

**Composition
and
Properties of
Concrete**

COMPOSITION AND PROPERTIES OF CONCRETE



Composition and Properties of Concrete

GEORGE EARL TROXELL

*Professor of Civil Engineering
University of California*

HARMER E. DAVIS

*Professor of Civil Engineering
University of California*

With Chapters on
Proportioning of Concrete Mixtures
and Strength of Concrete

McGRAW-HILL BOOK COMPANY, INC.

New York Toronto London

1956

7

K17-118

COMPOSITION AND PROPERTIES OF CONCRETE

Copyright © 1956 by the McGraw-Hill Book Company, Inc. Printed in the United States of America. All rights reserved. This book, or parts thereof, may not be reproduced in any form without permission of the publishers.

Library of Congress Catalog Card Number 56-8870

PREFACE

Today, more than ever before, the civil engineer is required to give thought and time to the problems of concrete making and utilization. The results accomplished in the field by the construction engineer and the concrete inspector depend upon their knowledge of concrete and of the materials from which it is made. Satisfactory designs of structures are dependent to a considerable extent upon the familiarity of the design engineer with the desirable and the undesirable characteristics of concrete.

The beginner may feel somewhat perturbed on undertaking his study of concrete because seemingly indefinite factors in the manufacturing process apparently tend to yield a product of somewhat indefinite properties. Be it said, however, that improved methods of testing and inspection are resulting in the control of the qualities of concrete within more and more well-defined limits.

Although the rapid advance during the last three decades in the use and knowledge of concrete has made a detailed study of this material quite extensive, there are certain simple principles which have been developed and which can be set down for the guidance of the beginner.

This text and manual is designed as a guide to the student in a comprehensive course in the study of plain concrete. Part I is a descriptive text in which sufficient information is provided so that he can intelligently understand the many factors having a bearing on the proportioning, production, testing, and control of plain concrete. Much of this information has appeared in publications of various technical societies and associations but has been selected and condensed here to make it more useful to the student. It may well serve as a guide to the practicing engineer in selecting and using the cement, fine aggregate, coarse aggregate, and admixtures for a given structure. It covers the proportioning and mixing of these materials, as well as the placing and curing of the concrete, to produce a finished product of suitable and predictable quality and economy.

Several chapters are devoted to the properties of concrete, their significance, and how they are affected by the many steps involved in the fabrication of the product. Attention is given not only to ordinary concrete as used in building and highways made of ordinary aggregates

but also to the problems involved in mass concrete, lightweight and heavyweight concrete, and other special concretes.

Competent inspection is essential for the attainment of the best results. Hence the problems of the inspector and information on the usual records that he must keep are included.

Part II comprises instructions for tests that have been selected to illustrate as efficiently as possible the most important facts and principles connected with the use of cement, aggregate, and concrete.

It is intended that by his laboratory work the student will become familiar with the nature and properties of concrete as well as with the methods of testing cement, aggregate, mortar, and concrete. By following the instructions given herein and by referring to published standards, he should gain familiarity with current specifications for cement and concrete. Through a study of his test results, supplemented by a study of data given in the text, he should come to recognize the properties of these materials and to distinguish between satisfactory and defective samples. It is hoped that by the combination of these exercises he will acquire a thorough understanding of the factors which contribute to the production and control of quality concrete. By summarizing his work in written form, the student will obtain practice in the formulation of engineering reports.

Appendix I is a list of references, classified by subject. Brief comments indicating the scope and content of a work are given under some of the items. Throughout the text, references to sources of data or suggestions as to material for further study are made by use of numbers in brackets, which numbers refer to the corresponding bibliographical item listed in Appendix I. Reference to ASTM specifications and methods of testing are made by indication of the ASTM Serial Designation in brackets.

This work includes information from many sources, and the authors have endeavored to give credit where it is due. Special acknowledgment is given to the Portland Cement Association, the American Concrete Institute, the American Society for Testing Materials, and the U.S. Bureau of Reclamation for permission to use material from their publications.

GEORGE EARL TROXELL
HARMER E. DAVIS

CONTENTS

PART I. COMPOSITION AND PROPERTIES OF CONCRETE

CHAPTER 1. THE NATURE OF THE PROBLEM	3
1.1. Composition of Concrete	3
1.2. Functions of the Paste and Aggregate	4
1.3. General Proportions of Ordinary Concretes	5
1.4. Influence of Quality of Paste upon Properties of Concrete	7
1.5. Concrete Making	7
CHAPTER 2. CONCRETE-MAKING MATERIALS—PORTLAND CEMENT	10
2.1. Cementing Materials	10
2.2. Portland Cement	10
2.3. Manufacture of Portland Cement	11
2.4. Elementary Composition of Cement	13
2.5. Compound Composition of Cement	14
2.6. Influence of Composition upon Characteristics of Portland Cement	16
2.7. Influence of Cement on Durability of Concrete	17
2.8. High-early-strength Cement	18
2.9. Fineness of Cement	19
2.10. Setting and Hardening	22
2.11. Soundness	24
2.12. Strength	25
2.13. Heat of Hydration	26
2.14. Current Types of Portland Cement	30
2.15. Acceptance Tests and Specification Requirements	30
2.16. Slag Cements	30
2.17. Portland Blast-furnace-slag Cement	30
2.18. Masonry Cements	31
CHAPTER 3. AGGREGATES	33
3.1. Preliminary Remarks	33
3.2. General Characteristics	34
3.3. Data Needed for Proportioning Mixtures	35
3.4. Specific Gravity	37
3.5. Unit Weight and Voids	39
3.6. Moisture and Absorption	45
3.7. Gradation	47
3.8. Sieve Analyses	48
3.9. Grading Charts	53
3.10. Maximum Size of Aggregate	54

3.11. Grading Requirements	56
3.12. Quality Requirements	58
3.13. Deleterious Substances	58
3.14. Reactive Aggregates	60
3.15. Handling and Storing Aggregates	63
CHAPTER 4. WATER, ADMIXTURES, AND MISCELLANEOUS MATERIALS	65
4.1. Mixing Water	65
4.2. Water for Washing Aggregates	66
4.3. Water for Curing Concrete	66
4.4. Types of Admixtures	66
4.5. Workability Admixtures	67
4.6. Air-entraining Agents	68
4.7. Gas-forming Agents	70
4.8. Accelerators and Antifreeze Agents	70
4.9. Retarders	72
4.10. Pozzolanic Materials	72
4.11. Curing Aids	73
4.12. Miscellaneous Materials	74
4.13. Steel Reinforcement	74
CHAPTER 5. PROPERTIES OF FRESH CONCRETE	76
5.1. Workability and Consistency	76
5.2. Measures of Consistency: The Slump, Flow, and Ball Tests	77
5.3. Measure of Workability: The Remolding Test	81
5.4. Bleeding, or Water Gain	83
5.5. Preset Subsidence, or Setting Shrinkage	83
5.6. Effect of Entrained Air on Properties of Fresh Concrete	84
5.7. Measurement of Entrained Air in Fresh Concrete	84
5.8. Unit Weight, Cement Content, and Yield of Fresh Concrete	86
5.9. Determination of Composition of Fresh Concrete	87
5.10. Temperature of Fresh Concrete	88
5.11. Stiffening and Set of Fresh Concrete	88
5.12. Lateral Pressure of Fresh Concrete on Forms	89
CHAPTER 6. PROPORTIONING OF CONCRETE MIXES	91
6.1. General	91
6.2. Methods of Expressing Proportions	92
6.3. Review of Aggregate-Paste Relationships	94
6.4. Variables in Proportioning	96
6.5. Trial Method of Proportioning	97
6.6. Mix Adjustments	101
6.7. ACI Method of Proportioning	102
6.8. ACI Method for Small Jobs	109
6.9. Arbitrary Proportions	110
6.10. Proportioning by Maximum Density of Aggregate	111
6.11. Proportioning by Surface Area of Aggregate	112
6.12. Proportioning by Fineness Modulus of Aggregate	112
6.13. Proportioning by Voids-Cement Ratio and Mortar Voids	114
CHAPTER 7. MANUFACTURE OF CONCRETE	118
<i>Batching</i>	
7.1. Batching	118

CONTENTS

7.2. Weight-batching Equipment	118
7.3. Checking Weighing Equipment	121
7.4. Volumetric Batching Equipment	122
7.5. Batching Cement	122
7.6. Irregularities in Batching	122
7.7. Water-measuring Equipment	123
<i>Mixing</i>	
7.8. Mixing	124
7.9. Types of Mixers	124
7.10. Time of Mixing	125
7.11. Mixer Efficiency	126
7.12. Hand Mixing; Retempering	127
7.13. Ready-mixed Concrete	128
<i>Conveying</i>	
7.14. Conveying	129
7.15. Batch Containers	132
7.16. Pump and Pipeline	132
7.17. Pump Sizes	135
7.18. Cleaning the Concrete Pump	136
7.19. Pneumatic Method	136
7.20. Chutes and Belts	137
CHAPTER 8. PLACING AND CURING CONCRETE	139
8.1. Preparations for Placing	139
8.2. Placing	141
<i>Compaction</i>	
8.3. Compaction	144
8.4. Hand Tamping	144
8.5. Vibrators	145
8.6. Vibrator Efficiency	145
8.7. Concrete Mix for Vibratory Compaction	146
8.8. Proper Use of Vibration	147
<i>Curing</i>	
8.9. The Curing Period	148
8.10. Curing Methods	148
8.11. Curing of Pavements and Other Structures	149
8.12. Curing Temperatures	151
8.13. Steam Curing	152
8.14. Concrete Work during Cold Weather	153
8.15. Calcium Chloride in Concrete during Cold Weather	156
8.16. Concrete Work during Hot Weather	157
8.17. Curing in the Laboratory	159
<i>Operations after Curing</i>	
8.18. Removal of Forms	160
8.19. Patching	162
8.20. Prevention of Damage	163
CHAPTER 9. FORMS FOR CONCRETE	165
9.1. Requirements of Forms	165
9.2. Form Pressures	165
9.3. Form Ties	167

9.4. Construction of Forms	169
9.5. Metal Forms	169
9.6. Oiling of Forms	169
9.7. Absorptive Form Linings	170
9.8. Precast Concrete Forms	170
9.9. Plaster Waste Molds	171
CHAPTER 10. STRENGTH OF CONCRETE	172
10.1. Properties of Hardened Concrete	172
<i>Significance of Strength</i>	
10.2. Resistance to Applied Forces	172
10.3. Strength as a Measure of General Quality	173
10.4. Nature of Strength	173
<i>Kinds of Strength</i>	
10.5. Compressive Strength	176
10.6. Tensile Strength	177
10.7. Flexural Strength	178
10.8. Shear Strength	178
10.9. Bond with Reinforcement	179
<i>Factors Affecting Strength</i>	
10.10. Effect of Component Materials	180
10.11. Effect of Proportions	182
10.12. Effect of Curing Conditions	182
10.13. Effect of Loading Conditions	186
<i>Factors Affecting Results of Strength Tests</i>	
10.14. Specimens vs. Structures	187
10.15. Effect of Size and Shape of Specimen	189
10.16. Effect of Conditions of Casting	191
10.17. Effect of Moisture Content of Specimen	191
10.18. Effect of Temperature of Specimen	191
10.19. Effect of Bearing Conditions	192
10.20. Effect of Rate of Loading	193
CHAPTER 11. PERMEABILITY AND DURABILITY	197
<i>Permeability</i>	
11.1. Pore Structure of Concrete	197
11.2. Significance of Permeability	197
11.3. Permeability Tests	198
11.4. Factors Affecting Watertightness	199
11.5. Effect of Water and Cement	199
11.6. Effect of Aggregates	199
11.7. Effect of Curing	199
11.8. Effect of Admixtures and Coatings	201
11.9. Uniformity of Concrete	202
11.10. Absorption	203
<i>Durability</i>	
11.11. Deterioration of Concrete	203
11.12. Weathering	203
11.13. Weathering Resistance as Affected by Aggregate, Cement, and Water	204
11.14. Air-entrained Concrete	207
11.15. Freeze-thaw Tests	208
11.16. Reactive Aggregates	210

11.17. Sulfate Waters	212
11.18. Leaching	213
11.19. Chemical Attack	215
11.20. Wear	222
11.21. Restoration of Disintegrated Concrete	224
CHAPTER 12. VOLUME CHANGES AND CREEP	228
12.1. Types of Volume Change in Concrete	228
12.2. Significance of Volume Changes and Creep	229
12.3. The Gel Structure as Related to Volume Changes	229
12.4. Shrinkage of Fresh Concrete	230
12.5. Autogenous Volume Changes	230
<i>Shrinkage and Expansion Due to Moisture Changes</i>	
12.6. Factors Affecting Shrinkage and Expansion	232
12.7. Effect of Composition and Fineness of Cement	232
12.8. Effect of Type and Gradation of Aggregate	235
12.9. Effect of Cement and Water Contents	236
12.10. Effect of Admixtures	238
12.11. Effect of Age at First Observation	239
12.12. Effect of Moisture and Temperature Conditions	239
12.13. Effect of Duration of Tests	240
12.14. Effect of Size and Shape of Specimen	241
12.15. Effect of Absorptiveness of Forms	242
12.16. Effect of Reinforcement	243
12.17. Prepacked Concrete	243
12.18. Thermal Volume Changes	244
<i>Creep of Concrete</i>	
12.19. Factors Affecting Creep	245
12.20. Effect of Stress and Age When First Loaded	245
12.21. Effect of Water-Cement Ratio and Mix	247
12.22. Effect of Composition and Fineness of Cement	248
12.23. Effect of Character and Grading of Aggregate	248
12.24. Effect of Moisture Conditions of Storage	249
12.25. Effect of Size of Mass	250
12.26. Creep in Axial Tension and Compression	250
12.27. Creep Recovery	251
12.28. Reinforced-concrete Columns under Sustained Loads	251
CHAPTER 13. OTHER PROPERTIES	254
<i>Elastic Properties of Concrete</i>	
13.1. Modulus of Elasticity	254
13.2. Methods for Determining Moduli of Elasticity	254
13.3. Effect of Method of Test on Modulus of Elasticity	257
13.4. Effect of Characteristics of Concrete on Modulus of Elasticity	259
13.5. Relationship of Modulus of Elasticity to Strength	261
13.6. Effect of Type of Loading on the Modulus of Elasticity	261
13.7. Sustained Modulus of Elasticity	262
13.8. Significance of Poisson's Ratio	262
13.9. Factors Affecting Poisson's Ratio	262
<i>Thermal Properties</i>	
13.10. Thermal Conductivity	263
13.11. Condensation as Related to Thermal Conductivity	264

13.12. Thermal Properties and Their Relationships	265
13.13. Temperature Rise in Mass Concrete	267
<i>Extensibility and Cracking; Fire Resistance; Unit Weight</i>	
13.14. Cracking of Concrete	271
13.15. Extensibility and Cracking	271
13.16. Thermal Stress and Cracking	274
13.17. Fire Resistance	276
13.18. Unit Weight	278
 CHAPTER 14. SPECIAL TYPES OF CONCRETE	 280
14.1. Architectural Concrete	280
<i>Floor Surfaces</i>	
14.2. Types and Requirements	281
14.3. Preparation of Base	281
14.4. Concrete Mix	282
14.5. Placing and Finishing	282
14.6. Curing and Protection	283
14.7. Surface Hardeners	283
<i>Sprayed Mortar: Gunite and Shotcrete</i>	
14.8. Use and Limitations	284
14.9. Equipment	285
14.10. Preparation of Base	285
14.11. Sand	286
14.12. Rebound	286
14.13. Mortar Mix	286
14.14. Mixing and Placing	287
14.15. Curing	288
<i>Mass Concrete</i>	
14.16. Characteristics of Mass Concrete	288
14.17. Special Treatment of Mass Concrete	288
14.18. Effect of Temperature and Other Variables on Properties of Mass Concrete	289
<i>Miscellaneous Concretes</i>	
14.19. Concrete Placed under Water	290
14.20. Vacuum Concrete	292
14.21. Heavyweight Concrete	292
14.22. Lightweight Concrete	293
14.23. Grouting without Pressure	295
14.24. Pressure Grouting	296
14.25. Grouted Concrete	297
 CHAPTER 15. INSPECTION.	 299
15.1. Need for and Scope of Inspection	299
15.2. Inspection Organization	300
15.3. Qualifications of the Inspector	301
15.4. Responsibility	302
15.5. Inspector Training	302
15.6. Relations with Superior Officers	303
15.7. Relations with the Contractor	303
15.8. Authority of the Inspector	305
15.9. Specification Is Inspector's Guide	306

15.10. Inspection before Concreting	306
15.11. Inspection of Concreting	307
15.12. Inspection after Concreting	307
15.13. Concrete Samples for Tests	307
15.14. Molding Specimens	308
15.15. Storing and Shipping Specimens	308
15.16. The Field Laboratory	309
CHAPTER 16. INSPECTION RECORDS AND REPORTS.	312
16.1. General Comments	312
16.2. Batching and Mixing Record	313
16.3. Record of Materials	313
16.4. Record of Placing and Curing	314
16.5. Daily Reports	314
16.6. Diary	315
16.7. Photographs	315
16.8. Summary Report	316
CHAPTER 17. ANALYSIS AND PRESENTATION OF DATA.	318
17.1. The Problem of Transmission of Information	318
17.2. Variations in Data	319
17.3. Grouping of Data	319
17.4. Central Tendency	321
17.5. Dispersion	321
17.6. Probable Error	323
17.7. Limits of Uncertainty of an Observed Average	325
17.8. Number of Tests to Obtain a Desired Accuracy	327
17.9. Significant Figures to Retain in Presenting Test Results	327
17.10. Statistical Summaries	328
17.11. Tables	328
17.12. Figures	329

PART II. INSTRUCTIONS FOR LABORATORY WORK

GENERAL INSTRUCTIONS	335
Test 1. Normal Consistency and Time of Set of Portland Cement	338
2. Strength of Type I Portland Cement and Type III High-early-strength Cement Mortars at Various Ages	341
3. Effect of Curing Conditions upon Compressive Strength of Portland- cement Mortars	345
4. Sieve Analysis of Concrete Aggregates	347
5. Specific Gravity, Unit Weight, Moisture Content and Absorption of Concrete Aggregates	350
6. Characteristics of Fresh Concrete	356
7. Effect of Water-Cement Ratio upon Compressive Strength and Con- sistency of Concrete of Uniform Mix	359
8. Effect of Water-Cement Ratio upon Compressive Strength Cement Factor, and Cost of Concrete of Uniform Consistency	363
9. Trial-mix Proportioning of Concrete	366
10. Concrete-mix Proportioning by ACI Calculation Method	368
11. Adjustment of Concrete Mix to Give Desired Cement Factor or Water- Cement Ratio at Constant Consistency	369

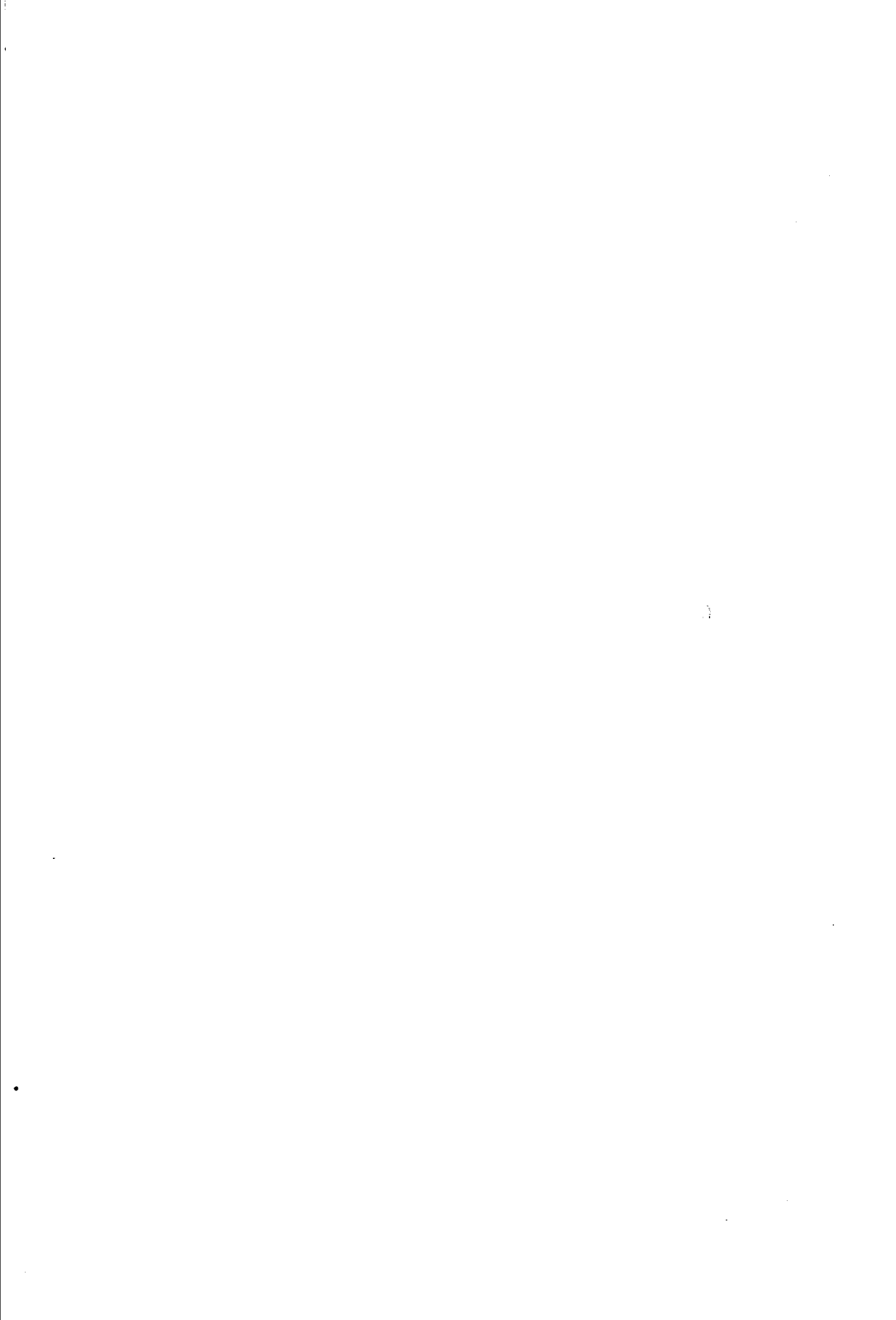
12. Adjustment of Concrete Mix to Produce a Given Change in Consistency	371
13. Effect of Capping Materials and End Conditions before Capping upon Compressive Strength of Concrete Cylinders	373
14. Effect of Shape of Test Specimen upon Indicated Compressive Strength of Concrete	375
15. Demonstration of Entrained Air in Concrete.	377

APPENDIXES

A. Summary of Useful Values	379
B. Instructions on Operation of Testing Machines.	380
C. Procedure for Making the Slump Test	382
D. Procedure for Making the Flow Test.	383
E. Procedure for Making the Remolding Test	384
F. Procedure for Batching and Mixing Concrete and Molding Compression-test Cylinders	386
G. Procedure for Capping Compression Cylinders with Gypsum Compounds	388
H. Procedure for Capping Compression Cylinders with Sulfur Compound	389
I. Selected References and Specifications Pertaining to Plain Concrete.	391
INDEX	425

PART I

COMPOSITION AND PROPERTIES OF CONCRETE



CHAPTER 1

THE NATURE OF THE PROBLEM

1.1. Composition of Concrete. Concrete is a composite material which consists essentially of a binding medium within which are embedded particles or fragments of a relatively inert mineral filler. In portland-cement concrete the binder or matrix, either in the plastic or in the hardened state, is a combination of portland cement and water. The filler material, called "aggregate," is generally graded in size from a fine sand to pebbles or fragments of stone which, in some concretes, may be several inches in diameter.

In practical concrete mixtures, the over-all proportions of these principal components, the binder and the aggregate, are controlled by the

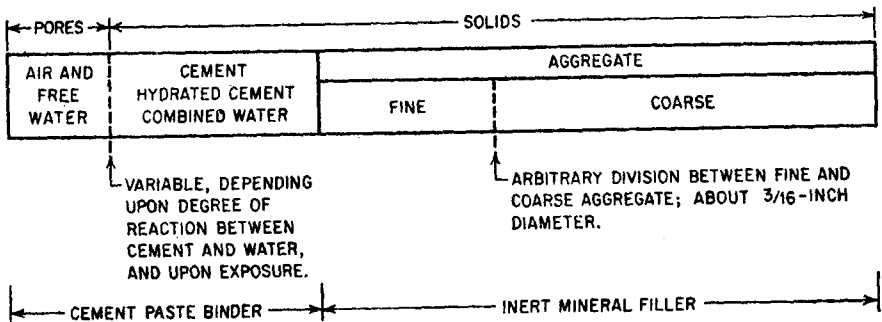


FIG. 1.1. Composition of concrete.

requirements that, (1) when freshly mixed, the mass be workable or placeable, (2) when the mass has hardened, it possess strength and durability adequate to the purpose for which it is intended, and (3) cost of the final product be a minimum consistent with acceptable quality. A diagrammatic representation of the composition of concrete of the proportions used in construction is shown in Fig. 1.1.

The aggregate occupies roughly three-quarters of the space within a given mass. For convenience, particles smaller than about $\frac{3}{16}$ in. in diameter are designated as fine aggregate or sand. Natural coarse aggregates may consist of gravel or crushed stone. Other materials employed

as aggregates include slag, cinders, and artificial lightweight aggregates made of burned clay or shale.

The space not occupied by aggregate, roughly one-quarter of the entire volume of an average concrete, is filled with cement, water, and air voids. After concrete has been placed, even though it has been compacted with considerable thoroughness, some entrapped air remains within the mass. In a freshly made and compacted concrete of suitable proportions, the volume of unavoidably entrapped air is comparatively small, usually not over 1 or 2 per cent. For particular purposes, however, there has developed in recent years the practice of incorporating in the mixture special air-entraining agents, with the result that small air voids, amounting sometimes to several per cent of the volume of the mass, are distributed throughout the paste.

The solid portion of hardened concrete is composed of the mineral aggregate, some of the original cement, and a new product formed by combination of the remainder of the cement with some of the water. After any period, the amount of free water left depends upon the extent of combination of cement and water, and upon possible loss of water from the mass due to evaporation under drying conditions.

1.2. Functions of the Paste and Aggregate. The binder material, the cement-water paste, is the active component of concrete and has two main functions: (1) to fill the voids between the particles of the inert aggregates, providing lubrication of the fresh, plastic mass and water tightness in the hardened product, and (2) to give strength to the concrete in its hardened state. The properties of the hardened paste depend upon (1) the characteristics of the cement, (2) the relative proportions of cement and water, and (3) the completeness of chemical combination between the cement and water. This chemical process is often referred to as "hydration," although other processes are undoubtedly involved. Hydration of the cement requires time, favorable temperatures, and the presence of moisture. The period during which concrete is definitely subjected to favorable temperature and moisture conditions is known as the "curing" period. Curing periods varying from 3 to 14 days are commonly used on construction work. In the laboratory, a common curing period is 28 days. Adequate curing is essential for the production of quality concrete.

The aggregate has three principal functions: (1) to provide a relatively cheap filler for the cementing material; (2) to provide a mass of particles which are suitable for resisting the action of applied loads, abrasion, the percolation of moisture, and the action of weather; and (3) to reduce the volume changes resulting from the setting and hardening process and from moisture changes in the cement-water paste. The properties of concretes resulting from the use of particular aggregates depend upon