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Effect of Vibrations on Concrete Strength

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Abstract

There is a relative lack of understanding of the process of compacting concrete by vibration, especially in hot and dry weathers where some problems may arise when delaying the casting of concrete.

The Research on the effect of vibration on concrete strength has indicated that the vibration of fresh concrete immediately after casting is very important.

The experimental study has been carried out to investigate the effects of delaying vibration, revibration and repeated vibration of concrete to help better understanding of the effects and processes involved.

The study reports on the test results of nine medium workability mixes and six high workability mixes investigated using a vibrating table for different vibration time.

The cubes (150 mm size) were used and tested after 3, 7, 28, 90 days, beams (100 mm × 100 mm × 500 mm) and cylinder (300 mm height 150 mm dia.) were used and tested after 28 days in an attempt to study the effects of delay in vibration, revibration and repeated vibration on the development of concrete strength.

It is concluded that vibration of concrete should be performed promptly after casting it . Revibration improved the strength when it was carried out within the first one hour. The repeated vibration at closer intervals produced positive effects on concrete strength.

الخلاصة

هنال عدم ادراك كافي لعملية دمك الخرسانة عن طريقة الهزاز خصوصاً في المناطق الحارة والجافة حيث تظهر بعض المشاكل نتيجة لتأخير عملية صب الخرسانة.

خلال الفتره الماضيه أ جريت عدة دراسات حول تأثير عملية الهز على مقاومة الخرسانة،و تبين أن عملية الهز مباشرة بعد الصب ضرورية جداً.

في هذا البحث تمت دراسة تأثير الهز وإعادة الهز وتكرار عملية الهز علي فترات زمنية متقاربة وأثره على مقاومة الخرسانة.

في هذه الدراسة تم أستخدام تسعة عينات من خلطة خرسانية درجة تشغيلها متوسطة، وستة عينات درجة تشغيلها عالية تم هزها بواسطة منضدة الاهتزاز في فترات زمنية بالمعمل .

تم اختبار مكعبات حجم (15 سم) في فترة زمنية ثلاثة ايام ، سبعة أيام ،ثمانية وعشرون يوما ، وتسعون يوماً وكذلك عارضات حجم (10سم × 10سم × 50 سم) واسطوانات (ارتفاع 30سم وفطر 15سم) تم اختبارها بعد 28 يوم وذلك بغرض دراسة أثر تأخير الهز وإعادة الهز وتكرار عملية الهز في فترات زمنية متقاربة وأثره على مقاومة الخرسانة.

ومن خلال الدراسة تبين أن هز الخرسانه بعد الصب مباشرة ضروري وهام وإعادة الهز خلال ساعة من الصب أعطت نتائج أفضل في مقاومة الخرسانة وتكرار عملية الهز في فترات زمنية متقاربة أعطت نتائج إيجابية في مقاومة الخرسانة.

CHAPTER ONE
INTRODUCTION

1.1 OPJECT AND SCOPE:

Concrete is an artificial stone casted in place when in plastic condition. Concreting can be faced by many problems which may lead to the deterioration of the properties of hardened concrete.

The Object of this project is to investigate the effect of vibration on Concrete properties, both in its fresh and hardened stages , specially the strength .

The scope of this experimental work is to study the effect of delaying the vibration, revibration and repeated vibration of concrete to help better understanding of the effects and processes involved. The influence of the hot-dry climates of the Sudan and the time of useful vibration are particularly targeted.

1.2 GENERAL ABOUT CONCRETE:

Concrete in general is a commonly used structural material and it consists essentially from mixing water, cement, aggregate and if necessary special additives with selected correct proportions of the ingredients to produce concrete mix with specific properties.

The chemical reaction of cement and water is relatively slow and needs several days to complete the reaction, therefore, the strength of concrete is not attained quickly after casting. Concrete should be cured to prompt the hydration of cement and to keep the concrete saturated or nearly saturated.

The concrete has to be satisfactory in its hardened state and also in its fresh state while being transported form the mixer and placed in the form-work. The requirements in the fresh state are that the consistence of the mix be such that it can be compacted by the means desired without excessive effort, and also that the mix be cohesive enough for the method of placing used, not to produce segregation with consequent lack of the finished product.

The usual primary requirement of the a good concrete in its hardened state is satisfactory compressive strength, density, durability, tensile strength, impermeability… etc .

The properties of fresh concrete are important only in the first few hours of its history whereas the properties of hardened concrete assume an importance which is retained for the remainder of the life of concrete. The important properties of hardened concrete are strength, deformation under load, durability, permeability and shrinkage.

In general, strength is considered to be the most important property and quality of concrete is often judged by its strength. There are, however, many occasions when other properties are more important, for example, low permeability and low shrinkage are required for water-retaining structures. Although in most cases an improvement in strength results in an improvement of the other properties of concrete with few exceptions. For example, increasing the cement content of a mix improves strength but results in higher shrinkage which in extreme cases can adversely affect durability and permeability.

Since the properties of concrete change with age and environment, it is not possible to attribute absolute values to any of them.

1.3 COMPACTION OF CONCRETE:

1.3.1 General:

During the initial stage, while concrete is fresh two properties are of particular importance:

(1) Workability.

(2) Cohesiveness (determines the resistance of concrete to segregation of constituents during transporting, placing and compaction).

Resistance to flow comes largely from viscous drag of concrete and interference between the aggregate and cement particles. If there is more water, further a part, the solids are pushed and greater workability will be produced. Plastic concrete will begin to flow when the applied stress is sufficient to overcome the resistance between the solid particles. The resistance is normally overcome by vibration.

During the manufacture of concrete a considerable quantity of air is entrapped and during its transportation there is a possibility of partial segregation taking place. If the entrapped air is not removed and the segregation of coarse aggregate not corrected, the concrete may be porous, non homogenous, and of reduced strength.

The process of removal of entrapped air and of uniform placement of concrete to from a homogenous dense mass is termed compaction. It makes it difficult to spread the concrete in the forms. The friction also prevents the concrete from coming in close contact with the reinforcement there by leading to poor bond between the reinforcement and surrounding concrete. The compaction helps to overcome frictional forces. The friction can also be reduced by adding more water than that required to hydrate the cement.

Compaction of concrete is the process adopted for expelling the entrapped air from the concrete, in the process of placing and mixing of concrete. In order to achieve full compaction and maximum density, with reasonable compaction efforts available at site, it is necessary to use a mix with adequate workability. It is also of common knowledge that the mix should not be too wet for easy compaction which also reduces the strength of concrete. The following methods are adopted for concrete compaction :

1.3.2 Compaction by Hand Tamping :

Hand compaction of concrete is adopted in case of unimportant concrete work of small magnitude. Hand compaction consists of rodding, ramming or tamping.

When hand compaction is adopted, the consistency of concrete is maintained at a high level. The thickness of the layer of concrete is limited to about 15 to 20 cm. Rodding is nothing but poking the concrete with about 2 meter long, 16 mm diameter rod to pack the concrete between the reinforcement and sharp corners and edges. Rodding is done continuously over the complete area to effectively pack the concrete and drive away entrapped air. Sometimes, instead of iron rod, bamboos or cane is also used for rodding purpose.

Ramming should be done with care. Light ramming can be permitted in unreinforced foundation concrete or is permitted in case of reinforced concrete or in the upper floor construction, where concrete is placed in formwork supported on struts. If ramming is adopted in the above case the position of reinforcement may be disturbed or the formwork may fail, particularly, if steel rammer is used.

Tamping is one of the usual methods adopted in compacting roof or floor slab or road pavements where the thickness of concrete is comparatively less and consists of beating the top surface by wooden cross beam of section about 10 cm X 10 cm. Since the tamping bar is sufficiently long it dose not only compact, but also levels the top surface across the entire length.

1.3.3 Compaction by vibration:

A literature search on the effect of vibration on the quality of concrete, has indicated that, vibration of fresh concrete at the time of casting is very important. Vibration has been proved to be the best mean by which concrete particles are dawn into a compact mass. However, it is not quite uncommon that concreting may occur nearby a source of vibration which might continue for whole or part of the setting time and early age of concrete.

Recently, there has been a number of studies in the effect of revibration which indicate that, it may produce benefits, particularly for wetter mixtures, in eliminating water gained under reinforcing bars, reducing bugholes, all of which will increase the strength.

This experimental study has been carried out to investigate the effects of delaying the vibration, revibration and repeated vibration of concrete to help better understanding of the effects and processes involved. The influence of hot dry climate of the Sudan and the time of useful vibration are particularly considered.

Research by Allen Hulshize indicates that vibration on fresh and maturing concrete does not affect its properties. However, his investigation maintained such a broad facus on the vibration of concrete that specific time periods may need further investigation, Bastion, considered the effects of vibratry concrete during the setting period (Allen 1970).

Due to decreased floor mass and longer span lengths, floor vibrations have become an area of concern. Design criteria (Allen and Rainer, Allen: 1990 b, Murray, 1991) are available to help designs minimize annoying vibrations in floor systems. In general, hours that comply with the criteria and are used for their original purpose are found to be acceptable to the occupants.

It is pointed out that the compaction, if properly carried out on concrete with sufficient workability, gives satisfactory results, but the strength of the hand compacted will be necessarily low because of higher water cement ratio required for full compaction. Where high strength is required, it is necessary that stiff concrete, with low water/cement ratio be used. To compact such concrete, mechanically operated vibratory equipment, must be used. The vibrated concrete with low water/cement ratio will have many advantages over the hand compacted concrete with higher water/cement ratio.

The modern high frequency vibration makes it possible to place economically concrete which is impracticable to place by hand. A concrete with about 4 cm slump can be placed and compacted fully in a closely spaced reinforced concrete work, whereas, with hand compaction, much higher consistency say about 12 cm slump may be required. The action of vibration is to set the particles of fresh concrete in motion, reducing the friction between them and affecting a temporary liquefaction of concrete which enables easy settlement. While vibration itself does not affect the strength of concrete which is controlled by the water/cement ratio, it permits the use of less water.

Compaction of concrete by vibration has almost completely revolutionized the concept of concrete technology, making possible the use of low slump stiff mixes for production of high quality concrete with required strength and impermeability. The use of vibration may be essential for the production of good concrete where the congestion of reinforcement or the inaccessibility of concrete in the formwork is such that hand compaction methods are not practicable. Vibration may also be necessary if the available. Concrete is of such poor workability unless large amount of water and cement is used. In this way, vibration can, under suitable conditions, produce better quality concrete than by hand compaction. Low cement content and lower water cement ratio can produce equally strong concrete more than by hand compaction.

Although vibration properly is a great step forward in the production of quality concrete, it is more often employed as a method of placing ordinary concrete easily than as a method of obtaining high grade concrete at an economical cost. All potential advantages of vibration can be fully realized only if proper control is exercised in the design and manufacture of concrete and certain rules are observed regarding the proper use of different types of vibration.

1.3.3.1 Internal vibration:

Of all the vibration, the internal vibrator is most commonly used. This is also called (Needle vibrator) or (poker vibrator). This essentially consists of a power unit, a flexible shaft and a needle. The power unit may be electrically driven or operated by petrol engine or air compressor. The vibrations are caused by eccentric weights attached to the shaft or the motor or to the rotor of vibrating element. Electromagnet, pulsating equipment is also available. The frequency of vibration varies up to 12000 cycles of vibration per minute. An average frequency of 3500 to 5000 has been normally used. The needle diameter varies from 20mm to 75mm and its length varies from 25cm to 90cm. The bigger needle is used in the construction of mass concrete dam. Sometime, arrangements are available such that the needle can be replaced by a blade of approximately the same size. The blade facilitates vibration of members, where, due to the congested reinforcement, the needle would not go in, this blade can effectively vibrate. The internal vibrator are portable and can be shifted from place to another very easily during concreting operation. It can also be used in difficult positions and situations.

1.3.3.2 External vibrator (Formwork vibrator):

This vibrator is used for concreting columns, walls or in the casing of precast unit. The machine is clamped on to the external wall surface of the formwork. The vibration is given to the formwork so that the concrete in the vicinity of the shutter gets vibrated. This method of vibrating concrete is particularly useful and adopted where reinforcement, lateral ties and spacers interfere too much with the internal vibrator. Use of surface vibrator will produce a good finish to the concrete surface. Since the vibration is given to the concrete indirectly through the formwork, it consumes more power and the efficiency of external vibrator is lower than the efficiency of internal vibrator.

1.3.3.3 Table vibrator:

This is a special case of a formwork vibrator, where the vibrator is clamped to table. Any article kept on the table gets vibrated. The vibration tables are very efficient in compacting stiff and harsh concrete mixes required for the manufacture of pre-cast elements in the factories and test specimens in the laboratories.

1.3.3.4 Platform vibrator:

Platform vibrator is nothing but a table vibrator, but it is larger in size. This is used in the manufacture of large prefabricated concrete elements such as electric poles, railway sleepers, prefabricated roofing elements etc. Sometime, the platform vibrator is also coupled with jerking or shock giving arrangements such that a thorough compaction is to the concrete.

1.3.3.5 Surface Vibrators:

Surface vibrators are sometimes known as, (Screed Board Vibrator). A small vibrator placed on the screed board gives an effective method of compaction and leveling of thin concrete members, such as floor slabs, roof slabs and road surface. Mostly, floor slabs and roof are so thin that internal vibrator or any other type of vibrator cannot be easily employed. In such cases, the surface vibrator can be effectively used. In general, surface vibrators are not effective beyond about 15cm. Sometimes, the concrete is vibrated by using vibratory roller moved on the surface. Vibrating roller is used for compaction of road slabs.

1.3.3.6 General Points on Using Vibrators:

Vibrators may be powered by any of the following units:

(a) Electric motors either driving the vibrator through flexible shaft or situated in the head of the vibrator.

(b) Internal combustion engine driving the vibrator needle through flexible shaft.

(c) Compressed-air motor near the head of the vibrator.

Where reliable supplies of electricity is available the electric motor is generally the most satisfactory and economical power unit. The speed is relatively constant, and the cables supplying current are light and easily handled.

Small portable petrol engines are sometimes used for vibrating concrete. They are more easily put out of action by site conditions. They are not so reliable as the electric or compressed-air motors. They should be located conveniently near the works to be vibrated and should be properly secured to their base.

Compressed-air motors are generally quite suitable but pneumatic vibrators are sometimes difficult to manipulate when the compressor cannot be placed adjacent to the work such as on high scaffolding or depths below ground level due to the heavy weight of air hoses.

Compressed-air vibrators give trouble especially in cold weather, by freezing at exhaust unless alcohol is trickled into the air or dry air is used. Glycol type antifreeze agents tend to cause gumming of the vibrator. There is also a tendency for moisture to collect in the motor, hence care should be taken to remove the possible damage.

The speed of both the petrol and compressed-air motors tend to vary giving rise to variation in the compacting effect of the vibrator.

1.3.3.7 Further Instructions on the Use of Vibrators:

Care shall be taken that the vibrating head does not come into contact with hard objects like hardened concrete, steel and wood, as otherwise the impact may damage the bearings. The prime mover should be, as far as possible, started only when the head is raised or resting on soft support. Similar precautions shall be observed while introducing or withdrawing the vibrator in the concrete to be consolidated.

When the space for introduction is narrow, the vibrator should be switched on only after the vibrator head has been introduced into the concrete. Unnecessary sharp bends in the flexible shaft drive shall be avoided.

Vibrators conforming to the requirements of ISS 2505-1963 (i.e specification for concrete vibrators, immersion type) shall be used. The size and characteristics of the vibrator suitable for a particular job vary with the concrete mix design, quality and workability of concrete, placing conditions, size and shape of the member and shall be selected depending upon various requirements.

Correct design of concrete mix and an effective control in the manufacture of concrete, right from the selection of constituent materials through its correct proportioning to its placing, are essential to obtain maximum benefits of vibration. For best results, the concrete to be vibrated shall be of the stiffest possible consistency, generally within a range of 0.75 to 0.85 compacting factor, provided the fine mortar in concrete shows at least a greasy wet appearance when the vibrator is slowly withdrawn

from the concrete and the material closes over the space occupied by the vibrator needle leaving no pronounced hole. The vibration of concrete of very high workability will not increase its strength, it may on the contrary, cause segregation.

For vibrated concrete, the formwork shall be stronger than is necessary for hand compacted concrete and greater care is exercised in its assembly. It must be designed to take up increased pressure of concrete variations caused in the neighbourhood of the vibrating head which may result in excessive local stress on the formwork. More exact details on the possible pressures are not available and much depend upon experience, judgment and the character of works. The joints of the formwork shall be made and maintained tight and close enough to prevent the squeezing out of grout or sucking in of air during vibration. Absence of this precautions may cause honey-combing in the surface of concrete, impairing the appearance and sometimes weakening the structure.

The amount of mortar leakage or the permissible gap between sheathing boards will depend on the desired final appearance of the works but normally gaps more than 1.5 mm between the boards should not be permitted. Sometimes even narrower joints may be objectionable from the point of view of their effect on the surface be made as small as possible by making the shutter sections large. Applications on the formwork, if any, to prevent the adhesion on concrete should be very thin as otherwise they may mix with the concrete under the effect of vibration.

The vibrator may be vertically, horizontally or at an angle depending upon the nature of the job. The concrete to be vibrated shall be placed in position in level layers of suitable thickness not greater that the effective length of the vibrator needle.

The concrete at the surface must be distributed as horizontally as possible, since the concrete flows in slopes while being vibrated and may segregate. The vibration shall, therefore, not by done in the neighbourhood of slopes. The internal vibrator should not be used to spread the concrete from the filling as this can cause considerable segregation of concrete.

It is advisable to deposit concrete well in advance of the point of vibration. This prevents the concrete from subsiding non-uniformly and prevents the formation of incipient plastic cracks.

1.3.3.8 Height of Concrete Layer:

Concrete is placed in thin layers consistent with the method being used to place and vibrate the concrete. Usually concrete shall be placed in a thickness not more than 60 cm and on initial placing in thickness not more than 15 cm. The superimposed load increasing with height of the layer will favour the action of the vibrator, but as it is also the path of air forced upwards, it may trap air rising up by vibration. Very deep layers (Say more than 60 cm) should, therefore, be avoided although the height of layer can also be one metre provided the vibrator used is sufficiently powerful.

1.3.3.9 Speed of Insertion and Withdrawal of the Vibrating Head:

The vibrating head shall be regularly and uniformly inserted in the concrete so that it penetrates of its own accord and shall be withdrawn quite slowly whilst still running so as to allow redistribution of concrete in its water and allow the concrete to flow faster into the hole belind the vibrator. The rate of withdrawal is determined by the rate at which the compaction in the active zone is completed. Usually a speed of 3 cm/s gives sufficient consolidation without undue strain on the operator.

1.3.3.10 Duration of Vibration:

New filling shall be vibrated while the concrete is plastic, preferably within one hour. The duration of vibration in each position of insertion is dependent upon the height of the layer, the size and characteristics of the vibrator and workability of the concrete mix. It is better to insert the vibrating head at a number of places than to leave it for a long time in one place, as in the latter case, there is a tendency for formation of motor pocker at the point of insertion of the vibrator.

The vibrator head shall be kept in one position till the concrete within its influence is completely consolidated which will be indicated by formation of circular shaped cement grout on the surface of concrete, appearance of flattened glistening surface and cessation of the rise of entrapped air. Vibration shall be continued until the coarse aggregate particles have tended into the surface but have not disappeared.

The time required to a effect complete consolidation is readily judged by the experienced vibrator operator through the feel of the vibrator, resumption of frequency of vibration after the short period of dropping off frequency when the vibrator is first inserted.

1.3.3.11 Over-vibration:

There is a possibility of over-vibration while trying to achieve thorough vibration, but it is exceedingly unlikely in well proportioned mixes containing normal weight aggregates. Generally, with proper mixes, extended vibration will be only a waste of effort without any particular harm to the concrete.

However, where the concrete is too workable for the conditions of placing, or where the quantity of mortar is un excess of the volume of voids in the coarse aggregate, or where the grading of aggregate is unsatisfactory, over-vibration will encourage segregation, causing migration of the lighter and smaller constituents of the mix to the surface, thereby producing layer of mortar or laitance on the surface and leakage of motor through the defective joints in the formwork. This may produce concrete with poor resistance to abrasion and attack by various agencies, such as frost, or may result in planes of weakness where successive lifts are being placed. If over vibration occurs, it will be immediately evident to an experienced vibrator operator or supervisor by a frothy appearance due to the accumulation of many small air bubbles on the surface. These results are more liable to occur when the concrete is too wet and the proper correction will be to reduce the workability (not the vibration), until the evidence of over-vibration disappears during the amount of vibration judged necessary to consolidate the concrete and to eliminate air-bubble blemishes.

1.3.3.12 Revibration:

Revibration is delayed vibration of concrete that has already been placed and compacted. It may occur while placing successive layers of concrete, when vibrations in the upper layer of fresh concrete partially hardened or may be done intentionally to achieve certain advantages.

Except in the case of exposed concrete and provided the concrete becomes plastic under vibration, re-vibration is not harmful and may be beneficial. By repeated vibration over a long period (repetition of vibration earliest after one hour from the time of initial vibration), the quality of concrete can be improved because it rearranges the aggregate particles and eliminates entrapped water from under the aggregate and reinforcing steel, with the consequence of full contact between mortar and coarse aggregate or between steel and mortar and thus produces stronger and watertight concrete. Plastic shrinkage cracks as well as other disturbances like hollow space below the reinforcement bars and below the coarse aggregate, can thereby be closed again provided the concrete becomes soft again when the vibrator head is introduced. Re-vibration of concrete results in improved compressive and bond strength, reduction of honey-comb, release of water trapped under horizontal reinforcing bars and removal of air and water pockets.

Re-vibration is most effective at the lapse of maximum time after the initial vibration, provided the concrete is sufficiently plastic to allow the vibrator to sink under its own weight into the concrete and make it momentarily plastic.

CHAPTER TWO

LITERALRE REVIEW

2.1 CONCRETE MATERIALS

2.1.1 CEMENT:

2.1.1.1 General:

The history of cement material is as old as the history of engineering construction. Some kind of cementing materials were used by Egyptians, Romans and Indians in their ancient construction.

The story of the invention of Portland Cement is however attributed to Joseph Aspdin, a leeds builder and bricklayer, even though similar procedures has been adopted by other inventors.

In the early period cement was used for making mortar only. Later the use of cement was extended for making concrete. As the use of Portland Cement was increased for making concrete, engineers called for consistently higher standard material for use in major works. Association of Engineers, Consumers and Cement Manufacturers have been established to specify standards for cement.

The early scientific study of cement did not reveal much about the chemical reactions that take place at time of burning. A deeper study of the fact that the clayey constituents of properties in lime was not undertaken.

Systematic work on the composition and chemical reaction of Portland Cement was first begun in the United States. The study on setting was undertaken by the Bureau of standards and since 1926 much work on the study of Portland Cement was also conducted by the Portland Cement Association, U.K. by this time, the manufacture and use of Portland Cement had spread to many countries.

2.1.1.2 Manufacture of Portland Cement:

The raw materials required for manufacture of Portland Cement are calcareous materials, such as limestone or Chalkr, and argillaceous material such as Shale or Clay.

The process of manufacture of cement consists of grinding the raw materials, mixing them intimately in certain proportions depending upon their purity and composition and burning them in a kiln at a temperature of about 1300 to 1500 C°, at which temperature, the material sinters and partially fuses to form nodular shaped clinker. The clinker is cooled and ground to a fine power with addition of about 2 to 3% of gypsum. The product formed by using this procedure is Portland Cement.

There are two processes known as wet and dry processes depending upon whether the mixing and grinding of raw materials is done in wet or dry conditions.

In the met process, the limestone brought from the quarries is first crushed to smaller fragments. Then it is taken to a ball or tube where it is mixed with clay or shale as the case may be and ground to a fine consistency with water content of about 35 to 50 percent. The slurry is pumped to slurry tanks or basins where it is kept in an agitated condition by means of rotating arms with chains or blowing compressed air from the bottom to prevent setting of limestone and clay particles. The fuel is either powdered coal, oil or natural gas. By time the material rolls down to the lower end of a series of chemical reactions until finally, in the order of 1500 C°, about 20 to 30 percent of the materials get fused. Lime, silica and Alumina get recombined. The fused mass turns into nodular clinker drops into a rotary cooler where it is cooled under controlled conditions. The cooled clinker is then ground in a ball mill with the addition of 2 to 3 percent of Gypsum in order to prevent flash-setting of the Cement.

In the dry and semi-dry process the raw materials are crushed dry and fed in correct proportions into a grinding mill where they are dired and reduced to a very fine powder. The dry powder called the raw meal is then further blended and corrected for its right composition and mixed by means of compressed air. The aerated powder tends to behave almost like liquid and in about one hour of aeration a uniform mixture is obtained. A quantity of water about 12 percent by weight is added to make the blended meal into pellets. This is done to permit air flow for exchange of heat for further chemical reactions and conversion of the same into chinker further in the rotary kiln.

The equipment used in the early process kiln is comparatively smaller. The process is quite economical.

2.1.1.3 Chemical composition:

As a result of the chemical change which takes place within several compounds are formed in the resulting cement although only for (see Table 2-1) are general considered to be important. A direct determination of the actual proportion of these principle compounds is a very tedious process and it is more usual determined more easily.

The two silicates, C_3S and C_2S, which are the most stable of these compounds, together form 70 to 80 percent of the constituents in the cement and contribute most to the physical properties of concrete. When cement comes into contact with water, C_3S begins to hydrate rapidly, a significant contribution to the development of the early strength, particularly during the first 14 days. In contrast C_2S, which hydrates slowly and is mainly responsible for the development in strength after about 7 days, may be active for a considerable period of time. It is generally believed that cement rich in C_2S results in a greater resistance to chemical attack and a smaller drying shrinkage than do other Portland Cement. The hydration of C_3A is extremely exothermic and takes place very quickly, producing little increase in strength after 24 hours. Tetracalcium aluminoferrite, CuAf, is of less importance than other three compounds when considering the properties of hardened cement mortars or concrete.

Table (2-1)

Main chemical compounds of Portland Cement

Name of compounds	Chemical Composition	Usual abbreviation
Tricalcium silicate	$3C_aO\text{-}Sio_2$	C_2S
Dicalcium silicate	$2CaO\text{-}SIO_2$	C_2S
Tricalcium aluminate	$3C_aO\text{-}Al_2O_3$	C_3A
Tetracalcium aluminoferrite	$4CaO\text{-}Al_2O_3\text{-} Fe_2O_3$	C_uAF

2.1.1.4 Fineness:

The reaction between the water and cement starts on the surface of cement particles and in consequence the greater the surface area of a given volume of cement the greater the hydration. It follows that for a given composition, a fine cement will develop strength and generate heat more quickly than a coarse cement. It will, of course, also cost more to manufacture as the chinker must be more finely ground. Fine cements, in general, improve the cohesiveness of fresh concrete and can be effective in reducing the risk of bleeding, but they increase the tendency for shrinkage cracking. The measured fineness is an over-all value known as specific surface and is expressed in square centimeters per gram.

2.1.1.5 Hydration:

The chemical combination of cement and water, known as hydration, produces a very hard and strong binding medium for the aggregate particles in concrete and is accompanied by the liberation of heat, normally expressed as calories per gram. The rate of hydration depends on the relative properties of silicate and aluminate compounds, the cement fineness and the ambient conditions. Factors affecting the rate of hydration have a similar effect on the liberation of heat.

Concrete is a poor conductor of heat and the heat generated during hydration can have undesirable a effects on the properties of the hardened concrete as a result of microcracking of the binding medium. Other factors which effect the temperature of the concrete are the size of the structure, the ambient conditions, the type of formwork and the rate at which concrete is placed. The heat characteristics must be considered when determining the suitability of cement for a given job.

2.1.1.6 Setting and hardening:

Setting and hardening of the cement paste are the main physical characteristics associated with hydration of cement. Hydration results in the formation of a gel around each of the cement particles and in time these layers of gel grow to the extent that they come into contact with each other. At this stage the cement paste begins to lose its fluidity. The beginning of a noticeable stiffening in the cement paste is known as the initial set. Further stiffer occurs as the volume of gel increases and the stage at which this is complete and the final hardening process, responsible for its strength, commences is known as the final set. The times from the addition of water to the initial and final set are known as the setting times. In practices, when mixes have a higher water content than that used in the standard tests, the cement paste takes a correspondingly longer time to set. Setting time is affected by cement composition and fineness, and also, through its influence on the rate of hydration, by the ambient temperature.

Two further phenomena are a flash set and a false set. The former takes place in cement with reaction generating a considerable amount of heat and causing the cement to stiffen within a few minutes after mixing. This can only be overcome by adding more water which results in a reduction in strength. A false set also produces a rapid stiffening of the paste but is not accompanied by excessive heat.

2.1.1.7 Soundness:

An excessive change in volume, particularly expansion of cement past after setting indicates that the cement is unsound and not suitable for the manufacture of concrete. In general, the effects of using unsound cement may not be apparent for some considerable period of time, but usually manifest themselves in cracking and disintegration of the surface of the concrete.

2.1.8 Types of Cement:

The use of additives, changing chemical composition, and use of different raw materials have resulted in the availability of many types of cement to cater for the need of construction industries for purposes. The cements are classified as Portland Cements and Non-Portland Cements. The distinction is mainly based on the methods of manufacture. The Portland and Non-Portland are Cements generally used. The types are:

2.1.8.1 Portland Cements:

(a)Ordinary Portland Cement:

Has a medium rate of hardening, making it suitable for most concrete work. It has, however, a low resistance to chemical attack.

(b)Rapid-hardening Portland Cement:

Is in many ways a much higher early strength. The increased rate of hydration is accompanied by a high rate of heat of concrete, although this may be used to advantage in cold weather.

(c)Low-heat Portland Cement:

Has a limited use but is suitable for very large structures, such as concrete dams, where the use of ordinary cement would result in unacceptable large temperature gradients within the concrete.

(d)Sulphate resisting Portland Cement:

Except for its high resistance to sulphate attack, has principal properties similar to those of ordinary Portland Cement. Calcium chloride should not be used with this cement as it reduces its resistance to sulphate attack.

(e)Extra-rapid-hardening Portland Cement:

Is used when very high early strength is required or for concreting in cold conditions because of its rapid setting and hardening properties of concrete.

(f)Ultra-high early-strength Portland Cement:

A part from its much greater fineness and larger gypsum content, is similar in composition to ordinary Portland Cement. Although the early development in strength is considerably higher than with rapid-hardening cement there is little increase after 28 days.

(g)White and Coloured Portland Cement:

Are similar in basic properties to ordinary Portland Cement.

(h)Waterproof and water-repellent Portland Cement:

Produces a more impermeable fully compacted concrete than ordinary Portland Cement.

Air-entraining Portland Cement produces concrete with a greater resistance to frost attack. The cement is produced by intergrinding an air-entraining agent with ordinary clinker during manufacture. However, in practice, it is more advantageous to add an air-entraining agent during mixing since its quantity can be varied to meet particular requirements.

(j) Slag Cements:

Different type of slag cement can be produced by intergrinding varying properties of granulated blastfurnace slag with activators such as ordinary Portland Cement and gypsum. The chemical composition of the granulated slag is similar to that of Portland Cement but the proportions are different. One general requirement is that the slag used must have a high lime content.

(k)High-alumina Cement:

This cement, which is manufactured by melting a mixture of limestone, chalk and bauxite. The high proportion of aluminate, about 40 percent, brings about a very high early strength and consequently wet Portland 24 hours to avoid damage from the associated heat of hydration. The cement can be beneficially employed for concreting in winter condition. It has a wide application in refractory concrete. Its resistance to chemical attack is greater than that of Portland Cement although in its concerted, more porous, state it is very susceptible to alkali and sulphate attack.

(l)Pozzolanic Cement:

Pozzolanic cement is made by grinding together up to 40 percent of a pozzolanic material with ordinary Portland Cement. Pozzolanic materials combine with the lime released during the setting and hardening of Portland Cement and from cementitious materials. The rate of gain in strength and liberation of heat is slower than for ordinary Portland Cement, and this can be useful for mass concrete work. Like sulphate resisting Portland Cement, it has a high resistance to chemical attack.

(m) Hydration of Cement:

Anhydrous cement compounds when mixed with water, react with each other to form hydrated compounds of very low solubility. The first is "through solution" mechanism. In this the cement compounds dissolve to produce a supersaturated solution from with different hydrated products get precipitated.

The second possibility is that water attacks cement compounds in the solid state converting the compounds into hydrated products. Starting from the surface and proceeding to the interior of the compounds with time. The former mechanism may predominate in the early stages of hydration in view of large quantities of water being available, and the latter mechanism may operate during the later stages of hydration.

The hydration process is not instantaneous one. The reaction is faster in the early period and continues indefinitely at a decreasing rate. Complete hydration cannot be obtained under a period of one year or more unless the cement is very finely ground and reground with excess of water to expose fresh surfaces at intervals.

2.1.1.9 Structure of Hydrated Cement:

To understand the behaviour of concrete it is necessary to acquaint ourselves with the structure of hydrated cement paste. If the concrete is considered as two phase material, namely, the paste phase and the aggregate phase, the understanding of the paste phase becomes more important as it influences the behaviour of concrete to a much greater extent.

The mechanical properties of the hardened concrete depend more on the physical structure of the products of hydration than on the chemical composition of the cement.

2.1.2 AGGREGATE:

Aggregates are the important constituents in concrete. They give body to the concrete, reduce shrinkage and effect economy. The mear fact that the aggregate occupy 70-80 percent of the volume of concrete, their impact on various characteristics and properties of cement is undoubtedly considerable. To know more about the concrete it is very essential that one should know more about the aggregate which constitute the major volume in concrete. Without the study of the aggregate in depth and range, the study of the concrete is incomplete. Cement is the only factory made standard component in concrete. Other ingredients, namely, water and aggregates are natural materials and can vary to any extent in many of their properties.

2.1.2.1 Classification:

Aggregates can be classified as:

(I) Norman weight aggregates.

(II) Light weight aggregates.

(III) Heavy weight aggregates.

Norman weight aggregate can be further classified as natural aggregates and artificial aggregates.

Natural:

Sand, Graval, Crushed Rock such as Granite, Quartzite, Basalt and Sandstone.

Artificial:

Broken Brick, Air-cooled Slag. Aggregate can also be classified on the basis of the size of the aggregates as coarse aggregate and fine aggregate.

2.1.2.2 Physical properties:

The properties of the aggregate known to have a significant effect on concrete behaviour are its strength, deformation, durability, toughness, hardness, volume change, porosity, specific gravity and chemical reactivity.

The strength of an aggregate limits the attainable strength of concrete only when its compressive strength is less than or the same order as the design strength of concrete. In practice the majority of rock aggregates used are usually considerably stronger than concrete. While the strength of concrete does not normally exceed 80 N /mm-2 and generally between 30 and 50 N mm^{-2} the strength of the aggregate commonly used is in range 70 to 350 N mm^{-2}. In general, igneous rocks are very much stronger then sedimentary and metamorphic rocks. Because of the irregular size and shape of aggregate particles a direct measurement of their strength properties is not possible. These are normally assessed from compressive strength tests on cylindrical specimens taken from the parent rock and from crushing value tests on the bulk aggregate. For weaker materials, that is, those with crushing values greater than 30, the crushing value may be unreliable and load required to produce 10 percent fines in the crushing test should be used. The results of these tests for the strength properties of aggregates are only a guide to aggregate quality, however, which may also be assessed from the intensity of aggregate fracturing in ruptured concrete specimens.

The deformations of aggregate also play an important part in the creep and shrinkage properties of concrete as the restraint afforded by the aggregate to the creep and shrinkage of the cement paste depends on their relative moduli of elasticity.

A commonly used definition for aggregate toughness is its resistance to failure by impact and this is normally determined from the aggregate impact test. Hardness is the resistance of an aggregate to water and is normally determined by an abrasion test.

Volume changes due to moisture movements in aggregate derived from sandstones, greywackes and some basalts may result in considerable shrinkage of the concrete. If the concrete is restrained this produces internal stresses, possible tensile cracking and subsequent deterioration of concrete.

Aggregate porosity is an important property since it affects the behaviour of both freshly mixed and hardened concrete through its effect on the strength, water absorption and permeability of aggregate. An aggregate with high porosity will tend to produce a less durable concrete, particularly when subjected to freezing and thawing, than an aggregate with low porosity. The water absorption is defined as the weight of water absorbed by a dry aggregate in reaching a saturated surface-dry state and is expressed as a percentage of the weight of the dry aggregate.

The total moisture content, that is the absorbed moisture plus the free or surface water, of aggregate used for making concrete varies considerably. The water added at the mixer must be adjusted to take account of this if the fee water content is to be kept constant and the required workability and strength of concrete maintained. Concrete mix proportions are normally based on the weight of aggregate in their saturated surface-dry condition. Any change in their moisture content must be reflected in adjustments to the weights of aggregates used in the mix.

2.1.2.3 Shape and Surface Texture:

Aggregate shape and surface texture can affect the properties of concrete in both its plastic and hardened states. These external characteristics may be assessed by observation of the aggregate particles and classification of their particle shape and texture in accordance with Table (2-2) and Table (2-3) from BS S12. The classification is somewhat subjective, however, and the particle shape may also be assessed by direct measurement of the aggregate particles to determine the flakiness, elongation and angularity.

Table (2-2)

Shape of aggregate, BS 812

Classification	Description
Round	Fully water-worm or completely shaped by attribution
Irregular	Naturally irregular, or party shape by attribution and having rounded edges
Angular	Possessing well-defined edges formed at the intersection of roughly planar faces
Flaky	Material of which the thickness is small relative to the other two dimensions
Elongated	Material, usually angular, in which the length is considerably larger than the other two dimensions
Flaky and elongated	Material having the length considerable larger than the width, and the width considerably larger than thickness

Table (2-3)

Surface texture of aggregate, BS 812

Surface texture	Characteristics
Classy	Conchoidal fracture
Smooth	Water-worn, or smooth due to fracture of laminated or fire-grained rock
Granular	Fracture showing more or less uniform rounded grains
Rough	Rough fracture of fire or medium-grained rock containing no easily visible crystalline constituents
Honey combed	With visible pores and cavities
Crystalline	Containing easily visible crystalline constituents

The angularity is expressed in terms of the angularity number. This is difference between the solid volume of rounded aggregate particles the after compaction in a standard cylinder, expressed as a percentage of the volume of the particular aggregate being investigated when compacted in a similar manner.

2.1.2.4 Source:

Almost all natural aggregate materials originate from bed rocks. There are three kinds of rocks, namely, igneous, sedimentary and metamorphic. These classifications are based on the mode of formation of rocks. It may be recalled that igneous rocks are formed by the cooling of molten magma or lava at the surface of the crest or deep beneath the crest (granite). The sedimentary are formed originally below the sea bed and subsequently lifted up. Metamorphic rocks are originally either igneous or sedimentary rocks which are subsequently metamorphosed due to extreme heat and pressure. The concrete making properties of aggregate are influenced to some extent on the strength of geological formation of the parent rocks together with the subsequent processes of weathering and alteration. Within the main rock group, say granite group, the quality of aggregate may vary to a very great extent owing to change in the structure and texture of the main parent rock from place to place.

2.1.2.5 Strength:

When we talk of strength we do not imply the strength of the parent rock from which the aggregates are produced, because the strength of the rock does not exactly represent the strength of the aggregate in concrete. Since concrete is an assemblage of individual pieces of aggregate bound together by cementing material, its properties are based primarily on the quality of the cement paste. This strength is dependent also on the bond between the cement paste and the aggregate. If either the strength of the paste or the bond between the paste and aggregate is low a concrete of poor quality will be obtained irrespective of the strength of the rock or aggregate. But when cement paste of good quality is provided and its bond with the aggregate is satisfactory, then the mechanical properties of the rock or aggregate will influence the strength of concrete. In other words, from a week rock or aggregate strong concrete cannot be made. By en large naturally available mineral aggregate are strong enough for making normal strength concrete. The test for strength of aggregate is required to be made in the following situations:

(I) For production of high strength and ultra high strength concrete.

(II) When contemplating to use aggregate manufacture from weathered rocks.

(III) Aggregate manufactured by industrial process.

Strength of rock is found out by making a test specimen of cylindrical shape of size 25 mm subjected to compressive stress. Different rocks samples one found to give different compressive strength varying from a minimum of about 450 kg/cm^2 to maximum of 5450 kg/cm^2.

As said earlier, the compressive strength of parent rock does not exactly indicate the strength of aggregate in concrete. For this reason assessment of strength of the aggregate is made by using a sample of bulk aggregate in a standardised manner. This test is known as aggregate crushing value test.

The crushing value of aggregate is rather insensitive to the variation in strength of weaker aggregate. This is so because having been crushed before the application of the full load of 40 ton, the weaker materials become compacted, so that the amount of crushing during the later stages of the test is reduced.

2.1.2.6 Soundness of aggregate:

Soundness refers to the ability of aggregate to resist excessive changes in volume as a result of changes in physical conditions that affect the soundness of aggregate are the freezing and thawing, variation in temperature, alternate wetting and drying in salt water. Aggregate which are porous, weak and containing any undesirable extraneous matters undergo excessive volume change when subjected to the above conditions. Aggregated which undergoes more than the specified amount of volume changes is said to be unsound aggregate. If concrete is llabel to be exposed to the action of frost the coarse and the fine aggregate which are going to be used should be subjected to soundness test.

2.1.2.7 Grading of Aggregates:

Aggregate comprised about 55 percent of the volume of mortar and about 85 percent volume of mass concrete. Mortar contains aggregate of size of 4.72 mm and concrete contains aggregate up to a maximum size 150 mm.

This is not surprising that the way particles of aggregate fit together in the mix, as influenced by the gradation, shape and surface texture, has an important effect on the workability and finishing characteristic of fresh concrete, consequently on the properties of hardened concrete.

It is well known that the strength of concrete is dependent upon water/cement ratio provided the concrete is workable. In this statement, the qualifying clause "provided the concrete is workable" assumes full importance. One of the most important factors for producing workable concrete is good gradation of aggregate. Good grading implied that a sample of aggregate contains all standard fractions of aggregate is required proportion such that the sample contains minimum voids. A sample of the well graded aggregate containing minimum voids will require minimum paste to fill up the voids in the aggregates. Minimum paste will mean less quantity of cement and less quantity of water, which will further mean increased economy, higher strength, lower-shrinkage and greater durability.

The advantages due to good grading of aggregate can also be viewed from other angle. If concrete is viewed as a two phase material, paste phase and aggregate phase, it is the paste phase which is vulnerable to all of concrete. Paste is weaker than average aggregate in normal concrete with rare exceptions when very soft aggregates are used.

2.1.2.8 Sieve Analysis:

This is the name given to the operation of dividing a sample of aggregate into various fractions each consisting of particles of the same size. The sieve analysis is conducted to determine the particle size distribution in a sample of aggregate, which it called gradation.

A convenient system of expressing the gradation of aggregate is one in which consecutive sieve openings are constantly doubled, such as 10 mm, 20 mm, 40 mm etc. Under such a system, employing a logarithmic scale, lines can be spaced at equal intervals to represent the successive sizes.

The aggregate used for making concrete are normally of the maximum size 80 mm, 40 mm, 20 mm, 10 mm, 4.75 mm, 2.36 mm, 600 micron, 300 micron and 150 micron.

2.1.2.9 Combining aggregate to obtain specified gradings:

Some time aggregate available at sites may not be of the specified or desirable grading. In such cases two or more aggregate from different sources may be combined to get the desired grading. Often, mixing of available fine aggregate with available coarse aggregate in appropriate percentages may produce desirable gradings. But sometimes two or more fractions of coarse aggregate are mixed first and then the combined coarse aggregate is mixed with fine aggregate to obtain the desired grading. Knowing the gradings of available aggregate, proportions of mixing different sizes can be calculated, either graphically or arithmetically.

2.1.3 WATER:

Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. Since it helps to form the strength giving cement gel, the quantity and quality of water is required to be looked into very carefully.

Some specifications require that if the water is not obtained from a source that has proved satisfactory, the strength of concrete or mortar made with questionable water should be compared with similar concrete or mortar made with pure water. Some specifications also accept water for making concrete if the PH value of water lies between 6 and 8 and the water is free from organic matter. Instead of depending upon PH value and other chemical composition, the best course to find out whether a particular source of water is suitable for concrete making or not, is to make concrete with this water and compare its 7 days and 28 days strength with companion cubes made with distilled water. If the compressive strength is up to 90 percent, the source of water may be accepted.

This criteria may be safely adopted in places like coastal area or marshy area or in other places where the available water is brackrish in nature and of doubtful quality. However, it is logical to know what harm the impurities in water do to the concrete and what degree of impurity is permissible for mixing concrete and curing concrete.

Carbonates and bi-carbonates of sodium and potassium effect the setting time of cement. While sodium carbonate may cause quick setting, the bi-carbonates may either accelerate or retard the setting. The other higher concentrations of these salts will materially reduce the concrete strength.

Brackrish water contains chlorides and sulphates. When chloride does not exceed 100.000 ppm and sulphate does not exceed 3.000 ppm the water is harmless, but water with even higher salt content has been used satisfactorily.

Salts of Manganese, Tin, Zn, Copper and lead cause a marked reduction in strength of concrete. Sodium iodate, sodium phosphate and sodium borate reduce the initial strength of concrete to an extra-ordinarily high degree.

Algae in mixing water may cause a marked reduction in strength of concrete either by combining with cement to reduce the bond or by causing large amount of air entrainment in concrete. Algae which are present on the surface of the aggregate have the same effect as in that of mixing water.

Sea water has a salinity of about 3.5 cent. It is reported that the use of sea water of mixing concrete does not appreciably reduce the strength of concrete although it may lead to corrosion of reinforcement in certain cases. Research workers are unanimous in their opinion, that sea water slightly accelerates the setting time of cement.

Water containing large quantities of chlorides in sea water may cause efflorescence and persistent dampness.

The use of sea water is also not advisable for plstering purpose which is subsequently going to be painted.

It is pertinent at this point to consider the suitability of water for curing. Water that contains impurities which cause staining, is objectionable for curing concrete members.

The most common cause of staining is usually high concentration of iron or organic matter in the water. In other cases, the water, normally fit for mixing can also be used for curing.

2.1.4 ADMIXTURES:

Admixture is defined as a material, other than cement, water and aggregate, that is used as an ingredient of concrete and is added to the batch immediately before or during mixing.

These days concrete is being used for many purposes in different conditions. In these conditions ordinary concrete may fail to exhibit the required quality or durability. In such cases, admixture is used to modify the properties of ordinary concrete so as to make it more suitable for any situation.

Until about 1930 additives and admixtures though used, were not considered an important part of concrete technology. Since then, there has been an increase in the use of admixture, foster the use and development of admixture as it imparts many desirable characteristics and a effects economy in concrete construction.

It will be slightly difficult to predict the effect and the results of using admixtures because many a time the change in the brand of cement, aggregate grading, mix proportions and richness of mix alter the properties of concrete. Sometimes many admixtures affect more than one property of concrete, sometimes they affect the desirable properties adversely. Therefore one must be cautious in the selection of admixtures and in predicting the effect of admixture in concrete.

An admixture may be considered when it is desired to modify for a particular reason the properties of fresh or hardened concrete, or both thy consist chiefly of those which improve workability, Retarders and Acceleraters. Others are water proofers, Pigments, Air entraining agents and Pozzolanas.

Concrete can be formed by mixing cement, water and aggregate. Initially the resulting paste is plastic and workable but a few hours later hydration reaction takes place between cement and water of the mix. Properly engineered concrete mixes are designed to meet the requirement of a given job at the lowest cost, and admixture can play an important part in achieving this aim.

2.1.4.1 Types of admixtures:

Several hundred proprietary admixtures are available and since a great many usually contain several chemicals intended simultaneously to change several properties of concrete, they are not easy to classify. Moreover, as many of the individual constituents and their proportions are not widely known the selection of an admixture must frequently be based on the information provided by the suppliers. They are different types of admixture:

(a)Air-entertaining agents:

These are probably the most important group of admixtures. They improve the durability of concrete, in particular its resistance to effects of frost and deicing salts. The entertainments of air form of very small and stable bubbles can be achieved by using foaming agents based on natural resins, animal or vegetable fast and synthetic detergents which promote the formation air bubbles during mixing or by using gas-producing chemicals such as zinc or aluminum powder which react with cement to produce gas bubbles. The first method is general more effective and is the most widely used. The beneficial effects of entrained air are produced in two ways:

(I) First:

By disrupting the continuity of capillary pores and thus reducing the permeability of concrete.

(II) Second:

By reducing the internal stresses caused by the expansion of water on freezing

Air-entraining agents also improve the workability and cohesiveness of fresh concrete and tend to reduce bleeding and segregation. However, entrained air results in some reduction in concrete strength. Since improvements in workability can permit a reduction in the water content the loss in strength can be minimized. The amount of entrained air is dependent on the type of cement, mix proportions and ambient temperature and it should therefore only be used when adequate supervision is assured.

(b)Accelerating agents:

These can be divided into groups, namely, setting accelerators and setting and hardening accelerators.

The first of these are alkaline solutions which can considerably reduce the setting time and are particularly suitable for repair work involving water leakage. Because of their adverse effect on subsequent strength development these admixtures should not be used where the final concrete strength is an important consideration. Setting and hardening accelerators increase the rate of both setting and early strength development.

(c) Retarders:

Most admixtures in this group are based on lignosulphonic or hydroxylated-carboxylic acids and their salts with cellulose or starch. They are used mainly in hot countries where high temperatures can reduce the normal setting and hardening times.

A slightly reduced water content may be used when using these retarding agents, with a corresponding increase in final concrete strength.

(d)Water reducers or plasticizers:

These admixtures are also based on lignosulphonic and hydroxylated-carboxylic acids. Their effect is thought to be due to an increase of dispersion of cement particles causing a reduction in the viscosity of the concrete. They are used to increase workability and are normally employed with harsh mixes or where placement is difficult. They can also be used to increase strength and durability since for a given workability less water is necessary.

(e)Pigments:

Colouring pigments are normally used for architectural purposes and the best effect is produced when they are interground with the cement clinker rather than when added during mixing.

(f)Pozzolanas:

The most commonly used pozzolanas are pumicite and pulverized fuel ash. Because of their reaction with lime, which is liberated during the hydration of cement, these materials can improve the durability of concrete. Since they retard the rate of setting and hardening but have no long term effect on strength (provided proper curing is maintained) they can be used in mass concrete work.

(g)Pore fillers:

These are chemically inactive finely ground materials such as bentonite, kaoline or rock flour.

These admixtures are thought to improve workability, stability and impereability of concrete.

(h)Water-repelling agents:

These are the least effective of all admixtures and are based on metallic scraps or vegetable or mineral oils. Their use gives a slight temporary reduction in concrete permeability.

2.2 CONCRETE PROPERTIES

2.2.1 FRESH CONRETE:

2.2.1.1 General

Fresh concrete is a mixture of water, cement, aggregate and admixture (if any). After mixing, operations such as transporting, placing, compacting and finishing of fresh concrete can all considerably affect the properties of hardened concrete. It is important that the constituent materials remain uniformly distributed within the concrete mass during the various stages of its handling and that full compaction is achieved. When either of these conditions is not satisfied the properties of the resulting hardened concrete, for example, strength and durability, are adversely affected.

The characteristics of fresh concrete which effect full compaction are its consistency, mobility and compactability. In concrete practice these are often collectively known as workability. The ability of concrete to maintain its uniformity is governed by its stability, which depends on its consistency and its cohesiveness. Since the methods employed for conveying, placing and consolidating a concrete mix, as well as the nature of the section to be cast, may vary from job to job it follows that the corresponding workability and stability requirements will also vary. The assessment of the suitability of fresh concrete for a particular job will always to some extent remain a matter of personal judgment.

2.2.1.2 Concrete Mixing:

Thorough mixing of the materials is essential for the production of uniform concrete. The mixing should ensure that the mass becomes homogeneous, uniform in co lour and consistent. There are two methods of mixing concrete:

(a) Hand mixing.

(b) Machine mixing.

(a) Hand Mixing:

Hand mixing is practiced for small scale unimportant concrete works. As the mixing cannot be thorough and efficient, it is desirable to add 10 percent more cement to cater for inferior concrete produced by this method.

Hand mixing should be done over an impervious concrete or brick floor of sufficiently large size to take one bag of cement. Spread out the measured quantity of coarse aggregate and fine aggregate in alternate layers. Pour the cement on the top of it, and mix them dry by a shove, turning the mixture over and over again until uniformity of co lour is achieved. This uniform mixture is spread out in the thickness of about 20 cm. Water is taken in water-can fitted with a rose-head and sprinkled over the mixture and simultaneously turned over. This operation is continued for such a time till a good uniform, homogenous concrete is obtained. It is of particular importance to see that the water is not poured out but it is only sprinkled. Water in small quantity should be added towards the end of the mixing to get the just required consistency. At that stage, even a small quantity of water makes a difference.

(b) Machine Mixing:

Mixing of concrete is almost invariably carried out by machine, for reinforced concrete work and for medium or large scale mass concrete work. Machine mixing is not only efficient, but also economical, when the quantity of concrete to be produced is large.

Many types of mixers are available for mixing concrete. They can be classified as batch mixers and continuous mixers. Batch mixers produce concrete, batch by batch with time interval, whereas continuous mixers produce concrete continuously with out stoppage till such a time as the plant is working. In this, materials are fed continuously by screw feeders and the materials are continuously mixed and discharged. This type of mixers are used in large works such as dams. In normal concrete work, it is the batch mixers that are used. Batch mixer may be of pan type or drum type. The drum type may be further classified as tilting or reversing or forced action type.

Very little is known about the relative mixing efficiencies of the various types of mixers, but some evidences are there to suggest that pan mixers with a revolving star of bladers are more efficient. They are specially suitable for stiff and lean mixes, which present difficulties with most other types of mixers, mainly due to sticking of mortar in the drum. The shape of the drum, the angle and size of blades, the angle at which the drum is held, affect the efficiency of mixer. It is seen that tiling drum to some extent is more efficient than non-tiling drum. In non-tiling drum for discharging concrete, a chute is introduced into the drum by operating a lever. The concrete which is being mixed in the drum, falls into the inclined chute and gets discharged out. It is seen that a little more of segregation takes place, when a non-tiling mixer is used. It is observed in practice that, generally, in any type of mixer, even after thorough mixing in the drum, while it is discharged, more of coarse aggregate comes out first and at the end matrix gets discharged. It is necessary that a little bit of remixing is essential, after discharged from mixer, on the platform to off set the effect of segregation caused while concrete is discharged from the mixer.

2.2.1.3 Mixing time:

Concrete mixers are generally designed to run at a speed of 15 to 20 revolutions per minute. For proper mixing, it is seen that about 25 to 30 revolutions are required in a well designed mixer. In the site, the normal tendency is to speed up the outturn of concrete by reducing the mixing time. This results in poor quality of concrete. On the other hand, if the concrete is mixed for a comparatively longer time, it is uneconomical from the point of view of rate of production of concrete and fuel consumption. Therefore it is of importance to mix the concrete for such duration which will accrue optimum benefit. It seen from the experiments that the quality of concrete in terms of compressive strength will increase with increase in the time mixing, but for mixing time beyond two minutes, the improvement in compressive strength is not very significant.

2.2.1.4 Placing concrete:

It is not enough that a concrete mix is correctly designed, batched, mixed and transported, it is of utmost importance that the concrete must be placed in a systematic to manner to yield optimum results.

2.2.1.5 Workability:

A theoretical water-cement ratio calculated from the consideration discussed above is not going to give an ideal situation for maximum strength. Hundred percent compaction of concrete is an important parameter for contributing to the maximum strength. Lack of compaction will result in air voids whose damaging effect on strength and durability is equally or more predominant than presence of capillary activities.

A concrete which can be readily compacted is said to be workable, but to say merely that workability determines the ease of placement and the resistance to segregation is too loose a description of the vital property of concrete. Furthermore, the desired workability in any particular case would depend on the means of compaction available, likewise, a workability suitable for mass concrete is not necessarily sufficient for thin, inaccessible, or heavily reinforced section. For these reasons, workability should be defined as a physical property of concrete done without reference is not necessarily sufficient for thin, inaccessible, or heavily reinforced section. For these reasons, workability should be defined as a physical property of concrete alone without reference to the particular type of construction. Workability has so far been discussed merely as a property of fresh concrete. It is, however, also a vital property as far as the finished product is concreted because must have a workability such that compaction to maximum density is possible with a reasonable amount of work or with the amount that we are prepared to put in under given conditions.

The need for compaction becomes apparent from a study of the relation between the degree of compaction and the resulting strength. It is convenient to express the former as a density ratio, i.e. ratio of the actual density of the given concrete to the density of the same mix when fully compacted.

2.2.1.5.1 Measurement of workability

Three tests widely used for measurement of workability are the slump, compacting factor and V-B consistometer tests .They are standard tests in the United Kingdom .It is important to note that there is no single relationship between the slump , compacting factor and V-B results for different concretes .

Slump Test , primarily measures the consistency of plastic concrete and although it is difficult to see any significant relationship between slump and workability as defined previously ,it is suitable for detecting changes in workability .

Compacting Factor test requires measurement of the weights of the partially and fully compacted concrete and the ratio of the partially compacted weight to fully compacted weight. The test is particularly useful for drier mixes for which the slump test is not satisfactory

2.2.1.5.2 Factors Affecting Workability:

Workable concrete is the one which exhibits very little internal friction between particle and particle or which overcomes the friction resistance offered by the formwork surface or reinforcement contained in the concrete with just the amount of compacting efforts forth-coming. The factors helping concrete to have more lubricating effect to reduce internal friction for helping easy compaction are given below:

(a) Water content:

Water content in a given volume of concrete, will have significant influences on the workability. The higher the water content per cubic meter of concrete, the higher will be the fluidity of concrete, which is one of the important factors affecting workability. At the work site, supervisors who are not so much well versed with practice of making good concrete, resort to adding more water for increasing workability. This practice is often resorted to because this is one of the easiest corrective measures that can be taken at site. It should be noted that from the desirability point of view, increase of water content is the last recourse to be taken for improving the workability even in the case of uncontrolled concrete. For controlled concrete one cannot arbitrarily increase the water content, in case all other steps to improve more water can be considered. More water can added, provided a corresponding higher quantity of cement is also added to keep the water/cement ratio constant, so that the strength remains the same.

(b) Mix proportion:

Aggregate/cement ratio is an important factor influencing workability. The higher the aggregate/cement ratio, the leaner is the concrete. In lean concrete, less quantity of paste is available for providing lubrication per unit surface area of aggregate and hence the mobility of aggregate is restrained. On the other hand, in case of rich concrete with lower aggregate/cement ratio, more paste is available to make the mix cohesive and fatty to give better workability.

(c) Size of aggregate:

The bigger size of the aggregate, the less is the surface area and hence less amount of water is required for wetting the surface and less matrix or paste is required for lubricating the surface to reduce internal friction. For a given quantity of water and paste a bigger size of aggregate will give higher workability. The above, of coarse will be true within certain limits.

(d) Shape of aggregate:

The shape of aggregate influences workability in good measure. Angular, elongated or flaky aggregate makes the concrete very harsh when compared to rounded aggregates or cubical shaped aggregates. Contribution to better workability of rounded aggregate will come from the fact that for the given volume or weight it will have less surface area and less voids than angular or flaky aggregate. Not only that, being round in shape, the frictional resistance is also greatly reduced. This explains the reason why river sand gravel provides greater workability to concrete than crushed sand and aggregate.

(e) Surface texture:

The influence of surface texture on workability is again due to the fact that the total surface area of rough textured aggregate is more than the surface area of smooth rounded aggregate of same volume. It can be inferred that rough textured aggregate will show poor workability and smooth or glassy textured aggregate will give better workability. A reduction of inter particle frictional resistance offered by smooth aggregate also contributes to higher workability.

(f) Grading of aggregate:

This is one of the factors which will have maximum influence on workability. A well graded aggregate is the one which has least amount of voids in a given volume. Other excess amount of paste, the mixture becomes cohesive and fatty which prevents segregation of particles. Aggregate particles will slide past each other with the least amount of compacting efforts.

2.2.1.6 Segregation:

Segregation can be defined as the separation of the constituent materials of concrete. A good concrete is one in which all the ingredients are properly distributed to make a homogeneous mixture.

There are considerable differences in the sizes and specific gravities of the constituent ingredients of concrete. Therefore it is natural that the materials show a tendency to fall apart. Segregation may be by of three types, firstly, the coarse aggregate separating out or setting down from the rest of the matrix, secondly, the paste or matrix separating away from coarse aggregate and thirdly, water separating out from the rest of the material being a material of lowest specific gravity.

A well made concrete, that is, the concrete made taking into consideration various parameters such as grading, size, shape and surface texture of aggregate with optimum quantity of water makes a cohesive mix. Such concrete will not exhibit any tendency for segregation. The cohesive and fatty characteristics of matrix do not allow the aggregate to fall apart, at the same time, the matrix itself is sufficiently contained by the aggregate. Similarly water also does not find it easy to move out freely from the rest of the ingredients.

The conditions favorable for segregation are, as can be seen from the above para, the badly proportioned mix where sufficient matrix is not there to bind and contain the aggregates.

Insufficiently mixed concrete with excess water content shows a higher tendency for segregation. Dropping of concrete from heights as in the case of placing concrete in column concreting will result in segregation. When concrete is discharged from a badly designed mixer, or from a mixer with worn out blades, concrete by Conveyer Belts, wheel Barrow, long distance haul by dumper, long lift by skip and hoist are the other situations promoting segregation of concrete.

Vibration of concrete is one of the important methods of compaction. It should be remembered that only comparatively dry mix should be vibrated. If too wet a mix is excessively vibrated, it is likely that the concrete gets segregated. It should also be remembered that vibration is continued just for the required time for optimum results. If the vibration is continued for a long time, particularly, in too wet a mix, it is likely to result in segregation of concrete due to settlement of coarse aggregate in matrix.

Segregation is difficult to measure quantitatively, but it can be easily observed at the time of concreting operation. The pattern of subsidence of concrete in slump test or the pattern of spread in flow test gives a fair idea of quantity of concrete with respect to segregation.

2.2.1.7 Bleeding:

Bleeding is sometimes referred to as water gain. It is a particular form of segregation, in which some of water from the concrete comes out to the surface of the concrete, being of the lowest specific gravity among all the ingredients of concrete. Bleeding is predominantly observed in a highly wet mix, badly proportioned and roof slab or road slabs and when concrete is placed in sunny weather excessive bleeding is observed.

Due to bleeding, water comes up and accumulates at the surface. Sometimes, along with this water, certain quantity of cement also comes to the surface. When the surface is worked up with the trowel and flacts, the aggregate matter goes down and the cement and water comes up to the top surface. This formation of cement paste at the surface of slabs and pavements will not have good wearing quality. This laitance produces dust in summer and mud in rainy season.

Water while traversing from bottom to top, makes continuous channels. If the water cement ratio used is more than 0.7, the bleeding channels will remain continuous and unsegmented by the developing gel. These continuous bleeding channels are often responsible for causing permeability of the concrete structures.

While the mixing water is in the process of coming up, it may be intercepted by aggregates. The bleeding water is likely to accumulate below the aggregate. This accumulation of water creates water voids and reduces the bond between the aggregates and the paste. The above aspect is more pronounced in the case of flaky aggregate. Similarly, the water that accumulates below the reinforcing bars, particularly below the cranked bars, reduces the bond between the reinforcement and the concrete. The poor bond between the aggregate and the paste or the reinforcement and the paste due to bleeding can be remedied by revibration of concrete. The formation of laitance and the consequent bad effect can be reduced by delayed finishing operations.

Bleeding rate increases, with time up to about one hour or so and there after the rate decreases but continues more or less till the final setting time of cement.

Bleeding is an inherent phenomenon in concrete. All the same, it can be reduced by proper proportioning and uniform and complete mixing. Use of finely divided up pozzolanic material reduces bleeding by creating a longer path for the water traverse. It is also reported that the bleeding can be reduced by the use of finer cement or cement with low alkali content. Rich mixes are less suceptible to bleeding than lean mixes.

The bleeding is not completely harmful if the rate of evaporation of water from the surface is equal to the rate of bleeding. Removal of water, after it had played its rote in providing workability, from the body of concrete by way of bleeding will do good to the concrete. Early bleeding when the concrete mass is fully plastic, may not cause much harm, because concrete being in fully plastic condition at that stage, will get subsided and compacted. It is delayed bleeding, when the concrete has lost its plasticity, that causes undue harm to the concrete. Controlled revibration may be adopted to overcome the bad effect of bleeding.

2.2.2 HARDENED COCNCRETE:

2.2.2.1 General:

The properties of fresh concrete are important only in the first few hours of its history whereas the properties of hardened concrete assume an importance which is retained for the remainder of the life of concrete. The important properties of hardened concrete are strength, deformation under load, durability, permeability and shrinkage.

In general, strength is considered to be most important property and quality of concrete is often judged by its strength. There are, however, many occasions when other properties are more important, for example, low permeability and low shrinkage are required for water-retaining structures. Although in most cases an improvement in strength results in an improvement of the other properties of concrete there are exceptions. For example, increasing the cement content of a mix improves strength but results in higher shrinkage which in extreme cases can adversely affect durability and permeability.

Since the properties of concrete change with age and environment it is not possible to attribute absolute values to any of them.

Laboratory tests give only an indication of properties which concrete may have in the actual structures as the quality of concrete in the structure depends on the workmanship on site.

2.2.2.2 Strength:

The strength of concrete is defined as the maximum loads (stress) it can carry. As the strength of concrete increase its other properties usually improve and since the tests for strength, particularly in compression, are relatively simple to perform concrete compressive strength is commonly used in the construction industry for the purpose of specification and quality control. Concrete is a comparatively brittle material which is relatively weak in tension.

(a) Compressive strength:

The compressive strength of concrete is taken as the maximum compressive load it can carry per unit area. Concrete strengths of up to 80 N/mm^2 can be achieved by selective use of the type of cement, mix proportions, method of compaction and curing conditions.

Concrete structures, except for road pavements, are normally designed on the basis that concrete is capable of resisting only compression, the tension being carried by steel reinforcement.

In the United Kingom a 150 mm cube is commonly used for determining the compressive strength. The standard method described in BS 1881 Part 3 requires that the test specimen should be cured in water at

$20^{\circ} \pm 1\ C^{\circ}$ and crushed immediately after it has been removed from the curing tank.

(b) Tensile strength:

The tensile strength of concrete is of importance in the design of concrete roads and runways. For example, its flexural strength or modulus of rupture (tensile strength in bending) is utilized for distributing the concentrated loads over a wider area of road pavement. Concrete members are also required to withstand tensile stresses resulting from any restraint to contraction due to drying or temperature variation.

Unlike metals, it is difficult to measure concrete strength in direct tension and indirect methods have been developed for assessing this property. Of these the split cylinder test is the simplest and most widely used.

The flexural strength of concrete is another indirect tensile value which is also commonly used (BS. 1881 Party 4). In this test a simple support plain concrete beam is loaded at its third points, the resulting bending moments inducing compressive and tensile stresses in the top and bottom of the beam respectively.

2.2.2.3 Factors influencing strength:

Several factors affect the strength of concrete. In this section their influence is discussed with particular reference to compressive strength.

(a) Influence of the constituent materials:

(i) Cement:

The influence of cement on concrete strength, for given mix proportions, is determined by its fineness and chemical composition through the process of hydration. The gain in strength is most marked at early ages and after 28 days the relative gain in strength is much reduced. At some later age the strength of concrete made with fine cements may not be very different from that made with normal cement.

(ii) Water:

A concrete mix containing the minimum amount of water required for complete hydration of its cement, if it could by fully compacted, would develop the maximum attainable strength at any given age. A water-cement ratio of approximately 0.25 (by weight) is required for full hydration of the cement but with this water content a normal concrete mix would be extremely dry and virtually impossible to compact.

A partially compacted mix will contain a large percentage of voids and the concrete strength will drop. On the other hand, while facilitating placing and compaction, water in excess of that required for full hydration produces water, even for a fully compacted concrete.

(iii) Aggregate:

When concrete is stressed, failure may originate within the aggregate, the matrix or at the aggregate-matrix interface, or any combination of these may occur.

In general the aggregates are stronger than concrete itself. In such cases the aggregate strength has little effect on the strength of concrete. A smooth rounded aggregate will result in a weaker bond between the aggregate and matrix than an angular or irregular aggregate or an aggregate with a rough surface texture.

Aggregate shape and surface texture affect the tensile strength more than the compressive strength.

(b) Influence of the methods of preparation:

When concrete material are not adequately mixed into a consistent and homogeneous mass, some poor quality concrete is inevitably the result. Even when a concrete is adequately mixed care must be taken during placing and compaction to minimize the probability of the occurrence of bleeding, segregation and honey combing all of which can result in batches of poor quality concrete. A properly designed concrete mix is one that does not demand the impossible from site operatives before it can be fully compacted in its final location. If full compaction is not achieved the resulting voids produce a marked reduction in concrete strength.

(c) Influence of curing:

Curing of concrete is a prerequisite for hydration of the cement content. For a given concrete, the amount and rate of hydration is essential .

Generally the longer the period during which concrete is kept in water, the greater its final strength. It is normally accepted that a concrete made with ordinary Portland Cement and kept in normal curing conditions will develop about 75 percent of its final strength in the first 28 days. The gain in strength depends on a number of factors such as relative humidity, wind velocity and the size of structural member or test specimen and condition of the concrete at the time of testing. It should also be noted that moist (or water) curing after an initial period in air results in a resumption of the hydration process and that concrete strength is further improved with time, although the optimum strength may not be realized.

The temperature at which concrete is cured has an important bearing on the development of its strength with time. The rate of gain in strength of concrete made with ordinary Portland cement increases with increase of temperature at early ages.

2.2.2.3 Deformation:

Concrete deforms under load, the deformation increasing with the applied load and being commonly known as elastic deformation. Concrete continues to deform with time, under constant load, this is known as time-dependent deformation or creep (figure 2-4).

(a) Elastic Deformation:

Unlike that for metals, the load-deformation relationship for concrete subjected to a continuously increasing load is nonlinear in character. The nonlinearity is most marked at higher loads. When the applied load is released the concrete does not fully recover its original shape. Under repeated loading and unloading the deformation at a given load level increases, although at a decreasing rate, with each successive cycle. All these characteristics of concrete indicate that it should be considered as a quasi-elastic material and when computing the elastic constants, namely, the modulus of elasticity and Poisson's ratio, the method employed should be clearly stated. It is only for simplicity and convenience that the elastic modulus is assumed to be constant in both concrete technology and the design of concrete structures.

Concrete is a multiple material and its resistance to deformation under load is dependent on the stiffness of its various phases, such as aggregate cement paste and voids, and the interaction between individual phases. In general the factors which influence the strength of concrete also affect deformation although the extent of their influence may well vary.

The modulus of elasticity increases with strength, although the two properties are not directly related because different factors exert varying degrees of influence on the strength and modulus of elasticity.

(b) Creep Deformation:

When concrete is subjected to a sustained load it first undergoes an instantaneous deformation (elastic) and thereafter continues to deform with time. The increase in strain with time is termed creep.

The influence of the constituent materials of concrete on creep is somewhat complex. The different types of cement influence creep because of the associated different rates of gain in concrete length. For example, concrete made with rapid-hardening Portland Cement shows less creep than concrete made with ordinary Portland Cement and loaded at the same age. Normal rock aggregates have a restraining effect on concrete creep and the use of large, high modulus aggregate can be beneficial in this respect.

The environmental conditions of concrete subjected to a sustained load can also have a marked effect on the magnitude of creep. For example, concrete cured under humid conditions and then loaded in a relatively dry atmosphere undergoes a greater creep strain than if the original conditions has been maintained. Creep decreases as the mass of concrete increases owing to the slow rate at which losses of water can take place within a large mass of concrete.

2.2.2.4 Shrinkage

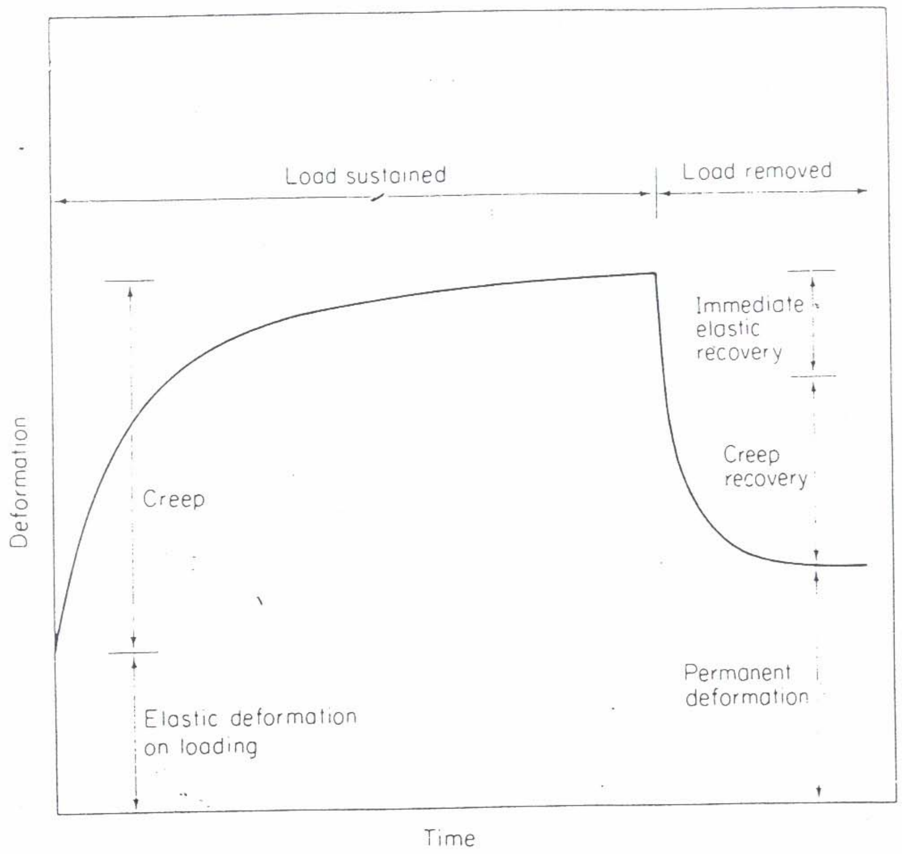
Shrinkage of concrete is caused by the settlement of solids and the loss of free water from the plastic concrete (plastic shrinkage), by the chemical combination of cement with water (autogenous shrinkage) and by the drying of concrete (drying shrinkage). Where movement of the concrete is restrained, shrinkage will produce tensile stresses within the concrete which may cause cracking. Most concrete structures experience a gradual drying out and the effects of drying shrinkage should be minimized by the provision of movement joints and careful attention to detail at the design stage.

The shrinkage which takes place before concrete has set is known as plastic shrinkage. This occurs as a result of the loss of free water and the settlement of solids in the mix. Since evaporation usually accounts for a large proportion of the water losses plastic shrinkage is most common in slab construction and is characterized by the appearance of surface cracks which can extend quite deeply into the concrete. Preventive measures are usually based on method of reducing water loss.

When a hardened concrete, cured in water, is allowed to dry it first loses water from its voids and capillary pores and only starts to shrink during further drying when water is drawn out of its cement gel. This is known as drying shrinkage.

Several factors influence the over-all drying shrinkage of concrete. These include the type, content and proportion of the constituent materials of concrete, the size and shape of the concrete structure, the amount and distribution of reinforcement and relative humidity of the environment.

In general, drying shrinkage is directly proportional to the water-cement ratio and inversely proportional to the aggregate-cement ratio (figuer2-5). Because of the interaction of the effects of aggregate-cement and water-cement ratios, it is possible to have a rich mix of a higher water-cement ratio. For a given water-cement ratio shrinkage increases with increasing cement content. Since the aggregate exerts a restraining influence on shrinkage the maximum aggregate content compatible with other required properties is desirable. The composition and fineness of cement can also affect its shrinkage characteristics.



Figure(2-1) *A typical illustration of deformation of concrete subjected to constant load*

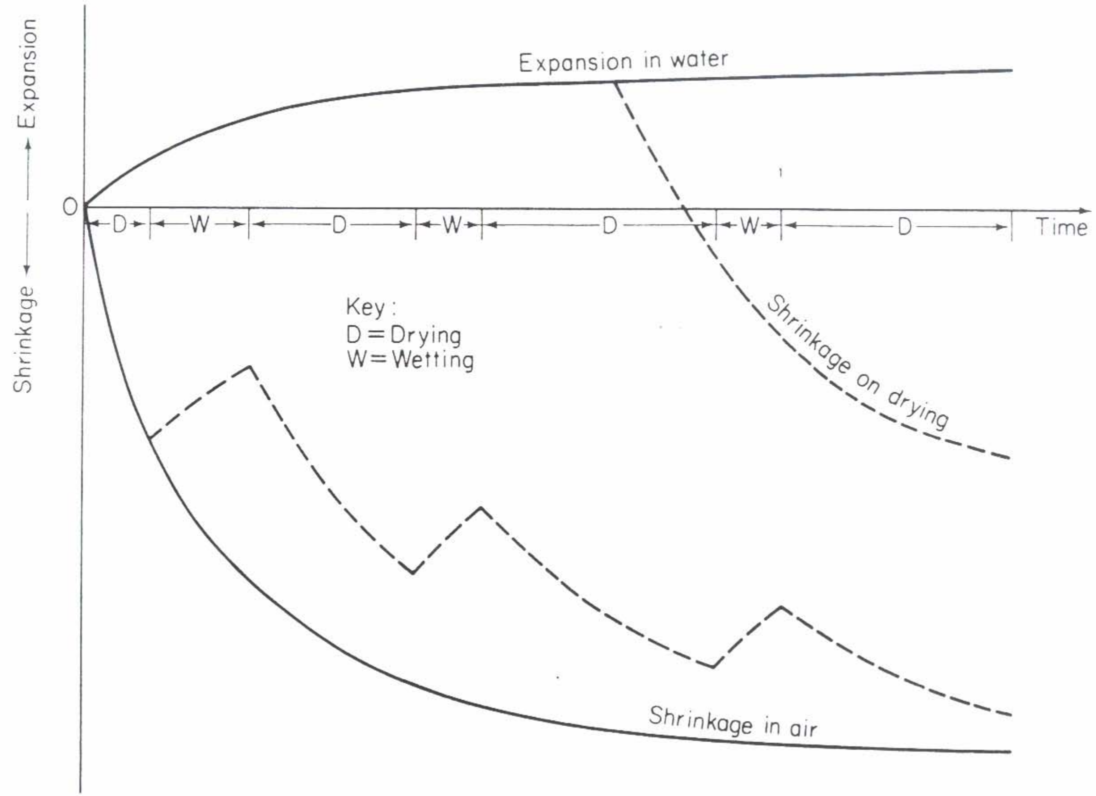


Figure (2.2) *Drying shrinkage and expansion characteristics of concrete*

2.2.2.5 Durability

Besides its ability to sustain loads, concrete is also required to be durable. The durability of concrete can be defined as its resistance to deterioration resulting from external and internal causes (figure 2-6). The external include the effects of environmental and service conditions to which concrete is subjected, such as weathering, chemical actions and water. The internal causes are the effects of interaction between the constituent materials, such as alkali-aggregate reaction, volume change, absorption and permeability.

In order to produce a durable concrete care should be taken to select suitable constituent materials . It is also important that mix contains adequate quantities of materials in proportion suitable for producing a homogeneous and fully compacted concrete mass.

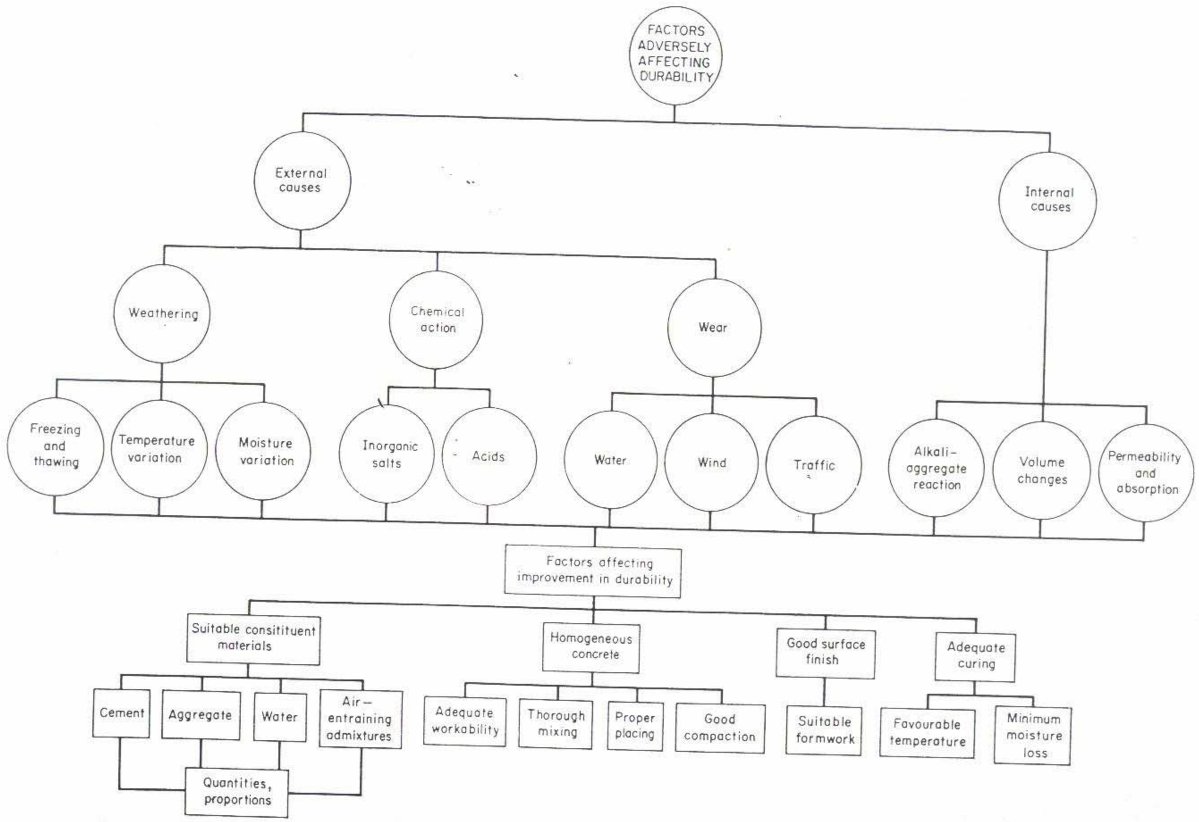


Figure (2-3) *Factors affecting durability of concrete*

CHAPTER THREE

MIX DESIGN AND EXPERIMENTAL PROGRAM

3.1 CONCRETE MIX DESIGN:

One of the ultimate aims of studying the various properties of the materials of concrete, plastic concrete and hardened concrete, is to enable a concrete technologist to design a concrete mix for a particular strength. The design of concrete mix is not a simple task on account of the widely varying properties of the constituent materials, the conditions that prevail at the site of work and the conditions that are demanded for a particular work for which the mix is designed. Design of concrete mix requires compete knowledge of the various properties of these constituent materials , the implications in case of change on the conditions at the site, the impact of the properties of plastic concrete on the hardened concrete and the complicated inter relationship between the variables.

With better understanding of the properties, the concrete is becoming more and more an exact material than in the past.

Mix design can be defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible.

The purpose of designing a mix as can be seen from the above definitions is two fold. The first object is to achieve the stipulated minimum strength. The second object is to make the concrete in the most economical manner. Cost wise all concretes depend primarily on two factors, namely cost of material and cast of labour. Labour cost, by way of formworks, batching, mixing, transporting and curing is nearly same for good concrete and bad concrete. Therefore attention is mainly directed to the cost of materials. Since the cost of cement is many times more than the cost of other ingredients, attention is mainly directed to the use of as little cement as possible consistent with strength and durability.

3.1.1 CONCEPT OF MIX DESIGN:

It will be worthwhile to recall at this stage the relationships between aggregate and paste which are the two essential ingredients of concrete. Workability of the mass is provided by the lubricating effect of the paste and is influenced by the amount of dilution of paste. The strength of concrete is limited by the paste strength , since mineral aggregates with rare exceptions, are far stronger than the paste compound. Essentially the permeability of concrete is governed by the quality and continuity of the paste, since little water flows through aggregate either under pressure or by capillarity. Further, the predominant contribution to drying shrinkage of concrete is that of paste.

Since the properties of concrete are governed to a considerable extent by the paste, it is helpful to consider more closely the structure of the paste. The fresh paste is a suspension, not a solution of cement in water.

The more dilute the paste, the greater the spacing between cement particles, and thus the weaker will be the ultimate paste structure. The other conditions being equal, for workable mixes, the strength of concrete varies as an inverse function of the water/cement ratio. Since the quantity of water required also depends upon the amount of paste, it is important that as little paste as possible should be used and hence the importance of grading.

3.1.2 VARIABLES IN PROPORTIONING:

With the given materials, the four variable factors to consider, in connection with specifying a concrete mix are:

(a) Water-cement ratio.

(b) Cement content or cement-aggregate ratio.

(c) Gradation of the aggregates.

(d) Consistency.

In general all four of these inter-related variables cannot be chosen or manipulated arbitrarily. Usually two or three factors are specified, and the others are adjusted to give minimum workability and economy. Water/cement ratio expresses the dilution of the paste, cement content varies directly with the amount of paste. Gradation of aggregate is controlled by varying the amount of given fine and coarse aggregates. Consistency is established by practical requirements of placing. In brief, the effort in proportioning is to use a minimum amount of paste (and therefore cement) that will lubricate the mass while fresh ad after hardening will bind the aggregate particles together and fill the space between them. Any excess of paste involves greater cost, greater drying shrinkage, greater susceptibility to percolation of water and therefore attack by aggressive water and weathering action. This is achieved by minimizing the voids by good gradation.

3.1.3 MIX DESIGN:

To design a mix based on the given grading of gravel and sand, a combined grading curve was produced. The following particulars of the two designed as medium workability and high workability .

Trial Mix : The necessity for trial mixes arises , for example , since the relationships between concrete strength and water –cement ratio depend to some extent on the local aggregates and the sources of cement. Experience in a particular locality of the quality and characteristics of both cement and aggregates can be of considerable value at mix design stage.

(I) Medium workability:

1- Water/cement ratio (w/c) = 0.52

2- Water content 180 kg/m^3.

3- Cement content 345 kg/m^3.

4- Total aggregate content 1850 kg/m^3.

5- Workability (medium) slump = 47 mm.

6- Mix proportions per cubic meter.

Table (3.1-a)

Mix design for medium workability

Volume	Cement (kg)	Water (kg)	Sand (kg)	Gravel (kg)
m^3	345	180	685	1165

(II) High workability:

1- Water/cement ratio 0.52.

2- Water content 195 kg/m^3.

3- Cement content 375 kg/m^3.

4- Total aggregate 1790 kg/m^3.

5- Workability (high) slump 110 mm.

6- Mix proportions per cubic meter.

Table (3.1-b)

Mix design for high workability

Volume	Cement(kg)	Water (kg)	Sand (kg)	Gravel (kg)
m^3	375	195	660	1130

A mechanical mixer was used. Six mix batches were considered in the study using cubes, beams and cylinder, and tested at 3, 7, 28, 90 days. The study considers the effect of delayed vibration, repeated vibration and without vibration.

A mechanical mixer was used to produce a homogenous mix and medium strength concrete (25 - 38 N/mm^2). Medium workability mixes were used in this investigation. Nine mix batches were considered in the study using cubes, beams, and cylinders tested at 3, 7, 28, 90 days. The study considers the effect of delayed vibration, revibration, repeated vibration and without vibration.

The elements casted for each mix were:

(1) Cubes 150 mm to be tested of 3, 7, 28 and 90 days.

(2) Beams 500 X 100 X 100 mm to be tested at 28 days.

(3) Cylinders 150 mm diameter and 300 height to be tested at 28 days.

The relevant details and calculations are shown in standard mix design form.

3.2 EXPERIMENTAL PROGRAM:

The laboratory program comprised tests on the basic materials and on concrete cube specimens , cylinder specimens and prisms subjected to different vibration conditions. The materials tested include cement, coarse aggregate and fine aggregate. Tests on concrete speciments are carried out to determine cube crushing strength, cylinder splitting strength and beam-flexural strength. Variables included the starting time of vibration, revibration interval and repeated vibration for different periods up to the age of 2 hours.

3.2.1 Cement:

Ordinary Portland cement (Egypt-sea Bulk) was used in this study. A number of laboratory test were performed to ensure that the quality of cement is to the desired standard. Table (3-2) below shows the results of tests on the physical properties of cement.

Table (3.2)

The cement test result

Test No.	Test conducted	Results	Requirements of BS 12 = 1996
1	Consistency	28.5%	(26-33) per cent
2	Soundness	-	Not more than 10 mm
3	Setting Time a) Initial b) Final	 2 : 10 hrs 3 : 05 hrs	 Not less than 60 min Not more than 10 hrs.
4	Compressive strength a) 2 - days 1 2 3 c) 28 days 1 2 3	 25.0 N/mm^2 26.3 N/mm^2 28.1 N/mm^2 53.3 N/mm^2 53.0 N/mm2 54.0 N/mm2 53.1 N/mm2	 Equal or Greater than 20 (- 2 N/mm^2) Not less than 42.5 (N/mm^2)

Fig.(3-1) (Cement test)

Fig.(3-2) Aggregate Test

3.2.2 Aggregate:

3.2.2.1 Coarse Aggregate:

Natural gravel with maximum size 20 mm, was used. Beside the sieve analysis, a test on the crushing properties was conducted and the results were as presented below:

(1) The crushing value of gravel use 25.3% (less than 30%).

(2) Table (3-3) show the Sieve analysis of coarse aggregate

Table (3.3)

Sieve analysis of coarse aggregate

Sieve size(mm)	Percentage passing	BS limits
20 mm	100	90 – 100
14 mm	72	60 – 80
10 mm	42.1	30 – 60
5 mm	9.5	0 – 10

3.2.2.2 Fine Aggregate:

Table (3.4)

Natural Sand Sieve Analysis used as given in below

Sieve size(mm)	Percentage passing	Bs, 882 Zone
10.0	99.7	-
5.0	98.6	-
2.36	92.98	65 – 100
1.18	67.52	45 – 100
0.6	31.76	25 – 80
0.3	10.98	5 – 48
0.15	3.18	-

3.2.3 Testing Program

The testing program is shown in Table (3.5)

Table (3.5)

Description	Mix No.	Time (hrs) at which vibration took place
I- Delayed vibration	MD1 MD2 MD3 MD4	0 1/2 1 2
II- Revibration	Mv1 Mv2 Mv3	0,1/2 0,1 0,2
III- Repeated vibration	MR	0, 10, 20, 30, 40, 50, 60, 90, 120 minutes
IV- Without vibration	WV	0

Chapter Four

Test Results and Discussion

4.1 DELAYED VIBRATION:

There are some special problems involved when concreting in hot weather, arising from a higher temperature of the concrete, and in many cases, from an increased rate of evaporation from the fresh mix. It is usual to vibrate concrete immediately after placing so that consolidation is generally completed before concrete has stiffened.

It has been noticed, however, that in quite a number of construction sites, in this country, vibration process is delayed for some time after mixing and placing has taken place. This fact raises the question of what is the allowable time after which vibration can be of no use. An experimental study on some four mixes of medium workability and four mixes of high workability to investigate the effect of delaying the start of vibration has been conducted.

The result of the reference mix, and those vibrated after an initial delay of 1/2 hours, one hour and two hour are shown in Figures (4-6)to (4-7), which compare the strength developments with time. For medium workability if vibration is done after first 1/2 hour the loss of strength of 8 percent has been recorded, 22 percent has been recorded at one hour and 35 percent has been recorded after two hours. For high workability 4.5 percent increase in strength has been recorded after first 1/2 hour, 3.5 percent loss in strength has been recorded after one hour and 18 percent less has been recorded after two hours. This has confirmed that vibration of concrete immediately after casting is very important since it provides the best result.

4.2 REVIBRATION :

Revibration of concrete may occur in many ways during construction. It has been the practices, however, that revibration of concrete one hour after initial consideration may be needed in order to weld successive lifter together.

The successful application of revibration raises the question whether revibration can be more generally used. Test results of three mixes of medium workability revibrated after different periods from the casting time are presented in Figure (4-8), in comparison with the reference mix. On the basis of these experimental results, it appears that concrete can be successfully revibrated 1/2 hour up to 1 1/2 hours from the time of casting. In comparison with the reference mix, an increase in strength of approximately 2 percent has been recorded at the first 1/2 hour, but actual values would depend on the workability of the mix.

In general, the improvement in strength is more pronounced at earlier ages, and is expected to be greatest in concrete liable to high bleeding since the trapped water is expelled on revibration. It is possible also that some of the improvement in strength is due to a relief of the plastic shrinkage stresses around particles.

4.3 REPEATED VIBRATION:

To study the effect of continuous or repeated vibrations on the strength of concrete, two mixes were considered. The vibration is repeated at closer intervals (10, 20, 30, 40, 50, 60, 90 and 120 minutes).

Figures (4-9) and (4-10) show the strength development in relation to reference mix and without vibration mix. The concrete test cubes did not suffer any adverse effects when subjected to the repeated vibration.

In fact, all of the test results indicated that , repeated vibration produces increase in the strength of concrete over the control specimens by up to about 5 percent for medium workability and 10.5 percent for high workability. However in this case, workability of concrete mix is very important.

4-4-1 Effect of Vibration on Concrete Strength (medium workability) Cubes tested After 3,7,28,90 Days

Test results of the effect of vibration on concrete compressive strength medium workability were recorded . Cubes are tested after 3, 7, 28 and 90 days. (see Tables 4.4.1).

Table (4.4.1 – a) Delayed vibration

Mix. Description	**Comp. Strength (N/mm*2)**			
	3days	**7days**	**28days**	**90 days**
Ref-Mix	21.8	28.1	33.0	37.2
after 1/2hr	20.3	26.5	31.3	34.8
after 1 hr	16.7	21.8	25.3	29.3
after 2 hr	11.6	16.0	20.4	24.0

Table (4.4.1 – b) Revibration

Mix. Description	**Comp. Strength N/mm*2)**			
	3days	**7days**	**28days**	**90 days**
Ref. Mix	21.8	28.1	33.0	37.2
after ½ hr	23.4	30.0	35.0	38.0
after1 hr	22.0	29.0	33.5	37.0
after 2 hr	22.0	28.1	33.0	37.0

Table (4.4.1 – c)

Repeated vibration

Mix. Description	Comp. Strength (N/mm*2)			
	3days	7days	28days	90 days
Ref. Mix	21.8	28.1	33.0	37.2
Repeated vibration	24.1	31.0	35.6	39.0

Table (4.4.1 – d)

d. without vibration

Mix. Description	Comp. Strength (N/mm*2)			
	3days	7days	28days	90 days
Ref. Mix	21.8	28.1	33.0	37.2
Without vibration	11.5	15.0	19.4	23.0

4-4-2 Effect of Vibration on Concrete Strength (high workability) Cubes tested After 3,7,28,90 Days

Test results of the effect of vibration on concretes compressive strength for high workability were recorded . Cubes are tested after 3, 7, 28 and days. (see Tables 4.4.2).

Table (4.4.2 – a) Delayed vibration

Mix. Description	Comp. Strength (N/mm*2)			
	3days	7days	28days	90 days
Ref-Mix	21.4	27.2	33.4	37.3
after 1/2 hr	24.2	29.0	34.4	39.0
after 1 hr	21.0	27.0	31.0	36.0
after 2 hr	15.0	21.0	26.5	30.5

Table (4.4.2 – b)

Repeated vibration

Mix. Description	**Comp. Strength (N/mm*2)**			
	3days	**7days**	**28days**	**90 days**
Ref. Mix	21.4	27.2	33.4	37.3
Repeated vibration	23.5	29.7	34.8	40.0

Table (4.4.2 –c)

c. without vibration

Mix. Description	**Comp. Strength (N/mm*2)**			
	3days	**7days**	**28days**	**90 days**
Ref. Mix	21.4	27.2	33.4	37.3
Without vibration	14.5	20	25	**29.5**

Fig.(4-1) Flexural Strength Test

4-4-3 Effect of Vibration on Concrete flexural Strength (medium workability)

The stress may be calculated on the assumption that beam behaves according to hook's low and it is usually referred to as the modules of rupture (f)

F=6m/bd2 , m=PL/6

When m=maximum bending moment

,b=breadth of beam

,d=depth of the beam

p= maximum load applied

f=PL/bd2

Test results of the effect of vibration on concrete flexural strength (medium workability) were recorded. Beams ware tested after 28 days, for delayed vibration, revibration, repeated and without vibration. (see Table 4.4.3).

Table (4.4.3)

Design Description .	**Load (KN)**	**(N / mm2) Flexural strength**
Ref . Mix	42 42 40	3 . 81
Delayed vibration after ½ h	40 38 42	3 . 72
after 1 h	40 35 30	3 . 23
After 2 h	29 35 38	3 . 14
Revibration after ½ h	40 45 50	4.15
after 1 h	55 50 45	4.61
after 2 h	53 50 45	4.50
Repeated vibration	45 55 50	4. 61
Without vibration	39 55 50	3.10

4-4-4 Effect of Vibration on Concrete Strength (high workability) Flexural strength

Test results of the effect of vibration on concrete flexural strength (high workability) were recorded .Beams ware tested after 28 days , for delayed vibration, revibration, repeated and without vibration, (see Table 4.4.4).

Table (4.4.4)

Design Description.	**Load (KN)**	**(N / mm2) Flexural Strength**
Ref . Mix	42 42 40	3 . 81
Delayed vibration after ½ h	40 41 45	3 . 87
after 1 h	41 40 40	3 . 72
after 2 h	38 39 37	3 . 50
Repeated Vibration	47 47 43	4. 21
Without vibration	38 40 37	3.50

4-4-5 Effect of Vibration on Concrete Cylinder splitting Strength (medium workability)

The splitting test : indirect tensile strength made on cylinders , and the cylinder is placed in the compression testing machine horizontally , so that the load is applied along two line on opposite sides of the curved surface (see fig. 4-4).

The cylinder splits with a vertical fractural and it can be shown that a tensile stress acts on the vertical diameter of cylinder with an intensity which is almost uniformly distributed. This stress may be calculated from the formula:

$F=2P/\pi \, dL$

When P=maximum load

,d =diameter

L=length

Test results of the effect of vibration on concrete cylinder splitting strength (for medium workability) were recoded .**Cylinders ware** tested after 28 days, for delayed vibration, revibration, repeated and without vibration, (see Table 4.4.5).

Table (4.4.5)

Design Description	**Wt/kg**	**Load (KN)**	**(N / mm2) Tensile Strength**
Ref . Mix	13.480 13.505 13.546	200 245 200	3.13
Delayed vibration after ½ h	13.445 13.455 13.546	160 170 190	2.45
after 1 h	13.370 13.080 13.360	140 150 180	2.21
after 2 h	12.975 12.800 12.674	165 140 105	2.01
Revibration after ½ h	13.420 13.510 13.450	220 225 230	3.18
after 1 h	13.465 13.405 13.650	220 210 210	3.02
after 2 h	12.580 12.760 12.520	220 220 200	3.02
Repeated vibration.	13.540 13.615 13.610	210 330 215	3.09
Without vibration	12.975 13.000 12.675	140 140 125	2.00

4-4-6 Effect of Vibration on Concrete Cylinder splitting strength (high workability)

Test result of the effect of vibration on concrete Cylinder splitting strength(high workability)were recoded . Cylinders ware tested after 28 days, for Delayed vibration, revibration, repeated and without vibration, (see Table 4.4.6).

Table (4.4.6)

Design Description .	**Wt/kg**	**Load (KN)**	**(N / mm2) Tensile Strength**
Ref . Mix	13.420 13.400 13.400	180 175 170	2.52
Delayed vibration after ½ h	13.490 13.485 13.855	175 180 180	2.52
after 1 h	13.247 13.330 13.020	170 175 180	2.47
after 2 h	13.580 13.600 13.550	180 140 160	2.26
Repeated vibration.	13.580 13.600 13.550	190 180 180	2.59
Without vibration	13.430 13.110 13.000	180 170 175	2.13

Fig.(4-2)Delayed Vibration (2 hours)

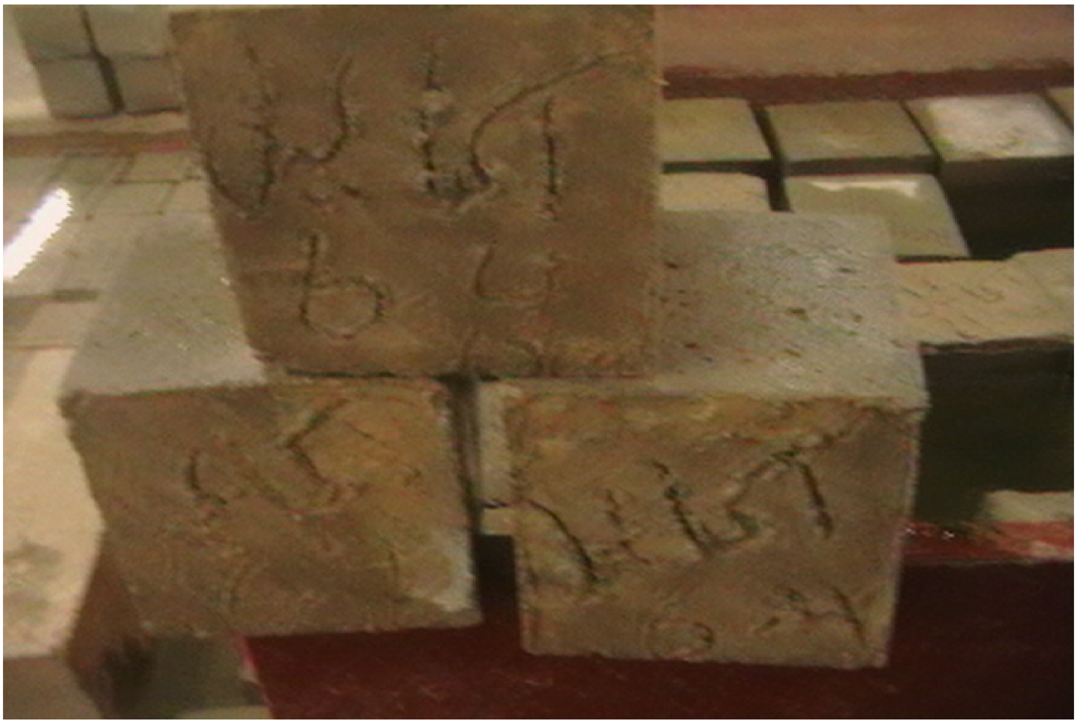


Fig.(4-3) Ref. Mix

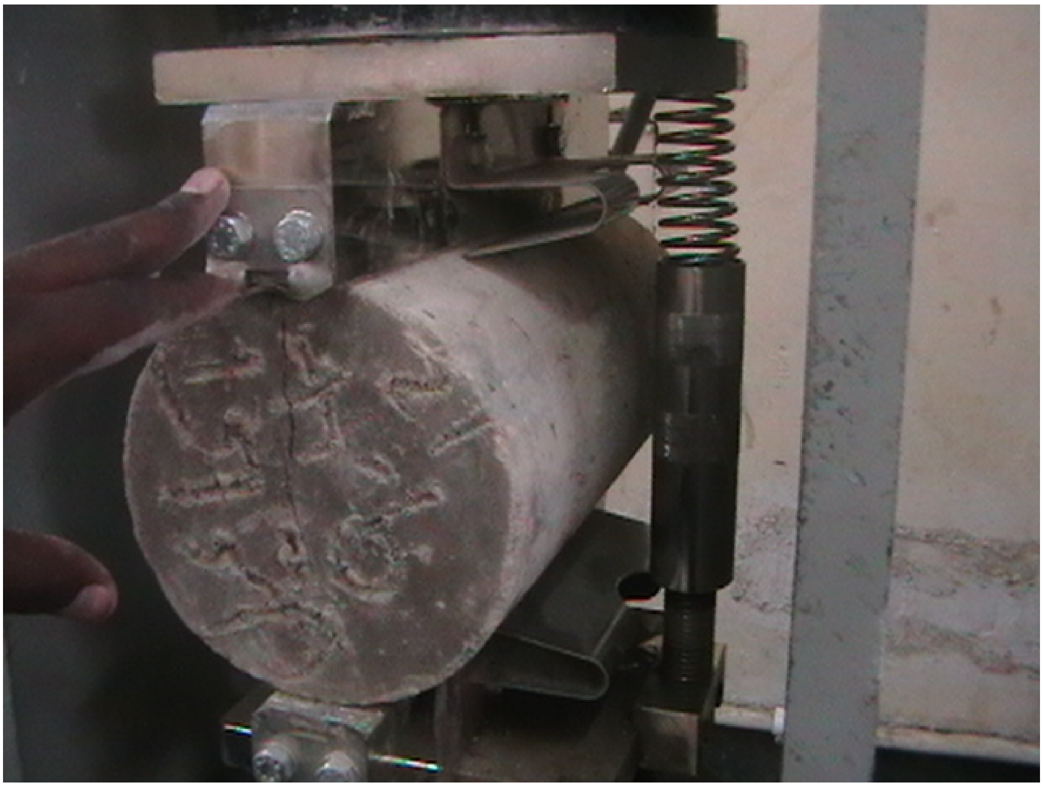


Fig.(4-4)Cylinder Splitting Tension Test

Fig.(4-5) Beam after test

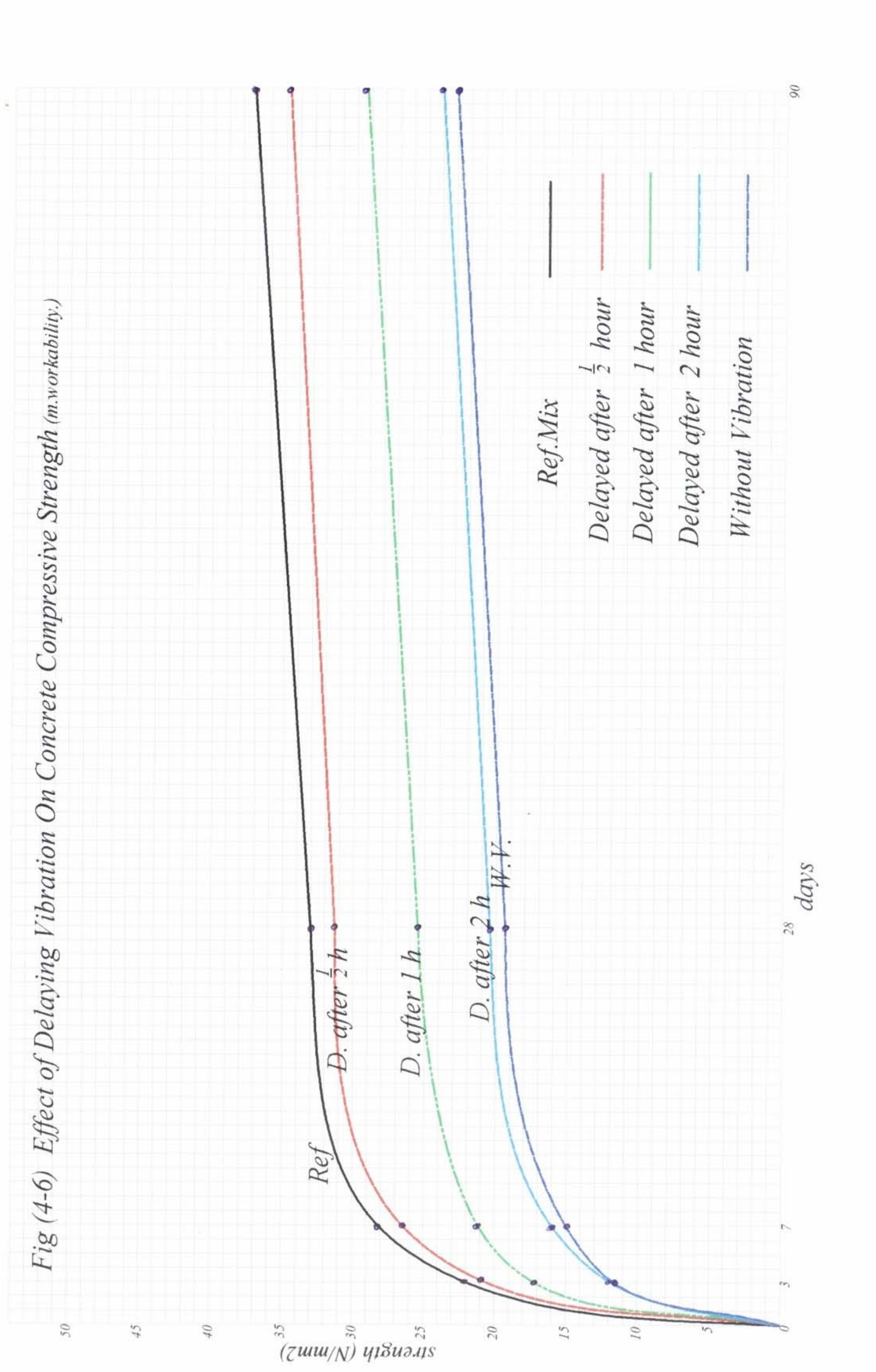
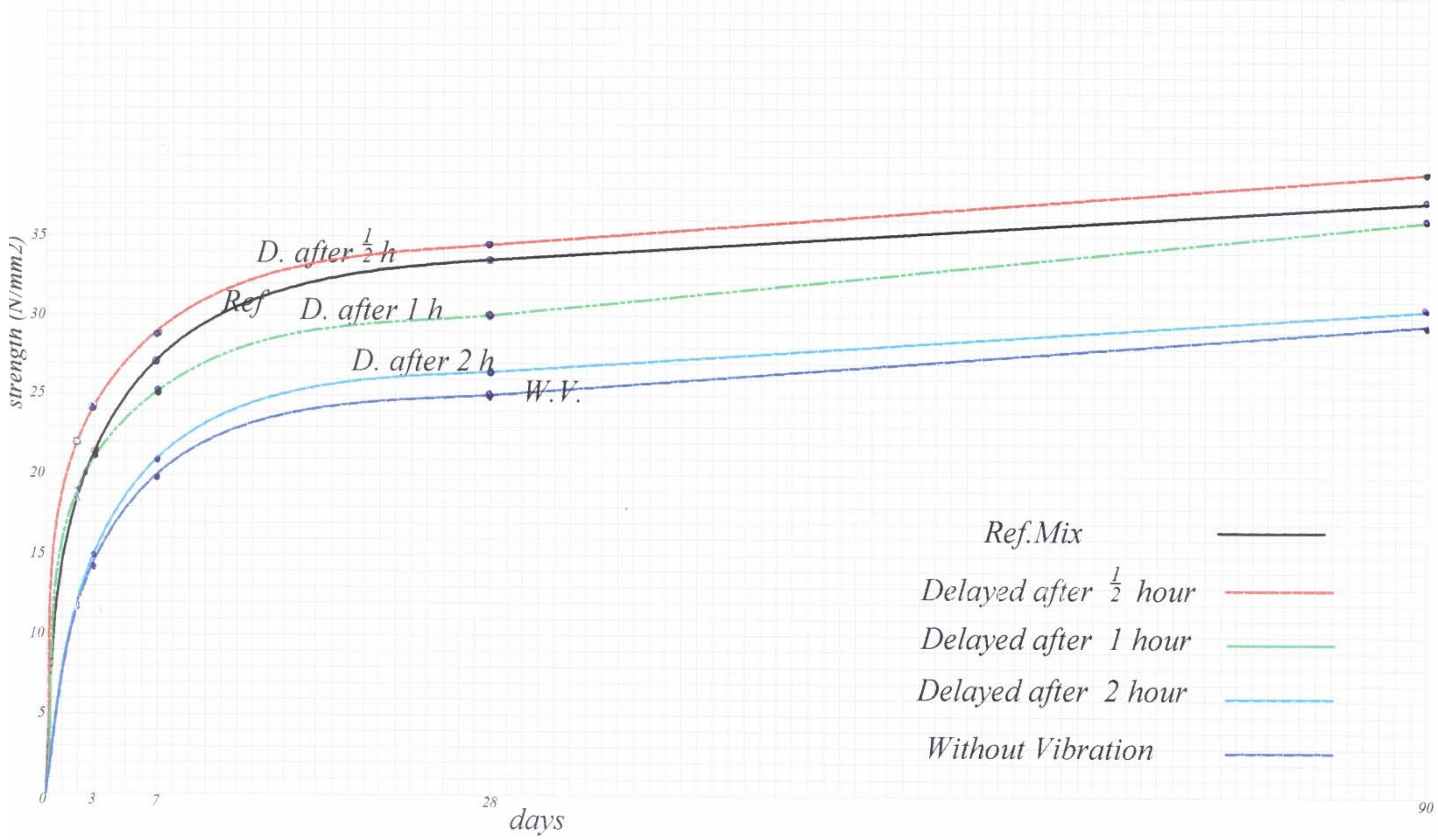


Fig (4-6) Effect of Delaying Vibration On Concrete Compressive Strength (m.workability.)

Fig (4-7) Effect of Delaying Vibration On Concrete Compressive Strength (h.workability.)



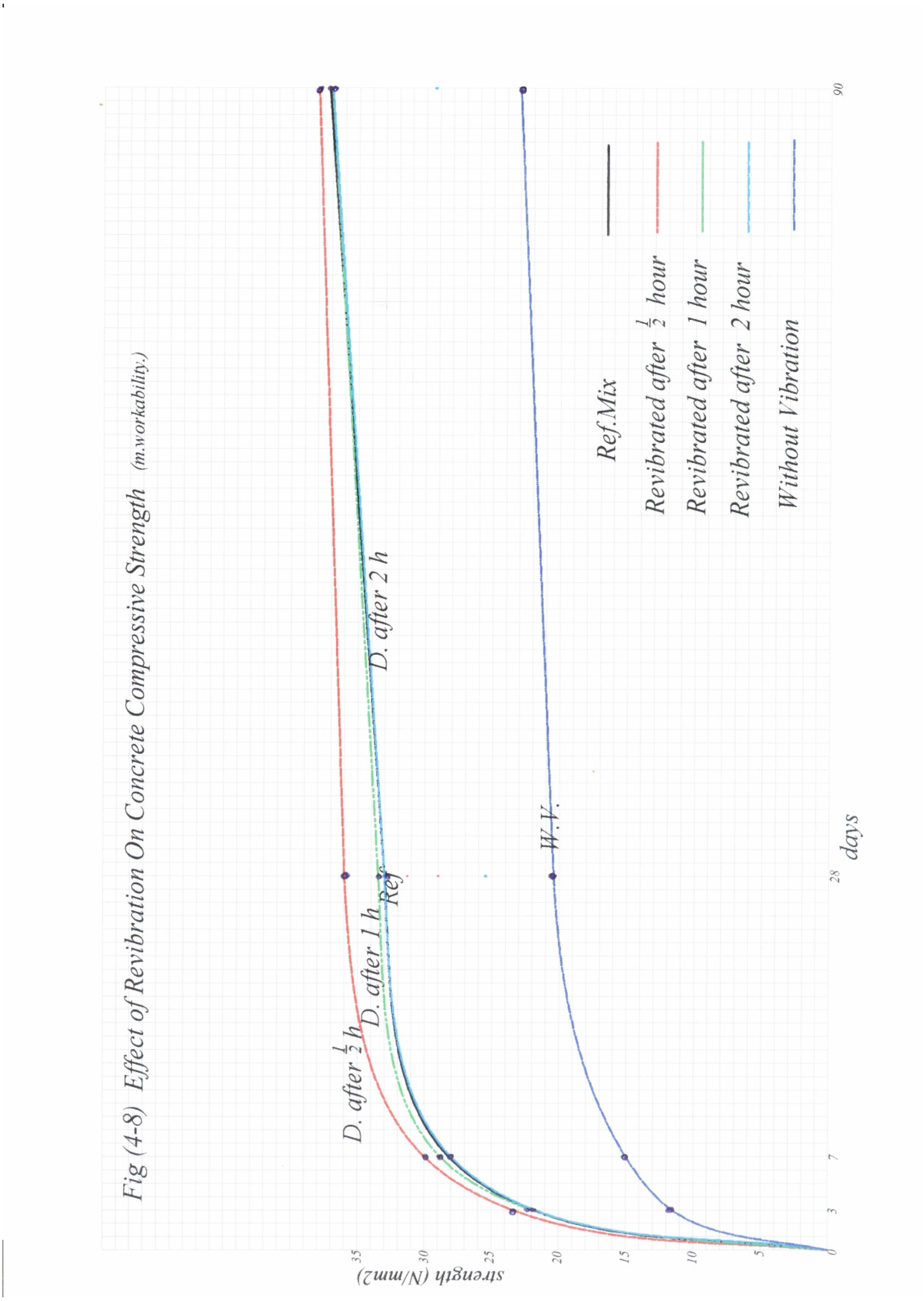


Fig (4-8) Effect of Revibration On Concrete Compressive Strength (m.workability.)

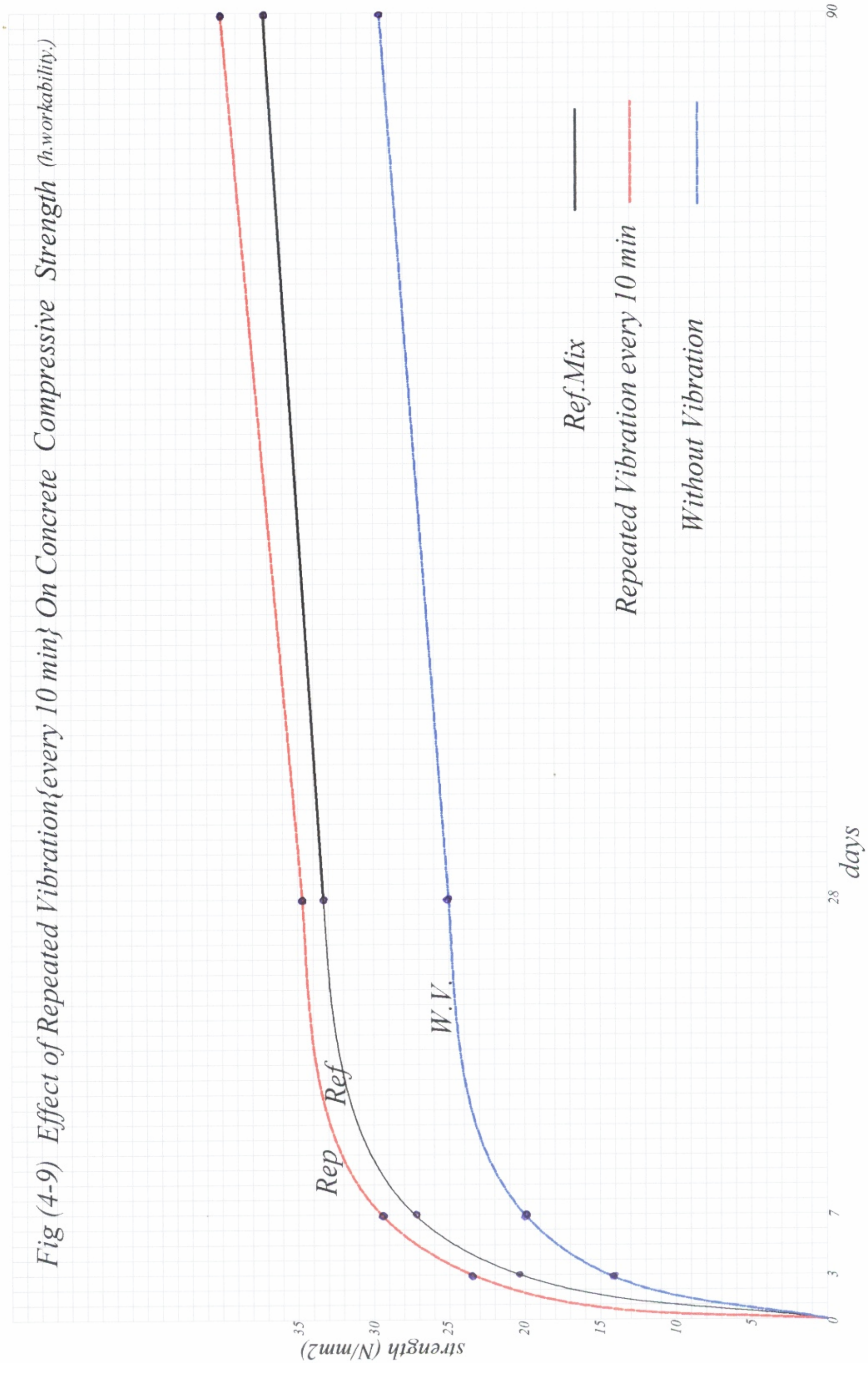


Fig (4-9) Effect of Repeated Vibration{every 10 min} On Concrete Compressive Strength (h.workability.)

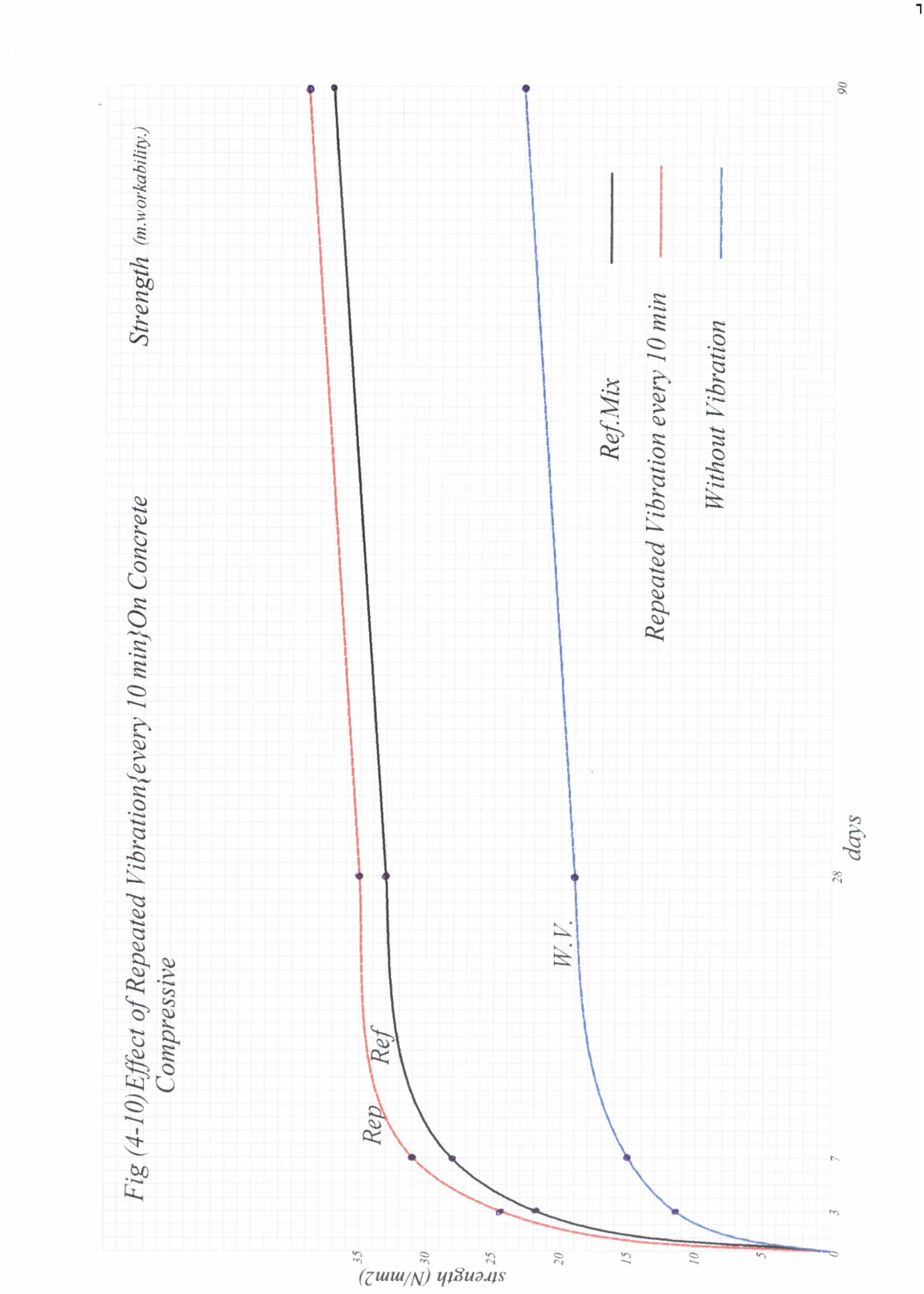
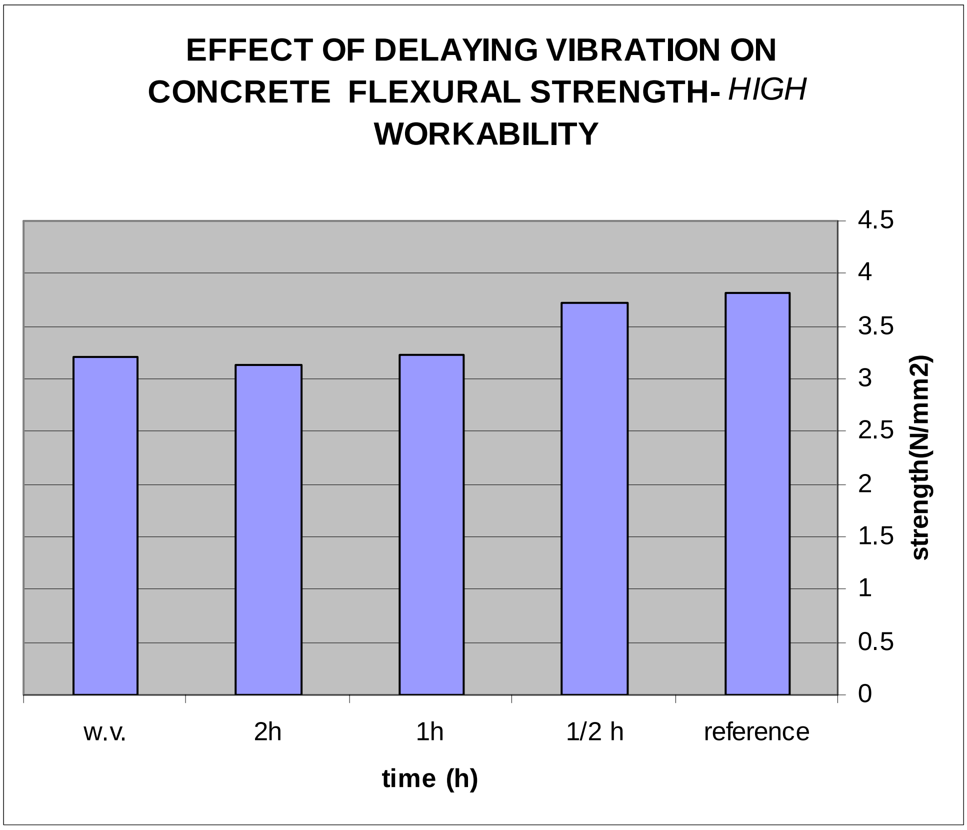
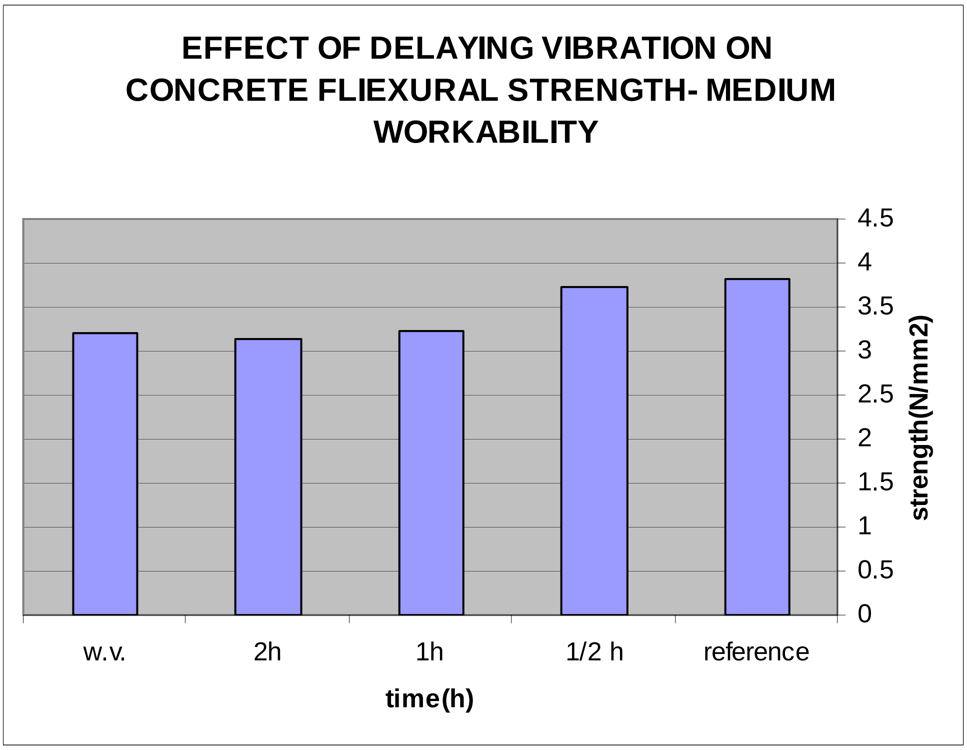


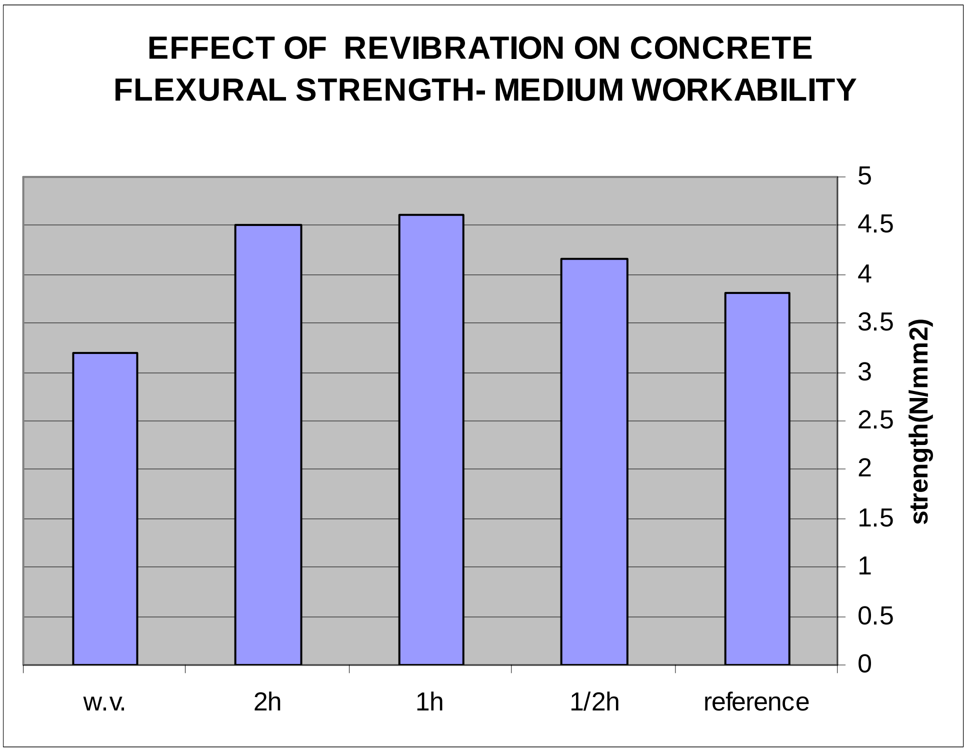
Fig (4-10)Effect of Repeated Vibration{every 10 min}On Concrete Compressive



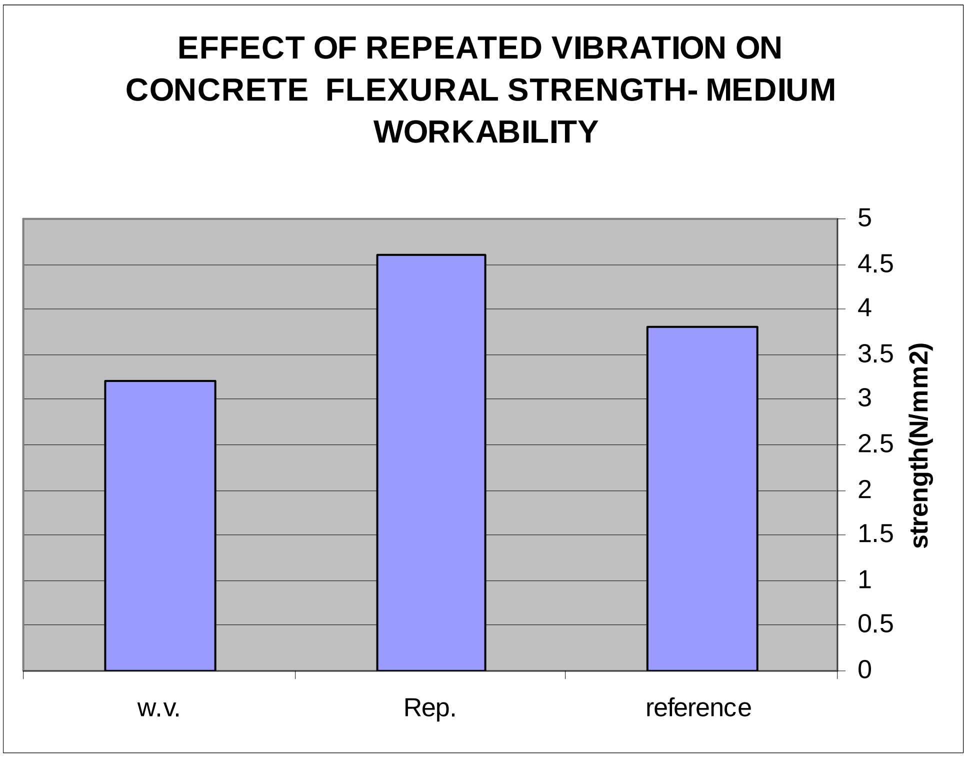
Figure(4-11)



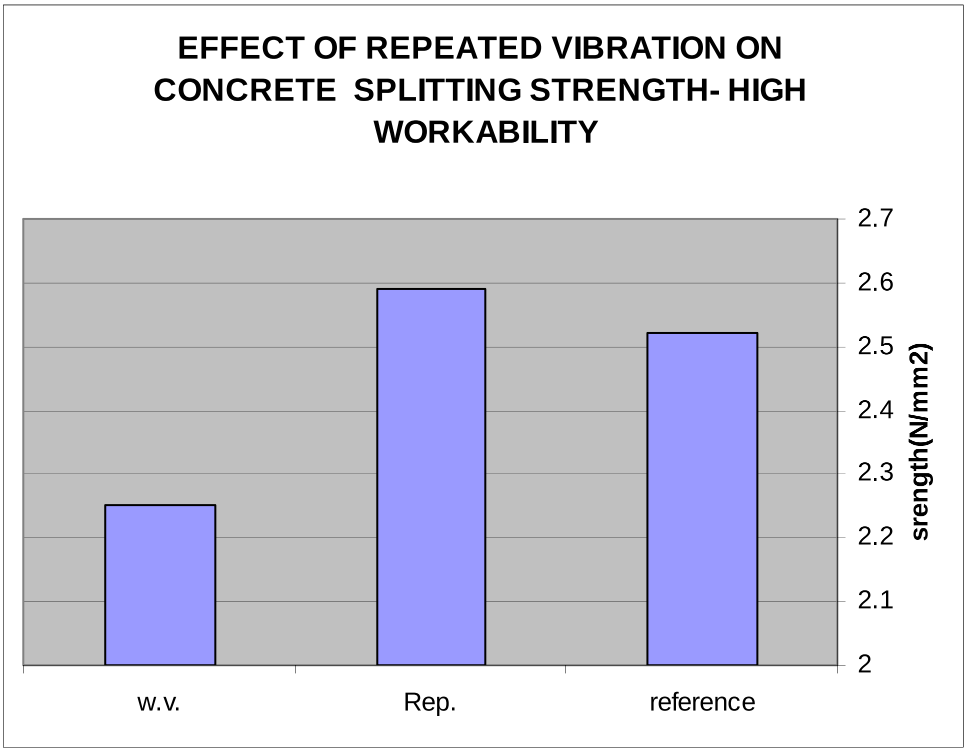
Figure(4-12)


EFFECT OF REVIBRATION ON CONCRETE FLEXURAL STRENGTH- MEDIUM WORKABILITY
strength(N/mm2)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
w.v.
2h
1h
1/2h
reference

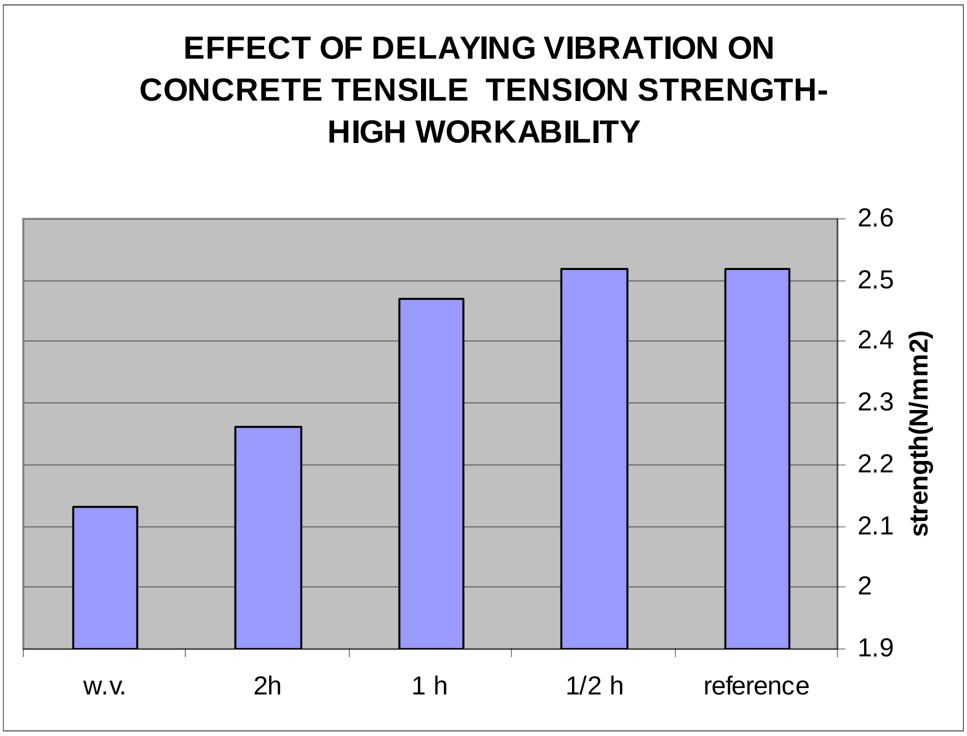
Figure(4-13)



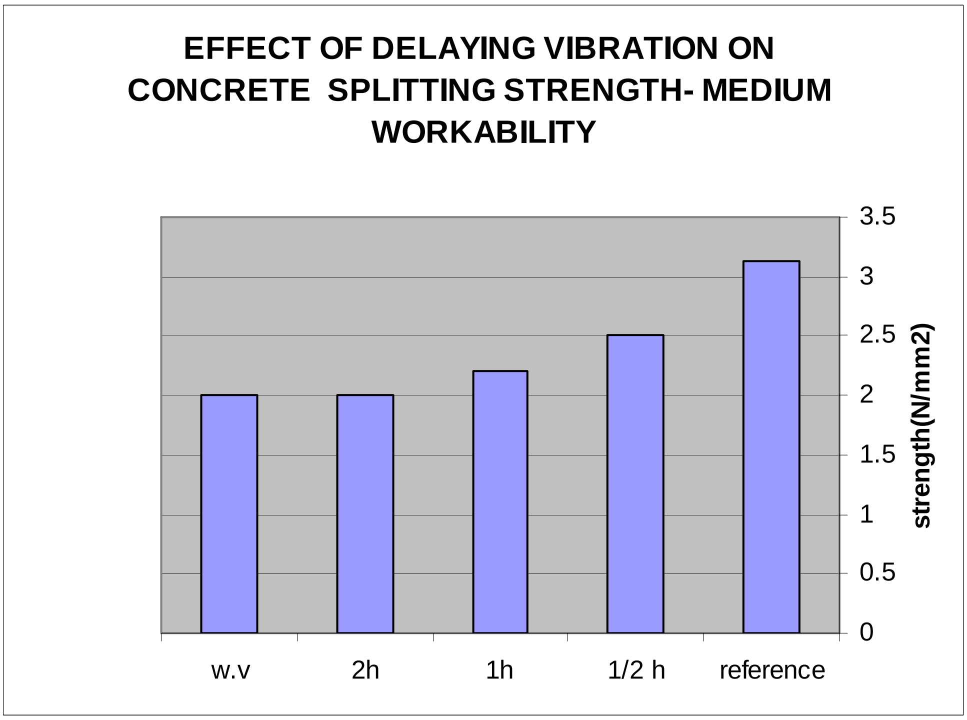
Figure(4-14)



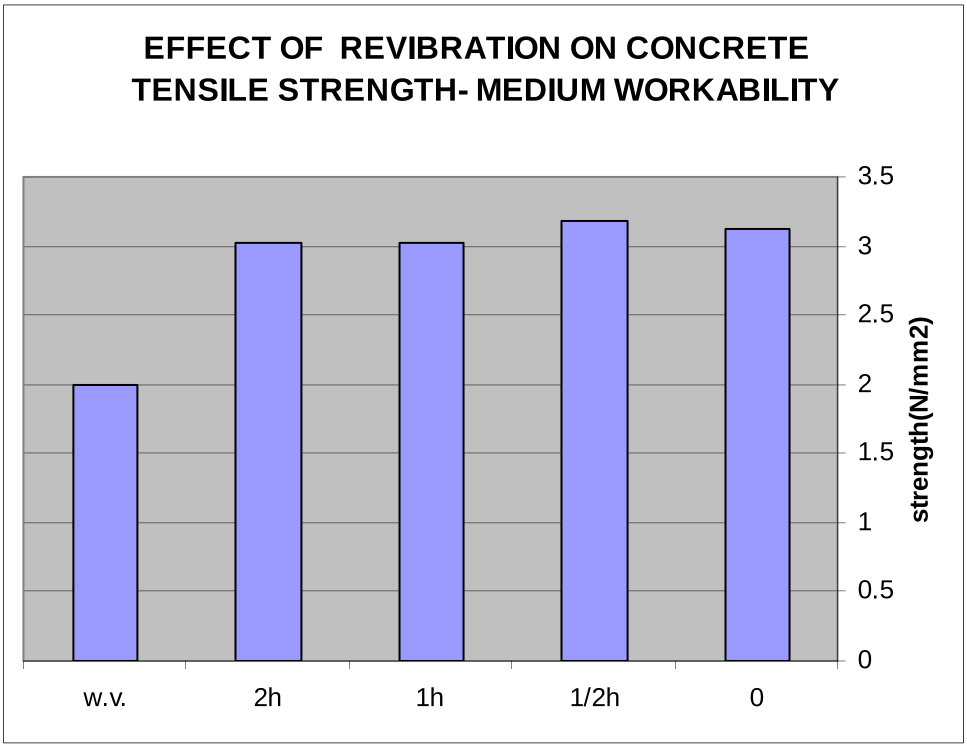
Figure(4-15)



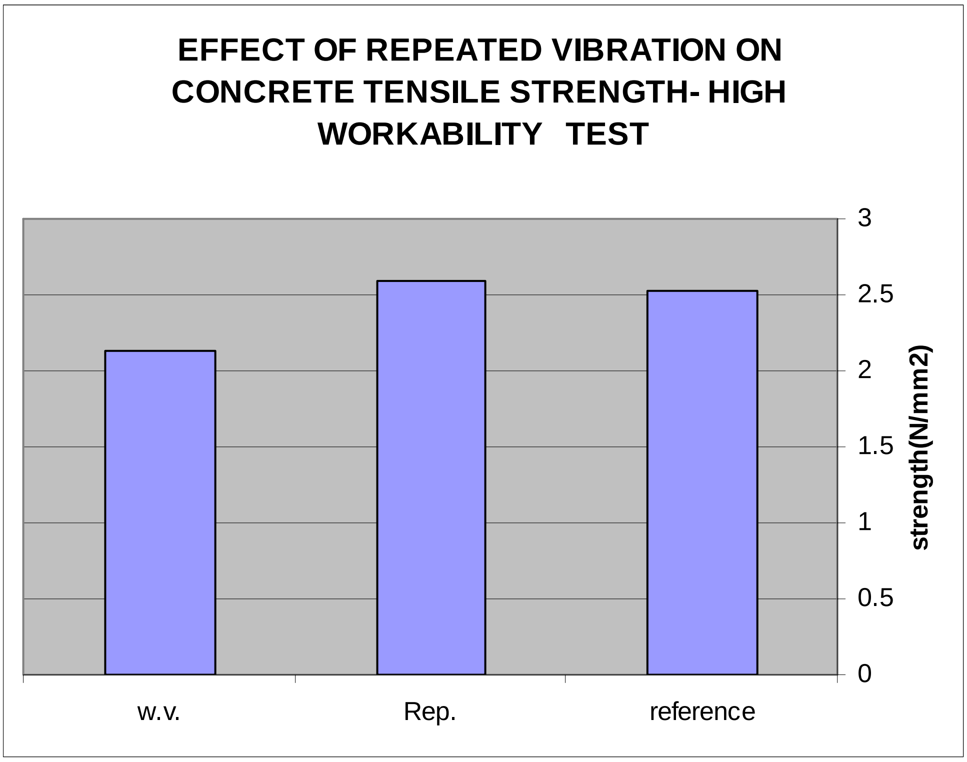
Figure(4-16)



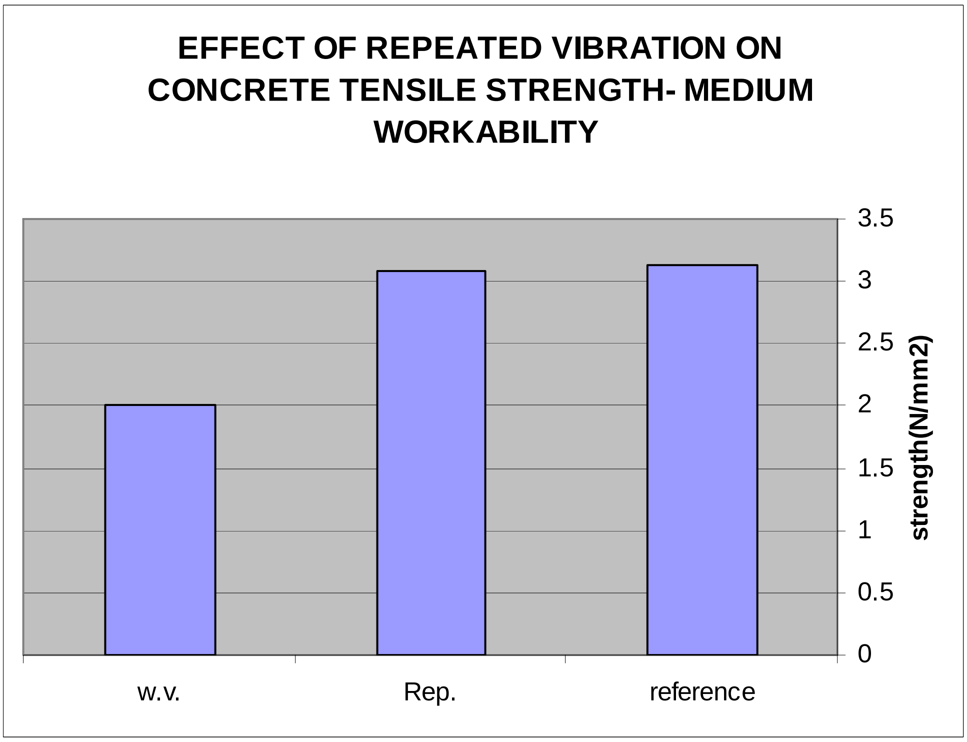
Figure(4-17)


EFFECT OF REVIBRATION ON CONCRETE TENSILE STRENGTH- MEDIUM WORKABILITY
3.5
3
2.5
2
1.5
1
0.5
0
strength(N/mm2)
w.v.
2h
1h
1/2h
0

Figure(4-18)



Figure(4-19)



Figure(4-20)

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5-1 CONCLUSIONS:

* Concrete vibration is needed for proper compaction of mixes, especially those with lower workability as (medium and lower).
* It is important to vibrate concrete immediately after placing so that consolidation is completed before the concrete has a stiffened. Delay in vibration will result in loss of strength reaching up to about 18 percent for 2 hours delay from the time of mixing (high workability) and 35 percent for 2 hours delay for medium workability.
* With reference to hot and dry environment of Sudan , revibration of concrete once within half hour after mixing and initial vibration can produce better concrete.
* Repeated vibrations at close intervals showed that concrete did not suffer any adverse effects. In fact, all the results (medium, high workability) showed that continuous vibration produces a beneficial effect and increases the strength over the control specimen by up to about 10.5 percent for high workability and 5 percent for medium workability.
* For concrete manufacturing ,special attention should be given to vibration in order to reduce the great loss in the strength, durability of concrete and reduction of bond stress between concrete and reinforcement. In other words poor vibration leads of in effective use of our materials.

5-2 Recommendations

It is recommended that further studies should be done for better understanding of Effect of vibration on concrete. Investigations suggested are to:

1- To continue studying the effect of different workability on the various strength .

2- Different vibration techniques and study the concrete effect

3- To study the effect of different concrete grades

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Appendix (A)
Effect of Vibration in Concrete Strength (medium workability)
Test After 3,7, Days (cubes)

Table (4.3 – a)

Design Description	**3 Days**			**7 Days**		
	Wt/kg	Load(T)	St. N/mm2	Wt/kg	Load(T)	St. N/mm2
Ref . Mix	8.085	450		8.290	620	**28.1**
Delayed V.	8.345	520	**21.8**	8.550	630	
	8.460	500		8.350	650	
At ½ h	8.330	495	**20.3**	8.280	600	**26.5**
	8.170	440		8.300	575	
	8.270	440		8.360	615	
At 1 h	8.130	390	**16.7**	7.820	430	**21.8**
	7.540	360		7.860	560	
	7.780	380		8.05	480	
At 2 h	7.265	220	**11.6**	7.820	370	**16.0**
	7.600	305		7.340	350	
	7.650	260		7.840	340	
Revibration	8.460	535	**23.4**	8.390	685	**30.0**
At ½ h	8.400	520		8.340	680	
	8.340	530		8,400	660	
At 1 h	8.250	495	22.2	8.100	660	**29.1**
	8.175	490		8.160	655	
	8.280	500		8.350	650	
At 2h	8.305	495	**22.0**	8.170	645	**28.1**
	8.300	490		8.220	645	
	8.260	495		8.220	610	
	8.260	575	**24.1**	8.350	750	**31.o**
Repeated v.	8.230	510		8.266	645	
	8.320	540		8.420	700	
Without	7.980	270	**11.5**	7.800	350	**15.0**
vibration	7.990	250		8.000	330	
	7.930	260		8.33o	340	

Test After 28, 90 , Days (cubes)

Table (4.3 – b)

Design Description	28 Days			90 Days		
	Wt/kg	Load(T)	St. N/mm2	Wt/kg	Load(T)	St. N/mm2
Ref . Mix Delayed	8.280 8.305 8.310	755 740 740	**33.1**	8.360 8.465 8.420	870 870 770	**37.2**
At ½ h	8.300 8.280 8.155	710 725 675	**31.3**	8.320 8.205 8.143	835 840 675	**34.8**
At 1 h	8.140 7.760 7.760	650 465 580	**25.3**	7.880 7.556 8.03	630 620 730	**29.3**
At 2 h	7.580 7.540 7.920	470 450 455	**20.4**	7.610 7.66 8.10	560 565 510	**24.2**
Revibration At ½ h	8.280 8.340 8.350	800 790 780	**35.1**	8.360 8.369 8.330	860 850 855	**38.0**
At 1 h	8.280 8.125 8.320	750 760 755	**33.5**	8.260 8.200 8.330	820 850 840	**37.1**
At 2 h	8.210 8.310 8.320	775 760 720	**33.4**	8.305 8.395 8.325	800 795 795	**35.4**
Repeated V.	8.340 8.370 8.305	785 835 790	**35.6**	8.400 8.320 8.645	890 875 870	**39.0**
Without vibration	8.180 8.200 8.000	435 432 440	**19.4**	8.100 8.000 8.050	520 515 519	**23.0**

Effect of Vibration in Concrete Strength (high workability)
Test After 3,7, Days (cubes)

Table (4.4- a)

Design Description	**3 Days**			**7 Days**		
	Wt/kg	Load(T)	St. N/mm2	Wt/kg	Load(T)	St. N/mm2
Ref . Mix	8.250 8.320 8.210	475 480 495	**21.4**	8.400 8.340 8.400	600 605 610	**27.2**
At ½ h	8.300 8.200 8.190	570 515 550	**24.2**	8.150 8.185 8.110	655 660 650	**29.1**
At 1 h	8.030 8.035 8.185	480 475 470	**21.1**	8.110 8.070 8.020	620 610 600	**27.1**
At 2 h	8.040 8.260 8.120	335 340 335	**15.1**	7.900 7.900 8.000	480 470 475	**21.1**
Repeated V.	8.230 8.245 8.350	560 515 515	**23.5**	8.345 8.365 8.375	655 680 670	**29.7**
Un-vibrated	8.000 7.850 7.800	325 330 330	**14.5**	7.900 8.000 8.050	445 455 450	**20.0**

Test After 28, 90 , Days (cubes)

Table (4.4 – b)

Design Description	28 Days			90 Days		
	Wt/kg	Load(T)	St. N/mm2	Wt/kg	Load(T)	St. N/mm2
Ref . Mix	8.150 8.290 8.200	745 740 750	**33.4**	8.235 8.320 8.645	840 845 830	**37.2**
At ½ h	8.145 8.200 8.165	770 751 800	**34.4**	8.240 8.200 8.140	840 900 930	**38.0**
At 1 h	8.060 8.150 7.970	705 750 665	**31.4**	8.080 8.070 8.090	810 815 805	**36.0**
At 2 h	7.930 8.120 8.200	630 705 750	**30.9**	7.950 7.880 7.200	690 685 690	**30.5**
Repeated vibration	8.280 8.300 8.320	850 790 710	**34.8**	8.320 8.320 8.400	900 910 890	**40.0**
With out vibration	7.850 7.950 8.000	565 560 570	**25.1**	8.000 7.900 8.050	670 660 655	**29.1**

Appendix(B)

Table: Concrete mix design form (medium workability)

Stage	Item		Reference or calculation	Values
1	1.1	Characteristic strength Proportion defective 5 per cent	Specified	25 N / mm² at 28 Days
	1.2	Standard deviation	Fig	8 N/mm² or no data-------- N/mm²
	1.3	Margin	C1	(k = 1.64) * 8 = 13 N/mm²
	1.4	Target mean strength	C2	25 + 13 = 38 N/mm²
	1.5	Cement type	Specified	OPC/SRPC/RHPC
	1.6	Aggregate type: coarse Aggregate type: fine		Uncrushed
	1.7	Free-water/cement ratio	Table 2, Fig 4	0.52 Use the lower value
2	2.1	Slump or V-B	Specified	slump 30-60 mm or
	2.2	Maximum aggregate	Specified	20 mm
	2.3	Free-water content	Table 3	180 kg/m³
3	3.1	Cement content	C3	180 ÷ 0.52 = 346 Kg/m³
	3.2	Maximum cement content	Specified	Kg/m³
	3.3	Minimum cement content	Specified	-------Kg/m³----- Use if greater then Item 3.1 and calculate Item 3.4
	3.4	Modified free-water/cement ratio		---
4	4.1	Relative density of aggregate (SSD)		2.7 Known/assumed
	4.2	Concrete density	Fig5	2375 Kg/m³
	4.3	Total aggregate content	C4	2375 - 180 - 346 = 1850 Kg/m³
5	5.1	Grading of fine aggregate		
	5.2	Proportion of fine aggregate	Fig 6	37 Pre cent
	5.3	Fine aggregate content		1850* 0.37 = 685 Kg/m³
	5.4	Coarse aggregate content	C5	1850 – 685 =1165 Kg/m³

Quantities	Cement (Kg)	Water (Kg)	Fine aggregate (Kg)	coarse aggregate (Kg)
Per m³ (to nearest 5 Kg)	345	180	685	1165
Per trial mix of 0.067 m³	22.11	12.73	49.92	78.06

Appendix (B)

Table: Concrete mix design form (high workability)

Reference or Stage	Item	calculation	Values
1 1.1	Characteristic strength Proportion defective 5 per cent	Specified	25 N / mm² at 28 Days
1.2	Standard deviation	Fig	8 N/mm² or no data-------- N/mm²
1.3	Margin	C1	(k = 1.64) * 8 = 13 N/mm²
1.4	Target mean strength	C2	25 + 13 = 38 N/mm²
1.5	Cement type	Specified	OPC/SRPC/RHPC
1.6	Aggregate type: coarse Aggregate type: fine		Uncrushed
1.7	Free-water/cement ratio	Table 2, Fig 4	0.52 Use the lower value
1.8	Maximum free-water/cement ratio	Specified	-----------------
2 2.1	Slump or V-B	Specified	slump 60-180 mm or
2.2	Maximum aggregate	Specified	20 mm
2.3	Free-water content	Table 3	195 kg/m³
3 3.1	Cement content	C3	195÷ 0.52 = 375 Kg/m³
3.2	Maximum cement content	Specified	Kg/m³
3.3	Minimum cement content	Specified	-------Kg/m³----- Use if greater then Item 3.1 and calculate Item 3.4
3.4	Modified free-water/cement ratio		---
4 4.1	Relative density of aggregate (SSD)		2.7 Known/assumed
4.2	Concrete density	Fig5	2360 Kg/m³
4.3	Total aggregate content	C4	2360 - 195 - 375 = 1790 Kg/m³
5 5.1	Grading of fine aggregate		
5.2	Proportion of fine aggregate	Fig 6	37 Pre cent
5.3	Fine aggregate content		1790* 0.37 = 660 Kg/m³
5.4	Coarse aggregate content	C5	1790 – 660 =1130 Kg/m³

Quantities	Cement (Kg)	Water (Kg)	Fine aggregate (Kg)	coarse aggregate (Kg)
Per m³ (to nearest 5 Kg)	375	195	660	1130
Per trial mix of 0.067 m³	22.11	12.73	49.92	78.06