

EXPERIMENTAL STUDY ON MECHANICAL PROPERTIES OF POLYURETHANE POWDER COMPOSITES

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ABSTRACT

In recent years, there have been cases of strengthening bridge structures with polyurethane cement mortar. To further explore the properties of polyurethane materials, the effects of emery, lime, quartz sand and cement on the mechanical properties of polyurethane powder composites are studied by three-point flexural test. In the flexural test, the polyurethane cement composite formed a control group by changing the content of polyester polyol. The flexural strength and ductility are improved to a certain extent due to the addition of polyester polyol. The average flexural strength of other polyurethane powder composites such as polyurethane emery test block is 45.1 MPa and the corresponding strain is 6203 $\mu\epsilon$, the average flexural strength of polyurethane lime test block is 33.4 MPa and the corresponding strain is 6470 $\mu\epsilon$, the average flexural strength of polyurethane quartz sand test block is 49.23 MPa and the corresponding strain is 7521 $\mu\epsilon$. The results show that the flexural strength of polyurethane emery material and polyurethane quartz sand material is higher than that of polyurethane cement, which can be used to replace cement to a certain extent to reduce the cost of polyurethane composite material.

KEYWORDS

Polyurethane cement (PUC) material, Mechanics performance tests, Polyurethane powder composites, Constitutive relation

INTRODUCTION

Bridges are important parts of roads and railways, which play indispensable roles in logistics and transportation [1-3]. However, with the development of society, traffic has become increasingly busy. Under certain conditions, such as vehicle load, acid rain, and the rapid increase of temperature, a series of defects of stress cracks, concrete deterioration, and steel corrosion have occurred in the bridge structure [4-6]. After decades of operation, the Bridges built in the early stage are generally aged, and most of them are in the working state of "defcet". Although after years of reinforcement and transformation, the number of dangerous Bridges is still very large. The practice shows that the bearing capacity of the old bridge structure can be restored and improved by using appropriate reinforcement methods. Countries all over the world try to improve the service life of the old bridge by means of reinforcement, so that its bearing capacity can be effectively guaranteed.

Therefore, how to strengthen the bridge economically, quickly, and effectively becomes one of the key points in the development of bridge industry [7-10].

Polyurethane cement composite (PUC) has the characteristics of light weight, high strength and high toughness, and the material itself has good bonding strength and acid and alkali corrosion resistance, which can not only solve the durability problems of reinforced beams caused by composite mortar cracking and falling off, but also the material itself can be reinforced for the main beam. The traffic management department has used the reinforcement method of polyurethane cement composite material in some actual old bridge reinforcement in recent years. Some domestic scientific research institutions not only study the mechanical properties of polyurethane cement, but also use it comprehensively with the reinforcement method of prestressed steel wire rope, as the embedded material to participate in the stress of the structure, so that the active and passive reinforcement methods cooperate, and become the additional passive reinforcement material for the prestressed reinforcement [11-13]. Scholars have carried out a series of studies on its excellent properties in building materials:

Sun Quansheng et al. [14] tested the tensile and flexural resistance of polyurethane cement through laboratory tests. Zhang Shengran et al. [15] used steel wire rope and polyurethane cement composite steel wire rope to strengthen the bending of 3 m ordinary reinforced concrete T beam and made a total of 5 test beams without reinforcement, with 5 separate steel wire rope reinforcement and 3, 5 and 7 steel wire ropes reinforcement of polyurethane cement. They analyzed and verified the reinforcement effect of polyurethane cement steel wire rope on rigidity, strength and bearing capacity. Liu Guiwei, Wang Jianlin et al. [16] through the preparation of materials received pu concrete composite material (MPC), Ningbo-Taizhou-Wenzhou highway of Zhejiang Ningbo Bai Xi bridge has carried on the polyurethane composite reinforcement concrete. Zhang Hongxiang et al. [17] and Gao Feng [18] completed the experimental study of taking MPC composite materials to strengthen 13m hollow slab girders. During the whole test, the MPC material and the concrete section did not slip. They established the calculation formula of strain and bending capacity of hollow slab beams after MPC reinforcement, and also verified the feasibility of ANSYS software in the study of simulating MPC reinforcement of RC beams. Gu Dandan et al. [19,20] found that the material can improve the bearing capacity of hollow slab bridges. Haleem K. Hussain et al. [21-23] tried to get polyurethane cement (PUC) composites with polyurethane and fly ash. They carried out flexural and flexural tests on the composites and obtained the stress-strain curves of the materials at different densities. Based on the material research, the bending reinforcement tests of seven T-section beams under different failure degrees are carried out. The results show that the ultimate bearing capacity of the beams strengthened by polyurethane cement composite (PUC) is improved.

However, the cost of the cement in the polyurethane cement is high. If other cheaper materials are used as filling materials, it is a feasible way to greatly reduce the cost of the polyurethane cement material. In this paper, the same weight of quartz sand, lime, emery and other materials will be added to the polyurethane material, through flexural test to explore its mechanical properties.

POLYURETHANE RAW MATERIALS AND PREPARATION

Polyurethane Cement Composite (PUC)

The main chemical composition is shown in Table 1. Polyols usually account for 49% and isocyanates account for 51%. Polyurethane has excellent performance in mechanical property of good wear resistance, molding properties and chemical corrosion resistance.

Tab.1 - Polyurethane ratio

Composition		Percentage (%)
Polyols raw material	Polyether	49
	Silicone Oil	1
	Water	0-1
Isocyanate raw material		50-51

Preparation of Polyurethane Powder

Polyurethane raw materials and silicon carbide, limestone, quartz sand and cement powder according to the quality than the mixture of polymerization reaction, the quality ratio of polyester polyols: isocyanate: powder = 1:1:2, by comparing polyurethane concrete stress and strain characteristics, set up the control group, formulate the polyester polyols: isocyanate: powder = 1.15:1 and polyester polyols: Isocyanate: powder = 1.3:1:2 high density polyurethane powder composite material, and for the convenience of explanation. Three groups of polyurethane cement test blocks are named as group A, group B, and group C shown in Table 2. The preparation process is shown in Figure 1 and Figure 2. The size of the test mold is based on the Chinese cement mortar strength inspection method GB/T 17671-2020. The polyurethane powder composite material and defoaming agent are mixed mechanically for 3-5 mins, then molded into a 40 mm × 40 mm × 160 mm cuboid specimen and 70 mm × 70 mm × 70 mm cube specimen. The test blocks after molding are shown from Figure 3 to Figure 6.

Tab. 2 - Specific composition table of polyurethane material sample block

Types of Polyurethane Powder	Composition	Percentage (%)
Group A Polyurethane Cement	Polyether Polyols	25
	Isocyanate	25
	Cement	50
Group B Polyurethane Cement	Polyether Polyols	28
	Isocyanate	24
	Cement	48
Group C Polyurethane Cement	Polyether Polyols	30
	Isocyanate	23
	Cement	47
Polyurethane Emery	Polyether Polyols	25
	Isocyanate	25
	Silicon Carbide	50
Polyurethane Lime	Polyether Polyols	25
	Isocyanate	25
	Calcium Carbonate	50
Polyurethane Quartz Sand	Polyether Polyols	25
	Isocyanate	25
	Quartz Sand	50



Fig. 1 - Pouring diagram of polyurethane material



Fig. 2 - Compression strength specimen



Fig. 3 - Polyurethane cement specimen



Fig. 4 - Polyurethane emery specimen



Fig. 5 - Polyurethane quartz specimen



Fig. 6 - Polyurethane lime specimen

LOADING AND MEASURING SCHEME

Because polyurethane composite material is a new type of material, there is no current specification for its use. Therefore, JTG E30-2005 Test Rules for Cement and Cement Concrete in Highway Engineering is adopted for experimental study. Referring to the test method for the flexural strength of cement concrete cube in the code, the three-point flexural strength test is carried out on the universal tester. According to the rules, the test process should first be the center of the test piece and the press geometric alignment, and then determine the test loading speed. When the test is ready, start loading. When the polyurethane material test block is close to failure and begins to deform rapidly, the test machine is no longer adjusted; When the failure of the polyurethane material test block is determined, the failure ultimate load F is recorded. After the completion of the test, the

test data are statistically processed. The flexural strength of polyurethane cement specimens should be calculated as follows:

$$\sigma_c = \frac{1.5Fl}{bh^2} \quad (3-1)$$

In the formula:

σ_c The flexural strength of polyurethane cement, Mpa;

F The ultimate load, N;

L Distance between support points, mm;

b The width of the prism, mm;

h The height of the prism, mm;



Fig. 7 - Loading device diagram

EFFECT OF DIFFERENT POWDERS ON MECHANICAL PROPERTIES OF POLYURETHANE COMPOSITES

Bending test results

In bending test, a multifunctional testing machine is used to load and dynamic strain acquisition instrument is used to collect. By averaging the values of the two strain gauges, the actual strain value can be derived. There are three flexural test blocks of group A polyurethane cement participating in the flexural test this time. The flexural stress-strain curve of group A polyurethane cement test blocks is shown in Figure 8 and the average is shown in Figure 9. Strain and stress present a positive proportional function in the curve. The peak strength is 37.2 MPa. The peak strain is 10848 $\mu\epsilon$. The peak stress of each block is shown in Table 3.

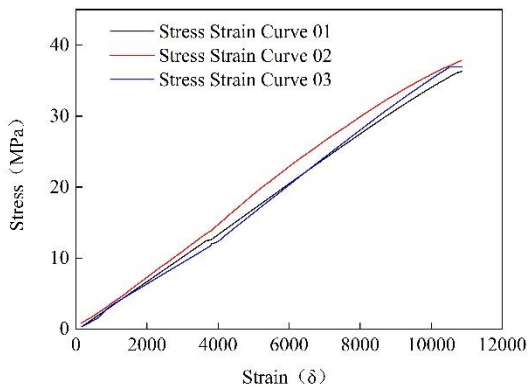


Fig. 8 – Stress and strain curve of group A
(The material ratio is 1:1:2)

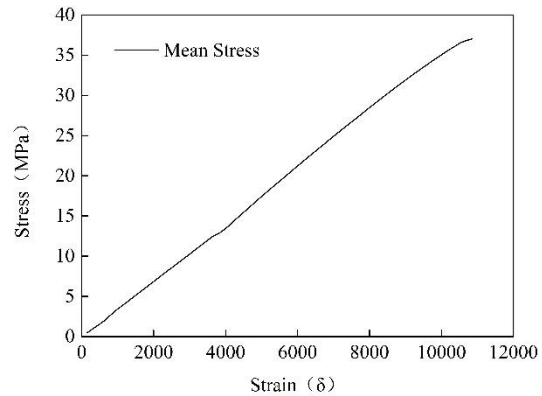


Fig. 9 – Stress and strain curve of group A
(The material ratio is 1:1:2)

Tab. 3 - The flexural strength of group A polyurethane cement

Serial Number	1	2	3	Average
Strength (MPa)	36.3	37.8	37.0	37.2

There are three flexural test blocks of group B polyurethane cement (polyol: isocyanate: cement =1.15:1:2) participating in the flexural test this time. The flexural curve of group B polyurethane cement test blocks are shown in Figure 10 and Figure 11. The curve reveals a linear relationship with the load increasing. The average peak flexural strength is 38.9 MPa. Meanwhile, the strain peak value is 23520 $\mu\epsilon$. The peak stress of each bending specimen is shown in Table 4. The results show that the stress of polyurethane cement increased by 1.8MPa and strain increased by 116.7% compared with group A polyurethane cement (polyol: isocyanate: cement =1:1:2) due to the addition of polyester polyols. The flexural strength of cement =1.15:1:2 is slightly improved, and the ductility is greatly enhanced.

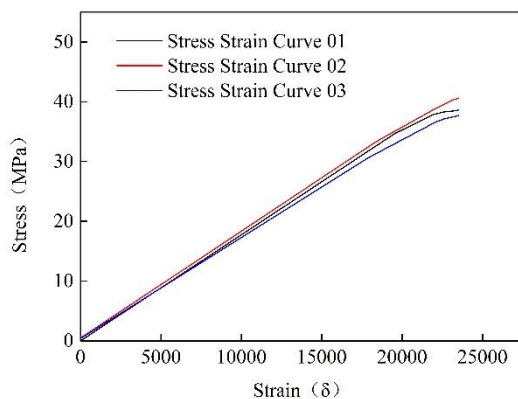


Fig. 10 - Stress-strain curve of group A polyurethane cement
(Polyol: isocyanate: cement =1.15:1:2)

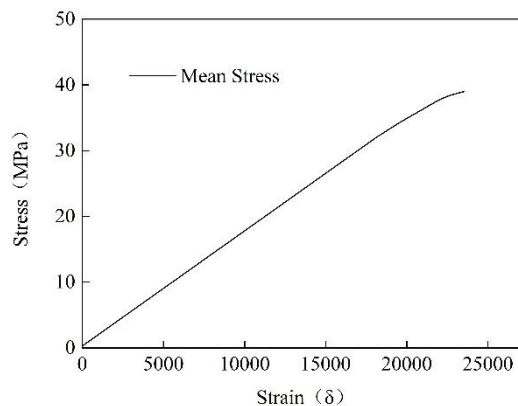


Fig. 11 - Stress-strain curve of group A polyurethane cement (average)
(Polyol: isocyanate: cement =1.15:1:2)

Tab. 4 - The flexural strength of group B polyurethane cement

Serial Number	1	2	3	Average
Strength (MPa)	38.6	40.6	37.7	38.9

The flexural curve of group C is shown in Figure 12. There are three flexural test blocks of group C polyurethane cement (polyol: isocyanate: cement =1.3:1:2) participating in the flexural test this time. The average curve of flexural capacity is shown in Figure 13. The peak stress of each flexural specimen is shown in Table 5. The results showed that the stress of polyurethane cement increased by 5.4 MPa and the strain increased by 203.5% compared with group A polyurethane cement (polyol: isocyanate: cement =1:1:2) due to the addition of polyester polyols. Compared with group B polyurethane cement (polyol: isocyanate: cement =1:1:2), the stress of polyurethane cement increased by 5.4 MPa and the strain increased by 203.5%. (polyol: isocyanate: cement =1.15:1:2) increased by 3.6 MPa and strain increased by 40.1%, indicating that the flexural strength and ductility of polyurethane cement (polyol: isocyanate: cement =1.3:1:2) are improved to a certain extent with the increase of the content of polyurethane polyol.

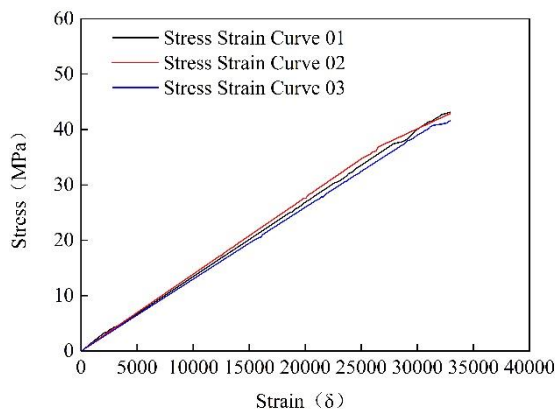


Fig.12 - Stress-strain curve of polyurethane cement (Polyol: isocyanate: cement =1.3:1:2)

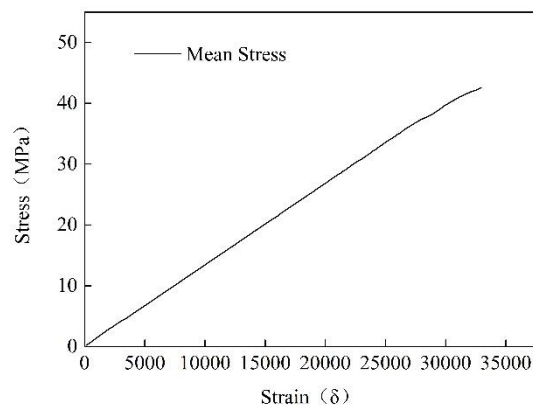


Fig.13 - Stress-strain curve of polyurethane cement (average) (Polyol: isocyanate: cement =1.3:1:2)

Tab.5 - The flexural strength of group B polyurethane cement

Serial Number	1	2	3	Average
Strength (MPa)	43.1	42.9	41.6	42.5

Three pieces of polyurethane emery flexural test blocks were used in the test. Its stress-strain curve are shown in Figure 14 and Figure 15. The average flexural strength at the peak is 45.1 MPa, and the strain is 6203 $\mu\epsilon$. The peak stress of each flexural test block is shown in Table 6.

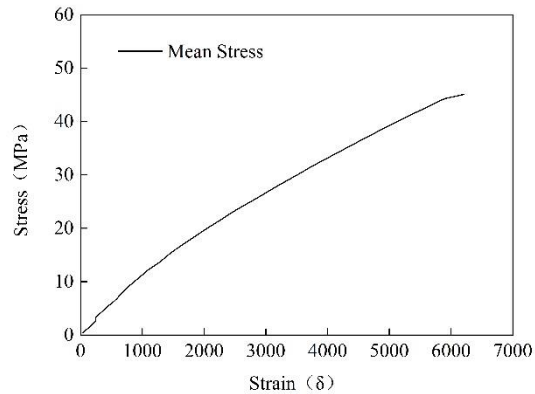
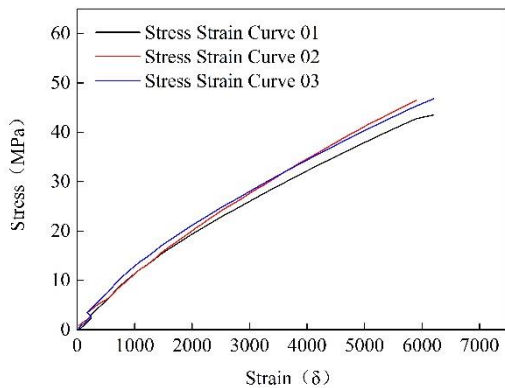


Fig.14 - Polyurethane emery curve Fig.15 - Polyurethane emery curve (average)

Tab. 6 - The flexural strength of polyurethane emery test block

Serial Number	1	2	3	Average
Strength (MPa)	43.5	46.5	45.3	45.1

There are three polyurethane lime flexural test blocks participating in the flexural test, which are collected by dynamic strain acquisition instrument. The flexural curve of polyurethane lime test block is shown in Figure 16 and Figure 17. The peak average flexural strength is 31.4 MPa. At the same time, the strain is 5723 $\mu\epsilon$. When the loading reached a certain peak, the stress increased more slowly than the strain. When the load reaches the peak value. The peak flexural strength of each polyurethane lime test block is shown in Table 7.

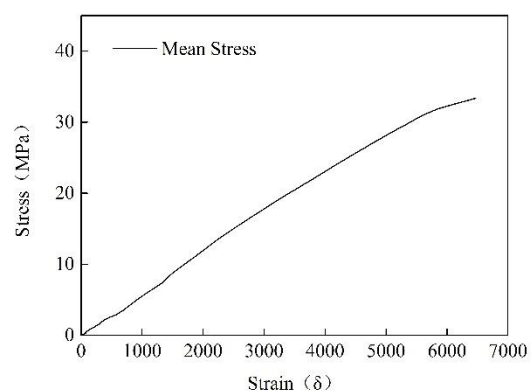
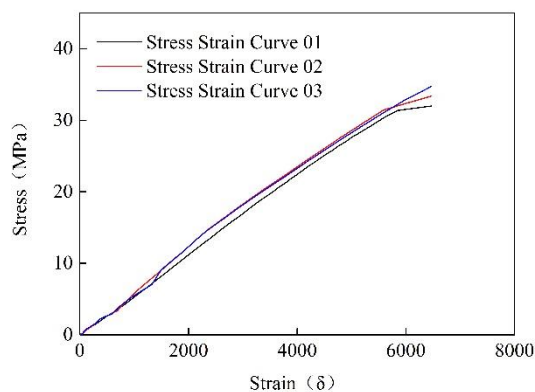


Fig. 16 – Stress and strain curve of polyurethane lime

Fig. 17 – Stress and strain curve of polyurethane lime (average)

Tab. 7 - The flexural strength of polyurethane lime test blocks

Serial Number	1	2	3	Average
Strength (MPa)	32.0	33.4	34.7	33.4

There are three flexural test blocks of polyurethane quartz sand participating in the flexural test this time. The curve of polyurethane quartz sand test blocks is shown in Figure 18 and Figure 19. The peak stress of each polyurethane flexural test block is shown in Table 9. The slope of the stress-strain curve decreases slightly when the loading reaches the middle and late stage, and the stress increases more slowly than the strain. When the loading reaches the peak, the average flexural strength is 49.2 MPa, and the strain is 7521 $\mu\epsilon$. It can be seen that in the rubber sand sample composed of polyurethane, emery, lime and quartz sand, the test block of polyurethane quartz sand has the best flexural strength and higher strain than other composites, indicating that its ductility is also better than other composites.

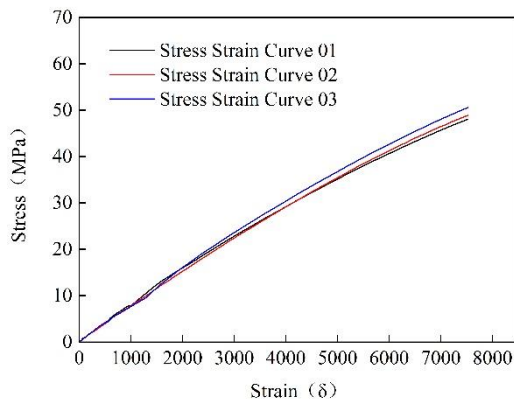


Fig. 18 – Stress and strain curve of polyurethane quartz sand

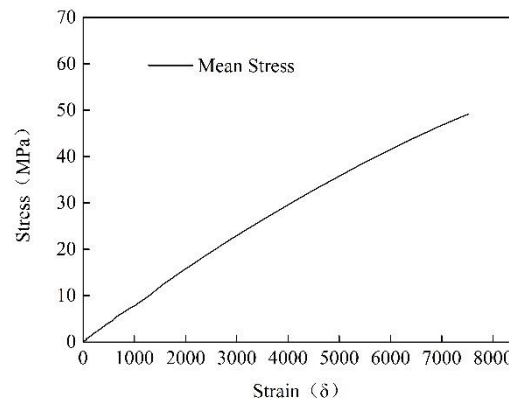


Fig. 19 – Stress and strain curve of polyurethane quartz sand (average)

Tab.9 - The flexural strength of polyurethane quartz sand test block

Serial Number	1	2	3	Average
Strength (MPa)	48.1	48.9	50.6	49.2.

Table 10 is a summary of the average flexural strength of each polyurethane powder composite. As shown in Table 10, the flexural strength of the polyurethane cement in the polyurethane mortar test blocks with the same composition ratio is 37.1 MPa, and the average flexural strength of the polyurethane emundant test block is 45.1 MPa, which is 21.6% higher than that of the polyurethane cement test block in group A. The average flexural strength of polyurethane lime test block is 33.4 MPa, which is 9.9% lower than that of group A polyurethane cement test block. The average flexural strength of polyurethane quartz sand test block is 49.2 MPa, which is 32.6% higher than that of group A polyurethane cement test block. These three kinds of the strength of the polyurethane lime block only less than the flexural strength of polyurethane cement group A, while polyurethane emery block polyurethane and quartz sand block strain less than polyurethane cement, but its flexural strength is superior to polyurethane, the flexural strength of cement in theory can replace cement with silicon carbide, quartz powder to reduce the cost of PU composite material.

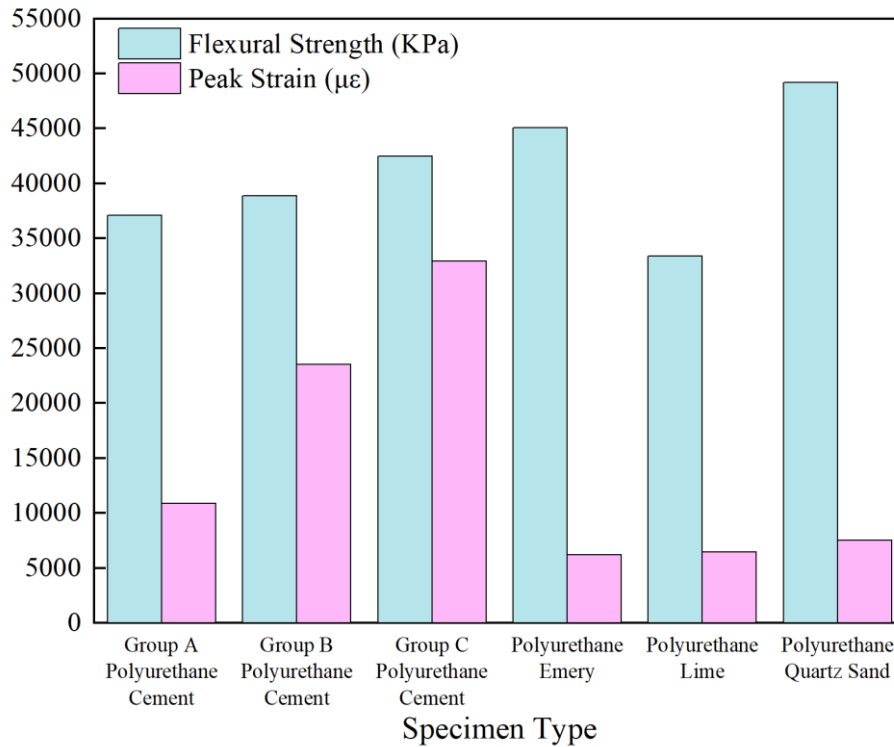


Fig. 20 – Summary of the flexural strength of each specimen

4.2 Compression test results

In compression test, the strain value is the average of the measured values of the two resistance strain gauges. The compressive stress-strain curve of each test block is shown in Figure 21 and Figure 22. At the initial stage of loading, the compressive strength of the six groups of cube specimens is very similar. In the later stage of loading, the stress-strain curve is nonlinear. In the three groups of polyurethane cement. The compressive strength of group C is the highest with a value of 71.52 MPa. In the three groups of other materials. In the other three groups of polyurethane powder types, polyurethane quartz sand has the greatest compressive strength. Its maximum compressive strength is 76.70 MPa.

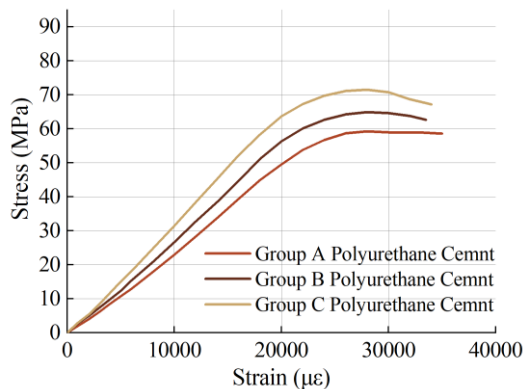


Fig. 21 – Compression strength of polyurethane cement

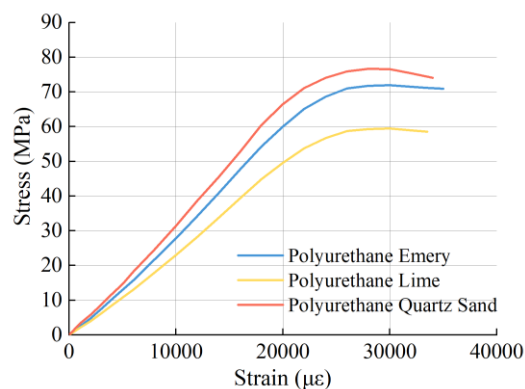


Fig. 22 – Compression strength of other polyurethane powder

CONCLUSION

In this paper, by studying the influence of different powders on the mechanical properties of polyurethane powder composites, the powder is mainly divided into emery, lime, quartz sand and cement. The stress-strain curve and the following conclusions can be listed as follows:

1. The average peak flexural strength of group A polyurethane cement (polyol: isocyanate: cement =1:1:2) is 37.1 MPa, and the strain is 10854 $\mu\epsilon$. The average peak flexural strength of polyurethane cement of group B (polyol: isocyanate: cement =1.15:1:2) is 38.9 MPa, and the strain is 23520 $\mu\epsilon$. Compared with group A, the stress of polyurethane cement of group B is 1.8 MPa higher and the strain is 116.7%. The average peak flexural strength of group C polyurethane cement (polyol: isocyanate: cement =1.3:1:2) is 42.5 MPa, and the strain is 32942 $\mu\epsilon$. Compared with group A polyurethane cement, the stress increases by 5.4 MPa and the strain increases by 203.5%. The results show that the flexural strength and ductility of polyurethane cement are improved obviously because the composition proportion of polyester polyols is increased in polyurethane cement. In the compressive test, the maximum compressive strength is 76.70 MPa. The material composition with maximum compressive strength is polyurethane quartz sand.

2. The average peak flexural strength of polyurethane emery test block is 45.1 MPa, and the strain is 6203 $\mu\epsilon$. The average peak flexural strength of polyurethane lime test block is 33.4 MPa, and the strain is 6470 $\mu\epsilon$. The average peak flexural strength of polyurethane quartz sand test block is 49.2 MPa, and the strain is 7521 $\mu\epsilon$. In the flexural test blocks composed of polyurethane and emery, lime and quartz sand, the flexural strength of polyurethane lime test block is less than that of polyurethane cement, and the flexural strength of polyurethane emery test block and polyurethane quartz sand test block is greater than that of polyurethane cement. As a summary, emery and quartz sand powder can be used to replace cement in order to reduce the cost of polyurethane composites.

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