Effect of Clay Bricks Powder on the Fresh and Hardened Properties of Self-Compacting Concrete

Oday A. Abdulrazzaq[1]

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Abstract

Fresh and hardened properties of self-compacting concrete were experimentally examined by replacing different percentages of cement by soft clay powder, which resulting from crushing the wastes of clay bricks. Three percentages (5%, 10%, and 15%) of cement were replaced with clay powder to study their effect on the properties of cement mortar and concrete of Grade (C35) in both fresh and hardened states. It was found that development rates of the compressive and tensile strengths for the mortar between ages of 7 to 28 days, decreased with increasing the percentage of the clay powder. Compared to the mix without clay powder, it was found that replacing (5%) from the cement causes a significant increase in the workability of the self-compacting concrete and the properties of the resulting hardened concrete such as compressive strength, tensile strength, and modulus of elasticity. While using (10%) and (15%) of the clay powder causes a significant decrease in the workability of the fresh concrete and the properties of the hardened concrete compared to mix without clay powder.

Key wards: Fresh concrete, Fly ash, Self-compacting concrete, Waste crushed brick, workability of concrete, burnt clay.

تأثير مسحوق االطابوق الطيني على خصائص االخرسانة ذاتية الرص في الحالة الطرية والصلبة

عدي عدنان عبد الرزاق

الخلاصة

يهدف هذا البحث الى اختبار الخواص الطرية والمتصلبة للخرسانة ذاتية الرص عند استبدال جزء من وزن الاسمنت فيها بالمسحوق الناتج من طحن نفايات الطابوق الطيني. حيث تمت هذه الدراسة باستبدال (٥%، ١٠%، و ١٥%) من وزن الاسمنت بمادة مسحوق الطابوق في كل من مونة الاسمنت والخلطة الخرسانية ذات الصنف (C3S). حيث وجد أن استعمال المسحوق أعلاه يؤدي الى تأخر تطور مقاومة الانضغاط والشد لمونة الاسمنت المقاسة بعمر (٧ و٢٨) يوم وأن هذه التأخر في تطور المقاومة للعجينة يزداد مع زيادة محتوى المسحوق في المونة نسبة الى وزن الاسمنت. بالمقارنة مع الخرسانية الخالية من مادة مسحوق الطابوق الطيني، فقد وجد أن استبدال (٥%) من وزن الاسمنت في الخلطة الخرسانية بمسحوق الطابوق يؤدي الى تحسين قابلية التشغيل للخرسانة الطرية بشكل ممتاز وكذلك زيادة مقاومة الانضغاط والشد للخرسانة الصلبة الناتجة عنها وكذلك زيادة في مقدار معامل المرونة المقاس لهذه الخرسانة. كما وجد أن استبدال (١٠%) و(١٥%) من وزن الاسمنت بمسحوق الطابوق يؤدي الى تقليل قابلية التشغيل للخرسانة بشكل مهم بالاضافة الى تقليل خواص الخرسانة الصلبة الناتجة عنها كمقاومة الانضغاط والشد ومعامل المرونة.

1. Introduction

Self-compacting concrete (SCC) can be defined as a fresh concrete that possesses superior flow ability under its own weight where it can flow through restricted sections without segregation and bleeding. In addition, it does not require any application of vibration or energy during placing. In fresh state, such type of concrete should have a relatively low yield value to ensure the high flow ability, a moderate viscosity to resist segregation and bleeding, and to maintain its homogeneity

[1] Assistant Professor at College of Engineering, University of Basrah-Iraq. adiadnan72@yahoo.com

during transportation and placing. This is to ensure adequate structural performance and long term durability (Aggarwal et al., 2008).

The mix composition of SCC generally differs from that of a normal concrete through a higher proportion of ultra-fines and through the use of highly effective superplasticizers. There are three approaches to the production of SCC; i: Raising the ultra-fines content by addition of fine fractions in the form of fly ash or stone powder, ii: Use of suitable stabilizing additives and or superplasticizer (viscosity agent type), and iii: Combination of above two mentioned approaches (combination type). For SCC, it is necessary to use superplasticizers in order to obtain high mobility. Adding a large volume of powdered material or viscosity modifying admixture can eliminate segregation. The powdered materials that can be added are fly ash, silica fume, limestone powder, glass filler and quartzite filler and others (Chapagain, 2008).

The development of SCC begun in Japan in the early 1980's, when the aim was to build durable concrete structures with a reduced number of skilled workers. The concept of SCC was proposed by Okamura at Tokyo University in 1986. He gave the first prototype of SCC using materials already available in the market. Then, Ojawa and Maekawa in 1989 carried out some initial investigations, at Tokyo University, to develop self-compacting concrete including a fundamental study on the workability of the concrete (Okamura and Ouchi, 2003).

Okamura and Ozawa (1995) have proposed a mix proportioning criteria for SCC. In this criteria, the coarse aggregate and fine aggregate contents are fixed and self-compacting ability is to be achieved by adjusting the water /powder ratio and super plasticizer dosage. The coarse aggregate content in SCC is generally fixed at 50 percent of the total volume of solids. The fine aggregate content is fixed at 40 percent of the mortar volume and the water /powder ratio is assumed to be (0.9-1.0) by volume depending on the properties of the powder and the super plasticizer dosage. The required water/powder ratio is determined by conducting a number of trials.

Chapagain (2008) conducted an experimental study to identify the mechanical properties of SCC by optimizing the use of pozzolanic materials and local aggregates with some proposed statistical models. The research was focused in investigating compressive strength, modulus of elasticity and drying shrinkage behavior of concrete. A dosage of 14 kg/m3 of superplasticizer, 0.39 W/C ratio and 19 mm maximum size of aggregate were produced satisfactory SCC with a good fluidity satisfying the requirement of targeted slump flow for all the selected mix models. He found that a small percent 3% of silica fume with fly ash could be added to reduce the drying shrinkage in concrete. There was a decrease in the modulus of elasticity with the increasing of fly ash up to 20%, but 3% silica fume with fly ash considerably increased it. He also explained that there was no significant difference observed between SCC with different fly ash percentages above 20% of cement.

Ulagadde and Kumbhar (2013) presented an experimental study to develop SCC of M60 grade by using Nan Su method of mix design and incorporated different mineral admixtures of flay ash (FA), silica fume (SF) and ground granulated blast furnace slag (GGBFS) with appropriate dosage of superplasticizers (SP). They studied the workability and 28 days-compressive strength properties using different replacement values from weight of cement. These values were (15%, 20% and 25%) of FA and GGBFS and (5%, 10% and 15%) of SF. They found that 45% of total replacement (FA15%, SF15%, and GGBFS15%) gave good results for both fresh and hardened properties.

Zine Abib et. al. (2013) studied experimentally the effect of using silica fume and fine clay on the compressive and splitting tensile strengths of SCC. In their study, the fine clay was resulted from crushing the wastes of clay bricks. They performed experiments included replacing 5% of cement with silica fume or with fine clay. The maximum size of course aggregate used in these experiments, was 12.5mm. They found that replacing 5% of cement with silica fume caused an increasing in the compressive and splitting tensile strengths about 22.2% and 15.5%, respectively. While, replacing 5% of cement with fine clay caused an increasing in the compression and splitting tensile strengths about 2.2% and 5.5%, respectively. Also they found that decreasing of sand/paste ratio from 0.8 to 0.67 caused an improvement in the workability of SCC. This improvement in the workability was achieved in the case of replacing 5% of cement with fine clay.

Bhoopathi and Madadi (2016) made an experimental investigation on strength aspects like compressive, flexural and split tensile strength for self-compacting concrete containing fly ash (FA). They carried out workability tests for various mineral admixtures such as slump, L-box, V-funnel, U-box and T50. The methodology of mix design adopted in this study was Nan–Su method (Nan Su et al., 2001). The mix proportion was obtained according to the rules given by EFNARC (2005) specifications. The influence of mineral admixtures on the workability, compressive strength, and flexural strength of self-compacting concrete was investigated. As a result, overall improvements within the flow ability, filling ability and segregation resistance of the self-compacting concrete were recorded when the ratio of fine aggregate to total aggregate increased from 55% to 58%. Compressive strength, splitting tensile strength and flexural strength of concrete were increased when the ratio of fine aggregate to total aggregate increased to 57%.

The objective of this study is to examine the effect of using the soft clay powder which resulting from crushing the wastes of clay bricks, as a percentage from the cement weight, on the properties of the SCC at the fresh state and exploring the possibility of using this powder to improve the workability for this type of concrete. Also, the effect of using this powder on the properties of the hardened state of SCC such as compressive strength, splitting tensile strength, modulus of rupture, and modulus of elasticity will be studied. Three percentages of soft clay powder were adopted in this study to investigate their effects on the above properties for concrete mix of Grade (C35). These percentages were (5%, 10%, and 15%). At the same time, this study included examining the effect of using the above three percentages of the soft clay powder on the properties of cement mortar such as compressive strength and modulus of rupture.

2. Experimental investigations

2.1 Materials

2.1.1 Cement

Ordinary Portland cement of specific gravity (3.15) which conforms with Iraqi Standards No. 5 (1984) was used. Table (1) lists the chemical and physical properties of cement which confirm Iraqi Guiding References No. 472 (1993) and No. 198 (1990), respectively.

2.1.2 Powder of clay bricks

Powder of the wastes of clay bricks (PWCB) which contain sizes smaller than (80μm) was used. The specific gravity and absorption values for PWCB are (2.6) and (26.6%), respectively. Table (1) shows the chemical compositions of PWCB which is conformable to ASTM C618 (2015).

Table 1. Chemical and physical properties for the used cement and PWCB.

The property	Cement	PWCB
SiO_2 (%)	20.0	58.4
CaO (%)	61.32	13.7
Fe_2O_3 (%)	4.72	5.2
Al_2O_3 (%)	4.56	17.8

MgO (%)	2.34	1.6
So_3 (%)	2.07	1.5
C_3S (%)	54.35	-----
C_2S (%)	16.4	-----
C_3A (%)	3.68	-----
Loss on ignition (%)	2.40	3.0
Insoluble residue (%)	1.1	-----
Blaine fineness (cm^2/g)	3965	-----
Initial setting time (min)	145	-----
Final setting time (min)	265	-----

2.1.3 Coarse aggregate (Gravel)

Crushed coarse aggregate of (20mm) maximum size and (2.64) specific gravity was used in this study (ASTM, 2015). The Iraqi Guiding Reference No. 368 (1996) was used to find chloride content which equals to (0.053%). According to Iraqi Guiding Reference No. 500 (1994), the sulfate content in the gravel was (0.02%). Figure (1) shows the results of sieve analysis for the gravel according to ASTM C33 (2013).

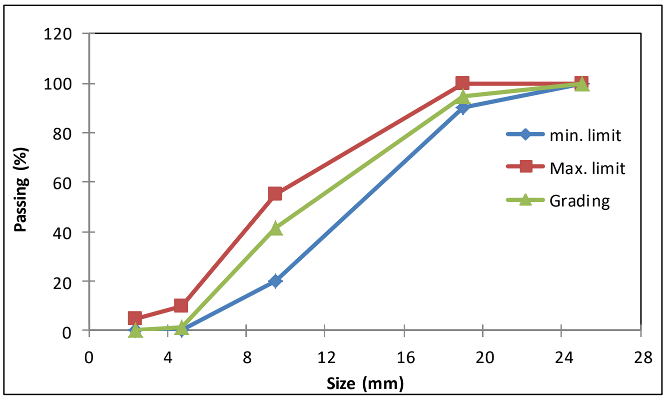

Figure 1. Results of sieve analysis for gravel.

2.1.4 Fine aggregate (Silica sand)

Locally available natural sand was used with specific gravity of (2.6) (ASTM, 2015). ASTM C33 (2013) was used to find fineness modules (2.98) and sieve analysis, as shown in Fig. (2). Chloride and sulfate contents were equal to 0.0٤٦% and 0.٣٩%, respectively (Iraqi Guiding References No. 368, 1996 and No. 500, 1994).

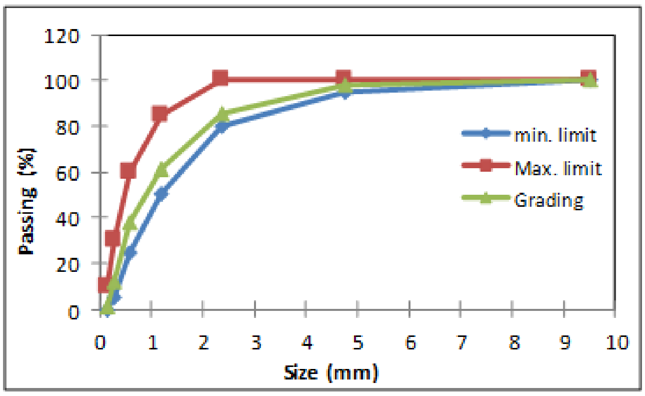

Figure 2. Results of sieve analysis for sand.

2.1.5 Water

Ordinary potable water was used for mixing mortar and concrete samples in addition to curing process. Table (2) lists the properties of the used water which conforms to Iraqi Standards No. 1703 (1992).

Table 2. Water properties.

Type of test	Result (ppm)
SO_3	54.38
PH	7.6
Cl	63.9
TDS	40
Turbidity	107.63
CO_3 & HCO_3	50.03
Organic Mater	6.98

2.1.6 Superplasticizer

A high range water reducing admixture superplasticizer is used for improving the flow or workability for decreased water cement ratio without sacrifice in the compressive strength. PACTOPlast P16 was used in the present work. It conforms ASTM C494 types A and B (2004). The specific gravity for this material is (1.19).

2.2 Mortar

Three percentages of weight from the cement content were replaced with PWCB to study their effect on the behavior of cement mortar were made according to the Iraqi Guiding References No. 198 (1990). These percentages were (5%, 10%, and 15%).

2.3 Concrete mixes

The same above three percentages of PWCB were used in concrete mixes that designed according to ACI 211.1 (1991). One concrete mix was designed in this study to achieve a compressive strength (35MPa). This mix was adjusted to achieve water content needed in SCC which equals to (44.3%). Table (3) shows the final results of the concrete mixture components.

Table 3. Components of mixes.

Components	PWCB (0%)	PWCB (5%)	PWCB (10%)	PWCB (15%)
Cement (kg/m^3)	469	445.55	422.1	398.65
PWCB (kg/m^3)	0	23.45	46.9	70.35
Gravel (kg/m^3)	1136.5	1136.5	1136.5	1136.5
Sand (kg/m^3)	555.3	555.3	555.3	555.3
Water (kg/m^3)	208	208	208	208
SP (kg/m^3)	4.69	4.69	4.69	4.69

2.4 Casting and curing

All standard moulds were coated with oil before casting the mortar and concrete mixes to prevent escape of water out of fill materials (mortar and concrete mixes) and to avoid adhesion with the moulds surface after hardening.

The controlled components of mortar were mixed by hand to become of a uniform color, then they were cast in their moulds and stored in a humidity condition for 24hrs. Thereafter, these specimens were removed from their moulds and stored in a curing tank until date of test (Iraqi Guiding Reference No. 198, 1990).

Controlled components of concrete were mixed using a concrete mixer, cast in their moulds under its own weight, and then cured using damp canvas for 24hrs. Thereafter, the concrete specimens were removed from their mould and stored in a curing tank until date of test.

2.5 Tests performed

Specimens of (70.7mm) cubes and (40mm×40mm×120mm) prisms were used to find compressive strength and modulus of rupture, respectively, for the cement mortar at ages of (7 and 28) days (Iraqi Guiding Reference No. 198, 1990).

Workability of self-compacting concrete was examined in this study by slump flow, flow rate (T50cm), L-box, and T-funnel that usually used for self-compacting concrete (EFNARC,2005). See Figs. (3 to 5).

For hardened state of SCC, the effect of PWCB on the compressive strength were investigated using (150mm) cubes at ages of (7 and 28) days (British standard, 1983). Modulus of rupture (One point load) for SCC were conducted using (100mm×100mm×500mm) prisms at age of (28) days (ASTM, 2010). Splitting tensile strength (ASTM, 2011), and modulus of elasticity (ASTM, 2011) was investigated at age of (28) days using cylindrical specimens of (150mm diameter and 300mm height). See Figs. (6 to 8).

Figure 3. Slump flow and Flow rate (T_{50cm}) tests

Figure 4. V-funnel test.

Figure 5. L-box test.

Figure 6. Instrument test to find splitting tensile strength for concrete.

Figure7. Instrument test to find modulus of elasticity of concrete.

Figure 8. Instrument test to find modulus of rupture.

3. Discussion of the test results

3.1 Effect of PWCB content on the cement mortar

Effect of PWCB content on the compressive strength and tensile strength (modulus of rupture) are shown in Figs. (9 and 10), respectively. In comparison with mortar without PWCB, Fig. (9) shows that replacing (5%, 10%, and 15%) from the cement with PWCB causes a decrease in the compressive strength of the mortar. These reductions at age of (7 days) are about (2.4%, 4.4%, and 10.5%), respectively. While at age of (28 days), the compressive strength of the mortar decreased about (2.1%, 16%, and 24.4%), respectively.

Figure (10) shows that the above mentioned behavior for compressive strength for mortar at ages of (7 and 28) days is true for tensile strength. Replacing (5%, 10%, and 15%) from cement with PWCB causes a decrease in the tensile strength at (7 days) about (2%, 10%, and 12%), respectively. Also, these contents of PWCB in the mortar cause a decrease in the tensile strength at (28 days) about (1.5%, 13.6%, and 22.7%), respectively.

The above mentioned reductions in compressive and tensile strengths, might be attributed to the reduction in the formation of cement gel (CSH) which is the main source of adhesion property. This is due to the reduction of cement with the increase of clay powder percentages.

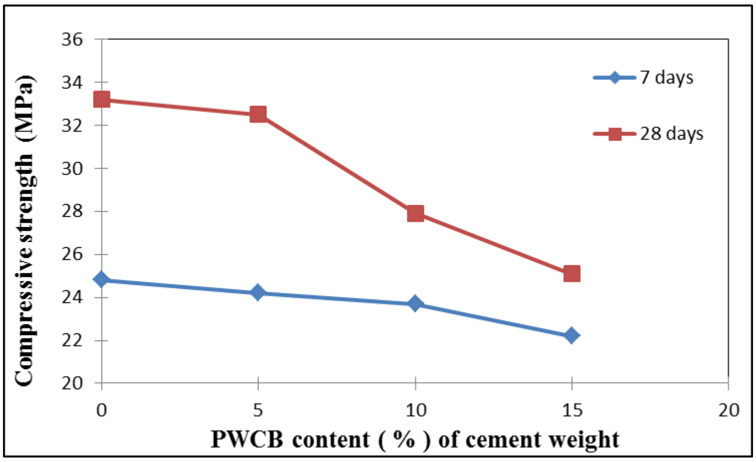

Figure 9. Relationship between PWCB content and compressive strength for the mortar.

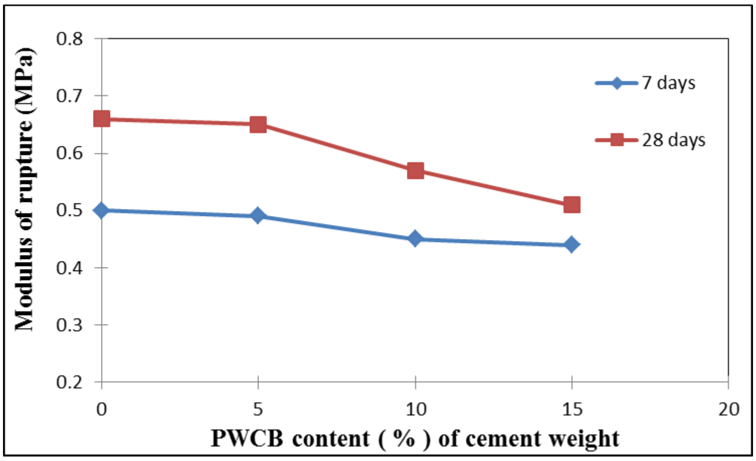

Figure10. Relationship between PWCB content and modulus of rupture for mortar.

3.2 Effect of PWCB content on the workability of fresh concrete

The results of fresh concrete tests compared to the limit values specified by EFNARC (2005) for

SCC are listed in Table (4). This table shows that replacing (5%) from cement weight in the tested concrete mix with PWCB causes an increase in the slump flow about (9.8%), while the recorded times in the T50cm and V-funnel tests for this mix were less about (50%) and (18.2%), respectively. This is indicating that replacing (5%) from cement weight by PWCB causes an improvement in the workability of self-compacting concrete mix. This percent is able to decrease the fresh yield value enabling to cause an improvement on other properties such as viscosity. Accordingly, its flow rate, filling ability, and its resistance to segregation were increased. The recorded height ratios in L-box test show that replacing (5%) from cement weight in the SCC mix by PWCB causes an increase in this ratio about (6%), hence the characteristics of the fluidity and the passing ability were increased.

It can be concluded from Table (4) that replacing (10% or 15%) from the cement weight by PWCB causes a decrease in the workability of these mixes compared to that without PWCB. The mix of 10% PWCB replacement causes a decrease in the recorded slump flow and the height ratio in L-box test about (11.5% and 2.4%), respectively, while the recorded times in the T50cm and V-funnel tests for this mix increased about (25% and 63.6%), respectively. However, the mix of 15% PWCB replacement is unable to achieve the SCC requirements in all tests. This behavior could be illustrated due the high absorption property for the clay (26.6%) which causes reducing in the content of the free water in the mix.

Table 4. Results of fresh concrete tests.

Test	PWCB (0%)	PWCB (5%)	PWCB (10%)	PWCB (15%)	Limits
Slump flow (mm)	610	670	540	400	650-800
T_{50cm} (sec)	4	2	5	-----	2-5
V-funnel (sec)	11	9	18	24	6-12
L-Box	0.83	0.88	0.81	0.77	0.8-1.0

3.3 Effect of PWCB content on the properties of hardened concrete

Figure (11) shows the relationship between PWCB content and compressive strength for concrete at ages of (7 and 28) days. It can be concluded that the compressive strength for concrete at ages of (7 and 28) days increased about (1.1% and 2.7%), respectively, in the case of replacing (5%) from the cement content in the mix with PWCB. But increasing PWCB content to (10% and 15%) caused a decrease in the compressive strength at ages of (7 and 28 days). At age of (7 days), this decrease in the compressive strength was about (12.9% and 15.8%), respectively, while it was about (15.9% and 26.0%), respectively at age of (28 days).

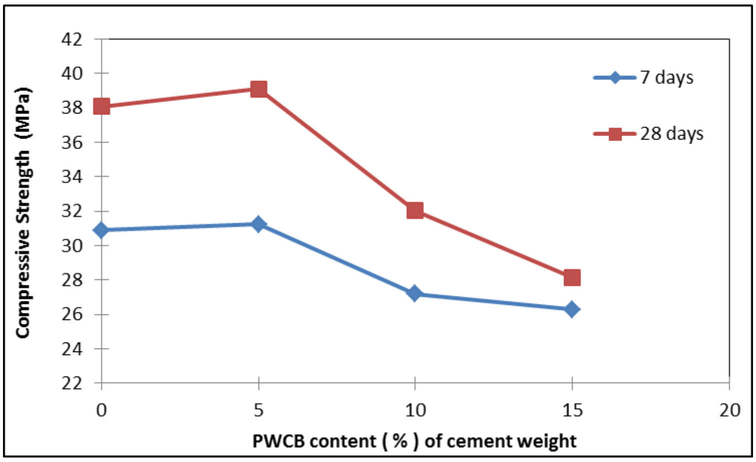

Figure11. Relationship between PWCB content and compressive strength for concrete.

As shown from Figs. (12 and 13), it can be notice that the effect of using different content ratios of PWCB to cement on the behavior of the other properties for hardened concrete of Grade (C35), at age of (28 days), is same to that previously mentioned for compressive strength. Figure (12) shows that the modulus of rupture increased about (1.9%) in the case of replacing (5%) from cement content in the concrete mix with PWCB, while it decreased about (2.1% and 6.3%) in the cases of 10% and 15% replacements, respectively. Also, splitting tensile strength increased about (4.3%) in the case of using (5%) of PWCB, while there was a decrease in the splitting tensile strength of about (1.3% and 3.8%) due to increase of PWCB to (10% and 15%), respectively. Figure (13) shows that the modulus of elasticity increased about (4%) in the case of 5% PWCB replacement. But it decreased about (0.1% and 0.8%) in the cases of adopting 10% and 15% replacements, respectively.

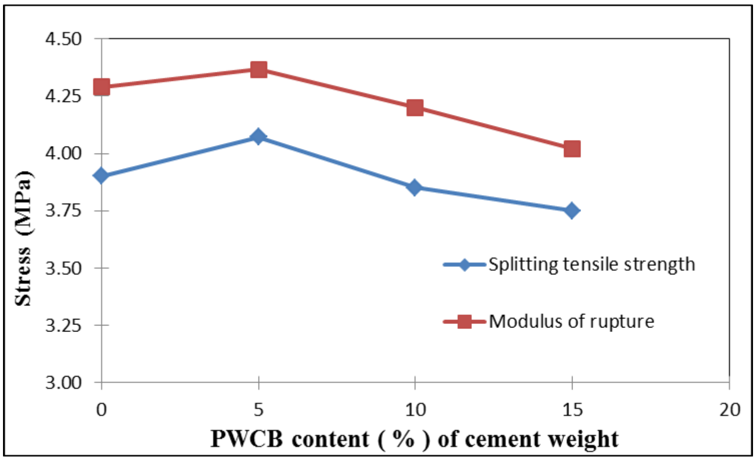

Figure 12. Change of modulus of rupture and splitting tensile strength with PWCB content in concrete.

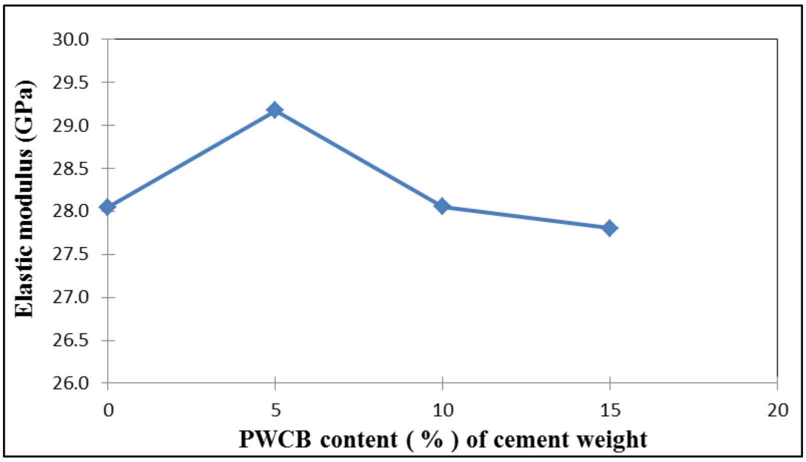

Figure13. Relationship between PWCB content and elastic modulus for concrete.

Although there was a small decreasing in the compressive and tensile strengths of the mortar in the case of replacing (5%), the improvement of the workability in the mix of Grade (C35) caused an improvement in the properties of the resulting hardened concrete compared to that without PWCB. While increasing the content ratio of PWCB to (10% and 15%) causes a weakness in the resulting properties of the hardened concrete because of the decreasing in each of the workability of the fresh concrete and the strength of cement mortar which contain these two ratios of PWCB.

4. Conclusions

Based on the test results presented in this study, the following conclusions could be drawn;

1- Replacing (5%, 10%, and 15%) from the cement weight in the mortar with powder of the wastes of clay bricks (PWCB) causes a decrease in compressive strength at ages of (7 and 28) of about (5%, 10%, and 15%) and (0.6%, 16%, and 24.4%), respectively.

2- Replacing (5%, 10%, and 15%) from the cement weight in the mortar with PWCB causes a decrease in tensile strength at ages of (7 and 28) of about (2%, 10%, and 12%) and (1.5%, 13.6%, and 22.7%), respectively.

3- Replacing (5%) from cement weight in the self-compacting concrete mix of Grade (C35) with PWCB causes an increase in the slump flow and height ratio in the L-box test about (9.8% and 6%), respectively, while it causes a decrease in the recorded times in the T_{50cm} and V-funnel tests about (50% and 18.2%), respectively.

4- Replacing (10%) from cement weight in the self-compacting concrete mix of Grade (C35) with PWCB causes a decrease in the slump flow and height ratio in the L-box test about (11.5% and 2.4%), respectively, while it causes an increase in the recorded times in the T_{50cm} and V-funnel tests about (25% and 63.6%), respectively.

5- The mix of 15% PWCB replacement is unable to achieve the SCC requirements in all tests of the fresh concrete.

6- Replacing (5%) from cement weight in self-compacting concrete mix of Grade (C35) with PWCB causes an increase in the compressive strength, at ages of (7 and 28) days, 1.1% and 2.7%, respectively.

7- Replacing (5%) from cement weight in self-compacting concrete mix of Grade (C35) with PWCB causes an increase in the modulus of rupture and splitting tensile strength of about (1.9% and 4.3%), respectively.

8- Replacing (5%) from cement weight in self-compacting concrete mix of Grade (C35) with PWCB causes an increase in the modulus of elasticity of about 4%.

9- Replacing (10% and 15%) from the cement weight, in self-compacting concrete mix of Grade (C35), with PWCB causes a weakness in the resulting properties of the hardened concrete such as compressive strength, modulus of rupture, splitting tensile strength, and modulus of elasticity.

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