SYNOPSIS

Concrete is a versatile material which can be used in structures required to perform in aggressive environments. The marine environment is considered to be the most severe and destructive natural environment. For several reasons, the effect of sea water on concrete deserves special attention. First, coastal and offshore structures are exposed to the simultaneous actions of a number of physical and chemical deterioration processes, which provide an excellent opportunity to understand the complexity of concrete durability problems in practice. Second, oceans make up 80% of the surface of the earth; therefore, a large number of structures are exposed to sea water directly or indirectly e.g., winds can carry sea water spray up to a few miles inland from the coast.

Sea water attack is more dangerous in the parts standing above the water levels rather than in the submerged parts. The concrete is subjected to alternate drying and wetting due to the action of the tides, waves spray and capillary rise. As a result, sea water firstly fills in the pores of concrete and then evaporates. In such conditions, salts dissolved in the sea water precipitate. Repeated cycles of wetting and drying lead to growth of a gradual build up of crystals and the formation of internal stress which can cause the concrete to crumble.

The use of pozzolanic and ground granulated blast furnace slag cements rather than Portland cement is therefore, recommended for marine structures. This is due to the fact that the effective diffusion coefficients of the various ions (Cl and SO₄) are less in blended cements than in OPC.

The major cause of deterioration of reinforced concrete structures in marine environment is the corrosion of embedded steel resulting from the penetration of chlorides through the cover concrete to the steel. The shrinkage is a common phenomenon generally encountered in almost all cementitious products due to contraction of total mass upon loss of moisture. Hence, the durability and service life of a marine structure is dependent on the adequacy of design and a judicious choice of the constituent materials of concrete.

Recent developments in concrete technology like the use of materials such as mineral admixtures viz. fly ash, ground granulated blast furnace slag (GGBS), silica
fume, rice husk ash (RHA) and metakaolin and chemical admixtures have given a new direction to the construction industry. By an appropriate choice of mineral admixtures and a proper amount of chemical admixtures, if necessary, a concrete technologist can produce concretes for any specific applications, especially to perform in aggressive environments.

The use of mineral admixtures as cement replacement material has gained importance due to the improved performance characteristics of concrete achieved and the economy obtained in the production of cement or concrete. Addition of mineral admixtures with cement reduces the water demand which in turn reduces the shrinkage and creep. Also the higher alumina contents in these materials improve chloride bonding of concrete thus making the concrete best suited for marine environment.

Sulphate attack on concrete is a complex process. The soluble Sulphates react with tricalcium aluminate content of cement and hydraulic lime in presence of moisture and form products which occupy much bigger volume than that of the original constituents. This expansive reaction results in weakening of concrete and formation of cracks. The Sulphate attack also takes the form of a progressive loss of strength and mass due to deterioration in the cohesiveness of the cement hydration products. Water and soils containing Sulphate ions attack the concrete through the formation of Ettringite and occasionally gypsum. The formation of these compounds causes the concrete to swell, thus creating stresses.

It is observed that, protection against Sulphate attack is obtained by using a dense, compact concrete with low water cement ratio. Use of blended cement has beneficial effects on the permeability of concrete. The mineral admixtures i.e., pozzolan and slag in blended cement combine with the alkalis and calcium hydroxide released during the hydration of cement and thus reduce the potential for gypsum and Ettringite formation.

All along concrete was considered as a two phase material namely aggregate phase and paste phase. However today the concrete technologist are of the opinion that concrete should be considered as three phase material, transition zone is considered as the third phase. The interface between surface of aggregates and bulk cement paste is called the transition zone also referred to as interfacial zone.
Concrete is a heterogeneous material. Homogeneity is pronounced between bulk cement paste and aggregate. When examined more closely there is no homogeneity even within the bulk cement paste. The composition of cement paste very close to surface of aggregate is different from the one which is little away from surface of aggregate. The quality of paste in plastic concrete and subsequently in hardened condition, the paste structure very close to aggregate surface is found to be poorer when compared to paste structure away from aggregate face. Therefore the paste near the aggregate face will have large number of cracks, deformities, collectively called “faults”. These micro cracks and faults are the strength limiting factors in the concrete. The micro cracks deformities and faults do not allow the effective transfer of stress from paste to aggregate. However the use of blended cement improves characteristic properties of transition zone by its pozzolanic action and also from micro filler effect.

In this context, laboratory investigations carried out on Portland Pozzolana Cement (PPC) & Portland Slag Cement (PSC) both are factory blended cements, 43 & 53 grade OPC concrete to study and compare the different parameters of concrete prepared from the above four types of cement and a comparison is made to ascertain the quality and performance of the concrete incorporating the above parameters discussed and reported.

The investigation is carried out for M20, M25, and M30 grade of concrete mix with water cement ratio of 0.55, 0.50 and 0.45 respectively. The design of concrete mix is carried out according to BIS method.

The physical properties of ingredient materials were determined in accordance with BIS specifications and the results are tabulated in the respective tables. On fresh concrete the workability related tests such as Slump, Compaction factor and Vee-Bee Consistometer tests are conducted in accordance with BIS specifications and the results are listed in the respective tables. On hardened concrete the strength related tests such as Compression, Split tensile and Flexural tests are conducted as per BIS specifications and durability related studies such as Acid Attack (acid used is Sulphuric Acid), Sea Water Attack (direct immersion in sea water back water at Kadekar, Ambalpady, Udupi), Capillary Measurement, Rapid Chloride Penetration Test and Drying Shrinkage Test are conducted (for M30 grade of concrete) and the results are presented in the respective
tables. In addition, X-Ray Diffraction (XRD) Test and Scanning Electron Microscope tests (for M25 grade of concrete at 90 days of curing and for M30 grade of concrete at 150, 180 and 210 days of curing) are also conducted to study the Mineralogy and Microstructure of concrete.

The setting time of cement both initial and final, indicates that, the setting time of blended cements both initial and final generally gets delayed. This may be attributed to the slow pozzolanic reaction because of the presence of SCM’s in blended cement. The delayed time can be of benefit during mass concreting especially in hot weather concrete.

The results of workability tests reported reveals that, the workability performance of blended cement concretes both PPC and PSC concrete is better than 43 & 53 concretes. Even though there is not much of difference in workability in terms of slump, concrete mixes made with PPC and PSC were more cohesive than concrete mixes made with OPC. This is due to the increased fineness of SCM’s in the blended cements. The SCM particles act as ball bearings for moving the ingredients.

The results of the investigation indicated that, the strength of blended cement concrete is low at initial ages but the strength is higher at later ages compared to 43 & 53 grade OPC concrete. It is observed from capillary measurement test that the percentage of water absorption rate in fly ash based and slag based concretes is less when compared to 43 & 53 grade OPC concretes. The water absorption rate is found to be constant for PPC and PSC concretes from the 7th and 6th day respectively, but for both 43 and 53 grade OPC concretes the water absorption rate remain constant from 10th day. This shows that blended cement concretes are more impermeable compared to 43 & 53 grade OPC concretes. It can be seen from RCPT results that the PSC concrete showed significantly much higher penetration resistance followed by PPC concrete when compared to 43 & 53 grade OPC concretes. The average charge passed (Coulombs) in blended cement concrete is less when compared to 43 & 53 OPC concretes. The variations between PSC and PPC concretes are marginal. From the results of drying shrinkage test it is evident that the performance of PPC and PSC blended cement concretes are better than that of 43 & 53 grades OPC concretes.

The investigation on the resistance of concrete to acid attack reveals that, there is a percentage loss of weight and reduction in strength in all the four types of cement
concrete, however it is found that slag based blended cement concrete followed by fly ash based concrete shows better resistance to acid attack than that observed for 43 and 53 grade OPC concretes.

The experimental result on the resistance of concrete to seawater attack reveals that, there is an appreciable loss of weight in all four types of concretes resulting in the deterioration of concrete. The compressive strengths are also found which indicates that there is a reduction in strength when compared to normal curing concrete. However there is a gradual increase in strength up to 180 days and thereafter there is a reduction in strength till 1080 days (i.e. up to 3 years). This decrease in strength is about 2.85%, 3.58%, 4.72% & 3.79% at the age of 1 year and 9.1%, 9.9%, 12.24% and 11.05% at the age of 3 years w.r.t to 180 days for the concrete produced with PPC, PSC, 43 & 53 grade OPC respectively. This reveals that, PPC concrete is performing well followed by PSC and 43 & 53 grade OPC concretes. This is due to the fact that the effective diffusion coefficients of the various ions are less in pozzolanic and slag cements.

The XRD test indicates that the free calcium hydroxide content in case of OPC based concrete samples remain more or less at the same level and its content is distinctly higher than the concrete based on PPC and PSC. In the case of PPC concrete, the lime is consumed in the pozzolanic reaction with reactive silica of the fly ash and gives rise to C-S-H phase. Similarly, in PSC concrete Ca (OH)$_2$ is much less due to its reaction with glassy phases of the granulated slag resulting in stratilignite type of phases. In case of 43 grade OPC concrete the un-hydrated peaks are more prominent while 53 grade OPC concrete shows higher degree of hydration as evidenced from lesser intensity of cement peaks. The concrete containing blending components like fly ash and slag show secondary hydration reactions with free calcium hydroxide liberated from the primary hydration reactions of the cement phases. This indicates the continuation of the pozzolanic reaction i.e. secondary hydration reaction for a longer time.

The important aspects of concrete such as strength development, durability and toughness can be addressed by microscopy studies of cement hydration, which reveal the complex mechanisms of hydration.

At 150, 180 & 210 days of curing (M30 grade of concrete) and 90 days of curing (M25 grade of concrete), the blended cement concrete still contains some free calcium
hydroxide, and fine spherical silica in the case of PPC concrete, and angular glassy particles in the case of PSC concrete, indicating that they would continue to improve the later age strength of the concrete, through formation of additional C-S-H gel due to continued hydration. Reduction of calcium hydroxide due to the pozzolanic reaction of blended cement leads to more durability.

Hence it is concluded that, the behaviour & performance characteristics including durability of blended cement concrete is better than that of the 43 & 53 grade OPC concrete.