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THE MECHANICAL STRENGTH AND DRYING SHRINKAGE BEHAVIOR OF HIGH PERFORMANCE CONCRETE WITH BLENDED MINERAL ADMIXTURE

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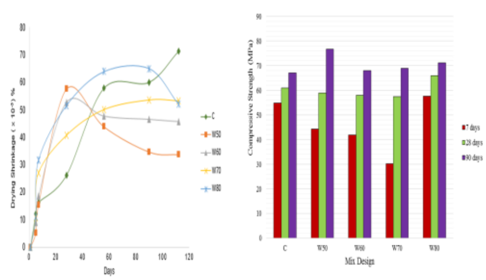
Graphical abstract



Abstract

With the fast in population development, there are a higher demand in housing and infrastructure such as high-rise buildings and long-span bridges. Therefore, high performance concrete (HPC) is used massively due to its technical and economical advantages to fulfil people demands towards the concrete usage. Optimum mineral blended admixture replacement ratio with the addition of superplasticizer are the main component which contributed to the formation of HPC in terms of high workability, high strength and high durability. Hence, the optimal cement to blended mineral admixture ratio with the optimum addition of PCE type superplasticizer to achieve the targeted mechanical strength performance of G60 and reduce the drying shrinkage behavior which will results in crack of the ternary blended concrete is highlighted in this report. The influence of the addition of two mineral blended admixture, ground granulated blast furnace slag (GGBS) and pulverized fly ash (PFA) with the ordinary Portland cement (OPC) in different ratio on engineering performance and its drying shrinkage behavior in the age of 7 days, 28 days and 90 days based on different mineral blended admixture replacement level in 50%, 60%, 70% and 80% which GGBS to PFA ratio are controlled in 4:1 and the water to cement ratio was kept in 0.35 is studied. There are two types of PCE type superplasticizer (SP) was added to enhance the workability of the fresh concrete and act as slump retainer. Ternary blended concrete results in low early age (7 days) strength but the performance at later age (28 days and beyond) was encouraging. Results revealed that 80% replacement level have the remarkable result in terms of mechanical strength and drying shrinkage behavior. The study showed that, presence of mineral additives with superplasticizer will produce a similar or enhance the concrete strength properties with the inclusion of GGBS and PFA at the ratio of 4:1 up to 80% as cement replacement.

Keywords: High strength concrete, flowable concrete, mineral admixtures, mechanical properties, drying shrinkage behavior

Abstrak

Permintaan perumahan dan infrastruktur seperti bangunan bertingkat dan jambatan semakin meningkat. Oleh itu, konkrit prestasi tinggi (HPC) digunakan secara berleluasa disebabkan ciri-ciri seperti teknikal dan ekonomik untuk memenuhi permintaan terhadap penggunaan konkrit. Optimum nisbah mineral campuran memainkan peranan penting terhadap pembentukan konkrit pretasi tinggi (HPC) dengan ciri-ciri seperti kebolehkerjaan yang tinggi, kekuatan yang tinggi dan ketahanan yang tinggi. Kertas kerja ini bertujuan untuk membentangkan optimum nisbah campuran mineral dengan optimum pertambahan bahan campuran kimia untuk mencapai prestasi kekuatan mekanikal G60 dan mengurangkan tingkah laku pengeringan pengecutan yang akan menyebabkan retak kepada konkrit percampuran dengan campuran mineral. Pengaruh daripada penambahan bahan campuran, tanah pasir sanga relau bagas (GGBS) dan abu terbang lumat (PFA) dengan simen Portland biasa (OPC) dalam nisbah yang berbeza kepada prestasi kejuruteraan dan pengeringan kelakuan pengecutan dalam ujian eksperimen dalam 7 hari, 28 hari dan 90 hari. Prestasi kejuruteraan dan pengecutan kering kelakuan yang telah dikaji berdasarkan mineral dicampur tahap penggantian bahan tambah yang berbeza iaitu dalam 50%, 60%, 70% dan 80% dengan nisbah GGBS dan PFA dengan 4: 1 dan nisbah air dikawal dengan 0.35. Terdapat dua jenis bahan campuran kimia jenis PCE (SP) telah ditambah untuk meningkatkan kebolehkerjaan konkrit segar dan bertindak untuk mengurangkan kemerosotan konkrit. Konkrit percampuran dengan bahan campuran mineral dalam kekuatan ujian eksperimen awal adalah rendah tetapi prestasi umur kemudian adalah menggalakkan. Hasil kajian menunjukkan bahawa 80% tahap penggantian mempunyai keputusan yang luar biasa dari segi kekuatan mekanikal dan kelakuan pengecutan kering. Kajian ini menunjukkan bahawa kehadiran bahan tambahan mineral dengan bahan campuran kimia akan menghasilkan sama atau mempertingkatkan sifat-sifat kekuatan konkrit berbanding dengan konkrit biasa.

Kata kunci: Konkrit kekuatan tinggi, konkrit beredar, *campuran mineral,* sifat mekanikal, tingkah laku pengecutan

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1.0 INTRODUCTION

There is a significant increase in the CO_2 emissions due to the production of cement worldwide. Therefore, the construction industry has been looking for alternative building materials or mineral admixtures which can partially or fully replace the use of Portland cement (PC) with similar properties and characteristics to reduce the impact towards the environment. Portland cement has so far been the primary content in the binder of concrete. Hence, reduction of the amount of the cement in the binder is one of the solutions to reduce the concrete's carbon footprint [1]. Nowadays, mineral admixtures such as ground granulated blast furnace (GGBS) and pulverised fly ash (PFA) are becoming more and more widely be used in the concrete industry. Both materials can improve the durability and quality of the concrete yet reduce the negative impact towards the environment, especially regarding carbon's footprint and energy consumption [2].

PFA, a type of mineral admixture that are spherical and glassy particles which captured by the electrostatic or mechanical precipitators from the combustion process in the pulverised coal-burning power plant. Its usage is common action in control of expansion due to its low heat of hydration and helps to reduce the possibility of cracking at the early ages. Advantages are inevitably accompanied by disadvantages. The disadvantages of using PFA as one of the supplementary cementitious material (SCM) has slow strength development. On the other hand, GGBS is a by-product of the steel industry. It is commonly defined as "the non-metallic product consisting essentially of calcium silicates and other bases that are developed in a molten condition simultaneously with iron in a blast furnace" based on ASTM C989-99. GGBS is commonly found, cheap and usually used in large quantities as SCM due to its inherent cementitious properties [3]. Generally, it helps to slightly reduce the water demand while improving the strength and improve the workability of the fresh concrete that requires less energy for movement. Similar as PFA, GGBS also repeated proved that despite its relatively slow rate of reaction [4], it has the higher later-age strength [5], and superior resistance towards aggressive media [6].

Ternary blended concrete is a product from the combination of both materials with cement as SCMs. By combination, GGBS and PFA tend to complement each other which generally known as ternary blended concrete. Thus, ternary blended concrete generally exhibits some properties which perform superior to OPC concrete. Drying shrinkage is one of the primary concern of the concrete members as drying shrinkage could probably turn in to endanger the service life and the safety concern. According to Yang *et al.* [7], concrete containing mineral admixtures has a higher increasing rate of drying shrinkage as compared to plain concrete at a later age. In contrast, *Şahmaran et al.* [8] stated that the incorporation of mineral admixtures such as PFA reduces the drying shrinkage of the concrete. Due to the addition of PFA, the possible mechanism that contributes to the reduction of drying shrinkage is the matrix densification, which may prevent internal moisture evaporation thus reducing the shrinkage of the concrete. An alternative mechanism is that unhydrated fly ash particles serve as fine aggregates to restrain the shrinkage deformation of concrete [9]. However, Mokarem *et al.* [10] concluded that the addition of mineral admixtures such as GGBS and PFA results in greater the drying shrinkage of the concrete.

High-performance concrete (HPC) generally exceeds the characteristics of conventional normal concrete. HPC is popularly used in specially designed structures which possess a combination of performance. The characteristic of HPC included high strength, high early strength, high modulus of elasticity, high abrasion resistance, high durability, volume stability, compaction without segregation. HPC usually are the products from SCMs and superplasticiser. Typically, such concrete possesses low water to cement ratio of 0.25 to 0.45. Superplasticizer plays an essential role in the manufacturing of HPC. Different type of superplasticiser results in a different function. It is commonly found that superplasticiser contributes to improving the workability, setting properties, mechanical performance, durability and the shrinkage behaviour. Polycarboxylate (PCE) type of superplasticiser used in this research with the commercial code PCE 8703 which works as high range water reducing retarder and PCE 8109 which work as high range water reducer. The primary function of these two types of superplasticiser is to reduce the water demand and slower the hydration reaction which results in enhancing the mechanical performance of the concrete.

This study aimed to establish mechanical strength and the drying shrinkage properties of the ternary blended concrete with the use of GGBS and PFA as cement replacement. The GGBS to PFA ratio was kept constantly at 4:1 and subsequently replace the cement content from 50% to 80%. Besides, the workability of the ternary blended concrete was evaluated to study the influence of the inclusion of the mineral admixtures, particularly, GGBS and PFA in ternary blended binder system at high cement replacement level. The evaluated mechanical strength properties of the ternary blended concrete included bulk density properties, compressive and mechanical strength performance, ultrasonic pulse velocity (UPV) and dynamic modulus of elasticity assessment.

2.0 METHODOLOGY

This section has briefly discussed the materials used in the experimental program. Besides, the methods to fabricate the test samples and method to conduct laboratory work included flow test, compressive and flexural strength test, bulk density test, ultrasonic pulse velocity (UPV) test, dynamic modulus of elasticity performance and drying shrinkage assessment have been briefly discussed in the following sub-section. All of the laboratory assessment were being assessed with the aid of appropriate standards prescribed.

2.1 Materials

Materials used in the experiment program such as ordinary Portland cement (OPC), ground granulated blast furnace slag (GGBS), pulverised fly ash (PFA), PCE type superplasticiser (8703, high range water reducing retarder and 8109, high range water reducer), natural river sand, 20 mm aggregates and water. Several binder ratios between OPC, PFA and GGBS were used with fixed water to binder ratio. Superplasticizers were added to achieve the desired slump. The chemical composition of binder materials is tabulated as shown in Table 1.

2.1.1 Ordinary Portland Cement (OPC)

OPC used in this study was CEM 1 42.5 supplied by Negeri Sembilan Cement (CIMA) with a specific gravity OPC used is general purposed OPC complies with MS EN 197-1:2014 requirement under CEM I 42.5N.

2.1.2 Pulverized Fly Ash (PFA)

PFA obtained from the combustion of pulverised coal in local coal-fired electric power stations with a specific surface area of 3244 cm^2/g and specific gravity of 2.8. The X-ray diffraction pattern shows the presence of several oxides with silica, alumina, ferrite and calcium oxide as major oxide with the proportion of 43.22%, 17.61%, 13.73% and 11.28% respectively. Other oxides which found in minor quantities are 5.94% of MgO, 0.43% of Na_2O, 0.23% of P_2O_5, 1.31% of K_2O, 0.88% of TiO_2 and 0.14% of MnO as tabulated in Table 1.

2.1.3 Ground Granulated Blast-furnace Slag (GGBS)

GGBS is the by-product derived from the steel and iron manufacturing industry and obtained during at the temperature of 1500˚C and fed carefully with a controlled mixture of iron-ore, coke and limestone. The iron ore is then reduced to iron and the remaining materials is the key of the formation of the slag which will floats on top of the iron in molten liquid state. GGBS used in this study was supplied by Micro Dimensional Concrete (MDC) Sdn. Bhd in ground form. Based on Blaine fineness test conducted, the specific surface area of GGBS used was found to be 4650 cm^2/g with specific gravity was determined to be 2.86.

2.1.4 Aggregates and Mixing Water

Wash river sand has been used as fine aggregate with passing 5 mm sieve sizes with referral grading limits by BS EN 12620 [11] with specific gravity of 2.65. Coarse aggregate used was uncrushed granite stone mainly passing 20 mm retained on 5 mm sieve sizes with specific gravity of 2.60. Both Coarse and fine aggregate used were under saturated surface dry condition. In addition, local water source was used as the mixing water for this research. Superplasticizer used was a combination of polycarboxylate Type G high range water reducer with slump retention properties (PCE 8703) and Type F high range water reducer compliance with specification prescribed in ASTM C494 [12] from BASF to enhance the workability and reduce the setting time of flowable concrete. The different dosage of superplasticisers was added based on the mix design. Further addition of superplasticizers is to ensure the targeted slump was achieved with constant water to binder ratio.

Table 1 Chemical composition of binder materials

Chemical Compound	Value (% by total mass)		
	OPC	GGBS	Fly Ash
SiO_2	22.4	32.43	43.22
TiO_2	0.17	0.45	0.88
Al_2O_3	3.60	11.92	17.61
Fe_2O_3	2.90	3.58	13.73
MnO	0.03	0.30	0.14
MgO	1.50	4.52	5.95
CaO	65.60	37.68	11.28
Na_2O	-	0.23	0.43
K_2O	0.34	0.32	1.31
P_2O_5	0.06	0.02	0.23
SO_3	3.10	1.72	-
SrO	0.04	-	-
PbO	0.01	-	-
ZnO	trace*	-	-
Rb_2O	trace*	-	-
C_3S	59.58	-	-
C_2S	19.60	-	-
C_3A	4.64	-	-
C_4AF	8.82	-	-

2.1.5 Mixing, Curing and Samples Preparation

All mix were designed followed ACI 211.1-90, absolute volume method [13] for grade 60 concrete. Binder materials were prepared by replacing OPC with a constant combination of cementitious binder ratio of GGBS:PFA at 4:1 with varying replacement level from 50% up to 80%. Superplasticizers, PCE 8703 and PCE 8709 were added according to the total binder weight with equal ratio. Water to binder ratio incorporated were fixed to 0.35. Various mix design with nomenclature system of C as control mix which is 100% OPC, while Wx where x referred to replacement percentage of cementitious materials (GGBS:PFA) by mass as shown as the Table 2. Titling drum mixer was used in the fabrication of the concrete.

In the beginning, all dry materials were poured separately which were divided into three times. Materials such as OPC, GGBS, PFA, sand and course aggregate were added in the sequence. Each time of dry mix required at least 1 minute at low speed. This process is to ensure the material homogeneously mixed before the addition of water and superplasticiser. After finishing the addition of all the materials, the materials were dry mixed for 3 minutes. The water was gradually added to the mixture and mix for 1 minute. Subsequently, the initial dosage of superplasticisers was added at least after 80% of the mixing water has been added and mix for 1 minute. Further dosage was added until the sample achieve the targeted slump value of more than 220 mm for class F5 as prescribed in BS 206 [14]. Once addition of dosage added, the mix needs to be remixed for another 1 minute and the total dosage added should be recorded and express in percentage.

Once the mixing process completed, the concrete was gradually poured into the steel mould in 3 layers which each layer requires to fill up one-third of the mould volume. Each layer was compacted in vibrating table for not more than 10 seconds. All specimens were left in the mould for 24 hours at ambient temperature and covered with plastic sheet to avoid evaporation. Specimens were later demoulded and subjected to water curing until the subsequent testing age.

Table 2 Mix design proportioning (kg/m^3)

Mix Design	OPC	PFA	GGBS	Sand	Coarse aggregate	Water	w/b ratio	PCE 8703	PCE 8709
C	487	-	-	964	950	168	0.35	4.62	6.57
W50	244	195	49	788	950	168	0.35	3.65	5.60
W60	195	234	58	785	950	168	0.35	3.65	4.89
W70	146	273	68	781	950	168	0.35	3.65	4.82
W80	97	312	78	778	950	168	0.35	1.95	2.73

2.2 Laboratory Methods

2.2.1 Workability Performance Assessment

Workability of the fresh concrete is conducted based on the standard from BS EN 12350: Part 2, [15]. The concrete was added into the slump cone with the dimension of 300 mm in height, 200 mm in the base diameter and 100 mm of top diameter. The addition process of the concrete should be carried out in two times which occupy half of the volume of the cone mould. Manually compaction in 25 times was carried out when the concrete reaches half of the cone mould. The S class slump is measured as the difference between the top of the concrete to the top of the mould while F class slump was measured as the largest diameter of the concrete flow. Further addition of PCE type superplasticizer is required to achieve the targeted slump in S5 and F3.

2.2.2 Bulk Density Test

The procedure of bulk density test was carried out based on the standard of BS EN 12390: Part 7, [16]. The purpose of bulk density was used to determine the density of hardened concrete at 28 days. This is to follow up of the concrete hardening state is it same as a result of strength development, permeability and durability of the concrete. The sample was weighted in air and weight in the water, and the calculation has been done based on three different specimens.

2.2.3 Compressive Strength Test

Compressive test carried out according to the procedures in BS EN 12390: Part 3 [17]. Cube specimens with the size of 100 x 100 x 100 mm and prism with specimens' size of 40 x 40 x160 mm were used in this test. The surface of the cube specimens was cleaned and placed on the platens. The cube is placed at the centre of the platen to test under the continuous load of GoTech GT-7001-BS300 universal testing machine 3000 kN with a maximum capacity of 3000 kN and testing speed of 3.0 N/sec which applied on the surface of the specimen until the maximum resisting load of the specimen is found. The result should be recorded in MPa based on average compressive strength given by three number of specimens for each mix design and specific curing ages namely, 7, 28 and 90 days.

2.2.4 Flexural Strength Test

Flexural strength was carried out to examine the indirect tensile strength of the concrete with the dimensions 40 x 40 x 160 mm prism at the age of 7, 28 and 90 days. The test was carried out according to the procedure prescribed in ASTM C348-14, [18]). Similarly, the results were recorded based on average flexural strength for three prisms tested in MPa.

2.2.5 Ultrasonic Pulse Velocity (UPV) Assessment

UPV was performed to check the quality of the concrete through the propagation of transverse pulse velocity within the concrete specimen [19]. UPV test was accessed using Portable Ultrasonic Non-destructive Digital Indicating Test (PUNDIT) on a 100 x 100 x 500 mm prism. The test was carried out according to the procedure in BS EN 12504: Part 4, [20]. The results obtained were recorded in ms^{-1}.

2.2.6 Dynamic Modulus of Elasticity

Dynamic modulus of elasticity was carried out according to the procedure in ASTM C215-14 , [20]. Prisms with a dimension of 100 x 100 x 500 mm were prepared to conduct the test. The specimen was supported at the midpoint of its length. A small impactor was used to strike on one end of the specimen while the other end should install with the vibration receiver. The fundamental frequency and dynamic modulus elasticity are calculated and analyse by the waveform analyser through fourier transform senses. The results were recorded in GPa.

2.2.7 Drying Shrinkage Behavior

Drying shrinkage is a parameter measuring the reduction in volume of concrete after losing moisture to the surrounding by using comparator. The dying shrinkage is carried out according to the procedure in ASTM C878 / C878M - 14a, [21]. 2 samples with dimension 75 mm square with a gage length of 250 mm were prepared. The specimens are covered with polyethylene sheet to prevent further loss or gain of moisture on the surface of the specimens. The length of specimens is measured with the comparator at 3 days, 7 days, 28 days, 56 days, 90 days and 112 days.

3.0 RESULTS AND DISCUSSION

The results obtained from the experimental programs such as workability, bulk density, flexural and compressive strength of ternary blended concrete by using GGBS and PFA as supplementary cementitious materials. Ultrasonic Pulse Velocity and dynamic modulus of elasticity were carried out to investigate the effect of different replacement level of SCMs as mineral admixtures towards the internal framework of the specimens. Measuring of drying shrinkage is to observe the overall performance of the mineral admixtures towards the durability of the concrete.

3.1 Workability

Based on the result, the overall workability of the fresh concrete have achieved S5 and F3 slump with minimum addition of superplasticizer and recorded. Based on the result, addition of mineral blended admixture tends to reduce the addition of superplasticiser in order to achieve the targeted slump level. Presence of cement with the addition of superplasticiser tends to increase the viscosity of the concrete which results in less flowable of the fresh concrete. Addition of finer mineral admixture such as PFA and GGBS result in reduce in water demand and superplasticizer dosage. Since at the early stage the water to cement ratio were fixed, manipulation of superplasticizer is the only way to improve the workability of the fresh concrete in order to achieve S5 and F3 slump level. The results showed, W50 with 50% replacement level required the least addition of superplasticizer while at W80 with 80% replacement level require higher addition of superplasticizer among the ternary blended concrete as tabulated in Table 3 below.

Table 3 Workability result with superplasticizers dosage

Mix Design	Flow (mm)	Slump (mm)	Addition of superplasticizer (%)
C	460	220	0.60
W50	440	240	0.20
W60	500	220	0.35
W70	500	240	0.25
W80	480	240	0.45

3.2 Bulk Density

Bulk density was used to determine the density of hardened concrete. Based on density tested result on the 28 days shown in Figure 1 bar chart, the bulk density of W50, W70 and W80 specimens with 50%, 70% and 80% of mineral admixture replacement level are lower than the C mix except for W60 specimen with 60% of mineral admixture replacement level. High-density concrete is generally proved that hardened concrete with high density will possess higher performance in terms of strength and durability [22]. W60 was the highest level among other specimens with 2.41 kg/m^3 was believed that possess through more full development of matrix compared the lowest which was W50 with only 2.36 kg/m^3.

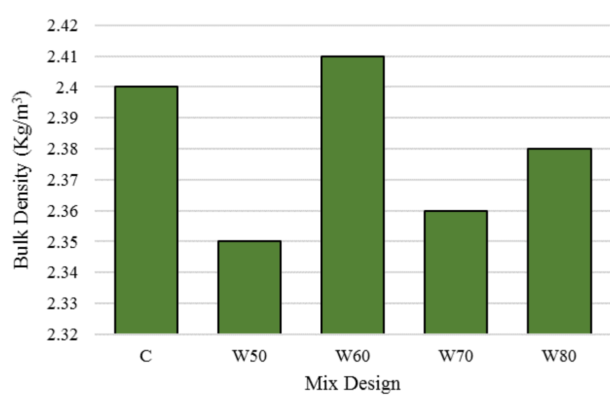

Figure 1 Bulk density of concrete

3.3 Compressive Strength

The overall compressive strength development of W50, W60 and W70 as shown in Figure 2 have significant increase from 7 to 90 days. In comparison with the control mix (C), this ternary blended concrete showing the low early age strength except for W80 which has slightly higher strength than C mix. This is believed that due to the slow pozzolanic reaction of PFA stated by Papadakis [23] and the statement was supported by Antiohos & Tsimas, [24] which reported that PFA does not contribute towards the early strength development due to slow formation of calcium hydroxide and subsequently contribute to the lower early strength of the concrete. Based on the results, we can observe that the compressive strength of the specimens reduce as the mineral admixtures replacement level increased which compromises to the research done by Zhou *et al*. [25]. W80 with 80% mineral admixture replacement level showing higher compressive strength than the control mix is believed that due to the pozzolanic reaction as discussed earlier. At all ages, the concrete results slightly higher to the compressive strength of the control mix and shows a higher rate of strength development. Presence of GGBS would increase the compressive strength of the concrete. Subsequently, W50 and W80 showing a good ratio which results in improve the compressive strength at the later age while only 80% of replacement level shows a good result in early strength of the concrete in overall.

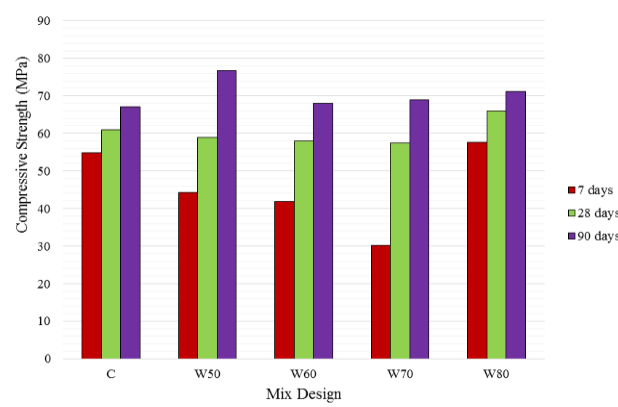

Figure 2 Compressive strength results

3.4 Flexural Strength

At all testing ages, W60 specimen with 60% replacement level possess the overall good result among the other replacement level as shown in Figure 3. At 7 days, W80 shown apparent low early strength with only 4.11 MPa compared to W60 which can achieve 9.74 MPa. The lower of the early age strength was believed that due to slow pozzolanic reaction than the hydration reaction in the fully OPC mix which contribute to the gain of strength. At 90 days onwards, the flexural strength of all ternary blended concrete specimens was observed higher than the control mix that only achieved 10.1 MPa. This result can be supported by the study by Zhou *et al*., [25] which noted that the presence of PFA enhances the strength development of the flexural strength. The results were more significant as increasing the replacement level. In addition, GGBS tends to enhance the later age strength of the concrete.

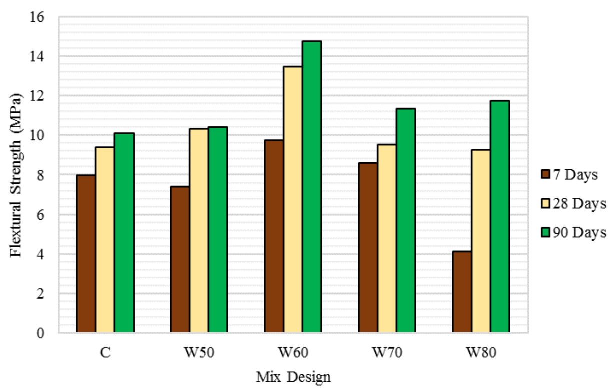

Figure 3 Flexural strength results

3.5 Dynamic Modulus of Elasticity

Based on the result tabulated in Table 4, the presence of GGBS and PFA showed slightly lower dynamic modulus of elasticity results than the control mix at 7 days. As the cement contain reduces, the formation of C-S-H matrix have subsequently reduced. Such phenomenon have contributed to the overall stiffness of the concrete matrix Zhou *et al*. [25]. Besides, the dynamic modulus of elasticity result showing with the increase of replacement level, there was an increasing trend in terms of dynamic modulus of elasticity value. However, the results showed that the trend decreases once it achieved an optimum level which was at W60's specimen at 7 days, W50 at 28 days and W70 at 90 days. Based on the overall result, W70 specimen with a 70% replacement level have the optimum value of the dynamic modulus of elasticity which is 49.5 GPa at 90 days. As the content of mineral admixtures increase with a corresponding reduction in OPC, the microstructure of the binder becomes relatively less porous. Hence, there will be an increase in the dynamic modulus of elasticity observed [22].

Table 4 Dynamic modulus (GPa) of elasticity results

Mix Design	Age of Specimens (days)		
	7	28	90
C	42.9	44.7	45.0
W50	41.3	44.9	46.0
W60	42.8	44.5	47.8
W70	42.3	44.2	49.5
W80	41.8	44.3	45.6

3.6 Ultrasonic Pulse Velocity (UPV)

In this study, the subjected concrete specimens were subjected to water curing at total duration of 90 days. As prolong curing, it was observed that there was an increment in ultrasonic pulse velocity value for all mix designs as shown in Table 5. The overall results in terms of early age and later age showed the quality of the concretes content mineral admixture were better than the fully cement mix. The results can be explained because of the formation of dense microstructure and pozzolanic reaction as prolong curing was subjected in the concrete contain mineral admixtures was improved than the control mix which subsequently making the void in the framework lesser than control specimen [22]. All specimens exhibit excellent UPV values based on classification of quality of concrete by Solis-Carcano & Moreno, [26] at all curing ages with the exception of C mix at 7 and 28 days and W50 at 7 days which belong to good quality concrete. W60 achieve the optimal value at 28 and 90 days while W70 at 7 days with only 0.04 km/s difference than W60 before decreasing while further increase the replacement level.

Table 5 Ultrasonic pulse velocity (kms^{-1}) results

Mix Design	Age of Specimens (days)		
	7	28	90
C	4.22	4.47	4.68
W50	4.56	4.65	4.67
W60	4.65	4.85	4.87
W70	4.69	4.68	4.80
W80	4.53	4.63	4.67

3.7 Drying Shrinkage Behavior

Based on Figure 4, the shrinkage value of ternary blended concrete with different replacement level showed smaller shrinkage value than the control mix at the early age and shown an agreement with the study by [27]. Lower drying shrinkage at the early age was due to the hardening mechanism of concrete contain mineral admixtures that making metric densification which preventing internal moisture evaporation [25]. However, it was noticed that all specimens with blended mineral admixtures only W80 specimens which contain 80% mineral admixture has high shrinkage value than concrete with only OPC in early age. On 28 days onwards, most of the specimens having the increasing of shrinkage value and concrete contain 50% admixtures shown higher shrinkage than other samples and the shrinkage appear to be decreasing as the curing age increase. This phenomenon observed was believed due to formation of C-S-H gel that plays an important riles towards the reducing shrinkage behaviour. 56 days have become the dividing crest which most of the specimens started facing an increase in shrinkage value especially the W80 and control specimen with

80% and 0% replacement level of mineral admixture respectively while other specimens achieving adverse result. The result can contribute from the amount of superplasticizer dosage used in both mix design as high superplasticizer content can making the capillary pore fine and subsequently increase the shrinkage [28].

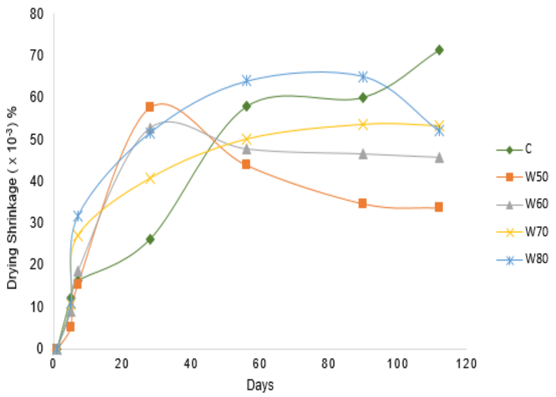

Figure 4 Drying shrinkage behavior

4.0 CONCLUSION

Based on all the data obtained from laboratory investigation, there are several conclusions can be derived. The presence of the mineral admixture included GGBS and PFA tends to reduce the demand of superplasticizer to achieve the targeted range of flow diameter, while, without any added water. Generally, the presence of mineral admixture does not improve the early strength development of the concrete, however, the results showed the presence of GGBS and PFA as cement replacement material tends to promote the later age mechanical strength performance of the concrete, in terms of compressive and flexural strength, particularly, the cement replacement up to 80% does not impair the mechanical strength performance of the concrete. Besides, the inclusion of GGBS and PFA as cement replacement material in the form of ternary blended binder system tends to reduce the magnitude of length change due to drying shrinkage. In short, the study can be concluded that with the inclusion of GGBS and PFA as cement replacement material tends to improve the mechanical strength of the concrete, while, reduced the magnitude of length change due to drying shrinkage.

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