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Concrete: A Man-Made Versatile Composite

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Abstract

It is apparent, if the history of materials that could be regarded as concrete-like is studied, the user finds the most suitable opportunity to improve and change the properties that was offered by these materials. The overall advancements were driven by practical need but rooted in unawareness. Such are often the ingredients of invention. Indeed, knowledge can restrain creativity giving rise to warning for fear of peer judgement. Consequently, concretes progressed slowly and somewhat erratically in one form or another. In the last 40 years or so there have been significant changes in cement manufacture and composition, in understanding the basic mechanisms of cement hydration and the transition from plastic to solid, making and placing of concrete, admixtures, additions, fibres, curing, surface treatments and coatings. These options will settle into a pattern of uses in the years to come.

Introduction

Since the earliest known use of concrete over 7000 years ago, the motive behind its development has been opportunity and opportunism. Practical advances have been made based more upon inventive flair than logical change routed in scientific understanding.

Concrete was an expedient and seen as a suitable means to achieving whatever was required as an alternative to masonry, brick and wood. Such opportunism changed to opportunity in this century as concrete and construction became more complex. For instance:

1. Invention of Portland cement
2. The alchemic manufacture of cement replaced by controlled factory-based production
3. Incorporation of metallic reinforcement

Concrete and steel are the two most commonly used structural materials. They sometimes complement one another, and sometimes compete with one another so that structures of a similar type and function can be built in either of these materials. And yet, the engineer often knows less about the concrete of which the structure is made than about the steel.

Steel is manufactured under carefully controlled conditions; its properties are determined in a laboratory and described in a manufacturer's certificate. Thus, the designer need only specify the steel as complying with a relevant standard, the site engineer's supervision is limited to the workmanship of the connections between the individual steel members.

On a concrete building site, the situation is totally different. It is true that quality of cement is guaranteed by the manufacturer in a manner similar to that of steel and, provided suitable materials are chosen, it is hardly ever a case of faults in a concrete structure. But it is concrete, and not cement, that is the building material. The structural members are more often than not made in situ, and their quality is almost exclusively dependent on the workmanship of concrete making and placing.

The disparity in the methods of steel and concrete making is, therefore, clear and the importance of the control of the quality of the concrete work on the site is apparent. These facts must be borne in mind by the designer, as careful and intricate design can be easily perverted if the properties of the actual concrete differ from those assumed in the design calculations. Structural design is only as good as the materials used.

From the above it must not be concluded that making good concrete is difficult. ‘Bad’ concrete- often a substance of unsuitable consistency, hardening into a honeycombed, non-homogeneous mass- is made simply by mixing cement, aggregate and water. Surprisingly, the ingredients of a good concrete are exactly the same, and it is only the ‘know-how’, backed up by understanding, that is responsible for the difference.
What, then, is good concrete? There are two overall criteria: the concrete has to be satisfactory in its hardened state, and also in its fresh state while being transported from the mixer and placed in the formwork. The requirements in the fresh state are that the consistency of the mix be such that it can be compacted by the means desired without excessive effort, and also that the mix be cohesive enough for the methods of transporting and placing used so as not to produce segregation with a consequent lack of homogeneity of the finished product. The primary requirements of a good concrete in its hardened state are a satisfactory compressive strength and an adequate durability.

The key phrase is: ‘economically, rapidly and safely’. These were attributes that concrete was seen to offer the construction industry.

What is it about concrete that allows it to compete in so many markets and to be used in so many ways? What are the characteristics – both those inherent to the material and those imparted by decades of development – that have led to such a wide variety of uses over the years?

Perhaps most fundamental is its plasticity and the variability of its constituents. Unlike any of its rivals, it can be formed into its final shape on site or at the factory. What other material can offer this flexibility? Plastics, iron and steel, glass, and clay products are all produced in the factory or foundry, in the glass-house or brick kiln. Manufactured products are brought to site and assembled as components of the building. Asphalt, conversely, is laid only in situ. Timber, perhaps, lends itself both to prefabrication and to cutting or carving on site. But concrete alone can be moulded into its final form on site as well as in the factory, and that opens up many more options for construction – the method of placing, size of element possible, flexibility of form, adjustability of construction program – though it does leave concrete vulnerable to charges of inconsistency and difficulties in quality control.

There is also the composition of concrete. To use a well-worn analogy, concrete technology is similar to cake-baking – a wide variety of results can be achieved by mixing a small number of basic ingredients in varying proportions (e.g., flour, fat and sugar), choosing a binder (e.g., eggs or milk), and combining extras for special effects (e.g., fruit, spice, chocolate, essence or food colouring). A sticky mixture is usually moulded to the required shape and a change of state takes place in the presence of heat. The resulting material can then be embellished with a range of surface treatments if desired (icing, chopped nuts etc).

Some inherent characteristics of plain concrete

Hydraulicity

Cement is concrete’s active binding constituent, and the principal cement of the past 200 years – what commentators in the early years of the 20th century have called the ‘Concrete Age’ – is Portland Cement. However, there have been other cements during that period and certainly there are many cementitious materials on the market today, but the development of an artificial hydraulic cement capable of industrial production was the aim of cement pioneers from John Smeaton to Joseph Aspdin. The hydraulicity of a proportioned mixture of chalk and mud was cement’s key attribute: when hydrated it hardened and strengthened, rather than slaked or dispersed. Concrete made with Portland cement could be placed effectively in water.

Adhesion

The power to stick is also a function of the cement content. During the formative years of the British cement industry, the comparative testing of different types of cement was a preoccupation. Portland’s superiority over Roman cement, for instance, was demonstrated in a series of published tests by John Grant in the 1860s. This adhesive quality permits the continuous pours that characterize concrete construction and allow it to combine with other materials.

Plasticity

The consistence or workability of concrete in its plastic state can lie at any point on a continuum from a flowable slurry to a stiff mix before reaching solidity. Its plasticity allows the concrete not only to be moulded, but also affects the method of production and placement. A stiff concrete can be simply tipped down into an excavation, but not if the destination is remote, inaccessible or above the point of discharge from the mixer.

Formlessness or fluidity of form

One of the defining characteristics of concrete is the lack of its own form. It takes up the shape into which it is moulded while in its plastic state. It is cast – pre- or in situ – into a mould or formwork, or a void to be filled.

Compressive strength

'Concrete is strong in compression but weak in tension'. How often is that heard? Yet this is, without doubt, one of the fundamental characteristics of concrete. Why else would concrete have so quickly found a niche as the foundation material par excellence and become so closely associated with the requirements of civil engineering?

The strength conferred on concrete by the choice of cement was a matter of constant experimentation in the 19th century, and Portland cement's success over rivals such as 'Roman' and 'British' cement was largely down to strength. Concrete's strength was celebrated in the building materials section of the Great Exhibition in 1851, where several concrete products were tested to destruction.

In the decades following the Exhibition concrete was used in its plain or mass form, for docks, foundations, dams etc, applications that required the bearing of compressive loads.

Weight

Concrete is inherently heavy, consisting largely of aggregate derived from stone – be it crushed rock or gravel. Often this is a desirable quality in providing solidity and resistance to movement, e.g., in early coastal defences. Concrete has been used consciously as a weight, often a counterweight, but the greater challenge has been to find ways of lessening the weight of concrete, of developing a lightweight aggregate that does not necessitate the sacrifice of strength.

Durability

Durability is taken to mean resistance to internal and external deteriorative processes, to long-term degradation. This aspect of concrete is of ongoing interest and there is an immense amount of literature on it, but for the purposes of this article it is suffice to say that a measure of concrete's durability is the state of repair of early concrete structures. The Pantheon of ancient Rome is the obvious example, even the great pyramids of Egypt according to some theories, but this paper takes a look at a form of concrete more akin to present-day Portland cement concretes and looks at its long-term performance in highly aggressive, marine conditions. The concrete ships built at the end of the First World War form a readily-identifiable corpus of examples of concrete structures subject to torsional forces at sea, impact from collision and the effects of corrosion from saltwater.

Economic advantage

Though there is nothing new in the desire to cut costs and maximize profits, the construction process might be thought of as leaner as a result of changes to concrete technology. New codes of practice, reflecting technical advances, permit concrete to be designed with more slender elements and longer unsupported spans. Concrete's naturally heavy weight has been reduced, not just by the traditional use of lightweight aggregates, aeration or foaming, but by void-former systems such as Bubble deck and its equivalents. Systems of reusable formwork, proprietary reinforcement, prefabrication of elements and the use of self-compacting concrete for congested or inaccessible areas have all contributed to the efficiency of concrete construction, of what was once a labour-intensive process.

Concrete is a hugely versatile material, allowing structural designers enormous scope to meet and optimise application requirements with concrete in the most sustainable manner.

Something people don't often realise is that concrete is environmentally friendly. This means that long periods of transportation aren't needed, helping to keep our carbon footprint to a minimum. To further complement this, concrete is completely inert when cured, meaning it will not emit:

- Gas
- Toxic compounds
- Volatile organic compounds

Concrete is also 100% recyclable. It can be ground down into pieces and mixed with other materials to produce aggregate. Aggregate can be used as a sub-base for many structures, and is often used to protect shorelines. This reduces the amount of waste that is sent to landfill, something which helps the environment even further and aids in keeping carbon footprint down.

Concrete is highly cost-effective

Due to its high durability and resilience, concrete is incredibly easy to maintain, often lasting for many decades without reconstruction work being needed. Due to its renowned strength, insurance costs for buildings or other structures made from concrete will be relatively low in comparison to buildings made from other, more fragile or combustible materials. The low cost, together with the durability that concrete provides, makes it a highly popular material within the construction industry.

Concrete is versatile

Despite being strong, sturdy and incredibly resilient when hardened, concrete can be adapted and moulded into several shapes and forms. As well as this, concrete is also available in a variety of textures, each offering different finishes. Whether you'd like a smooth or decorative surface, concrete can provide optimum versatility, making it the perfect building material.