Inorganic Polymer Concrete-A Review

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Abstract: The physical and mechanical properties of IPC (inorganic polymer concrete) and its influencing factors are introduced on the basis of references to domestic and foreign papers. Moreover, the paper made a forecast of IPC's application prospects. Integrated with the various physical and mechanical properties and environmental performance of IPC, it is found that inorganic polymer concrete has very important application value, which is of great significance for developing countries with energy shortage.

1 INTRODUCTION

The IPCis high performance concrete. Its Cementitious materials are aluminum silicate minerals or industrial waste (such as fly ash, slag, etc.), which are mixed into the sodium silicateand sodium hydroxide composite alkali activator. IPC has many advantages such as corrosion resistance[7], high strength, good impermeability and frost resistance. The use of industrial waste such as fly ash can not only reduce cement consumption and carbon dioxide emissions, but also save energy and reduce costs. [1]

Data shows that the transport industry and Portland cement are the two largest producers of carbon dioxide, which contribute to 7% of the global carbon dioxide emissions [2]. In addition, the whole world produces a large number of industrial waste every year. So it's a good example of industrial ecology to substitute Portland cement with fly ash produced from coal-fired power plants and abrasive slag produced from iron smelters. Therefore, IPC becomes new structural material with good development prospects internationally. At present, the international research on IPC has been for many years, [3] mainly covering its performance and application domain.

2 PHYSICAL MECHANICAL PROPERTIES

2.1 Durability

The durability of Portland cement concrete is poor due to the low stability of calcium hydroxide and other substances produced by Portland cement hydration.[4]Under the influence of chemical activator, the depolymerization of -O-Si-O-Al-O- chains in the vitreous structure of inorganic polymer cementitious materials produces [Si04]4- and [Al04]4-, which in turn form new -O-Si-O-Al-O- grid structure. It's more stable than the Portland cement's hardened body composed of inorganic small molecule structures such as C-S-H, CH, etc. In addition to the C-S-H gel, the hydrated product of IPC also contains a large amount of hardly soluble zeolite-type minerals. As a result, IPC has excellent durability.

2.1.1Frost Resistance

Paper [5] studied the frost resistance of slag-based IPC. The study found that IPC has a frost resistance rating of F300 or higher and a frost resistance durability coefficient of 0.9-0.95. It fully meets the freezing requirements of concrete in cold regions. The reason for good frost resistance is that there are relatively few large pores in the IPC structure, it contributes largely to IPC's dense structures. At the same time, IPC has high strength and good impermeability, it's not easy for external moisture to enter and cause damages to the inner structure.

2.1.2 High Temperature Resistance

Wang Qing [6] et al. studied the high temperature resistance of slag-based IPC at different temperatures. The study found that the high temperature performance of IPC is much better than ordinary Portland cement concrete. Under high temperature, the IPC has excellent surface characteristics compared to ordinary silicate concrete.

At 800 °C, the strength loss of IPC is only 40%, which is much less than 60% of ordinary Portland cement concrete.

2.1.3 Anti-penetration

D. Cao [5] et al. studied the impermeability of slag based IPC. The study found that IPC has impermeability rating of S40 or more and excellent resistance to chloride ion penetration which can effectively prevent the invasion of water, chloride ions and other erosion media.

Kaituo S[8] et al. studied the resistance of IPC to chloride penetration when the calcium oxide content was 10%, 15% and 20% respectively. The study found that when the chlorine ion content is 20%, the chloride ion permeability is minimal. The main reason is that as the content of calcium oxide increases, the internal polymerization degree of IPC increases, the internal pores shrink, the concrete structure becomes denser and the resistance to chloride ion becomes better.

2.2 Compressive Strength

Abundant researches have demonstrated that IPC has excellent early strength.

Gang Wang et al. measured that the 3d compressive strength of the inorganic polymer reached 39.27 MPa. Mingyu Hu et al. obtained fly ash IPC with compressive strength of not less than 26 MPa for 28 days. Yuzhu Su et al. made fly ash-silica fume IPC, its 7d and 28d compressive strength were measured to be 78.5 MPa and 89.0 MPa, respectively.

Factors such as concrete mix ratio, raw material types and curing temperature will also affect the strength of IPC.

J. Wongpa [9] et al. analyzed the relationship between compressive strength of IPC specimens with fly ash/mineral powder = 4, sodium silicate/sodium hydroxide = 2.5 and S/A (solution/ash) and P/Agg(paste/aggregate). Elie Kamseu [10] et al. studied the effect of fine aggregate types on the compressive strength of IPC. It can be seen that when the amount of aluminum in the aggregate is higher, the concrete structure is denser.AS 3600 [11] proposed that different types of fly ash and activator composition can also affect the strength of the IPC. Y. Fu et al. proposed that curing temperature will affect the compressive strength of slag IPC.

2.3 Deformation Performance

2.3.1 Modulus of Elasticity

According to the specification [12], the modulus of elasticity of ordinary Portland cement concrete is proportional to the square root of the compressive strength. Research shows that the elastic modulus and compressive strength of IPC are also closely related, different scholars have given different empirical formulas. The specific formulas are shown in Table 1.

Table 1: IPC relationship formulas between elastic modulus and compressive strength.

paper	formula	serial number
paper[9]	$E = 1687\sqrt{f_c'} - 16078$	(1)
paper [11]	$E = 0.043\rho^{1.5}\sqrt{f_{cm}} \pm 20\%$	(2)
paper [13]	$E = (0.024\sqrt{f_{cm}} + 0.12)\rho^{1.5}$	(3)
paper [14]	$E = (3320\sqrt{f_c'} + 6900)(\frac{\rho}{2320})^{1.5}$	(4)
paper [15]	$E = 3.38\rho^{2.5}(\sqrt{f_c'})^{0.65} \times 10^{-5}$	(5)
paper [16]	$E = 0.043\rho^{1.5}\eta\sqrt{f_{cm}}$	(6)

Notes:

f_c': compressive strength of concrete, in MPa;

f_{cm}: average compressive strength of the cylinder, in MPa;

ρ: density of IPC, in kg/m3;

η: correction coefficient, $\eta = 1.1 - 0.002f_c' \leq 1.0$.

Formula (2) only applies to concrete with strength less than 40 MPa, and the values obtained by the formula are the upper and lower limits of the elastic modulus. Formula (3) is suitable for concrete with strength greater than 40 MPa. Formula (5) is closer to AS 3600. Formula (4) is closer to the lower limit of elastic modulus in formula (2). For high-strength concrete, the modulus of elasticity obtained with formula (3) is higher, and formula (6) introduces parameter η on the basis of AS 3600, which is an improvement over the normative formula.

X. Fan [17] measured the elastic modulus of IPC and OPC (ordinary Portland concrete) with the strength of 60 MPa. According to the test, the elastic modulus of IPC is 3.16×10^4 MPa, which is 11.8% smaller than that of 3.6×10^4 MPa of OPC.

2.3.2 Poisson's Ratio

M. Sofi[18] et al. made six IPC specimens with the strength of 50 MPa and tested their Poisson's ratios. Tests have shown that IPC's Poisson's ratio is between 0.23-0.26, which is larger than that of OPC's 0.11-0.21 [19]. X. Fan [17] measured the Poisson's ratio of IPC and OPC with a strength class of 60 MPa. The test found that the Poisson's ratio of IPC was 0.26, which was 22.2% greater than that of OPC.

The researches show that the IPC's elastic modulus is smaller than that of OPC, while IPC's Poisson's ratio is relatively larger, which indicate that IPC has better deformation performance than OPC.

2.4 High Temperature Resistance

Due to the unique grid structure of IPC gels, it has similar properties to ceramic materials and better fire resistance than ordinary Portland concrete.

Zuda [20] et al.used vermiculite and calcium carbide as IPC aggregates, resulting in excellent fire resistance. Vermiculite can increase the internal void of IPC and tightly bind the cementitious materials and aggregates through internal voids. Calcium carbide has very small deformation under high temperature.Junaid [21] studied the deformation properties of fly ash-based IPC at high temperatures. IPC will undergo constant temperature creep and transient thermal creep in the high temperature environment.Pan [22] et al. studied the transient thermal creep of inorganic polymer gels at high temperatures and compared them with ordinary concrete. Studies have shown that the transient thermal creep of inorganic polymer cementitious materials can contribute to the accommodation of the uneven deformation caused by inconsistent deformation of various components, and it's beneficial to the high temperature performance of IPC.

3 HPC APPLICATION AND OUTLOOK

IPC has high strength and short setting period, so it has been used in many projects such as rapid road repairs and dam repairs. Y. Fu et al. used slag and activator as cementitious materials to deploy rapid repair IPC that was used in airport pavement repair. Its slump is over 160mm, its flexural strength and compressive strength at 4h is 3.03 MPa and 26.19 MPa respectively, which can meet the technical requirements for road surface repairs of the airport.

Due to the high temperature resistance of IPC, some scholars have studied the incorporation of lightweight aggregates into inorganic polymer gels for rocket diversion tanks and kiln liners.

IPC is resistant to chloride ion permeability and sulfate corrosion, it can be applied to marine engineering, such as bridge piers for offshore bridges, offshore drilling platforms and subsea tunnels, etc. These considerations have not yet been formally implemented and the feasibility remains to be further studied.

4 CONCLUSIONS

Inorganic polymer concrete has very excellent physical and mechanical properties, and its outstanding advantages such as fire resistance, corrosion resistance, frost resistance, high strength and quick setting make it easy to put into engineering. Because of its green energy saving property, IPC has received extensive attention in the field of concrete research. The cement that will generate a lot of carbon dioxide in the production process is replaced with industrial waste such as fly ash and slag, which meets the concept of sustainable development. IPC has important research significance for countries such as China and India, which are relatively short of energy and need to build a large number of infrastructure.

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