FRESH CONCRETE AND ITS PROPERTIES

The word “concrete” in English means “grow together” and is derived from the Latin word “concretus”. The word “concrete” entered Turkish from French. By definition, concrete is a construction material obtained by mixing aggregate, cement, water and, if necessary, some chemical admixtures and mineral additives together. Although neither aggregate nor cement is used as a construction material alone, when both are used together, they constitute the most common building material used in the construction industry.

Generally speaking, concrete is considered as a composite formed by aggregates interspersed in hydrated cement paste. Hydrated cement paste is composed of tobermorite, portlandite and ettringite crystals, known as hydration products. This composite structure contains dry or water-filled capillary spaces as well as unhydrated cement grains.

On the other hand, aggregates can be considered as composites with different mineralogical structures and a certain porosity. In this respect, concrete has a complex structure. For this reason, some mathematical models have been realized by making some simplifying assumptions based on determining the relationship between the structure of concrete and its physical properties.

In this sense, the basic assumption made is that the aggregate and cement paste phases in concrete are homogeneous and isotropic. It is assumed that the mathematical models to be established if the properties of these two phases are well known will form the basis for explaining the mechanical behavior of concrete.

In terms of composition, there is a general rule of 10:20:30:40 for concrete. This means that by volume, concrete consists of 10% cement, 20% water and air, 30% fine aggregate and 40% coarse aggregate. Therefore, this rule only applies to conventional concrete. Not applicable for air-entrained concretes and special concretes. Roughly mixing ratios for air-entrained and non-air-entrained concretes are schematically given below.

	Cement	Water	Air	Fine aggregate	Coarse aggregate	
1	%15	%18	%8	%28	%31	Air entrained concrete
2	%7	%14	%4	%24	%51	
3	%15	%21	%3	%30	%31	Non-air entrained concrete
4	%7	%16	%0.5	%25.5	%51	

Bars 1 and 3 show rich mixtures with few aggregates; Bars 2 and 4 show lean mixtures with excess aggregates.

Schematic representation of concrete components by absolute volume

Approximately 70% of the hardened concrete by volume consists of aggregate, the remainder consists of cement paste and air. It is accepted that the aggregate forms the skeleton of the concrete.

The factors that necessitate the use of aggregate in concrete are given as follows:

- Aggregate is cheaper than cement.
- Volume changes such as shrinkage and swelling that occur in cement paste during setting and hardening do not occur in the aggregate. In fact, aggregate greatly limits the volume change in concrete.
- Aggregate is more resistant to atmospheric effects, chemical effects and abrasion effects compared to cement paste.

The primary goal in concrete design is to produce as high-strength and durable concrete as possible. However, even in concrete produced under the best conditions, undesirable defects and voids may occur in the concrete due to material and workmanship errors. In order to produce concrete suitable for the purpose, the proportions of aggregate, cement, water and chemical admixtures and mineral additives used when necessary should be well adjusted, mixed thoroughly until the concrete becomes uniform, placed in the mold appropriately, compacted and cured for a certain period of time after casting.

The basic properties sought in fresh and hardened concrete are:

- In the fresh state, the concrete should be easily placed in the mold and compacted and should not segregate during these operations. In short, it should be workable.
- In the hardened state, the strength of the concrete must be sufficiently high and durable. That is, it must be able to carry external loads and be resistant to various physical and chemical effects.
- Concrete should be economical. That is, the costs of materials, production, casting, placement and compacting should be as low as possible.

In order to meet all these criteria, the following steps must be strictly followed:

- The material selection should be made correctly and the mix proportions should be calculated precisely.
- Appropriate methods and reliable tools should be employed in the preparation of the concrete mix, mixing, placing and compaction of the concrete.
- Concrete should be properly cured.

Whether these requirements are met or not should be checked with tests to be carried out in the laboratory and at the construction site.

Fresh concrete is concrete whose mixing process has been completed but has not yet lost its plasticity by setting. The properties provided during the transportation, placement and compaction of fresh concrete are also reflected in the hardened properties of the concrete. At this stage, the most important characteristics sought in fresh concrete are workability and uniformity.

CONSISTENCY AND WORKABILITY

The term “workability” is a concept that includes several properties of fresh concrete and its value depends on various factors. Workable concrete is concrete that can be easily placed in the mold and can be easily and fully compacted. Good workability ensures an easy and fast execution of placing and compaction processes, thus reducing the cost, as well as significantly improving the properties of hardened concrete.

Factors affecting workability can be given as follows:

- The composition of the concrete and the properties of the components that make up the concrete.
- Features of the formwork.
- Congestion and quantity of reinforcing steel.
- Placement and compaction methods.

Since the properties of formwork and reinforcement are very variable, when the workability of concrete is mentioned, the properties related to the composition of the concrete such as compactability, ease of movement in the formwork and stability are understood. Therefore, workability is a concept that gives information about at least five different properties of fresh concrete. These features are:

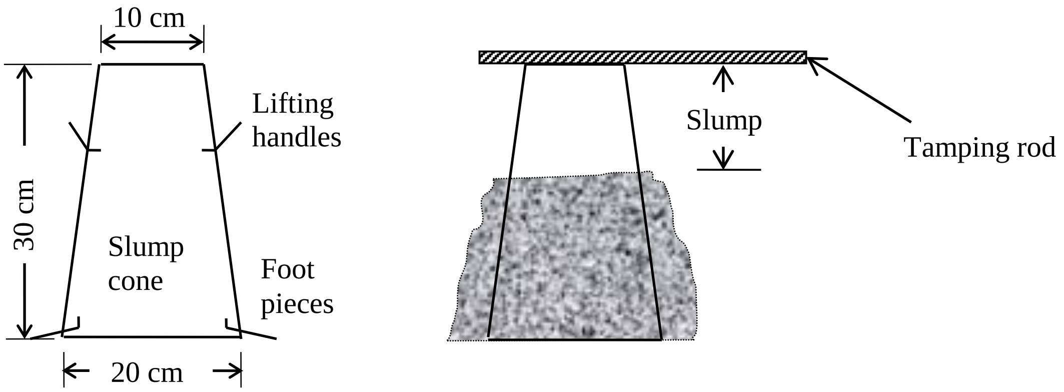
- Stability: It is the ability of concrete to maintain its homogeneity and uniformity without segregation during transportation, placement and compaction processes.
- Mobility: It is the property related to how easily the concrete moves in the mold.
- Compactability: It is the property related to the compaction of fresh concrete.
- Placeability: It is the ability of fresh concrete to be placed and compacted without segregation.
- Finishability: It is the ability of concrete to be easily placed, compacted and smoothed.

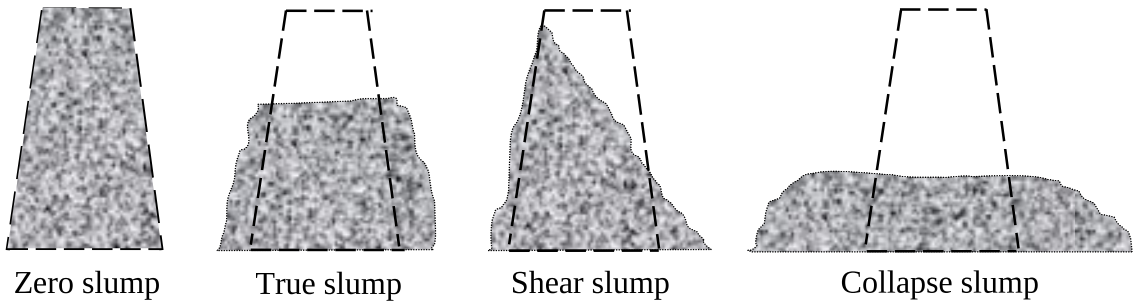
Workability of fresh concrete is usually expressed by “consistency” and consistency is measured by slump. However, this is not a very realistic approach. Because the workability of concretes with the same slump can be very different. Slump test, compaction factor test, Vee-Bee test, and flow table test are commonly used to determine the consistency of fresh concrete. The simplest of these tests and the most widely used in the laboratory and in the field is the slump test. As the slump increases, the flowability of the concrete increases, and on the contrary, as the slump decreases, the concrete loses its flowability.

SLUMP TEST

A truncated cone shaped apparatus with an upper diameter of 10 cm, a lower diameter of 20 cm and a height of 30 cm is used in the test. Concrete is filled into this apparatus in three layers of equal volume, and each layer is tamped 25 times with a 16 mm diameter steel bar, and after the top is smoothed with a trowel, the apparatus is pulled up in a controlled manner. The amount of slump gives an idea of the workability of fresh concrete. As shown schematically below, as a result of the slump test, four different conditions occur depending on the consistency of the concrete: zero slump, true slump, shear and collapse.

Of these four cases, only "true slump" is considered slump for concrete. When the shear condition occurs, the test is repeated and if the result does not change, this is reported. The test can be repeated when collapse occurs, but it would not be correct to rely on measurements made in situations other than true slump.





The TS EN 206 standard defines five different consistency classes according to the measured slump as follows:

Consistency	Slump, mm	Workability description
S1	10-40	Stiff
S2	50-90	Plastic stiff
S3	100-150	Plastic
S4	160-210	Flowable
S5	≥220	Very flowable

True slump is more common in concretes with sufficient sand and cement in their composition, and in cement-rich concrete. In this type of concrete, if the maximum aggregate particle size does not exceed 31.5 mm, deviations in the mixing water and coarse/fine aggregate ratio are effective on slump. For this reason, the slump test is a simple and effective method used to quickly determine whether there is a change in the concrete composition at the construction site. Shear is mostly observed in concretes with less cement and sand, and collapse is observed in very flowable concretes. In concretes with very little water, none of these slumps can be seen. In the slump test, the concrete generally retains the shape of the slump cone. By means of the slump test, the water content of the concretes with the same composition can be easily distinguished.

As can be seen, the slump test does not give meaningful results for concretes with low cement, sand or water and very flowable concretes. In addition, it should be noted that the test only gives an idea about the consistency of the concrete, while it does not give any information about the ease of action and compactability of the concrete. However, the amount of energy consumed while placing and compacting two concretes with the same slump may be different. The reason for the widespread use of the slump test is that it is simple and the apparatus is cheap compared to other workability test devices.

COMPACTION FACTOR TEST

By means of this test, it is measured how densely free-falling concrete fills a container from a certain height. The test apparatus consists of two truncated cone-shaped containers with lids mounted on a pillar and a cylindrical container placed under them, as seen in the figure below. In the test, after the upper conical container is filled with fresh concrete, the lower cover of the container is opened and the concrete is transferred to the lower conical container. The bottom cover of this container is opened and the concrete is transferred to the cylindrical container.

The amount of concrete filling the cylindrical container is determined by weighing. The cylindrical container is well tightened and weighed again. The cylindrical container is tightly squeezed and once again weighed in this way. Thus, the amount of concrete that can be filled into the cylindrical container in compacted state is determined and the compression factor is calculated as follows:

$$\text{Compaction factor, CF} = \frac{\text{weight of partially compacted concrete}}{\text{weight of fully compacted concrete}}$$

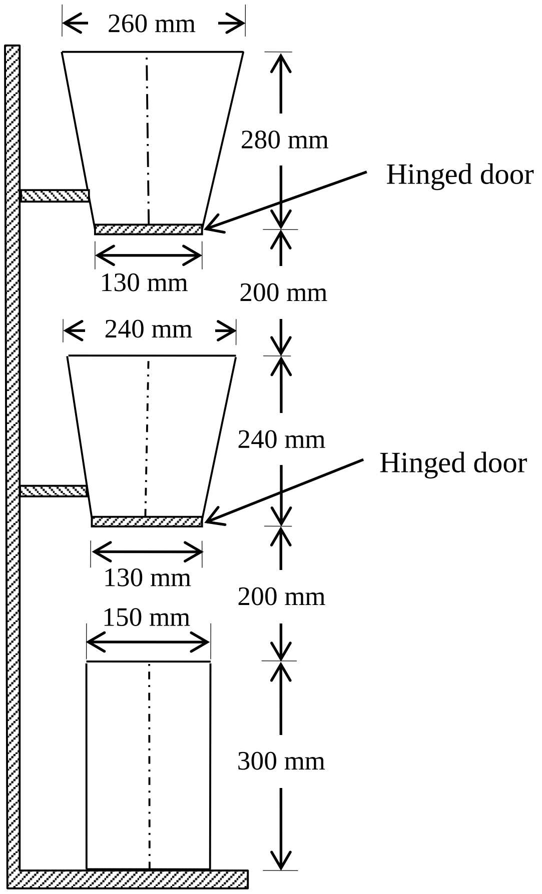
The compaction factor test is suitable for dry concrete with a plastic consistency, that is, with a compaction factor between $0.78 \le \text{CF} \le 0.95$. It is difficult to have an idea about the consistency of the concrete, since the compaction factor of very flowable concretes takes values close to 1. Generally, the $\text{CF} \ge 0.92$ state is not suitable for consistency assessment.

The compaction factor test gives more reliable information about the compactability of concrete compared to the slump test. Compaction factor test results can be correlated with slump, although the relationship is not linear. In the table given below, compaction factor test results are associated with slump and workability degree.

Workability degree	Slump, mm	Compaction factor, CF	Applications
Very low	0-25	0.78	Vibrated concrete in roads or other large sections.
Low	25-50	0.85	Mass concrete foundations without vibration. Simple reinforced sections with vibration.
Medium	50-100	0.92	Normal reinforced work without vibration and heavily reinforced sections with vibration.
High	100-175	0.95	Sections with congested reinforcement. Not normally suitable for vibration.

Strictly speaking, the compaction factor test indirectly measures workability. This test has been found to be more precise than the slump test, especially for concrete mixes with "medium" and "low" workability (i.e. compaction factor of 0.8 to 0.9). In this regard, its use in laboratory conditions has become more popular.

For concretes with very low workability (i.e. with a compaction factor of 0.70 and lower) this test is not suitable. This test gives appropriate results for the concretes in which the maximum aggregate particle size is 20 mm.



Compaction factor test apparatus

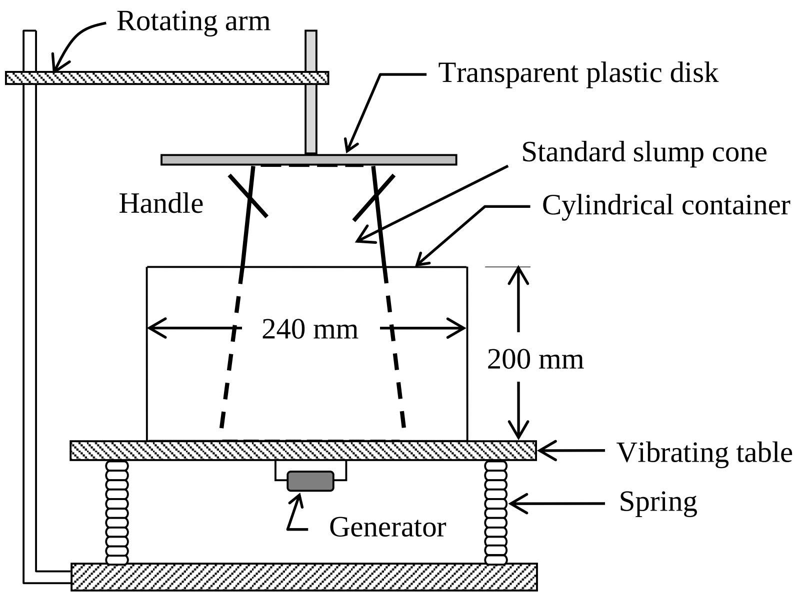
This test finds application mostly in prefabrication and large construction sites. Compared to the slump test, the compaction factor test apparatus is rather bulky and requires a smooth surface to perform the test. In addition to these disadvantages, there are several other shortcomings that reduce the accuracy of the test results. The most important of these is that vibration, which is the main compaction method used in the field, is not used in the implementation of the compaction factor test.

VEE-BEE TEST

The setup used for this test consists of a conical container and a tamping rod used in the slump test, a cylindrical container with a diameter of 24 cm and a height of 20 cm, and a vibrating platform to which this container is attached, and a transparent disc that is bedded vertically in the container. In the experiment, the truncated cone is placed in the cylindrical container and the procedures in the slump test are carried out. Then, the cylindrical container is vibrated and the time it takes for the fresh concrete to spread into the container is measured with a precision of half a second. The time measured is the time elapsed between the initiation of vibration and the moment when the cement slurry rises to the surface of the concrete, giving a good idea about the workability as it is directly related to the consistency, ease of action and compaction properties of the concrete.

Therefore, the test is suitable for concrete with dry consistency as well as for concrete with plastic consistency. However, since it is very difficult to compact dry concrete, this period may be very long. Sometimes even full compaction may not be possible. In such cases, the Vee-Bee duration becomes very difficult to determine. Measurements should not be fully relied upon. Since the flowable concrete spreads very quickly, the Vee-Bee time can be in the order of 1-1.5 seconds.

Short Vee-Bee times are difficult to accurately determine. In cases where the maximum aggregate particle size is larger than 20 mm, the reliability of the test decreases. The apparatus of the Vee-Bee test is shown schematically below:

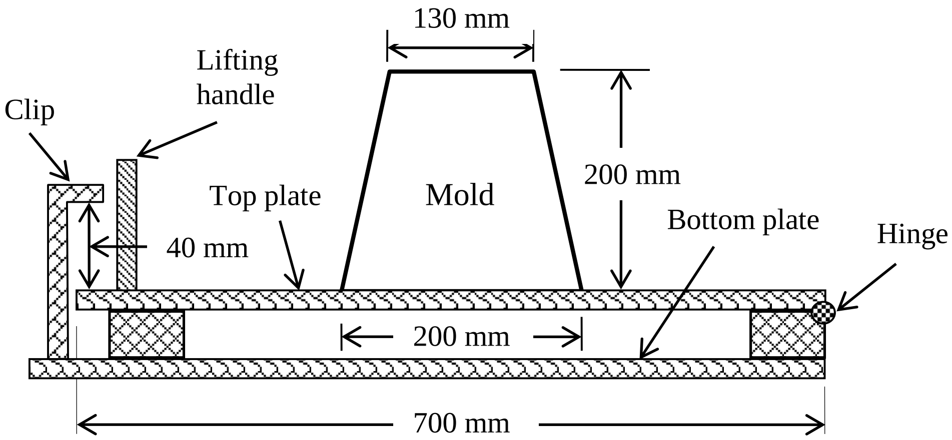


The Vee-Bee test apparatus

The Vee-Bee test is sensitive to aggregate properties as well as to changes in concrete composition. In addition, the test can be used in a wide range of consistency. The test apparatus is expensive and the method is not simple. For this reason, it is not recommended to use the test device at the construction site. The device is recommended for ready-mixed concrete plants, workplaces producing prefabricated concrete elements, laboratories rather than construction site use.

FLOW TABLE TEST

This test is suitable for the evaluation of concrete mixes that show collapse. The test setup consists of a square wooden plate with a side of 700 mm, a metal plate resting on this plate, and a metal truncated cone with a base diameter of 200 mm, an upper diameter of 130 mm and a height of 200 mm. In addition, a metal rod with a square section of 40 mm on one side and a length of about 200 mm is used. The test setup is schematically given below.



Flow table test setup

In the test, the plate is placed on a smooth surface. A metal top plate is placed on it and a truncated cone is placed in the middle of this plate. Fresh concrete is filled into the truncated cone in two layers. Each layer is tamped 10 times with a tamping rod and the top surface of the cone is smoothed. The truncated cone is pulled out by holding the handles as in the collapse test. One edge of the upper plate is then raised 40 mm and dropped freely onto the lower plate 15 times.

After this process is completed, the spreading diameter of the fresh concrete is measured in both directions and the average is taken. This value is determined as the spreading diameter of the concrete. The evaluation of the workability of concrete based on the spreading diameter is given below in tabular form, as given in TS EN 206.

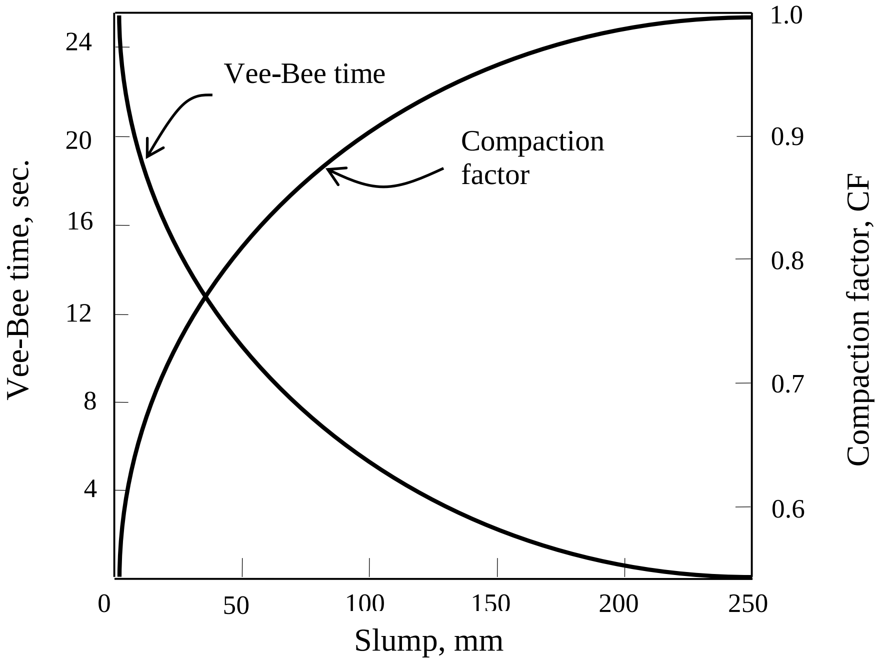
Class	F1	F2	F3	F4	F5	F6
Spreading diameter, mm	≤340	350-410	420-480	490-550	560-620	≥630

Results such as the water film around the diameter of the concrete spreading on the flow table and aggregate clustering in the middle give important clues about the segregation tendency of the mixture. The workability level obtained as a result of the test may not fully reflect the concrete at the construction site.

Although many workability tests have been proposed over the years, none of the existing tests alone is sufficient to measure the workability of concrete. Moreover, since the existing tests provide information about the different properties of fresh concrete, it is often not possible to even compare them with each other.

As the hydration progresses and accordingly the water in the fresh concrete is depleted, the workability of the concrete decreases over time. In this regard, workability tests should be carried out immediately after the mixing of the concrete is completed.

The relationship between slump, Vee-Bee time and compaction factor is given below.



FACTORS AFFECTING WORKABILITY

- The consistency and amount of cement paste: The consistency of cement paste depends on the amount of water and cement used. Workability increases as the water to cement ratio (W/C) increases. This means that the amount of water increases or the amount of cement decreases. Workability is affected more by changes in the amount of water than by the amount of cement. Changes in cement content can only make a difference in the workability of cement-rich concretes. It is a cement paste that adds fluidity to the concrete. Cement paste also coats aggregate grains, allowing them to move easily within the cement paste. Therefore, as the amount of cement paste increases, the workability of concrete improves. The cement paste amount in concrete is expressed as aggregate/cement ratio (A/C). As the A/C ratio increases, the amount of cement paste in concrete decreases; hence, workability is adversely affected.

- Cement properties: Workability decreases as the cement fineness increases. Because the cohesion of the cement paste increases due to the increased specific surface. This results in reduced workability.

- Aggregate properties: Parameters such as aggregate granulometry, maximum size of aggregate particle, aggregate particle shape and surface texture, and fine aggregate amount are important in terms of workability. Workability increases as aggregate granulometry becomes appropriate, aggregate grains become round and surface texture becomes smoother. As the maximum aggregate size of particle increases, the total surface area of the particles in the concrete mixture decreases. In this case, since less cement paste will be required to coat them, the increased cement paste affects the workability positively by making a lubricating effect in the mixture.

- Time and ambient conditions: The workability of fresh concrete decreases over time. The reason for this is that water is used up in the cement paste and thus the water to cement ratio decreases. The depletion of water in the concrete mixture may be due to hydration on the one hand, and wind effect and/or high temperature on the other hand.

- Chemical and mineral additives: The workability of concrete can be consciously increased by using additives. In addition, as the amount of finely ground mineral material additives in production increases, the workability increases.

- Air content: Workability increases as the amount of air increases in fresh concrete. The workability of air entrained concrete in this case will be better than that of non-air entrained concrete. Thanks to the air-entraining agents, millions of tiny spherical air bubbles are formed in the cement paste. As a result, the flowability of concrete increases and the workability of concrete is positively affected.

HOMOGENEITY-UNIFORMITY OF FRESH CONCRETE

Homogeneity or uniformity means that the properties in any part of the fresh concrete mixture are like the properties in another part. It is very important for the quality of hardened concrete that fresh concrete properties are the same or similar at every point. It should not be forgotten that in terms of quality concrete, it is important to ensure uniformity inside the batch as well as between batches.

Factors affecting batch uniformity are:

- The mixer palettes (blades) are worn,
- The mixing process is shorter or longer than necessary,
- Mixer is overloaded.

The differences between concretes produced at different times but desired to be of the same quality (lack of uniformity between blends) may be caused by one or more of the reasons listed below:

- Changes in mixing ratios for any reason,
- Changes in moisture content of aggregates,
- Changes in aggregate granulometry,
- Changes in the aggregate type and particle shape,
- Changes in the cement type,
- Supply of cement of the same type but from a different factory,
- Changing the method applied in the mixing process,
- Changing the mixer used in the mixing process,
- Changes in air and concrete temperature during production.

SEGREGATION IN CONCRETE

The tendency of aggregate and cement paste phases to separate into groups in fresh concrete is called "segregation". This tendency increases as the cohesion of the concrete decreases. The cohesion depends on the total surface area of all solid particles, including cement, and the amount of cement paste in the concrete mixture. Very wet or very dry concretes and concretes with little sand and fine material are easily segregate. The structure of fresh concrete where segregation is observed becomes heterogeneous and the amount of coarse aggregate in some parts of the same concrete mixture is higher than in other regions. This situation causes variation in strength and durability in concrete.

The factors leading to segregation in fresh concrete can be listed as follows:

- Poor granulometry, excessive amount of coarse aggregate, maximum aggregate particle size > 25 mm,
- Big difference between coarse and fine aggregate specific gravities,
- Less cement paste phase in the mixture,
- Improper mixing process,
- Too wet or too dry mixture,
- Improper mixing, placing, and compaction (prolonged vibration) of the concrete.

HONEYCOMBING IN CONCRETE

Honeycombing is a sort of segregation and occurs because the spaces between the coarse aggregate cannot be effectively filled by the fine aggregate. Honeycombing is noticeable as bee-honey-like defects on the concrete surface.

The main reasons for honeycombing are given as follows:

- Congested reinforcement,
- Unsuitable fine/coarse aggregate ratio and poor granulometry,
- Extremely dry-consistency concrete,
- Improper placement and compaction methods,
- Cement grout leaking from form joints.

BLEEDING IN CONCRETE (SWEATING)

During the compression of fresh concrete and its hardening, the aggregate particles in the mixture settle on the bottom of the formwork because of gravity. In the meantime, excess water in fresh concrete is dragged to the upper side and accumulates on the surface of the concrete. This phenomenon is called "bleeding" or "sweating". In this case, the water to cement ratio increases in the part close to the upper surface of the concrete and consequently the strength of this part decreases. The amount of water accumulating on the concrete surface as a result of bleeding depends on the composition of the concrete, especially the water to cement ratio and the amount of fine material (such as cement, mineral additives, fine sand) in the mixture. Increasing the water to cement ratio increases the bleeding, while the increase in the amount of fine material reduces the bleeding. The amount of bleeding also depends on the thickness of the concrete placed.

The main drawbacks of bleeding are given below:

- As a result of the increase in the water to cement ratio on the upper part of the concrete, a porous, weak layer with low wear resistance is formed.
- Water pockets are formed as a result of the accumulation of water under the aggregate particles and the reinforcement, resulting in loss of adherence at the interface between aggregate-cement paste and concrete-reinforcement.

Measures to reduce bleeding are given as follows:

- Using cement with high fineness: As the fineness of the cement increases, the hydration will progress faster, so the water is consumed quickly, thus the water holding capacity of the concrete increases.

- Cement composition and amount: Excessive amounts of C_3A and C_3S, which are among the main components, accelerate hydration at an early age and consequently, water depletion accelerates. Mixtures rich in cement will have less bleeding than those with less cement.

- The use of mineral additives: As the total surface area of solid particles in concrete will increase with the use of mineral additives, the depletion of the water in the mixture is accelerated.

- Amount of mixing water: Concrete with low water to cement ratio naturally bleeds less water. The water should be adjusted to ensure a reasonable level of workability.

- Use of air entraining admixtures: As the workability increases in air entrained concrete, the amount of water needed to achieve the target workability decreases. In addition, many small air bubbles prevent the concrete from settling towards the bottom of the formwork.

- Concrete composition and placement: The composition of the concrete should be well adjusted and placed in the formwork in layers to prevent or minimize bleeding.

In addition to the tests carried out to determine the workability, homogeneity and water bleeding properties, other main tests frequently performed on fresh concrete are:

- Unit weight: If the difference between the unit weights determined on samples belonging to different batches is greater than 16 kg/m^3, it means that uniformity is not ensured.

- Air content: If the difference between the air contents measured on samples both inside and between batches is greater than 1%, it means that uniformity cannot be achieved.

- Compressive strength: The difference between the compressive strengths of specimen taken from the same concrete in the laboratory is greater than 3-5%, which indicates that uniformity is not achieved.

CASTING CONCRETE IN ABNORMAL WEATHER CONDITIONS

The weather condition in which the average daily air temperature is below +5^{o}C for three consecutive days and above +30^{o}C for three consecutive days is considered as "cold weather" and "hot air" for concrete pouring, respectively. Accordingly, the air temperature between 5 and 30^{o}C or 32^{o}C during concreting is considered "normal" for concreting. If the temperature drops below +5^{o}C, the chemical reactions between cement and water slow down significantly.

Pouring Concrete in Cold Weather Conditions

Since the air temperature is low, the temperature of fresh concrete is lower than its normal temperature. The decrease in the temperature of fresh concrete adversely affects the strength development of concrete. When the temperature of the concrete is 0^{o}C or lower, the water in the capillary cavities starts to freeze. In the production of concretes that will be exposed to such conditions, air entraining chemical admixtures must be used.

In cases where the necessary precautions are not taken, the following problems may occur for concrete poured in cold weather conditions:

- The setting time of fresh concrete is longer than the setting time of concrete under normal conditions, and the rate of gaining strength becomes slower.
- Freezing of the water in fresh concrete even once significantly reduces the strength and durability of the concrete.
- If the difference between the temperature of fresh concrete and the ambient temperature is large, thermal stresses may occur in the concrete and eventually the concrete may crack.

In practice, the following measures can be taken in order to reduce and/or eliminate the adverse effects of cold weather conditions:

- The materials that make up the concrete should be heated before use.
- Cement and admixtures that increase the early strength of concrete should be used.
- Suitable formwork, insulation materials and appropriate curing methods should be applied.
- Necessary planning and preparations should be made before pouring concrete.
- The curing time should be kept longer than the curing time applied for concrete poured under normal conditions.

Pouring Concrete in Hot Weather Conditions

While pouring concrete in hot and dry weather conditions, some problems may arise during the preparation of the concrete, its placement and curing. High air temperature first of all accelerates the hydration of the cement and causes the temperature of the concrete to increase. On the other hand, water loss in fresh concrete increases through evaporation in hot weather. To prevent this, the amount of mixing water is used more than necessary. This causes the strength of concrete to decrease.

The drawbacks of hot and dry air can be summarized as follows:

- Slump loss increases in fresh concrete.
- Fresh concrete sets in a shorter time.
- Plastic shrinkage cracking increases significantly.
- The amount of mixing water is increased for the target consistency. Therefore, concrete becomes more porous and its performance is adversely affected.
- As more water is added to fresh concrete than necessary, the risk of cracking in concrete increases as a result of drying shrinkage.
- Although the early strength of concrete is slightly higher than the strength of concrete poured under normal conditions, a slight decrease in long-term strength can be seen.

In practice, the following measures can be taken in order to reduce and/or eliminate the adverse effects of hot and dry weather conditions:

- The materials that make up the concrete, especially water, should be cooled as much as possible. Some of the water should even be used as ice.
- A cement type with a low hydration heat should be used.
- Retarding admixtures should be used.
- Measures should be taken to prevent the evaporation of the mixing water.
- The curing process should be started immediately after pouring and the concrete surface should be kept constantly wet. For this, the first 24 hours is very important.