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Cement and concrete as an engineering material: An historic appraisal and case study analysis

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ABSTRACT

Today, second only to water, concrete is the most consumed material, with three tonnes per year used for every person in the world. Twice as much concrete is used in construction as all other building materials combined. There is little doubt that concrete will remain in use as a construction material well into the future. However, with such extensive use of the material, discovery of any shortcoming or problem associated with concrete or reinforced concrete structures will become a matter of considerable public concern – both from a safety perspective and associated costs of rectification. Accordingly, this paper will initially review the historic development of cements and concrete and will then focus on the mechanical response of concrete and reinforced concrete to its working environment. At appropriate points within the narrative, case study input will be used to illustrate or highlight principal themes.

1. Introduction

There is a general lack of understanding of the difference between cement and concrete, with the two terms often used interchangeably. However, cement is actually an ingredient of concrete and can be considered the 'glue' that binds aggregates together to form concrete. Therefore, concrete is basically a mixture of aggregates and paste – the aggregates being sand and gravel or crushed stone; the paste being water and Portland cement. Portland cement is not a brand name it is the generic term for the type of cement used in virtually all concrete, just as stainless is a type of steel. Cement will constitute 10 to 15 percent of the concrete mix by volume and, through a process of hydration the cement and water harden and bind the aggregates into a rocklike mass. This hardening process will continue for years implying that concrete will get stronger as it gets older.

Varying the mix of cement, sand and aggregate used in a concrete blend enables its use in a range of applications. Construction of a typical family home will require 14 tonnes of cement, a kilometre of motorway will contain as much as 2,500 tonnes of cement, and a building can be made to last for 100 years. Products can be designed, coloured and shaped to accommodate a variety of environmental conditions, architectural requirements and to withstand a wide range of loads, stresses and impacts.

Today, second only to water, concrete is the most consumed material, with three tonnes per year used for every person on earth [1]. Twice as much concrete is used in construction as all other building materials combined. There is little doubt that concrete will remain in use as a construction material well into the future. However, with such extensive use of the material,

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discovery of any shortcoming or problem associated with concrete or reinforced concrete structures will become a matter of considerable public concern – both from a safety perspective and associated costs of rectification. Accordingly, this paper will initially review the historical development of cements and concrete and will then focus on the mechanical response of concrete and reinforced concrete to its working environment. At appropriate points within the narrative, case study input will be used to illustrate or highlight salient themes.

2. Cement and concrete

'Cement' is a generic term that can be applied to all binder materials. From earliest times, builders have used binders in conjunction with rock and stone to form more stable structures. Simple mud was employed as a binder, and is still in use in parts of the world today. In the days of early civilisations of Egypt, Greece and Rome, a lime cement was made by a process of 'burning limestone' to give Quicklime [2,3]. When mixed with water, quicklime formed slaked lime (calcium hydroxide) and, when mixed with more water to form a paste (now a lime mortar), slaked lime slowly hardened by reacting with carbon dioxide in the air to form calcium carbonate – or chalk. This production process is one of the oldest in the chemical industry, the reactions of which are described as:

1. Calcining or burning of chalk/limestone to produce quicklime

$$CaCO_3 + HEAT = CaO + CO_2$$

2. Hydration or slaking of quicklime to produce hydrated lime

$$CaO + H_2O = Ca(OH)_2$$

3. Carbonation of hydrated lime to produce calcium carbonate.

$$Ca(OH)_2 + CO_2 = CaCO_3$$

2.1. Hydraulic cement

In contrast to lime mortars that harden by the action of carbon dioxide, the Greeks and Romans also developed cements that harden by reacting chemically with water – hydraulic cements – that, once hardened, form a product unaffected by further water contact. In particular, these civilisations discovered that when mixing a volcanic material (Pozzolana) and burnt brick with quicklime, the resultant cement was of far superior quality than simple lime mortars [2]. Known as Roman cement, these mortars set slowly, attained a much higher ultimate strength when cured in water than air, and became extremely hard. The hydraulic setting reaction of Roman cement is a testament to its quality as demonstrated by the many examples of Roman brickwork still standing today (Fig. 1).

The knowledge of making hydraulic cements was lost with the fall of the Roman Empire. It was not until the mid-eighteenth century before hydraulic cement was rediscovered by John Smeaton (1724–1792), a civil engineer commissioned by the Royal Society to rebuild the Eddystone lighthouse over a four year period in 1755–59 (Fig. 2). Smeaton began experimenting with cementitious materials that would harden (and stay hard) in severe marine conditions, and that would set and develop some strength in the twelve hour period between successive high tides. He found that the best water-resistant hydraulic cements were obtained by burning limestone with considerable quantities of clay. However, the discovery of cement used today was still some years away.

Fig. 1. The Colosseum or Coliseum, origionally the Flavian Amphitheatre, in the centre of the city of Rome.