

# Construction of Civil Engineering Course Incorporating Carbon Reduction Concept

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## ABSTRACT

In the context of the global "double carbon" strategy, the civil engineering industry, as a key field of carbon emission, urgently needs to integrate the concept of sustainable development into its personnel training. Based on the course of civil engineering materials, this paper explores the deep integration path of its teaching system and the concept of carbon emission reduction. The research first clarified the core role of the course in talent cultivation, that is, it is not only the key link of professional knowledge teaching, but also an important platform for shaping engineering ethics and sustainable values. Furthermore, a new course system with "carbon footprint" analysis as the main line and the integration of cutting-edge content such as industrial solid waste recycling was constructed; The teaching innovation mode of "theory case practice" as the chain and emphasizing the feedback of scientific research on teaching is proposed to cultivate students' ability of low-carbon design and innovative application of materials. Teaching practice shows that the reform has significantly improved students' engineering literacy, scientific research ability and complex engineering problem-solving ability, and provided a replicable course paradigm for the green development of civil engineering majors.

## KEYWORDS

Carbon emission reduction; Civil engineering materials; Course construction; Teaching reform; Industrial solid waste; Sustainable development

## 1 Introduction

With the promotion of China's "double carbon" strategy, the full life cycle carbon emission control of the construction industry has become the key to achieve emission reduction targets. As the material basis of building structures, the production, use and waste of civil engineering materials are accompanied by significant energy consumption and environmental pollution<sup>[1]</sup>. Therefore, in the cultivation of civil engineering talents, enhancing students' cognition, design and innovation ability of low-carbon materials is not only the inevitable requirement of responding to the national strategy, but also the core measure to drive the green transformation of the industry.

Civil engineering materials is a basic course for civil engineering majors. Traditional teaching focuses on the basic properties, performance indicators and engineering applications of materials, and lacks systematic explanations on environmental properties, life cycle carbon emissions and resource recycling of materials<sup>[2]</sup>. This knowledge structure is significantly out of line with the green development needs of the industry. At the same time, under the guidance of the concept of Engineering Education Accreditation (OBE), the course teaching needs to pay more attention to the cultivation of students' ability to solve complex engineering problems and professional quality, which requires that the course design must integrate the cutting-edge technology and the concept of sustainable development<sup>[3]</sup>.

This study focuses on the deep integration of the concept of "carbon emission reduction" and the course of "civil engineering materials". Combining with the scientific research practice in the field of resource utilization of industrial solid waste, this paper aims to transform the scientific research achievements into high-quality teaching resources and reconstruct the course content and teaching methods. Through systematic course construction, students are guided to change from the traditional material evaluation dimension of "performance cost" to the multidimensional comprehensive decision-making paradigm of "performance carbon footprint sustainability", laying a solid foundation for their future engagement in green building materials research and development, low-carbon engineering design and project management.

## 2 Analysis of the Role of "Civil Engineering Materials" in Civil Engineering Talent Training System

### 2.1 The Nature And Teaching Rule of Civil Engineering Materials Course

The course of civil engineering materials is essentially a professional basic course with a high degree of combination of theory and practice, and its teaching rule shows distinctive engineering education characteristics.

(1) Interdisciplinary and basic. The course content spans materials science, chemistry, mechanics, physics and other disciplines, and is the bridge and link between public basic courses and professional courses. Through the systematic

study of the internal relationship between material composition, structure, performance and application, students build a complete cognitive framework about the material basis of engineering.

(2) Synergy of knowledge transfer and ability training. The rule of course teaching is by no means a one-way knowledge infusion. It follows the cognitive logic of “theory guides practice and practice deepens theory”. Classroom teaching focuses on the explanation of the basic properties of materials, technical standards and action mechanism; The experimental teaching focuses on cultivating students' rigorous scientific attitude, standardized operation skills and preliminary scientific research ability of analyzing and processing experimental data through practical links such as cement performance test, concrete mix design, strength test, etc.

(3) Enlightenment of engineering decision making. The selection and application of materials is a multi-objective optimization decision-making process, which requires comprehensive consideration of performance, cost, process and environmental benefits. Through a large number of engineering case teaching, the course imperceptibly guides students to abandon single thinking and initially establish a systematic and critical engineering decision-making thinking mode based on multiple constraints.

## 2.2 Teaching Objectives of Civil Engineering Materials Course with Carbon Emission Reduction as the Core

Under the guidance of the “double carbon” goal, the teaching goal of the course should be strategically upgraded and focused on the basis of the traditional knowledge ability goal, aiming to cultivate students' innovation and application ability of low-carbon building materials for the future.

(1) The goal of knowledge is to build a full life cycle carbon footprint knowledge system. So that students can not only master the mechanics and durability of materials, but also systematically understand their life cycle carbon emission characteristics from cradle to grave. Focus on the emission reduction path of high carbon emission traditional materials (such as cement and steel), as well as the performance advantages and industrial application knowledge of low carbon alternative materials (such as industrial solid waste based cementitious materials and recycled aggregate).

(2) The ability goal is to cultivate students' ability to design and evaluate low-carbon materials. Cultivate students' low-carbon design ability and quantitative evaluation ability. Based on the engineering requirements and environmental protection specifications, the concrete mix design with fly ash, mineral powder and other industrial solid wastes can be carried out, and the material combination can be optimized under the premise of ensuring the performance, so as to reduce the carbon emission intensity per cubic meter. Guide students to master the basic life cycle assessment (LCA) methodology, and be able to use the carbon footprint database to quantitatively compare and evaluate the environmental impact of different material schemes, so as to provide a scientific basis for green design and decision-making<sup>[4]</sup>.

(3) The goal of values is to shape green engineering ethics and social responsibility. Deeply clarify the social and environmental responsibilities of civil engineers, guide students to establish the multi-dimensional comprehensive engineering values of “performance cost carbon footprint” by showing the huge carbon emission reduction potential of the building materials industry, internalize the concept of sustainable development and ecological civilization into their professional trust and code of conduct, and actively become the practitioner and promoter of the national “double carbon” strategy.

## 3 Course Design of “Civil Engineering Materials” based on the Concept of Carbon Emission Reduction

### 3.1 Design of teaching Knowledge System of Civil Engineering Materials Course

In order to integrate the concept of carbon emission reduction into the course, the course knowledge system was reconstructed to form a new system of “one main line, four modules and multi-dimensional integration”, as shown in Figure 1.

A core thread is the “carbon footprint” analysis of materials. Taking the concept of LCA as a thinking tool throughout, it guides students to comprehensively consider the learning of each material from the three dimensions of performance, cost and environment, and realizes the cognitive upgrading from “understanding materials” to evaluating and selecting materials<sup>[5]</sup>.

Module 1 is the connotation extension of carbon emission reduction in basic theory. When teaching the knowledge of traditional material properties, the environmental properties are embedded synchronously. For example, when explaining the hydration mechanism of cement, analyze the process carbon emissions generated by the decomposition of calcium carbonate in the production of Portland cement, and lead to the technical demand for reducing the amount of cement. When expounding the workability of concrete, the indirect emission reduction contribution of water reducing agent technology to reducing water binder ratio, improving strength and reducing cement consumption is analyzed.

Module 2 is the teaching unit of “material carbon footprint and life cycle assessment”. A 4-hour special topic will be

added to systematically introduce the LCA methodology, so that students can master the scientific tools for quantitative analysis of the environmental impact of materials.

Module 3 is to strengthen the case teaching of industrial solid waste recycling. Industrial solid wastes such as slag, fly ash, desulfurization gypsum and steel slag will be the key teaching content<sup>[6]</sup>. It not only explains its activity mechanism, hydration characteristics and the improvement of concrete performance, but also focuses on the huge carbon emission reduction benefits brought by its replacement of cement or natural aggregate. For example, this paper expounds the dual advantages of high volume fly ash concrete technology in reducing carbon emissions and improving durability, and introduces relevant engineering cases (such as a green building certification project) for empirical analysis.

Module 4 is the introduction of low-carbon new materials and cutting-edge technologies. Set up cutting-edge lectures or discussion sessions to introduce low-carbon cutting-edge technologies such as geopolymer cementitious materials<sup>[7]</sup>, carbon dioxide curing concrete technology, and recycled aggregate efficient utilization technology, broaden students' horizons, and guide them to pay attention to the scientific and technological innovation trends in the field of materials.

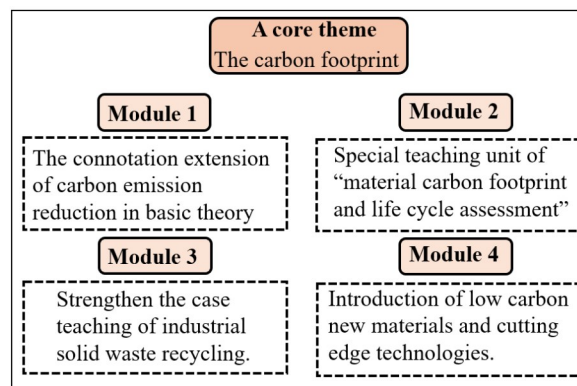


Figure 1 Course knowledge system integrated with the concept of carbon emission reduction

### 3.2 Selection and Arrangement of Case Teaching Content of Civil Engineering Materials

Case teaching is a bridge connecting theory and practice. According to the principle of authenticity, cutting edge and inquiry, the following cases are selected and arranged.

Basic cognitive cases (theory teaching stage). (1) Comparison of positive and negative cases. Through the traditional engineering failure cases such as "the accident of chloride ion corrosion of steel bars in sea sand", the long-term risk of improper material selection and the high carbon emissions caused by potential maintenance are emphasized. At the same time, the successful case of "application of fly ash concrete in large-scale water conservancy projects" is displayed to explain its dual advantages of reducing hydration heat, improving durability and reducing carbon emissions. (2) LCA tool case. Taking "1 cubic meter C30 concrete" as the object, the carbon emission calculation process and results of the traditional formula and the formula mixed with 30% fly ash were compared, so that students can intuitively feel the emission reduction value of solid waste recycling.

Frontier development cases (special lectures). Invite enterprise experts or arrange special lectures to share the latest engineering practices such as "large-scale application of solid waste based green building materials in major projects such as xiong'an New Area" and "industrialization progress of carbon dioxide mineralized maintenance products", so that students can understand the cutting-edge trends of the industry and stimulate their sense of mission to participate in the innovation of green materials.

Through the collaborative design of the above knowledge system and case teaching, the course successfully transformed carbon emission reduction from an abstract concept into specific learnable knowledge, operable methods and evaluable projects, which strongly supported the cultivation goal of students' low-carbon ability.

## 4 Innovation of Teaching Methods of "Civil Engineering Materials" based on Ability Requirements

### 4.1 Innovation of Teachers' Teaching Methods

According to the OBE capability output requirements, the following teaching methods are proposed to achieve the synchronous improvement of knowledge transfer and capability training.

Research-Led Teaching. The scientific research projects of teachers (the author) in the field of comprehensive utilization of industrial solid waste (such as research on the influence mechanism of alkali residue on concrete workability and durability, SAP internal curing technology, etc.)<sup>[8-9]</sup> are transformed into comprehensive and designed teaching

experiments. Students are no longer just verifying the classical theory, but in the form of a group, simulating the scientific research process, designing the low-carbon concrete mix proportion based on fly ash/mineral powder, and testing its workability, strength and durability indicators. Finally, based on the experimental results and carbon footprint calculation, they complete a comprehensive analysis report on technical, economic and environmental benefits. This has greatly trained students' research ability and innovative thinking.

Project-Based Learning (PBL). Around the core task of “designing low-carbon building materials solutions for a small building”, students need to go through the whole process of data collection, scheme comparison and selection, LCA analysis, report writing and defense. The project integrates multi-disciplinary knowledge such as material selection, structural concept and environmental assessment, and effectively cultivates students' comprehensive ability to solve complex engineering problems and team spirit.

Case teaching and immersive experience. Using virtual simulation technology, the virtual walkthrough system of material production line and construction site is developed to enable students to intuitively feel the high-energy consumption link and pollution emission point of material production, as well as the practical application of green construction technology, and strengthen the immersive cultivation of their low-carbon consciousness.

Diversified Assessment and evaluation system. Reform the single final examination mode and build a “process + result” multiple evaluation system. The final written examination (50%) focused on mastering basic knowledge; The experimental report and PBL project results (30%) assess the comprehensive application and innovation ability; Classroom discussion and special report (20%) evaluated their ability of communication and collaboration and frontier tracking. This evaluation method more comprehensively and objectively reflects the students' ability achievement.

## 4.2 Innovative Ways of Students' Learning

The innovation of teaching methods will inevitably drive the fundamental change of students' learning methods, from passive reception to active construction and cooperative exploration.

Project based learning. Students are the main body of the learning process. Learning is driven by complex projects such as “design and demonstrate the low-carbon concrete scheme for the main structure of the extension of the campus landmark building (such as the Library)”. Students in groups can independently complete data collection, formula design, LCA carbon footprint calculation, technical and economic comparison, report writing and final defense within a few weeks. This process seamlessly integrates multi-disciplinary knowledge of materials, environment, economy and management, and completely simulates the real work process of engineers. It is the most effective way to cultivate their comprehensive innovation ability and professional quality.

Collaborative inquiry learning. In the comprehensive and exploratory experiments, students cooperate in groups. For example, in the experiment of “effect of compound industrial solid waste on sulfate corrosion resistance of concrete”, each group can choose different types and contents of solid waste as variables to independently complete the experimental design, sample preparation, performance test and data interpretation. Finally, each group shared and discussed each other's findings in class, and finally formed a more universal conclusion beyond a single experiment under the guidance of the teacher. This way cultivates students' critical thinking, teamwork and scientific communication ability.

Autonomous expansive learning. Encourage and guide students with spare capacity to carry out personalized in-depth learning. Teachers provide a list of cutting-edge Literature (such as the latest research papers on “carbon dioxide mineralization maintenance” and “geopolymer concrete”), recommend videos of academic reports by top experts in the industry, and open laboratory resources. Support students to conduct more in-depth literature study or try exploratory experiments around the specific low-carbon technology direction they are interested in, and convert their achievements into course papers or academic competitions (such as “Challenge Cup”), so as to maximize their academic interest and scientific research potential.

Through the above dual innovation of teaching and learning, the course has successfully constructed a new teaching ecology with students as the center, ability output as the guidance, and scientific research frontier as the nourishment, ensuring that students can not only master knowledge, but also internalize ability, and grow into innovative talents to meet the needs of green change in the industry.

## 5 Conclusions

Integrating the concept of carbon emission reduction into the course construction of civil engineering materials is an inevitable requirement to comply with the development of the times and promote professional upgrading. By reconstructing the course content and innovating teaching methods, this study has reached the following main conclusions.

The reconstruction of curriculum knowledge system is the foundation. Through the introduction of cutting-edge

content such as material carbon footprint analysis, industrial solid waste recycling and low-carbon new materials, a new curriculum system with basic, cutting-edge and ideological features has been successfully constructed, enabling students to re-examine and select engineering materials from the perspective of sustainable development.

Scientific research nurturing teaching and project-based learning are the key. The teachers' scientific research achievements are transformed into teaching cases and experimental projects, and students are guided to complete the whole process training from material design to comprehensive evaluation through PBL mode, which effectively breaks through the barriers of teaching and scientific research, realizes the virtuous cycle of "learning research application", and significantly improves students' practical innovation ability and scientific research literacy.

The teaching reform has achieved remarkable results. The preliminary teaching practice shows that the reformed curriculum not only stimulates students' interest and initiative in learning, but also cultivates their sense of mission facing the major strategic needs of the country and the ability to solve complex engineering problems, providing an effective path for cultivating innovative and compound civil engineering talents needed in the new era.

In the future, the course team will continue to deepen cooperation with enterprises, develop richer entity case base and virtual simulation resources, and explore the establishment of standardized tools for the calculation and evaluation of carbon emissions in the course, so as to continue to promote the iteration and optimization of the course.

## About the Author

Kaiyue Zhao, a Ph.D. candidate and lecturer, specializes in the resource utilization of solid waste.

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