Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 November 2020 doi:10.20944/preprints202011.0634.v1

Article

Comparative Analysis of Flexural Strength and Modulus Elasticity of Sustainable Concrete Using Supplementary Cementitious Material (SCM)

Sahahab Samad [1, ‡] and Attaullah Shah [2,‡]

1 Department of Civil Engineering, Kingston University London UK. shahabsamad54@hotmail.com
2 Department of Civil Engineering Technology, Karakoram International University Pakistan.

* Correspondence author: vc@kiu.edu.pk Tel: (+92-333-5729809)

‡ These authors contributed equally to this work.

Abstract: The use of Supplementary Cementitious Material (SCM) is widely used in production of sustainable concrete. Blended cements, incorporating SCM such as Pulverized Fly Ash (PFA) and Ground Granulated Blast Furnace Slag (GGBFS) have been widely used to reduce the cement contents and avoid adverse environmental impacts of CO_2 produced during cement manufacturing. The analysis of various structural properties of concrete such as compressive strength, flexural strength and modulus of elasticity is important for its structural application. In this research, flexural strength of 100mmx100mmx500mm beams made from blended cement were tested under three curing conditions i.e. winter, summer and under water and the flexural strength was calculated using EN-12390-5 at the ages of 28 days and 56 days. For modulus of elasticity, concrete cylinders 150mmx300mm were tested as per procedure described in BS 1881-121(1983) at the age of 28 days. The compressive strength, flexural strength and modulus of elasticity for blended cement incorporating PFA and GGBFS has been increased under summer curing environment. The experimental values of Modulus of Elasticity are compared with the provision of BS 1881.

Keywords: flexural strength, modulus of elasticity, Fly Ash, Slag.

1. Introduction

The use of concrete in the built environment has been increased manifold over the last five decades. The annual production of concrete has reached about 25 billion tonnes each year at global level. This is twice the other material used in construction such word, steel, wood and plastics etc. The extensive use of natural resources in the manufacturing of cement has forced the researchers to explore the sustainable concrete by using of low water binder ratio *(w/b)* and use of Supplementary Cementitious Material (SCM) and fillers [1]. The cement produced with the addition of SCM is often called Binary Cement [2]. The use of binary cement incorporating Supplementary Cementitious Material (SCM) in concrete to replace cement, has been the major area of research during last 50 years, which was initially aimed at reducing the cost of concrete production. However, the enhanced awareness about the environmental degradation due to human activities towards the last quarter of 20th century created the need for "Sustainable development and Sustainability in concrete production". [3]. It is generally believed that Green House Gases including CO2, NOx and SOx are mainly responsible for Global Warming, Climate Changes and other environmental issues. The cement manufacturing leads to heavy emissions of CO2 in the atmosphere as one tonne of CO2 is liberated during manufacturing of one tonne of cement [4]. The concrete technologists and researchers, have thus laid high emphasis over reducing the consumption of cement in concrete by exploring SCM like Pulverized Fly Ash (PFA), Ground Granulated Blast Furnace Slag (GGBFS), Rice Husk Ash (RHA), Silica Fumes (SF). SCM have been used in various proportions as replacement of cement, to modify the properties of concrete in fresh and hardened forms. Several agricultural and industrial wastes are used for production of concrete to reduce the consumption of cement during this process [5-6]. SCM have also been used in High Performance Concrete (HPC) to achieve better workability, higher compressive strength and more durability of concrete [7-8]. Tehmina *et al* [9], presented a comprehensive review of the earlier research on the partial replacement of cement by various mineral admixtures such as Pulverized Fly Ash (PFA), Silica Fume (SF), Ground Granulated Blast Furnace Slag (GGBS), Metakaolin (MK), and Rice Husk Ash (RHA). They reported that besides compressive strength, tensile strength, flexural strength, and modulus of elasticity of concrete has been increased with the increase in replacement level of mineral admixtures.

The compressive strength of concrete is one of the basic mechanical property of concrete, which is used for determination of other properties like flexural strength, modulus of elasticity and creep etc. Various Building and Concrete Codes have suggested empirical equations to determine these mechanical properties of structural concrete in terms of 28 compressive strengths for standard cylinder or cube. Such equations are based on experimental and empirical evidences. The compressive strength of concrete is affected by many factors such as mix design, age, curing conditions etc. The curing conditions have however direct impact on the compressive strength of concrete if other factors remain unchanged [10].

The flexural strength of concrete is taken as function of 28 days compressive strength of concrete. Siddique [11] reported increase in the flexural strength of blended concrete by replacing the fine aggregates with FA in the range of 10-50% by weight. However very limited research is available on the flexural strength of GGBS blended cement [12]. The compressive strength and flexural strength of Class C Fly Ash up to 30% level of replacement of cement was observed almost the same or higher than the normal strength [13]. Bouzoubaâ, Zhang and Malhotra [14], used High Volume Fly Ash (HVFA), to study the mechanical properties and durability of blended concrete including flexural strength and modulus of elasticity and reported its better performance as compared to normal concrete. Solanki and Pitroda [15] performed flexural strength test on mini beams of size 100 mm x 100 mm x 500 mm. A concrete mix M20 grade was designed as per IS10262:2009 method. The water/cement ratio was 0.48 for all the mixes. Flexural strength test was performed at the age of 28 days. It was concluded that the 28 days flexural strength of concrete is increased up to 11.1 % with 20 % replacement level of PC by fly ash.

Modulus of Elasticity (*E*) of concrete also play key role in predicting the deflection in a structure. The elastic modulus of concrete is function of several parameters, hence theoretical modeling of concrete may not be possible to explain it [16]. The equation for *E* are based on empirical approaches from static and dynamic testing, are widely used by various Codes [17]. These Codes describe the *E* as function of compressive strength and are restricted to normal strength concrete having *fc'* up to 40MPa. Various changes have been proposed by researchers in the equation of *E* for normal concrete to cater with high strength Concrete and HPC. The role of aggregates sizes and aggregates interlocking becomes more important for High Strength Concrete and hence its *E* is also affected due to aggregate size. The researchers generally believe that the exiting equations of Codes cannot be used for HSC to determine Elastic Modulus [18-19]. Takafumi Noguchi *et al* [20] proposed equation to determine *E*, applicable to wide range of aggregates and admixture for various types of concrete, based on multiple regression model of the available test database. They observed that the *E* of both normal and high strength concrete varies with cube root of compressive strength as reported by European Code [21]. The modulus of elasticity of blended concrete with PFA and GGBS was observed as lower at the initial age as compared to normal concrete, however this at later ages of 28 days and 56 days, the blended concrete showed better results, which is attributed to the slow pozzolonic action of blended concrete [22]. Khatib and Hibbert [23], found that the early age strength gain of concrete containing GGBS decreases with increasing percentage of GGBS in concrete but the strength between 28 days and days increased as compared to the PC concrete. According to the findings of Kayali and Ahmed [18], if the total cementitious content of concrete is kept constant and it is cured for a limited time, there is a decrease in the compressive strength and modulus of elasticity of concrete containing PFA, compared to the PC only concrete and this decrease in strength is increased with the replacement level.
The curing process also affects the properties of concrete made from ordinary cement or blended cement incorporating GGBS. The water curing was found more effective than heat curing [24], [26]. The slow steam curing of slag added concrete has gained strength more than water and air cured specimen [27]. In this research the mechanical properties of blended concrete incorporating PFA and GGBFS have been determined under three different curing condition which include compressive strength, flexural strength and modulus of elasticity.

2. Research Significance

Little research work is available on the mechanical properties specially modulus of elasticity and flexural strength of blended concrete with GGBFS and PFA under various curing conditions. This fact has been the major motivation for this experimental work. The research on flexural strength of GGBFS concrete has been done in limited scale. Hence the results of current research would add to the data of research in the area.

3. Experimental Program

3.1 Material

3.1.1 Ground Granulated Blast Furnace Slag (GGBS)

GGBS is a by-product obtained during the manufacture of iron in the blast furnace. GGBS is economically available in large quantities and suitable for production of large quantities of ready-mix concrete at site in precast product manufacturing. The granulated slag is dried and ground to a fine powder that is called GGBS. It is off-white in color and has a bulk density of 1200 kg/m^3.

3.1.2 Pulverized Fly Ash (PFA)
PFA conforming to BS-EN 450-1(2012) [22], was used as binary cement component in the production of concrete. PFA used in the concrete is commercially available in the UK and is classified as CEM IV according to BS EN 197-1 (2011) [23].

3.1.3 Portland cement
Ordinary Portland cement (OPC) used conformed to BS EN 197-1 and was classified as CEM-I. The Portland cement was stored in the laboratory to avoid exposure to humidity.

3.1.4 Superplasticizer (SP)
High performance liquid superplasticizers conforming to BS-EN 934-2 was used, to achieve the required workability.

3.1.5 Aggregates
Graded natural sand with a maximum particle size of 5 mm and complying with the requirements of BS EN 12620-1 (2009) , was used as fine aggregate in the concrete mixes. Thames valley natural aggregates of lime stone were used as coarse aggregate in the concrete mixes. The maximum size of the aggregate used was 20 mm.

3.2 Concrete Mix Proportions
Trial mixes of concrete were designed to achieve an equal 28 days compressive strength of 40 MPa and the strengths of 10 MPa after 16 hours and 25 MPa after 38 hours to meet the practical requirement of post tensioned concrete beams. The trial mixes are shown in Table 1. To achieve a practical level of workability and cohesion, suitable for pumping, concrete was designed for a target slump of 200 mm. The overall maximum water/cement ratio was kept 0.45 and overall minimum cement content of 340 kg/m^3. Superplasticizer was used to minimize water and cement contents to achieve low free w/c ratio.

Table 1 Mix proportioning of blended concrete using Slag and GGBS

Mix	**water**	**Binder** (Kg)		**Aggregates** (kg)		**w/c**	**Superplasticizer**	**Density**
	Litres	OPC	GGBS/PFA	Coarse	Fine		ml/100kg of OPC	kg/m^3
70PC/30GGBS (30% GGBS)	160	320	137	1285	500	0.35	1200	2400
60PC/40GGBS (40% GGBS)	160	274	183	1285	500	0.35	1200	2400
50PC/50GGBS (50% GGBS	160	229	228	1285	500	0.35	1200	2400
90PC/10FA (10%PFA)	150	360	40	1325	540	0.375	1200	2415
80PC/20FA (20%PFA)	150	370	92	1310	495	0.325	1200	2415
70%PC/30FA (30% PFA)	150	324	138	1310	495	0.325	1200	2415
100PC-Control (No GGBS)	160	457	-	1285	500	0.35	1200	2400

Two batches of concrete were made for each concrete mix, to cast samples. Sixty 100 mm x 100 mm cubes were cast for each mix to measure the compressive strength development according to the British standard test method (BS EN 12390) (2009), at the age of 1,2,3,5,7,14,28 and 56 days cured under different curing regimes.

3.4 Curing Environments
Engineering performance of concrete cured under three different regimes was recorded. The following three methods were chosen for curing the concrete which have a close resemblance with the onsite curing environment in the UK.

3.4.1 Summer Curing Environment (C1)

After casting concrete in the molds, it was stored for 24 hours at a laboratory temperature of about 20 ± 2 °C and covered with plastic sheets to minimize the loss of moisture. After 24 hours concrete was demolded and sealed in air-tight plastic bags so that there is no loss of moisture and stored at a laboratory temperature of 20 °C. This curing environment has been titled as C1 and shown in Figure 1a.

3.4.2 Winter Curing Environment (C2)

After casting concrete, it was stored for 24 hours with in the molds in the environmental chamber controlled at a temperature of 7 °C and 55 % relative humidity which resembles the normal winter temperature in the UK. Molds were covered with plastic sheets to minimize the loss of moisture. After 24 hours, concrete was demolded and sealed in the air-tight plastic bags to avoid any loss of moisture and stored in the environmental chamber controlled at 7 °C. Concrete cubes cured under the C2 curing environment as shown in Figure 1b.

3.4.3 Water Curing Environment (C3)

After casting concrete in the molds, it was stored at a laboratory temperature of 20 °C and was covered with plastic sheets. After 24 hours, concrete was demolded and was immersed in the water chamber controlled at a temperature of 20 ± 2 °C. Concrete stored under curing environment C3 is shown in Figure 1c.

3.5 Testing setup:

The flexural strength of the low carbon concrete was tested at the age of 28 and 56 days and compared with the Portland cement concrete. The flexural Test was carried out on 100 mm x 100 mm x 500 mm beams after curing for 28 days using the three different conditions as discussed above. Two specimens were tested of each concrete mix and each curing regime. In case of more than 10 % difference in the two results a third specimen was also tested. The flexural strength was calculated following the method described in EN 12390-5 (2009) using simple bending theory. The flexural strength test is shown in Figure 1

Figure 1. Flexural strength test using EN 12390-5 (2009) test procedure

The static modulus of elasticity of concrete specimens was determined following the procedure described in BS 1881-121(1983). A step loading was applied on a standard cylinder up to a maximum of one third of the failure load. The change in length of the test specimen was recorded at each load step, and converted to strain (ε). The load at each step was converted to stress (δ). The stress-strain relationship was established and its slope gave the static modulus of elasticity expressed in kN/mm^2. A RUBICON-MAYES testing machine was used for determining the modulus of elasticity and it was operated by a computer program to apply the load cycles at a precise rate. The testing machine setup with the specimen during testing is shown in Figure 2. The modulus of elasticity test was carried out on 150 mm diameter and 300 mm high cylinder specimens cured for 28 days under the three curing conditions.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 November 2020 doi:10.20944/preprints202011.0634.v1

Figure 2 Modulus of elasticity test by RUBICON-MAYES testing machine using BS 1881-121(1983) procedure

4. Results and Discussions

4.1 Flexural strength:

- The compressive strength development for blended concrete under various curing conditions are given in Fig3. For each concrete mix, flexural test was performed after curing in the three curing regimes for 28 days. Flexural test results for the different concrete mixes cured under different regimes are given in Table 2. The flexural strength of GGBS concrete and PC concrete cured under the different regimes are compared in Figure 4, and the flexural strength of the PFA concretes in Figure 5. Curing environments have an effect on the flexural strength. Concrete cured under C2 (7 ºC) curing regimes have slightly lower flexural strength than the other regimes considered. Concretes cured under the C3 (curing at 20 ºC under water) regime have higher flexural strength for GGBS and 100PC-Control concrete mixes than those cured under the C1 (20 ºC) environment.
- The 60PC/40GGBS concrete mix gained slightly more flexural strength than the other concrete mixes cured under different curing regimes. The 70PC/30GGBS and 50PC/50GGBS concrete mixes have slightly higher flexural strength than the 100PC-Control concrete mix, which was expected according to the literature reviewed.
- Curing environments have an effect on the flexural strength of PFA concrete mixes and the flexural strength of PFA concrete mixes are reduced after being cured under the C2 regime compare to the concrete cured under other regimes. The 80PC/20PFA concrete mix has the highest flexural strength compared to the other concrete mixes cured in the C1 environment and is 11.5 % more than the flexural strength of 100PC-Control concrete mix. The 90PC/10PFA and 70PC/30PFA concrete mixes have slightly higher flexural strength than the 100PC-Control concrete mix cured under the C1 regime. PFA concrete mixes have slightly lower flexural strength than the 100PC-Control concrete cured under environment C3.
- The winter temperature curing environment, C3 reduces the flexural strength of PFA concrete. In order to enhance the flexural strength of concrete, curing time needs to be extended for a long time and the temperature of the curing environment needs to be kept at least 20 Cº
- It is concluded that the concrete mixes, designed for equal 28 days strength , the use of GGBS up to 50 % and PFA up to 30 % slightly increase the 28 days flexural strength in comparison to PC only concrete, which is according to the earlier research due to the better microstructure and packing of concrete.

Table2: 28 day cube/cylinder compressive strength, flexural strength& modulus of elasticity

Concrete Mix	Compressive Cube Strength (MPa)			Compressive Cylinder Strength (MPa)			Flexural Strength (MPa)			Modulus of Elasticity (GPa)		
Curing conditions	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C[9] 2	C3
90PC/10PFA	68.0	59.5	71.0	55.0	50.0	58.5	6.0	5.0	5.5	42.0	40.0	42.8
80PC/20PFA	67.5	57.0	68.5	53.0	48.5	49.0	7.0	5.0	6.5	41.5	39.1	42.2
70PC/30PFA	68.0	61.0	70.0	50.5	42.5	43.0	6.0	6.0	6.5	39.1	37.5	39.6

70PC/30GGBS	68.5	57.0	72.0	56.5	49.0	58.5	6.5	6.0	7.0	40.0	38.5	40.5
60PC/40GGBS	71.5	62.0	72.0	57.0	48.0	58.0	6.5	6.0	7.0	40.5	39.0	41.0
50PC/50GGBS	68.0	55.0	68.0	53.0	47.5	54.0	6.5	6.0	7.0	40.5	38.5	40.0
100PC-Control	69.0	64.0	77.0	56.0	55.0	57.5	6.0	6.0	7.0	39.8	38.5	39.8

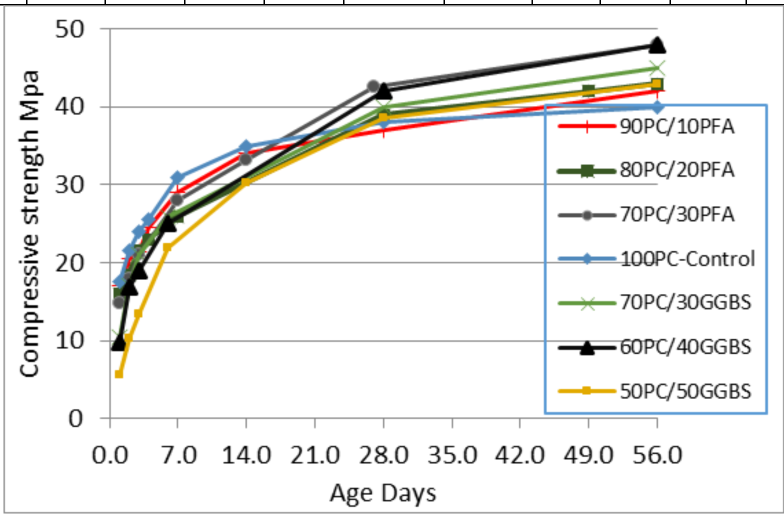

Figure 3. Compressive strength development

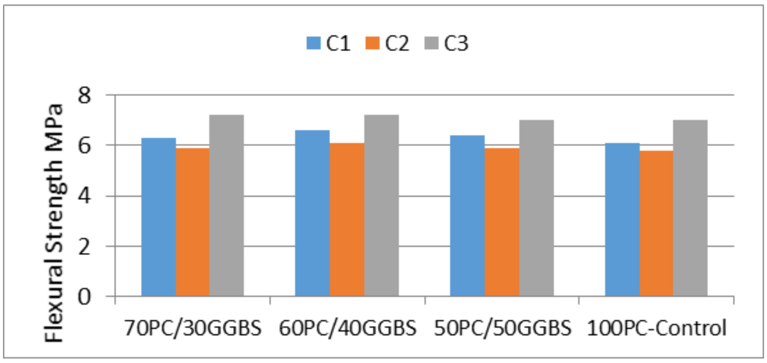

Figure 4 Flexural strength of GGBS concrete at the age of 28 days

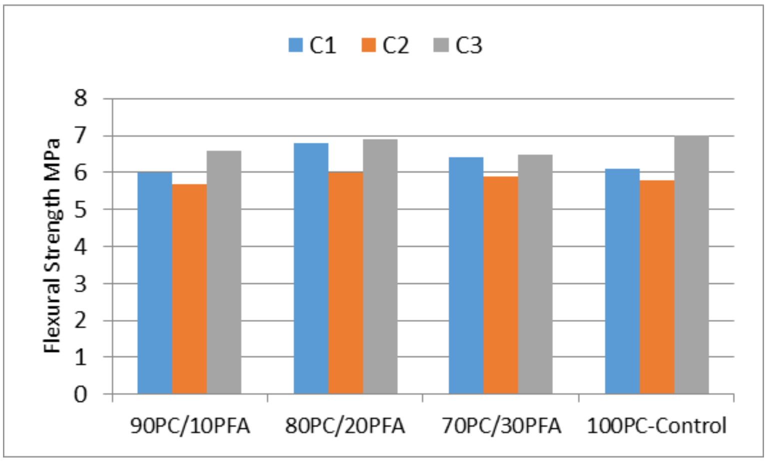

Figure 5 Flexural strength of PFA concrete at the age of 28 days

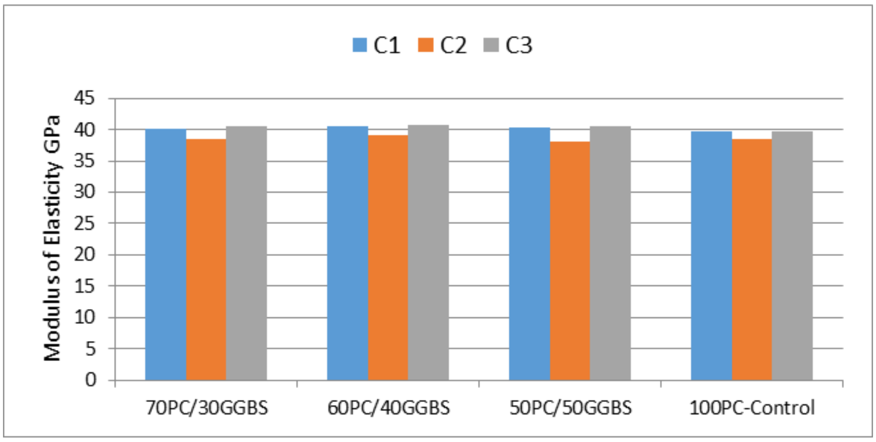

Figure 6. Modulus of elasticity of GGBS concrete at the age of 28 days

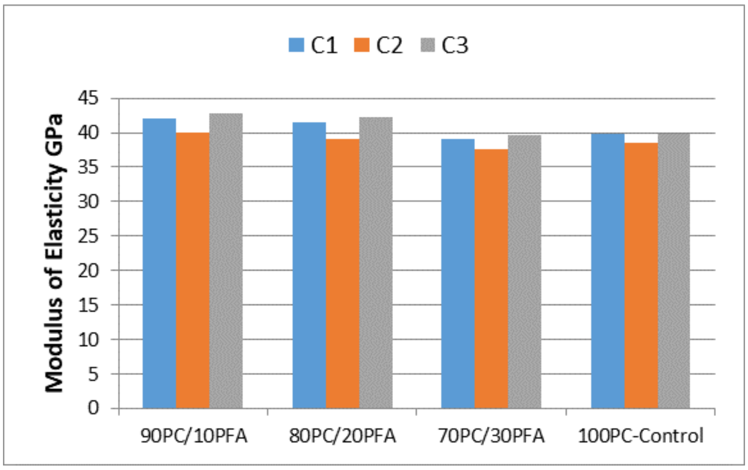

Figure 7 Modulus of elasticity of PFA concrete at the age of 28 days

Table 3 Modulus of elasticity estimates

Concrete mixes	Cube strength	Cylinder strength	Cylinder/Cube strength	Experimental Modulus of elasticity	BS8110 estimates	BSEN1992-1 estimates
	MPa	MPa		GPa	GPa	GPa
70PC/30GGBS	68.5	56.5	0.83	40.0	33.5	37.0
60PC/40GGBS	71.5	57.0	0.84	40.5	34.5	37.0
50PC/50GGBS	68.0	53.0	0.78	40.5	33.5	36.5
90PC/10PFA	68.0	55.0	0.8	42.0	33.5	36.5
80PC/20PFA	67.5	53.0	0.75	41.5	33.5	36.5

70PC/30PFA	68.0	50.5	0.75	39.0	33.5	36.0
100PC-Control	69.0	56.0	0.8	40.0	34.0	37.0

4.2 Modulus of Elasticity

The modulus of elasticity increases with the compressive strength and depends on the type of aggregate used. According to BS 8110-2 (1985), the mean value of modulus of elasticity for normal weight concrete at the age of 28 days, are calculated from the following equation.

$$E_{c,28} = K_o + 0.2\, f_{cu,28} \qquad (1)$$

Where $E_{c,28}$ is the static modulus of elasticity at 28 days.

$f_{cu,28}$ is the characteristic cube strength at 28 days (in N/mm^2)

K_o is a constant closely related to the modulus of elasticity of the aggregate (taken as 20 kN/mm^2 for normal-weight concrete).

For strength class C 40/50 the mean value of modulus of elasticity for normal weight concrete will be as follows.

$E_{c,28} = 20 + 0.2 \times 50 = 30$ GPa

According to BS-EN 1992-1 (2004), the mean value of the modulus of elasticity is estimated according to the following equation.

$$E_{cm} = 22\, [(f_{cm})\, /10]^{0.3}$$

Where E_{cm} is the mean value of modulus of elasticity at the age of 28 days in GPa.

f_{cm} is the mean cylinder strength in MPa.

For strength class C 40/50 the mean value of modulus of elasticity for normal weight concrete is calculated as follows, according to BS-EN 1992-1 (2004).

$E_{cm} = 22\, [(40)\, /10]^{0.3} = 33.4$ GPa

The estimate of the mean value of modulus of elasticity for normal weight concrete, according to BS-EN 1992-1 (2004), is slightly more than the estimate of BS 8110-2 (1985).

For 100PC-Control mix, the 28 day, compressive cube strength is 68.0 MPa and the compressive cylinder strength is 56.0 MPa according to Table 2. The elastic modulus of elasticity will be 33.6 GPa according to BS-EN 1992-1 (2004) and 36.9 GPa according to BS-EN 1992-1 (2004). The modulus of elasticity determined in the laboratory is 39.8 GPa, which is slightly more than these estimates.

In Table 3, the experimental values of modulus of elasticity, estimates of BS 8110-2 (1985) and BS EN 1992-1 (2004) are presented. It can be seen that the experimental values of modulus of elasticity are slightly higher than estimates of the codes of practices. The ratio of cylinder /cube strength is also presented in the Table 3, and is in the range of 0.75 to 0.84.

5. Conclusion:

5.1 Flexural Strength

- From the flexural strength results, it is concluded that the flexural strength of concrete is increased with the addition of GGBS and PFA in concrete, compared to the flexural strength of PC concrete. Concrete containing GGBS up to 50 % and PFA up to 30 % have higher values of flexural strength than the PC concrete when cured under the summer curing environment (20C^o). Concrete containing 20 % PFA has higher flexural strength than the other PFA concretes. The 28 day flexural strength of 30 %, 40 % and 50 % GGBS concrete mixes are 3.3 %, 8.2 % and 4.9 % higher respectively than the PC concrete mix cured under the summer temperature.
- Curing environments have an effect on the flexural strength of GGBS and PFA concrete mixes and this is reduced after being cured under winter environments (7 C^o) compared to summer temperatures of 20 C^o in sealed plastic bags or under water.
- GGBS concrete and the PC concrete mixes cured under water at 20 C^o have higher flexural strength than the concrete cured in sealed plastic bags at 20 C^o.

5.2 Modulus of Elasticity:

- From the modulus of elasticity results, it is concluded that concrete containing GGBS and PFA have higher values of modulus of elasticity than the PC concrete at the summer curing temperatures (20 C^o). The value of 28 day modulus of elasticity is increased by 8 % for 10 % PFA and 6 % for 20 % PFA concrete mix. The 30 % PFA has nearly similar value of modulus of elasticity as that of the control PC concrete mix. Values of the 28 day modulus of elasticity of concrete containing 30 %, 40 % and 50 % GGBS are respectively 1 %, 2 % and 1.3 % higher than the PC concrete mix, cured under the summer curing environment.
- The winter curing environment has an adverse effect on the twenty-eight days modulus of elasticity values of GGBS, PFA and PC concrete, similar to the compressive strength values. It is concluded that proper curing of PFA and GGBS concrete under water at 20 C^o or by the prevention of loss of moisture and storing at 20 C^o enhances the modulus of elasticity.
- Concrete mixes cured under water at 20 C^o have the higher value of modulus of elasticity than the concrete cured in sealed plastic bags at 20 C^o.

-

6. References:

[1] Sustainability of concrete, Editor(s): Sidney Mindess, In Woodhead Publishing Series in Civil and Structural Engineering, Developments in the Formulation and Reinforcement of Concrete (Second Edition), Woodhead Publishing, 2019.

[2] Costa, C.; Marques, J.C. Feasibility of Eco-Friendly Binary and Ternary Blended Binders Made of Fly-Ash and Oil-Refinery Spent Catalyst in Ready-Mixed Concrete Production. *Sustainability* **2018**, *10*, 3136.

[3] UN (1983) 'Report of the World Commission on Environment and Development' [online] Available at: http://www.un.org/documents/ga/res/42/ares42-187.htm (Accessed 4 May, 2010).

[4] United Kingdom Quality Ash Association'Embodied CO_2 of UK cement, additions and cementitious material' Technical data sheet 8.3, *MPA; UK* ***quality Ash association***; [online], Available at http://www.ukqaa.org.uk ;(Accessed 4th October, 2012).

[5] Aprianti, S.E. A huge number of artificial waste material can be supplementary cementitious material (SCM) for concrete production—A review part II. *J. Clean. Prod*. **2017**, *142*, 4178–4194

[6] Paris, J.M.; Roessler, J.G.; Ferraro, C.C.; Deford, H.D.; Townsend, T.G. A review of waste products utilized as supplements to Portland cement in concrete. *J. Clean. Prod*. **2016**, *121*, 1–18.

[7] Sabir. B.Mechanical properties and frost resistance of silica fume concrete. *Cement and Concrete Composites*, *1997*, 9(40) 285–294

[8] K. Ganesan, K. Rajagopal, and K. Thangavel. Rice husk ash blended cement: assessment of optimal level of replacement for strength and permeability properties of concrete," *Construction and Building Materials*, **2008,** 22(8), 1675–1683

[9] Tehmina Ayub, Sadaqat Ullah Khan, and Fareed Ahmed Memon. Mechanical Characteristics of Hardened Concrete with Different Mineral Admixtures: A Review" *The Scientific World Journal* **2014** , Hindwai Publishing Corp.

[10] Peter.P. The effect of curing conditions (In Situ vs. Laboratory) on compressive strength of Higher Strength Concrete. ***Procedia Engineering***, 2013,*65*,113-119

[11] R. Siddique. Effect of fine aggregate replacement with class F fly ash on the mechanical properties of concrete. *Cement and Concrete Resear*ch, 2003, 33(4), 539–547

[12] Naik, T.R., Singh, S.S., Gillot, M.A., and Hossain, M.M. Mechanical and Structural Properties of Concrete Containing Fly Ash*. CBU Report No. 185, Center for By-Products Utilization,* University of Wisconsin-Milwaukee, A Final Progress Report Prepared for EPRI, Palo Alto, CA, June **1994.**

[13] Bouzoubaâ .N, Zhang. M. H and V. M. Malhotra , " Mechanical properties and durability of concrete made with High-Volume Fly Ash blended cements using a coarse fly ash" *Cement and Concrete Research*, **2001**,31(3), 1393-1402.

[14] Solanki,J.V and Pitroda.J. Flexural Strength of Beams by Partial Replacement of Cement with Fly Ash and Hypo Sludge in Concrete, *International Journal of Engineering Science and Innovative Technology,* **2013**,2 .

[15] Aïtcin P.-C., *High-Performance Concrete*, E&FN Spon, London, UK, **1998**, 591 pp.

[16] Shah, S. P., and Ahmad, A., *High-Performance Concretes and Applications*, Edward Arnold, London, UK, **1994**, 403 pp.

[17] Gutierrez, P. A., and Canovas, M. F., "The Modulus of Elasticity of High-Performance Concrete," *Materials and Structures*,**1995**, 28(10), 559-568.

[18] Baalbaki, W.; Benmokrane, B.; Chaallal, O.; and Aïtcin, P.-C. Influence of Coarse Aggregate on Elastic Properties of High-Performance Concrete. *ACI Materials Journal*, **1991**, 88(5), 499-503.

[19] Takafumi N, Fuminori T, Kamran M. N, Bernardino M. C and Alessandro P. F. A Practical Equation for Elastic Modulus of Concrete" *ACI Structural Journal*, **2009,** 106(5)

[20] ENV 1992-1-1. Eurocode 2. Design of Concrete Structures—Part 1: General Rules and Rules for Buildings. **2004,** 225 pp

[21] T. R. Naik, S. Singh, and B. Ramme. Mechanical properties and durability of concrete made with blended fly ash. *ACI Materials Journal*, **1998**, *95(4),*454–462,

[22] Khatib, J.M. & Hibbert, J.J. Selected Engineering properties of concrete incorporating slag and metakaolin. *Construction and Building Material journal,* **2005***,* 460-472.

[23] Kayali.O., Ahmed,M.S. Assessment of high volume replacement fly ash concrete – Concept of performance index. *Construction and Building Materials,* **2013**,*39*,71-76

[24] Islam M.M, Islam M.S, Mondal.B.P and Islam M.R. Strength behavior of concrete using slag with cement in sea water environment. *Journal of Civil Engineering (IEB),***2010**, *38* , 129-140

[25] Barnett.S.J, Soutsos.M.N., Millard.S.G and Bungey.J.H. Strength development of mortars containing ground granulated blast-furnace slag: Effect of curing temperature and determination of apparent activation energies. Cement and Concrete Research, **2006**, *36*, 434 – 440

[26] British standard institute *BS EN 197-1:2011: Composition, specifications and conformity criteria for common cements:* **2011***,* London: British Standard Institute.

[27] British standard institute (2011) *BS EN 197-1:2011: Composition, specifications and conformity criteria for common cements:* **2011**, London: British Standard Institute.