CHAPTER 2

PROPERTIES OF FRESH CONCRETE

2.1 Introduction

The *performance requirements* of hardened concrete are more or less well defined with respect to *shape*, *finish*, *strength*, *durability*, *shrinkage* and *creep*. To achieve these objectives economically, the fresh concrete, in addition to having a suitable composition, in terms of quality and quantity of cement, aggregate and admixtures, should satisfy a number of requirements from the mixing stage till it is transported, placed in formwork and compacted. The requirements may be summarized as follows:

i. The mix should be able to produce a homogeneous fresh concrete from the constituent materials of the batch under the action of the mixing forces. A less mixable concrete mix requires more time to produce a homogeneous and uniform mix. The property is termed *mixability*.

ii. The mix should be stable, in that it should not *segregate* during *transportation* and *placing* when it is subjected to forces during handling operations of limited nature. Any segregation that is caused during the transportation operation does not correct during remaining operations that follow. The tendency of bleeding should be minimized. These properties are termed *consistency*, *transportability*, and *placeability*. These properties enable concrete mixes to be *consistent* to resist segregation after mixing, and to be *transported* and *placed* in forms without the occurrence of segregation

iii. The mix should be cohesive and sufficiently *mobile* to be placed in the forms around the reinforcement and should be able to cast into the required shape without losing continuity or homogeneity under the available techniques of placing the concrete at a particular job. The property is termed *flowability* or *mobility* of fresh concrete.

iv. The mix should be amenable to proper and thorough compaction into a dense, compact concrete with minimum voids under the existing facilities of compaction at the site. A best mix from the point of view of compactibility should achieve a 99 per cent elimination of the original voids present. This property is termed the *compactability* of concrete.

v. It should be possible to attain a satisfactory surface finish without honeycombing or blowing holes from formwork and on free surface by troweling and other processes. This capability is termed *finishability*.

2.2 Workability

The diverse requirements of mixability, stability, transportability, placeability, mobility, compactability and finishability of fresh concrete mentioned above are lectively referred to as *workability*. The workability of fresh concrete is thus a composite property. It is difficult to define precisely all the aspects of the workability in a single definition. Workability is defined as that property of freshly mixed concrete which determines the *ease* and *homogeneity* of concrete mix during mixing, placing, compaction and finishing.

Ease is related to *rheology* of fresh concrete which includes performance parameters of stability, mobility and compactability. These parameters are redefined *rheology* in terms of forces involved in transmission of mechanical stresses, resistance to segregation and bleeding, and resistance to flow by cohesive, viscous frictional forces. The equivalence of parameters defining workability and rheology of fresh concrete is shown in Fig. 2.1. These parameters are predominately dependent on the consistency of the mixture as explained later. On the other hand parameters of mixability, placeability, compactibility, and finishability are performance variables that are dependent on the consistency and homogeneity. Thus, workability of fresh concrete is a complex system of two critical parameters, consistency and homogeneity. A mixture could have a very fluid consistency and be very placeable but if it segregates it would not be considered to have good workability due to lack of homogeneity. Thus, for optimal performance the consistency and homogeneity must be balanced. The optimum workability of fresh concrete varies from situation to situation e.g. the concrete which can be termed as workable for pouring into sections with minimum reinforcement may not be equally workable for pouring heavily reinforced thin sections. A concrete may not be workable when compacted by hand but may be satisfactory when vibration is used.

Consistency is the relative mobility or ability of a freshly mixed concrete to flow and the usual measurements are: slump for concrete, flow for mortar or grout, penetration resistance for neat cement paste. It is thus a measurement of one dimension of workability. It does not indicate whether or not a low viscosity mix has the cohesion to be placed without segregation and bleeding. Different concrete mixes with the same consistency can have different workability characteristics. Major factors affecting consistency are: water content; cement content and its plasticity of the cement paste; aggregate content and its characteristics, air content; temperature; mixing conditions; chemical admixtures and mineral additives used. Addition of superplasticizer improves consistency by dispersing the cement particles and reducing the viscosity of the cement paste. Increasing the water content will also improve consistency and can be resorted to if the negative effects of extra water represented by bleeding, segregation and lower strength can be tolerated.

Homogeneity which means uniform and stable distribution of cement, aggregate and water, and resistance to segregation is a critical physical property of plastic concrete. This property does not have standardized test methods for its measurement. The standardized tests for measurement of workability, namely flow, spread, and slump tests, measure consistency, not the homogeneity. To measure the homogeneity properties it is necessary to use a *rheometer,* an instrument that measures yield stress and plastic viscosity. A reduction in viscosity increases flow and improves consistency. Low viscosity is essential for ease of placement with cohesion, and for resistance to segregation and bleeding that is necessary for homogeneity. The presence of excess mixing water, under mixing and over mixing are common causes of many problems related to physical properties of concrete in plastic and hardened states. The addition of superplasticizer improves the wetting out and mixability of the concrete mix. It reduces yield stress which means less mixing energy and time is required. It improves homogeneity of the various mineral additives and admixtures.

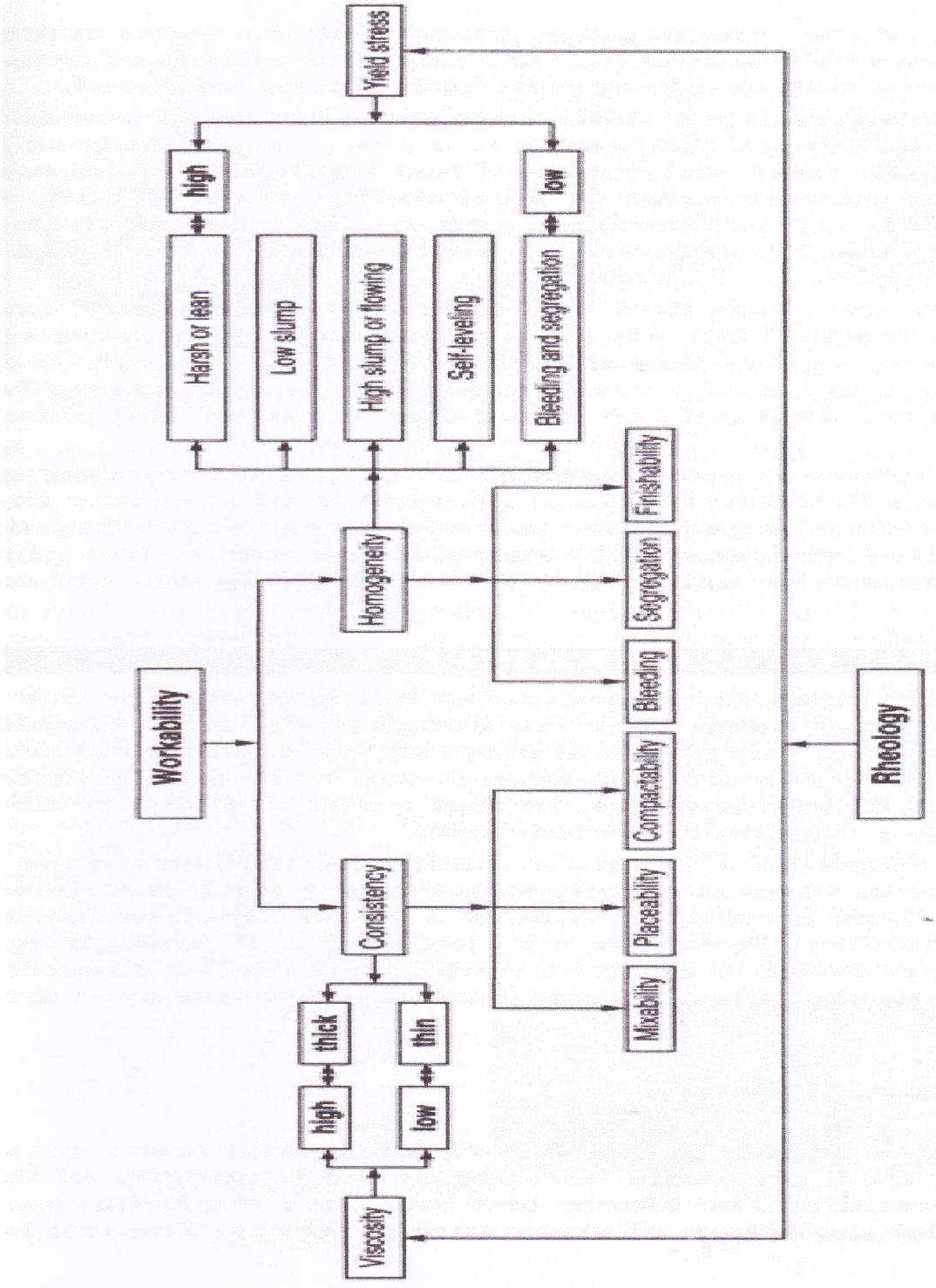

Fig. 2.1 Equivalence of parameters defining workability and rheology of fresh concrete

2.3 Factors Affecting Workability

The workability of fresh concrete depends primarily on the *mix proportions, properties of constituent materials, environmental conditions, and time*. Workable concrete exhibits very little

internal friction between particles and overcomes the frictional resistance offered by the formwork surface or reinforcement contained in the concrete with an appropriate amount of compacting efforts. Figure 2.2 represents diagrammatic sketch showing the factors those affecting workability of concrete.

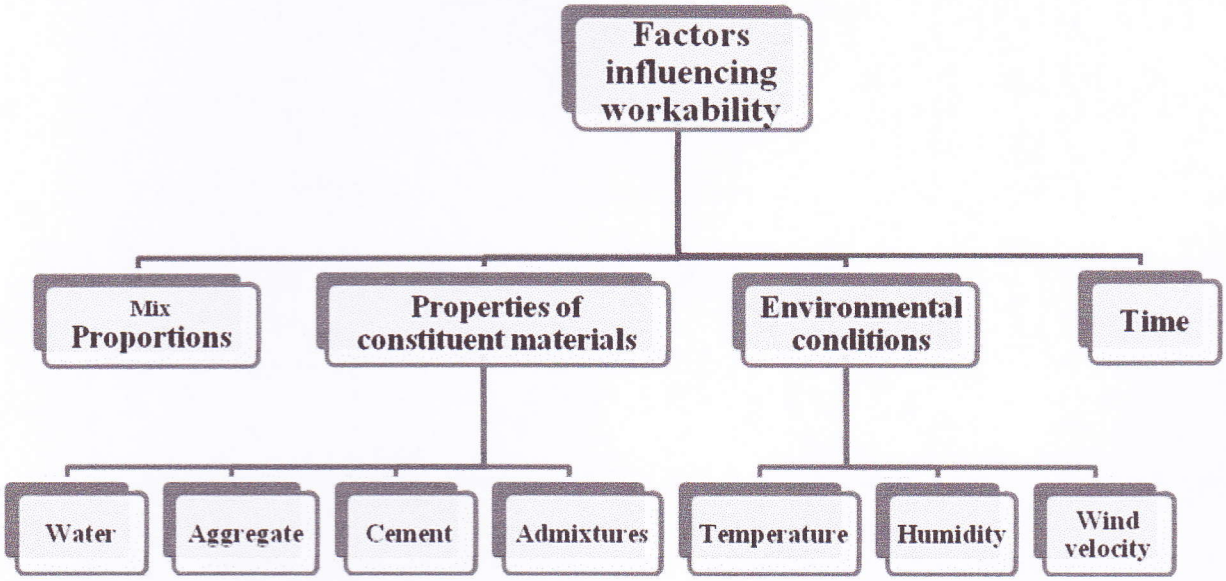

Fig. 2.2 Factors affecting workability of fresh concrete

2.3.1. Influence of Mix Proportions

In the concrete comprising a cement-aggregate-water system, the aggregate occupy approximately 70 to 75 per cent of the total volume of concrete and economy demands that the volume of aggregates should be as large as possible. The total specific area of the aggregate is to be minimized to the extent possible by proper choice of *size*, *shape* and *proportions of fine and coarse aggregates*. In a well graded aggregate different size fractions are so chosen as to minimize the void content, and such a mixture will need more water for lubricating effects to overcome the reduction in mobility due to dense packing of particles. However, when the total voids are less, for the given amount of paste volume, excess paste is available to give better lubricating effect. With excess amount of paste, the mixture becomes cohesive and fatty which prevents segregation of particles and lubricated aggregate particles slide past each other with the least amount of compacting effort. It has been noticed that the change in the measured value of workability of concrete due to relative change in water content is independent of the composition of concrete within wide limits. An increase of water content results in monotonous increase in workability but eventually a state is reached where segregation and bleeding occur, and use of higher water content will result in the more serious problems of shrinkage and creep of hardened concrete. However, the water content is limited to some maximum value given by the water-cement ratio which is dependent on the target design strength of hardened concrete. The water-cement ratio in itself determines the intrinsic properties of cement paste. The requirements of workability state that there is sufficient cement paste to surround or lubricate the aggregate particles as well as fill the voids in the aggregate. In a *lean* concrete, i.e. a concrete with high aggregate-cement ratio, less quantity of cement paste per unit surface area of aggregate is

available for providing lubrication, and hence the mobility of aggregates is restrained. On the other hand in case of rich concrete with low aggregate-cement ratio, more paste is available to make the mix cohesive and fatty to give better workability.

2.3.2 Influence of Properties of Constituent Materials

2.3.2.1 Water

The main factor governing the workability of concrete is the water content of the mix. Increasing the amount of water will increase the ease with which concrete flows and can be compacted. However apart from reducing the strength, increased water may lead to segregation and to bleeding. In general any collection of particles requires a certain amount of water to achieve plasticity so that it can be worked.

There must be enough water to:-

- Adsorb on the particle surfaces.
- Fill the spaces between particles.

Additional water lubricates the particles by separating them with water film. From this it follows that finer particles, which have a high specific surface area require more water. On the other hand, without some minimum quantity of fine material, the concrete cannot exhibit plasticity. Thus, the water content of the mix cannot be considered in isolation from the aggregate grading. For optimum workability finer aggregate grading require high water contents, as explained in section 2.3.1.

2.3.2.2 Aggregate

The effect of aggregate properties on the workability of fresh concrete can be summarized as follows:

i. When considering the effect of aggregate on workability, two factors are important, the amount of aggregate and the relative proportions of fine and coarse aggregate. Figure 2.3 presents the effect of the amount of aggregate on the workability of concrete, as increasing the volume of aggregate in concrete mix increases concrete workability to an optimum aggregate content then workability reduces with further increase in aggregate content.

ii. For the same volume of aggregate in concrete, the use of coarse aggregate of larger size and /or rounded aggregate gives higher workability because of reduction in total specific surface area and inter-particle frictional resistance. The lesser the surface area the lesser will be the amount of water required for wetting the surface and consequently lesser cement paste will be required for lubricating the surface of aggregates to reduce internal friction. The influence of surface texture on workability is due to the fact that the total surface area of rough textured aggregate is more than the surface area of smooth rounded aggregate of same volume, see Fig. 2.4. The use of angular, *elongated* or *flaky* aggregates results in low workability, primarily due to increase in the void content and inter-particle interference. This explains the reasons why river *sand and gravel* provide *greater* workability to concrete than crushed sand and aggregate. The size and shape of the aggregate is of paramount importance, as in the case of present day the high strength and high performance concretes where very low water-cement ratios of the order of about 0.25 are used.

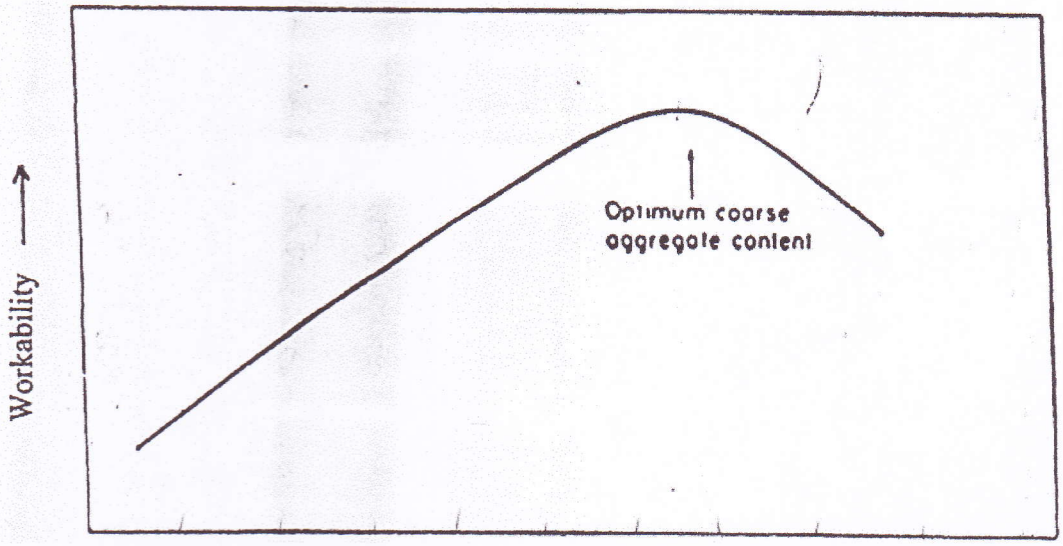

Fig. 2.3 Influence of aggregate content on the workability of concrete

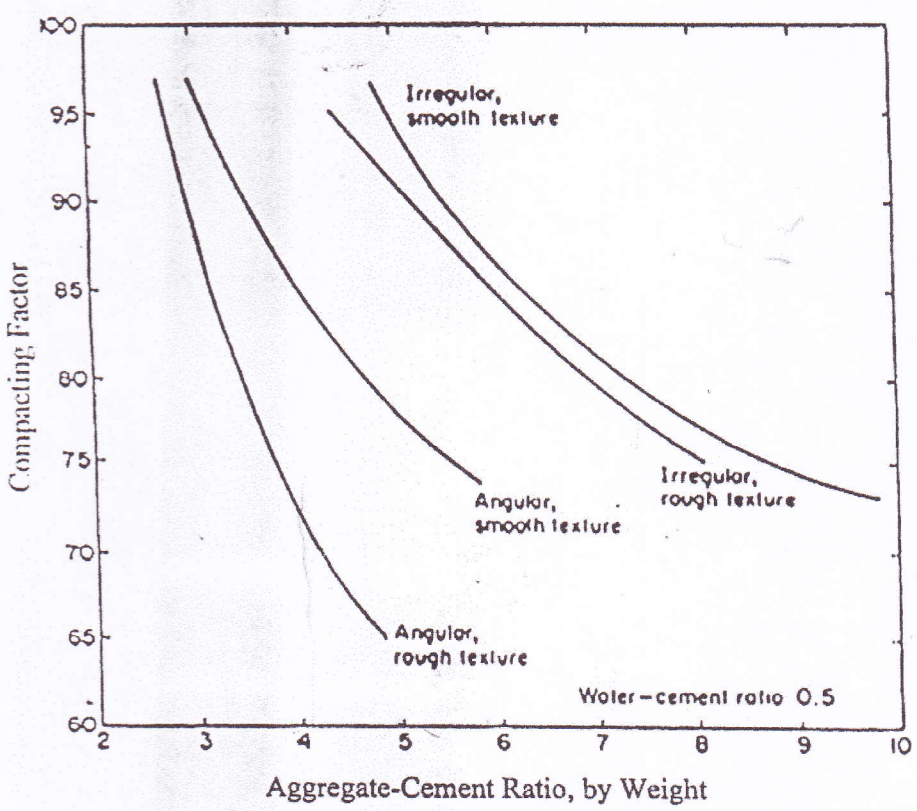

Fig. 2.4 Effect of aggregate shape, and texture on the workability of concrete

iii. The use of finer sand increases the specific surface area, thereby increasing the water demand for the same workability. In the other words, for the same water content, the use of finer sand decreases workability.

iv. Because of the greater contribution to the total specific surface area, the grading of fine aggregate is more critical than the grading of coarse aggregate. Nevertheless, the proportion of fine to coarse aggregates should be so chosen as neither to increase the total specific surface area *(by excess of fine aggregate)* nor to increase the particle interference *(due to deficiency in fine aggregate)*. An unsuitable choice of overall grading can produce honeycombing or segregation. In normal range of mixes though an increase in fines content decreases workability but in practice there is an optimum fines content for maximum workability such that either an increase or decrease of fines reduces workability.

v. Generally, the mixes with higher water-cement ratio would require a somewhat finer grading and for mixes with low water-cement ratio *(as in case of high strength concrete)* a coarser grading is preferable. The effect of water content and aggregate size is shown in Fig. 2.5.

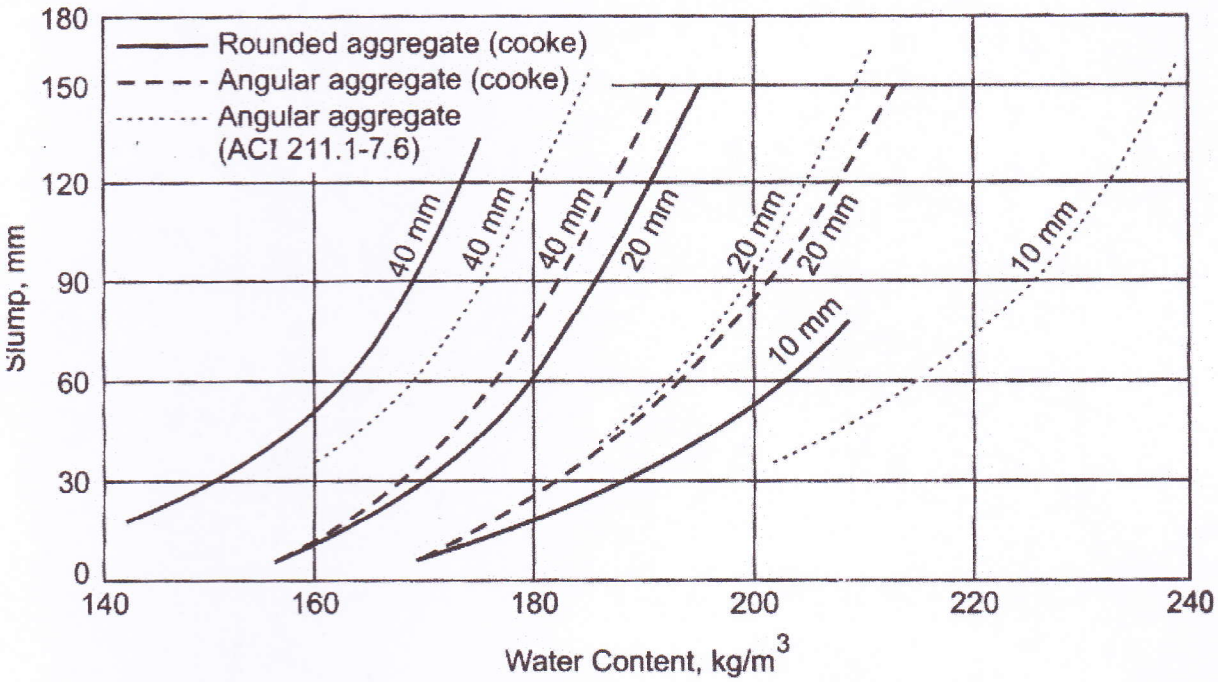

Fig. 2.5 Effect of water content and aggregate size on the workability of concrete

2.3.2.3 Cement

The workability is also affected by the physical and chemical properties of cement, but to a much lesser extent than that by the aggregate properties. The influence of cement properties may have to be taken into account for richer mixes. Rapid-Hardening Cement will have reduced workability as compared to Ordinary Portland Cement because of its higher specific surface area, and the fact that it hydrates more rapidly, and also the fineness of cement has an influence on bleeding.

2.3.3 Influence of Admixtures

The presence and nature of admixtures, and mineral additives affect the workability considerably. The plasticizers and superplasticizers improve workability many folds. It is to be

noted that initial slump of concrete mix, is also called the slump of reference mix should be about 20-30 mm to enhance the slump many folds at a minimum dosage. Use of air-entraining agents which are normally surface-active, reduce the internal friction between the particles. The air bubbles may be considered as artificial fine aggregate of very smooth surface. They also act as a sort of ball bearing between the particles to slide past each other and give easy mobility to the particles. Similarly, the fine glassy pozzolanic materials, in spite of increasing the surface area, offer better effects for giving better workability.

2.3.4 Effect of Environmental Conditions

The workability of a concrete mix is also affected by the temperature of concrete and therefore, by the ambient temperature. On a hot day it becomes necessary to increase the water content of the concrete mix in order to maintain the desired workability. The amount of mixing water required to bring about a certain change in workability also increases with temperature.

2.3.5 Effect of Time

The fresh concrete loses workability with time mainly because of the loss of moisture due to evaporation. A part of mixing water is absorbed by aggregate or lost by evaporation in the presence of sun and wind, and part of it is utilized in the chemical reaction of hydration of cement. The loss of workability varies with the type of cement, the concrete mix proportions, the initial workability and the temperature of concrete. On an average a 125 mm slump concrete may lose about 50 mm slump in the first one hour. The workability in terms of compacting factor decreases by about 0.10 during the period of one hour from the time of mixing. The decrease in workability with time after mixing may be more pronounced in concrete with admixtures like plasticizers. For some particular total time after mixing, the loss in workability is small and initial level could be regained without loss in the strength of hardened concrete simply by adding extra water.

2.4 References

1- Amr. E. Salama, and Gouda M. Ghanem, "Concrete Technology", Lecture notes for students of the 2nd year Civil, Civil Engineering Department, Faculty of Engineering, Mataria, Helwan University, Cairo, Egypt.

2- M. L. Gambhir, "Concrete Technology-Theory and Practice", Text book, The McGraw Hill Education Private Limited, New Delhi, Fourth Edition.

2.5 Problems

1. Draw the following with net sketches
 a. the effect of aggregate content on workability of concrete
b. factors affecting workability
c. the effect of aggregate shape and texture on workability
d. the effect of water content and aggregate size on workability

2. Choose the right answer a, or b, or c, or d to make the following statement correct.

1. Rheology of fresh concrete includes the following except (a) stability, mobility and compactability of concrete (b) knowledge of water-cement ratio (c) study of forces involved in transmission of stress through concrete mass (d) deformation curve of fresh concrete

2. Rheological properties of concrete are independent of (a) water-content (b) ggregate shape, texture and grading (c) type of mixer (d) temperahre (e) type of cement

3. The flow properties of fresh concrete are mainly dependent upon (a) the factors affecting resistance to deformation (b) the water-cement ratio (c) the richness of the mixture (d) shape and texhre ofthe aggregate (e) fineness moduli and gradings of the aggregates

4. Chemical admixtures are (a) essential constituent material of concrete (b) types of coarse aggregates (c) Natural stone (d) ingredients in concrete other than Portland cement, water, and aggregates

5. Workability is (a) a long-term requirement (b) a property of hardened concrete (c) a short-term requirements (d) non of the other choices
6. Mobility contributes (a) reheology (b) consistency (c) plasticity (d) shrinkage