CONCRETE

Concrete is a composite, man-made stone which consist of a rationally chosen mixture of binding material such as cement (10% of the total volume), well graded fine and coarse aggregates (75% of the total volume), water (15% of the total volume) and admixtures (to produce concrete with special properties – less than 2% of weight of cement). If concrete is poured with reinforcing materials (such as rebar), a different product called reinforced concrete will be yielded.

Aggregate consists of coarse (generally a coarse gravel or crushed limestone or granite) along with fine (sand) particles. The size distribution of the aggregate determines how much binder is required. Aggregate with a very even size distribution has biggest gaps, whereas adding aggregate with smaller particles tends to fill these gaps. The binder must fill the gaps between aggregate as well as pasting the surface of the aggregate together and is typically the most expensive ingredient. Thus variation in size of aggregate reduces the costs. The aggregate is nearly always stronger than the binder, so its use does not negatively affect the strength of concrete.


granite


sand

Cement, most commonly Portland cement, is the main binder. Other cementitious materials are sometimes added as mineral admixtures – either pre-blended with cement or directly as a concrete ingredient and become a part of the binder for the aggregate.

To produce concrete, water is mixed with the dry ingredients (cement and aggregate) which produces a semi-liquid slurry / a paste or matrix, which in addition to filling the voids of the fine aggregate, coats the surface of fine and coarse aggregates and binds them together and this matrix can be shaped typically by pouring it into a form / mold. Concrete solidifies and hardens through a chemical process called hydration.

A lower water- to- cement ratio yields a stronger, more durable concrete, whereas more water gives a freer-flowing concrete. Impure water used to make concrete can cause problems when setting or in causing premature failing of the structure.

Hydration involves many different reactions, often occuring at the same time. As the reaction proceed, the products of the cement hydration process gradually bond together the individual fine and coarse aggregate particles to form a solid mass.

Chemical admixtures are materials in the form of powder or liquids that are added to the concrete to give it certain characteristics not obtainable with plain concrete mixes.

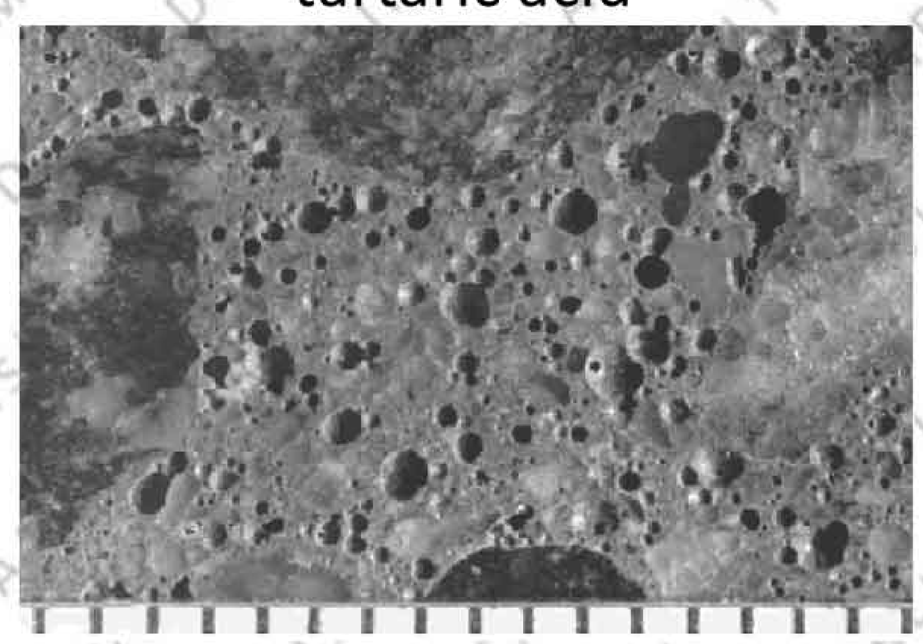
Accelerators speed up the hydration (setting) of the concrete. Typical materials used are $CaCl_2$, $Ca(NO_3)_2$ and $NaNO_3$. However, use of chlorides may cause corrosion in steel reinforcing, so that nitrates may be preferred. Accelerating admixtures are especially useful for modifying the properties of concrete in cold weather.


calcium nitrate

Retarders slow the hydration of concrete and are used in large or difficult pours where partial setting before the pour is complete is undesirable. Typically sugar, sucrose, solium gluconate, glucose, citric acid and tartaric acid are used.


tartaric acid

Air entraining agents add and entrain tiny air bubbles in the concrete which reduces damage during freeze-thaw cycles, increasing durability. However, entrained air entails a trade off with strength, as each 1% of air may decrease compressive strength 5%. If too much air becomes trapped in the concrete, defoamers can be used to encourage the air bubble to agglomerate, rise to the surface of the wet concrete and then disperse.



Plasticizers increase the workability of plastic or fresh concrete, allowing it to be placed more easily. A typical plasticizer is lignosulfonate. Plasticizers can be used to reduce the water content of a concrete while maintaining workability.

Pigments can be used to change the color of concrete.

Corrosion inhibitors are used to minimize the corrosion of steel and steel bars in concrete.

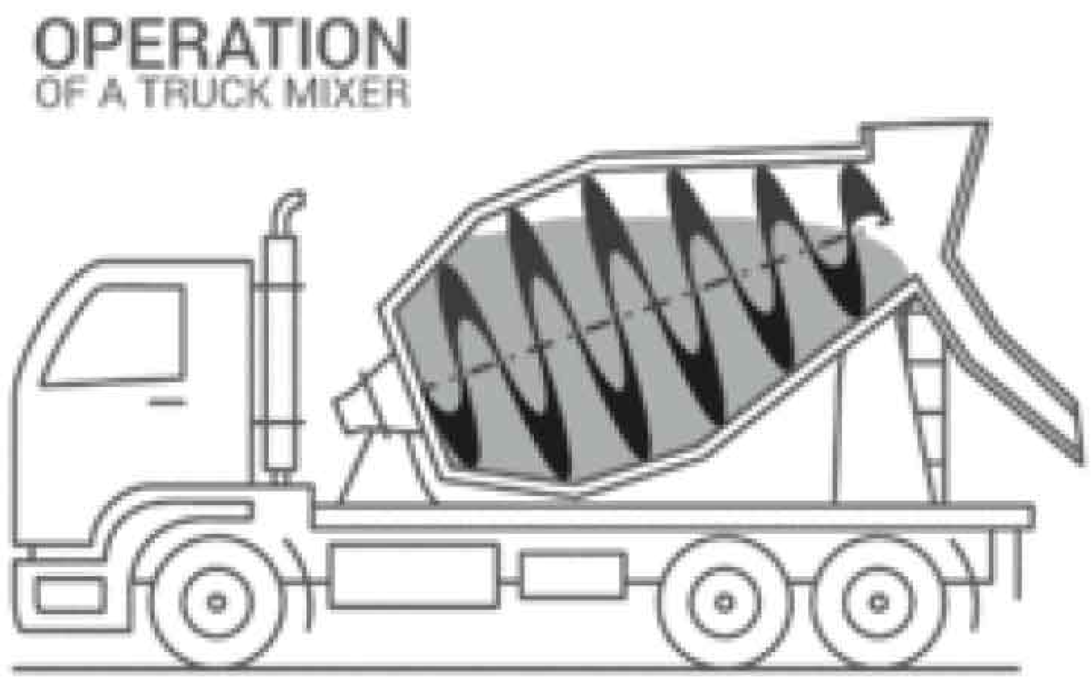
Waterproofing admixtures can be used depending on the function of the concrete and the nature of its exposure. As a naturally porous material, though and one that is prone to cracking, concrete is vulnerable to water infiltrations. Waterproofing admixtures reduce concrete's permeability. One of the additive categories for waterproofing consists of hydrophobic or water repellent chemicals derived from soaps or fatty acids, vegetable oils and petroleum. These materials form a water repellent layer along pores in the concrete, but the pores themselves remain open. The other category is finely divided solids – either inert or chemically active fillers such as talc, siliceous powders, hydrocarbon resins and coal-tar pitches. These materials densify the concrete and physically limit the passage of water through the pores.

Concrete Production

Concrete production is the process of mixing together the various ingredients (water, aggregate, cement and any additives) to produce concrete. This process is time sensitive, once the ingredients are mixed, this mixture must be put in molds before it sets (katılaşmak). Most concrete production takes place in a large type of industrial facility called a concrete plant or often a batch plant. In general usage, concrete plants come in two main types, ready mix plants and central mix plants. A ready mix plant mixes all the ingredients except water while a central mix plant mixes all the ingredients including water. A central mix plant offers more accurate control of the concrete quality through better measurements of the amount of the water added, but must be placed closer to the work site where concrete will be used since hydration begins at the plant.

a concrete plant facility showing a concrete mixer being filled from the silos

A concrete mixer is a device that homogeneously combines cement, aggregate and water to form concrete. A typical concrete mixer uses a revolving drum to mix the ingredients. Special concrete transport trucks (in-transit mixers) are made to transport and mix concrete up to the construction site. They can be charged with dry ingredients and water, with the mixing occurring during transport. They can also be loaded from a central mix plant, with this process the material has already been mixed prior to loading. The concrete mixing transport truck maintains the materail's liquid state through agitation – turning the drum – until delivery. The interior of the drum is fitted with a spiral blade. In one rotational direction, the concrete is pushed deeper into the drum. This is the direction the drum is rotated while the concrete is being transported to the building site. When the drum rotates in the other direction, the arrangement discharges or forces the matrix out of the drum.



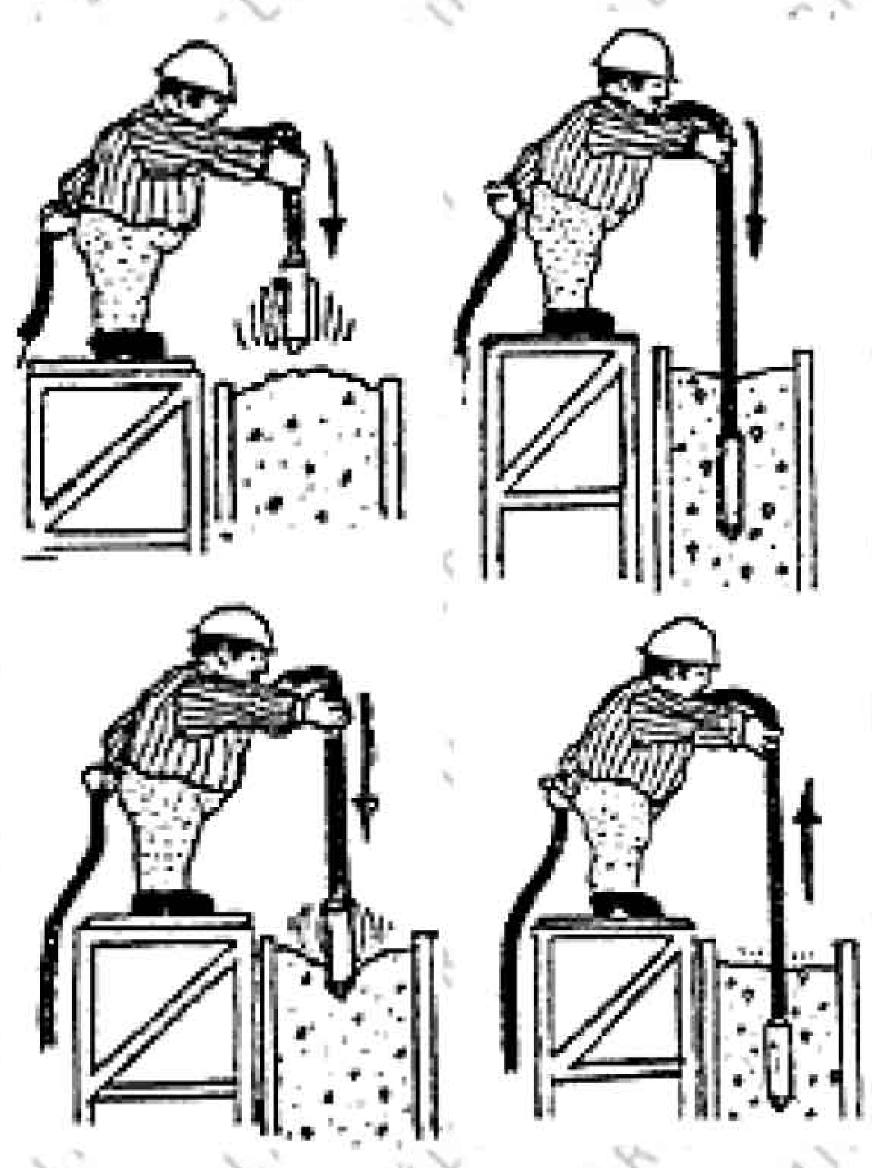
For smaller volume works portable mixers are often used so that the concrete can be made at the construction site. To service this small batch concrete market, there are many types of small portable concrete mixers available with a small revolving drum which may be powered by a gasoline engine, electric motors or by hand.

After the mixer discharges the viscous matrix, it may go onto chutes to guide it directly to the concrete site. If the truck cannot get close enough to the site to use the chutes, the concrete may be discharged into a concrete pump, connected to a flexible hose or onto a conveyor belt which can be extended some distance. A pump provides the means to move the material to precise locations, multi-floor buildings and other distance prohibitive locations. The most common type of concrete pump is attached to a truck and is known as a boom pump because it uses a remote-controlled articulating robotic arm (a boom) to place the matrix accurately. Boom pumps are used on most of the larger construction projects as they are capable of pumping at very high volumes.

Because concrete is usually prepared as a viscous fluid, it needs to be poured into forms, which are containers erected in the site to give the concrete its desired shape until it sets. Forms can be temporary or permanent. Forms can be built on site out of timber and plywood, moisture resistant particleboard (can be produced on site, time consuming, short lifespan); steel, aluminum (prefabricated, fast construction, long lifespan); plastic, etc.

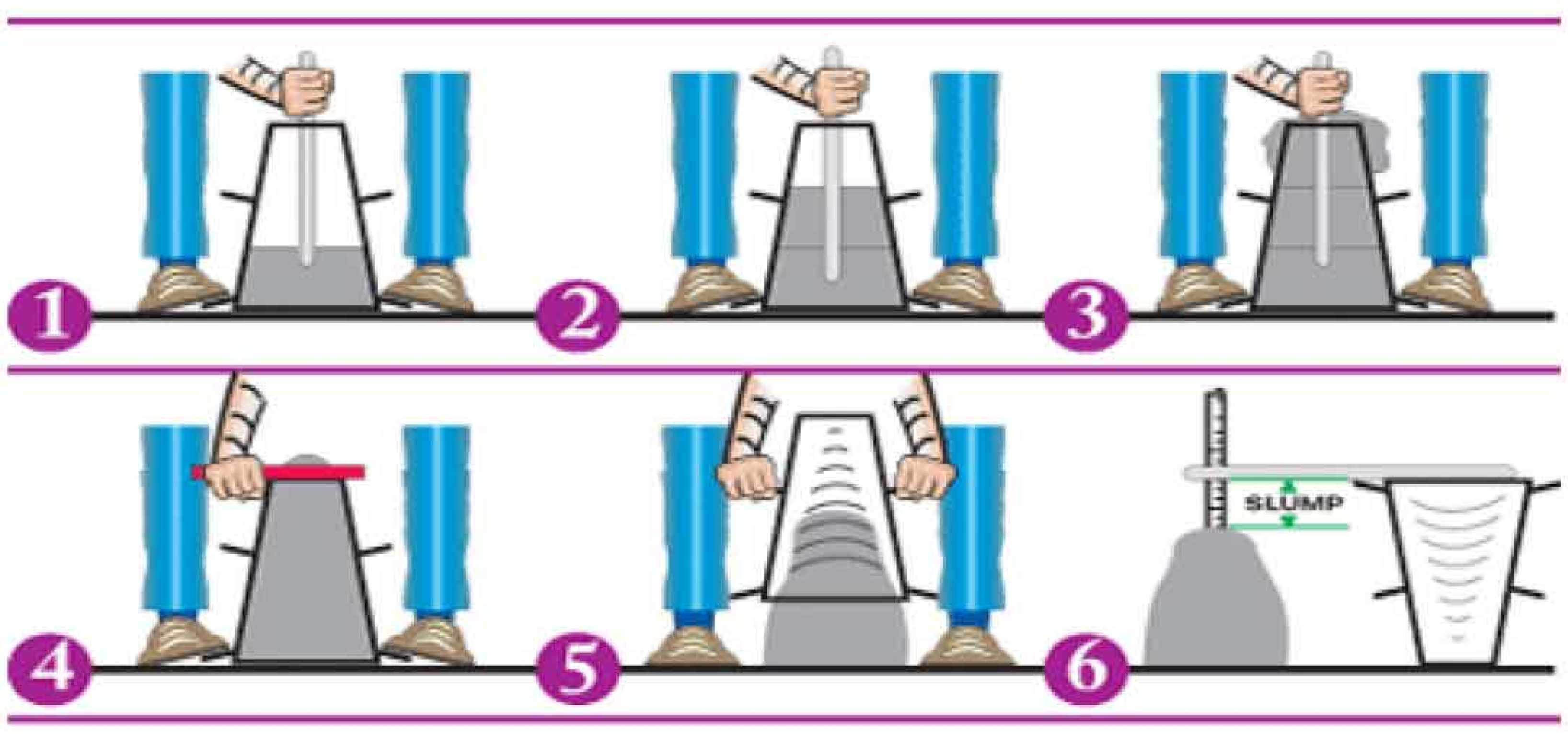
Falsework consists of temporary structures used in construction to support spanning or arched structures in order to hold the components in place until its construction is sufficiently advanced to support itself.

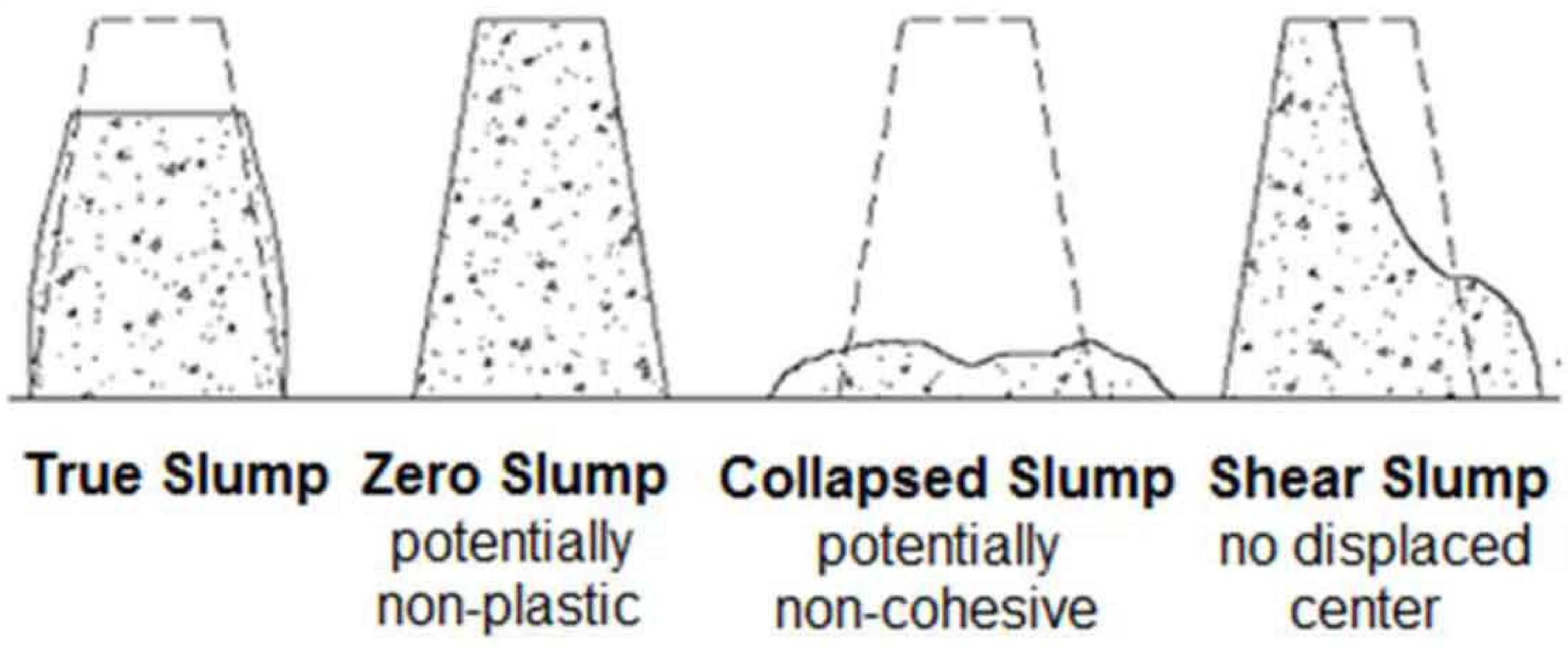
When the concrete matrix is poured into a form, from 10 to 30 % of the concrete is irregularly distributed depending on the mix, size and shape of the form and amount of reinforcing steel. A vibrator causes a violent agitation of the particles in the mix and makes them flow under this effect tightly against the form and around the reinforcement. Mostly vibrator is immersed in the matrix and waves carry outward to the surfaces.



When initially mixed, cement and water rapidly form a gel of tangled chains of interlocking crystals and ingredients of the gel continue to react over time. At first the gel is fluid, which improves workability and aids in placement but as the concrete sets, the chains of crystals join into a rigid structure, counteracting the fluidity of the gel and fixing the particles of aggregate in place.

Workability is the ability of fresh (plastic) concrete mix to fill the form properly without reducing the concrete's quality. Workability depends on water content, aggregate (shape and size distribution), cementitious content, age (level of hydration) and presence and type of admixtures. Workability can be measured by the concrete slump test, a simple measure of the plasticity of a fresh batch of concrete. Slump is normally measured by filling an Abrams cone with a sample from a fresh batch. The cone is placed with the wide end down onto a level, non-absorptive surface. It is then filled in three layers of equal volume, with each layer being tamped with a steel rod to consolidate the layer. When the cone is lifted off,the enclosed material slumps a certain amount. A relatively dry sample slumps very little, having a slump value of 25 – 50 mm out of 300 mm. A relatively wet concrete may slump as much as 200 mm.

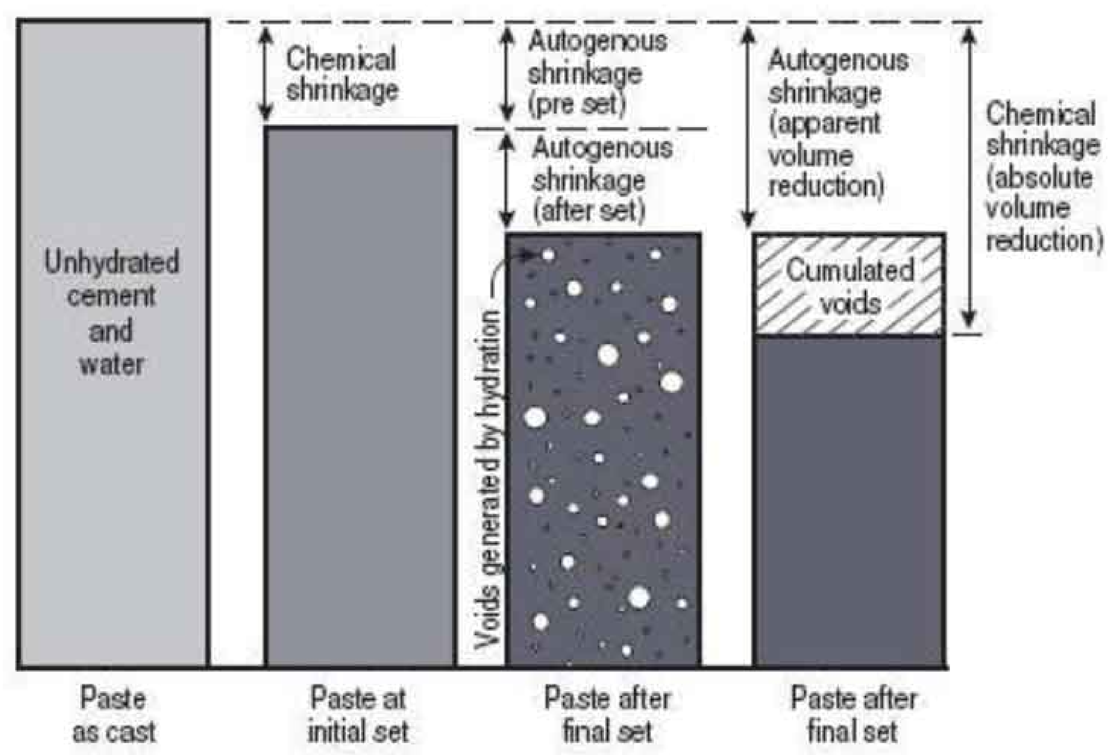




Source: ACI 238 State of the Art Report

A common misconception is that concrete dries as it sets, but the opposite is true – damp concrete sets better than dry concrete. Cement needs water to become strong. Too much water is counterproductive, but too little water is deleterious. Curing is the hydration process that occurs after the concrete has been placed. To gain strength and harden fully, concrete curing requires time. In around four weeks, typically over 90% of the final strength is reached, although strengthening may continue for decades.

Hydration and hardening of concrete during the first three days is critical. Abnormally fast drying and shrinkage due to factors such as evaporation from wind during placement may lead to increased tensile stresses at a time when it has not yet gained sufficient strength, resulting in greater shrinkage cracking. The early strength of the concrete can be increased if it is kept damp during the curing process. Minimizing stress prior to curing minimizes cracking.



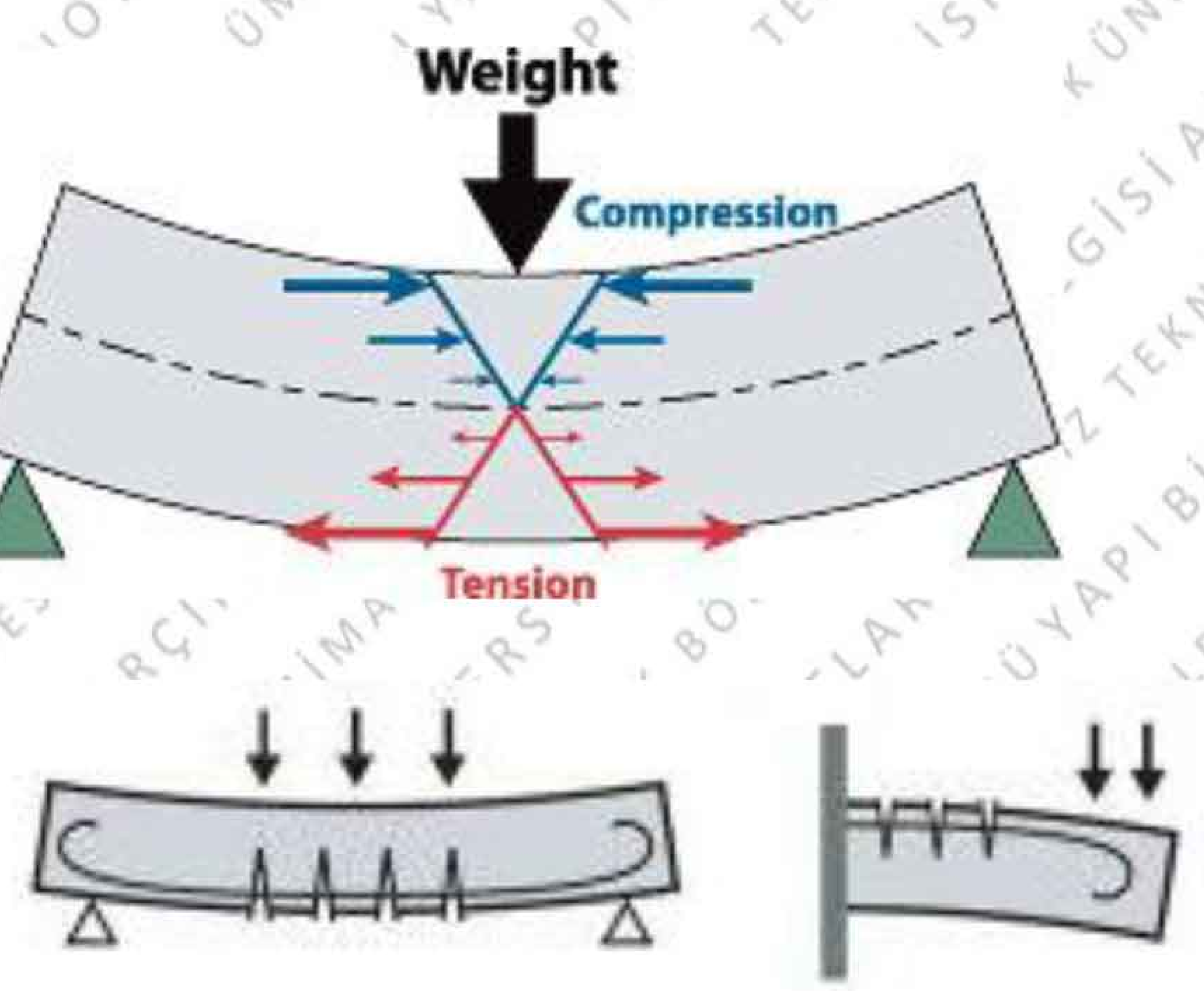
Properly curing concrete leads to increased strength and lower permeability and avoids cracking where the surface dries out prematurely. Care must also be taken to avoid freezing or overheating due to exothermic setting of cement. Improper curing can cause scaling, reduced strength, poor abrasion resistance and cracking. During the curing period, concrete is ideally maintained at controlled temperature and humidity.

Traditional conditions for curing involve by spraying or ponding the concrete surface with water. Also fresh concrete can be covered with wet burlap and / or plastic sheeting to prevent dehydration. To ensure full hydration during curing, concrete slabs are often sprayed with curing compounds which create a water retaining film over the concrete. Typical film is wax.

Any interruption in pouring the concrete can cause the initially placed concrete to begin to set before the next batch is added on top. This creates a horizontal plane of weakness called a cold joint between two batches.

Properties of Concrete

Concrete has relatively high compressive strength, but much lower tensile strength. For this reason, it is usually reinforced with materials that are strong in tension (often steel). The elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracking develops. Concrete has a very low coefficient of thermal expansion and shrinks as it matures. All concrete structures crack to some extent, due to shrinkage and tension. Concrete that is subjected to long duration forces is prone to creep[2].



Tests can be performed to ensure that the properties of concrete correspond to specifications for the application. Different mixes of concrete ingredients produce different strengths. Concrete strength values are usually specified as the compressive strength of either a cylindrical or cubic specimen.

For cube test two types of specimens either cubes of 15 cm x 15 cm x 15 cm or 10 cm x 10 cm x 10 cm depending upon the size of aggregate are used. For most of the works cubical moulds of size 15 cm x 15 cm x 15 cm are commonly used. This concrete is poured in the mould and tempered properly so as not to have any voids. After 24 hours these moulds are removed and test specimens are put in water for curing. These specimens are tested by compression testing machine after 7 or 28 days curing. Load should be applied gradually till the specimens fails. Load at the failure divided by area of specimen gives the compressive strength of concrete.

[2] A common example of creep is the permanent sag in the shelf of an inexpensive bookshelf. When books are set on the wood shelf, it may sag slightly. If the books are removed after a short time, the shelf returns to a level position. However, if the books remain on the shelf for a long time, the sag increases, and when the books are removed, the shelf does not return to its original level position. The permanent sag is from creep.

Concrete of given strength is identified by its "class" - a Class 25/30 concrete has a characteristic cylinder crushing strength (fck) of 25 N/mm^2 and cube strength of 30 N/mm^2 (1 MPa = 1 N/mm^2).

According to this:

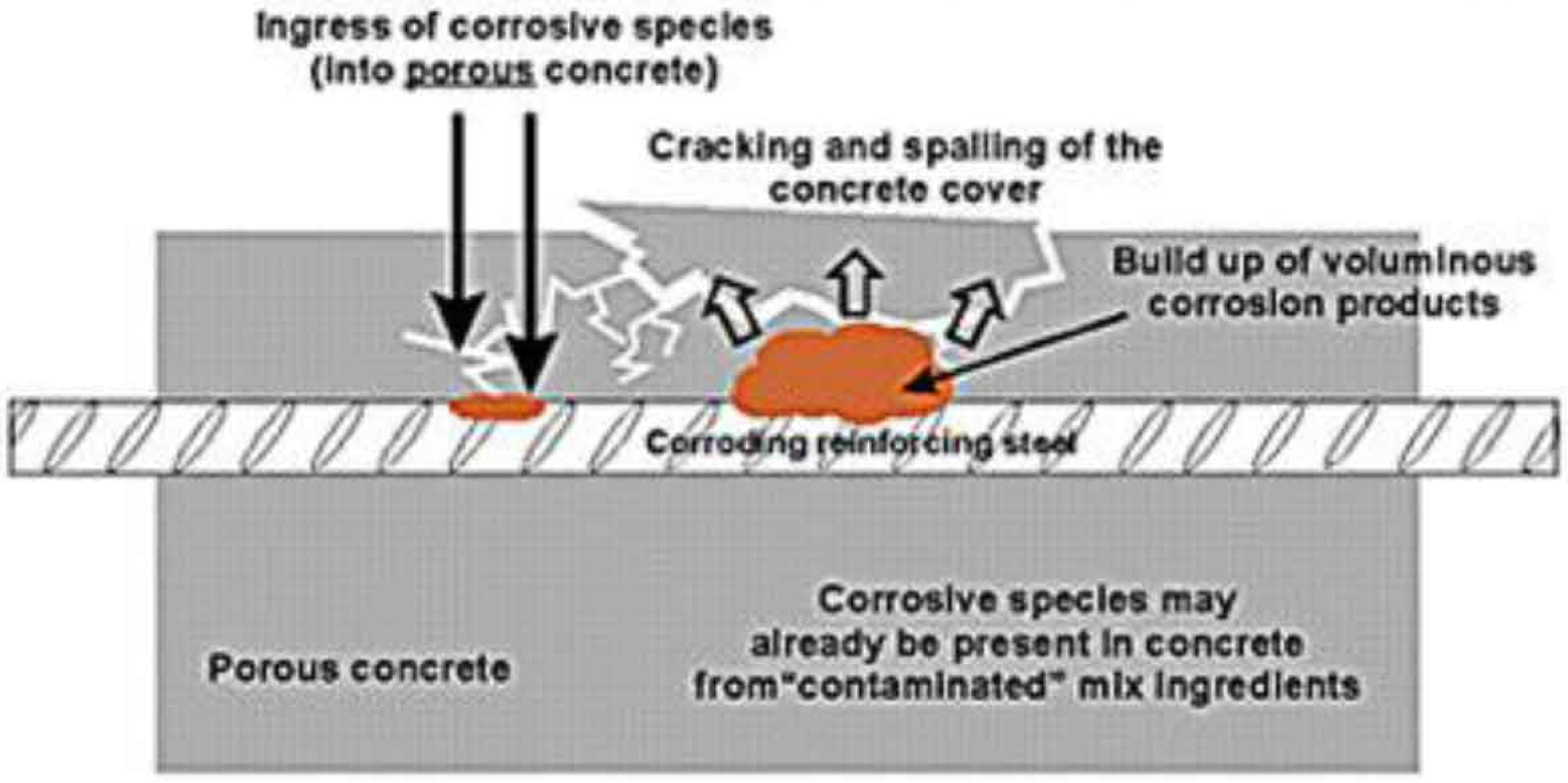
14 MPa	very low strength	lightweight concrete
20 – 32 MPa	normal strength	routine uses
40 – 80 MPa	high strength	for large spans and very heavy loads

28 Days-Compressive Strength (MPa)						
Cylinder (150 mm dia, 300 mm height)				**Cube** 150 mm		
Concrete Class (cyl/cube)	Minimum Characteristic Compressive Strength (Fck)	Average Compressive Strength (Fcm)	Any Single Minimum Compressive strength Test Result (Fci)	Minimum Characteristic Compressive Strength (Fck)	Average Compressive Strength (Fcm)	Any Single Minimum Compressive strength Test Result (Fci)
C8/10	8	12	4	10	14	6
C12/15	12	16	8	15	19	11
C16/20	16	20	12	20	24	16
C20/25	20	24	16	25	29	21
C25/30	25	29	21	30	34	26
C30/37	30	34	26	37	41	33
C35/45	35	39	31	45	49	41
C40/50	40	44	36	50	54	46

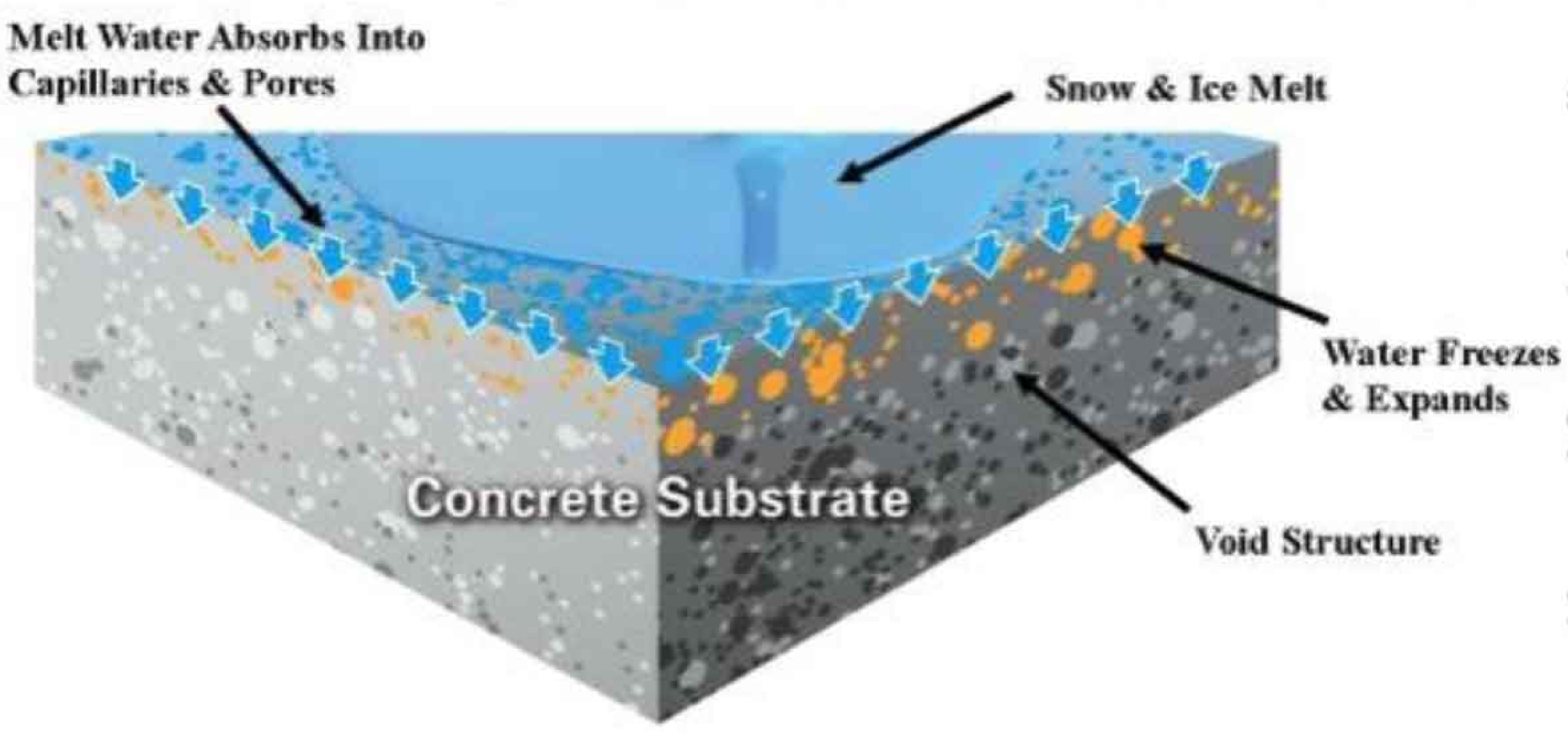
Extreme weather conditions (extreme heat or cold; windy condition, and humidity variations) can significantly alter the quality of concrete. In cold weather concreting, many precautions are observed. Low temperatures significantly slow the chemical reactions involved in hydration of cement, thus affecting the strength development. Preventing freezing is the most important precaution, as formation of ice crystals can cause damage to the crystalline structure of the hydrated cement paste. If the surface of the concrete pour is insulated from the outside temperatures, the heat of hydration will prevent freezing.

Concrete can be damaged by many processes, such as:

the expansion of corrosion products of the steel reinforcement bars,



freezing of trapped water



fire or radiant heat

sea water effects [Sea salts (NaCl) can enter a material by flooding or by wind (marine spray)]

physical damage

chemical damage: Carbonation is a slow process that occurs in concrete where lime (calcium hydroxide) in the cement reacts with carbon dioxide from the air and forms calcium carbonate.

The water in the pores of Portland cement concrete is normally alkaline with a pH in the range of 12.5 to 13.5. This highly alkaline environment is one in which the steel rebar is passivated and is protected from corrosion. The carbon dioxide in the air reacts with the alkali in the cement and makes the pore water more acidic, thus lowering the pH. Carbon dioxide will start to carbonate the cement in the concrete from the moment the object is made. This carbonation process will start at the surface, then slowly move deeper and deeper into the concrete. The rate of carbonation is dependent on the relative humidity of the concrete - a 50% relative humidity being optimal. If the object is cracked, the carbon dioxide in the air will be better able to penetrate into the concrete.

Eventually this may lead to corrosion of the rebar and structural damage or failure. Carbonation can be controlled by using low water – cement ration or by supplying low relative humidity or it can be prevented by using barrier coatings to prevent ingress of water and CO_2.