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Research Article

Test Research for Basic Mechanics Performance of Inorganic Polymer Concrete

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Abstract: The main objective of this study is to evaluate the basic mechanics properties (compressive strength, modulus of elasticity, Poisson's ratio and splitting tensile strength) of inorganic polymer concrete whose mix proportion is ripe recipe and try to provide an experimental and theoretical foundation for application of inorganic polymer concrete in the practical engineering. In this study, the basic mechanics properties of inorganic polymer concrete have been studied by test. At the same time, the same tests researches are made for the common Portland cement concrete for comparison. Through the comparison research, it can be found that the compressive bearing capacity of inorganic polymer concrete is stronger and the modulus of elasticity and Poisson's ratio is slightly bigger than those of common concrete and that the splitting tensile strength is as poor as those of ordinary Portland cement concrete. In order to investigate its long-term performance, the shrinkage and creep tests of inorganic polymer concrete have been studied as well. The change rules of shrinkage and creep in inorganic polymer concrete with time are obtained. It is that initial deformation is bigger and late deformation gradually becomes small and stable. These rules are basic similar as common Portland cement concrete.

Keywords: Compressive strength, inorganic polymer concrete, modulus of elasticity, poisson's ratio, splitting tensile strength, shrinkage and creep

INTRODUCTION

Different from the ordinary Portland cement, the Inorganic Polymer material is a new type of cementing material. In recent years, it is greatly concerned in construction engineering and environmental engineering field. With the research gradually thorough, the scope of application field for inorganic polymer materials is also enlarging. Inorganic polymer material is made by using fly ash and met kaolin as main raw materials. It is molded and hardened by adding alkaline excitation agent to raw materials in normal environment. These raw materials mainly come from industrial solid waste, whose cost is lower and reserves is abundant. Compared with cement bond material, the fabrication process of inorganic polymer materials is simple. And it does need high temperature firing process which need by cement material. So it is lower energy consumption and less pollution. The inorganic polymer concrete is made through replacing Portland cement by inorganic polymer material in common concrete. It has been proved by tests that the inorganic polymer concrete has the advantages of rapid hardening, early strength and durability (Abdul-Aleem and Arumairaj, 2012).

In present, the study of working capability for inorganic polymer concrete has made great progress. Tests performed to measure absorption, void and permeability coefficient have shown that geopolymer concrete has the potential to be a durable concrete (Cheema *et al*., 2009). The water absorption of fly ash geopolymer, on average, was less than 5%, which can be classified as "low". The water permeability test revealed that the concrete had "average" quality, judging by coefficient permeability in the range 2.46×10^{-11} to 4.67×10^{-11} m/s. The void content measured from the test showed similar "average" criteria, varying from 8.2% to 13% (Olivia and Nikraz, 2011). The heat-cured fly ash-based geopolymer concrete has an excellent resistance to acid and sulphate attack when compared to conventional concrete (Sanni and Khadiranaikar, 2012). The drying shrinkage of heat-cured fly ash-based geopolymer concrete is generally very low compared to that of ordinary Portland cement concrete (Wallah, 2009). Curing temperature at 60°C affects early compressive strength of concretes more than those at a later age (Smith, 2006).

These studies suggest that, as a kind of engineering material, inorganic polymer concrete has better workability and environmental adaptability. In order to the material application in structure engineering, in this study, the test research on basic mechanical properties

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Table 1: The mix proportions of raw materials in inorganic polymer concrete

Code	Inorganic polymer binding material (kg/m^3)	Water (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water -binder ratio	Sand ratio (%)
IPC	425	153	615	1262	0.36	33

Table 2: The mix proportions of raw materials in ordinary concrete

Code	Cement 425# (kg/m^3)	Water (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Mineral powder (kg/m^3)	Poly carboxylic acid water reducing agent (kg/m^3)
C	340	160	692	1128	80	4.2

Table 3: The test results of concrete compressive strength (MPa)

Specimen	Test cube f_{cu}	Prism block f_c
Inorganic polymer concrete	46.3	37.6
Ordinary concrete	37.91	29.86

for inorganic polymer concrete whose mix proportion is ripe recipe has been performed. And this study discusses the bearing capacity under the states of tension and compression, as well as modulus of elasticity and Poisson's ratio which are the main parameters to measure elastic deformation and stiffness of inorganic polymer concrete. At the same time, the same tests researches are made for the common Portland cement concrete for comparison. In order to investigate its long-term performance, the shrinkage and creep tests of inorganic polymer concrete have been studied as well. The studies of the study provide a test data support for inorganic polymer concrete in the use of structural engineering.

MATERIALS AND METHODS

Raw materials: Mineral powder: Adopted the S095 mineral powder which comes from Wuhan iron and steel corp.

Inorganic binding material: It is a powder mixture compounded by mineral powder and alkaline excitation agent which applied the mixture of sodium hydroxide and sodium silicate solution;

Coarse aggregate: Selected the continuous grading fine stone whose size is from 5 mm to 26.5 mm.

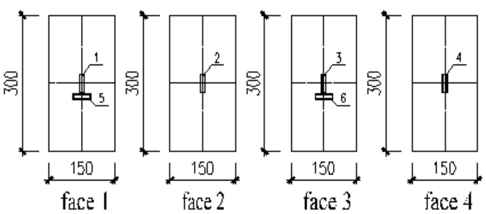
Fine aggregate: Selected the medium-coarse sand whose the fineness modulus is from 2.6 to 2.8.

Mix proportions The mix proportions of raw materials in inorganic polymer concrete and in ordinary concrete are respectively shown in Table 1 and 2.

RESULTS AND DISCUSSION

Experiments and results of concrete compressive strength: The specimens specification are adopted by cube of side length 150 mm and by prism block of 100×100×400 mm respectively. And the specimens are manufactured according to the standard for test method of mechanical properties on ordinary concrete (GB/T 50081, 2002). The test is completed through using pressure testing machine in structural engineering lab of Wuhan University of technology.

Fig. 1: The compression fracture face of inorganic polymer concrete test cube



1~6 for strain gauge (Each face numbered clockwise)

Fig. 2a: The arrangement of strain gauge for specimen of inorganic polymer concrete

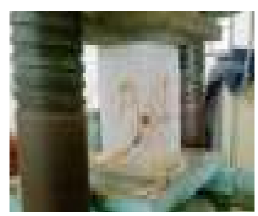
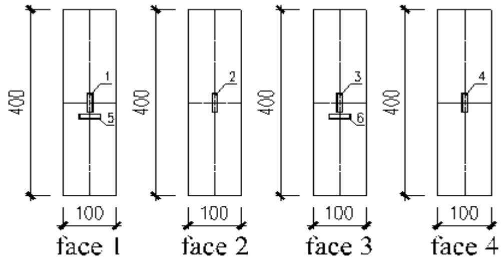


Fig. 2b: The test of elastic modulus and Poisson's ratio for inorganic polymer concrete

The test results of concrete compressive strength are shown in Table 3. According to the test results, the compressive strength of inorganic polymer concrete can meet the use requirement for general structure. The ratio of prism compressive strength to cubic compressive strength of inorganic polymer concrete and of ordinary concrete are 0.81 and 0.79 respectively. The conversion ratio of both are between 0.76~0.88 which is in accordance with the experience of concrete.

The compression fracture face of inorganic polymer concrete test cube is shown in Fig. 1.

Experiments and results of concrete elastic modulus and Poisson's ratio: The specimen specification of inorganic polymer concrete is adopted by prism block of 150×150×300 mm. And the arrangement of strain gauge for specimen and the test of elastic modulus and



1~6 for strain gauge (Each face numbered clockwise)

Fig. 3a: The arrangement of strain gauge for specimen of ordinary concrete

Fig. 3b: The test of elastic modulus and Poisson's ratio for ordinary concrete

Poisson's ratio for inorganic polymer concrete are shown in Fig. 2a and b respectively. The specimen specification of ordinary concrete is adopted by prism block of 100×100×400 mm. Similarly, the arrangement of strain gauge for specimen and the test of elastic modulus and Poisson's ratio for ordinary concrete are shown in Fig. 3a and b respectively. The test is completed through using pressure testing machine in structural engineering lab of Wuhan University of technology.

Test loading system: Loading to initial load F_0 when the stress of specimen gets to 0.5MPa, keeping the constant load within the 30s to 60s and at the same time putting down the strain value ε_0; Immediately evenly loading to load F_a when the stress of specimen gets to a third compressive strength, keeping the constant load within the 30s to 60s and at the same time putting down the strain value ε_a. Comparing with the strain difference of two opposite, when the ratio of the strain difference to average strain of specimen is less than 20%, the next test can be performed. Otherwise the specimen should be adjusted to ensure that the specimen is in the middle of load line position. After confirming specimen in the center, the specimen must be repeatedly preloaded for at least two according to the above test loading system. Only last preloading is completed, should the results of elastic modulus and Poisson's ratio test be recorded.

Elastic modulus is the main index of material deformation performance, which continuously varies with stress or strain. In general, the value of secant modulus corresponding to the operating stress of member between 0.5MPa to one third of axial compressive strength is known as the value of elastic modulus.

Table 4: The test results of concrete elastic modulus and Poisson's ratio

	Elastic modulus E_c ($\times 10^4$MPa)	Poisson's ratio μ_c
Inorganic polymer concrete	3.586	0.236
Ordinary concrete	3.13	0.22

The elastic modulus E_c and Poisson's ratio μ_c are calculated by the following mode (GB/T 50081, 2002):

$$E_c = \frac{F_a - F_0}{A} \times \frac{1}{\varepsilon_{ax}}$$

$$\mu_c = \frac{\varepsilon_{lat}}{\varepsilon_{ax}}$$

In which ε_{lat}, ε_{ax} = respectively specimen horizontal strain difference, specimen axial strain difference.

F_a, F_0 = Respectively the load when the specimen stress gets to a third compressive strength and 0.5 MPa
A = The cross sectional area of specimen

The test results are shown in Table 4. Due to the concrete elastic modulus increasing monotonously with its strength, for ease of comparison between them, it is necessary that the compressive strength of concrete is the same. Using the elastic modulus experience formula:

$$E_c = \frac{10^5}{2.2 + 33 / f_{cu}}$$

The elastic modulus value of ordinary concrete can be calculated corresponding to the compressive strength of inorganic polymer concrete (Guo, 1999). The calculated value is 3.43×10^4MPa. The Poisson's ratio of ordinary concrete in the beginning stages is generally stable, about 0.16~0.23. By contrast the values between the simple calculation and test, the inorganic polymer concrete elastic modulus and Poisson's ratio visible are a bit high than ordinary concrete, but the difference is not big.

Experiments and results of concrete splitting tensile strength The tests of concrete splitting tensile strength are shown in Fig. 4. The specimens are adopted by the test cube of side length 150mm.
Test requirements:

- Place the specimen in the intermediate position of the tester base plate and the fracturing pressure surface and cleavage plane must be vertical to the top surface of the specimen molding
- Fill up the circular arc pad and wood mat between the specimen and the upper pressure plate and the

Fig. 4a: The splitting tensile strength test of inorganic polymer concrete

Fig. 4b: The splitting tensile strength test of ordinary concrete

base plate respectively and the pad or mat should be center alignment with the upper face or lower face of specimen and should be vertical to the top surface of specimen molding

The concrete splitting tensile strength f_{ts} can be calculated by the following formula(GB/T 50081, 2002):

$$f_{ts} = \frac{2F}{\pi A} = 0.637\frac{F}{A}$$

In which,

F = The failure load of specimen (N)
A = The cleavage surface area of specimen (mm^2)

The test results are shown in Table 5. From the Table 5, it can be seen that the tensile splitting strength of both the inorganic polymer concrete and the ordinary concrete are smaller. For the actual project, it should be taken into account that adding reinforced to endure the tension rather than using the inorganic polymer concrete or the ordinary concrete alone.

Experiments and results of inorganic polymer concrete shrinkage and creep: Under the condition of specified temperature and humidity, the change in length of specimen that is not affected by external force is referred to as the shrinkage. The deformation property of the specimens in the long-term constant axial pressure is known as creep.

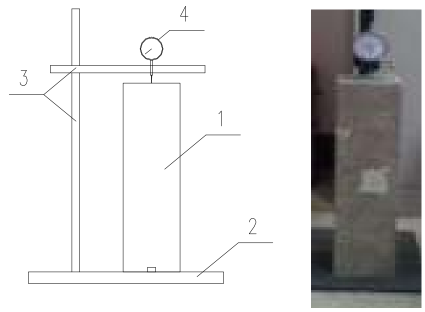
According to the test methods of long term performance and durability of concrete, the shrinkage and creep tests are carried out by using the prism specimen of 150×150×400 mm, whose aggregate diameter does not exceed 40mm. The period of inorganic polymer concrete shrinkage and creep test is 1, 3, 7, 14, 28, 45, 60 days.

Table 5: The test results of concrete splitting tensile strength (MPa)

	Test cube (150 mm)
Inorganic polymer concrete	4.04
Ordinary concrete	3.81

Table 6: The shrinkage value of inorganic polymer concrete ($\times 10^{-4}$)

	ε_{s3}	ε_{s7}	ε_{s14}	ε_{s28}	ε_{s45}	ε_{s60}
Shrinkage	1.308	1.875	2.342	3.242	3.533	3.900
Shrinkage /day	0.436	0.142	0.067	0.064	0.017	0.024



1-specimen; 2-base plate; 3-trestle; 4-clock gauge

Fig. 5: The shrinkage test of inorganic polymer concrete

Fig. 6: The creep test of inorganic polymer concrete

Shrinkage test is shown in Fig. 5. After cured three days, the specimen is used to shrinkage test. The gage length of specimen is 400 mm.

The inorganic polymer concrete shrinkage value ε_{st} can be calculated by the following formula (GB/T 50082, 2009):

$$\varepsilon_{st} = \frac{L_0 - L_t}{L_b}$$

where,

ε_{st} = The concrete shrinkage values when the test period is t day. The test period t is numbered from the time of measuring the initial length of specimen
L_b = The gage length of specimen (mm);
L_0 = The initial reading of the specimen length (mm)
L_t = The measured reading of specimen length when the test period is t day (mm)

The shrinkage test results of inorganic polymer concrete are shown in Table 6.

The creep test of inorganic polymer concrete is shown in Fig. 6 and the specimen gage length is

Table 7: The creep test results of inorganic polymer concrete

$\times 10^{-4}$	ε_{c1}	ε_{c3}	ε_{c7}	ε_{c14}	ε_{c28}	ε_{c45}	ε_{c60}
Creep	0.438	0.775	1.188	1.600	2.175	2.438	2.688
Creep/day	0.438	0.258	0.103	0.059	0.041	0.015	0.017
$\times 10^{-4}$ 1/MPa	C_1	C_3	C_7	C_{14}	C_{28}	C_{45}	C_{60}
Creep degree	0.036	0.063	0.096	0.130	0.177	0.198	0.218
Creep degree/day	0.036	0.021	0.008	0.005	0.003	0.001	0.001
	φ_1	φ_3	φ_7	φ_{14}	φ_{28}	φ_{45}	φ_{60}
Creep coefficient	0.100	0.176	0.270	0.362	0.493	0.553	0.609
Creep coefficient /day	0.100	0.059	0.023	0.013	0.009	0.004	0.004

200 mm. The dial gauges are installed in two opposite of specimen surface. Firstly, preloading whose value is twenty percent of creep test load was carried out on the specimen. Whether the specimen is placed flat and centered can be judged by the deformation difference generated by preloading. The judgment standard for align center is that the deformation difference on both sides is less than ten percent of the average deformation. The load when the specimen stress gets to 40% of the prism block compressive strength is taken for the creep test load. Only the specimen is cured to certain strength, it is can be loaded. So, in this study, the creep tests are carried out in 60 days later after the specimen is produced. At the same time, the shrinkage has been basically stable at this moment, so the creep test doesn't take into account the effect of shrinkage.

The creep value ε_{ct} can be calculated by the following formula (GB/T 50082, 2009):

$$\varepsilon_{ct} = \frac{\Delta L_t - \Delta L_0}{L_b}$$

where,

ε_{ct} = The concrete creep values when the test period is t day

ΔL_0 = The initial deformation of the specimen when it is loaded (mm)

L_b = The gage length of specimen (mm)

ΔL_t = The total deformation of the specimen when it is loaded in t day (mm)

The creep degree ε_{ct} can be calculated by the following formula (GB/T 50082, 2009):

$$\mathrm{C}_t = \varepsilon_{ct} / \delta$$

where,

C_t = The concrete creep degree when the test period is t day (1/MPa)

δ = The stress of specimen which is loaded by the creep test load (MPa)

The creep coefficient φ_t which is called the generalized ratio of creep deformation to elastic deformation can be calculated by the following formula (GB/T 50082, 2009):

$$\varphi_t = \varepsilon_{ct} / \varepsilon_0$$

where,

φ_t = The concrete creep coefficient when the test period is t day

ε_0 = The initial strain of the specimen when it is loaded (mm), namely $\varepsilon_0 = \Delta \mathrm{L}_0 / \mathrm{L}_b$

The creep test results of inorganic polymer concrete are shown in Table 7.

From Table 6 and 7, it can be inferred that along with the growth of the time, the shrinkage and creep of inorganic polymer concrete continues to grow, on the contrary, the shrinkage and creep rate is gradually disappearing. Compared with the final shrinkage of ordinary concrete which is 3.24×10^{-4} under standard state, the shrinkage of inorganic polymer concrete is larger (Wang, 1997). Similar to this, the creep degree of inorganic polymer concrete is larger too, compared with the creep degree of the same strength ordinary concrete which is 7.4×10^{-6} (1/MPa) under standard state (JTG D62, 2004). But the creep coefficient of inorganic polymer concrete is smaller than the ordinary concrete nominal creep coefficient which is 1.61. It is indicated that the ratio of creep deformation to elastic deformation of inorganic polymer concrete is smaller than those of ordinary concrete.

CONCLUSION

Through this study studies, the following main conclusions can be drawn:

- As with normal concrete, the inorganic polymer concrete has the performance of higher compressive strength. At the same time, the relationship between prism compressive strength and cubic compressive strength of inorganic polymer concrete is consistent with that of ordinary concrete. It can meet the strength requirement for general structure. Along with the in-depth study of material performance, its strength performance may be further enhanced.
- The inorganic polymer concrete elastic modulus and Poisson's ratio are a bit higher than ordinary concrete, but the difference is not big. These performances can be reflected in the structure

engineering to the characteristic of strong rigidity and resistance to deformation ability.

- The tensile splitting strength of inorganic polymer concrete is low. And it is obvious discrepancy with the higher compression strength. So it can be concluded that its failure characteristics will also have the stronger brittleness.
- The shrinkage and creep deformation of inorganic polymer concrete is large in the early days and the later period deformation is small. Over time the deformation would be disappeared. So the long-term working performance of inorganic polymer concrete is relatively stable.

Visibly, due to its rich raw materials, convenient for production and easy to process, inorganic polymer concrete can be used as a kind of engineering material. At the same time, it has the advantages of high compressive strength, strong rigidity and resistance to deformation ability and the stable long-term work performance. The basic mechanical properties of inorganic polymer concrete have no big difference compared with those of ordinary concrete. So it can be used in structural engineering. As a kind of new material, its other performances and the constitutive relation should be further experimental studies.

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