## 3.2 PROPERTIES OF CONCRETE RELATED TO MIX DESIGN

The mix design of concrete is the process of deciding what type of raw material and how much of each raw material needs to be selected to make concrete that can meet prerequisites such as strength, durability, and workability.

The required properties of hardened concrete are specified by the designer of the structure and the properties of fresh concrete are governed by the type of construction and by the techniques of placing and transporting. These two sets of requirements are the main factors that determine the composition of the mix, also taking account of the construction experience on site. Mix design can, therefore, be defined as the processes of selecting suitable ingredients and determining their relative quantities, with the purpose of producing an economical concrete that has certain minimum properties, notably workability, strength, and durability.

It should be pointed out that the mix design of concrete is frequently done by trial and error. Hence, mix design of concrete is an art, not a science. This means that the mix design of concrete in the strict sense is not possible: the materials used vary in a number of respects and their properties cannot be assessed truly quantitatively, so that we are really making no more than an intelligent guess at the optimum combinations of the ingredients onthe basis of relationships established in the earlier sections.

It is not surprising, therefore, that to obtain a satisfactory mix, we must check the estimated proportions of the mix by making trial mixes and, if necessary, make appropriate adjustments to the proportions until a satisfactory mix has been obtained (Neville and Brooks, 1994).

**Workability**

As discussed earlier, the workability of concrete consists of two aspects, flowability and cohesiveness. Two factors have to be taken into consideration when determining the workability. One is the geometry of the member to be cast, including size of cross section and the amount and spacing of reinforcement. The other is the compaction method, including the equipment for compacting and duration of consolidation.

It is clear that when the cross section of the member to be cast is narrow and complicated in shape, the concrete must have a high fluidity so that full compaction can be achieved. The same applies when the member is heavily reinforced with steel bars that make placing and compaction difficult. Moreover, it is important to choose proper compacting equipment, such as a plate-type vibrator or a sticker-type vibrator, and a compaction duration to ensure that concrete can be fully compacted during the entire progress of construction.

After choosing the workability, the water content of the mix (mass of water per unit volume of concrete) can be estimated by considering the workability requirement. Well-shaped coarse aggregates and, although the water requirement is influenced by the texture and shape of the aggregate.

Water content is regarded as the most important factor influencing the workability of concrete. After adding water to a concrete mix, the water is absorbed on the surface of the particles of the cement and aggregates. Additional water fills the spaces among the particles and “lubricates” the particles by a water film. Decreasing the water content will result in a low fluidity. If the water content is too small, the concrete will become too dry to mix and place. Increasing the amount of water will increase the amount of water for lubrication and hence improve the fluidity and make it easy to be compacted. However, too much water will reduce cohesiveness. This not only leads to segregation and bleeding, but also reduces the concrete strength. The water content in a concrete is determined by $w/c$ or $w/b$ and cement or binder content.

Cement content influences the workability of concrete in two ways. First, for given *w*/*c* ratio, the larger the cement content, the higher the total water amount in the concrete; hence, the consistency of concrete will be enhanced. Second, cement paste itself plays the roles of coating, filling, and lubrication for aggregate particles. In normal concrete, a considerably low cement content tends to produce a harsh mixture, with poor consistency and, subsequently, poor finish-ability.

**Durability**

Severe exposure conditions require a stringent control of the *w* /*c* ratio because it is the fundamental factor determining the permeability and diffusivity of the cement paste and, to a large extent, of the resulting concrete. In addition, adequate cover to embedded reinforcing steel is essential. However, the *w*/*c* ratio can be assessed indirectly through the workability of the mix, the cement content, and strength. If the *w*/*c* ratio is determined due to durability requirements, the cement content can be reduced by the use of a larger-size aggregate.

It must be remembered that air entrainment is essential under conditions of freezing and thawing or exposure to deicing salts, although entrained air does not protect concrete containing coarse aggregate that undergoes disruptive volume changes when frozen in a saturated condition.