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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 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. Byproducts 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 correlated 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 suitable 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.


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