# INFLUENCE OF GGBS ON THE PERFORMANCE OF HIGH PERFORMANCE CONCRETE

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**Abstract -** *The necessity of concrete with improved performance is increasing because of demands in the construction industry. Studies done in this direction over the past few years suggest that the strength and durability characteristics of concrete can be improved by using cement replacement materials along with mineral & chemical admixtures. GGBS and Fly ash are pozzolanic materials that can be utilized to produce highly durable concrete composites. This study investigates the performance of concrete mixture containing variable percentages of GGBS and constant percentage of fly-ash(FA) in terms of fresh state characteristics like workability, hardened properties like compressive strength, split tensile strength, flexural strength, elastic modulus and sorption characteristics like water absorption and sorptivity. Result show that concrete containing GGBS and FA as partial replacement of cement showed improved workability, strength properties and durability characteristics. An optimum dosage of GGBS is also suggested.*

***Key words:*** HPC, GGBS, Fresh and Hardened Characteristics, Modulus of Elasticity, Sorption characteristics

## 1. INTRODUCTION

High performance concrete (HPC) is required as a construction material in structures especially in severe exposure conditions. ACI defines HPC as concrete, which meets special performance and uniformity requirements that cannot be always be achieved routinely by using conventional materials and normal mixing, placing and curing practices. This concrete contains one or more of the cementitious materials such as fly ash, silica fume, rice husk ash, GGBS etc. Cement is the main item in concrete which is artificially manufactured. Studies have shown that production of a single tonne of cement yields one tonne $CO_2$ which is a major green house gas which leads to mainly environmental issues. Many Supplementary Cementitious Materials have been used to decrease the weight of cement used in concrete which in turn in the long run will lead to lesser production of cement and hence lesser consequences. Applications of such concrete are increasing day by day due to their superior performance, environmental friendliness and energy conserving implication. Blast furnace slag is a by-product of blast furnace used to make iron ore and steel. These are manufactured from a controlled mixture of limestone, coke and iron ore at 1500$^0$C. During manufacturing the molten slag which is lighter floats on the top. The slag contains alumina and silicates from iron ore and oxides from limestone. Granulated Blast Furnace Slag is obtained by rapidly chilling (quenching) the molten ash from the furnace with the help of water. During this process, the slag gets fragmented and transformed into amorphous granules (glass), meeting the requirement of IS 12089:1987 (manufacturing specification for granulated slag used in Portland Slag Cement). The granulated slag is ground to desired fineness for producing GGBS. The chemical composition of GGBS contributes to the production of superior cement. Over the period of time, its load-bearing properties continue to increase as it absorbs surplus lime released during hydration to form more calcium silicate hydrates. These hydrates add to the strength of the cement. As per the information provided in the *Indian Minerals Year Book 2014 (Part II- Metals and Alloys)* [1] for ore feed containing 60-65% of iron , slag production is about 300-540kg per tonne production of pig or crude iron and that of steel slag is 20% by mass of crude steel input. GGBS incorporation showed reduced amount of strength and mass reduction when exposed to sulphate and silage acid environment (*PawełŁukowski and Ali Salih*, *2015*) [2]. Slag added concrete exhibits significant reduction in permeability and enhanced resistance to freeze and thaw (*Jerzy Wawrzeńczyk et al, 2016)* [3]. Earlier experimental investigations by (*Ping Duan et.al, 2013)* [4] *have proved that* pore size distribution is more optimized and reasonable; ITZ becomes denser, gradual increase in compressibility and enhanced durability when GGBS is used as supplementary cementitious material. Studies revealed that fast track constructions involving GGBS concrete is capable of attaining early strength if the in-situ temperature increases beyond the standard curing temperature *(S.J. Barnett et al, 2006*) [5]. Studies in the past shows that reacted slag percentage increases with higher w/c especially when the temperature of hydration is more owing to the enhancement of the activating environment for slag reaction due to hydration of cement. *(J.I. Escalante et al, 2001)* [6]. The compressive strength of specimens containing GGBS when tested at 200 C and 100 C was found to be higher than the ones without GGBS; which shows the performance in high temperature conditions (*Rafat Siddique &Deepinder Kaur, 2012*) [7]. HPCs containing combination of GGBS and Metakaolin had higher compressive strength due to higher content of Alumina and also the combination filled more spaces in the hardened pore structure leading to less porosity (*Alaa.M.Rishad and Dina.M.Sadek, 2017*) [8]. Case study about the construction of Masdar City in UAE revealed that they adopted two mixes one with 360 kg of total binder with 80% GGBS and 0.35 w/c and the other one with 300 kg of total binder with 60% GGBS and 0.38 w/c which gave them a compressive strength of 68.3 MPa in 28 days with excellent resistance to water penetration, chloride attack and met sufficient slump and durability requirements as well as full filled the very aim of the project of reducing the carbon foot print of the building (*M. Elchalakani et al, 2014*) [9]. Studies conducted by (*Souvik Das et.al 2015*) [10] about usage of GGBS based concrete in marine structures indicated that about 40% - 60% incorporation of GGBS increased the strength considerably and this percentage also confirms to the sustainability and chloride penetration requirements. The study by Souvik Das et.al also demonstrated that increase in GGBS percentage increased the strain rate thereby indicating that samples fail at higher strains which meant they are more durable. Rate of strength gain is slow in GGBS mixes whereas its long term strength is high when compared with ordinary PC concretes. These effects will be prominent if the temperature is 20 C and the replacement level is 50%. Also the GGBS incorporated mixes showed improved workability and hence lowers the entrapped air (*S.Samad and A.Shah, 2017*) [11]. Comparative studies on concretes containing only fly ash as SCM and those with both slag and fly ash as SCMs showed that the former one showed a lesser value of compressive strength and the latter one showed comparatively higher value *(Mehmet Gesog˘lu, et.al 2009)* [17]. In order to understand the strength development of various pozzolans mixed with OPC at two different ages to elaborate the correlation exist between blended concrete and strength development need to be studied. Strength Activity Index (SAI) is to note down the development of strength gaining of various pozzolans at various ages and it is defined by ASTM C 311 as SAI = [A / B] x 100 Where, A = average compressive strength of blended concrete cube and B = average compressive strength of control concrete cube *(P.Jagadesh, A.Ramachandramurthy, and R.Murugesan, 2015*) [20] . Ultra-fine materials are mineral admixtures which are gaining popularity nowadays. This study highlights the experimental results of a systematic study on the performance of using ultra-fine slag and flyash as partial replacement material in concrete.

## 2. MATERIALS AND METHODS

Commercially available 53 grade OPC confirming to IS: 12269-1987 with specific gravity 3.15, 5% fineness, 30% Normal consistency and a 7 day compressive strength of 38.2 MPa was used as the binding material. Fly ash confirming to class C and GGBS was used as the supplementary cementitious materials. The GGBS used had a specific gravity of 2.9, Blaine's Air Permiabilty of 1200m$^2$/kg and a bulk density of 800kg/m$^3$. Locally available river sand confirming to zone II of IS: 383 1970, with specific gravity 2.465, fineness modulus of 3.08 and a maximum percentage bulking of 40 was used. Crushed blue granite stones as per IS: 383-1970 of sizes 20mm (60%) and 6mm (40%) were used as Coarse aggregates. These were of specific gravity 2.84, with a crushing strength of 32% confirming to standards and a fineness modulus of 6.99. Since the study was done on HPC, use of super plasticizer became mandatory and hence super plasticizer Sikament 170-1 with a specific gravity of 1.21 were made use of.

### 2.1 Mix Proportion

The target strength of our study was M50 by keeping a constant cement content of 450 kg/m$^3$, fly ash content of 47 kg/m$^3$, w/c = 0.3 and the super plasticizer dosage was 0.6%. The coarse aggregate used were of sizes 20 mm (60%) and 6mm (40%). Control mix of strength M50 with 0% GGBS replacement was prepared with 450 kg/m$^3$, fly ash content of 47 kg/m$^3$, w/c = 0.3 and the super plasticizer dosage was 0.6%. 574 kg/m$^3$ of fine and 1279 kg/m$^3$ of coarse aggregate (512 kg/m$^3$ of 6 mm and 767 kg/m$^3$ of 20mm) was used in the control mix. Then mixes were prepared with keeping the fly ash level constant and by replacing cement with 6%, 8% and 10% by weight of cement. The dosages of GGBS used in the study were 6%, 8%and 10%. Water cement ratio was taken 0.30 which is less than maximum w/c ratio as per IS 456:2000 for moderate exposure condition. The various mixes used in this experimental study are given in Table 1.

IS standard cubes, beams and cylinders were casted.

- Workability of each mix is found out by doing slump and compacting factor test as per IS: 1199-1959.
- Concrete cubes of size of 150mm×150mm×150mm confirming to IS: 516-1959 were cast for doing compressive strength test, water absorption and sorptivity.
- Modulus of Elasticity of concrete by means of Extensometer was determined using cylinders of 150mm dia and 300mm long confirming to IS: 516-1959.
- Cylinder compressive strength was also determined from the standard cylinder samples.
- Flexural strength test was done using beam specimens of size 100 mm x100 mm cross section and 500 mm span with loads applied through two rollers mounted at the third points of the supporting span as per IS: 516-1959

Various hardened and sorption properties are measured after 3 and 28 days of normal curing in water Sorptivity is an easily measurable property which characterises the tendency of a porous material to absorb and transmit water by capillarity, a main mechanism responsible for the ingress of contaminated water through the surface skin of the unsaturated above-ground structures.

The movement of water into building material is described through classical square-root-time relationship by Hall (1989)

$$i = A + S\,t^{0.5}$$

Where;
$t$ = elapsed time,
$i$= cumulative volume absorbed per unit area of inflow surface
$S$ = sorptivity of the material obtained from the slope of, $i$ versus $t^{0.5}$ curve using best fit linear regression
$A$= constant term which is the intercept at $t$ =0.

**Table – 1:** Mix Designations

| Mix Designation | Percentage of GGBS by weight of Cement |
|---|---|
| C0 | Mix with 0% GGBS |
| C6 | Mix with 6% GGBS |
| C8 | Mix with 8% GGBS |
| C10 | Mix with 10% GGBS |

## 3. RESULTS AND DISCUSSIONS

### 3.1 Workability

The workability measured for various mixture compositions are given in Table 4. It can be seen from the table that as the percentage of replacement of cement increases the workability in terms of slump and compacting factor. This result is in good agreement with the results by ***S.Samad and A.Shah*** **[10]**

**Table – 2:** Workability

| Mix | Slump (mm) | Compaction Factor |
|---|---|---|
| C0 | 25 | 0.74 |
| C6 | 25.5 | 0.76 |
| C8 | 27 | 0.78 |
| C10 | 28 | 0.79 |

### 3.2 Compressive strength

The 3 and 28 day compressive strength for varying percentage of slag replacement for concrete cube and cylinder is given in Fig 1 and 2. It can be seen that compressive strength increases with increase in percentage of slag up to 8 % and then it decreases both at 3 and 28 days of age. The increase in strength is due to the pozzolanic reaction and filler effect. But above 8 %, the pozzolanic effect reduces due to the dilution of cement at these percentages of replacement. Our compressive strength results also show that there is reduction in the strength with increase in the replacement level. The results are given in Table 3. The results are in line with the experimental values obtained by **(Mehmet Gesog˘lu, Erhan Güneyisi , Erdog˘an Özbay (2009)) [17]** which states that concretes containing fly ash alone has lower compressive strength but when blended with slag it had a comparatively higher value.

**Table – 3:** Cube Compressive Strength

| Mix | 3 Days ($N/mm^2$) | 28 Days ($N/mm^2$) | SAI (3 Days) | SAI (28 Days) |
|---|---|---|---|---|
| C0 | 27.22 | 51.48 | 100 | 100 |
| C6 | 29.12 | 52.54 | 106.98 | 102.06 |
| C8 | 31.34 | 56.80 | 107.62 | 108.11 |
| C10 | 30.20 | 53.60 | 96.36 | 94.37 |

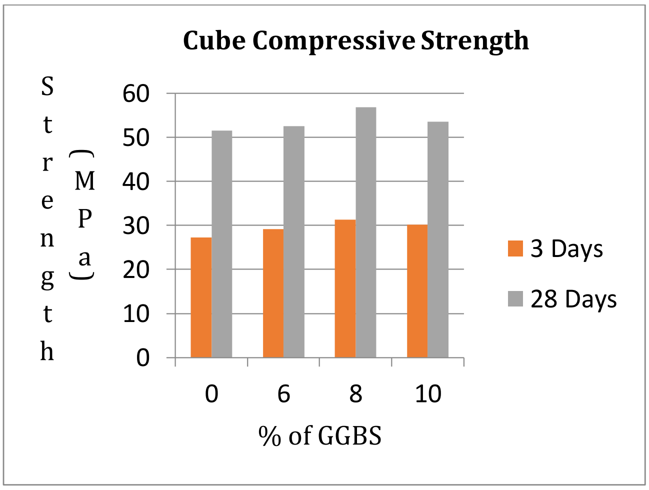


**Chart -1:** Cube Compressive Strength

**Table – 4:** Cylinder Compressive Strength

| Mix | 3 Days ($N/mm^2$) | 28 Days ($N/mm^2$) | SAI (3 Days) | SAI (28 Days) |
|---|---|---|---|---|
| C0 | 21.78 | 42.21 | 100 | 100 |
| C6 | 23.88 | 42.82 | 109.65 | 101.44 |
| C8 | 24.73 | 46.01 | 103.55 | 107.44 |
| C10 | 24.46 | 41.81 | 98.93 | 90.87 |

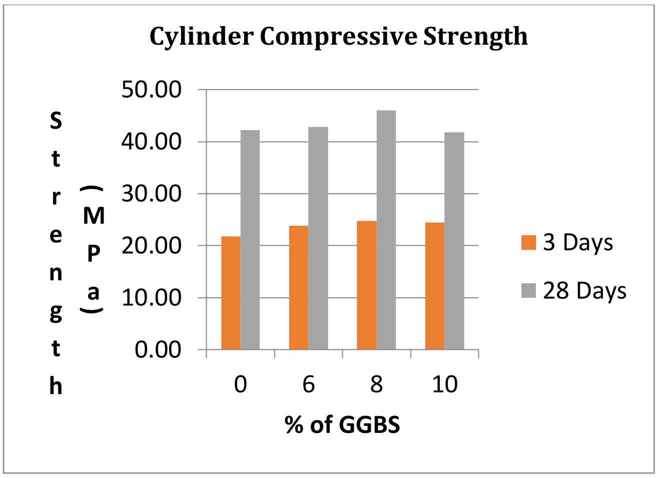


**Chart -2:** Cylinder Compressive Strength

### 3.3 Flexural strength

The 3 and 28 day flexural strength for varying percentage of slag replacement is given in Fig 2. It can be seen that flexural strength increases with increase in percentage of slag up to 8 % and then it decreases both at 3 and 28 days of age. These observations are in line with the compressive strength values. Results are given in Table 5.

**Table - 5:** Flexural Strength

| Mix | 3 Days ($N/mm^2$) | 28 Days ($N/mm^2$) | SAI (3 Days) | SAI (28 Days) |
|---|---|---|---|---|
| C0 | 1.66 | 4.70 | 100 | 100 |
| C6 | 1.76 | 4.96 | 106.02 | 105.53 |
| C8 | 1.94 | 5.30 | 110.23 | 106.85 |
| C10 | 1.86 | 5.04 | 95.88 | 95.09 |

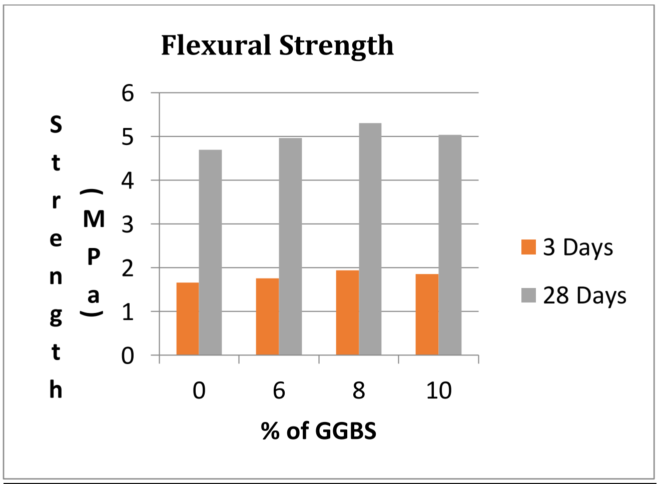


**Chart -3:** Fexural Strength

### 3.4 Modulus of Elasticity

Modulus of Elasticity (using concrete cylinders) was determined at age of 28 days using extensometer and is given in Table 6. It can be observed from the table that as the percentage replacement increases, modulus of elasticity also increases. Elastic modulus was calculated corresponding to 25% of ultimate strength.

**Table – 6:** Modulus of Elasticity at 28 Days

| Mix | Elastic Modulus x $10^4$($N/mm^2$) |
|---|---|
| C0 | 9.04 |
| C6 | 9.56 |
| C8 | 9.76 |
| C10 | 12.6 |

This results follow the pattern similar to that indicated in the study by ***Souvik Das et.al,*** [9] which demonstrated that increase in GGBS percentage increased the strain rate thereby indicating that samples fail at higher strains which meant they are more durable.

### 3.5 Sorption characteristics

The sorption characteristics in terms of water absorption and sorptivity are given in Table 6 for different replacement levels

**Table – 7:** Sorption Characteristics

| Mix | Sorptivity coefficient kg /$m^2$/$min^{0.5}$ | Water absorption % |
|---|---|---|
| C0 | 0.0296 | 0.59 |
| C6 | 0.0268 | 0.40 |
| C8 | 0.0178 | 0.28 |
| C10 | 0.0146 | 0.22 |

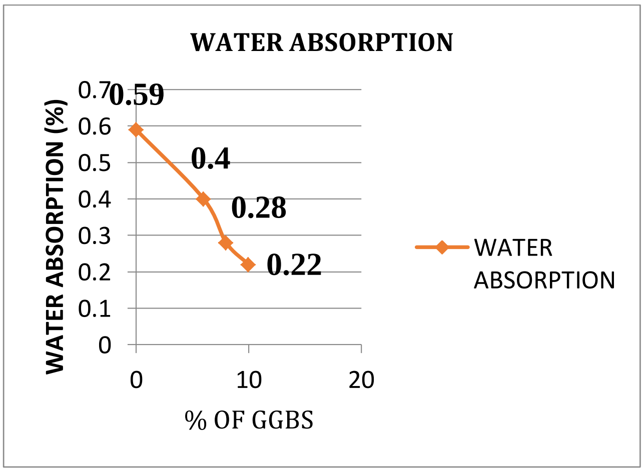


**Chart - 4:** Water Absorption

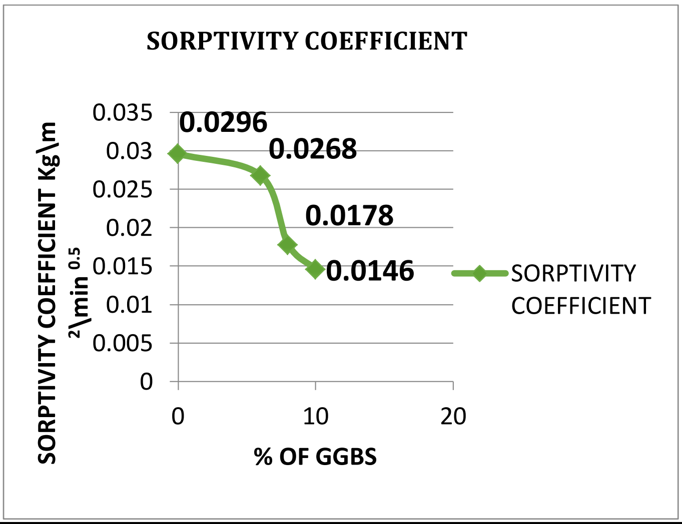


**Chart – 5:** Comparison of Sorptivity Coefficient

Both sorption and water absorption reduces with increase in percentage replacement.

This reduction may be attributed to the delay in water transport through the sample due to pore refinement by pozzolanic reaction and filler effect. The reduced sorption characteristics indicates that the durability is improved by the addition of ultra-fine materials **(*Alaa.M.Rishad and Dina.M.Sadek, 2017*) [7].** Incorporation of fly ash by also played a role in decreasing sorptivity and water absorption. SCMs like fly ash and GGBS will also reduce chloride penetration ***(P.Nath , P.Sarker (2011)*** **[13].**

The actual MPa or percentage change in various properties at optimum replacement level of 8% are shown in Table 8 which shows that the strength and durability properties improved along with workability by the addition fine slag as a partial replacement material for cement and thus helps in achieving high performance concrete.

**Table - 8:** Percentage change in properties at optimum replacement level of 8%

| **Property** | **Actual MPa or % -change** |
|---|---|
| Compressive strength (3 days) | +4.14 MPa |
| Compressive strength(28 days) | +5.4 MPa |
| Flexure strength(3 days) | +16.86 |
| Flexure strength(28 days) | +12.76 |
| Modulus of elasticity | +39.98 |
| Sorptivity | -50.68 |
| Water absorption | -62.72 |

- On comparing the 28 day compressive strength of cubes and flexural strength of beams, the following relationship was obtained

**Table - 9:** Comparison of Compressive strength and Flexural strength

| Mix | Cube Compressive Strength (Mpa) | Flexural Strength (MPa) | 0.7*sqrt (comp strength) |
|---|---|---|---|
| C0 | 51.48 | 4.7 | 5.0 |
| C6 | 52.54 | 5.0 | 5.1 |
| C8 | 56.80 | 5.3 | 5.3 |
| C10 | 53.60 | 5.0 | 5.1 |

**Flexural Strength $_{(28\ days)}$ ~ = 0.7 x (cube compressive strength $_{(28\ days)}$) $^{0.5}$**

The above relation follows the same relation as given in IS 456:2000

- Analysis of compressive strength of cubes and cylinders showed that cylinder strength is approximately **81%** of cube strength. This may be due to the lateral restrain in cubical specimens due to Platen Effect which lead to increase in confinement and hence a greater strength than cylinders

  **Cylinder Compressive Strength ~ = 0.81 x (Cube compressive strength)**

## 4. CONCLUSION

In this study, the effect of ultra-fine slag as the supplementary cementitious material and the filler material on the strength and durability of concrete was investigated. The conclusions from the experimental investigations are listed below, which are applicable to the characteristics of the materials used and the range of parameters investigated.

- Workability of mixes was found to be increasing, as slump and compaction factor showed an increasing pattern with increase in ultra-fine levels.
- There was an increase in of 5.4 MPa in compressive strength.
- Compressive strength of concrete cylinder was found to be 19% less than that of cube
- The maximum value of compressive strength and flexure strength was obtained at 8% replacement level and then showed a decreasing pattern

- Compressive strength and flexural strength results obtained was in good agreement with the relationship given in IS: 456-2000.
- The value of elastic modulus of concrete showed an increasing trend with increase in the replacement level.
- Water absorption and sorptivity coefficient exhibited a reducing tendency with the increase in the content of ultra-fine slag in the mix pointing towards increased durability.

## 5. REFERRENCE

1. Indian Minerals Year Book (2014), Part II : Metals & Alloys, Indian Bureau Of Mines, Ministry Of Mines, Government Of India
2. Paweł Łukowski and Ali Salih, (2015), "Durability of mortars containing ground granulated blast-furnace slag in acid and sulphate environment", Procedia Engineering, Volume - 108, pp 47-54
3. Jerzy Wawrzenczyk, Agnieszka Molendowska, Adam Klak, (2016), "Effect of Ground Granulated Blast Furnace Slag and Polymer Microspheres on Impermeability and Freeze-Thaw Resistance of concrete", Procedia Engineering, Volume - 161, pp 79-84
4. Ping Duan, Zhonghe Shui, Wei Chen, Chunhua Shen, (2013), "Enhancing microstructure and durability of concrete from ground granulated blast furnace slag and metakaolin as cement replacement materials", Journal of Materials Research and Technology, Volume – 2(1), pp 52-59
5. S.J. Barnett , M.N. Soutsos, S.G. Millard, J.H. Bungey (2006), "Strength development of mortars containing ground granulated blast-furnace slag: Effect of curing temperature and determination of apparent activation energies", Cement and Concrete Research, Volume-36, pp 434-440
6. J.I. Escalante, L.Y. Gomez, K.K. Johal, G. Mendoza, H. Mancha, J. Mendez, (2001), "Reactivity of blast-furnace slag in Portland cement blends hydrated under different conditions", Cement and Concrete Research, Volume-31, pp 1403-1409
7. Rafat Siddique, Deepinder Kaur, (2012), "Properties of concrete containing ground granulated blast furnace slag (GGBFS) at elevated temperatures", Journal of Advanced Research, Volume – 3, pp 45-51
8. Alaa M. Rashad , Dina M. Sadek, (2017), "An investigation on Portland cement replaced by high-volume GGBS pastes modified with micro-sized metakaolin subjected to elevated temperatures", International Journal of Sustainable Built Environment, Volume - 6, pp 91–101
9. Mohamed Elchalakani , Tarek Aly , Emad Abu-Aisheh, (2014), "Sustainable concrete with high volume GGBFS to build Masdar City in the UAE", Case Studies in Construction Materials, Volume- 1, pp 10–24
10. Souvik Das, Gaurav Singh, Abdulaziz Abdullahi Ahmed, Showmen Saha, SomnathKarmakar, (2015), "Ground Granulated Blast Furnace Slag (GGBS) based Concrete Exposed to Artificial Marine Environment(AME) and Sustainable Retrofitting using Glass Fiber Reinforced Polymer (GFRP) sheets", Procedia - Social and Behavioral Sciences,Volume – 195, pp 2804 – 2812
11. S. Samad, A. Shah, (2017), "Role of binary cement including Supplementary Cementitious Material (SCM), in production of environmentally sustainable concrete: A critical review", International Journal of Sustainable Built Environment.
12. Juan Lizarazo-Marriaga; Peter Claisse; and Eshmaiel Ganjian, (2011), "Effect of Steel Slag and Portland Cement in the Rate of Hydration and Strength of Blast Furnace SlagPastes", Journal Of Materials In Civil Engineering, Volume – 23(2), pp 153-160
13. P.Nath , P.Sarker (2011), "Effect of Fly Ash on the Durability Properties of High Strength Concrete", Procedia Engineering, Volume - 14, pp 1149-1156.
14. J. Rosales, M. Cabrera, F. Agrela (2017), "Effect of stainless steel slag waste as a replacement for cement in mortars. Mechanical and statistical study", Construction and Building Materials, Volume – 142, pp 444-458
15. Arash Aghaeipour, Morteza Madhkhan (2017), "Effect of ground granulated blast furnace slag (GGBFS) on RCCP durability", Construction and Building Materials, Volume – 141, pp 533-541
16. Jihui Zhao , Dongmin Wang, Peiyu Yan (2017), "Design and experimental study of a ternary blended cement containing high volume steel slag and blast-furnace slag based on Fuller distribution model", Construction and Building Materials, Volume – 140, pp 248-256

17. Erdog˘an Özbay , Mustafa Erdemir , Halil _Ibrahim Durmus (2016), "Utilization and efficiency of ground granulated blast furnace slag on concrete properties – A review", Construction and Building Materials, Volume – 105, pp 423-434

18. Mehmet Gesog˘lu, Erhan Güneyisi , Erdog˘an Özbay (2009), "Properties of self-compacting concretes made with binary, ternary, and quaternary cementitious blends of fly ash, blast furnace slag, and silica fume", Construction and Building Materials, Volume – 23, pp 1847-1854

19. Hrvoje Mikulcic ,Jirí Jaromír Klemes, Milan Vujanovic, Krzysztof Urbaniec, Neven Duic (2016), "Reducing greenhouse gasses emissions by fostering the deployment of alternative raw materials and energy sources in the cleaner cement manufacturing process", Journal of Cleaner Production, Volume – 136, pp 119-132.

20. Jagadesh, A.Ramachandramurthy, R.Murugesan (2015), "Effect of water to cementitious ratio on the strength development of unary blended concrete – an overview", International Journal of Earth Sciences and Engineering

21. Codes of Bureau of Indian standards : IS 456 2000, IS 10262 2009, IS 1199 1959 and IS 516 1959

22. Shetty,M.S, "Concrete Technology "S.Chand Publications, India.

23. Alcofine Micrometerials, www. alccofine.com, July 2013