THE IMPACTS OF DIFFERENT CONCRETE CONSTITUENTS ON CONCRETE PROPERTIES

Compiled By Martha Mwatile

Concrete is the most widely used construction material in the world, due to the various benefits it offers in both the fresh and hardened states. It is a composite material composed of different constituents, namely:

- fine aggregate (sand)
- coarse aggregate (stone)
- cement (also called a binder) and
- water

Additionally, concrete may also contain cement extenders (as part of the cementitious material) as well as concrete admixtures, which are typically added to the concrete during the mixing stage.

All these materials play certain roles in the concrete mix and have an impact on the fresh and hardened properties of the concrete. Altering any of the characteristics of the constituents therefore also alters the properties of the concrete. The influences of the different concrete constituents on the concrete properties will be discussed.

AGGREGATES

Aggregates are divided into two categories, namely fine aggregate (sand) and coarse aggregate (stone). Fine aggregate is defined as material that passes through a sieve with 4.75mm square openings. Coarse aggregate is material that is too big to pass through the 4.75mm sieve. Aggregates serve the main purpose of increasing the concrete volume, reducing the cost of concrete and improving the dimensional stability of concrete. Aggregates typically make up over 70% of the concrete volume and for this reason, their characteristics have a significant impact on the properties of concrete. One of the biggest impacts that aggregates have on concrete is that the grading and geochemical characteristics of sand and stone have a major influence on the workability, cohesiveness and bleeding properties of concrete.

FINE AGGREGATE (SAND)

The grading of sand has an impact on the workability of concrete. SABS 1083:2018 specifies that sands with the fineness modulus range of 1.2 - 3.5 are satisfactory for concrete work, even though it has been noted that some sands outside of this range may also work well. In most sands, the most important particle sizes are those passing through the 0.3, 0.15 and 0.075mm sieves (Addis, 2008). A guideline in construction is that the optimal distribution is to have 30% of the sand particles passing the 0.3mm sieve, 15% of the sand particles passing the 0.15mm sieve and 7.5% of the sand particles passing the 0.075mm sieve (Addis, 2008).

Particles passing the 0.15 and 0.3mm sieves play a big role in determining the cohesiveness and workability of the fresh concrete (Grieve, 2009). If these fractions are in low proportions, the concrete is likely to segregate and bleed. However, if a mix has a very high proportion of these sizes, then it tends to be sticky and difficult to handle. In some cases, having these particles in excess may also result in the entrapment of excessive air in the concrete, leading to reduced strength.

Having an excessive amount of the particles passing the 0.075 sieve (this fraction of the sand is referred to as 'dust') results in a high water requirement which can lead to drying shrinkage in the concrete (Grieve, 2009). Having a sufficient content of the particles passing the 0.075mm sieve is important as this fraction of the sand helps to control bleeding in fresh concrete, which if not controlled, may negatively impact concrete compressive strength, bond, permeability and durability (Grieve, 2009). Although a sufficient dust content is desirable, this fraction may also contain clay, and particularly deleterious clay. Active smectite clay can lead to undesirably high drying shrinkage in concrete and therefore needs to be controlled. SANS 1083: 2018 defines the clay content as the material of particle size smaller than 5µm (i.e 0.005mm). This standard also specifies that the clay content of the sand should not exceed 2%.

The particle shape of sand also has an impact on the workability of the concrete. Rounded particles make concrete with good workability, as opposed to elongated, flat and angular particles which make the concrete harsh and difficult to mix and work with.

An aggregate with a smooth surface texture results in a reduced water requirement and better workability due to the ease of concrete mixing.

COARSE AGGREGATE (STONE)

The average or nominal size of aggregate affects the water requirement of concrete. The larger the aggregate size, the smaller the surface area per unit concrete volume which has to be covered by the cement paste at a given water-cement ratio. This in turn has an impact on the workability of the concrete.

The effect of particle shape in stones is similar to that of sand, in that rounder stones make concrete with good workability. However, this effect is not as great with stone as it is with sand, and the effects of poor stone shape can normally be overcome with a good concrete mix design.

In fresh concrete, a smooth aggregate surface texture results in a reduced water requirement and better workability due to the ease of concrete mixing. In hardened concrete, a rough surface texture improves the bond between the aggregate and the cement paste and therefore increases the strength of the concrete.

The coarse aggregate crushing strength has no impact on the strength of conventional concrete (20-40 MPa). This is due to the fact that the crushing strength of most coarse aggregates is usually higher than that of conventional concrete. Aggregates are reported to have crushing strengths in excess of 70 MPa. The aggregate crushing strength of coarse aggregate is however very important in high strength concrete as it can reduce the strength of the concrete.

Aggregate type may affect the durability of concrete as some aggregate types can create a favourable environment for deterioration mechanisms such as Alkali Silica Reaction to take place. This is a reaction which occurs between the alkali in cement and the reactive silica in certain aggregate types, forming an expansive gel which swells in the presence of water and eventually causes extensive cracking in the concrete. Figure 1 shows the geological map of Namibia, showing the rock distribution throughout the country. So far in Namibia, most of the reported cases of ASR were found to contain aggregates from granite and gneiss rocks. These cases were mainly reported in water retaining structures and foundations at the coastal areas of Namibia. It should be noted that other rocks such as sandstones, shales and schists have also been identified as potentially deleteriously reactive with alkalis in concrete and therefore the necessary caution should be employed when they are used. It is advisable to test aggregates for potential ASR reactivity prior to their use, if there is suspicion of deleterious material at the aggregate source, or if there is historic record of ASR from the use of those aggregates.

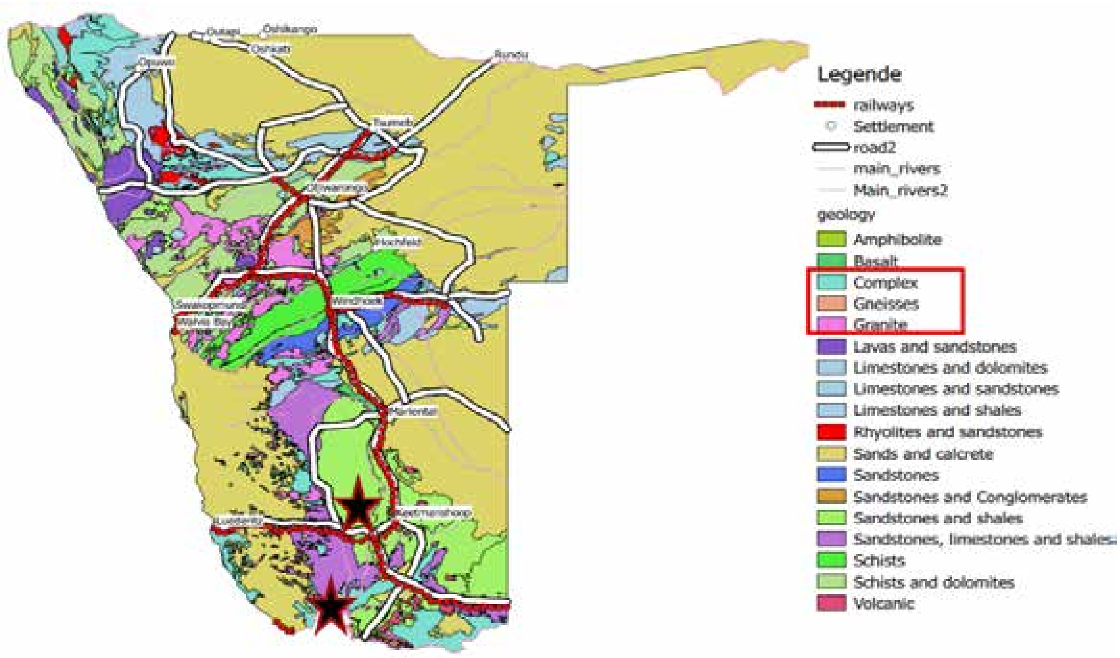

Figure 1: Geological Map of Namibia

CEMENT

Cement (also called a binder) is a fine powder, which when mixed with water, reacts chemically in a set of reactions called hydration reactions. The water-cement mixture then sets and hardens to form a rigid mass which binds all the concrete constituents together, and then gains strength over time thereafter. Ohorongo Cement produces five different cement types, namely:

- CEM II B-LL 32.5N
- CEM II A-LL 42.5N
- CEM II B-V 42.5N
- CEM I 42.5R
- CEM I 52.5N

These different cement products all conform to the requirements of SANS 50197-1, EN 197-1 and NAMS 197-1. The cement types each have different properties, which make them suitable for different concrete applications. For a specific mix design, the different cement types differ in their compressive strength, workability properties, setting times as well as their durability properties. Figure 2 shows a typical comparison in the cement strength growth between the five cement products.

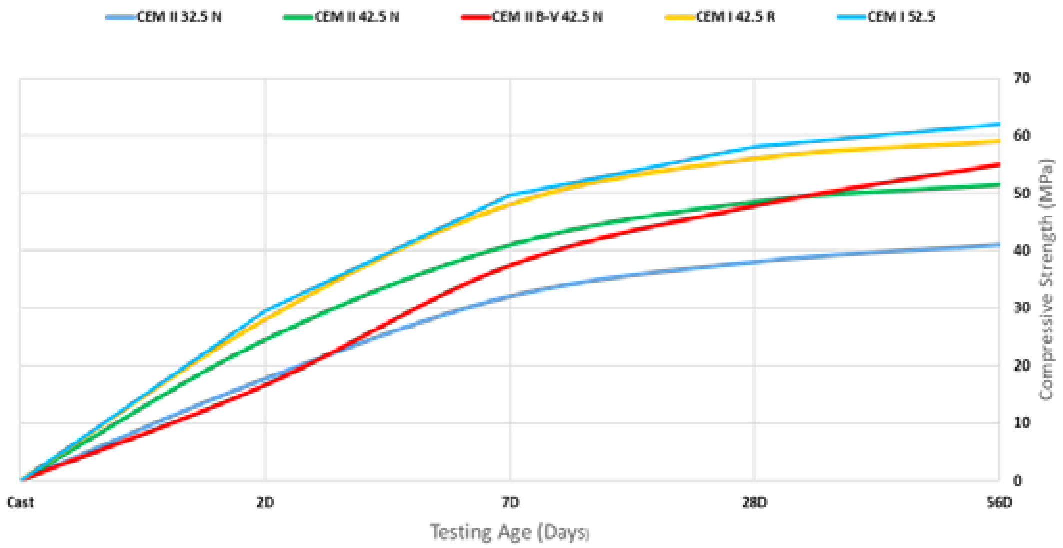

Figure 2: Comparison of strength development in different cement types

It is important to note that whichever cement type is utilized in the concrete, the properties of the concrete will be very dependent on the concrete mix design, because as mentioned before, other concrete constituents also play a significant role in the properties of the concrete. For a given concrete mix design (i.e. where all the concrete constituents are kept constant and only the cement type is changed), a CEM II A-LL 42.5N will produce a stronger concrete than a CEM II B-LL 32.5N. Also, a CEM I 42.5R, which is a rapid setting cement will set/harden quicker than other cement types. This makes it appropriate for use in precast concrete applications. The CEM II B-V 42.5N is a blended cement, containing Fly Ash. The presence of Fly Ash results in a concrete with a denser concrete pore structure, and therefore a more impermeable concrete. The workability of a concrete made with this type of cement is also enhanced.

It is best to enquire from the cement manufacturer about the most suitable cement to use for specific applications and in specific environments. It is also important to note that in addition to determining the correct cement, the concrete mix design determines the fresh and hardened concrete properties and must therefore be accurately performed by an experienced professional, particularly for more complex projects.

The strength of the concrete is provided by the strength of the cement-water paste and is dependent on the ratio of the water to the cement. At a certain cement content, the lower the water content, the higher the concrete strength, and the higher the water content, the lower the concrete strength.
Increasing the cement content in a concrete mix, without changing the other materials, typically increases the strength of the concrete.

If a concrete mix has too much cement in it relative to the water content, the mix will likely be sticky and difficult to place due to a higher fines content.

Increasing the content of cement in a concrete mix also increases the heat of hydration, which is the heat produced by the hydrating reactions between the cement and the water. The increase in heat of hydration results in additional water being required to hydrate the cement, the absence of which, causes drying shrinkage and associated cracking.

CEMENT EXTENDERS

Cement extenders (also called supplementary cementitious materials) are materials that have cementing properties when used in combination with cement. They are used by substituting a certain portion of the cement with the extender. They are usually used to enhance the durability properties of concrete.

FLY ASH

The most commonly used cement extender in Namibia is Fly Ash. Fly Ash is a waste product in coal fired power stations. The Fly Ash content typically employed in construction is 15-30% of the total cementitious material i.e. 15-30% of the Portland cement in a concrete mix is usually substituted with Fly Ash. When used in combination with cement, Fly Ash affects concrete in the following ways:

- It enhances the durability of concrete by making it less permeable and thus preventing harmful agents from penetrating the concrete. This is particularly important when construction takes place in an aggressive environment such as in coastal regions with salty water
- It enhances the durability of concrete by preventing the occurrence of alkali silica reaction, where the use of a non-reactive aggregate cannot be avoided or is not economically viable
- It reduces heat of hydration and associated cracking
- It increases the later age strength of concrete, for example the strength after 90 days
- It enhances concrete workability
- It slows down the setting of the concrete.

Varying the replacement quantity of Fly Ash also affects the strength and durability properties of the concrete. Typically, increasing the Fly Ash portion of the cementitious material reduces the concrete permeability (Figure 3), sorptivity (Figure 4), chloride penetration (Figure 5), and drying shrinkage (Figure 6). Durability is therefore enhanced with the use of Fly Ash. An increase in the Fly Ash content also typically reduces the concrete compressive strength development (Figure 7).

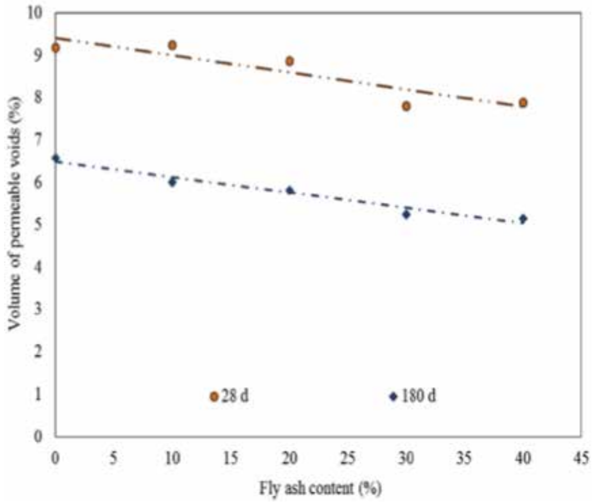

Figure 3: Effect of FA on volume of permeable voids

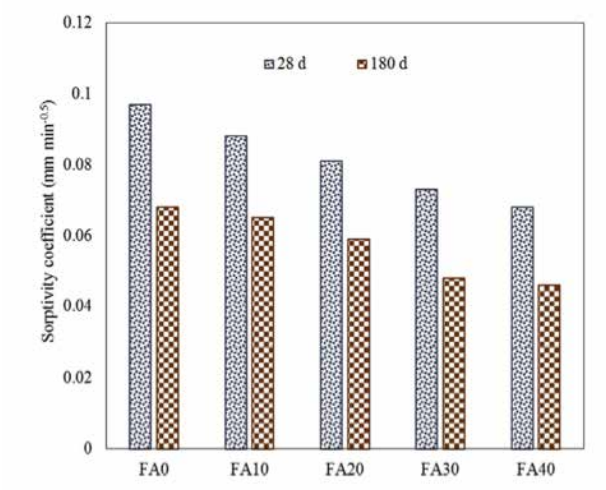

Figure 4: Effect of FA on sorptivity of concrete

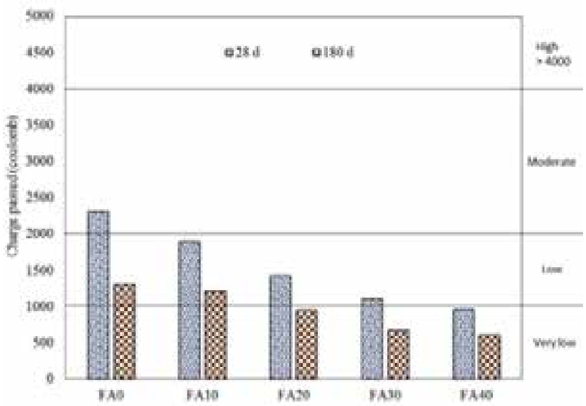

Figure 5: Effect of FA on chloride permeability

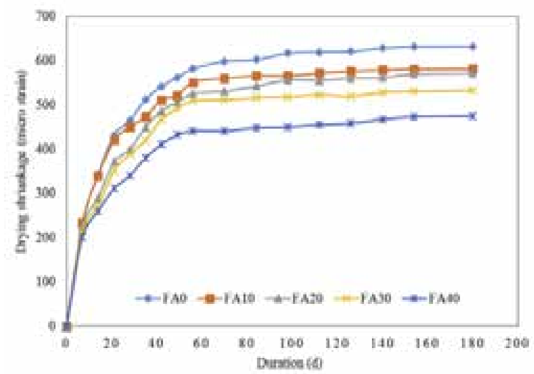

Figure 6: Effect of FA on drying shrinkage of concrete

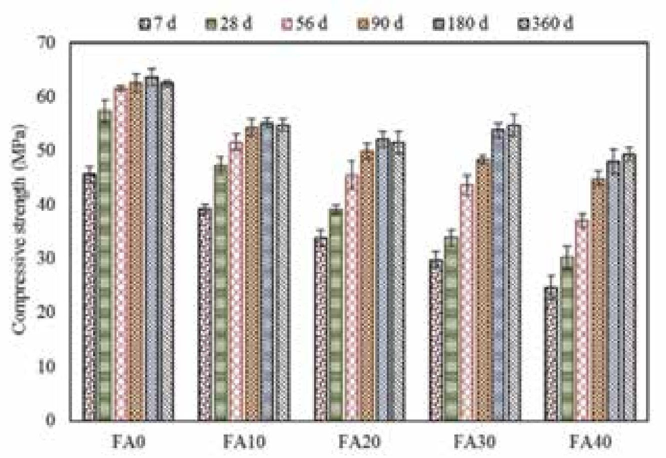

Figure 7: Compressive strength growth development at different FA contents

One of the important factors to consider when Fly Ash is to be used, is its quality. For Fly Ash to perform as required in concrete, it should be sourced from a reputable supplier, and it should conform to all the requirements set out in SANS 50450-1: 2014. Using substandard Fly Ash may result in concrete that does not meet the design and durability specifications. Another important factor to consider is the cost of Fly Ash. Fly Ash is not produced in Namibia but is imported into the country, most often from South Africa. Due to this, the cost of purchasing and delivering Fly Ash to Namibia is relatively high. The price per ton of Fly Ash is typically similar to that of a ton of cement and sometimes even higher.

GROUND GRANULATED BLASTFURNACE SLAG (GGBS)

Another cement extender that is used is Ground Granulated Blastfurnace Slag (GGBS). GGBS is a waste product from the iron and steel manufacturing processes. When used as an extender, its content is typically 15-50% of the total cementitious material, depending on the intended application. It impacts the concrete in a very similar way as Fly Ash, however, its effect on workability is that it only offers a slight improvement, unlike the case of Fly Ash.

CONDENSED SILICA FUME (CSF)

Condensed Silica Fume (CSF) is a by-product of the ferrosilicon smelting process and is also used as a cement extender. The cement replacement with CSF is typically between 5 and 15%. The impacts of CSF on concrete are:

- An increase in the concrete compressive strength
- Improved durability due to reduced permeability
- A significant reduction in bleeding
- An increase in cohesiveness, which makes it particularly suitable for shotcrete applications
- A reduction in workability.

Cement extenders can be blended with cement by the manufacturer, whereby the user may purchase an already blended product which they can use straight away. This is the case with the CEM II B-V 42.5N cement discussed earlier, which is a blend of Portland cement and Fly Ash and is supplied as such by the manufacturer. Cement extenders can also be mixed with cement by the user, in which case the user sources cement and Fly Ash separately and then blends them in their required proportions.

WATER

The type, quality, and content of water in a concrete mix has an impact on the concrete properties.

Potable water (water that is fit for human consumption) is the most suitable water for concrete construction and it is advised that this water be used for all concrete mixing. However, in the absence of potable water, there are other types of water that may be used, subject to certain conditions, which are stipulated in BS EN 1008. Water recovered from processes in the concrete industry; water from underground sources; natural surface water and industrial wastewater; wash water and other waste waters may be used in concrete, but only if they are tested and they conform to BS EN 1008.

Salt water can only be used in concrete that does not contain any steel reinforcement and where the cement and aggregates are not prone to alkali-silica reaction. This is because sea water contains a high content of dissolved salts which are majority sodium chloride and therefore present a very high risk of corrosion of the steel reinforcement.

The content of water affects the workability and the strength of concrete. For a given concrete mix, increasing the water content improves the workability and reduces the strength of the concrete. Reducing the water content reduces the workability and increases the strength of the concrete. Controlling the ratio of water to cement (the water cement ratio) is one of the most important factors to consider when designing a concrete mix, as it has a direct impact on both the workability and the strength of the concrete. Therefore, striking the correct balance between the contents of the two constituents is critical. When designing a concrete mix, topics such as concrete mixing method and duration, concrete transporting, concrete placement method and duration, as well as concrete compaction and finishing duration need to be considered, as they will impact the amount of water required for the concrete mix to remain workable throughout the process. Additionally, weather conditions such as temperature, rain and wind also negatively impact different concrete properties, and will thus affect the water requirement of the concrete in order to counter those negative impacts. For some projects, it is not possible to strike the balance between water and cement in order to meet all the construction and final concrete quality and durability requirements. In these cases, it then becomes necessary to include concrete admixtures in the concrete mix.

ADMIXTURES

Admixtures (also called additives) are materials other than cement, extenders, water and aggregate that are used as an ingredient of concrete. They are added to the concrete batch immediately before or during the concrete mixing. They are added with the purpose of modifying the properties of concrete in accordance with the specific requirements either in the fresh or hardened state. Some of the concrete properties that are most commonly modified with the use of admixtures are the setting time, workability, air entrainment, segregation and many others. Admixtures are normally added to concrete in specific quantities, and the over dosage with admixtures can have negative impacts on the properties of concrete. There are many different admixtures available, but only some of the most common ones and their impacts on concrete properties will be discussed.

PLASTICIZERS

Plasticizers either increase the workability of freshly mixed concrete without increasing water cement ratio or maintain the workability with a reduced amount of water and are therefore referred to as water reducing admixtures. Their function is to reduce the water content of the mix, usually by 5 to 10%, and sometimes even up to 15% (Shah, 2014). Thus, the purpose of using a water reducing admixture in a concrete mix is to allow a reduction in the water cement ratio while retaining the desired workability or, alternatively, to improve its workability at a given water cement ratio. The actual reduction in water depends on dose of admixtures, cement content, type of aggregate used, etc. Therefore, in order to achieve the optimum properties of the concrete, it is essential to do trial mixes with the actual materials to be used in the mix. With the use of plasticizers, it is possible to increase the workability of the concrete without changing water-cement ratio and thus without reducing the compressive strength of the concrete. This is particularly useful when concrete pours are restricted either due to congested reinforcement or due to thin sections.

SUPER-PLASTICIZERS

Super-plasticizers perform a similar function to plasticizers but can reduce the water content even further, by up to 30% (Shah, 2014). These admixtures are a different class of water-reducers which may be used without facing the problems associated with using plasticizers in larger quantities, such as bleeding, segregation, and hardening. They are an extended version of plasticizers, and they increase the workability of concrete, with the capability of increasing the slump by more than double, while maintaining the cohesiveness of the concrete (Shah, 2014). Super-plasticizers are particularly useful for self-compacting/flowing concrete, for application in elements such as heavily reinforced sections and inaccessible areas. They don’t entrain air and therefore reduce permeability.

ACCELERATORS

These admixtures increase the rate of hydration of hydraulic cement. When added to concrete, they shorten the setting time and accelerate the hardening or strength development of the concrete. They enable earlier release of concrete from precast moulds thus speeding up construction. They also reduce segregation and increase density and compressive strength. Concrete cures faster and therefore uniform curing in winter and summer can be achieved. Accelerators allow for early use of concrete floors by accelerating the setting of concrete. They reduce water requirement, bleeding, shrinkage, and time required for initial set.

RETARDERS

This type of chemical admixtures decreases the initial rate of reaction between cement and water and thereby retards the setting of concrete. Retarders act by forming a coating around certain components of the cement and they slow down the formation of reaction products in the concrete. Setting and hardening are therefore delayed, and early compressive strength is reduced. These admixtures are particularly useful in conditions where the rate of stiffening of concrete is too fast for the time required for concrete transportation and placement before it sets. Retarders can delay setting for up to more than 6 hours. Retarding admixtures improve the workability, cohesion and they extend the setting time of concrete. They provide protection against delays and stoppages in construction work. They keep concrete workable for extended periods of time in large constructions, and they help to prevent cold joints. They also reduce bleeding and segregation of concrete where poor sand grading is unavoidable. Retarders also improve pumpability of concrete by extending the setting time and improving the workability.

It is very important to note that admixtures can also have negative impacts on concrete. Some of these impacts are:

- Overdosing of some admixtures may cause retardation in setting time of concrete
- Higher dosages of super-plasticizer affect the shrinkage and creep properties of concrete
- Higher dosages of plasticizer may cause segregation and premature stiffening under certain conditions
- Higher dosages of super- plasticizer may increase rate of loss of workability
- One of the most used retarders is gypsum. Addition of excess amount of gypsum may cause undesirable expansion and indefinite delay in setting of concrete
- Excess use of accelerators causes more heat evolution and there are chances of cracks in the concrete.

CONCLUSION

Concrete is a composite construction material made up of different constituents. Each constituent plays a unique role in the properties of the concrete and therefore, varying any of the characteristics of those constituents will influence the properties of concrete. It is critically important to determine the correct concrete mix design for a specific concrete application.

Aggregates are used to increase the volume of concrete and to improve dimensional stability of the concrete. However, the grading, size and shape of aggregates affect the workability of concrete. The type of aggregate also has an impact on the durability of the concrete because certain aggregate types promote ASR.

The cement type and quantity have an impact on the compressive strength, workability, durability parameters and heat of hydration of the concrete. The relationship between the cement and water (the water cement ratio) has a significant impact on the workability and the compressive strength of the concrete.

Cement extenders are introduced to the concrete as part of the cementitious material, with the purpose of improving certain properties of the concrete. Each type of extender has a specific impact on the concrete, and it is therefore important to know how an extender is expected to behave in the concrete. Varying the content of the extender also affects the properties of the concrete.

The type of water may affect the concrete properties. Potable water is suitable for use in concrete, but it is possible to use water from other sources as long as it is tested and meets standard requirements. Sea water causes corrosion of steel reinforcement in concrete and is therefore not to be used in concrete which contains steel reinforcement.

Different admixtures may be added to concrete to enhance or modify certain properties of the concrete. Each admixture plays a unique role suitable for meeting specific requirements either in the fresh or hardened concrete. When using admixtures, it should also be noted that they may have negative impacts on the concrete if not used correctly.

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