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Current status of research on steel tube ground polymer concrete

Xin Deng, Hongwei Ren

College of Civil Engineering, North China University of Science and Technology, Tangshan 063210, China

Abstract

Geopolymer concrete is a new type of green building material with industrial solid waste as the main raw material. In recent years, the stock of industrial waste is increasing day by day, and its chemical composition is complex, causing great damage to the ecological environment. The combination of geopolymer concrete and steel tube can not only absorb a large amount of industrial waste, but also make it "waste to treasure" as a building material. In this paper, the characteristics of geopolymer concrete, reaction mechanism and steel tube geopolymer concrete are reviewed. Based on the existing research results are analyzed to provide reference for further research and combined structure utilization of geopolymer concrete.

Keywords

Geopolymer concrete, steel tube, influencing factors, research progress.

1. Introduction

Accompanied by the rapid development of the global economy, cement, as the building material with the widest scope of application and the largest amount of use in the construction industry, has brought a severe test to the global ecological environment. Relevant research shows that every 1t of cement production will emit CO_2 of the same quality, and the CO_2 emitted from the production of cement accounts for about 7% of the total global CO_2 emissions [1]. The environmental problems caused by the production of cement are becoming more and more prominent, not only causing damage to the ecological environment, but also huge energy consumption. Therefore, geopolymer is favoured by scholars around the world as a new green alternative to building materials. The concept of geopolymer was first proposed by French scholar Davidovits in 1978 [2], which is an inorganic silicate-aluminium compound with ceramic-like properties. It was originally intended to be an aluminosilicate mineral polymer formed by geochemical action or artificial simulation of geopolymerisation, which has a similar microcrystalline structure to that of zeolite-like types formed at high temperatures [3-5]. It is also able to significantly reduce CO_2 emissions, and has the advantages of abundant raw materials, fast-hardening and early-strengthening, low energy consumption for production, and green environmental protection, and has a wide range of applications in the field of building and construction [6,7].

Nowadays, ordinary reinforced concrete columns are limited by technological development as the scope of infrastructure continues to expand, and have been unable to meet the design and use requirements in certain high-rise buildings, large-span bridges and other projects. Steel tube concrete columns are favoured due to their advantages of high load bearing capacity, good plasticity and toughness, and good economic results. The steel tube concrete combined structure makes use of the interaction between the steel tube and the concrete in the stressing process, i.e., the restraining effect of the steel tube on the concrete puts the concrete under a complex stress state, which not only improves the strength of the concrete in the core area [8], but also improves its plasticity and toughness properties greatly. In addition, the presence of concrete can avoid or delay the occurrence of local buckling of the steel tube to ensure the full

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play of its material properties. Steel tube concrete composite structure has the advantages of high bearing capacity, good ductility and easy construction [9]. If the geopolymer concrete and steel tube together constitute a combined structure, it can meet the design requirements and actual working conditions. At the same time, it can also reduce CO_2 emissions, in line with the sustainable development strategy, is a good way to achieve green development. This paper analyses the existing research results and discusses the characteristics of geopolymer concrete and the current research status of geopolymer steel tube concrete.

2. Properties of geopolymer concrete

The development of geopolymer originates from the research results of cement hardening mechanism, using natural silica-aluminate minerals or industrial solid wastes such as metakaolin, slag, fly ash, etc. as cementitious materials instead of silicate cement, which are excited by alkali metal oxides and prepared by mixing with other raw materials, such as coarse and fine aggregates, water, and additives. Compared with silicate cement-based materials, geopolymer concrete has better mechanical and physicochemical properties:

1) Geopolymer concrete is environmentally friendly and green. Geopolymer concrete often uses industrial solid waste (such as blast furnace slag, red mud, coal gangue and other highly active primary silica-aluminate materials) as the main raw material, and avoids the use of non-renewable limestone resources in the preparation process. Meanwhile, its production energy consumption is about 1/5 of that of the cement industry, and its carbon emission is only 1/10 to 1/5 of that of producing the same weight of cement, and it can avoid the emission of harmful gases such as SOx and NOx [10].

2) Geopolymer concrete has the characteristics of early strength, fast hardness and good mechanical properties. Normally, the compressive strength range of geopolymer concrete is generally 30~80MPa, and has faster strength development, and its mechanical properties are even better than those of ordinary concrete materials when the materials are properly proportioned [11].

3) Ground polymer concrete has the characteristics of freeze-thaw resistance. Due to the phenomenon of alternating positive and negative ambient temperatures, the free water retained in the internal pores of the concrete will be frozen at lower ambient temperatures. Compared to ordinary silicate cement with more capillary pores, geopolymer concrete has more gel pores that allow solution freezing to develop more slowly [12].

4) Geopolymer concrete is characterised by good interfacial bonding. Compared with silicate cement-based materials, geopolymer concrete does not have the hydration reaction of calcium silicate with mineral particles, and it is tightly bonded to the aggregate interface with good interfacial affinity, forming a three-dimensional network colloid dominated by covalent bonding [13], which improves the shortcomings of weak interfacial bonding of ordinary concrete.

As a new type of green building material, some of the physical and chemical properties of geopolymer concrete are even better than those of ordinary silicate cement-based materials, with advantages such as early strength and fast hardening, low shrinkage, corrosion and freeze-thaw resistance, and fixation of heavy metal ions. If it is further promoted, it can not only promote the recycling of industrial solid waste, but also significantly reduce environmental pollution and resource waste, and has a broad development prospect.

3. Reaction mechanism of geopolymer concrete

The polymerisation mechanism of geopolymer concrete is completely different from the hydration reaction of silicate cement-based materials, and up to now, no unity has been reached

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among academics on the reaction mechanism of geopolymer concrete, and most scholars [14] believe that the formation process of geopolymer is composed of three stages, namely monomer dissolution, monomer recombination and condensation. Due to the influence of OH- ions in alkali excited solution, covalent bonds such as (-Al-O-) and (-Si-O-) in silica-aluminium based material break, releasing Si and Al monomers [15], and the dissolved Si and Al monomers are able to further reconfigure and react with alkali metal ions to form oligomers such as silicates and aluminosilicates. The reaction mechanism is shown in equations (1) to (4).

$$(Si_2O_5,Al_2O_2)_n+3_nH_2O \xrightarrow{NaOH/KOH}_n (OH)_3\text{-Si-O-}Al^{(-)}\text{-}(OH)_3 \quad (1)$$

$$n(OH)_3\text{-Si-O-}Al^{(-)}\text{-O-Si-}(OH)_3 \xrightarrow{NaOH/KOH} (Na,K)^+\text{-}\left(\text{-}\underset{\underset{O}{|}}{Si}\text{-O-}\underset{\underset{O}{|}}{Al^{(-)}}\text{-O-}\right)_n +3nH_2O \quad (2)$$

$$(Si_2O_5,Al_2O_2)_n+2_nSiO_2+4nH_2O \xrightarrow{NaOH/KOH}_n (OH)_3\text{-Si-O-}\underset{\underset{(OH)_2}{|}}{Al^{(-)}}\text{-O-Si-}(OH)_3 \quad (3)$$

$$n(OH)_3\text{-Si-O-}Al^{(-)}\text{-O-Si-}(OH)_3 \xrightarrow{NaOH/KOH} (Na,K)^+\text{-}\left(\text{-}\underset{\underset{O}{|}}{Si}\text{-O-}\underset{\underset{O}{|}}{Al^{(-)}}\text{-O-}\underset{\underset{O}{|}}{Si}\text{-O-}\right)_n +4nH_2O \quad (4)$$

4. Properties of steel tube geopolymer concrete

The development of steel tube concrete originates from the strong reinforced concrete, according to the form of force can be divided into two forms of steel tube concrete and steel tube restrained concrete, the difference is whether the steel tube is subjected to axial load, when the steel tube and the concrete are jointly subjected to the vertical load, the concrete of the core will be in the state of three-way compression [16]. Compared with with reinforced concrete columns and steel columns, steel tube concrete has many advantages and characteristics:

1) Steel tube concrete is characterised by high bearing capacity. Steel tube and core concrete can complement each other and work together, which can not only improve the brittleness of concrete, but also improve its compressive strength, effectively avoid local buckling of the steel tube, and improve the load carrying capacity of the component.

2) Steel tube concrete has good plasticity and toughness. The constraint of the steel tube on the core concrete makes the overall elastic properties and plastic deformation capacity improved to a large extent , which makes the structure have good plasticity and toughness when the bearing capacity is large.

3) Steel tube concrete is characterised by good fire resistance. As the core concrete absorbs a large amount of heat energy, the fire resistance of the steel tube is subsequently improved, and it can avoid problems such as bursting and spalling of the protective layer when ordinary concrete is heated, and the mechanical properties of the members at high temperatures are greatly improved.

4) Steel tube concrete has good economic efficiency. Numerous engineering practice shows that: the use of steel tube concrete as a pressure-bearing components, the amount of concrete is only half of the reinforced concrete components, the combination of steel tube and concrete greatly saves the amount of concrete.

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5. Current status of research on steel tube ground polymer concrete

At present, the research on geopolymer concrete has achieved fruitful results, and a more mature and complete theoretical system has been established for steel tube ordinary concrete, but geopolymer concrete for steel tube is still in the initial stage. At the same time, there are obvious differences between geopolymer concrete and ordinary concrete in terms of material properties, mechanical properties, etc. Whether it affects the mechanical properties of members still needs to be studied, so it is necessary to further investigate its compression mechanism and bearing capacity.

Zheng et al [17] designed and fabricated 20 square geopolymer recycled brick aggregate steel tube concrete short columns, and analysed the damage morphology, load-strain curves and ultimate bearing capacity of the specimens with concrete strength, recycled brick aggregate substitution rate and steel tube wall thickness as experimental variables. The results showed that compared with the specimen with 0% substitution rate, the ultimate bearing capacity decreased with the increase of the substitution rate of recycled aggregate, and the decrease of ultimate strength decreased with the increase of concrete strength.

Liu et al [18] investigated the mechanical properties of steel tube concrete slender columns under axial compression using section type, brick aggregate substitution rate and length-to-diameter ratio as study parameters. Geopolymer recycled brick aggregate steel tube concrete slender columns had significant lateral deformation and bulging in the span of the steel tube. Compared with the square specimens, the circular specimens exhibited planar fracture characteristics similar to those of concrete, with higher load carrying capacity and plastic deformation.

LI K [19] investigated the axial repetitive compression performance of steel tube geopolymer concrete columns, and the influencing factors included the strength grade of geopolymer concrete, the wall thickness of steel tube, and the length-to-diameter ratio. The study showed that: the axial deformation increased rapidly when the specimen bearing capacity was greater than the ultimate bearing capacity; there were different damage forms of steel tube geopolymer concrete, with strength damage occurring in short columns, elastic-plastic damage occurring in medium-length columns, and instability damage occurring in slender columns.

MA Y J [20] carried out axial compression test on short columns of steel tube geopolymer concrete with hollow interlayer. The results show that compared with the hollow sandwich steel tube ordinary concrete short columns, the trend of axial load-strain relationship curve of hollow sandwich steel tube geopolymer concrete short columns is similar to it, and the structural ductility decreases with the increase of the diameter-thickness ratio of the outer steel tube and the concrete strength.

6. Conclusion

1) Geopolymer concrete has the characteristics of environmentally friendly, early strength and fast hardening, low shrinkage, green environmental protection, and some of the physicochemical properties of geopolymer concrete are even better than ordinary silicate cement-based materials. If it is further promoted, it can not only promote the recycling of industrial solid waste, but also significantly reduce environmental pollution and resource waste, and has a broad development prospect.

2)The polymerisation mechanism of geopolymer concrete is completely different from the hydration reaction of silicate cementitious materials, and its formation process is composed of three stages: monomer dissolution, monomer reconstruction and condensation.

3) The constraints of the steel tube make it possible to improve the brittle defects of geopolymer concrete, and significantly improve the load-bearing capacity and ductility performance. Overall, compared with ordinary concrete columns, the higher bearing capacity of steel tube concrete columns makes its performance better than that of ordinary concrete columns under certain working conditions and environments, which has a very broad development space.

4) Geopolymer concrete as steel tube filling can give full play to their respective advantages, in line with the sustainable development strategy, is a good way to achieve green development, has a broad space for development.

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