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WSSO Technical Guidelines for Recycling of Construction Solid Wastes

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Introduction

Abstract: This standard specifies the technical principles, technical requirements, and management points throughout the entire process of construction solid wastes, including source control, classification and collection, transportation, pretreatment, recycling, application of recycled products, information management, and performance evaluation.

It is applicable to the recycling and management of construction solid wastes generated from construction, demolition, renovation, and other activities in building projects, covering new construction, renovation, expansion, and demolition (including renovation) projects in cities and townships, as well as solid wastes generated from road and bridge, rail transit, municipal pipelines, landscaping, water conservancy, and other engineering projects.

This standard aims to establish a systematic, standardized, and operable technical system for the recycling of construction solid wastes, improve resource utilization efficiency, reduce environmental load, and promote green, low-carbon, and circular development in the construction industry.

Keywords: Construction Solid Wastes; Recycling; Resource Utilization; Recycled Building Materials; Technical Guidelines; Life Cycle Management; Energy Saving and Carbon Reduction.

Content

Technical Guidelines for Recycling of Construction Solid Wastes

1 Overview

1.1 Scope

This standard specifies the overall technical framework and basic requirements for the recycling of construction solid wastes, covering the entire process from source generation to end-use, including: source reduction and classification management; collection, storage, and transportation; pretreatment and recycling; production and engineering application of recycled products; information recording, performance evaluation, and continuous improvement.

This standard is applicable to the recycling activities of construction solid wastes generated from new construction, renovation, expansion, and demolition projects, as well as to the planning, design, operation, and management of construction solid wastes treatment facilities. The applicable geographical scope includes construction wastes generation, transportation, and disposal areas within urban built-up areas and their surroundings, with a focus on construction solid wastes management in prefecture-level and above cities. The applicable entities include construction owners, design units, construction units, demolition units, transportation and treatment enterprises, recycled material production enterprises, and users and other relevant participants.

1.2 Purpose

The purpose of this standard is to:

a) Clarify the technical requirements and management processes for the recycling of construction solid wastes, standardize operations at each stage of the life cycle, with emphasis on strengthening the coordination and synergy of key technical links such as pretreatment, recycling, and engineering application;

b) Guide the reduction, recycling, and harmless treatment of construction solid wastes, significantly improve resource utilization efficiency through technical grading and refined management;

c) Improve the engineering applicability and application safety of recycled building materials, establish a full-chain quality assurance mechanism from product certification and quality inspection to engineering application, and expand the application scope of recycled products;

d) Provide technical support for policy formulation, project management, and effectiveness evaluation, establish a data-driven performance evaluation system, and contribute to the achievement of energy conservation and carbon reduction goals;

e) Promote green, low-carbon, and circular development in the construction industry, and facilitate the construction of "zero-waste cities."

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14001, Environmental management systems — Requirements with guidance for use

ISO 14040 / ISO 14044, Environmental management — Life cycle assessment — Principles and framework / Requirements and guidelines

ISO 9001, Quality management systems — Requirements

Waste Framework Directive (2008/98/EC) — European Waste List (EWC)

EN 12620, Aggregates for concrete

ISO 14025, Environmental labels and declarations — Type III environmental declarations — Principles and procedures

GB/T 25177, Recycled coarse aggregate for concrete

GB/T 25176, Recycled fine aggregate for concrete and mortar

GB/T 1596, Fly ash for use in cement and concrete

GB/T 18046, Ground granulated blast furnace slag for use in cement and concrete

GB 50204, Code for acceptance of constructional quality of concrete structures

GB 50003, Code for design of masonry structures

JTG/T F20, Technical rules for construction of highway pavement base courses

JTG F80/1, Quality inspection and evaluation standards for highway engineering

GB 5085.3, Identification standards for hazardous wastes — Identification of leaching toxicity

GB 6566, Limits of radionuclides in building materials

GB 12523, Emission standard of environment noise for construction site

ISO 14067, Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification

GB/T 51366, Standard for building carbon emission calculation

EN 15804, Sustainability of construction works — Environmental product declarations — Product category rules

3 Terms and definitions

3. 1
Construction Solid Wastes

Solid wastes generated during construction, maintenance, demolition, and renovation of building projects, including engineering spoil, waste concrete, waste bricks and tiles, waste mortar, scrap metal, waste wood, waste plastics, waste glass, engineering mud, and decoration and renovation wastes.

3. 2
Recycling

The process of converting construction solid wastes into reusable materials, products, or energy through physical, chemical, or other engineering and technical means, including primary utilization (on-site

backfilling), intermediate utilization (recycled aggregate production), advanced utilization (recycled product manufacturing), and composite utilization.

3.3
Recycled Building Materials

Building materials or products made primarily from construction solid wastes through processing, which comply with relevant technical standards and engineering application requirements, such as recycled aggregates, recycled concrete, recycled bricks, recycled mortar, and recycled road materials.

3.4
Source Reduction

Activities aimed at reducing the generation of construction solid wastes during the construction phase through optimized design, construction organization, and material management, including promoting prefabricated construction, standardized design, and green construction measures.

3.5
Life Cycle Management

A systematic management approach that runs through the entire chain of "source reduction - classification collection - transportation supervision - disposal utilization - recycled product application" of construction solid wastes, achieving coordinated control at each stage and ensuring that data are measurable, reportable, and verifiable.

4 General Principles

4.1 Reduction Principle

Construction projects shall take effective measures to reduce the generation of construction solid wastes during the planning, design, and construction stages, including:

a) Promoting prefabricated construction and standardized design to reduce waste generation at the source;
b) Reasonably selecting material specifications to reduce on-site cutting and processing waste;
c) Strengthening refined management of construction processes to control material consumption and waste;
d) Including construction waste reduction costs in project budgets to ensure financial support for reduction measures.

4.2 Classification Principle

Construction solid wastes shall be subject to classified management at the source. Different categories of wastes shall be collected separately, stored in designated areas, and processed separately to prevent mixed contamination. Hazardous wastes (such as waste batteries, waste paint, oil-containing parts, paint buckets, waste lamps, etc.) shall be separately classified and handed over to qualified hazardous wastes treatment units, and does not fall within the scope of conventional recycling. The refinement level of classification management shall meet the technical requirements of subsequent pretreatment processes and high-value utilization.

4.3 Resource Optimization Principle

Under the premise of safety, environmental protection, and technical feasibility, mature and reliable recycling technologies shall be prioritized to improve the level of high-value-added utilization. It is encouraged to establish a graded utilization system (Level I, Level II, Level III) based on raw material characteristics, using high-quality aggregates for high-performance concrete and products, and low-quality aggregates for backfilling and road base courses, achieving "graded treatment and cascading utilization," and building an industrial system of "sorting - processing - application."

4.4 Safety and Environmental Protection Principle

The entire process of recycling of construction solid wastes shall comply with laws and regulations on production safety and environmental protection, preventing secondary pollution such as dust, noise, and wastewater, and ensuring that emissions of air pollutants, wastewater, and noise meet relevant standards. Before engineering application, the environmental safety of recycled products (such as heavy metal leaching, radioactivity, etc.) shall be assessed to ensure no potential harm to human health and the environment.

4.5 Life Cycle Management Principle

The entire chain of "source reduction - classification collection - transportation supervision - disposal utilization - recycled product application" of construction solid wastes shall be managed throughout, achieving coordinated control at each stage and ensuring that data are measurable, reportable, and verifiable. Digital means (such as construction wastes integrated supervision platforms) are encouraged to be used for data collection, flow tracking, and performance evaluation across the entire chain, providing a basis for decision-making for continuous improvement.

5 Classification and Management of Construction Solid Wastes

5.1 Classification Requirements

Construction solid wastes shall be classified and managed according to the following categories:

a) Inert Wastes: Waste concrete, waste bricks and tiles, sand and gravel, spoil, etc., which shall be prioritized for entry into the resource treatment system;

b) Metal Wastes: Waste steel bars, scrap steel, scrap aluminum, etc., which shall be sent to metal smelters for recycling after recovery;

c) Wood Wastes: Formwork, timber, wooden packaging materials, etc., which can be used as biomass fuel or raw materials for artificial boards after crushing;

d) Recyclable Wastes: Plastics, glass, wires, and other recyclable materials, which shall be incorporated into specialized recycling channels;

e) Other Wastes: Non-recyclable wastes or wastes requiring special treatment (excluding hazardous wastes).

5.2 Collection and Storage

Construction solid wastes shall be provided with dedicated collection and storage areas according to classification requirements, equipped with corresponding classified collection containers and clearly

marked, and measures shall be taken to prevent dust, leakage, and scattering. For wastes containing higher value-added components (such as high-grade concrete blocks, complete metal components, etc.), separate storage is recommended at the time of collection to facilitate subsequent high-value utilization.

5.3 Transportation Management

The transportation of construction solid wastes shall adopt enclosed or covered transportation methods. Transporters shall possess corresponding qualifications, and transportation routes and schedules shall comply with urban management requirements. The "one vehicle, one code" electronic waste ticket system shall be implemented, and real-time supervision of the transportation process shall be achieved through GPS trajectory monitoring, video surveillance, and other means. During transportation, mixed loading of different categories of wastes shall be prevented to ensure that the results of classification collection are maintained during the transportation stage.

5.4 Information Recording

Construction units or management units shall establish management ledgers for construction solid wastes, recording the amount, category, destination, treatment methods, and related vouchers of wastes. The "construction wastes disposal approval document" system shall be implemented, and the "construction wastes recycling information management platform" shall be used for online declaration, manifest management, and data statistics to ensure a closed chain. Information records shall be interfaced with the data systems of subsequent pretreatment and recycling stages to achieve full traceability.

5.5 Requirements for Stakeholder Management

Requirements for stakeholders managements including:

a) Construction Owners: Responsible for overall management, requiring design and construction parties to implement relevant requirements, including construction wastes reduction costs in project budgets, and encouraging the use of recycled products that meet standards in projects;

b) Design Units: Prioritize the use of recycled materials and design solutions that facilitate dismantling and recycling, considering the convenience of end-of-life disposal of buildings throughout the life cycle at the design stage;

c) Construction Units: Responsible for on-site classification, collection, and recording, and handing over to compliant enterprises for treatment, ensuring that classification quality meets resource treatment requirements;

d) Demolition Units: Develop demolition plans, prioritize the "demolition - classification - recycling" integrated model, and carry out demolition in zones and layers according to the sequence of "top to bottom, inside to outside, non-structural to structural";

e) Transportation and Treatment Enterprises: Shall possess corresponding qualifications, operate in accordance with specifications, ensure no mixed loading or spillage during transportation, and ensure that treatment processes meet environmental protection and product quality requirements;

f) Recycled Material Production Enterprises and Users: Ensure product quality and promote application within the permitted scope, encouraging production enterprises to carry out green product certification and Environmental Product Declarations (EPD).

6 Pre-treatment and Recycling Technology

6.1 Pre-treatment Technology

Construction solid wastes shall be subjected to differentiated pretreatment processes based on subsequent utilization pathways before recycling. Pretreatment shall follow the principles of "precise classification, quality-based treatment, and graded utilization" to improve the quality of recycled aggregates and expand utilization pathways.

6.1.1 Pre-treatment Process Route

Pre-treatment shall adopt a modular combined process of "multi-stage crushing - multi-stage screening - multi-stage sorting," which can be flexibly combined according to material characteristics and product requirements:

a) Primary Pretreatment (Coarse Crushing and Primary Screening): Jaw crushers or hammer crushers shall be used for coarse crushing of raw materials to control particle size below 100mm, and grid screens or trommel screens shall be used to preliminarily separate soil and light impurities;

b) Secondary Pretreatment (Fine Crushing and Shaping): Impact crushers, cone crushers, or vertical shaft impact crushers shall be used for fine crushing and particle shaping to improve the particle size distribution and surface morphology of recycled aggregates, enhancing their interfacial bonding performance with cementitious materials;

c) Tertiary Sorting (High-Precision Sorting): Comprehensive use of magnetic separation (for iron removal), air separation (for removing light impurities such as paper, wood chips, plastics), water separation (for removing mud and organic matter), optical sorting (for separation by color or material), and eddy current separation (for separating non-ferrous metals) shall be employed to ensure that the impurity content in recycled aggregates complies with relevant standards such as GB/T 25177 "Recycled coarse aggregate for concrete."

6.1. 2 Enhanced Impurity Removal and Purification Technology

Enhanced impurity removal and purification technology including:

a) Light Impurity Removal Rate Control: A combination of air separation and gravity separation shall be used to ensure that the light impurity content (by mass) in recycled aggregates is not greater than 1‰;

b) Mud Content and Micro Powder Control: Washing processes or dry air classification de-powdering systems shall be used to control the content of particles smaller than 75 μm in recycled fine aggregates not exceeding the requirements of the corresponding grade standards.;

c) Chloride and Sulfate Control: For construction wastes from saline environments or industrial residues, washing desalination or neutralization treatment processes shall be added to ensure that the chloride and sulfate ion contents in recycled aggregates meet engineering safety requirements.

6.1. 3 Configuration of Construction Wastes Recycling Production Lines

Fixed, semi-fixed, or mobile production lines shall be configured according to different processing scales:

a) Fixed Production Line: Suitable for large-scale centralized treatment centers with an annual processing capacity of over 1 million tons, equipped with comprehensive sorting, crushing, screening, storage, and environmental protection dust removal systems, and equipped with DCS centralized control systems for fully automated operation.

b) Mobile Production Line: Suitable for demolition sites or space-restricted areas, with advantages of rapid relocation and flexible combination, capable of processing construction wastes into recycled graded aggregates directly at the source for on-site backfilling or road base courses.

c) Modular Production Line: Adopting standardized, detachable functional module combinations, capable of rapidly adjusting process routes according to material changes, adapting to the parallel processing needs of multiple materials.

6.2 Recycled Aggregate Utilization Technology

6.2.1 Recycled Aggregate Graded Utilization System

A three-level utilization system shall be established according to aggregate quality and application scenarios:

Table1 Three-Level Utilization System

Grade	Quality Requirements	Recommended Application Scenarios
Level I	Crushing index ≤ 12%, water absorption ≤5%, impurity content ≤ 0.5%	C20~C40 recycled concrete structural components, precast components
Level II	Crushing index ≤ 20%, water absorption ≤8%, impurity content ≤ 1.0%	Road base courses, cement-stabilized layers, recycled bricks (blocks)
Level III	Crushing index ≤ 30%, water absorption ≤12%, impurity content ≤ 3.0%	Backfill engineering, site hardening, subgrade fill

6.2.2 High-Quality Recycled Aggregate Preparation Technology

a) Particle Shaping and Enhancement Technology: Vertical shaft impact crushers with high-speed rotating rotors and anvils shall be used to perform particle shaping on recycled aggregates through the "rock-on-rock" or "rock-on-iron" principle, improving surface morphology and angularity, reducing water absorption, and increasing bulk density;

b) Surface Enhancement Treatment Technology: Chemical enhancement methods using silane coupling agents, polymer emulsions, or nano-silica sol shall be applied to coat the surface of recycled aggregates, reducing water absorption and crushing index, and improving the density and bond strength of the interfacial transition zone (ITZ);

c) Carbonation Enhancement Technology: Recycled aggregates shall be placed in a carbonation chamber with CO_2 volume concentration not less than 20% and relative humidity of 50%-70% to accelerate the reaction of CO_2 with hydration products in the cement paste attached to the aggregate surface to form calcium carbonate ($CaCO_3$), thereby reducing water absorption (by 20%-30%), increasing apparent density and soundness, while achieving carbon reduction benefits of approximately 30-60 kg CO_2 per ton of aggregate sequestered;

d) Microbial Mineralization Remediation Technology: Urease-producing microorganisms (such as Sporosarcina pasteurii) shall be used to induce calcium carbonate precipitation to fill micro-cracks and pores on the surface of recycled aggregates, thereby improving the denseness of the aggregate and reducing water absorption.

6.2.3 Engineering Application Limitations and Applicable Conditions of Recycled Aggregates

a) Concrete Structural Engineering: The replacement rate of recycled coarse aggregate shall be controlled at 30%-50% (for C30 and below) and 20%-30% (for C35-C40), and shall be supplemented with mineral admixtures (fly ash, ground slag, silica fume, etc.) and high-performance water-reducing agents to regulate workability and long-term durability;

b) Road Engineering: Recycled graded aggregates can be used for highway subbase, base courses, and pavement cushion layers, and shall comply with the requirements of JTG/T F20 "Technical rules for construction of highway pavement base courses.";

c) Backfill Engineering: Recycled aggregates can be used for trench backfilling and abutment backfilling, and shall be compacted in layers with a compaction degree not less than 93%.

6.3 Recycled Building Material Product Technology

6.3.1 Recycled Concrete Technology

a) Mix Design Principles: A design strategy of "low water-to-binder ratio, high binder content, and high-quality admixtures" shall be adopted. Mineral admixtures such as fly ash, ground slag, and silica fume shall be added to improve the workability and durability of recycled concrete, compensating for the increase in effective water-to-binder ratio caused by the high water absorption of recycled aggregates;

b) Key Performance Control Technologies:Pre-wetting treatment: Recycled aggregates shall be pre-wetted to the saturated surface-dry state before mixing to effectively control the slump loss of concrete over time;

c) Application of polycarboxylate superplasticizer: The dosage shall be 1.0%-2.5% of the total binder content to regulate the water-to-binder ratio and ensure strength and workability;

d) Fiber reinforcement technology: Polypropylene fiber (dosage 0.6-1.2 kg/m^3) or steel fiber (volume fraction 0.5%-1.5%) shall be added to recycled concrete to effectively improve its crack resistance and flexural toughness;

e) Engineering Application Grades: Recycled concrete shall be used for concrete structures with strength grades C15 to C40, among which C15-C25 can be used for cushion layers, non-load-bearing structures, and filling structures, while C25-C40 can be used for load-bearing components such as beams, slabs, and columns (subject to special demonstration and suitability testing).

6.3.2 Recycled Brick (Block) Technology

Product Types and Performance Requirements:

a) Recycled solid brick/perforated brick: Compressive strength not less than MU10, suitable for infill walls and non-load-bearing partition walls.

b) Recycled permeable brick: Permeability coefficient not less than 1.0×10^{-2} cm/s, compressive strength not less than Cc40, suitable for sponge city permeable paving.

c) Recycled curbstone: Flexural strength not less than Cf4.0, suitable for sidewalks and green belt edges.

d) Recycled grass-planting brick: Compressive strength not less than Cc30, suitable for ecological parking lots and slope protection works.

e) Curing System: A combination of steam curing (60° C constant temperature for 4-6 hours) and natural curing (not less than 14 days) shall be used to ensure early strength development and volume stability.

6.3.3 Recycled Road Material Technology

a) Recycled Cement-Stabilized Layer Material: Recycled aggregates shall replace natural crushed stone (replacement rate up to 60%-100%), with 3%-5% cement or 4%-6% lime added as binder for road base and subbase courses. The 7-day unconfined compressive strength shall be ≥3.0 MPa (for base course) or ≥2.0 MPa (for subbase course);

b) Recycled Asphalt Pavement (RAP): The blending ratio of reclaimed asphalt pavement material shall be controlled at 15%-40%, with rejuvenators (such as aromatic oils or vegetable oil-based rejuvenators at 3%-8% of RAP mass) added to restore aged asphalt performance, and gradation adjusted to meet the technical requirements of AC-13, AC-20 and other hot-mix asphalt mixtures;

c) Recycled Aggregate Inorganic Mixture: Recycled aggregates shall be mixed with cement, fly ash, etc. in proportion for base and subbase courses under heavy-load traffic.

6.3.4 Recycled Powder and Micro Powder Utilization Technology

d) Activation Treatment of Recycled Micro Powder: Concrete and waste brick powder shall be ground to a specific surface area ≥450 m^2/kg (using ball mills, vertical roller mills, or vibration mills), and subjected to thermal activation at 600° C-800° C for 0.5-2 hours to stimulate pozzolanic activity.

e) Application as Cement Admixture: Recycled micro powder can be used as a cement admixture at a dosage of 5%-15% (by mass), complying with the requirements of GB/T 1596 "Fly ash for use in cement and concrete" and GB/T 18046 "Ground granulated blast furnace slag for use in cement and concrete."

f) Application as Concrete Admixture: Recycled micro powder can replace 10%-20% of cement in concrete of C30 and below strength grades, with the addition of high-performance water-reducing agents to ensure fluidity.

6.4 Collaborative Utilization Technology

6.4.1 Cement Kiln Co-processing Technology

a) Utilization Pathways: The calcium, silica, and aluminum components in waste concrete and waste bricks and tiles can serve as alternative raw materials for cement production

(replacement rate up to 5%-15%), while the calorific value of combustible wastes (such as waste wood, waste plastics, etc.) can serve as alternative fuel for cement kilns (replacement rate up to 10%-30%).

b) Technical Requirements: The chloride ion content in feed materials shall be ≤0.02%, and heavy metal content shall comply with relevant environmental protection standards for cement kiln co-processing.

6.4.2 Collaborative Utilization of Construction Wastes and Industrial Solid Wastes

a) Steel Slag - Recycled Aggregate Composite Utilization: Steel slag (dosage 10%-30%) shall be composited with recycled aggregates for road base materials, effectively improving base strength and crack resistance.

b) Desulfurization Gypsum - Recycled Micro Powder Composite Cementitious Material: Recycled micro powder (60%-70%), desulfurization gypsum (20%-30%), and ground slag (10%-20%) shall be used to prepare low-carbon cementitious materials for soft soil stabilization, mine backfilling, and other applications.

6.4.3 Collaborative Utilization in Agriculture and Ecology

a) Ecological Slope Protection Materials: Recycled aggregates shall be mixed with planting soil to prepare ecological slope protection blocks or vegetated concrete for riverbanks and road slope greening.

b) Artificial Reefs and Ecological Revetments: High-strength, high-porosity ecological concrete components made from recycled aggregates shall be used for artificial reefs and ecological revetments, combining structural and ecological functions.

6.5 Featured Technical Solutions

6.5.1 Mobile Crushing Production Technology

Mobile crushing stations integrate feeding, crushing, screening, magnetic separation, and other units, using crawler or tire chassis. They are suitable for scattered demolition projects and areas with insufficient treatment capacity below the county level, avoiding long-distance transportation of construction wastes and achieving significant carbon reduction effects (reducing transportation-related carbon emissions by approximately 30%-50% compared to centralized treatment).

6.5.2 Decoration Wastes Fine Sorting Technology

In view of the complex composition of decoration wastes, the following fine sorting process is recommended: pre-screening → manual/mechanical pre-sorting (large debris) → primary crushing → magnetic separation → trommel screening (classification) → air separation (removal of light materials) → secondary crushing → eddy current separation (removal of non-ferrous metals) → color sorting (removal of colored impurities) → washing → finished product. Through this process, the total impurity content in recycled aggregates can be controlled below 1‰, with recycled material purity ≥99%.

6.5.3 Demolition and Recycling Integration (DfD) Technology

a) Design Requirements: The "deconstructability" and "recyclability" of buildings shall be considered at the design stage, using standardized components, bolted connections, and dry construction methods to facilitate classification and recycling during future demolition.
b) Construction Requirements: Demolition shall be carried out in zones and layers according to the sequence of "top to bottom, inside to outside, non-structural to structural," with simultaneous material classification to achieve "demolition and separation simultaneously."
c) Management Requirements: Professional companies shall be responsible for the full-chain service from demolition, classification to recycling, ensuring material purity from the source.

6.5.4 Intelligent Management Technology

a) **Integrated Supervision Platform**: Internet of Things (IoT) and big data technologies shall be used to build a comprehensive construction wastes supervision platform for full-process traceability management of "generation - transportation - disposal - application" of construction wastes, achieving automatic data collection, abnormal automatic alerting, and real-time flow tracking.
b) **Automated Sorting Line**: AI vision recognition sorting robots (using deep learning algorithms to identify and classify different materials) shall be configured, combined with near-infrared spectroscopy (NIR) and X-ray fluorescence spectroscopy (XRF) to achieve precise identification and automatic sorting of wastes.
c) **Full-Process Intelligent Management**: IoT, big data, and artificial intelligence technologies shall be integrated to establish an information traceability system from construction sites to treatment plants. AI image recognition technology shall be used for automatic measurement and statistical analysis of waste classification, and blockchain technology shall be used to ensure the immutability and traceability of full-chain data.
d) **Online Quality Monitoring**: Online particle size analyzers (using laser diffraction or digital image processing technology for real-time particle size distribution analysis) and near-infrared moisture meters (for real-time moisture content detection) shall be installed on crushing and screening lines to achieve real-time monitoring of recycled aggregate quality and automatic adjustment of process parameters.

6.6 Typical Recycling Technology Routes

Based on raw material characteristics and product requirements, the following typical technology routes are recommended:

Raw Material Type	Recommended Process Route	Main Products	Value-Added Grade
Waste concrete blocks	Secondary crushing → screening → magnetic separation → air separation →	Level I/II recycled coarse and fine aggregates	High

Raw Material Type	Recommended Process Route	Main Products	Value-Added Grade
	particle shaping → (optional carbonation enhancement)		
Waste bricks and tiles	Primary crushing → screening → (optional grinding)	Recycled fine aggregate, recycled micro powder	Medium-High
Decoration mixed wastes	Pre-sorting → secondary crushing → tertiary sorting → washing	Level II/III recycled aggregates, RDF fuel	Medium
Waste asphalt pavement	Milling → crushing → screening → rejuvenator addition → hot mixing	Recycled asphalt mixture (RAP)	High
Engineering spoil	Screening → dewatering → (optional sintering/stabilization)	Backfill soil, sintered bricks, stabilized soil	Low→Medium
Scrap metal	Magnetic separation/eddy current separation → baling/shearing	Scrap steel, scrap aluminum, etc.	High
Waste wood	Crushing → screening → (optional pressing/gasification)	Artificial boards, RDF fuel	Medium

7 Application and Quality Control of Recycled Products

7.1 Product Quality Control

7.1.1 Quality Control System Requirements

Production enterprises of recycled building materials shall establish a quality control system covering the entire chain of raw material incoming inspection, production process control, and finished product outgoing inspection, and shall meet the following requirements:

a) **Certification Requirements:** Enterprises shall pass ISO 9001 quality management system certification, and recycled products shall pass relevant national product certifications (such as green building material product certification, low-carbon product certification).

b) **Type Inspection:** Each product type and specification shall undergo type inspection at least once a year. Type inspection shall be re-conducted when raw material sources or production processes undergo significant changes.

c) **Factory Inspection:** Each batch of products shall undergo factory inspection in accordance with corresponding product standards. Products may leave the factory only after passing inspection, and a quality certificate shall be issued.

7.1.2 Key Performance Index Requirements

Recycled Product Type	Key Performance Indicators	Technical Index Requirements (Reference)
Recycled coarse aggregate	Crushing index, water absorption, apparent density, flakiness content, impurity content	Crushing index ≤12% (Level I), ≤20% (Level II), ≤30% (Level III)
Recycled fine aggregate	Fineness modulus, methylene blue value, water absorption, mud content, light impurity content	MB value ≤1.4, mud content ≤ 3% (Level I)
Recycled concrete (C30)	Slump, compressive strength, impermeability grade, chloride diffusion coefficient	28d compressive strength ≥ 30MPa, impermeability grade ≥ P8
Recycled brick (MU10)	Compressive strength, flexural strength, freeze-thaw cycles	Average compressive strength ≥ 10MPa, freeze-thaw cycles ≥25
Recycled permeable brick	Permeability coefficient, compressive strength, frost resistance	Permeability coefficient ≥1.0×10^{-2} cm/s, compressive strength ≥Cc40
Recycled cement-stabilized layer material	7d unconfined compressive strength, compaction degree	Base course ≥3.0MPa, subbase ≥2.0MPa, compaction degree ≥ 98%
Recycled micro powder	Specific surface area, activity index, fluidity ratio, loss on ignition	Specific surface area ≥450m^2 /kg, 28d activity index ≥70%

7.1.3 Quality Inspection and Third-Party Certification

a) Inspection Institutions: Quality inspection of recycled products shall be undertaken by third-party inspection institutions with CMA/CNAS qualifications.
b) Inspection Frequency: Sampling shall be conducted at frequencies specified in product standards. Where no clear provisions exist, sampling shall be conducted in batches of 500 tons.
c) Information Disclosure: Inspection results shall be publicly displayed on enterprise websites or product packaging, subject to social supervision.

7.2 Engineering Application Management

7.2.1 Principles for Selection of Recycled Products

a) Priority Application Scenarios: Municipal engineering (road base courses, cement-stabilized layers, curbstones), landscape engineering (permeable paving, grass-planting bricks), non-load-bearing parts of building engineering (infill walls, partition walls, plastering mortar);
b) Encouraged Application Scenarios: Priority use of recycled building materials in non-load-bearing structures and auxiliary facilities of large public buildings such as sports venues, subway stations, schools, and hospitals to play a demonstration and leading role;
c) Exploratory Application Scenarios: Based on technical demonstration and verification, gradually promote the application of recycled concrete in low-rise building load-bearing structures, precast components, and prefabricated construction.

7.2.2 Pre-application Special Technical Demonstration

For recycled building material applications beyond the scope of standard application (such as recycled concrete for load-bearing structures, recycled aggregate replacement rate exceeding specified limits, etc.), special technical demonstration shall be conducted, including:

a) Raw material characteristic analysis (aggregate source, gradation, performance indicators);
b) Mix design and verification testing;
c) Long-term durability assessment (frost resistance, impermeability, carbonation resistance, chloride ion erosion resistance, etc.);
d) Structural safety assessment (bearing capacity, crack control, deformation performance);
e) Environmental safety assessment (heavy metal leaching, radioactivity, etc.).

7.2.3 On-site Construction and Quality Control

Special Requirements for Recycled Aggregate Concrete Construction:

a) Mixing Time: Shall be extended by 20-30 seconds compared to ordinary concrete to ensure mixture uniformity.
b) Transportation and Pouring: Due to rapid slump loss of recycled concrete, transportation time shall be shortened, and pouring shall preferably be completed within 1.5 hours.
c) Curing Requirements: Early-age moist curing shall be strengthened, with curing time not less than 14 days (compared to 7 days for ordinary concrete), and the concrete surface shall be kept continuously moist.

d) Quality Acceptance: Quality acceptance of recycled concrete structural works shall comply with GB 50204 "Code for acceptance of constructional quality of concrete structures."

e) Construction Requirements for Recycled Bricks (Blocks):Before masonry, recycled bricks (blocks) shall be wetted with water, with moisture content controlled at 10%-15%.The strength grade of masonry mortar shall not be lower than M5.The setting of wall tie bars, construction columns, and ring beams shall comply with GB 50003 "Code for design of masonry structures."

f) Construction Requirements for Recycled Road Materials:The moisture content of recycled cement-stabilized layer mixtures shall be controlled within ±1% of the optimum moisture content.Rolling construction shall follow the principle of "light first then heavy, slow first then fast, edges first then center."Construction quality inspection shall comply with JTG F80/1 "Quality inspection and evaluation standards for highway engineering" and other relevant requirements.

7.2.4 Quality Acceptance

a) Incoming Inspection: When recycled building materials enter the site, the construction unit shall verify quality certification documents (product certificate, type inspection report, factory inspection report, etc.), and conduct incoming re-inspection according to the batch and frequency specified in relevant standards.

b) Concealed Work Acceptance: When recycled building materials are used in concealed works, concealed work acceptance shall be conducted with photographic documentation retained.

c) Sub-project Acceptance: Sub-projects using recycled building materials shall undergo quality acceptance in accordance with relevant national standards, and may proceed to the next procedure only after passing acceptance.

7.3 Risk Control

7.3.1 Technical Risk Control

a) Durability Risk: Recycled aggregates may have high water absorption, low frost resistance, and low carbonation resistance. Special durability design shall be conducted in humid, freeze-thaw, or salt-erosion environments.

b) Source Risk: Construction wastes from different sources vary greatly in quality. A strict raw material incoming inspection system shall be established, and non-conforming raw materials shall be firmly rejected.

c) Performance Fluctuation Risk: A strict production process quality control system shall be established, with at least one sampling inspection per shift to ensure product performance stability.

7.3.2 Environmental Risk Control

Heavy Metal Leaching Risk: Before use, heavy metal leaching testing shall be conducted in accordance with GB 5085.3 "Identification standards for hazardous wastes - Identification of leaching toxicity" to ensure compliance with environmental protection standards.

Radioactivity Risk: The radioactivity nuclide limits of recycled building materials shall comply with the requirements of GB 6566 "Limits of radionuclides in building materials."

Construction Dust and Noise Control: During construction with recycled products, dust suppression measures (sprinkling, covering, enclosures, etc.) shall be implemented, and noise control shall comply with "Emission standard of environment noise for construction site" (GB 12523).

7.3.3 Market and Promotion Risk Control

Market Trust Deficiency: Demonstration projects can be used to showcase the performance advantages of recycled products, and green building material certification and carbon footprint certification can enhance product credibility.

Price Competitiveness: Costs can be reduced through large-scale production and technological optimization, while seeking government subsidies and tax incentive policy support.

7.4 Product Carbon Footprint and Green Certification

7.4.1 Carbon Footprint Accounting Requirements

Production enterprises of recycled products are encouraged to conduct product carbon footprint accounting in accordance with ISO 14067 "Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification" or GB/T 51366 "Standard for building carbon emission calculation," quantifying the carbon reduction benefits of recycled products compared to natural resource products. The accounting scope shall include the entire life cycle stages of raw material acquisition, transportation, and manufacturing.

7.4.2 Environmental Product Declaration (EPD)

Production enterprises of recycled building materials are encouraged to prepare Environmental Product Declarations (EPD) in accordance with ISO 14025 and EN 15804, publicly disclosing product environmental impact data (including Global Warming Potential GWP, Acidification Potential AP, Eutrophication Potential EP, etc.), providing a basis for green building material selection and carbon footprint calculation.

7.4.3 Green Product Certification

Recycled building materials shall actively apply for green product certification. The certification level (one-star, two-star, three-star) can serve as an important reference for engineering selection and bidding evaluation.

7.5 Demonstration and Promotion

7.5.1 Demonstration Project Construction

In cities and projects with suitable conditions, priority shall be given to the construction of demonstration projects for recycling of construction solid wastes. Typical application scenarios (such as roads, municipal works, residential buildings, public buildings, etc.) shall be selected, and full-process data collection and effect evaluation mechanisms shall be established to form replicable and scalable engineering experience.

7.5.2 Technology Promotion and Training

Regular technical training on recycling of construction solid wastes shall be organized for design, construction, supervision, inspection, and other practitioners.

Typical case collections and technical application manuals shall be compiled and widely distributed within the industry.

Through industry conferences, technical forums, and other platforms, the exchange and promotion of advanced technologies and successful experiences shall be facilitated.

7.5.3 Policy Coordination and Incentives

The inclusion of recycled building material usage ratio in green construction scoring items in project bidding shall be encouraged.

Efforts shall be made to incorporate recycling of construction solid wastes into policy frameworks such as "zero-waste city" construction, green building evaluation, and low-carbon community certification, forming positive incentive mechanisms.

Local governments shall be promoted to issue management measures for the promotion and application of recycled products, clarifying the minimum usage ratio requirements for recycled products in government investment projects (such as not less than 15%).

8 Performance Evaluation and Continuous Improvement

8.1 Performance Evaluation Indicators

The performance of recycling of construction solid wastes shall be evaluated from the following aspects:

8.1.1 Recycling Rate

Within a certain statistical period, the proportion of recycled construction solid wastes to total generation (excluding engineering spoil, calculated by volume: Recycling Rate = Volume of recycled construction wastes ÷ Total volume of construction wastes generated in the same period × 100%). This indicator is the core evaluation indicator, reflecting the overall level of recycling, and shall be separately counted and calculated by categories such as inert wastes, metal wastes, and wood wastes.

8.1.2 Recycled Product Application Rate

Within a certain statistical period, the proportion of engineering volume using recycled products to the total engineering volume of similar materials (Recycled Product Application Rate = Engineering volume using recycled products ÷ Total engineering volume of similar materials × 100%). This reflects the effectiveness of promotion and application of recycled products, and shall be separately counted by product category (recycled concrete, recycled bricks, recycled road materials, etc.).

8.1.3 On-site Classification Rate

Within a certain statistical period, the proportion of construction solid wastes collected by classification on-site to total on-site generation (On-site Classification Rate = On-site classification collection volume ÷ Total on-site generation × 100%). This evaluates the effectiveness of source classification management.

8.1.4 Resource Savings

The amount of natural resources (such as natural sand and gravel, cement clinker, etc.) replaced by the use of recycled aggregates, recycled micro powder, and other recycled products shall be calculated in tons. Replacement amount = Recycled product application amount × Natural resource replacement coefficient.

8.1.5 Environmental Benefits (Emission Reduction, Waste Reduction)

The carbon emissions avoided by recycling of construction solid wastes shall be calculated using standard coefficient methods (such as IPCC or nationally published emission factors). The accounting scope shall include:

a) Emission reduction per ton of waste: the carbon emissions avoided per ton of construction solid wastes recycled;

b) Landfill area reduction: the reduction in landfill area (in square meters) due to recycling;

c) Transportation emission reduction: the reduction in carbon emissions from long-distance transportation through on-site or nearby utilization.

d) The carbon dioxide emission reduction shall be estimated using the following simplified formula:

e) Carbon Emission Reduction (tCO_2e) = [Construction Solid Wastes Treatment Volume (t) × Waste Landfill Carbon Emission Factor (tCO_2e/t)] + [Recycled Product Replacement Volume (t) × Natural Material Production Carbon Emission Factor (tCO_2e/t)]

f) Where the carbon emission factors may be taken from the regional grid emission factors published by the competent national authorities and relevant industry average values.

8.1.6 Economic Benefits

This includes savings in resource mining costs, transportation costs, landfill costs, etc., which can be comprehensively accounted for in conjunction with annual statistical data.

8.2 Verification Methods and Basis

8.2.1 Ledger Verification

The "Construction Wastes Generation, Transportation, and Disposal Ledger" established by the construction owner/treatment enterprise shall be reviewed, including types, quantities, destinations (treatment plant names, recycled product uses, etc.), requiring complete vouchers and a closed chain. Ledger records shall be cross-verified with the process parameters and production records in Chapter 6 (Pretreatment and Recycling Technology) to ensure data consistency and reliability.

8.2.2 On-site Verification

a) Construction Site: Inspection of classification collection containers, signage, and storage conditions, and verification of the authenticity and accuracy of on-site classification rate indicator data;

b) Treatment Plant: Inspection of treatment equipment, sorting effectiveness, recycled product inventory and sales records, with emphasis on verifying whether the pretreatment process route and sorting accuracy indicators (such as light impurity content, mud content, etc.) comply with the technical requirements of Chapter 6;

c) Application Site: Verification of procurement contracts and test reports, with sampling and retesting when necessary to confirm that recycled products comply with relevant product standards, with particular attention to whether recycled aggregate grading (Level I, Level II, Level III) matches the engineering application scenario.

8.2.3 Measurement and Monitoring

Weighing using weighbridges, GPS trajectory monitoring, video surveillance, and other means shall be employed to ensure data authenticity. IoT technology is encouraged to be used for automatic collection and uploading of weight data and flow data, reducing manual intervention and recording bias.

8.2.4 Third-Party Assessment

Qualified third-party institutions shall be commissioned to conduct audits or life cycle assessments (LCA) and issue verification reports. Third-party assessment reports shall cover core dimensions such as resource utilization efficiency, environmental benefits (carbon emission reduction), and economic benefits, and shall propose improvement recommendations for non-conformities identified during the verification process.

8.3 Continuous Improvement

The level of recycling of construction solid wastes shall be continuously improved through technological progress, management optimization, and policy guidance. The functions of the "Construction Wastes Recycling Information Management Platform" shall be improved, and advanced technologies and solutions shall be promoted to achieve continuous improvement of the system, contributing to the construction of "zero-waste cities" and the achievement of "dual carbon" goals.

8.3.1 Technical Improvement

The high-quality recycled aggregate preparation technologies described in Chapter 6 (such as carbonation enhancement technology, microbial mineralization remediation technology, particle shaping technology, etc.) shall be tracked and applied to continuously optimize the performance of recycled building material products and broaden high-value-added utilization pathways.

8.3.2 Management Improvement

Through feedback from performance evaluation results, the management processes of classification management, transportation scheduling, pre-treatment process matching, and other links shall be continuously optimized to promote the efficient operation of the recycling system.

8.3.3 Policy Coordination

Coordination with policy mechanisms such as green building evaluation, low-carbon community certification, and government investment project procurement shall be strengthened. The minimum usage ratio requirements for recycled products in government investment projects shall be gradually increased to form a sustained and stable market demand.

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