Calicut Tile Waste as an Alternative Coarse Aggregate for Lower Grade Concretes

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Abstract – *The possibility of utilizing waste Calicut tiles as coarse aggregates for concretes was experimentally investigated. Calicut Tile Aggregate (CTA) produced by manual fragmentation of broken tiles, applied to volume batched nominal concrete mixes resulted in expected strength compliance only for a higher strength mix where cement/sand paste fraction was high as compared to coarse aggregate. Modified Standard mixes based on guidelines of ICTAD & BS, ST4 and ST5 were successful in fulfilling workability and one step downgraded strength grade requirements. It was established through this study that CTA is a viable substitute to rock based coarse aggregates for lower grade mass concrete, further substantiated by a cost analysis.*

Keywords: *Concrete, Alternative Materials, Standard Concrete Mixes*

Nomenclature

ICTAD -	Institute for Construction Training & Development	*CTA -*	Calicut Tile Aggregate
		BS -	British Standard

1 INTRODUCTION

Recent development boom in Sri Lanka is mainly manifested in the implementation of infrastructure projects. As a result, construction projects are being executed at a very rapid rate. In a country such as Sri Lanka, apart from funding the major factor affecting construction operations is the availability of construction materials. Concrete being the major material for construction, the availability of concrete at locations in required Grades is a primary consideration for economical and practical operations.

For production of concrete, its primary ingredients in the form of granular bulk (aggregates) and binder (cement) are needed according to stipulated specifications to achieve required workability and stability in the fresh state and strength coupled with durability in the hardened state. Since in concrete, also known as 'Artificial Rock', almost all the solid bulk is aggregate, availability of suitable material for such would be the primary factor governing production. Traditionally, the aggregate subdivided in to coarse and fine gradations is derived from natural rock in the form of crushed rock and sand. Since these natural materials are gradually being depleted from the earth crust without replenishment, scarcity and implications on the environment are inevitable repercussions of long term and wide scale usage. Owing to the fact that even at present, we are faced with both problems mentioned above , alternative solutions should be expediently found.

Fundamentally, the solution could be in the form of either finding of alternative materials or recycling. If waste or demolished concrete could be utilized for new concrete production, it could be considered as recycling, while different materials or the by-products/waste of other production processes could be considered as alternative materials.

Being a hot and humid tropical country, Sri Lankan buildings were traditionally topped with earth clay tiles of different types, over several centuries. Even today with more economical and convenient sheeting materials available for roof cladding, clay tiles are the preferred option especially for domestic dwellings. It has been observed that the production of one such heat sintered pressed clay roof tiles also known as 'Calicut Tiles', results in about 3-4% waste due to various reasons. This waste, generally in the form of broken tiles creates problems of disposing and environmental issues due to generated dust. One area with significant number of tile factories is Waikkala in the Western Province, where over 1000 tons per month of calicut tile waste is estimated to be produced.

Compared with other clay based construction materials, water resistant durable and relatively dense nature of broken Calicut tile particles, makes it a potential candidate as an alternative to coarse aggregate in concrete. As compared to crushed rock aggregate, both density and compressive strength of broken tile particles are substantially low. Therefore, the range of the concrete strengths where successful substitution of coarse aggregate is envisaged should be limited to lower grades of around 20 MPa characteristic compressive strength.

The main aim of this study has been to investigate the possibility of substituting broken Calicut tile particles for natural rock coarse aggregates in lower strength concretes. The lower grades of concrete are generally used for mass concrete screeds, un-reinforced slabs and low axle load concrete road bases.

With the above aim in mind, the following objectives were compiled for this study;

1. Identify a suitable method to transform Calicut tile waste to a grading size suitable for a coarse aggregate.
2. Evaluate physical properties of Calicut Tile Aggregate (CTA).
3. Identify the fresh and hardened concrete properties for nominal mix proportions stipulated by ICTAD with CTA as coarse aggregate.
4. Modify as necessary, the ICTAD & BS stipulated concrete standard mixes to achieve acceptable concrete properties pertaining to envisaged Grade.
5. Assess the financial feasibility of using CTA in concrete.

Major procedure generally adopted in studies of this nature, where substitutive material investigations are involved, is the experimental approach. In order to realize the above objectives following methodology was adopted in this study;

1. Identification of studies through literature review on the use of alternative light weight coarse aggregates, especially pertaining to ranges of material properties and strength.
2. Collection of data on Calicut tile waste generation and identification of a suitable method for the preparation of single sized coarse aggregate from Calicut tile waste.
3. Determination of particle density and water absorption of prepared CTA (according to BS 812 Part 2).
4. Determination of workability and consistency of fresh concrete with CTA as the coarse aggregate, for selected mix proportions.
5. Determination of compressive strength of concrete with CTA as the coarse aggregate, for selected mix proportions.
6. Comparison of cost and benefits of concrete with CTA as the coarse aggregate, and concrete with normal rock as coarse aggregate.

2 REVIEW OF LITERATURE

Essential requirements to be satisfied by an aggregate in concrete are to provide required strength and remain stable within the environment during the service life. The desirable properties of aggregates for concrete have been extensively reviewed in texts on concrete technology such as American Society for Testing Materials (ASTM 1987), Neville (1995), etc. Accordingly, one significant factor contributing to the strength of concrete is its density, which is significantly influenced by the density of the coarse aggregate occupying much of the bulk. Concrete with normal aggregates has a density ranging from 1800-3200 kg/m^3 with an average of 2400 kg/m^3, while concretes with densities <1800 kg/m^3 & >3200 kg/m^3 are considered light weight and heavy weight respectively.

With a bulk density of around 1300 kg/m^3, CTA could be considered as a light weight aggregate. According to Short & Kinniburgh (1978), concretes with compressive strengths exceeding 20 MPa and densities in the range of 1000 – 2000 kg/m^3 have been produced with light weight aggregates. Therefore, possibility of using CTA to produce concretes in the range of 20 MPa characteristic strength is promising if desirable properties in the fresh state could be achieved.

2.1 Studies on Use of Lightweight Materials as Aggregate

Several ad-hoc uses of Calicut tile waste could be observed in the areas where tile production is carried out, such as Waikkala and Wennappuwa. Prominent application observed was the straight forward use as a fill for reclaiming marshy lands. Some other uses such as pot hole filling of rural roads and stacking to form barriers or boundary walls have also been observed. However, no organized study on the use of Calicut tile waste for concrete could be identified from literature.

Use of alternative aggregates for concrete however, has received long term attention of researchers in many countries. A significantly long history of application of by products of production processes such as blast furnace slag, in the production of light weight concrete could be found while some initiatives for the use of glass waste for aggregate were identified in Briton and Ireland. Further, following studies form an interesting background in the study of the use of alternative aggregates derived through the by-products or waste of other processes.

A research by Woon-Kwong Yip & Joo-Hwa Tay (1990) has successfully used the hard residue generated by dried and incinerated municipal waste sludge, broken down to fragments as coarse aggregate for light weight concrete.

A research study by Tommy & Cui (2004) has revealed that a "Green-lightweight" aggregate produced from fly ash and clay could be used to produce structural grade light weight concrete. It is reported that this mix has a high strength, resulting in producing a lightweight concrete with a density of 1590 kg/m^3 and a crushing strength of 34 MPa even though the water absorption of the aggregate is high (13%).It should be noted that, for the same mix proportions, normal weight aggregate concrete gives a crushing strength of no more than 30 MPa.

According to Mir (2001), using low density aggregate types such as Pumice, Vermiculite, Perlite, Herculite and Polystyrene beads lightweight concretes in the region of 800 kg/m3 density could be produced with crushing strengths in the range of 7 – 17 MPa.

2.2 Specifications for Concrete and Constituents

Specifications in the Sri Lankan practice commonly require compliance with requirements of ICTAD-SCA/4/I or the BS 882 for aggregates from natural sources for concrete, ICTAD-SCA/4/I or the BS 5328-Part 1 for specifying concrete and ICTAD-SCA/4/I or the BS 5328-Part 2 specifying concrete mixes. Quality control testing standards for concrete in the fresh as well as hardened state is stipulated by the BS1881.

The BS 882:1992 contains quantitative compliance requirements for particle shape, grading and mechanical properties such as Aggregate Impact Value (AIV). Long term acceptance of this standard in the country has created adequate experience and confidence to justify the validity and sufficiency of these limited requirements. Though the BS 812 which covers the test methods for aggregates gives a wider range of properties to be evaluated, it lacks guidance on interpretation of the test results.

According to ICTAD-SCA/4/I:2004 and BS 5328:1990, concrete could be specified as described below;

Designed Mixes: The mix is specified by required performance in terms of a strength grade, subject to any restriction on materials, range of cement content, maximum allowed free water cement ratio and any other required properties. Strength testing forms an essential part of the assessment of compliance with specification.

Prescribed Mixes: The mix is specified by constituent materials and the properties or quantities of those constituents to produce a concrete with required workability, strength and durability. The assessment of mix proportions forms an essential part of the compliance requirements, so that strength tests are generally not used to assess compliance.

Standard Mixes: The mix is selected from a list of weight based mix proportions, provided by standards and specifications. Standard mix specifications tabulated in ICTAD-SCA/4/I and BS 5328:1990 provides concrete strengths up to 25 MPa and workability in the range of 75 – 125 mm of standard slump.

Nominal Mixes: The mix is generally stipulated in terms of volume based mix proportions. Specified mixes are available for concrete strengths up to 30 MPa. This type of mixes is normally used in small construction operations such as dwelling construction. In Sri Lanka, widest used concrete mixes are Nominal mixes where batching at site is involved.

3 EXPERIMENTAL INVESTIGATION ON CTA BASED CONCRETE

The possibility of total substitution of rock based coarse aggregates in normal concrete mixes with CTA was investigated through an experimental study. For this study both concrete mix proportions for 'Nominal' and 'Standard' mixes were used.

3.1 Constituent Materials for Experimental Concrete Mixes

The main constituent materials for concrete, namely Cement, Aggregate (fine & coarse) and water have to fulfil certain requirements and specifications as stipulated in guidelines and codes of practice. In this study, Ordinary Portland Cement (OPC) conforming to SLS 107 & BS 12 was used throughout with fine aggregate in the form of river sand satisfying the overall grading limits of BS 882:1992 as shown in Table 3.1.

Table 3.1 – Grading of fine aggregate

BS 410 Sieve size (mm)	Percentage by mass passing BS sieve	
	Grading range for fine aggregate (BS 882)	River sand used for this study
10	100	100.0
5	89 – 100	91.0
2.36	60 – 100	76.2
1.18	30 – 100	49.6
0.60	15 – 100	31.8
0.30	5 – 70	14.1
0.15	0 – 15	3.3

Coarse aggregate which is the variable in this study was CTA while normal rock aggregate was used for control tests. Normal rock aggregate used was 20 mm single sized particles derived from gneissic rock. Details on the preparation of CTA and properties are elaborated below.

3.1.1 Preparation of CTA

In the Waikkala area there are about 500 tile factories, which are operational. Broken Calicut tile samples for this study were obtained from three such factories in the area. In the collection of the samples, unburned or surface contaminated waste was excluded. Since 20 mm nominal size aggregate was envisaged for this study, the collected samples needed to be further broken down to this size.

Straight forward manual breaking process was used in the preparation of CTA for this study. This involved fragmenting the tile waste with a mallet to the required size using individual judgement and screening through 28.0 mm sieve. Though the process is labour intensive and slow, wastage and dust generation were low. It was experimentally evaluated that a single labourer could produce about 0.19 m^3 of CTA per hour with less than 7.5% waste.

Mechanical crushing was also investigated by applying waste samples to a jaw crusher set for 20 mm final size. It was noted that by using this method over 40% waste was generated with less than 5 mm particle size with a very high fraction of dust. Therefore, refinement in mechanical crushing through a careful study is required for this method to be adopted in the preparation of CTA. It should be noted that for CTA to be a commercially viable substitute for coarse aggregate, a mechanical mode of crushing should be formulated so that consistent particle size and shape could be obtained.

3.1.2 Particle size distribution of CTA

Physical properties of CTA in the form of particle size distribution and water absorption were measured. Based on the particle size distribution, the produced CTA complied well with the grading limits stipulated for 20 mm single sized aggregates in ICTAD:SCA/4/I :2004 and BS 882:1990 as shown in Table 3.2. An 'immersion in water test' conducted for 30 days with intermediate readings for CTA indicated that a maximum saturation of about 21% moisture content is achieved in 72 hours and 24 hours immersion gives about 17% moisture content which is over 80% of the maximum.

Table 3.2 – Grading of CTA

BS 410 Sieve size (mm)	**Percentage by mass passing BS sieve**	
	Grading range for 20 mm single size coarse aggregate (BS 882)	**CTA**
37.5	100	100.0
20.0	89 – 100	96.0
14.0	0 – 70	41.0
10.0	0 – 25	12.0
5.0	0 – 5	0.2

3.1.3 Other relevant physical properties of constituent materials

Several other properties such as Specific gravity and Bulk density are relevant for constituents of a concrete mix especially as the mix proportions are considered both in volume as well as mass. The evaluated physical properties are listed in Table 3.3.

Table 3.3 – Physical Properties of Constituent Materials of Concrete mixes

Constituent Material	Specific gravity	Bulk density (kg/m^3)
Cement		1442
Sand	2.90	1579
CTA	2.11	1307*
Rock aggregate	2.65	1464*

* Measured under Saturated Surface Dry (SSD) condition

3.2 Properties of Experimental Concrete Mixes

The two most important properties of a concrete mix are the workability in the fresh state and the strength in the hardened state. Consequently, the suitability of CTA as coarse aggregate in concrete has to be ascertained by satisfactory compliance of CTA based concretes with accepted requirements and standards. The investigation was initially based on 'Nominal mixes' and extended to 'Standard mixes'.

The procedure adopted in the experimental study was to mix adequate quantities of constituents for each mix proportion to cast four standard concrete cubes with 150 mm sides. Before casting the cubes as stipulated in BS1881, workability was ascertained using the standard slump cone according to BS1881. All mixes were batched by weight, including the Nominal mixes stipulated by volume. Following steps were adopted in general.

- Cement and fine aggregate dry mixed on a flat steel sheet, about 75% of the measured water added and thoroughly mixed to form a uniform paste.
- Coarse aggregate in SSD condition added and mixed with balance water gradually dispensed.
- Slump measured to comply with the expected slump. If less, measured water amounts gradually added until compliance.
- Standard cube moulds (150 mm cube) filled with the concrete in three layers with each layer compacted with 35 blows of 1.8 kg tamper.
- Surface covered cubes de moulded in 24 hours and cured in a water bath until time of testing.
- Cubes tested under compression until crushing failure.

Relevant data recorded at each stage are used for ascertaining compliance according to standards or level of main properties achieved.

3.2.1 Nominal concrete mixes with CTA as coarse aggregate

Most commonly used concrete mixes for general applications in Sri Lanka are the volume batched 'Nominal mixes'. The popularity of this category of mixes mainly comes from the ease with which constituents can be batched (by volume) and the simple ratios used. However, applicability of such mixes is limited by the range of strength grades and workability requirements. Table 3.4 gives the summary details of three nominal mixes with CTA as the coarse aggregate, along with fresh state properties of the mixes. First column of the table also indicates the equivalent grade stipulated by ICTAD:SCA/4/I.

Table 3.4 – Mix Proportions & Fresh State Properties of Three Nominal Mixes with CTA

Mix [Eq. Grade]	Nominal mix proportions (by volume)	Nominal mix proportions (by weight)	w/c ratio	Slump (mm)
M1 [C10]	1 : 3 : 6	1 : 3.29 : 5.44	0.85	75
M2 [C20]	1 : 2 : 4	1 : 2.19 : 3.63	0.75	75
M3 [C25]	1 : 1.5 : 3	1 : 1.64 : 2.72	0.54	125 *

* high slump with low w/c ratio due to higher cement content providing better lubricity.

Standard cubes cast with these concretes were tested in compression with one cube at 7 days and the other three cubes pertaining to one mix in 28 days. These strength test results along with indicated equivalent grade are presented in Table 3.5.

Table 3.5 – Compressive Strength and Grade Compliance of Three Nominal Mixes with CTA

Mix [Eq. Grade]	Compressive strength at 7 days (MPa)	[1]Average Compressive strength at 28 days (MPa)	[2]Target Average Compressive strength at 28 days (MPa)	[2]Achieved intermediate Grade	[2]Achieved Standard Grade
M1 [C10]	5.38	8.28	11	7.28	~ C7.5
M2 [C20]	8.26	15.20	22	14.2	~ C15
M3 [C25]	17.53	25.70	27	23.7	~ C25

[1] Out of three samples [2] According to BS 5328 Part 4:1990

Table 3.5 shows that nominal concrete mixes with CTA are capable of only achieving compliance to a lower grade as compared with normal rock aggregate concrete. Nevertheless, CTA based nominal mixes could be used for the lowered Grades approximately.

3.2.2 Standard concrete mixes with CTA as coarse aggregate

Through the results on nominal mixes, it was evident that good strength as well as workability is achieved when high cement content coupled with higher fraction of fine aggregates is used. Therefore, for the investigation of CTA based concretes using standard mixes, ST4 and ST5 as stipulated in ICTAD:SCA/4/I and BS 5328 were adopted. Standard mixes ST4 and ST5 using normal aggregates have been formulated to produce concretes of Grade 20 and Grade 25, respectively.

Preliminary trial mixes based on fine : coarse aggregate proportions stipulated for ST4 & ST5 indicated lack of cohesion and stability of the mix. Therefore, to circumvent the situation, higher fine aggregate proportions than the stipulated range of 25% -45% by weight, had to be used for the experimental investigation. Thus investigated modified standard mixes were constituted with fine aggregate fraction over 45% by weight. For each of ST4 and ST5 mixes stipulated by both ICTAD and BS guidelines, four mix proportions with fine aggregate content varying from 45% - 60% in 5% increments were investigated, which resulted in 16 different mixes. For each of the mixes, four cubes were cast to be tested in compression.

For all modified mixes 20 mm single sized coarse aggregates were assumed with a higher targeted slump of 125 mm for ST4 and a lower targeted slump of 75 mm for ST5 mixes. Standard cubes cast with these concretes were tested in compression with one cube at 7 days and the other three cubes pertaining to one mix in 28 days. Concrete mix proportions, fresh state workability in terms of slump and crushing strength properties for the modified standard mixes with CTA are given in Table 3.6.

Table 3.6 – Mix Proportions & Fresh State & Strength Properties of Sixteen Standard Mixes with CTA as the coarse aggregate

Standard Mix [Eq. Grade]	Mix No.	Cement (kg/m^3)	Total Agg. (kg/m^3)	Sand (kg/m^3) [%]	CTA (kg/m^3) [%]	w/c ratio	Slump (mm)	Comp. strength 7d. (MPa)	Av.Comp. strength 28d. (MPa)
BS-ST4 [C20]	MT1	330	1800	1080[60]	720[40]	0.60	120	9.60	15.27
	MT2			990[55]	810[45]	0.61	125	12.20	16.92
	MT3			**900[50]**	**900[50]**	**0.63**	**130**	**13.07**	**19.29**
	MT4			810[45]	990[55]	0.65	120	12.80	18.32
ICTAD-ST4 [C20]	MT5	350	1750	1050[60]	750[40]	0.65	130	12.09	15.61
	MT6			963[55]	788[45]	0.62	125	11.00	17.12
	MT7			**875[50]**	**875[50]**	**0.58**	**130**	**12.80**	**19.63**
	MT8			788[45]	963[55]	0.55	130	12.40	18.74
BS-ST5 [C25]	MT9	340	1830	1098[60]	732[40]	0.60	95	13.47	21.95
	MT10			1007[55]	824[45]	0.60	90	13.42	21.44
	MT11			**915[50]**	**915[50]**	**0.58**	**90**	**15.91**	**22.25**
	MT12			824[45]	1007[55]	0.55	80	11.40	21.83
ICTAD-ST5 [C25]	MT13	360	1750	1050[60]	700[40]	0.63	90	11.40	19.14
	MT14			963[55]	788[45]	0.60	90	15.70	22.53
	MT15			**875[50]**	**875[50]**	**0.55**	**95**	**16.30**	**23.78**
	MT16			788[45]	963[55]	0.52	100	16.89	22.74

Highlighted mixes exhibited the highest strengths for each standard mix type

It is clearly seen that highest strength values were obtained by the mixes with sand : CTA ratio of 50 : 50. Therefore this ratio could be assumed as the optimum value for modified standard mixes with CTA. In order to compare the workability and strength values obtained with standard mixes containing normal rock coarse aggregates, four mix proportions corresponding to the four standard mix specifications were adopted. Since the surface area of the coarse aggregates in CTA based mixes were indicated to be instrumental in the workability and strength, the sand : rock aggregate ratio was selected so that approximately the same surface area of the CTA counterpart was presented for the mix. For this purpose the weight ratios were selected to result in approximately same volume of CTA in the counterpart mixes. Thus calculated sand : rock aggregate ratio was 44 : 56, since CTA and rock have different bulk densities. These mixes were intended to act as control tests to ascertain the performance of CTA as a substitute for normal rock aggregate. Concrete mix proportions, fresh state workability in terms of slump and crushing strength properties for the modified standard mixes with normal rock aggregate are given in Table 3.7.

Table 3.7 – Mix Proportions & Fresh State & Strength Properties of four Standard Mixes with Normal Rock as the coarse aggregate

Standard Mix [Eq. Grade]	Mix No.	Cement (kg/m³)	Total Agg. (kg/m³)	Sand (kg/m³) [%]	Rock (kg/m³) [%]	w/c ratio	Slump (mm)	Comp. strength 7d. (MPa)	Av. Comp. strength 28d. (MPa)
BS-ST4 [C20]	MR3	330	1800	792 [44]	1008 [56]	0.62	130	16.20	23.45
ICTAD-ST4 [C20]	MR7	350	1750	770 [44]	980 [56]	0.60	130	15.33	24.59
BS-ST5 [C25]	MR11	340	1830	805 [44]	1025 [56]	0.59	130	17.20	26.52
ICTAD-ST5 [C25]	MR15	360	1750	770 [44]	980 [56]	0.54	125	19.29	28.52

For comparison and ascertaining compliance according to BS 5328 Part 4:1990, the optimum CTA based concrete mix strength results and normal rock based concrete strength results are compiled in Table 3.8. It should be noted that the fresh state workability of all these mixes have satisfied the specification requirements. The first BS 5328 compliance criterion is based on the average of three consecutive cube samples tested at 28 day in compression, not to be less than intended Grade strength plus 2 MPa. The second compliance criterion of the minimum strength result not to be below the intended Grade strength minus 3 MPa, had been satisfied by all investigated mixes.

Table 3.8 – Compressive Strength and Grade Compliance of Modified Standard Mixes with Both CTA and Normal Rock as Coarse Aggregates

Ref. Standard Mix [Eq. Grade]	Mix No.	Compressive strength at 7 days (MPa)	[1]Average Compressive strength at 28 days (MPa)	[2]Target Average Compressive strength at 28 days (MPa)	[2]Achieved intermediate Grade	[2]Achieved Standard Grade
BS-ST4 [C20]	MT3	13.07	19.29	22	17.29	C15
	MR3	16.20	23.45	22	21.45	C20
ICTAD-ST4 [C20]	MT7	12.80	19.63	22	17.63	C15
	MR7	15.33	24.59	22	22.59	C20
BS-ST5 [C25]	MT11	15.91	22.25	27	20.25	C20
	MR11	17.20	26.52	27	24.52	~ C25
ICTAD-ST5 [C25]	MT15	16.30	23.78	27	21.78	C20
	MR15	19.29	28.52	27	26.52	C25

[1] Out of three samples [2] According to BS 5328 Part 4:1990

In Table 3.8 it is shown that modified standard mixes based on normal rock aggregates satisfy the intended grade requirements, while modified standard mixes based on CTA only satisfy one Grade step below. Since modified standard mixes based on ST4 and ST5 satisfy C15 and C20 grades respectively, they could be successfully adopted for lower grade mass concrete applications.

3.3 Cost Comparison of CTA Based Concrete with Conventional Aggregate Concrete

It is of significant interest in a study using an alternative constituent for concrete, to ascertain the economic dimension of the substitution. For the comparison to be realistic, significant properties of the two mixes being compared should be the same, while substituted constituent is the variable parameter. Two mixes, one with CTA (MT15 - Grade C20) and the other with normal rock aggregates (MR3 – Grade C20) were selected for the cost comparison. Further, following assumptions were used in the evaluation.

- Waste Calicut tiles are available from factories at Rs. 100/m^3 and transport cost was not considered.
- Dust generation of 7.5% was assumed in the manual preparation of CTA.
- Skilled and unskilled labour is available for Rs. 1000 and Rs. 800 per day respectively.
- Cement at Rs. 800 per bag, Sand at Rs. 3200/ m^3 and Rock aggregate at Rs. 2800/m^3 were used.

Based on the above, production cost of 1 m^3 of CTA was estimated to be Rs. 708. Then the production cost for 1 m^3 of CTA based MT15 concrete (1 : 2.43 : 2.43 w/w) was estimated to be Rs. 10,070. Similarly, the production cost of normal rock based MR3 concrete (1 : 2.62 : 2.84 w/w) was estimated to be Rs. 11,183. Therefore, as compared with normal aggregate concrete, CTA based concrete indicates a cost saving of about 10%. This indicates that apart from intangible benefits on environment and saving of natural resources, CTA based concretes exhibit a tangible cost benefit too.

4 CONCLUSION

Based on the experimental study, CTA based nominal mixes are only successful for the higher expected strength of Grade 25. The volume batched mix of 1:1.5:3 (Cement : Sand : CTA) fulfilled the compliance requirements for Grade 25 concrete according to ICTAD-SCA/4/I.

CTA based standard mixes ST4 & ST5 (intended for Grade 20 & Grade 25 respectively with normal rock aggregate) could not achieve the targeted strengths. However, modified weigh batched mixes of 1:2.49:3.01 & 1:2.22:2.68 based on ST4 & ST5 fulfilled compliance requirements for Grade 15 & Grade 20 respectively with a significant margin. These modified mixes were achieved with the optimum sand: CTA ratio identified by the experimental study which stood at 1 : 1 by weight. In all above usages of CTA, it is necessary to maintain SSD condition of aggregates

Further, it was identified that, the w/c ratio should be limited to 0.63 for the CTA based Grade 15 concrete, while cement content and total aggregate content are maintained at 330 kg/m^3 and 935 kg/m^3 respectively. Similar consideration for CTA based Grade 20 concrete stipulates that the w/c ratio should be limited to 0.55, while cement content and total aggregate content are maintained at 360 kg/m^3 and 921 kg/m^3 respectively.

In the direct cost comparison of Grade 20 concrete with CTA against normal rock aggregate, 10% saving was indicated. Even though this is seen as a marginal saving, when the indirect benefits due to conservation of good rock aggregates for higher strength concretes, recycling of production waste and reduction of environmental pollution are taken in to account, CTA based concrete for lower grade requirements is a viable proposition.

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