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PERFORMMANCE CHARACTERISTICS OF CEMENT GROUT IN PRECAST CONSTRUCTION

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Abstract: Investigations on mechanical, elastic and performance of cement grout at different ages have been reported. The compressive strength of cement grout at the ages of 1 day, 3, 7, 28 and 90 days has been observed to be 40.10, 53.90, 60.30, 75.20 and 76.02 MPa respectively, while the corresponding flexural and direct tensile strengths are 6.1, 9.3, 9.6, 12.2, and 12.4 MPa, and 2.2, 3.15, 4.34, 6.02 and 6.49 MPa. The strength development in cement grout within 3 days has been observed to be excellent, while the strength development in 7 days is impressive. The strength development is normal up to 28 days and very negligible after 28 days. The direct shear strength of cement grout at 28 days is 3.6MPa. The bond strength of cement grout at 7 and 28 days have been observed to be 25.30 and 35.66 MPa respectively. The dynamic modulus of elasticity, quality and durability of cement grout have been found to be very well acceptable. Water absorption of cement grout is just 2.70%, which is well below limits. The anchorage bond strength of cement grout to be used for precast system has been observed to be extremely good in structures subjected to fatigue loading. The cement grout seems to be an excellent bonding material for various repair and precast concrete applications.

1. INTRODUCTION

The precast construction has witnessed a significant adavancement. The application of high strength cement grout for fresh and repair construction activities is gaining popularity for structural applications. Precast construction adopts high strength fasteners and bonding materials for connecting various structural components, for ensuring their integrity and performance under design loads. Anchors and cement grout are widely used in precast applications. Grouting is an effective method of repair or joining of various structural components in precast construction. Grout fills the gap between the structural components, which is non-shrinkable, and ideal for foundation of heavy machinery. The cement grout should possess high flowability, and develop high compressive strength within a short time. The cement grout should be an efficient material for precast construction in seismic regions. The cement grout is also used for setting anchor bolts, and filling large cracks in concrete roads, pavements and other bridge works. In bridge repair and under water constructions and foundation repair, grouting technique is efficiently implemented. In view of its importance, various properties of cement grout need to be investigations.

2. REVIEW OF LITERATURE

Shamsuddoha et al. [1] investigated various mechanical and thermal properties of epoxy grouts. The modulus of elasticity in direct tension ranges between 3.0 to 17.0 GPa, while its flexural modulus ranges between4.0–13.0 GPa. The development of compressive strength of grouts at 28 days by adding coarse fillers is reported. *Colangelo et al*. [2] characterized metakaolin based geopolymer mortars using organic epoxy resin. The compressive strength and toughness have been improved in the hardened stage. The microstructure exhibits an interfacial transition zone similar to that of cement mortars and concretes. A correlation between micro structural features and mechanical properties has been developed. *Ismeik* [3] investigated the mechanical properties of concrete with mineral admixtures and local Jordanian materials. The compressive and flexural strengths increase with increase in the mineral admixture content. Optimum percentage of replacement of mineral admixtute varies with w/cm ratio of the mix. SF contributes better on both short and long-term properties of concrete, whereas FA exhibits beneficial effect on long-term behavior. Addition of both SF and FA show improvement of the compressive strength in the long-term.

Ortega et al. [4] reported on durability and compressive strength in cement grout with blast furnace slag cement at different w/c ratios have been characterized and compared with a reference Portland cement grout. The results show that slag grout exhibits improved durability and complies with the compressive strength requirements as per the codes. *Satyarno et al.* [5] reported that there is a lack of practical method to carry out grout mix design. The practical method to carry out cement-based grout mix designs is based on some graphics or empirical equations. *Mohammed* [6] studied composition and properties of cement-based materials, concrete and grout. Grouts based on Portland cement are fluid and enable penetrate deeper into the fractures. The cement based materials are suitable for sealing of richly fine-fractured rock where quick strengthening is not required. For fracture zones with fewer but wider fractures, grouts with Portland cement and talc can be optimal. *Kamal et al.* [7] investigated on different types of mixes of cement grouts used for ground treatment, quality control, and frequency and types of tests. Workability of grout was maintained to transfer, place and still retain enough workability to fill the designated cavity. The compressive strength was greater than the design strength. *Simsir et al.* [8] reported on materials and techniques, and methods of evaluation, on grouts produced from lime and hydraulic lime. A variety of materials have been studied for application as injection grouts. Though numerous commercial and custom-mixed grouts are available, there are few standards or well-established methods available to assess them for their preparation, characterization, and evaluation. Therefore, a systematic study on performance, test methods, and preparation and curing conditions are essential for grouts to be adopted.

Shah et al. [9] reported on cost effective and user friendly repair methods with synthetic epoxies and cement grout by injection in to cracked concrete. Three beams loaded to a point where four to five moderate cracks of 3mm to 4mm width running through 3/4th of the depth of beam appeared and considered for comparison. After the cracks were sealed and filled with epoxies by pressure injection using two different chemicals and cement grout, then the repaired beams were then loaded till the cracks again formed, and then also loaded to its full capacity. *Aggelis et al*. [10] reported a repair methodology of injecting epoxy to seal the crack sides keeping out any aggressive substances also to recover the strength. A combination of Rayleigh and longitudinal waves were applied. Rayleigh waves demonstrate the filling condition of the material into the shallow layer near the surface while tomography using longitudinal waves through the thickness yields information about the area inside the structure. Wave propagation dispersion features have been exploited by the proposed tomography at different frequencies, demonstrating that higher frequencies lead to more accurate characterization. *Ahmad et al.* [11] atudied on failure mechanisms in grouted concrete masonry and the corresponding failure criteria. These criteria account for the interaction of the block, mortar, and grout under multi-axial states of stress. The criteria are based on strength which are easily determined from standard strength tests of the individual components. Also, the formulations developed were to account for the strength or geometric characteristics such as the net-to-gross area ratio of the block, tapering of the grout cores, joint thickness, and even un-grouted masonry. The predicted ultimate strengths are compared with the experimental results for ungrouted and grouted prisms incorporating a wide range of mortar and grouts. *Silva et al.* [12] reported that grout can be a repair/strengthening solution for earth constructions. The structural damage is in the form of cracks or voids, caused by drying shrinkage, thermal movements, foundation settlements, plant growth and earthquakes. Repairing the cracks can lead to an improved behavior when the earth construction is built in a seismic zone. The design methodology also needs to be refined, requiring an extensive experimental research, several possibilities to improve the mud grout properties and evaluating their effect in secondary properties.

3. RESEARCH SIGNIFICANCE

Precast construction adopts high strength cement grout as bonding material for joining various structural components and ensure their integrity and performance by withstanding the design loads. Use of cement grout in precast construction needs precision and care for adequate strength in jointing structural components. Prevention of corrosion of steel reinforcement near the openings and hence filling up of cracks in concrete with cement grout is essential for improving the performance and longevity of distressed members. Several structural components distressed under various loading effects can be repaired by grouting process. In view of its efficient application, and gaining popularity and importance, various properties of cement grout need to be characterised through experimental investigations.

4. EXPERIMENTATAL RESULTS

To charecetrise the various properties and understanding the behaviour of cement grout to be used in several structural applications, the following standrad tests as prescribed by the codes of practices have been investigated and discussed.

4.1. Flowability

As a repair material, it should possess adequate flowability to fill the gap or voids easily in the structural components. The cement grout was tested for its flow properties in the fresh stage with different water-binder ratios. Since the material contains small size particles of aggregate, flow table test was adopted and performed as per *IS 1199* [13]. The percentage flow of cement grout on a flow table under a standard set of blows was determined. In order to identify the best mix for free flowability, three sets of of cement grout mixes with different water/binder ratios have been studied. The percentage flow achieved using different water-binder ratios is shown in Table 1. The mix with a low water-binder ratio of 0.130 produces very stiff mix, which makes the compaction difficult. The cement grout mix with water-binder ratio of 0.140 exhibits excess overflowability, which results in segregation and bleeding of water. Out of three sets of grout mixes, the grout mix with water-binder ratio of 0.135 produces a flow of 100% with 3.3litres of water added in 25 kg of binder. This flow is adequate for the grout to compact properly and fill the moulds without any gap or voids.

Table 1 Flow table test on cement grout

S. No	Water-Binder Ratio	Initial Diameter, (D_1)	Spread Diameter (D)	Flow, %
1	0.130	100	150	50
2	0.135	100	200	100
3	0.140	100	Over Flow	---

4.2. Compressive strength

Compressive strength of cement grout was determined on standard cubes made and tested as per the standard procedure laid down by *IS 4031* [14]. The cement grout with water-binder ratio 0.135 was mixed thouroughly in the mortar mixer for about three minutes. The fresh grout mix was poured into the standard cube moulds of dimensions 70mm x 70 mm x 70 mm. Proper compaction and trimming off the top surface were done in the fresh state. In order to prevent the evaporation of water, the moulds were covered with steel plates and placed at a room temperature of 27^0 C. After 24 hours, the cube specimens were de-moulded and submerged in water for curing. The cube specimens were surface dried before testing in a compression testing machine at any required age. The cube specimens were tested in 200 kN compression testing machine. The test set-up for compressive strength is shown in Figure 2. The compressive strength of cement grout was determined at different ages of 1 day and 3, 7, 28 and 90 days as an average value of three cube test results. The variation of compressive strength of grout with age of cement grout is shown in Figure 1. The compressive strength of cement grout at the age of 24 hours is 40.10MPa. At the age of 3 days, the compressive strength has been observed to be 53.90 MPa. The compressive strengths of cement grout at the ages of 7, 28 and 90 days have been observed to be 60.29MPa, 75.20 MPa and 76.05 MPa respectively.

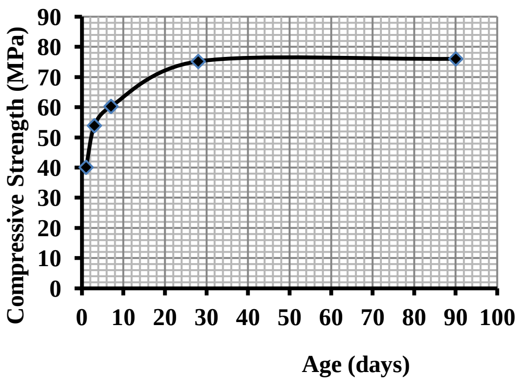

Figure 1. Compressive strength vs. age.

The increase in compressive strength of cement grout between 1 day and 3 days is 34.41%. The increase in compressive strength of cement grout between 3 days and 7days is 11.86%. The compressive strength of cement grout has been increased by about 20 percent between 7 days and 28 days. The compressive strength of cement grout has been found to increase by 1.1 percent between 28 days and 90 days. In terms of 28 days compressive strength as reference value, the cement grout could achieved one day strength equal to 53 percent, more than 70 and 80 percent respectively at 3 and 7 days. The rate of strength development in one day is very significant in cement grout used for precast construction, which is 40.10 MPa/day (1.67 MPa/hr). The rate of strength development between 1 day and 3 days is 6.9 MPa/day (0.288 MPa/hr), while it is 1.60 MPa/day (0.0665 MPa/hr) between 3 and 7 days. The rate of strength development between 7 and 28 days is 0.71 MPa/day (0.0296 MPa/hr). From the experimental observations, it has been found that the rate of strength development in one day is extremely high, while it is rapid between 1 day and 3 days. Between 7 and 28 days, the rate of strength development is reasonably good. However, the strength development between 28 and 90 days is negligible. There is a negligible strength increment in the cement grout after 28 days. The strength development in the early days of cement grout is significantly high, which facilitates the early removal of form work. This early strength development is highly essential for repair works and fresh precast construction activities.

4.3. Flexural Tensile Strength

The flexural strength of cement grout was determined as per the procedure laid down in the Indian standard IS: 516 [15]. The flexural strength of cement grout was studied on beams specimens of size 40mm x 40mm x 160 mm with an effective span of 120 mm under three-point loading. The beams were supported on two roller supports of 10mm diameter, spaced at 120 mm apart. The prisms was placed on the roller supports on the bottom face and the third point loading was transmitted on the opposite and top face using a third roller, placed symmetrically and at equidistant from the supports. Two support rollers are simply supported, which allow free rotation of beam about their line of contact in order to distribute the line load uniformly over the beam width as point load. The rate of loading on the beam was 50 N/s. The flexural tensile strength of cement grout is reported as an average of three beam tests at the ages of 1, 3, 7, 28 and 90 days. The flexural tensile strength of cement grout at different ages in Figure 2.

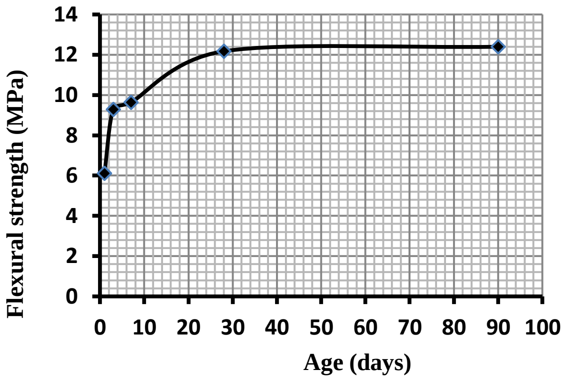

Figure 2. Flexural strength of cement grout vs. Age

The observed flexural tensile strength of cement grout after 24 hours (one day) is 6.11 MPa. The flexural strength of cement grout at the age of 3 days is 9.29 MPa; 52% increase in the strength after one day. The flexural tensile strength of cement grout at the age of 7 days is 9.64 MPa; 58 percent and 8.5 percent increase after 3 days and 7 days respectively. At the age of 28 days the flexural tensile strength of cement grout is 12.18 MPa; 31 percent and 26.45 percent increase after 3 days and 7 days respectively. With reference to the strength of cement grout at the age of 28 days, the strength achieved at the age of 24 hours is almost 50 percent. 75 percent of the strength was achieved at the age of 3 days and about 80 percent was achieved in 7 days. At the age of 90 days, the flexural tensile strength of cement grout is 12.40 MPa, which is just 1.84% increase after 28 days. From the experimental results, it has been observed that the rate of strength development is very high up to 3 days. The strength development between 3 and 7 days is impressive. However, the rate of strength development decreases after 7 days and up to 28 days is nromal. Very negligible strength develomnet in cement grout was observed after 28 days.

The variation of Load vs. deflection response in the beam is demonstarted in cement grout at the age of 1 day and 3, 7, 28 and 90 days respectively. Figure 3 shows a typical variation of load vs. deflection response on cement grout beams at the age of 90 days. The variation of a typical stress vs. strain response on cement grout beam at the age of 90 days is shown in Figure 4. The stress vs. strain response of the beam was also investigated at the ages of 1 day, and 3, 7, and 28 days also.

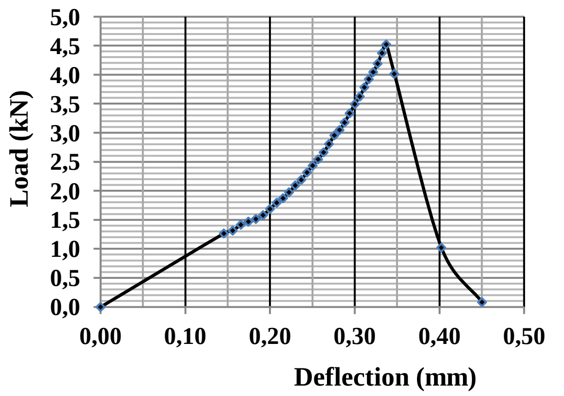

Figure 3. Load vs. Deflection in cement grout beam.

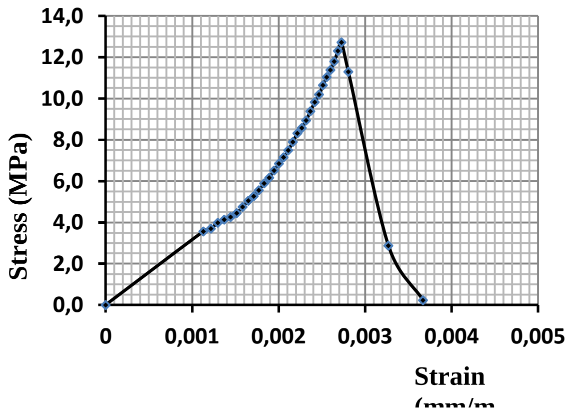

Figure 4. Stress vs. Strain on cement grout beam.

4.4. Direct Tensile Strength

The direct tensile strength of cement grout was determined on briquettes with neck having cross-section dimensions of 25mm x 25 mm. The set-up for testing of briquettes of dumbbell shape for studying the direct tensile strength of cement grout is shown in

Figure12. The direct tension tests were carried out in a Universal Testing Machine (UTM). The direct tensile strength of cement grout is reported as an average of three test results. The direct tensile strength was determined at different ages of 1 day, 3, 7, 28 and 90 days The variation of direct tensile strength of cement grout with age is shown in Figure 5.

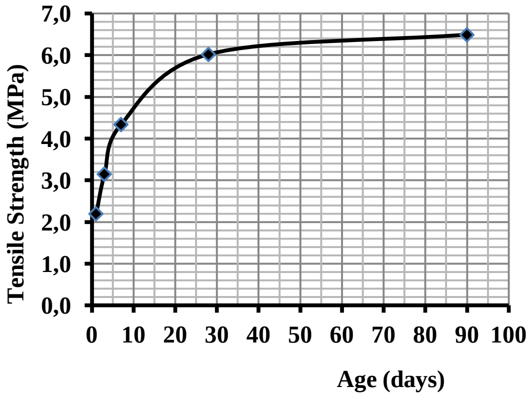

Figure 5. Tensile Strength of cement grout vs. Age.

The direct tensile strength at the age of 1 day is 2.20 MPa. In cement grout at the ages of 3, 7, 28 and 90 days the direct tensile strength has been observed to be 3.15, 4.34, 6.02 and 6.49 MPa respectively. The rate of direct tensile strength development of cement grout in one day is 2.20 MPa/day. From 1 day to 3 days, the direct tensile strength development in cement grout is 0.475 MPa/day, between 3 and 7 days it is 0.30 MPa/day. The rate of direct tensile strength development is 0.08 MPa/day between 7 and 28 days. The rate of strength development is significantly high within one day and reasonably good up to 3 days. Between 7 and 28 days, the strength development if very normal. It gradually decreases with age of cement grout after 28 days. After 28 days, the direct tensile strength development is very negligible. The high strength development in the early hours of casting of cement grout is very essential in repair of important structures, road works and other civil engineering applications for easy and early removal of formwork, resulting in significant benefits such as early strength development, speedy construction and removal of supporting formwork. Overall, there seems to be a tremendous advantages of the application of cement grout in Civil Engineering.

4.5. Direct Shear Strength

The direct shear strength of cement grout is very essential in the joining of two structural components with butt-grove type perforations. Cement grout is used to glue the structural compoments using bond and shear mechanism of the joining structural components. A new geometry for performing very ideal and direct shear tests on cement grout specimens was developed. The standard prism specimens of 40mm x 40mm x 160mm were adopted for preparation of direct shear strength specimens. The beam specimen is divided in to three equal portions. At the location where the specimen is dived in to three equal and symmetrical parts, a 5mm wide groove was made all around the perimeter of the beam differentiating the three parts each of length 50mm measured along the span. The net cross-section in the grooved plan directs the failure of specimen in direct shear. The direct shear strength test was carried out using a standard test set-up designed to test in a 600kN capacity UTM**.** The load was applied through a specially fabricated frame in order to achieve shearing of the cement grout only through grooved plane. The two ends of the loads frame were provided with roller supports on either end of the beam. The test set-up for direct shear strength is shown in Figure 6. The direct shear strength of cement grout was determined at the age of 28 days using the following relationship

S. No.	Load (P), N	Sheared Area, mm^2	Shear Strength (MPa)
1	1109	300	3.70
2	1077	340	3.17
3	1148	336	3.42

Shear Strength of cement grout = $\frac{P}{2A}$

Where P = Load at failure, Newton

A = Area of cross section, mm^2

The direct shear strength is reported as the average from three tests at the age of 28 days. The load corresponding to failure and the actual failure cross-sectional dimensions were used to determine the shear strength. The loads and the corresponding shear strength obtained from the experimental observations are shown in Table 2. The average direct shear strength of cement grout at the age of 28 days has been found to be 3.42 MPa.

Table 2 Shear strength of cement grout.

Figure 6. Direct shear test on cement grout beam.

4.6. Pull-out Bond Strength

Pull-out bond strength tests were

S. No	Age (Days)	Bond Strengt (MPa)	Mode of failure
1.	7	28.30	Bar pullout
2.	28	35.66	Bar pullout

performed on cement grout using cube moulds, which were specially designed with spiral reinforcement as specified in *IS 2770-1(1967)* [16]. The cement grout cube specimens were of 150mm x 150mm x 150mm dimensions. A 20 mm diameter reinforcing steel bar was embedded/bonded over a length of 50 mm only in the middle of 150mm total depth of cement grout. The top and bottom 50mm end lengths of the rebar was not bonded in order to prevent the influence of end region compression and errors involved in the calculation of the bond strength of cement grout. The pull-out bond specimen is mounted with three Linear Variable Differential Transducer (LVDT); one at the free end of the rod to measure the free end slip and other two LVDTs on either side of the forced end of the rod diametrally on top of concrete surface. At bond stress levels shown in Table 3, 20 mm diameter HYSD bar did not yield, since the embedment length was only 50mm in the middle region of the cube length. Over a small embedment depth, the bond strength of cement grout seems to be very high compared with the ordinary cement concrete. The load was applied gradually. The bond strength was determined at the ages of 7 and 28 days on three pull-out specimens.

The bond strength of cement grout has been observed to be 28.30 MPa at the age of 7 days and 35.66 MPa at the age of 28 days. At the age of 7 and 28 days at the bond stress levels of 28.30MPa and 35.66 MPa, 20 mm bar was pulled out from cement grout. The bond strength achieved in the cement grout seems to be very good. The variation of bond strength with age of cement grout is shown in Figure16. The average bond strength of cement grout is shown in Table 8 at different ages. With adequate confinement of grout fromt eh surrounding regions, the pull-out bon strength of cement grout has been observed to be very high. It is a good character of the cement grout to be used in precast construction activities for joining two structural components.

Table 3. Bond strength of cement grout

4.7. Water Absorption

Water absorption test on cement grout was carried out on cylindrical specimens of 100 mm diameter and 200 mm height. *The test procedure and calculations for water absorption test for grout specimen is carried out as per ASTM C90-11a* [17]. Water absorption test was carried out on the cylindrical cement grout specimens of dimensions 100mm x 200mm. The cement grout cylinders, after casting and demoulding, were fully immersed in water for 28 days for curing at room temperature. They shall be removed from the water and allowed to dry for one minute by placing them on a 10 mm or coarser wire mesh, visible surface water being removed with a damp cloth and immediately weighed. The water absorption test on four cylindrical cement grout specimens was conducted. The average water absorption capacity of the cement grout is 2.70 %. Water absorbing capacity of cylindrical cement grout specimens is shown in Table 4.

Table 4 Water absorption in cement grout.

S. No	Wet Weight, W_1 (kg)	Dry Weight, W_2 (kg)	Water Absorption (%)
1	3.703	3.604	2.75
2	3.627	3.54	2.46
3	3.656	3.556	2.81
4	3.653	3.554	2.79

4.8. Ultrasonic Pulse Velocity

Ultrasonic pulse velocity was measured in the cement grout using the standard procedure in *IS: 13311(Part1)* [18] *on* cylindrical specimens of 100mm x 200mm. The ultrasonic pulse wais generated from a transducer held in contact with cement grout at one end of the cylinder. After traversing directly through a length (L) of the cement grout, the pulse of vibrations has been converted into electrical signal in the second transducer held in contact with the other end of the cylinder. An electronic device displayed the transmit time (T) of the pulse. The pulse velocity (V) is determined by dividing the travel distance by its travel time, V = L/T. The ultrasonic pulse velocity in the cement grout depends up on its quality and strength, water-binder ratio, surface conditions, moisture content, and length of passage, shape and size of the member, temperature conditions, presence of steel reinforcement and its distance from the location of sensors. The surfaces of the cement grout cylindrical specimen at the two opposite ends were abraded with metal brush to make the surface even. Then, the abraded surfaces of the specimens were cleaned with a neutral solvent (Acetone). After the grout surfaces were completely dried, a thin layer of lubricant or grease was applied between the cement grout surface and the transducers (both transmitter and receiver). The natural frequency of the transducers was 54 kHz. At the time of observations, a calibrated reference bar was used. The time taken to travel the length of cement grout was used from the display unit. The ultrasonic pulse velocity was calculated as the length of the grout divided by the time travelled by the pulse waves, expressed in km/sec. The time taken to travel the grout length is measured in micro (μ) seconds and the length is 200mm. The ultrasonic pulse velocity is determined on various grout samples and shown in Table 5. The average pulse velocity in cement grout has been observed to be 4.60 km/sec**,** showing excellent quality.

Table 5. Ultrasonic Pulse Velocity in grout.

S. No.	Length of Grout (mm)	Time (μ secs)	UPV (km/sec)
1	200	43.55	4.60
2	200	44.95	4.44
3	200	42.90	4.66
4	200	43.15	4.65

4.9. Dynamic Modulus of Elasticity

The dynamic modulus of elasticity, E_d (kN/mm^2) can be calculated by using the following equation. The static modulus of elasticity, E_c = 0.83 E_d. The dynamic modulus of elasticity, E_d can be calculated by knowing the ultrasonic pulse velocity, density of material and poisson's ratio from the following relationship.

Dy. modulus of Elasticity, $E_d = \frac{V^2 \rho}{K}$

Where V = Ultrasonic pulse velocity (km/s)

ρ = density (2400 kg/m^3)

$$K = \left(\frac{(1-\gamma)}{(1+\gamma)(1-2\gamma)} \right)$$

γ = dynamic Poisson's ratio (0.2)

Dy. Modulus of elasticity, E_d= 45126 N/mm^2

St. modulus of elasticity, E_c = 37455 N/mm^2

The value of static modulus of elasticity of cement grout can be estimated. The dynamic modulus of elasticity of cement grout is 45126 N/mm^2 where as the static modulus of elasticity is 37455 N/mm^2. The cement grout seems to be very efficient in quality and also the stiffness of the structural members using cement grout seems to be excellent.

5. CONCLUSION

The cement grout investigated in the present study possesses very good qualitites, which can be used for repair in various structural applications including precast construction. The compressive strength, flexural and, direct tensile strength, direct shear strength of cement grout have been found to be very high in the early days after casting. Within 1 day after casting more than 50 percent of the strength has been achieved and witnin 3 days more than 75 percentage of the strength was achieved in cement grout. The bond strength of the cement grout appears to be very good. In general, the strength of grout at the early age has been rapidly increasing from 1 day to 3 days, very impressive between 3 and 7 days, normally increasing between 7 and 28 days, while the strength development after 28 days has been very negligible. The quality of cement grout using ultrasonic pulse velocity seems to be excellent with very high stiffness. The water absorption of cement grout has been observed to be 2.70%. In view of its better performance under various loading conditions, the cement grout seems to be graded as an excellent material for repair and fresh concrete applications in various structural practices, and also as a prospective product for road work and heavy machine foundations.

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