Mehran University Research Journal of Engineering and Technology

https://doi.org/10.22581/muet1982.2713

2025, 44(1) 1-7

Combine effect of fly ash and aggregate size on flexural strength of reinforced concrete

Dileep Kumar [a], Dhanik Vikrant [b], Kashif Rafique Memon [c], Alyas Khan Mandokhail [d]

[a] *U.S.-Pakistan Center for Advanced Studies in Water (USPCAS-W), Mehran University of Engineering & Technology Jamshoro, Pakistan*

[b] *Department of Civil Engineering, DHA Suffa University, Karachi Pakistan*

[c] *Department of Civil Engineering, Ziauddin University Faculty of Engineering, Science, Technology and Management, Karachi Pakistan*

[d] *Department of Civil Engineering, Sir Syed University of Engineering and Technology, Karachi Pakistan*

[*] Corresponding author: Dhanik Vikrant, Email: dhanikvikrant@gmail.com

Received: 16 January 2023, Accepted: 26 December 2024, Published: 01 January 2025

K E Y W O R D S

Density

Flexural Strength

Ultimate Deflection

Fly Ash

Coarse Aggregate size

A B S T R A C T

The study emphasizes the importance of utilizing fly ash and optimized aggregate sizes to enhance structural performance while promoting sustainable construction practices by reducing cement usage. In this research study, the combined effect of fly ash and aggregate size on the flexural strength of reinforced concrete is investigated. In this experimental study, a total of 12 batches were prepared with varying fly ash proportions and coarse aggregate sizes. For all batches, cement was replaced with fly ash by 0%, 5%, 10%, and 15% by weight of cement, and three different sizes of coarse aggregates (6.25 mm, 12 mm, and 20 mm) were used. The mix design and water cement ratios were set to (1:2:4) and 0.48, respectively. Prism-type RCC beams of size 100mm x 100mm x 500mm were casted for testing to evaluate density, ultimate load, and ultimate strength. Results revealed that reinforced concrete batch B2, containing 5% fly ash and 12.5 mm aggregate size, achieved a higher density and sustained an ultimate load 56.48% higher than nominal concrete. Furthermore, deflection in reinforced concrete batch D1 containing 15% fly ash and 20-mm aggregate size decreased by 12.13% compared to nominal concrete. The results showed that the combined effect of fly ash and aggregate size will minimize deflection and will provide sufficient flexural strength to sustain structural load effectively.

1. Introduction

Ordinary Portland Cement (OPC) is a substitute for concrete used as a binder, which resists cracking. Shrinkage also strengthens the bonding between aggregates. OPC concrete is a widely used material in the construction industry, and its demand is rising day by day in order to fulfil the need for development in infrastructure. Production of OPC consumes a high amount of energy and natural resources, and it causes global warming in the environment by releasing a significant amount of carbon dioxid [1]. In addition, excessive extraction of raw materials like aggregate is also turning industries away from its limited use. Aggregates play a very effective role in concrete strength, and 75% of concrete composition is aggregates. To meet the demands of the construction industry, it is critical to find alternative materials that are cost-effective, environmentally friendly, emit no CO_2, and have the same binding properties as OPC. There are several industrial by-products are available such as fly ash, which is an industrial by-product generated by coal combustion, and it is an abundant material throughout the world[2]. It also possesses pozzolanic properties and is rich in silica and alumina[3]. Fly ash as a supplementary material in concrete and it can significantly enhance the properties of the material [4]. The global production of fly ash was 380.5 million tonnes 2022 and will 475.4 million tonnes by 2028. Pakistan alone generates 212,000 tons of fly ash annually. Fly ash lowers the water demand of concrete for similar workability and, as well, reduces bleeding and the evolution of heat [5]. It has also been discovered that, under a given load, the strength, concrete cover, and bonding between steel and aggregate could vary due to the aggregate size. The mechanical properties of concrete are determined not only by the bonding between cement and aggregates, but also by the bonding between aggregates and the reinforcement, which ensures the safety of the concrete against failure, as well as the geometry of the concrete cover around the reinforcement[5][6][7]. P.S. Joann A. Jessy Rooby et al. (April 2013) investigated the structural behaviour of a reinforced fly ash concrete beam by replacing 50% of the cement with fly ash and by using SP430 plasticizer. Results of his study revealed that the flexural strength of concrete significantly improved after 28 days of curing, along with moment capacity, which increased by 23%, whereas ultimate moment capacity decreased by 16% [8]. Arivalagan S. conducted a research study on the flexural strength of fly ash reinforced concrete beams by replacing cement at 10% and 20% with fly ash and tested under a two-point load and revealed that fly ash has improved the tensile strength [9]. Sunilaa George and Dr. R. Thenmozhi investigated the flexural strength of concrete by replacing cement at 10%, 20%, 30%, 40%, 50%, and 60% with chemically activated fly ash and by adding 0.48 ratio of water binder. Results indicated that maximum 50% of cement can be replaced with fly ash because the ultimate load of chemically activated fly ash concrete beams was comparatively less than nominal concrete beams[10] Y.M. Pudale and Dr. D.N. Shinde both investigated the initial crack load, ultimate load carrying capacity, and deflection of fly ash and RCC beams wrapped with GFRP sheet. He tested 8 beams with dimensions of 150 x 150 mm and a rectangular cross section span of 700 mm, and the results revealed an increase in average cracking load and average ultimate load after retrofitting reinforced concrete beams, while the average for fly ash reinforced concrete beams was nearly the same [11]. K. Krishna Teja (2018) investigated that by replacing 50% cement with high volume fly ash has improved workability of concrete by reducing water demand ratio and also the properties such as flexural strength and deflection shown improvement when compared to nominal concrete [12]. Additionally Mahdi Arezoumandi et al found that high volume fly ash concrete has comparable flexural strength to conventional concrete [13]. B.K. Narendra, T.M. Mahadeviah [2014] compared flexural strength of reinforced fly ash concrete beams of three different grades of concrete by replacing cement at (20%, 35%, and 50%) with reinforced nominal concrete beams (0% Fly ash) . Results found that cracking load of M40 and M50 Grade was 21% and 23% respectively whereas; M30 sustained 18% of the flexural load. Deflection is one of the important serviceability limit states to be satisfied in the design of concrete structures. So the flexural behaviour of these beams is discussed in terms of load deflection[14]. V. Bhikshma et al (2012) investigated the effect of aggregate size on higher grade concrete with high volumes of fly ash. Three different mixes of M50 grade concrete were prepared with coarse aggregate of three different sizes (10 mm, 12.5 mm, and 20 mm), whereas, cement was replaced with fly ash at 0%, 10%, 20%, 30%, 40%, and 50%. After 56 days of curing, specimens were tested, and it was observed that a mix containing 30% fly ash with 12.5 mm of aggregate has an optimum flexural strength of 5.95 Mpa. It was increased by 5% compared to conventional concrete[15].

2. Experimental Program

2.1 Materials and Methodology

Ordinary Portland cement is used in this research, which is locally manufactured, and coarse aggregate was used with sizes of 6.25mm, 12.5mm, and 20mm. To achieve the required coarse aggregate sizes, the crushed material was sieved as per ASTM C136 "Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates". The sieve analysis test was conducted to precisely determine the particle size distribution of the aggregate, ensuring it meets the required specifications for strength and workability in concrete. By passing the material through specific sieves, such as the 1/4-inch sieve for 6.25 mm, 1/2-inch sieve for 12.5 mm, and 200-mm sieve for 20-mm, the aggregates were classified into appropriate sizes that optimize their performance in construction, ensuring the desired structural integrity and mix consistency. The coarse aggregates were thoroughly washed to achieve a saturated surface dry (SSD) condition as per ASTM C33 "Standard Specification for Concrete Aggregates" to ensure accurate testing and performance in concrete[16]. Fine aggregate was also used and sieved as per ASTM C136 "Standard Test Method for Sieve Analysis of Fine and Coarse

Aggregates"[17]. The fly ash used in these experiments was sourced from a nearby local industry in Nawabshah city, specifically from a coal-fired power plant or industrial facility involved in coal combustion. Fly ash is a by-product of the combustion process, where coal is burned to generate electricity or for other industrial purposes. In this case, the fly ash is likely Class F fly ash, which is produced by burning bituminous coal as per ASTM C618[18]. Sixty-grade steel is used in specimens. Table No.1 shows batch details.

Table 1

Batches details

Batch	Size of C.A (mm)	Fly Ash (%)
RFC-A1	20	
RFC-A2	12.5	0
RFC-A3	6.25	
RFC-B1	20	
RFC-B2	12.5	5
RFC-B3	6.25	
RFC-C1	20	
RFC-C2	12.5	10
RFC-C3	6.25	
RFC-D1	20	
RFC-D2	12.5	15
RFC-D3	6.25	

2.2 Mix Proportion

The mix design for this experimental study was developed based on the guidelines provided by ACI 211.1-91[19] and ASTM C192/C192M, ensuring consistency in material proportions, water-cement ratio, and curing practices[20]. The water-cement ratio was maintained at 0.48 across all batches, with curing conducted for 28 days as per the standard recommendations. Total 12 batches prepared for the testing according to different replacement levels of fly ash at 0%, 5%, 10%, and 15% by weight of cement with coarse aggregate sizes of 6.25mm, 12.5mm and 20mm. Table No. 2 presents the mix proportions in accordance with these standards.

Table 2

Mix proportions of concrete mixtures

Materials (KG)	Fly Ash 0%	Fly Ash 5%	Fly Ash 10%	Fly Ash 15%
Cement	5.25	4.98	4.72	4.46
Fly Ash	0	0.262	0.525	0.78
Fine Aggregate	10.5	10.5	10.5	10.5
Coarse Aggregate	21	21	21	21
Water Cement Ratio	0.48	0.48	0.48	0.48

3. Testing Procedure

Density test was conducted to measures the compactness of the concrete specimens. It evaluates the mass per unit volume (kg/m³) and is critical for determining the overall quality and void content within the concrete matrix[21]. Flexural test conducted on RCC beams, this test determines the load-bearing capacity under bending. It provides insight into the tensile strength of the concrete, especially for evaluating its performance in structural elements. Furthermore, deflection test conducted by using deflection meters, this test measures the vertical displacement of beams under applied loads. It evaluates the stiffness and ductility of the concrete beams and how well they resist deformation[22]. The testing procedure was followed by the ASTM C78 code[23]. All the prepared specimens had the same dimension of 500mm x 100mm x 100mm and were reinforced with sixty grade steel bars, of which 4No bars are used for main reinforcement and 2No bars are embedded for stirrup purposes as shown in Fig 1. All specimens were cured in ponds for 28 days to achieve maximum strength up to 99% [24], and also to gain uniformity and surface texture of concrete [25]. Because below 28 days of curing period would also decrease strength to < 90% [26]. All the specimens were then loaded in universal testing machine under center point load for flexural strength, and a deflection meter gauge was installed with universal testing machine (UTM) to record deflection in mm.

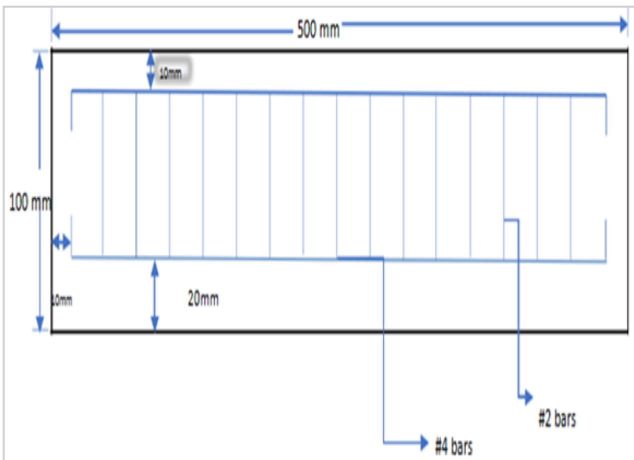

Fig. 1. Beam Dimensions

Fig. 2. Universal Testing Machine

4 Results and Discussion

4.1 Density

The bar chart demonstrates the impact of fly ash content and aggregate size on the density of reinforced concrete. It shows that as the percentage of fly ash increases from 0% to 15%, the overall density of the concrete tends to decrease. This can be attributed to the lower density of fly ash compared to traditional cement. The mix containing 5% fly ash exhibits the highest density, suggesting that moderate fly ash substitution is beneficial for maintaining the concrete's density. However, when the fly ash content increases beyond 5%, the density starts to drop, likely due to the reduced cohesion of the mix and the introduction of more air pockets, as fly ash replaces a portion of the denser cement particles.

Furthermore, the size of the coarse aggregate also plays a significant role in the density of the concrete. Concrete mixes with larger aggregates, such as the 20mm size, generally show lower density compared to those with 12.5mm and 6.25mm aggregates. Larger aggregates tend to create more voids between particles, reducing the overall packing efficiency of the mix [27]. On the other hand, smaller aggregates (like 6.25mm) provide better packing, which increases the density. The optimal combination of 5% fly ash and 12.5mm aggregates results in the highest density, emphasizing that both the fly ash content and aggregate size need to be carefully balanced to achieve desired concrete properties. These findings highlight the importance of selecting the right proportion of fly ash and aggregate size for achieving concrete mixes with optimized density, which is crucial for the strength, durability, and workability of concrete structures. and its result from that given chart reveals that reinforced concrete beam with 0% fly ash has slight change in density compared to reinforced concrete beam with different proportion of fly ash. Different coarse aggregate size also had shown small effect on the density. It is also concluded that with aggregate size 12.5mm and 5% fly ash in concrete by weight of cement has shown higher density compared to 10% and 15% of fly ash with aggregate size of 20mm and 6.25mm. Further results showed that rising proportion of fly ash above 5% and aggregate size less than 6.25mm will decrease the density of concrete.

Table 3

Density variation with fly ash and aggregate size

S.No	Fly Ash (%)	Average: Density (Kg/m3) with different size of C.A		
		20mm	12.5mm	6.25mm
1	0	2693.333	2708.67	2573.33
2	5	2780	2813.33	2733.33
3	10	2700	2733.33	2606.66
4	15	2646.66	2700	2560

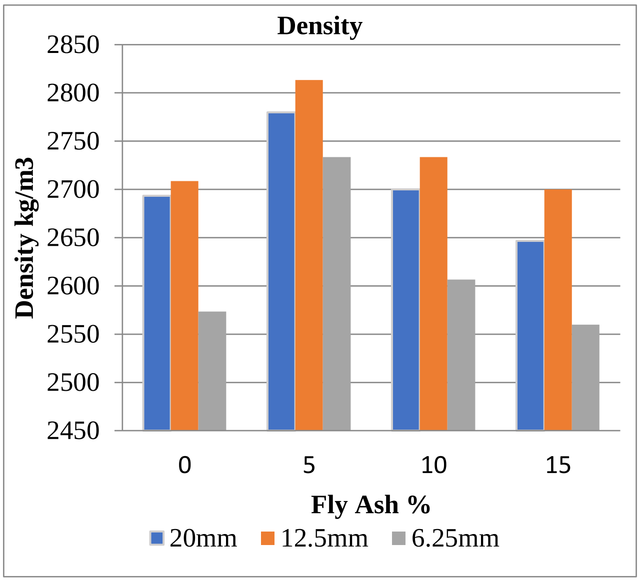

Fig. 3. Density Variation with Fly Ash and Aggregate Size

4.2 Flexural Strength

It is clear from bar chart that show the relationship between fly ash content, aggregate size, and the flexural strength of reinforced concrete. It is evident that the optimal flexural strength occurred with 5% fly ash, which showed a significant increase in ultimate load (about 56.5% higher) compared to the control sample with no fly ash. As the fly ash content was increased to 10% and 15%, the flexural strength showed a diminishing return. Specifically, the ultimate load raised only 36.24% at 10% fly ash, and with 15% fly ash, the strength decreased by around 12.14% compared to the 5% fly ash mix.

Fig. 4. Beam Loaded in UTMs

Additionally, the aggregate size influenced the flexural strength of the concrete. On average the highest ultimate load of 30.59 KN was achieved using 12.5mm aggregates, while the 6.25mm aggregates had a slightly higher ultimate load (29.5 KN) compared to the 20mm aggregates (27.85 KN). This indicates that smaller aggregates contribute to better distribution of loads and improve the development of gel bonds in the matrix, thus increasing the overall strength. Larger aggregates (20mm) can cause heterogeneity in the concrete mix, leading to lower strength due to reduced surface area for bonding.

The combination of fly ash content and aggregate size plays a crucial role in determining the flexural strength of reinforced concrete. While a 5% fly ash content optimizes strength, increasing it further results in a decrease in flexural strength. Similarly, an aggregate size of 12.5mm yields the best performance in terms of strength. These findings emphasize the importance of balancing both fly ash content and aggregate size for achieving desired concrete properties, particularly in structures requiring high flexural strength.

Table 4

Ultimate load and flexural strength results

S.No	Fly Ash (%)	Average ultimate Deflection (mm) with different size of CA			Variation in Ultimate Deflection by %		
		20 mm	12.5 mm	6.25 mm	20 mm	12.5 mm	6.25 mm
1	0	2.39	3.698	4.01			
2	5	2.364	3.658	3.967	-1.08	-1.08	-1.07
3	10	2.34	3.62	3.933	-2.09	-1.87	-1.92
4	15	2.1	3.25	3.53	-12.1	-11.9	-11.97

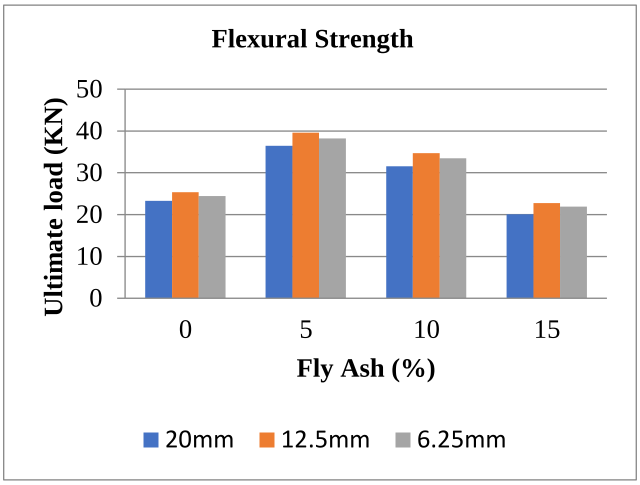

Fig. 5. Ultimate Load and Flexural Strength Results

4.3 Ultimate Deflection

The data from the deflection test reveals that reinforced concrete beams with 0% fly ash (nominal concrete) exhibit the highest deflection values, particularly as the coarse aggregate size decreases. For instance, deflection increased from 2.39 mm (20 mm aggregate) to 4.01 mm (6.25 mm aggregate). Adding fly ash to the concrete mix resulted in reduced deflection across all aggregate sizes, with the most significant reduction observed in the beams with 15% fly ash and 20 mm aggregate size, where deflection was reduced by 12.13% compared to the nominal concrete. The reduction in deflection is linked to the combined effect of fly ash and aggregate size: as the fly ash content and aggregate size increase, the deflection decreases. This behavior suggests that both fly ash and larger aggregate sizes contribute to a more rigid concrete mix, reducing bending deflection under load. The findings are supported by the deflection data, where the addition of fly ash in varying proportions consistently led to improved deflection performance across different aggregate sizes.

Table 5

Ultimate deflection

S.No	Fly Ash (%)	Average Ultimate Load (KN) with different size of C.A			Variation in Ultimate load by %	
		20 mm	12.5mm	6.25mm	20mm	12.5mm
1	0	23.32	25.36	24.46		
2	5	36.44	39.63	38.22	56.26	56.64

3	10	31.57	34.68	33.44	35.33	36.75
4	15	20.07	22.72	21.913	-13.93	-12.46

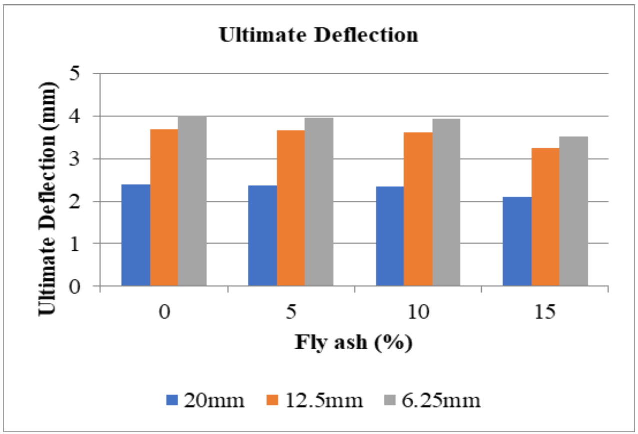

Fig. 6. Ultimate Deflection

Fig. 7. Beam Loaded in UTM with Deflection Meter

5. Conclusion

- Reinforced concrete batch B2, containing 5% fly ash and 12.5 mm aggregate size has achieved 2813.33kg/m3 density which was higher than all other batches.
- From the statistical results, it was observed that reinforced fly ash concrete beams containing 5% fly ash and 12.5 mm coarse aggregate size exhibited the highest flexural strength, achieving a 56.48% improvement over nominal concrete.
- Additionally, deflection in reinforced concrete batch D1 containing 15% fly ash mix with 20 mm aggregate size decreased by 12.13% compared to nominal concrete.
- Across all aggregate sizes, the introduction of fly ash reduced deflection, with larger aggregate sizes (20 mm) and moderate fly ash content (5–10%) contributing to improved load-carrying capacity and minimized bending. These results emphasize the complementary effects of aggregate size and fly ash proportion in optimizing the structural performance of reinforced concrete.

6. References

[1] A.Chithambar Ganesh and D. M. Muthukannan, “A review of recent developments in geopolymer concrete”, Int. J. Eng. Technol., vol. 7, no. 4.5, p. 696, 2018, doi: 10.14419/ijet.v7i4.5.25061.

[2] E. Khankhaje et al., “On blended cement and geopolymer concretes containing palm oil fuel ash”, Mater. Des., vol. 89, pp. 385–398, 2016, doi: 10.1016/j.matdes.2015.09.140.

[3] M. Safiuddin, M. A. Salam, and M. Z. Jumaat, “Utilization of palm oil fuel ash in concrete: A review”, J. Civ. Eng. Manag., vol. 17, no. 2, pp. 234–247, 2011, doi: 10.3846/13923730.2011.574450.

[4] Putte Gowda , A. M, and M. K, “Experimental investigation on flexure behaviour of fly ash concrete beams”, Int. J. Adv. Sci. Tech. Res., vol. 2, no. 3, pp. 184–199, 2013.

[5] A. Ali, S. Iqbal, K. Holschemacher, and T. A. Bier, “Bond of reinforcement with normal-weight fiber reinforced concrete”, Period. Polytech. Civ. Eng., vol. 61, no. 1, pp. 128–134, 2017, doi: 10.3311/PPci.8660.

[6] E. Fehling, P. Lorenz, and T. Leutbecher, “Experimental investigations on anchorage of rebars in UHPC”, Proc. Hipermat 2012 3rd Int. Symp. UHPC Nanotechnol. High Perform. Constr. Mater., no. March 2012, pp. 533–540, 2012, [Online]. Available: http://www.bau.uni-siegen.de/subdomains/massivbau/publikationen/download/experimental_investigations_on_anchorage_of_rebars_in_uhpc.pdf

[7] G. A. Mohammed and S. A. A. Al-Mashhadi, “Effect of maximum aggregate size on the strength of normal and high strength concrete”, Civ. Eng. J., vol. 6, no. 6, pp. 1155–1165, 2020, doi: 10.28991/cej-2020-03091537.

[8] P. Joanna, J. Rooby, and A. Prabhavathy, “Behaviour of reinforced concrete beams with 50 percentage fly ash”, Int. J. Civ., no. April 2013, pp. 36–48, 2013.

[9] A. S, “Flexural Behaviour of Reinforced Concrete Beams”, Int. J. Struct. Civ. Eng., vol. 1, no. 1, pp. 497–508, 2009.

[10] S. GEORGE, "Flexural Behaviour of Activated Fly Ash Concrete", Int. J. Eng. Sci. Technol., vol. 3, no. 0975–5462, pp. 7633–7643, 2011.

[11] Y. M. Pudale, D. N. Shinde, and F. Ash, "Comparative study of flexural behaviour of R . C . C beam and fly ash reinforced concrete beam wrapped with gfrp sheet", vol. 8354, no. 3, pp. 562–570, 2014.

[12] K. Krishna Teja and B. Kameswara Rao, "Strength and durability of high volume flyash concrete", Int. J. Civ. Eng. Technol., vol. 9, no. 6, pp. 109–116, 2018, doi: 10.1680/stco.2008.9.2.101.

[13] M. Arezoumandi, C. A. Ortega, and J. S. Volz, "Flexural behavior of high-volume fly ash concrete beams: Experimental study", Transp. Res. Rec., vol. 2508, no. November, pp. 22–30, 2015, doi: 10.3141/2508-03.

[14] B. K. Narendra and T. M. Mahadeviah, "Flexural behavior of Reinforced Fly Ash Concrete in Comparison to Reinforced Normal Concrete beams in Terms of Cracking Load and Ultimate Load Carrying Capacity", Int. J. Eng. Adv. Technol., vol. 8958, no. 2, pp. 37–40, 2014.

[15] V. Bhikshma, "Studies on effect of maximum size of aggregate in higher grade concrete with high volume fly ash", vol. 14, no. 1, pp. 101–109, 2013.

[16] ASTM C33/ C33M, "Standard specification for concrete aggregates, ASTM C 33-86", Annu. B. ASTM Stand., vol. 11, p. 11, 2008.

[17] ASTM, "ASTM C 136-06: Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates", vol. 04, 2006.

[18] S. Kamara, E. H. Foday Jr, and W. Wang, "A Review on the Utilization and Environmental Concerns of Coal Fly Ash", Am. J. Chem. Pharm., vol. 2, no. 2, pp. 53–65, Jul. 2023, doi: 10.54536/ajcp.v2i2.1609.

[19] V. D. Gorgots, "About drawdown drilling parameters design procedure at primary formation exposing by a horizontal wellbore", Neft. khozyaystvo - Oil Ind., no. 9, pp. 120–121, 2006.

[20] ASTM, "ASTM 6433 Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys", vol. 04, pp. 1–8, 2007, doi: 10.1520/C0192.

[21] M. Chai, C. Hu, and M. Cheng, "Study on the Effect of Vibrating Process on the Compactness of Slipform Concrete", Appl. Sci., vol. 13, no. 14, 2023, doi: 10.3390/app13148421.

[22] C. Li, T. Liu, H. Fu, X. Zhang, Y. Yang, and S. Zhao, "Test and evaluation of the flexural properties of reinforced concrete beams with 100% recycled coarse aggregate and manufactured sand", Buildings, vol. 11, no. 9, 2021, doi: 10.3390/buildings11090420.

[23] ASTM, "ASTMC 78: Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)ASTM International. USA", Annu. B. ASTM Standards, vol. 04.02, pp. 1–3, 2002.

[24] I. I. Akinwumi, I. I. Akinwumi, and Z. O. Gbadamosi, "Effects of curing condition and curing period on the compressive strength development of plain concrete sustainable landfill liner material view project characterization of innovative construction materials and structural health monitoring view project effects of curing condition and curing period on the compressive strength development of plain concrete", Int. J. Civ. Environ. Res., vol. 1, no. 2, pp. 83–99, 2014, [Online]. Available: https://www.researchgate.net/publication/264276085

[25] R. P. Memon, A. R. M. Sam, A. Z. Awang, and U. I. Memon, "Effect of improper curing on the properties of normal strength concrete", Eng. Technol. Appl. Sci. Res., vol. 8, no. 6, pp. 3536–3540, 2018, doi: 10.48084/etasr.2376.

[26] M. S. Mamlouk and J. P. Zaniewski, "Materials for Civil and Construction Engineers", 4th ed., SI Units. Upper Saddle River, NJ, USA: Pearson, 2018

[27] P. K. Mehta and P. J. M. Monteiro, "Concrete: Microstructure, Properties, and Materials", 4th ed. New York, NY, USA: McGraw-Hill Education, 2014.

