

Guifen Hunningtu
Peihebi Youhua Jiqi Xingneng

硅粉混凝土 配合比优化及其性能

丁琳 编著



中国计量出版社
CHINA METROLOGY PUBLISHING HOUSE

硅粉混凝土 配合比优化及其性能

丁 琳 编 著

中国计量出版社

图书在版编目(CIP)数据

硅粉混凝土配合比优化及其性能/丁琳编著.——北京:中国计量出版社,2007.7

ISBN 978-7-5026-2710-2

I. 硅… II. 丁… III. ①硅酸盐水泥—配合料—比例 ②硅酸盐水泥—性能 IV. TU528.59

中国版本图书馆 CIP 数据核字(2007)第 126661 号

内 容 提 要

本书系统、深入地论述了高性能硅粉混凝土配合比优化设计及硅粉混凝土的各种性能,重点介绍了水胶比和硅粉掺量等参数对硅粉混凝土的抗压强度、抗拉强度、超声波脉冲速度、抗渗性和抗冻性的影响,从而确定不同要求情况下硅粉的最优掺量。

本书可供土木工程专业的科研人员、工程技术人员、高等院校的教师及研究生、本科生参考使用。

中国计量出版社 出版

地 址 北京和平里西街甲 2 号(邮编 100013)

电 话 (010)64275360

网 址 <http://www.zgjl.com.cn>

发 行 新华书店北京发行所

印 刷 北京长宁印刷有限公司

开 本 850mm×1168mm 1/32

印 张 7

字 数 200 千字

版 次 2007 年 7 月第 1 版 2007 年 7 月第 1 次印刷

定 价 20.00 元

如有印装质量问题,请与本社联系调换
版权所有 侵权必究

前言

硅粉是一种高效的活性掺和料,能够显著提高混凝土的强度、抗渗性、抗冻性和耐久性。硅粉混凝土的特性得到人们的重视,硅粉混凝土被广泛应用到水利水电工程、建筑工程、公路工程和桥梁工程等。目前我国寒区水利工程亟需大量优质的材料以改善混凝土的抗冻性和耐久性。掺入硅粉是解决混凝土抗冻性和耐久性问题的有效措施之一。硅粉混凝土作为一种新型的高性能混凝土,适于在高寒地区的水利工程和公路路面工程的需要,其应用前景十分广阔。硅粉混凝土配合比优化的研究具有重要的学术意义、有着广泛的工程应用价值。

在使用硅粉混凝土时,首先需要进行混凝土配合比设计,以满足工程对混凝土性能的要求。同时根据不同地区的环境条件,合理地选择水泥等胶体品种、适宜的骨料(砂、石料)以及其他组成材料,包括掺和料与外加剂的选择。本书结合黑龙江省科技攻关等项目,采用试验的方法,研究了水胶比和硅粉掺量等参数对硅粉混凝土的抗压强度、抗拉强度、超声波脉冲速度、抗渗性和抗冻性的影响,从而确定不同要求情况下,硅粉的最优掺量。根据试验结果建立回归方程,以便于硅粉混凝土的配合比设计。主要进行了以下研究。

1. 通过对 $100\text{mm} \times 100\text{mm} \times 100\text{mm}$ 的立方体试块、 $150\text{mm} \times 150\text{mm} \times 150\text{mm}$ 标准试块和直径 100mm 、高 200mm 圆柱体试块硅粉混凝土抗压强度的试验分析,得到了 150mm 正方体标准试块的抗压强度小于 100mm 的正方体试块测得的抗压强度。直径 100mm 高 200mm 的圆柱体试块的抗压强度试验结果,较标准试块小很多。

对不同水胶比、不同硅粉掺量的混凝土抗压强度进行了讨论,研究结果指出:水胶比从 $0.2 \sim 0.45$ 时,掺入硅粉都能明显提高混凝土的抗压强度。硅粉掺量小于 25% 时,硅粉混凝土的抗压强度随着硅粉掺量的增加而增大,而当硅粉掺量超过 25% 后,再继续加入硅粉,硅粉混凝土的抗压强度反而下降,所以最优的硅粉掺量不是固定。

2. 采用试验的方法,评价了水胶比和硅粉掺量对混凝土抗拉强度的影响。掺入硅粉可以明显提高混凝土的劈裂抗拉强度和抗弯抗拉强度,但是过高掺量的硅粉会使混凝土劈裂抗拉强度和抗弯抗拉强度下降。在试验结果的基础上,建立了混凝土抗拉强度回归方程,通过公式计算结果与试验结果的比较,获得的公式结果比较精确。

3. 基于试验,研究了水胶比和硅粉掺量对硅粉混凝土抗渗性能的影响。研究表明:硅粉能够有效地提高混凝土的抗渗性,开始时混凝土抗渗性能随着硅粉掺量的增加而提高,当硅粉掺量为 12.5% 附近时,硅粉混凝土的抗渗性能最好,硅粉掺量再增加,抗渗性能反而下降。

4. 通过硅粉混凝土超声波测强试验,分析了水胶比和硅粉掺量的变化对超声波脉冲速度的影响。超声波脉冲速度随着硅粉掺量的增加而变慢,水胶比增大,超声波脉冲速度变慢,水胶比为 0.2 时,超声波脉冲速度最快。根据超声波脉冲速度试验结果建立了超声波脉冲速度的回归方程。方程可精确地计算超声波脉冲速度,最大相对误差仅 1%,最大绝对误差仅 51.3m/s 。

根据对超声波脉冲试验结果和抗压强度试验结果的对比分析,按水胶比分段给出了抗压强度的回归方程,对应不同的水胶比,硅粉混凝土抗压强度与超声波脉冲速度之间的相关方程是不同的。依据超声波脉冲速度拟合得到的硅粉混凝土抗压强度值精确,误差在实际工程允许范围内。

5. 通过试验探讨了水胶比和硅粉掺量对硅粉混凝土干缩性能的影响,硅粉混凝土初期收缩应变随着硅粉掺量增加而增大,当硅粉掺量为 10% 时,收缩应变达到最大值,如果硅粉掺量再增加,收缩应变迅速减小。混凝土的干缩变形主要发生在第 1 周以内,28 天附近试件干缩变形量基本稳定。

在进行硅粉混凝土干缩性试验分析的同时,研究了水胶比和硅粉掺量对混凝土重量损失的影响。得出了水胶比为 0.2 和 0.25 时,硅粉混凝土的重量损失较普通混凝土小。水胶比大于 0.3 时,硅粉混凝土的重量损失较普通混凝土大,且硅粉掺量为 10% 时,混凝土重量损失最大。

6. 为了分析外加剂、硅粉掺量和水胶比对混凝土抗冻性能的影响,进行了硅粉混凝土冻融试验研究。根据冻融试验结果,提出了抗

冻耐久性指数 DF 的回归方程。加入减水剂和引气剂能够在一定程度上提高混凝土的抗冻性能,但相对于硅粉掺量和水胶比,减水剂和引气剂对混凝土的抗冻性影响较小。加入硅粉可明显提高混凝土的抗冻性能。其中以硅粉掺量为 10% 的混凝土尤为明显,抗冻耐久性指数 DF 均大于 0.4;当水胶比为 0.3 和 0.35 时,抗冻耐久性指数 DF 大于 0.6。混凝土的抗冻性开始随着硅粉掺量的增加而提高,然后随着硅粉掺量的增加而降低。

Preface

Silica fume is a highly effective pozzolanic material due to its extreme fineness and high silica content. Silica fume have been used in concrete to improve its properties. It has been found that silica fume improves compressive strength, bond strength, frost resistance and abrasion resistance; reduces permeability and therefore helps in protecting reinforcing steel from corrosion. Silica fume concrete has been extensively used in regulations of water resources and hydropower engineering, construction engineering, highway engineering and bridge engineering. At present, regulations of water resources engineering in freezing regions in China need great deal of concrete which is permanent stability and frost resistance. Silica fume is used in concrete to improve permanent stability and frost resistance. Silica fume concrete is suitable for freezing regions. Silica fume concrete will be more extensively used in regulations of water resources and highway engineering in cold regions. Research on mix proportions of silica fume concrete has important theoretical meaning and can provide a basis for applications.

When silica fume concrete is used, mix design was made. At the same time, we should choose reasonably binder, sand, and coarse aggregate. In this paper, results of this comprehensive experimental investigation were analyzed for compressive strength, tensile strength, ultrasonic pulse velocity, permeability and frost resistance. The main objective of this investigation is determine the different effects silica fume has when added a partial substitute to Portland cement. The main contests and conclusions are listed as follows:

1. The compressive strengths are measured on three different types of specimens. The compressive strength of 150mm cubes standard specimen is lower than the compressive strength of 100mm cubes specimen. The compressive strength of 100mm × 200mm cylinder specimen is lower

than the standard specimen.

Extensive experimentation is performed to determine the isolated effect of silica fume on the properties of concrete over a wide range of water-to-binder ratios. On the basis of analysis of a large number of experimental results, silica fume incorporation can highly increase the compressive strength of concrete in the range of 0.2 ~ 0.45 water-to-binder ratio when silica fume content is beyond 25%. The compressive strength of concrete reduces with the increase of silica fume content over 25%.

2. Extensive experimentation is performed to research the effect of silica fume content and water-to-binder ratio on the split tensile strength of concrete. Silica fume content incorporation increases the split tensile strength of concrete. Very high percentages of silica fume do not significantly increase the split tensile strength, and the increase is almost insignificant beyond 15%. Silica fume incorporation also increases the flexural tensile strength of concrete. But the flexural strength will reduce if silica fume content is too much.

3. Based on tests results, water penetration of silica fume concrete is investigated. Silica fume incorporation can increase the water penetration of concrete. At the beginning, water penetration increases with the increases of silica fume content. Finally, water penetration reduces with the increases of silica fume content. The optimum silica fume replacement percentage for water penetration is near 12.5%.

4. Nondestructive testing is also performed to evaluate performance of concrete mixtures. The increased silica fume content results in reduced ultrasonic pulse velocity. On the other hand the increase in water content has led to an equivalent decrease in velocity values. In general, water-to-binder ratio of 0.2 showed the highest values of velocity. A model defining the relation between the ultrasonic pulse velocity and different factors affecting the performance of concrete is developed.

According to compressive strength and ultrasonic pulse velocity test results, Correlation between pulse velocity and compressive strength showed different trends depending on silica fume content. For all silica fume levels, nonlinear quadratic models describing the relation between

pulse velocity and compressive strength are obtained. The formula is very exact, and the Maximum error is acceptable.

5. Drying shrinkage increases with silica fume content up to 10% replacement level. However, with 15% silica fume the drying shrinkage registered at 28 day shows a different trend. The increase in shrinkage strain is major in the first week, and then it was almost stabilized until the age of 28 days.

In the range of 0.2 ~ 0.25 W/C , weight loss of silica fume concrete is lower than plain concrete. If water-binder-ratio is beyond 0.3, weight loss of silica fume concrete is higher than plain concrete. The maximum weight loss is obtained at a silica fume replacement of 10%. Less weight loss was observed for 15% silica fume concrete.

6. Antifreeze and superplasticizer incorporation can increase frost resistance of concrete. Compare to silica fume and water-binder-ratio, the effect of Antifreeze and superplasticizer on frost resistance of concrete is very little. Silica fume incorporation increases highly frost resistance of concrete. The optimum silica fume replacement percentage for s frost resistance is 10%. If silica fume is 10%, index of frost resistance DF is larger than 0.4. If water-binder-ratio is from 0.3 to 0.35, index of frost resistance DF is larger than 0.6. At the beginning, frost resistance of concrete increases with the increase of silica fume. Then, frost resistance of concrete reduces with the increase of silica fume.

目 录

前言	(I)
Preface	(IV)
1 现代土木工程与现代混凝土	(1)
1.1 土木工程的发展现状	(1)
1.2 现代混凝土的发展历程及在现代土木工程中的意义	(4)
1.3 混凝土的高强与超高强化	(6)
1.4 混凝土工程的耐久与超耐久化	(7)
1.5 现代混凝土与环境	(10)
2 高性能混凝土的制备途径与原理	(13)
2.1 高性能混凝土的定义	(13)
2.2 高性能混凝土的界定	(15)
2.3 制备高性能混凝土的技术途径与原理	(18)
2.4 高效减水剂的主导作用与减水机理	(20)
3 高性能混凝土中活性矿物掺料的重要效应	(25)
3.1 水化硅酸钙及其他水化物的强度	(25)
3.2 活性矿物掺料的火山灰反应和增强效应	(30)
3.3 活性矿物掺料的填充效应	(31)
3.4 活性矿物掺料的增塑效应	(32)
3.5 混凝土水化热与活性矿物掺料的温峰削减效应	(34)
3.6 活性矿物掺料的耐久性改善效应	(36)

3.7 活性矿物掺料的掺入方式	(38)
4 混凝土结构耐久性概述	(40)
4.1 混凝土结构耐久性的重要意义	(40)
4.2 国内外研究概况	(43)
4.3 影响混凝土结构耐久性的因素	(47)
4.4 混凝土结构耐久性研究的内容	(54)
4.5 混凝土结构耐久性损伤实例	(60)
5 高性能硅粉混凝土	(70)
5.1 国内外对硅粉混凝土的研究现状	(75)
5.2 本课题的意义	(80)
5.3 本课题研究的主要内容	(81)
6 硅粉混凝土及水胶比	(82)
6.1 硅粉混凝土的性能特点	(82)
6.2 硅粉在混凝土中的作用机理	(83)
6.3 硅粉混凝土的应用	(85)
6.4 水胶比对混凝土结构与性能的影响	(87)
6.5 本章小结	(94)
7 硅粉混凝土的强度和抗渗性	(96)
7.1 引言	(96)
7.2 硅粉混凝土的抗压强度的初步研究	(98)
7.3 硅粉混凝土的抗拉强度	(102)
7.4 硅粉混凝土的抗渗性	(113)
7.5 结果分析	(115)
7.6 本章小结	(116)
8 硅粉混凝土配合比	(119)
8.1 引言	(119)
8.2 硅粉混凝土砂率的选择	(125)

8.3	试验方案	(128)
8.4	试验结果分析	(130)
8.5	本章小结	(167)
9	硅粉混凝土抗冻性能研究	(169)
9.1	混凝土冻融破坏的机理	(169)
9.2	硅粉的作用机理	(171)
9.3	混凝土抗冻性试验方法	(171)
9.4	正交试验设计	(173)
9.5	试验结果与分析	(174)
9.6	本章小结	(184)
结论		(186)
参考文献		(189)

English Contents

Abstract (in Chinese)	(I)
Abstract (in English)	(IV)
1. Modern Civil Engineering and Modern Concrete	(1)
1.1 Present state of civil engineering development	(1)
1.2 The course of development of modern concrete and its significance in modern civil engineering	(4)
1.3 High strength and super high strength of concrete	(6)
1.4 Durability and super durability of concrete engineering	(7)
1.5 Modern concrete and environment	(10)
2. Preparation Ways and Principles of High Performance Concrete	(13)
2.1 Definition of high performance concrete	(13)
2.2 Identification of high performance concrete	(15)
2.3 Ways and principles of preparation of super high strength high performance concrete	(18)
2.4 The leading role of water reducing agents and mechanism of water reduction	(20)
3. Important Effects of Active Mineral Additives in High Performance Concrete	(25)

3.1	Strength of calcium silicate hydrates and other hydrates	(25)
3.2	Pozzolanic reactions and strengthening effect of active mineral additives	(30)
3.3	Filling effect of active mineral additives	(31)
3.4	Plasticizing effect of active mineral additives	(32)
3.5	Hydration heat of concrete and temperature peak reducing effect of active mineral additives	(34)
3.6	Durability improving effect of active mineral additives	(36)
3.7	Manners of addition for active mineral additives	(38)
4.	Introduction of Durability of Concrete Structure	(40)
4.1	The Significance of durability of concrete structures	(40)
4.2	General Survey	(43)
4.3	The influence factors on the durability of concrete structures	(47)
4.4	The research subjects on the durability of concrete structures	(54)
4.5	The damage examples on the durability of concrete structures	(60)
5.	High Performance Silica Fume Concrete	(70)
5.1	Background of this Dissertation	(75)
5.2	Research on Silica Fume Concrete	(80)
5.3	Meaning of this Dissertation	(81)
6.	Silica Fume Concrete and Water-binder-ratio	(82)
6.1	Characteristic of Silica Fume Concrete	(82)

6.2	Mechanism of Silica Fume	(83)
6.3	Applications of Silica Fume Concrete	(85)
6.4	Effect of Water-binder-ratio on Structures and Behavior of Concrete	(87)
6.5	Summary	(94)
7.	Strength of Silica Fume Concrete and Water Penetration of Silica Fume Concrete	(96)
7.1	Introduction	(96)
7.2	Compressive Strength of Silica Fume Concrete	(98)
7.3	Tensile strength of silica fume concrete	(102)
7.4	Water Penetration of Silica Fume Concrete	(113)
7.5	Result Analysis	(115)
7.6	Summary	(116)
8.	Silica Fume Content and Water to Enhance Performance of Concrete	(119)
8.1	Introduction	(119)
8.2	Selection of Sand Factor	(125)
8.3	Experimental Procedures	(128)
8.4	Test Result Analysis	(130)
8.5	Summary	(167)
9.	Research on Frost Resistance of Concrete with Silica Fume	(169)
9.1	Mechanism of Concrete Destruction during Freezing and Thawing Cycles	(169)
9.2	Mechanism of Silica Fume	(171)
9.3	Test methods of Frost resistance of Concrete	(171)
9.4	Orthogonal Test Design	(173)

9.5	Test Result Analysis	(174)
9.6	Summary	(184)
Conclusion		(186)
References		(189)

现代土木工程与现代混凝土

1.1 土木工程的发展现状

人类从古至今的发展都与土木工程密切相关,为解决居住问题,必须建造住房;为解决粮食问题,必须兴修大量的水利设施;为解决穿衣问题,除种植棉麻、植桑养蚕以外,必须兴建纺织企业,特别是现代人造纤维的发展,必须兴建规模宏大的化学纤维合成工厂;为解决人员流动及货物运输问题,必须兴建铁路、公路、港口、机场等设施。由此可见,土木工程与整个国民经济及人们生活息息相关,密不可分。

在历史上,我国曾兴建了大量的世界闻名的土木工程,体现了中华民族的智慧,如都江堰、长城、大运河、赵州桥、应县佛宫寺木塔、北京故宫等等。但这些工程基本以土、石、砖、木为建筑材料。

自从19世纪中叶以后,钢材及混凝土在土木工程中的应用,以及20世纪20年代后期预应力混凝土技术发展以来,钢材和混凝土在土木工程中的用量急剧增大。

随着土木工程规模不断扩大,科技水平不断提高,工程力学、结构科学与建筑材料科学的不断发展,使得土木工程技术取得了突破性、飞跃式的发展,这主要表现在工程量极大,技术难度极高的摩天大楼、超大跨桥梁及巨型水利枢纽工程的建设等方面。

(1) 超高层建筑及摩天大楼

随着城市规模不断扩大,人口不断增多,地价不断升高,建筑技术的不断进步,以及经济的高速发展,建筑物越来越向空中延伸,建