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Properties of Controlled Low-Strength Material Mixes Made from Wastepaper Sludge Ash and Recycled Fine Aggregate

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Abstract: As demarcated in the American Concrete Institute (ACI 229R-13), CLSM stands for controlled low-strength material, which is a self-consolidating cementitious material that can be used as a backfill instead of compacted fill. However, the usage of CLSM in the construction industry was limited to backfilling, structural filling, void filling, and erosion control due to low compressive strength. On the other hand, using materials that can replace the material responsible for greenhouse gases has been promoted globally to halt the incidence of global warming instigated by releasing greenhouse gases, mainly CO_2, into the atmosphere. Waste paper sludge ash (WPSA) is one among them, and researchers have discovered that it can be used to substitute cement in the manufacture of CLSM effectively. In this research, CLSM were made using recycled fine aggregate (RFA) as fine aggregate and WPSA as cement replacement to determine the plastic and in-services properties of CLSM mixes made from both materials mentioned. For the plastic properties, the test included are flowability, bleeding and hardening test as for in-services properties, including the testing of density and compressive strength of CLSM produced. The testing of CLSM in terms of plastic and in-services properties was influenced by the water-to-cementitious ratio, WPSA replacement and total cementitious material. The flowability of CLSM is influenced by the amount of RFA and WPSA used in the design. The lower the water absorption, the more water will be absorbed and gives less bleeding. Therefore, different proportions of w/cm, WPSA replacement and total cementitious material of CLSM mixtures influence a product's plastic in-service properties. Its compressive strength was between 0.3 MPa to 4 MPa, which satisfied the backfill strength required by ACI 229R-13, and it can also be concluded that samples with higher cement content show higher compressive strength results than others.

Keywords: Controlled low-strength material, flowability, hardening time, bleeding, compressive strength

1. Introduction

Controlled low-strength material (CLSM) is a technology widely used in construction projects and is mainly produced from a combination of water, cement, aggregates, and adding additives to the mixtures improves performance [1,2]. According to the American Concrete Institute [3], CLSM can be called a self-consolidating material utilised as backfills. This is because of the materials' properties, enabling them to consolidate faster without extra compaction efforts. CLSM can be described as flowable fill, flowable mortar, soil-cement slurry materials, controlled density fill,

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and plastic soil-cement. The requisite strength depends on the applications that materials can be used for, depending on the materials' use. If it is for structural fillers, such as road pavement, the needed strength should be in the range of 2 MPa and above [3]. The allowable compressive strength for these materials should be between 0.3 and 0.7 MPa, equivalent to a well-compacted fill [4].

The tremendous growth in the manufacturing sector and production by developing countries saw leads to industrial waste accumulation and production speed. Based on the scheduled waste managed under the superior management for industrial waste generation in Malaysia in 2018, there were 879,844.03 metric tonnes in the system and for waste paper sludge ash (WPSA) was 4696.09 tonnes (0.53% of the total waste generated) by the Quality Environment Malaysia Report 2018, Department of Environment, Malaysia [5]. Ash from wastepaper will be sent to safe landfills. So far, landfill disposal is not a sustainable solution.

Construction challenges may grow because of scarcity and availability of the materials, limitations on establishing new resources, and increased manufacturing costs. The use of recycled aggregates (RA) will help overcome these problems [6–9]. RA may be generated as recycled concrete aggregate from the used concrete (RCA). Florea and Brouwers [10] stated that several European countries had to make lofty targets for the recycling of waste – amongst 50% and 90% of construction and demolition (C&D) waste, because of the costly waste disposal process, some of which are more expensive than recycling than in some instances. RCA has beneficial impacts in terms of climate and industry rather than natural aggregates (NA). NA consumption should also be maintained to mitigate the need to open up new mining areas to conserve the atmosphere [11]. When RCA's unit weight is lower than NA's, the energy intended to manage, RCA is less than that of NA for the same hauling distance. However, RCA's use reduces waste disposal, which generally ends in landfills [11,12]. Construction costs may also be minimised with RCA. The price of different RCA items for each ton (1000 kg) differs from $1 and $18 and varies in regions [13]. According to a report by the Environmental Council, accommodation is expected to save as much as 60% by combining NAs with RAs [14].

As population growth increased in Malaysia, this led to an increase in waste produced in the country. It is because population growth in the country means that more development will have occurred. This development includes opening new housing areas, office buildings, highway construction, and any other infrastructure. Therefore, C&D waste becomes one of the most considerable municipal wastes produced. According to the Construction Industry Development Board (CIDB), C&D waste contribute 30% of Malaysia waste. C&D waste mainly consists of pavement tar, concrete debris, ceramic or tiles and brick after processing [2]. As cited from The Star Online, some 66% (consisting of aggregate and crushed concrete), only 15% of this waste was collected by contracted waste management, and the remaining 85% remained uncollected. New projects and constructions do not produce C&D, but it also consumes massive natural resources [1]. There would be insufficient natural resources such as aggregates obtained from various natural resources, such as rivers. Therefore, these materials will be collected and crushed with the requirement to replace NA, such as producing CLSM.

Numerous WPSA recycling studies have been performed. Heo et al. [15] claimed that WPSA could be used as a lightweight embankment material, as the engineering characteristics are excellent compared to fly ash and soil. They also noticed that WPSA has no environmental concerns since the lime (CaO) proportion is nine times greater than fly ash, and the heavy metal toxic concentrations are smaller than the threshold set for this reason. The WPSA recycling research was conducted by Lee et al. [16] studied the consistency properties of concrete and clay mixed bricks as building materials. The physical and technical properties achieved through the use of cement mixing materials by WPSA and fly ash were evaluated by Seo [17]. The potential was assessed in [18] to stabilise the soil by improving clay tolerance using WPSA. Bujulu et al. [19] tested the viability of utilising WPSA as a supplement for quick-clay stabilising lime and cement and considered up to 50% of regular usage of lime cement to be substituted by WPSA. The WPSA corporation was verified by Ahmad et al. [20] by contrasting the compressive and tensile strength of the concrete, with which WPSA substitutes 5–20% cement and the strength of ordinary concrete as a concrete replacement. In contrast, between the curing time feature's compression strength, 50–100% WPSA replaces Ordinary Portland Cement (OPC). At 16.4 MPa, the inclusion of 50% WPSA improves the strength of the mortar. To fit lower strength mortar construction at 12.5MPa, 70% replacement may be used for economic, environmental mortar [21]. In its replacement of Portland cement, Ridzuan et al. [22] tested the mixing characteristics of RCA and WPSA and measured its strength based on its optimal content in WPSA (which generated the optimal strength). The strength of the WPSA and RCA mixtures is evaluated by Fauzi et al. [23] and Azmi et al. [24]. By utilising it as mixing materials and contrasting the mixes' strength, comprising them with mixtures comprising OPC, Bai et al. [25] and Mozaffari et al. [26] measured the applicability of WPSA and blast furnace slag.

Several kinds of research have shown that, by using recycled fine aggregate (RFA), the strength to compressive effects was significantly more accurate relative to the usage of the natural sand because of the RFA's more irregular and porous surfaces (which may contribute to a better area) that improve the interaction between aggregate and paste [27,28]. The fluid intake (hydration) between non-hydrated OPC particles in the RFA with moisture may also be a cause to improve strength with time [29]. Alike or stronger compressive strength was observed compared to control mortar containing NA in a mortar made of fine recycled masonry aggregate (FRMA) [30–32]. This improvement is attributed to the reaction that occurs over time between calcium hydroxide in cement paste and FRMA alumina/silica (Al_2O_3/SiO_2) [30–32].

CLSM was successfully tested for waste materials such as gas desulfurising materials, sand castings, wood ash, dry ash, and glass rolls [33]. Nevertheless, the reuse of industrial waste (WPSA and RFA) as CLSM has not been studied yet. Furthermore, concerns about the disposal of hazardous materials from the WPSA prevent researchers from considering the potential reuse of waste ash. The focus of this paper was to introduce a paradigm change in the fraternity of civil engineering to explore methods and means of industrial waste reuse. Therefore, the new research was conducted to evaluate the plastic and in-service properties of CLSM mixes produced from RFA and WPSA as sand and cement replacements and identify the appropriate mix proportions for low-strength materials used to produce CLSM for backfill materials using industrial waste materials.

2. Materials Collection

2.1 Binder Materials

Ordinary Portland Cement (OPC) - CLSM binder materials consist of OPC type I and have been added to the development of CLSM.

Waste Paper Sludge Ash (WPSA) - WPSA was collected in powder form, which is very similar to cement texture. WPSA is obtained from Asia Honour Paper Industries (M) Sdn. Bhd., Mentakab, Pahang. WPSA was partly and fully a cement replacer in this study, which acts as a binder in mortar mixtures. Therefore, WPSA has identical properties to cement, and Table 1 depicts the chemical composition of WPSA and OPC.

Table 1 - Chemical composition of WPSA and OPC

Binder material	Chemical composition (%)									
	Al_2O_3	SiO_2	CaO	Na_2O	P_2O_5	K_2O	Fe_2O_3	MgO	TiO_2	Loss of ignition
OPC	3.40	15.07	62.88	0.36	0.19	0.56	2.26	3.18	0.20	1.30
WPSA	12.10	20.46	54.20	0.21	0.28	0.42	0.82	0.40	0.32	17.23

2.2 Aggregate Materials

Concrete waste (cube samples) obtained from KTK Concrete Sdn. Bhd. at Kulim, Kedah. Most high-quality aggregate produced from concrete waste is used in concrete testing to prepare concrete mix since most of this material is made within strengths between 25 MPa to 30 MPa. The RFA was obtained by crushing the concrete or mortar waste from concrete waste (Fig. 1). As seen in Table 2, the properties (specific gravity, oven-dry specific gravity, bulk density, water absorption, and moisture content) of NA and RFA aggregates were tabulated, and Fig. 2 illustrate the particle size distribution analysis of RFA was utilised in the research. The sieve analysis testing used ASTM C 33/33M to identify the size, composition and grading of RFA.

Fig. 1 - RFA sieved passing 5 mm sieve

Table 2 - Properties comparison between NA and RFA

Aggregates	Specific gravity	Oven-dry specific gravity	Bulk density, kg/m^3	Water absorption, %	Moisture content, %
NA	2.78	2.73	1656.25	1.91	3.48
RFA	2.35	2.18	1375.49	5.84	9.10

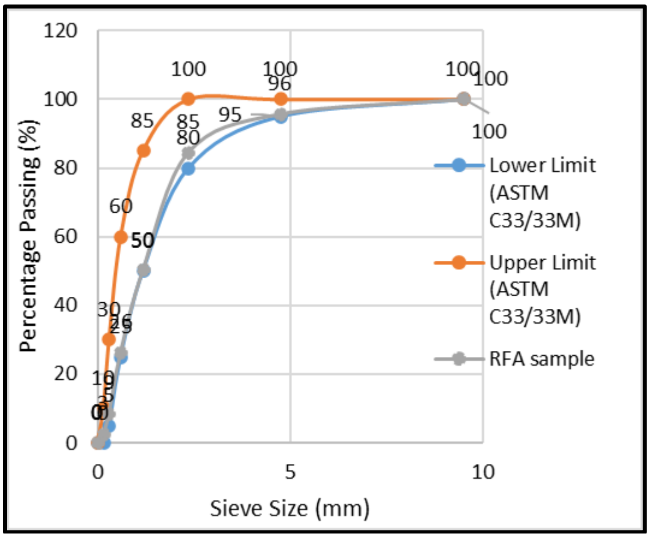

Fig. 2 - Particle size distribution for RFA samples obtained from sieve analysis

RFA's water absorption was conducted by referring to the gravimetric (pycnometer) method to determine the mass of water absorbed by RFA samples. The percentage of water absorption of RFA was shown using ASTM C 128. The water absorption rate of RFA obtained was 5.84% and higher than NA due to the RFA containing many particles or impurities when the concrete was crushed to a smaller size.

3. Experiment Programme

3.1 Parameters in the Research Study

The parameters included in this research are water-to-cementitious (w/cm) ratio, WPSA replacement, and total cementitious material. These parameters used as a benchmark to determine the plastic and in-services properties of CLSM produced. The effects of different w/cm, WPSA replacement and total cementitious effects in the mixtures were selected from the experimental results obtained from both testing's of CLSM in terms of plastic and in-services properties. Table 3 shown the various proportion of w/cm, WPSA replacement and total cementitious material. For the w/cm ratio, the range selected was between 2.37 to 2.73. As for WPSA replacement, the percentage of cement replacement with WPSA was between 33% to 117%, and for total cementitious material, the selected value was 160 kg/m^3 to 214 kg/m^3. The selection of these ranges based on the research gap of the previous study by the researcher on the application of CLSM.

Table 3 - CLSM mix proportion

Mix ID	w/cm	WPSA replacement (%)	Total cementitious materials (kg/m^3)	Cement (kg/m^3)	WPSA (kg/m^3)	Water (kg/m^3)	RFA (kg/m^3)
S1	2.53	50	160	80	80	405	1285
S2	2.73	50	160	80	80	437	1253
S3	2.53	100	160	0	160	405	1285
S4	2.73	100	160	0	160	437	1253
S5	2.37	50	200	100	100	473	1177
S6	2.57	50	200	100	100	513	1137
S7	2.37	100	200	0	200	473	1177
S8	2.57	100	200	0	200	513	1137
S9	2.37	75	180	45	135	427	1243
S10	2.71	75	180	45	135	487	1183
S11	2.54	33	180	121	59	457	1213
S12	2.54	117	180	0	211	457	1182
S13	2.71	75	146	37	110	396	1307
S14	2.42	75	214	53	160	518	1119
S15	2.54	75	180	45	135	457	1213

*Total density for each batch mix = 1850kg/m^3

3.2 Mixing preparation of CLSM

For the CLSM samples, there will be about 15 mixtures comprising various percentages of cement replacement, water content, fine aggregates and OPC, as shown in Table 3. Fig. 3 shows the materials used. In addition, the CLSM were tested, including the plastic and in-services properties based on ACI 229R-13 as shown in Figs. 4 and 5.

Fig. 3 - Materials preparation used for mixing of CLSM

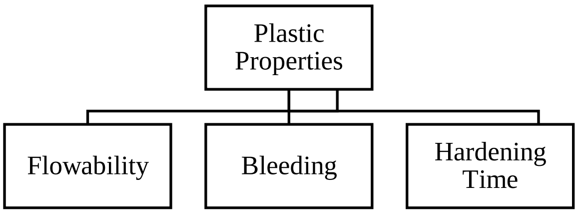

Fig. 4 - Testing of plastic properties of CLSM

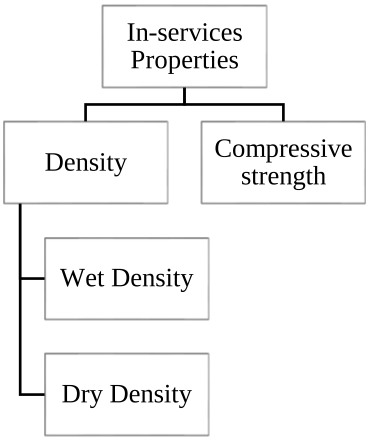

Fig. 5 - Testing of in-services properties of CLSM

3.3 Testing Procedures

Plastic properties - Flowability and bleeding are conducted to determine the performance of CLSM produced. Flowability was measured using ASTM D6103 by using an open cylinder of 75 mm x 100 mm. Bleeding test conducted using ASTM C940, in which the CLSM samples placed into a 1000 ml cylinder with a bulk of 800±10 ml. For hardening/setting time, the test was conducted to determine the duration needed by CLSM samples to change from wet state to dry (hardened) state. This test measured using ASTM C191, which was determined through penetration resistance on the mortar using a Vicat's apparatus.

In-service's properties - A density test was performed in governing the total mass of the fresh CLSM mixture. For the density test, the CLSM was measured in two states; wet and dry density. The wet density of concrete should be in the range of 1840 – 2320 kg/m^3 [34]. The density of CLSM was measured by referring to ASTM D 6023 using mould size 100 mm x 100 mm x 100 mm. Compressive strength tests one of the most significant tests to determine the strength of CLSM, which may vary according to the application or purposes of CLSM. The strength of CLSM had been stated in

ACI 229R-13; for high strength, CLSM normally results in compressive strength of 8.3 MPa. The excavatable CLSM has a maximum strength between 0.3 – 2.1 MPa. The compressive strength of CLSM was measured according to ASTM D 4832. For this testing, cylindrical moulds of size 50 mm x 100 mm used for casting CLSM. Fifteen (15) batched were prepared for this testing. CLSM samples' strength was tested for 3, 7 and 28 days using Universal Testing Machine (UTM) with a 0.5 mm/min loading rate for every mix ID prepared.

4. Results and Discussion

From Fig. 6, the flowability of CLSM samples varies with a different value of w/cm, WPSA replacement and total cementitious material. When the w/cm increases, the flowability will increases [35]. The flowability is highest when the value of w/cm is 2.54 and 2.57, with flowability of 340 mm. For the WPSA replacement percentage, the higher the percentage of WPSA higher the flowability since more water required as the WPSA has higher water absorption [36]. When WPSA utilise at 75% and 100%, increasing water content increase the flowability. As for total cementitious material, the highest flowability obtained is with the utilisation of the total binder at 180 kg/m^3 and 200 kg/m^3.

The bleeding rate of CLSM produced mainly affected by the amount of water content present in the mixtures. Based on Fig. 7, the CLSM tends to have a high bleeding rate when the w/cm ratio is equal to 2.57 as for the WPSA replacement 100% and the total binder are at 200 kg/m^3. Both RFA and WPSA have higher water absorption; therefore, more water will be absorbed and less bleeding. The impact of bleeding affecting the setting time of the CLSM. The less amount of water produced or 'bleed' by the mix design, the rate of hardening time will increase. The incorporation of RFA to CLSM also led to a higher bleeding rate due to the porous surface texture, and the angular shape of RFA retained additional initial water, which was later released to the top layer of the mixture after placement. But, when WPSA was used together with RFA, bleeding was reduced compared to the control mix. In contrast, lower bleeding values were obtained for mixtures containing WPSA, with a 100% replacement of the bleeding becoming insignificant.

From the comparison between Table 4 and Fig. 8, it can be concluded that samples S7, S8, S10, S12, S14 and S15 takes a shorter time to harden within 25 minutes. Meanwhile, sample S11 take the longest time to become set. The setting time of CLSM varies depending on the bleeding process of the design itself. Researcher such as [37] stated that the higher the RA in the mixtures, the higher the absorption of water in CLSM. On the other hands, the amount of cement replacement with WPSA also causing the same effects as the CLSM produced.

Table 4 - Summary result testing of CLSM samples

Mix ID	Plastic properties			In-service's properties				
	Flowability (mm)	Bleeding (%)	Hardening time (hr)	Density (kg/m^3)		Compressive strength		
				Wet density	Dry density @ 28 days	3 days	7 days	28 days
S1	275.0	0.0617	0.98	1597.10	1556.12	0.3300	0.8450	1.0050
S2	285.0	0.0617	0.51	1582.50	1591.84	0.6300	0.5750	0.8550
S3	252.5	0.0747	1.04	1580.40	1673.47	0.7400	0.8250	1.2550
S4	260.0	0.0746	0.44	1580.50	1640.31	0.5800	0.8250	0.9850
S5	285.0	0.0617	0.53	1693.80	1832.65	2.7050	2.4250	3.7850
S6	315.0	0.0624	0.52	1612.50	1750.51	1.0800	1.6050	2.7800
S7	330.0	0.0624	0.42	1968.30	1681.12	0.2305	0.2352	0.2201
S8	340.0	0.1247	0.42	1960.20	1618.88	0.1424	0.1428	0.1358
S9	337.5	0.0625	0.54	2005.00	1765.31	0.4371	0.5392	0.7754
S10	320.0	0.0623	0.42	2025.40	1773.47	0.7117	0.8081	0.7979
S11	317.5	0.0624	1.11	2033.40	1894.90	1.9484	1.8514	3.3954
S12	315.0	0.1244	0.42	1961.00	1556.12	0.2795	0.2548	0.3052
S13	267.5	0.0624	0.43	2046.50	1591.84	0.6033	0.5038	0.6134
S14	317.5	0.0624	0.42	1992.10	1673.47	0.8468	1.8813	2.4223
S15	340.0	0.0623	0.42	1969.60	1640.31	0.8031	0.8889	1.1042

Table 4 shows that the wet density is higher for the mixture ID S13 with 2046.50 kg/m^{3,} and the lowest is mixture ID S3 with a density of 1580.40 kg/m^3. By referring to Fig. 9, the w/cm, WPSA replacement percentage and total cementitious material are 2.71, 75% and 146 kg/m^3. At period 28 days, it is shown that the dry density is higher for mixture ID S11 with a density of 1894.90 kg/m^3. The RFA content for this mix ID is slightly higher than that of other mixtures; therefore, this contributes to the fresh density of CLSM. It is proven with the research conducted by [28], the density affected by RFA's percentage in the mix design as the density keeps decreasing with RFA's amount.

On the other hand, the higher the WPSA replacement in the mixture, the CLSM becomes lighter [20]. The density also affected by the partial or full replacement of cement inside the mixture of CLSM. It is notified that the density also affected by WPSA content in the CLSM mixture.

Table 4 shows that the highest compressive strength among the CLSM samples is sample S5 at 28 days with a value of the strength of 3.7850 MPa, respectively. For the lowest compressive strength, the mix design of S8 shown the most moderate strength with 0.1358 MPa for 28 days among all the mix design of CLSM. Based on the results, the compressive strength of CLSM depends on the percentage replacement of cement with WPSA. As a comparison, in Fig. 10, WPSA replacement was about 50% with total cementitious material of 200 kg/m^3 for mix ID S5 (highest compressive strength) meanwhile for mix ID S8 (low compressive strength) have WPSA replacement and total cementitious material of 100% and 200 kg/m^3 (no cement present) respectively. When the percentage of WPSA increases, the compressive strength of the CLSM decreases [38]. Mixture ID S8 showed that the strength keeps gradually decreasing within 3, 7 and 28 days. It is because the cement was utterly replaced with WPSA. The increment in the strength of CLSM produced depending on the high percentages of RFA because of the high amount of ceramics as the component [39]. The development of the strength of CLSM with WPSA will reduce water being used in the hydration process and pozzolanic activity used by this material which eventually affects the strength of CLSM. Higher the WPSA replacement, lower the strength of the materials produced. Overall, the results are considered acceptable as it complies with the ACI 229R-13 in term of the strength of CLSM.

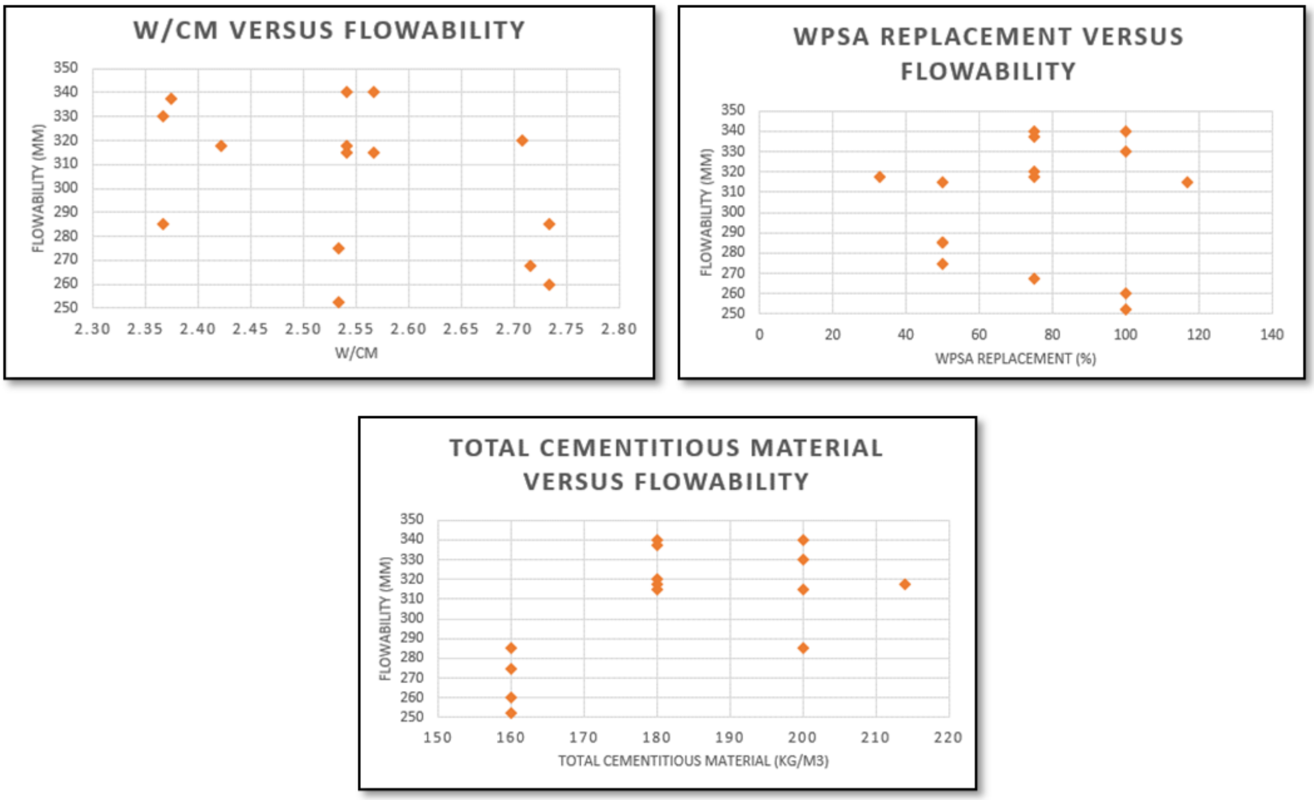

Fig. 6 - Variation of flowability with different parameters

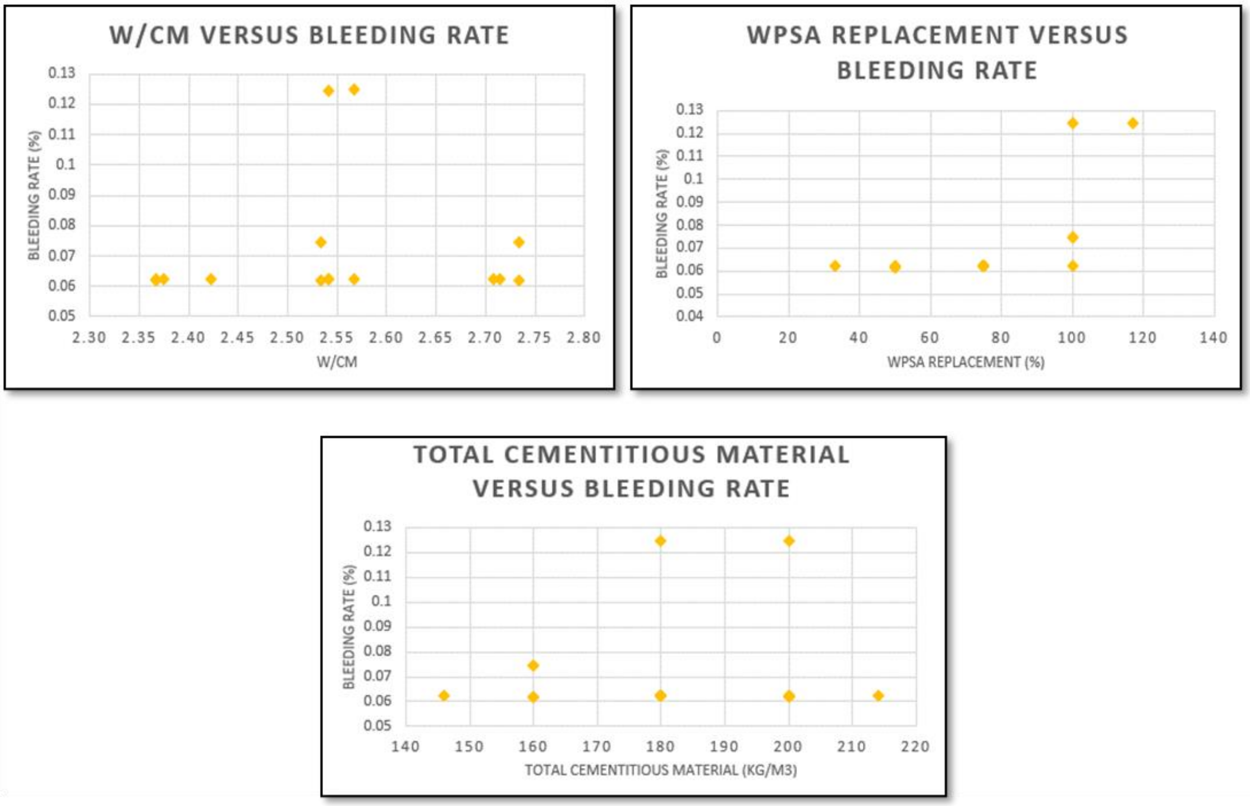

Fig. 7 - Variation of bleeding rate with different parameters

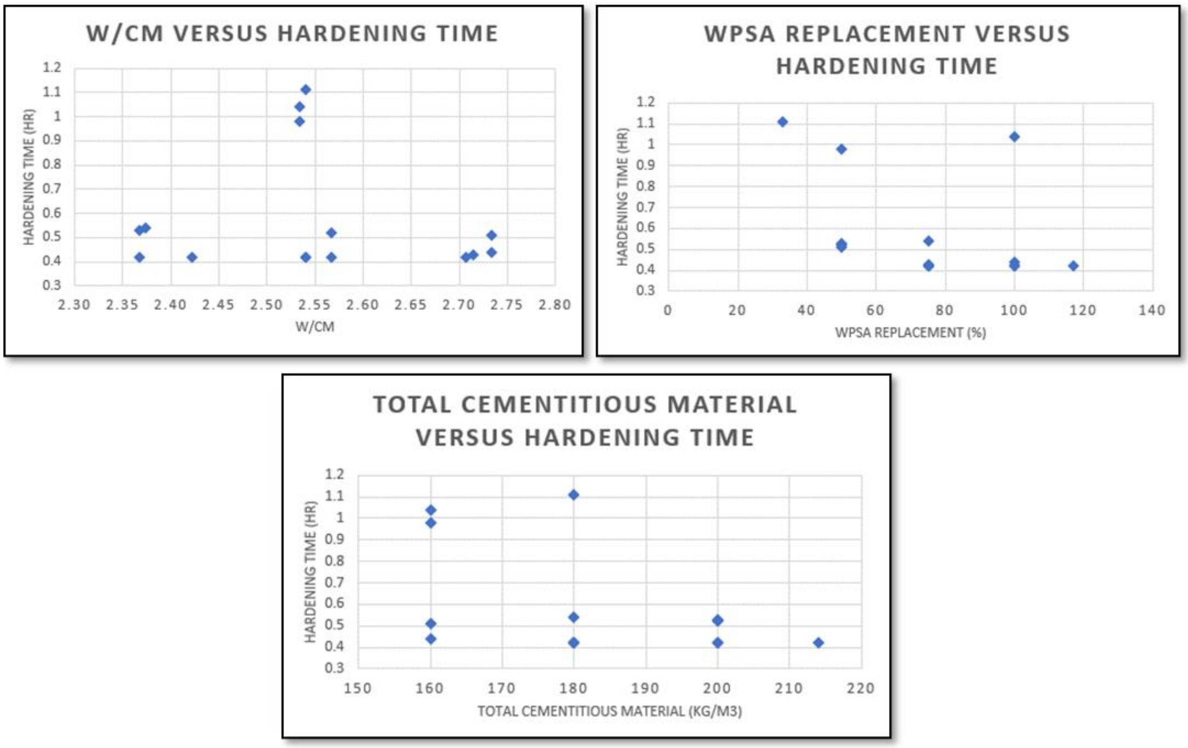

Fig. 8 - Variation of hardening time with different parameters

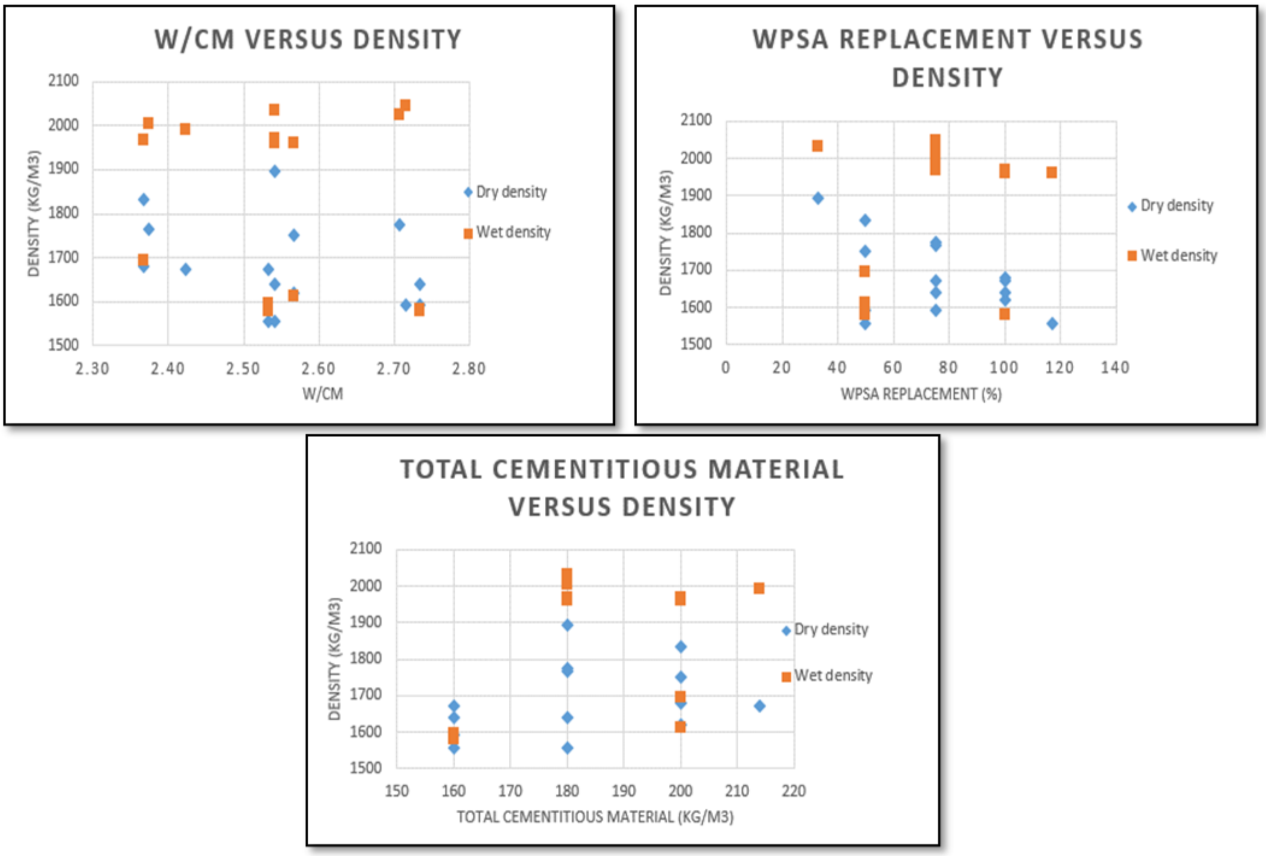

Fig. 9 - Variation of density with different parameters

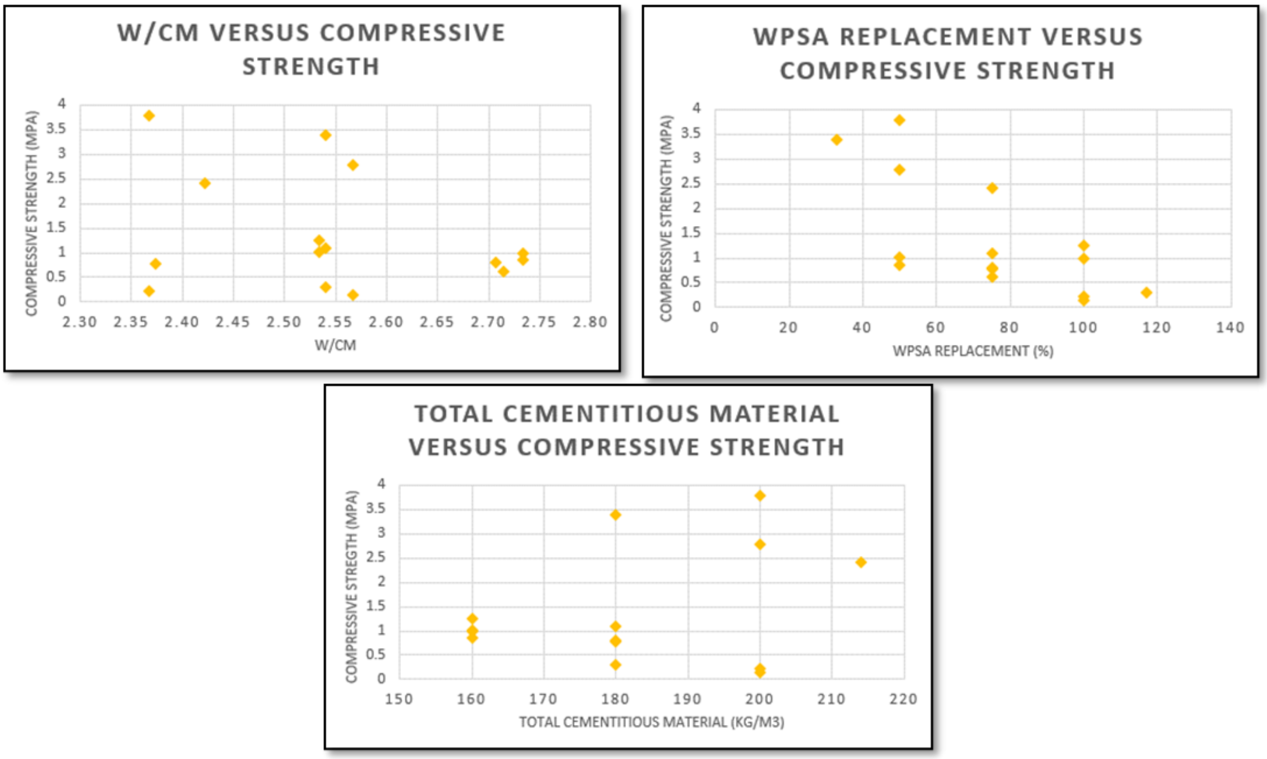

Fig. 10- Variation of compressive strength (28 days) with different parameters

5. Conclusions

A few conclusions can be made as follows, based on the result obtained;

- The flowability of CLSM obtained more significant than 200 mm, which has a higher flowability according to ACI 229R-13. The flowability is affected by the amount of RFA and WPSA used in the design. Both RFA and WPSA have higher water absorption; therefore, more water will be absorbed and less bleeding.
- The impact of bleeding affecting the setting time of the CLSM. The less quantity of water produced or 'bleed' by the mix design, the rate of hardening time will increase.
- The compressive strength of the CLSM design has been achieved at 3, 7 and 28 days of curing. The strength obtained was between the range of 0.3 MPa to 4 MPa which satisfied the compressive strength ACI 229R-13. The lower the WPSA content in the design mix, the higher the compressive strength of the CLSM. Sample with higher cement content will produce higher compressive strength as it can be notified on the compressive strength results attained.
- From this research, the utilisation of WPSA and RFA in CLSM was affected by the various w/cm ratio, WPSA replacement and total cementitious material of CLSM mixtures.
- Different proportion of w/cm, WPSA replacement and total binder content gives different results in terms of plastic and in-services properties of CLSM produced.

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