Committee Report : JCI- TC231A

Technical Committee on Practical Utility of Limestone Powder for Concrete

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Abstract

The authors aimed to provide detailed guidance on employing limestone powder as a carbon-neutral material in concrete through various surveys and experimental studies. The Limestone Powder Usage Survey Working Group (WG) conducted an extensive survey to clarify its historical applications and intended uses in reinforced concrete (RC) structures and concrete products. The Cement Production Carbon-Neutral Technology Survey WG examined domestic and international uses of limestone powder and identified potential applications, including Synthetic calcium carbonate. The Ready-mixed Concrete and Concrete Product Manufacturing and Effectiveness Study Working Group assessed the performance of the material through full-scale experiments and evaluated proposed quality standards.

Keywords: Limestone powder, usage history, carbon-neutral, synthetic calcium carbonate, full-scale experiments

1. Introduction

Through fiscal year (FY) 1997, the Limestone Powder Technical Committee (former committee) of the Japan Concrete Institute evaluated the effectiveness of limestone powder in enhancing concrete performance and mitigating deteriorated aggregate conditions. That discussion presented the current state of concrete technology under the proposed classification of limestone powder as a non-binding admixture, as well as proposed limestone powder quality standards and a construction manual. Thereafter, the JCI Technical Committee on Bleeding Control for Improving the Durability of Structures examined the effectiveness of limestone powder, whereas the Japan Society of Civil Engineers (JSCE) Technical Subcommittee evaluated its role in mix design and construction techniques for high-fluidity concrete requiring compaction. Limestone effectiveness of the powder as a concrete admixture was recognized to some extent and seems to have been used in the industry for 25 years preceding the former committee; however, the precise status remained unclear. Meanwhile, emerging technologies for reducing CO_2 emissions related to concrete have emerged, including techniques for absorbing CO_2 into concrete and producing calcium carbonate powder by reacting unreacted cement with CO_2. International initiatives to achieve carbon neutrality through cement standards incorporating limestone powder have fostered the notion that limestone powder may address environmental issues.

The survey conducted in preparation for launching the technical committee revealed that: (1) previously published literature and industry association statistics lacked detailed information on limestone powder performance in concrete; (2) international cement standards such as EN endorse limestone powder use in concrete, implying potential strength improvements when limestone powder is incorporated; (3) details concerning the manufacturing process and distribution of limestone powder remain unclear, raising concerns regarding material supply, storage at ready-mix concrete plants, and suggesting that limestone powder may effectively improve the surface quality of concrete products. Consequently, the technical committee was established to conduct detailed investigations and experimental studies to verify its effectiveness and to provide accurate information to users for the active utilization of limestone powder as a carbon-neutral material in the concrete industry.

2. Composition of Technical Committee

Table 1 lists the composition of the Technical Committee. The committee established three working groups (WGs) to address the issues identified in the survey.

(1) Concrete Limestone Powder Usage Survey

WG1 resolved to clarify the current performance of concrete incorporating limestone powder by reviewing its application to concrete structures, its manufacturing and shipping records, and by administering a detailed questionnaire survey on the characteristics, shipping records, and management practices related to limestone powder production and distribution.

(2) Cement Production Carbon-Neutral Technology Survey

WG2 conducted a literature-based survey on the utilization of limestone powder in cement manufacturing, encompassing international applications. Furthermore, the working group examined case studies of limestone powder and synthesized $CaCO_3$ powder as carbon-neutral technologies and assessed future prospects.

(3) Ready-Mixed Concrete and Concrete Product Manufacturing and Effectiveness Study

WG3 performed experiments to evaluate the effects of limestone powder in concrete products and other applications, clarifying its effectiveness and guiding proposed quality standards.

Table 1: Committee Members

Chair	Shigeki Seko	(Aichi Institute of Technology)
Vice-chair	Yoshitaka Kato	(Tokyo University of Science)
Secretary	Shuzo Otsuka	(Institute of Technologists)
	Yusuke Kirino	(Taiheiyo Cement Corporation)
	Kuniaki Sakurai	(Obayashi Corporation)
	Sumie Suzuki	(Kogakuin University)
Committee member	Daiki Atarashi	(Shimane University)
	Koji Ito	(Japan Ready-Mixed Concrete Industry Association (ZENNAMA))
	Takeshi Iyoda	(Shibaura Institute of Technology)
	Takashi Kamigouchi	(Sumitomo Osaka Cement)
	Sang Cheol Shin	(Kongju National University)
	Masashi Shinsugi	(Obayashi Corporation)
	Kengo Seki	(Kajima Corporation)
	Shigeyuki Sogo	(Near Future Concrete Association)
	Ryota Takagi	(Ube Material Industries Ltd.)
	Masahito Shizuno	(Shimizu Kogyo Co., Ltd.)
	Yuta Furukawa	(Tokyu Construction)
	Kazuhide Hoshi	(Yamaso Chemical Co., Ltd.)
	Tadashi Yanagita	(Nitto Kogyo Corporation)
Advisor	Etsuo Sakai	(Professor Emeritus, Institute of Science Tokyo)

3. Results of Activities in the Concrete Limestone Powder Usage Survey WG

3.1 Purpose and Method of Questionnaire Survey

(1) Purpose of Survey

In this survey, the working group reviewed the application of limestone powder in concrete within Japan from the former committee to the present, with emphasis on RC structure types and concrete products. The investigation targeted four organization categories: general contractors, concrete product manufacturers, limestone powder manufacturers, and ready-mix concrete plants. This comprehensive study assessed the current situation in Japan, including applications of limestone powder in RC structures and concrete products, limestone powder–related items, quality control issues in limestone powder–infused concrete, and the newly developed synthetic $CaCO_3$ powder.

(2) Survey Method

The survey spanned July–August 2024 and included Organizations Representing Nationwide General Contractors, the Japan Concrete Products Association for concrete product manufacturers, the Limestone Association of Japan and Japan Lime Association for limestone powder manufacturers, and the Japan Ready-Mixed Concrete Industry Association (ZENNAMA) for ready-mix concrete plants.

The respondents could choose online or paper formats; paper responses were returned by mail or email.

The technical committee report detailed the survey items and questions. The items were broadly categorized as impressions of limestone powder; examples of its applications; manufacturing; quality control; distribution/supply; measurement/storage; quality control of concrete incorporating limestone powder; challenges in its utilization; and new calcium carbonate powders. Specific questions and respondent populations were designated for each category.

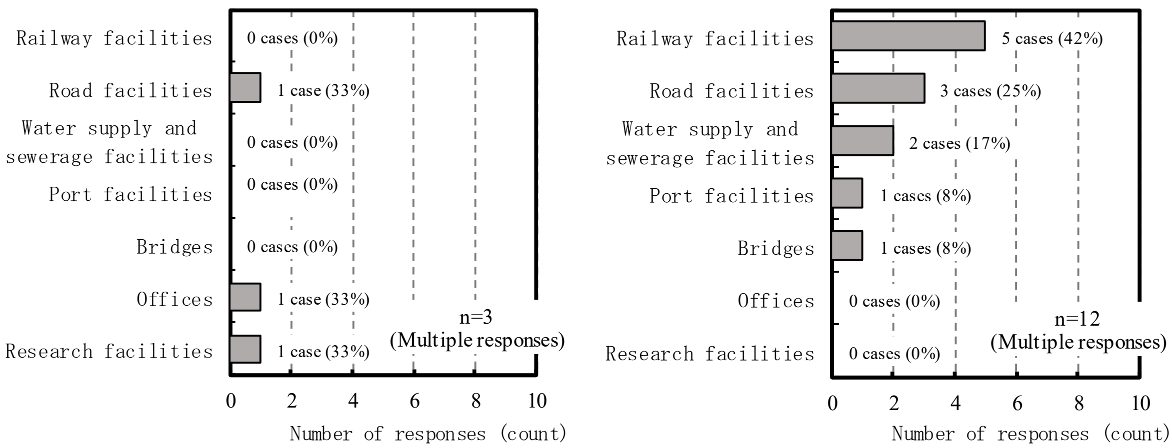
3.2 Summary of Survey Results

(1) Limestone Powder Application to RC Structures

When asked about the application of limestone powder in RC structures, 74% of general contractors and 90% of ready-mix concrete plants reported “no application cases,” with only three cases among general contractors.

(2) Uses of RC Structures Using Limestone Powder

Figure 1 illustrates the uses of RC structures incorporating concrete mixed with limestone powder. Among general contractors, the top uses were “road facilities,” “offices,” and “research facilities”; at ready-mix concrete plants, they were “railway facilities,” “road facilities,” and “water supply and sewerage facilities.” Meanwhile, a 2024 survey report[1)] by ZENNAMA on slump flow–managed concrete mixes at ready-mix plants indicated that, among 445 mixes reported by 312 plants, seven utilized limestone powder in RC structures.



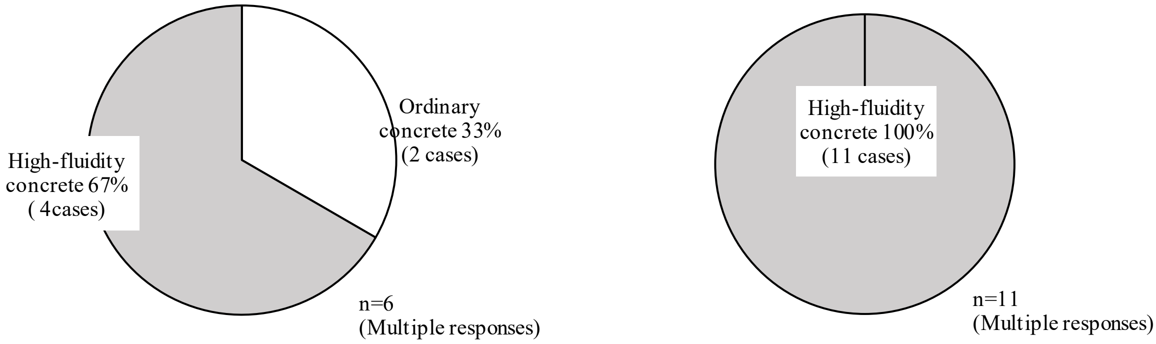
(a) general contractors (b) ready-mix concrete plants

Fig. 1: Uses of concrete mixed with limestone powder in RC structures

The seven RC structures comprised tunnel top slabs, filled concrete, box culverts, high-rise RC buildings or large-span structural members, substructures for seismic isolation foundations, and two unidentified uses. All mixes were high-fluidity concrete with slump flows of 60–70 cm.

(3) Types of concrete mixed with limestone powder used in RC structures

Figure 2 illustrates the types of concrete mixed with limestone powder in RC structures. “High-fluidity concrete” was employed in 67% of general contractor applications and 100% of ready-mix concrete plants. This trend aligns with the former committee's report[2)], which determined that high-fluidity concrete comprised approximately 80% of applications and indicates its ongoing prevalence.

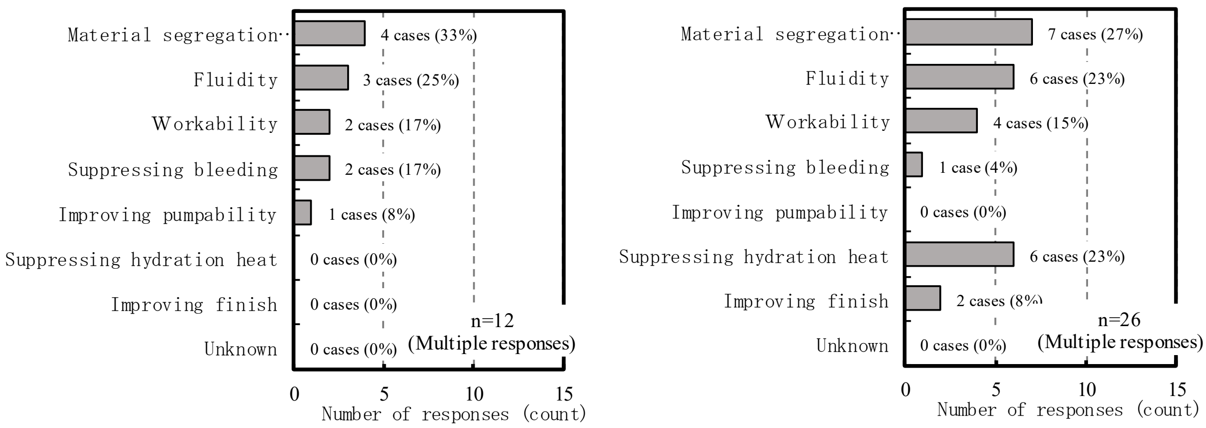


(a) general contractors (b) ready-mix concrete plants

Fig. 2: Types of concrete mixed with limestone powder used in RC structures

(4) Purposes of use of concrete mixed with limestone powder used in RC structures

Figure 3 illustrates the purposes of using concrete mixed with limestone powder in RC structures. Among general contractors, objectives included "material segregation resistance," "fluidity," and "workability," whereas ready-mix concrete plants aimed to ensure "material segregation resistance," "fluidity," "reduced heat of hydration," and "workability."



(a) general contractors (b) ready-mix concrete plants

Fig. 3: Purposes of Use of Concrete Mixed with Limestone Powder in RC Structures

As noted previously, most concrete mixed with limestone powder is high-fluidity, likely accounting for the respondents' similar selections.

(5) Use of Limestone Powder in Concrete Products

As shown in **Figure 4**, 58% of respondents reported "no application cases" when asked about the application of limestone powder in concrete products, exceeding the proportion indicating "application cases present." This percentage was considerably higher than that for the use of limestone powder in RC structures, suggesting that limestone powder is employed more often in concrete products than in cast-in-place concrete.

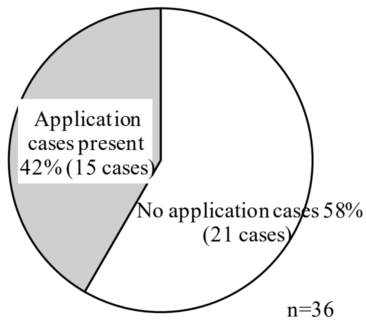


Fig. 4: Use of Limestone Powder in Concrete Products

(6) Uses of Concrete Products Using Concrete Mixed with Limestone Powder

Figure 5 illustrates the uses of concrete products incorporating concrete mixed with limestone powder. The primary applications were "underground drains," "retaining walls," "irrigation and drainage channels," and "road drainage gutters," with little difference in their frequency.

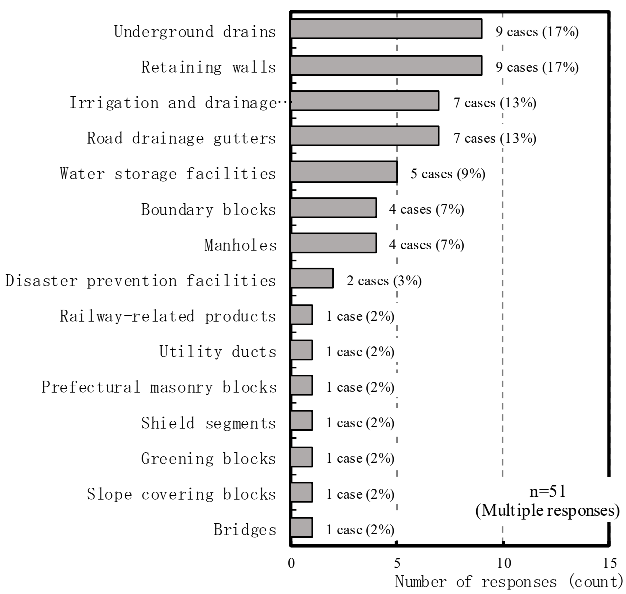


Fig. 5: Uses of concrete products using concrete mixed with limestone powder

(7) Types of concrete mixed with limestone powder used in concrete products

Figure 6 illustrates the types of concrete mixed with limestone powder employed in concrete products. “High-flow concrete” accounted for 90% of such products, a trend similar to that observed in RC structures.

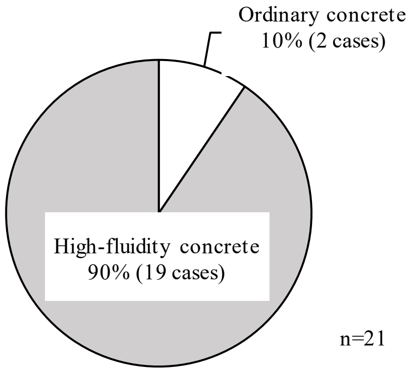


Fig. 6: Types of concrete mixed with limestone powder used in concrete products

(8) Purposes of use of concrete mixed with limestone powder used in concrete products

Figure 7 illustrates the purposes of using concrete mixed with limestone powder in concrete products. The key purposes were to ensure fluidity, prevent material segregation, and maintain workability, in that order. As noted in the previous section, most responses regarding the use of concrete mixed with limestone powder pertained to high-fluidity concrete.

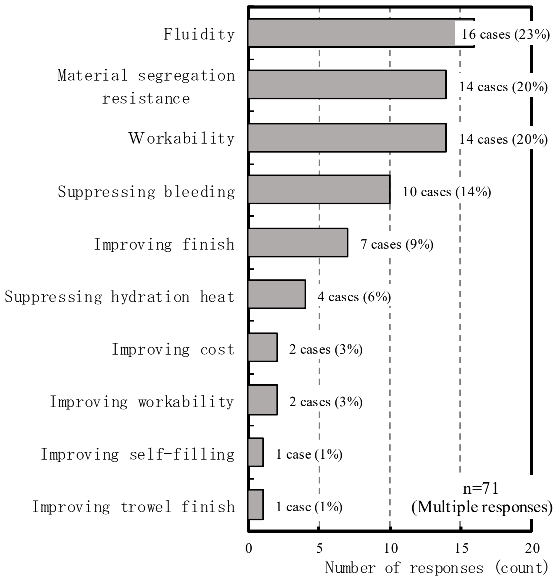


Fig. 7: Purposes of use of Concrete Mixed with Limestone Powder in Concrete Products

4. Results of Activities in the Cement Production Carbon-Neutral Technology Survey WG

4.1 Environmental Impact Reduction Effect of Limestone Powder

(1) Environmental Impact Reduction Effect of Limestone Powder in Concrete

Assessing the environmental impact reduction effect of limestone powder requires comparisons with concrete mixtures of equivalent compressive strength. Replacing limestone powder with cement reduced compressive strength; therefore, modifications such as reducing the water–powder ratio or altering the cement design were required[3)]. A study by the Japan Cement Association[4)] demonstrated that using triisopropanolamine (TIPA) to increase C4AF activity and a superplasticizer to reduce unit water content maintained compressive strength without changing the unit powder amount even with added limestone. Consequently, the CO_2 reduction effect was proportional to the amount of limestone added.

(2) Environmental Impact Reduction Effect of Synthetic Calcium Carbonate

Recent developments have focused on reducing CO_2 emissions by capturing CO_2 from factory emissions and fixing it in CaO present in waste and by-products such as waste concrete, thereby forming synthetic calcium carbonate. These technologies, which also fix CO_2, are expected to yield a greater environmental impact reduction than limestone powder. They can also increase the utilization of waste and by-product, and decrease mineral resource consumption.

An accurate determination of CO_2 reduction effects requires accounting for both CO_2 sequestration and the emissions from electricity and fuel use during CO_2 fixation and CaO extraction. Moreover, if other raw materials are needed for CaO extraction, the CO_2 emissions associated with their manufacture must be considered.

Although evaluations of CO_2 fixation and emissions in synthetic $CaCO_3$ remain limited, this technical committee report describes a case study in which synthetic $CaCO_3$ was produced by extracting CaO from concrete sludge with water and reacting it with exhaust□gas CO_2. The report also outlines a method to improve CO_2 absorption efficiency with other CaO sources, such as municipal waste incineration ash or steelmaking slag.

4.2 Limestone Powder in Cement Standards

(1) Limestone Powder in Japan Cement Standards

The Japan cement standard (JIS R 5210:2019 Portland Cement) specifies limestone quality as a minor additional constituent, with ordinary, high-early-strength, and ultra-early-strength Portland cement requiring 0–5%. Similar requirements appear in JIS R 5211:2019 Portland Blast-furnace Slag Cement, JIS R 5212:2019 Portland Pozzolan Cement, and JIS R 5213:2019 Portland Fly-ash Cement. JIS R 5214:2019 Ecocement specifies limestone content from 0% to 5%.

The draft Technical Report on Limestone Filler Cement recommends a specific limestone quality. This requirement aims to optimize limestone resource utilization and limit clay content, which influences dosage of admixture during concrete production.

(2) Draft Technical Report on Limestone Filler Cement in Japan

The Japan Cement Association proposed a draft Technical Report on Limestone Filler Cement[4)]; however, its quality specifications were based on EN 197-1:2000, and all items except compressive strength conformed to the JIS cement quality standards at that time.

(3) Limestone Powder in EU Cement Standards

EN 197-1 and EN 197-5 specify limestone criteria by classifying material into classes L and LL according to total organic carbon content. Other than total organic carbon, only $CaCO_3$ content and methylene blue adsorption are specified, presenting fewer criteria than the draft JCI quality standard (1998). Furthermore, the EN specifications are less stringent. Although the methylene blue adsorption method differed, the specified values varied by a factor exceeding 10. EN 197-5 mandates a minimum $CaCO_3$ content of 40 %, representing less than half the limit set in the draft JCI quality standard (1998). This likely arises from distinct EN cement specifications and the assumption that concrete employs limestone at low unit content.

(4) Quality Comparison of Limestone-blended Cement in Each Country

The quality of the limestone-blended cement in the EU (EN 197-1), US (ASTM C595), and Japan (Draft Technical Report on Limestone Filler Cement, 2001) is comparatively outlined in

Table 2. The EU standard and the Japanese standard use the same compressive strength grade. Although the EU and Japan do not impose strict standards for loss on ignition, the US stipulates an upper limit of 10%. Therefore, despite several similarities between national standards, differences exist based on the construction environment of each country and technical requirements such as strength level classification, specific surface area requirements, mortar air content, chemical composition limits, and ignition loss control standards.

4.3 Case Studies of Synthetic Calcium Carbonate Development

Technologies aiming to achieve carbon neutrality have been developed by incorporating synthetic calcium carbonate—produced by reacting calcium in waste materials with carbon dioxide—into cement and concrete. Recent advances in synthetic calcium carbonate production were investigated and are summarized below.

Some synthetic calcium carbonates possess a significantly larger specific surface area than limestone powder, and others exhibit chemical compositions that do not meet the draft JCI quality standard (1998). This discrepancy is attributed to the synthesis method, such as precipitation in the liquid phase. Moreover, although synthetic calcium carbonate tends to reduce fluidity when incorporated into concrete, no significant effects on strength or durability have been confirmed, and studies demonstrated that quality can be maintained by modifying the concrete mixture and chemical admixtures. Certain synthesis methods have minimal impact on fluidity, suggesting potential for improvement, and reports of synthetic calcium carbonate applications in concrete products and structures indicate that its use as an admixture is expected to expand in the future.

Table 2. Comparison of limestone powder cement quality in each country

Item		EU (EN 197-1)						US (ASTM C595)	Japan (Draft Technical Report, 2001)			
Mix proportion (%)		Type A : 6~20, Type B : 21~35						5~15	Type A : 6~20, Type B : 21~35			
Strength class		32.5N	32.5R	42.5N	42.5R	52.5N	52.5R	IL & IT	32.5N	32.5R	4.25N	42.5R
Density (g/cm^3)		-						Report	-			
Specific surface area (cm^2/g)		-						Necessary	≧2500			
Settling	Initial (min)	≧75		≧60		≧45		≧45	≧60			
	Final (h)							≦7	≦10			
Soundness	Autoclave expansion (%)	-						≦0.8	-			
	Autoclave shrinkage (%)	-						≦0.2	-			
	Le Châtelier method (mm)	≦10							≦10			
Mortar air content (%)								≦12				
Compressive strength (MPa)	2d	-	≧10	≧10	≧20	≧20	≧30		-	≧10	≧10	≧20
	3d	-	-	-	-	-	-	≧13	-	-	-	-
	7d	≧16	-	-	-	-	-	≧20	≧16	-	-	-
	28d	≧32.5 ≦52.5		≧42.5 ≦62.5		≧52.5		≧25	≧32.5 ≦52.5		≧42.5 ≦62.5	
Magnesium oxide (%)		-						-	≦5.0			
Sulfur trioxide (%)		≦3.5			≦4.0			≦3.0	≦3.0			
Total alkali(%)		-						-	≦0.75			
Chloride ion (%)		≦0.1						-	≦0.02			
Ignition loss(%)		-						≦10	-			

5. Results of Activities in the Ready-Mixed Concrete and Concrete Product Manufacturing and Effectiveness Study WG

As reported in Vol. 47 of the Proceedings of the Japan Concrete Institute, the WG conducted full-scale experiments using concrete blended with limestone powder in proportions relative to cement. An overview follows.

5.1 Full-Scale Experiment Combinations

Table 3 lists seven experimental combinations of limestone powder types and quantities.

Table 3: Experimental Combinations

Limestone powder type {fineness}	Presence of reaction accelerator	Calcium carbonate mixing ratio (%) (outer percentage of cement)		
		0	10	15
Calcium carbonate [4000 Blaine]	None	○	○	○
	Present*	—	○	—
Calcium carbonate [3000 Blaine]	None	—	○	—
Calcium carbonate [1000 Blaine]	None	—	○	—
Artificial calcium carbonate [6000 Blaine]	None	—	○	—

*Triisopropanolamine used as reaction accelerator

5.2 Experimental Conditions

The full-scale experiment mixed concrete at a 44 % water–cement ratio and a 15 cm design slump using a real-scale machine; it assessed fresh and hardened properties and determined final surface characteristics by comparison with those of a full-scale L-shaped retaining wall. The complete experimental setup is depicted in **Figure 1**, including various tests and the pouring process into the L-shaped retaining wall formwork.

Photograph 1. Various tests and pouring into L-shaped retaining wall formwork

5.3 Summary of Experimental Results

Overall, the experimental procedure was comprehensive and systematic, and the results are as follows:

1) At 91 d, concrete produced with a 4000 Blaine fineness limestone powder blend at 10% exhibited higher compressive strength compared with mixtures incorporating other fineness levels, types, or proportions.

2) The color measurements recorded up to 5 months indicated that lightness (L* value) increased gradually with age. Variations in fineness and type did not significantly affect lightness; nevertheless, the chroma values (a* and b*) for calcium carbonate at 4000 Blaine fineness were higher than those obtained using other variants.

6. Summary

This technical committee investigated the use of limestone powder in the concrete industry by summarizing its potential as a carbon-neutral material, its historical applications, and current challenges to provide stakeholders with accurate information.

Although the objectives and content regarding limestone powder usage have largely aligned with the previous committee's findings, a questionnaire survey identified persistent issues in concrete manufacturing. Combining limestone powder and synthetic $CaCO_3$ powder with cement presents the potential to reduce CO_2 emissions, and continued evaluation of material quality standards remains essential. Full-scale experiments with concrete incorporating various limestone powder types clearly demonstrated their effects. The authors assert that the committee's report will foster technological advancement by promoting widespread adoption of these results.

References

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3) Japan Concrete Institute: Report of the Technical Committee on Environmental Impact Assessment of Cement and Concrete, September 2024

4) Japan Cement Association: Report of Committee on Limestone Filler, 2001