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Performance of Clay Roofing Tile Waste as A Coarse Aggregate in Self Compacting Concrete

Lekshmy Raghavan P.[1,*], Nalanth N.[2]

[1]Noorul Islam Center for Higher Education, India
[2]Department of Civil Engineering, Rajadhani Institute of Engineering and Technology, India

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Abstract Due to its superior performance in terms of strength, durability, affordability, flexibility to mould into any shape and size, etc., and to fulfil the increasing needs in the building sectors, concrete is utilized fairly in various construction projects. Concrete that self-compacts (SCC) can be laid down and compacted by itself without vibration or segregation. SCC provides improved compaction and, by adequately covering reinforcement, lowers the cost of formwork and machinery. Additionally, it significantly reduces noise pollution. The most practical strategies for sustainable productivity and a healthier ecology are to limit the use of renewable resources and ensure proper removal of industrial wastes. Industries in India are releasing a lot of waste into the environment as they produce different products. It requires more land area for the safe disposal of these waste materials from the industries and the environment is being impacted at the same time. This type of waste materials from the industries can be effectively used for the making of concrete. This work proposed importance of clay roofing tiles and clay roofing tiles as a replacement of natural aggregates in the production of Eco-Friendly Self-Compacting Concrete. Recycled clay roof tiles are used in self-compacting concrete in an effort to produce environmentally friendly building materials that reuse waste from modern development. This high strength SCC is a booming technology in the building sector, particularly in precast construction. The experimental investigation was carried out to understand the fresh and hardened state properties of SCC prepared with different proportions of recycled clay roofing tile aggregates in coarse aggregate part with water cement ratios 0.475. The slump flow test was carried out to find the fresh state properties of SCC and tests were carried out to determine the compressive strength, split tensile strength and flexural strength of concrete were also studied on the hardened concrete of 28 days.

Keywords Self-Compacting Concrete, Waste Material, Water Cement Ratio, Clay Roofing Tiles, Compressive Strength Test, Slump Flow Test

1. Introduction

Infrastructure development and housing are required due to the city's rapid population expansion and rising percentages of the people moving there. One of the biggest problems of today is the lack of accessible building materials and the environmental effects of the over use of non-renewable resources [1]. Huge demand for raw materials causes unchecked quarrying, which removes top soil and badly impacts the local flora and animals. It might cause the extinction of some beneficial species and a decline in the water table. These regular behaviours have a negative impact on human life quality and the natural eco system. As it is affordable, superior durability performance, readily availability of its basic materials, ease of moulding to any shape and size, etc., concrete is the most versatile and frequently used man-made construction material worldwide. Therefore, in-depth study of the various facets of this special material is being conducted globally, leading to its presented improvement.

Ordinary Portland Cement (OPC), a key ingredient of concrete, is what holds the fine and coarse particles together to form the substance. The manufacturing of 1 tonne of cement is said to require the usage of 1.4 tonnes of quarry material, 5.6 GJ/ton of energy, and almost 0.9 tonnes of CO_2 emissions, or 5% of all anthropogenic CO_2 emissions [2]. Additionally, it contributes to climate change and global warming by releasing particulate matter into the atmosphere, including NOx, SOx, and other toxic gases. Workers' health is negatively impacted by noise pollution, vibration from mechanical operations, and blasting during quarrying operations. According to the reports, ground water pollution is caused by stocking fuel to run the manufacturing machinery used in the industry and other machinery. Without a doubt, the production of cement contributes significantly to environmental deterioration from conception to death. Besides that, the construction business produces a sizable amount of solid trash each year. According to a recent estimate, India produces 48 million tonnes of solid garbage annually, 25% of which comes from the building industry. Due to their weight, these wastes cannot be composted or incinerated [3].

Self-Compacting Concrete (SCC), initially developed in Japan in 1980, has a remarkable resistance to deterioration and segregation. This can migrate under its weight and even totally fill the structures while they are being strengthened in a congested region. Some appealing characteristics of SCC are its high flow capacity, great resistance to segregation, self-compatibility, lack of vibration, and noiselessness [1]. The rate of placing concrete is quick with a short time frame. SCC is more frequently utilised today and gives the same technical characteristics and durability as conventional concrete (CC).

It is challenging to fill complex reinforcement without vibration with standard ordinary concrete. Self-compacting concrete (SCC) has the benefit of setting down under the weight of itself. The SCC complies with the requirements for workability, including filling and passing capability and segregation resistance. The enhancement of concrete's strength and durability performance is facilitated by the high strength concrete. Utilising readily available mineral admixtures and significantly lowering the water cement ratio are both necessary for the making of high strength concrete [4].

The usage of clay roof tiles in SCC was driven by two main factors. Initially, the use of such wastes as recyclable items and the aforementioned tiles, which are available in India as residential debris, has a positive impact on the country's ecology. Uncontrolled quarrying adopted to meet the increasing demand of infrastructure and other related facilities, the environment and human life are adversely affecting. Since the coarse aggregates can not be wholly avoided in the construction work, the only available option is to depend on the recycled aggregates as partial replacement for the same. So, this study focused on the utilization of recycled clay roofing tiles instead of natural aggregates. Second, these disposals include a silica material that might be used as a pozzolanic component theoretically. Pozzolana waste has the potential to be both a great binding agent and a good filler provider. Clay roof tiles may improve the consistency and workability of SCC with suitable mixture formulation. This study proposes to use recycled Clay Roofing Tiles (CRT), which are inexpensive, plentiful, and economically viable, partially replacing the coarse aggregates while creating SCC. Further, the importance of clay roof tiles in enhancing the workability and strength of self-compacting concrete is analysed.

1.1. Literature Review

Many researchers looked into the possibility of partially or entirely substituting fine recycled concrete aggregates for natural fine aggregates in the manufacturing of structural concrete. This section presents a review of the literature on experimental research and numerical analysis for cement replacement as a mineral additive in conventional and SCC.

In 2018, Omar Almuwbber et al. [5] studied the impact of variations in cementitious properties on the strength and workability of SCC with slag additives and fly ash. On both the fresh and hardened characteristics of SCC, the effects of fly ash and slag were discussed. The ratio of concentration of C_3 A, C_2 S/C_3 S, cement's specific surface area, and the kind of super plasticizers utilised were the main determinants of the compatibility of cement and admixtures. The sensitivity of an SCC mix design to a particular type of cement is evaluated using a specified technique. Nadine Hani et al. [6] investigated the effects of increasing water/binder ratio on raw and hardened properties of SCC contains nano-silica with different dosages by using three different water/binder (w/b) ratios by replacing cement by nano-silica. The prepared samples underwent Scanning Electron Microscope (SEM) exams as well as fresh state and hardened state property checks. According to a report, concrete with increased water-binder ratio (w/b) responds to a nano-silica dosage differently from concrete with a low w/b in terms of compressive strength.

Elias Molaei Raisi et al. [7] analysed the mechanical behaviour of SCC integrating rice husk ash. It was conducted with partial cement replacement with RHA from 0-20 % and concrete aged (3, 7, 28, 90, 180, and 270 days), and water to binder ratios (from 0.38 to 0.68 with an interval of 0.06), and the behaviour of SCC was examined. Tests were conducted to study the fresh and hardened state properties. The test findings demonstrated that raising the RHA replacement ratio reduces the workability of SCC containing RHA. Alireza Habibi et al. [8] investigated how to establish the best mix design approach for SCC based on experiments. The objective function in the optimisation issue, which must be minimised, is the overall cost of producing one cubic metre of SCC, which is the focus of concrete manufacturing costs. The difficulty of mix design has been settled for numerous case studies in order to validate the suggested methodology. At last, the ideal mix designs were created in a lab, and the mechanical characteristics of the samples were assessed. The findings demonstrated that the suggested method minimises the cost of the concrete while simultaneously satisfying the mechanical properties of SCC.

Anhad Singh Gill et al.'s [9] study on the strength and microstructural characteristics of SCC containing metakaolin as partially replaced in fine aggregate and rice husk ash replaced in mineral admixture. Up to 365 days, the mechanical and fresh properties remain present. They came to the conclusion that the experimental results showed that SCC mixes made with Metakaolin, Rice Husk Ash, and in combination with MK & RHA met the requirements of the EFNARC. The results for the compressive strength and split tensile strength were showed to be favourable. SCC using recycled concrete aggregate was researched, as well as its long-term characteristics, by Stefania Manzi et al. [10]. According to the findings, recycled aggregates preserve their self-compacting qualities when used, and their excellent quality encourages high mechanical properties. Although their impact is lessened in comparison to what happens in conventional concrete with recycled aggregates, the content and assortment of recycled aggregates have a greater impact on the creep and pores size distributions.

Vengadesh Marshall Raman et al. [11] investigated the effect of GGBS on partial replacement of cement in SCC for sustainable building. When employed as a filler, GGBS lowers the overall void content in self-compacting concrete. To improve the powder content and achieve workability, the fly ash amount is kept constant for all mix combinations. The water/cement ratio (w/c), which was determined via iterative trial mixes, was set at 0.40. At ages 7, 14, and 28 days, SCC mixtures were prepared and the test results were compared with the ordinary concrete in terms of compressive strength, split tensile, and flexural strength; it was determined that the role of mineral admixtures is to increase the mechanical properties. Ha Thanh Le et al.'s study [12] was focused on the effects of mineral admixtures and superplasticizer (SP) on the self compactability and the compressive strength of the mortar and the Self Compacting High-Performance Concrete (SCHPC). It was determined that the integration of RHA stopped the chances of bleeding in the SCHPC. The SF, RHA was successful in enhancing the SCHPC's compressive strength as it aged, especially when there was a greater percentage of cement replacement. In terms of self-compactability and compressive strength, RHA and FA had synergestic effect. Abdulkader Ismail Al-Hadithin et al. [13] made an attempt to enhance the properties of SCC by using Waste Plastic Fibres (WPF) made from broken beverage bottles. Numerous studies were conducted to determine the effects of adding WPF on the characteristics of freshly laid concrete, while additional tests on the same type of concrete examined the impacts of this type of waste on the characteristics of cured concrete. At a given water binding ratio of 0.35, various SCC mixes were created. The experimental findings show that plastic fibers have a negative impact on self-compacting concrete's initial qualities while improving its hardened properties.

Aswathy Mohan et al. [14] investigated the possibilities of using clay tile chips as coarse aggregates in ordinary concrete. The coarse aggregate in concrete was replaced by 25, 50, 75 and 100% by volume. The laboratory tests were carried out with ordinary concrete with partially or full replacement of clay roofing tile chips for understanding the hardened properties. According to the test results, it is possible to advise replacing 25% of the volume of natural aggregate with broken clay tile. After that, it is discovered that the strength has significantly decreased. Herbudiman et al. [15] investigated the properties of self-compacting concrete of recycled roof tile powder of tile composite. The results show that the ideal formulation configuration has a maximum compressive strength of 67.72 MPa and the 65 cm slump test has sufficient flow rate in the V-funnel. Additionally, using recycled roof tile powder increases compressive strength by about 17% and tensile strength by 42%. Instability between aggregate and concrete cement may result from clay concentration on aggregate, which can then reduce concrete intensity. Several treatments, including specific washing, are necessary for aggregate that has a high proportion of clay. The environment is significantly impacted by quarrying. Land degradation, erosion, noise pollution, air and water pollution, sinkholes, damage to biodiversity, and the improper disposal of quarry waste are all environmental problems. Rapid infrastructural development in India caused an excessive demand for stones, which resulted in unrestrained stone quarrying. Tanushree Mahapatra [16] studied the effect of quarrying of stones in the Balasore district's Mitrapur panchayat in India. Although the livelihood of a significant portion of the local tribal population depends on activities related to stone quarrying, 83% of the people were significantly affected by the noise pollution brought on by activities related to stone quarries. About 40% of respondents voiced complaints about how dust pollution affects agriculture. The availability of water resources in the study area varied from site to site. Stone quarrying has been linked to numerous negative health effects. Despite the fact that it aids in development, quarrying has a number of detrimental effects on the environment and the economy, particularly when it is done carelessly.

1.2. Objective

The majority of the research literature [5–13] evaluated focused on experimental research on the novel features of SCC. SCC is supposed to have high level of flowability, passing ability, filling ability and segregation stability, according to the literature. Good flowability and good segregation resistance cannot be attained simultaneously. The aggregate particles interlocking between themselves presents another challenge. It is a good idea to add more powder to SCC mixes to promote cohesion and decrease particle interlocking activities. When utilized as a coarse aggregate replacing material, CRT has been demonstrated to enhance the concrete's mechanical characteristics and durability. Thus, the objectives of this research are formulated accordingly.

1. To find out the feasibility to use Clay Roof Tiles wastes as a substitute medium to the normal coarse aggregate in SCC.
2. To evaluate hardened and fresh state features of SCC with partial replacement of Clay Roof Tile wastes as coarse aggregate and determine the optimum replacement level for Clay Roof Tiles Wastes in terms of workability and strength properties.
3. To produce high-strength concrete using a blend of Clay Roof Tiles Wastes.

2. Materials and Methods

The production of high strength concrete requires a substantial reduction in water cement ratio. There are various mineral admixtures available and the usage of these mineral admixtures in the concrete gives its contribution towards the improvement in strength of concrete. The samples of every constituent material are tested in the laboratory for their physical and chemical properties. Due to the negative effects of stone quarrying, an alternative is needed to significantly reduce the use of these resources. The Clay Roof Tiles waste materials are used in this study. The properties of Clay Roof Tiles Wastes materials, mix proportions and methodology of high strength SCC are mentioned in this study. The SCC process is graphically depicted in Figure 1.

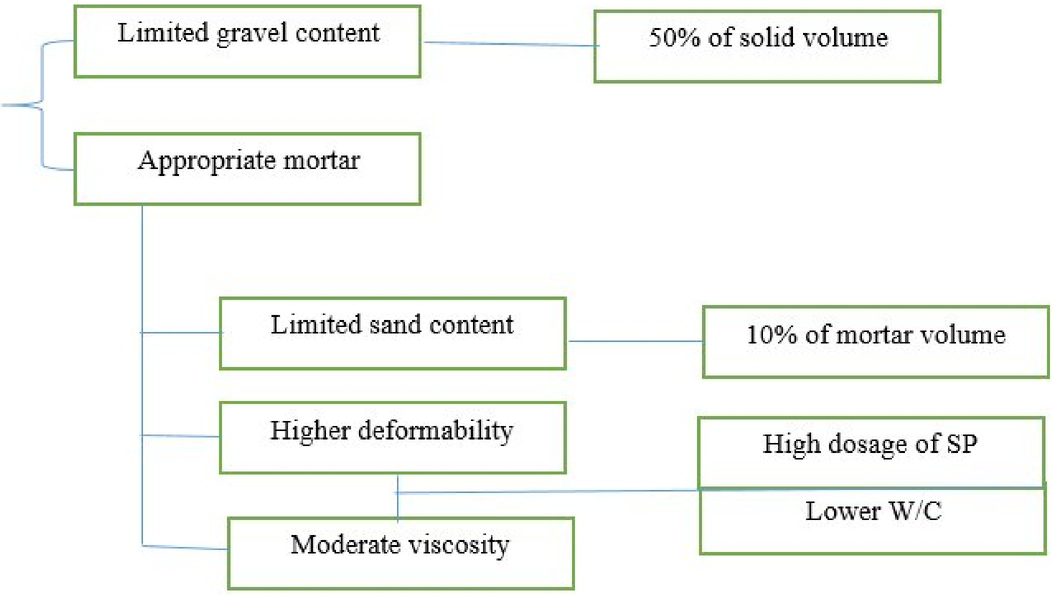

Figure 1. Graphical representation of SCC

2.1. Clay Roof Tiles Wastes

Clay is one of the most used raw materials for ceramics. This inexpensive component, which is present naturally in large quantities, is frequently utilised as it is with no quality improvement. Clay's popularity is also attributed to how easily it can be shaped. When combined in the right amounts, clay and water create a plastic mass that is easy to shape. To increase its mechanical strength, the produced component is burned at a high temperature after being dried to remove part of the moisture [17].

Figure 2. Clay Roof Tiles

The majority of clay-based products can be broadly divided into two categories: white wares and structural clay products. Sewer pipes, tiles and construction bricks are examples of structural clay products. After being fired at a high temperature, ceramic white wares become white. Porcelain, pottery, dinnerware, china wares, and sanitary wares are all included in this category. Many of these products contain non-plastic ingredients in addition to clay, which affects how the drying and firing processes change the final product's characteristics [18]. A type of the burned red clay in the ceramic ware group is represented by the clay roof tiles in Figure 2. The shape of tiles via hydraulic pressing is very common in industry. High compaction force, great productivity, uniformity, and easy adjustment are all features of modern hydraulic presses. Nowadays, many presses are equipped with electronic control units that can measure unit height and change the cycle automatically to maintain size uniformity. In order to create clay roof tiles, plastic clay "bats" that have been cut from an extruded column are often pressed. The steps of clay roof tile manufacture include raw material extraction from mines or quarries, raw material storage, raw material preparation, shaping, drying, fire, and post-processing. Surface treatment through glazing, engobing, or profiling is necessary to meet special criteria for the surface and colour of the items. Clay-based ceramic formulas (or bodies) can be made up of one clay or multiple clays combined with so-called non-plastic mineral modifiers like feldspar and quartz powder [19]. Clays have layered structure. Tetrahedral sheets, which contain four oxygen atoms around a silicon atom, and octahedral sheets, which contain eight oxygen atoms around a metal like magnesium or aluminium, are used to build the layers. By sharing oxygen atoms, the tetrahedral and octahedral sheets are fused together. The hydroxyl form has unshared oxygen atoms. The structure of clay is made up of two primary configurations of tetrahedral and octahedral sheets bonded together [20].

For the production of roof tiles, clay is mostly used. We can increase the pore volume by adding organic and inorganic additives. Metallic oxides like MnO_2, Fe_2O_3, and minerals like $CaCO_3$ are frequently added to roof tile products in order to get the desired colour and/or increase porosity. These additives, which can be provided in solid or liquid form, are introduced right before the pressing process or during the production of the raw materials [21].

Standard chemical composition of pastes from roof tiles can be seen in Table 1. Both SiO_2 and Al_2O_3 are often the principal oxides and its proportion relies on the natural clay utilized. The allocation of object dimensions could be regulated with the wrecking procedure. A few of the wastes from the clay tiles reveals pozzolanic properties, too. Aggregates manufactured from the recycling from clay tiles possess excellent resistance, impact strength, and are highly immune to physiological, chemical, and biological disruption. Recent years have seen substantial research into the utilization of leftover clay tile in ordinary concrete, with several encouraging results.

Table 1. Roof tile paste chemical composition

Chemical name	Composition
SiO_2	29.1
Al_2O_3	20.3
Fe_2O_3	7.7
CaO	1.2
MgO	1.1
Na_2O	0.4
K_2O	4.2
TiO_2	0.9

Table 2. Mix proportions of proposed SCC

Mix Designation	Cement (Kg)	W/C Ratios	Silica Fumes (Kg)	Fine Aggregates (Kg)	Coarse Aggregates (Kg)		Water (L)	SP (%)
				Sand	Natural	Recycled		
					Gravel	Clay roof tiles		
CC0	410	0.475	55	905	750	0	190	1.5
RA25	410	0.475	55	905	562.5	187.5	190	1.5
RA50	410	0.475	55	905	375	375	190	1.5
RA75	410	0.475	55	905	187.5	562.5	190	1.5
RA100	410	0.475	55	905	0	750	190	1.5

2.2. Materials and Mix proportions

The production of high strength concrete requires a substantial reduction in water cement ratio. There are various mineral admixtures available and the usage of these mineral admixtures in the concrete gives its contribution towards the improvement in strength of concrete. The materials such as cement, fine aggregate, coarse aggregate, fly ash, silica fume, recycle aggregate, super plasticizers and water are used in this study. The recycling and waste management facilities run by C&D provided the crushed clay roofing tiles. To produce aggregates with the right size and a specific gravity of around 2.44, tiles are broken with a shovel and sieved suitably. The samples of every constituent material are tested in the laboratory for their physical and chemical properties. Self-compacting concrete indicated that approximately 10 percent density substitution of cement using silica fume could improve the yields of compressive strength. Consequently, throughout this analysis, silica fume has been substituted by 10% of cement content that is deemed consistent across all configurations of the mix. Superplasticizers have become an integral element of SCC to achieve the flowability required. Extremely effective for SCC are the latest technology super plasticizers called Poly-Carboxylated Ethers (PCE). Water is an essential component in concrete construction, since it constantly interacts with the mortar in the chemical process. It assists to establish the friction that provides gel consistency in cement.

The mix proportions of the proposed SCC are given in Table 2. The reference specimen i.e. the control concrete is composed of natural aggregate particles and the recycled aggregate (clay tiles) is null. The cement, coarse aggregate and super plasticizer quantities are kept constant for all mixes. Different mixes were prepared with different water cement ratio by trial and error methods and a final w/c ratio of 0.475 was selected as it satisfied the workability criteria and that mix was considered as control concrete (CC0). For each scenario, 25% of raw aggregates were replaced by recycled clay aggregates(RA). The detail of mix designation for the proposed high strength self-compacting concrete is CC0 (Control Concrete with 0 % tile content) and Recycle Aggregate is 25, 50, 75 and 100. The quantity of cement, W/C, Silica Fumes, Fine Aggregate, Water and super plasticizer is 410, 0.475, 55, 905, 190 and 1.5.

3. Test Methods and Results

Concrete's workability refers to how easily it can be compacted completely regardless of the method and location of deposition. The water content, mix proportions, aggregate size, shape, surface texture, aggregate grading, and additive use are only a few of the variables that affect how workable concrete is. To determine the flowability, passability, fillability, and segregability of high strength SCC, the workability test is carried out. Slump flow testing on fresh state concrete and hardened state tests are carried out on the sample specimens.

3.1. Slump Flow Test

The Slump test was conducted as per BIS 1199-1959 to find out the workability of SCC mixes. The slump cone of top and bottom diameter is 100 mm and 200 mm with a height of 300 mm. The slump cone was placed over the graduated levelled surface. The water was sprinkled over the steel plate prior to unloading the mixture from the mixer to avoid absorption of water from the SCC mix. The fresh concrete mix was placed in three layers into the cone without compaction. The cone is to be lifted to allow the flow of concrete in the plate. After the concrete had stopped flowing, the spread's diameter was measured. Concrete's capacity to fill a circle is gauged by its diameter [22]. This test is the most popular one for determining workability and it provides a reliable evaluation of concrete's filling capacity.

For all mix combinations of SCC, the test results for workability properties such slump cone were calculated in accordance with BIS 1199-1959. Table 3 displays the concrete's fresh state properties. Figure 3 illustrates the slump flow diameter of the SCC mix for w/c of 0.475, which reveals that the values of slump flow for all mixes were in the range of 600 - 770 mm. The slump flow range value should fall between 550 and 850 mm, according to the European Guideline for the SCC [23]. The Mix RA100 has lowest value of slump flow with a diameter of 600 mm and a water-cement ratio of 0.475, while Mix CC0 has the high slump flow with a diameter of 770 mm.

Table 3. Slump flow test result

Mix Designation	Slump (mm)
CC0	770
RA25	745
RA50	725
RA75	705
RA100	600

All of the RA mixes with a 0.475 water-cement ratio were found to have a similar slump flow diameter. Due to the curved edges of the natural coarse aggregates and the razor-edged appearance of the recycled tile aggregates, it can be inferred that while sharp-shaped aggregates require more water than round-edged aggregate particles, the curved edges of the aggregates also make it to possibly fall into one another.

As a result, the slump flow would decrease as the amount of recycled clay tile aggregate increased.

3.2. Hardened State Test

The test samples were cast in 150 mm cubic mould cavities and 150 mm diameter and 300 mm height cylinders, and the slump was evaluated after mixing. The compressive and split-tensile strengths of cylinder composites have been tested on universal testing machines (UTM) after 28 days of moist curing.

The specimens were compacted and dried in accordance with IS: 516-1959. With a w/c ratio 0.475. Table 4 displays the compressive strength of samples of 28 days. For day 28, the compressive strength for the mix CC0 ranges from 47.35 MPa to 56.55 MPa. This finding showed that RA25 has higher compressive strength than other RA mixes for up to 28 days. For a w/c ratio of 0.475, Figure 4 depicts the development of compressive strength in SCC. RA25 has higher compressive strength than other RA mixes for upto 28 days. In this analysis, the W/C ratio was constant for all mixes, but as the amount of recycled clay tile aggregate increases, the compressive strength decreases when the recycled aggregates being added by more than 50%.

The outcomes of all the formulations are shown in Figure 5 with respect to the split tensile strength. The tensile property for the cylindrical specimens has been calculated after curing a period of 28 days. Split tensile intensity has been defined as per IS: 5816–1999. The tensile performance declined with an improvement in RA volume.

For all mixtures, the findings acquired for flexural strength can be seen graphical form in figure 6. In the hardened concrete, flexural strength was calculated in compliance with ASTM C293-16 after 28 days for a prism sample of 100x100x400 mm [24]. The recycled tile aggregates analyzed within this could not however contribute to a significant disparity comparable to CC in respect to flexural strength. The values are nearly consistent but hardly endure 2 to 4 percent differences.

The use of CRT as partial replacement of coarse aggregates displayed improved workability and strength characteristics together with remarkably good performance characteristics.

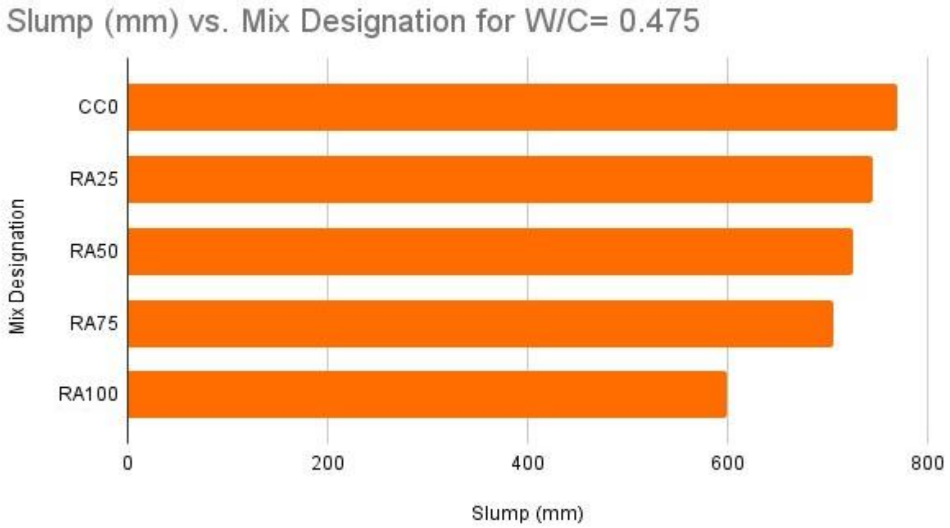

Figure 3. Slump (mm) vs. Mix Designation for W/C= 0.475

Table 4. The compressive strength test result

Mix Designation	Compressive strength (MPa)
CC0	47.35
RA25	56.55
RA50	55
RA75	49
RA100	50

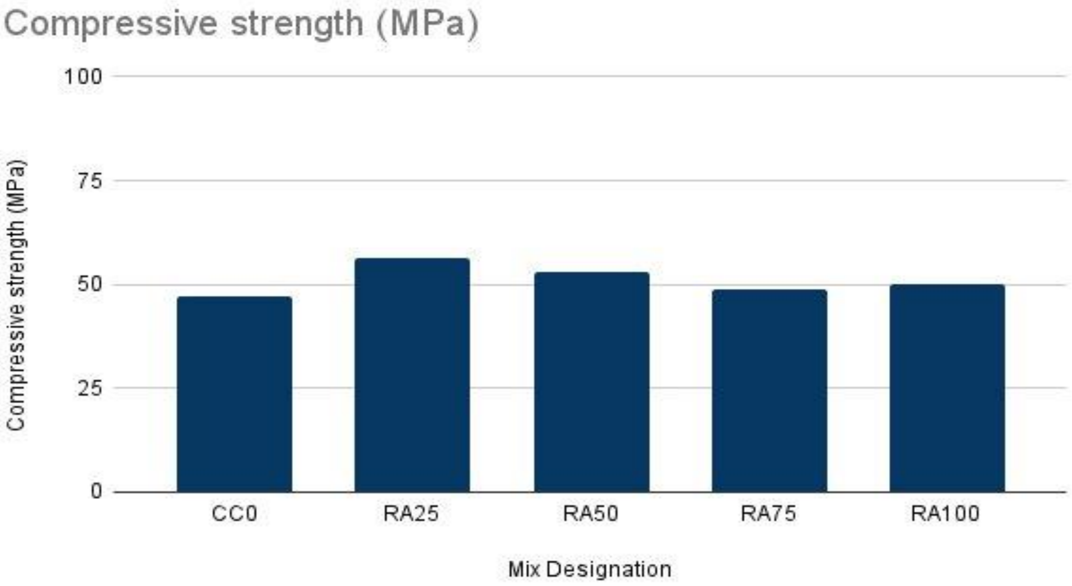

Figure 4. Compressive strength of SCC mixes

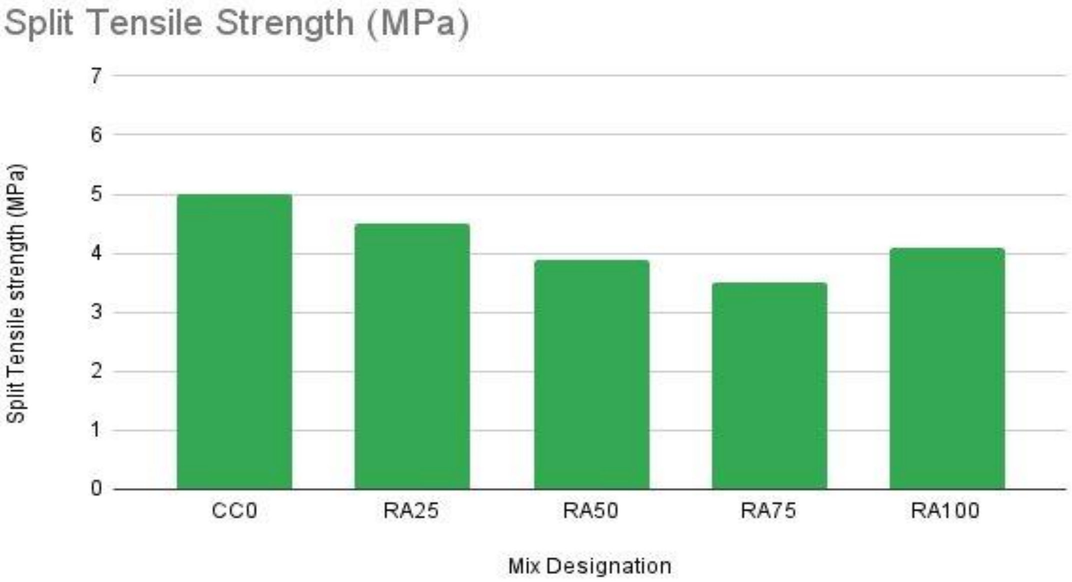

Figure 5. The split tensile strength of SCC

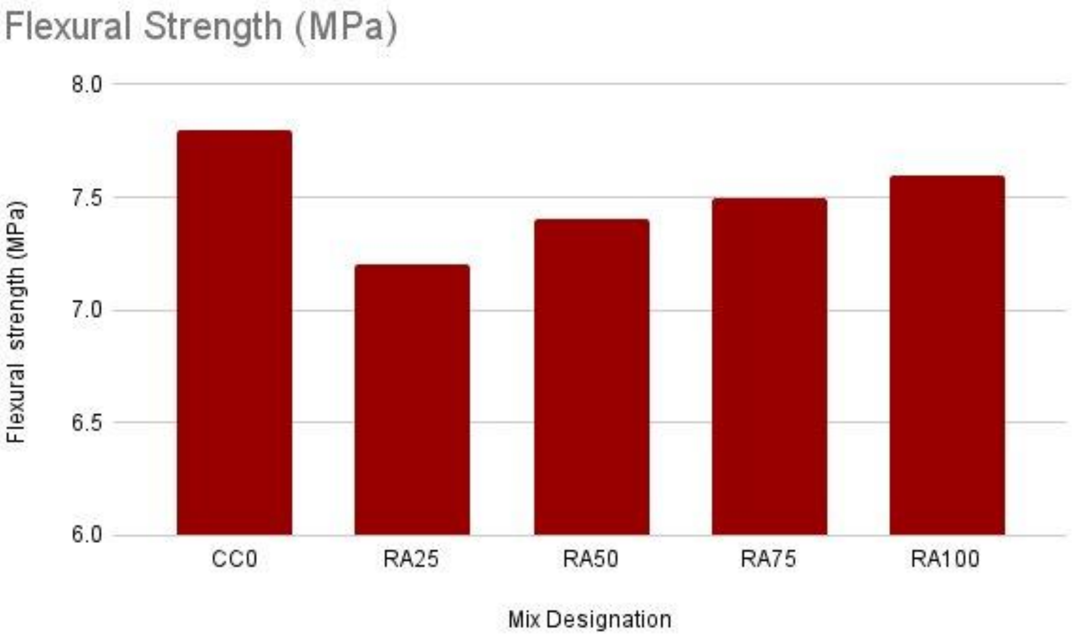

Figure 6. Result of flexural strength

4. Conclusions

Self-Compacting Concrete is a very fluid concrete mixture which can compress under its own weight and will not segregate. The goal of this study was to examine how the properties of Self-Compacting Concrete (SCC) change when recycled clay roofing tiles are used to replace some of the coarse aggregates. Enhancing the proportion of crushed tile by substituting natural aggregate and then by evaluating self-compacting concrete, decreases the slump flow that suggests improved concrete porosity.

It can be found out that the recycled clay roofing tile waste can be partially used as a substitute to the regular coarse aggregate in SCC thus the environment related problems especially due to uncontrolled quarrying can be minimized. The issue regarding the usages of clay aggregates is of its trait of moisture absorption. This impacts practical flowability. Thus; such aggregates have to be saturated for certain period and left to dry on the ground once they could be used in producing concrete. According to reports, it is possible to achieve compression strengths of up to 55 MPa by replacing 50% of clay tile for those in natural aggregates with a w/c ratio of 0.475. This significant intensity is a result of the replacement aggregates' rough surface texture, which provides more bonding strength. Its compressive strength appears to be exceptional, consistent with the structure used in the manufacturing of concrete, and completely suitable for use in building components. From the study it is found that the waste clay tile is substituted for natural aggregate, the tensile strength decreases. Mix design of recycled tile aggregates revealed no discernible change in flexural strength compared to CC.

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