

## NON-DESTRUCTIVE EVALUATION OF FLOWING CONCRETES INCORPORATING QUARRY WASTE

S.N. Raman<sup>a\*</sup>, Md. Safiuddin<sup>b</sup> and M.F.M. Zain<sup>a</sup>

<sup>a</sup>Department of Architecture, Universiti Kebangsaan Malaysia, 43600 UKM Bangi,  
Selangor Darul Ehsan, Malaysia

<sup>b</sup>Department of Civil and Environmental Engineering, University of Waterloo,  
200 University Avenue West, Waterloo, ON N2L 3G1 Canada

### ABSTRACT

Flowing concretes were produced using quarry waste as a partial replacement of natural mining sand. The non-destructive properties such as dynamic modulus of elasticity, ultrasonic pulse velocity, and initial surface absorption were investigated. The slump, slump flow, V-funnel flow, air content and compressive strength of the concretes were also determined. The variation of dynamic modulus of elasticity, ultrasonic pulse velocity, and initial surface absorption with compressive strength was observed. In addition, the correlation among the aforementioned non-destructive properties was examined. Test results indicate that quarry waste did not severely affect the non-destructive properties of the concretes. Dynamic modulus of elasticity, ultrasonic pulse velocity, and initial surface absorption varied linearly with compressive strength. Moreover, dynamic modulus of elasticity and ultrasonic pulse velocity were well correlated.

**Keywords:** Flowability, flowing concrete, non-destructive properties, quarry waste

### 1. INTRODUCTION

The use of superplasticizers (high-range water-reducing chemical admixtures) and mineral admixtures has driven major advancements in the area of concrete engineering and technology for the past few decades. Both superplasticizers and mineral admixtures have been exploited significantly to produce flowing concretes. Flowing concrete refers to a concrete, which possesses good flowability and eases concrete placement in hardly accessible areas and locations of congested reinforcement [1,2]. The use of superplasticizers is essential to produce flowing concretes. Superplasticizers increase the flowability as well as contribute to improve the compressive strength of concrete [1,2]. Furthermore, mineral admixtures such as silica fume, fly ash, and ground granulated blast-furnace slag have been used in flowing concretes to improve flowability as well as other properties of concrete [3-7].

---

\* Email-address of the corresponding author: snraman@gmail.com

Except chemical and mineral admixtures, flowing concretes include the basic constituent materials used for ordinary concrete. These are coarse aggregate, fine aggregate or sand, cement and water. The sand used for concrete production is mostly obtained from natural sources such as rivers and pits. The worldwide consumption of sand in concrete is very high. Therefore, several developing countries including Malaysia have encountered some strain in the supply of natural sand to meet the increasing needs of infrastructural development in recent years. This situation has also caused to increase the cost of sand, resulting in an overall cost increase in concrete production. Hence, there has been a pressing need among researchers and practitioners to identify alternative sources of fine aggregate. Quarry waste, a by-product from quarrying activities, can be a potential alternative of natural sand. In concrete production, it could be used as a partial or full replacement of natural sand. Besides, the utilization of quarry waste, which itself is a waste material, will reduce the cost of concrete production.

Vast quantities of wastes are generated from aggregate quarrying industry. Some of these quarry wastes have been used to serve different purposes. The most common use is in the construction of roads and highways [8,9]. Nataraja et al. produced concrete utilizing the large-size quarry wastes as coarse aggregates [10]. Nagaraj and Banu produced concrete using rock dust as an alternative to natural sand [11]. They studied the effect of rock dust on the strength and workability of concrete. Celik and Marar used crushed stone dust as a partial replacement of fine aggregate in concrete production [12]. They investigated the effects of crushed stone dust on some key properties of concrete. Also, Ho et al. utilized quarry dust in self-compacting concrete [13]. They used quarry dust as a partial replacement of cementing material. In comparison, limited research has been conducted in the area of flowing concretes incorporating quarry waste as a partial or full substitute of natural sand.

This paper reports the results of an experimental study undertaken to evaluate the non-destructive properties of different flowing concretes containing quarry waste as a partial replacement of natural mining sand. The non-destructive properties investigated were dynamic modulus of elasticity, ultrasonic pulse velocity and initial surface absorption (ISA). The flow properties and air content of the fresh concretes as well as the compressive strength development in hardened concretes were also determined. The variation of the above-mentioned non-destructive properties with compressive strength was observed. In addition, attempts were made to correlate the non-destructive properties of the concretes.

## 2. RESEARCH SIGNIFICANCE

Quarry waste is generally considered as a waste material and causes an environmental load due to disposal problem. The successful utilization of quarry waste as fine aggregate would turn this waste material into a valuable resource. In addition, the strain in the supply of natural sand will be reduced, and the cost of concrete production will be offset if the quarry waste is used as a partial replacement of natural sand. However, it should be ensured that the incorporation of quarry waste does not harm the strength, and other key hardened properties and durability of concrete. More precisely, the quality of concrete should not be severely downgraded at the expense of cost reduction. Nevertheless, the non-destructive properties such

as dynamic modulus of elasticity, ultrasonic pulse velocity, and initial surface absorption are useful to indicate the strength and durability of the concrete. Thus, this study provides some basis to judge the quality of flowing concretes incorporating quarry waste.

### 3. EXPERIMENTAL PROCEDURE

#### 3.1 Materials

Crushed granite stone, natural mining sand, quarry waste, ordinary (ASTM Type I) portland cement, silica fume, Class F Malaysian fly ash, tap water, a sulfonated naphthalene formaldehyde condensate-based superplasticizer, and an air-entraining agent were used to produce flowing concretes. Crushed granite stone and mining sand were used as coarse and fine aggregates, respectively. Quarry waste, obtained from a local aggregate quarry, was used as a partial replacement of mining sand. Both silica fume and fly ash were used in flowing concretes as a partial replacement of cement. Table 1 presents the major properties of the materials. In addition, the gradation of the aggregates has been shown in Figure 1.

Table 1. Major properties of the materials.

Material	Properties
Crushed granite stone	Specific gravity: 2.62; Absorption: 0.90 %; Maximum size: 19.00 mm; Fineness modulus: 6.64; Aggregate crushing value: 26 %; Flakiness index: 28 %
Natural mining sand	Specific gravity: 2.60; Absorption: 1.20 %; Maximum size: 4.75 mm; Fineness modulus: 3.01; Aggregate crushing value: 18 %
Quarry waste	Specific gravity: 2.63; Absorption: 0.60 %; Maximum size: 9.5 mm; Fineness modulus: 3.20; Aggregate crushing value: 49 %; Flakiness index: 55 %
Ordinary portland cement	Specific gravity: 3.15; Mean particle size: 23 $\mu\text{m}$ ; Specific surface area (Blaine): 325 $\text{m}^2/\text{kg}$
Silica fume	Specific gravity: 2.20; Mean particle size: 0.15 $\mu\text{m}$ ; Specific surface area (nitrogen adsorption): 26,000 $\text{m}^2/\text{kg}$
Class F Malaysian fly ash	Specific gravity: 2.26; Mean particle size: 20 $\mu\text{m}$ ; Specific surface area (Blaine): 440 $\text{m}^2/\text{kg}$
Tap water	Chloride content = nil; pH = 6.9; Dissolved solids < 2000 ppm
Superplasticizer	Specific gravity: 1.21; Solid content: 40 %
Air-entraining agent	Specific gravity: 1.02; Solid content: 8 %

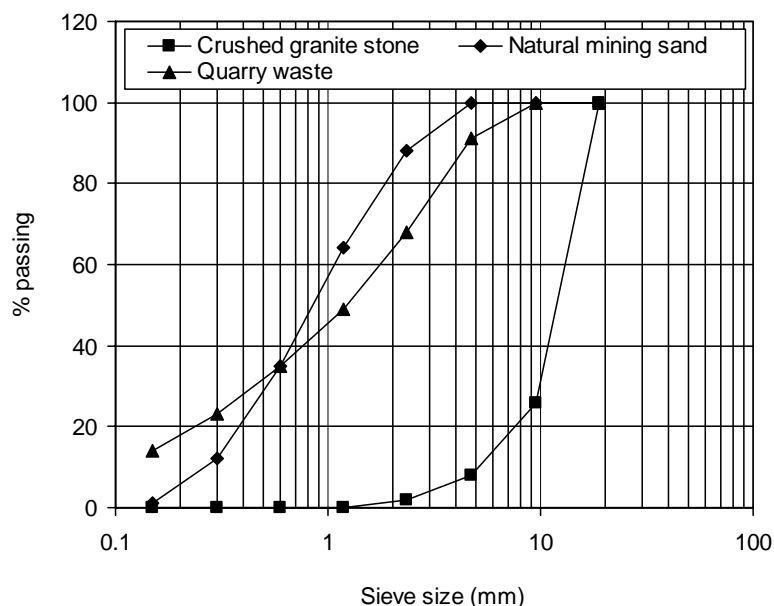


Figure 1. Gradation of crushed granite stone, natural mining sand, and quarry waste

### 3.2 Mixture proportions

Four types of flowing concretes, namely OPC, CQW, SFQW and FAQW were prepared with a water-binder ratio of 0.45. For all concretes, the coarse aggregate to fine aggregate ratio was fixed at 60:40. OPC concrete was the control concrete with no replacement of sand and cement. In CQW, SFQW and FAQW concretes, 20% of mining sand (by weight) was replaced with quarry waste. Silica fume and fly ash were used to replace 10% of cement (by weight) in SFQW and FAQW concretes, respectively. The dosages of superplasticizer and air-entraining agent were fixed by monitoring the desired flowability and air content in trial mixtures. The details of the mixture proportions are presented in Table 2.

### 3.3 Scope of tests

Component materials were mixed at ambient temperature by using a rotating pan type mixer (capacity: 0.05 m<sup>3</sup>). The quantity of the concrete prepared for each batch was at least 15% in excess of the required amount. The mixing of the constituent materials was undertaken for six and a half minutes. Immediately after completion of the mixing process, the fresh concrete was sampled for the determination of slump, slump flow, V-funnel flow and air content. The slump was measured in accordance with ASTM C143 [14]. In slump test, the average spread of the deformed concrete was also measured to obtain the slump flow. The air content was determined based on BS 1881: Part 106 [15]. The V-funnel flow was measured by using the V-funnel apparatus shown in Figure 2 by adopting the procedure recommended by Japanese researchers [16]. In this test, the flow time of concrete passing through a V-shaped funnel was recorded and the V-funnel flow was computed as volume flow rate.

Table 2. Mixture proportions of different flowing concretes (water-binder ratio = 0.45)

Material	Type of concrete			
	OPC	CQW	SFQW	FAQW
Crushed granite stone ( $\text{kg/m}^3$ )	1026	1027	1017	1018
Natural mining sand ( $\text{kg/m}^3$ )	684	547	542	543
Quarry waste ( $\text{kg/m}^3$ )	-	137	136	136
Ordinary portland cement ( $\text{kg/m}^3$ )	450	450	405	405
Silica fume ( $\text{kg/m}^3$ )	-	-	45	-
Class F Malaysian fly ash ( $\text{kg/m}^3$ )	-	-	-	45
Tap water ( $\text{kg/m}^3$ )	202.5	202.5	202.5	202.5
Superplasticizer ( $\text{l/m}^3$ )	6.525	7.200	11.700	7.200
Air-entraining agent ( $\text{l/m}^3$ )	0.225	0.225	0.315	0.405

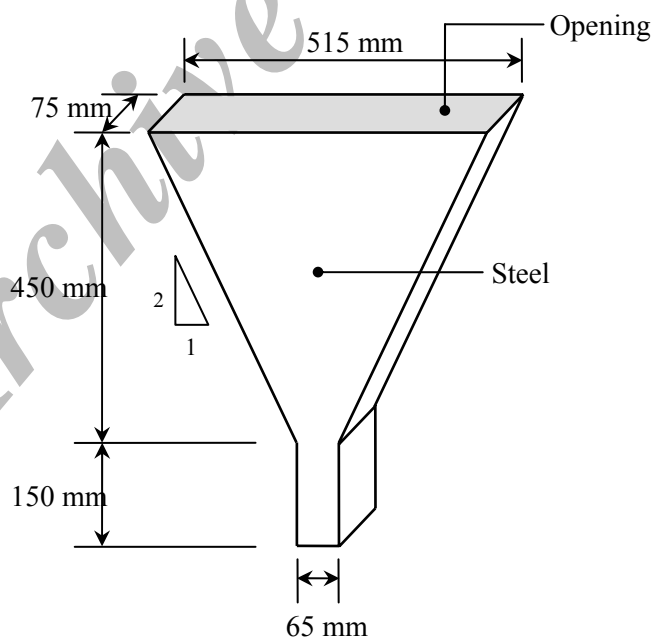


Figure 2. V-funnel apparatus

Cylinder and cube specimens were prepared from fresh concretes. After testing slump, slump flow, V-funnel flow and air content, the fresh concrete was placed into cast iron cylinder moulds of 100mm (diameter)×200mm (height) and cube moulds of 150 mm in two layers. Each concrete layer was compacted by rodding in the specified manner. The capping of freshly moulded cylinder specimens was undertaken to ensure plane and parallel end surfaces. The compressive strength and the non-destructive properties such as dynamic modulus of elasticity and ultrasonic pulse velocity of the hardened concretes were determined at ages of 7, 14, 28, and 56 days by using cylinder specimens. The initial surface absorption of the concretes was determined at 28 and 56 days by using 150 mm cubes. The compressive strength of the concretes was determined according to ASTM C39 [17]. The dynamic modulus of elasticity and ultrasonic pulse velocity were measured in accordance with BS 1881: Part 209 [18] and BS 1881: Part 203 [19], respectively, testing cylinder specimens in longitudinal mode. The initial surface absorption of the concretes was determined according to BS 1881: Part 5 [20], where the cube specimens were oven-dried at 105°C for 48 hours prior to testing. In all tests for hardened concretes, triplicate specimens were used.

#### *3.4 Curing methods*

Two types of curing were used. These were water and air curing. In water curing, the specimens were immersed under water. No lime was used to saturate the water. In air curing, the specimens were exposed to dry air. In both curing methods, the curing temperature was maintained at 20±2 °C. The cylinder specimens were cured until 7, 14, 28 and 56 days, whereas the cube specimens were cured until 28 and 56 days. Moreover, cube specimens were only subjected to water curing.

### **4. RESULTS AND DISCUSSION**

#### *4.1 Fresh properties*

The fresh concrete properties determined were slump, slump flow, V-funnel flow and air content. In general, all fresh concretes exhibited the required level of flowability recommended for flowing concretes. The concrete mixtures produced the slump values from 230 to 245mm, slump flow from 520 to 550 mm and V-funnel flow in the range of 0.355 to 0.425 L/s. Flowing concretes generally provide a slump higher than 190 mm [1, 21], a slump flow greater than 500 mm [3, 4], and a V-funnel flow higher than 0.333 L/s [3]. Hence, all concretes possessed a good flowability. Besides, CQW concrete provided the highest values of 245 mm, 550 mm and 0.425 L/s for slump, slump flow and V-funnel flow, respectively. These values were even higher than those of OPC (control) concrete, thus giving an indication that the inclusion of 20% quarry waste as a partial replacement of sand did not affect the flowability of the concretes. Moreover, the air content of the concretes ranged from 1.6% to 2.2%. SFQW and FAQW concretes had the highest and lowest air content, respectively. It was observed that the air content of CQW concrete was slightly higher than that of control concrete. Further discussion on flowability and air content of the concretes is beyond the scope of the present paper.

#### 4.2 Compressive strength

The compressive strength development of different concretes has been presented in Table 3. It is evident from Table 3 that CQW concrete provided lower compressive strength than control concrete for both curing methods. The maximum reduction in compressive strength was 9.7% at 56 days, which occurred in case of water curing. This indicates that 20% replacement of mining sand with quarry waste slightly affected the compressive strength of concrete. This is perhaps due to excessive flakiness and grading deficiency of quarry waste. As presented in Table 1, the flakiness index of quarry waste was 55%. It implies that more than half of the quarry waste was flaky. The aggregates with flaky particle shape have the tendency to be oriented in one plane forming air voids and bleeding water underneath [2]. Table 1 also shows that the crushing value of quarry waste was much higher than that of crushed granite stone and mining sand. Therefore, quarry waste was weaker than mining sand and might contribute to reduce the compressive strength of concrete. In addition, the grading curves presented in Figure 1 shows that quarry waste had a relatively high content of particles smaller than 150  $\mu\text{m}$ . It might cause to reduce the compressive strength of concrete [2]. However, the reduction in compressive strength of CQW concrete was overcome when mineral admixtures such as silica fume and fly ash were used. Silica fume was more effective than fly ash to overcome the loss of strength and produced the highest level of compressive strength at any age. In comparison with silica fume, fly ash was not very efficient to overcome the loss of strength caused by quarry waste. This is perhaps due to poor microfilling ability and slow pozzolanic activity of fly ash. Also, only 10% fly ash was used in the present study. It may not be a significant quantity to react with entire calcium hydroxide liberated from cement hydration, and thus to maximize the production of secondary hydration products. In general, 25 to 40% fly ash is effective for improving concrete properties [2, 22].

Table 3. Compressive strength development of different flowing concretes.

Type of concrete	Compressive strength (MPa)							
	Water cured specimens				Air cured specimens			
	7 days	14 days	28 days	56 days	7 days	14 days	28 days	56 days
OPC	28.9	32.8	36.3	38.2	26.7	31.0	33.6	33.1
CQW	26.5	30.5	33.5	34.5	25.0	28.4	32.6	32.9
SFQW	31.2	34.2	37.3	39.6	30.9	33.9	36.2	37.2
FAQW	26.5	32.6	36.2	38.7	24.3	28.6	34.7	35.1

#### 4.3 Dynamic modulus of elasticity

Modulus of elasticity of concrete generally indicates its stiffness. It is correlated with the strength and porosity of concrete. Therefore, it gives an indication for the quality of concrete. The results for dynamic modulus of elasticity of the concretes have been presented in Figure 3 and Figure 4. In both curing methods, the dynamic modulus of elasticity showed

continuous development as the age of the concretes progressed. In addition, the use of quarry waste did not cause any severe adverse effect on the dynamic modulus of elasticity of concrete. From the results presented in Figure 3, it can be seen that CQW concrete subjected to water curing provided slightly higher dynamic modulus of elasticity than OPC concrete. This is probably attributed to the surface texture of quarry waste particles, which were rougher than natural mining sand. The rougher surfaces increase the contact area between aggregates and hydration products, and thus improve the microstructure of concrete in paste-aggregate and mortar-aggregate interfaces. In contrast with water cured CQW concrete, the dynamic modulus of elasticity of air cured CQW concrete was slightly lower than that of control concrete, which is obvious from Figure 4. It suggests that the surface roughness of quarry waste did not play any role to improve the microstructure of interfaces due to abated production of hydration products in presence of dry environment.

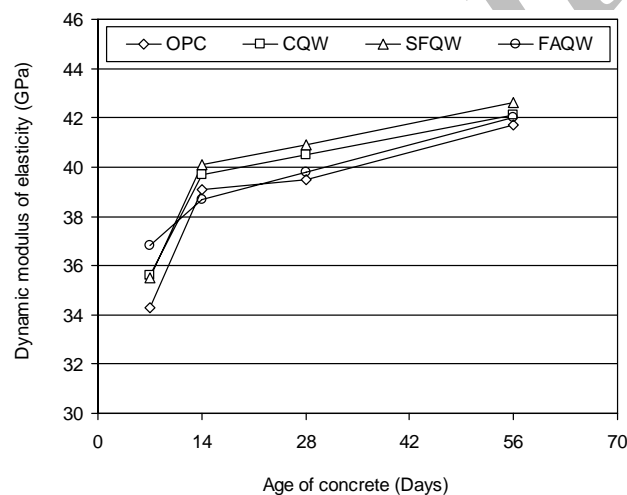


Figure 3. Dynamic modulus of elasticity of different water cured flowing concretes

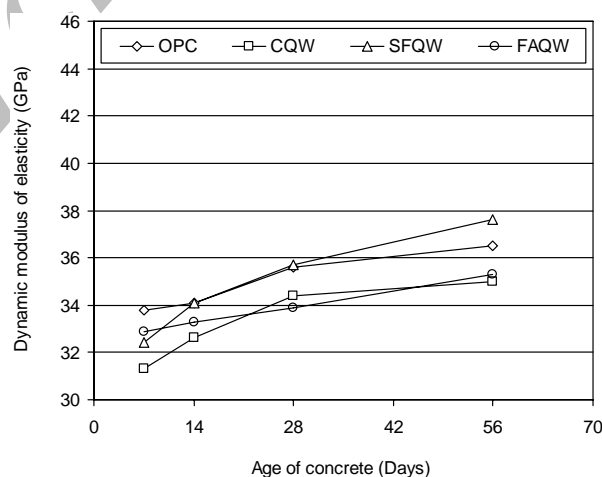


Figure 4. Dynamic modulus of elasticity of different air cured flowing concretes



The dynamic modulus of elasticity of concrete largely depends on the elastic properties of the aggregates and hydrated cement paste. The modulus of elasticity of aggregates is generally higher than that of hydrated cement paste. The difference between the moduli elasticity of aggregates and hydrated cement paste affects the elasticity of concrete. The modulus of elasticity of aggregates is reduced in presence of weaker quarry waste fine aggregate. Consequently, the difference between the moduli of aggregates and hydrated cement paste is decreased. The reduced difference between the moduli of hydrated cement paste and aggregates enhances the composite action of concrete, and thus tends to improve its dynamic modulus of elasticity.

The dynamic modulus of elasticity of the flowing concrete incorporating both quarry waste and silica fume was improved at any age under both curing conditions. This is mostly due to the effective microfilling ability and pozzolanic activity of silica fume that contribute to produce denser matrix and lower porosity in SFQW concrete. Furthermore, the accelerated pozzolanic activity of silica fume improves the microstructure of the interfacial transition zones. As compared to silica fume, fly ash exhibited lower efficiency to improve the dynamic modulus of elasticity. The reasons are probably the same, as discussed in case of compressive strength.

#### *4.4 Ultrasonic pulse velocity*

Ultrasonic pulse velocity is an established non-destructive property of hardened concrete. It depends upon the porosity and density of concrete matrix. When the porosity is lower, i.e., the density is higher, the ultrasonic pulse velocity becomes higher. The results for ultrasonic pulse velocity of the flowing concretes have been presented in Figure 5 and Figure 6. The results of ultrasonic pulse velocity followed similar trend, as compared to the results for dynamic modulus of elasticity. The ultrasonic pulse velocity was improved continuously for both curing methods, as the age of the concretes progressed. The effect of quarry waste on ultrasonic pulse velocity was in agreement with the observation in dynamic modulus of elasticity. It was noted that CQW concrete provided slightly higher ultrasonic pulse velocity than control concrete at all ages under water curing. In dry air curing, it provided lower ultrasonic pulse velocity than control concrete at all ages except 56 days. In general, the results for ultrasonic pulse velocity of CQW concrete indicate that the inclusion of quarry waste as a partial replacement of sand did not harm the quality of hardened concrete. The ultrasonic pulse velocity of CQW concrete varied from 4.06 to 4.61 km/s, which indicates a 'very good' quality of concrete [23].

The ultrasonic pulse velocity of concrete increased when silica fume was used in presence of quarry waste. In both curing methods, SFQW concrete exhibited the highest ultrasonic pulse velocity, which is obvious from Figure 5 and Figure 6. The incorporation of silica fume results in much denser and less porous matrix in concrete that contributes to produce higher ultrasonic pulse velocity. Conversely, fly ash could not produce any significant improvement in ultrasonic pulse velocity. It can be seen from Figure 5 and Figure 6 that the ultrasonic pulse velocity of FAQW concrete was lower than that of CQW and SFQW concretes in both curing methods. Also, it produced the lowest ultrasonic pulse velocity in dry air curing. This is due to significant moisture movement from concrete specimens. The pozzolanic activity of fly ash was hindered in absence of water. In case of

fly ash, the pozzolanic reaction mostly occurs at later stage of hydration. But it could not take place since the concrete specimens became dry.

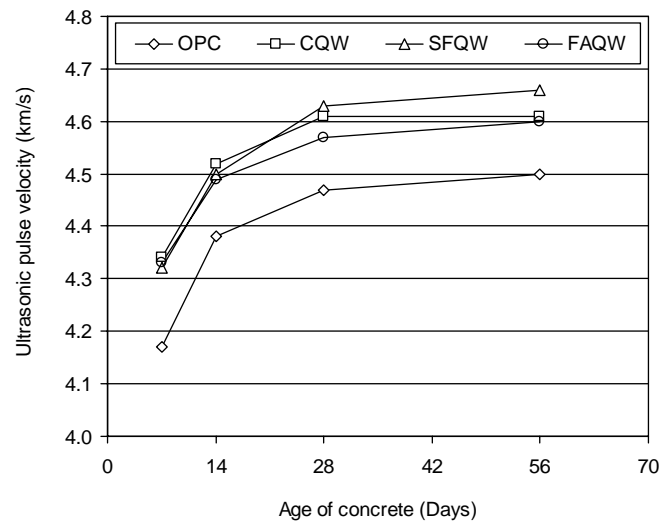


Figure 5. Ultrasonic pulse velocity of different water cured flowing concretes

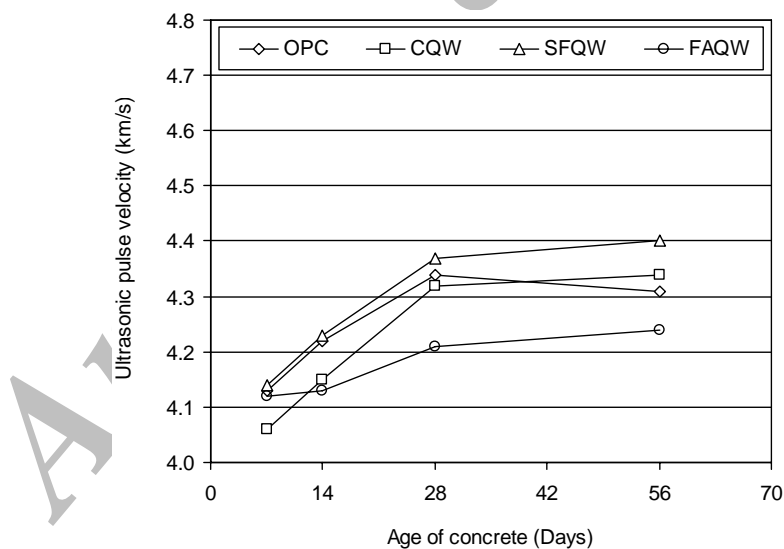


Figure 6. Ultrasonic pulse velocity of different air cured flowing concretes

#### 4.5 Initial surface absorption

Initial surface absorption is a measure of the rate of water absorption into cover concrete. It has been widely accepted to indicate the level of concrete durability. The results of the initial surface absorption test have been illustrated in Figure 7 and Figure 8. CQW concrete

provided higher initial surface absorption than control concrete in both curing methods. The initial surface absorption of CQW concrete at 28 days varied from 0.52 to 0.13 ml/m<sup>2</sup>/s after 10 and 120 minutes, respectively. The corresponding values were 0.46 and 0.11 ml/m<sup>2</sup>/s at 56 days. An initial surface absorption after 10 minutes is considered high if it becomes greater than 0.50 ml/m<sup>2</sup>/s, and low if less than 0.25 ml/m<sup>2</sup>/s. The corresponding higher and lower values after 120 minutes are 0.15 and 0.07 ml/m<sup>2</sup>/s, respectively [2]. Hence, quarry waste increased the initial surface absorption of concrete. It indicates that the porosity of cover concrete was increased in presence of quarry waste. This is due to excessive flakiness and grading deficiency of quarry waste, as discussed in case of compressive strength.

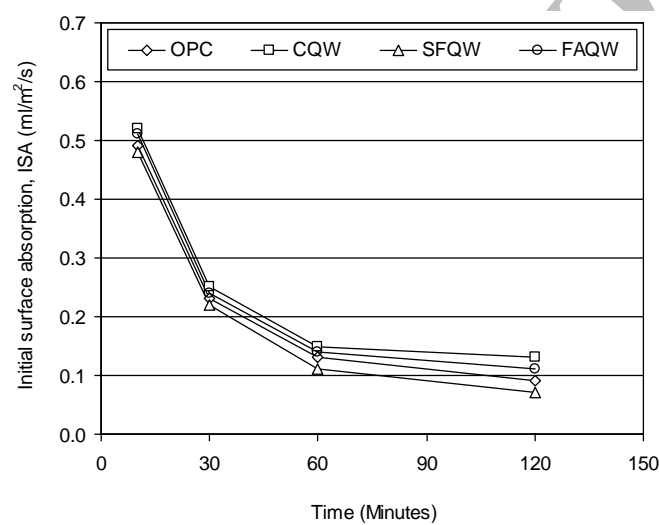


Figure 7. Initial surface absorption of different water cured flowing concretes at 28 days

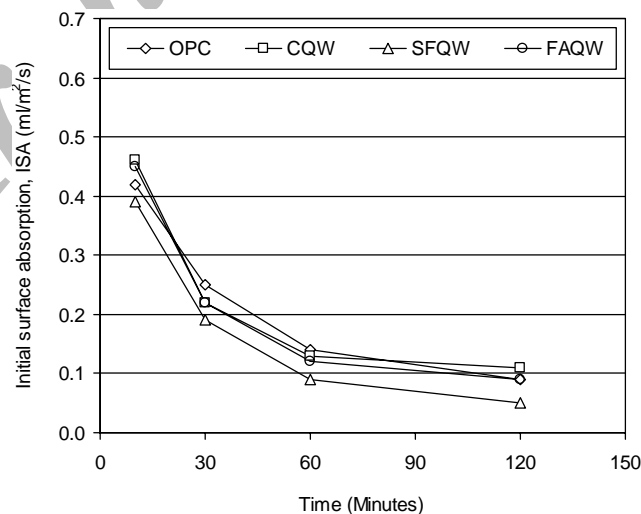


Figure 8. Initial surface absorption of different water cured flowing concretes at 56 days

The initial surface absorption of concrete was decreased significantly when silica fume was used with quarry waste. It can be seen from Figure 7 and Figure 8 that SFQW concrete exhibited the lowest level of initial surface absorption in both curing methods. Similar findings were observed in a previous research of Zain et al. [24]. Silica fume refines the pore structure of concrete by filling the spaces within cement particles and by blocking the pore channels existing in paste matrix. Therefore, the transport of any liquid into cover concrete is greatly reduced in presence of silica fume. As compared to silica fume, the contribution of fly ash was not very effective. The reasons are perhaps the same as discussed in previous sections. The overall findings of the initial surface absorption test reinforce that the incorporation of quarry waste into flowing concretes demotes the quality of concrete, which can be compensated using an efficient mineral admixture such as silica fume.

#### 4.6 Variation of dynamic modulus of elasticity with compressive strength

The variation of dynamic modulus of elasticity with compressive strength can be seen from Figure 9. Two linear trendlines were obtained for two curing methods. It can be observed that the variation occurred in similar fashion. However, the rate of variation was slightly different. In general, the dynamic modulus of elasticity of different flowing concretes increased linearly with the increase in compressive strength. Similar relationship was reported by Khatri et al. [25]. The position of the trendlines shows that water curing provided greater dynamic modulus of elasticity than air curing. Also, the slope of the trendlines indicates that rate of increase in dynamic modulus of elasticity was slightly higher in case of water curing.

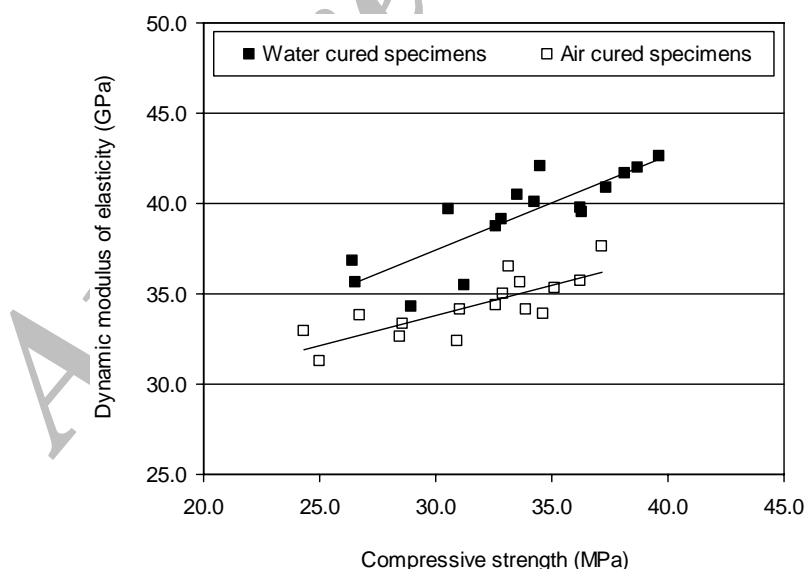


Figure 9. Variation of dynamic modulus of elasticity with compressive strength

#### 4.7 Variation of ultrasonic pulse velocity with compressive strength

The variation of ultrasonic pulse velocity with compressive strength can be seen in Figure

10. It is obvious from Figure 10 that the variation was similar to that observed in case of dynamic modulus of elasticity and compressive strength. The ultrasonic pulse velocity was increased with increasing compressive strength. Similar relationship has been reported by Naik and Malhotra [26]. Figure 10 also shows that water curing provided higher ultrasonic pulse velocity than air curing. However, the rate of increase in ultrasonic pulse velocity was identical in both curing methods, as the trendlines had almost the same slope. It may be related to the less sensitivity of ultrasonic pulse to the changes in hydrated cement paste.

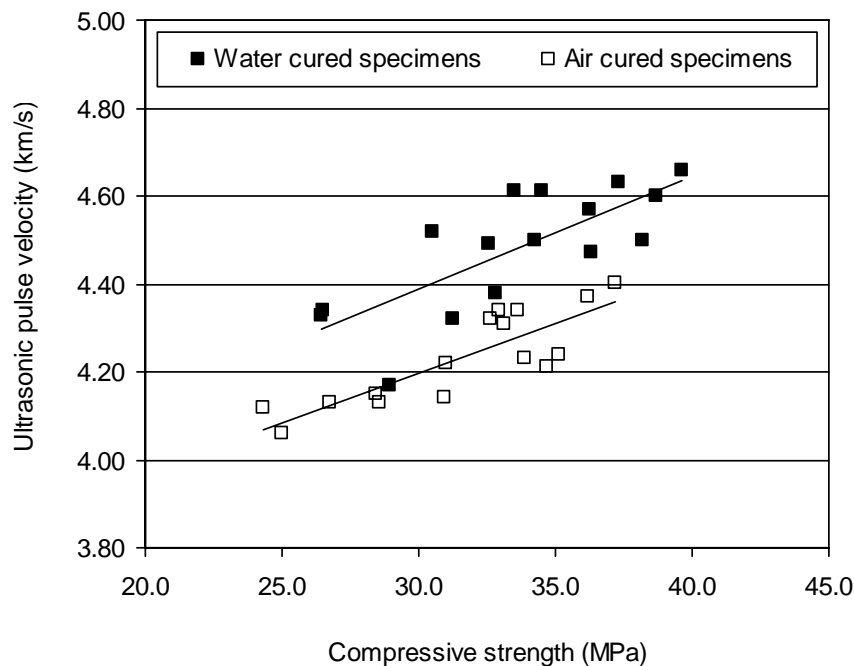


Figure 10. Variation of ultrasonic pulse velocity with compressive strength.

#### 4.8 Variation of initial surface absorption with compressive strength

The variation of initial surface absorption with compressive strength can be seen in Figure 11. Similar trendlines with identical slopes were observed for ISA values after 10 and 120 minutes. It indicates that the variation was identical for both test conditions. For both cases, the initial surface absorption was decreased with increase in compressive strength. It reveals that the quality of cover concrete affects the compressive strength of concrete. The cover concrete contributes to produce the compressive strength of entire concrete. But it may not have the same strength as the concrete's inner zone. The porosity of cover concrete is relatively high due to wall effects. The increased porosity results in greater initial surface absorption but lower compressive strength. Therefore, the initial surface absorption and compressive strength of concrete are inversely related, as observed in Figure 11.

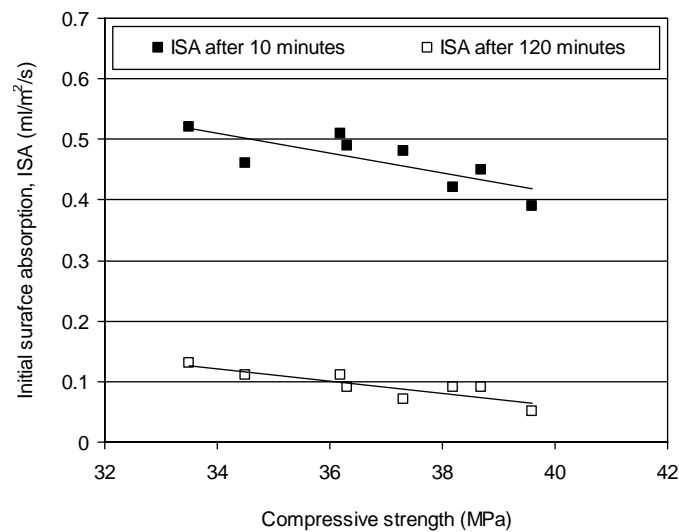


Figure 11. Variation of initial surface absorption with compressive strength

#### 4.9 Relation of tested non-destructive properties

Attempts were taken to examine the relation of dynamic modulus of elasticity, ultrasonic pulse velocity, and initial surface absorption. An excellent correlation was observed between dynamic modulus of elasticity and ultrasonic pulse velocity, as can be seen from Figure 12. This is because both dynamic modulus of elasticity and ultrasonic pulse velocity were similarly affected by the changes in concrete, as obvious from Figure 9 and Figure 10. Furthermore, a single trendline was obtained for all ages and for both curing methods. Therefore, the relationship between dynamic modulus of elasticity and ultrasonic pulse velocity was independent of concrete age and curing method.

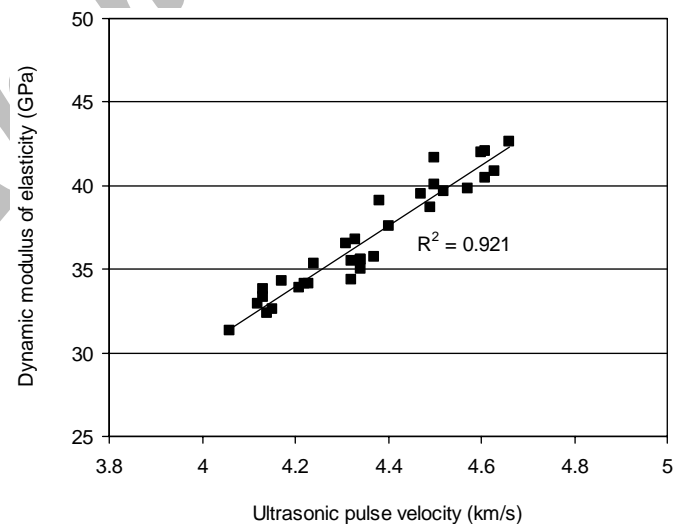


Figure 12. Correlation between dynamic modulus of elasticity and ultrasonic pulse velocity

No good correlation was observed between dynamic modulus of elasticity and initial surface absorption. Also, there was no good correlation between ultrasonic pulse velocity and initial surface absorption. This is perhaps due to the reason that the surface zone of the concrete cubes was dealt for initial surface absorption whereas both dynamic modulus of elasticity and ultrasonic pulse velocity were determined using the central zone of concrete cylinders. The transport of water depends on the microstructure of the hydrated cement paste, which is different in surface and central zones of the concrete. In addition, the drying of cube specimens at 105°C causes microcracking and may remove some of the combined water resulting in changes in the microstructure of concrete in case of initial surface absorption test. Such changes did not occur in case of ultrasonic pulse velocity and dynamic modulus of elasticity tests. Therefore, the concretes tested for initial surface absorption, dynamic modulus of elasticity and ultrasonic pulse velocity differed in quality.

## 5. CONCLUSIONS

The following conclusions can be made based on the results and discussion of the study conducted:

1. All fresh concretes exhibited the slump, slump flow and V-funnel flow required for flowing concretes. The use of quarry waste did not affect the flowability of the concretes.
2. Quarry waste caused slight reduction in compressive strength due to excessive flakiness, greater weakness to crushing, and lack in gradation.
3. Quarry waste resulted in slightly improved dynamic modulus of elasticity and ultrasonic pulse velocity, and thus indicated that it did not affect the physical quality of concrete.
4. The use of quarry waste resulted in higher initial surface absorption mostly due to increased porosity in cover concrete.
5. Silica fume was very effective to overcome the negative effects of quarry waste. It produced the highest level of compressive strength, dynamic modulus of elasticity and ultrasonic pulse velocity, and the lowest level of initial surface absorption in both curing methods due to excellent microfilling ability and accelerated pozzolanic activity.
6. Dynamic modulus of elasticity and ultrasonic pulse velocity were linearly decreased whereas initial surface absorption was linearly increased with reduced compressive strength of the flowing concretes.
7. Dynamic modulus of elasticity and ultrasonic pulse velocity were well correlated but no good correlation was observed between initial surface absorption and dynamic modulus of elasticity, and between initial surface absorption and ultrasonic pulse velocity.
8. The incorporation of quarry waste as a partial replacement of natural mining sand did not significantly affect the non-destructive properties of the flowing concretes except for initial surface absorption, which was compensated in presence of silica fume. Thus, quarry waste can be utilized to produce flowing concretes.

**Acknowledgements:** Sincere gratitude is expressed to the Ministry of Science, Technology

and Innovation of Malaysia and Universiti Kebangsaan Malaysia for providing the adequate funds to accomplish the research program, and to Ready Mixed Concrete (M) Sdn. Bhd. and W. R. Grace (M) Sdn. Bhd. for the supply of testing materials.

## REFERENCES

1. Mindness, S., Young, J.F. and Darwin, D., *Concrete*, 2nd Edition, Pearson Education Inc., New Jersey, US, 2003.
2. Neville, A.M., *Properties of Concrete*, Fourth and Final Edition, Pearson Education Limited, Essex, UK, 2002.
3. Zain, M.F.M., Safiuddin, Md. and Yusof, K.M., A study on the properties of freshly mixed high performance, *Cement and Concrete Research*, No. 9, **29**(1999) 1427-1432.
4. Yen, T., Tang, C.-W., Chang, C.-S. and Chen, K.-H., Flow behaviour of high strength high-performance concrete, *Cement and Concrete Composites*, Nos. 5-6, **21**(1999) 413-424.
5. Kim, J.-K., Han, S.H., Park, Y.D. and Noh, J.H., Material properties of self-flowing concrete, *Journal of Materials in Civil Engineering*, No. 4, **10**(1998) 244-249.
6. Su, N. and Miao, B., A new method for the mix design of medium strength flowing concrete with low cement content, *Cement and Concrete Composites*, No. 2, **25**(2003) 215-222.
7. Noor, M.A. and Uomoto, T., Rheology of high flowing mortar and concrete, *Materials and Structures*, No. 8, **37**(2004) 513-521.
8. Safiuddin, Md., Zain, M.F.M., Mahmud, M.F. and Naidu, R.S., Effect of quarry dust and mineral admixture on the strength and elasticity of concrete, *Proceedings of the Conference on Construction Technology*, Kota Kinabalu, Malaysia, 11-13 October 2001, pp.68-80.
9. Rezende, L.R.D. and Carvalho, J.C.D., The use of quarry waste in pavement construction, *Resources, Conservation and Recycling*, No. 1, **39**(2003) 91-105.
10. Nataraja, M.C., Nagaraj, T.S. and Reddy, A., Proportioning concrete mixes with quarry wastes, *Cement, Concrete and Aggregates*, No. 2, **23**(2001) 81-87.
11. Nagaraj, T.S. and Banu, Z., Efficient utilization of rock dust and pebbles as aggregates in portland cement concrete, *The Indian Concrete Journal*, No. 1, **70**(1996) 53-56.
12. Celik, T. and Marar, K., Effects of crushed stone dust on some properties of concrete, *Cement and Concrete Research*, No. 7, **26**(1996) 1121-1130.
13. Ho, D.W.S., Sheinn, A.M.M., Ng, C.C. and Tam, C.T., The use of quarry dust for SCC applications, *Cement and Concrete Research*, No. 4, **32**(2002) 505-511.
14. ASTM C143, Standard test method for slump in hydraulic cement concrete, *Annual Book of ASTM Standards*, Vol.04.02, American Society of Testing and Materials, Philadelphia, USA, 1996.
15. BS 1881: Part 106, Methods for determination of air content of fresh concrete, *Testing Concrete*, British Standards Institution, London, UK, 1983.
16. Uomoto, T. and Ozawa, K., Committee report on super-workable concrete, *JCI Proceedings*, No. 1, Vol. 16, Japan Concrete Institute, Tokyo, Japan, 1994, pp. 11-14.



17. ASTM C39, Standard test method for compressive strength of cylindrical concrete specimens, *Annual Book of ASTM Standards*, Vol.04.02, American Society of Testing and Materials, Philadelphia, USA, 1996.
18. BS 1881: Part 209, Recommendations for the measurement of dynamic modulus of elasticity, *Testing Concrete*, British Standards Institution, London, UK, 1990.
19. BS 1881: Part 203, Recommendations for measurement of velocity of ultrasonic pulses in concrete, *Testing Concrete*, British Standards Institution, London, UK, 1986.
20. BS 1881: Part 5, Methods of testing hardened concrete for other than strength, *Testing Concrete*, British Standards Institution, London, UK, 1970.
21. ASTM C1017, Standard specification for chemical admixtures for use in producing flowing concrete, *Annual Book of ASTM Standards*, Vol.04.02, American Society of Testing and Materials, Philadelphia, USA, 1998.
22. Mahmud, H., Engineering properties of fly ash concrete, *Journal of Industrial Technology*, No. 2, **8**(1999) 85-91.
23. Shetty, M.S., *Concrete Technology: Theory and Practice*, S. Chand & Company Ltd. New Delhi, India, 2001.
24. Zain, M.F.M., Safiuddin, Md. and Mahmud, H., Development of high performance concrete at relatively high water-binder ratios, *Cement and Concrete Research*, No. 9, **30**(2000) 1501-1505.
25. Khatri, R.P., Sirivivatnanon, V. and Gross, W., Effect of different supplementary cementitious materials on mechanical properties of high performance concrete, *Cement and Concrete Research*, No. 1, **25**(1995) 209-220.
26. Naik, T.R. and Malhotra, V.M., The ultrasonic pulse velocity method, *CRC Handbook on Nondestructive Testing of Concrete*, CRC Press, Florida, USA, 1991, pp. 169-188.