.49 MPa and 37.55 MPa respectively. The increase in the strength of the elevated temperature cured samples compared to the control samples can be attributed to the accelerated hydration reaction of the cement and in the blends comprising of GGBS and the fly ash which leads to production of $Ca(OH)_2$ in the paste since the pozzalanic activities of these materials was further enhanced with elevated curing temperature and these were earlier reported [6] on the roles elevated curing temperature plays in the strength development of the mix containing GGBS and fly ash [6].

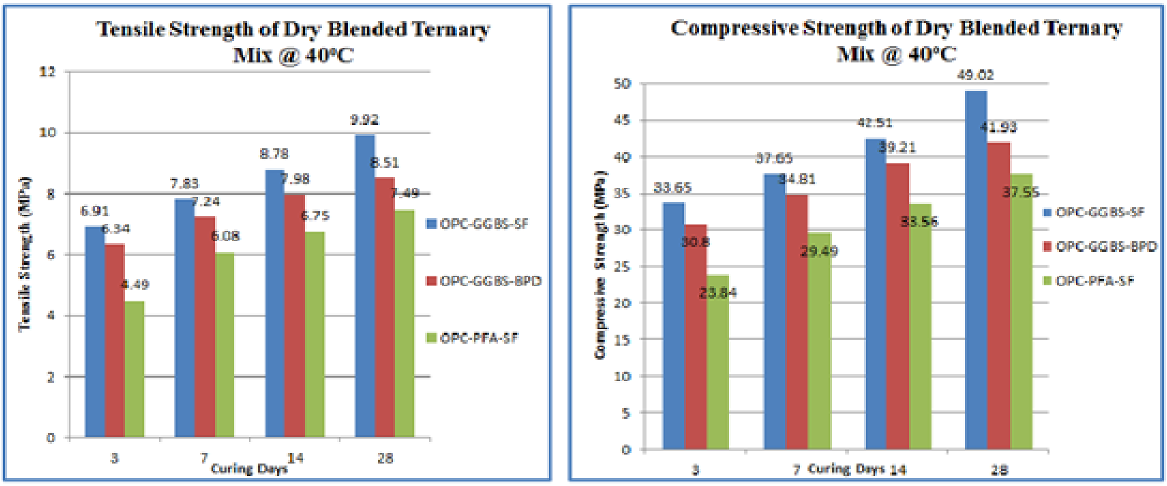

Figure 2: The summary of results of Split tensile and Compressive strength test of the 50mm× 50 mm Ternary blended mix cured at elevated temperature @ 40 °C.

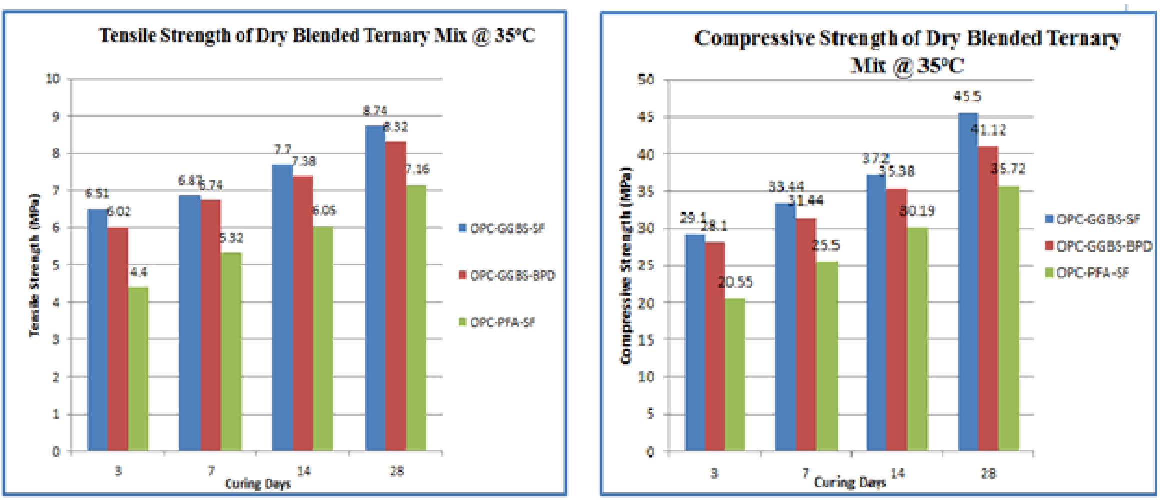

Figure 3: The summary of results of Split tensile and Compressive strength test of the 50 mm× 50 mm Ternary blended mix paste cured at elevated temperature @ 35 ^{o}C.

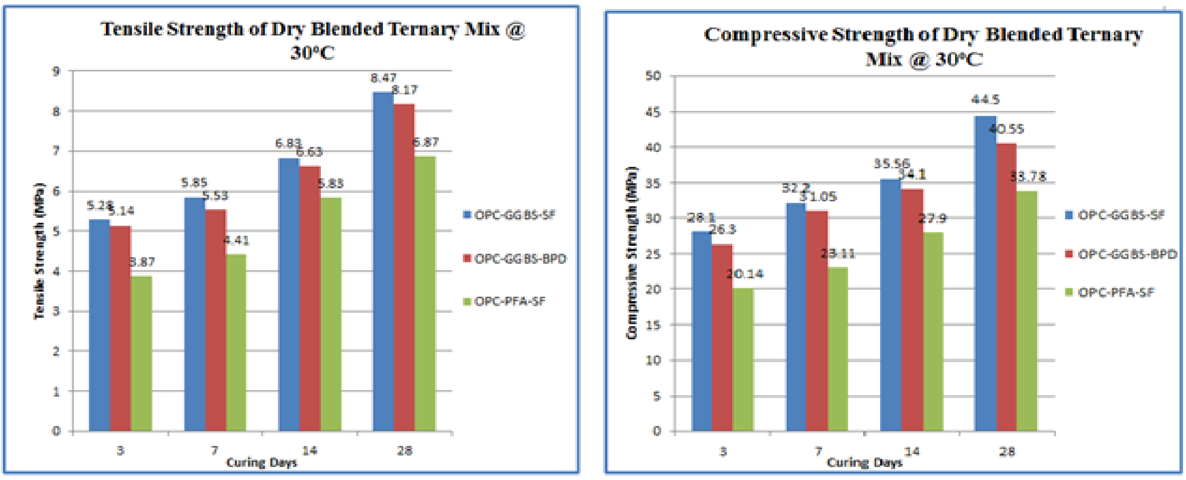

Figure 4: The summary of results of Split tensile and Compressive strength test of the 50 mm× 50 mm Ternary blended mix paste cured at elevated temperature @ 30 ^{o}C.

Conclusions

Based on the results obtained on the potential of using elevated curing temperature to improve the mechanical properties of mortar made combination of different from industrial by-products and ordinary Portland cement. It can be concluded that ternary blends mix of industrial by-product such as GGBS, PFA, Silica Fume and BPD can be improved on with elevated curing temperature at 40 ^{o}C at 24 hours as there is also increase in 28 days compressive and tensile strength compared to the sample cured at normal room temperature as the curing procedure facilitates quick hydration process in the mix.

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