Sixth International Conference on Construction in the 21st Century (CITC-VI)
"Construction Challenges in the New Decade"
July 5-7 2011, Kuala Lumpur, Malaysia

Investigation of Ultrasonic Pulse Velocity on S+WPSA Brick

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Abstract
This paper presents an investigation of pulse velocity by using Pundit test on S+WPSA Brick. S+WPSA Brick is a brick that is produced by using sand and waste paper sludge ash (WPSA) as cement replacement. WPSA is collected from a paper recycle manufacturing industry. The S+WPSA brick mixes were made into 215 mm x 102.5 mm x 65 mm at normal consistency for compressive strength. The aim of the study is to estimate the mechanical properties and to evaluate homogeneity by identify void and honeycomb. 8 specimens of S+WPSA Brick of proportion 1: 2 were tested. The results obtained were compared with classification of concrete quality criteria. The results of this study illustrate that S+WPSA brick is classified as an excellent in quality and integrity. Therefore, S+WPSA brick is suitable for light construction that not use as a sustain load.

Keywords
Brick, Waste Paper Sludge Ash (WPSA), Cement Replacement, Ultrasonic Pulse Velocity

1. Introduction

The bricks for construction of houses, buildings and others are divided into two types. Clay brick that produced by using clay and it will be fired in high temperature and another brick is called sand brick or mortar brick. The clay brick is in red color and the sand brick in white color. Brick is an important component in the construction and used as the wall in building that contribute high cost. Clay bricks are bricks with high compressive strength when compared with sand brick. The sand bricks are made from a mixture of sand, cement and water known as the mortar. Sand Brick made of sand is easier, cheaper, required less maintenance and more widely produced.

Therefore, new solid sand brick with using natural sand, waste material and water were been produced. Waste material that used as cement replacement in this study is Waste Paper Sludge Ash (WPSA). WPSA in the form of powder discharged in large quantities every day easily obtained from the newspaper industry at Temerloh area in Pahang. This material is reviewed and found to be highly suitable size that is used as a cement replacement in the production of cement sand bricks.

In Malaysia, the high volume of wastepaper has increased tremendously due to the high utility of paper and paperboards from paper industries. In Temerloh district for instance, it was reported that the disposal of about 80 tons per day of wastepaper from newspaper industries to a landfill area which eventually imposes a considerable load and shortens the life span of the facility (Malaysian Newsprint (MNI), 1999).

The problem to find additional sites is also becoming more difficult due to acute shortage of land as the pace of development around Temerloh progresses. Apart from that, conventional construction material depends on natural resources, which are now becoming scarce. The process of taking materials in the hills to make cement also causes a lot of geological problems and are exposed to landslide risk. In addition, cement and brick production sites extensive will cause air pollution, ecosystem problem and noise pollution is severe. Besides that, the usage of cement or ordinary portland cement is promoting carbon emissions and increasing the impact on the environment. In order to overcome of these problems, there is a need to provide viable solution by reducing the use of natural resources and by reusing waste material.

The use of WPSA as a component in the production of cement and special grade in concrete is not new to the cement industries and has proven records in term of application. Previous studies conducted by Bai et al. (2003), Ishimoto (2001) and Mozaffari (2006) indicated that the WPSA is suitable for use in cement replacement and civil engineering applications. Studies by O'Farrell et al. (2002) revealed that at very high replacement levels of WPSA to the Portland cement, for example, above 60%, the concrete did not remain intact. This is attributed to the effect of the water reducing-retarding admixture added to offset the high water demand of WPSA. However, it is viable to replace up to 60% of PC with WPSA and still obtain concrete with compressive strength in excess of the control.

Non destructive test (NDT) is analysis equipment and techniques that are used in civil, structural and forensic engineering. NDT is widely used to evaluate the properties of a material, quality and uniformity of a material. This test can save time and money as they assess the material properties without causing damage. Examples of NDT test are Pundit test, rebound hammer, impact echo, strain measurement, penetration resistance, initial surface absorption, half cell potential and etc. So that in this study, Pundit test was used to calculate pulse velocity, transit time, elastic modulus and path length of the specimen or material. Pulse velocity (PV) as shown in Figure 1 has been used in civil engineering and concrete application to evaluate the quality of concrete structure, measure of concrete uniformity and evaluate the properties of concrete for certain life. PV can be used not only for concrete but also for timber, ceramics, cast iron, geological specimens and other materials. Besides that, pulse velocity also can be used as detection of internal cracking, transit time, path length, perpendicular crack depth and elastic modulus. Void and other defect detection and possible to investigate the concrete strength. Mechanical wave techniques that been used in estimating pulse velocity of the concrete surface. This technique could not bring damage to the specimen and can test every time.

PV is can classify into 3 categories of reading/orientation, direct test, indirect test and semi direct test. The schematic diagram of these 3 categories of reading is illustrated in Figure 2. PV is used to assess of concrete quality for different structural components like roof beams, crane girders, shell beams, columns, shell roof and etc (Sahu and Jain, 1998). According to Whitehurst, 1951 concrete with density of 2400 kg/m^3 are considered excellent for 4500 m/s and above, good for 3500 – 4500 m/s, doubtful for 3000 – 3500 m/s, poor for 2000 – 3000 m/s and very poor for 2000 m/s and below. Besides that, the lower limit for good quality concrete is between 4100 – 4700 m/s (Jones, 1955). As per IS: 13311 (Part 1) – 1992, concrete quality can be classified according to Table 1.

Figure 1: Pundit tester for ultrasonic pulse velocity

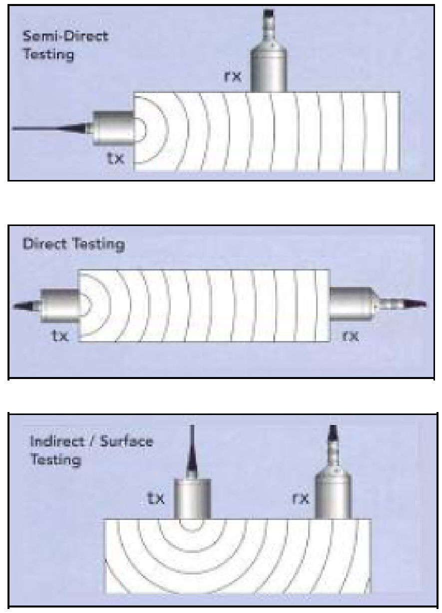


Figure 2: UPV test for semi-direct, direct and indirect test

Table 1: Concrete quality and pulse velocity classification according to IS: 13311 (Part 1) –1992

Pulse Velocity (km/second)	Concrete Quality (Grading)
Above 4.5	Excellent
3.5 to 4.5	Good
3.0 to 3.5	Medium
Below 3.0	Doubtful

Many researchers had used the pulse velocity in their study to determine the compressive strength of the brick. Study by Brozovsky and Zach (2007) of non-destructive test of solid burnt brick (290 x 140 x 65 mm and 303 x 145 x 70 mm) compression strength in structures. Usage of ultrasonic pulse velocity to investigates the potential use of cotton waste and limestone powder wastes for producing new low cost and lightweight composite as a building material (Algin and Turgut, 2008). Study was undertaken to investigate the feasibility of using ultrasonic pulse velocity methods for evaluating the properties of clay bricks and their durability (Koroth et al, 1998).

Thus, this study to check and investigate the properties of a serial of S+WPSA Brick specimens made of 100% replacement of WPSA which was obtained from a newsprint industry as a cement replacement material in brick production as shown Figure 3.

Figure 3: S+WPSA Brick

2. Methodology

2.1 Materials

The cementitious materials used in this study were the WPSA as Ordinary Portland Cement (OPC) replacement as shown in Figure 4. The WPSA chemical properties were tested prior to mixing in concrete. The chemical analysis was performed to determine the silica, alumina, calcium oxide and magnesium contents in the ash and the results are shown in Table 2. ASTM C618 (2008) specifies the minimum of the total percentage of the three major combined oxide namely silicon dioxide (SiO_2), aluminium oxide(Al_2O_3) and ferric oxide (Fe_2O_3) ash has to be at least 50% before any ash can be declared as a pozzolanic. In the present study, the total percentage of the three combinations of SiO_2, Al_2O_3 and Fe_2O_3 was nearly 45% and expected to possess low pozzolanic reactivity. The percent of particle size of WPSA was also determined and is shown in Table 3. The data show that the size of WPSA particles is in the range of 150 - 2000 µm. The concentration of heavy metals in WPSA was also determined and is shown in Table 4. The result indicated that arsenic, barium, cadmium, chromium and lead were present. In addition, WPSA is classified as non-schedule waste (non-toxic) by the Department of Environmental (DOE) (MNI, 1999).

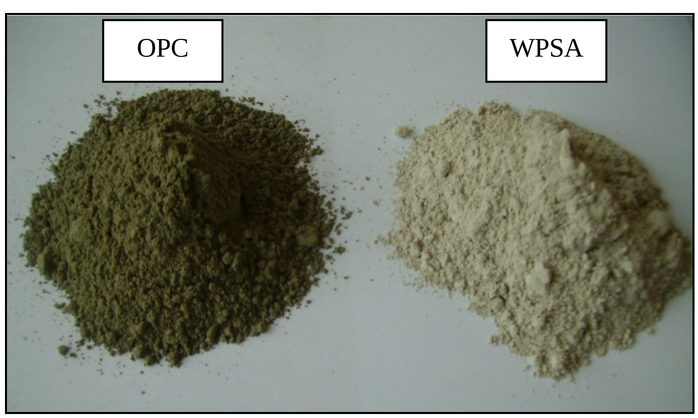


Figure 4: OPC and WPSA

Table 2: Chemical compositions of OPC and WPSA

Chemical Components		**Chemical Composition (% w/w)**	
Chemical constituents	Empirical Formula	OPC*	WPSA**
Calcium oxide (lime)	CaO	64.8	30.52
Silicon dioxide (silica)	SiO_2	20.6	28.15
Aluminium troxide	Al_2O_3	5.8	15.77
Ferric trioxide	Fe_2O_3	3.5	1.05
Magnesium oxide	MgO	0.6	1.94
Sulphate	SO_3	2.4	0.57
Loss of ignition	LOI	1.3	17.23

* Amin (2008)
** MNI (1999)

Table 3: Percentage of WPSA particle size

Particle Size, µm	**Mass, %**
> 2000	1.17
150 < X < 2000	94.32
125 < X < 150	2.22
100 < X < 125	0.49
90 < X <100	0.75
15 < X < 90	0.9
53 < X < 75	0.16
45 < X < 53	0

Table 4: Concentration of heavy metals in WPSA used in the present study

Element	**µg/g**
Lead, Pb	62.2
Arsenic, As	0.012
Barium, Ba	123.9
Cadmium, Cd	0.11
Copper, Cu	210.3
Zinc, Zn	101.1
Selenium, Se	0.38
Silver, Ag	0.14
Chromium, Cr	23.6

2.2 Mix Proportion

Details of the mix proportions of mortar mixes are given in Table 5. Sand that used in this mix was size below 5 mm and water took directly from tap water. The water cement ratio was fixed at 0.5.

Table 5: Mix proportions of mortar specimens by volume

WPSA (ml)	Sand (kg)	Water (kg)	Water/WPSA ratio
6530	18	4.50	0.5

2.3 Testing

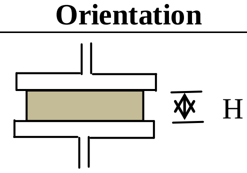
All the procedures and methods of conducting the tests were measured by the procedure given in standard. The S+WPSA brick mixes were cast into 215 mm x 102.5 mm x 65 mm at normal consistency for compressive strength. All the brick were cast in fabricated timber formwork. Specimens were compacted using a slump rod and vibrating table until the mortar mix compacted. After 24 hours of casting, the specimens were removed from the formwork and cured in water for 3 days. After the curing process, the S+WPSA brick surface were cleaned and removed the water on surface of brick by using a piece of cloth. Finally, the brick was tested of pundit test for pulse velocity, transit time, path length and modulus of elasticity.

The ultrasonic test equipment that used in this study is PUNDIT (Portable Ultrasonic Non-destructive digital Indicating Tester) test and followed the BS 1881-203 standard. UPV method based on measuring the velocity of compression wave and the velocity travelling in a solid material depends on the density and elastic properties of material. The equipment consists of a transducer for transmitter and transducer for receiver. Transducer for transmitter is which wave or pulses are transmitter while transducer for receiver is wave are received and directly indicate the time of travel. Solid material surface must be smoothed from rough so that the transducers easy to be placed. The data was obtained by using method that specified in the BS 1881-203. In this study, UPV data for S+WPSA brick is conducted only in direct testing as shown in Figure 2. This is because the S+WPSA brick surface having three faces or orientations. Data of pulse velocity, path length, transit time and elastic modulus were taken directly from Pundit equipment.

3. Results

The brick was tested in 3 orientations that identified as bed, stretcher and header face as shown in Figure 5. For bed, stretcher and header face, the transducers for transmitter and receiver were subjected to face to face between the orientations. The reason is taking 3 orientations in Pundit Test because it's similar to standard testing of compressive strength for brick. Strength of mortar and concrete relate with the presence of air void/pores. If there are too many air void/pores the strength will be reduced. Therefore, it is significant to evaluate the presence of air void by using Pundit equipment or pulse velocity value. The 8 S+WPSA bricks with the individual length, width, height and mass were measured as shown in Table 6. The complete results for 8 numbers of S+WPSA brick for 3 faces are illustrated in Table 7.
More no. of brick sample use, were give the accurate result.

Figure 5: Orientation of the S+WPSA brick

Orientation	Face
	BED FACE

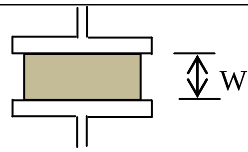
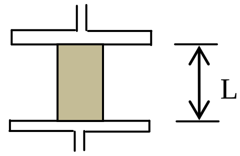
	STRETCHER FACE
	HEADING FACE

Table 6: Individual S+WPSA bricks dimension for length, width, height and mass.

Brick No.	Length, L (mm)	Width, W (mm)	Height, H (mm)	Mass (kg)
1	214.68	104.00	64.76	2.38
2	214.70	102.64	65.37	2.55
3	216.12	102.56	64.85	2.61
4	214.89	103.60	65.81	2.62
5	214.77	102.78	66.00	2.14
6	215.57	103.00	65.04	2.25
7	216.02	102.35	65.18	2.10
8	215.45	102.48	65.02	2.23

Table 7: Result of pundit test experiment for 8 S+WPSA bricks

Brick No.	Bed Face				Stretcher Face				Heading Face			
	Pulse velocity (m/s)	Transit time (μsecs)	Path length (m/mm)	Elastic Modulus (GN/m^2)	Pulse velocity (m/s)	Transit time (μsecs)	Path length (m/mm)	Elastic Modulus (GN/m^2)	Pulse velocity (m/s)	Transit time (μsecs)	Path length (m/mm)	Elastic Modulus (GN/m^2)
1	16393	39.1	136	108.6	9596	50.9	218	106.0	4921	101.0	392	81.2
2	16129	30.5	126	160.1	9225	50.5	218	102.0	4198	140.8	482	50.4
3	14409	34.3	137	157.9	6756	74.7	243	91.0	4370	112.2	452	67.3
4	17241	28.1	114	148.8	10940	45.7	186	173.1	5440	91.5	364	95.6
5	19264	33.8	134	204.9	8474	76.6	316	136.1	5065	100.5	392	93.3
6	16181	30.9	123	210.8	8726	49.0	223	146.6	4892	94.4	372	103.8
7	14836	32.8	133	149.5	9041	54.6	216	159.0	4578	112.1	434	81.5
8	18450	26.6	107	229.1	9560	55.9	201	106.0	4401	104.8	421	72.6
AVG	16612.9	32.0	126.3	171.2	9039.8	57.2	227.6	127.5	4733.1	107.2	413.6	80.7

3. Discussion

Table 4 show the results of Pundit test for transit time, path length, velocity and elastic modulus. Bed faces orientation for brick no. 5 illustrates the highest pulse velocity value is 19264 m/s. While brick no. 4 show the highest pulse velocity for stretcher face and heading face of 10940 m/s and 5440 m/s respectively. Since there are no standard of quality based on pulse velocity been identified for brick or mortar. Therefore, the standard quality of concrete was used to justify the quality of S+WPSA brick. According to standard IS for concrete in Table 1; all brick were graded as excellent quality category that above 4500 m/s. The results are relevant because theoretically or practically mortar brick structure is made by sand, cement and water. The brick structure which is the air voids/ pores between the particle of materials or mortar ingredients is smaller compared to concrete. Concrete with consists coarse aggregate will give more air voids/pores in the structure. Heading face for brick no. 2, 3 and 8 indicated below 4500 m/s that can be classified as good quality. When compared with normal mortar brick in the market with the average 12339.3 for bed face, 6011.6 for stretcher face and 3457.4 for heading face. It showed that the S+WPSA brick is appropriate for construction regarding of the pulse velocity value.

The result show that the brick with decreasing distance between transducers were gave high value of pulse velocity. This is because the brick composition were not in fully compacted when distance increase. Besides that, the production of the brick show the value became inaccurate because of lack compact when in casting process. Then, the result showed that the brick no. 3 is very low in pulse velocity value for every face. This can be concluded that the brick having a lot of air void in brick structure. The brick moulds are laid in bed face of the brick when in moulding process. Velocity of pulse in brick structure decreases also if there are any obstacles such as air void, cracks, other defects or any presence of other foreign materials.

Result of path length also can be used in detecting the air void or porosity condition. With higher porosity or the presence of void on the path will increase the path length. This is because the wave goes around the air void and gave higher value. Path length for brick no 3, no 5 and no. 2 prove the highest value for bed face, stretcher face and heading face with 137 m/mm, 316 m/mm and 482 m/mm respectively. The transit time of S+WPSA brick is increased when the path length increase.

The maximum elastic modulus for S+WPSA brick for bed face is 229.1 GN/m^2 while for stretcher face is 173.1 GN/m^2. For heading face, the maximum value of elastic modulus is 103.8 GN/m^2. It shows that the elastic modulus of S+WPSA brick is increased when the orientation of transducers increased. On the other way, elastic modulus of these three orientations demonstrated the S+WPSA brick tendency to be deformed elastically when a load is applied. The elastic modulus of S+WPSA is higher when compared with high strength concrete (30 GPa). With the value of elastic modulus, the S+WPSA is capable to return its original shape after been distorted.

4. Conclusion

The chemical and physical of WPSA are investigated and show that it's suitable to replace of PC and suggested as a green material in construction. Then, the pulse velocity of S+WPSA brick are studied and show the suitability in the production of new brick material.

From the experimental data, the following conclusions can be drawn:

1. The average of pulse velocity for bed face, stretcher face and heading face is 16612.9 m/s, 9039.8 m/s and 4733.1 m/s respectively.
2. The average of elastic modulus for bed face, stretcher face and heading face is 171.2 GPa, 127.5 GPa and 80.7 GPa respectively.
3. The highest value of path length shows the high presence of air void in brick structure.

The Pundit test equipment has been used to evaluate the concrete structures is not sufficient in this study. This is because the equipment just had result on the surface of the concrete structure. Some other NDT method and equipment should be used in this study to investigate the precise data such as pull out tester, half cell potential and strain measurement. The use of combined methods also can produces results that are more reliable when compared with the use of the above equipment separately (Hobbs and Kebir, 2007).

The following recommendation can be made from the study:

1. Investigate the inner texture of the brick by using Scanning Electron Microscope (SEM) and determine the percentage of air void.
2. Compare S+WPSA Brick with existing or in market brick.
3. Extension the study by checking the temperature of concrete and minimize the length of transducers.
4. Extension the study by using other NDT method or equipment or by using combined methods.
5. Compare and discuss the strength and pulse velocity according to 3 orientations of S+WPSA brick.

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