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ABSTRACT

Data from new experiments and from work published during the past 40 years are subjected to regression analysis to determine the relationship between strength and the composition and fineness of cement. The original authors differed in their opinions on the relative importance of C_3S* and C_3A. The controversy is examined against a background of experience with a group of materials that are representative of Portland cement in general, and in terms of an analysis based on a model in which, during the first weeks of hardening, the strength developed by C_3S depends on the proportion of C_3A in the cement.

Die Daten neuer Versuche und in den letzten 40 Jahren veröffentlichter Arbeiten werden der Regressionsanalyse unterworfen, um die Beziehung zwischem der Festigkeit und der Zusammensetzung und Feinheit des Zements zu bestimmen. Die ursprünglichen Verfasser sind verschiedener Meinung über die relative Bedeutung von C_3S und C_3A. Die Streitfrage wird aufgrund der Erfahrung mit einer Gruppe von Materialien, typisch für Portlandzement, allgemein untersucht und analysiert an einem Modell, in dem die, in den ersten Wochen des Abbindens entwickelte Festigkeit von C_3S, von dem C_3A-Anteil im Zement abhangt.

*In abbreviated formulas: C=CaO, $A=Al_2O_3$, $F=Fe_2O_3$, $S=SiO_2$.

Introduction

Over the years, many laboratories throughout the world have studied the relationship between strength and the composition and fineness of Portland cement. Information is available from experiments in which each of the cement compounds is examined individually, as in the classical work of Bogue and Lerch (1), which is widely quoted in the standard texts of reference. However, the method which is most commonly used is to determine the strength, composition and fineness for a range of cements and to subject the data to regression analysis. Extensive investigations along these lines have been carried out in, for example, the United States, where the work of Gonnerman (2), Gonnerman and Lerch (3), and Blaine, Arni and DeFore (4) covers the wide variety of cements that have been manufactured, at one time or another, during the present century. Interest continues to be shown in this approach, and several publications along these lines have appeared in recent years (4, 5, 6).

Despite the attention given to the subject, some of the most vital issues remain unresolved. For example, from the viewpoint of concrete strength, the importance of C_3A relative to that of C_3S is still a matter for controversy (5). It is with this issue in particular that the present investigation is concerned.

From an examination of published evidence it appears that a great deal of the uncertainty in this area can be traced to two causes, namely, working with a range of materials that is not representative of Portland cement in general, and basing the regression analysis on an unsuitable model. It is the purpose here to present evidence from a study in which particular attention has been given to minimising errors from these sources.

In this investigation, errors attributable to biased sampling are reduced by working with the combined data from new experiments and from studies published during the last 40 years. The data are for 228 cements, and the results of 16,400 strength tests on these materials are used in the regression analysis. Regarding the second cause of uncertainty, the approach adopted is to explore the limitations of the model that is traditionally employed in this field of research, and then to repeat the analysis using what is believed to be a more realistic model of the way in which the various cement compounds contribute to the strength of concrete.

The Cements

The data for the present analysis are taken from a number of independent studies, each based on a different group of cements. The main characteristics of these cements are as follows:

GROUP A: The 71 cements used by Gonnerman (2) which were produced by the Portland Cement Association Fellowship at the U.S. Bureau of Standards during 1930-33. The range of compositions was purposely expanded beyond that of normal Portland cement, but the range of fineness is narrow, since each cement was ground to the same residue on 200 mesh sieve. Thus the coefficient of variation for surface area is only one third of the average for series B to E. The SO_3 content is constant at 1.8 percent.

GROUP B: This comprises 50 cements of known composition which were part of the "series 73" studied by Gonnerman and Lerch (3). These cements were manufactured in the United States during 1916-1950. In this group, SO_3 is constant at 1.75 percent, C_3A is almost constant at 10.2 percent with a standard deviation of only 1.1 percent, and there is a strong association between C_3S and surface area (correlation coefficient (R) of 0.75).

GROUP C: The twenty "series 308" cements used by Gonnerman and Lerch (3), manufactured in 1940, and representing the five types of cements specified in ASTM C 150-40T.

GROUP D: The 23 non-air-entraining cements used in the long term study conducted by the Portland Cement Association (7).

GROUP E: Consists of 64 commercial Portland cements produced in Australian factories during 1965-70. Alexander, Taplin and Wardlaw (5) have studied 30 of these cements, and the remainder are new materials used in the present investigation.

Although the results for each of the groups A-E were analysed separately, most of the analytical work reported here was done on composite series in which the data were combined, and in which the C_3A content of the cements was limited to a maximum of 14.0 percent. The need for this limit is illustrated by the data for 28-day and 1-year strengths of group A concretes (Fig. 1). Over the range 0 to 14 percent C_3A, strength increases linearly with C_3A*, and the two variables are strongly associated. At 28 days, for example, the correlation coefficient is .80. At higher C_3A, strength decreases with increasing C_3A, the rate of decrease being greater at 1 year.