Research Article

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Influence of recycling waste hardened mortar and ceramic rubbish on the properties of flowable fill material

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Abstract: Fly ash (FA) cement and water make up flowable fill material, which is also generally produced from waste and utilized in place of compacted granular fill as a cost-effective fill or backfill material. The capability to produce mixtures from various inexpensive, locally available by-products is one of the main benefits of flowable fill material. To considerably reduce costs, this study designed flowable fill mixtures utilizing cement, recycled fine aggregate (RFA; recycling waste hardened mortar and ceramic rubbish), FA, superplasticizers (SPs), and water for various uses. Initially, FA, Portland cement, fine natural aggregate, and water were combined to create a control mixture. Recycled aggregate (recycling waste hardened mortar and ceramic rubbish) was used instead of normal aggregate in various mix proportions in weights of 10, 20, 30, 40, and 50%. They performed well and conformed to the requirements of flowable fill material concerning flow consistency, unit weight, compressive strength, direct tensile strength, and thermal conductivity. Finally, when compared to ordinary concrete, flowable fill material can be produced with minimal mechanical criteria, such as a compressive strength of fewer than 5.71 MPa after 60 days and a unit weight between 1,993 and 1,961 kg/m^3. Additionally, it was discovered that using more RFA to replace normal fine aggregate in flowable fill materials could result in a relative decrease in thermal conductivity.

Keywords: compressive strength, crushed aggregate, recycled tiles, thermal conductivity, unit weight

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1 Introduction

As an inexpensive fill or backfill material in place of compacted granular fill, flowable fill is a self-compacting, low-strength material with a flowable consistency [1]. Both flowable fill and concrete are not the same thing. Controlled low-strength material (CLSM) is a term used by ACI Committee 229. Alternative names for this substance include lean mix backfill, flowable mortar, controlled density fill, and unshrinkable fill [1–3]. As measured in concrete, the slump is typically greater than 200 mm in terms of its flowability [1,3]. Although the definition is more expansive and includes materials with compressive strengths lower than 1,200 psi (8.3 MPa), most applications use mixes lower than 300 psi (2.1 MPa). According to the compressive strength of cylinders, the late-age strength of detachable CLSM materials should be between 30 and 200 psi (0.2 and 1.4 MPa). When specifying or ordering the material, define the anticipated future excavation of flowable fill material [2,3].

The utilization of CLSM or flowable fill material, a relatively new technology, has increased lately. In its fresh state, CLSM, also known as flowable fill, is a highly flowable substance that primarily consists of water, cement, fine aggregates, and occasionally fly ash (FA) [4]. For backfill, utility bedding, void fill, and bridge approaches, CLSM or flowable fill mixtures are frequently specified and used instead of compacted fill [4,5]. FA, cement, and water comprise CLSM, which is also frequently made up of waste by-products. Very high workability and lower compressive strength define them. When applying granular fill is impossible or challenging, flowable fill material is mainly used to fill voids and trenches in civil engineering projects. FA, cement, water, and sometimes fine aggregates are common flowable fill material mix ingredients [6,7]. In many applications, especially for backfill, utility bedding, void fill, and bridge approaches, CLSM or flowable fill material is frequently specified and used instead of compacted fill. In certain instances, adopting CLSM rather than compacted fill has intrinsic advantages [4,7]. These advantages include quicker construction, the capacity to lay material in limited spaces, and lower labor and equipment expenses (because of the self-leveling characteristics and lack of compaction). CLSM's relatively low strength is helpful since it enables possible future excavation. Using by-product materials like FA and foundry sand that would otherwise be dumped in landfills is another advantage of flowable fill material [4]. Recycling garbage for use in flowable fill material has a huge positive impact on the environment. However, to reduce disposal issues, there is still a need to identify new, environmentally friendly uses for waste materials. Large-scale use of FA in CLSM mixes appears to be the ideal utilization strategy. Due to CLSM's hybrid nature between soils and concrete, it can be tested in regular geotechnical or concrete testing laboratories [8]. Depending on the needs of the project, non-standard, locally affordable materials or by-products may be utilized in flowable fill material combinations [9]. CLSM has several benefits frequently highlighted in the literature. The following are the primary benefits of regulated low-strength materials: readily accessible, versatile, strong, durable, lower levels of inspection, allows for an immediate return to traffic, would not settle, improves worker safety, permits building in all weather conditions, simple to place and deliver, needs no storage, easily excavatable, uses less equipment and lowers excavating costs, and allows for by-product utilization [7,10–12].

The literature analysis indicates that earlier experiments used waste materials to create flowable fill materials. Bassani et al. [13] investigated the use of cement kiln dust and cement by-pass dust combined with powdered incinerator bottom ash and aggregates to create non-traditional CLSMs and then compared these mixtures with traditional CLSMs obtained by combining natural sand with regular Portland and sulfa-aluminate cement. The outcomes demonstrated that substitute binders might produce mixtures with attributes similar to those of reference mixtures. They proved successful only when recycled CLSMs replaced 50% of natural sands. Using a hydrophobic agent and stannous sulfate, the high concentration of several harmful pollutants was reduced to tolerable level. Jurczak and Szmatuła [14] investigated the feasibility of using recovered waste glass instead of FA in CLSM mixtures. Reference mixes were created in the first stage of the testing process with 22.5 and 45% fly ash contents in proportion to cement content. The same specifications were used to create mixtures in the following stage, except that glass powder (GP) was added instead of FA. They concluded that mixes containing GP are not only on par with mixes containing FA but even outperform them by a significant margin in terms of durability, based on the test results and their analysis. Additionally, Xiao et al. [15] examined the pozzolanic interaction between waste GP and hydrated lime as a basis for the creation of cement-free CLSM.

The impact of adding ground waste glass to low-strength concrete mixtures on their strength and durability was examined by Jurczak et al. [16]. This article examines how adding waste glass affects CLSM's characteristics, which are utilized, for instance, as bedding material for concrete drains and curbs. Ground scrap glass was added to the mixture without reducing the cement as a filler. The findings indicated that the 28 days compressive strength has improved.

Abdulmunem [12] investigated how glass wastes affected the fundamental properties of CLSMs. By substituting waste glass for FA and natural sand as the low-strength materials in control, an experimental evaluation was started to determine the practicability of the material. With the replacement of quality glass, unit weight increased to some extent. Although it was more significant at 90 days, the compressive strength of 28 days in acceptable glass replacement was lower than the reference mixture.

In their study of the mechanical properties of green CLSMs, Wang et al. [17] also compared the variations in technical specifications and performance test procedures in CLSM-related specifications. They provided an overview of the different types of solid waste and the characteristics of their chemical composition in CLSM in other nations. Additionally, the impacts of the aggregates, water-binder ratio, and binding material content on the mechanical characteristics and durability of CLSM made from solid waste were clarified.

The growing number of construction waste poses a threat to the ecosystem. As a result, managing these resources is one of the biggest problems in the modern world. Researchers worldwide are constantly looking for novel ways to use waste materials that have been treated or left in their raw form for various industrial processes [18]. The technology of building materials in Iraq has undergone significant advancements, particularly in cement composites like concrete. Natural fine and coarse aggregates can be replaced by recycled and waste materials in the form of crushed materials. In literature, using recycled materials is a common subject of discussion. As an illustration, previous studies [12,17–20] have presented a thorough literature analysis on the potential use of recycled buildings and demolition waste in creating various types of concrete.

This study proposes the creation of flowable fill materials enhanced in sustainability through recycled fine aggregate (RFA) from Baghdad. So, this study's objective is to assess if RFA can partially replace fine natural aggregate in a controlled low-strength (flowable fill material). The percentage of recycled waste hardened mortar (RM) or ceramic trash replacement of fine natural aggregates served as the study's primary variable.

2 Materials

The ability to create mixtures from various inexpensive, locally available by-products is one of the key benefits of CLSM or flowable fill mixtures [21]. The production efficiency of CLSMs is significantly influenced by the proper selection, sourcing, and quality control of all components used with CLSM [13]. In this experiment, type 32.5 R Portland cement has been used. Testing of cement against Iraqi Standard No. 5/2019 demonstrates conformity [22]. After being sieved via a 600 μm sieve, two types of sand (natural and recycled) were employed as a fine aggregate. The grade of natural and RFA (recycling waste hardened mortar and ceramic rubbish) and its physical characteristics met both Iraqi requirements IQS No. 45/1984 and ASTMC778, 2017 (graded sand) [23,24]. A hammer was used to break the fine recycled aggregate (FRA; crushed mortar and ceramic rubbish) into small pieces, the ceramic rubbish included flowerpots and tiles. These tiny pieces are then placed into a vibratory sieve to be reduced in size to less than 600 μm. The class C-FA used in this study is produced by the "EUROBUILD FLY ASH" company, and it conforms to ASTM C-618 (Class-C) and BS 3892 Part 1 [25,26]. All CLSM mixes were created for this study using tap water. To enhance flow, Sika® ViscoCrete®-5930 L I.Q. high-range water-reducing and super plasticizing additive for concrete and mortar that complies with ASTM C-494 requirements was used.

3 Details of flowable fill material mix design

As shown in Table 1, eleven slurry flowable fill mixtures were used to investigate the effects of replacing the normal sand (NS) with FRA. The first CLSM mix represents the original/CLSM, while the other additional mixes represent the CLSM produced by replacing 10, 20, 30, 40, and 50% of standard sand with FRA as a partial replacement by weight. This study contains two series. In series 1 (CT10, CT20, CT30, CT40, and CT50), 10, 20, 30,40, and 50% were used instead of the typical fine aggregate. The fine natural aggregate in series 2 (CM10, CM20, CM30, CM40, and CM50) was replaced with 10, 20, 30, 40, and 50% RFA (recycled hardened mortar) by weight, respectively. The current study tested various mix proportions to construct the original/CLSM (60 kg/m^3 cement, 178 kg/m^3 FA, 1,390 kg/m^3 sand, and 653 kg/m^3 water). All mixtures were blended using the ASTM C305-14 as a guide [27]. There are often no specifications for flowable fill curing. Nevertheless, it may be advised to cover the exposed surfaces of flowable fill in hot weather to reduce evaporation and the subsequent emergence of drying shrinkage [28].

Table 1: Details of all flowable fill material mixes

Mix no.	Mix title	% replacement (by weight)	Series no.
1	CLSM	0	Control
2	CT10	10	Series-1 partial
3	CT20	20	replacement of NS with
4	CT30	30	recycled tiles
5	CT40	40	
6	CT50	50	
7	CM10	10	Series-2 partial
8	CM20	20	replacement of NS with
9	CM30	30	recycled hardened
10	CM40	40	mortar
11	CM50	50	

4 Results and discussion

4.1 Flow consistency test

One of the essential characteristics of flowable fill material is flow constancy. It is measured in accordance with the 2013 ACI Committee 229 [29]. A cylindrical molding with dimensions of 0.150 m in length and 0.075 m in diameter was utilized. Table 2 contains the results of the flow consistency test. We can observe that the standard flowable fill material or CLSM has a flowing consistency of 291 mm, while concrete incorporating recycling waste hardened mortar (RM) or ceramic rubbish (RC) has a flow consistency value that varies in mm. The flow consistency reading for CLSM mixes that contain RM or RC will be lower compared to the reference flowable fill material (CLSM) mix because the flow consistency pattern decreases as the amount of RFA increases.

Additionally, it can be deduced that the flow consistency test result decreased as the percentage replacement of both RM and RC increased. This outcome was similar to that of the studies by Abdulmunem and Hasan [7] and Azmi et al. [30], in which the value of the flow consistency test increased as the percentages of RFA increased. The flow of all mixtures is less than the reference mixture

Table 2: Flow consistency for all flowable fill material mixes

Mix no.	Mix title	Flow spreading (mm)	SP by weight (%)	Modified flow spreading (mm)	Series no.
1	CLSM	291			Control
2	CT10	261			Series 1 partial replacement of NS with recycled tiles (ceramic rubbish)
3	CT20	225			
4	CT30	188*	0.4	228	
5	CT40	162*	0.6	220	
6	CT50	135*	0.8	208	
7	CM10	274			Series 2 partial replacement of NS with recycled hardened mortar
8	CM20	252			
9	CM30	231			
10	CM40	190*	0.2	228	
11	CM50	177*	0.4	217	

*Minimum limit = 200 mm so that SP is used with these mixes [1,3].

(291 mm), as can be seen in Table 2, and it should be noted that the flow-ability values for the mixtures (CT30, CT40, CT50, CM40, and CM50) were below the minimum allowable level (according to ACI 229-13) [29], which is less than 200 mm. As a result, super-plasticizing was used to correct the flow-ability, as can be seen in Table 2 and Figure 1. Figure 2 shows the flow consistency for all flow-able fill materiel mixes.

4.2 Unit weight test

One of the key considerations when choosing a material to utilize as a compact or backfill is its density. The CLSM material's fresh density aids in determining if it is appropriate for a given civil activity [31]. According to ASTM (D 6023) [32], the fresh density (unit weight) findings are displayed in Table 3. Increases in the proportion of RM or RC used in place of the natural aggregate are observed to cause a modest drop in density. Due to the RM's or RC's somewhat lower specific weight than that of ordinary aggregate, the unit weight has dropped. Figure 3 represents the unit weight (fresh density) for all flowable fill material mixes. The unit weight of the CLSM decreased when more recycled hardened mortar and ceramic waste were used. The porous nature of the mortar and ceramic waste grain is the reason for this. Figure 4 represents the variation ratio (%) of flowable fill material mixes containing RFA concerning the reference mixture.

4.3 Unconfined compressive strength test

For the unconfined compressive strength test, samples of each mixture were cast into 5 cm cubes. Three cubes were crushed at the ages of 28 and 60 days for the unconfined compressive strength test utilizing a digital testing instrument with a capacity of 1,900 kN and a loading rate of

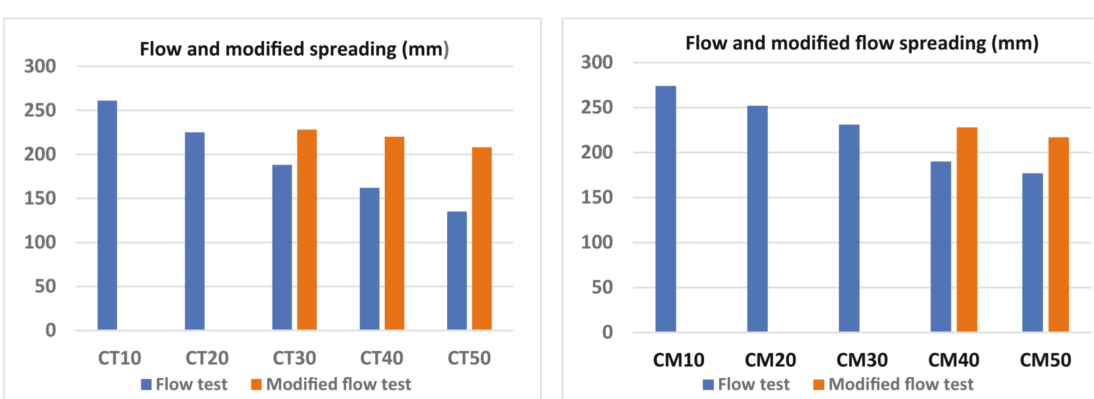


Figure 1: Flow consistency for all flowable fill material mixes.

Figure 2: (a) Cylinder test. (b) Flowable mixture.

Table 3: Compressive and direct tensile strength for all flowable fill material mixes

Mix title	Unit weight (kg/m^3)	Direct tensile strength (MPa, 60 days)	Compressive strength (MPa, 28 days)	Compressive strength (MPa, 60 days)	Series no.
CLSM	1,993	0.812	1.44	1.75	Control
CT10	1,986	0.811	1.39	1.96	Series 1 partial replacement of NS with recycled tiles(ceramic rubbish)
CT20	1,978	0.809	1.37	2.37	
CT30	1,970	0.812	1.33	3.93	
CT40	1,963	0.819	1.31	4.72	
CT50	1,955	0.820	1.30	5.31	
CM10	1,989	0.814	1.40	2.15	Series 2 partial replacement of NS with recycled hardened mortar
CM20	1,981	0.815	1.39	2.54	
CM30	1,975	0.820	1.38	3.22	
CM40	1,969	0.829	1.36	4.95	
CM50	1,961	0.831	1.35	5.71	

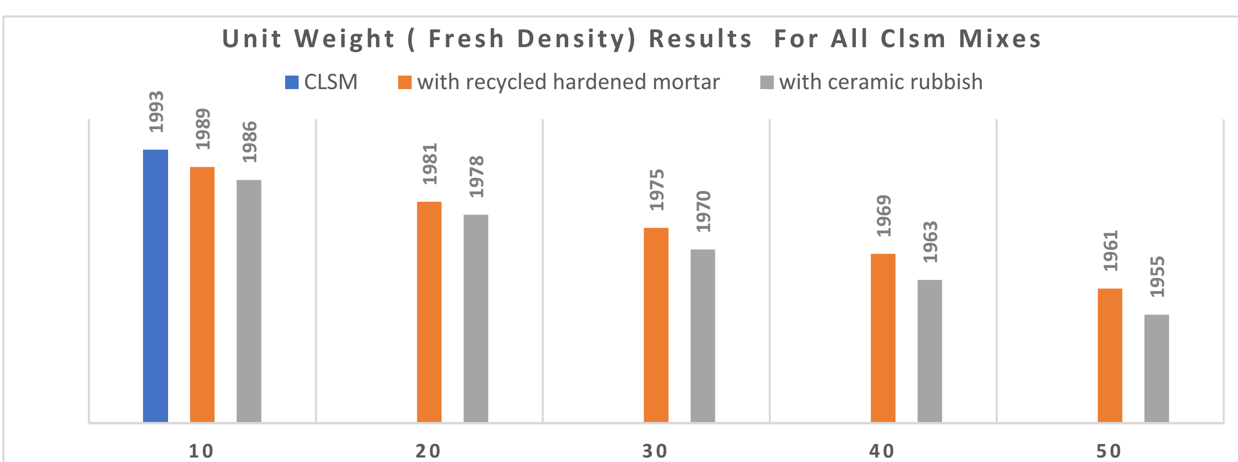


Figure 3: Unit weight (fresh density, kg/m^3) for all flowable fill material mixes.

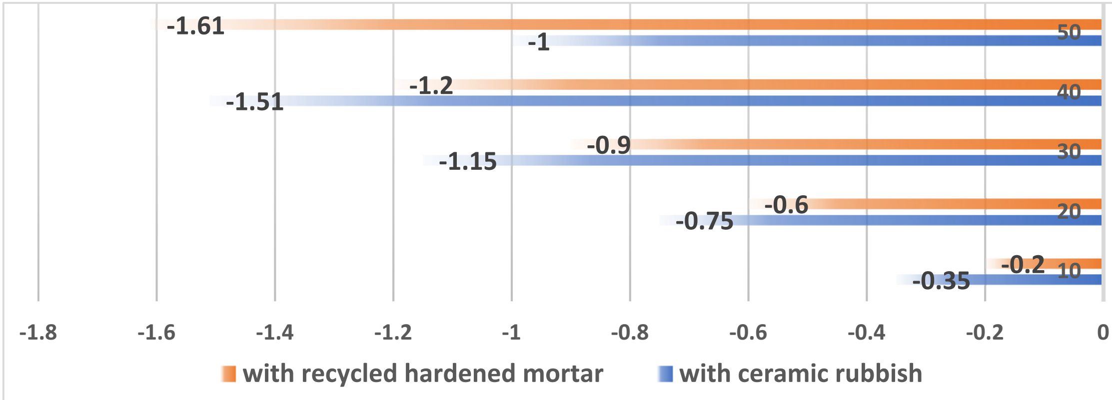


Figure 4: Variation ratio (%) of compressive strength for all flowable fill material mixes concerning reference mixture.

0.3 MPa/s. According to ASTM C109/C109M [33], Figure 5 shows the compressive strength test equipment used for stress-strain behavior testing. Due to its excellent flowability, CLSM's 3 days strength is negligible, while the compressive strength of the CLSM 28 days is a crucial characteristic. Table 3 displays the compressive strength data. The reference sample flowable fill material constructed with exclusively natural aggregates showed the highest compressive strength values, ranging from 1.44 to 5.71 MPa. However, utilizing recycled aggregate in a concrete mixture frequently yields a mixture with a lower concrete strength than the one that uses conventional materials. Microcracks that may be present in recycled mortar or ceramic particles due to the crushing process and the existence of weak and/or porous mortar in the recycled aggregate are the reasons for reduction in the strength of flowable fill material mixes. This was consistent with other researchers, such as Abdulmunem and Hasan [7] and Azmi et al., 2016 [30]. Figure 6a represents the unconfined compressive strength of all flowable fill material mixes. The unconfined compressive strength test demonstrates that when recycled sand is used in place of standard sand, the results decrease by 3.5, 4.9, 7.6, 9, and 9.7% for RC and by 2.8, 3.5, 4.2, 5.6, and 6.3% for RM, respectively. The results are compared to the reference mixture, which had a compressive strength of 1.44 MPa. This finding supports what Solanki et al. [34] and Abdulmunem [12] stated. When comparing the results for the age of 60 days with the control mixture, which was 1.75 MPa, there was a significant increase following the increase in the compensated ratio from 10 to 50% for RC) and RM, respectively, (12, 35.4, 124.6, 169.7, and 203.4%) and (22.9, 45.1, 84, 182.9, and 226.3%) as shown in Figure 7. This finding runs counter to results from Solanki et al. [34] and Abdulmunem [12], which were backed by Solanki et al. [34] and Jurczak [35], among other scholars. Figure 6 displays the unconfined compressive strength percent variation ratio at 28 and 60 days.

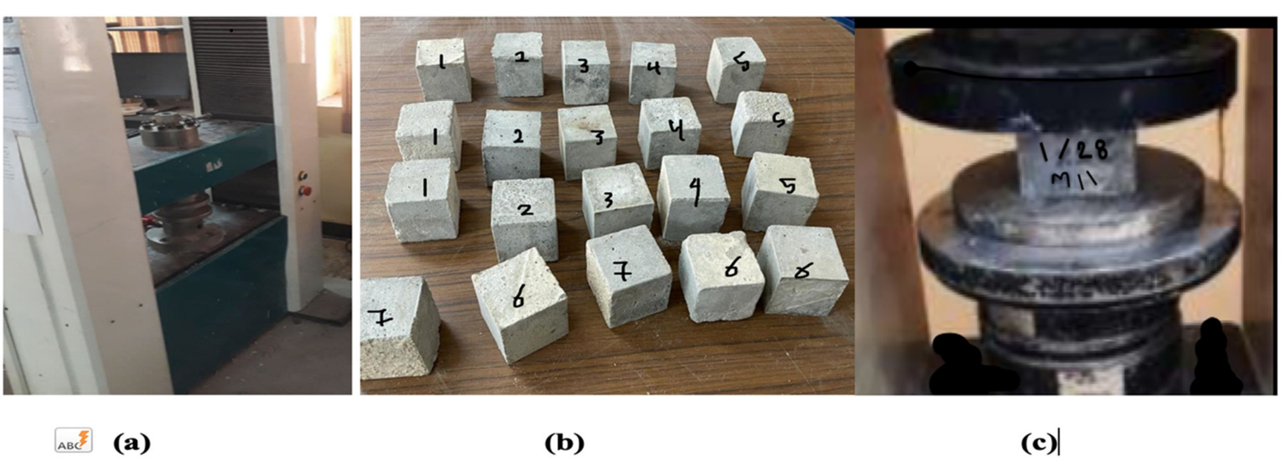


Figure 5: (a) Unconfined compressive strength machine. (b) 5 cm cubes. (c) Specimen under test.

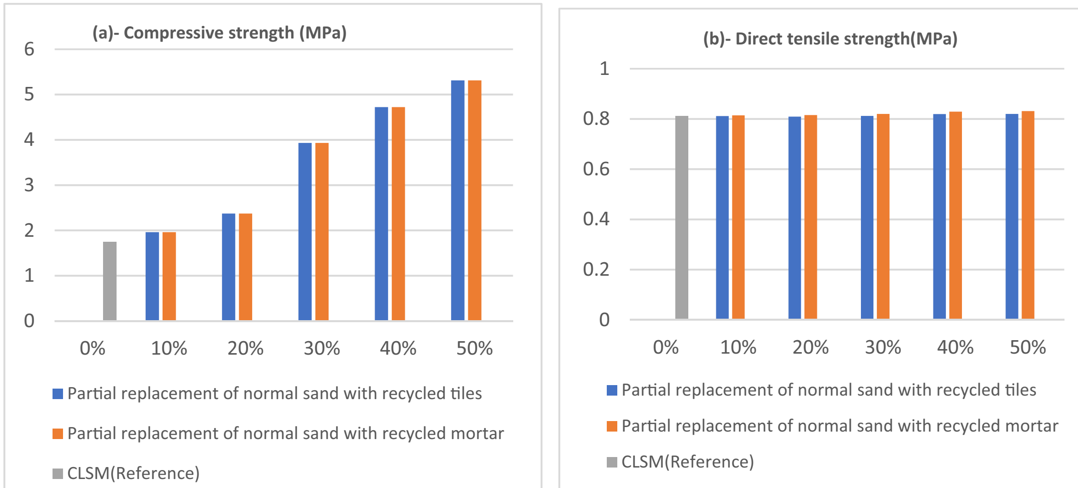


Figure 6: (a) Compressive strength (MPa). (b) Direct Tensile strength (MPa) at 60 days of all flowable fill material mixes.

4.4 Direct tensile strength testing

As depicted in Figure 8, the direct tensile strength test was performed in accordance with (B.S. 6319 part:7 1985) [36]. On specimens with an eight shape, a specific direct tensile device with a capacity of about 10 kN was employed to apply the load until it broke constantly. An average of three specimens (60 days of various replacement proportions) were used at each testing age. Compared to the reference, Figure 6b illustrates the slight increase in resistance with a rise in replacement ratio, which is higher in RM than in RC Similar findings were made by researchers, who found that substituting RM or RC for normal fine aggregate had a negligible impact on the splitting tensile strength [18,37,38]. When comparing the results for the age of 60 days with the control mixture, which was 0.812 MPa, there was a slight increase in accordance with the rise in the compensated ratio from 40 to 50% for RC and a significant boost for RM from 10 to 50%, respectively (0.86 and 0.99%) and (0.25, 0.37, 0.99, 2.1, and 2.34%). This result is similar to those of Solanki et al. [34], backed by academics Mahdi et al. and Abdulmunem [12,39]. Figure 9 displays the direct tensile strength percent variation ratio at 60 days.

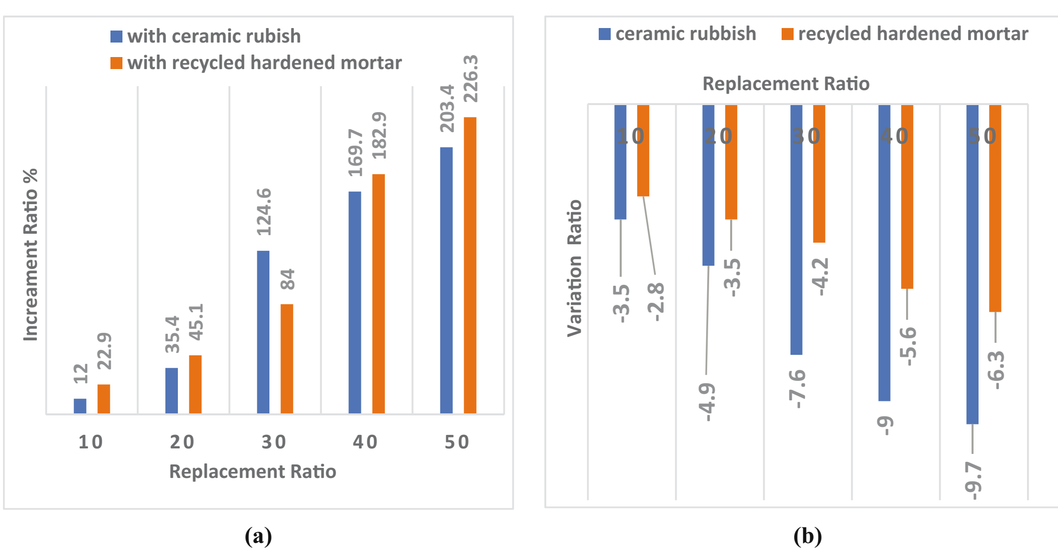


Figure 7: (a) Increment ratio percent in unconfined compressive strength at 60 days and (b) variation ratio percent in unconfined compressive strength at 28 days.

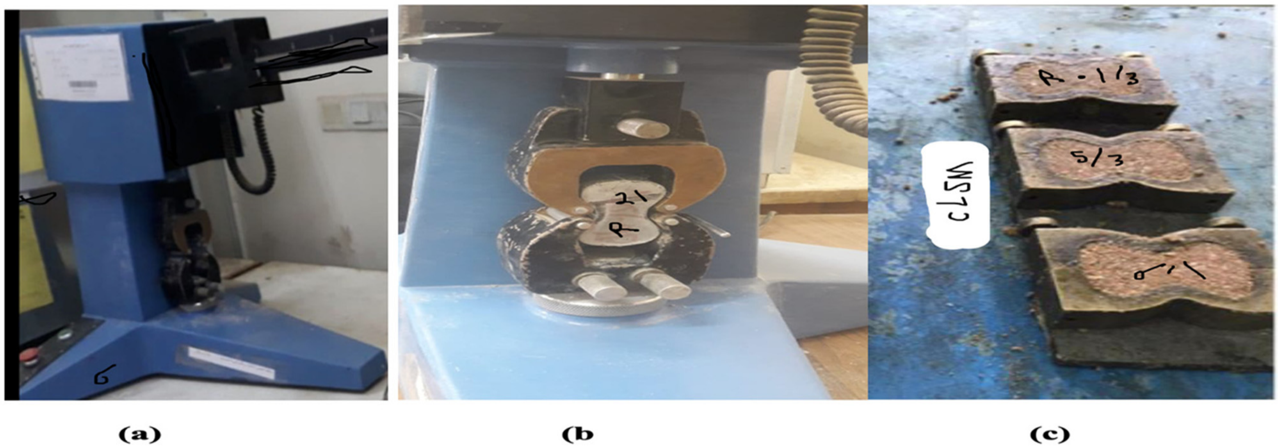


Figure 8: (a) Direct tensile strength machine. (b) Image of specimen is under test. (c) Image of the specimen in molds in the shape of eight.

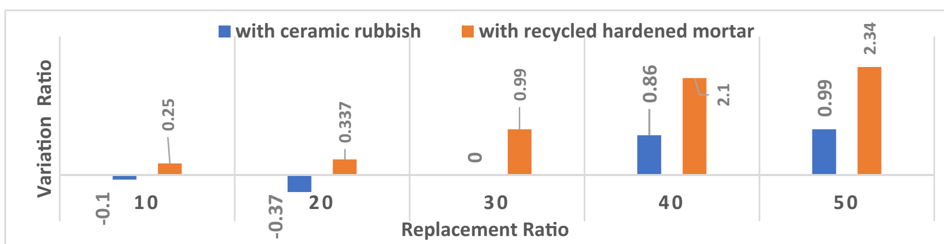


Figure 9: Variation ratio percent indirect tensile strength at 60 days.

4.5 Thermal conductivity

There is a strong relationship between CLSM's thermal conductivity and degree of saturation. This study compares the thermal conductivity of recycled flowable fill material from waste and ordinary all-flowable fill materials. Using the apparatus depicted in Figure 10, the thermal conductivity was calculated using the Lee disk method. Figure 11 shows that the proposed CLSM's thermal conductivity at 28 days was 1.133 W/m °C and that the saturation states and moisture content had a more significant impact on these values than the amount of binder. The highest value was 1.133 W/m °C for the reference mixture (regular flowable fill material CLSM), and a modest drop was seen when RFA (recycling waste hardened mortar and ceramic rubbish) was used in its place. The thermal conductivity of flowable fill material (CLSM) with recycled tiles (CT10, CT20, CT30, CT40, and CT50) varied in ranges of 1.127, 1.105, 1.094, 1.081, and 1.066 W/m °C, respectively. In contrast, the thermal conductivity of flowable fill material (CLSM) with recycled mortar (CM10, CM20, CM30, CM40, and CM50) varied in ranges of 1.13, 1.126, 1.115, 1.101, and 1.0.99 W/m °C. Perhaps one of the reasons for this decrease was the higher moisture content due to the increased absorption of recycled aggregate compared to normal aggregate [32,33,36]. The thermal conductivity of the mixture significantly decreased when the adjusted ratio for RC and RM increased from 10 to 50%. Mix CM50 with RM, and CT50 with ceramic trash are 3 and 5.9%, respectively.

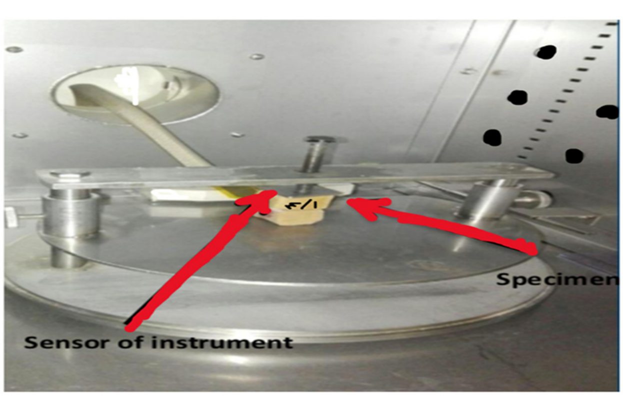
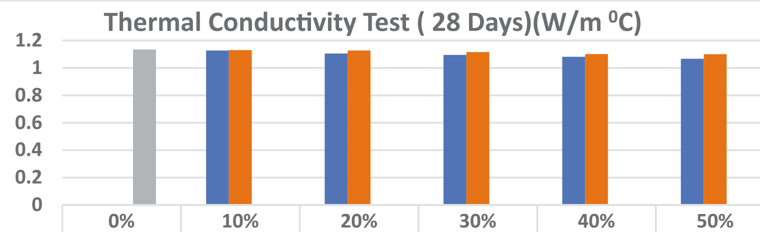


Figure 10: Thermal conductivity machine.



	0%	10%	20%	30%	40%	50%
Partial replacement of normal sand with recycled tiles	0	1.127	1.105	1.094	1.081	1.066
Partial replacement of normal sand with recycled mortar	0	1.13	1.126	1.115	1.101	1.099
CLSM(Reference)	1.133	0	0	0	0	0

Figure 11: Thermal conductivity test at 28 days.

5 Conclusion

The flowable fill material was subjected to laboratory tests to see whether replacing some of the usual aggregates with recycled mortar or ceramic would be feasible.

- The flowability was reduced with a rise in recycled aggregate percentage (RM% or RC%) in the produced mixture. All created flowable fill material mixtures nevertheless met the ACI 229R performance standard for good flowability grade for flowable fill material, which is a flowability of greater than 200 mm.
- With increasing curing ages, all the flowable fill material mixtures showed increased unconfined compressive strength. Despite utilizing less cement and recycled material, all proposed combinations' compressive and tensile strengths were measured and conformed to the strength requirements of re-excavation.
- In general, the replacement of conventional aggregates with RM and RC yields results that are comparable in terms of flow consistency, unit weight, compressive strength, and direct tensile strength; however, more research is required to determine the impact on setting time and other properties.
- The unit weight of the CLSM was reduced due to greater utilization of RM and RC. The porous nature of the mortar and ceramic waste grain causes this.
- Due to the delay of the pozzolanic reaction, the strength of mixes compensated with waste aggregate (RM and RC) is lower than that of the reference mixture before 28 days.
- The thermal conductivity was decreased, and, as a result, the capacity for thermal insulation was improved when normal aggregate was substituted with RFA (RM and RC). Because of the recycled composite's increased porosity and lower density, a drop in heat conductivity was expected.
- Finally, all mixes are good in terms of strength, united weight, and thermal conductivity so that waste materials (RM and RC) as acceptable aggregate replacement in flowable fill material production may assist in resolving a vital environmental problem

Because the results indicate a potential for using these forms of concrete in buildings, further study of these materials, or CLSM, fits into the idea of sustainable development.

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Data availability statement: Most datasets generated and analyzed in this study are in this submitted manuscript. The other datasets are available on reasonable request from the corresponding author.

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