Feasibility of Waste Calicut Tiles as Aggregates in Structural Concrete

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***Abstract*— This study is intended to investigate the feasibility of using Calicut Tile Aggregates (CTA) sourced from industrial waste and construction and demolition waste as a replacement for Natural Aggregates (NA) use in the construction industry. An experimental program was conducted regarding the characteristics of Natural Coarse Aggregates (NCA), CTA, and the characteristics of concrete containing CTA. The results of the investigation conducted on aggregates revealed that there is a significant difference between the characteristics of NCA and CTA such as particle size distribution, bulk density, and specific gravity. Subsequently, concrete specimens were cast by replacing the NA from CTA in the proportions of 0%, 20%, 40%, 60%, 80%, and 100%, and density, and compressive strength were investigated to study the characteristics of concrete with CTA. According to the overall results of the study, a range of concrete with up to 40% replacement ratio was identified as the optimum range for replacement of CTA in the concrete mix with marginal deviations of characteristics compared to conventional concrete.**

Keywords—Calicut tile aggregates, Coarse aggregates, Construction and demolition waste, Recycled aggregates, Recycled aggregates concrete..

I. INTRODUCTION

Concrete is known as the most widely used man-made material since its invention [1,2]. Urbanization is the foremost cause of the high consumption of concrete, which shows the global use of about three tonnes of concrete yearly per person [3,4]. The aggregate is the highest fraction of concrete, which is about 75 % of its total volume and therefore it plays a vital role in the overall performance of concrete [4,5]. Natural Aggregate (NA) have been used as aggregates in concrete and the NA resources are become limited in the present day due to their excessive use of them and due to a large expansion of the construction industry. Therefore, the availability of the NA also has become questionable as they are being rapidly depleted. Furthermore, the mining process of NA generally takes place in vast aggregate quarries, and for that high manpower, and high technology is needed, and also aggregate production consumes a large amount of energy. In addition, the long-term use of quarries will affect badly on the environment. Due to the aforementioned reasons, more attention has been paid to developing concrete with various alternatives for NA [6].

To preserve natural resources and to improve project sustainability, the use of Recycled Aggregates (RAs) is increasing in the modern construction field. Industrial and agricultural waste can be used as potential material to replace aggregates in concrete constructions [7–9]. The use of waste material in the construction field is a green approach. The alternative materials to replace constituent materials of concrete is a high-demand research area that is currently in focus globally. The use of waste material in the construction field provides the value added to the waste constituents and helps to achieve the sustainable goals in the construction [10]. One of the main objectives of the new waste reuse and recycling policies in the construction and industrial fields is to use RAs as a replacement for conventional NA, by reducing both the use of natural resources and ecological impacts caused by dumping [11].

In last few decades, a high amount of Calicut tile waste was generated due to the construction and demolition activities, due to replacement of Calicut tiles with asbestos and other roofing materials, and the failures during the production process, transportation, and uses. In Sri Lanka, Calicut tile waste contains 3-4% amount from the total construction and demolition waste generated annually [12]. Generally, these broken tiles produce problems of disposing and ecological issues due to the strong broken parts and generated dust [12]. Due to the aforementioned reasons, the use of aggregates from Calicut tile waste as an alternative for NA will be a sustainable solution in the construction sector. Developing RA is one of the foremost concepts in Sri Lanka. Therefore, the development of RAC will reduce the cost of construction material and it will contribute to the proper waste management. Hence incorporation of waste material in construction and building materials is a novel way of ensuring sustainable consumption that is a key goal pointed out by the United Nations Development Programme due to the enormous consumption of the natural environment and resources that causes destructive effects on the planet [13,14].

II. Materals and Methods

A. *Materials*

Commercially available Ordinary Portland Cement with strength class 42.5N requirement was used in this study. Locally available river sand was used as the Fine Aggregate (FA). Natural Coarse Aggregate (NCA) which was used in this study is locally sourced from 19.5 mm downgrade crushed stones. Calicut tiles were obtained from a construction site located at Kilinochchi region, Sri Lanka, and CTA was obtained by crushing and the crushed aggregates were sieved by using 19.9mm and 4.75mm sieves [Fig. 1].

Fig. 1. Calicut tile aggregates

B. *Investigation of aggregate properties*

Aggregate properties were obtained by conducting relevant tests according to ASTM standards. Particle size distribution and fineness modulus of aggregates were determined according to the ASTM C136 [16]. Specific gravity and water absorption of aggregates were determined according to the ASTM C127 [17]. The bulk density of aggregates was investigated according to the ASTM C29[18] .

C. *Preparation of concrete specimen with waste Calicut tile aggregates*

In this study, 25 MPa was used as the target compressive strength. The replacement ratio of CTA was done at five levels based on the volume ratio of NCA, particularly 0%, 20%, 40%, 60%, 80%, and 100%. Cubic specimens with 150 × 150 × 150mm dimensions were prepared. After preparing the specimens, they were de-molded after 24 hours, and then they were added to a curing tank until the testing date.

D. *Investigation of the characteristic of concrete with waste Calicut tile aggregates*

The density test was done according to the ASTM C642 [15]. The samples were pieces of cubes of any desired size or shape, except that the volume of each portion was not less than 350 cm^3 and each portion was free from observable cracks, fissures, or shattered edges. The compressive strength test was done according to the ASTM C39 [19]. Cube specimens with 150 × 150 × 150mm dimensions were used for this test. Dry compressive strength was measured at 7 days, 14 days, and 28 days. Six specimens were used to determine each characteristic.

III. Results and Discusiion

A. *Characteristics of aggregates*

As shown in Fig. 2, the particle size distributions of NCA, and CTA were within the acceptable range. The specific gravity and bulk density of fine aggregates were 2.58 and 1673.2 kg/m^3 respectively. The water absorption of the fine aggregates was 1.77%. The specific gravity of the NCA was 2.70 and the bulk density of the NCA was 1461.76 kg/m^3, and a 0.495% of water absorption value was shown. The specific gravity, bulk density, and water absorption of CTA were 2.12, 1010.46 $kg/m^{3,}$ and 18.195% respectively.

CTAs represented a lower specific gravity than NCAs due to the high porosity of CTA. Mohan et al. (2018) obtained specific gravity values of CTAs and NCAs as 2.1 and 2.73 respectively, for their research and those values are similar to the results of this study [10]. And also, Dembatapitiya et al. (2013) have obtained similar results as specific gravity values obtained in this study [12]. 1461.76 kg/m^3, 1010.46 $kg/m^{3,}$ and 1673.2 kg/m^3 densities were obtained for NCA, CTA, and FA

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respectively. According to the obtained results, the bulk density of CTA was lower than the NCA and CTA can be considered as a lightweight aggregate. The lesser bulk density of CTA compared to NCA is due to the greater volume of voids between particles in CTA. Similar compatibility in bulk density of NCAs and CTA can be identified from the study of Ceesay and Miyazawa (2019) [11]. The water absorption capacity of CTA was higher than the water absorption capacity of NCA due to the higher porosity of CTA. Therefore, it can absorb a high amount of water compared to the NCA during the mixing and service life.

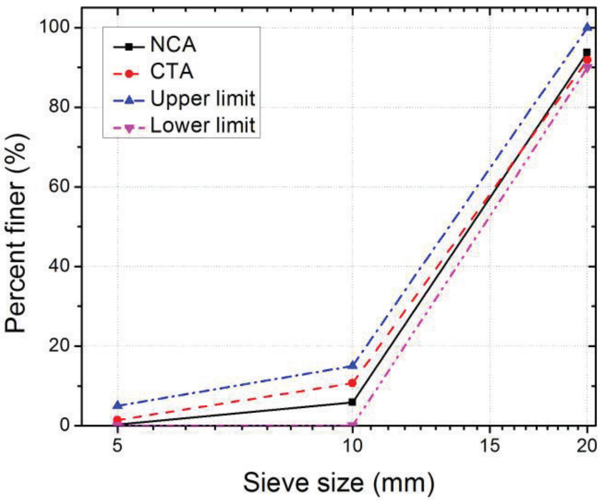

Fig. 2. Comparison of the average particle size distribution of CTA and NCA.

B. *Dry Bulk Density of Concrete*

The variation of the bulk density of hardened concrete for different replacement percentages at 28 days is shown in Fig.3. It demonstrates that the bulk density decreased when higher replacement ratios were used due to the lower particle density of CTAs compared to the NCAs. Therefore, with the incorporation of CTAs, the volume of less dense CTAs increases, and the density of concrete decreases. According to the obtained results, the maximum reduction of the bulk density was 17.30% and obtained when all NCA were completely replaced by CTA. The percentage reduction of bulk density for 20%, 40%, 60% and 80% was found as 3.46%, 9.93%, 14.32% and 14.69% respectively.

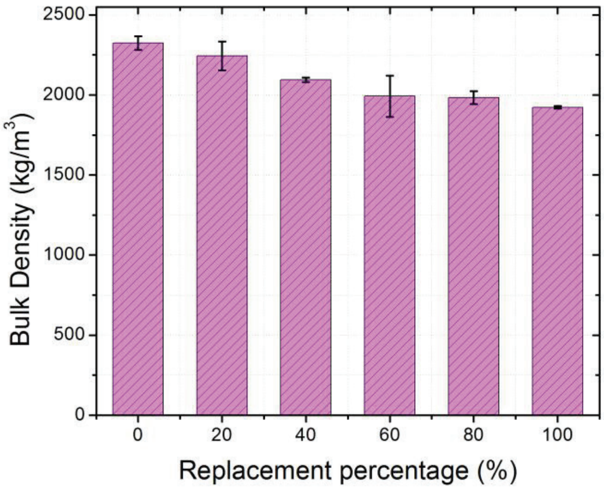

Fig. 3. Bulk density of hardened concrete.

C. *Compressive Strength*

Fig.4-6 shows the graphical view of the variation of the average compressive strength of concrete under dry state with the age according to different replacement percentages of CTA. When considering the results, the compressive strength of concrete showed a slight increment at the 20% replacement and then the compressive strength of concrete was reduced with a further increment of CTA replacement percentage at the age of 7 days and 14 days. 20% and 40% replacement ratios of CTA showed a slightly higher 7 days and 14 days compressive strength compared to control concrete specimens. B. Gonzalez-Fonteboa (2005) states that CTA contains a higher water absorption capacity than NCA, and is initially dry, it takes up a certain amount of water that fails to react with the cement [20]. The smaller amount of water in the concrete with CTA than in conventional concrete paste may lead to greater strength in the former due to the slow reaction of cement with water. But, an excessive decrease in free water can deteriorate the compressive strength of RAC due to lesser hydration of cement particles and poor workability of the mix than in conventional concrete. 28 days of compressive strength was reduced with the addition of CTA and 23% strength loss was observed with 100% replacements. However, the target compressive strength (i.e., Grade 25) was achieved at 28 days for 0%, 20%, and 40% replacement ratios.

According to the least-square linear regression analysis method, the respective equation and R^2 value for compressive strength at different curing ages were determined by considering a linear variation of the compressive strength with the replacement percentage. These respective equations can be used to determine the compressive strength values at different curing ages for different replacement percentages. The respective equations and R^2 values are listed in Table 1.

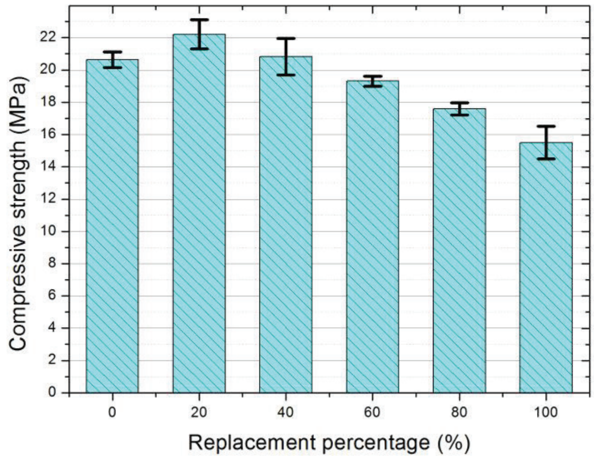

Fig. 4. 7th-day compresive strength.

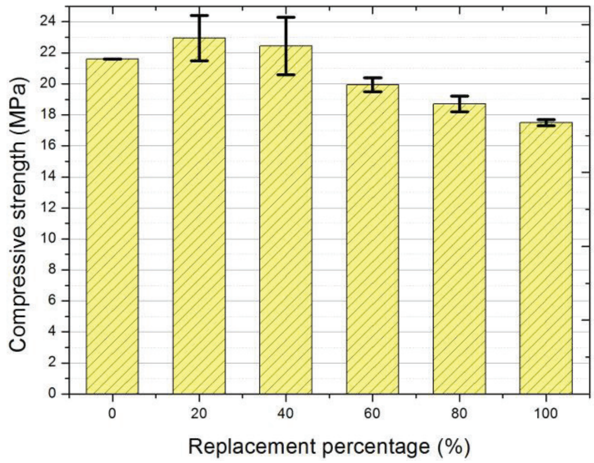

Fig. 5. 14th-day compresive strength.

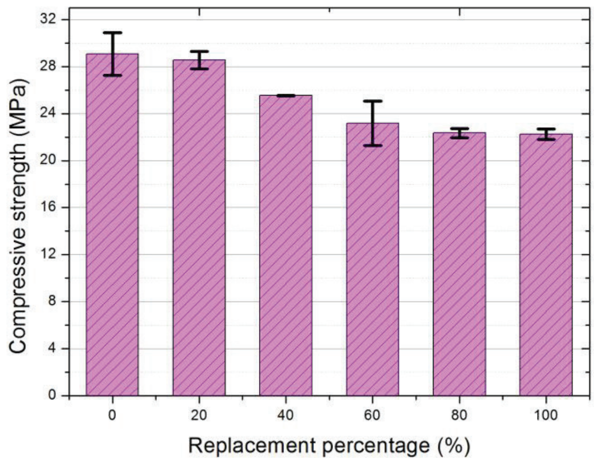

Fig. 6. 28th-day compresive strength.

Table 1: Regression analysis for compressive strength

Category	Equation	R^2
7 days (dry state)	Y = -0.0586 X + 22.273	0.8044
14 days (dry state)	Y = -0.0511 X + 23.079	0.7752
28 days (dry state)	Y = -0.0786 X + 29.08	0.9162
28 days (wet state)	Y = -0.0562 X + 22.668	0.9123

X and Y represent the replacement percentage of CTA and corresponding compressive strength values respectively and six number of specimens were used to develop the above equations. These equations only can be used when the characteristics of CTA and NCA are around this study. The further improvements of equations can be done by using aggregates with different characteristics and characteristics of aggregates will be used as the independent variable for the development of equations in subsequence studies.

With the addition of CTA increases, the compressive strength decreases at the age of 28 days, mainly due to the low strength of CTAs compared to NCAs. The strength loss in compressive strength due to the addition of CTAs for different curing ages is shown in Fig.7. The maximum strength loss in the compressive strength was observed for 100% replacement of CTAs, which is found to be 23% for 28 days of dry compressive strength. The reduction for 7 days and 14 days of dry compressive strength for 100% replacement of CTA is found to be 24% and 18% respectively. Mohan et al. (2018) observed similar results for strength loss in 7 days of compressive strength as this study, showed 30% strength loss with 100% replacement of NCAs with CTA [10].

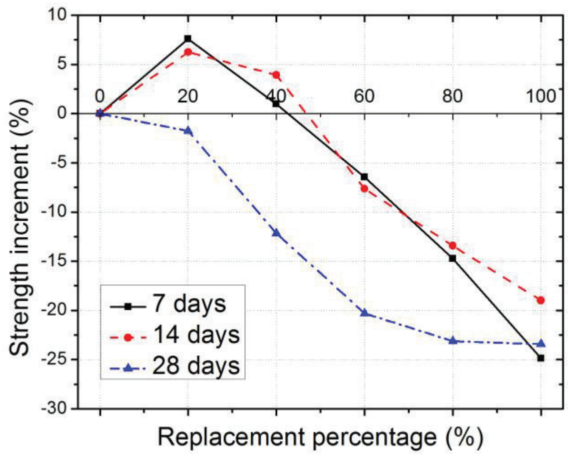

Fig. 7. Compressive strength increment at different curing ages under dry state.

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According to Fig.7, concrete with 20% CTAs and 40% CTAs at 7 days and 14 days curing ages showed strength increments than conventional concrete mix. By considering the percentage reduction of compressive strength in 28 days of curing age, the respective equation for 28 days of compressive strength reduction can be defined as Y = 0.2697 X (Y and X are compressive strength and percentage of replacement are respectively) and R^2(Coefficient of determination) value can be defined as 0.9162. This equation can be used to estimate the percentage reduction of compressive strength at 28 days of dry state for different replacement percentages.

IV. Conclusions

The particle size distribution of CTAs was almost similar and was within the acceptable range for construction purposes. The bulk density of CTA was lower than that of NCA due to the greater volume of voids between particles in CTA and CTA can be considered as a lightweight aggregate. The water absorption capacity of CTA was higher than that of NCA due to the higher porosity of CTA than NCA. The bulk density of concrete containing CTA was decreased when a higher replacement percentage was used, due to the lower particle density of CTAs compared to NCAs. The addition of CTA reduced the 28-day compressive strength mainly due to the low strength of CTA compared to NCA. Based on the overall findings, up to 40% of CTA addition (volume-based) as alternatives for NCA can be recommended for structural concrete applications. This will provide a novel and feasible way to reuse construction and demolished waste for a sustainable future while reducing construction costs.

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