EFFECT OF WATER AND ACCELERATED CURING ON IMPACT AND COMPRESSIVE STRENGTH OF ARTIFICIAL AGGREGATES WITH NANO SILICA

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ABSTRACT. This research was aimed to study the effect of different curing methods on impact and compressive strength of artificial aggregates manufactured with fixed 17min of pelletization time and 28% of water content by pelletization method. The aggregates manufactured with the combination of materials like fly ash, cement, hydrated lime, GGBFS and metakaolin, followed by strengthening of aggregates with nano silica. The curing methods are normal water curing (Cold-bonded) at 28 Days, 56 Days and Accelerated curing at 100^0 C for 3.5 hrs after 28Days of cold-bonding. Nano-silica is used as an admixture with variable content (0, 0.5, 1 and 1.5) % by total weight of materials as an addition. The best performance is demonstrated with cold-bonded at 56 Days by flyash, hydrated lime and steel slag combination aggregate with 0.5% Nano-silica. This aggregate has highest compressive strength at all the ages.

Keywords: Pelletization method, High strength artificial aggregate, Nano silica, Cold-bonded method, accelerated curing method, Impact and compressive strength, SEM and EDX

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INTRODUCTION

Artificial lightweight aggregates (LWA) are produced either by means of ordinary materials or with industrial by-products [1]. LWA manufactured from industrial by-products by pelletization consist of cohesive as well as tumbling forces which bonds moisture particles. The fresh pellets were taken out from pelletizer and air-dried for 24hrs achieve enough strength for handling however not to the level for its utilization in concrete. Therefore hardening techniques should be followed to produce the pellets strong enough to be utilized in concrete. Hardening of artificial aggregates involves different methods like sintering, cold-bonding and autoclaving. Among three methods sintering is a power demanding method, though it leads to high strength aggregates [1-8][9]. Cold-bonding is an alternative method of sintering which is an economical method. The cold-bonded artificial aggregates have been manufactured both with Class-C and Class-F fly ash [10, 11, 12, and 13]. Addition of binder with Class-F fly ash which has an origin of calcium hydroxide for enhancing the properties of aggregates like production efficiency, density, specific gravity, water absorption and strength of aggregates [11, 14, 15]. Mostly Cold-bonded artificial aggregates are heavier than sintered artificial aggregates. C-S-H gel forms during the reaction which results in the strengthening of aggregates [16]. LWA properties with their related effect on concrete depend on its microstructure. For the manufacturing of artificial aggregates type of binder added with fly ash and hardening method has an important impact on the microstructure of aggregate. Further, improvement of the dense microstructure of aggregate nanomaterial is added at the time of pelletization.

The use of nanotechnology in construction industry particularly in cement mortar and concrete has involved significant technical interest in present years. Nanotechnology includes controlling issue and materials in the nanometer scale under 100 nm. The majority of nanoscale structure materials shows to be a capable approach for the improvement of advanced sources of cement-based materials through better properties [17-20]. Therefore, nanoparticles have been utilized in concrete with the quick improvement of nanotechnology. The existing information in the literature showing that there are different types of nanoparticles like nano-SiO_2 [21,22], nano-Al_2O_3, nano-TiO_2 [23], nano-ZnO_2, nano-$CaCO_3$ [24], carbon nanotubes [25], and carbon nanofibers [26,27] which are utilized in concrete to change the properties. Among them, nano-SiO_2 has gained the interest and has been noted effectively because of its pozzolanic reaction with cement-based materials, in addition to the filling effect due to its fine particle size [28]. The present study was to assess the manufacturing and testing for different artificial aggregates manufactured and hardened through cold-bonding and accelerated curing method of different combinations with Nano SiO_2. The influence of Nano SiO_2 with binders on the impact and individual aggregate compressive strength is noticed with possible strengthening mechanism are set further and discussed.

EXPERIMENTAL STUDY

Materials Used

Low calcium fly ash (F-Type) an industrial by-product collected from Ennore thermal plant is the base material for manufacturing lightweight aggregates. The fly ash (FA) aggregate bonding was attained through the binding materials like cement (OPC-53grade), hydrated lime (HL), metakaolin (MK) and Steel slag (GGBFS). Nano SiO_2(NS) of 99.5% purity was added by the total weight of material. Water was sprayedon materials at the time of pelletization. Detail chemical and physical properties of different materials are given in Table 1. The physical and chemical tests for Nano SiO_2 are specified in Table 2, 3 which was provided by Nano Labs Jharkhand.

Table 1 Typical chemical and physical characteristics of materials utilized

PARAMETERS	FA	HL	OPC	MK	GGBFS
Chemical Characteristics					
SiO_2	39.4	0.3	22.3	51.35	35.0
Fe_2O_3	18.54	0.23	3.0	1.21	0.95
Al_2O_3	17.9	0.42	6.93	40.31	17.7
CaO	17.45	69.0	63.5	0.32	41.0
MgO	2.88	0.5	2.54	0.11	11.3
TiO_2	0.95			2.13	
Na_2O	0.28			0.06	0.2
K_2O	1.78			0.52	
$Ca(OH)_2$		91.0			
MnO_2	0.15	-			2.7
SO_3	1.70	-	1.72		
$CaCO_3$					10.0
P_2O_5	0.45				0.65
Glass content					92.0
Physical Characteristics					
Specific Gravity, g/cm³	2.12	2.24	3.12	2.6	2.85
Specific surface area, m²/kg	407		290	805	409
P^H Value		12.4	6.3	5.1	
Loss on Ignition, %	1.76		0.84	2.02	0.26
Appearance (powder)	Grey	White	Grey	Off-white	Off-white
Moisture, %	0.5			0.7	0.10

Table 2 Physical characteristics of Nano SiO_2

SI NO	NANO SiO_2 PROPERTIES	
1	Type	Nano powder
2	Size, nm	50-80
3	Puirity, %	99.5
4	Colour	Pure white
5	Specific Gravity	2.1

Table 3 Chemical compositions of Nano SiO_2

SiO_2	Al	Fe	Mg	Ca
>99.5%	<0.02%	<0.05%	<0.1%	<0.08%

Preparation of artificial lightweight aggregates

The initial part of investigation is the manufacturing of artificial lightweight aggregates through cold-bonding and accelerated curing by means of fly ash and other binder materials with addition of Nano SiO_2. This method involves the pelletization of various materials in a rotating disc type pelletizer. For the efficient production of fly ash aggregates, it is important to decide the angle and speed of disc pelletizer with desired water content added at the time of pelletization. To observe the relationship between the best rotation speed and the inclination angle of disc pelletizer, an investigation was carried out by observing pellet development phases, the shape with the quality of pellets. To fix the angle and speed of the disc pelletizer various trials have been carried out.

In the present study, manufacturing of aggregates using a specially made-up disc pelletizer as shown in Figure1. The pelletizer disc was fabricated with diameter of 500mm with 250mm depth. The inclination angle could be modified among 35° to 50° with the rotating speed modified from 40 to 55 rpm. Depending on the preliminary investigations conducted on the pelletization method, the inclination angle was fixed at 36º, the rotation speed of 55 rpm with standard pelletization time as 17minutes for attaining the utmost efficiency in addition to preferred size and shape of aggregates. Furthermore, 28% of water was sprayed onto the materials for the duration of first 8 minutes of the pelletization process to get the spherical balls. Additional 9 minutes was allotted to extra stiffening of the pellets to enhance their strengths.

In total 12 types of lightweight aggregates were manufactured with and without Nano SiO_2 from various binder materials with fly ash. In the beginning, base material fly ash with binders was added in the disc pelletizer and mixed homogeneously for 2 minutes duration and then nano material were added and mixed for another 1 minute; then required mix water is sprayed within the disc and pelletization continued. During this method, initially the pellets are small as the duration increases the pellets size increase and stops at some point in time. Finally, after the completion of pelletization, the fresh pellets were collected from the disc. After manufacturing, the fresh pellets were air dried for 24hrs and subsequent hardening of pellets through water curing for 28, 56 days and accelerated curing at 100^{o}C for 3.5hrs after 28Days of cold-bonding at room temperature, in detail manufacturing process of aggregates as shown in Fig 1.

Table 4 Mix combinations of various artificial aggregates with and without Nano SiO_2

MIX ID	BINDER CONTENT (%)						NANO MATERIAL (%)
	COMBINATIONS	FA	HL	OPC	MK	GGBFS	NS
M1	0FCH	80	10	10	-	-	-
M2	0FHM	80	10	-	10	-	-
M3	0FHG	80	10	-	-	10	-
M4	0.5FCH	80	10	10	-	-	0.5
M5	0.5FHM	80	10	-	10	-	0.5
M6	0.5FHG	80	10	-	-	10	0.5
M7	1FCH	80	10	10	-	-	1
M8	1FHM	80	10	-	10	-	1
M9	1FHG	80	10	-	-	10	1
M10	1.5FCH	80	10	10	-	-	1.5
M11	1.5FHM	80	10	-	10	-	1.5
M12	1.5FHG	80	10	-	-	10	1.5

Fig 1 (a). Different materials Fig 1 (b). Disc pelletizer Fig 1 (c). Air dry for

24hrs

Fig 1 (d). Cold-bonding Fig 1 (e). Accelerated curing tank Fig 1 (f). Final aggregate

Figure 1 Manufacturing process of artificial lightweight aggregates

Tests on artificial lightweight aggregates

After the hardening process the aggregates were tested with impact and individual aggregatecompressive strengthas given below.

Impact strength of lightweight Aggregates

The impact strength was to determine the toughness of lightweight aggregates for moving loads by means of an impact testing apparatus as shown in Figure2.as per IS: 2386-(Part IV)-1963 [29]and it is calculated by using formula as given below.

Aggregate Impact Value (A.I.V) = $\{W_2 / W_1\} \times 100$

Where, W_1 is the weight of the fly ash lightweight aggregate sample utilized for testing and

W_2 is the weight of fractions passing 2.36 mm sieve size.

Individual Aggregate compressive strength

The individual aggregate compressive strength was determined with California bearing ratio (CBR) testing apparatus by placing the aggregate between two corresponding plates and loaded slowly until failure occurred. The test was conducted on different sizes of aggregates like 20, 16, 12, 10, 8 and 6mm by utilizing 28 KN power load-ring. The compressivestrength test apparatus as shown in Fig 3. An average of 20 randomly selected aggregates was tested so as to determine the average compressive strength for every type of lightweight aggregates by using formula as given below [30].

Individual crushing strength ‘σ’ = $\{2.8 \text{ X } P / \text{Pie X } d^2\}$

Where, P = The failure load and

d = The distance between the two plate of the aggregate or Diameter of aggregate

Fig 2. Aggregate impact test apparatus

Fig 3. Compressive strength test apparatus

SEM studies of artificial lightweight aggregates with and without Nano SiO_2

Standard pieces of 1cm size were kept in an oven for 24hrs at 105 ± 5 ^{o}C to eliminate evaporable water content and mounted on alloy stubs and sputter covered before subjecting to the electron beam from a ZEISS EVO/18 scanning electron microscope (SEM) studies were carried out with required magnificationwith related energy dispersive X-ray analysis (EDX).

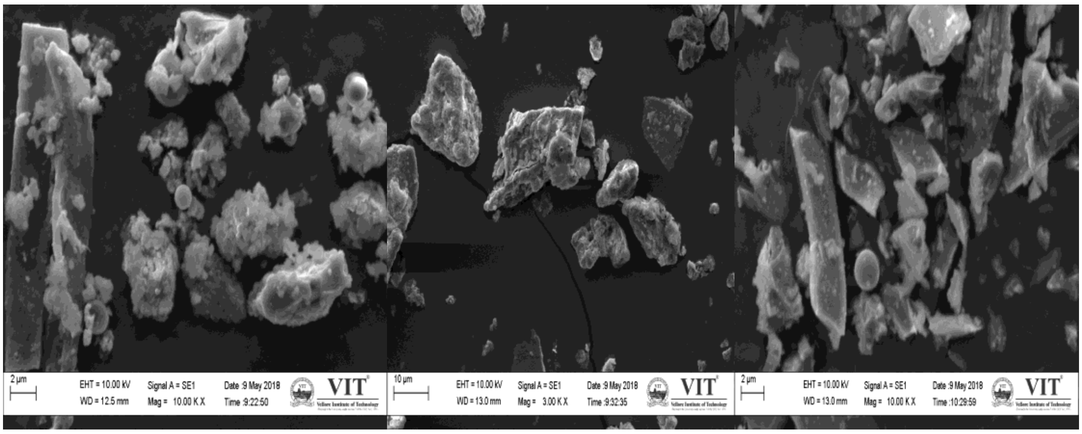


Fig 4(a): Cement Fig 4(b): Fly ash (F-type) Fig 4(c): GGBFS

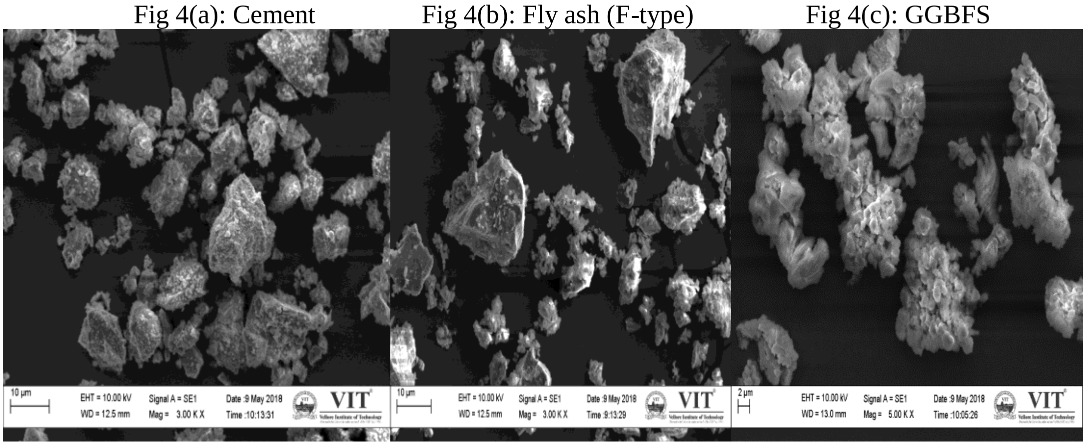


Fig 4(d): Hydrated lime Fig 4(e): Metakaolin Fig 4(f): Nano SiO_2

Figure 4(a-f) Grain shape and surface of different materials

Correlate with the SEM pictures, EDX spectrums had to determine the mineral contents present in the material. The structure of cold-bonded artificial aggregates with different binder materials shows different patterns of pores in general are uneven, round and disconnected, whereas others are stretched out and interconnected as shown in Figure 4.

Microstructure of artificial lightweight aggregates with and without Nano SiO_2

In this part, the SEM was engaged to explain the microstructure of artificial aggregates used in this study. Wasserman and Bentur [31] noted that strength of artificial aggregates depends on physical and chemical interfacial action. As a result, the interfacial transition zone (ITZ) of the artificial aggregate was investigated through SEM observations at different magnifications related with EDX spectrum (Figure.5 and Figure.6). Microstructural study recommended that development in the strength of artificial aggregates with hydrated lime and GGBFS binder combination possibly reaction taking place between minerals and calcium hydroxide (portlandite), therefore results to a solid structure combined with peak Si content as shown in Figure.6 (a, b and c). At the time of hydration, the $Ca(OH)_2$ go in reaction with GGBFS ingredients developing the calcium silicate hydrate (C-S-H), which helps for filling empty spaces. Crystals of calcium hydroxide (portlandite), long with slender needles of ettringate and crystals of C-S-H can be seen at 0.5% of Nano SiO_2 as shown in Figure.5 (d, e and f).

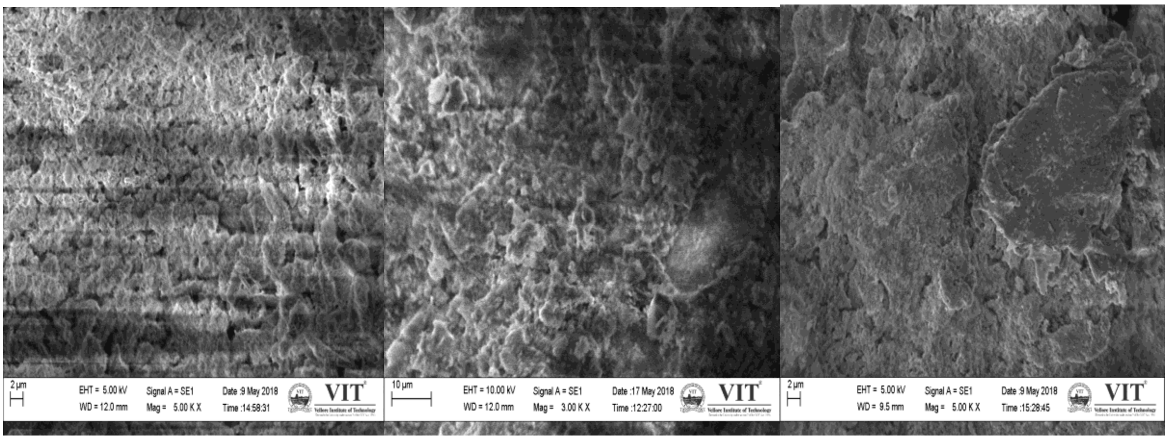


Fig 5(a): M1 Type Fig 5(b): M2 Type Fig 5(c): M3 Type

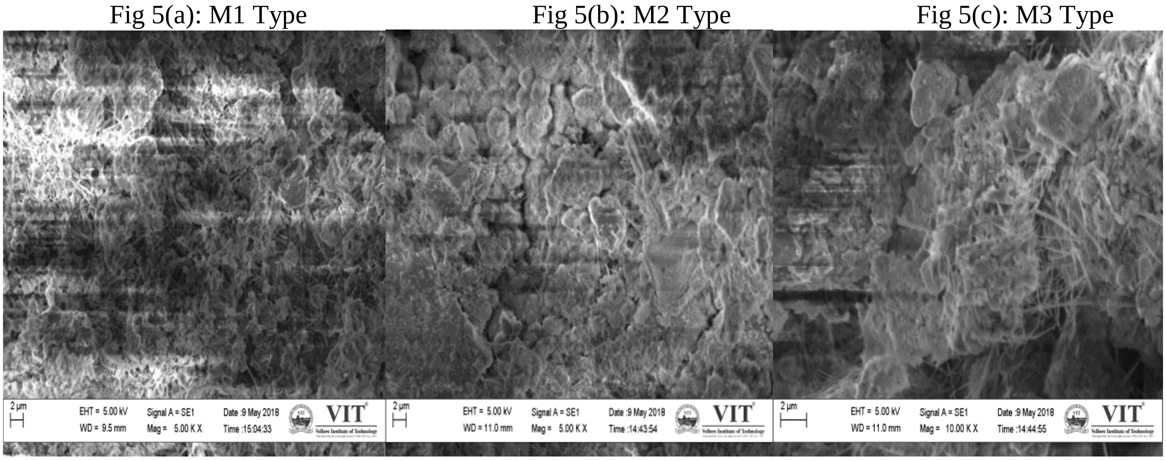
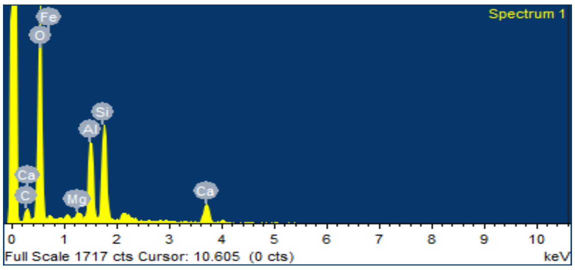


Fig 5(d): M4 Type Fig 5(e): M5 Type Fig 5(f): M6 Type

Figure 5(a-f) SEM observations of different type of aggregates



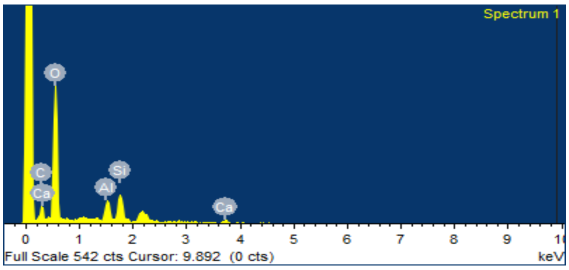


Fig 6(a): M4 Type

Fig 6(b): M5 Type

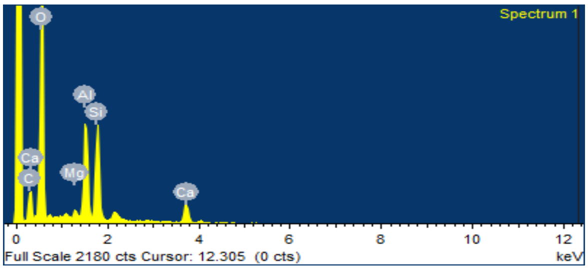


Fig 6(c): M5 Type

Figure 6(a-c) EDX observations of different type of aggregates

RESULTS AND DISCUSSIONS

Aggregate impact values of lightweight aggregates

The impact strength values for different aggregates manufactured with 28 and 56 days of cold-bonding and accelerated curing after 28 days of cold-bonding as shown in Figure 7. All the mix combination of aggregates with various binders and Nano SiO_2 satisfies the structural demand as per IS: 2386 (part IV) – 1963 [19].

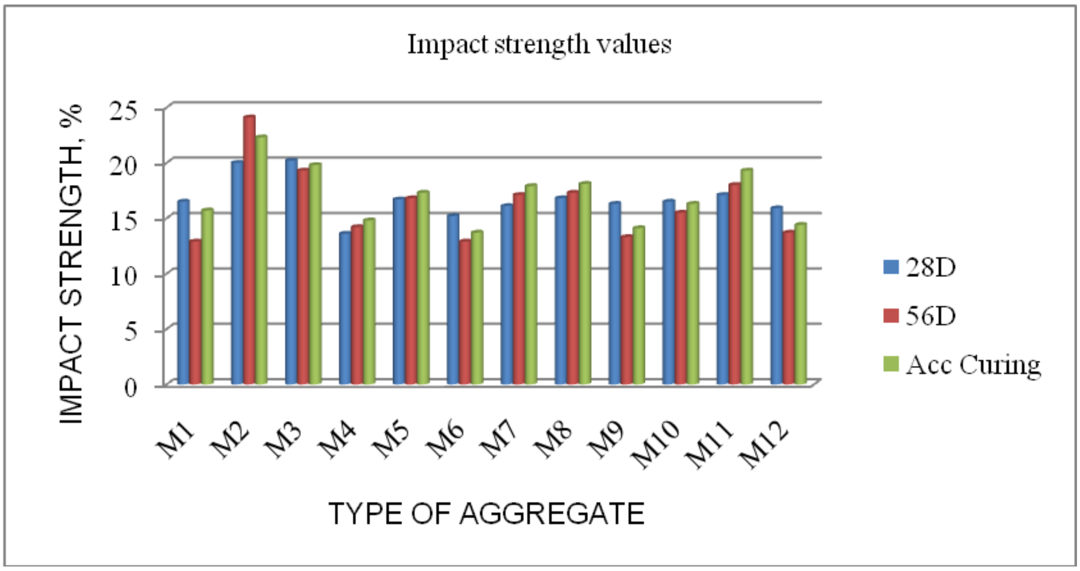


Figure 7 Impact strength V_s Type of aggregate

The highest impact value of as 24.1% for hydrated lime and metakaol in binder without Nano SiO_2(M2) and the least impact value as 12.9% for hydrated lime and GGBFS binder with 0% and 0.5%of Nano SiO_2(M1 and M6). The highest percentage decrease of about 21.8 for 56 days cold-bonding with reference to 28 days for hydrated lime and cement binder without

Nano SiO_2(M1) and similarly the highest percentage increase about 20.5 for hydrated lime and metakaol in binder without Nano SiO_2(M2).It can be concluded from the test results that, the impact strength of various lightweight aggregates manufactured depends on the type of binder and percentage addition of Nano SiO_2. As the increase in percentage of Nano $SiO_{2,}$ the higher the impact values till 0.5% again increasing the dosage the values getting decreased. Hence, 0.5% of Nano SiO_2 can be used as the optimum dosage value. This enhanced the bonding properties with added increase of micro-structure. In general, all the aggregates manufactured with Nano SiO_2 exhibit higher impact values.

Individual aggregate compressive strength values of lightweight aggregates

The experimental results on the individual compressive strength of lightweight aggregates produced with a diameter varying from 10 mm to 20 mm as shown in Figure 8, 9, 10, 11 and the strength investigations were considered based on the type of binder and percentage addition of Nano SiO_2.

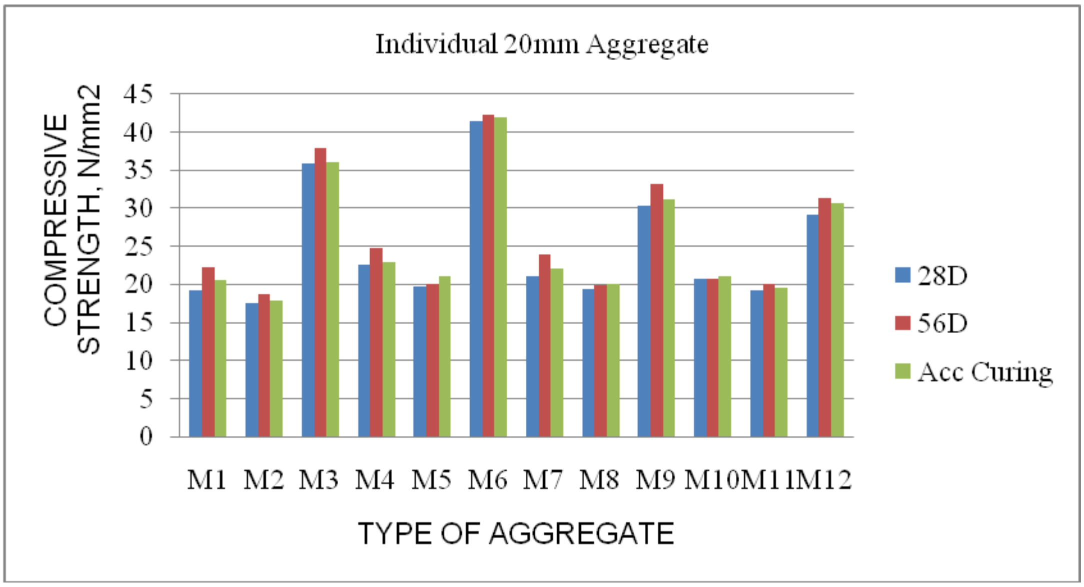


Figure 8 Compressive strength V_s Type of aggregate

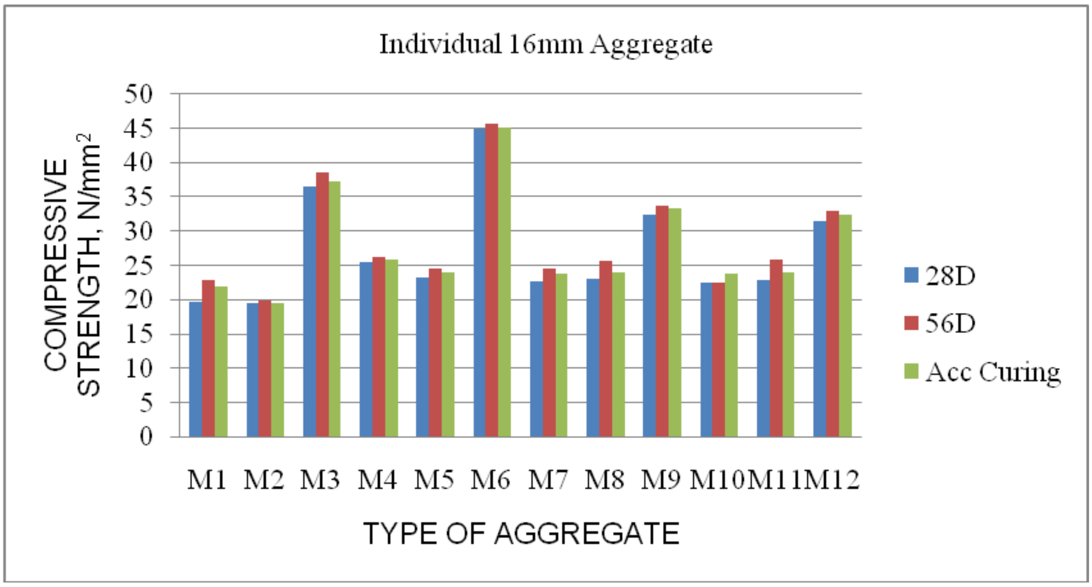


Figure 9 Compressive strength V_s Type of aggregate

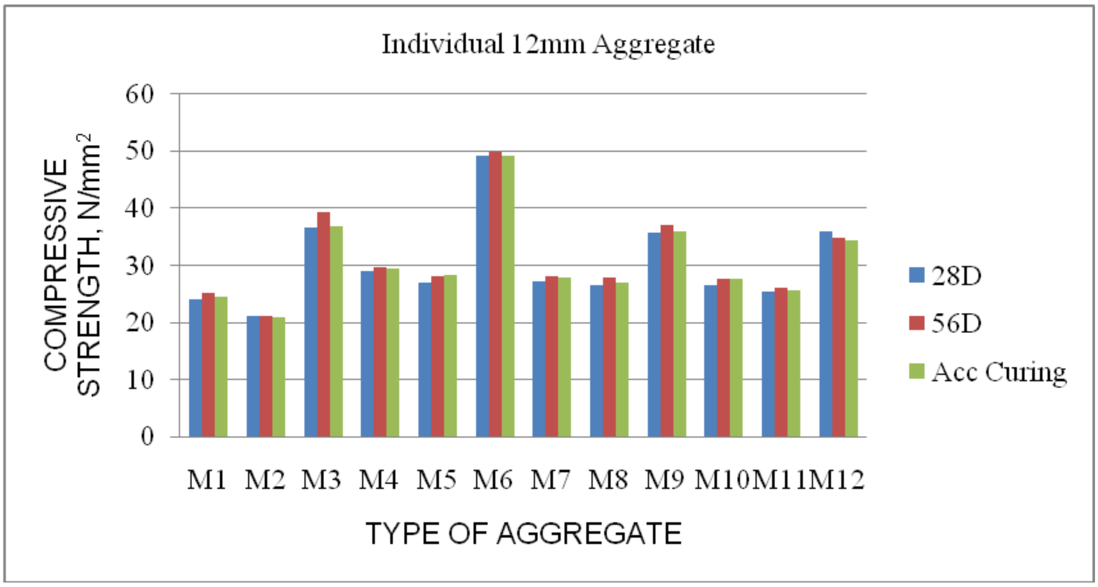


Figure 10 Compressive strength V_s Type of aggregate

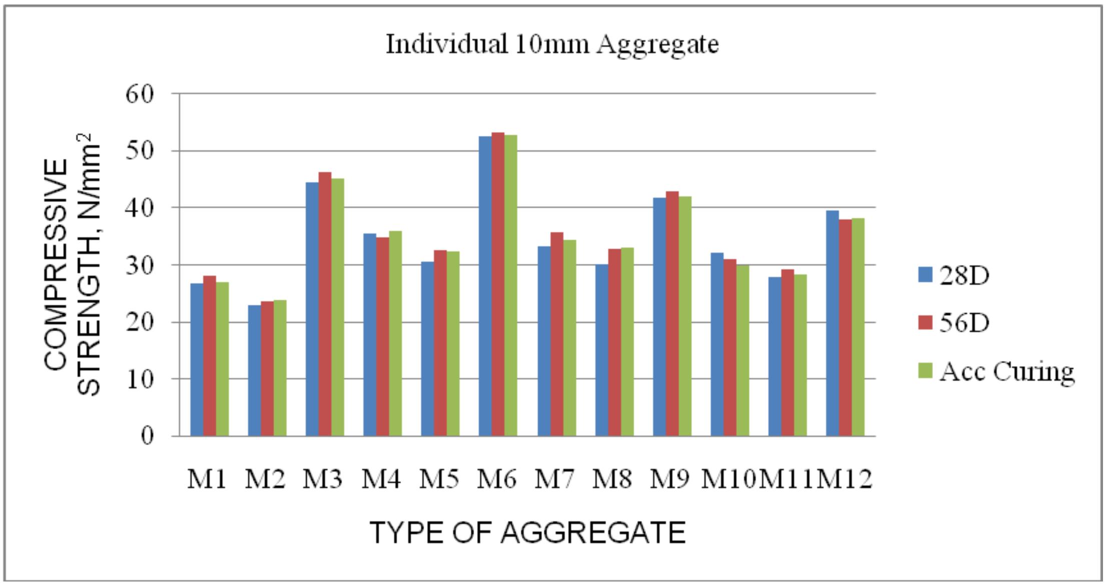


Figure 11 Compressive strength V_s Type of aggregate

The results show that, the strength values depend on the binder with the additional dosage of Nano SiO_2 at the time of pelletization. Moreover, the fineness of materials had offered the major amount of adjacent packing of particles caused due to greater efficiency in the form of strength. In the present study, cold-bonded and accelerated curing aggregates produced were found to be acceptable in terms of strength due to their strong bonding efficiency because of intergranular particles bonding. It is additionally necessary that the specific surface area (SSA) increases when the binding material particles are finer and can produce closer stuffing of intergranular particles. It is noticed that, as the percentage increase in Nano SiO_2 the compressive strength increases till 0.5% again increasing in the dosage the values getting decreased for all the types of aggregates. A highest compressive strength of 53.2 MPa was noted for hydrated lime and GGBFS binder with 0.5% Nano SiO_2 (M6) for 10mm aggregate compared to other binder and the lowest compressive strength of 17.5 MPa for hydrated lime and metakaol in binder without Nano SiO_2 (M2) for 20mm aggregate. Irrespective of Nano SiO_2

dosage and different curing methods, as the size of aggregate decreases from 20 mm to 10 mm the compressive strength increases. Also, the aggregates manufactured with and without Nano SiO_2 from pozzolanic binder exhibits higher strengths. The average highest percentage increase in compressive strength for 56 days cold-bonding is 5.3 for M8 type aggregate with reference to 28 days reference aggregate and the highest percentage decrease in compressive strength of 0.2 for accelerated curing of hydrated lime and GGBFS binder at 0.5% Nano SiO_2 (M6) with 28 days reference aggregate. In general, it can be concluded that the different aggregates manufactured in this study gives a reasonable strength gaining meeting the performance demands of artificial lightweight aggregate.

CONCLUDING REMARKS

This study mainly focused on effect of Nano SiO_2 on artificial lightweight aggregates under cold-bonding and accelerated curing methods in the aspects of Impact and individual aggregate compressive strength. Based on the investigations, the following conclusions are drawn.

- The addition of Nano SiO_2 with different binders during pelletization provided an extra stable production of aggregates with improved properties.
- The highest impact value of 24.1% was observed for hydrated lime and metakaolin binder without Nano SiO_2 (M2) and the lowest impact value observed as 12.9% for hydrated lime and cement binder without Nano SiO_2 (M1) and hydrated lime and GGBFS binder with 0.5% Nano SiO_2 (M6).
- A highest individual aggregate compressive strength of 53.2Mpa was noticed for hydrated lime and GGBFS binder with 0.5% Nano SiO_2 (M6) for 10mm aggregate compared to other binder and the lowest compressive strength of 17.5 MPa for hydrated lime and metakaolin binder without Nano SiO_2 (M2) for 20mm aggregate. Irrespective of fibre content and binder material, as the size of aggregate decreases pellet crushing strength increases.
- From all the curing methods cold-bonding for 56 days exhibits higher strengths than 28 days of cold-bonding and accelerated curing at 100^0C for 3.5 hrs.
- The artificial aggregates with different binders, addition of Nano SiO_2upto 0.5% dosage the strength has increased. It is observed that increasing in the percentage of Nano SiO_2 the compressive strength of individual aggregate is getting decreased. Hence 0.5% of Nano SiO_2 can be used as an optimum dosage.

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