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Characteristics of crushed and alternative fine aggregates based on flow, shear and impact behaviour

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Crushed sand has been found to be an excellent replacement for river sand as the latter is not readily available. As a part of sustainable construction methods and practices, industrial by- products such as copper slag, cinder etc., can be used as alternative sands. In this work, an attempt has been made to study the performance of crushed stone sand for its flow properties based on large sample analysis. For this, 30 samples of crushed sand were procured from different sources. In addition, few alternative sands were also considered for the analysis which included copper slag, Ennore sand and two types of cinders. The parameters tested are flow time based on New Zealand flow cone, loose bulk density, uncompacted voids and specific gravity. In order to enhance the performance of the poor crushed sand, different samples of crushed sands were blended which results in acceptable flow characteristics. Similar exercise was done for alternative sands by considering double or triple blending which finally resulted in good flow properties for possible use in concrete. In addition, few samples were also tested and evaluated for their shear and impact behaviour. Conclusions are drawn based on the results obtained.

Keywords: Flow time, Un-compacted air voids, Alternative sands, Blending of sand, New Zealand flow cone test, Shear and Impact behaviour

1 Introduction

Presently natural river sand is very scare and costly and hence efforts are being made to explore alternative sands in civil engineering applications. Different Industrial by-products and alternatives materials can be safely used as sand as reported in the literature. IS:383-2016 recommends many such alternatives and manufactured sands. Though there are many advantages of these alternative sands such as easy availability, lack of impurities and affordable cost, they have many disadvantages such as presence of high fine content, irregular shape and surface characteristics which play a major role in the quality control of concrete.

Generally fine aggregate must be of proper gradation having representative fractions from 150µm to 4.75 mm, in proper proportion which results in minimum voids and maximum density. Such aggregates require less quantity of cement leading to economical concrete mix design and the amount of free water for a given workability is also the least. Hence, it is important to know the engineering properties such as water absorption, specific gravity and dry density to name a few, of alternative fine aggregates, as these properties are used to determine other properties which control the mix design. In addition to these properties, the flow characterization of aggregates plays an important role in the design of special concretes such as self compacting and high-performance concretes. This characterization requires properties such as flow time, impact value, resistance to abrasion and presence of deleterious materials as these properties greatly affect the strength, workability and durability of cement concrete and hence the performance of structural elements. Insufficient knowledge, wrong calculation and interpretation of these properties might lead to faulty mix design which can finally affect the performances of concrete during laboratory and field studies.[1]

Natural river sand and crushed stone aggregates are generally used for all civil engineering construction works. Due to non availability of sufficient quantity of natural sand, many alternatives sands have emerged and their performances are not fully explored. In addition, these days, large amounts of construction and demolition wastes are generated in

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the cities and they are usually disposed in illegal landfills due to poor enforcement of law. Such wastes are to be recycled through a process involving selection, crushing, sieving and storage in order to reuse effectively as recycled aggregates or recycled concrete aggregates. IS:383-2016[2] recommends the use of such aggregates partially in structural concrete. Recycled concrete aggregate (RCA) differ from natural aggregate as it contains hardened cement mortar which has higher porosity and water absorption and when used has detrimental effects on the physical, rheological, mechanical and durability properties of concrete. The flow characteristics of alternate aggregates are also affecting the performance of concretes and mortars.

It is reported that shape, texture and gradation characteristics of fine aggregates affect the workability, finishing, bleeding and segregation of fresh concrete. In addition, they also affect the strength, stiffness, permeability and durability of hardened concrete[3] As such, alternate aggregates and manufactured sand have contrasting surface characteristics which affect the quality of concrete tremendously. Cement is the costly component of concrete and its paste fills the void spaces among aggregates and contributes to workability of concrete and provides adhesion among aggregates once the concrete is hardened. The percentage of air voids in an aggregate mass is mainly related to its gradation, shape and texture[4].

Another important factor which influences the fresh properties of concrete is the specific surface area of both fine and coarse aggregates. River sand, its particles being cubical in shape, have lower specific surface area and require lesser amount of cement paste in order to achieve the same workability, than a concrete mix made with aggregates such as crushed aggregates which generally have higher specific surface area, because of larger amount of flaky and irregular particles. In addition, flat, elongated, angular and rough textured sands will result in higher amounts of voids thereby demanding more cement for good flow. In addition highly textured crushed sand produce mortars that make the concrete surface finishing rough and sometimes difficult. A higher demand of water to obtain a given workability reduces strength and increases concrete bleeding. Durability of concrete is mainly associated with a low w/c ratio and hence angular, flat and elongated particles of crushed or manufactured aggregates decrease the concrete durability since they increase the water demand. As reported by Tasong *et al.*[5] that the determination of surface texture is important and they proposed new experimental technique to quantitatively characterize this property. Alexander[6] stated that shape and texture of the aggregates have a direct effect on various strengths of concrete and finally on the shape of stress-strain curve, since aggregates morphology influences the formation of initial cracks in the transition zone. During recent days advanced methods such as image analysis techniques have been used to assess the shapes and textures of aggregate particles[7], which define surface properties quantitatively. Though in concrete mix proportioning, the shape effect is partially taken into account by considering the fineness modulus of sand, it may not fully satisfy the requirement of concrete from the point of all rheological properties.

Almost all alternative sands contain large quantities of fines which have some advantages in self compacting concrete (SCC) as it adds to its flow and rheological properties[8]. Lime stone dust is added as a replacement to sand in order to improve the performance of concrete in its fresh stage[9]. Different alternative sands are considered to characterize the performance of SCC through mix design as reported by Nataraja *et al.*[10,11]. Kalgal *et al.*[12] have reported on the strength and durability behaviour of concrete containing pond ash used as fine aggregates and its characterization is very important to control the workability of concrete. Fly ash is also used as a sand replacement material and can be effectively used to produce different grades of concrete as reported by Rajamane *et al.*[13]. Even quarry dust is used to the extent of 40% in the production of SCC as a local material whose fines add to its paste content[14]. Crushed sand is successfully used along with GGBFS to produce medium to high strength concretes[15]. Sometimes, crushed sand may have excess harmful deleterious materials which affect the durability of concrete and methylene blue test has been found to be very effective in this regard[16]. The amount of fines and the surface characteristics also depend on the type of crusher being used and hence the performance of concrete will be different as reported by Muhit *et al.*[17].

As seen from the literature, there exist many methods to characterise the shape of aggregates. For coarse aggregates, shape is normally characterized by the flakiness and elongation indices. Few methods are developed to characterize the finer part of the aggregate and the procedure is reported in ASTM[18]. One such test for characterising the fine aggregate is by New Zealand flow cone test[19]. This development in testing and evaluating sand can be easily and quickly applied to any fine aggregate, at minimum cost in equipment and time. Flow time of sand usually depends on the particle shape, size and texture. Void content determines the water demand of the fine aggregate which directly affects the workability of concrete and mortar mixes.

Objectives of the present work- As per IS:383-2016[2], blending of crushed stone aggregate with natural river sand is recommended. Any two sand samples can be suitably mixed in order to get a better sand that can be safely used as its performance would be superior to the previous two sand samples.The main objectives of the present work is to characterise the behaviour of 30 samples of crushed stone sand procured from different sources based on a 'large sample analysis'of the test results. In addition, five samples of alternative fine aggregates are also considered for the study. Properties tested are -the specific gravity from pycnometer test, loose density, flow time and un-compacted void from NZ flow cone test. Quality of the underperforming samples has been modified by proper blending of different crushed sands only and a few combinations of crushed sand with alternate sands. These blended samples namely Blend-1 (copper slag, river sand, crushed stone sand), Blend-2 (copper slag, crushed stone sand) and Blend-3 (light cinder, crushed stone sand) have been tested to determine their loose density, flow time anduncompacted void content and their performance is evaluated. In addition, two additional analyses based on direct shear-box test and modified impact test are performed to know the shear and impact resistance of different types of sands.

2 Materials and methods

2.1 New Zealand Flow cone test

In NZ flow cone test, two parameters are measured, namely flow time i.e., time taken by a fixed quantity of fine aggregate (1kg in the present work) to flow through the cone, and loose density, which later can be used to calculate the % uncompacted air voids of the sample, collected in the receiver (370.68 cm^3 in the present work). The apparatus for testing is fabricated and it consists of a sand flow cone with a 12.7 mm orifice, a stand, a receiver and an overflow container as seen in Fig. 1. In order to determine the % uncompacted air voids, the specific gravity and loose density of the samples are determined. Specific gravity is determined by Pycnometer method, whereas loose density is calculated using data obtained from New Zealand Flow cone test[20]. Following formula are used;

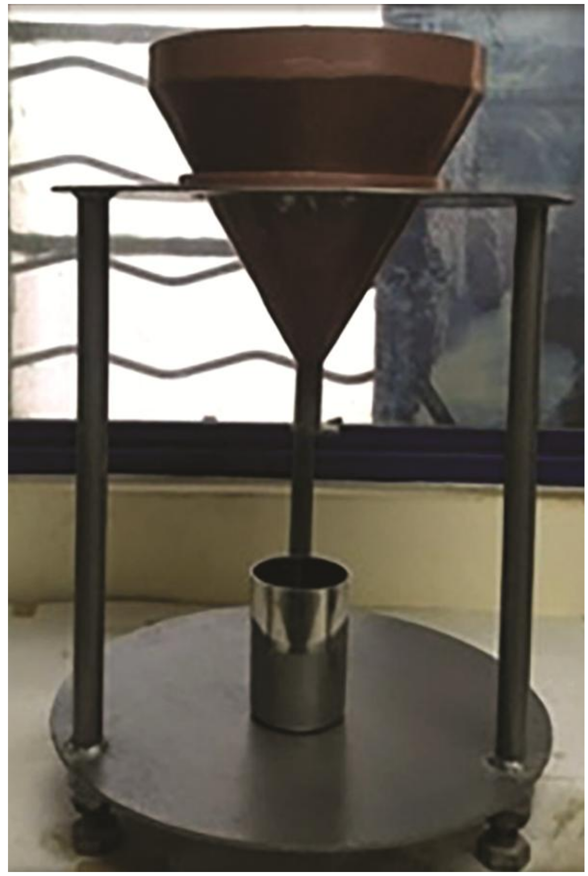

Fig. 1 — New Zealand flow cone apparatus.

$$\Upsilon = M_R / V_R \quad \ldots(1)$$

$$AV = (G - \Upsilon) / G \quad \ldots(2)$$

where, Υ = loose density in g/cm^3

AV = Uncompacted air voids content in %

M_R = weight of the sample collected in the receiver in g

V_R = volume of receiver in cm^3

G = Specific gravity of the aggregate

The NZS 3111 flow time limits graph is shown in Fig. 2 and it is clear that if a point lies within the envelop, it represents the nature of either a processed dust or coarse river sand which can be safely used in concrete. Points outside the envelop indicate that the sand sample is very fine or very coarse or poorly graded depending on its position and such sand will have high water demand and leads to poor workability. This graph is used regularly to control

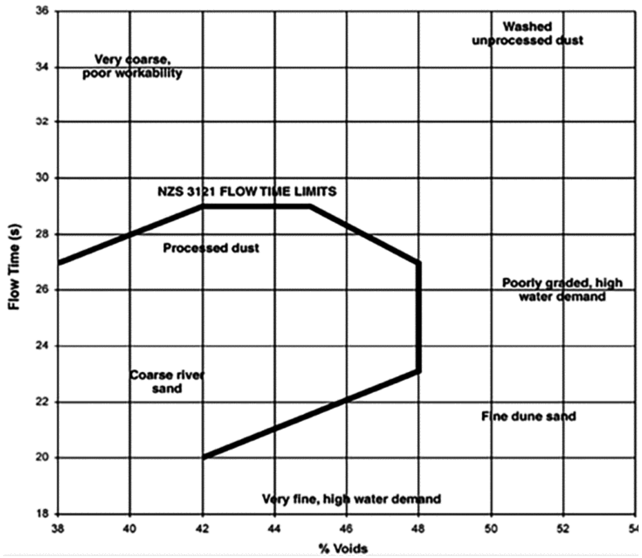

Fig. 2 — NZ Flow cone envelope for sand quality.

the quality of sand, by the manufacturers during crushing and also by the users at the site, in Australia and New Zealand. Flow time, loose density and uncompacted voids as obtained from this test for all 30 samples of crushed sand are presented in Table 1. In order to get the accurate flow time, flow time is recorded for each 1kg sample by repeating the test three times. Trial times and the average time in seconds are presented and the average time is considered for the calculation. Loose density is calculated based on the weight of the sample collected in the third trial. From Table 1, it is clear that the loose density of samples varies from 1468 to 1611kg/m^{3}with an average 1534 kg/m^3. For all 30 samples, specific gravities are calculated corresponding to the SSD condition, using the pycnometer which are later used to calculate the uncompacted voids. These results are presented in Table 2.

Percentage of uncompacted air voids indirectly helps in differentiating the samples according to shape of the particles. It can be concluded that, more the % of un-compacted air voids, more will be the irregularity; i.e., the fine aggregate is flakier and more elongated. The scatter relation between uncompacted air void and the loose density is shown in Fig. 3 and it fits to straight line with a low r^2=0.6, representing wide variation. As loose density decreases, air void increases based on the scatter-plot results.

For determining the quality of the tested crushed aggregates, the NZ envelop shown in Fig. 2 is superposed on to the test results as shown in Fig. 4. Points which lie inside the envelop, performwell, as compared to points laying outside as reported in the literature. There are 10 points (1/3rd)lying outsidethe envelop and the remaining 19 points lie inside which indicates that about 2/3rd of samples are ’satisfactory’, belonging to ‘possessed dust sand’ or ‘coarse river sand’ type and can be used for concrete production.

The standard distribution curves for percentage of uncompacted air voids and loose density of all the 30 samples are plotted in Figs (5 and 6), in which y axis represent the frequency and the horizontal axis represent the observed values of data. From Fig. 5 it is clear that the values of uncompacted air voids fits to normal distribution with an average of 41.07% and a standard deviation of 2.11% which are characteristically distributed [$f_{u,max,min}=f_{mean}\pm1.64\sigma$, =44.53, 37.61]. Similarly the loose density values are also distributed characteristically with an average of 1.534 g/cc and standard deviation of 0.039g/cc as shown in Fig. 6 [$f_{ld,max,min}=f_{mean}\pm1.64\sigma$, =1.60, 1.47]. There exists just one sample or none within ±5% results indicating that these values are characteristically distributed within ±5% tolerance statistically.

The information provided in Fig. 3 gives an idea about the performance of 30 crushed sand samples obtained from different sources. From Fig. 3 one can make out the suitable blending of two or more samples that can produce a relatively good blended sample which has acceptable properties. In order to observe the nature of the blend, three samples lying outside namely S14, S26 and S22 and three samples lying inside namely S21 S15 and S5 are considered and the performance is analysed. The percentage of blend can be decided based on the relative positions of the points and the intended final positions in envelop. The results are presented in Table 3 and in Fig. 7 as well. From Fig. 7 it is clear that the modified blended samples lies inside envelop which are nearer to processed dust type.

The samples outside the envelope have been successfully shifted inside the envelope by mixing with the samples which were already inside the envelope. The new mixed sand which is brought inside the envelope can be used for making any type of concrete. Hence it can be concluded from the above plot that when two different samples of same materials are mixed, the resulting sample’s point lies between the points of those two former samples and its location depends upon the proportions in which they are mixed.

Table 1 — Average flow time and loose density for all samples

Sample No.	Time (s) Trial 1	Trial 2	Trial 3	Average Time (s)	Dry weight of sample in 500ml bulk, g	Loose density, g/cc
S1	30.67	30.85	29.86	30.46	597	1.611
S2	30.74	29.3	27.32	29.12	593	1.600
S3	30.51	32.12	32.22	31.62	553	1.492
S4	27.17	28.89	27.62	27.90	564	1.522
S5	25.05	25.03	24.93	25.01	549	1.481
S6	26.32	27.14	28.07	27.18	567	1.530
S7	24.6	24.05	24.11	24.26	553	1.492
S8	28.49	27.6	28.89	28.33	583	1.573
S9	23.97	23.87	24.74	24.20	551	1.486
S10	26.94	26.06	26.53	26.51	712	1.565
S11	25.5	25.7	24.62	25.28	567	1.530
S12	26.6	25.88	28.21	26.90	586	1.581
S13	24.83	25.06	25.1	25.00	584	1.575
S14	31.9	30.75	32.32	31.66	544	1.468
S15	24.34	24.2	24.58	24.38	544	1.468
S16	30.9	36.5	33	33.47	573	1.546
S17	25.93	26.02	26.7	26.22	569	1.535
S18	27.8	27.37	28.87	28.02	570	1.538
S19	26.84	26.96	24.82	26.21	577	1.557
S20	28.4	24.65	25.93	26.33	572	1.543
S21	24.45	25	25.07	24.84	551	1.486
S22	30.05	28.82	28.52	29.13	582	1.570
S23	29.16	28.17	27.31	28.22	571	1.540
S24	30.22	30.59	30.28	30.37	571	1.540
S25	23.75	24.3	24.6	24.22	552	1.489
S26	32.69	29.52	32.92	31.71	582	1.570
S27	27.06	26.97	26.77	26.94	570	1.538
S28	Did not pass through the orifice				NA	NA
S29	25.72	26.08	25.74	25.85	566	1.527
S30	25.18	25.91	25.97	25.69	564	1.522
Cu Slag	20	21	21	20.67	780	2.104
Natural Sand	27	27	28	27.33	520	1.404
Ennore Sand	24	23	25	24	600	1.619
Light Cinder	53	52	51	52	341	0.920
Heavy Cinder	35.5	35.6	35.4	35.5	508	1.370

Note: For sample 28 flow time could not be determined as the particles were highly irregular leading to chocking of the orifice.

3 Results and Discussions

3.1 Performance of alternative sands

In order to explore the advantages of alternative sands, their performance is similarly evaluated. For this, different types of sand belonging to natural, crushed, manufactured and hand processed type are selected as mentioned in Table 4, whose positions in the graph are relatively different as represented in Fig. 8 based on the test results.

It can be clearly seen from Fig. 8 that manufactured aggregates like copper slag, light cinder and heavy cinder, do not lie inside the prescribed envelope. The heavier particles fall down through the cone at faster rate compared to the lighter particles. As the specific gravity of the copper slag is maximum (3.68) and being the heaviest, its flow time is less compared to other materials. Heavy cinder is next to copper slag as its specific gravity is 2.99 which has relatively more flow time compared to copper slag. The light cinder has less specific gravity and was having irregular particles, as they were crushed manually, resulted in much more flow time compared to any other sand

Table 2 — Specific gravity, loose density and uncompacted air void of all samples

Sample No.	Specific gravity[20]	Loose Density	% Uncompacted Air Voids
S1	2.55	1.611	36.87
S2	2.69	1.600	40.49
S3	2.51	1.492	40.44
S4	2.61	1.522	41.69
S5	2.66	1.481	44.35
S6	2.66	1.530	42.41
S7	2.68	1.492	44.32
S8	2.64	1.573	40.43
S9	2.62	1.486	43.26
S10	2.62	1.565	40.23
S11	2.66	1.530	42.49
S12	2.69	1.581	41.19
S13	2.63	1.575	40.06
S14	2.65	1.468	44.56
S15	2.62	1.468	43.98
S16	2.48	1.546	37.61
S17	2.60	1.535	40.98
S18	2.57	1.538	40.27
S19	2.52	1.557	38.11
S20	2.52	1.543	38.64
S21	2.64	1.486	43.74
S22	2.55	1.570	38.51
S23	2.54	1.540	39.36
S24	2.63	1.540	41.39
S25	2.63	1.489	43.34
S26	2.63	1.570	40.38
S27	2.59	1.538	40.61
S28	2.59	NA	NA
S29	2.53	1.527	39.52
S30	2.61	1.522	41.72
Average or mean =		1.534	41.07
Standard deviation=		0.039	2.11
Cu Slag	3.68	2.104	42.82
Natural Sand	2.61	1.404	46.22
Ennore Sand	2.62	1.619	38.21
Light cinder	1.71	0.92	46.20
Heavy Cinder	2.99	1.730	52.76

considered and volume of uncompacted voids is about 46% in it.

3.2 Blending of alternative sands

In order to produce good blend which results in appropriate density and voids and also to bring the points inside the envelope, certain percentages of different sands are mixed or blended, based on the irinitial relative positions as shown in Fig. 8. Fine aggregate which are present within the envelope can be characterised as good fine aggregates which give satisfactory results for concrete and mortar. The industrial by- products which lie outside the envelope, however, can be pulled into the envelope by

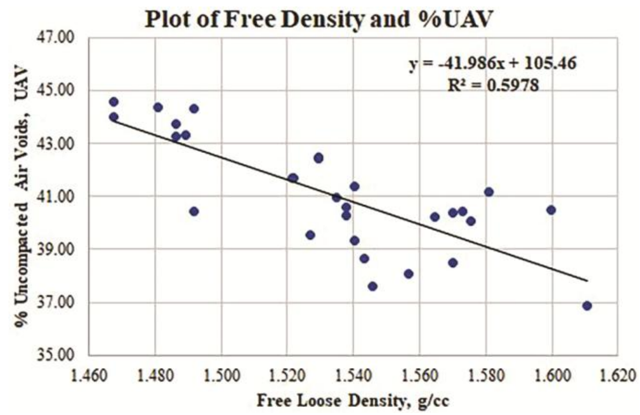

Fig. 3 — Scattered plot of uncompacted air void vs. loose density of all samples.

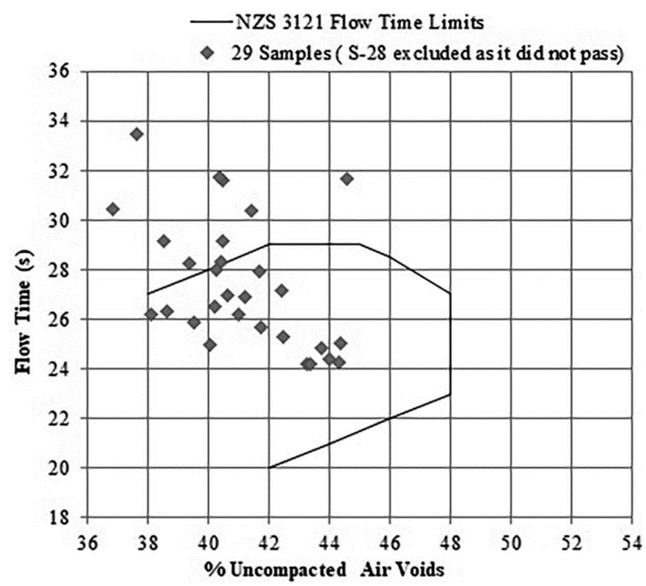

Fig. 4 — Scattered plot of all the samples on the New Zealand flow cone plot.

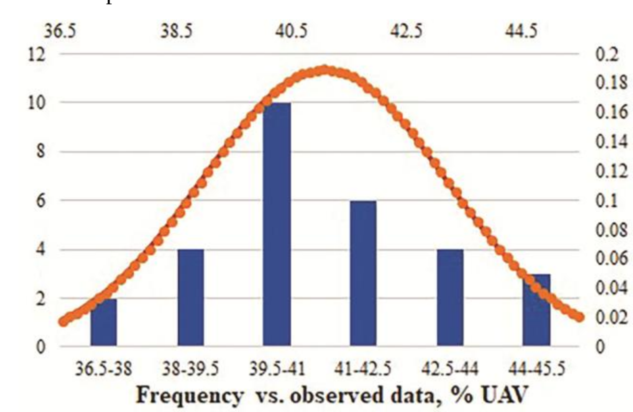

Fig. 5 — Standard distribution Curve - Uncompacted air voids.

Table 3 — Observations of samples selected to bring inside the envelope

Modified sample	Sample outside envelop	Mix	Specific Gravity[20]	Free Density (g/cc)	% Uncompacted Air Void	Time (S)
M-1	S-14	Sample14+21 (1:1)	2.69	1.492	44.50	28
M-2	S-26	Sample26+15 (1.5:1)	2.62	1.562	40.33	26
M-3	S-22	Sample22+5 (1.5:1)	2.62	1.508	42.39	26

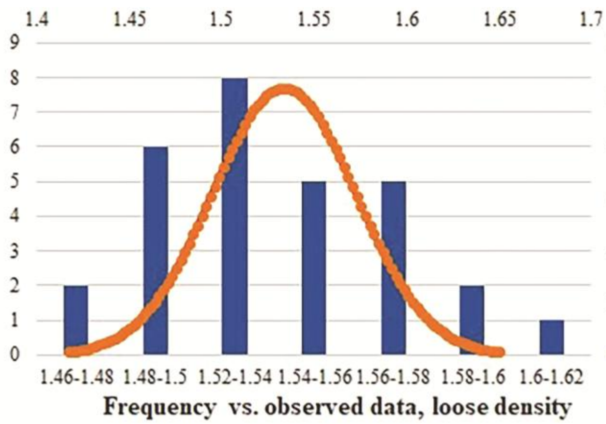

Fig. 6 — Standard distribution Curve - Loose density.

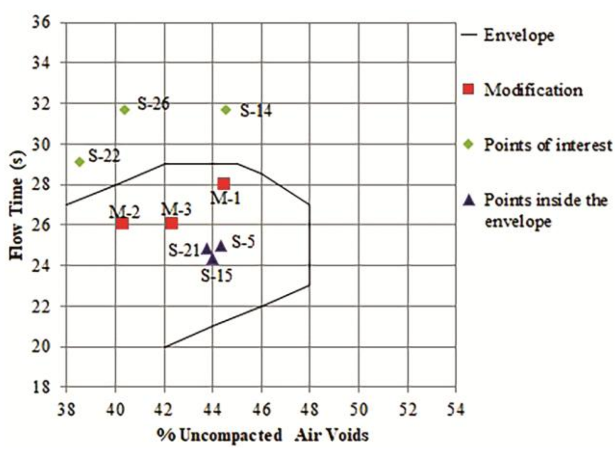

Fig. 7 — Samples shifted from outside to inside the envelope.

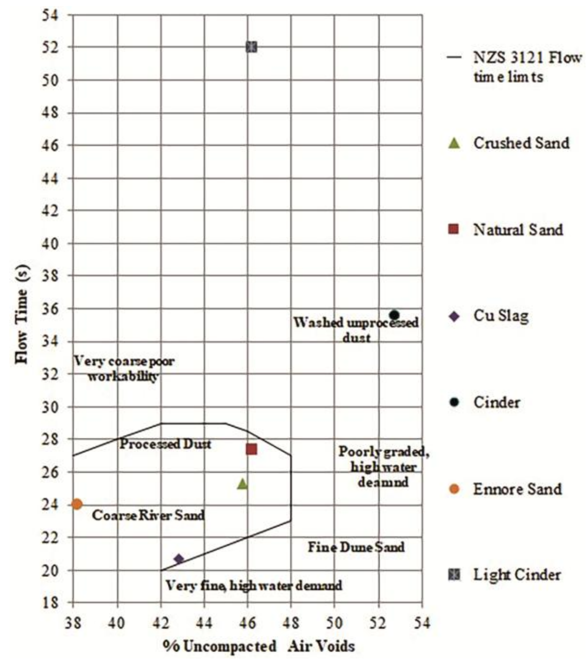

Fig. 8 — Plot of flow time vs. % uncompacted air voids for different aggregates.

appropriate blending with the fine aggregates which lie within the envelope and used as blended fine aggregates for concrete and mortar.

3.2.1 Blendingof Copper slag, crushed stone sand and natural sand (Blend-1)

Triple blending of copper slag is carried out with crushed stone sand and river sand in the following percentages, by weight, randomly i.e., Cu Slag-30%, crushed stone sand-40% and natural sand-30% and the result is shown in Fig. 9. From Fig. 9 it can be seen that the flow time of the blended sample has been increased desirably and % uncompacted air voids has also been reduced, compared to that of copper slag, because the dust present in the crushed stone sand and the river sand have occupied the voids present in the copper slag. Thus, the selected blend appears to be close to coarse river sand and can be used as any other aggregates in concrete production.

3.2.2 Blendingof Copper slag with crushed stone sand (Blend-2)

Double blending of copper slag with crushed stone sand is carried out in the following percentages, by weight, randomly i.e., Cu Slag-40% and crushed stone sand-60%.

From Fig. 10 it can be seen that flow time of the blended sample has increased considerably but % uncompacted air voids has increased compared to that in the previous case. The absence of finer content in the blend and irregularity of crushed stone sand might have contributed to increase of air voids. However, the blended sample has moved into the prescribed envelope which serves the purpose of partial replacement of crushed stone sand with copper slag for possible use as blended fine aggregate for concrete.

3.2.3 Light cinder with crushed aggregates (Blend-3)

From Fig.11, it can be observed that light cinder individually has very high time of flow due to its low

Table 4 — Test results of alternative sand samples

Sl. No.	Sample	Specific gravity[20]	Loose density (g/cm^3)	Flow time (s)	Uncompacted air voids (%)
1	Crushed Stone sand	2.66	1.443	25.33	45.74
2	River Sand	2.61	1.404	27.33	46.22
3	Ennore Sand	2.62	1.619	24	38.21
4	Copper Slag	3.68	2.104	20.67	42.82
5	Heavy Cinder	2.99	1.73	35.5	52.76
6	Light Cinder	1.71	0.92	52	46.20
7	Blend-1	2.81	1.611	23	42.67
8	Blend-2	3.05	1.694	23	44.46
9	Blend-3	2.39	1.352	27	43.43

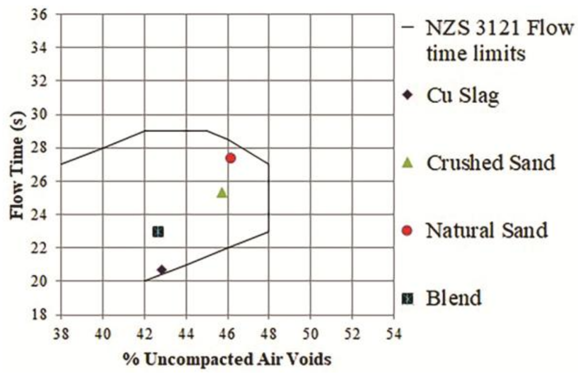

Fig. 9 — Copper slag shifted into the prescribed envelope by blending with crushed stone sand and natural sand.

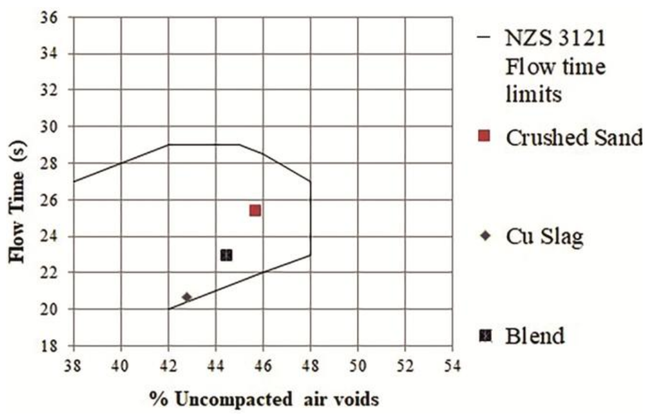

Fig. 10 — Copper slag shifted into the prescribed envelope by blending with crushed stone sand.

density and has lower strength compared to crushed aggregate. Hence to have a desirable blend which fits into the envelope and also retains reasonable strength parameters, proportion of crushed stone sand used for blend is in a higher percentage i.e., 85% by weight. It can be seen that materials having very high flow time must be used in very lower proportions comparatively to pull the blend into the envelope. Thus, it can be seen that about 15 to 20% of light cinder can be used as a blend in this situation. The physical appearance of all three blends can be seen in Fig. 12.

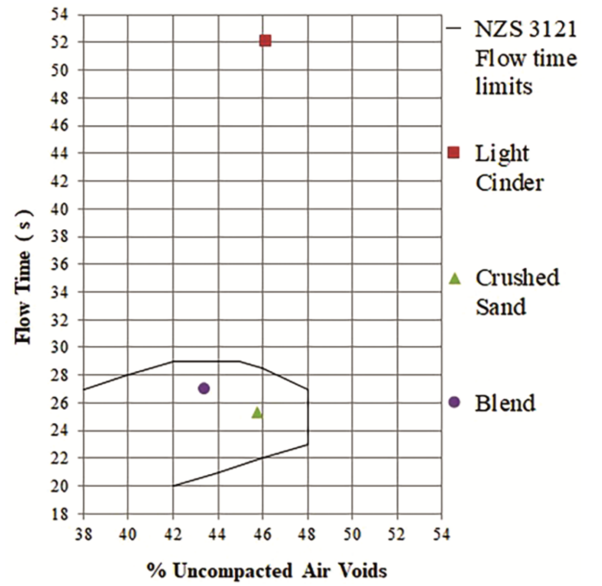

Fig. 11 — Light cinder shifted into the prescribed envelope by blending with crushed stone sand.

3.3 Direct shear test

Direct shear test is carried out to find the relationship between the shear stress and normal stress applied to the sand samples and also to find their shear parameters.For this test, three samples of crushed sand namely S1, S14 and S20 are selected randomly. Shear box with sample is paced inside the container of the shear box and the required normal stress is applied on the specimen inside the shear box through a lever arrangement. Test is conducted by applying a horizontal shear load to failure or to 20% longitudinal displacement, whichever occurs first. Proving ring dial readings (Loads) corresponding to known displacement dial readings are taken. Test is repeated under increasing normal stresses in the range 0.25– 2.5 kgf/cm^2, at increments of 0.5 kgf/cm^2. A minimum of three tests are made on separate specimens of the same density The samples are tested as they are and also by eliminating fraction passing through 150µm to know the effect of fines on shear resistance. The results are presented in Table 5. The angle of internal friction is calculated from the graph shown in Figs (13-15) for three samples with and without dust.

From Table 5, it is observed that as the % uncompacted air voids increases (or when the

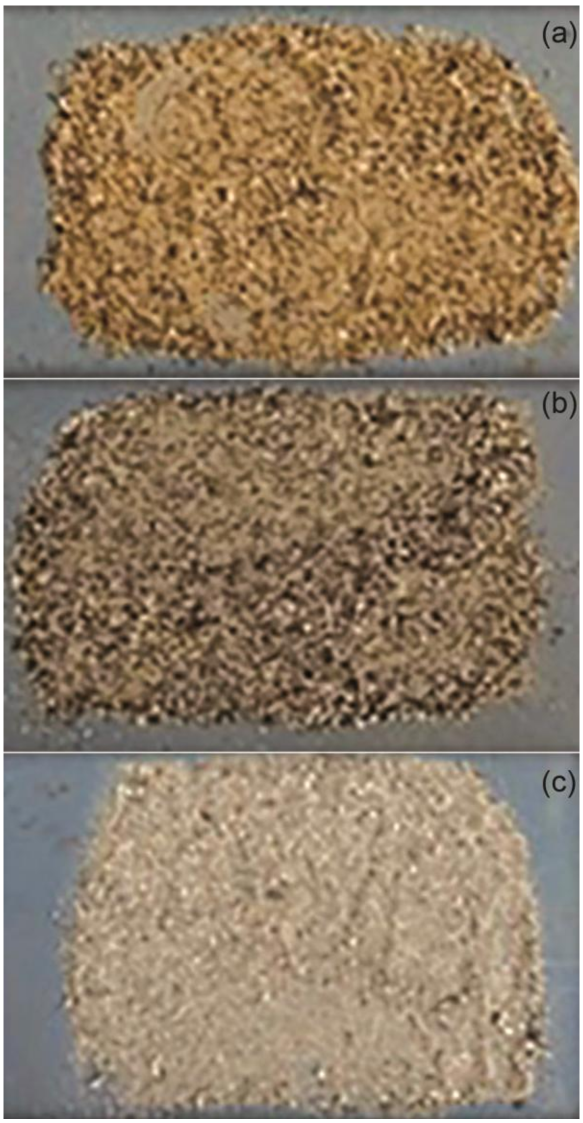

Fig. 12 — Physical appearance of three blends.

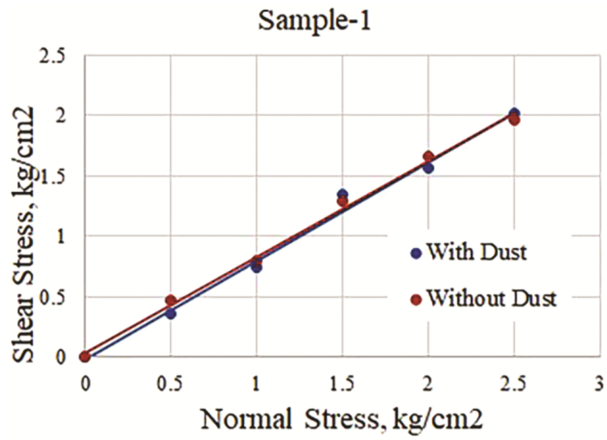

Fig. 13 — Variation of shear resistance of different crushed sands - with and without dust, S1.

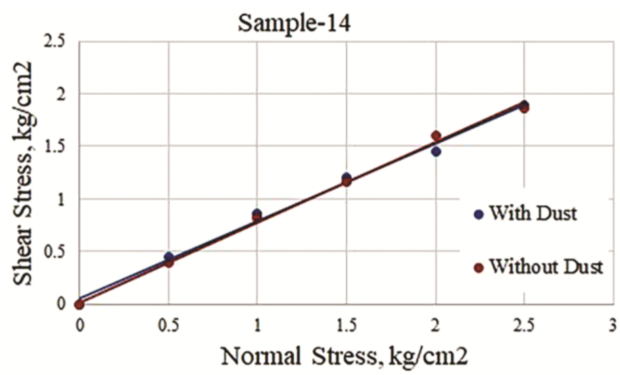

Fig. 14 — Variation of shear resistance of different crushed sands - with and without dust, S14.

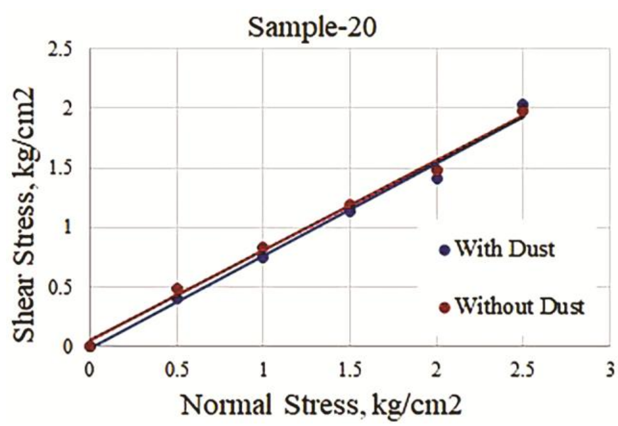

Fig. 15 — Variation of shear resistance of different crushed sands – with, and without dust, S20.

Table 5 — Comparison of angle of internal friction with, and without the presence of dust

Sample No.	With Dust (D)			Without Dust (WD)		
	% Uncompacted Air Voids	Loose density (g/cc)	Angle of Internal Friction (Φ, Degrees)	Uncompacted Air Voids, %	Loose density (g/cc)	Angle of Internal Friction (Φ, Degrees)
1	36.87	1.611	38.90	39.59	1.540	39.21
20	38.64	1.543	37.49	40.91	1.489	38.03
14	44.56	1.468	37.49	45.03	1.457	37.70

loosedensity decreases), the angle of internal friction decreases marginally. The reason for this variation is that as the density of the sand increases it is tightly packed and the bonding between the particles is very good. Hence more loads are to be applied to cause the shear failure of the sample. As a result, the shear strength of the sample is more which gives the higher value of angle of internal friction (Φ). Same trend is seen in both cases i.e.,with and without dust.

It was also observed that the Φ values and thus the shear strength of the sand tends to increase marginally when the dust is removed.The possible reason for reduced shear strength, in the presence of dust, could be due to the fact that dust may have been acting as ball bearing surface causing a slip between the particles when shear force was applied and thus causing the shear failure relatively easier than in case of the samples without dust in it.

Direct shear tests are also conducted on some of the samples of crushed aggregates, natural river sand and copper slag to know their performances and the results are presented in Table 6 and in Fig. 16. The sample of crushed sand is having better shear resistance compared to natural river sand or copper slag sand. Performances of copper slag and natural river sand appear to be almost the same.

3.4 Impact test

Impact testing equipment recommended for coarse aggregate is only used for impact testing of fine aggregates and the same procedure is followed with certain modifications. Sand is taken in the same manner as that of coarse aggregate keeping impact loading and the number of blows the same. Sample of weight w1 passing through 2.36 mm and retaining on 1.18 is subjected to impact test and after the test, weight w2 of fraction passing through 150µm is considered. Impact strength is defined as w2/w1, expressed as a percentage. Higher the percentage, lesser is the impact strength and vice versa. The results are presented in Table 7.

From Table 7 is clear that the impact strength of copper slag is very high and is 2.1% compared to light cinder for which the strength is 16.87%. Copper slag is 8 times tougher compared to light cinder and nearly two times tougher as compared to natural river sand. Natural sand is twice stronger as compared to crushed sand. The low impact strength (low toughness) of crushed sand compared to natural sand may be due to irregular surface characteristics in addition to flaky and elongated nature of particles. High impact resistance of copper slag is attributed to its high specific gravity and density.

Table 6 — Shear resistance of copper slag, natural river, and crushed sand

Normal Stress, (kg/cm^2)	Shear Stress, (kg/cm^2)		
	Copper Slag (Φ=35.22)	Natural Sand (Φ=35.26)	Crushed Sand, S5 (Φ=37.49)
0.5	0.430	0.365	0.44
1	0.671	0.796	0.77
1.5	1.086	1.061	1.22
2	1.436	1.411	1.50
2.5	1.732	1.732	1.90

Table 7 — Impact strength of sand samples by modified impact test

Type of sample	w1, g	w2, g	Impact Value, w2/w1, %	Specific gravity[20]	Density, g/cc	Remarks
Crushed sand	270	26	9.63	2.66	2.635	
Natural Sand	317	14	4.42	2.61	2.327	
Light Cinder	166	28	16.87	1.71	0.92	Low impact resistance
Copper Slag	429	9	2.10	3.68	2.695	High impact resistance

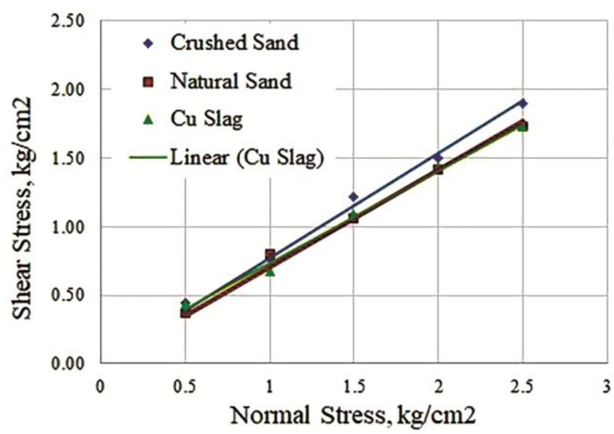

Fig. 16 — Variation of shear resistance of copper slag, natural river and crushed sand.

4 Conclusion

Based on the discussion of the results following few conclusions are drawn

- New Zealand flow cone method is one of the best ways to characterize the properties all types of fine aggregates. The plot of flow time and the uncompacted voids indicates many characteristics of the fine aggregates from the point of their water and paste requirements which serve as a tool in the design of special concretes such as self-compacting concrete.
- Performance of poor crushed sands, whose position lies outside envelop, can be improved by proper

blending with other crushed sands whose position lies within the envelop. The flow time of such blended sample decreases substantially with increased density and reduced voids, which further enhances the performance of concrete.

- Performance of alternative and unconventional sands can also be assessed which further helps in the selection of proper blend material and its percentage to produce blended aggregates whose performance is close to that of natural river sand or crushed sand.
- This test gives idea regarding the flow properties and shape of the particles of artificial aggregates or the blends of them with natural aggregates, which are physical entities but their chemical composition and characters individually or as blends have to be examined separately to use them as fine aggregates for construction purposes.
- The shear resistance of sand increases marginally as the dust passing through 150mm is eliminated indicting the negative effect of dust whose percentage need to be restricted.
- Though there is marginal variation in the shear resistance of different types of sand, representative sands considered in the study have more or less, a comparable angle of shearing resistance.
- The conventional impact tests on aggregates can be used with modifications to evaluate the impact resistance of fine aggregates and the results provide good information regarding the shear strength of different types of sand.
- Copper slag used in the study has highest impact strength and is many times superior to other sand samples.

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