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Characteristics of Polyvinyl Chloride Powder Cement Paste and Concrete

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Abstract

This work is on the use of Polyvinyl chloride powder (PVC) powder waste for cement paste and concrete production. The characterization of the PVC powder material showed that it has a CaO (63 %) value almost that of Portland cement. Thus, it has cementing value and can be used as cement material. The x-ray diffraction analysis of the material contained major mineral like Nacrite, Wollastonite and Gypsum with trace minerals like Illite, Muscovite and Tobermorite. The PVC powder material was used in proportions of 0 % to 40 % by wt. % of cement to produce cement pastes and concrete specimens. Results from the cement paste on consistency and setting times showed that using PVC powder material would require more water for consistency and workability. The results on the setting time showed the material is a retarder and could be used for hot weather concreting. The PVC-powder concrete showed a normal weight concrete, decreased water absorption, but decreased the compressive strength. However, the statistical characteristics of the concrete mixture showed good quality concrete. A linear regression model was used to represent this behavior and is significant.

Keywords: PVC powder characterization; X-ray diffraction; Basic statistical; Mechanical strength of concrete

Introduction

The reuse of wastes has become an important component in the revolutionalization of our researches. This is because it helps to save and sustain our natural resources that are fast depleting. The use of wastes decreases pollution levels, and saves and recycles energy production processes. Plastic wastes are among these wastes whose disposal have harmful effects on the environment due to their long biodegradation period. Hassani et al. [1] postulated that one of the ways of reducing these harmful effects is using them in other forms in other industries. According to recent research, PVC now ranks the third in global plastic output as well as global consumption. Each year, we produce more than 33 million tons of PVC – a figure that will only increase annually. Chlorine makes up for approximately 57 percent of PVC's mass, so it uses less petroleum than other polymers.

Many studies using these wastes as partial replacements or additives and for cement and aggregates have been carried out. In his review works on recycled plastics Siddique et al [2] they stressed that the development of new construction materials using recycled plastics is important to both the construction and plastic recycling industries. Marzouk et al [3] studied the use of plastic bottle waste as sand substitution for aggregate for composites materials in building applications. The polyethylene terephthalate (PET) bottles were shredded into small PET particles before using them to replace part of the fine aggregate and concluded that they are suitable as low cost material for cementitious concrete composite with consistent properties. Bolat and Erkus [4] used PVC powder and granules as aggregate replacement in concrete mixtures to determine the physical and mechanical properties of PVC concrete. They used replacement levels of 10 %, 20 %, and 30 % by volume of the coarse aggregate and concluded that that characteristics like the unit weight, water absorption and compressive strength decreased as the replacement levels increased.

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In this study polyvinyl chloride (PVC) wastes powder, a by-product of PVC, are used to mount experiments that would study the effects of the PVC material as a replacement by weight of cement on PVC-dust cement paste and concrete. Studies on the basic statistical characteristics of the PVC-dust cement paste and concrete mixtures, apart from the mechanical properties, that would enhance the understanding of the hydration processes are done using Minitab 18 Software.

Materials

The cement used for this work is ‘Ashaka’ ordinary Portland cement conforming to BS EN 196 Part 2 [5]. The physical and chemical characteristics of the cement and PVC powder is shown in Table 1. The polyvinyl chloride (PVC) used for this work was obtained in ground form from PANAR Plastic Industry, Kano, Kano State, Nigeria, and was subjected to further grinding and sieved using sieve 150 µm. The PVC powder has a specific gravity of 1.19 and a density of 1.52 g/cm. However, specific gravities and densities of 1.4/1.45g/cm^3 [7] (Patel et al, 2014) and 1.18/0.28 g/cm^3 [8] (Janardhanan and Mohana, 2018), respectively have been reported in the literature. The oxide composition using XRF and XRD analyses were carried out in the National Steel and Raw Material Agency, Kaduna, Kaduna State, Nigeria. The physical and chemical properties of the PVC were done in the Chemistry Laboratory of Abubakar Tafawa Balewa University, Bauchi, Bauchi State, Nigeria. The physical and chemical properties of the PVC are shown in Table 4. The SiO_2, CaO and Al_2O_3 composition of the PVC are almost the same with that of cement. PVC could be said to have a cementing factor like cement, and therefore it is not a pozzolana. The amounts of the Alkalis (K_2O and Na_2O) are 1.03 % and 1.21 %, respectively for cement and PVC, and are not likely to cause any alkali-aggregate reaction. The fine aggregate used is a river sand and passed through 2 mm sieve and retained on 1 mm sieve (Zone 2). The specific gravity of the fine aggregate is 2.59, with a fineness modulus of 2.6 and a bulk density of 1515 kg/m^3. The coarse aggregate is crushed and has a maximum size of 25 mm. Both the fine and coarse aggregates are free from dust and deleterious materials. The coarse aggregate has a specific gravity of 2.67, moisture content of 2.4, aggregate impact value (AIV), and aggregate crushing value (ACV) of 8.5 and 15. Both the fine and coarse aggregates fall into zone 2 of the classification chart of BS 812 [6]. The sieve analysis of the PVC dust is shown in Table 2 and falls into zone 2 on the classification chart according to BS 812 [6].

Table 1: Physical and Chemical Properties of Ashaka Portland Cement

Property	Percentage (%)	Pvc power [ref]	PVC [ref]
Normal consistency (%)	32.5	-	-
Initial/final setting time (min.)	90/190	-	-
Fineness modulus	< 10	6.36	75
Specific gravity	3.15	2.47	2.47
Bulk density (kg/m^3)	-	-	839.25
Dry density (kg/m^3)	-	-	698.44
Moisture content (%)	-	-	20.16
Melting point (oc)	-	128	-
Thermal conductivity (w/mk)	-	0.11	-
Chemical (%)			
CaO	64-67	63.0	63.30
SiO_2	17-25	19.18	19.18

Al_2O_3	3.0-8.0	3.90	3.90
Fe_2O_3	0.5-6.0	2.40	2.40
MgO	0.1-1.0	2.30	2.25
Na_2O/K_2O	0.2-1.3	0.8/0.5	0.75/0.46
SO_3	1.0-3.0	1.40	1.44
H_2O	-	0.10	0.08
BaO	-	0.03	0.03
LOI	-	2.32	2.32

Sieve size	Mass Retained (%)	Cumulative percent. Retained (%)	Mass passing (%)
6.30 mm	0.00	0.0	100.00
5.00 mm	0.30	0.30	99.90
3.35 mm	0.20	0.50	99.97
2.00 mm	0.70	1.20	99.10
1.18 mm	37.90	39.10	61.30
600 µm	53.40	92.50	7.80
425 µm	5.90	98.40	1.90
300 µm	0.80	99.20	1.10
212 µm	0.30	99.50	0.80
150 µm	0.30	99.80	0.50
75 µm	0.30	100.10	0.20
Receiver	0.00	100.10	0.20
	Total	$\sum = 630.60$	

Table 2: Sieve Analysis of PVC Powder

Fineness Modulus = 6.31

X-Ray Diffraction of the PVC Powder

X-ray diffraction (XRD) is a nondestructive technique that provides detailed information about the crystallographic structure, chemical composition, and physical properties of materials. This process leads to the higher level of understanding needed to resolve important issues, such as causes of failure and process-related problems, and allows the researcher to make critical materials decisions. Figure 1 and the accompanying Table 3 show the diffractogramme and the three major peaks, respectively found in PVC powder sample, at 2Theta (deg) of 26.9336, 33.4845 and 24.1050. The various compounds in the PVC, their chemical names and properties are shown in Table 4. There are thirteen minerals confirmed in the X-ray diffraction analysis. The major minerals are Nacrite, Gypsum, Orthoclase, and Wollastonite. Also dictated are some minor minerals like Illite, Muscovite and Tobermorite. The detection of gypsum in the x-ray compound confirms the higher percentage of CaO, and therefore, the reactivity with cement should be studied further.

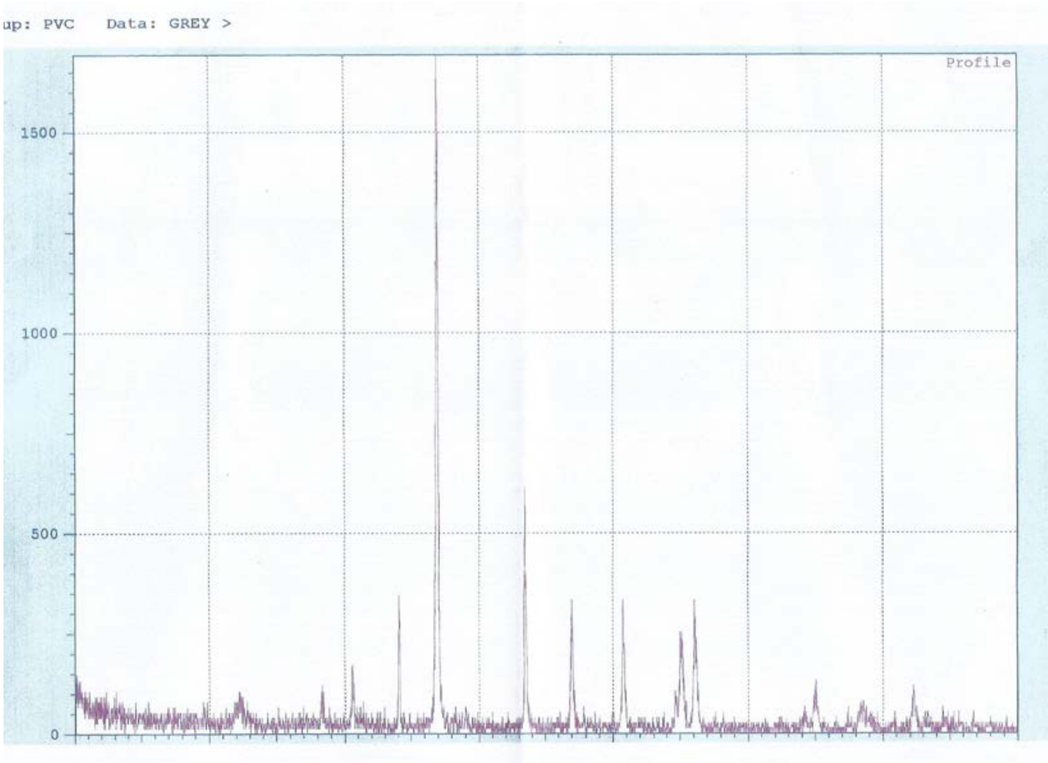

Figure 1: X-Ray Difractogram

Table 3: Strongest Three (3) Peaks

No	Peak No.	2 Theta (deg)	d (Å)	I/II	(deg)	Intensity (Counts)	Integrated Int (Counts)	Mineral
1	4	26.9336	3.30769	100	0.12010	173	1746	Nacrite
2	7	33.4845	2.67403	33	0.13490	57	445	Gypsum
3	3	24.1050	3.68904	17	0.16000	30	262	Tobermorite-IIA

Table 4: X-Ray Diffraction Results of PVC Power

S/No	Card No	Chemical Name	Mineral Name	Chemical Composition	Phase
1	25-0645	Magnesium silicate hydroxide	Chrystolite	$H_4Mg_3SiO_9$	Monoclinic
2	23-1405	Sodium Calcium Magnesium Aluminum Silicate	Edenite	$NaCa2Mg5AlSi_7O_{22}$ $(OH)_2$	Monoclinic
3	45-1486	Calcium Silicate Hydrate	Tobermorite-IIA	$CaSi_6$ $(O,OH)_{18}.5H_2O$	Monoclinic
4	16-0606	Aluminum Silicate Hydroxide	Nacrite	$Al_2Si_2O_3$ $(OH)_4$	Monoclinic
5	31-0794	Magnesium Aluminum Silicate Hydroxide Hydrate	Palygorskite	$(MgAl)_9$ $(Si,Al).8O_{20}$ $(OH)_{10}4H_2O$	Monoclinic
6	10-0446	Aluminum Silicate Hydrate	Dickite-2	$Al_2Si_2O_5$ $(OH)_4$	Monoclinic
7	21-0912	Calcium Sulphate Hydrate	Gypsum	$CaSO_4.2H_2O$	Monoclinic
8	46-1045	Silicon Oxide	Quartz	SiO_2	Triclinic
9	27-0096	Calcium Silicate	Wollastonite	$CaSiO_3$	Hexagonal
10	29-1016	Potassium Magnesium Aluminum Silicate	Osumulite	KMg_2Al_3 $(Si_{10}Al_2)O_{30}$	Hexagonal
11	6-0263	Potassium Aluminum Silicate Hyroxide	Muscovite	KAl_2 $(OH)_2$ $(AlSi_3O_{10})$	Monoclinic
12	31-0966	Potassium Aluminum Silicate	Orthoclasse	$KAlSi_3O_8$	Monoclinic
13	26-0911	Potassium Aluminum Silicate Hyroxide	Illite	(K,H_3O) $Al_3Si_3O_{10}$ $(OH)_2$	Monoclinic

Experiment

Consistency and Setting Time of PVC-Powder Cement Paste

The experiment on the PVC-powder-cement paste was to determine the effect of PVC as it was partially used to replace cement to prepare a PVC-powder cement paste. They are the consistency which is the water requirement of paste when the PVC powder is mixed with cement and the setting times of the paste, important for stripping the formworks. These were achieved using cement content of 300 gm. This quantity of cement was replaced by PVC-powder by wt. % in proportions of 0 %, 5 %, 10 %, 20 %, 30 %, and 40 % respectively to have PVC-cement paste. These are labeled as P-00, P-05, P-10, P-20, P-30, and P-40, respectively, and the paste labeled P-00 is the control paste and others with suffices in line with their replacements. Table 5 shows the values for consistency and setting times. The observations from this table showed that the water affinity for the use of PVC in cement paste and concrete is high, and therefore, its use in concrete may require the use of a water reducing plasticizer. Again, the setting times showed an increasing tendency which shows the PVC material may be used as a retarder. This can be used for hot weather concreting. The gypsum detected is a hardening retarder which controls the speed at which concrete sets.

Table 5: Consistency and Setting Time of PVC-Powder Cement Paste

Mix	Consistency (%)	Setting Time (Min.)	
		Initial	Final
P-00	32.5	90	190
P-05	32.8	96	253
P-10	33.2	99	271
P-20	34.0	105	280
P-30	36.8	108	290
P-40	39.5	113	300

Slump, Density, Water Absorption and Compressive Strength of PVC-Powder Concrete

The experiment to determine the mechanical characteristics of PVC-powder concrete was in two phases using a mix proportions of 1: 1.76: 2.83 and a water-cement ratio of 0.5. The cement content of 390 kg/m^3 was used and designed for a concrete strength (fcu) of 20 kN/m^3. The first phase of this experiment was on the fresh state, that is for the slump of the PVC-powder concrete, and the second phase, the hardened state. The PVC-powder was added to the mix in proportions of 0 %, 5 %, 10 %, 20 %, 30 %, and 40 % by wt. % of the cement, and labeled accordingly as M-00, M-05, M-10, M-20, M-30, and M-40, respectively. M-00 is the control mix while rest of the mixes are having their various replacements.
The slump test addresses the issues of workability which determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished as defined by ACI Standard 116R-90 [9]. Table 6 shows the slump of PVC-dust concrete.

Table 6: Slump of PVC-Powder Concrete

Mix No	Slump (mm)
M-00	79
M-05	42
M-10	27

M-20	22
M-30	13
M-40	0

For the density, water absorption and compressive strength cube molds of 100 mm were used and cured from 3 days to 60 days in water at laboratory temperature. The density and water absorption were tested in accordance to BS 1881-107 [10] and BS EN 1097-6 [11] respectively, while, the compressive strength was tested in accordance to EN 12390-3 [12]. A total of seventy two (72) samples were prepared for the test and at end of the curing regime three samples were weighed in terms of the density and water absorption. For the compressive strength three samples each were tested to failure at end of the curing regime using a universal testing machine (Model CT-700) of capacity of 100 tonnes, and a uniform rate of loading of 0.3 kN/min. Table 7 shows the results of the slump, density, water absorption and compressive strength of PVC-powder concrete.

Table 7: Mechanical Characteristics of PVC-Dust Concrete

Parameter		**Concrete Age (Days)**			
	Mix No	3	7	28	63
Density (kg/m^3)	M-00	2420	2340	2293	2300
	M-05	2413	2237	2197	2433
	M-10	2417	2350	2337	2407
	M-20	2303	2433	2363	2328
	M-30	2213	2270	1490	2250
	M-40	2040	2100	2127	2171
Water Absorption (%)	M-00	1.5	1.7	2.2	2.5
	M-05	1.4	1.5	1.6	1.7
	M-10	1.3	1.4	1.5	1,5
	M-20	1.2	1.2	1.3	1.6
	M-30	1.1	1.2	1.2	1.3
	M-40	1.1	1.1	0.9	0.8
Compressive Strength (kN)	M-00	15.1	19.4	23.2	39.9
	M-05	19.6	18.3	23.1	25.3
	M-10	16.3	15.5	22.3	23.9
	M-20	16.2	15.1	20.7	22.0
	M-30	12.8	12.5	19.1	15,7
	M-40	5.7	7.9	13.2	8.8

Discussion

Slump, Density, and Water Absorption of PVC-Powder Concrete

Table 6 shows that the slump of the PVC-powder concrete decreases as the percentage replacement increases. This behavior suggests a dehydrating effect of the PVC-powder on the concrete matrix and it is in line with the fineness of PVC-powder which is lesser than that of the cement. A phenomenon that will give rise to higher surface area, and thus more water demand. Thus in using PVC-powder for concrete production a higher water/binder ratio may be required. The workability of mix containing PVC-dust therefore will lead to hash mixes leading to lack of cohesion in the mix. For this reason the use of PVC-powder for concrete production may require the use of workability improvement admixture.

The density of PVC-powder concrete and water absorptions are shown in Table 7. The density is the measure of the concrete solidity. The observation here is that the replacement of cement by weight using PVC-powder still gave the range of the densities for a normal concrete which is between 2200 kg/m^3 – 2300 kg/m^3. This is comparable with the range from this work. The probable reasons for this may be found in the physical and chemical composition of cement and PVC-powder (Tables 1 and 4), and also, the properties of the aggregate used. The cement and PVC-powder have almost the same composition of SiO_2, Al_2O_3 and CaO. The X-ray diffraction analysis of PVC showed major compounds like Nacrite, Gypsum, Orthoclase, Wollastonite, and minor mineral like Illite, Muscovite and Tobermorite, which may have additional influence on the properties of the concrete, thereby producing a more dense concrete as reflected in the results. However, since the density of the PVC powder is approximately half of the cement, the dense concrete is formed partly due to the filling effects of the PVC-powder material and the aggregate which contributes approximately 75 % of the concrete density. The same analogy could be drawn on the effect of PVC-powder on water absorption of concrete (Table 7). There is reduction in the water absorption as the replacement levels increase and curing proceeded.

Compressive Strength of PVC-Powder Concrete

The compressive strength of PVC-powder-concrete (Table 7) showed that as the replacement levels increased, the compressive strength decreased. The maximum strength was at 5 % which is only 16 % and 26.5 % of the design strength (20 kN/m^2). The results also showed that other replacements (10 % and 20 %) can also be used since the strengths are minimally greater than 20 kN/m^2 at 28 days and 63 days respectively. Other benefit other than strength is the fact that the use of PVC power with cement creates a method for disposal. This addresses the environmental aspect of the material. The decrease in compressive strength as the replacement levels increased may be attributed to the decrease in the adhesion between the surface of the PVC powder material and the cement paste. Thus, the hydrophilic nature of the PVC material can reduce the water necessary for cement hydration. But the appearance of mineral like Osumulite Tobermorite, and Wollastonite can act as a stabilizer, influencing the performance of cement paste and concrete [13].

Statistical Characteristics of PVC-Powder Concrete Mix

In order to accurately indicate the variations in concrete production a sufficient number of tests are required. This is important because it will form the basis for determining from such results the potential quality and strength of the concrete and for expressing results in the most useful form. Statistical procedures provide a sound basis for determining from such results the potential quality and strength of concrete and for expressing results in the most useful form. The basic characteristics of the PVC-powder Concrete will assist in understanding better the interactions of the various materials used for the concrete production. Tables 8 showed in details the various degrees of performances and interactions of the PVC-powder-concrete, carried out using the Minitab 18 Software [14, 15 16]. It is the statistical parameters for the within-test, and the between-test results. The within-test is the variation that occurred in the cement matrix as curing proceeded within the same mix. Thus, this was for a particular mix, measured along the row, for instance M-00 has in row the performances at 3 days, 7 days, 28 days and 63 days of curing. The between-test is test down the column, involving different mixes, and measured at the same age of curing, for instance at the age of say 3 days, and running down the column, we have M-00, M-05, M-10, M-20, M-30, and M-40, respectively. This is termed the batch to batch measurement. Measurements were made on the mean, standard error of the mean (SE.Mean), standard deviation (St.Dev) and coefficient of variation (Coef.Var), and the confidence limit of the means at $\alpha = 0.05$.

The mean value characterizes the central tendency or location of the data. These ranged from 8.90 to 24.40 for the within-test, and 14.28 to 22.10 for the between-test. The within-test value for the coefficient of variation ranged from 20.47 to 44.47, while the between-test is from 18.76 to 47.30. The coefficient of variation provides a general feeling about the performance of a method and its distribution around the mean, and expresses the variation as a percentage of the mean. Thus, the larger the coefficient of variation is, the greater the spread in the data. The standard error, standard deviation and variance for the within- and between-tests are 1.54-5.43/1.55-4.27, 3.08-10.85/4.17-10.45, and 9.46-117.73/14.45-109.28, respectively. The standard error of the mean (SE Mean) estimates the variability between sample means, and the standard deviation and thus, establishes a benchmark for estimating the overall variation of a process [15, 16]. Whereas, the standard error of the mean estimates the variability between samples, the standard deviation measures the variability within a single sample. The variance (standard deviation squared) measures how spread-out the data are about their mean. A higher standard deviation value indicates greater spread in the data [15]. The greater the variance is the greater the spread in the data. Figures 2 and 3 show the plot of the confidence limit at 95 % against the age and PVC replacement.. They showed that as the days of curing increased the strength of the PVC-dust concrete increased and vice versa as the replacement level increased. A similar conclusion was derived by Elinwa and Kabir [16] working with hospital waste ash (HWA).

Table 8: Statistical Characteristics of the In-Between Test Values for PVC-powder Concrete

Test Type	Variable	Mean	SE Mean	StDev	Variance	CoefVar	95 % CI Lower	95 % CI Upper
	M-00	24.40	5.43	10.85	117.73	44.47	18.81	29.99
	M-05	21.58	1.60	3.21	10.28	14.86	15.98	27.17
In-Between Test	M-10	18.75	1.68	3.36	11.26	17.90	13.16	24.34
	M-20	18.50	1.68	3.36	11.31	18.18	12.91	24.09
	M-30	15.03	1.54	3.08	9.46	20.47	9.43	20.62
	M-40	8.90	1.57	3.15	9.91	35.38	3.32	14.49
	3Days	14.28	1.94	4.74	22.51	33.2	8.84	19.73
Batch-Batch Test	7 Days	14.78	1.70	4.17	17.38	28.20	9.34	20.23

28 Days	20.27	1.55	3.80	14.45	18.76	14.82	25.71
63 Days	22.10	4.27	10.45	109.28	47.30	16.65	27.53

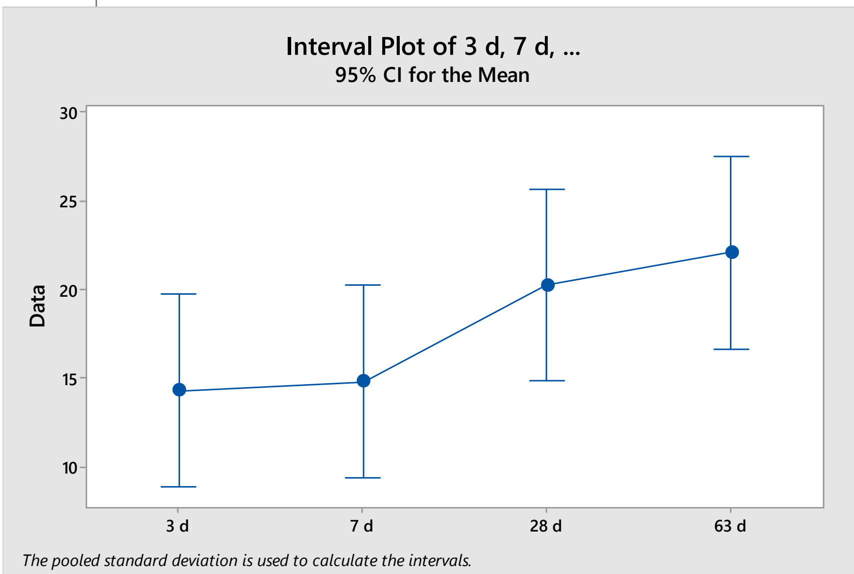

Figure 2: Confidence Limit against Age (Days)

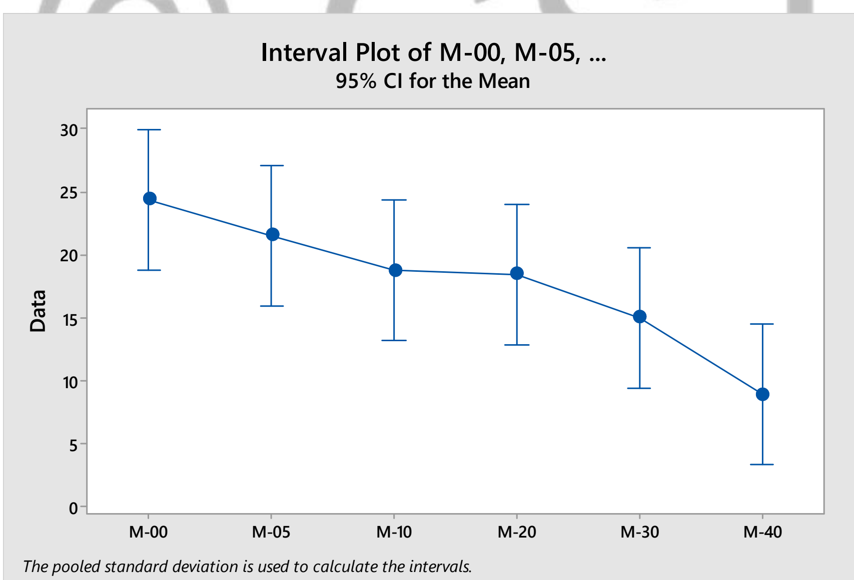

Figure 3: Confidence Limit against PVC Replacement (%)

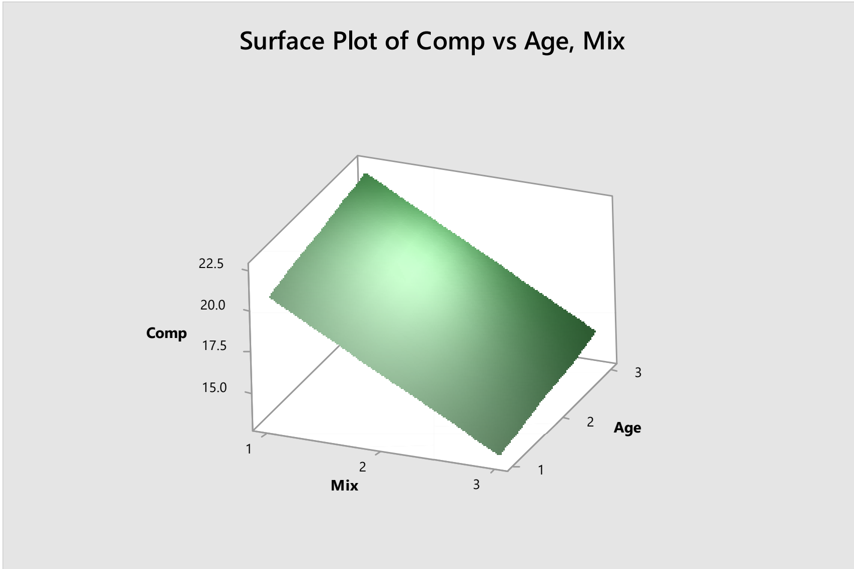

Figure 4: 3D interaction of the Dependent and Independent Variables

Conclusion

The physical and chemical properties of the PVC-powder showed that it has cementing value with a CaO (63 %) almost the same with that of Portland cement (64 % - 67 %). The SiO_2 and Al_2O_3 are also within the same range of 19 % and 3.9 % respectively. The Alkali contents (K_2O and Na_2O) are not likely to cause any alkali-aggregate reactions. The dominant minerals in PVC-power material are Nacrite, Gypsum, Orthoclase, and Wollastonite. There are of course trace elements like Illite, Muscovite and Tobermorite. The high amount of CaO showed that the PVC material can be used as a cement material.

The PVC powder material has a very high affinity for water and therefore, maybe used in conjunction with a water reducing material.

The results of the setting time showed that the PVC powder material has the characteristics of a retarder. Therefore it could be used for hot weather concreting. The detection of gypsum mineral which has hydrating retarding effect.

The mechanical characteristics of the PVC-powder concrete is a normal weight concrete. It reduces the water absorption and compressive strength as the replacement level increased. The maximum compressive strength was recorded at 5 %, however, higher percentages of 10 % and 20 %, can be successfully used.

The basic statistical characteristics (mean, standard deviation, etc.) showed acceptable concrete quality, and within the 95 % confidence limit (CI) with high correlation factors. The linear regression model for compressive strength development is significant.

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