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An Investigation Report on Durability Properties of Self Compacting Concrete Made with Recycled Fine Aggregates

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Abstract: Self-compacting concrete (SCC) is a unique type of concrete that possesses the remarkable ability to be effortlessly placed within formwork without requiring external compaction through vibration. Introduced in Japan in 1988, SCC has rapidly gained widespread recognition and acceptance in Japan, Europe, and the USA, primarily due to its numerous inherent advantages. The utilization of SCC yields enhanced concrete quality, particularly in structural elements with complex reinforcement arrangements or areas where reducing permeability and improving concrete durability are crucial. SCC's most notable feature is its ability to flow freely and effortlessly into intricate formwork, thanks to its exceptional workability. This self-leveling property is achieved by incorporating specifically designed chemical admixtures that improve fluidity and cohesiveness without compromising the concrete's stability. Unlike conventional concrete, SCC eliminates the need for compaction through mechanical vibration, significantly reducing labor and time requirements during construction. The application of SCC is particularly advantageous in scenarios where reinforcing bars are densely packed or congested within the concrete element. Conventional concrete often struggles to fill such areas effectively, resulting in voids or inadequate compaction, compromising the structural integrity. In contrast, SCC's exceptional flowability ensures complete filling, resulting in a uniform and robust concrete matrix, effectively enhancing the overall quality and strength of the structure. Furthermore, SCC exhibits improved durability characteristics, contributing to its widespread adoption. The reduction in permeability achieved by SCC results in decreased water and chemical ingress, minimizing the likelihood of deterioration caused by corrosion or other chemical reactions. This enhanced durability extends the service life of structures, reducing the need for costly repairs and maintenance.

Keywords: Self compacting concrete (SCC), Workability, Reinforcement congestion, Durability, Permeability.

1. INTRODUCTION

Cement-based materials hold great significance as they are the most abundant and vital construction materials, and their importance is expected to persist in the future. However, these materials face new and elevated demands in terms of productivity, economy, quality, and environmental considerations. They must compete with alternative construction materials like plastic, steel, and wood. In response to these challenges, one notable development is the emergence of self-compacting concrete (SCC), a modified product that can flow and consolidate under its own weight without requiring additional compaction energy. Self-compacting concrete, as the name suggests, is a type of concrete that can compact itself, eliminating the need for additional compaction efforts. The introduction of SCC has been highly desirable in the construction industry, as it helps overcome various issues associated with cast-in-place concrete. One key advantage of SCC is that it is not reliant on the skills of workers, the configuration and quantity of reinforcing bars, or the arrangement of the structure. Additionally, its high fluidity and resistance to segregation enable it to be pumped over longer distances, expanding its range of applications (Bartos, 2000).

2. BACKGROUND OF SELF COMPACTING CONCRETE (SCC)

While it is true that concrete structures have been constructed without the use of vibration in certain cases, such as underwater placement using tremie methods, mass concrete, and shaft concrete, these examples generally involve lower-strength concrete and pose challenges in achieving consistent and reliable quality. The advent of modern self-compacting concrete (SCC) has focused on addressing these limitations and aiming for high-performance concrete with improved uniformity and reliability. The concept of self-compacting concrete is not entirely new. Early versions of self-compacting concrete relied on high proportions of cement paste, and with the introduction of superplasticizers, they were incorporated into concrete mixes. However, these mixes required specialized and carefully controlled placement methods to prevent segregation, and the high cement paste content made them susceptible to shrinkage.

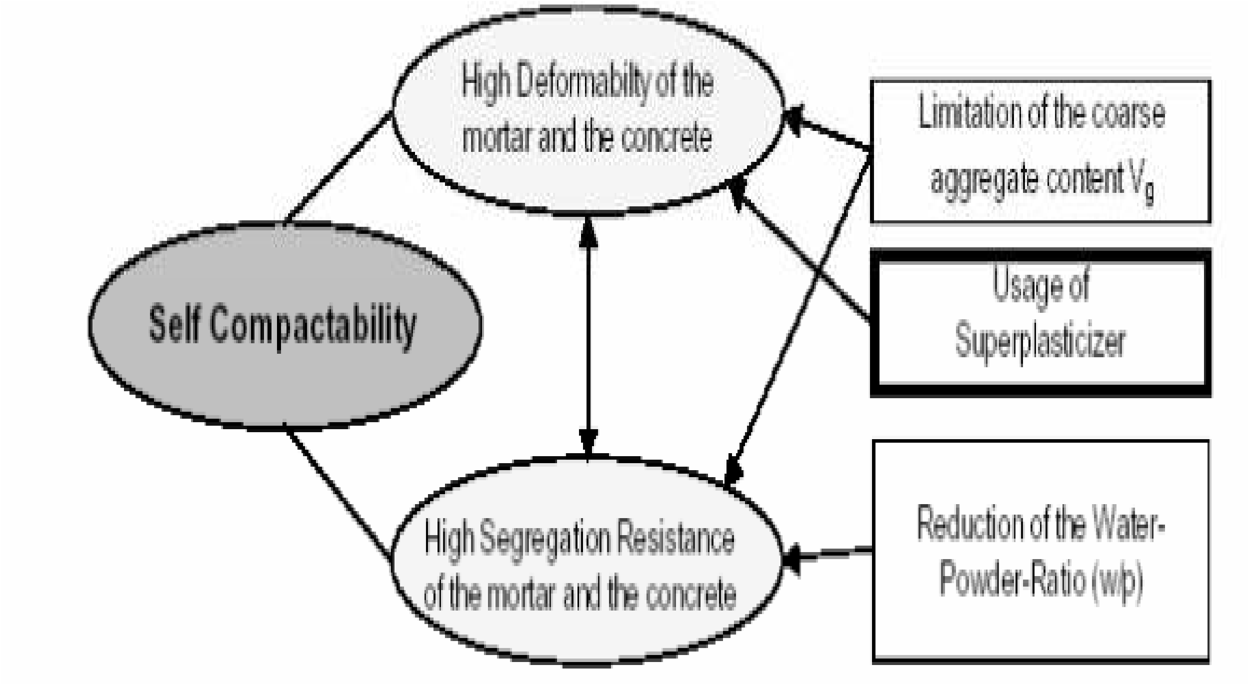

Figure 1: Basic principles for the production of SCC (Dehn et al., 2000)

3. ADVANTAGES OF SELF COMPACTING CONCRETE (SCC)

Self-compacting concrete (SCC) can be considered as one of the most groundbreaking advancements in concrete construction in recent decades. Initially developed to address the shortage of skilled labor, it has proven to be economically beneficial for several reasons, as outlined below (Krieg, 2003 and ENFARC, 2002).

- Accelerated Construction
- Manpower Reduction
- Ease of Placement
- Uniform Consolidation

- Enhanced Surface Finishes
- Improved Durability
- Increased Bond Strength
- Design Flexibility
- Reduced Noise Levels
- Safe Working Environment

4. RECYCLING OF WASTE CONCRETE AGGREGATES

Concrete recycling has become increasingly popular as a method of utilizing rubble when structures made of concrete are demolished or renovated. In the past, concrete was often sent to landfills for disposal, but recycling offers several benefits that make it a more attractive option in today's environmentally conscious era, with stricter environmental regulations and a focus on cost reduction in construction. The process of concrete recycling involves crushing the concrete aggregate obtained from demolition sites using specialized crushing machines. These facilities only accept uncontaminated concrete, which means it must be free from materials such as trash, wood, paper, and other contaminants. However, metals like rebar are accepted since they can be separated using magnets and other sorting devices and then melted down for recycling purposes elsewhere. The remaining chunks of aggregate are then sorted based on size, and larger pieces may undergo another round of crushing if needed. Once the crushing process is complete, additional particulates are filtered out using various techniques, including manual picking and water flotation. By recycling concrete, several advantages are realized. Firstly, it helps to reduce the burden on landfills and promotes sustainability by reusing materials. Additionally, concrete recycling minimizes the extraction and consumption of natural resources required for producing new concrete. It also contributes to cost savings in construction projects, as recycled concrete can be used as a substitute for new aggregates. Furthermore, recycling concrete helps to lower carbon emissions associated with transportation and manufacturing processes. In summary, concrete recycling has gained popularity due to its ability to utilize demolished or renovated concrete structures effectively. By crushing and sorting the concrete aggregate, contaminants are removed, and the recycled material can be used in various construction applications. This approach aligns with environmental goals, adheres to regulations, and offers cost-effective solutions in the construction industry.

5. LITERATURE REVIEW

This section presents a comprehensive overview of the research conducted on the testing of self-compacting concrete using different cementitious materials and admixtures. It discusses the extensive work carried out by various researchers in the field of self-compacting concrete, with a primary emphasis on the durability aspects of SCC.

Gesoglu et al.(2015) The experimental study yielded the following conclusions: (i) The incorporation of recycled concrete aggregates (RCA) and/or recycled fine aggregates (RFA) led to an increase in chloride-ion permeability in self-compacting concretes (SCCs) due to their highly permeable and porous structure. Series II mixes demonstrated better resistance to chloride ingress compared to Series III mixes, and the negative impact of recycled aggregates on chloride ion permeability diminished when the water-to-binder (w/b) ratio was decreased and supplementary cementitious materials (such as silica fume) were added. (ii) SCCs incorporating RCAs and/or RFAs exhibited higher sorptivity coefficient values, indicating increased capillarity due to larger mean pore size and total porosity in the concrete containing recycled aggregates. (iii) The SCC mix with a combination of 43% RCA, 100% RFA, and 100% silica fume (denoted as mix 0.43RCA100RFA100SF0) demonstrated the highest gas permeability coefficient of 8.82 × 10^(-16) m². The increased gas permeability can be attributed to the addition of recycled aggregates, which resulted in an augmented pore structure within the concrete.

Archbold et al.(2016) There is a growing demand for substituting virgin materials in the production of construction materials on a large scale, driven by environmental concerns regarding traditional production methods and waste disposal. To address these concerns, using recycled materials in concrete production has emerged as a viable approach to simultaneously meet these demands and reduce landfill waste. This study focuses on the preliminary testing of two types of waste ceramics: ceramic foundry casts and ceramic waste sludge. These ceramics were examined as partial replacements for both the cementitious material and fine aggregates in self-compacting concrete. The assessment involved evaluating properties such as rheology, compressive strength, and durability. The study compared the impact of this partial replacement with findings from similar studies. The results align with previously published values and suggest that these waste ceramics have potential for further investigation and utilization. They indicate that incorporating ceramic materials in self-compacting concrete can enhance durability and maintain satisfactory compressive strength. However, it should be noted that the addition of ceramic materials reduces the passing and filling ability of the self-compacting concrete mix.

Hadadi et al.(2018) To overcome the challenge of natural aggregate availability, various alternatives are being explored. These include manufactured aggregates, quarry waste, crushed sandstone aggregates, recycled materials from construction and demolition waste, copper slag, crushed sand from different mineral sources, and waste aggregates from marble and granite, among others. Research studies have shown that these waste or by-products can be utilized as partial replacements for river sand in concrete production. Fly ash, a waste product from the coal industry with pozzolanic properties, is particularly recommended as a cement replacement material for environmentally-friendly initiatives. This paper presents the results of laboratory investigations on self-compacting concrete (SCC) following the guidelines set by the European Federation of National Associations Representing Concrete (EFNARC). The study focuses on using Processed Slag Sand (PSS) as a complete replacement for fine aggregates and Class C fly ash as a partial replacement for cement. The results of flow, strength, and durability tests for this innovative SCC formulation were found to be highly satisfactory when compared to the control concrete.

Prakash et al.(2018) The results demonstrate that incorporating recycled concrete aggregates (RCA) as a partial replacement for coarse aggregate allows for the production of sustainable concrete. The self-compacting concrete (SCC) containing RCA achieved the target strength and complied with the EFNARC specifications. However, an increase in the amount of RCA replacement led to a reduction in the strength properties of SCC at all curing ages, although the optimal results were observed at a replacement level of 20-25%. Carbonation testing revealed a decrease in carbonation depth with higher percentages of RCA. The water absorption and sorptivity of SCC with RCA were higher compared to conventional SCC. However, the ultrasonic pulse velocity (UPV) test indicated that the quality of concrete was not significantly affected by the use of RCA as a coarse aggregate. It should be noted that SCC with RCA is not recommended for marine environments due to its higher susceptibility to chloride ion permeation compared to conventional SCC.

Nili et al.(2019) The research conducted in this study yielded several noteworthy results: (1) The use of recycled aggregates in concrete led to a decrease in slump flow, but this reduction could be mitigated by incorporating higher amounts of superplasticizer. Furthermore, self-compacting recycled concrete demonstrated acceptable passing ability in the J-ring test. (2) Replacing recycled aggregates in mixtures with an air-entraining admixture resulted in a reduction in compressive strength, although there was no significant impact on splitting tensile strength. (3) Complete replacement of coarse recycled concrete aggregates did not adversely affect the compressive and tensile strength of silica fume mixtures. However, the incorporation of fine recycled aggregates had a negative influence on the compressive and tensile strength of the corresponding recycled aggregate concrete mixes.

Sasanipour et al.(2019) This study focused on enhancing the properties of self-compacting concrete (SCC) by incorporating silica fume as part of the cementitious materials. The SCC was prepared using both fine and coarse recycled aggregates. Three series of mixtures were created for experimentation. The first and second series involved the replacement of coarse recycled aggregates with 25%, 50%, 75%, and 100% replacements, with and without silica fume. In the third series, 25% of the fine recycled aggregates were substituted with fine natural aggregates. The fresh state properties of the SCC were assessed using slump flow and J-ring tests. For hardened concrete, tests were conducted to evaluate compressive strength, water absorption, ultrasonic pulse velocity, electrical resistivity, and chloride ion penetration. The results indicated that the addition of silica fume improved the fresh properties of SCC. Silica fume also contributed to a reduction in water absorption and porosity of the concrete. Additionally, it significantly increased the electrical resistivity. However, the replacement of 25% of the recycled aggregates did not have a significant impact on electrical resistivity, whereas higher replacement levels led to a decrease in electrical resistivity. Silica fume exhibited a strong ability to control chloride ion penetration and reduce the total charge passed through the concrete.

Barroqueiro et al.(2020) The primary aim of this research paper is to offer the industry a practical and straightforward method for managing and reusing rejected precast reinforced concrete elements through the utilization of recycled waste. This approach aims to minimize the consumption of natural resources in concrete production and significantly reduce the environmental impact associated with construction and demolition waste, as well as the extraction of natural aggregates. The study focuses on evaluating the feasibility of producing high-performance self-compacting concrete (SCC) with reduced environmental impact by substituting natural aggregates with fine and coarse recycled aggregates obtained from the precast industry. The goal is to demonstrate that these recycled aggregates can be used in the industrial process without concerns about the expected durability performance. To achieve this, six different types of SCC incorporating varying proportions of recycled aggregates were produced. Tests were conducted to characterize the concrete's transport and degradation mechanisms, including water absorption, capillary water absorption, oxygen permeability, chloride migration, electrical resistivity, and carbonation. The results clearly indicate that despite the negative influence of recycled aggregates, it is still possible to produce high-performance SCC with durability properties that meet acceptable standards.

Kapoor et al.(2020) This article presents an experimental investigation into the fresh and hardened properties of Self Compacting Concrete (SCC) incorporating Recycled Aggregates (RA). The study involves replacing Natural Coarse Aggregates (NCA) with Recycled Coarse Aggregates (RCA) at 0%, 50%, and 100% replacement levels, as well as replacing Natural Fine Aggregates (NFA) with Recycled Fine Aggregates (RFA) at 0%, 25%, 50%, 75%, and 100% replacement levels. Additionally, Fly Ash (FA) partially substitutes Portland cement (PC) by 30% weight to promote sustainable development. The main objective of this study is to assess the practical application of RCA and RFA in SCC mixes and evaluate their performance in both fresh and hardened states. Workability tests such as the Slump-flow test, T500 test, V-funnel test, and L-box test were conducted to examine the fresh properties of the different SCC mixtures. The Ultrasonic Pulse Velocity (UPV) test was performed to assess the hardened state of all SCC mixes, and the compression strength results are also presented in relation to the concrete's workability. The findings indicate that the substitution of RCA and RFA for NCA and NFA, respectively, reduces the workability properties of the concrete due to the higher water absorption and larger surface area of RCA and RFA compared to NCA and NFA, respectively.

Poongodi et al.(2021) This research focused on assessing the durability properties of self-compacting concrete (SCC) incorporating recycled aggregate for pavement applications. The study aimed to compare the performance of the developed SCC mixture with that of normal pavement concrete through permeability, water absorption, and chloride penetration tests. Three different replacement percentages of recycled concrete aggregates (RCA) were considered: 20%, 40%, and 60%, in addition to the control concrete with no replacement (0%). A ternary blended concrete with Ordinary Portland cement (OPC), fly ash, and silica fume was designed for achieving a grade M40 level. The fresh properties of the concrete were evaluated using slump flow and V-funnel flow tests. The results demonstrated that the SCC mixture containing up to 40% RCA exhibited enhanced resistance to water absorption and chloride penetration compared to a similar mixture made with normal-weight concrete.

Kapoor et al.(2021) This paper examines the durability properties of Self-Consolidating Concrete (SCC) incorporating fine and coarse recycled concrete aggregates. The SCC mixtures were prepared by substituting Fine Natural Aggregates (FNA) with Fine Recycled Concrete Aggregates (FRCA) at 0%, 25%, 50%, 75%, and 100% levels, while Coarse Natural Aggregates (CNA) were partially replaced (50%) with Coarse Recycled Concrete Aggregates (CRCA). To enhance durability, Ordinary Portland Cement (OPC) was blended with 30% Fly Ash (FA), further substituted with 10% Metakaolin (MK). The durability parameters were evaluated through various tests, including Initial Surface Absorption Test (ISAT), Water Penetrability Test, Rapid Chloride Penetrability Test (RCPT), and Capillary Suction Test (CST). Compressive strength and Ultrasonic Pulse Velocity (UPV) tests were also conducted. The results indicated that the durability and compressive strength properties of the SCC mixtures deteriorated with the replacement of both CNA and FNA. However, the addition of MK proved effective in maintaining the durability properties, with values comparable to the control mix even with 75% FRCA and 50% CRCA content. The compressive strength showed a 9.3% decrease with 100% FRCA and 50% CRCA content, but the presence of MK compensated for this, resulting in only a 4.5% drop. Additionally, all SCC mixtures containing CRCA, FRCA, and MK exhibited excellent UPV values.

Panaite et al.(2022) This article presents an experimental study on self-compacting concrete (SCC) that utilizes various percentages of recycled aggregates, aiming to achieve a sustainable and environmentally friendly construction material. Ten different compositions of SCC were prepared, with the main recipe determined through trial and error based on Eurocode recommendations. The cement, limestone, and fine aggregates were replaced with different recycled materials, including fly ash, blast furnace slag, crumb rubber, and brick dust, as specified in Table 1. The article focuses on analyzing the properties of SCC incorporating these recycled materials. To enable a meaningful comparison between the ten recipes, no changes were made except for variations in water and superplasticizer quantities to account for the different absorption characteristics of the recycled materials. The water-to-cement (w/c) ratio ranged from 0.38 to 0.63, while the superplasticizer dosage varied from 0.8% to 1.3% of the cement content.

Changming et al.(2022) This paper presents a review of research investigating the impact of recycled fine aggregates (RFAs) on various durability aspects of concrete, including permeability, drying shrinkage, carbonation, chloride ion penetration, acid resistance, and freeze-thaw resistance. The findings indicate that the durability of RFA concrete is influenced by factors such as the content of old mortar and the quality of the recycled concrete. For instance, the drying shrinkage of concrete with 100% RFA replacement is twice that of normal concrete, and the carbonation depth increases by approximately 110%. Additionally, the durability of RFA concrete tends to decrease with higher RFA replacement rates and improved water-cement ratios. However, the incorporation of zeolite materials like fly ash, silica fume, and metakaolin as surface coatings for RFAs or as external admixtures for RFA concrete demonstrates positive effects on enhancing durability.

Kumar et al.(2023) The incorporation of manufactured sand in concrete brings several advantageous effects to its overall performance. Both M40 and M50 grade concretes show a significant reduction in water absorption when manufactured sand is used, compared to conventional sand concrete. This reduction is achieved by employing a lower water-binder ratio, resulting in impermeable concrete with enhanced resistance to water penetration. Additionally, the inclusion of manufactured sand leads to a decrease in chloride ion penetrability, indicating improved durability and lower permeability of the concrete. Another benefit is the increased resistance to acid and alkaline attacks, resulting in reduced weight loss compared to traditional sand concrete. Moreover, concrete mixes incorporating synthetic sand demonstrate enhanced resilience against impact and abrasion, making them more durable in challenging conditions. Overall, the utilization of manufactured sand has a positive impact on various aspects of concrete performance.

Hathiram et al.(2023) In developing nations, where population growth is rapidly increasing, achieving a strong economy and a pollution-free environment in the construction industry are crucial to meet the diverse human needs. To fulfill the demand for aggregates, utilizing waste materials in the production of a new type of concrete has become essential. Industrial waste and demolition waste are the primary sources of these waste materials. Recycling, reusing, and exchanging this waste material offer an effective and appropriate solution. This research focuses on exploring the desirable characteristics of recycled aggregate concrete. The experiments conducted evaluate the split tensile strength of concrete at different ages, specifically 7 and 28 days. Workability properties of the concrete mix are assessed through flow tests. The study includes experiments on various mixes of self-compacting concrete, including one with fresh coarse and fine aggregates, and others with different proportions of recycled fine aggregates (15%, 30%, 45%, 60%, 75%, 90%, and 100%). The design mix proportion follows the M25 standard, with a proportion of 1:1:2 for self-compacting concrete.

Kumar et al.(2023) In an experimental investigation focusing on bituminous mixes, specifically Stone Matrix Asphalt (SMA) and Bituminous Concrete (BC), several significant findings were observed. The fillers used in Bituminous Concrete (BC), including cement, fly ash, and stone dust, met the required specifications, highlighting their suitability for use. BC with cement filler demonstrated the highest stability, while alternatives like fly ash and stone dust fillers proved to be viable and cost-effective options. The addition of fibers up to 0.3% improved the stability of BC, although further incorporation of fibers did not yield significant enhancements compared to SMA. The incorporation of fibers led to a decrease in the flow value of BC, but interestingly, the addition of 0.5% fibers resulted in an increase in the flow value. SMA showed superior tensile strength compared to BC, and the inclusion of fibers reduced deformation in both types of mixes. Notably, SMA with sisal fiber exhibited excellent performance for flexible pavement applications, indicating its potential in various construction projects.

Gandhi et al.(2023) This study examined the possibility of substituting recycled concrete aggregates (RCA) in different proportions (0%, 50%, 75%, and 100%) in self-compacting concrete (SCC) mixes. The SCC mixes incorporated PVA fibers and supplementary cementitious materials (SCMs) such as nano-silica (NS), fly ash (FA), and metakaolin (MK). The research focused on evaluating the flexural behavior of SCC beams, including load-carrying capacity, crack pattern, mid-span deflection, and flexural stiffness, as well as assessing the fresh properties (slump flow, V-funnel, and L-box test) and hardened properties (compressive strength, splitting tensile strength, and flexural strength). The results indicated that it is indeed feasible to produce SCC with a complete replacement of RCA, with minimal alterations to the concrete characteristics. The optimal combination, meeting the EFNARC requirements and exhibiting good fresh qualities, consisted of SCC with 100% RCA replacement, 20% MK, and 22% FA. Although the compressive strength decreased by 8.20% with 100% RCA substitution, the maximum load and flexural stiffness increased by 3.20% and 16.25%, respectively.

6. SUMMARY

This investigation report focuses on the durability properties of self-compacting concrete (SCC) that incorporates recycled fine aggregates (RFA). The study aims to assess the potential of using RFAs as a sustainable alternative in concrete production. Various durability parameters were evaluated, including permeability, water absorption, carbonation, chloride ion penetration, acid resistance, and freeze-thaw resistance. The results indicate that the durability of SCC made with RFAs is influenced by factors such as the content of old mortar and the quality of the recycled concrete. It was observed that the drying shrinkage of the concrete with 100% RFA replacement was twice that of normal concrete, and the carbonation depth increased significantly. The durability of the RFA concrete also deteriorated with increasing RFA content and water-cement ratio. However, the introduction of zeolite materials like fly ash, silica fume, and metakaolin as surface coatings or external admixtures showed positive effects on durability. The findings suggest that careful consideration should be given to the quality and content of RFAs when using them in SCC production. Overall, this investigation highlights the potential for utilizing RFAs in SCC while emphasizing the importance of incorporating appropriate supplementary materials to enhance the durability performance of the concrete.

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