POTENTIAL USE OF TROPICAL LANDFILL LEACHATE IN MANUFACTURING PORTLAND CEMENT CONCRETE

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Abstract*– Landfills are known sources of environmental contamination through the formation of leachate, which is a contaminated aqueous effluent produced when water percolates through the waste in landfills. Previous research has shown that landfills pose a direct threat to water resources and health in Trinidad and Tobago (T&T), and that there is the need to find efficient ways to manage landfill leachate. A recent study showed that landfill leachate was able to be used in the production of sand-lime products. As Portland Cement Concrete (PCC) is a common construction material used within the Caribbean, it is being proposed that tropical landfill leachate can be utilised in the making of concrete products. Treated (TL) and Untreated (UTL) tropical landfill leachate at 25%, 50%, 75% and 100% were used as a replacement of water in making concrete cubes. Compressive strength of those cubes was then measured against the controls at 3, 7, 14, 21 and 28 days. Cube samples were then analysed for hydrated products using Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD). The concrete cubes made with UTL produced similar and even greater compressive strengths than cubes made with TL and the controls. It is postulated that the higher content of sodium, calcium and solids in the leachate could have possibly contributed to the higher compressive strength. This study is the first of its kind to use leachate in concrete and supports the possibility that tropical landfill leachate can serve as a replacement of water in the making of concrete products.

***Keywords*- Landfill Leachate, Tropical, Concrete, Caribbean, Environmental Contamination**

I. INTRODUCTION

The landfills within Trinidad and Tobago (T&T) are known sources of environmental pollution and health hazards caused by harmful contaminants resulting from the mismanagement of leachate. Landfill leachate is a contaminated aqueous effluent produced when water percolates through the waste in the landfill caused primarily by precipitation, surface run-off, and infiltration [1]. Currently within T&T there are three major landfill sites – The Beetham, Forres Park and Guanapo managed by The T&T Solid Waste Management Company Limited (SWMCOL). The Forres Park Landfill site is the only landfill facility that was designed using engineering principles and is equipped with a leachate collection system. Studies carried out by the Environmental Management Authority (EMA) in December 2003 have indicated that the aquifer systems in northern Trinidad may be at risk of contamination from several sources of anthropogenic pollutants such as landfill leachate [2]. SWMCOL and by extension the services of a consulting firm, DFA Infrastructure International Inc. (DFA) developed a surface water and ground water monitoring program at each of the Beetham and Guanapo landfills. The values obtained exceeded certain parameters such that they are well above the values stipulated by various standards, namely, Trinidad and Tobago Environmental Management Authority Water Pollution Rules Second Schedule, Guidelines for Canadian Drinking Water Quality and The World Health Organisation(WHO) Guidelines for Drinking Water Quality. It was suggested that the landfill leachate is contaminating the surface and groundwater resources. The study covered an initial characterisation of the surface and groundwater quality in the vicinity of the Guanapo and Beetham Landfills and showed that the operations at the landfills and the expected generation of leachate were adversely impacting the water resources. In addition, while the results of this study indicated that the surface and ground waters at both landfills is contaminated by leachate, and there is off site migration of contaminants, the extent to which this has impacted the surrounding areas of water is unknown, compared to other potential sources of contamination. Given the environmental implications of landfill leachate runoff from the other two landfills, it is imperative that an adequate leachate collection system be developed and or that said leachate is utilised in an environmentally sensitive manner in Trinidad and Tobago.

A recent study was able to show that landfill leachate can be used sustainably in the making of sand-lime bricks. However, similar investigations haven't been adopted in Portland Cement Concrete (PCC) which is the primary construction material used within the T&T. As such it is imperative to determine if landfill leachate can be utilised in the making of PCC products. This study therefore aimed to investigate the compressive strength of concrete cubes that have been modified using UTL and TL with emphasis on mechanical and microstructural properties of the concrete cubes. UTL is leachate in its fresh state (raw) and is by no means altered physically, biologically or chemically. TL represents leachate obtained from an Engineered Biological Wetland Leachate Treatment System at the Guanapo Landfill Site as a pilot study. The usage of "tropical" denotes leachate taken from a landfill in T&T or elsewhere where landfill sites have both solid and hazardous wastes and where the weather system involves cyclic wet and dry conditions.

II. LITERATURE REVIEW

Globally, the practice of MSW disposal by landfilling is widespread due to low-cost, moderately easy operation, and landscaping re-establishing abilities [3]. Likewise the current method of waste disposal in the Caribbean and in T&T (SWMCOL). A major drawback of landfilling however is the production of leachate [4]. The Guanapo Landfill Site is positioned at the foothills of the northern range within the Tunapuna/Piarco Region at elevation of 457 to 610m. The natural ground surface slopes towards the south with overland flow drainage to the southeast and southwest along defined drainage swales near the south property boundary. The swales drain to rivers east and west of the site. The leachate mixes with surface runoff and groundwater seepage and is directed via swales to the east and west of the property [2]. The 12 ha landfill site receives approximately 270 tonnes of waste each day and is situated between El Cedro and Maturita tributaries which flow into the Guanapo River joined to the Caroni River. The surrounding area is mainly agricultural in conjunction with quarrying, residential and light industrial activities. Guanapo landfill site experiences heavy rainfall in the rainy seasons [5]. A recent study in 2016 [6] on landfill leachate as a modifier of properties, was observed in sandlime products. In comparison to the controls, the modified product with landfill leachate gained higher compressive strength, and, had a notable impact on bulk density. Furthermore, leachate combined with admixture exhibited similar compressive strength to the original product. SEM analysis of the modified samples with leachate and admixture revealed the occurrence of hydrated calcium silicate (C-S-H) phase, tobermorite and xonotlite. Sand-lime products are common in temperate countries whilst cement is a common material used in the construction industry in T&T and by extension the wider Caribbean. Generally potable water is needed in the mixing of concrete [7].

Reference [8] discovered that the polluting influences caused by impurities in nonpotable water utilised in concrete can debilitate the compressive strength of concrete. Moreover, reference [9] showed that nonpotable water utilised for curing concrete can weaken concrete strength. Impurities and contaminating substances are most likely to inhibit hydration and effective bonding between aggregates [9]. Scientists have conducted feasibility studies of various mixing water for concrete production using grey water [10], river water [11] well water and wastewater [12] among others and showed a positive effect on compressive strength. As such the possibility exists that landfill leachate can be used as a replacement of potable water in concrete mixing. Finding ways to replace water in the construction industry is essential as a great quantity of water is expected in the making and curing process of concretes annually worldwide. In Iran for instance, 80 MCM of concrete is produced for general cement grade and approximately require 11,000 MCM of water annually for concrete production [13]. Using landfill leachate as a replacement for water in concrete mixing can possibly assist in reducing the amount of water needed for the construction industry in T&T.

III. MATERIALS AND METHOD

A. Leachate Collection: Leachate samples were collected from Guanapo Landfill Site. This facility was designed without engineering principles, is dome-shaped and overland flow occurs at the east and west sides. The cover material is northern hill. It has a liner and is not equipped with leachate collectors and by gravity leachate drains from the waste heaps (Fig.1).

Fig.1 – Guanapo Landfill Site

The leachate samples were diluted into various percentages-precisely, 100%, 75%, 50% and 25%. Experiments were carried out using UTL from pond # 1(GPS coordinates of N’06°89.657’, W’11°78.327’) and TL from an Engineered Wetland System (GPS coordinates of N’06°89.494’, N’11°78.134’). Leachate samples were collected from a depth of 3-5m, dispensed into 4 separate bottles, placed in a cooler with ice and transported to the laboratory. UTL sample was black and smelly. TL sample was very light brown in colour. A number of analytical measurements were conducted using the United States Environmental Protection Agency (USEPA), American Society for Testing and Materials (ASTM) and Standard Method for Examination of Water and Wastewater (SMEWW) protocols. Table 1 shows the physicochemical properties of the leachate samples.

B.Portland cement: The cement used was a locally manufactured and eco-efficient cement from Trinidad Cement Limited (TCL) known as *Type 1P OPC (Pozzolan) Premium Plus.*

Table 1- Physicochemical properties of Tropical Landfill Leachate

Reported average			
Parameter	Unit	UTL	TL
Turbidity	NTU	64	42
Temperature	°C	27 (field); 22.9 (lab)	26 (field); 23.38 (lab)
Salinity	ppt	3.5	2.8
Hardness	mg/L	318	375
Nitrate	mg/L	11.6	15.4
Phosphate	mg/L	7.96	5.35
TDS	mg/L	3692	2418
TOC	mg/L	200	125
TOG	mg/L	4.9	0.4
TSS	mg/L	188	65
Dissolved oxygen	mg/L	0.23	0.84
Conductivity	µs/cm	6209	5475
pH	-	8.2	7.15
TDS	g/L	4.2	3.67
BOD_5	mg/L	4.74	1.33
Potassium	mg/L	1916	1474
Silicon	mg/L	3462	2118
Sodium	mg/L	4711	4317
Alkalinity	mg/L	1275.92	953.38
Ammonia	mg/L	292.8	99.6
COD	mg/L	186	25
Chlorides	mg/L	24.82	34.24
Magnesium	mg/L	38.78	34.93
Calcium	mg/L	63.75	93.05
Aluminium	mg/L	<0.0001	<0.0001
Barium	mg/L	<0.0001	<0.0001
Cadmium	mg/L	0.016	0.003
Chromium $^{6+}$	mg/L	1.665	0.104
Iron	mg/L	6.75	19.5
Lead	mg/L	<0.0001	<0.0001
Copper	mg/L	<0.0001	<0.0001
Mercury	mg/L	<0.0001	<0.0001
Zinc	mg/L	0.398	0.01
Manganese	mg/L	3.6	5.8

C.Aggregate: Naturally-extracted Guanapo Quartzite aggregate from National Quarries limited, Guanapo Quarry in Trinidad was used in the study.

D.Coarse aggregate: Crushed Guanapo quartzite of maximum nominal aggregate size 20 mm was thoroughly washed with the laboratory's tap water, oven dried at 105°C and cooled to room temperature until ready for use. The fineness modulus was 3.6.

E.Fine aggregate: The fine aggregate was thoroughly washed with tap water to discard impurities such as silt particles, fine dust, clays, and other substances like organic materials. Sand was oven-dried for 24 hours and cooled to room temperature before using. The fineness modulus was found to be 3.02.

G.Potable Water: The laboratory's tap water (local pipe borne) supply was used in the study. The water was free from organic substances and acid. The properties of the water used are provided in Table 2.

Table 2 - Analysis of Laboratory Water Supply

Reported average			
Parameter	Results	WHO drinking water guideline	Conformity
Alkalinity	60mg/L	≤200	Yes
Aluminium	0.10mg/L	≤0.2	Yes
Bicarbonate	73mg/L	≤1000	Yes
Calcium	26mg/L	≤200	Yes
Chlorides	27mgL	≤250	Yes
Colour	25HU	≤15	No
Conductivity	250 umhos	-	NA
Magnesium	5.8mg/L	≤0.5	No
pH	6.7	6.5-8.5	Yes
Residual Free Chlorine	0.2mg/L	≥0.5	No
Total Dissolved Solids	164mg/L	≤500	Yes
Total Hardness	88mg/L	≤300	Yes
Total Iron	0.45mg/L	≤0.3	No
Turbidity	3,2	≤5	Yes

H.Mix Design: The mix design in the study was based on the principles of British Standard, part 1, BS 8500-1:2015+AI: 2016 code. The design was made for a compressive strength of 30MPa at 28 days with a slump range of 90 to 160mm belonging to class S3 (see Table 3).

Table 3 – *Mix proportions per concrete batch (15 specimens)*

Mix Proportion	Water	Cement	Fine Aggregate	Coarse Aggregate
By weight (kg/m^3)	287	0.0188	1160	771
Weight (Kg)	2.7	6.04	21.8	14.5
Leachate mix: Percentage of water replaced for TL and UTL mix:				
Leachate Percent	100%	75%	50%	25%
Leachate Volume (ml)	2700	2025	1350	675
Leachate Amount (kg)	2.7	2.025	1.350	0.675
Water (ml)	0	675	1350	2025
Water (Kg)	0	0.675	1.350	2.025

I.Manufacturing of Test Specimens: Concrete cubes of 100mm sides were manufactured at the UWI Civil Engineering, Structural Laboratory using the above design mix. A minimum of thirty (30) cubes were casted for each treatment. Individual constituents were accurately measured and poured into a mechanical cement mixer (see table 4). Mixing was performed for 3 minutes. The room temperature was 27 ± 2 ° C and relative humidity 60%. Mortar was added into greased cube molds to approximately half level. During the vibration period of 3 minutes, the remaining quantity of mortar was added and prodded with a trowel. The top surface was smoothened. The compacted mix was securely stored at controlled temperature of 27 ± 2 ° C and relative humidity 90% for 24 hours.

Table 4 – Preparation of cubes

Mix	ID.	Matrix	Water %	Leachate %	Cubes/batch (n)	Total cubes (n)	Weight(kg)
1	CTL	Control	100	0	15	30	3.0
2	UTL 100	Untreated	0	100	15	30	3.0
3	UTL 75	Untreated	25	75	15	30	3.0
4	UTL 50	Untreated	50	50	15	30	3.0
5	UTL 25	Untreated	75	25	15	30	3.0
6	TL 100	Treated	0	100	15	30	3.0
7	TL 75	Treated	25	75	15	30	3.0
8	TL 50	Treated	50	50	15	30	3.0
9	TL 25	Treated	75	25	15	30	3.0

J.Curing of Specimens: Cubes were demolded after 24 hours and immersed into corresponding water baths to be cured until they were ready to be tested. The specimens were cured for 3-day, 7-day, 14-day, 21-day and 28-day strength.

K.Compressive Strength: Three representative standard-cured test specimens were tested at age breaks of 3d, 7d, 14d, 21d and 28d and average compressive strength was computed conforming to specifications in ASTM C39. The cubes were tested on their sides between the steel plates of the ELE Compression Testing Machine (CTM) at pacing rate of 150kN/minute (Fig.2) Compressive strength was calculated using equation 1 below. Variations in the type of break and angle of fracture were noted.

Compressive Strength (MPa**)** = Maximum Failure Load (kN)/Cross- sectional area of cubes…………Equation 1

Fig. 2 – Compressive Strength Testing

L.Powdered X-Ray Diffraction Analysis – Mineral Content Test: XRD is a non-destructive and non-contact method ideal for in situ study specifically nanomaterials and information about microstructural properties and crystallographic structure, chemical composition and physical properties of materials [14]. Prior to testing samples were crushed mechanically using a Braun Chipmunk Crusher and then sieved using BS 410 300µm aperture laboratory test sieve to obtain a desired powder form.

M.Scanning Electron Microscopy (SEM)/Energy Dispersive System (EDS) Analysis – ED: In this study, the morphology of selected concrete samples were analyzed through SEM-EDS to describe the microstructural properties, the degree of cement hydration and phase composition changes for test units. The equipment used was Phillips SEM 505 with EDAX Genesis Software, and images were taken from Gatan Digi scan (Digital Micrograh) System. The samples were prepared in powder form and placed in the Denton Desk II cold sputter unit to be gold sputter coated. Sputtering and evaporation produces a thin layer of metal on the sample surface. The sample was introduced to a vacuum chamber with a metal target to which gas (Argon, Ar) was introduced. A potential was applied between target and sample generating an electric field which ionizes Ar gas which is accelerated at the cathode. Ar ions collides with the target and sputters off metal atoms. When the metal atoms are in the gas phase collision with Ar ions it produces a metal atom "cloud". Finally metal atoms settle on the samples. SEM-EDS were done on sample of ages 3d, 7d, and 28d only.

N.Data Analysis: IBM SPSS Statistics 21 software was used to conduct inferential statistics on data obtained and Microsoft Excel 2016 Software.

IV. RESULTS AND DISCUSSION

Table 5 – Compressive Strength obtained for control, UTL and TL test units

ID.	N	Mean	Std. Dev.	Std.Error	95% Confidence Interval for Mean		Min.	Max.
					Lower Bound	Upper Bound		
CTRL	15	41.006	6.23314	1.6093	37.554	44.4585	28.00	48.40
UTL 25	15	39.506	6.42845	1.6598	35.946	43.0666	27.30	49.20
UTL 50	15	44.093	4.61526	1.1916	41.537	46.6492	35.80	51.80
UTL 75	15	43.026	5.09502	1.3155	40.205	45.8482	33.10	50.40
UTL 100	15	43.213	4.19334	1.0827	40.891	45.5355	36.60	49.60
TL 25	15	20.580	6.33180	1.6348	17.073	24.0864	12.90	29.40
TL 50	15	37.573	3.82837	.98848	35.453	39.6934	31.20	44.40
TL 75	15	8.0000	1.19523	.30861	7.3381	8.6619	5.70	9.70
TL 100	15	37.660	4.43216	1.1443	35.205	40.1144	28.20	44.60

A.Compressive Strength: Table 5 summarizes the results obtained. It was noted that the use of UTL had no adverse effect on compressive strength of concrete cubes (Fig.3) while TL 25% and 75% were denatured easily producing smaller strengths (Fig.4). As the curing time increased the compressive strength increased for control, UTL and TL groups (Fig.5). Statistical analysis determined that the compressive strength was greater than or equal to the controls for all the UTL samples. The highest compressive strengths were achievable with UTL 50% and TL 100%. TL 25% and 75% did not produce strengths comparable to the other percentages and to the control. UTL manufactured cubes had a normal breakage appearance (Fig. 3), however, TL 25% and TL 75% cubes were naturally breaking down and unable to hold together (Fig. 4). The study proved that 50% UTL and 100% TL can be used in PCC production and that it is possible that the higher contents of sodium, calcium and solids in the leachate could have possibly contributed to the higher compressive strengths.
Increased strength in the UTL can be attributed to the literature taken from publications by references [15], [16] and [17]. The greater compressive strength associated with UTL concrete cubes may perhaps be a result of the physical and chemical properties of UTL because not only does it differs in many respects from TL and PW, the higher concentration of solids and chloride ions could be an advantage.

Fig.3 – Samples of UTL manufactured cubes

Fig. 4 – Samples of TL manufactured cubes (25% and 75%)

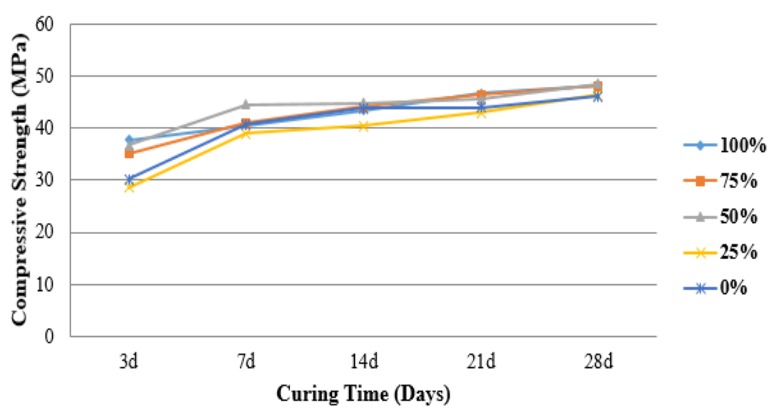
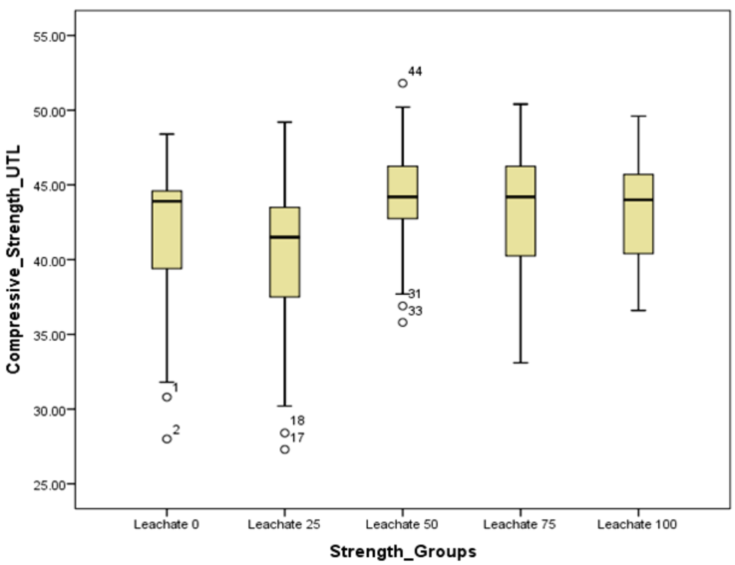


Fig. 5 – Compressive Strength with curing time (days)

The results of meeting a minimum compressive strength of 90% at 7 days and 28 days were shown in all the UTL proportions (Table 6). The mix design desired compressive strength of 30 MPa at 28 days were achievable in all the UTL proportions and at even greater values in UTL 50%, 75% and

100%. This confirms that UTL can give PCC desirable compressive strength (Fig. 6). The TL values were not on par with the standards besides TL 100% at day 28. According to IS 456-2000 compressive of strength ≥ 85% of control can be taken. Hence only TL 50% and 100% were significant in that case. TL 25% and TL 75% did not produce strengths to meet any standards and may not be the best consideration. The use of TL 50%, TL 100% and all the UTL proportions were validated and can be used in PCC.

(a)



(b)

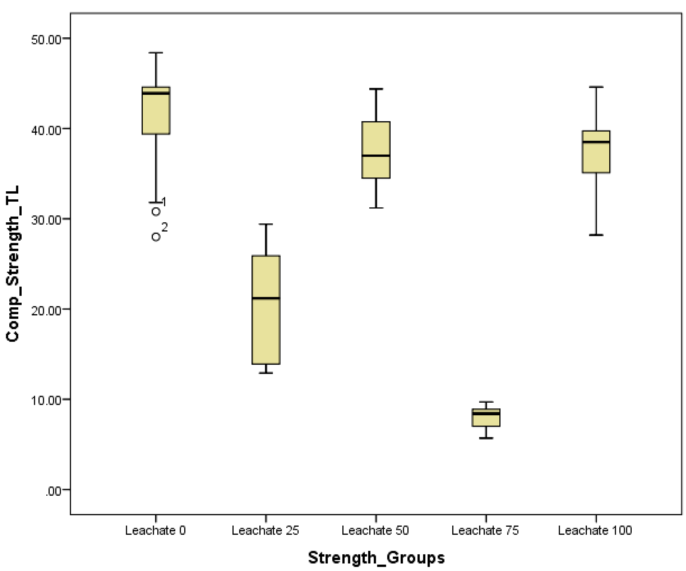


Fig.6 - *Box and Whiskers Plot of (A) UTL and (B) TL of Compressive strength vs Leachate Percentage*

Table 6 - *Compressive strength based on concrete standards using wastewater as mixing water*

Matrix	ASTM C94/ASTM C1602 – Min. 90% of control at 7d	IS 456 – Min. 90% of control at 28d
CTRL	100%	100%
UTL 25%	96%	100%
UTL 50%	107%	106%
UTL 75%	100%	104%
UTL 100%	100%	104%
TL 25%	35%	61%
TL 50%	86%	90%
TL 75%	18%	20%
TL 100%	87%	94%

Unlike organic matter and oils, fine solids from the leachate may possibly fill voids within the concrete matrix increasing its strength. It was additionally discussed that higher sodium chloride and calcium chlorides can contribute to the superiority of concrete and that was established by authors [18] and [19]. In their work sodium and calcium chlorides were reported to have increased the early strength of concrete due to their higher concentrations. The calcium and sodium concentrations for UTL were 63.75mg/L and 4711mg/L respectively. The calcium of PW was 26mg/L suggesting that UTL concentration was higher. In TL sodium was 4317mg/L and calcium was 93.05mg/L. The reduction in compressive strength for TL 25% and TL 75% could be due to the higher organic content.

B.Microstructural analysis: Scanning Electron Microscopy (SEM) images showed gradual microscopic changes between 3 to 28 days during the hydration process for the controls as well as the treated and untreated leachate samples (Fig.6). However, for the UTL samples there appeared to be more hydrated products being formed at the 28-day compared to the controls and TL concrete samples. X-Ray Diffraction (XRD) is a state-of-the-art technique applied to materials for (i) qualitative and quantitative phase analysis, (ii) crystalline structure identification, and (iii) crystallites size and crystallographic texture among other [20]. In this study, it was performed for qualitative phase analysis (identification of their crystalline phase) which occupies more than 3-4% of mass. Diffraction results in a reflection at well-defined angles. Based on the conclusions from reference [20]'s study on XRD for hydration processes of OPC it was shown that the largest peaks were produced after 3 days and corresponded to tobermorite gels, portlandite for the second peak and ettringite showed the smallest values. Therefore, tobermorite was the most abundant phase at the end of 3 days. Subsequently at 28 days, tobermorite develops as a dense and more compact mass. There will still be non-hydrated belite grains and ettringite will be difficult to recognize. A reduction in values between tobermorite and portlandite phases happens with time between 3 to 28 days. As type I Portland cement in the first 3 days of the hydration process tobermorite originates as alite is more abundant than belite and they are both sources for portlandite development which happens slowly. The results more or less dictated that trend and it was revealed that an improved hydrated calcium silicate (C-S-H) phase was established in the leachate specimens with highest compressive strength [20].

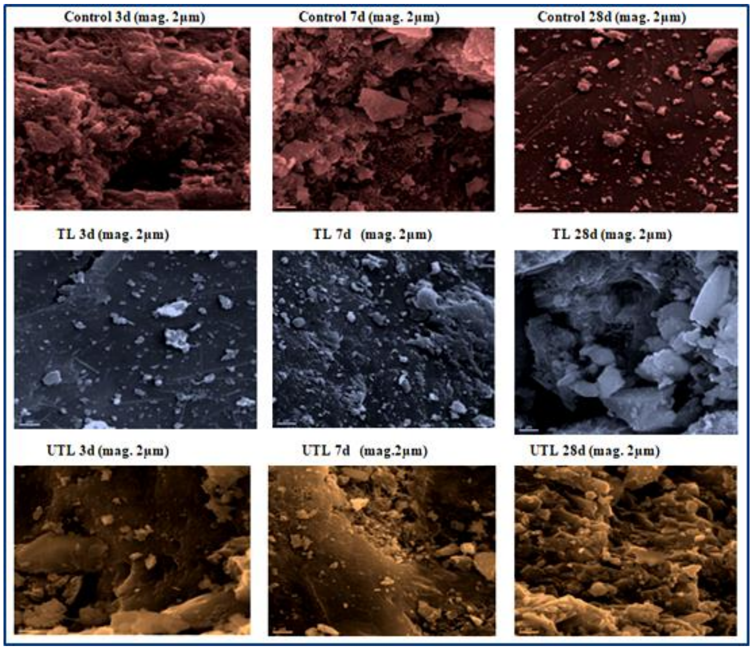


Figure 7 – SEM images obtained for the samples tested

V. Conclusion and Recommendations

- Considering the huge availability, tropical landfill leachate can satisfactorily be used as a potential mixing water source in PCC manufacture. Most of the parameters tested met the Trinidad and Tobago Environmental Management Authority's Water Pollution Rule with the exception of *ammonia, dissolved oxygen* and *faecal coliforms*. The laboratory results when compared with tolerable limits published by various researchers suggests that tropical landfill leachate can be used in PCC without adverse harmful effects.
- The use of UTL had no adverse effect on compressive strength of concrete while TL 25% and 75% were denatured easily producing smaller strengths. As the curing time increased the compressive strength increased for control, UTL and TL groups. Statistical analysis determined that the compressive strength was greater than or equal to the controls for all the UTL samples. The highest compressive strengths were achievable with UTL 50% and TL 100%. TL 25% and 75% did not produce strengths comparable to the other percentages and to the control. The study proved that 50% raw landfill leachate and 100% treated leachate can be used in PCC production and that it is possible that the higher content of sodium, calcium and solids in the leachate.
- SEM images showed gradual microscopic changes between 3 to 28 days during the hydration process for the controls as well as the UTL and TL samples. However, for the UTL samples there appeared to be more hydrated products being formed at the 28 day compared to the controls and TL concrete samples.

Each type of impurity found in the leachate causes a different reaction with the cement constituents. Certain reactions can affect the concrete strength. Some will react in a positive way that the net outcome may be harmless and may improve the properties of concrete. Many researchers in the past have determined tolerable limits of impurities in potable and nonpotable water and based on those thresholds it is safe to predict when the impurity becomes harmful. Thus, it can be suggested that tropical landfill leachate can be used as a mixing water replacement in PCC without drastic harmful impacts because most of the parameters were below the limits established. In many urbanized regions of T&T and the wider Caribbean, with the rapidly escalating population growth and industrial expansions, the use of tropical landfill leachate as a replacement of potable water in concrete will assists in reducing water scarcity and assist greatly in sustainable development.

Recommendations

- ***Future Studies:*** Determination of the impacts of landfill leachate as a mixing water in PCC on other concrete properties such as shrinkage, durability, long term strength and corrosion of steel reinforcement.

- ***Concrete design:*** A trial experiment conducted at the UWI Civil Structural Laboratory showed an increased workability with 45mls of superplasticizer (Conplast SP 430). Different cement grades can possibly produce different compressive strengths between 3 and 28 days as determined using Trinidad Cement Limited, Ordinary Portland Cement (TCL, OPC).

- ***Public awareness:*** To educate the populace of T&T on alternative use of waste material such as, tropical landfill leachate as efforts to build a more comprehensive environmental water quality baseline with specific physicochemical and structural properties as well as codes in PCC manufacture. Furthermore, reclamation of landfill leachate or reuse of wastewaters such as sewage and domestic, should be legislated and enforced for the production of nonstructural concrete and if possible structural concrete.

- ***Usage of leachate concrete products:*** Although it was recognized that there was some leaching of certain heavy metals from the concrete cubes produced with the leachate, it can still be utilize in varying ways (non-domestic) that prevents any negative effects on humans and possibly the environment. Some of these involve the use of concrete produced with leachate in culverts and sewers, streets, parking areas, sidewalks, drains, retaining walls, and construction of structures that store/utilize waste. Not only does the utilization of leachate in concrete production seen as an opportunity to utilize a contaminant in a more environmentally sensitive manner, it can also be said that in the face of climate change most countries including T&T and the wider Caribbean is occasionally faced with water shortages. The use of leachate as a replacement of potable water will therefore reduce the quantity of water needed in the construction industry enabling greater water security.

Acknowledgment

The Department of Civil and Environmental Engineering for allowing the usage of laboratory resources. Trinidad Cement Limited (TCL) and ReadyMix Trinidad Limited for timely assistance with laboratory testing and mix design advice. Financial assistance from Market Facts and Opinion (MFO). Mentors, Professor Emeritus Winston Mellowes and Dr. Abrahams Mwasha.

References

[1] A.Mojiri, H.A. Aziz, N.Q.Zaman, S.Q.Aziz and M.A Zahed, "Powdered ZELIAC augmented sequencing batch reactors (SBR) process for co-treatment of landfill leachate and domestic wastewater", *Journal of Environmental Management* vol. 139, p. 1- 14, 2014.

[2] SWMCOL, "Surface Water and Groundwater Monitoring Programme Beetham and Guanapo Landfill Sites Final Version". DFA Infrastructure International Inc. GNF & Associates Company Limited," unpublished.

[3] M.L. Davis and D.A.Cornwell, "Introduction to Environmental Engineering". 4th Edition. International Editions, *McGraw Hill*, New York 2008.

[4] S.Q Aziz, H.A.Aziz, M.S.Yusoff, M.J. Bashir and M. Umar, "Leachate characterization in semi-aerobic and anaerobic sanitary landfills: A comparative study", *Journal of Environmental Management*, vol. 91, no.12, pp.2608 -2614, August 2010

[5] SWMCOL, Trinidad and Tobago Solid Waste Management Company Limited 2018, available at: http://www.swmcol.co.tt/

[6] R. Dachowski and M.Nowek, "Landfill Leachate as an Additive in Sand-Lime Products," *World Multidisciplinary Civil Engineering- Architecture –Urban Planning Symposium,"Procedia Engineering, no. 161, 2016,* pp: 7, 25-314, p 572-576

[7] A.M.Neville, "Properties of concrete". Sixth and Final Edition. England: Addison Wesley Longman Occupational Health and Safety Administration 2005.

[8] D.A. Abrams, "Tests of Impure Waters for Mixing Concrete". *Proceedings of the American Concrete Institute.* vol. 20, 1924, pp.442–486.

[9] B.Smith, "Curing of Concrete". In the Proceedings of the Lewis H. Tuthill International Symposium on Concrete and Concrete Construction, ACI SP-104, *American Concrete Institute*, Michigan, USA. 1976

[10] R.T.Peche, Dr. S. S. Jamkar and Dr. P.A. Sadgir, "Influence of greywater as mixing water on properties and strength of cement". *International Journal of Technology Enhancements and Emerging Engineering Research*, vol.3, no.5, 2015.

[11] ATA, Olugbenga, "Effect of Different Sources of Water on Concrete Strength: A Case Study of Ile-Ife," *Civil and Environmental Research*, vol. 6, no.3, pp 39-43, 2014.

[12] A.R.More and S.K. Dubey, "Study on the effect of different types of water on compressive strength of concrete," *International Journal of Research in Engg and Technology*, vol.5, no. 2, pp 40-50, October 2014.

[13] K.E. Shirzai and R.Marandi, "Evaluation of Heavy Metals from Leakage from Concretes Containing Municipal Wastewater Sludge". *Environment and Pollution*, vol 1, No. 2, June 2012.

[14] R. Sharma, D.P. Bisen, U. Shukla and B.G. Sharma. "X-ray Diffraction: a powerful method of characterizing nanomaterials". *Recent Research in Science and Technology*, vol.4, no. 18, 2012, pp: 77-79.

[15] A.H. Noruzman, B. Muhammad, M. Ismail and Z. Majid. (2012), "Characteristics of treated effluents and their potential applications for producing concrete". *Journal of Environmental Management*. vol.110, June 2012, p. 27-32.

[16] A.M.Ghair, O.A.Al-Mashaqbeh, S.K.Mohmd, A.Nedal, M. Farouraand and S.B.Megdal, "Influence of grey water on physical and mechanical properties of mortar and concrete mixes," *Ain Sharms Engineering Journal November 2016*

[17] G.Asadollahfardi, M.Delnavaz, V.Rashnoiee and N. Ghonabadi, "Use of treated domestic wastewater before chlorination to produce and cure concrete," *Construction and Building Materials*, no.105, pp. 253-261, December 2015

[18] S.O. Lee, M.R. Saliu, M. Ishmail and M.I. Ali, "Reusing Treated Effluent in Concrete Technology". *JurnalTecknologi*, no. 34, pp. 1-10, 2001.

[19] S.Mindness and J.F.Young, "Concrete". Prentice-Hall,

Inc. Eaglewood Cliffs, NJ, New York, pp. 112-116, 1981.
[20] E. Jumate and D.L. Manea, “Application of X Ray Diffraction (XRD) and Scanning Electron Microscopy (SEM) to the Portland Cement Hydration Processes”, *Journal of Applied Engineering Sciences*,vol. 2, no.15, pp.35-42 May 2012.