International Journal of Innovative Science and Modern Engineering (IJISME)
ISSN: 2319-6386, Volume-5 Issue-2, February 2018

Effect of Limestone Filler and Waste Ceramic Tile Aggregates on the Workability of Self-Compacting Concrete

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***Abstract:** During the period between 1990 to 2017, self-compacting concrete (SCC) has been developed to reduce workmanship errors and improve the durability of the concrete. Despite many benefits of the self-compacting concrete, its cost still remains high, due to the high proportion of the cement required. To mitigate this issue many researchers urged the use of mineral additions as partial replacement of the cement. On the other hand, the management of the solid waste is a global concern in every country nowadays. The fact that there currently lacks a universally acceptable strategy for recycling ceramic waste is significant. The physical and chemical properties of the waste ceramic make it suitable for the concrete production. This study assessed the effect of partial replacement of the cement the limestone filler (LF) at 0%, 10%, 15%, 20%, and 25% and replacement of the natural coarse aggregate with the waste ceramic tiles aggregates (WCTA) at 25%, 50%, 75%, and 100% within the validity range of self-compacting concrete properties at the fresh state. Sika Viscocrete 3088 was used to assess the saturation dosage of the superplasticizer. The flowability, viscosity, passing ability and resistance to segregation of self-compacting concrete containing the limestone filler and waste ceramic tile aggregates were assessed. The results showed that the saturation dosage of the superplasticizer Sika Viscocrete 3088 is 0.07% in solid content. Furthermore, high proportion of waste ceramic tile aggregates (75%) with optimum percentage of limestone filler (20%) satisfy the properties of SCC in the fresh state.*

***Keywords:** Limestone Filler, Self-Compacting Concrete, Superplasticizer, Waste Ceramic Tile Aggregates, Workability.*

I. INTRODUCTION

Self-compacting concrete (SCC) is a fluid concrete that is able to flow in congested reinforcements, filled esthetic molds and restricted sections under its own weight without any external and internal vibrations. The workability of self-compacting concrete must satisfy a good viscosity, filling ability, passing ability, resist to segregation, and bleeding. A good self-compacting concrete remains homogeneous and stable during the mixing, transportation, placing, finishing and curing. To ensure this workability, the use of super plasticizer is necessary but it is more expensive than any other material in the concrete. Hence the necessity to increase the amount of cement. High cement content in concrete causes bleeding and thermal shrinkage and it is neither economic nor environmental. To mitigate the environmental impact of the cement in order to produce a green concrete, many researchers and the latest European Standard EN 206/CN urge the use of mineral additions such as limestone filler (LF), fly ash, natural pozzolana, metakaolin, silica fumes, and ground granulated-blast furnace slag. The incorporation of the mineral additions improves the properties of the concrete in the fresh and hardened states [1], [2], [3], [4].

The demand of the concrete is increasing day by day due the increase of the population in the world. Hence the increase of the demand of natural coarse aggregate which represent up to 80% of the concrete. The wastes from Construction and Demolition (C&D) represent 75% of the worldwide waste of which the waste of ceramic materials represents 54%. The management of the waste ceramic is a big concern for all the ceramic companies and suppliers and there is no process of recycling the waste ceramic up to present days [5].

The most critical point of a successful self-compacting concrete is to achieve its characterization in the fresh state. The study investigated the effect of the limestone filler and waste ceramic tile aggregates (WCTA) on the workability of self-compacting concrete. The limestone filler was substituted with the cement at 10%, 15%, 20% and 25% whereas the natural coarse aggregate was replaced with the waste ceramic tile aggregates at 25%, 50%, 75% and 100%. The mix design adopted for this research is referred to the Formulation and rheology of eco-self-compacting concrete (Eco-SCC) developed in the university of Tlemcen, Algeria [4]. The saturation dosage of the superplasticizer was assessed. Furthermore, the compacity of the binary and ternary mixtures of the dry aggregates (sand, coarse aggregate, and waste ceramic tile aggregates) were evaluated. Fourteen mixes of self-compacting concrete were prepared and their workability was evaluated by the Slump flow, V-Funnel, L-Box and Sieve Resistance tests.

II. MATERIALS

All the materials: cement, limestone filler, super plasticizer, sand, coarse aggregate and waste ceramic tile aggregates used for this research are local (Kenya) and the experimental works were carried out in the Materials and Structural Engineering Lab in JKUAT.

Revised Version Manuscript Received on January 15, 2018.

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A. Cement

Bamburi Power Plus 42.5 N cement from Mombasa was used in this study. Bamburi Power Plus is a CEM I for early high strength and conforms to the specification EN 197-1. Its specific gravity is 3197 Kg/m^3. The chemical composition of Bamburi Power plus is reported in Table I.

Table I. Chemical Composition of Bamburi Power Plus 42.5

Parameters	Percentage (%)
SiO_2	20.61
Al_2O_3	5.05
Fe_2O_3	3.24
CaO	63.37
MgO	0.81
SO_3	2.75
Na_2O	0.15
K_2O	0.52
Free CaO	0.63
Na Eq.	0.49
Cl-	< 0.01
LOI	2.90
I.R.	1.00
C_3A	7.91

B. Limestone filler

The commercial name of the limestone filler used in this research is MELWIT 16 from Mineral Enterprises LTD, Athi River, Kenya. MELWIT 16 is a natural calcium carbonate powder manufactured from high purity white limestone. Its water absorption is 0.81% and its particle size distribution is ranging from 0.523 to 186 micrometers. The characterization of the limestone filler is based on its calcium carbonate content, Methylene Blue test (MB), specific area and granularity. MELWIT 16 is classify as limestone filler Category B which is entitled to be used with CEM I according to EN 206/CN [6]. The specific area and the chemical composition of the limestone filler were provided by the manufacturer, see Table II. The characterization of the limestone filler according to EN 206/CN is reported on Tables III and IV.

Table II. Chemical Composition of the Limestone Filler

Parameters	Percentage (%)
$Al_2Si_2O_3$	12.2
Fe_2O_3	0.3
$CaCO_3$	85.5
MgO	0.9
TiO_2	0.5
Brightness	93
Moisture content	0.2
pH	8.9
Oil absorption	23
Acid insoluble	0.2

Table III. Parameters of the Limestone Filler Category B

Parameters of Category B	Results	Limit
$CaCO_3$ (%)	85.5	≥ 65
Methylene Blue (g/Kg)	0.1	< 10
Specific surface (m^2/Kg)	290	> 220

Table IV. Granularity of the Limestone Filler

Passing Percent	Results	F_M
through 0.063 mm sieve	86.2	> 70
through 0.125 mm sieve	98.7	> 85
through 2 mm sieve	100	100

C. Superplasticizer

In this study, the 3rd generation superplasticizer called Sika Viscocrete 3088 from Semco Industrial Park, Kenya was used. This High Range Water Reducer (HRWR) is an aqueous solution of modified polycarboxylate (PCE) based and it is a yellowish liquid with a solid content of 26%. It has a density of 1.06 Kg/l with a pH value of 5.5 ± 0.5. This superplasticizer is conformed to EN 934-2 with a dosage between 0.2 – 2.0% by weight of cement/binder.

D. Sand

Meru river sand with particles size 0/4.75 mm was used in this study. This fine aggregate has a finesse modulus value of 2.3, sand equivalent value of 94.89%, silt content value 5.41% and Methylene Blue value of 0.06. The above results proved that this sand is suitable for the production of hydraulic concrete. The particle size distribution of the sand is reported in Table V. Other physical properties of the sand such as bulk density (in SSD condition), apparent and absolute densities (in Oven-dry condition) and water absorption are summarized in Table VI.

E. Coarse Aggregate

Local coarse aggregate (CA) from Mlolongo quarries (Kenya) was used. The coarse aggregates have a maximum particle size of 10 mm with a finesse modulus of 5.83. The cleanliness of the coarse aggregate known in French as “Propreté des granulats” is 1.95% which is below the limit 5% according to NF P 18-597. The physical properties of the coarse aggregate are reported to Table VI whereas the particles size distribution is highlighted in Table V.

F. Waste Ceramic Tile Aggregates

The waste ceramic tiles are brought from local construction sites in Juja, Kenya. The waste ceramic tiles were crushed into aggregate size and were sieved through 10 mm sieve in order to have the same dimension of the coarse aggregate. The waste ceramic tile aggregates have a white plain color and it is in the category of white paste ceramic based on the source of the raw materials. As the waste ceramic tile aggregates was replacing the coarse aggregate so its physical properties were determined in the same way as the coarse aggregate. The finesse modulus of the waste ceramic tile aggregates was 5.82 whereas its cleanliness was 0.6% hence the waste ceramic tile aggregates was used directly in this study without any washing process. The particle size distribution of the waste ceramic tile aggregates is summarized in Table V. The loose and rodded bulk densities, the apparent and absolute densities, and water absorption of the waste ceramic tile aggregates were reported in Table VI.

Table V. Particles Size Distribution of the Aggregates

Sieve Size (mm)	Percentage Passing		
	Sand	CA	WCTA
10.00	-	98.74	82.06
4.75	100	15.53	21.08
2.36	97.10	2.27	11.39
1.20	89.25	0.45	2.75
0.60	49.76	0.23	0.64
0.30	28.06	0.20	0.51
0.15	1.43	0.00	0.13

G. Water

The water used for the production of self-compacting concrete in this research is the drinkable tap water of the University (JKUAT).

III. EXPERIMENTAL PROGRAM

The mix design adopted for this research is referred to the Formulation and Rheology of Eco-Self-Compacting Concrete developed by Dr. Taleb *et al,* in 2016 in University of Tlemcen, Algeria. In this study, the exposition class XF1 according to EN 206/CN was adopted. The experimental plan is divided into 3 phases: the saturation dosage of the superplasticizer of the paste, the optimization of the aggregates and workability of the self-compacting concrete.

A. Saturation Dosage of the Superplasticizer

Cement, water, limestone filler, and superplasticizer were used to assess the saturation dosage of the superplasticizer on the paste. The pastes were prepared in a mortar mixer. A mini cone placed at the center of a plate was filled with the paste then lifted vertically to let the paste flow. The final spread of the flow (fluidity) was recorded. As per the adopted mix design, the fluidity of the cement paste noted SR1 was assessed. Then the fluidity of the pure limestone filler paste noted SR2 by varying water to LF ratio such that SR1 = SR2 was determined. The above tests were carried out on the proportion of the cement and limestone filler of 1 Kg and without the superplasticizer. Five mixes were evaluated with different percentages of the limestone filler: PLF00 (reference paste), 10%, 15%, 20% and 25% of the limestone filler noted respectively PLF10, PLF15, PLF20, and PLF25. The saturation dosage of the superplasticizer was found by trial within the range given by the manufacturer (SIKA Kenya) from 0.2 to 2.0% by weight of cement/binder.

Table VI. Physical Properties of Aggregates

Aggregates	Loose Bulk density (Kg/m3)	Rodded Bulk density (Kg/m3)	Apparent density (Kg/m3)	Absolute density (Kg/m3)	Water absorption (%)
Sand	1440	1590	1470	2650	1.3
CA	1240	1420	1330	2520	4.5
WCTA	1330	1490	1430	2370	1.4

B. Optimization of Aggregates

The optimization of the sand, coarse aggregate and waste ceramic tile aggregates were evaluated with LCPC shaking table No. 61 [7]. First the compacity of the binary mixture of the dry aggregates (Sand and coarse aggregate) was assessed in two modes without and with compaction. Then the packing factor (PF) was deducted by the ratio of the compacity in the vibration (compaction) mode to the compacity without vibration.

Once the optimum of the binary mixture of the sand and coarse aggregate was determined, for the ternary mixture, the coarse aggregate was replaced with the waste ceramic tile aggregates at 25%, 50%, 75%, and 100% whereas the quantity of the sand remained constant in the total aggregates and the same procedures of the binary mixture mentioned above were repeated.

C. Workability

The flow ability, viscosity, passing ability and resistance to segregation of fourteen mixes of self-compacting concrete were evaluated by using the Slump flow test, V-Funnel test, L-Box test, and Sieve segregation resistance test respectively. In these tests, there were 3 references concretes. SCCLF00 (0% limestone filler) was the reference of the four mixes: SCCLF10, SCCLF15, SCCLF20, and SCCLF25 (10%, 15%, 20%, and 25% limestone filler respectively) with the same total binder dosage of 520 Kg/m^3. SCCLF00* was the reference of SCCLF10*, SCCLF15*, SCCLF20*, and SCCLF25* with 10%, 15%, 20%, and 25% of the limestone filler respectively at 600 Kg/m^3 as total binder. In the case of the incorporation of the waste ceramic tile aggregates, the quantity of the limestone filler was fixed at 20% of the total binder. The reference of SCCWC25, SCCWC50, SCCWC75 and SCCWC100 (25%, 50%, 75%, and 100% of waste ceramic tile aggregates respectively) was SCCLF20* as it has also 20% of limestone filler (600 Kg/m^3 dosage of binder) with 100% natural coarse aggregate.

IV. RESULTS AND DISCUSSIONS

A. Influence of the Limestone Filler

The results on the fluidity of the pastes in Table VII indicated that for the same water to cement/limestone filler ratio value, the fluidity of the limestone filler paste increased. However, the water demand of the limestone filler for the same fluidity of the cement paste decreased. These results conformed the other results found in literature [4]. The incorporation of the superplasticizer increases the fluidity of the paste with constant W/C and W/LF. Furthermore, the substitutions of the cement with the limestone filler increase the fluidity of the paste for the same percentage of the superplasticizer and can be clearly seen on.

Fig. 1 beyond 0.05% dosage of superplasticizer. This observation can be explained by the contribution of the limestone filler to fill the interparticle micro pores of the paste thus increase the amount of free water that participate in the fluidity of the paste.

The substitution of the cement with the limestone filler at the saturation dosage, PLF15 and PLF25, at 15% and 25% have significant fluidity 301 mm and 305 mm respectively compare to the reference PLF00 which has only 249 mm. As portrayed in Fig. 1, beyond 0.08% dosage of the superplasticizer in solid content, there was a total loss of fluidity of the paste except PLF25 which lost its fluidity just after 0.07%. The saturation dosage of the superplasticizer Sika Viscocrete 3088 with the cement CEM I was found at 0.07% in solid content which is equivalent to 0.27% by weight of binder. At the saturation dosage, the cement particles are saturated by adsorbing the polycarboxylate polymer molecules of the superplasticizer and further addition of the superplasticizer does not have significant increase of the fluidity or leads to total loss of consistency of the paste. These results fall in the range provided by the manufacturer [0.2 to 2.0% by weight of cement/binder].

Table VII. Fluidity of the Cement and Limestone Filler Pastes

Parameters	Cement paste	Limestone filler paste		Cement paste	Limestone filler paste	
W/C or W/LF	0.35	0.35	0.30	0.43	0.43	0.36
Spread Dmax (mm)	137	210	137	236	310	236

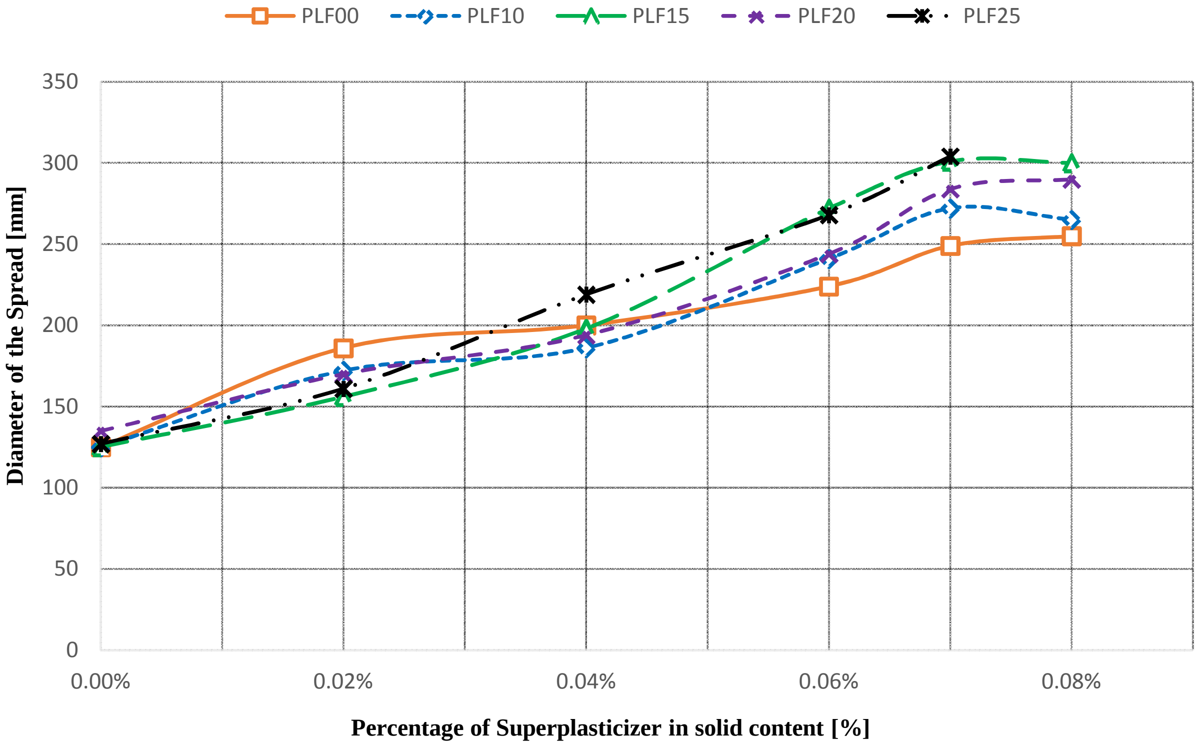

Figure 1. Influence of the Limestone Filler on the Paste for Self-Compacting Concrete

B. Compacity of the Dry Mixture of Aggregates

As depicted in Fig. 2, the results of the compacity of the binary dry mixture of the sand and the coarse aggregate showed that the optimum compacity (maximum compacity) was in the mode without compaction 0.624 which correspond to 50% of sand in the total aggregate and 0.688 at 60% (S/(S+G)) in the mode with compaction. We observed that the optimum is the range at the apex of the two curves (50% to 70%) In this study, the coarse aggregate to sand ratio (G/S) is taken as 1 which means 50% of the sand and 50% of coarse aggregate of the total aggregates was used.

As portray in Fig. 3, the optimum compacity of the ternary mixture was found at 50% waste ceramic tile aggregates (0% coarse aggregate) and 50% sand was 0.647 without compaction and 0.704 in the mode with compaction. From these results, we concluded that the compacity in both modes of the waste ceramic tile aggregates is higher than the one of the natural coarse aggregate. This observation can be explained by the fact that the regular shape of the ceramic tiles facilitates their packing thus decrease the pores. The packing factor of the binary and the ternary mixture are deducted from the above results. The proportion of the sand, the coarse aggregate, and the waste ceramic tile aggregates in self-compacting concrete based on the referred mix design [4] is proportional to the packing factor. The increase of the packing factor increases the quantity of the aggregates in the concrete, see Table VIII.

Table VIII. Mix Proportion of SCC

Mix N°	Mix ID	PF	Cement (Kg/m^3)	LF (Kg/m^3)	Sand (Kg/m^3)	CA (Kg/m^3)	WCTA (Kg/m^3)	Water (l/m^3)	Sp (Kg/m^3)
1	SCCLF00	1.080	520	0	778	670	0.0	262	1.40
2	SCCLF10	1.080	468	52	778	670	0.0	259	1.40
3	SCCLF15	1.080	442	78	778	670	0.0	257	1.40
4	SCCLF20	1.080	416	104	778	670	0.0	255	1.40
5	SCCLF25	1.080	390	130	778	670	0.0	253	1.40
6	SCCLF00*	1.080	600	0	778	670	0.0	297	1.62
7	SCCLF10*	1.080	540	60	778	670	0.0	292	1.62
8	SCCLF15*	1.080	510	90	778	670	0.0	290	1.62
9	SCCLF20*	1.080	480	120	778	670	0.0	288	1.62
10	SCCLF25*	1.080	450	150	778	670	0.0	286	1.62
11	SCCWC25	1.087	480	120	783	505	170	284	1.62
12	SCCWC50	1.088	480	120	783	337	337	278	1.62
13	SCCWC75	1.089	480	120	784	170	506	273	1.62
14	SCCWC100	1.090	480	120	785	0.0	725	268	1.62

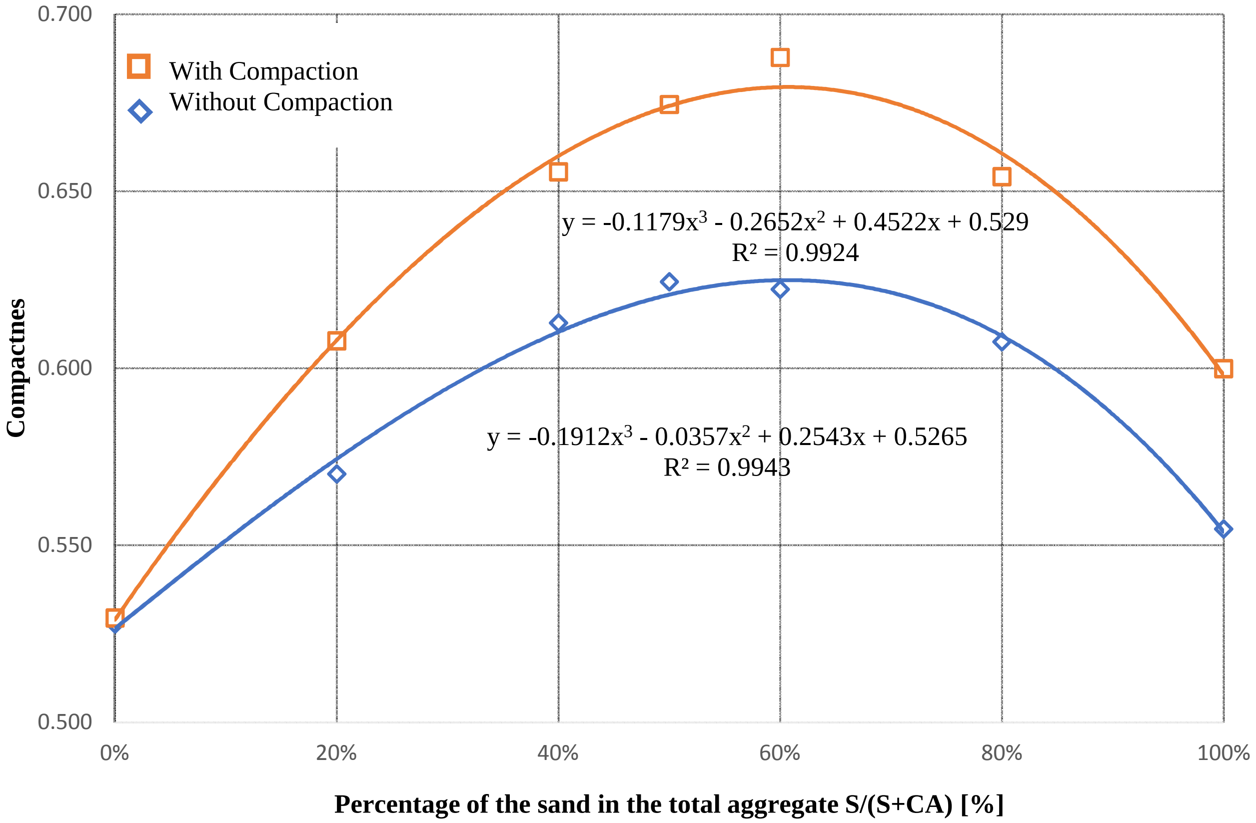

Figure 2. Evolution of the Compacity of the Binary Mixture

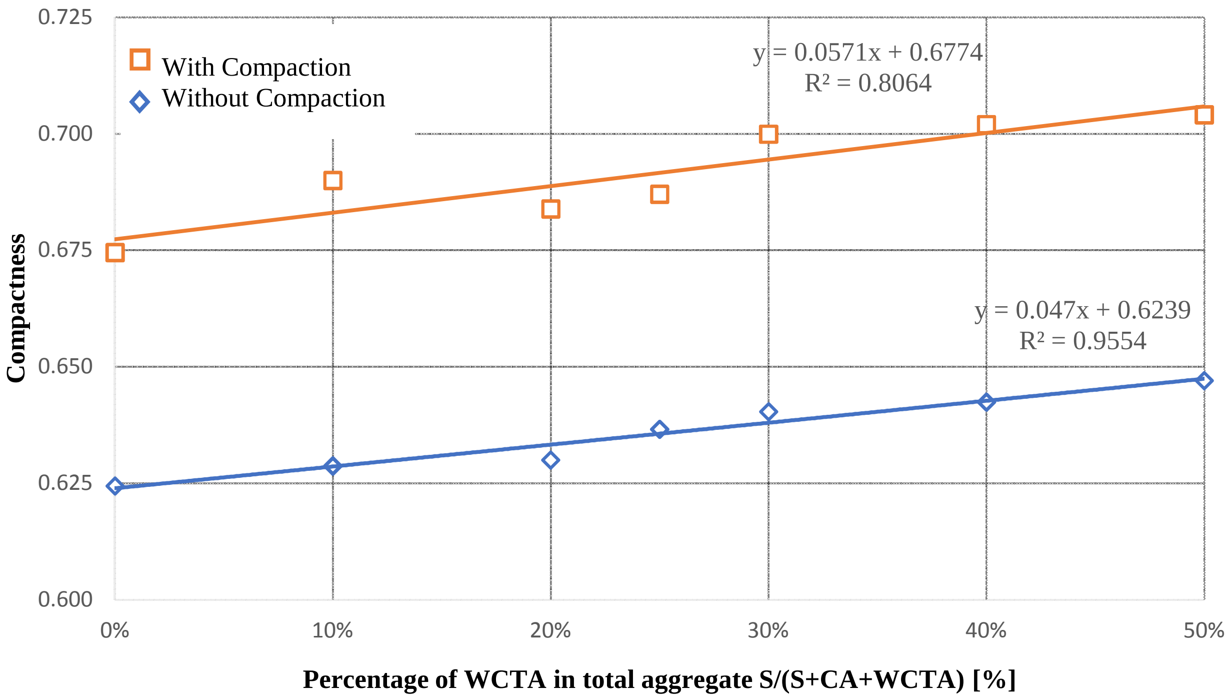

Figure 3. Evolution of the Compacity of the Ternary Mixture

C. Slump Flow

The flowability of the SCC was evaluated with the Slump flow (SF) test. The substitution of the cement with limestone filler at all the percentage showed an increase of the flowability of the concrete, see Fig. 4. For the dosage of binder at 520 Kg/m^3, we observed a low flowability for the mixes, 500 mm to 595 mm. Hence the increase of the dosage of the binder up to 600 Kg/m^3 and the flowability increases from 615 mm to 720 mm.

Further, the increase of the waste ceramic tile aggregates slightly increases the flowability of the concrete from 635 mm to 685 mm compared to the reference SCCLF20* except SCCWC25 where we observed only 595 mm, see Table A1 in the appendix. This slight increase of the flow can be explained by the light density of the waste ceramic tile aggregates which can flow easily in the paste without any obstructions.

D. V-Funnel

The viscosity of the SCC was carried out using the V-Funnel (VF). The results in Fig. 5 indicated that the incorporation of the limestone does not significantly affect the viscosity time of the self-compacting concrete. However, we observed a slight increase of the viscosity time with the increase of the waste ceramic tile aggregates, 4 to 5s compared to the reference concrete SCCLF20*. The viscosity time of the V-Funnel test is an indicator of the plastic viscosity of the self-compacting concrete. The increase of the viscosity time increases the plastic viscosity thus increase the cohesion between the aggregates and paste. This observation can be explained by the increase of the friction with the increase of the proportion of the waste ceramic tile aggregates.

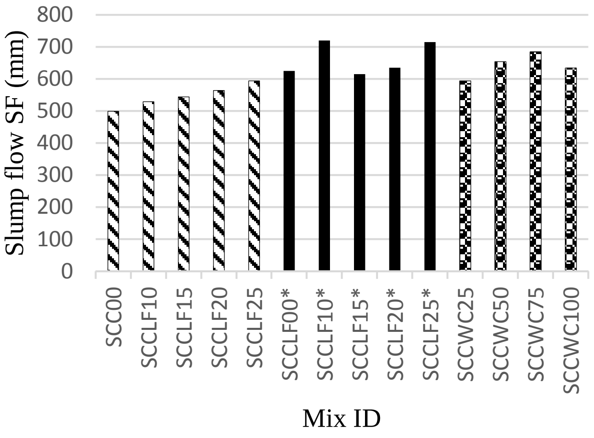

Figure 4. Evolution of the Flowability

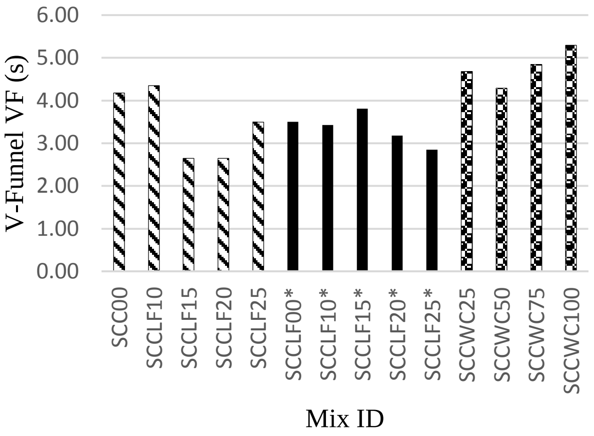

Figure 5. Evolution of the Viscosity Time

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E. L-Box

The passing ability of the self-compacting concrete was assessed with L-Box (PL2). As depicted in Fig. 6, the results showed that for the dosage at 520 Kg/m^3, all the mixes failed the test (< 0.80) even with the presence of the limestone filler. At 600 Kg/m^3, the increase of the limestone filler increases the passing ability of the concrete from 0.83 for the reference SCCLF00* to the peak at 0.93 (SCCLF15*) then decrease to 0.82 (SCCLF25*). Due to the filling ability of the micro pores of the limestone filler, the passing ability improved up to 15% of limestone filler in the total binder then decrease due to excess amount of the limestone filler where the friction within the fine particles becomes significant (Van Der Wiel forces).

On the other hand, we observed that the waste ceramic tile aggregates decrease the passing ability of the concrete. Only SCCWC75 meets the requirement of the test. This reduction of the passing ability is due to high friction between the waste ceramic tile aggregate that tend to block in the presence of the obstacle/reinforcement thus decrease the passing ability of self-compacting concrete.

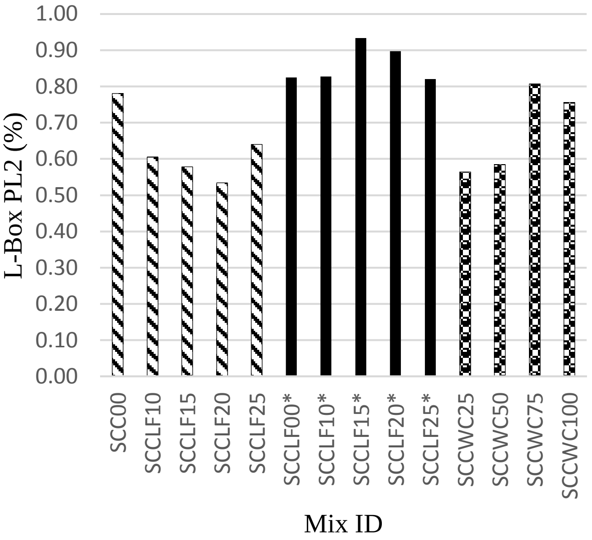

Figure 6. Evolution of the Passing Ability

F. Sieve Resistance

The stability of the SCC was evaluated with the Sieve Resistance to segregation test. The results in Fig. 7 showed that all the mixes are stable and have a good resistance against the segregation and the bleeding. The incorporation of the limestone filler and the waste ceramic tile aggregates have no significant effect of the stability of the self-compacting concrete (limit is 15%). This observation can be explained by the homogeneity of the self-compacting concrete between the concrete constituents i.e. a good cohesion between the aggregates and the paste. All the results of the workability: Slump flow (SF), V-Funnel (VF), L-Box (PL2), and Sieve resistance (SR) tests are summarized in Table. A1 in the appendix.

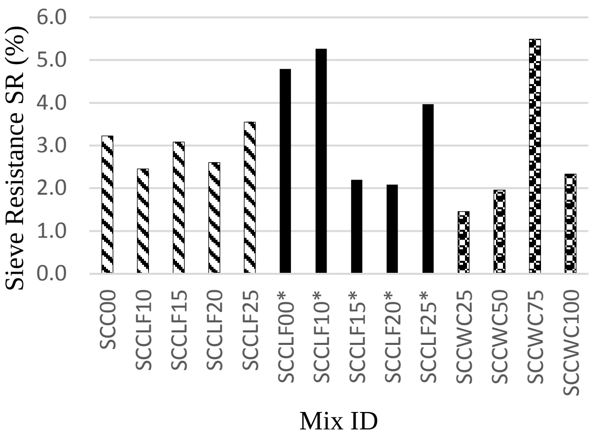

Figure 7. Evolution of the Resistance to the Segregation

V. CONCLUSION

Based on the results of the experimental program, the following conclusion can be drawn:

- The incorporation of the limestone filler increases the fluidity of the paste up +22.5% when close to the saturation dosage. The water demand of the limestone filler for the same fluidity of the cement paste decreases to -14% and -16% respectively with W/C at 0.35 and 0.43. Hence it can be concluded the limestone filler requires less water compare to the cement.
- It was indicated in Fig. 1 that the saturation dosage of Sika Viscocrete 3088 with CEM I is 0.07% in solid content. Hence, we concluded that Sika Viscocrete is extremely effective.
- The compacity of the waste ceramic tile aggregates at 100% substitution of the coarse aggregate increases up to +3.68% and +4.29% in the mode without and with compaction respectively. Based on this observation, we concluded that the waste ceramic tile aggregates improve the compacity of the concrete which enhance the durability of the concrete.
- The substitution of the cement with the limestone filler in the self-compacting concrete increases: the flowability up to +21%, and the passing ability up to +12%. Further, the resistance to segregation with limestone filler is 2.1% whereas for the reference SCC is 4.8% hence the limestone filler is more stable against the segregation and bleeding. The optimum substitution of the limestone filler is 20% in the total quantity of the binder.
- The substitution of the coarse aggregate with the waste ceramic tile aggregates in the self-compacting concrete decreases to -38% in the passing ability. Only SCCWC75, the substitution at 75% of waste ceramic tile aggregates with 20% limestone filler was valid for self-compacting concrete: SF = 710 mm, VF = 4.85s, PL2 = 0.81, and SR = 5.5%.
- The use of this high proportion of waste ceramic tile aggregates and limestone filler in self-compacting concrete is economic and eco-friendly.

APPENDIX

Table IX. Summarize of the Results of the Workability

Mix ID	SF (mm)	VF (s)	PL2	SR (%)
SCCLF00	**500**	4.18	**0.78**	3.2
SCCLF10	**530**	4.35	**0.61**	2.5
SCCLF15	**545**	2.65	**0.58**	3.1
SCCLF20	565	2.65	**0.53**	2.6
SCCLF25	595	3.50	**0.64**	3.6
SCCLF00*	625	3.50	0.83	4.8
SCCLF10*	720	3.43	0.83	5.3
SCCLF15*	615	3.81	0.93	2.2
SCCLF20*	635	3.18	0.90	2.1
SCCLF25*	715	2.85	0.82	4.0
SCCWC25	595	4.68	**0.56**	1.5
SCCWC50	655	4.29	**0.59**	2.0
SCCWC75	685	4.85	0.81	5.5
SCCWC100	635	5.30	**0.76**	2.3

ACKNOWLEDGMENT

We, authors thank Pan African University, Institute of Basic Science Technology and Innovation (PAUSTI) and Africa Union Commission for their financial support for this research.

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