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Effect of Crushing Process Parameters on Quality of Fly Ash Aggregates Produced After Crushing High Strength Fly Ash Blocks: A Laboratory Investigation

S. Singh*, S. Patel

Department of Civil Engineering, S. V. National Institute of Technology, Surat, Gujarat, India

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ABSTRACT

The demand for aggregates for civil engineering construction is high in the market. The broad adoption of fly ash for producing fly ash aggregate is the best sustainable solution to fulfill aggregate demand and utilization of unused fly ash. Crushing is an essential step for producing angular-shaped aggregate. In this paper, an experimental study using a laboratory-scaled impact crusher was carried out to investigate the effect of crushing process parameters (feed block size, crusher speed and outlet sieve size) on the quality (particle size distribution, flakiness-elongation index and mechanical properties) of angular-shaped fly ash aggregates produced after crushing high-strength fly ash blocks. Particle size distribution and flakiness-elongation index were found to be changed with crushing parameters. Higher crushing speed resulted in small-size fly ash aggregates. Better particle size distribution of crushed fly ash aggregate was produced using a 60 mm outlet sieve compared to a 30 mm one. Well-graded fly ash aggregates with good particle shape (less flaky and less elongated) for the subbase layer of the road were obtained after crushing fly ash blocks of one-third feed size in a laboratory-scaled impact crusher at a crushing speed of 527 rpm and an outlet sieve of 60 mm. Mechanical properties (impact, crushing and abrasion values) of the fly ash aggregate were not much affected by crushing process parameters. The findings of this study will help in optimizing the crushing operation of the industrial impact crusher to produce high-quality angular-shaped fly ash aggregate on a large scale.

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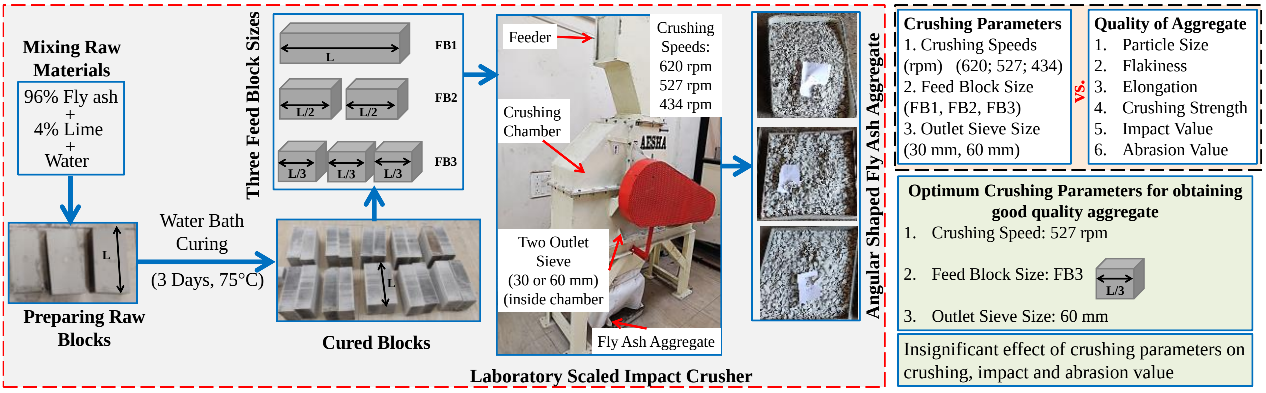
Graphical Abstract



1. INTRODUCTION

Aggregate is the primary material required for making roads. India has the second biggest road network globally, covering more than 5.6 million kilometers (1). The road ministry had planned to build 12000 km of roadways in 2022. One of the biggest challenges in this field is fulfilling the demand for road aggregates, which

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*Corresponding Author Email: ssinghcivil11@gmail.com (S. Singh)

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results in the consumption of natural rocks. Continuous consumption of natural rocks adversely affects the environment (2). Extraction of rocks from the earth causes habitat destruction, soil erosion, water pollution, air pollution, greenhouse gas emissions and land disturbance.

Conversely, the massive generation of fly ash by thermal power plants has caused many problems, including a lack of disposal areas and threats to public health and the environment (3). In 2020, 7575 million tons of coal ash was produced globally (4). In 2020–2021, India produced 232 million tons of fly ash with a utilization rate of 92.4% (5). There is still a gap between the production and utilization of fly ash. Due to the presence of significant amounts of silica and alumina in fly ash, it is quite useful for producing construction materials (6). The Indian government promotes the use of fly ash in the production of building materials and construction activities. The above data shows that a surplus amount of fly ash is available and has a broad scope for civil engineering applications.

Worldwide aggregates market value was $507.46 billion in 2021 and will likely be $837.3 billion by 2030 (7). Governments and industry stakeholders typically engage in strategic planning, resource management and infrastructure development to mitigate the adverse effects of a shortage in stone aggregates. Implementing policies and investing in sustainable practices may mitigate the negative impacts of rock consumption and unutilized fly ash. These may include reducing rock consumption through recycling and exploring alternative materials (i.e., waste composites) with a lesser environmental footprint (8, 9). The broad adoption of fly ash for producing fly ash aggregates as pavement material will prevent the rapid depletion of natural resources and the destruction of valuable land due to fly ash dumps (10, 11). Pelletization and compaction are the two primary agglomeration techniques used to combine fly ash particles into larger shapes. In the method of pelletization, agglomerated fly ash granules are formed using centrifugal forces, while in the compaction method, agglomerated fly ash blocks are formed using compacting forces (12). Sintering, autoclaving and cold bonding are the three most common methods for hardening agglomerated fly ash granules or blocks. The pelletization-sintering process is complicated as it requires high energy and more time to produce fly ash aggregates. Furthermore, pelletized aggregates are round in shape, leading to low interlocking and load-bearing capacity. These drawbacks limit the production and utilization of pelletized-sintered aggregates in the construction industry.

Shahane and Patel (13) developed angular-shaped fly ash aggregate using compaction and cold-bonding processes to overcome the problems related to pelletized aggregate, which is simple and requires less energy and time. Fly ash blocks were prepared using a fly ash-binder mix. These blocks were cured in a hot water bath. Then, cured high-strength fly ash blocks (HSFB) were crushed manually to produce angular-shaped fly ash aggregate. It was concluded that the developed aggregate is angular in shape and also fulfills the requirement of the Ministry of Road Transport and Highways (MoRTH), India, for its application in pavement construction.

Stone aggregates are produced by crushing rocks in crushers. The most common types of crushers in use are ball mills, jaw crushers, and gyratory crushers. Impact crushers are the most recent type of crusher in use. They are widely used because of their superiority in reducing particle size (14). Generally, rocks are crushed in two or more steps in a heavy crusher to obtain stone aggregates. Single crushing stages and jaw crushers are generally used for producing coarse aggregates for unbound applications, whereas two or more crushing stages and other crushers are used for producing aggregates for bound applications like concrete or asphalt. A heavy crusher with a multi-crushing stage requires more energy, space and time. Local aggregates are produced using portable crushing and screening machines, which require a simple setup due to cost and space constraints. Räisänen and Mertamo (15) produced good-shaped aggregates using a laboratory crusher. Eloranta (16) investigated the crushing operation and found that the feed gradation and crusher stroke are the most important properties for producing aggregates with good particle shape. The operating parameters of the crusher significantly impact the final shape of the aggregate (17). Particle shape in cone crusher output is influenced by crusher setting, feed size and crusher speed. The flakiness index rises with increasing feed size and decreasing crusher speed (18). It was concluded that larger aggregates are generally better in shape.

Literature proves that producing angular-shaped fly ash aggregate has several advantages over pelletized-sintered fly ash aggregate and can potentially replace natural aggregates in the subbase layer of roads. Bulk production of good-quality angular-shaped fly ash aggregate is highly needed to meet market demand for aggregate. Several studies have focused on producing good-quality stone aggregates from rocks after optimizing the crushing operations. Also, previous research has focused on the mix proportions, hardening process and enhancement of angular-shaped fly ash aggregate properties. Crushing of high-strength fly ash blocks (HSFB) in a crusher is required for the bulk production of these aggregates. The effect of the crushing process parameters on the quality of crushed fly ash aggregates is unknown. None of the presented research had focused on fly ash aggregates after crushing high-strength fly ash blocks in an impact crusher.

The aim of the current study was to produce high-quality angular-shaped fly ash aggregate after crushing

HSFB in a laboratory-scale impact crusher in a single crushing stage. The gradation, flakiness, elongation and mechanical properties of aggregate were used to assess the quality of fly ash aggregates. Feed block size, crusher speed and outlet sieve size were used as the operating crusher parameters. This paper presents the effect of crusher parameters on the gradation, flakiness, elongation and mechanical properties of fly ash aggregate. The findings of the present study will help in optimizing the crushing operation of an industrial impact crusher to generate high-quality angular-shaped fly ash aggregate on a large scale.

2. MATERIALS

The fly ash was procured from Reliance Industries Limited, Surat. The specific gravity of 2.01 was found for the present fly ash. This study used hydrated lime with 68.4% CaO as a binder. The chemical composition of fly ash is presented in Figure 1. Based on CaO content, the fly ash was classified as Class F, as per ASTM C-618 (19). The fly ash had a CaO content of 10.6% and 75.7% of combined silica, alumina and iron. Fly ash and lime percentages adopted were percentage by weight. A 91.2% of fly ash particles were found to be less than 0.075 mm IS sieve size. This shows that most of the fly ash particles were less than 0.075 mm. Using a modified proctor test (20), optimum moisture content (OMC) of 26.9% and 27.1% and maximum dry unit weight of 13.83 kN/m^3 & 13.87 kN/m^3 were found for only fly ash (100F) & 96% fly ash + 4% lime (96F+4L), respectively.

The mix proportion, pressing force and water bath curing technique were adopted following Shahane and Patel (13). Identical blocks were prepared by homogeneously mixing 96% fly ash, 4% lime, and 27.1% (=OMC) water. Blocks of size 200mm×100 mm×60mm with dry unit weight (= maximum dry unit weight determined using modified proctor test) were prepared after pressing the wet mix in a brick pressing machine.

Raw blocks were cured at 75°C for 3 days and then cured high-strength fly ash blocks (HSFB) were crushed in an impact crusher after 24 hours to obtain angular-shaped fly ash aggregate. The compressive strength of HSFB was in the range of 22 MPa to 24 MPa. Before being fed to the crusher, HSFB of 200mm×100mm×60mm (Full size: FB1), 100mm×100mm×60mm (Half size: FB2) and 67mm×100mm×60mm (One-third size: FB3) sizes were prepared. Small sizes (FB2 and FB3) of blocks were prepared by breaking FB1. The average weight of one HSFB (FB1) was found to be about 2.1 kg.

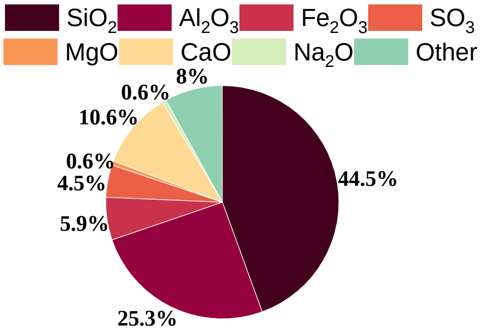

Figure 1. Chemical composition of fly ash

3. METHODOLOGY

Figure 2 shows the process flow sheet followed for studying the effects of crusher parameters on aggregate quality in the laboratory. FB1, FB2 and FB3 were used as feed material sizes. Samples of FB1, FB2 and FB3 were dropped into the feeder separately. As the crusher was switched on, blocks were fed continuously to the feeder and immediately impacted by the moving hammers inside the crusher. Each crushing trial was carried out with a feed weight of 42±2 kg in the feeder and at three different crushing speeds (620 rpm, 527 rpm and 434 rpm). Circular-shaped outlet sieve (30 mm or 60 mm) was provided at the lower side of the crusher to prevent oversized crushed aggregates from passing through. A summary of the different parameters used for the study is shown in Table 1.

The percentage of material recovered and crushing capacity for the impact crusher were also calculated using Equations 1 and 2, respectively. The crushing capacity is defined as the mass of material in kg/h.

$$Material\ recovered\ (\%) = \frac{Material\ mass\ output}{Material\ mass\ input} \qquad (1)$$

$$Crushing\ capacity = \frac{Average\ mass\ after\ crushing}{Average\ time\ taken\ to\ crush} \qquad (2)$$

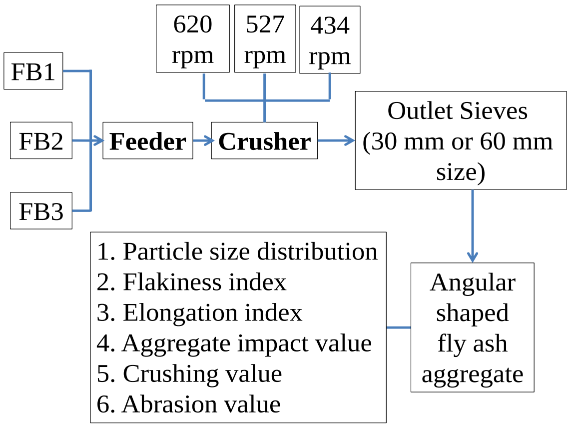

Figure 2. Process flow sheet for studying the effect of crusher parameters in the laboratory

TABLE 1. Combinations of different crusher parameters

Trial No.	Feed size	Number of blocks	Feed weight (kg)	Crusher speed (rpm)	Outlet sieve size (mm)
T1	FB1	20	42.5	620	30
		20	42.3	527	
		20	42.7	434	
T2	FB1	20	42.5	620	60
		20	42.8	527	
		20	42.7	434	
T3	FB2	40	42.1	527	60

TABLE 2. Grading requirement for Granular Sub-base (GSB) materials (21)

IS Sieve size (mm)	Percentage by weight passing the IS sieve (Grading I)
75	100
53	80-100
26.5	55-90
9.5	35-65
4.75	25-55
2.36	20-40
0.85	-
0.425	10-15
0.075	<5

Sieve analysis of obtained fly ash aggregates was carried out in dry conditions. The sieve sizes mentioned in MoRTH [21] for the granular sub-base (GSB) layer were used. Three samples were tested for each study of sieving and an average of three was reported. Table 2 summarises the sieves used for particle size distribution. Flakiness and elongation index were investigated for each trial to study the effect of crusher parameters on the shape and size of fly ash aggregates. The tests were conducted as per IS 2386-Part 1 (22).

Aggregates should have sufficient toughness, strength and hardness to resist their disintegration due to upcoming impact load, gradually applied compressive load and surface wear caused by friction, respectively. Mechanical properties such as aggregate impact value, crushing value and Los Angeles abrasion value were determined as per IS 2386-Part 4 (23). Each test was performed thrice for each sample. The aggregate impact and crushing value were determined for aggregates of size 10-12.5 mm. During the crushing test, the load in the compression testing machine was applied at the rate of 4 tons per minute until it reached a maximum load of 40 tonnes. Then, the crushed sample was passed through a 2.36 mm IS sieve. The grade A aggregate (40 mm to 10 mm in size) was used in the Los Angeles abrasion test.

4. RESULTS AND DISCUSSION

4. 1. Effect of Crusher Speed and Outlet Sieve Size on the Particle Size Distribution

In T1 and T2 trials, the samples with feed size FB1 were crushed at three different speeds (434 rpm, 527 rpm and 620 rpm) for two different outlet sieve sizes. Figure 3 shows the effect of three crusher speeds on particle size distribution for 30 mm and 60 mm outlet sieve sizes. A higher percentage finer for both outlet sieves can be observed for higher crushing speeds. Reducing crushing speed produces a coarser product (24). Higher crushing speeds can lead to more frequent and intense particle collisions within the crushing chamber. These particle-to-particle interactions can cause more breakage and fragmentation, resulting in higher finer particles. The particle size distribution curve shifted towards well gradation when the crushing speed was reduced. These results are consistent with the previous study carried out by Fladvad and Onnela (24) for crushing stones. The reduction in the percentage finer for all particle sizes was observed when the size of the outlet sieve was increased from 30 mm to 60 mm. In trial T1, 85.30%, 90.30% and 94.20% of particles lesser than 26.5 mm and 31.90%, 44.48% and 52.37% lesser than 4.75 mm particle size can be observed for crushing speed of 434 rpm, 527 rpm and 620 rpm, respectively. In trial T2, 74.5%, 84.1% and 88.5% of particles lesser than 26.5 mm and 24.1%, 35.2 % and 49.1% lesser than 4.75 mm particle size can be observed for crushing speed of 434 rpm, 527 rpm and 620 rpm, respectively.

It can be seen in Figure 3 that particle size distribution is not within the limits specified in MoRTH (21) for the GSB layer, as some of the particle sizes are either on the

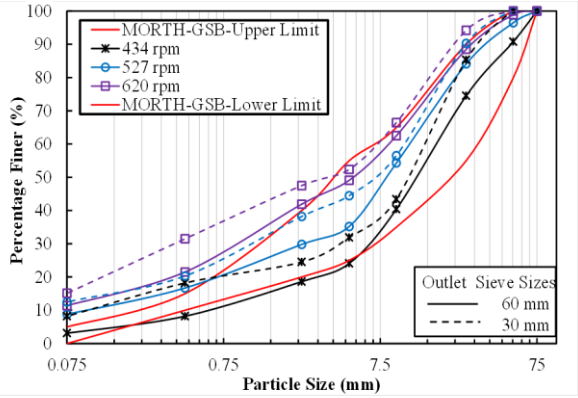

Figure 3. Effect of crusher speed and outlet sieve size on the particle size distribution

higher or lower side of the limits. In Figure 3, the percentage finer for the 30 mm outlet sieve size, corresponding to 4.75 mm particle size, was found to be higher than that of the 60 mm outlet sieve size. When a 30 mm outlet sieve was used, multiple crushing of larger particles (>30 mm) led to the production of smaller particles as smaller particles (<30 mm) were only allowed to pass through 30 mm. However, when the outlet sieve size is set to 60 mm, the impact crusher may produce particles that are, on average, slightly larger. A particle size greater than 53 mm was also obtained in the 60 mm outlet sieve. It can be seen in Figure 3 that the particle size distribution of 527 rpm crushing speed and 60 mm outlet sieve is better than that of other crusher speeds and outlet sieve sizes. In order to improve the particle size distribution, the feed block size was varied for further investigation while maintaining a crusher speed of 527 rpm and an outlet sieve size of 60 mm.

4. 2. Effect of Feed Block Size on the Particle Size Distribution

Figure 4 shows the effect of feed block size on particle size distribution for a 60 mm outlet sieve at 527 rpm crushing speed. On reducing the feed block size, improvement in particle size distribution can be seen in Figure 4. When the feed block size is larger, there is a higher chance of producing oversized particles that cannot pass through the outlet sieve of the crusher. These oversize particles may circulate within the crusher, undergoing multiple impact cycles, which can produce more finer particles. 64.8%, 67.8% and 71.8% aggregates were found to be retained on a 4.75 mm sieve for a crushing speed of 527 rpm and feed block size of FB1, FB2 and FB3, respectively. The production of oversized particles is minimized by reducing the feed block size. This leads to an improvement in particle size distribution. Particle size distribution for a feed block size of FB3 is within the limits specified in MoRTH (21) for the GSB layer.

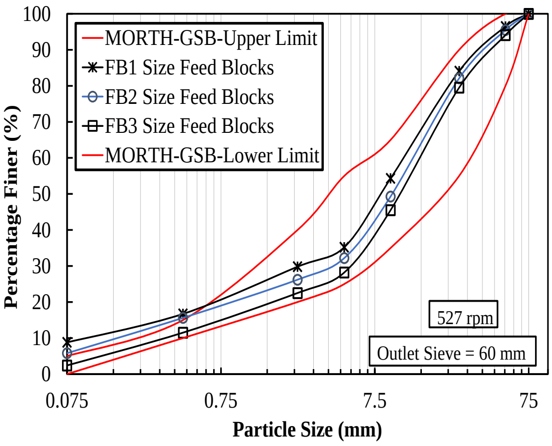

Figure 4. Effect of feed block size on the particle size distribution

4. 3. Effect of Crusher Speed and Feed Block Size on the Flakiness-elongation Index

The effect of crusher speed on flakiness and elongation index was also studied after crushing FB1, FB2 and FB3 sizes HSFB and using an outlet sieve of 60 mm. The variation of flakiness and elongation index with the change in crusher speed and feed block size can be seen in Figures 5 and 6, respectively.

The maximum flakiness index of 6.6%, 5.9%, 5.8% for FB1 size feed block; 5.9%, 5.4%, 5.5% for FB2 size feed block and 5.4%, 4.8%, 5.5% for FB3 size feed block were found corresponding to the size range of 10-6.3 mm for crushing speed of 434 rpm, 527 rpm and 620 rpm, respectively. The maximum elongation index of 4.9%, 4.2%, 4.1% for FB1 size feed block; 4.2%, 3.5%, 3.5% for FB2 size feed block and 3.6%, 3.2%, 3.1% for FB3 size feed block were found corresponding to the size

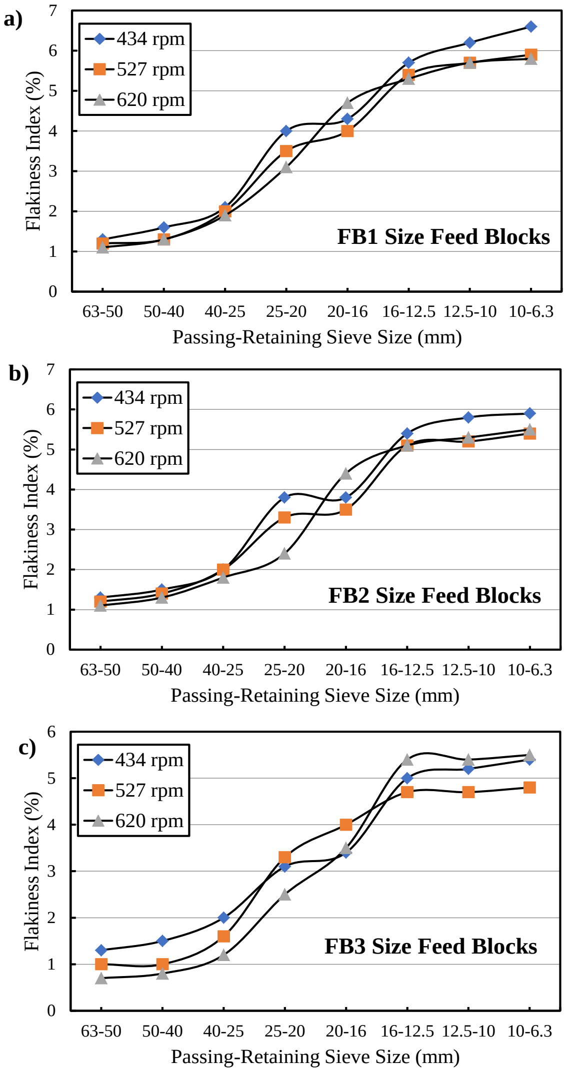

Figure 5. Effect of crusher speed and feed block size on the flakiness index

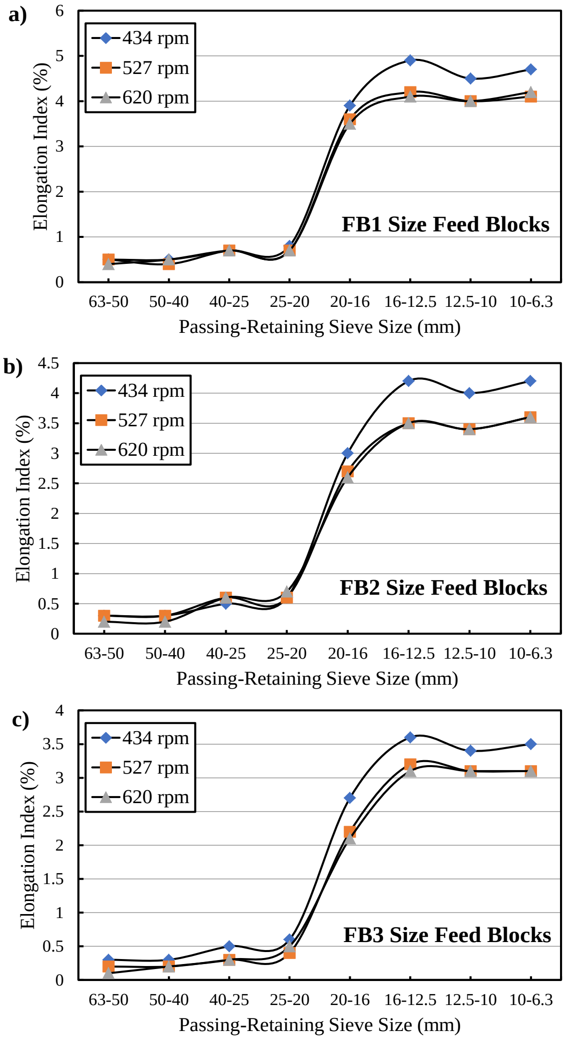

Figure 6. Effect of crusher speed and feed block size on the elongation index

range of 16-12.5 mm for crushing speed of 434 rpm, 527 rpm and 620 rpm, respectively. The flakiness and elongation indices were found to be lower for larger particles and higher for decreased particle size. Similar results were reported by Fladvad and Onnela (24) for crushing stones in a jaw crusher. Larger particles tend to travel through the crusher more quickly due to their higher weight and are less likely to experience multiple impacts. This results in lower elongation and flakiness. Smaller particles may undergo more collisions and impacts, leading to higher flakiness.

Lower flakiness and elongation indices were found for crushing speeds of 434 rpm and 527 rpm compared to 620 rpm. Lower crushing speed allows the material to spend more time inside the crusher, increasing the chances of re-crushing already crushed particles. This re-crushing process can flatten and elongate the particles, increasing their flakiness and elongation index.

Reduction in flakiness and elongation index with smaller feed block size can be observed in Figures 5 and 6, respectively. Fladvad and Onnela (24) also reported that coarser feed material in a jaw crusher results in more flaky crushing stones. Less elongated or flaky particles were likely to form because smaller size HSFB were more quickly and effectively broken down into smaller particles. When the feed block size is smaller, it allows for more efficient and uniform impact forces to be applied to the material. This results in a greater likelihood of fracturing the HSFB along its natural boundaries, leading to reduced flakiness and elongation.

The variation of combined flakiness and elongation index (FI+EI) with the change in crusher speed for different feed block sizes is also presented in Figure 7. The FI+EI was found to be highest for 434 rpm crushing speed. FI+EI for crushing speeds of 620 and 527 rpm are almost the same. Reduction in FI+EI with lower feed

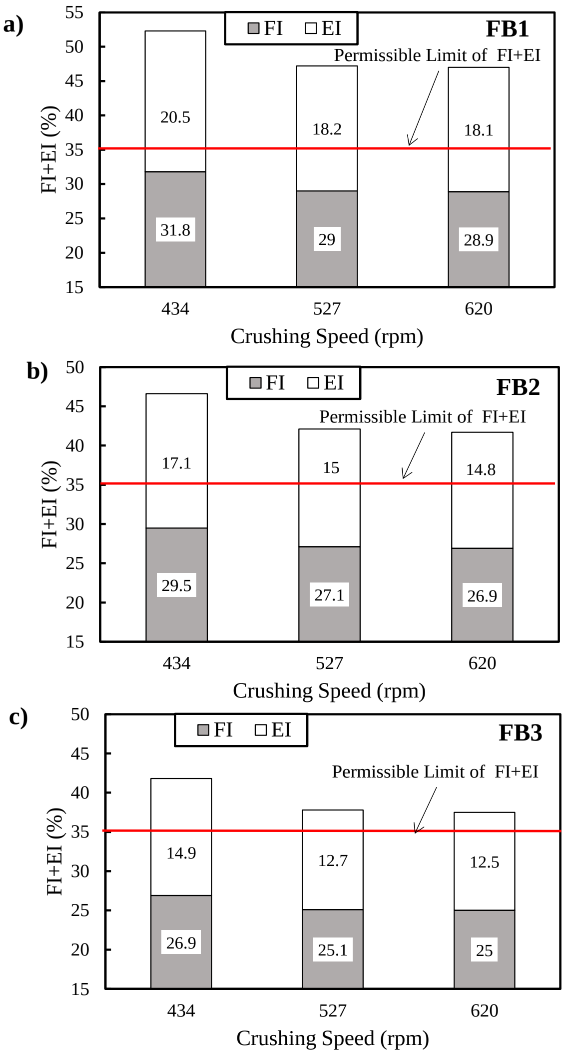

Figure 7. Comparison of combined flakiness-elongation index for different crusher speeds and feed block sizes

block size can also be observed in Figure 7. FI+EI of 47.2%, 42.1% and 37.8% were found after crushing FB1, FB2 and FB3 sizes at a speed of 527 rpm for aggregates of 6.3 to 63 mm. The FI+EI was found to be near the permissible limit of 35% as per MoRTH (21) after crushing FB3 size HSFB at 527 rpm.

Based on the above results of particle size distribution and flakiness-elongation index, well-graded fly ash aggregates with good particle shape (less flaky and less elongated) were produced after crushing FB3 size HSFB in impact crusher at a speed of 527 rpm and outlet sieve of 60 mm.

4. 4. Mechanical Properties

Mechanical properties of angular fly ash aggregate obtained after crushing FB3 size HSFB at different speeds using an outlet sieve of 60 mm are presented in Table 3. It was found that there is not much variation in the mechanical properties of aggregates with crusher parameters. The mechanical properties of a material mainly depend on its intrinsic composition and structure; in this case, FB1, FB2 and FB3 had the same composition and structure except for the size. Ranges of 24.2-25.1%, 27.4-28.3% and 35.3-36.5% were found for impact, crushing and abrasion values at different crushing speeds. Values are within the permissible limit of MoRTH (21) for the GSB layer and IS 9142 (Part 2) for lightweight aggregate.

4. 5. Crushing Capacity

Table 4 shows the crushing time and material mass recovery results for different crusher parameters. It was found that the impact crusher used in the present study takes a minimum time of 5.3 minutes to crush the HSFB, with a 98.81% recovery rate for FB3 feed size, 527 rpm speed and 60 mm outlet sieve size. On average, 41.61 kg of aggregate was collected after crushing 42.40 kg bricks in 5.6 minutes. Only about 1.87% is lost on average during the crushing operation.

This loss may be due to the formation of dust during crushing and aggregates retained inside the crusher. Crushing capacity in the range of 373.1 to 498.0 kg/h was achieved for the present impact crusher.

TABLE 3. Mechanical properties of angular fly ash aggregate for different speeds

Properties	**620 rpm**	**527 rpm**	**434 rpm**	**MoRTH (21)**	**IS 9142-Part 2**
Impact value (%)	25.1	24.5	24.2	≤40 for sub-base ≤30% for base	≤40
Crushing value (%)	28.3	28.0	27.4	-	≤45
Abrasion value (%)	36.5	36.1	35.3	≤40 for base	≤40

TABLE 4. Crushing time and material mass recovery

Crusher speed (rpm)	**Feed size**	**HSFB Mass (kg)**	**Outlet Screening size**	**Time Taken (min)**	**Mass of aggregates (kg)**	**Material recovered (%)**
620	FB1	42.50	30	5.5	41.03	96.54
527	FB1	42.30	30	6.0	41.31	97.66
434	FB1	42.70	30	6.8	42.28	99.02
527	FB1	42.80	60	5.5	42.06	98.27
527	FB2	42.10	60	5.3	41.45	98.46
527	FB3	42.00	60	5.0	41.50	98.81

5. CONCLUSIONS

The present study leads to the following conclusions:

- Higher crushing speeds in the impact crusher resulted in a higher percentage of small-size fly ash aggregates. This may be due to increased impact forces between crushing surfaces and materials with speed. A crushing speed of 527 rpm in a laboratory-scaled impact crusher was found suitable for obtaining quality fly ash aggregate.
- The particle size distribution of produced fly ash aggregate was observed better with a 60 mm size outlet sieve than with a 30 mm one. The percentage of small-size fly ash aggregate was obtained higher in the output of a 30 mm size outlet sieve, resulting in poor particle size distribution.
- On varying crusher parameters, insignificant changes in the mechanical properties of the produced fly ash aggregate were found because mechanical properties mainly depend on the composition and structure of the material. In the present study, all feed blocks used for producing fly ash aggregates had the same composition and structure.

Based on the investigation, well-graded fly ash aggregates with good particle shape (less flaky and less elongated) for the subbase layer of the road were produced after crushing HSFB of one-third size (feed size) in a laboratory-scaled impact crusher at a crushing speed of 527 rpm and an outlet sieve of 60 mm. The findings of the present study are helpful for optimizing single-stage crushing in terms of impact crusher operation and fly ash aggregate quality on a large scale. The study was performed for a laboratory-scaled impact crusher. The results may differ for different types of crusher. Future studies using different crushers in the field or laboratory may be carried out for producing high-quality fly ash aggregate.

6. REFERENCES

1. Bakare M, Pai R, Patel S, Shahu J. Environmental sustainability by bulk utilization of fly ash and GBFS as road subbase materials. Journal of Hazardous, Toxic, and Radioactive Waste. 2019;23(4):04019011. https://doi.org/10.1061/(asce)hz.2153-5515.00004502
2. Turkane S, Chouksey S. Partial replacement of conventional material with stabilized soil in flexible pavement design. International Journal of Engineering, Transactions B: Applications. 2022;35(5):908-16. https://doi.org/10.5829/ije.2022.35.05b.07
3. Patel S, Shahu J. Comparative study of slags stabilized with fly ash and dolime for utilization in base course. Journal of Materials in Civil Engineering. 2017;29(10):04017168. https://doi.org/10.1061/(asce)mt.1943-5533.0002017
4. Widodo S, Alfirahma R, Prawiranegara A, Amir MF, Dewi A. Development of Eco-friendly Self-compacting Concrete Using Fly Ash and Waste Polyethylene Terephthalate Bottle Fiber. Civil Engineering Journal. 2023;9(2):437-52. https://doi.org/10.28991/CEJ-2023-09-02-014
5. Bakare M, Shahu J, Patel S. Complete substitution of natural aggregates with industrial wastes in road subbase: A field study. Resources, Conservation and Recycling. 2023;190:106856. https://doi.org/10.1016/j.resconrec.2022.106856
6. Rangan PR, Tumpu M, Mansyur M, Mabui D. Assessment of Fly Ash-Rice Straw Ash-Laterite Soil Based Geopolymer Mortar Durability. Civil Engineering Journal. 2023;9(06):1456-70. https://doi.org/10.28991/CEJ-2023-09-06-012
7. Singh S, Patel S. Development of angular-shaped lightweight coarse aggregate with low calcium fly ash using autoclave curing-Experimental and microstructural study. Journal of Building Engineering. 2023;79:107860. https://doi.org/10.1016/j.jobe.2023.107860
8. Al-Hindawi LAA, Al-Dahawi AM, Sh J Al-Zuheriy A. Use of Waste Materials for Sustainable Development of Rigid Pavement. International Journal of Engineering, Transactions A: Basics,. 2023;36(10):1919-31. https://doi.org/10.5829/ije.2023.36.10a.16
9. Nistratov AV, Klimenko NN, Pustynnikov IV, Vu LK. Thermal regeneration and reuse of carbon and glass fibers from waste composites. Emerg Sci J. 2022;6:967-84. https://doi.org/10.28991/ESJ-2022-06-05-04
10. Singh S, Patel S. Potential Use of Fly Ash for Developing Angular-shaped Aggregate. International Journal of Engineering, Transactions C: Aspects. 2023;36(6):1114-20. https://doi.org/10.5829/ije.2023.36.06c.09
11. Joshi AR, Patel S. Application of Class C Fly Ash and Quarry Dust Mix for Utilization as Subbase Material in Flexible Pavement. International Journal of Engineering, Transactions C: Aspects. 2023;36(9):1597-604. https://doi.org/10.5829/ije.2023.36.09c.02
12. Bijen J. Manufacturing processes of artificial lightweight aggregates from fly ash. International Journal of Cement Composites and Lightweight Concrete. 1986;8(3):191-9. https://doi.org/10.1016/0262-5075(86)90040-0
13. Shahane HA, Patel S. Influence of curing method on characteristics of environment-friendly angular shaped cold bonded fly ash aggregates. Journal of Building Engineering. 2021;35:101997. https://doi.org/10.1016/j.jobe.2020.101997
14. Terefe TO, Tefera GA. Design of impact stone crusher machine. Int J Sci Eng Res. 2019;10:904-9.
15. Räisänen M, Mertamo M. An evaluation of the procedure and results of laboratory crushing in quality assessment of rock aggregate raw materials. Bulletin of engineering geology and the environment. 2004;63:33-9. https://doi.org/10.1007/s10064-003-0218-1
16. Eloranta J. Influence of crushing process variables on the product quality of crushed rock: Tampere University of Technology; 1995.
17. Briggs C, Evertsson CM. Shape potential of rock. Minerals Engineering. 1998;11(2):125-32. https://doi.org/10.1016/S0892-6875(97)00145-3
18. Bengtsson M, Evertsson CM. An empirical model for predicting flakiness in cone crushing. International Journal of Mineral Processing. 2006;79(1):49-60. https://doi.org/10.1016/j.minpro.2005.12.002
19. Concrete ACC-o, Aggregates C. Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete: ASTM international; 2013.
20. Standard I. Determination of water content-dry density relation using heavy compaction. 1983.
21. Transport IMoR, Highways, editors. Specifications for road and bridge works2013: Indian Roads Congress.
22. IS. Methods of test for aggregates for concrete. Indian Standard, Bureau of Indian Standards New Delhi, India; 1963.
23. BIS. IS 2386 (Part 4): Methods of test for aggregates for concrete–mechanical properties. BIS New Delhi, India; 1963.
24. Fladvad M, Onnela T. Influence of jaw crusher parameters on the quality of primary crushed aggregates. Minerals Engineering. 2020;151:106338. https://doi.org/10.1016/j.mineng.2020.106338

Persian Abstract

چکیده

تقاضا برای مصالح ساختمانی مهندسی عمران در بازار زیاد است. استفاده گسترده از خاکستر بادی برای تولید خاکستر بادی بهترین راه حل پایدار برای برآوردن تقاضای کل و استفاده از خاکستر بادی استفاده نشده است. خرد کردن یک مرحله ضروری برای تولید سنگدانه های زاویه ای است. در این مقاله، یک مطالعه تجربی با استفاده از یک سنگ شکن ضربه ای در مقیاس آزمایشگاهی به منظور بررسی تاثیر پارامترهای فرآیند خرد کردن (اندازه بلوک خوراک، سرعت سنگ شکن و اندازه غربال خروجی) بر کیفیت (توزیع اندازه ذرات، شاخص پوسته پوسته شدن-طولانی و) انجام شد. خواص مکانیکی سنگدانه های خاکستر بادی زاویه ای شکل که پس از خرد کردن بلوک های خاکستر بادی با استحکام بالا تولید می شوند. توزیع اندازه ذرات و شاخص پوسته پوسته شدن-طولانی شدن با پارامترهای خرد کردن تغییر یافتند. سرعت خرد شدن بیشتر منجر به ایجاد دانه های خاکستر بادی با اندازه کوچک شد. توزیع اندازه ذرات بهتر دانه های خاکستر بادی خرد شده با استفاده از الک خروجی ۶۰ میلی متر در مقایسه با ۳۰ میلی متر تولید شد. سنگدانه های خاکستر بادی خوب با شکل ذرات خوب (کمتر پوسته پوسته شدن و کمتر کشیده) برای لایه زیرپایه جاده پس از خرد کردن بلوک های خاکستر بادی با اندازه خوراک یک سوم در یک سنگ شکن ضربه ای مقیاس آزمایشگاهی با سرعت خرد کردن ۵۲۷ به دست آمد. دور در دقیقه و غربال خروجی ۶۰ میلی متر. خواص مکانیکی (مقادیر ضربه، خرد شدن و سایش) دانه‌های خاکستر بادی تحت تأثیر پارامترهای فرآیند خرد کردن قرار نگرفت. یافته های این مطالعه به بهینه سازی عملیات خرد کردن سنگ شکن ضربه ای صنعتی برای تولید سنگدانه های خاکستر بادی زاویه ای شکل با کیفیت بالا در مقیاس بزرگ کمک می کند.