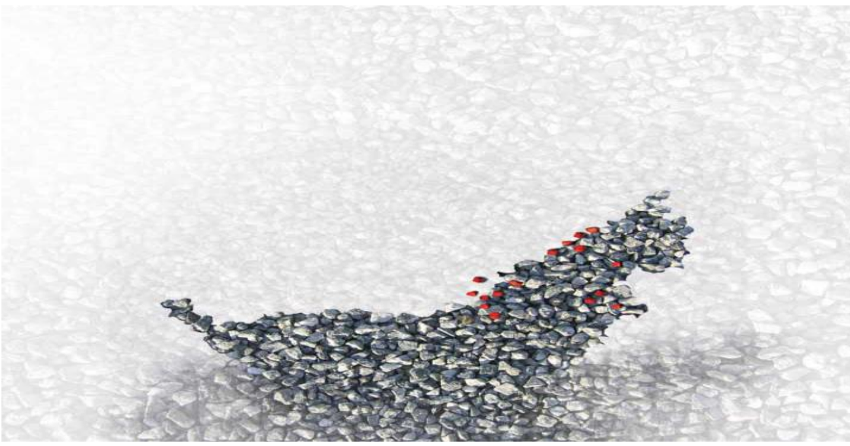
Ready- Mixed Concrete

2022

Bulletin-01 **Fundamentals of Concrete and Concrete Properties**



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TECHNICAL READY MIX CONCRETE COMPANY

Introduction

TREMIX is a leading supplier of concrete and innovative solutions in the United Arab Emirates with more than 40 years of experience. Tremix founded in 1977 and we are proud to say that we are part of the UAE success story.

We produce a full range of concrete mixes and solution from our 4 locations in **AL Ain, Abu Dhabi, Dubai and Doha**, our network includes 22 ready-mix concrete plants.

TREMIX at Dubai is certified as qualified concrete supplier complied with DM certification technical requirements for the operations of ready mixed concrete plants and transit mixers.

TREMIX has supplied concrete to most of the iconic projects in the UAE such as Dubai Airports (Beirut tunnel), DM, RTA, DEWA, SEWA, Trakhees, Jable Ali Parks, institutional, hospitals, mixed use towers, and many hundreds of individual villas.

TREMIX has a range of low carbon concrete mixes supplied as a **Green concrete** comply with DM and authorities' regulations for sustainable concrete and green environment**.** Using a recycled product (GGBS/Fly Ash & Micro silica), we have produced a high performing and high durability concrete that contains significantly less carbon than traditional concrete. Our concrete complied with the requirement of Leadership in Energy and Environmental Design (LEED) for a green building certification.

Fundamentals of Concrete and Concrete Properties

Concrete

Concrete principally is a mixture of Portland cement, aggregate and water, with or without the incorporation of Additives (admixtures), which develops its properties by hydration of the cement.

To produce the basic form of concrete, a mixture of three different materials (also called "components" or "ingredients") needed, these are Cement, Water and aggregates (sand & stones), When these three materials are mixed, water and cement react chemically to form a paste that gradually hardens and bonds (glues) the aggregates together. The chemical reaction between cement and water called "Hydration". The process generates heat, known as "Hydration Heat".

The modern and advanced concrete mixes including more than these basic ingredients, a cementitious materials such as ground granulated blast-furnace (GGBF) slag, fly ash, natural Pozzolan, and silica fume in Fig.1 may be used in conjunction with Portland or blended cement for economy or reduced early heat of hydration, improved late-age strength development or improved concrete durability which increased resistance to alkali-aggregate reaction, chloride and sulfate attack, decreased permeability, and resistance to the intrusion of aggressive solutions.

Fig.1

the paste is composed of cementitious materials, water, and entrapped air or purposely entrained air, the paste constitutes about 20% to 35% of the total volume of concrete. The absolute volume of cement is usually between 7% and 15% and the water between 12% and 20%. the air content in air-entrained concrete ranges from about 4% to 8% of the volume and in non-air-entrained concrete 0.5-3% and the aggregates make up about 60-75 % of the total volume of concrete Fig.2

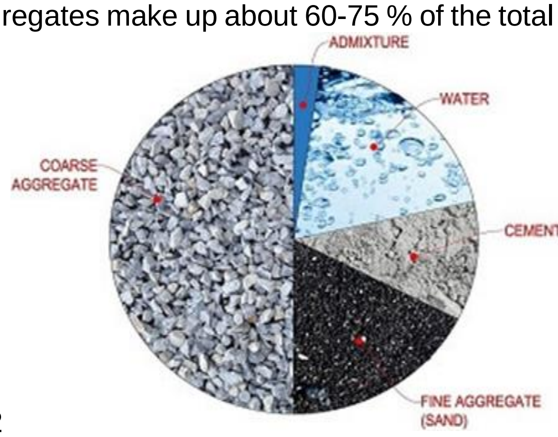

Fig.2

The quality of the concrete depends upon the quality of the paste and aggregate, and the bond between the two. In properly made concrete, each and every particle of aggregate is completely coated with paste and all of the spaces between aggregate particles are completely filled with paste, as illustrated in Fig.3

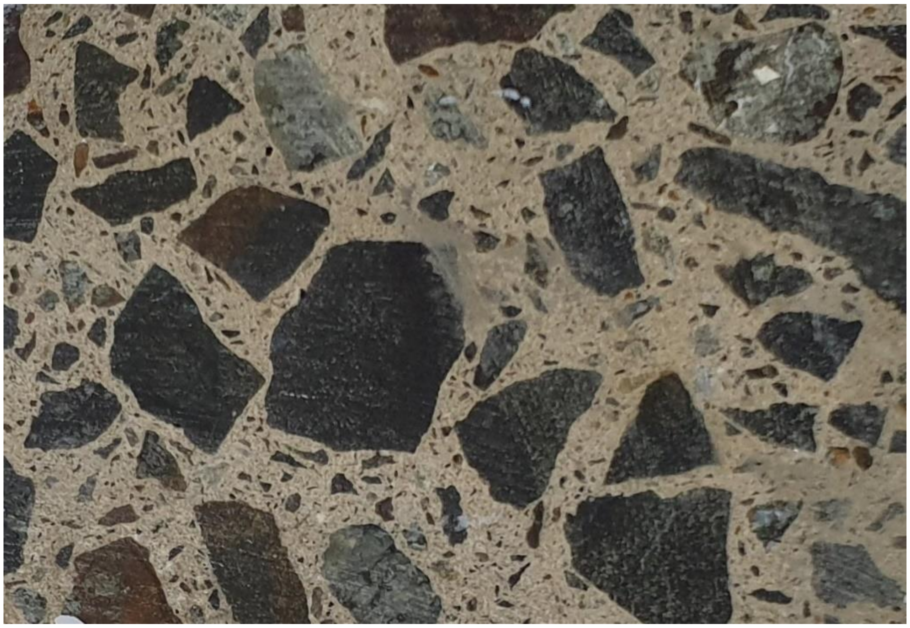

Fig.3

Chemical admixtures are frequently used in concrete to retard, accelerate, improve workability, reduce mixing water requirements, increase strength and improve durability.

Why to use Concrete?

- Strength — high load-bearing capacity and stability
- Durability — long lasting service life
- Economy — cheap, globally available raw materials
- Shaping — Concrete can be shaped into any desired geometrical form.

Where to use Concrete?

Concrete is used for all types of construction; it is a useful exercise to reflect on the major market sectors for concrete application, which are:

- Infrastructure (Roads, Bridges, Air/sea port, dams)
- Residential (private housing, Apartment buildings)
- Commercial (Shop, Supermarkets, Offices)
- Industrial (Factories, power / Desalination Plants, Refineries)
- Institutional (Schools, Hospitals, Banks, Ministries)

Concrete Classification

Concrete is classified by weight as follows:

Light Weight Concrete

Which is mostly used as thermal insulation layer on roof slabs, it can be produced by either increasing the air voids with air entraining agents, or by using light weight aggregates such as extruded clay (Lytag), rubber pellets (Vermiculite), or volcanic material (Cicolite, Perlite).

Concrete Density: 500 - 1850 kg/m3

Normal Weight Concrete

Which is the staple material in plain and reinforced concrete for general construction purposes?
As limestone, gabbro…. etc.

Concrete Density: 2300 - 2600 kg/m3

Heavy Weight Concrete

Mainly used as a protection shield against radiation from x-rays or nuclear research facilities and nuclear power plants, it can be produced by using heavy weight natural aggregates like magnetite, or steel furnace slag, or steel pellets…etc.

Concrete Density: 2700 - 6500 kg/m3

There is a correlation between concrete density and compressive strength. As a rule of thumb, "the lower the density, the lower the compressive strength".

Concrete stage

Concrete has two stages **fresh (plastic) and hardened**, in its plastic state possesses characteristics different from when it becomes hardened. The properties of concrete in it plastic state are important during the few hours of it mixture, while the properties at the hardened state is very important throughout the lifespan of the concrete.

1. **Fresh (plastic) concrete**: Concrete which is fully mixed and still in a condition (semi-liquid consistency) that easily to handle it (discharging, forming, compaction and finishing).
2. **Hardened Concrete**: Concrete which is in a solid state and developed certain strength.

Fresh Concrete

Properties of Fresh Concrete

The quality of the concrete depends upon and strongly influenced by the quality of the paste and aggregate, and the bond between the two in properly made concrete, each and every particle of aggregate is completely coated with paste and all of the spaces between aggregate particles are completely filled with paste. The following properties of fresh concrete will be addressed in detail:

1. Water / Cement ratio
2. Temperature
3. Workability / Slump & Flow
4. Setting Time
5. Air Content
6. Bleeding
7. Hydration Heat
8. Cold Joint
9. Plastic Shrinkage

1. Water / Cement ratio (W/C)

The ratio of the mass of free water (exclusive only of absorbed water by the aggregates), to the mass of total cement in one cubic meter of concrete, mortar, or grout.
Example: weight of water = 168 kg/m3
Weight of cement = 400 kg/m3
W/C-ratio = 168 / 400 = 0.42
More water at the same cement weight gives a higher W/C-ratio:
Weight of water = 180 kg/m3
W/C-Ratio = 180 / 400 = 0.45

The W/C-Ratio is the most important quality factor in concrete. It regulates the strength moreover, durability of concrete according to the following principle:

- Low W/C-ratio = high strength & high durability

- High W/C-ratio = low strength & low durability

From this principle, two very important conclusions can be drawn:

1. Adding water to concrete results in low strength and low durability, as water addition will increase the W/C ratio (see example above).

2. The W/C-Ratio has also a direct influence on the consistency of concrete. Higher W/C-Ratio produce more liquid mixes; lower W/C-Ratios produce more stiff mixes.

In most cases, our customers are specifying the W/C-Ratio in a range from 0.30 to 0.45, depending on the targeted concrete strength and consistency. That is much more than required for the hydration process, which needs a W/C-Ratio of 0.20 only. In other words, the amount of water required for the chemical reaction with cement is only 20% of the cement weight. The additional amount of water to reach W/C-Ratio of 0.40 and above is added only to make the concrete conveniently mixable and placeable. Therefore, this additional water is in some publications referred to as Water of “convenience".

2. Concrete Temperature

The temperature of fresh concrete mainly dependent on:

- Raw materials Temperature
- Ambient Temperature
- Type of additives

These affecting directly the concrete temperature, in order to control it there are appropriate measures shall be taken:

- Painting cement silos and truck mixer drums (Light color) white to reflect sun radiation
- having sufficient cement storage to keep cement for two days in silos to cool down prior to use, (FIFO)
- Shaded aggregate stock bays
- Using chilled mixing water
- Replacing a part of the mixing water with flaked ice

In accordance with ACI 301 stated that unless otherwise specified or permitted, the temperature of concrete as delivered shall not exceed 32 °C. In accordance with **BS 8500-2** the temperature of fresh concrete at the time of delivery shall not exceed:

- The specified value
- 35°C in all other cases

The temperature measured by thermometer having a range of – 5°C to +110°C, and records the temperature to the nearest 1°C.

3. Workability/Slump

3.1 Workability

It is a measure of concrete capacity and ease of placing, consolidating, and finishing freshly mixed concrete and the degree to which it resists segregation is **called workability**. The relation between slump and workability is often misunderstood, in a sense that a high slump would always result in good workability, because such a concrete can be easily placed and leveled that is not a true measure of workability. A good workability means a slump suitable for the job to be done. If that job is pouring a steeply inclined roof slab for instance, then a high slump concrete is not workable at all. That example explains perfectly well the difference between slump and workability.

3.2 Slump

Slump is a measure of consistency of the freshly concrete. The word means, "A drop in height of molded and taped concrete", as a result of the slump testing method.

The specified slump is subject to tolerances given in ASTM C-94 and BS 8500-1: 2015 (see table at the end of this section). These tolerances have been introduced, because it is technically impossible to produce concrete precisely to a specified slump value, for two reasons:

1. The slump testing method is not very accurate.

2. There are many variables that affect the slump of concrete, such as:

- Moisture content of the aggregates
- Concrete & air temperature

- air content in the concrete
- mix proportions
- aggregate gradation
- Method and duration of transportation

Acceptable slump tolerances according to BS 8500-1:2015+A2:2019 table B.2

As most of specified concrete slump is ≥100 mm, the tolerance should **be ±50 mm**

Specified Slump (mm)	**Tolerance (mm)** for spot samples taken from initial discharge
≤ 40	±30
50 -90	±40
≥ 100	**±50**

For **flow** & **slump-flow** concrete the tolerance according BS 8500-1:2015+A2:2019 table B.4 & B.6

Specified Flow (mm)	**Tolerance (mm)** for spot samples taken from initial discharge
All values	**±60**

Acceptable slump tolerances according to ASTM C-94

1. When the slump is specified as "maximum" or "not to exceed"

Specified Slump (mm)	**Tolerance (mm)**
75 mm (3")	+ 0 & - 40 (1½")
More than 75 mm (3")	+ 0 & - 65 (2½")

2. When the slump is stated as a target or nominal slump:

Specified Slump (mm)	**Tolerance (mm)**
≤ 50 mm	±15 (½")
50 –100 mm (2" - 4")	± 25 (1")
More than 100 mm (4")	± 40 mm (1½")

When the purchaser states a slump flow for self-consolidating concrete, the tolerance for flow

Specified flow (mm)	**Tolerance (mm)**
≤ 550 mm (22")	±40 (1½")
More than 550 mm (22")	± 65 (2½")

4. Setting Time

It is the period of time after which fresh concrete get certain stiffness and load-bearing capacity. Setting Time is measured from the time of mixing the concrete in the plant, precisely from the moment when the cement first comes in contact with water. We recognize two different setting times:

- **Initial Setting Time:** is reached when fresh concrete has lost its workability due to the first stiffening of the mix, at this stage, surface finishing works can still be done, but the concrete shall no longer be moved or compacted, as that would result in low strength and durability.

- **Final Setting Time:** Physically is reached when the concrete has become hard enough to walk on it without leaving marks on the concrete surface. At this stage, surface finishing works can no longer be done.
  Under local conditions and with locally used raw materials, the following Setting Times of concrete can be expected:
  - Initial Setting Time 3 - 4 hours
  - Final Setting Time 8 - 12 hours

Setting Times of concrete are mainly ruled by the Setting time of the cement used in the mix, but depend also on other factors:

Ambient temperature.	The higher the temperature, the shorter the Setting time.
Type of cement	The high early strength cements the shorter the setting time.
Cementitious additives	The high content GGBS or Fly ash the longer the setting time**.**
Fineness of cement.	The finer the cement, the shorter the Setting time.
Cement content.	The more cement in the concrete, the shorter the Setting time.
Water content.	The more water in the concrete, the longer the Setting time.
Chemical Admixtures.	The more retarding admixtures in the concrete, the Longer the Setting time.

As concrete is no longer allowed to be moved or compacted once the Initial Setting time is reached, it means concrete must be mixed in the plant, transported to the site, poured / pumped into the formwork and compacted within **two hours** to be on the safe side.

5. Air Content

Air voids in concrete are created in two different ways:

- Entrapped Air
- Entrained Air

5.1 Entrapped Air

Entrapped air is generated when fresh concrete is mixed, Air voids are reducing the compressive strength of concrete. Therefore, when casting concrete on site or manufacturing concrete test specimens in the

laboratory, concrete must be compacted by external or/and internal vibrator to reduce the entrapped air to the lowest possible amount.
However, even after the most intensive compaction, there will be about 2% of entrapped air remaining in concrete. This amount of air is considered accordingly in mix designs for regular concrete. Each additional 1% percent of air above this amount will reduce the compressive strength by about 5%.
ACI 214.4 stated that Concrete is usually consolidated by vibration to expel entrapped air after placement, unless it is a self-consolidating concrete (SCC). Strength is reduced by approximately 7% for each percent by volume of entrapped air remaining when concrete is insufficiently consolidated (Popovics 1969; Concrete Society 1987; ACI 309.1R).

5.2 Entrained Air

That is air artificially introduced into concrete by means of chemical admixtures called "air entraining agents". The sole purpose of air entrainment is to make concrete more resistant to freezing - thawing cycles. As freezing thawing cycles never occur in UAE, air entrainment does not serve any purpose here.

When wet, hardened concrete is subject to freezing - thawing cycles, the water inside the concrete will expand when ice is formed, thus generating pressure that can lead to cracking and scaling of the concrete surface. Air entraining agents produce millions of very small, closed-cell bubbles in concrete, from 1 micron (0.001 mm) to 1mm in diameter. As the bubbles are not connected to each other, they provide spaces in between them for the water to expand, thus preventing cracking and scaling.

Air entrainment is commonly specified in ranges, such as 3 - 5%, or 4 - 6%. The air content in fresh concrete can be measured by a simple testing method in the laboratory. The test results must comply with the specified values within a tolerance of ± 1.5%.
Also entrained air is reducing the compressive strength of concrete, at the same rate as entrapped air.

6. Bleeding

Bleeding is the development of a layer of water at the top or surface of freshly placed concrete. It is caused by sedimentation (settlement) of solid particles (cement and aggregate) and the simultaneous upward migration of water. Bleeding is normal and it should not diminish the quality of properly placed, finished, and cured concrete.

Excessive bleeding increases the water-cement ratio near the top surface; a weak top layer with poor durability may result, particularly if finishing operations take place while bleed water is present. A water pocket or void can develop under a prematurely finished surface. Excessive bleed water is an indication that too much water was mixed in the concrete initially or added at the job site. Bleeding test determined in accordance of ASTM C 232 shall not exceed 0.5 %

7. Hydration Heat

As mentioned before, when cement and water are mixed, a chemical reaction called "Hydration" takes place. This chemical reaction generates heat, which is therefore called "Hydration Heat", or "Heat of Hydration".
Hydration Heat is an important issue for concrete structures, because it can adversely affect their durability. If a high amount of Hydration Heat is generated, concrete will shrink excessively when cooling down, and

the stresses created by the shrinking may lead to the formation of cracks in the concrete. This process is known as "Thermal Shrinkage Cracking". The problems with Hydration Heat are compounded in our local environment, with high ambient temperatures prevailing most of the time.
The development of Hydration Heat in fresh concrete depends on the following factors:

- **Type of cement:** Normal/low heat/moderate heat/rapid hardening
- **Fineness of cement:** The finer the cement, the higher the Hydration Heat
- **Cement additives**: the higher content of GGBS/Fly ash/ Micro silica the lower Hydration Heat
- **Cement content**. The more cement in the concrete, the higher the Hydration Heat.
- **Structural dimensions**. The thicker a wall, slab, or foundation, the higher the Hydration Heat.

Mass Concrete

Mass concrete is defined in ACI 116R as “any volume of concrete with dimensions large enough to require that measures be taken to cope with generation of heat from hydration of the cement and attendant volume change to minimize cracking.
Heat exchanging measures are sometimes used to control the development of Hydration Heat in extremely massive structures like raft foundations and concrete dams, in order to avoid or reduce the risk of thermal shrinkage cracking, Hydration Heat should be reduced by appropriate measures:

- Using Normal or low heat of hydration Portland cement
- Keeping the cement content in the mix as low as possible.
- It is advisable to replace a part of the cement with heat-reducing cementations additives like GGBS, Fly Ash and/or Micro silica.
- Insulation of surfaces to minimize the differentials between the interior and exterior of concrete **especially during winter season**.
- Precooling and post cooling

8. Cold Joints:

Exact knowledge of the Initial Setting Time can be important for placing concrete on site. During such operations, the principle of concrete placement is "fresh on fresh". If a portion of concrete already poured into a wall or a slab and still within the Initial setting time up 3- 4 hours you can place the next portion without cold joint formation.
but if the next portion placed on the top and the previous portion initial setting time exceeded (dependent on the initial setting time), then we talk about the formation of a Cold Joint, because the two Portions of concrete can no longer be homogenously connected to each other.
A cold joint in vertical structures is not detrimental to its load bearing capacity, but if water tightness and bending forces is important, a cold joint must not be occurred.
In order to avoid the cold joint occurrence, the contractor engineer should manage with concrete supplier the concrete supply and truck interval based on:

- Type of structure
- Placement method
- Traffic situation

9. Plastic Shrinkage Cracking

Plastic shrinkage cracks appear mostly on horizontal concrete surfaces (slabs & pavements), during or/and after placing concrete. it is range from hair cracks to 5 mm width and When the top layer of freshly poured concrete dries out, the concrete in that layer will shrink, causing tensile stresses within the layer while the bottom layer still fresh, since concrete at that time has not yet developed any tensile strength, cracks will take place on concrete surface.
This kind of cracks not appeared on external sides of slab or bottom surface because it is protected by shutter against sunshine and wind.
Such rapid drying of concrete surfaces happens when the rate of moisture evaporation from the concrete surface is higher than the rate of bleeding water rising to the concrete surface. This is the official definition of “Hot Weather Concreting".

High evaporation rates can be expected when:

- Ambient temperatures are high
- Strong winds with high velocity are prevailing
- The relative humidity is low.

ACI 305 provides a chart that can indicate the possibility of plastic shrinkage cracking to occur, by estimating the evaporation rate under certain weather conditions.

Some concrete mixes with a reduced rate of bleeding are subject to plastic shrinkage cracking even at low evaporation rates, such as mixes with high cement content, low water/cement content, and mixes containing Micro Silica requires particular attention, as Micro Silica is preventing the development of bleeding water entirely.
Suitable precautions against the formation of plastic shrinkage cracks are:

- Erection of temporary wind breakers to reduce moisture evaporation by strong winds
- Covering the surface of concrete by plastic polyethylene sheets during and after placement.
- Use fog sprays on freshly placed concrete to avoid a quick drying out of concrete surfaces.
- Start curing (keeping concrete surfaces moist) instantly after surface finishing by covering the surface of concrete by wet burlap and plastic polyethylene sheets.

The plastic shrinkage cracks do not compromise the stability of slabs or pavements, but can have an adverse effect on durability, as they allow aggressive substances to penetrate into the structure easily.

Hardened Concrete

It is the second phase of concrete which is in a solid state and has developed certain strength.
The following properties of hardened concrete will be addressed in detail:

1. Strength
2. Volume Change & Cracking
3. Durability

1. Strength

Concrete is strong in compression but relatively weak in tension and bending. It takes a great deal of force to crush concrete, but very little force to pull it apart or cause bending cracks. There are two entirely different types of strength in hardened concrete:

- Compressive Strength
- Tensile / Flexural Strength

1.1 Compressive Strength

The compressive strength is a measure of the concrete's resistance against breaking under a vertical load. It is tested by breaking concrete specimens in a compressive strength-testing machine. The specimens are manufactured either at the station or on site. BS specifies cube specimens with 150mm edges and ASTM specifies cylindrical specimens, with a diameter of 150mm and a height of 300mm. Cube specimens achieve 15 - 20% higher strength test results than cylinder specimens made from the same concrete.

Curing of Specimens

Compressive strength tests are also regularly conducted at the age of 7 days, because these results can be used to forecast the 28 days results when safe correlations between 7 and 28 days results have been established. At 7 days, normal concrete produced with local raw materials will achieve approximately 85% of its ultimate (28 days) strength.

For each compressive strength test, at least two concrete specimens from the same batch or truckload must be tested. The average of the two cube results recorded as a one compressive strength test results.

The testing itself is done in a compressive strength-testing machine, which works by means of an electrically powered hydraulic system. The specimen is placed on the bottom platen of the machine, while the machine's upper platen is brought down on the specimen's top surface, applying a steadily increasing load until the specimen breaks. The load at breakage is recorded as "failure load" in Kilo Newton [kN].

In order to calculate the compressive strength, the failure load is divided by the specimen's cross section area, and recorded in one of the four following compressive strength units, depending on the project specification:

- N/mm2 (Newton per square millimeter)
- Mpa (Mega Pascal)
- kg/cm2 (Kilogram per square centimeter)
- Psi (Pounds per square inch)

There is no difference between N/mm² and Mpa. Conversion factors between the other strength units are:

1 N/mm² (or 1 Mpa) = 145 Psi	1 kg/cm² = 14.2 Psi
1 N/mm² (or 1 Mpa) = 10.2 kg/cm²	1 kg/cm² = 0.098 N/mm² (or Mpa)

The compressive strength of concrete is mainly ruled by the W/C-ratio and the cement content, but also depends on other factors:

- low W/C ratio → high strength
- high cement content → high strength
- big aggregate size → high strength
- high air content → low strength
- low density → low strength

The factors above have a direct influence on the <u>actual</u> concrete strength. There are other factors which have an influence on the measured concrete strength this is very important.

Remember that the compressive strength of concrete is measured on concrete test specimens manufactured either on site or in the laboratory. From manufacturing to final strength testing a lot of things can go wrong, which may generate test results that are mostly lower than the actual compressive strength of the concrete, but in some cases also higher. If low strength test results are reported, typically the ready mix supplier will be blamed, but in more than 90% of all cases, the supplier is not at fault.

The variations of strength test results mostly caused by non-standard testing procedures and mishandling of the concrete test specimens.

Conformity of concrete compressive strength is assessed on specimens tested at 28 days.

Conformity criteria for compressive strength BS EN 206-1:2014

Production	Number n of test results Criterion 1 Criterion 2 for compressive strength in the group	Criterion 1	Criterion 2
		Mean of n results (*fcm*) N/mm2	Any individual test result (*fci*)N/mm2
Initial	3	≥ fck + 4	≥ fck − 4
Continuous	Not less than 15	≥ fck + 1,48 σ	≥ fck − 4

Conformity is confirmed if both the criteria given in above table for either initial or continuous production are satisfied. Where this method is applied to a concrete family, the mean of all non-transposed test results (f_{cm}) for a single family member shall be assessed against the criterion given in BS EN 206-1:2014 Table-18.

Table 18 — Confirmation criterion for family members

Number *n* of test results for compressive strengthfor a single family member	**Mean of *n* results (f_{cm})for a single family member** N/mm^2
2	≥ f_{ck} - 1,0
3	≥ f_{ck} + 1,0
4	≥ f_{ck} + 2,0
5	≥ f_{ck} + 2,5
6	≥ f_{ck} + 3,0
7 to 9	≥ f_{ck} + 3,5
10 to 12	≥ f_{ck} + 4,0
13, 14	≥ f_{ck} + 4,5
≥ 15	≥ f_{ck} + 1,48 σ

1.2 Tensile / Flexural Strength

The tensile strength is a measure of the concrete's resistance against pulled apart. The tensile strength of concrete is relatively low, reaching approximately 8-10% of the compressive strength only. That is the reason why steel reinforcement bars of high tensile strength were introduced for concrete structures. Reinforced concrete structures are designed so that:

- The concrete takes care of pressure, mostly from vertical loads
- The reinforcement bars take care of tensile stresses, mostly from horizontal or bending forces

Because it would be difficult to directly test the tensile strength of concrete, flexural strength testing is being used instead. This test determines the bending moment at which a concrete test beam breaks when a vertical load is applied to its midsection.
Standard concrete test beams have a cross section of 150 x 150mm, and a length of 500mm.
For testing, the concrete beam, resting on support blocks at both ends, is placed in a compressive strength testing machine, while the upper platen is brought down on the beam's midsection, applying a steadily increasing load until the beam brakes. The load at breakage is recorded as failure load, which is used to calculate the flexural strength in the same units as the compressive strength (N/mm2, MPa, Psi, Kg/cm2).

There are not many projects for which a flexural strength is specified, because in normal reinforced concrete structures all tensile stresses are transferred to the reinforcement bars. Specifications for flexural strength are therefore limited to un-reinforced concrete structures subject to tensile stresses, such as concrete pavements for highways, walkways, and airport runways.
Factors that affect the actual flexural strength of concrete are the same as those mentioned for the compressive strength (W/C-ratio, cement content, aggregate size, air content, density).
In addition, the factors that affect the measured flexural strength are the same as those for the compressive strength, but with a greater focus on mishandling of the beam specimens, because they are easy to damage due to their elongated shape.

2. Volume Change & Cracking

2.1 Volume Change

There are three major factors that cause volume changes in hardened concrete:

- Moisture
- Temperature
- Vertical Loads (stress)

Simply expressed, when hardened concrete gets wet, it will expand (volume increase); and when it dries out, it will shrink (volume reduction). Likewise, when hardened concrete gets hot, it will expand; and when it cools down, it will shrink, the amount of shrinkage also depends upon several factors:

1. The primary factor influencing the amount of drying shrinkage is the water content of the freshly mixed concrete.
2. The amount of aggregate used
3. Properties of the aggregate
4. Size and shape of the concrete element
5. Relative humidity and ambient temperature
6. Method of curing
7. Degree of hydration.

Under a continuous vertical load, a concrete structure will reduce its height. That is called "Creeping", and is most noticeable in columns and walls. A part of such a vertical load is the own weight of a concrete structure. Consequently, concrete buildings will be reduced in height over time, the more so the higher they are. However, the reduction is minimal and not obvious to the naked eye. Creeping is a slow process which does not cause any structural damage.

2.2 Cracking

Two basic causes of cracks in concrete are:

1. stress due to applied loads and
2. Stress due to drying shrinkage or temperature changes when concrete is restrained.

When concrete is subject to volume changes but cannot freely expand or shrink due to structural restrains, it will crack, such restrains can occur when a concrete slab is rigidly held in place by surrounding walls, or due to the friction between the soil and the concrete at a slab cast on ground.

Most cracks occur due to shrinkage in unreinforced concrete, as shrinkage causes tensile stresses against which the concrete is not resistant. The type of shrinkage mainly responsible for cracking is the long term drying shrinkage, when the initially fresh concrete is slowly drying out over a long period of time.
Shrinkage is a direct function of the structural dimension, which means that a 20 m long slab will shrink by double as much as a 10 m long slab. The more shrinkage, the higher the tensile stresses, and the more cracks will occur.
Drying shrinkage is an inherent, unavoidable property of concrete, therefore, properly positioned reinforcing steel is used to reduce crack widths, or joints are used to predetermine and control the location of cracks.
Thermal stress due to fluctuations in ambient temperature also can cause cracking, particularly at an early age.
In order to avoid uncontrolled cracking, large slabs are therefore divided into smaller parts by cutting joints into the surface. That is called "Crack Control", as the concrete will then crack along the lines of the joints instead of cracking in an irregular, unsightly pattern. Joints shall have a depth of 1/4 of the thickness of a slab, and shall divide a slab in parts 5 X 5 m not larger than 6 X 6 m.

Joints:
Joints are the most effective method of controlling unsightly cracking, if a sizable expanse of concrete (**wall, slab, or pavement**) is not provided with properly spaced joints to accommodate drying shrinkage and temperature contraction, the concrete will crack in a random manner.

Contraction joints are grooved, formed, or sawed into sidewalks, driveways, pavements, floors, and walls so that cracking will occur in these joints rather than in a random manner. Contraction joints permit movement in the plane of a slab or wall. They extend to a depth of approximately one-quarter the concrete thickness.

Isolation joints separate a concrete placement from other parts of a structure and permit horizontal and vertical movements. They should be used at the junction of floors with walls, columns, footings, and other points where restraint can occur. They extend the full depth of slabs and include a remolded joint filler.

Construction joints occur where concrete work is concluded for the day; they separate areas of concrete placed at different times. In slabs on-ground, construction joints usually align with and function as control or isolation joints. They may require dowels for load transfer.

3. Durability

Durability related to concrete defined as:

- The ability of concrete to resist weathering action, chemical attack, abrasion, and other conditions of service -ACI 116.
- The period of useful service life of concrete structure without expensive repairs

Different concretes require different degrees of durability depending on the **exposure environment** condition and the properties desired. Durable concrete is designed to be resistant against abrasion, and to prevent the ingress of aggressive substances, which may either destroy the concrete itself or the embedded steel reinforcement.

Major threats to concrete durability:

1. **Abrasion**: Occurs on concrete slabs with a dense traffic of heavy loads, such as highways, airport runways, bridges, or warehouse floors. It gradually destroys the concrete surface.

2. **Carbonation**: Concrete in its original form is a highly alkaline product with a pH-value of about 13. Steel reinforcement embedded in this material develops a fine layer of iron oxide on the surface that prevents further corrosion. When carbon dioxide (CO2) penetrates concrete, it will react with hydroxides, when reacts with calcium hydroxide a calcium carbonate is formed, carbonation significantly lowers the alkalinity (**pH**) of the concrete. That in turn will destroy the protective iron oxide layer on the steel reinforcement, and make it susceptible to corrosion. Carbonation became dishonorable as "concrete cancer". **High alkalinity is needed to protect embedded steel from corrosion.**

3. **Chloride Attack**:
   Chloride attack is one of the main causes of deterioration of reinforced concrete structures that is exposed on a marine environment or deicing salts, Chloride ions, highly concentrated in the salt-laden atmosphere of the Gulf countries, create the greatest threat to the steel reinforcement. Their potential to damage the concrete itself is negligible. But when chloride ion concentrations at the reinforcement bars reach the so called "threshold level of activation", corrosion occurs under forceful volume expansion, which generates pressures on the surrounding concrete, that is sufficient to blast off whole chunks of concrete from the reinforcement bars.
   As the hydration of C_3A is related to a formation of expansive ettringite, the higher C_3A in cement substantially produced the denser pore structure.

   (**Ettringite** is formed in hydrated Portland cement system as a result of the reaction of calcium aluminate with calcium sulfate, both present in Portland cement). $C3A + 3\ CaSO4 \rightarrow$ ettringite
   The reactivity of C_3A with chloride ions in the concrete pore solution often forms crystallized salt in terms of Friedel's salt, which could remove chlorides from the pore solution and thus not participate in the corrosion process. Thus, a high concentration of C_3A is regarded as an inhibitive nature against chloride-induced corrosion of steel in concrete.

   Chloride ions alone can also penetrate the passive film, on the reinforcement, they combine with iron ions to form a soluble iron chloride complex that carries the iron into the concrete for later oxidation (rust) (Whiting 1997, Taylor, Whiting, and Nagi 2000 and Whiting, Taylor and Nagi 2002).
   The resistance of concrete to chloride can be increased by:

1. Using a low water-cement ratio (< 0.40).
2. Supplementary cementitious materials, such as GGBS and silica fume to reduce permeability.
3. Increasing the concrete cover over the steel also helps slow down the migration of chlorides.
4. At least seven days of moist curing.
5. Include the use of corrosion inhibiting admixtures, epoxy-coated reinforcing steel (ASTM D 3963 or AASHTO M 284), surface treatments, concrete overlays, and catholic protection.

1. **Sulphate Attack**:
   Excessive amounts of sulfates in soil or water can attack and destroy a concrete that is not properly designed. Sulfates (for example calcium sulfate, sodium sulfate, and magnesium sulfate) are available in soil and groundwater. Once penetrated into hardened concrete, Sulphate salts react with the cement to form Sulpho-aluminates under extreme volume expansion, which results in the gradual disintegration of the concrete.

   The hydration of C_3A, together with added gypsum to cement, provide ettringite formation, which later becomes a Monosulfate, the Monosulfate, when in contact with the sulfate that came from the external environment became unstable and reacts back to ettringite in a strongly expansive reaction. This, occurring in the hardened concrete, produces intense material degradation
   Therefore, producing impermeable (watertight) concrete will prevent the penetration of aggressive chemicals into the concrete. Impermeable concrete has obviously a high density and a hard, non-porous surface, which in turn would make concrete also resistant against premature abrasion.

Note: Concrete to be durable, it must be impermeable!

In order to produce impermeable concrete, the following factors must be considered in the mix composition:

- **Low W/C-Ratio** reduces permeability by reducing capillary voids that form after the evaporation of surplus mixing water. Capillary voids make concrete porous, and allow easy penetration of aggressive chemicals. At W/C-ratio below 0.40, these voids will be gradually filled with expanding hydration products as hydration proceeds.
- **Cement Content** is required to form a sufficient volume of hydration products to fill capillary voids; to support workability at low W/C-ratios; and to yield high alkalinity for the formation of a protective coating on reinforcement bars.
- **Combination of Aggregates** (sand & stones) according to the concrete principle of filling the utmost possible amount of voids, resulting in concrete of high density and surface quality.
- **Cementitious Additives** such as silica fume, ground granulated blast furnace slag (GGBS) and fly ash, combined with Portland Cement can increase the resistance of concrete against penetration of chlorides by many times over that of concrete with Portland Cement alone.

Durability test
To make sure that concrete is durable, there are many test could be conducted on concrete specimens (cube / cylindrical), the most test required as per UAE condition and project's specification in Dubai are:

• Rapid Chloride Penetration (RCP)- Coulombs	ASTM 1202 / AASHTO 277
• Water permeability -mm	DIN 1048: Part 5
• Water Absorption %	BS 1881 Part 122:1983
• Initial surface absorption test – ml/m²/esc	BS 1881: P208:1996
• Chloride content %	ASTM C1152
• Sulphate content %	ASTM C856

Self-Consolidating Concrete (SCC)

This concrete flows under its own weight and does not require any external vibration for compaction, it is highly flowable, no segregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation ACI 237R-07.
The use of SCC has gained wide acceptance in Japan since the late 1980s, SCC is concrete made with conventional concrete materials and high range water reducing admixture HRWRA(Polycarboxylate-PC).

SCC was developed to:

- Ensure proper consolidation in congested applications where concrete durability and service life were of concern.
- Used to facilitate construction operations and reduce construction time and cost.

SCC design should achieve the following properties:

- Highly flow ability
- Segregation resistance.
- High passing ability
- High filling ability.
- Encapsulate the reinforcement without any mechanical consolidation

Filling Ability Tests	**Passing ability Tests**	**Segregation resistance Test**
Slump Flow Test	J-Ring Test	V-funnel at T5 minutes
T50cm Slump Flow	L-Box Test	
V-Funnel Test	U-Box Test	

Acceptable Flow tolerances according to BS 8500-1:2015+A2:2019 table B.4 & B.6

Specified Flow (mm)	**Tolerance (mm) for spot samples taken from initial discharge**
All values	±60

Formwork for SCC

- Formwork should be watertight (no leaking) so as to avoid honeycombs and surface defects.
- Formwork should be clean and nonabsorbent otherwise there will be a chance of:
  - Discoloration
  - Deformation
- Formwork enough strong that accommodate the expected liquid head (exerted pressure).

Light Weight Concrete

Lightweight concrete mixture is made with a lightweight aggregate and sometimes a portion or entire fine aggregates may be lightweight instead of normal aggregates. Structural lightweight concrete has an in-place density (unit weight) (**500 to 1850 kg/m³).**

The first known use of lightweight concrete dates back over 2000 years in the Mediterranean region, but the three most notable structures were built during the early Roman Empire and include the Port of Cosa, the Pantheon Dome, and the Coliseum.

Naturally occurring lightweight aggregates are mined from volcanic deposits that include pumice and scoria.

Lightweight concrete placement

Concrete shall be placed nearest to its final position; placing techniques shall not cause segregation.

- Direct discharge from transit mixer chute
- crane and bucket
- pumping

In all placement method the rough handling should be avoided to reduce the volume loss. Pump and pump system Listed as follows are some of the key items pertinent to the pump and pumping system.

- Use the largest size line available, with a recommended minimum of 5 in. (125 mm) diameter without reducers
- All lines should be clean, the same size, and "buttered" with grout at the start.
- Avoid rapid size reduction from the pump to line.
- Reduce the operating pressure by:

    1. Slowing down the rate of placement
    2. Using as much steel line and as little rubber line as possible
    3. Limiting the number of bends.

REFERENCES

1. *ACI 318-19, Building Code Requirements for Structural Concrete and Commentary,*
2. *ACI 301-16 Specifications for Structural Concrete*
3. *ACI 214.4 Guide for Obtaining Cores and Interpreting Compressive Strength Results*
4. *ACI 201.2R-16, Guide to Durable Concrete*
5. *ASTM C94/C94M-21 Standard specifications for Ready-mixed Concrete*
6. *BS 8500-1:2015+A2:2019*
7. *BS 8500-2:2015+A2:2019*
8. *BS EN 206-1:2014*