Potential of Fly Ash Polymerized Sand as an Alternative for River Sand in Concrete- A State of the Art Report

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Abstract. The depletion of the natural resources and the growing demand for the natural river sand in both developing countries and developed countries paved way for the evolution of new trends in the complete and partial replacement of the natural sand as the fine aggregate. Many natural admixtures and by-products were so far analyzed for the feasibility of the replacement of the natural sand. Some of such traditional sources suggested by the researchers were foundry sand, M-sand, quarry dust, I-sand and treated sea sand. Among which M-sand tend to meet the standards and in practice too for construction in India (Author’s native) and other countries without any ordeal. However, a new technique for the complete replacement of the fine aggregate was introduced which incorporates the polymerization technique in the byproducts (Fly Ash). Though the first introduced technique was quite tedious, the consequent authors proposed much simpler methodologies that develop fine aggregates with characteristics similar to that of the natural sand which is also lightweight, eco-friendly and economical as discussed in this article. These geopolymerized fine aggregates set a new era in the construction industry which in turn conserves the balance of the ecosystem.

1. Introduction
Being the second highest used material after water, concrete is vastly used enormously across the continents. Fine aggregate, a principal component and binding material in concrete, is of great demand in the current scenario. The river sand, obtained from the riverbeds, is the foremost source for the fine aggregate for decades. Over-utilization of the river sand has caused depletion of availability and increased the price [1]. Hence, to meet the burgeoning need of sand, engineers and researchers ought to discover a sustainable solution similar to the development of the M-sand which is currently in practice in the construction industry.

2. Necessity of alternative solution
Due to the increasing demand for the river sand [2] as fine aggregate, new ideas emerged in the concrete industry to replace the river sand partially or completely with no compromise in the quality of the concrete [3-14]. The restrictions by the government agencies protecting the environment and depletion of natural sources became a jump start for the evolution of new trends [15,16] for the fine aggregate in most of the developing countries. By-products and waste materials were the main sources for the researchers so that cost-effective alternative fine aggregate can be
developed. Consequently, alternative fine aggregates such as manufactured sand (M-sand), iron slag sand (I-sand), crushed rock dust, glass powder, foundry sand, and others were developed in the last two decades.

3. Traditional sources for replacing river sand

3.1 Foundry sand
Foundry sand (FS) is a by-product developed during the manufacturing process of metal alloys. The rich silica content sand (silica sand) when finally becomes non-recyclable by the foundries after many cycles, it is then dumped off [17]. This foundry sand is deposited in the open area millions of tons affecting the ecosystem, though they are used in the laying of highways [18,19]. Many studies were carried out recently for the incorporation of foundry sand in concrete structures so that they can be utilized to the maximum [20-22]. The possibility of using FS in ready mix concrete [23] indicated a negative effect by lower concrete strength and higher water demand. However, in another study [24] the results indicate that replacement of fine aggregate by up to 20% of FS efficiently behaved in the concrete with minimal reduction in the compressive and flexural strengths which in turn develops better concrete without any impact on the standards of concrete diversely when the foundry sand exceeds the limit of 20%, inferior behavior is recorded in concrete mixture when compared to that of the control specimen owing to the presence of sawdust, clay, wood flour and also the fineness of foundry sand.

3.2 Crushed rock sand /M sand
The crushed rock sand was obtained from the crushed quarried stone by allowing the crushed particles to pass through a 4.75mm sieve. Better mechanical properties and a lower slump were noted upon the replacement of fine aggregate with 30% of crushed rock sand [25]. The low workability with crushed rock sand can be rectified by the usage of high range water reducers [26]. Another study [27] reported that both the mechanical and durability properties improved by 14% compared to the properties of the normal concrete. Reduction of cost is an advantage [28] while using crushed rock sand in concrete. The strength parameters of M sand with natural river were compared and revealed that similar cement mortar with natural sand can be obtained with manufactured fine aggregates also without affecting the workability, absorptivity, inelastic deformation response and strength. These parameters were also analyzed with de Larrard’s Compressible Packing Model and the author correalted the packing density with the porosity of the mortars replicating as a primary property in the analysis [29]

3.3 Quarry dust
Quarry dust is a by-product obtained from the processing of stones. They are mostly not preferred in the industrial construction since the properties of the quarry dust vary based on the mineralogy of the parent rock. The compressive strength of the concrete was noted to increase up to 75% depending upon the type and quantum of the replacement [30-32]. The workability can also be improved by the usage of superplasticizers and fly ash at lower water/cement ratio [33]. The quarry dust with mica of more than 5% is however not suitable for construction purpose since it reduces the workability [34]. Quarry dust replacement is much effective when used along with fly ash in the concrete mixture [31]; however, the properties of quarry dust depends on the mineralogy analysis before it is integrated with the concrete mixture [35].

3.4 I-Sand
A detailed study [36] was conducted by replacing fine aggregate with iron sand (I-Sand) which is a by-product obtained from the steel and iron industries. Based on the earlier studies [37-39], 30% of I-Sand in concrete as a substitute of natural sand was found to be optimum for an effective concrete without degradation in the quality [40,41]. However, in another study [42], it was observed that the
slump values decreased after 40% replacement of fine aggregate by I-sand. Though I-sand seems to be a better alternative for river sand, more rigorous research on the various properties need to be studied.

3.5 Sea Sand:
A comparison study [43] was conducted between treated and untreated sea sand analyzing their feasibility in the normal concrete as well as geopolymer concrete in view of the earlier studies[44-46]. It was observed that the treated sea sand performed better than the untreated sea sand. The chlorides and the salt content in the untreated sea sand tend to hinder the strength parameters in the incorporation of untreated sea sand in the geopolymer concrete of 8M, 10M and 12M by 13%, 13.1% and 17% respectively whereas the treated sand developed similar compressive strength to that of the natural sand.

4. Geopolymerized sand
The over usage of natural sand in India (Author’s native) resulted in extensive depletion of the nature through various phenomenon. Thus, an alternative for the river sand in construction is the need of the hour almost across the globe. Only a limited amount (30%) of fly ash is used in India which were expelled out from the power plants [47,48]. The complete replacement of natural sand with fly ash were noted to reduce the compressive strength by 73% and lowered the workability by 14% [49]. However compressive strength with fly ash of marginal quantity were appreciable [50], since both the byproducts together qualified the concrete. This is achieved when the quarry dust enhances the early strength and the fly ash improves the workability of concrete. Only partial replacement of fly ash in concrete were observed to keep up the standards of concrete [51]. In order to utilize the large amount of fly ash which is dumped into the landfills from the thermal power plants [52] as well as to make the concrete more economical, fly ash is an effective supplementary cementitious material indeed[53].

4.1 Fly ash polymerized sand:
In view of the above scenario, fly ash was introduced into concrete as complete replacement of fine aggregate after geopolimerization process [54]. Thus, developed sand was termed as fly ash polymerized sand (polymerized fine aggregate). A complex mixture of fly ash and amorphous silica were dry mixed together with sodium hydroxide solution of 10M. The dry mix was then allowed to oven dry for about four hours at 50°C, which then tends the dry mix to agglomerate as fine aggregates which lies within the zonal limits obtained upon sieving of the oven dried slurry. These fine aggregates were further heated for 100°C for seven days which allows accomplishing the geopolymerization process. It is then washed continuously with distilled water till the electrical conductivity reaches within the limits and then oven dried for two hours and can be used as fine aggregates. These fine aggregates were tested for properties such as electrical conductivity, specific gravity, XRD patterns, pH value, grain size distribution, TDS measurements and compressive strength of the mortar samples. These fine aggregates were found to be within the zonal limits and IS Standards [55]. Also, it imparted compressive strength similar to that of the mortar specimens developed with the natural sand which enabled to stand out as an ideal substitute for natural sand as fine aggregate. These polymerized fine aggregates were modified in another study [56] by further refining the tedious process in which the fine aggregates were termed as GFS. The GFS particles were obtained by mixing together the geopolymer liquid solution(10M) and pre heated(60°C) fly ash which is then oven dried for one hour at 100°C after sieving with 2.36mm and 4.75mm sieve. Thus developed fine aggregate particles can be used after keeping in ambient temperature for 24 hours. Various parameters of the GFS particles were analyzed to compare its properties with the natural sand. Specific gravity, water absorption, direct shear test, alkali aggregate reaction, particle size distribution, soundness, pH value, XRF, XRD, and SEM were studied and noted to develop 93% of compressive strength similar to that of the normal river sand at 28 days. Thus, it was
concluded as an alternative for the normal river sand in concrete construction works. In another study [57] by the same author, the compressive strength and flexural strength of the concrete cubes developed with GFA for M25 grade concrete was 99% of the compressive strength compared to that of the Normal river sand at 56 days denoting a gain in the compressive strength with the increase in the curing period of concrete cubes. In the third case [58] of the geopolymerized fine aggregate (GFA), the author adopted much of the procedure similar to that of the later study[56] to synthesize the GFA. Both class C fly ash geopolymerized fine aggregate(C-GFA) and class F fly ash geopolymerized fine aggregate (F-GFA) were developed and compared with the properties of manufactured sand (M Sand) as well as natural sand. After studying the physical properties such as particle size distribution, specific gravity, water absorption, pH and frictional angle, these developed fine aggregate were tested for alkali silica reaction in mortar bars as well as the compressive strength of both the mortar cubes and concrete cubes were analyzed. The mortar specimens and the concrete specimens with C-GFA were noted to attain higher compressive strength like that of the natural sand and M-Sand when compared with that of the F-GFA due to the high calcium content. The specimens thus developed showcased lower weight and higher water absorption which need to be studied further so that they can be implemented in larger scale.

5. Conclusion

Based on the analysis of the literature, few conclusions were acquired on the feasibility of polymerized fine aggregate in the construction industry

- Though many other alternatives are available for river sand in the concrete mixture, usage of fly ash is considered as the most effective one owing to the following considerations:
  - Light weight
  - Environment friendly
  - Cheaper
- Apart from the above benefits, polymerized fine aggregate exhibits much similar mechanical and durability properties of the normal river sand.
- Polymerized fine aggregate particles showcased UN-reacted fly ash particles developed due to the partial break down of the fly ash particles during the production process which is also accountable for the porous nature in the surface of the polymerized fine aggregate particles.
- The high amount of water absorption thus builds out in the fly ash particles during synthesis need to be eradicated for the proper usage of polymerized fine aggregate in the construction industry.
- Altogether polymerized fine aggregate is an ideal alternative for the natural sand in the concrete structures.

6. Oncoming dimensions of polymerized fine aggregate

- Behavior of polymerized fine aggregate with other silicaceous materials can be analyzed for the enhancement of mechanical and durability properties of concrete
- Polymerized fine aggregate can be included in concrete to examine the nature of the concrete behavior under various environmental conditions (coastal structures, elevated temperatures, freezing and thawing etc.)
- Chances of implementing polymerized fine aggregate in various types of concrete like self compacting concrete and pumpable concrete in large scale construction for the reduction of cost and weight of the structures.
- Well organized complete utilization of the fly ash from the thermal power plants by the government itself for terminating the dumping of the by product (fly ash) into the landfills.
References
[1] Ilangoval R, Nagamani K 2008 Application of quarry dust in concrete construction *High performance Concrete, Federal highway Administration.*
[2] UNEP GEAS 2014. Sand rarer than one thinks. Thematic focus: Ecosystem management, Environmental governance, Resource efficiency. UNEP Global Environmental Alert Services (GEAS).
[3] Singh, Sarbjeet, Ravindra Nagar and Vinay Agrawal 2016 A review on properties of sustainable concrete using granite dust as replacement for river sand *Journal of cleaner production* **126** 74-87.
[4] Brindha D and S Nagan 2010 Utilization of copper slag as a partial replacement of fine aggregate in concrete *International Journal of Earth Sciences and Engineering* **3** no. 04 579-585.
[5] Beixing, Li, Zhou Mingkai and Wang Jiliang 2011 Effect of the methylene blue value of manufactured sand on performances of concrete *Journal of Advanced Concrete Technology* **9** no. 2 127-132.
[6] Manasseh J O E L 2010 Use of crushed granite fine as replacement to river sand in concrete production *Leonardo electronics journal of practice and technologies* **17** 85-96
[7] Elavenil S and B Vijaya. 2013 Manufactured sand, a solution and an alternative to river sand and in concrete manufacturing *Journal of engineering, computers & applied sciences* **2** no. 2 20-24.
[8] Saha, Ashish Kumer and Prabir Kumar Sarker 2017 Sustainable use of ferronickel slag fine aggregate and fly ash in structural concrete: Mechanical properties and leaching study *Journal of Cleaner Production* **162** 438-448.
[9] Vijayalakshmi M and A S Sekar 2013 Strength and durability properties of concrete made with granite industry waste *Construction and Building Materials* **46** 1-7.
[10] Ling, Tung-Chai and Chi-Sun Poon 2014 Use of recycled CRT funnel glass as fine aggregate in dry-mixed concrete paving block *Journal of cleaner production* **68** 209-215.
[11] M Magweswari and Dr B Vidivelli 2010 The use of sheet glass powder as fine aggregate replacement in concrete *The Open Civil Engineering Journal* Vol. **4** 65-71
[12] Siddique, Rafat, Geert De Schutter and Albert Noumowoe 2009 Effect of used-foundry sand on the mechanical properties of concrete *Construction and building materials* **23** no. 2 976-980.
[13] Ilangoval R and K Nagamani 2006 Studies on strength and behavior of concrete by using quarry dust as fine aggregate *CE and CR Journal, New Delhi* 40-42.
[14] Prem, Prabhat Ranjan, Mohit Verma and P S Ambily 2018 Sustainable cleaner production of concrete with high volume copper slag *Journal of Cleaner Production* **193** 43-58.
[15] Tekin, Ilker, Muhammed Yasin Durugun, Osman Gencel, Turhan Bilir, Witold Brostow and Haley E Hagg Lobland 2017 Concretes with synthetic aggregates for sustainability *Construction and Building Materials* **133** 425-432.
[16] Bilir, Turhan, Isa Yüksel, Ilker Bekir Topcu and Osman Gencel 2017 Effects of bottom ash and granulated blast furnace slag as fine aggregate on abrasion resistance of concrete *Science and Engineering of Composite Materials* **24** no. 2 261-269.
[17] Siddique Rafat, de Schutter Geert, Noumowoe Albert 2013 Effect of used-foundry sand on the mechanical properties of concrete *Constr Build Mater* **46** 1–7.
[18] Javed, Sayeed and C W Lovell 1995 Uses of waste foundry sands in civil engineering *Transportation Research Record* **1486**.
[19] Kleven, Jay R, Tuncer B Edil and Craig H Benson 2000 Evaluation of excess foundry system sands for use as subbase material *Transportation research record* **1714** no. 1 40-48.
[20] Kraus, Rudolph N, Tarun R Naik, Bruce W Ramme and Rakesh Kumar 2009 Use of foundry silica-dust in manufacturing economical self-consolidating concrete *Construction and Building Materials* **23** no. 11 3439-3442.
[21] Siddique, Rafat, Yogesh Aggarwal, Paratibha Aggarwal, El-Hadj Kadri and Rachid Bennacer 2011 Strength, durability, and micro-structural properties of concrete made with used-foundry sand (UFS) *Construction and Building Materials* **25** no. 4 1916-1925.
[22] Singh, Gurpree and Rafat Siddique 2012 Abrasion resistance and strength properties of concrete containing waste foundry sand (WFS) *Construction and building materials* **28** no. 1 421-426.
[23] Basar, H Merve and Nuran Deveci Aksoy 2012 The effect of waste foundry sand (WFS) as partial replacement of sand on the mechanical, leaching and micro-structural characteristics of ready-mixed concrete *Construction and Building Materials* **35** 508-515.
[24] Prabhuc, G Ganesh, Jung Hwan Hyun and Yun Yong Kim 2014 Effects of foundry sand as a fine aggregate in concrete production *Construction and building materials* **70** 514-521.
[25] Celik, Tahir and Khaled Marar 1996 Effects of crushed stone dust on some properties of concrete *Cement and Concrete research* **26** no. 7 1121-1130.
[26] Mundra, Sanjay, P R Sindhi, Vinay Chandwani, Ravindra Nagar and Vinay Agrawal 2016 Crushed rock sand–An economical and ecological alternative to natural sand to optimize concrete mix *Perspectives in Science* **8** 345-347.
[27] Hameed, M Shahul and A S S Sekar 2009 Properties of green concrete containing quarry rock dust and marble sludge powder as fine aggregate *ARPN J. Eng. Appl. Sci* **4** no. 4 83-89.
[28] Ilangoval R 2014 Experimental studies on strength and behaviour of concrete by using quarry rock dust as fine aggregate
[29] Gonçalves J P, L M Tavares, R D Toledo Filho, E M R Fairbairn and E R Cunha 2007 Comparison of natural and
manufactured fine aggregates in cement mortars Cement and Concrete Research 37 no. 6 924-932.

[30] Pofale A D and S V Deo 2010 Comparative long term study of concrete mix design procedure for fine aggregate replacement with fly ash by minimum voids method and maximum density method KSCE Journal of Civil Engineering 14 no. 5 759-764.

[31] Sivakumar A and M Prakash 2011 Characteristic studies on the mechanical properties of quarry dust addition in conventional concrete Journal of civil engineering and construction technology 2 no. 10 218-235.

[32] Sukesh, Chandana, Katakam Bala Krishna, P Sri Lakshmi Sai Teja and S Kanakambara Rao 2013 Partial replacement of sand with quarry dust in concrete International Journal of Innovative Technology and Exploring Engineering (IJITEE) 2 no. 6 254-258.

[33] Anzar Hamid Mir 2015 Int. Journal of Engineering Research and Applications www.ijera.com ISSN : 2248-9622 Vol. 5 Issue 3 ( Part -3) pp.51-58

[34] Properties of concrete A.M. Neville. Edition. 4th and final ed. Published. Harlow, Essex : Longman, 1995.

[35] Jayawardena U De S and D M S Dissanayake 2006 Use of quarry dust instead of river sand for future constructions in Sri Lanka IAEG Paper 38.

[36] Manju, Unnikrishnan 2016 I-sand: An environment friendly alternative to river sand in reinforced cement concrete constructions Construction and Building Materials 125 1152-1157.

[37] Cheng, An, Ran Huang, Jian-n-Kuo Web and Cheng-Hsin Chen 2005 Influence of GGBS on durability and corrosion behavior of reinforced concrete Materials Chemistry and Physics 93 no. 2-3 404-411.

[38] Wainwright P J and N Rey 2000 The influence of ground granulated blast furnace slag (GGBS) additions and time delay on the bleeding of concrete Cement and concrete composites 22 no. 4 253-257.

[39] Ganesh, Babu K and Rama Kumar V Sree 2000 Efficiency of GGBS in concrete Cement and Concrete Research 30 no. 7 1031-1036.

[40] Bureau of Indian Standards 2000 IS 456: Plain and Reinforced Concrete - Code of Practice

[41] IS : 2386 (Part 3) – 1963 – Method of test for aggregates for concrete (Part I) Particle size and shape.

[42] Humam, Tamara and Rafat Siddiqk 2013 Properties of mortar incorporating iron slag Leonardo Journal of Science 1 no. 23 53-60.

[43] Shinde B H and K N Kadam 2011 Strength properties of fly ash based geopolymer concrete with sea sand

[44] Huiguang, Yin, Li Yan, LiHenglin and Gao Quan 2011 Durability of sea-sand containing concrete: Effects of chloride ion penetration Mining science and technology (China) 21 no. 1 123-127.

[45] Dolage D A R, M G S Dias and C T Ariyawardena 2013 Offshore sand as a fine aggregate for concrete production Current Journal of Applied Science and Technology 813-825.

[46] Ratnayake N P, U G A Puswewala, S P Chaminda, E M T M Ekanayaka and M N Jayawardene 2014 Evaluation of the potential of sea sand as an alternative to river sand for concrete production in Sri Lanka Journal of Geological Society of Sri Lanka.

[47] Kumar V, R Anandkumar and M Mathur 2003 Management of fly ash in India: a perspective Proceedings of Third International Conference on Fly Ash Utilisation and Disposal, New Delhi vol. 1 pp. 1-18.

[48] Kumar, Vimal, Mukesh Mathur and Shashank Sherk Sinha 2005 A case study: manifold increase in fly ash utilization in India Fly Ash India 1-18

[49] Shehab, Hamdy K, Ahmed S Eisa and Ahmed M Wahba 2016 Mechanical properties of fly ash based geopolymer concrete with full and partial cement replacement Construction and Building Materials 126 560-565.

[50] Ravina Dan 1998 Mechanical properties of structural concrete incorporating a high volume of class F fly ash as partial fine sand replacement Materials and structures 31 no. 2 84-90.

[51] Parvati V K and K B Prakash 2013 Feasibility study of fly ash as a replacement for fine aggregate in concrete and its behaviour under sustained elevated temperature Int J of Sci & Eng Res 4 87-90.

[52] Ravina, Dan 1997 Properties of fresh concrete incorporating a high volume of fly ash as partial fine sand replacement Materials and Structures 30 no. 8 473-479.

[53] Hemalatha T and Ananth Ramaswamy 2017 A review on fly ash characteristics–Towards promoting high volume utilization in developing sustainable concrete Journal of cleaner production 147 546-559.

[54] Rao S M & Acharya I P 2014 Synthesis and characterization of fly ash geopolymer sand Journal of materials in civil engineering 26(5) 912-917.

[55] IS 2386:1963 Methods of Test for Aggregates for Concrete, Bureau of Indian Standards

[56] Agrawal U S, P S Wanjadi and D N Naresh 2013 Characteristic study of geopolymer fly ash sand as a replacement to natural river sand Construction and Building Materials 150 681-688.

[57] Wanjadi S P, U S Agrawal and D N Naresh 2018 Geopolymer Sand as a replacement to Natural Sand in concrete IOP Conference Series: Materials Science and Engineering vol. 431 no. 9 p. 092011. IOP Publishing.

[58] Sharma, Anil Kumar and K B Anand 2019 Comparative study on synthesis and properties of geopolymer fine aggregate from fly ashes Construction and Building Materials 198 359-367.