EFFECT OF CRUSHING METHODS OF VOLAGONJ STONE ON STRENGTH OF CONCRETE

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ABSTRACT

A comparative study was carried on Hand Crushed and Machine Crushed Volagonj stone (major rock of Bangladesh) graded between 1 in [25 mm] to 0.5 in [12.5 mm]. Stone crushed by both hand and machine were tested for abrasion value, crushing value, flakiness index, and elongation index. These stone groups were used to prepare concrete cylinders (6 in. [150 mm] diameter and 12 in. [300 mm] height) for W/C ratio ranging from 0.45 to 0.60. Hand crushed stone was showing abrasion and crushing value more than machine crushed stone by about three and one percent respectively. Machine crushed stone is flakier and elongated than hand crushed stone by about six and two percent respectively. Cylinders made with hand crushed stone showed more compressive strength than machine crushed stone with an exception of early age (1 day) and high W/C ratio (0.60). This phenomenon suggest low strength of cement matrix-aggregate interface bond firstly due to low maturity and secondly due to low strength of cement matrix to bond with aggregate.

Keywords: Aggregate; crushed stone; aggregate-cement bond; crushing method.

1.0 INTRODUCTION

Almost three fourth of concrete volume is occupied by aggregate. Coarse aggregate inhabits about half of total concrete volume. Due to its leading presence in concrete, it determines the structural performance and durability of concrete along with other parameters of cement, fine aggregate, water, fillers etc. Coarse aggregate when used in concrete, provides interlocking force and resist propagation of cracks in hardened cement paste. Thus aggregate shape and texture is of great significance during its performance in concrete. Cement consumption is effective parameter to indicate growth of concrete industry. As of 2007, Bangladesh produced 5.1 million metric tons of cement1. Wide areas of northern and north-eastern parts of Bangladesh are covered with gravel beds. In the north the gravels are well exposed at Dahagram-Angorpota, Patgram, Dalia, Chapani, Kaliganj in greater Rangpur and Tentulia, Vazanpur, Boalmari, etc in greater Dinajpur areas. The sphericity and roundness of these gravels are high and they have quartz, quartzite, granite, gneiss and schist as their dominant lithologies. Composition of these gravels is identical with that the Himalayan2. On the other hand, the gravels of the north-eastern part of Bangladesh are well exposed in the Jaintiapur-Volagonj area in greater Sylhet district. The older sub-unit in the Jaintiapur area and Binda Tila caps has been named the 'Sona Tila Gravel Bed'. Similarly, the younger sub-unit of the Volagonj area and the river bed deposits of the present river system have been named the Volagonj Gravel Bed. Volagonj Gravel Bed is equivalent to the Upper Pleistocene to Holocene Series. The gravels of both the beds are of igneous and metamorphic origin. Main source of coarse aggregate in our country is crushed natural stone obtained from local sources like Jafflong and Volagonj in Sylhet. Bangladesh being a developing country is still not been able to introduce automated crushing method in all regions; rather a large portion depends on hand crushing method by manual labour. This phenomenon is more pronounced for sub urban and district level constructions. Sphericity, roundness or angularity, smoothness or roughness, and coatings of a particle are the result of the interaction of the nature, structure, and texture of the rock (or other material, for example, slag) of which the particle consists and the forces to which it was subjected during and after its formation. Rocks having closely spaced partings or cleavages in one or two directions tend to yield flat or elongated particles of low sphericity3. Shape and surface texture of aggregate influence considerable the strength of concrete. This is more pronounced specially for high

strength concrete where aggregate-cement bond is at their optimum edge during cracking. However flexural strength of concrete is more affected than compressive strength. Compressive strength is affected 22% by shape of aggregate, 44% by surface texture and 34% by modulus of elasticity4. It is evident that a rougher texture results in a greater adhesive force between the particles and the cement matrix. Likewise the larger surface area of angular aggregate means that a larger adhesive force can be developed. Flakiness and shape of coarse aggregate in general have an appreciable effect on the workability of concrete. Some other mechanical properties of aggregate are of interest, especially when the aggregate is to be used in road construction or is to be subjected to high wear like resistance applied load. Flaky and elongated aggregate particles are more susceptible to cracking inside concrete. This roughness provides an effective interlocking between rock mass and cement matrix. Research suggested, in the initial stages of diagonal crack formation, the aggregate interlock action predominates while in later stages the development of dowel forces predominates5. Research by Zararis suggested the teeth model which indicates roughness of aggregate aids the interlocking and contribution to failure6. Due to the variation of crushing method, it is obvious to expect stone chips with different physical properties like surface texture, roughness, size and shape. This study enumerates the variations of properties of aggregate from the same origin (Volagonj) and effect on strength of concrete made with aggregates (machine crushed and hand crushed).

2.0 RESEARCH SIGNIFICANCE

Theory of aggregate interlock with cement matrix has been studied for individual aggregate grains so far. Aggregates especially coarse aggregates due to their crushing origin can show different properties. This study enumerates real life picture of deviation of properties of aggregate and strength of their by product concretes for various water-cement ratios. The authors believe that this detail research dealing with the aggregate interlock is carried out for the first time and will be very useful to concrete technology. This study will open new approach for improved crushing technique for better aggregate performance.

3.0 EXPERIMENTAL PROCEDURE

Stone was collected from indifferent origin and crushed by hand (skill labourer) and machine (power operated). Samples were equally graded and tested for abrasion value following ASTM C131, crushing value, elongation index and flakiness index following BS 812. These two category stones were used to prepare cylinders (6 in. [150 mm] diameter and 12 in. [300 mm] height) for W/C ratios 0.45, 0.50, 0.55 and 0.60 tested on 1, 3, 7, 14 and 28 days. Thus each of two types of aggregated cylinders was tested for four W/C ratio bands on five days having three specimens on each day. As other ingredients of concrete same cement brand and sand from same origin and grading were used

4.0 MATERIALS

To make the comparison effective, stone of same grading was utilized. Both machine crushed and hand crushed aggregates were graded as **Table 1**.

This grading neglects interim sizes which is not ideal for practical cases. More accurate comparison is possible if grading is narrower. Bulk specific gravity (oven dry basis) and absorption capacity of stone was found 2.59 and 0.40 as per C 127. Locally available Sylhet sand having bulk specific gravity 2.43 (oven dry basis) and absorption capacity 5.4% were used. **Table 2** refers.

Sieve Size Passing (mm)	Sieve Size Retained (mm)	Mix Content
25	19	0.5
19	12.5	0.5

Table 1– Aggregate Grading for Testing of aggregate and Mixing in Concrete

Materials	Properties	Average Value (mean of 3 results)
Volagonj Stone	Bulk Specific Gravity (Oven Dry Basis)	2.59
	Bulk Specific Gravity (SSD Basis)	2.60
	Apparent Specific Gravity	2.62
	Absorption Capacity (%)	0.40
Sylhet Sand	Bulk Specific Gravity (Oven Dry Basis)	2.43
	Bulk Specific Gravity (SSD Basis)	2.56
	Apparent Specific Gravity	2.80
	Absorption Capacity (%)	5.40
	Loose Unit Weight	85.05 lb/ft^3 (1364 kg/m^3)
	Compact Unit Weight	97.86 lb/ft^3 (1570 kg/m^3)
	Fineness Modulus	2.68
Cement	Compressive Strength	30.96 MPa / 4489 psi

Table 2– Specific Gravity and Absorption Capacity of Volagonj Stone and Sylhet Sand and Compressive Strength of Cement Mortar

Comparisons between various particle properties of machine crushed and hand crushed aggregate are shown in **Table 3**.

Loose and compact unit weights of sand were found 38.66 kg/ft^3 (1364 kg/m^3) and 44.48 kg/ft^3 (1570 kg/m^3). Sand having fineness modulus of 2.68 was used for both cases. Portland composite cement (PCC) was used for all specimens. 28 days compressive Strength of mortar by this cement was found 4489 psi (30.96 MPa) conforming C 109.

Test Properties	Type of Crushing Method	Value (%)			Average Value (%)
		Sample-1	Sample-2	Sample-3	
Abrasion Value	Machine Crushed	27.42	27.36	27.04	27
	Hand Crushed	29.22	26.56	29.78	30
Crushing Value	Machine Crushed	22.96	22.60	22.84	23
	Hand Crushed	23.64	23.89	23.34	24
Flakiness Index	Machine Crushed	18.91	19.19	18.43	19
	Hand Crushed	12.77	12.03	13.13	13
Elongation Index	Machine Crushed	18.30	18.59	18.84	19
	Hand Crushed	17.88	16.19	16.99	17

Table 3– Abrasion Values, Crushing Values, Flakiness Index and Elongation Index of Machine Crushed and Hand Crushed Volagonj Stone.

5.0 SPECIMENS

Volagonj crushed stone samples were tested for various physical properties i.e. Abrasion value, crushing value, flakiness index and elongation index for comparison. Samples were collected as per ASTM Guide line and properly washed and cleaned before test. Cylinder specimens of diameter 6 in. (150 mm) and height 12 in. (300 mm) were investigated. ASTM C 39 guideline was used to test the specimens. All samples were cured at room temperature. Samples were removed from curing tank one hour before test and soaked by cloth. Thus proper curing was ensured.

6.0 EXPERIMENTAL RESULTS

Coarse Aggregate when crushed, form rough surface texture. It is a very significant factor for cohesion and bonding with cement matrix. Obviously irregular and loose surface causes worn out surface when subjected to friction. Samples were tested for abrasion by Los Angeles Machine. Results obtained from the tests showed abrasion of machine crushed aggregate was 27% whereas hand crushed aggregate showed 30%. Thus hand crushed aggregate is rougher and more susceptible to wearing and tearing. The aggregate crushing value provides a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load. Machine crushed aggregate having average crushing value of 23%

less than hand crushed aggregate of 24%. Flakiness Index is expressed as the percentage by weight of particles (in a sample of more than 200) whose smallest dimension is less than 0.6 times the mean dimension. Machine crushed aggregate showed 6% more flakiness than that of hand crushed aggregate. The percentage by weight of particles whose long dimension is greater than 1.8 times the mean dimension measured with a standard gauge. Machine crushed aggregate showed 2% more elongation than that of hand crushed aggregate. Concrete specimens were tested for compression on day 1, 3, 7, 14 and 28 for W/C ratio 0.45, 0.50, 0.55 and 0.60 to see the relation of compressive strength with time for both types of crushing methods. Test results of specimens for machine crushed and hand crushed Volagonj stone are given in Table 4 and Table 5 respectively.

Days	W/C Ratio	Strength (MPa)			Average Strength (MPa)
		Sample-1	Sample-2	Sample-3	
1	0.45	3.91	3.37	3.76	3.68
	0.50	3.11	2.58	2.73	2.81
	0.55	1.95	2.41	2.06	2.14
	0.60	1.38	2.21	1.82	1.80
3	0.45	14.66	13.87	15.42	14.65
	0.50	11.33	12.07	11.25	11.55
	0.55	10.50	9.53	9.65	9.89
	0.60	8.15	6.85	9.58	8.19
7	0.45	16.75	16.96	17.60	17.10
	0.50	14.65	15.58	15.35	15.19
	0.55	10.25	13.57	12.68	12.17
	0.60	11.98	8.96	9.65	10.20
14	0.45	21.94	22.23	20.86	21.68
	0.50	19.80	20.08	17.51	19.13
	0.55	17.06	16.23	16.58	16.62
	0.60	13.09	13.25	12.72	13.02
28	0.45	25.63	27.29	26.50	26.47
	0.50	21.38	24.05	23.85	23.09
	0.55	22.31	20.70	23.59	22.20
	0.60	21.58	21.32	22.35	21.75

1 MPa = 145 psi

Table 4– 1, 3, 7, 14 and 28 days Compressive Strength of 6 in. (150 mm) X 12 in. (300 mm) Concrete Cylinders with Machine Crushed Volagonj Stone

Days	W/C Ratio	Strength (MPa)			Average Strength (MPa)
		Sample-1	Sample-2	Sample-3	
1	0.45	3.83	3.52	3.35	3.62
	0.50	3.01	2.97	2.85	2.98
	0.55	1.60	2.65	2.38	2.30
	0.60	1.98	1.62	1.87	1.74
3	0.45	15.75	15.41	14.38	15.52
	0.50	11.71	12.77	12.66	12.38
	0.55	10.04	9.87	11.56	10.49
	0.60	8.63	8.95	9.75	9.11
7	0.45	20.31	18.45	17.35	18.70
	0.50	17.64	14.36	15.83	15.94
	0.55	12.34	13.26	11.20	12.27
	0.60	9.75	8.96	9.56	9.42
14	0.45	22.67	24.62	23.38	23.56
	0.50	22.50	19.49	18.57	20.19
	0.55	17.46	16.28	16.1	16.61
	0.60	13.76	13.86	14.60	14.07
28	0.45	27.86	28.34	29.48	28.56
	0.50	23.84	25.21	24.45	24.50
	0.55	23.69	22.07	25.80	23.85
	0.60	19.72	23.63	20.89	21.41

Table 5– 1, 3, 7, 14 and 28 days Compressive Strength of 6 in. (150 mm) X 12 in. (300 mm) Concrete Cylinders with Hand Crushed Volagonj Stone

Figure 1 and Figure 2 illustrate the relation between compressive strength and water cement ratios over time for concrete with both machine crushed and hand crushed Volagonj stones respectively.

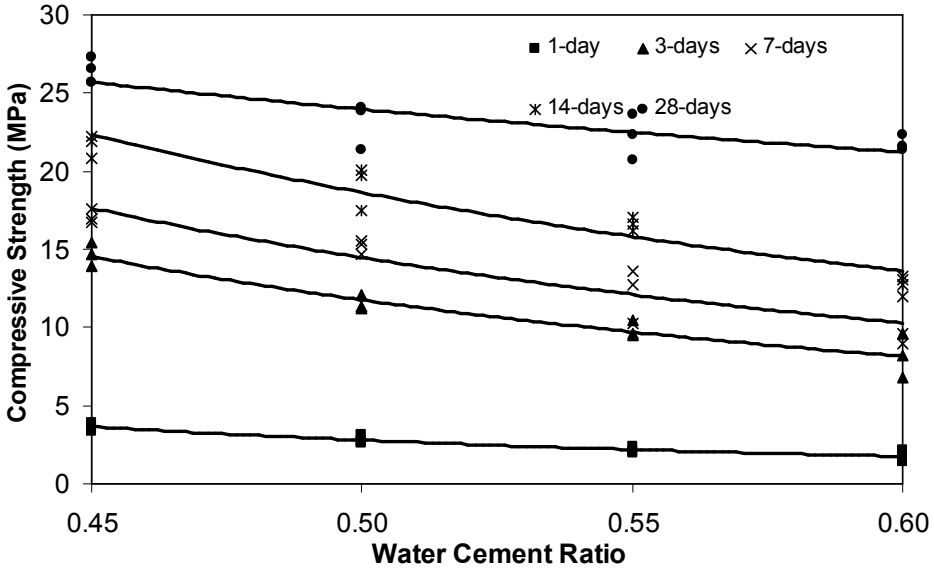

Figure 1– Relation between 1, 3, 7, 14 and 28-days Strength and Water-cement Ratio for Concrete made with Machine Crushed Volagonj Stone (1 MPa = 145 psi)

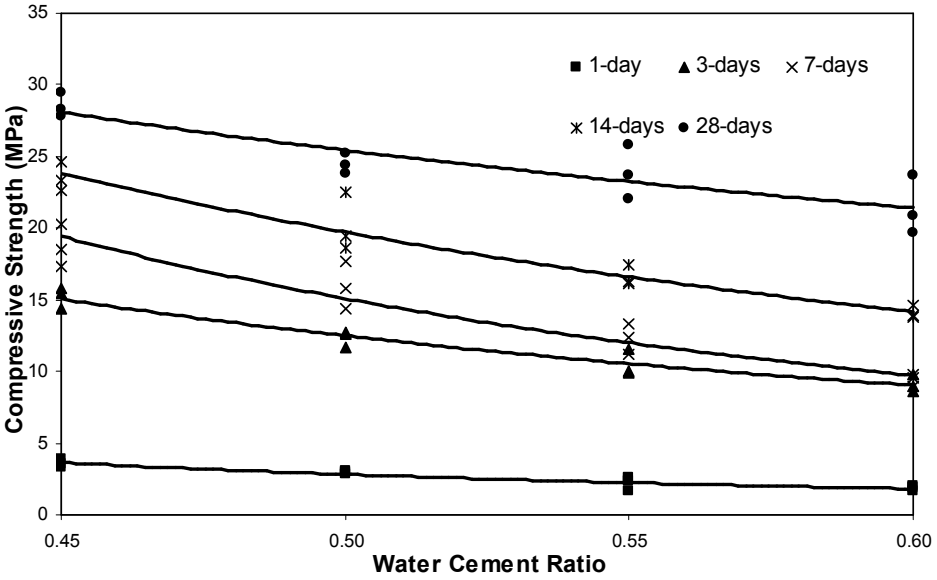

Figure 2 – Relation between 1, 3, 7, 14 and 28-days Strength and Water-cement Ratio for Concrete made with Hand Crushed Volagonj Stone (1 MPa = 145 psi)

Specific comparison between 1, 3, 7, 14 and 28-days strengths of both machine crushed and hand crushed Volagonj stone with water-cement ratios are shown in Figure 3, Figure 4, Figure 5, Figure 6 and Figure 7 respectively.

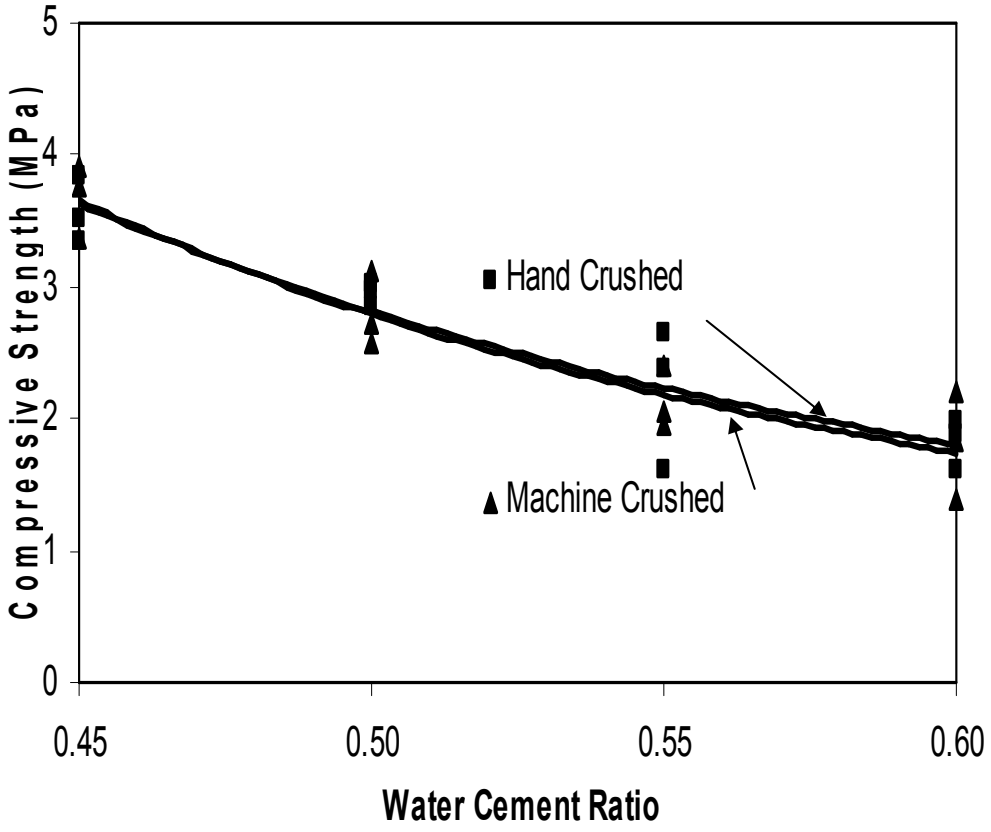

Figure 3 – Relation between 1 day Compressive Strength of Hand Crushed and Machine Crushed Volagonj Stone and Water-cement Ratio (0.45 to 0.60) (1 MPa = 145 psi)

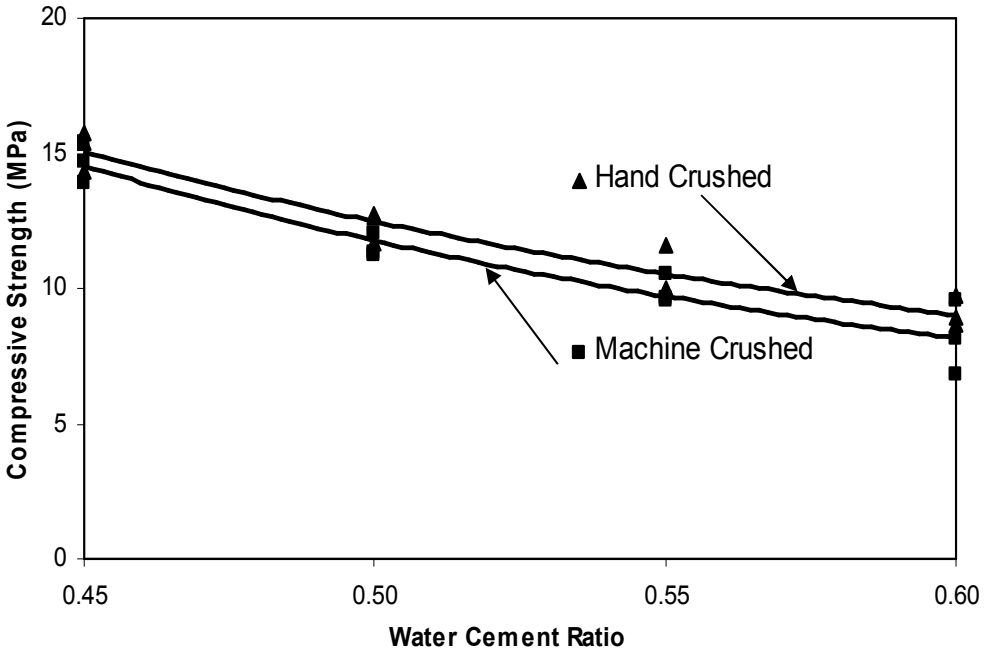

Figure 4 – Relation between 3 day Compressive Strength of Hand Crushed and Machine Crushed Volagonj Stone and Water-cement Ratio (0.45 to 0.60) (1 MPa = 145 psi)

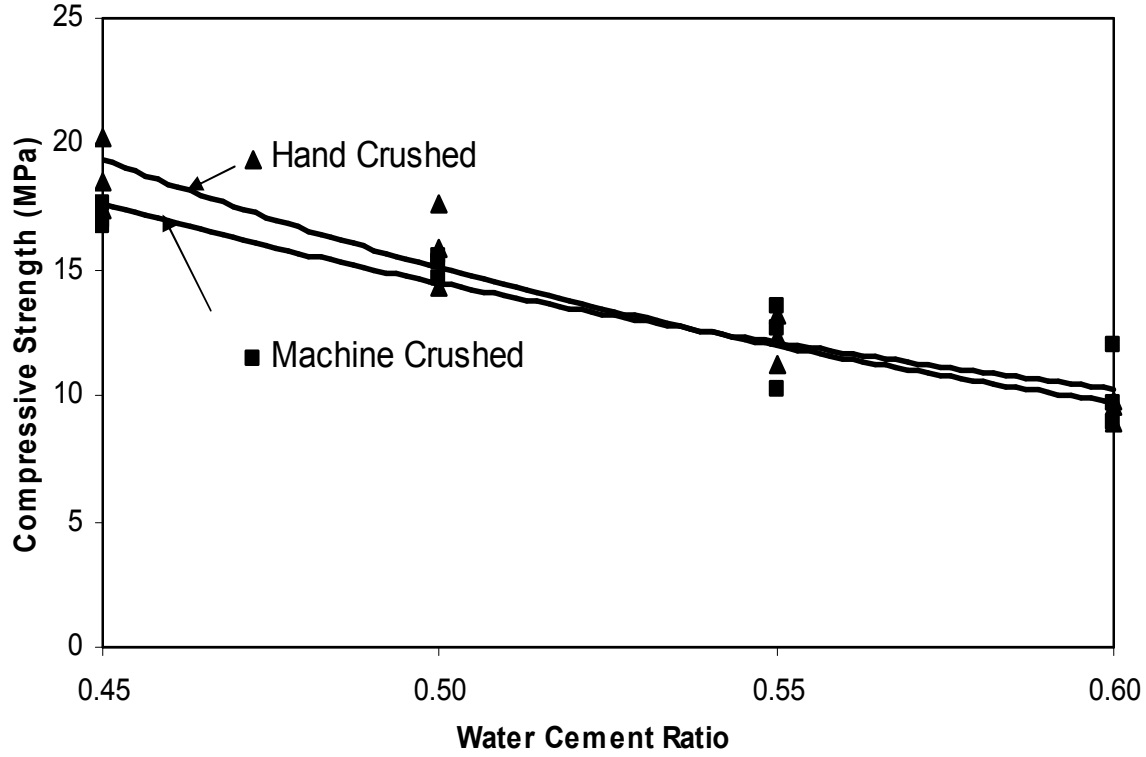

Figure 5 – Relation between 7 day Compressive Strength of Hand Crushed and Machine Crushed Volagonj Stone and Water-cement Ratio (0.45 to 0.60) (1 MPa = 145 psi)

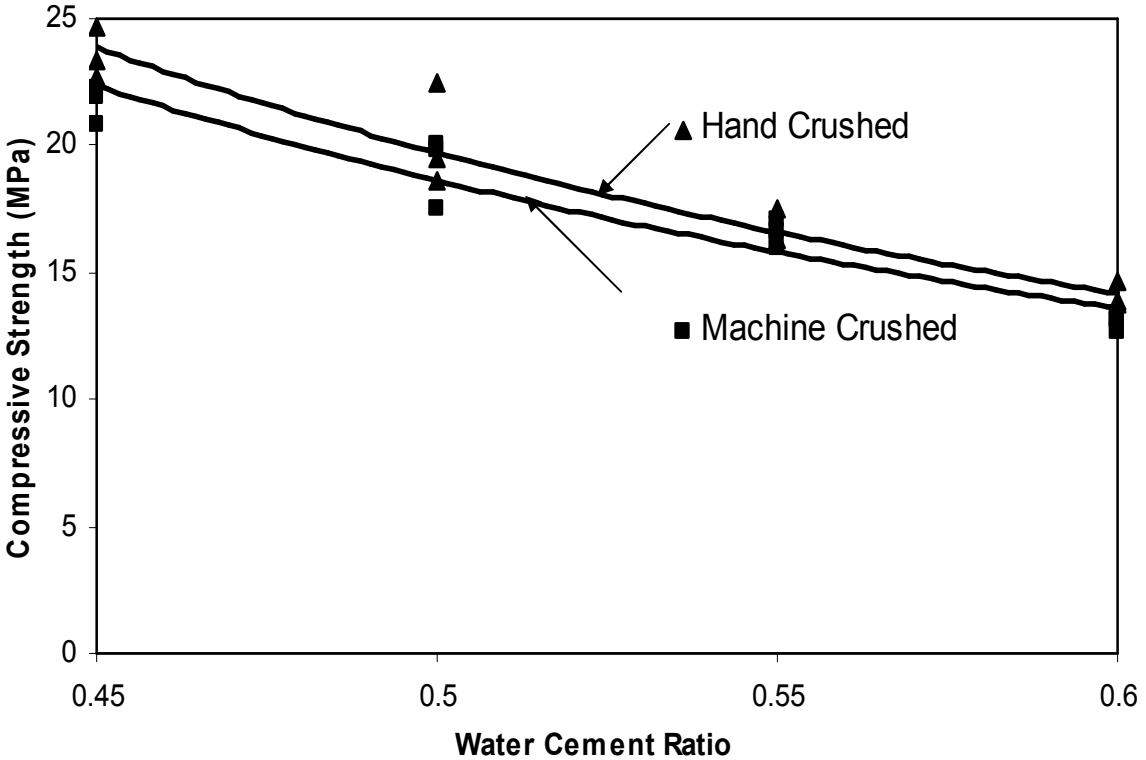

Figure 6 – Relation between 14 day Compressive Strength of Hand Crushed and Machine Crushed Volagonj Stone and Water-cement Ratio (0.45 to 0.60) (1 MPa = 145 psi)

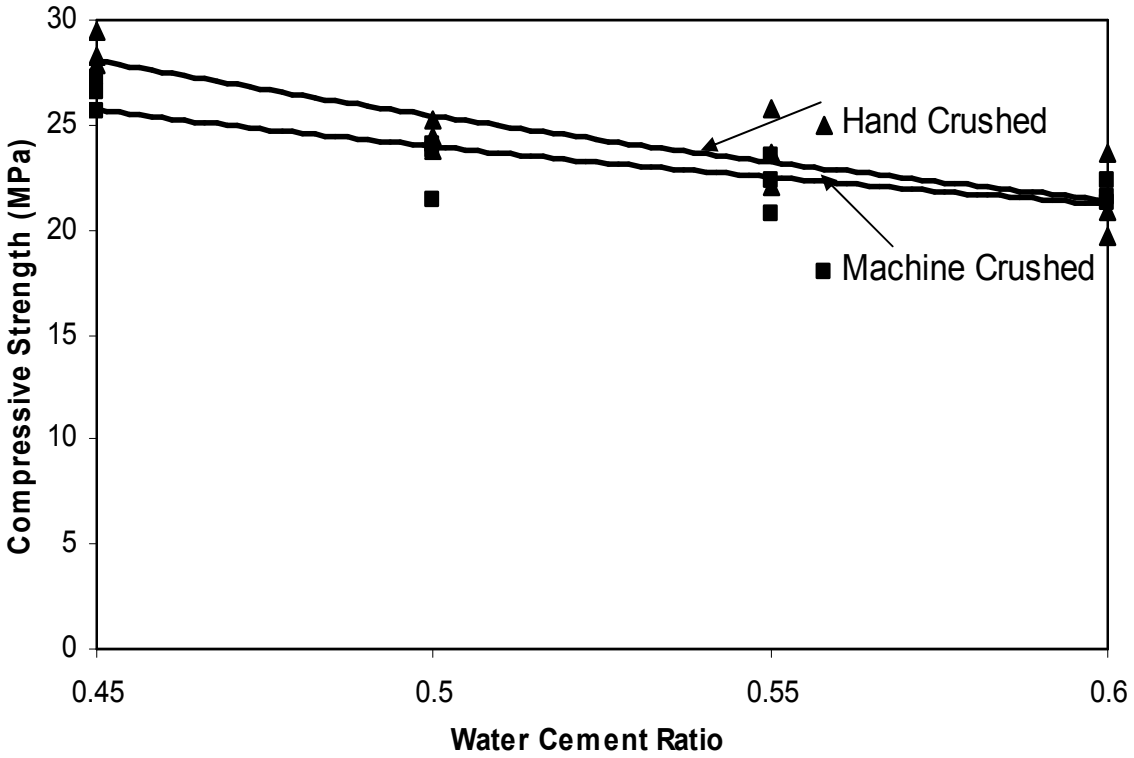

Figure 7 – Relation between 28 day Compressive Strength of Hand Crushed and Machine Crushed Volagonj Stone and Water-cement Ratio (0.45 to 0.60) (1 MPa = 145 psi)

Relations between compressive strength and age for various water-cement ratios (0.45, 0.50, 0.55, and 0.60) of concrete made with machine crushed and hand crushed Volagonj stone are illustrate by Figure 8, Figure 9, Figure 10 and Figure 11 respectively.

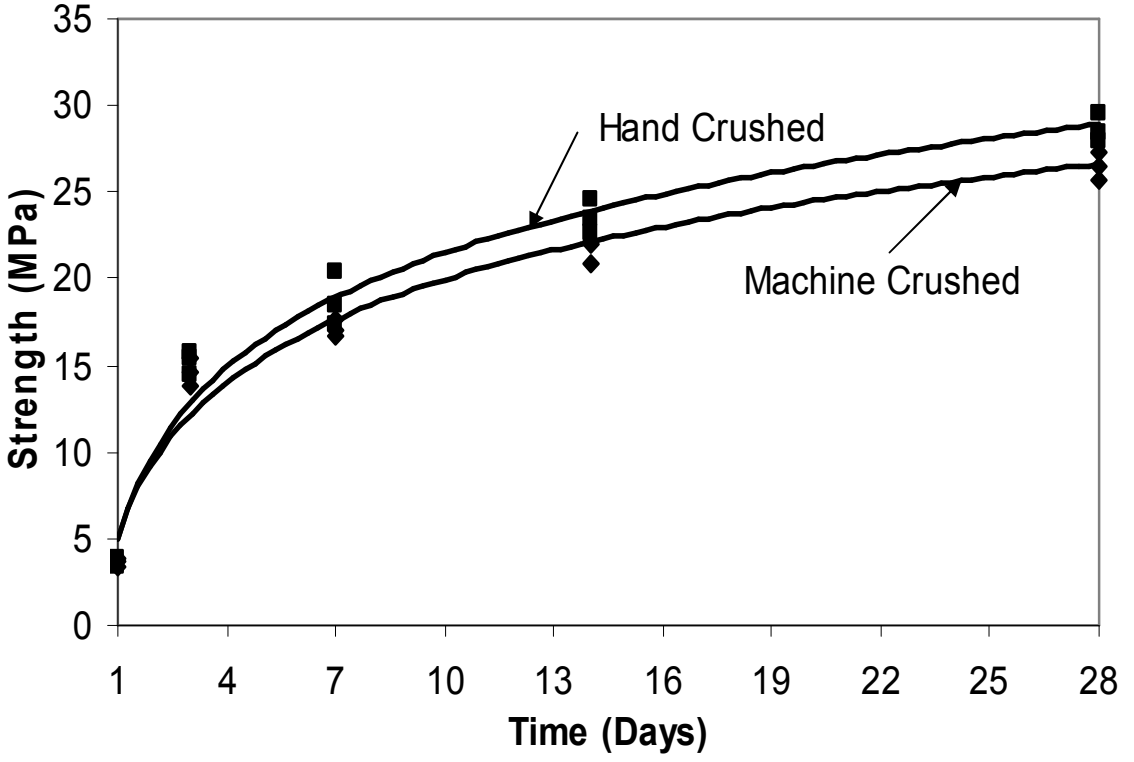

Figure 8 – Relation between Compressive Strength of Hand Crushed and Machine Crushed Volagonj Stone and Age for Water-cement Ratio (0.45) (1 MPa = 145 psi)

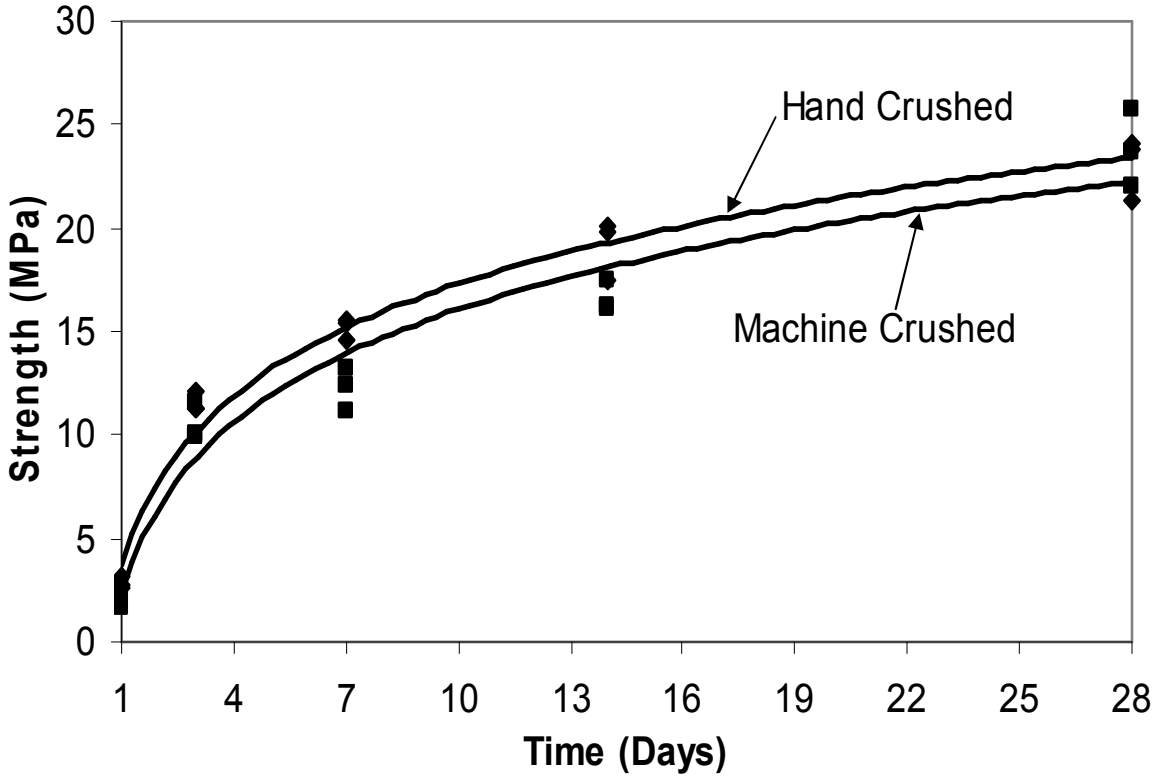

Figure 9 – Relation between Compressive Strength of Hand Crushed and Machine Crushed Volagonj Stone and Age for Water-cement Ratio (0.50) (1 MPa = 145 psi)

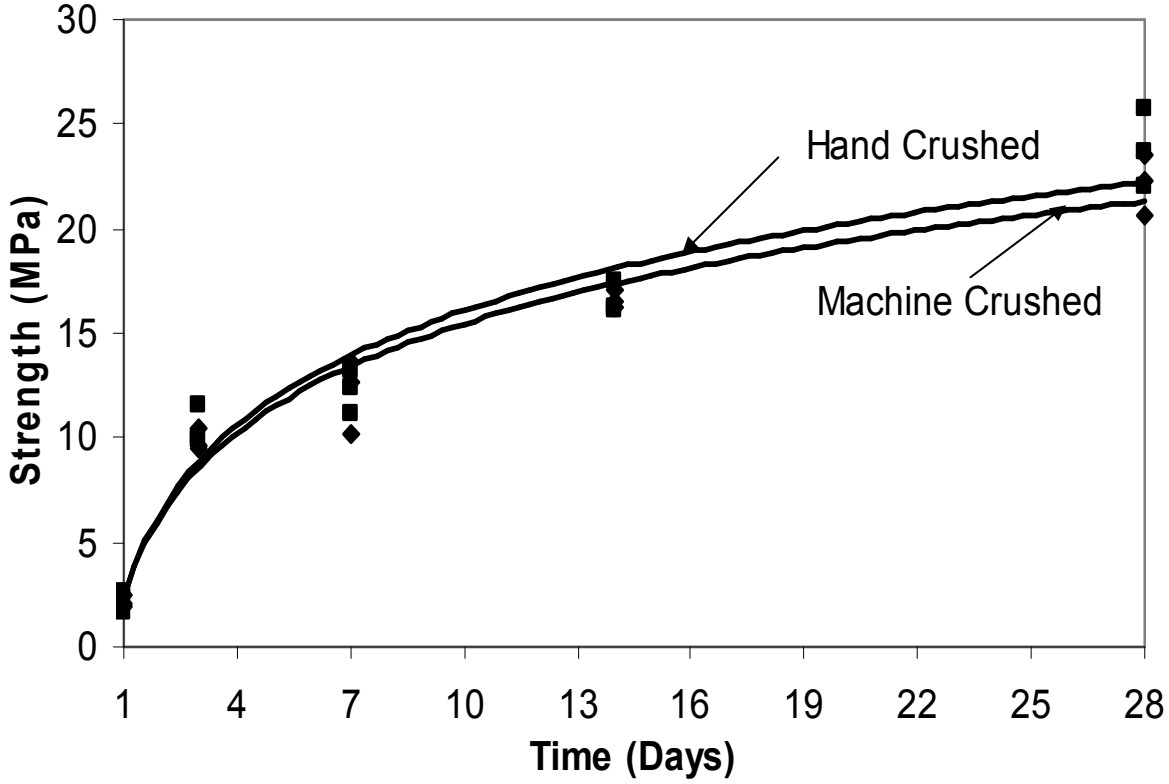

Figure 10 – Relation between Compressive Strength of Hand Crushed and Machine Crushed Volagonj Stone and Age for Water-cement Ratio (0.55) (1 MPa = 145 psi)

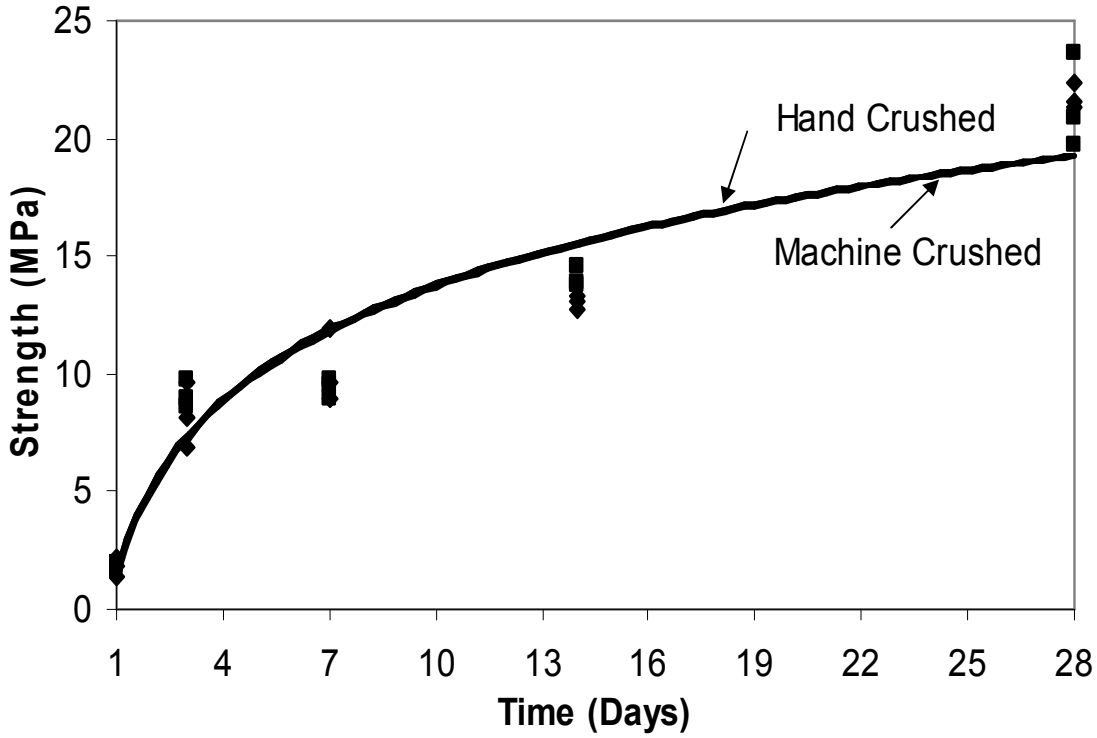

Figure 11 – Relation between Compressive Strength of Hand Crushed and Machine Crushed Volagonj Stone and Age for Water-cement Ratio (0.60) (1 MPa = 145 psi)

7.0 DISCUSSION

Machine crushed aggregate is more polished and smooth than hand crushed aggregate. Abrasion value indicates three percent more wearing of hand crushed aggregate than that of machine crushed aggregate. This roughness of the surface of the hand crushed aggregate in time will provide interlocking bond between aggregate and cement matrix. Visual examination makes it clear that a large proportion of the cracks occur at the cement paste-aggregate interfaces, which will be randomly oriented, which corroborate compressive stress induced crack theories7. Roughness of aggregate is more required at the cement paste-aggregate interfaces because hardened cement paste in the interface zone has a much higher porosity than the hardened cement paste further away from the particles of aggregate8. When taken under gradually applied compressive load, hand crushed aggregate due to its angular nature crushes about one percent more than machine crushed aggregate. Under gradual load aggregate particles tends to slip over their surfaces eventually wearing. Relatively sharp edges of hand crushed aggregate are more vulnerable to break. Machine crushed aggregate is flakier than hand crushed aggregate by an average value of six percent, which positively suggests possibility of propagation of cracks due to thin resistance and larger length/width ratio. Results suggest, machine crushing produces longer particles than hand crushing method. Elongated particles are more prone to cracking akin to flaky particles. Compressive strength results show hyperbolic decreases of compressive strength due to increase of water-cement ratio for cylinder made with both machine crushed and hand crushed Volagonj stone. Cylinder made with same size and graded aggregates showing reduced strength for increased water-cement ratio. This phenomenon as one of the most pronounced characters of concrete is expected. The data are used to draw best fitted power trend line to get easily understandable comparison. Relation between 1, 3, 7, 14 and 28 days strength with various water-cement ratios (0.45 to 0.60) evaluate comparison between hand crushed and machine crushed volagonj stone. For 1 day strength their differences are very low, but showing greater difference with time passes. Comparisons of strength over time between hand crushed and machine crushed volagonj aggregate for particular water-cement ratio (0.45 to 0.60) show gradual reduction of strength difference with increasing water-cement ratio even bordering on each other for water-cement ratio 0.60. This difference is diminutive for early days and greater for matured concrete.

8.0 FURTHER RESEARCH

Due to time and resource constrain, more cavernous study was not possible. It is expected to test concrete for more crushing methods of aggregate i.e. a variety of crusher size, different crusher jaws etc. and efforts should be made to find out the best possible ways to produce coarse aggregates with improved bonding quality. This study only focuses the effect on compressive strength of concrete; further study can be done on flexural strength of concrete. The results of such studies would directly benefit the construction industry to a great extent in producing effective concrete just by taking into account a small change in crushing method.

9.0 CONCLUSIONS

The major conclusions obtained from the results of stone aggregate and compressive strength of cylinder are given below.

a. Volagonj stone when crushed by hand produce less flaky and elongated particles giving more abrasion and crushing value. Flakiness and elongation is much higher in comparison to hand crushed stone. More abrasion indicates more roughness of particles advantaging more interlocking in the aggregate-cement interfaces. Hand crushed aggregate is slightly vulnerable to crushing due to sharp edges. Overall comparison shows hand crushed aggregate is having an upper hand over the machine crushed aggregate in particle properties point of view. More scrupulous study required to seek the ideal comparison.

b. Compressive strength of concrete made with hand crushed Volagonj stone for particular maturity is more than machine crushed Volagonj stone with an exception for early age (1 day). Concrete made with hand crushed Volagonj stone superior by compressive strength over machine crushed Volagonj stone for low water-cement ratio and almost equal for higher water-cement ratio.

c. It can be concluded that in two cases crushing methods provide similar strength. Firstly, when the maturity is low i.e. 1 day, secondly when water cement ratio is high i.e. 0.60. First case is due to low strength of cement matrix and not enough good interlock with adjacent aggregate particles at early stage. For second case cement matrix not having enough strength to build strong bond with aggregate interface.

i. A practical conclusion can be drawn suggesting further through and rigorous study for comparison of hand crushed and machine crushed aggregate as seen in this research that hand crushed aggregate is superior to machine crushed aggregate in perspective of compressive strength. This can also be added that crushing methods due to their differences can produce aggregate with dissimilar physical properties eventually properties with unlike product (concrete).

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