CHAO GAOQIANG
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国家自然科学基金“八五”重点项目
高校博士点科研基金资助项目

超高强
高性能混凝土

原理·配制·结构·性能·应用

SUPER HIGH STRENGTH
HIGH PERFORMANCE
CONCRETE

Principle · Preparation · Structure · Performance · Application

◎蒲心诚 著

重庆大学出版社

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内 容 摘 要

本书全面阐述了用常规原料及通用工艺研制 100～150 MPa 超高强高性能混凝土的制备技术途径及其基本原理，详述了这种混凝土的配制技术与配比参数，研究了超高强高性能混凝土水化产物的组成特点与孔结构、界面结构以及宏观结构的特征，讨论了这种混凝土的强度、变形及耐久性能，综述了超高强高性能混凝土的当前应用状态以及技术经济效益，以及未来应用前景。

本书适合于从事建筑材料研究的科研人员、高等院校的师生、商品混凝土企业、混凝土制品生产企业的工作人员，以及从事建筑工程设计与施工的工程师。

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序

混凝土是当今世界上用量最大的人造材料，由于原料丰富、价格低廉、制备简单、造型方便，相对耐久、耐火性好、维护费低等不可取代的优点，21 世纪仍将是最主要的建筑材料。2003 年我国水泥产量已达 8.25 亿吨，混凝土用量达 15 亿 m^3，均居世界首位，但混凝土应用的强度等级偏低。C40 及其以下的混凝土用量达 89.72%，占绝大多数；虽然近年来 C45 ~ C60 混凝土用量逐年增加，但至 2003 年也仅占总用量的 9.39%；C70 ~ C100 混凝土虽已有应用，但用量甚微，尚属起步；C110 ~ C150 的超高强混凝土则尚无真正意义上的应用。可见我国混凝土科技的发展水平尚处于相对滞后状态。

超高强高性能混凝土具有比强度高，负荷能力大，资源和能源消耗少、耐久性优异等优点，能满足土木与建筑工程轻量化、高层化、大跨化、重载化以及耐久化等诸多方面的要求，是混凝土科学与技术发展的主要方向。

过去，我国对超高强高性能混凝土的研究基本上未有涉及。但近 10 年来，蒲心诚教授及其合作者，依托国家自然科学基金及高校博士点科研基金的支持，对超高强高性能混凝土进行了持续地、卓有成效的研究工作，以常规的原材料及通用的工艺方法研制成功了强度达 100 ~ 165 MPa、流动性能优良的超高强高性能混凝土，并对这种混凝土的制备途径与基本原理、配制技术与配比参数、微观结构与宏观结构、强度性能与变形性能、收缩湿胀与耐久性能、应用现状与未来前景等诸多方面进行了系统的研究，取得了重要成就。

掺入高效活性矿物掺料是制成超高强高性能混凝土的必不可少的技术措施。蒲心诚教授提出的混凝土中活性矿物掺料火山灰效应的水泥用量比强度分析方法，不但可以准确地确定不同类别、不同来源的各种活性矿物掺料的活性，比较其活性的高低，而且还可以对其火山灰效应的历程与行为进行定量分析，并为混凝土的强度构成分析提供了工具。

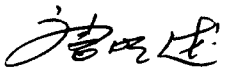
为了克服超高强高性能混凝土的高脆性，蒲心诚教授与其合作者，将超高强高性能混凝土与钢管复合，制成了承载能力极其巨大，变形性能十分优异的钢管超高强混凝土复合材料，可以用于千米高之超级建筑物之建造（研究者称之为千米承压材料）。可以预期，这种发挥了钢材及超高强混凝土两种材料的优点，克服了其缺点的钢管超高强混凝土复合材料，将能促进建筑结构材料及整个建筑科技的向前发展与

进步。

《超高强高性能混凝土》一书，总结了蒲心诚教授及其合作者近10年来在超高强高性能混凝土领域的研究成果，是一部系统论述超高强高性能混凝土的著作。在书中，作者对这种高强材料的诸多问题都提出了自己独特的见解。

《超高强高性能混凝土》一书的出版，将对混凝土科学与技术的进步与发展起到积极的促进作用。

鉴于这本书的意义，本人十分乐意为之作序。

中国工程院院士 

2004年11月

前　言

1992 年，国家自然科学基金委员会颁布了 1993 年度国家自然科学基金申报指南，其中列出了八五重点项目——超高强混凝土的结构及力学性态研究，指南要求研究 90 ~ 100 MPa 的超高强混凝土。该项目由基金委、铁道部、建设部、国家建材局联合资助，资助总金额 110 万元。作者（当时所在单位：重庆建筑大学）对此项目提出了申报并参加了答辩，后决定由清华大学（主持单位）、铁道科学研究院、中国建材研究院、重庆大学（原重庆建筑大学）共同承担。在分工中，作者承担项目中最高强度段（90 ~ 110 MPa）的研究工作，分配经费 20 万元。1 年后，该项目又更名为“高强与高性能混凝土的结构与力学性态研究”（59338120）。1999 年作者又申请到“超高强高性能混凝土的结构、力学性能及耐久性能研究”高校博士点基金项目（1999062002），资助金额 4 万元。在这两个项目的支持下，作者及合作者通过不懈努力，成功研究出 90 ~ 150 MPa 的超高强高性能混凝土，研究范围涉及到超高强高性能混凝土的诸多方面，取得了多项研究成果和重要进展。本书即是主要基于这两个项目的研究成果并综合相关文献资料写成的。

本书简述了现代混凝土与现代土木工程的密切关系；论述了进一步发展混凝土科学与技术的主要方向，即高强与超高强化和耐久与超耐久化；阐述了超高强高性能混凝土的制备途径与原理；详述了水化硅酸钙组成与强度性能，并基于此，阐述了高效活性矿物掺和料的火山灰反应对水化硅酸钙的组成改善与增强效应，以及活性矿物掺料的其他重要效应；提出了活性矿物掺料火山灰效应的比强度分析新方法，并以实例分析了超高强高性能混凝土的强度构成；然后，进一步讨论了以常规材料及通用工艺配制超高强高性能混凝土的具体方法，阐明了原材料及各种配比参数对超高强高性能混凝土强度及流动性的影响。为了使读者能从结构层次更深入地了解超高强高性能混凝土，本书详述了超高强高性能混凝土的水化产物组成特征，及其优异的孔结构，完美的界面结构和更为均匀的宏观结构；超高强高性能混凝土的强度性能和变形性能是这种材料获得应用的基本性能，本书讨论了超高强高性能混凝土的劈拉强度、抗弯强度、轴压强度、极限变形以及变形模量与抗压强度的关系，提出了相应的回归关系式，展示了超高强高性能混凝土的应力应变曲线特征，阐明了这种混凝土的高脆性。收缩是混凝土的基本属性，低水胶比的超高强高性能混凝土因水泥的水化进程引起的内部自干燥而产生的自收缩大增，增大了混凝土收缩开裂的可能性，但这并

不是不可解决的问题。本书详述了及时和良好的水养护、掺入膨胀剂及掺入减缩剂可以大幅度地减少超高强高性能混凝土的收缩值;讨论了超高强高性能混凝土各项耐久性指标极为优异的耐久性能,并比较了普通混凝土、高强混凝土与超高强混凝土的各项耐久性指标;作者认为,以普通混凝土建立起来的实验方法已不能适应超高强高性能混凝土的实验工作,应基于超高强高性能混凝土的特点,改进与建立新的试验方法。本书最后介绍了超高强高性能混凝土目前的实际应用情况及试用探索,论证了采用超高强高性能混凝土的经济性;基于超高强高性能混凝土的高脆性,作者提出了应用超高强高性能混凝土的最佳途径,即制成用超高强钢管约束的超高强混凝土的复合材料,并实际制成了混凝土强度达 164.9 MPa 的钢管超高强混凝土,其变形性能优异,承载能力极为巨大,用其可建造高度达千米以上的超级建筑,因此,作者将其称之为千米承压材料。讨论了超高强高性能混凝土及其千米承压材料的美好应用前景。

由于超高强高性能混凝土在国际上的研究不多,在国内总体而言,我们的研究也尚属起步,无论国际、国内,对许多问题的研究尚不够深入,特别是在结构工程中的应用研究,更是十分匮乏。作者期望更多的科技工作者能投入到这一研究领域里来,促进对超高强高性能混凝土更深入的认识与掌握,以期进一步促进超高强高性能混凝土在工程中的推广应用。

参加两个项目研究工作的有:严吴南教授、李立仁副教授以及作者的弟子们:王志军教授(博士后)、王冲讲师(博士)、王勇威(博士)、万朝均(博士)、谭克锋教授(博士);参加试验工作的有白光工程师、蒲怀京工程师、何桂实验师。作者对合作者们在研究工作中的辛勤工作和取得的成绩表示高度的赞赏,并致以衷心的谢意。特别感谢陈剑雄教授、蓝海研究员为作者提供的日文和德文文献,以及挪威埃肯公司北京代表处的赵筠工程师提供的珍贵资料。

由于作者学术水平有限,难免有疏漏甚至错误之处,敬请国内外专家批评指正。

蒲心诚

2004 年 11 月

Preface

In 1992, the National Natural Science Foundation Committee issued a guide for application to 1993 National Natural Science Foundation, where a key project for the eighth five-year plan, titled "Research on Structure and Mechanical Performances of Super-high Strength Concrete" was listed, and a study on 90 ~ 100 MPa of Super-high strength concrete was required. The Foundation Committee, Ministry of Railway, Ministry of Construction and the National Bureau of Building Materials sponsored jointly this project with total fund of RMB 1.1 million. The author (the affiliation at that time was Chongqing Jianzhu University) had applied to this project, then took part in the project defend. Finally, Tsinhua University (leading institution), the Research Institute of Railway, China Research Institute of Building Materials and Chongqing Jianzhu University had won jointly this project. This project has been divided into several parts and the author was in charge of the part to study the highest strength of concrete (90 ~ 110 MPa) with expense of RMB 0.2 million. One year later, this project was renamed as "Research on Structure and Mechanical Performances of High Strength and High Performance Concrete" (59338120). In 1999, the author had won the project of doctorate program fund from Ministry of Education with total expenses of RMB 40,000. Under the support from these two projects, the author and his colleague with great efforts succeeded in producing 90 ~ 150 MPa super-high strength high performance concrete. Their research work covered different aspects of the super-high strength high performance concrete and some success and important progress are gained. This monograph is based on the results of these two projects and review of related literature data.

In this monograph the close relationship between modern concrete and modern civil engineering is described in brief; the main direction of further development of concrete science and technology, that is to pursue high strength and super-high strength as well as durability and super-durability, is expounded; the preparation and principle of super-high strength high performance concrete are elaborated; the composition and strength performance of calcium silicate hydrates are described in detail, then the effect of pozzolanic reaction of active mineral additive on the strength and composition improvement of calcium sili-

cate hydrates and other effects of active mineral additives are elaborated; a new method of specific strength analysis for pozzolanic effect of active mineral additive is presented, the strength composition of super-high strength high performance concrete is analyzed with examples; then the method for preparation of super-high strength high performance concrete with ordinary materials and normal technology is discussed, the influence of raw materials and mix proportion parameters on the strength and flowability of super-high strength high performance concrete is expounded. In order to help the readers to understand the super-high strength high performance concrete deeply from the structural level, in this monograph, the composition characteristics of hydrates of super-high strength high performance concrete, their excellent pore structure, perfect interface structure and homogeneous macro structure are described in detail. The strength and deformation performances of super-high strength high performance concrete are the basic properties for their application, in this monograph, the relationship between compressive strength of super-high strength high performance concrete and its splitting strength, flexural strength, axial compressive strength, ultimate deformation and deformation modulus is discussed and the corresponding regression formula is presented; the character of stress-strain curve of super-high strength high performance concrete is demonstrated, which shows the high brittleness of such concrete. Shrinkage is the basic property of the concrete and the self-shrinkage of the super-high strength high performance concrete with low water cement ratio increases significantly due to internal self-drying caused by the hydration of the cement, leading to increase of possible shrinkage cracking, which is not an unsolvable problem. In this monograph, it is described that the shrinkage of super-high strength high performance concrete can be decreased in great degree by in time and good water curing, addition of expanding agent and shrinkage reducing agent. The author discussed the excellent durability of the super-high strength high performance concrete with its durability indexes, then these indexes are compared with those of ordinary and high strength concretes. The author suggests that the experimental methods based on ordinary concretes are not adapted to the experiments for super-high strength high performance concrete, they should be improved or new experimental methods should be setup according to the characteristics of super-high strength high performance concrete. Finally, in this monograph the application of super-high strength high performance concrete in practice and exploration for new use are introduced. The economical benefits from application of super-high strength high performance concrete are verified. Due to the high brittleness of super-high strength high performance concrete, the author presents an optimum way to use super-high strength high performance concrete, that is a composite material with super high strength concrete confined by super high strength steel tube, in practice, a steel tube super-high strength concrete with the strength of 164.9

MPa has been produced, which has excellent deformation performance and quite high bearing capacity, a kilometer super-high building could be built with such material. Therefore, the author called such material as kilometer compressive material. The bright future for application of super-high strength high performance concrete and kilometer compressive material is discussed.

There is a little has been done in the research of super-high strength high performance concrete in the world, in China, in general, our research work is just a start, there are many problems not studied deeply both at home and abroad, especially there is lack of the study on their application in structural engineering. The author hopes that more scientific and technical personnel are involved in this field of research to promote deeper understanding of super-high strength high performance concrete and its wide spreading in engineering.

Involved in these two projects are: Prof. Yan Wunan, Associate Prof. Li Liren and the pupils of the author: Prof. Wang Zhijun (post doctor), Lecturer Wang Cong (Doctor), Wang Yongwei (doctor), Wan Chaojun (doctor), Prof. Tan Kefeng (doctor); participants of the experimental works are: Engineer Bai Guang, Engineer Pu Huaijing, laboratory technician He Gui. The author highly appreciates and acknowledges the collaborators for their hard work and success in the research work. The special acknowledgement is given of Prof. Chen Jianxiong, research fellow Lan Hai for offering references in Japanese and German, and Engineer Zhao Jun, from Beijing representative of Eken Co., Norway for valuable information Thanks from the author are also given to Wang Cong and Wang Yong for pictures and editorial work in computer of the monograph.

Pu Xincheng
Nov, 2004

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