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Sustainable Utilization of Dumped Concrete Wastes as Fine Aggregates in Concrete – An Experimental Study

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ABSTRACT

Dumped construction waste (municipal solid waste) is a major threat to the environment in recent times due to its abundance in generation resulting from increased construction activities. Perhaps, the scarcity of construction materials is also alarming due to urbanization necessitating an alternative suitable material. Concerning the above complications, this research encompasses the sustainable use of concrete fractions of the construction waste as a suitable replacement for natural fine aggregate (NFA) termed fine recycled aggregate (FRA). However, the use of FRA disrupts the concrete properties due to a weak interfacial transition zone (ITZ) ensuing from the adherence of cement particles and finer dust particles. This study investigates the effective utilization of FRA through the mortar mixing approach (MMA) technique with varying percentages of FRA. The optimum proportion of FRA as a substitute to NFA was observed to be 30%, with an increase in the concrete strength by 7.85%, while it decreased by 23.5% with 100% of FRA at 28 days. Through MMA, the strength of concrete was increased by 9.93%, while it is decreased by 19.45% with 100% of FRA at 28 days. The stiff concrete matrix developed as a result of MMA tends to strengthen the ITZ and improve the strength of concrete.

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1. INTRODUCTION

The generation of construction wastes is rapidly increasing, which necessitated the option of recycling and reuse. European Aggregate Association (EAA) reported that nearly 843 metric tons of construction wastes were generated in 2016, and China reported 2.14 metric tons of construction wastes in 2018 [1, 2]. Also, 30 to 40% of construction and demolition (C&D) wastes among other municipal states, the European union (EU) reports 36%, and the USA reports nearly 67% [3]. Such generated C&D wastes are dumped in the landfills causing environmental degradation. In recent times, the use of FRA as a suitable alternative to NFA is increasing to overcome the effect of its scarcity and in the production of sustainable concrete. However, several research have described the adverse impacts of utilizing construction wastes as aggregates (both coarse & fine) in concrete owing to its increased porosity ensuing from the smeared cement particles [4-6]. The behaviour of recycled aggregate (both coarse & fine) depends on percentage replacement, size fraction, super plasticizers, source etc.

Concerning to optimal replacement of FRA, Ozbakkaloglu et al. [7] replaced NFA with 97% of FRA and 3% of brick aggregates and observed that substitution of FRA exceeding 25% affects the concrete properties due to its increased porosity. Similarly, Martinez et al. [8] utilized 50, 75 and 100% of recycled concrete, mixed and ceramic fractions as a substitute to NFA and inferred that all three aggregates posses' inferior density and higher water absorption (5 to 10%) compared to NFA resulting in sub-stranded concrete properties. However, the study suggests that conforming to the limitations framed by the manufacturers can increase its possibility of utilization even up to 100%. It could be observed that percentage replacement of FRA tend to vary depending on the type of recycled aggregate and its absorption capacity. To counteract the

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effect of higher absorption of FRA on concrete properties. Cartuxo et al. [9] used high range superplasticizers with 0, 10, 30, 50 and 100% of FRA and infer that with 100% of FRA, slump was increased to 16%, bulk density was reduced to 3.7%, strength was reduced to 29% and shrinkage was reduced to 57%. However, with the use of high range water reducers, the study observed an improvement in the behaviour of above-mentioned properties due to the compensation of water requirement by FRA with the addition of superplasticizers. However, zhao et al. [10] prepared recycled aggregate concrete with 0/0.63, 0.63/1.25, 1.25/2.5, 2.5/5 mm fractions of FRA at 0.5 and 0.6 w/c and concluded that higher fineness in FRA resulted in higher water absorption by FRA and thus inferior properties to concrete. Anastasiou et al. [11] observed that optimized utilization of FRA from construction wastes improves the properties of the concrete which in way promotes sustainability in the field of construction. Also, the study observed that higher water absorption by FRA (8%) reduces its replacement level in the concrete.

Vinay Kumar et al. [12] found that the use of FRA beyond 20% reduces the workability and strength of the recycled aggregate concrete (RAC), and in such cases, higher dosage of superplasticizers is required to achieve equivalent slump and better strength. Lizancos et al. [13] analyzed the kinetics of elastic modulus of RAC and its relationship with the strength and reported a negative influence of FRA on the elastic modulus at first 12 hours followed by an equivalent rise in the substitution of FRA with the loss of elastic modulus of the RAC. With respect to the source of collection, Pedro et al. [14] investigated the behaviour of RAC with FRA collected from laboratory and pre-casting plant and observed that increase in substitution of FRA decreases the strength of the RAC irrespective to the source. Fan et al. [15] collected FRA from diverse sources and found that in all cases, with an increase in the FRA, the slump of the RAC decreases, wherein the slump of the RAC reduces from 210 mm to 185 mm. Pereira et al. [16] observed that the reduction in the strength of RAC was counteracted with the addition of superplasticizers, even with higher substitution of FRA. The effect of a decrease in the workability of RAC due to an increase in the porosity of FRA was offset by inclusion of superplasticizers.

Al Hasan et al. [17] investigated the practical implications of recycled materials observed that use of 75% of RCA with 15% of polymer promote sustainable eco-friendly roads with enhanced properties. From the literature review, it is found that all the dependent parameters of recycled aggregates tend to affect the properties of concrete due to the weak ITZ resulting from the higher porosity of FRA.

So, various advanced mixing techniques were developed to overcome the effect of higher porosity of recycled aggregates. Tam et al. [18] proposed a two-stage mixing approach (TSMA) and observed that the strength of RAC was improved by 12.2% and 6.09% at 28 and 56 days. The study infers that thin slurry developed impregnates into the microcracks on the surface of RCA, filling the pores, improving the ITZ of the RAC, and thus resulting in better strength than normal mixing approach (NMA). Similarly, Tam et al. [19, 20] performed studies with TSMA and observed better properties in RAC even with 100% of recycled aggregates. Kong et al. [21] developed triple mixing approach (TMA) and double mixing approach (DMA) and found that the workability of RAC was equivalent to normal aggregate concrete (NAC), and the strength of RAC was reduced only by 19.4% with DMA and 12.02% with TMA. Liang et al. [22] proposed advanced mixing techniques and observed that RAC manufactured at 0.43 w/c by sand enveloped mixing approach (SEMA) and 0.49 w/c by mortar mixing approach (MMA) exhibit improved strength to RAC even with 100% of RCA.

Thus, it could be observed that advanced mixing techniques tend to improve RAC properties deprived of any treatments to recycle aggregates. However, the above mixing techniques were performed only with RCA, and no studies infer the influence of advanced mixing techniques with FRA. Thus, the present study investigates the properties of RAC with 0%, 10%, 30%, 50%, 70%, and 100% of FRA manufactured by MMA. The behaviour of concrete with different proportions of FRA manufactured by NMA and MMA was investigated by mechanical properties such as compression, tension, flexural and elastic modulus at 7, 14 and 28 days.

2. METHODOLOGY

43 grade ordinary Portland cement (OPC) as per IS 269 (2015) was used as binding material in the study. The properties of OPC determined as per IS 4031 (1988) are summarized in Table 1. The NFA was collected and sieved to 1.18~2.36 mm and NCA was quarried and sieved to 10 mm~20 mm sizes. The specific gravity and water absorption of NCA were found to be in the range of 2.59~2.71 and 0.15%~0.19%. The concrete fractions of the construction wastes were collected from the demolished building at the institution, crushed using a jaw crusher, sieved to 1.18 mm~2.36 mm, and used as FRA. Figure 1 depicts the appearance of FRA and NFA used in the study. It could be observed that the surface of FRA was highly rough and angular compared to NFA. The gradation curves of NFA and FRA are shown in Figure 2. The physical properties of NFA and FRA determined as per IS 383 are given in Table 2. It is found that except for water absorption, all the

characteristics of FRA were found to be within the BIS limitations. The presence of excess silt content (>5%) and smeared cement mortar increases the porosity of FRA [23-25], hence the FRA was surface saturated prior to its utilization in the concrete.

TABLE 1. Properties of OPC

TESTS	RESULTS
Initial set (s)	1500
Final set (s)	34500
Compressive strength (kg/cm^2)	439.90
Consistency (%)	28.6

(a)

(b)

Figure 1. Visual appearance (a) NFA (b) FRA

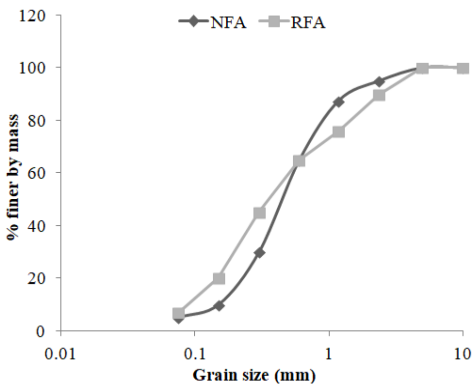


Figure 2. Gradation of fine aggregates

TABLE 2. Properties of fine aggregates

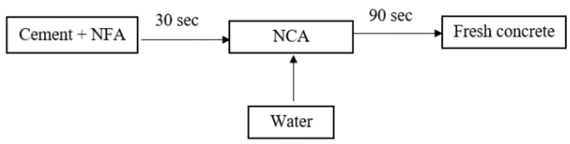
TESTS	NFA	FRA
Relative density	2.65	2.5
Water absorption (%)	0.87	6.93
Bulk density (kg/m^3)	1560	1456
Fineness modulus	3.15	3.79
Silt (%)	2.38	5.67

2. 1. Concrete Mixtures and Testing of Specimens

In this study, NMA and MMA technique was adopted to manufacture M20 grade concrete. Figure 3 shows the illustration of the NMA and MMA adopted in the study. The NFA was replaced by 0%, 10%, 30%, 50%, 70%, and 100% of FRA by its weight in the concrete. The quantities of raw materials required for the preparation of concrete mixtures are given in Table 3. The workability of the concrete mixtures with NFA and FRA was determined as per IS 1199 (1999). The compression, tension, flexure and elastic modulus of hardened concrete were evaluated with 100 mm cubes, 100 mm x 200 mm cylinders, and 500 mm x 100 mm x 100 mm prisms at 7, 14, and 28 days as per IS 516 (1959) in triplicate. After the respective ages, the specimens were tested in 1000 kN supporting universal testing machine (UTM) loaded at a 0.5 mm/min rate.

TABLE 3. Mix proportions (1-NMA; 2- MMA)

Materials	(kg/m^3)					
	F – 0	F –	F –	F –	F –	F– 100
Cement	372	372	372	372	372	372
NFA	829	746.1	580.3	414.5	248.7	0
FRA	0	82.9	248.7	414.5	580.3	829
NCA	1015	1015	1015	1015	1015	1015
w/c ratio	0.5	0.5	0.5	0.5	0.5	0.5
Mixing	1,2	1,2	1,2	1,2	1,2	1,2
Density	2295	2221	2208	2197	2173	2164



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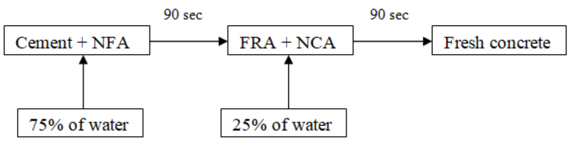


(b)

Figure 3. Schematic illustration of mixing approach (a) NMA (b) MMA

3. RESULTS AND DISCUSSIONS

3. 1. Characterization of Aggregates Figure 4 shows the XRD images of FRA used in the study. As we know, in NFA, the optimal compound would be quartz (SiO_2) that reacts with the calcium compounds from the cement to form C-S-H and that enhances the concrete's strength. In case of FRA, apart from the presence of quartz, traces of Portlandite (CH) and $CaCO_3$ owing to the smearance of cement mortar on the FRA were identified. Figure 5 shows the microstructure images of NFA and FRA magnified at 2µm. The observations on the microstructure image of NFA indicate irregular, angular and spherical-shaped particles. The observations on the SEM image of FRA indicate high angular shaped particles with pores and microcracks on the surface due to the different stages involved in crushing the large size concrete boulders into finer fractions.

3. 2. Workability The workability of the concrete mixtures is shown in Figure 6. The workability of the concrete reduces with increment in the percentage of FRA. This is due to the incidence of excess fine particles and adherence of mortar, thus increasing the FRA's porosity and decreasing the workability of the concrete mixes [26, 27]. So, the FRA was pre-saturated for 24 hours and dried up for 5 hours to attain surface saturated dry density condition. Upon pre-saturation, improvement in the workability of the concrete was observed. The pre-saturation of FRA prevents the additional water absorption by the FRA particles during concrete mixing. With MMA, the workability of the concrete tends to improve further. This is because the stiff less-porous mortar developed due to MMA coats the FRA particles, impregnates and seals the microcracks on the adhered surface of FRA particles. This, in turn, reduces the additional water requirement by FRA particles during mixing and thus improving the workability.

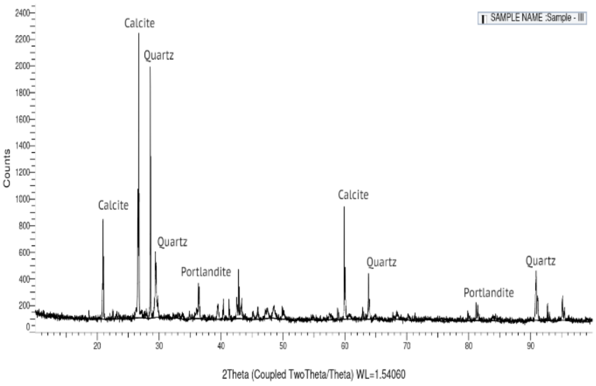
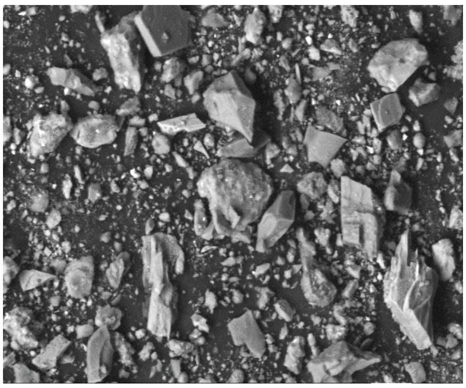
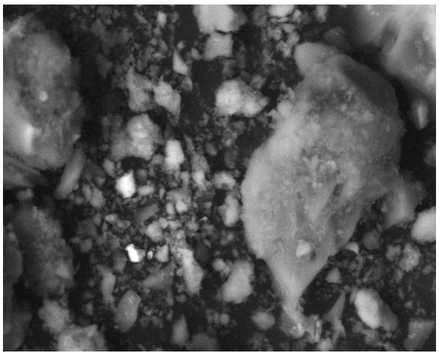


Figure 4. XRD pattern of FRA



(a)



(b)

Figure 5. SEM images (a) NFA (b) FRA

3. 3. Mechanical Properties The mechanical properties such as compressive strength, split tensile strength, flexural strength and elastic modulus determined at 7, 14 and 28 days for NMA and MMA; data are stated in Tables 4 and 5.

3. 3. 1. Improvement in Mechanical Properties Figure 7 shows the percentage improvement in the mechanical properties of MMA mixes compared NMA

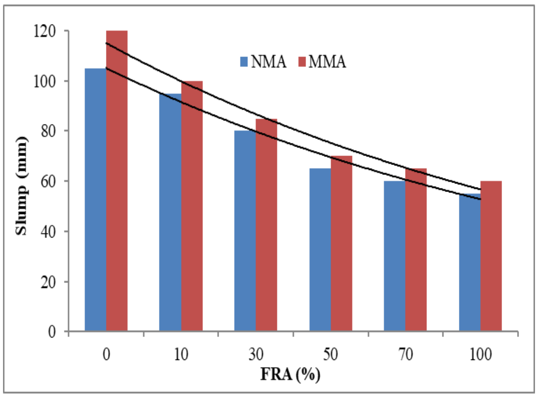
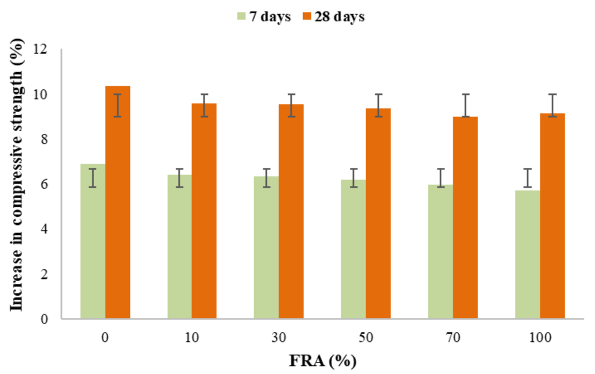


Figure 6. Workability of concrete mixes



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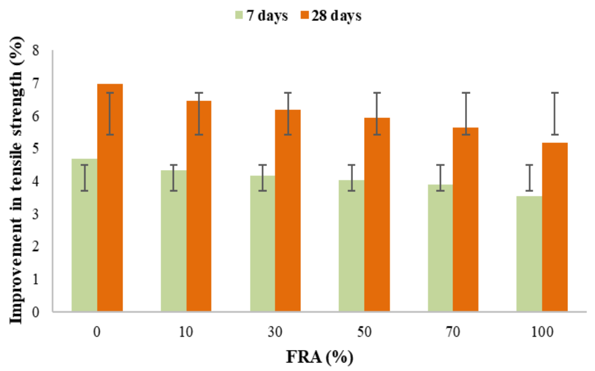

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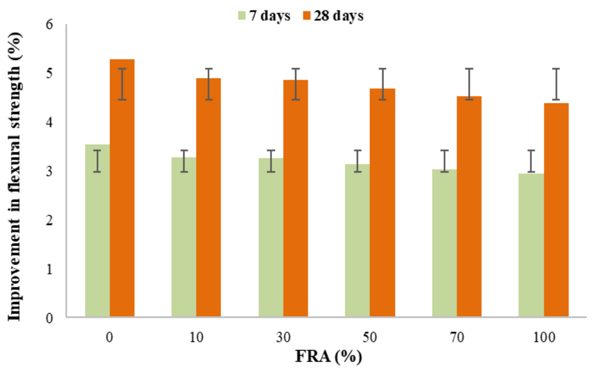

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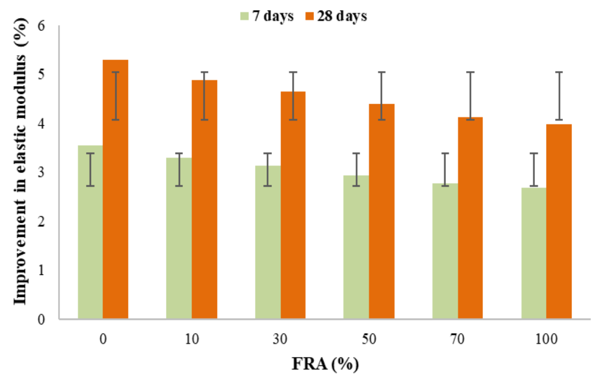

(d)

Figure 7. Improvement in the mechanical properties at 7 and 28 days (a) Compressive strength (b) Tensile strength (c) Flexural strength (d) Elastic modulus

mixes. The mechanical properties of the concrete reduce with increase in the replacement of FRA. The optimal proportion of FRA in the concrete was found to be 30%. The compressive strength of F – 10 and F – 30 was 7.05% and 8.57% higher than F – 0 at 7 days and 9.48% and 9.93% higher than F – 0 at 28 days. This is due to the higher angularity of FRA and effective particle packing of FRA with NFA [24]. However, the replacement of FRA beyond 30% decreases the strength of FRA mixes. The compressive strength of F – 50, F – 70, and F – 100 were 15.81%, 22%, and 23.50% less than F – 0 at 28 days. Such reduction is owing to the increased perviousness of FRA ensuing from the presence of smeared cement particles and high dust content [13, 22, 28]. However, with MMA, the compressive strength of the FRA mixes is found to be more than NMA mixes. The compressive strength of F – 10 and F – 30 mixes prepared by MMA was found to be 16.41% and 17.04% higher compared to F – 0 mix prepared by NMA at 7 days and 17.25% and 17.89% higher compared to F – 0 mix prepared by NMA at 28 days. Similarly, the compressive strength of F – 50, F – 70, F – 100 mixes prepared by MMA was only 6.15%, 12.96%, 15.09% less than the F – 0 mixes prepared by NMA at 28 days.

The tensile strength of F – 10 and F – 30 was 4.48% and 5.64% higher than F – 0 at 7 days and 6.52% and 6.93% higher than F – 0 at 28 days. However, similar to compressive strength, substitution of FRA beyond 30% reduces the tensile strength of FRA mixes also. The tensile strength of F – 50, F – 70, and F – 100 were 10.89%, 14.85%, and 16.17% less than F – 0 at 28 days. The smearance of cement particles on the FRA increases its porosity and thus reducing the split tensile strength of the concrete [12, 15]. Nevertheless, with MMA, the tensile strength of the FRA mixes is found to be more than NMA mixes. The strength of F – 10 and F – 30 mixes prepared by MMA was found to be 11.02% and 11.69% higher compared to F – 0 mix prepared by NMA at 7 days and 11.91% and 12.42% higher compared to F – 0 mix prepared by NMA at 28 days. Similarly, the strength of F – 50, F – 70, F – 100 mixes prepared by MMA was only 4.29%, 8.91%, 10.23% less than the F – 0 mixes prepared by NMA at 28 days.

The flexural strength of F – 10 and F – 30 was 3.63% and 4.50% higher than F – 0 at 7 days and 4.91% and 5.14% more than F – 0 at 28 days. However, similar to compressive strength, replacement of FRA beyond 30% decrease the flexural strength of FRA mixes. The flexural strength of F – 50, F – 70, and F – 100 were 8.26%, 11.36%, and 12.40% less than F – 0 at 28 days. The microcracks on the adhered surface of FRA absorb more water and thus leaving only less water for concrete mixing. This reduces the workability of the concrete and thus affects the flexural strength of the FRA mixes [26, 29]. Though with MMA, the flexural strength of the

TABLE 4. Mechanical properties for NMA

FRA (%)	COMPRESSIVE STRENGTH (MPa)			TENSILE STRENGTH (MPa)			FLEXURAL STRENGTH (MPa)			ELASTIC MODULUS (GPa)		
	7days	**14days**	**28days**	**7days**	**14days**	**28days**	**7days**	**14days**	**28days**	**7days**	**14days**	**28days**
0	20.68	27.48	30.55	2.34	2.82	3.03	3.18	3.67	3.87	22.74	26.21	27.64
10	22.25	30.37	33.75	2.45	3.02	3.24	3.30	3.86	4.07	23.58	27.55	29.05
30	22.62	30.52	33.92	2.48	3.03	3.25	3.33	3.87	4.08	23.78	27.62	29.12
50	17.41	23.14	25.72	2.08	2.52	2.70	2.92	3.37	3.55	20.86	24.05	25.36
70	16.13	21.63	24.07	1.98	2.41	2.58	2.81	3.26	3.43	20.08	23.25	24.53
90	15.82	21.11	23.46	1.95	2.37	2.54	2.78	3.22	3.39	19.89	22.97	24.22
100	20.68	27.48	30.55	2.34	2.82	3.03	3.18	3.67	3.87	22.74	26.21	27.64

TABLE 5. Mechanical properties for MMA

FRA (%)	COMPRESSIVE STRENGTH (MPa)			TENSILE STRENGTH (MPa)			FLEXURAL STRENGTH (MPa)			ELASTIC MODULUS (GPa)		
	7days	**14days**	**28days**	**7days**	**14days**	**7days**	**14days**	**28days**	**7days**	**7days**	**7days**	**14days**
0	20.68	27.48	30.55	2.34	2.82	3.03	3.18	3.67	3.87	22.74	26.21	27.64
10	22.25	30.37	33.75	2.45	3.02	3.24	3.30	3.86	4.07	23.58	27.55	29.05
30	22.62	30.52	33.92	2.48	3.03	3.25	3.33	3.87	4.08	23.78	27.62	29.12
50	17.41	23.14	25.72	2.08	2.52	2.70	2.92	3.37	3.55	20.86	24.05	25.36
70	16.13	21.63	24.07	1.98	2.41	2.58	2.81	3.26	3.43	20.08	23.25	24.53
90	15.82	21.11	23.46	1.95	2.37	2.54	2.78	3.22	3.39	19.89	22.97	24.22
100	20.68	27.48	30.55	2.34	2.82	3.03	3.18	3.67	3.87	22.74	26.21	27.64

FRA mixes is found to be more than NMA mixes. The strength of F – 10 and F – 30 mixes prepared by MMA was found to be 8.62% and 9.14% higher compared to F – 0 mix prepared by NMA at 7 days and 8.94% and 9.36% more compared to F – 0 mix prepared by NMA at 28 days. Similarly, the flexural strength of F – 50, F – 70, F – 100 mixes prepared by MMA was only 3.10%, 6.45%, 7.75% less than F – 0 mix prepared by NMA at 28 days.

The elastic modulus of F – 10 and F – 30 was 3.59% and 4.38% higher than F – 0 at 7 days and 4.87% and 5.11% more than F – 0 at 28 days. However, replacement of FRA beyond 30% decreases the elastic modulus of FRA mixes. The elastic modulus of F – 50, F – 70, and F – 100 were 9.17%, 12.34%, and 13.87% less than F – 0 at 28 days. The smearance of old mortar on the FRA disrupts its adherence with the new matrix, reducing the stiffness and thus reducing the elastic modulus of the concrete. When the concrete mixes are prepared by MMA, the elastic modulus of the FRA mixes is found to be more than NMA mixes. The elastic modulus of F – 10 and F – 30 mixes prepared by MMA was found to be 8.53% and 8.71% higher compared to F – 0 mix prepared by NMA at 7 days and 9.01% and 9.73% more compared to F – 0 mix prepared by NMA at 28 days. Similarly, the elastic modulus of F – 50, F – 70 and F – 100 mixes prepared by MMA was only 3.14%, 6.72%, 7.94% less than F – 0 mix prepared by NMA at 28 days.

Various studies infer that inferior quality of FRA was due to its higher perviousness ensuing from the smearance of cement particles on the surface of FRA. So, the FRA was pre-saturated and even after pre-saturation, higher perviousness of FRA weakens the ITZ of the concrete and thus affecting the properties of concrete. However, even after pre-saturation, no improvement in the properties were observed as in previous studies [8, 15] and so the concrete mixtures were prepared by MMA. Liang et al. [22] developed the MMA approach for RCA wherein a stiff non-porous matrix was developed under two stages of mixing, filling the microcracks on the surface of RCA. The same technique was implemented in this study with FRA particles. Upon mixing, it is observed that the stiff non-porous matrix formed during the first stage covers the FRA particles added during the second stage and finally develops a dense concrete structure with fewer voids. The hardened concrete prepared by MMA was evaluated for its compressive strength, split tensile strength, and flexural strength at 7, 14, and 28 days. The results indicate the optimum replacement of FRA as 30% for both NMA and MMA mixes. However, at all replacement percentages and various curing period, MMA mixes show improved properties than NMA. This is attributed to the densification of ITZ in RAC mixes owing to MMA. The FRA concrete mixes comprise dual ITZ, the former among the new matrix and FRA and the latter among the old matrix and the new matrix. Since the latter is the weakest zone with micro-cracks that affect the concrete's strength, the MMA technique was developed. The MMA approach develops a solid matrix that enhances the weak ITZ and thus improves the hardened properties of the concrete.

4. CONCLUSIONS

The effect of NMA and MMA on the properties of FRA concrete was studied, and the results were compared with NFA concrete. Nevertheless, higher porosity of FRA resulting from increased replacement affects the properties of the concrete. Based on the investigation, the following conclusions are drawn as follows:

1. All the properties of FRA were equivalent to NFA, whereas the water absorption of FRA (6.93%) was 87.44% higher than the NFA (0.87%) owing to the adhered mortar and thus affecting the concrete properties.
2. The optimal proportion of FRA for NFA in the concrete was observed to be 30% afar it the affects the properties of the concrete.
3. An increase in the substitution of FRA affects the workability of the concrete, owing to its inferior properties ensuing from the smearance of cement particles on its surface. Even though the workability of MMA mixes reduces with an increase in the FRA, but the values are higher than NMA mixes.
4. The compressive strength, tensile strength, flexural strength and elastic modulus of concrete mixtures with optimal percentage of FRA prepared to MMA was 17.04%, 12.42%, 9.36% and 9.73% more compared to the NMA at 28 days. However, with 100%, the properties of MMA mixed was reduced by only 15.09%, 10.23%, 7.75% and 7.94% at 28 days.
5. The concrete manufactured by MMA technique perform better in terms of fresh and hardened properties than NMA mixes at various replacement levels and curing ages.

This study could provide a clear evident on enhancement in the RAC properties by variation in the mixing approaches even at high replacement of FRA. Further research on its durability aspects would promote the utilization practice of FRA in industries and thus counteracting the consequence of shortage of river sand and ensuing the sustainability in the construction.

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Persian Abstract

چکیده

پسماند جامد شهری به دلیل تولید فراوان ناشی از افزایش فعالیت های عمرانی، تهدیدی بزرگ برای محیط زیست در دوران اخیر محسوب می شود .شاید کمبود مصالح ساختمانی نیز به دلیل شهرنشینی که نیاز به مصالح مناسب جایگزین دارد، نگران کننده باشد .با توجه به عوارض فوق، این تحقیق استفاده پایدار از قطعات بتنی زباله های ساختمانی را به عنوان جایگزین مناسب برای سنگدانه های ریز طبیعی (NFA) که به عنوان سنگدانه بازیافتی ریز (FRA) نامیده می شود، در بر می گیرد .با این حال، استفاده از FRAبه دلیل افزایش تخلخل ناشی از چسبیدن ذرات سیمان و ذرات ریز گرد و غبار، خواص بتن را مختل می کند .همچنین، مطالعات متعددی به عملکرد ضعیف بتن به دلیل ضعف ناحیه انتقال سطحی (ITZ) در نتیجه ملات چسبیده اشاره کرده‌اند .بنابراین، این مطالعه با هدف بررسی استفاده موثر از FRA برای تهیه مخلوط بتن با خواص افزایش یافته است .بخش های بتنی زباله های ساختمانی از دانشگاه جمع آوری و خرد شد تا FRA آماده شود .هر دو FRA و NFA از قبل اشباع شده بودند و مخلوط‌های بتن با روش اختلاط ملات (MMA) با درصدهای متفاوت FRA تهیه می‌شوند .تأثیر FRA در بتن از طریق کارایی، مقاومت فشاری، مقاومت کششی، مقاومت خمشی و مدول الاستیک بررسی شد .نسبت بهینه FRA به عنوان جایگزین30 NFA ٪ با افزایش مقاومت بتن9.93 ٪ مشاهده شد، در حالی که با100 ٪ FRA در 28 روز23.5 ٪ کاهش یافت.