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Article · January 2007

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Journal of Applied Sciences Research, 3(3): 202-208, 2007

Utilization of Quarry Waste Fine Aggregate in Concrete Mixtures

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Abstract: Four different types of concrete mixture were prepared, and tested in fresh and hardened states. Except for control concrete, quarry waste fine aggregate was used in all concretes as a partial replacement of natural sand. The effects of quarry waste fine aggregate on several fresh and hardened properties of the concretes were investigated. It was found that quarry waste fine aggregate enhanced the slump and slump flow of the fresh concretes. But the unit weight and air content of the concretes were not affected. In hardened concretes, the compressive strength was decreased in presence of quarry waste fine aggregate. In addition, the dynamic modulus of elasticity and initial surface absorption were marginally increased but the ultrasonic pulse velocity was unaffected. However, the best performance was observed when quarry waste fine aggregate was used in presence of silica fume. The overall test results revealed that quarry waste fine aggregate can be utilized in concrete mixtures as a good substitute of natural sand.

Key words: Concrete, Fresh properties, Hardened properties, Quarry waste fine aggregate

INTRODUCTION

Concrete is a widely used material in the world. Based on global usage, it is placed at second position after water. Fine aggregate is an essential component of concrete. The most commonly used fine aggregate is natural river or pit sand. The global consumption of natural sand is very high due to the extensive use of concrete. In particular, the demand of natural sand is quite high in developing countries owing to rapid infrastructural growth. In this situation, some developing countries like Malaysia and Thailand are facing a shortage in the supply of natural sand. Therefore, the construction industries of developing countries are in stress to identify alternative materials to lessen or replace the demand for natural sand.

Some alternative materials have already been used as a part of natural sand. For example, fly ash, slag, and limestone and siliceous stone powder were used in concrete mixtures as a partial replacement of natural sand[1, 2]. Also, the rock dust was used as an alternative to natural sand and its effects on the strength and workability of the concretes were investigated[3]. Very recently, several researchers have used manufactured fine aggregate as a partial replacement of natural sand, and investigated its effect on major concrete properties[4]. Similarly, quarry waste fine aggregate could be an alternative to natural sand. It is a by-product generated from quarrying activities involved in the production of crushed coarse aggregates. Quarry waste fine aggregate, which is generally considered as a waste material, causes an environmental load due to disposal problem. Hence, the use of quarry waste fine aggregate in concrete mixtures will reduce not only the demand for natural sand but also the environmental burden. Moreover, the incorporation of quarry waste fine aggregate will offset the production cost of concrete. In brief, the successful utilization of quarry waste fine aggregate will turn this waste material into a valuable resource. Unfortunately, limited research has been conducted to explore the potential utilization of quarry waste fine aggregate in concrete mixtures.

The present study has used quarry waste fine aggregate in concrete mixtures as a partial replacement of natural sand. It has investigated the effects of quarry waste fine aggregate on slump, slump flow, unit weight, and air content of the fresh concretes. In addition, this study has examined the effect of quarry waste fine aggregate on compressive strength, dynamic modulus of elasticity, ultrasonic pulse velocity, and initial surface absorption of the hardened concretes.

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MATERIALS AND METHODS

Concrete Materials and Their Properties: Crushed granite stone (CGS), pit sand (PS), quarry waste fine aggregate (QWFA), normal (ASTM Type I) portland cement (C), silica fume (SF), Class F Malaysian fly ash (FA), tap water (W), a naphthalene formaldehyde condensate based high-range water reducer (HRWR), and a synthetic air-entraining admixture (AEA) were used. The quarry waste fine aggregate was collected from a local aggregate quarry. Various physical properties of the concrete materials have been shown in Table 1. In addition, the results of sieve analysis for pit sand and quarry waste fine aggregate have been presented in Fig. 1.

Concrete Mixture Proportions: Four different types of concrete were prepared using a water-binder ratio of 0.40. The concrete mixtures were designated as NPCC, CQWC, SFQW and FAQW. In all concrete mixtures except NPCC, quarry waste fine aggregate was used as a 20% weight replacement of pit sand. Also, silica fume and fly ash were used in SFQW and FAQW concretes, respectively, as a 10% weight replacement of cement. The detailed mixture proportions of the concretes are given in Table 2.

Preparation of Fresh Concretes: The fresh concretes were prepared using a 50L rotating pan-type mixer. At first, the aggregates were mixed with some mixing water. Later further mixing was done with the addition of binding material. High-range water reducer was used at the earlier and later stages of mixing by splitting the entire dosage into two halves. In addition, an air-entraining admixture was added gradually at the later stage of mixing. The entire mixing operation was completed in 6 minutes.

Testing of Fresh Concretes: The fresh concretes were tested for slump, slump flow, unit weight, and air content. The slump and slump flow were determined based on a Japanese standard JSCE-F503. The air content and unit weight of the concretes were determined in accordance with BS 1881: Part 106 and BS 1881: Part 107, respectively.

Preparation of Concrete Specimens: Cylinder and cube specimens were prepared from the fresh concretes. 100 mm (diameter) by 200 mm (height) cylinders were cast for use in testing of compressive strength, ultrasonic pulse velocity, and dynamic modulus of elasticity. In addition, 150 mm cube specimens were cast for testing initial surface absorption. After casting, the specimens were covered with plastic sheet and wet burlap. The specimens were removed from their moulds at the age of 24±2 hours and cured in water until the day of testing. The curing temperature was maintained at 20±2^{0}C.

Testing of Hardened Concretes: The hardened concretes were tested at the age of 28 and 56 days to determine compressive strength, dynamic modulus of elasticity, ultrasonic pulse velocity, and initial surface absorption. The compression test was performed according to ASTM C 39/C 39M. The ultrasonic pulse velocity was measured following BS 1881: Part 203. The dynamic modulus of elasticity was determined based on the guideline given in BS 1881: Part 209. In addition, the initial surface absorption test was conducted in accordance with BS 1881: Part 5.

RESULTS AND DISCUSSIONS

Properties of Fresh Concretes:

Slump and slump flow: The slump and slump flow of the fresh concretes have been presented in Table 3. The slump varied from 230 to 245 mm whereas the slump flow differed from 520 to 550 mm. In general, a slump higher than 200 mm and a slump flow greater than 500 mm impart a good flowing ability[5-7]. Hence, the slump and slump flow results indicated a good flowing ability of the concretes.

Test results showed that quarry waste fine aggregate enhanced the flowing ability of the concretes. It can be seen from Table 3 that CQWC concrete provided higher slump and slump flow than any other concretes. This is primarily due to deviation in gradation of quarry waste fine aggregate. It can be seen from the results of sieve analysis presented in Fig. 1 that quarry waste fine aggregate had more materials coarser than 1.18, 2.36 and 4.75 mm sieve sizes. Also, higher fractions finer than 150 and 300 µm sieves were present. But the net result was the reduction in the total amount of fine materials, as reflected in the fineness modulus of quarry waste fine aggregate obtained from sieve analysis. The fineness modulus of quarry waste fine aggregate was 3.20 whereas pit sand had a fineness modulus of 3.01. Due to reduced amount of fine materials, the total surface area of fine aggregates was decreased in presence of quarry waste fine aggregate. Consequently, the water demand of the concrete mixture became lower, and thus the flowing

Table 1: Properties of the materials.

Material	Properties
Crushed granite stone (CGS)	Maximum size: 19 mm Saturated surface-dry basis relative density: 2.62 Absorption: 0.9% Moisture content: 0.20% Flakiness index: 28%
Pit sand (PS)	Maximum size: 4.75 mm Fineness modulus: 3.01 Saturated surface-dry basis relative density: 2.60 Absorption: 1.20% Moisture content: 0.10%
Quarry waste fine aggregate (QWFA)	Maximum size: 9.5 mm Fineness modulus: 3.20 Saturated surface-dry basis relative density: 2.63 Absorption: 0.60% Moisture content: 0.30% Flakiness index: 55%
Normal portland cement (C)	Relative density: 3.15 Mean particle size: 23 µm Specific surface area (Blaine): 325 m^2/kg
Silica fume (SF)	Relative density: 2.20 Mean particle size: 0.15 µm Specific surface area (nitrogen adsorption): 26,000 m^2/kg
Class F Malaysian fly ash (FA)	Relative density: 2.26 Mean particle size: 20 µm Specific surface area (Blaine): 440 m^2/kg
Water (W)	Density ≈ 1000 kg/m^3
High-range water reducer (HRWR)	Relative density: 1.21 Solid content: 40%
Air-entraining admixture (AEA)	Relative density: 1.02 Solid content: 8%

Table 2: Detailed mixture proportions of various concretes.

Concrete designation	CGS (kg/m^3)	PS (kg/m^3)	QWFA (kg/m^3)	Binder B* (kg/m^3)			W (kg/m^3)	HRWR (%B)	AEA (%B)
				C	SF	FA			
NPCC	1027	685	-	480	-	-	192	1.80	0.05
CQWC	1028	549	137	480	-	-	192	2.00	0.05
SFQW	1018	543	136	432	48	-	192	2.90	0.07
FAQW	1019	543	136	432	-	48	192	2.00	0.09

* cement plus silica fume or fly ash.

Table 3: Fresh properties of various concretes.

Concrete designation	Slump (mm)	Slump flow (mm)	Unit weight (kg/m^3)	Air content (%)
NPCC	230	520	2360	1.7
CQWC	245	550	2360	1.9
SFQW	235	540	2320	2.2
FAQW	230	530	2330	1.6

ability of CQWC concrete was increased for the same water content.

The flowing ability of SFQW and FAQW concretes were relatively low, as compared to CQWC concrete. It can be seen from Table 3 that both SFQW and FAQW concretes provided lower slump and slump flow than CQWC concrete. This is mostly due to the presence of silica fume and fly ash. Silica

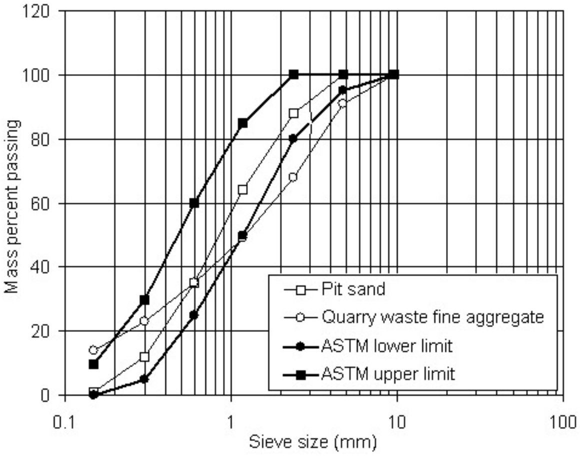

Fig. 1: Gradation of pit sand and quarry waste fine aggregate.

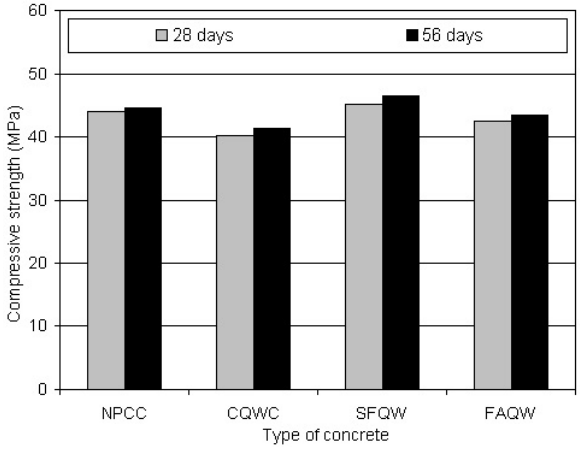

Fig. 2: Compressive strength of various concretes.

fume and fly ash increased the cohesiveness and viscosity of the fresh concretes mostly because of their lower particle size and greater specific surface. The mean diameter (0.15 µm) of silica fume is about 155 times lower than that of cement particle. Also, the specific surface area of silica fume was 80 times higher than that of cement. On the other hand, fly ash has slightly greater specific surface area than cement although its particles are not much smaller than cement grains, as can be seen from Table 1. Owing to the aforementioned particle characteristics, the amount of free water needed for the lubrication effect of the mortar was decreased in presence of silica fume and fly ash. This is why the flowing ability of SFQW and FAQW concretes was reduced, and the demand for high-range water reducer became higher to achieve similar flowing ability.

Unit weight: The unit weight of the fresh concretes varied from 2320 to 2360 kg/m^3, as can be seen from Table 3. The unit weight of SFQW and FAQW concretes was slightly lower than that of NPCC concrete although silica fume and fly ash are much lighter than cement. However, they also improve the physical packing in concrete. Therefore, the decrease in unit weight was insignificant (<2%). In addition, it was expected that the unit weight of CQWC concrete would be lower than NPCC concrete due to reduced packing resulting from excessive flakiness and flawed grading of quarry waste fine aggregate. But CQWC concrete produced a unit weight equal to that of NPCC concrete. This is possibly because quarry waste fine aggregate was heavier than pit sand, as reflected from its higher relative density. Besides, quarry waste fine aggregate possessed a greater amount of fines passing 150 and 300 µm sieves, as can be seen from Fig. 1. It might contribute to improve the unit weight of the concrete.

Air content: The air content of the concretes was in the range of 1.6 to 2.2%. The dosages of air-entraining admixture required to obtain this range of air content varied for different concretes. The presence of quarry waste fine aggregate in CQWC concrete did not increase the demand of air-entraining admixture, as can be seen from Table 2. However, SFQW and FAQW concretes required greater dosages of air-entraining admixture to obtain similar air content. It indicates that silica fume and fly ash destabilized some air voids due to increased viscosity.

Properties of Hardened Concretes

Compressive strength: The results for compressive strength are presented in Fig. 2. The 28 and 56 days compressive strength of the concretes varied from 40 to 47 MPa. CQWC concrete provided about 7 to 9% lower compressive strength than NPCC concrete. This is probably due to unfavourable gradation and excessive flakiness of quarry waste fine aggregate. It can be seen from Fig. 1 that a greater amount of fines smaller than 150 and 300 µm sieve sizes was present in quarry waste fine aggregate. The compressive strength of the concrete is usually decreased by an increased amount of fines passing 150 and 300 µm sieves[8]. Also, it can be seen from Table 1 that quarry waste fine aggregate provided a flakiness index of 55%. The maximum allowable flakiness index of aggregates is generally limited to 40%[9]. The higher flakiness index obtained for quarry waste fine aggregate reveals that many flat and flaky particles were present. Some bleeding water and air voids are generally formed underneath the flaky particles[8]. It may cause a negative impact on the compressive strength of concrete.

The compressive strength of quarry waste concrete was increased when silica fume was used.

Silica fume improved the compressive strength of concrete at both ages of 28 and 56 days, as can be seen from Fig. 2. It was also observed that SFQW concrete provided the highest level of compressive strength. This is mainly credited to the high microfilling ability and pozzolanic activity of silica fume[10]. In comparison, fly ash could not produce any significant improvement in compressive strength. However, FAQW concrete provided greater compressive strength than CQWC concrete. This is mostly attributed to the pozzolanic activity of fly ash that becomes more pronounced at the later stages of hydration[11].

Dynamic modulus of elasticity: The results for dynamic modulus of elasticity are presented in Fig. 3. At 28 and 56 days, the dynamic modulus of elasticity varied from 40.8 to 43.7 GPa. The dynamic modulus of elasticity was slightly increased in presence of quarry waste fine aggregate. It can be seen from Fig. 3 that CQWC concrete provided marginally better dynamic modulus of elasticity than NPCC concrete at both ages. In addition, CQWC concrete provided slightly higher dynamic modulus of elasticity than FAQW concrete at 28 days. But both CQWC and FAQW concretes exhibited almost identical dynamic modulus of elasticity at the age of 56 days. Therefore, it is obvious that the presence of quarry waste fine aggregate did not produce any adverse effect on the elastic behaviour of concrete. This is a good indication towards the quality of concrete incorporating quarry waste fine aggregate. The dynamic modulus of elasticity of concrete largely depends on the elastic properties of the aggregates and hydrated cement paste. The modulus of elasticity of aggregates is generally higher than that of hydrated cement paste. The difference between the moduli of elasticity of aggregates and paste affects the elasticity of the concrete. The modulus of elasticity of the aggregates is decreased in presence of weaker quarry waste fine aggregate. Consequently, the difference between the moduli of aggregates and hydrated cement paste is reduced. The reduced difference between the moduli of paste and aggregates enhances the composite action of concrete, and thus tends to improve its dynamic modulus of elasticity.

The dynamic modulus of elasticity of SFQW concrete was slightly greater than that of CQWC concrete. It provided the highest level of dynamic modulus of elasticity (42 GPa at 28 days and 43.7 GPa at 56 days), as can be seen from Fig. 3. This is because silica fume strengthens the hydrated cement paste and thus increases its modulus of elasticity[12]. Hence, the difference between the moduli of aggregates and hydrated cement paste is decreased again. It influences to increase the dynamic modulus of elasticity of SFQW concrete. In addition, the dynamic modulus of elasticity is increased with the reduction in the porosity of the concrete. Silica fume plays as an effective filler and porosity reducer because of finer particle size and greater pozzolanic activity. Also, the porosity is a paste-dependent property in a properly compacted concrete[13]. The paste volume of the concrete is increased in presence of silica fume. Hence, the overall porosity of the concrete is reduced, and therefore higher values for dynamic modulus of elasticity can be obtained. In comparison to silica fume, fly ash was less efficient to reduce the porosity of the concrete. Consequently, FAQW concrete resulted in lower dynamic modulus of elasticity than SFQW concrete.

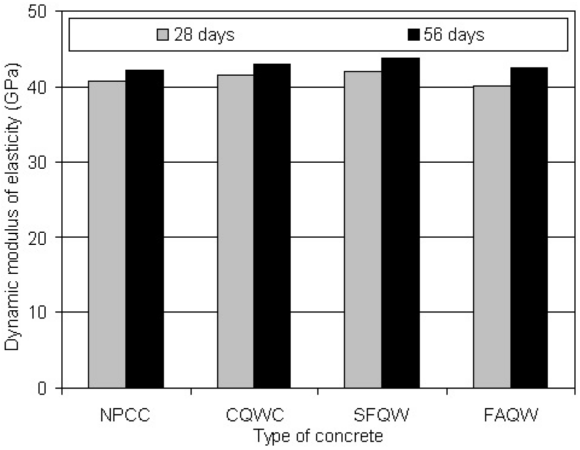

Fig. 3: Dynamic modulus of elasticity of various concretes.

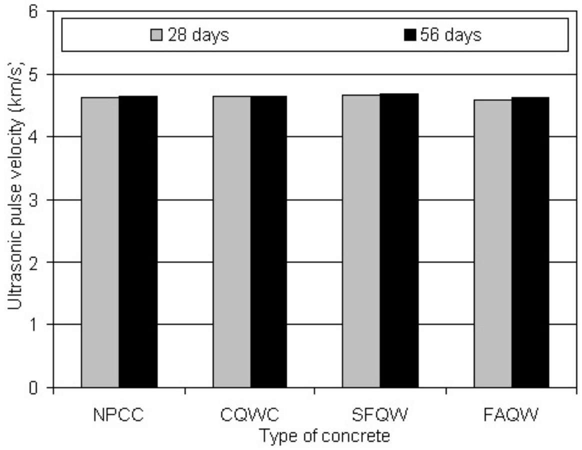

Fig. 4: Ultrasonic pulse velocity of various concretes.

Ultrasonic pulse velocity: The test results for ultrasonic pulse velocity have been presented in Fig. 4. The ultrasonic pulse velocity of different concretes varied from 4.59 to 4.69 km/s. Leslie and Cheesman produced some ratings for concretes based on ultrasonic pulse velocity[14]. They reported that an ultrasonic pulse velocity above 4.575 km/s presents the excellent physical condition of the concrete. The range of ultrasonic pulse velocity observed in the present study demonstrates the 'excellent' quality of the concretes. However, the variation of ultrasonic pulse velocity was very insignificant because all concretes were qualitatively in good condition.

The incorporation of quarry waste fine aggregate did not adversely affect the ultrasonic pulse velocity of the concrete, as can be seen from Fig. 4. CQWC and other concretes provided similar results of ultrasonic pulse velocity. It indicates that quarry waste fine aggregate can be used as a partial replacement of natural sand without harming the quality of the concretes.

Initial surface absorption: The test results for initial surface absorption at 28 and 56 days have been presented in Fig. 5 and Fig. 6, respectively. These figures present the rate of water penetration through the skin of different concretes at 10, 30, 60 and 120 minutes after the start of the initial surface absorption test. At later test stages, all concretes including CQWC exhibited an absorptivity much less than 0.25 ml/m^2/sec, which is considered as the maximum absorptivity of low absorptive concrete[15].

CQWC and FAQW concretes exhibited equivalent initial surface absorption at the age of 28 days. Also, CQWC concrete produced the highest level of initial surface absorption after 120 minutes from the start of testing at 56 days. The presence of fly ash could not take any significant role in reducing the initial surface absorption of quarry waste concrete. In contrast, SFQW concrete exhibited the lowest level of initial surface absorption at both 28 and 56 days, as can be seen from Fig. 5 and Fig. 6. This indicates that silica fume was very useful to decrease the absorptivity of the concretes. Silica fume can fill the voids between the larger cement grains because of extremely small particle size. This function, called microfilling, refines the microstructure of the concrete and creates a much denser pore structure. As a result, the number and size of capillary pores are lessened, the permeability is significantly reduced, and the concrete becomes more resistant to water penetration. Also, silica fume is very effective to produce additional calcium silicate hydrate from pozzolanic reaction with calcium hydroxide, which is liberated during cement hydration. The pore channels in concrete are blocked by this pozzolanic reaction product. Consequently, the porosity is greatly reduced and the concrete becomes much denser and impervious.

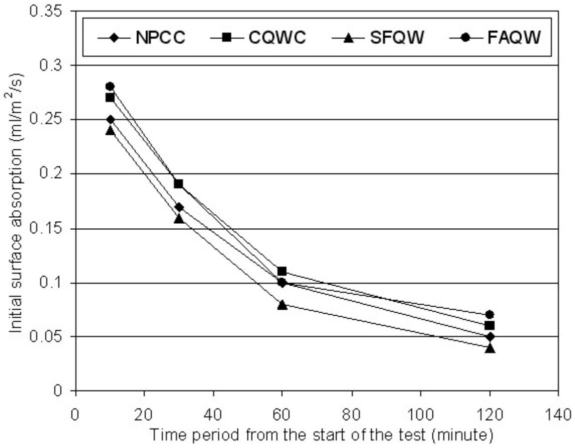

Fig. 5: 28 days initial surface absorption of various concretes.

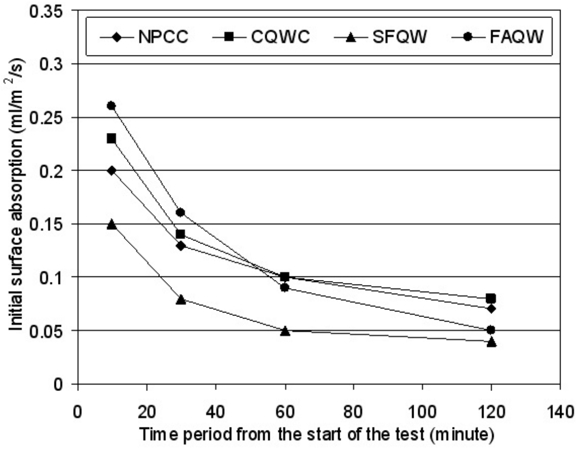

Fig. 6: 56 days initial surface absorption of various concretes

Conclusions: Quarry waste fine aggregate enhanced the slump and slump flow of concrete, as the water demand was decreased due to reduced surface area of fine aggregates.

Quarry waste fine aggregate did not affect the unit weight and air content of fresh concrete.

Quarry waste fine aggregate decreased the compressive strength of concrete due to deficient grading and excessive flakiness.

The use of quarry waste fine aggregate marginally improved the dynamic modulus of elasticity of concrete due to reduced difference between moduli of aggregates and hydrated cement paste.

All concretes provided excellent ultrasonic pulse velocity and quarry waste fine aggregate did not adversely affect the quality of concrete.

Quarry waste fine aggregate decreased concrete's resistance to water penetration but resulted in an initial surface absorption below the maximum absorptivity of low absorptive concrete.

The combined use of quarry waste fine aggregate and silica fume exhibited excellent performance due to efficient microfilling ability and pozzolanic activity of silica fume.

Quarry waste fine aggregate can be utilized in concrete mixtures as a good substitute of natural sand.

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