Longevity and Sturdiness and Silica

B. SURESH, G. SRUJAN, S. KIRAN KUMAR, B.SRINIVASA RAO
[1,2,3,4] ASSIT.PROFESSOR
Department of ECE, SWARNA BHARATHI INSTITUTE OF SCIENCE & TECHNOLOGY (SBIT), Pakabanda Street, Khammam - 507 002. Telangana, India.

Abstract

Recycling and proper disposal of demolition waste are becoming more pressing issues in the modern day. Finding structural uses for recycled aggregate combined with fly ash and silica fume is the primary objective of this project. We tested 126 specimens of concrete with different amounts of used aggregate, fly ash, and silica fumes to determine its permeability and strength properties. First, we measured the impact on the strength parameter and permeability when different percentages of recycled aggregate were used in place of natural aggregate (30% and 70%). For the second set of trials, we substituted recycled aggregate for 25% and 70% of the regular aggregate, respectively, and utilized 5% fly ash and 5% silica fume for the cement. Results from the third round of tests indicate that 10% fly ash and 10% silica fumes may be used in lieu of cement, with 30% and 70% recycled aggregate respectively remaining in place of natural aggregate.
The results show that compared to employing native aggregate, using recycled aggregate enhances permeability and decreases strength restrictions. The strength parameter of concrete is 70% recycled aggregate, with a decrease of 3%. There was a consistent trend for several strength indices and the permeability of concrete. Fly ash and silica fume improved the different strength characteristics in concrete mixes due to their tiny particle size. When cement was replaced with fly ash and silica fumes, the permeability of the concrete was lowered. Mixing 30% recycled aggregate with 5% fly ash and 2% silica fume increased the compressive strength of the combination by 2.1% compared to the standard mix. The results were consistent over a range of concrete strengths. The reference mix had a permeability that was 8.4 percent higher than a combination of 5% fly ash and 5% silica fumes. As the percentages of fly ash and silica fumes increased (up to 10% each), the compressive strength dropped relative to a blend with 5% fly ash and 5% silica fumes. A 10% improvement in permeability was achieved by combining 10% fly ash with 10% silica fume. Therefore, BR 2 with 30% recycled aggregate, 5% fly ash, and 5% silica fumes would be the optimal mixture for use in the field.

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Keywords: Strength; Durability; Recycled aggregate; Fly ash; Silica fume

1. Introduction

The most common building material on a global scale is concrete. Consequently, there is a very large carbon footprint associated with concrete production. The last decade has seen an unprecedented increase in the global amount of construction trash. Cement, water, and coarse aggregate (20 mm) are mixed to form concrete, a substance that solidifies when left to its own devices.

Nowadays, high-quality concrete with improved workability, strength, and durability and decreased permeability is made using pozzolana substances, such as silica fumes and fly ash, instead of cement. By reducing the amount of free calcium hydroxide (CH) and increasing the amount of calcium silicate hydrate, pozzolanic reactions change the microstructure of concrete, which in turn increases its strength, compact porosity, and durability.

The purpose of this study is to provide an overview of recently approved research into the incorporation of recycled aggregates. The objective is to determine if REC may achieve mechanical performances that are equivalent to regular concrete. The term "secondhand aggregate" refers to a kind of waste material that is defined in this article. The primary objective of this study was to investigate the consequences of partially substituting used aggregate, fly ash, and silica fume for conventional cement and aggregate.

2. Research objective

3. The study's overarching goal is to create M25 grade concrete utilising common ingredients including water, river sand that is readily accessible in the area, crushed natural coarse aggregates, and recycled aggregates, as well as standard Portland cement 43 grade. It compares new and used concrete of the same grade (M25) as well as conventional concrete of the same grade. This study aims to compare the strength parameters and durability of recycled aggregate concrete with concrete created from used aggregates, utilising different amounts of used aggregates and pozzolanic ingredients in the mix. This study aims to determine the impact of used aggregate on concrete's compressive, split tensile, and flexural strengths at different percentages (0%, 30%, and 70%) after being immersed in a water tank for different amounts of time (7 and 28 days), as well as the effect of used aggregate on concrete's durability at different percentages (0%, 30%, and 70%) after being partially substituted with OPC with fly ash and silica fumes at 0%, 10%, and 20% respectively.

4. Investigational approach

4.1 Material

Water, cement, sand, natural aggregate, recycled aggregate, fly ash, and silica fumes were all components of the study's material. Natural river sand from the Punjab area is one example of a locally accessible resource. The density of river beas sand is 2821 kg/m3, and its water absorption rate is 1.09%. Its specific gravity is 2.42. The Postgraduate lab's tested beam sample components were used to obtain the recycled aggregates. The utlratech cement ready mixed factory is a source of fly ash and silica fumes.

4.2 Concrete fusion

5. In accordance with the IS Code, the mixed-use design of recycled and natural aggregates was approved. This study investigates the feasibility of using a combination of fly ash and silica fume as a cement replacement with high substitution percentages for used aggregates and self-cementing materials. A batch of regular concrete was mixed with a variety of recycled aggregates and self-cementing ingredients. The recycled aggregate alternative ratio ranges from 30% to 70%, and the self-cementing material substitution level is between 0% and 10% (by weight).
Based on the water-to-cement (w/c) ratio of 0.48, the mixtures were sorted into three groups: A, B, and C. Each and every one of the mixes was classified according to a famous description that described the substitution degree. Mixtures A, B, and C were denoted by proportions of 0%+0%, 5%+5%, and 10%+10% of fly ash and silica fume, respectively; R 1, R 2, and R 3 were denoted by proportions of 0%, 30%, and 70% of used aggregate, respectively.

Table 3.1 Quantitynecessary for M 25 grade

Water (litres)	Cement (Kg)	Fine aggregate (Kg)	Coarse Aggregate (Kg)
191.52	399	643	1157.60
0.48	1	1.61	3.05

5.1 Casting, Curing and Testing of Specimens

6. The balanced components are mixed using a spinning grinder mixer. After the dry ingredients were put to the mixer, the waterless assortment was turned on for 1.5 minutes to incorporate. The rotary mixer was then filled with water and let to spin for an additional minute. Finally, the remaining water was added to the

rotating drum and left to mix for 2 minutes until a homogeneous consistency was achieved. All of the concrete mixes followed the same procedure for mixing the various ingredients. After eliminating any air bubbles, the concrete samples were cast into the moulds. Following the casting process, every sample of concrete was carefully placed in a temperature-controlled laboratory. Each sample was demoulded after 24 hours and left to cure in a controlled environment until testing day.

7. Specific procedures must be adhered to in order to get strength and durability metrics. The first step is to cast a 150 mm cube and test it for compressive strength at different ages. Then, for split tensile, cast a 150 mm diameter and 300 mm high cylinder. Finally, cast and test a 150 mm x 500 mm beam for flexural at different ages. A cylinder with a diameter of 150 mm and a height of 150 mm is cast and tested for water permeability.

8. Results and Discussions

8.1 Mechanical Properties

9. The 126 specimens that were produced were subjected to testing at various ages. The outcomes of the tests, which were based on the testing of concrete samples, are presented in detail. The next step in the concrete process was studying the effects of using recycled aggregate and cement mixed with fly ash and silica fumes as partial replacements for natural aggregate on the concrete's strength and durability parameters.

Table 2

Concrete mixtures composition

Mixseries	Mixcode	Binder (Kg/cm³)			Water	NCA	RCA	Sand
		OPC	FA	SF				
A	AR 1	399	0	0	191.56	1157.6	0	643
w/b=0.48	AR 2	399	0	0	191.56	810.32	347.3	643
	AR 3	399	0	0	191.56	347.3	810.32	643
B	BR 1	359.1	17.95	17.95	191.56	1157.6	0	643
w/b=0.48	BR 2	359.1	17.95	17.95	191.56	810.32	347.3	643
	BR 3	359.1	17.95	17.95	191.56	347.3	810.32	643
C	CR 1	319.1	39.9	39.9	191.56	1156.7	0	643
w/b=0.48	CR 2	319.1	39.9	39.9	191.56	810.32	347.3	643
	CR 3	319.1	39.9	39.9	191.56	347.3	810.32	643

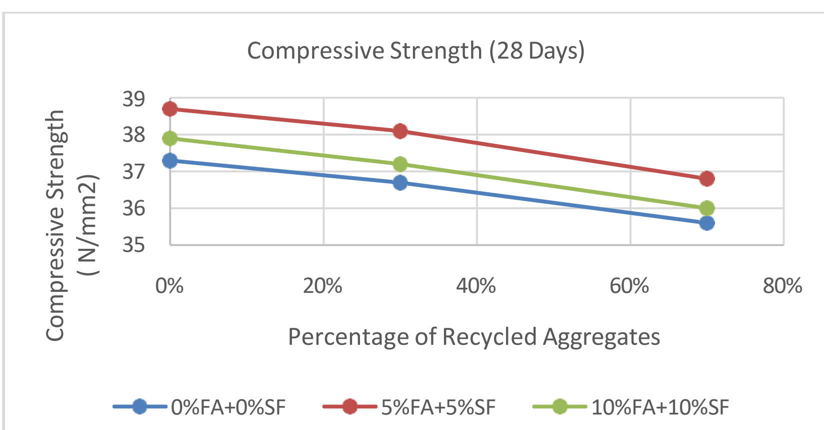

Fig. 1 Variation of second-hand Aggregate at 28 Days

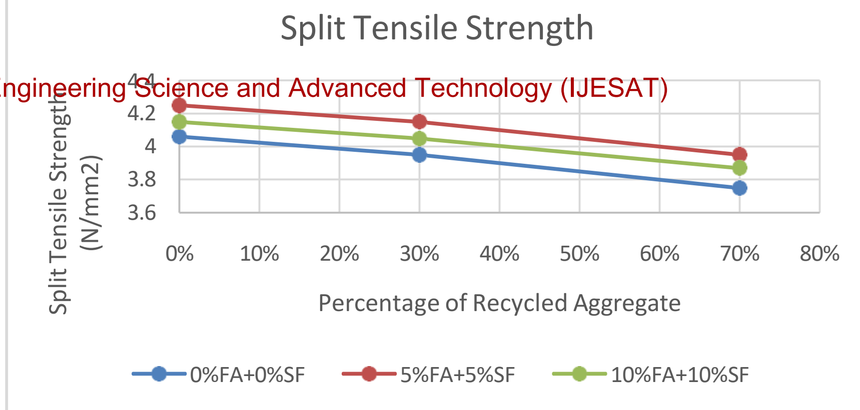

Fig. 2 Variation of second-hand Aggregate at 28 days

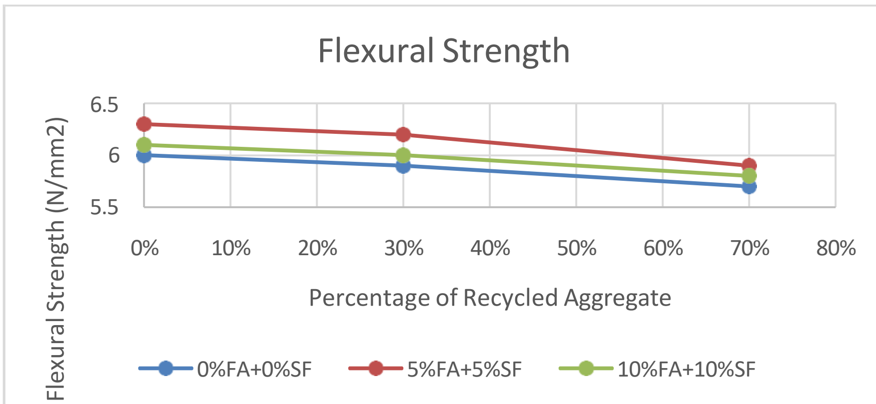

Fig. 3. Variation of Recycled Aggregate at 28 days

Compressive strength of concrete decreases as the amount of used aggregate increases, as seen in the tables and figures above. Compressive strengths of 36.7 N/mm2 and 35.6 N/mm2 were recorded for slots AR2 and AR3, which contained 30% and 70% recycled aggregate, respectively. It is worth noting that the reference mix reached a compressive strength of 37.3 N/mm2 after 28 days. The extra interfacial transition zone between the new mortar and the old mortar that was attached to the original aggregate is responsible for the decrease in compressive strength. The compressive strength of mix BR1, which is 5% FA and 5% SF, was 38.7 N/mm2 after 28 days, which is 3.8% higher than the reference mix AR1, which had a compressive strength of 37.3 N/mm2. The compressive strength of the BR2 and BR3 mixes, which comprise 5% FA and 5% SF and 30% and 70% recycled aggregate, respectively, was 38.1 N/mm2 and 36.8 N/mm2, were attained. It is evident that mix BR2 resulted in a 2.1% improvement in concrete's compressive strength. However, there was a little drop of 1.3% in the compressive strength of the BR3 mix. At 7 days, the compressive strength of mix CR1, which is 10% FA and 10% SF, is 37.9 N/mm2, which is higher than the 37.3 N/mm2 achieved by reference mix AR1. The compressive strength was 37.2 N/mm2 for mix CR2, which included 30% recycled aggregate, and 36.0 N/mm2 for mix CR3, which contained 10% FA and 10% SF. The results show that, when compared to the reference mix, mix CR2 significantly improves concrete's compressive strength by 0.27 percent. Having said that, mix CR3's compressive strength dropped 3.5%.
All of the concrete strength metrics are reduced as the fraction of used aggregate is increased, as seen in the figures above. The strength drops as the second-hand aggregate ratio rises, as shown in the graphs. The ideal alternative to the used aggregate was close to 30%. Because of the transition zone in, the strength tends to diminish fast when the replacement level is increased beyond the optimal level.

10. the used-goods total. Because the pore refinement of the concrete structure occurs when fly ash and silica fumes are added to concrete with used aggregate, the performance of the concrete tends to enhance. Yet, fly ash and silica fumes, up to a certain replacement level, do increase strength. The strength has been raised across all replacement positions as compared to the standard blend. The strength reduces when the degree of second-hand aggregate climbs over 30%. An additional zone of interfacial transition between the new mortar and the used aggregate and the old stick cement mortar causes a noticeable weakening of the mortar. All three of these strength metrics—compressive, split tensile, and flexural—show a consistent pattern when testing concrete with different self-cementing material substitutes.

Depending on whether you add reactive silica fumes or nonreactive fly ash, the strength will go up or down since the nonreactive fly ash will stuff the matrix. The pozzolanic reaction of class F fly ash is sluggish, therefore there may be up to 50% unreacted fly ash after a year. Thus, the inert part may alternatively be thought of as a microaggregate that adds to the material's strength. Despite the strength acquired from the unreactive fraction of fly ash via packing effect, the reactive portion plays a decisive and dominating role.

10.1 Durability Properties

10.1.1 Permeability

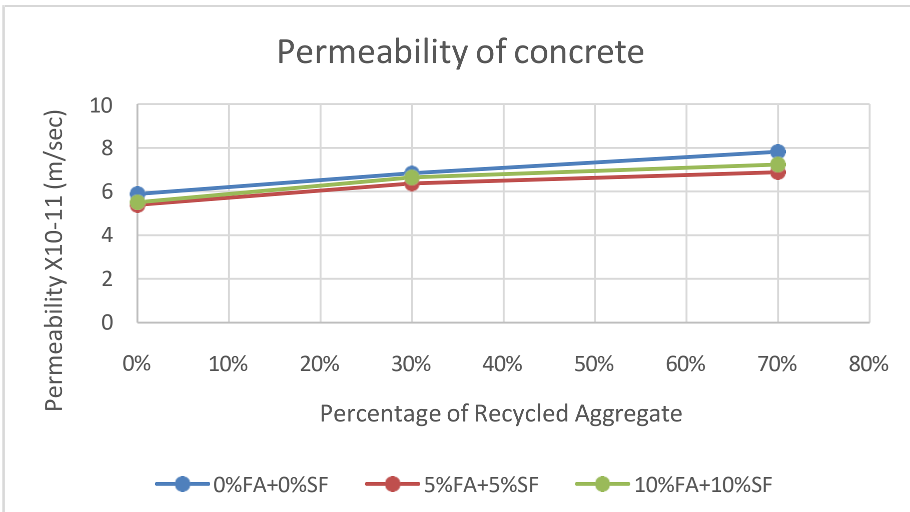

Fig. 4 Variation of Recycled Aggregate on Permeability of Concrete

11. The data shown above make it quite evident that using a higher percentage of recycled aggregate in concrete increases its water permeability. The permeability of concrete increases as the amount of used aggregate increases, as seen in the figures above. The figures show that the permeability increases as the percentage of used aggregates rises. As the replacement level goes above what is considered optimal, the permeability of the concrete starts to rise sharply because of the transition zone in the recycled aggregate and the remaining pores in the material. Because of the pore reinforcement they provide to the concrete's structure, fly ash and silica fume may reduce the permeability of concrete when mixed with recycled material. However, fly ash and silica fumes, up to a certain replacement level, may reduce the water permeability. The permeability has been reduced throughout all of the replacement slots as compared to the typical mix. Permeability begins to rise at a 30% replacement level of used aggregate and rises thereafter. An additional zone of interfacial transition between the aged bonded cement mortar, the used aggregate, and the new mortar allows for increased permeability.

12. Conclusions

The impact of recycled aggregate on strength and longevity is the subject of this investigation. In this, fly ash and silica fume were used in place of cement, and used aggregate was used in different proportions than usual. Results about the strength and durability of these alternatives were derived from an analysis of 126 samples.

1. Absorption of water of second hand aggregates was more than normal aggregates, due to the adherence of the mortar stick to second hand aggregate which is having weak and absorbent zone which give rise to absorption.
2. The substitute of normal aggregate by second hand aggregate result in lowering of all strength aspect of concrete however, the permeability of second hand aggregate concrete increased
3. The substitute of cement incorporating with fly ash & silica fumes in second hand aggregate augment in all aspect of concrete.
4. No noteworthy improvement in strength parameter was found when the fly ash & silica fumes were augmented to 10% each.
5. The mix comprising 30% second hand aggregate, 5 % fly ash & 5 % silica fumes showed strength of 38.1N/mm^2 which is superior to the strength display by conventional mix. Hence it can be suggested for site application use.
6. When the substitution increases beyond the optimum substitute level then the strength tends to reduce rapidly due to transition zone in the second hand aggregate.
7. When the fly ash & silica fumes is added to the concrete with the second hand aggregate then the performance of the concrete tends to increase due to the pore reinforcement of the structure of the concrete.
8. With comparison to conventional mix all the slots of replacement the strength has been increased. When the substitute level of second hand aggregate increases from above 30 % then the strength decreases.
9. The decrease in strength is recognized due the extra zone of interfacial transition connecting the aged stick cement mortar to the second hand aggregate and the fresh zone of mortar.

References

[1] [1] In China Build. Mater. 07 (2018) 36-38 (in Chinese), Y.Y. Hu discusses the future growth pattern of the industry and the China gravel industry, which is now undergoing change.
In their 2012 article "Mechanical properties of self-consolidating concrete blended with high volumes of fly ash and slag," Kuder et al. discuss the mechanical characteristics of self-consolidating concrete that contains large amounts of fly ash and slag. The article can be accessed online at https://doi.org/10.1016/j.conbuildmat. 2012.02.034.
[3] Research by M. H. Fu on the use and improvement of recycled fine aggregate made from demolition debris, Southeast University, Nanjing, China, 2016, pp. 2-4 (in Chinese).

G. Long, Y. Gao, and Y. Xie's work Creating environmentally friendly and long-lasting self-compacting concrete, in: Constr. Build. Mater. 84 (2015) 301-306, doi:10.1016/j. conbuildmat.2015.02.072.
In a study conducted by C.J. Shi, Y.K. Li, J.K. Zhang, W.G. Li, L.L. Chong, and Z.B. Xie, Journal of Cleaner Production 112 (2016) 466-472, https://doi.org/10.1016/j.jclepro.2015.08.057, reviews the literature on improving the performance of recycled concrete aggregate.
6. B. Wu and Z. Li Mechanical characteristics of mixed concrete with crushed concrete particles during freeze-thaw cycles, Constr. Build. Mater. 155 (2017) 187-199, https://doi.org/10.1016/j.conbuildmat.2017.07.150. Published in 2017.

[2] [2] Cem. Concr. Compos. 84 (2017) 83-92, https://doi.org/10.1016/j. cemconcomp.2017.08.016, Optimisation of normal and high strength recycled aggregate concrete mixes by utilising packing model, by M. Amario, C.S. Rangel, M. Pepe, and R.D. Toledo.
According to [3], X. Shan, J. Zhou, V.W.-C. Chang, and E.-H. Yang Journal of Cleaner Production 164 (2017) 918-926, https://doi.org/10.1016/j. jclepro.2017.07.015, examines the life cycle evaluation of using green concrete and local recycled aggregate from Singapore's viewpoint.
In their 2018 article "Life Cycle Assessment and Life Cycle Costing towards Eco-efficiency Concrete Waste Management in Malaysia," C.M. Mah, T. Fujiwara, and C.S. Ho discuss the use of LCA and LCC in the management of concrete waste in Malaysia. The article can be found at https://doi.org/10.1016/j.jclepro.2017.11.200.

A.L. Martínez, M.S. Lopez, C.L.-C. Perez, J.G. Perez, F.L. Gayarre, and C.L.-C. Perez Journal of Cleaner Production 113 (2016) 41–53, https://doi.org/10.1016/j.jclepro.2015.11.093. Life cycle evaluation for concrete kerbs made with recycled aggregate.
[...] Poon, C.S., Kou, S.C., and Lam, L. Mater. Struct. 40 (2007) 981-988, https://doi.org/10.1617/s11527-006-9192-y, examines the effects of recycled aggregate on the slump and bleeding of newly mixed concrete.
J.Z. Xiao, W. Li, Y. Fan, and X. Huang. Constr. Build. Mater. 31 (2012) 364-383, https://doi.org/10.1016/j.conbuildmat.2011.12.074. It provides a synopsis of research on recycled aggregate concrete in China from 1996 to 2011.
(Source: https://doi.org/10.1016/j.conbuildmat.2017.03.176) B. Wu and G. Ye, "Development of porosity of cement paste blended with supplementary cementitious materials after carbonation," Constr. Build. Mater. 145 (2017) 52-61.
According to G. Hannesson, K. Kuder, R. Shogren, and D. Lehman, How a high concentration of fly ash and slag affects self-consolidating concrete's compressive strength, Constr. Build. Mater. 30 (2012) 161-168, https://doi.org/10.1016/j.conbuildmat.2011.11.046.
"Z. Pan, J. Zhou, X. Jiang, Y. Xu, R. Jin, J. Ma, Y. Zhuang, Z. Diao, S. Zhang, Q. Si, W. Chen" published in [10] Using recycled aggregates in self-compacting concrete, we looked at how adding steel slag powder affected its characteristics. Reference: https://doi.org/10.1016/j.conbuildmat.2018.12.150, Constr. Build. Mater. 200 (2019) 570-577.
Flora, A.Z., Katya, B., and Carlo, P. [11] Mater. Des. 85 (2015) 687-694, https://doi.org/10.1016/j. matdes.2015.07.079. Valorization of co-combustion fly ash in concrete manufacturing.
In their work, R.K. Majhi, A.N. Nayak, and B.B. Mukharjee Concrete that is both environmentally friendly and made from recycled materials, including granulated blast furnace slag and coarse aggregate, Article published in 2018 in the journal Constr. Build. Mater., pages 417–430, with the DOI: 10.1016/j.conbuildmat.2017.10.118.
Jin, R., Chen, Q., and Soboyejo, A. (2013) Analyse the present state of environmentally friendly concrete manufacturing in the United States, The cited article is "Resour. Conserv. Recycl. 105 (Part A) (2015) 148-159" with the DOI number 10.1016/j.resconrec.2015.10.011.
A group of researchers included L.A. Pereira-de-Oliveira, M.C.S. Nepomuceno, J.P. Castro-Gomes, and M.F.C. Vila The article "Permeability properties of self-compacting concrete with coarse recycled aggregate" has a DOI of 10.1016/j.conbuildmat.2013.10.61 and was published in 2014 in the journal Constr. Build. Mater., volume 51, pages 113–120.
1. Grdic, Z.J., Toplicic-Curcic, G.A., Despotovic, I.M., and Ristic, N.S. Constr. Build. Mater. 24 (2010) 1129-1133, https://doi.org/10.1016/j.conbuildmat.2009.12.029. The article discusses the characteristics of self-compacting concrete that is made from coarse recycled concrete aggregate.
P.D. Kiousis, A. Savva, C.G. Fakitsas, and P.E.A. Papakonstantinou J. Mater. Civ. Eng. 24 (2012) 356–361, https://doi. org/10.1061/(ASCE)MT.1943-5533.0000397, examines how recycled concrete aggregate affects the compressive and shear strengths of high-strength self-consolidating concrete.
Evangelista, J. de Brito, P. Pereira, and L. Evangelista In a 2012 study published in the Journal of Concrete Research, the authors examined the impact of superplasticizers on the mechanical properties of concrete using fine recycled concrete aggregate. The results were published online at https://doi.org/10.1016/j.cemconcomp.2012.06.01.
S. Nayak, P. Rajhans, and S.K. Panda A microstructural examination into the effects of enhancing porosity and hydrated compounds on the durability of self-compacting concrete made from construction and demolition debris, Article published in 2018 in the journal Constr. Build. Mater., volume 174, pages 559-575, with the DOI: 10.1016/j.conbuildmat.2018.04.137.
By P. Rajhans, S.K. Panda, and S. Nayak, Structural Engineering and Materials, 163 (2018) 557–570, https://doi.org/10.1016/j.conbuildmat.2017.12.132, presents a method for producing environmentally friendly self-compacting concrete from construction and demolition debris by enhancing the microstructures of the material.
In [20],*Ezbay*, *Ertem*, *Durmus*, *H.I. Ground granulated blast furnace slag's use and effectiveness in improving concrete's characteristics: a literature review, Constr. Build. Mater. 105 (2016) 423-434,

https://doi.org/10.1016/j.conbuildmat.2015.12.153.
In a study conducted by K. Celik, C. Meral, A.P. Gursel, P.K. Mehta, A. Horvath, and P.J.M. Monteiro, Paper published in 2015 in the Journal of Concrete Research, detailing the mechanical characteristics, durability, and life-cycle evaluation of self-consolidating concrete mixes manufactured using blended Portland cements incorporating fly ash and limestone powder, with the DOI: 10.1016/j.cemconcomp.2014.11.003.

[22] In Properties of Concrete, 4th edition, A.M. Neville was published by Prentice Hall in Essex in 1995. Guo, Z.G., Chen, C., Lehman, D.E., Xiao, W.G., Zheng, S.L., and Fan, B.J. [23] How recycled coarse and fine aggregate affects the mechanical and durability properties of concrete, European Journal of Environmental Civil Engineering, 1-19, 2017, https://doi.org/10.1080/19648189. 2017.1371083.
[24]Beijing, China: Chinese Building Press, 2010 (GB 50010-2010), Code for Design of Concrete Structures.
Article cited as "Performance evaluation of structural concrete using controlled quality coarse and fine recycled concrete aggregate" (https://doi.org/10.1016/j.cemconcomp.2015.02.009) was written by A. Lotfy and M. Al-Fayez and published in the Journal of Concrete Research, Volume 61, Issue 3, pages 36–43 in 2015.
ACI 318-02 and ACI 318R-02 are the comments and requirements for structural concrete as outlined in the ACI 318 building code. The American Concrete Institute is located in Detroit, USA.
Improved mechanical and durability characteristics of recycled aggregate concrete, by G. Dimitriou, P. Savva, and M.F. Petrou, published in Constr. Build. Mater. 158 (2018) 228-235, https://doi.org/10.1016/j.conbuildmat.2017.09.137.
[28] A research on the strength of steel fibre reinforced fly ash recycled concrete was conducted by X.B. Zhang, C.G. Kuang, Z. Fang, X.H. Liu, G.Q. Wang, and S. Lai in the Journal of Building Materials, volume 17, issue 4, 2014, pages 677-685 (in Chinese).
The impact of silica fume and high-volume Class C fly ash on the mechanical characteristics, chloride penetration, and freeze-thaw resistance of self-compacting concrete was studied by H. Yazıcı in 2008 in the journal Constr. Build. Mater., number 22, pages 456-462. The article may be seen at https://doi.sg/10.116/j.conbuildmat.200701.002.
[30] inResearchers H. Guo, C.J. Shi, X.M. Guan, J.P. Zhu, Y.H. Ding, T.C. Ling, and colleagues, This article provides a comprehensive overview of the topic of recycled aggregate concrete's durability and can be accessed at https://doi.org/10.1016/j.cemconcomp.2018.03.008.
In a 2009 article published in Constr. Build. Mater., M.L. Berndt discussed the characteristics of sustainable concrete that includes fly ash, slag, and recycled concrete aggregate (https://doi.org/10.1016/j.conbuildmat.2009.02.011).
Referenced as [32] in J. Cleaner Prod. 115 (2016) 294-306, https://doi.org/10.1016/j.jclepro.2015.12.065, the study was conducted by J.A. Bogas, J.d. Brito, and D. Ramos to determine the freeze-thaw resilience of concrete made using fine recycled concrete aggregate.
The article "An approach to optimising mix design for properties of high-performance concrete" by P.K. Chang was published in the Journal of Concrete Research in 2004 and may be accessed online at https://doi.org/10.1016/j. cemconres.2003.10.010.
The use of fly ash in concrete was discussed in the ACI Manual of Concrete, section 232.2R-96, which is 34 pages long and was published in 2003 by the American Concrete Institute in Farmington Hills, Michigan.
[35] inIn 2020, Guo, Z., Jiang, T., Zhang, J., Kong, X., Chen, C., and Lehman, D. E. published... Sustainability in self-compacting concrete using recycled material, fly ash, slag, and silica fume: mechanical and durability characteristics Building and Construction Materials, 231(2019), 117115. doi:10.1016/j.conbuildmat.2019.117115.
[36] The specification for fly ash for use as pozzolona and admixture was published by the Bureau of Indian Standards in New Delhi in IS 3812-1981 (Reaffirmed 1999).
[37] IS 456:2000, Plain and Reinforced Concrete Code of Practice, Bureau of Indian Standards, New Delhi.
[38] Indian Standard 516:1959 (Reaffirmed 1999), Bureau of Indian Standards, New Delhi, Methods of

testing concrete strength.
IS: 8112:1989, New Delhi: Bureau of Indian Standards, specifies grade 43 ordinary Portland cement.