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A Comparative Study on the Effect of Curing on The Strength of Concrete

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Abstract- ***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 use of curing compound may be resorted to. The parameters of the study include the curing period [3, 7, 28 and 56 day], curing method [Air curing, plastic films, immersion under water] and the type of cement [Portland pozzolona Cement(PPC) 43 grade,]. In this study specimens i.e. cube, cylinders, Beams were cast and cured under different conditions before testing. Test curing by air, nearly the same results as that of Plastic film but by immersion under water curing strength increase by age. The study demonstrates that the method and duration of curing greatly affects the strength characteristics of concrete. Hence quality control for proper field curing is of the utmost importance.***

From the test results, it was observed that there was an increase of 41.7 percent, 31.7 percent and 42.1 percent in compressive strength at 7 days when compared to its strength at 3 days for specimens air cured, cured with plastic film and immersion under water curing respectively. On further curing a decrease as compressive strength at 28 days compared to its strength at 7 days was observed for air curing and plastic film curing. The percentage decrease was higher for air cured specimens than plastic film cured specimens. For water curing an increase of 61 percent of compressive strength at 28 days over its strength at 7 days was observed. There was also increase of 40.2 percent, 52.61 percent and 30.72 percent in compressive strength at 56 days when compared to its strength at 3 days for all specimens.

Index Terms— ASTM, IS, OPC, PPC,

I. INTRODUCTION

Curing of concrete stands for procedures devoted to promote cement hydration, consisting of control of time and humidity conditions immediately after the placement of concrete mixture in to form work.

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Curing is designed primarily to keep the concrete moist, by preventing the loss of moisture from the concrete during the period in which it is gaining strength. When the ambient temperature is sufficiently well above freezing, the curing of pavements and slabs can be accomplished by ponding or immersion, other structures can be cured by spraying or fogging.

Or moisture retaining coverings saturated with water, such as burlap or cotton. These methods afford some cooling through evaporation, which is beneficial in hot weather concreting. Another group of methods are based on prevention of moisture loss from concrete by sealing the surface through the application of water proof curing paper, polyethylene sheets, or membrane forming curing compounds. When the ambient temperature is low, concrete must be protected from freezing by the application of insulating blankets, the rate of strength gain can be accelerated by curing concrete with the help of live steam, heating oil's, or electrically heated forms or pads.

The amount of mixing water in concrete at the time of placement is normally more than must be retained for curing. However excessive loss of water by evaporation may reduce the amount of retained water below that necessary for development of desired properties. The potentially harmful effects of evaporation shall be prevented either by applying water or preventing excessive evaporation.

II. METHOD OF CURING

A. Water Curing

Water curing is carried out by supplying water to the surface of concrete in a way that ensures that it is kept continuously moist. The water used for this purpose should not be more than about 5°C cooler than the concrete Surface. Spraying warm concrete with cold water may give rise to 'thermal shock' that may cause or contribute to cracking. Alternate wetting and drying of the concrete must also is avoided as this causes volume changes that may also contribute to surface crazing and cracking.
Several methods of water curing are described below:
a) Ponding and Immersion: Ponding On flat surfaces, such as pavements and floors, concrete can be cured by ponding. Earth or sand dikes around the perimeter of the concrete surface can retain a pond of water. Ponding is an ideal method for preventing loss of moisture from the concrete; it is also effective for maintaining uniform temperature in the concrete. The curing water should not be more than about 11°C (20°F) cooler than the concrete to prevent thermal stresses that could result in cracking. Since ponding requires considerable labour and supervision, the method is generally used only for small jobs.

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The most thorough method of curing with water consists of total immersion of the finished concrete element. This method is commonly used in the laboratory for curing concrete test specimens. Where appearance of the concrete is important, the water used for curing by ponding or immersion must be free of substances that will stain or discolor the concrete. The material used for dikes may also discolor the concrete.

(b)Sprinkling or fog curing: Wet, moisture-retaining fabric coverings should be placed as soon as the concrete has hardened sufficiently to Prevent surface damage. During the waiting period other curing methods are used, such as fogging or the use of Membrane forming finishing aids. Care should be taken to cover the entire surface with wet fabric, including the Edges of slabs. The coverings should be kept continuously moist so that a film of water remains on the concrete surface throughout the curing period. Use of polyethylene film over wet burlap is a good practice; it will eliminate the need for continuous watering of the covering. Periodically rewetting the fabric under the plastic before it dries out should be sufficient. Alternate cycles of wetting and drying during the early curing period may cause crazing of the surface. Wet coverings of earth, sand, or sawdust are effective for curing and are often useful on small jobs. Sawdust from most woods is acceptable, but oak and other woods that contain tannic acid should not be used since deterioration of the concrete may occur. Layer about 50mm thick should be evenly distributed over the previously moistened surface of the concrete and kept continuously wet. Wet hay or straw can be used to cure flat surfaces. If used, it should be placed in a layer at least 150 mm thick and held down with wire screen, burlap, or tarpaulins to prevent its being blown off by wind. A major disadvantage of moist earth, sand, sawdust, hay, or straw coverings is the possibility of discoloring the concrete.

(c) Burlap, Cotton Mats, and Rugs: Burlaps, cotton mats, and rugs and other covering of absorbent material will hold water on the surface whether horizontal or vertical these materials must be free from of injurious amount of substances such as sugar or fertilizer that do harm to the concrete or cause deteriotion .burlap should be thoroughly rinsed in water to remove soluble substances or to make it more absorbent. Burlap that has been treated to resist rot and fire should be considered when it is to be soared between jobs. The heavier the burlap the more water it will hold and the less frequently it will need to be wetted. Double thickness may be used advantageously. Lapping the strips by half widths when placing will give greater moisture retention and aid in preventing displacement during high wind or heavy rain.

(d) Cotton mats and rugs hold water longer than burlap with less risk of drying out. They are handled much the same as burlap except that due to their greater mass application to a freshly finished surface must wait until the concrete has hardened to greater degree than for burlap.

(e) Sand and Sawdust: Wet clean sand and sawdust are used in the same manner as earth curing sawdust containing excessive amounts of tannic acid should not be used. Sand and sawdust are especially useful where carpenters and form setters must work on the surface since such covering help to protect the surface against the scars and stains.

(f) Termination: Saturated cover materials shall not be allowed to dry and absorb water from the concrete, but at the end of the required period of wetness shall be allowed to dry thoroughly before removal so that the concrete will dry slowly.

B. Sealing Compounds

Sealing compounds (sealers) are liquids applied to the surface of hardened concrete to reduce the penetration of liquids or gases such as water, deicing solutions, and carbon dioxide that cause freeze-thaw damage, corrosion of reinforcing steel and acid attack. In addition, sealing compounds used on interior floor slabs reduce dusting and the absorption of spills while making the surface easier to clean. Sealing compounds differ in purpose from curing compounds; they should not be confused as being the same. The primary purpose of a curing compound is to reperiod sealing exterior concrete is an optional procedure generally performed to help protect concrete from freeze thaw damage and chloride penetration from de-icers. Curing is not optional when using a sealer; curing is necessary to produce properties needed for concrete to perform adequately for its intended purpose. Satisfactory Performance of exterior concrete still primarily depends on an adequate air-void system, sufficient strength, and the use of proper placing, finishing and curing techniques. However, not all concrete placed meets those criteria. Surface sealers can help improve the durability of these concretes.

(a)Plastic sheets: Plastic sheet materials, such as polyethylene film, can be used to cure concrete. Polyethylene film is a lightweight, effective moisture retarder and is easily applied to complex as well as simple shapes. Its application is the same as described for impervious paper. Curing with polyethylene film (or impervious paper) can cause patchy discoloration, especially if the concrete contains calcium chloride and has been finished by hard steel troweling. This discoloration is more pronounced when the film becomes wrinkled, but it is difficult and time consuming on a large project to place sheet materials without wrinkles. Flooding the surface under the covering may prevent discoloration, but other means of curing should be used when uniform color is important. Polyethylene film should confirm American Society for Testing and Materials (ASTM) C 171, which specifies a 0.10-mm thickness for curing concrete, but lists only clear and white opaque film. However, black film is available and is satisfactory under some conditions. White film should be used for curing exterior concrete during hot weather to reflect the sun's rays. Black film can be used during cool weather or for interior locations. Clear film has little effect on heat absorption.

(b)Membrane-forming curing compounds*:* Liquid membrane-forming compounds consisting of waxes, resins, chlorinated rubber, and other materials can be used to retard or reduce evaporation of moisture from concrete. They are the most practical and most widely Used method for curing not only freshly placed concrete but also for extending curing of concrete after removal of Forms or after initial moist curing. However, the most effective methods of curing concrete are wet coverings or Water spraying that keeps the concrete continually damp. Curing compounds should be able to maintain the relative Humidity of the concrete surface above 80% for seven days to sustain cement hydration.

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Membrane-forming curing compounds are of two general types: clear, or translucent; and white pigmented. Clear or translucent compounds may contain a fugitive dye that makes it easier to check visually for complete coverage of the concrete surface when the compound is applied. The dye fades away soon after application. On hot, sunny days, use of white-pigmented compounds is recommended; they reduce solar-heat gain, thus reducing the concrete temperature. Pigmented compounds should be kept agitated in the container to prevent pigment from settling out. Curing compounds should be applied by hand-operated or power-driven spray equipment immediately after final finishing of the concrete. The concrete surface should be damp when the coating is applied. On dry, windy days, or during periods when adverse weather conditions could result in plastic shrinkage cracking, application of a curing compound immediately after final finishing and before all free water on the surface has evaporated will help prevent the formation of cracks. Power-driven spray equipment is recommended for uniform application of curing compounds on large paving projects. Spray nozzles and windshields on such equipment should be arranged to prevent wind-blown loss of curing compound. Normally only one smooth, even coat is applied at atypical rate of 3 to 4m^2 per litre (150 to 200 sq ft per gallon); but products may vary, so manufacturer's recommended application rates should be followed. If two coats are necessary to ensure complete coverage, for effective protection the second coat should be applied at right angles to the first. Complete coverage of the surface must be attained because even small pinholes in the membrane will increase the evaporation of moisture from the concrete. Curing compounds might prevent bonding between Hardened concrete and a freshly placed concrete overlay. And, most curing compounds are not compatible with adhesives used with floor covering materials. Curing compounds might prevent bonding between hardened concrete and a freshly placed concrete overlay. And, most curing compounds are not compatible with adhesives used with floor covering materials. Consequently, they should either be tested for compatibility, or not used when bonding of overlying materials is necessary.

(c)Chemical curing: Chemical curing is accomplished by spraying the sodium silicate (water glass) solution. About 50g of sodium silicate mixed with water can cover 1m^2 of surface and forms a hard and insoluble calcium silicate film. It actually acts as a case hardener and curing agent. The application of sodium silicate results in a thin varnish like film which also fills pores and surface voids, thus sealing the surface and preventing the evaporation of water.

C. Steam curing

Steam curing is advantageous where early strength gain in concrete is important or where additional heat is required to accomplish hydration, as in cold weather. Two methods of steam curing are used.

a) Low pressure steam curing**:** Steam curing at atmospheric pressure can be continuous or intermittent. In the continuous process the product move on the conveyor belts from one end of a long curing chamber to the other end, the length of the chamber and he speed of the conveyors being so designed that the products remain in the curing chamber for the required time. On the other hand in the intermittent process, the concrete products are stacked in the steam chamber and the steam is allowed in to the closed chamber. The steam curing cycle can be divided in to three stages.

- The heating stage
- Steam treatment
- Cooling stage

In the normal steam curing procedure it is advisable to start the steam curing a few hours after casting. A delay of two to six hours called the presetting or prestreaming period, depending upon the temperature of curing is usual. The prestreaming period helps to achieve a 15 to 30 percent higher 24 hour strength than the obtained when steam curing is resorted immediately. The rate of initial temperature rise after prestreaming period is the order of 10 to 20 degree per hour and the maximum curing temperature is limited to 85 to 90 degree c. a temperature higher than this does not produce any increase in the strength of concrete and In fact as discussed earlier a temperature of 70 degree c may be sufficient. For a particular product the maximum desired temperature is raised at a moderate rate and the steam is cut off and the product allowed soaking in the residual heat and moisture of the curing chamber. The product after steam curing and cooling off to 30 degree should be kept in a warm room at a temperature of about 25 degree c before being exposed to the outside temperature. By adopting a proper steam cycle more than 70 percent of the 28 day compressive strength of concrete can be obtained in about 16 to 24 hours.

a) High pressure steam curing: In the case of normal steam curing at atmospheric pressure, the ultimate strength of concrete may be adversely affected if the temperature is raised rapidly. This difficulty can be overcome by employing the steam at a pressure of 8 atmosphere .the process is termed as high pressure steam curing. High pressure steam curing is done in the cylindrical steel chamber called autoclaves. The concrete products, after a suitable prestreaming period, are wheeled on racks in to the autoclaves. The steam is let in gradually until the prescribed pressure or temperature (generally about 1 Map or 185 degree) is reached. This heating stage should be completed and the prescribed pressure reached in three hours. The increase in temperature allowed is up to 50 degree c in first hour, up to 100 degree c in second hour and up to 185 degree c in the third hour. The period of treatment under full pressure depend upon the strength requirements. This period is 7 to 10 hours for hollow block products and 8 to 10 hours for slab or beam elements, the period increasing with the thickness of concrete. The steam is cut off and the pressure released after the completion of this stage and the products are left in the autoclaves for two hours for cooling gradually. High pressure steam curing is usually applied to the precast products when any of the following characteristics is desired:

1. High early strength- With high pressure steam curing the compressive strength at 24 hours is at least equal to that of 28 days normally cured products.
2. High durability- High pressure steam curing results in an increased resistance to sulphate and other form of chemical attack, and to freezing and thawing.

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S.NO	characteristics	Test results	Relevant Codal Provision as per IS : 1489-1990
1	Normal Consistency	32%	-
2	Initial setting time	50min	30 min
3	Final setting time	160min	600min
4	Soundness by Le-chateliers apparatus	1mm	10mm
5	Specific gravity	3.15	-
6	Compressive strength at 3 days	18mpa	16mpa
7	Compressive strength at 7 days	25mpa	22mpa
8	Compressive strength at 28 days	34mpa	33mpa

D. Hot weather curing

Hot weather leads to more rapid drying of concrete, protection and curing are critical. Water curing, if used should be continuous to avoid volume changes due to alternate wetting and drying. The need for adequate continuous curing is greatest during the first few days after placement of concrete in hot weather. During hot weather, provided favorable moisture conditions are continuously maintained, concrete may attain a high degree of maturity in a very short time.

E. Cold weather curing

Concrete exposed to cold weather is not likely to dry at an undesirable rate; particular attention should be given to maintaining satisfactory moisture in concrete. Concrete should be protected from freezing at least until it develops a compressive strength of 3.4Mpa; non air concrete should never be allowed to freeze and thaw in a saturated condition. Air entrained concrete should not be allowed to freeze and thaw in a saturated condition before developing a compressive strength of 24 Mpa.These factors should be considered especially for concrete late in the fall.

III. EXPERIMENTAL PROGRAMME

The test programme involves the testing of control specimens i.e. beams, cubes and cylinders of size 100mm x 100mm x 500mm, 150mm and 150mm x 150mm and 150mm diameter and 300mm height respectively. The following three methods of curing namely air, plastic film and curing by immersion under water were used. The specimens were tested as per guidelines of IS: 516-1959 at the age of 3, 7 and 28 days. Concrete mix of grade M20 was used for investigation purposes. The effect of different curing methods on strength characteristics of cement concrete was studied. The various types of test specimens were shown in table1.1

Table 1.1

Detail of specimens

Duration of curing in days	Method of curing	Designation of specimens		
		Beams	Cubes	Cylinders
3	Air	B_1	C_1	S_1
7	Air	B_2	C_2	S_2
28	Air	B_3	C_3	S_3
56	Air	B_4	C_4	S_4
3	Plastic film	B_5	C_5	S_5
7	Plastic film	B_6	C_6	S_6
28	Plastic film	B_7	C_7	S_7
56	Plastic film	B_8	C_8	S_8
3	water	B_9	C_9	S_9
7	water	B_{10}	C_{10}	S_{10}
28	water	B_{11}	C_{11}	S_{11}
56	water	B_{12}	C_{12}	S_{12}

A. Materials used

a) Cement: Portland Pozzolona Cement 43 grade confirming to IS 383-1970 was used in the study. . Various Properties of cement which are studied are shown in Table 1.2.

Table No.1.2

Physical Properties of Portland Pozzolona Cement

b) Fine Aggregate: River sand procured from a nearby source was used as fine aggregate in this study. Fineness Modulus of sand 2.163 was used. The sand was Conforming to zone III of IS: 383-1970.

Table 1.3

Properties of Fine Aggregates

Sr.No	properties	Values
1	Bulk density loose	1600kg/m^3
2	Bulk density compacted	1780kg/m^3
3	Specific gravity	2.60
4	Water absorption	1%

c) Coarse Aggregate: The properties of coarse aggregate like size, shape, grading, surface texture etc play an important role on the workability and strength of concrete. Crushed stone Aggregate of Nominal size 10mm and 20mm were used in equal proportion by weight. The fineness modulus was found to be 6.538.

Table 1.4

Properties of Coarse Aggregates

Sr.No	properties	Values
1	Bulk density loose	1610kg/m^3
2	Bulk density compacted	1800kg/m^3
3	Specific gravity	2.40
4	Water absorption	0.5%

d) Water: Potable water was used in the investigations for both mixing and curing

B. Casting of specimens

The Moulds of cubes, cylinders and beams were cleaned throughly.A thin layer of oil was applied to inner surface of the moulds to avoid the adhesion of concrete with the inner side of the moulds; In this study, M20 grade standard concrete cubes of size 150 x 150 x150mm, beams of size 100mm x 100mm x 500mm and cylinders of size 150mm diameter and 300mm height were cast for determining the compressive strength, split tensile strength and flexural strength. The cast specimens were demoulded at the end of 24±2 hours and cured for the required number of days with different curing methods.

C. Strength properties

a) Compressive strength test: Compressive strength test is initial step of testing concrete because the concrete is primarily meant to withstand compressive stresses.

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Compressive strength tests were carried out on 150mm x 150mm x150mm cubes with compression testing machine of 2000KN capacity. The specimens after removal from the curing were cleaned and properly dried. The surface of the testing machine was cleaned. The cube was then placed with the cast faces in the contact with the platens of the testing machine. Cubes were tested at 3, 7, 28 and 56 days of curing.

b) Split tensile strength: Split tensile strength is an indirect method to determine tensile strength of concrete. The test consists of applying compressive line load along the opposite generators of concrete cylinder placed with its axis horizontal between the platens. Cylinders of size 150mm diameter and 300mm height were cast to check the splitting tensile strength of concrete. Specimens were tested after 3, 7, 28, and 56 days of curing.

c) Flexural strength test: Flexural strength test is essential to estimate the load at which the concrete members may crack. The specimens cast for this test were of shape of a square prism of 100mm and axis length 500mm. specimens were tested after 3,7,28 and 56 days of curing.

Table 1.5
Compressive strength of concrete

Sr. No	Curing in days	Curing with					
		Air curing		Plastic film		Water curing	
		Calculated value in N/mm²	Average value in N/mm²	Calculated value in N/mm²	Average value in N/mm²	Calculated value in N/mm²	Average value in N/mm²
1	3	18.3	17.40	20.1	20.07	19.5	19.30
		16.4		19.6		18.7	
		17.5		20.5		19.7	
2	7	23.9	24.67	26.6	26.43	26.4	27.43
		25.3		24.9		28.3	
		24.8		27.8		27.6	
3	28	23.5	24.43	32.1	31.50	40.5	44.30
		24.1		30.5		46.9	
		25.7		31.9		45.5	
4	56	23.5	24.40	30.4	31.33	43.4	44.53
		25.3		32.5		45.9	
		24.4		31.1		44.3	

Table 1.6
Split Tensile Strength of Concrete

Sr. No	Curing in days	Curing with					
		Air curing		Plastic film		Water curing	
		Calculated value in N/mm²	Average value in N/mm²	Calculated value in N/mm²	Average value in N/mm²	Calculated value in N/mm²	Average value in N/mm²
1	3	1.5		1.9		2.29	
		1.8	1.63	1.2	1.72	2.67	2.51
		1.6		2.07		2.56	
2	7	2.2		2.13		3.1	
		2.15	2.13	2.29	2.27	2.75	2.94
		2.05		2.38		2.98	
3	28	2.6		2.8		3.95	
		2.3	2.47	2.66	2.72	3.65	3.90
		2.5		2.7		4.1	
4	56	2.35		2.98		3.96	
		2.47	2.52	2.82	2.92	4.2	4.00
		2.73		2.97		3.85	

Table 1.7
Flexural strength of concrete

Sr. No	Curing in days	Curing with					
		Air curing		Plastic film		Water curing	
		Calculated value in N/mm²	Average value in N/mm²	Calculated value in N/mm²	Average value in N/mm²	Calculated value in N/mm²	Average value in N/mm²
1	3	3.2		3.95		4.3	
		2.95	3.08	3.7	3.75	3.95	4.12
		3.1		3.6		4.1	
2	7	4.5		4.1		4.65	
		4.37	4.54	3.97	3.92	4.9	4.63
		4.75		3.7		4.35	
3	28	5.5		6.1		6.12	
		5.97	5.76	6.25	6.08	6.7	6.44
		5.8		5.9		6.5	
4	56	5.56		5.93		6.15	
		6	5.84	6.19	6.12	6.6	6.48
		5.95		6.25		6.7	

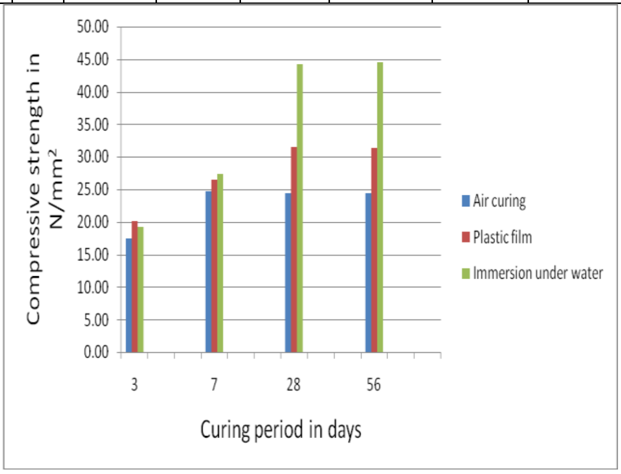

Fig 1.Bar chart between Compressive strength and Curing period in days

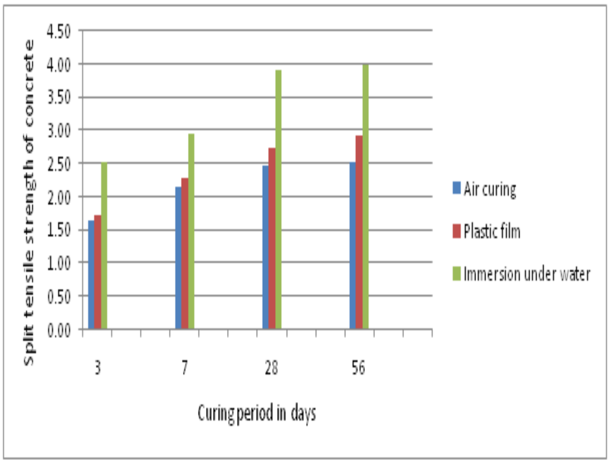

Fig 2.Bar chart between Split Tensile strength and Curing period in days

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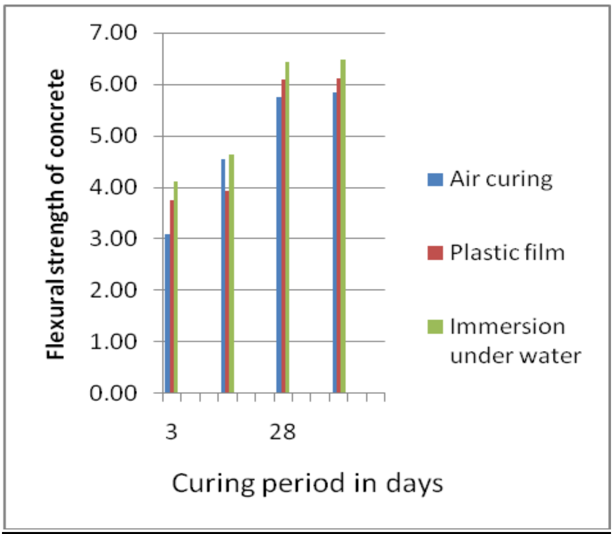

Fig3.Bar chart between Flexural strength and Curing period in days

IV. TESTS AND RESULTS DISCUSSIONS

A. Compressive Strength

The average compressive strength of concrete at different ages i.e. 3, 7, 28 and 56 days under the influence of three types of curing methods namely air, plastic film and curing by immersion under water is shown in Table 1.5 and fig1. It can be observed that average compressive strength of concrete at 3 days, in case of air curing is minimum where as it is maximum for plastic film curing. In case of air curing, the water of the test specimens after 3 and 7 days could not get enough time for complete evaporation and as the result of the presence of water into it, it could again strength. The strength gained by immersion under water was higher than of strength in air curing and plastic film curing. Plastic film acted as shielded and caused less evaporation and the water/moisture available as Gel voids was sufficient to cause hydration of cement, so it achieved strength. But for the case of 28 days strength, as all water got evaporated from air and plastic film cured specimens, so there was decrease in strength as compared to 7 days strength. But in case of curing, by immersion under water its strength increased as compared to its strength at 7 days. As observed the strength at 3 and 7 days were almost 43.5 and 61.9 percent of its 28 days strength respectively. However the rate of development of strength up to 7 days is faster than rate of development after 7 days.

B. Split Tensile Strength

The average split tensile strength of concrete at different ages under the influence of three types of curing methods namely air curing, plastic film curing and curing by immersion under water is shown in Table 1.6 and fig 2. It can be observed that average split tensile strength at 3 days, in case of air curing is minimum where as it is maximum for curing by immersion under water and in case of plastic film curing, split tensile strength follows, the strength for air curing. The split tensile strength increases with age of concrete for all curing methods.

D. Flexural Strength

The average flexural strength of concrete at different ages under the influence of different types of curing methods namely air curing, plastic film curing and curing by immersion under water is shown in Table1.7 and fig 3. It can be observed that average flexural strength of concrete at 3 days, in case of air curing is minimum where as it is maximum for curing by immersion under water and in case of plastic film curing, flexural strength the follows the strength for air curing. It can be also observed that average flexural strength of concrete at 7 days in case of plastic film curing is minimum where as it is Maximum for curing by immersion under water and in case of air curing flexural strength follows strength for plastic film curing.

Curing methods has more determinantal to the development of compressive strength. Curing methods seemed to be more determinantal to the development of compressive strength then to its flexural and split tensile strength.

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