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# Effect of Deviational Curing on The Strength Properties of Concrete

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**Abstract**— Concrete failures at site are associated to several reasons; right from concrete mix design, properties of materials used, mixing, placing, compaction, curing procedures and many more. There are many misconceptions about the duration of curing of concrete, especially when we refer to site conditions. Improper curing is considered as one of the significant reasons for concrete failures in columns, beams, slabs, pavements, etc, evident in the form of cracks, which are easily noticeable by the naked eyes. Unfortunately, curing is not given much importance on most of the sites which leads to reduction in the durability of the structure.

Curing is essential if concrete is to perform the intended function over the design life of the structure while excessive curing time may lead to the escalation of the construction cost of the project and unnecessary delays. Where there is a scarcity of water and on sloping surfaces where curing with water is difficult and in cases where large areas like pavements have to be cured.

The main objective of this experimental investigation is to study the effect of deviational curing on the strength properties of concrete produced by using market available fly ash based cement, slag based cement and metakaolin based cement. The different strength properties studied are compressive strength, tensile strength, flexural strength, shear strength and impact strength. The different deviational curing sequences adopted are (W0+A28), (W3+A25), (W7+A21), (W14+A14),(W28+A0),(A0+W28), (A3+W25), (A7+W21), (A14+W14) and (A28+W0).

In this discussion (W3+A25) means the concrete is cured in water for the first three days and cured in air for the next twenty five days. Also (A7+W21) means the concrete is cured in air for the first seven days and cured in water for the next twenty one days.

**Index Terms**— Deviational curing, Flyash, Metakaolin, Slag, Strength



## 1 INTRODUCTION

Curing of concrete plays a major role in developing the microstructure and pore structure of concrete. Curing of concrete means maintaining moisture inside the body of concrete during the early ages and beyond in order to develop the desired properties in terms of strength and durability. A good curing practice involves keeping the concrete damp until the concrete is strong enough to do its job. However, good curing practices are not always religiously followed in most of the cases, leading to a weak concrete.

Curing is the process of controlling the rate and extent of moisture loss from concrete during cement hydration. In order to obtain good quality concrete, an appropriate mix must be followed by curing in a suitable environment during the early stages of hardening. Curing must be undertaken for a reasonable period of time if concrete is to achieve its potential strength and durability. Curing is essential if concrete is to perform its function over the design life of the structure whereas excessive curing time may lead to the escalation of construction cost of the project and unnecessary delays. Curing encompasses the control of temperature as it affects the hydration rate in cement. If, within the curing period, natural temperatures of concrete are in the acceptable range of values, only the moisture content needs to be controlled. If the natural temperature is outside the acceptable range of values, some means will be required for controlling the temperature of concrete. The curing of concrete is performed both at normal and elevated temperatures also. Curing can be done in a number of ways while the most appropriate means of curing may be dictated by the site conditions or the construction method.

Curing is the process of controlling the rate and extent of moisture loss from concrete to ensure an uninterrupted hydration of Portland cement after concrete has been placed and finished in its final position. Curing also ensures to maintain an adequate temperature of concrete in its early ages, as this directly affects the rate of hydration of cement and eventually the strength gain of concrete or mortars. Curing of concrete must begin as soon as possible after placement and finishing and must continue for a reasonable period of time as per the relevant standards, for the concrete to achieve its desired strength and durability. Uniform temperature should also be maintained throughout the concrete depth to avoid thermal shrinkage cracks. Also protective measures to control moisture loss from the concrete surface are essential to prevent plastic shrinkage cracks. In a nut shell, curing process is designed primarily to keep the concrete moist by controlling the loss of moisture from the body of concrete, during the given period in which it gains strength.

The best method of curing concrete depend upon the conditions at site, or in a plant, or on the availability of curing materials, on the type of job, final appearance of the structure and the economics, and can be any one method or a combination of methods.

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The duration of curing of concrete depends on the grade and type of cement, mix proportion, desired concrete strength, shape and size of the concrete member and environmental and exposure conditions. As per IS-456:200 exposed surfaces of concrete shall be kept continuously damp or in a wet condition by ponding or by covering with sacks, canvas, hessian or other similar material and kept continuously wet for atleast 7 days from the date of placing, in case of Ordinary Portland Cement (OPC) and atleast 10 days when mineral admixtures or blended cements are used.

## 2 MATERIALS AND METHODOLOGY

The binder materials used in mixes were Ordinary Portland Cement (OPC) 43 grade conforming to IS: 8112 – 1989, Portland Pozzolana Cement (PPC), Portland Slag Cement (PSC) and metakaolin derived from the thermal activation of kaolin clay at about 750 - 800$^0$C.
Locally available river sand belonging to zone II of IS 383-1970 was used. Locally available crushed aggregates confirming to IS 383-1970 was used. Water fit for drinking and commercially available high performance super plasticizer admixture, Conplast SP430 conforming to ASTM C 494 (1992) were used in this experimentation.
Cement, sand and aggregate were taken in mix proportion 1:1.64:2.74 which correspond to M30 grade of concrete. All the ingredients were dry mixed homogeneously. To this dry mix, required quantity of water (W/C=0.45) and 0.6% superplasticizer (Conplast 430) was added and the entire mix was again homogeneously mixed. This wet concrete was poured into the moulds which was compacted through hand compaction in three layers and then kept on the vibrator for compaction. After the compaction, the specimens were given smooth finish and were covered with wet gunny bags. After 24 hours, the specimens were demoulded and transferred to curing tanks where in they were allowed to cure as per deviational curing times. The different deviational curing sequences adopted are (W0+A28), (W3+A25), (W7+A21), (W14+A14), (W28+A0),(A0+W28), (A3+W25), (A7+W21), (A14+W14) and (A28+W0).In this discussion (W3+A25) means the concrete is cured in water for the first three days and cured in air for the next twenty five days. Also (A7+W21) means the concrete is cured in air for the first seven days and cured in water for the next twenty one day

## 3 EXPERIMENTAL RESULTS

Tables 1,2, 3, 4, 5 and 6 gives the compressive strength, split tensile strength, flexural strength, shear strength and impact strength test results for concrete produced from fly ash based cement, slag based cement and metakaolin based cement when subjected to deviational curing. The variation in strength is depicted in the form of Figs 1, 2, 3, 4, 5 and 6

**Table 1 Compressive Strength Test Result**

| Description of deviational curing | Compressive Strength (MPa) | | |
|---|---|---|---|
| | Flyash | Slag | Metakaolin |
| W0+A28 | 23.26 | 25.63 | 22.22 |
| W3+A25 | 27.70 | 30.37 | 29.93 |
| W7+A21 | 32.00 | 37.48 | 33.93 |
| W14+A14 | 37.19 | 44.44 | 38.81 |
| W28+A0 | 40.15 | 49.19 | 43.11 |
| A0+W28 | 40.15 | 49.19 | 43.11 |
| A3+W25 | 34.67 | 38.52 | 37.78 |
| A7+W21 | 28.74 | 35.26 | 32.44 |
| A14+W14 | 27.56 | 28.74 | 28.00 |
| A28+W0 | 23.26 | 25.63 | 22.22 |

**Table 2 Split Tensile Strength Test Results**

| Description of deviational curing | Split Tensile Strength (MPa) | | |
|---|---|---|---|
| | Flyash | Slag | Metakaolin) |
| W0+A28 | 1.37 | 1.51 | 1.32 |
| W3+A25 | 1.93 | 2.17 | 1.84 |
| W7+A21 | 2.12 | 2.40 | 1.98 |
| W14+A14 | 2.50 | 2.55 | 2.22 |
| W28+A0 | 2.83 | 3.39 | 2.69 |
| A0+W28 | 2.83 | 3.39 | 2.69 |
| A3+W25 | 1.84 | 1.98 | 1.98 |
| A7+W21 | 1.65 | 1.79 | 1.56 |
| A14+W14 | 1.46 | 1.56 | 1.46 |
| A28+W0 | 1.37 | 1.51 | 1.32 |

**Table 3 Flexural Strength Test Results**

| Description of deviational curing | Flexural Strength (MPa) | | |
|---|---|---|---|
| | Flyash | Slag | Metakaolin |
| W0+A28 | 2.40 | 3.60 | 1.93 |
| W3+A25 | 4.93 | 5.87 | 4.53 |
| W7+A21 | 5.87 | 7.00 | 5.47 |
| W14+A14 | 7.93 | 8.27 | 7.53 |
| W28+A0 | 8.13 | 8.80 | 8.07 |
| A0+W28 | 8.13 | 8.80 | 8.07 |
| A3+W25 | 5.60 | 7.13 | 5.20 |
| A7+W21 | 5.00 | 6.00 | 4.60 |
| A14+W14 | 3.40 | 5.00 | 3.13 |
| A28+W0 | 2.40 | 3.60 | 1.93 |

**Table 4 Shear Strength Test Results**

| Description of deviational curing | Shear Strength (MPa) | | |
|---|---|---|---|
| | Flyash | Slag | Metakaolin |
| W0+A28 | 2.41 | 3.52 | 2.41 |
| W3+A25 | 5.19 | 5.74 | 5.37 |
| W7+A21 | 5.93 | 6.30 | 6.11 |
| W14+A14 | 7.22 | 8.33 | 7.04 |
| W28+A0 | 8.33 | 9.44 | 7.96 |
| A0+W28 | 8.33 | 9.44 | 7.96 |
| A3+W25 | 4.63 | 4.81 | 4.81 |
| A7+W21 | 4.07 | 4.63 | 4.26 |
| A14+W14 | 3.15 | 4.07 | 3.52 |
| A28+W0 | 2.41 | 3.52 | 2.41 |

**Table 5 Impact Strength Test Results**

| Description of deviational curing | Impact Strength (N-m) for first crack | | |
|---|---|---|---|
| | Flyash | Slag | Metakaolin |
| W0+A28 | 520.98 | 726.63 | 315.33 |
| W3+A25 | 925.43 | 1199.63 | 719.78 |
| W7+A21 | 1268.18 | 1309.31 | 1131.08 |
| W14+A14 | 1432.70 | 1569.80 | 1295.60 |
| W28+A0 | 2193.60 | 3681.14 | 1919.40 |
| A0+W28 | 2193.60 | 3681.14 | 1919.40 |
| A3+W25 | 1117.37 | 1268.18 | 911.72 |
| A7+W21 | 822.60 | 993.98 | 699.21 |
| A14+W14 | 664.94 | 870.59 | 459.29 |
| A28+W0 | 520.98 | 726.63 | 315.33 |

**Table 6 Impact Strength Test Results**

| Description of deviational curing | Impact Strength (N-m) for final failure | | |
|---|---|---|---|
| | Flyash | Slag | Metakaolin |
| W0+A28 | 637.52 | 781.47 | 383.88 |
| W3+A25 | 987.12 | 1309.31 | 863.73 |
| W7+A21 | 1343.58 | 1405.29 | 1268.18 |
| W14+A14 | 1576.65 | 1686.33 | 1460.12 |
| W28+A0 | 2289.57 | 3756.54 | 2029.08 |
| A0+W28 | 2289.57 | 3756.54 | 2029.08 |
| A3+W25 | 1192.77 | 1343.58 | 987.12 |
| A7+W21 | 884.3 | 1096.58 | 774.62 |
| A14+W14 | 740.34 | 932.28 | 527.84 |
| A28+W0 | 637.52 | 781.47 | 383.88 |

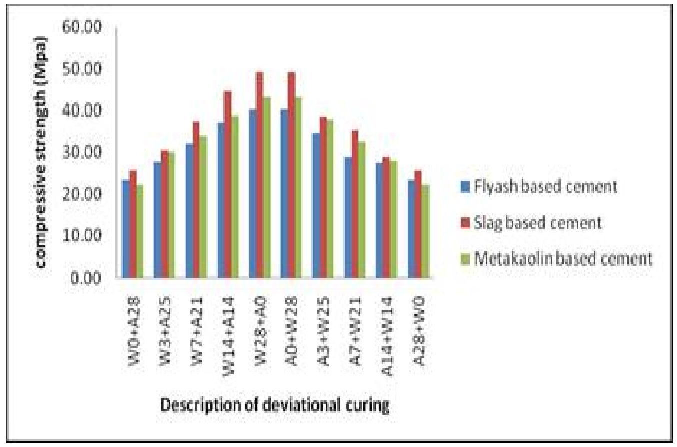


**Fig 1 Variation Of Compressive Strength When Subjected To Deviational Curing**

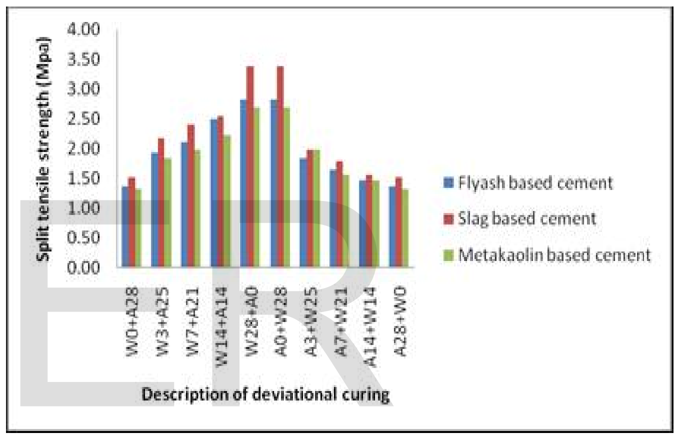


**Fig 2 Variation Of Split Tensile Strength When Subjected To Deviational Curing**

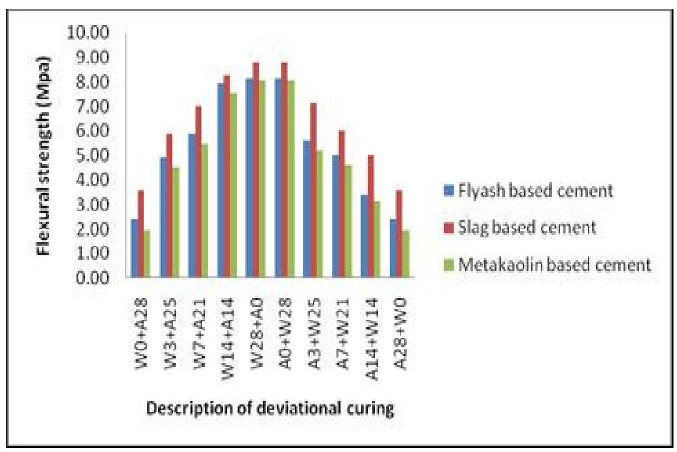


**Fig 3 Variation Of Flexural Strength When Subjected To Deviational Curing**

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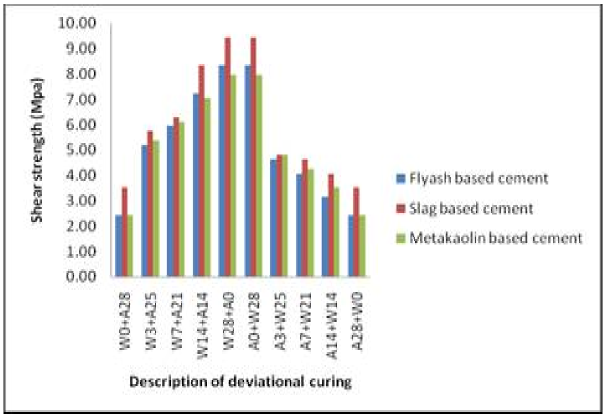


**Fig 4 Variation Of Shear Strength When Subjected To Deviational Curing**

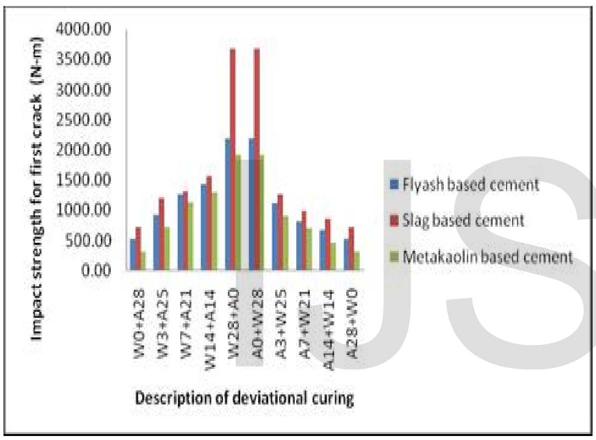


**Fig 5 Variation of Impact Strength for First Crack When Subjected To Deviational Curing**

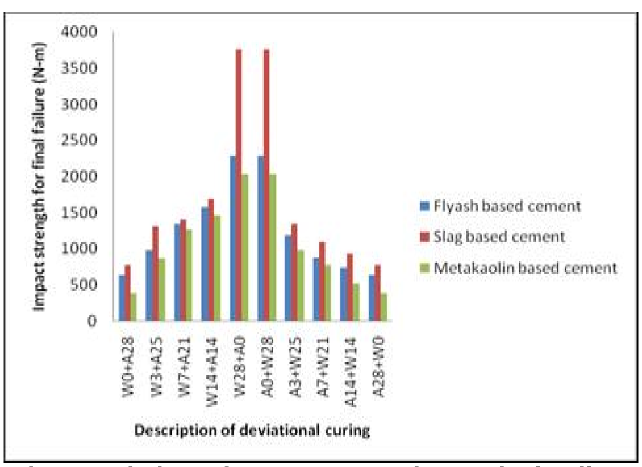


**Fig. 6 Variation Of Impact Strength For Final Failure When Subjected To Deviational Curing**

## 4 OBSERVATIONS AND DISCUSSIONS

It is observed that the compressive strength, split tensile strength, flexural strength, shear strength and impact strength of concrete goes on increasing with deviational curing of (W0+A28) to (W28+A0).When the concrete is cured for (W0+A28),the strength obtained is 23.26MPa where as that of the concrete when cured for (W28+A0) the strength obtained is 40.15 MPa. Intermediate values of strength were obtained for other deviational curing sequences such as (W3+A25), (W7+A21) and (W14+A14).Around 42.07% of strength is affected for concrete which is cured under (W0+A28), as compared to the reference mix which is cured for 28 days in water. This discussion holds good for concrete produced with fly ash based cement. Similar trends has been observed for concrete produced with slag based cement and metakaolin based cement.

Thus it can be concluded that as the initial water curing period increases the concrete gains the compressive strength.

It is observed that the compressive strength, split tensile strength, flexural strength, shear strength and impact strength for initial crack and final failure of concrete goes on decreasing with deviational curing of (A0+W28) to (A28+W0).When the concrete is cured for (A0+W28), the strength obtained is 40.15 MPa where as that of the concrete when cured for (A28+W0),the strength obtained is 23.26 MPa. Intermediate values of strength were obtained for other deviational curing sequences such as (A3+W25),(A7+W21) and (A14+W14).Around 42.07% of strength is affected for concrete which is cured under (A28+W0) as compared to the reference mix which is cured for 28 days in water. This discussion holds good for concrete produced with fly ash based cement. Similar trends are observed for concrete produced with slag based cement and metakaolin based cement.

Thus it can be concluded that as the initial air curing period increased, the concrete looses the compressive strength and it is severely affected at (A28+W0).

It is observed that the concrete produced from slag based cement and subjected to deviational curing show higher compressive strength than that of fly ash based cement and metakaolin based cement. This is true for all series of deviational curing.

## 5 CONCLUSIONS

The following conclusions can be drawn based on the studies made.

1. As the initial water curing period increases the concrete gains the compressive strength and (W28+A0) gives higher compressive strength. This is true for concrete produced from fly ash based cement, slag based cement and metakaolin based cement
2. As the initial air curing period increased, the concrete looses the compressive strength and it is severely affected at (A28+W0). This is true for concrete produced from fly ash based cement, slag based cement and metakaolin based cement
3. Concrete produced from slag based cement can exihibit higher compressive strengths when subjected to deviational curing
4. As the initial water curing period increases the concrete gains the split tensile strength and (W28+A0) gives higher split tensile strength. This is true for concrete produced from fly ash based cement, slag based cement and metakaolin based cement
5. As the initial air curing period increased, the concrete looses the split tensile strength and it is severely affected at (A28+W0). This is true for concrete produced from fly ash based cement, slag based cement and metakaolin based cement
6. Concrete produced from slag based cement can exihibit higher split tensile strengths when subjected to deviational curing
7. As the initial water curing period increases the concrete gains the flexural strength and (W28+A0) gives higher flexural strength. This is true for concrete produced from fly ash based cement, slag based cement and metakaolin based cement
8. As the initial air curing period increased, the concrete looses the flexural strength and it is severely affected at (A28+W0). This is true for concrete produced from fly ash based cement, slag based cement and metakaolin based cement
9. Concrete produced from slag based cement can exihibit higher flexural strengths when subjected to deviational curing
10. As the initial water curing period increases the concrete gains the shear strength and (W28+A0) gives higher shear strength. This is true for concrete produced from fly ash based cement, slag based cement and metakaolin based cement
11. As the initial air curing period increased, the concrete looses the shear strength and it is severely affected at (A28+W0). This is true for concrete produced from fly ash based cement, slag based cement and metakaolin based cement
12. Concrete produced from slag based cement can exihibit higher shear strengths when subjected to deviational curing
13. As the initial water curing period increases the concrete gains the impact strength and (W28+A0) gives higher impact strength. This is true for concrete produced from fly ash based cement, slag based cement and metakaolin based cement
14. As the initial air curing period increased, the concrete looses the impact strength and it is severely affected at (A28+W0). This is true for concrete produced from fly ash based cement, slag based cement and metakaolin based cement
15. Concrete produced from slag based cement can exihibit higher impact strengths when subjected to deviational curing



## REFERENCES

1. Killoh.D.C, Parrott.L.J, and Patel.R.G. "**Influence of curing at Different relative humidities on the hydration and porosity of a portland/flyash cement paste**" ACI SP Journal, Vol 114, 1989, pp 157-174
2. Thomas.M.D.A, Matthews.J.D, and Haynes.C.A, **"Effect of curing on the strength and permeability of PFA concrete**" ACI SP Journal, Vol 114, 1989, pp 191-218
3. Thomas.M.D.A, Matthews.J.D, and Haynes.C.A, **"Effect of curing on the strength and permeability of PFA concrete**" ACI SP Journal, Vol 114, 1989, pp 191-218
4. Austin. S. A, Robins. E. J & Issaad. A. "**Influence of curing methods on the strength and permeability of GGBFS concrete in a simulated arid climate**" Cement and Concrete Research, Vol 14, 1992, pp 157-167
5. Pierre-Claude Aitcin, Buquan Miao, William D. Cook, and Denis Mitchell, "**Effects of size and curing on cylinder compressive strength of normal and high-strength concrete**" ACI Material Journal, Vol 91(4), 1994, pp 349-355
6. Sivasundaram.V, Bilodeau. A, and Malhotra.V.M. "**Effect of curing conditions on high-volume fly ash concrete made with ASTM type I and III cements and silica fume**" ACI SP Journal, Vol 154 , 1995, pp

509-530

7. Ramezanianpour.A.A, & Malhotra.A.A,"**Effect of curing on the compressive strength, resistance to chloride-Ion penetration and porosity of concretes incorporating slag, fly ash or silica fume**" Cement and Concrete Research,Vol 17, 1995, pp 125-133
8. SasataniI. T, TorlII. K, and Kawamura. M. "**Five-year exposure test on long-term properties of concretes containing fly ash, blast-furnace slag, and silica fume**" ACI SP Journal, Vol 153, 1995, pp 283-296
9. Balaguru.P, "**Properties of normal- and high-strength concrete containing metakaolin**" ACI SP Journal,Vol 199, 2001, pp 737-756
10. Bai. J, Wild. S,. Sabir. B.B, " **Sorptivity and strength of air-cured and water-cured PC – PFA – MK**" Cement and Concrete Research, Vol 32, 2002, pp 1813-1821
11. Nasir Shafiq, Cabrera. J.G." **Effects of initial curing condition on the fluid transport properties in OPC and fly ash blended cement concrete**" Cement and Concrete Composites,Vol 26, 2003, pp 381-387
12. Baris Ozer, Hulusi Ozkul. M. " **The influence of initial water curing on the strength development of ordinary portland and pozzolanic cement concretes**" Cement and Concrete Research, 2003
13. Wu. F.-R, Masuda. Y, and Nakamura. S., "**Influence of different curing conditions on strength development of high-strength concrete using fly ash**"ACI SP Journal,Vol 221, 2004, pp 181-194
14. Krishna Rao. M.V, Rathish Kumar. P, Azhar M. Khan, "**A study on the influence of curing on the strength of a standard grade concrete mix**" Architecture and Civil Engineering ,Vol. 8, 2010, pp 23 – 34
15. Fathollah Sajedi, Hashim Abdul Razak, "**Effects of curing regimes and cement fineness on the compressive strength of ordinary portland cement mortars"** *Construction and Building Materials*, *Volume 25, Issue 4*, *April 2011*, *pp2036-2045*
16. Fathollah Sajedi, Hashim Abdul Razak, Hilmi Bin Mahmud, Payam Shafigh **"Relationships between compressive strength of cement–slag mortars under air and water curing regimes" "** Construction and Building Materials, Vol 31, 2012, pp 188-196
17. Fathollah Sajedi,"**Effect of curing regime and temperature on the compressive strength of cement-slag Mortars**" Construction and Building Materials, Vol 36, 2012, pp 549-556
18. Ernest K. Schrader **" Impact resistance and test procedure for concrete"**, ACI Journal, Title no 78-12, pp 141-146