Dynamic modulus of elasticity of geopolymer lightweight aggregate concrete

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Dynamic modulus of elasticity of geopolymer lightweight aggregate concrete

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Abstract: The production processes of ordinary Portland cement (OPC), accompanying with bad environment influences such as, huge energy consumption, greenhouse gases emissions and natural resource exploitation; but fly ash-based geopolymer concrete is produced without (OPC), yet that has many sustainable environment benefits. In this study locally artificial lightweight aggregate was used to produce lightweight fly ash geopolymer concrete. The dynamic modulus of elasticity for geopolymer lightweight concrete produced by using locally artificial aggregate was investigated. Reference lightweight geopolymer concrete containing natural normal weight fine aggregate without fiber, lightweight geopolymer concrete reinforced with two volume fractions of steel fibers (0.25 and 0.5); in addition to four concrete mixtures containing artificial coarse lightweight aggregate and artificial lightweight fine aggregate with 25, 50, 75 and 100% volumetric replacement to natural normal weight fine aggregate (sand) were prepared. The dynamic modulus of elasticity was tested at 28day age for all specimens using resonance frequency method. The results demonstrate that the incorporation of artificial fine lightweight aggregate as a volumetric replacement to natural fine aggregate in concrete geopolymer lightweight concrete reduces the dynamic modulus of elasticity gradually with the increase of artificial lightweight aggregate content.

1. Introduction

Geopolymer concrete (GPC) is an inorganic polymer composite, that has developed as a prospective binding material based on novel application of engineering materials. It has the credible to procedure a substantial component of an environmentally sustainable construction industry, by substituting the predictable concretes [1]. The geopolymeric concretes are normally produced by alkali activation of industrial alumina silicate waste materials like fly ash (FA) and ground granulated blast furnace slag (GGBS), that have very slight ways of greenhouse gases when compared to outmoded concretes [2].

Joseph Davidovits the French scientist, conceived the geopolymer, [3], which formed by reacting silica- rich and alumina-rich solids with a high alkaline solution, that relations the properties of polymers, ceramics, and cement [3, 4]. The geopolymer concrete has been probable as an additional durable "green" material with fewer CO_2 emission and less energy uncontrollable as related with the commonly used Portland cement (PC) concrete, that is predicted it will inductee a uprising in civil engineering by supernumerary the traditional concrete.

The static Young's modulus (E) of concrete is important to be known, as the engineers progressively use this value in the structural design process. As an example, E is required to analyze the cross-sectional response of a reinforced concrete beam [Leet and Bernal 1997].

The static Young's modulus (E) defined by Neville as the ratio of the axial stress to axial strain for a material that exposed to uni-axial load [Neville 1997]. In current years building specifications have even required a specific E of concrete to be met, typically to limit extreme deformation and sway in tall buildings. Nevertheless, once a structure is instituted the in situ elastic properties cannot be measured directly without hurtful the structure itself. Usually E is incidental from the compressive strength (fc) of companion cylinders, rather than directly measured, through the application of reputable empirical relations. In order to meet the minimum E requirement, concrete with higher fc is used than the specification requires, and that leads to unnecessary high material costs. The enhanced understanding of the relative between E and compressive strength, with respect to diverse types of concrete, would enhance the efficacy of the estimation of E from strength [5].

Concrete is the most wanted material in construction industry which is commonly produced by the combination of binding material, aggregate, admixtures and water. Ordinary Portland cement (OPC), granite and mining sand are mostly used as binding material, coarse aggregate and fine aggregate, respectively. The production of OPC, processing of granite and mining sand cause CO_2 emission and also liable for the ecological imbalance owing to continuous reduction of natural resources. As well as the environmental disaster by the construction material, the generation of massive amount of wastes and industrial by-product have made concern due to the lack of storage and producing environmental issues by earth, water and air pollution at the locality of the industrial area [6].

2. Experimental program

2.1. Materials

2.1.1. Fly ash

The fly ash used is recovered as a result of coal ignition during the manufacture of electricity in ISKENment-Turkey power station, it is a glassy powder. The fly ash is type F, satisfies the requirements of ASTM C 618-08 [7]. Table 1 presents the chemical composition of fly ash used in this investigation. The fly ash has a specific gravity of 2.33.

Table 1. Chemical analysis of Fly ash

Oxide	Content, %)
SiO_2	59.56
Al_2O_3	29.33
Fe_2O_3	3.36
CaO	2.20
MgO	0.66
SO_3	0.67
Na_2O	0.21
K_2O	2.24
L.O.I	2.77

2.1.2. Alkali-activated solutions

The alkali-activated solution was used as a combination of sodium silicate (Na_2SiO_3) solution and sodium hydroxide (NaOH) solution, so that forming the binder between the aggregates and the materials in the geopolymer concrete. Sodium hydroxide in the form of flakes (NaOH with 98 % purity), and sodium silicate solution (Na_2O= 13.0 %, SiO_2 = 32.0 %) were used. The concentration should be in the range of 38% to 55% with molar ratio of SiO_2:Na_2O in the range of 2:1 to about 3.22:1 [8].

The sodium silicate solution has a specific gravity of 1.5 g/ml at 20°C, silicate viscosity (CPS) at 20°C was 600. In order to prepare the solution of 1M, 40 g of NaOH flakes, molecular weight of

NaOH =40, was dissolved in one liter of distilled water. In the trial mixes of previous study [9], the molar concentration was formed dependent on the ratio of caustic soda flakes to water. The solution was prepared a day before mixing with sodium silicate in order to be cooled [10]. Then it was mixed with liquid sodium silicate in a chosen weight proportion just before the fraternization process.

2.1.3. Natural fine aggregate

Natural sand carried from Al-Ukhaider region was used as fine aggregate in some specimens of this work. The experimental tests show that it is within (zone 2) and satisfying the requirements of the Iraqi Specification No.45/1984 [11]. The fineness modulus of sand is 2.62, specific gravity and bulk density are 2.65 and 1670 kg/m^3 correspondingly.

2.1.4 Coarse aggregates

The coarse aggregate used in this work was locally manufactured artificial lightweight aggregate produced from bentonite clay and water glass (sodium silicate) [12, 13]. The maximum size of aggregate was 19mm. Table 2 shows the properties of the ALWCA used in this investigation. Figure 1 shows the grading of the produced artificial coarse lightweight aggregate. Artificial lightweight fine aggregate (ALWFa) was used as a partial replacement by volume of the natural sand in some specimens prepared in this investigation. The properties of ALWFa used in this investigation was prepared as shown in Table 2. Generally, the properties of this aggregate satisfy the requirements of ASTM C330-03 [14].

Table 2. Properties of the produced fine and coarse lightweight aggregate

Properties	Specifications	Results for coarse aggregate	Results for fine aggregate
Absorption, (%)	ASTMC127- 04[15]	11.5	17
Specific gravity	ASTM C127-04[15]	1.63	1.69
Dry rodded unit weight, ($kg/m^{3)}$	ASTM 29/C29M [16]	773.31	1180
Dry loose unit weight, ($kg/m^{3)}$	ASTM 29/C29M[16]	768.52**	1100
Aggregate crushing value, (%)	BS 812-part 110-1990 [17]	51.6	_
Sulfate content (as SO_3), (%)	BS 3797-part 2-1981 [18]	0.97	

*Physical analysis was conducted by National Center for Construction Laboratories and Researches.

**Within the limit of ASTM C330 ≤ 880 kg/m^3.

2.1.5. High range water reducing admixture (HRWRA)

A high-range water reducing admixture DARACEM 19CFMQ [19] was used. This type of superplasticizer is liquid based sulphonated naphthalene and complies with the ASTM C494-2005 Types F [20].

2.1.6 Hooked end steel fiber

High tensile steel hooked end fibers were used as shown in Figure 2. The length of fibers was 30mm, with diameter of 0.5mm, l/d=60 of steel fibers according to the manufacturer company (BASF).

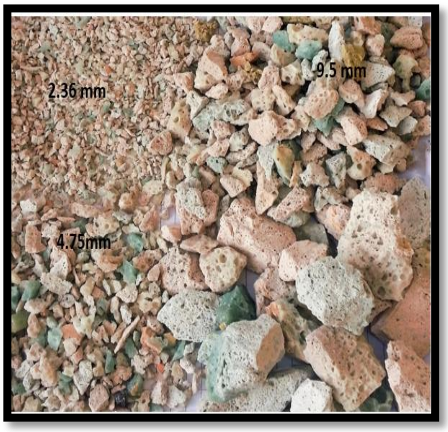

Figure 1. Artificial lightweight aggregates used in this research

Figure 2. Hooked end steel fiber used in this research

2.2. Mixing, Casting, and Curing of Lightweight Geopolymer Concrete

Lightweight aggregates and natural sand were dampened for 24 h and then air-dried for another 24 h to simulate the saturated surface dried-state. First, the coarse and fine aggregates were mixed in the rotary drum mixer for 3 minutes, then FA added and mixing for another 5 minutes. The alkaline solution (Sodium silicate and the sodium hydroxide solutions) were kept at room temperature for at least 24 h before mixing with concrete, and added to the mixture and mixed for two minutes. Superplasticizer and extra water were mixed for two minutes and added to the mixture, the mixing was continued for another 4 minutes (Rangan 2010) [21]. After the initial slump was tested, each mix was poured into various standard steel molds to measure its properties. The concrete was poured into molds in layers according to the standard specifications of each test and compacted to remove the entrained air with standard compaction rod or vibrating table. Directly after casting, all specimens were sheltered with plastic film to diminish water loss. Specimens were kept in ambient condition for 24h, after that the specimens were demolded and cured in an oven for 48h at 90^{o}C. The specimens were taken out of the oven and kept at ambient condition with an average temperature of 28°C till the time of testing. The procedure of mixing has a major effect on the workability and strength of geopolymer concrete.

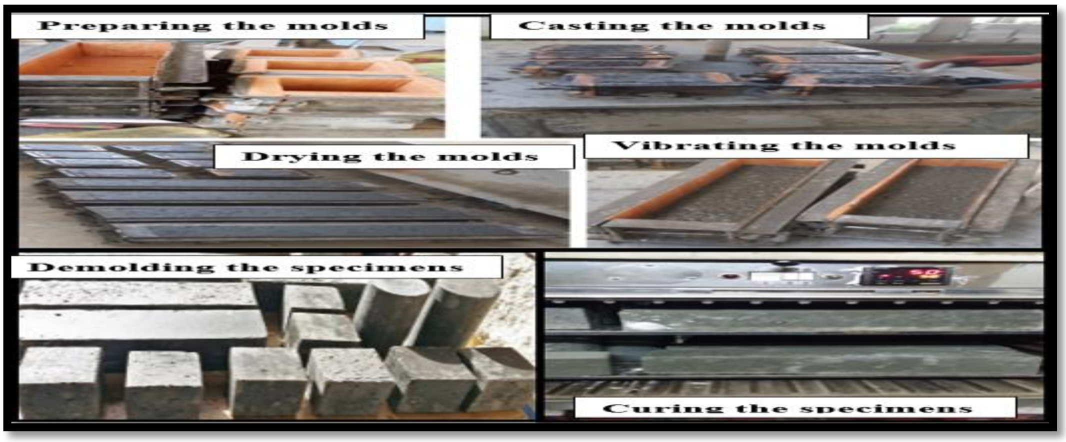

Figure 3. Preparing the geopolymer lightweight concrete samples

2.3. Concrete Mixes

In order to select a reference Geopolymer Lightweight Concrete (GPLWC) mix (MR), numerous trials mixes were carried out using trial and error method [9]. Then four mixes were organized using diverse contents (25, 50, 75 and 100%) of artificial lightweight fine aggregate as a volumetric replacement to natural normal weight fine aggregate, Table 3 shows the details of LWGPC mixes.

Table 3. Details of LWGPC mixes

Mix Symbol	Fine LWA Content	Fly ash (kg)	Sand (kg)	Fine LWA (kg)	W/Fa	Steel fibers kg /m^3	NaOH Solution kg /m^3	Sodium Silicate kg /m^3
MR	0	500	750	0	0.35	-	55.9	143
MF25	25	500	563	124	0.36	-	55.9	143
MF50	50	500	375	248	0.37	-	55.9	143
MF75	75	500	188	371	0.38	-	55.9	143
MF100	100	500	0	495	0.39	-	55.9	143
MSF0.25	0	500	750	0	0.35	19.63	55.9	143
MSF0.50	0	500	750	0	0.35	39.25	55.9	143

Note 1: Mix proportion by weight, Fa= fly ash, FA= fine aggregate, LWA=lightweight aggregate, W= water.
Note 2: The GPLWC mixes have a mix proportion of 1: 1.1:1.5 (fly ash: ALWCa: sand) by weight, alkali activator ratio to fly ash = 0.4, alkali activator molarity of 16, superplasticizer dosage =1.9% by weight of fly ash, sodium silicate: sodium hydroxide solutions =2.5 for all mixes, all specimens were cured at temperature of 90C for 48 hours.

2.4. Experimental tests
Many experimental tests were carried out in this investigation including:
1. Slump test: According to ASTM C143 [22].
2. Fresh density test: According to ASTM C138 [23].
3. Compressive strength test: According to BS. 1881: Part 116:(Cube specimens of 100 mm were prepared**)** [24].
4. Dry density test: According to ASTM C642 (cube specimens of 100 mm were prepared**)** [25].

2.5. Dynamic modulus of elasticity
The resonance frequency method was carried out to determine the dynamic elastic modulus of concrete specimens according to ASTM C 215-15 [26]. The essential resounding frequencies are determined using the forced resonance method. The resonant frequency of the specimen is the value of the frequency causing maximum response. Specimen of 100×100×400 mm size was supported on vibration stand by two points as it is able to vibrate easily, the support points are situated 0.224 of the length of the specimen from each end [27], as shown in Figure 4. This test was conducted at 28-day age. The dynamic Young's modulus of elasticity was premeditated as follows**:**

$$Ed = D \times M \times n^2 \times 10^{-9} \quad (1)$$

$$D = 0.9464(L^3T/bt^3)$$

where:
Ed: Dynamic modulus of elasticity, (GPa).
n: Fundamental transfer frequency, (Hz).
L: Length of the specimen, (m).
bt: Dimensions of cross section of prism, (m).
M: Mass of specimen in air, (kg).
T: Correction factor depends on the ratio of gyration for prism $t/3.464$ length of specimen and poissons ratio, see ASTM E1876-02 [28].

The test was carried out in National Center for Construction Laboratories and Researches.

Figure 4. Resonance frequency method

3. Results and Discussions

3.1 Fresh properties

The workability of fly ash has increase due to the hollow and spherical shape of its particles which have smooth surface texture [8]. Fly ash geopolymer concrete prepared in this work has a moral workability with slump value of 245 mm and fresh density of 1951 kg/m^3 for the reference mix (MR). While GPC mixes contain different contents of artificial fine lightweight aggregate suffer a loose in workability. This is due to the different specific gravity of the artificial lightweight fine aggregate comparative to natural sand, leading to a reduction in fresh density, as presented in Table 1. The used of different contents of steel fiber in geopolymer concrete mixes decrease the workability. This is due to the high density of steel fiber which causes an increment in fresh density. The results demonstrate a reduction in fresh density when the content of ALWFa was increased. This is because of the low density of ALWFa relative to the natural fine aggregate. The addition of steel fiber increases the density of steel fiber GPLWC mixes associated with the GPLWC mix due to the high specific gravity of steel fiber.

3.2. Hardened properties

3.2.1. Oven-dry density Oven-dry density for the reference GPLWC (MR) prepared in this work is 1835 kg/m^3 at 28 day age, and this gratified the requirements of lightweight concrete [14]. Table 4 shows a decrease in oven dry density for GPLWC with different contents of ALWFa compared to that containing sand (MR). This is due to the low density of the ALWFa. The dry density of GPLWC with 100% artificial lightweight fine aggregate is 1640 kg/m^3; the reduction is 10.6 % relative to the reference mix. The higher dry density of steel fiber GPLWC mixes than that of reference mix is attributed to the high specific gravity of steel fiber.

Table 4. Fresh and oven dry density of LWGPC

Mix designation	Slump (mm)	Fresh density (kg/m^3)	Oven dry density (kg/m^3)	Compressive strength (MPa)
MR	245	1910	1835	35.8
MF25	210	1860	1780	32.6
MF50	175	1810	1725	30.73
MF75	130	1755	1680	30.56
MF100	90	1725	1640	28.73
MSF0.25	215	1940	1860	36.11
MSF0.5	190	2000	1920	37.4

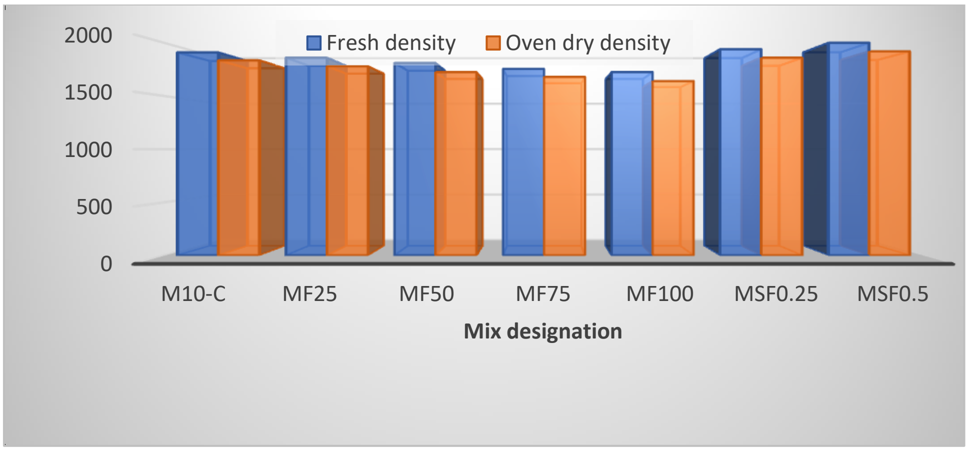

Figure 5. Fresh and oven dry density of LWGPC

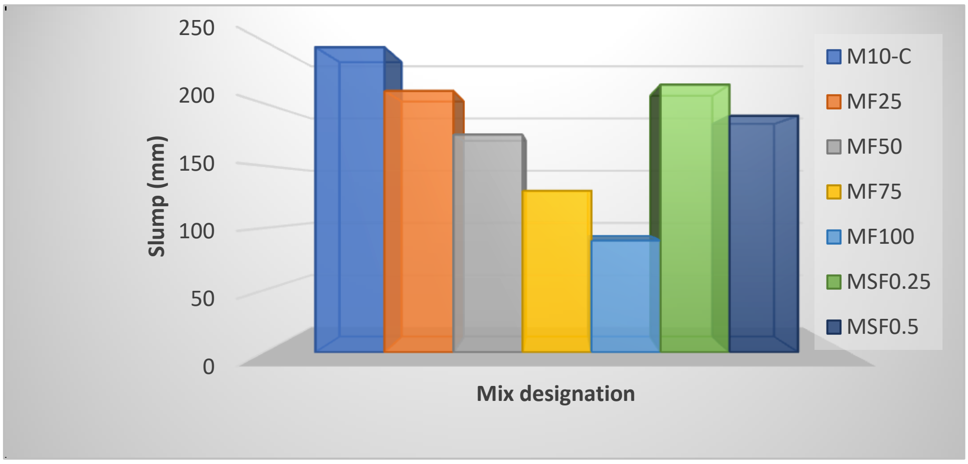

Figure 6. Workability of all GPLWC mixes

3.2.2. Compressive strength

The compressive strength of geopolymer lightweight concrete at 28 day was shown in Table (4). Reference GPLWC (MR) attained 28 day compressive strength of 35.8 MPa and according to ACI 213R-04 [29] this strength is within the range for structural lightweight concrete. The increase in the content of ALWFa causes adverse results in the compressive strength of GPLWC relative to reference mix at 28 day (the percentage reduction is in the range from 5.99 to 20.7 %) due to the low strength of ALWFa in comparison with natural sand. The addition of steel fiber leads to rise in the compressive strength of GPLWC relative to reference mix is in the range of 1.36 to 4.33 %, due to both; high stiffness of fibers and the large surface area of steel fibers that improves the bond resistance and restrictions crack propagation.

Lightweight aggregate has fewer aggregate crushing value than normal weight aggregate. So, cracks happened in the coarse aggregate before extending into the mortar [30]. In spite of the adding of steel fibres in the mixes, the increase in compressive strength was found least. Gao [31] reported that a sufficient bonding between steel fibres and binding material enlarged the compressive strength of lightweight concrete. Yet, insignificant enhancement of compressive strength was observed for GPLWC.

3.2.3. Dynamic modulus of elasticity

Table 5 and Figure 7 illustrated the dynamic modulus of elasticity for all concrete specimens that studied in this research. The results demonstration that the combination of ALWFa as a volumetric replacement to natural fine aggregate in concrete geopolymer lightweight concrete reduces the dynamic modulus of elasticity gradually with the increase of ALWFa content, because of the lower modulus of elasticity of this fine aggregate compared with that for natural fine aggregate.

GPLWC specimens with steel fiber illustration unimportant increase in dynamic modulus of elasticity and it somewhat increases with the increase in steel fiber content. The concrete specimens with 0.5% steel fiber show maximum increase due to the high modulus of elasticity of steel fiber. According to John [5] , the relationship between dynamic(Ed) and static modulus (Es) of elasticity is as obtainable in the following equation;

$$Es= Ed-5864, (MPa) \quad 3$$

Where:

Es, and Ed in (GPa).

This is for specimens tested in the longitudinal vibrations by using the forced resonance method.

From Figure 7 static modulus of elasticity of GPLWC can be predicted from the compressive strength value according to the following equation:

$$Es= 0.9044f_c^{1.9624} \quad 4$$

linearly increase of modulus of elasticity inclined to the square root of compressive strength. Eq. (4) shown the predicted form. The results according to this equation specified that the modulus of elasticity is between 23.86 and 29.86 for un reinforced mixes, yet its closed to the equation (5) that of ACI 318 [32] for normal concrete.

$$E = 4.73f_c^{o.5} \quad 5$$

where E is the modulus of elasticity (GPa)

f_c is compressive strength (MPa).

Table 5. Dynamic modulus of elasticity for GPLWC

Mix designation	Dynamic modulus of elasticity (GPa)28 days	Static modulus of elasticity from Eq. (3) (GPa) 28 days
MR	35.73	29.86
MF25	33.6	27.73
MF50	32.78	26.91
MF75	30.56	25.69
MF100	29.73	23.86
MSF0.25	39.0	33.13
MSF0.5	41.08	35.21

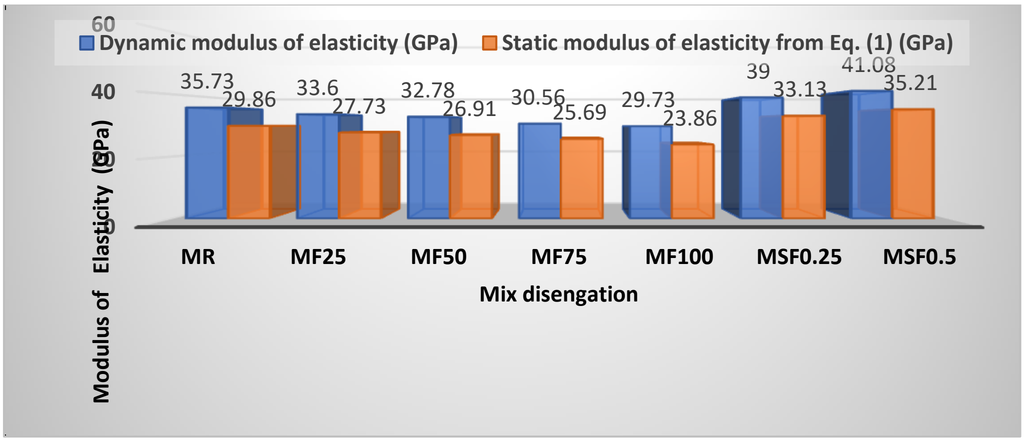

Figure 7. Dynamic modulus of elasticity

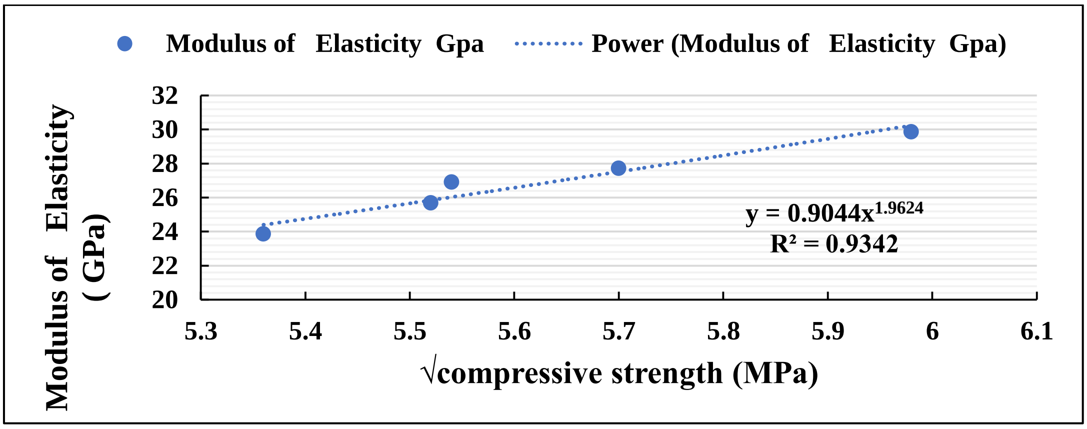

Figure 8. Static modulus of elasticity of GPLWC specimens related to the compressive strength

4. Conclusions

1 The modulus of elasticity tended to increase linearly to the square root of compressive strength
2 The combination of ALWFa as a volumetric replacement to natural fine aggregate in GPLWC reduces the dynamic modulus of elasticity. On conflicting, the dynamic modulus of elasticity somewhat rises with the increase in steel fiber content.
3 The maximum reduction in the dynamic modulus of elasticity is 16.7 % for concrete specimens with 100% replacement aggregate compared with the reference.
4 The maximum increase in the dynamic modulus of elasticity was noted for GPLWC specimens with 0.5% steel fiber.
5 The results showed that the modulus of elasticity is between 23.86 and 29.86 for unreinforced mixes, which is closed to the equation that of ACI 318.

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