Technical Note on production of Nano Concrete Aggregate for using as Coarse Aggregate in Cement Concrete

Abstract

The idea for this project stems out of the practice prevalent at Bangladesh where, in order to meet the need for aggregate of concrete in the absence of hillocks, they break clay bricks in jaw crushers as shown below:

The same can be seen in video link below:

https://drive.google.com/open?id=1tDuCrF0UVK2PtajgBw09Fx4hPbdN0UV2

But with passage of time and deterioration in quality of clay as well as brick, strength of brick bats have come down proving unsuitable for high strength concretes of above 20 MPa. To meet high strength concretes, Bangladesh import stone from India. Though not same, similar conditions prevail in north India, necessitating to procure Natural Stone Aggregate (NSA) from farther places. Thus there is a great market potential for alternate aggregate material as long as they meet the engineering properties of NSA.

Nano Concrete (NAC) is developed by Dr N Bhanumathidas and N Kalidas in 2008 as well patented vide Patent No. 279460/2010. NAC is field tested by casting 10.5 ft dia dome on FaL-G Mansion and installing a few sacred pillars for temples, as shown in the link below for one of the temples:

https://www.youtube.com/watch?v=NWV6Lxb7x24

RCC slab of 1200 s.ft. is cast with NAC for Vuyyala Kameswari Temple, Madhupada Village, Vizianagaram Dist, AP.

Since NAC offers strengths as high as 50-80 MPa, it was conceived to break NAC stone into aggregate. As of now, the only known art of producing aggregate from fly ash is in the form of Sintered Light Weight Aggregate (SLWA) against which NACA is far superior and cost effective as per comparative chart given below:

No.	Sintered Light Weight Aggregate (SLWA)	Nano Concrete Aggregate (NACA)
1.	Product is agglomerated in rotating drums. Spheroidal shape for aggregate is not ideal in rendering better bonding.	Product is cast as stone and then broken in jaw crushers. Broken multiple phases of aggregate are ideal for better bonding.
2.	Low specific gravity in the range of 1.0-1.2 gm/cc and high porosity with water absorption of not less than 15%.	High specific gravity in the range of 1.8 to 1.9 gm/cc; low porosity with water absorption of 2-4%.
3.	Strengths are attained through ceramic bond in the range of 4-5 MPa.	Strengths are attained through hydraulic bond in the range of 50-80 MPa.
4.	Energy intensive activity since the product needs to be sintered at about 1200 ^{o}C.	No thermal energy involved since the product attains strength through hydration chemistry.
5.	High cost product rendering low strengths. Hence not suitable for structural concrete.	Low cost product rendering high strengths. Hence ideal for structural concrete of grade strengths at 40-70 MPa.
6.	Hostile product for complying Sustainable Development Goals.	Ideal product to comply with Sustainable Development Goals.

It is ruled out to compare concrete of SLWA with that of NSA in view of drastic difference in engineering properties. Whereas, concrete with NACA behaves closer to that of NSA and hence acceptable for structural application. Before understanding the role of NACA it is desirable to perceive the performance of NSA in concrete.

Issues in comparison to Natural Stone Aggregate (NSA):

Though granite has compressive strength in the range of 60 to 200 MPa, its strength is not reflective in concrete. It is the bond strength of cement paste with stone at transition zone that reflects the characteristics strength of concrete. This is evident because as the input of cement is increased the grade strength of concrete increases by virtue of increased bond strength at transition zone with enhanced cement paste. But it is essential that coarse aggregate should have more strength than the grade strength of concrete, lest the concrete fails through broken aggregate rather than at transition zone.

With regard to flexural strength (MOR), concrete fails through broken stone in addition to transition zone. Thus the flexural strength of stone has a role to play in spelling out flexural strength of concrete. The flexural strength of low-density limestone is 2.8 MPa and for granite 4 to 10 MPa. Since the MOR of NAC stone is 5 to 7 MPa it can match good number of natural stones to meet the need of flexural strength of concrete.

Sheared surface of beams during study of flexure showing broken aggregate
(left is with natural stone aggregate and right is with Nano concrete Aggregate)

As against 2.6 of specific gravity and 1.4 t/cu.m bulk density for NSA, NACA contains 1.85 as specific gravity and 1.0 /cu.m as the bulk density. This is variable ± 5% depending on fly ash quality and water consistency. Thus NACA-concrete is lighter by about 15% as against that of NSA.

In the case of present project, NAC stones (blocks) are manufactured in first step. Cured stone with 50-80 MPa strength are fed to jaw crusher for getting crushed into aggregate. This could be set up as large scale plant (100 TPH) to medium scale plant (20 TPH). Machines used at Bangladesh are not identified in India. Otherwise small scale plants (1-2 TPH) also can be set up as micro scale units.

It is computed that, after taking Rs. 300/ton of fly ash towards transport, the manufacturing cost of NAC Stone comes to Rs. 4,440/cu.m with specific gravity of 1.85.

The bulk density of one cu.m of NACA is one ton as against about 1.5 ton for NSA. Even after taking granite crushing cost of Rs. 260/ton as conservative approach, ultimate cost of NACA comes to Rs. 2,660 per cu.m as against Rs. 2,400-3,000 per cu.m of NSA prevailed in northern market.

If cement and admixture are procured in bulk there would be scope for reduction in cost of NAC in mass scale production.

Since 76-80% of NACA being fly ash, this is one of the promising products for promoting mass scale utilisation of fly ash with potential to consume total fly ash generation.

Project Theme on Nano Concrete-Aggregate:

Aggregates (sand and stone) in concrete are indispensable inputs for three reasons:

- Without aggregates cement is liable to get shrinkage, leading to cracks.
- Strength of neat cement is around 70-90 MPa against 20-25 MPa strengths for popularly used concrete. Thus aggregates help to moderate strength of concrete to required grade.
- Cost of aggregates is certainly lesser than that of cement, thus bringing down the cost of concrete.

In concrete matrix, transition zone, the bonding-zone between stone and cement mortar, is the weak link yielding to stress that notifies its strength grade. So the first agenda was to avoid aggregate. If there is a cementitious paste which can overcome shrinkage and cost-issues, despite avoiding aggregate, why not use such cement paste as concrete!

This is exactly what Dr N Bhanumathidas and N Kalidas have invented and patented in 2010. This wonder product is called No-Aggregate Concrete (NAC), which means ***a concrete without sand and stone***. They have also named it as Nano Concrete (NAC) since the pore size is reduced to a few nanometers as against micro meters in conventional concrete.

NAC could be achieved by mixing 76% of fly ash with 20% cement along with 4% mineral admixtures resulting in least water consistency factor (0.12 to 0.18) for having used 4^{th} generation admixture.

NAC-Aggregate (NACA) is far superior to sintered lightweight aggregates (SLWA) of low strength and high permeability, where latter's application is limited to non-structural concrete. Since NAC could be developed as the stone-like mass with a strength range of 50 to 80 MPa, it is plausible in breaking this NAC-stone by which resultant aggregate can be used in producing structural concretes of 40-50 MPa. It is computed that manufacturing cost of NACA (10mm-20 mm) would be around Rs. 2600/- per cu.m.

<u>Process:</u>

NAC is produced, preferably with fine fly ash (25% retention on 45μ) which is available from 2^{nd} field onwards of ESP. Cement consumption goes up if coarse fly ash from 1^{st} field is to be used. NAC is prepared in roller mixers. The mixer of 5 ft dia gives 200 kg/batch of 4 minutes; thus 3 tons per hour. NAC is poured into gang moulds of suitable number and size. Mix preparation of NAC can be viewed at the following link:

https://www.youtube.com/watch?v=HS23Izwv6jE

After 48-hour from casting, product is demoulded out of gang mould and stacked for curing. Product attains 80% of its grade strength by 7^{th} to 10^{th} day, depending on ambience and humidity, and thus ideal for crushing. Crushed product is heaped and subjected for curing further till 28-day to attain its grade strength.

Thus each plant gives an output of 20 cu.m per shift. If micro crushers (1-2 t/hr), as being practiced in Bangladesh, are made to produce in India, then each small scale plant would set up one micro crusher also, bringing the total NACA production as small scale activity. This would encourage thousands of plants to be developed in the country.

Notwithstanding micro scale activity, depending on the size of large scale commercial crusher, number of NAC Stone manufacturing plants could be fixed. Thereby, production of NAC stone can be outsourced encouraging small scale entrepreneurs. For large scale production, mixer and casting systems can be designed with 200 cu.m/hr capacity, commensurate to the capacity of crushers.

Techno-Commercial Viability

As preliminary investigation, concrete was tested with NSA and NACA. Due to low specific gravity of NACA at 1.85, mix has resulted with NACA input at 4.2 in volume ratio as against 3.0 in weight ratio. By orienting mix ratios suitably, parallel strength with NSA can be achieved. Reduction in weight of concrete by 16% would prove as the main attraction for the market.

	Concrete with NSA	**Concrete with NACA**
Mix Ratio by weight:	1:2:4	1:1.7:3
Mix Ratio by volume:	1:2:4	1:1.7:4.2
Density of set concrete: kg/cu.m	2550	2140
Constituent	**Input- Kg/cu.m of concrete**	**Input- Kg/cu.m of concrete**
OPC	340	345
River sand	680	587
Coarse Aggregate 20 mm	1359	-
NACA 10 mm	-	1035
Water	171	173
Total:	2550	2140
W/C	0.503	0.50
Compressive Strength: MPa		
Acc. Curing (24-hr)	40.0	33.6
3-day	22.5	20.5
7-day	31.0	27.6
28-day	45.7	40.6
MOR - MPa: 28-day	6.0	4.6
Note: Though MOR has shown lesser value against that of NSA, as per the codal requirement of $0.7\sqrt{F_{ck}}$ which comes to 4.43 MPa, the derived value is satisfactory. This value does increase with progress of age due to enrichment of bond in matrix.		

In order to estimate the potential of Northern market for aggregate, the statistical guesstimate is computed based on production of cement in the country resulting in the data as below:

Description	Units	Quantity
Country's cement production	Million tons	297
Cement used for concrete as National average. Approx. 60%	Million tons	178
Concrete output at National level @ 0.33 tons of cement consumption per cu.m	Million cu.m	539
Aggregate market at an average input of 1200 kg/cu.m.= 539*1.2 t	Million tons	646
Considering 1/3rd as the Northern market, Scope of aggregate in northern india	Million tons	215
At the input of 0.76 tons of fly ash per ton of NACA, fly ash consumption	Million tons	163

Even at the penetration level of 50% into natural stone market in North India, it may be mentioned that there is a potential market for 107 million tons of NACA that can consume 81.5 million tons of fly ash.

Upon articulating the project as that of Sustainable Development, and tying up with one of the European countries for carbon foot print reduction, this project can be promoted in international arena for funding.

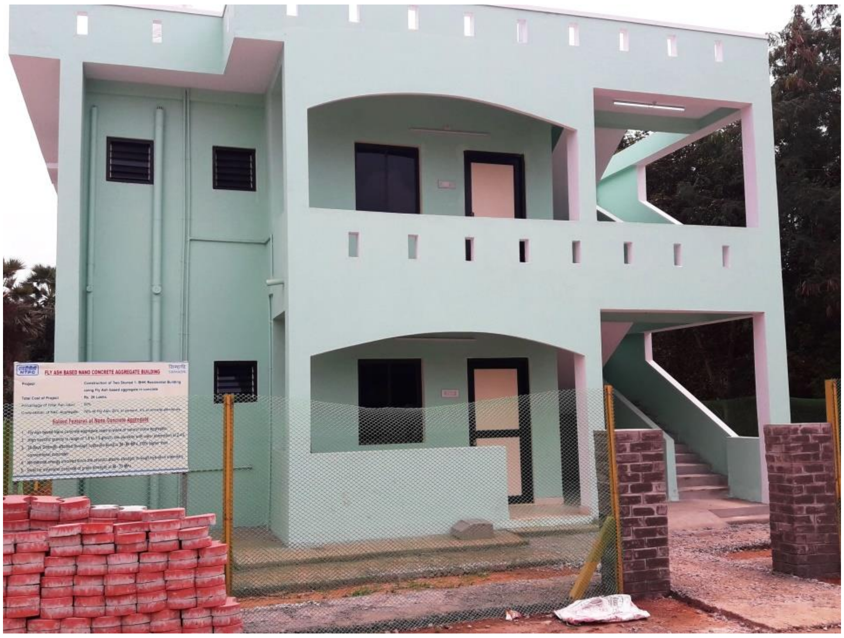
National Grand Challenge on Fly Ash Utilisation:

NTPC has conducted a national level contest in 2019 seeking for technological solutions to promote mass scale fly ash utilization. NACA has bagged the 1st Prize for its potential of mass scale utilization together with features of Sustainable Development.

National Grand Challenge: 1st prize received over the hands of Mr RK Singh, Union State Minister of Power (I/C)

Demo structure at Deepanjali Nagar, NTPC-Simhadri

In order to demonstrate the product at field level, a two storied building is constructed in 2020 using NACA totally against NSA. The concrete mix is 1.0 : 1.7 : 2.7 wherein the total cementitious input is 357 kg/cu.m (OPC: 153; fly ash: 204). W/CM is 0.37 since admixture is used at 0.4%. The density of concrete is 2,080 kg/cu.m and 28-day strength is 43 MPa.



Demo Building at Deepanjali Nagar, NTPC Simhadri Power Project, Paravada,
using Nano Concrete aggregate (NACA) as total replacement to natural stone aggregate.