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*https://doi.org/10.37358/Mat.Plast.1964*

# Experimental Study on Mechanical Properties of Polyurethane Cement Composite (PUC) Under Various Temperatures

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***Abstract:*** *This paper aims to investigate the mechanical properties of polyurethane cement (different ratios) at different ambient temperatures. The temperature and proportion which affect the constitutive relation of the material were analyzed by axial tensile test. The microstructure and failure mode of polyurethane cement were studied using scanning electron microscope technology. At -40°C ~40°C, the stress-strain curves of polyurethane cement with different proportions were roughly similar. When the temperature was higher than 40°C, with the rise of temperature, the ultimate tensile strength of polyurethane cement specimens would decrease but the ultimate strain would increase. When the temperature was lower than -40°C, with the decline of temperature, the ultimate strain and tensile strength of polyurethane cement specimens would decrease. The ultimate stress of polyurethane cement with different ratios was different. With the rise of the proportion of polyurethane components, the ultimate stress would increase but the elastic modulus would decrease. Macroscopically, the failure modes of polyurethane specimens were different with the change of temperature. Brittle fracture occurred at low temperatures. At high temperatures, the specimen did not fracture, but a large number of "V"shaped cracks appeared at the edge. The higher the temperature, the more obvious this phenomenon was. At the microscopic level, the fibers didn't break at high temperatures, and there were obvious cracks and more stubble on the surface of cracks at room temperature.*

***Keywords:*** *Polyurethane cement composite material, High temperature mechanical properties, Cryogenic mechanical properties, Stretch, Constitutive relation*

## 1. Introduction

As the throat of highway traffic, bridges are playing an irreplaceable role [1-3]. Due to the influence of natural and human factors, the bridge structure has a series of diseases such as stressed cracks, deterioration of concrete, corrosion of steel bars and so on [4-6]. If the bridge with diseases is dismantled, it will waste a lot of resources. It has become an urgent need to choose an active and effective strengthening method to repair and reinforce the bridge.

Common strengthening methods for Bridge include pasting carbon fiber reinforced polymer (CFRP) plates, pasting steel plates and so on. The construction of pasting CFRP plates is simple, but it does not significantly improve the stiffness of the reinforced structure, and the cost is high [7, 8]. Sticking steel plates can improve the bearing capacity and stiffness of the structure, but steel plates rust easily, and it is difficult to fit with uneven concrete surface [9, 10]. In recent years, polyurethane cement composite material (PUC) has been used for structural reinforcement due to its characteristics of light weight, high strength, high toughness and good adhesion. In addition, the material has the characteristics of early strength, which can realize the rapid recovery of traffic reinforcement [11]. Haleem et al. [12] conducted an experimental study on bending reinforcement of T-section beams based on PUC material research, and the test results showed that the bearing capacity increased by about 170% and the crack width decreased by about 58%. Zhang et al. [13] used polyurethane cement composite (PUC) material to reinforce a hollow slab bridge and carried out load tests before and after reinforcement. The test results showed that the maximum bearing capacity and stiffness of the main beam were increased by 20% and

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28% respectively, and the crack width was reduced in different degrees. Sun et al [14] cast 3 cm thick PUC on the bottom of hollow slab girders and carried out bridge load tests before and after strengthening. The results showed that the deflection and strain of the bridge were reduced by more than 15%, the measured section stiffness was increased by about 20%, and the transverse connection of the bridge was significantly improved after the reinforcement. Zhang et al. [11, 15] also used PUC material as bonding and anchoring material of prestressed steel wire ropes (PSWRs) and steel wire mesh (WM) respectively to study the bending reinforcement of T beam. The results showed that PUC material could significantly improve the yield load, ultimate load and stiffness of the reinforced beams, and effectively inhibit the propagation of cracks.

Many scholars have studied not only the reinforced concrete beams strengthened by polyurethane cement composite materials, but also the mechanical properties of the materials. Sun et al. [14] developed polyurethane cement composite material (PUC) by mixing polyurethane raw material with ordinary Portland cement and carried out a mechanical properties test of PUC. The results showed that PUC had high compressive strength, tensile strength and significant tensile deformability. Haleem et al. [16] conducted experimental studies on the compression, bending, tensile strength and bonding strength of polyurethane composite materials (PUC), and obtained the stress-strain curve relationship of materials at different densities. And, compared with ordinary concrete, the compressive strength, flexural strength, tensile strength and bonding strength of PUC were obviously improved, and the bonding property of PUC with concrete was good. Zhang et al. [17] studied the fatigue performance of polyurethane cement composite (PUC) and found that the fatigue life of PUC decreased with the decline of density. In order to study the bonding property of PUC material and steel bar, the author carried out a pull test of steel bar. The results showed that with the rise of the thickness of the protective layer, the bonding strength between steel bar and PUC would increase. And, the results also showed that with the increase of the anchorage length and diameter of steel bar, the bonding strength between steel bar and PUC would decrease. Gao et al. [18] prepared PUC specimens with four proportions by controlling the proportion of polyurethane raw materials and cement and carried out compressive and bending tests. The experimental results showed that different fit ratios had a great influence on the density and elastic modulus of PUC, but had little influence on the compressive strength.

In conclusion, the existing studies mainly focus on the preparation of polyurethane cement composite materials, the bonding property with concrete, the fatigue property, the bonding property with steel bars, and the influence of the different fit ratios on its mechanical properties. However, there are relatively few studies on the effect of temperature on the mechanical properties of polyurethane cement composites.

Polyurethane cement composite material has been applied to a certain extent in actual bridge reinforcement, as shown in Figure 1. Because of the large temperature difference between winter and summer in north China, the study on different temperatures responsible for the constitutive relationships has practical application significance. In this paper, axial tensile tests were carried out for materials at different ambient temperatures to compare and analyze the mechanical properties under different temperatures, so as to obtain the law of the influence of ambient temperature on the constitutive relationship of materials.

## 2. Materials and methods

Polyurethane cement, the main component is polyurethane, is a kind of polymer concrete material, which has good wear resistance, chemical corrosion resistance, fluidity, bonding and molding properties [19]. Polyurethane, polymerized by isocyanate and polyether polyols, is a kind of excellent polymer. The main ingredients are shown in Table 1.

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**Table 1.** Main chemical composition of polyurethane

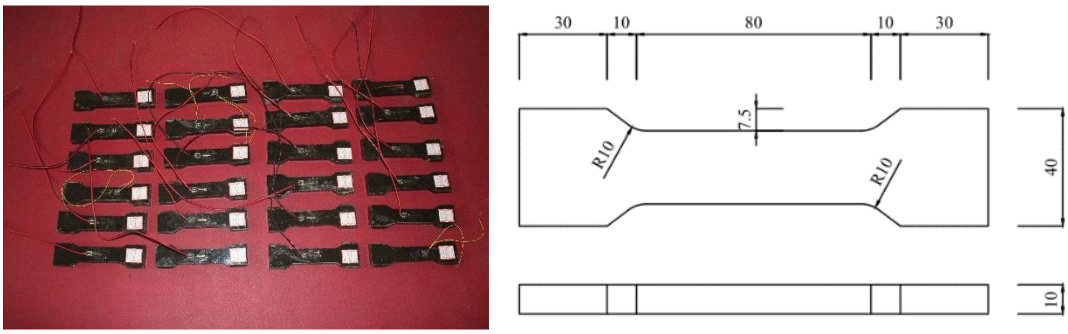
| **Chemical composition** | | **Percentage (%)** |
|---|---|---|
| **Polyols** | Polyether | 49 |
| | Silicone oil | 1 |
| | Water | 0-1 |
| **Isocyanate** | | 50-51 |

Polyurethane raw materials and cement powder, mixed according to the mass ratio 1:1, occur a polymeric reaction. In order to research the stress and strain characteristics of polyurethane cement in different mixing ratios, control groups were set for comparison. The high-density polyurethane composites with the polyurethane-cement ratio of 1.25:1 and 1:1.25 were prepared. For the convenience of explanation, the three groups of polyurethane cement test blocks were named group A, group B and group C. The specific ingredients are shown in Table 2.

**Table 2.** Specific composition of polyurethane material test block

| **Group** | **Composition** | **Percentage (%)** |
|---|---|---|
| Group A | Polyurethane | 50 |
| | Cement | 50 |
| Group B | Polyurethane | 55 |
| | Cement | 45 |
| Group C | Polyurethane | 45 |
| | Cement | 55 |

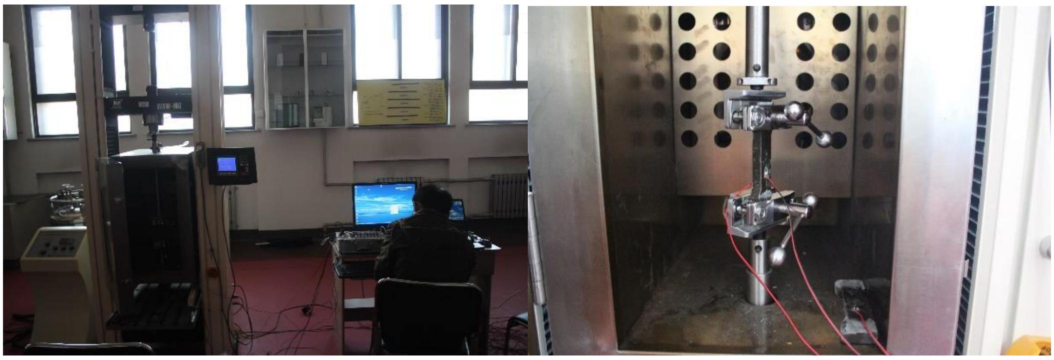
As shown in Figure 2, the specimens for this test were dumbbell-type thin sections [20-22]. Polyols, isocyanates and cement are the main raw materials in the mixture ratio. The dimensions are shown in Figure 2b. The thickness of the specimen was 10 mm, the middle width was 25 mm, and the width on both sides was 40 mm. The polyurethane powder composite material and defoaming agent were mixed and mechanically mixed for 3~5 min. The specimens were molded and cured for 7 d in a dry environment.




**(a) Specimens** **(b) Size of specimen**

**Figure 2.** Axial tensile specimens and size of polyurethane cement material (unit: mm)

In order to study the influence of natural ambient temperature on tensile mechanical properties of polyurethane cement materials, the test temperature was selected as -70℃~70℃ to simulate the natural ambient temperature. Tensile tests were carried out on 27 specimens (each 9 specimens in groups A, B and C) at -70℃, -60℃, -40℃, -20℃, 0℃, 20℃, 40℃, 60℃ and 70℃ respectively. These specimens were tested using dumbbell-shaped specimens of the dimensions shown in Figure 2. The tensile test was carried out on a small-range tester. First, clamped both ends of these specimens. Second, tested temperature environment, lowering the temperature by injecting enough nitrogen into the incubator or raising the temperature by using a resistive heater, was created. And, temperature stress was manually released by adjusting the loading device. Third, the temperature was kept for at least 15 min. Finally, an axial load was applied until fracture. The loading speed was 50 N/s. During the stretching process, resistance strain gauges were pasted in the middle of the specimens and pasted symmetrically on both sides along the stretching direction to measure variation. Dynamic strain acquisition instrument was used for data acquisition. These are shown in Figure 3.



**(a)** **(b)**

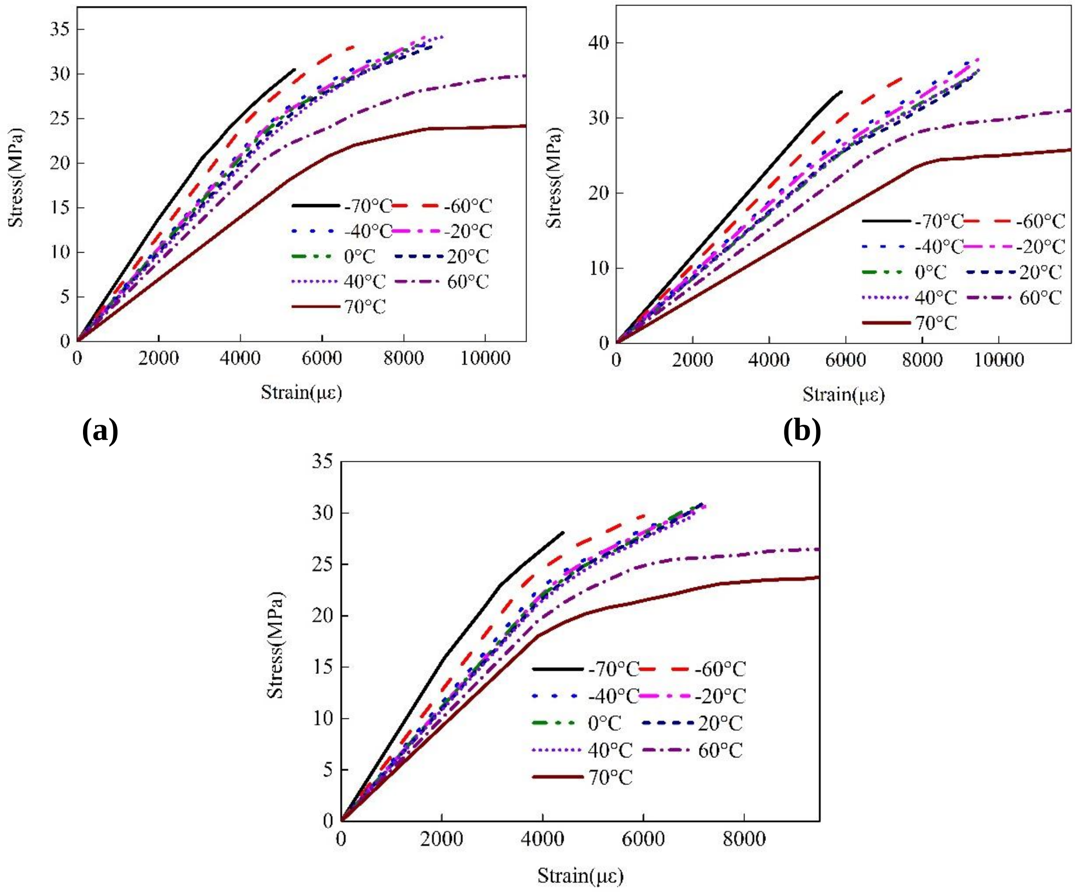
**Figure 3.** Tensile test under different temperatures:
(a) Small range testing machine, (b) inside of Small range testing machine

At the end of the tensile test, the fractured specimen was micro analyzed by scanning electron microscopy. The sections of the damaged specimens at different temperatures were enlarged 1000 times to 5000 times respectively, and the different failure modes were observed and compared with the macroscopic test phenomena, and the microscopic explanation was given. (Also, analyzed the reasons for its high durability through microscopic scanning of polyurethane cement materials)

## 3. Results and discussions

Figure 4 shows the axial tensile stress-strain curves of three groups of polyurethane cement specimens (different ratios) at different temperatures. It can be seen from the figure that temperature changes within a certain range have little influence on the tensile properties of specimens. If the temperature is beyond the range, the elastic modulus will change significantly regardless of whether it increases or decreases. Stress-strain curves at different temperatures can be roughly divided into the elastic stage and the parabolic strengthening stage. In the range of -40$^o$C ~40$^o$C, the stress-strain curves of specimens are roughly the same. The ultimate strength of group A specimens (polyurethane: cement =1:1) is about 34 MPa, and the ultimate strain is in the range of 7000-7500 με. The ultimate strength of group B specimens (polyurethane: cement =1.5:1) is about 37 MPa, and the ultimate strain is in the range of 9000~9500 με. The ultimate strength and ultimate strain of group C specimens (polyurethane: cement =1:1.25) are about 30 MPa and 7000 με, respectively. On this basis of -40$^o$C ~40$^o$C, whether the temperature continued to rise or fall, the curves of groups A, B and C will diverge at some point. When the temperature is higher than 40$^o$C and continued to rise, the elastic modulus and tensile strength of polyurethane cement specimens will decrease obviously and the ultimate strain will increase. When the temperature is lower than -40$^o$C, the ultimate strain and tensile strength of polyurethane cement specimens will decrease obviously with the decline of temperature.

Taking group B specimens (polyurethane: cement =1.25:1) as an example. The ultimate tensile strength of the specimens at 20$^o$C is 37.8 MPa and the ultimate tensile strain is about 9450 με. The ultimate tensile stress of the specimens at 60℃ is 31.3 MPa and the ultimate strength is 17.2% lower than that at room temperature. The ultimate tensile stress of polyurethane cement specimens at 70$^o$C is 26 MPa, and the ultimate strength is 31.2% lower than that at room temperature. The ultimate tensile stress of polyurethane cement specimens at -60$^o$C is 35.7 MPa and the ultimate strength is only 5.6% lower than that at room temperature. The ultimate tensile stress of polyurethane cement specimens at -70$^o$C is 33 MPa and the ultimate strength is 12.7% lower than that at room temperature. Preliminary analysis shows that the strength of polyurethane cement will decrease at extremely low or high temperature, and the ductility will increase along with the rise of temperature, and will decrease as the temperature goes down. The stress-strain curves of the other two groups of polyurethane cement specimens with different proportions are similar to the above law.




**(a)** **(b)**

**(c)**

**Figure 4.** Axial tensile stress-strain curves under different temperatures:
(a) (polyurethane: cement =1:1), (b) (polyurethane: cement =1.25:1),
(c) (polyurethane: cement =1:1.25)

The stress-strain curves of axial tension under different temperatures are compared, as shown in Figure 5. During the initial load, the specimens undergo a linear elastic stage at various temperatures. After the initial load, the specimens show different trends at different temperatures. At -70 and - 60°C, the stiffness of polyurethane cement specimens is obviously greater than that of other temperatures, the whole process is a linear elastic stage, and specimens fractured directly after loading to a certain extent. Since the stress-strain curves of -40°C~40°C are similar, only the stress-strain changes at 20°C are listed in this paper, as shown in Figure 5c. Its stiffness is lower than that in Figures 5a and b. The initial stage of the specimen is linear elasticity, and with the increase of axial tension load, the specimens began to enter the plastic stage. As shown in Figures 5d and e, at 60 and 70°C, the specimens began to enter the linear elastic stage and then enter the elastic-plastic deformation stage. Due to the higher test temperature, the ductility of the specimens is enhanced, and the deformation capacity is further increased. Finally, the specimens enter the stage of local failure. It is found that the material became softer and had better ductility at 70°C.

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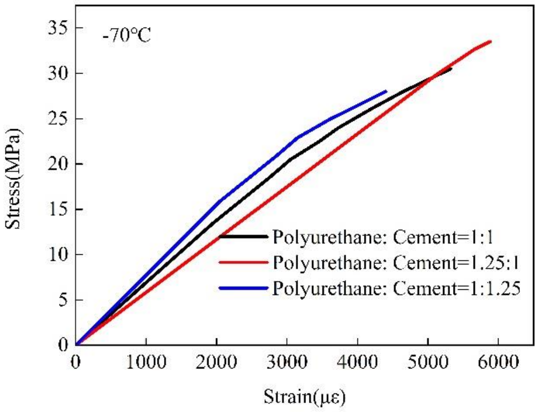
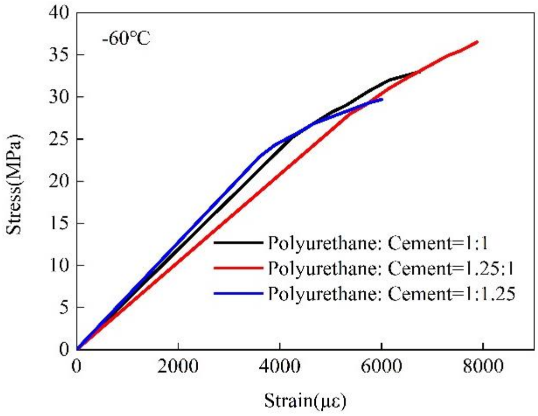
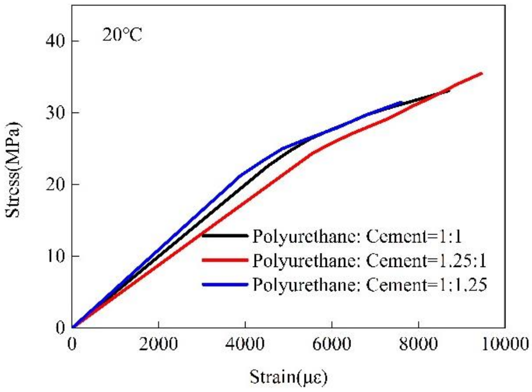


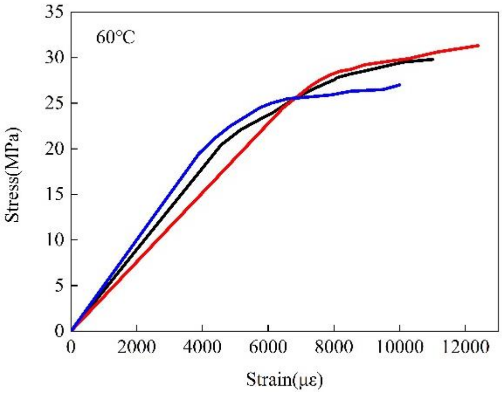

**(a) -70℃**



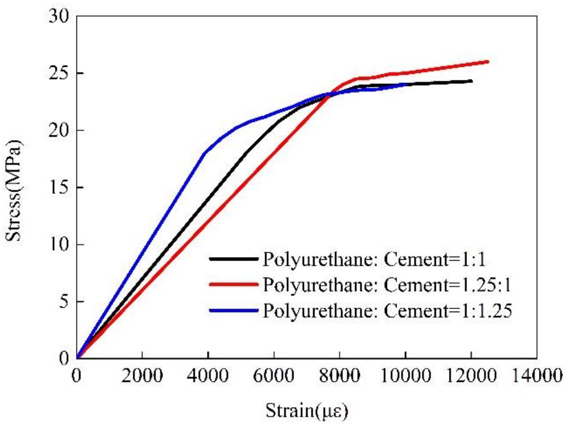

**(b) -60℃**




**(c) 20℃**




**(d) 60℃**




**(e) 70℃**

**Figure 5.** Axial tensile stress-strain curves at different ratios:
(a) (-70°C), (b) (-60°C), (c) (20°C), (d) (60°C), (e) (70°C)

The elastic modulus of polyurethane cement specimens under axial tension is shown in Figure 6a, b and c. It can be seen from the Figure 6 that with the increase of temperature, the elastic modulus of polyurethane cement at the same ratio will decrease gradually. When the temperature is -70 and 70°C, the elastic modulus reaches the maximum value and the minimum value respectively. At the same temperature, the elastic modulus of polyurethane cement specimens with different proportions is also different. The elastic modulus of group C (polyurethane: cement =1:1.25) is the largest, and that of group B (polyurethane: cement =1.25:1) is the smallest. Compared with group B, group C specimens increase by 32.8% at -70°C, 30.2% at 0°C and 48.4% at 70°C.

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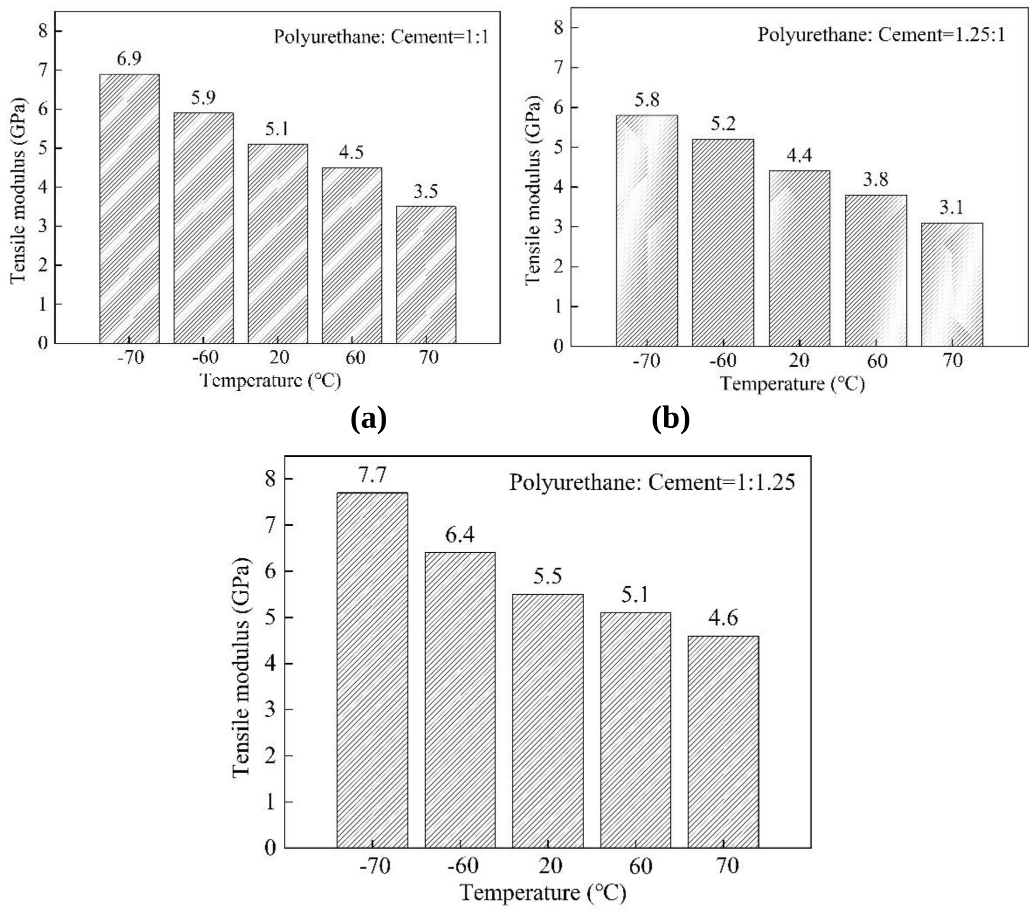



**(c)**

**Figure 6.** Comparison of modulus of elasticity of specimens under different temperatures: (a) (polyurethane: cement =1:1), (b) (polyurethane: cement =1.25:1), (c) (polyurethane: cement =1:1.25)

The ultimate tensile strength of polyurethane cement specimens is shown in Table 3. As the ultimate stress of -40~40°C is roughly similar, it is replaced by 20°C at room temperature. It can be seen from Table 3 that the ultimate stress of polyurethane cement specimens at the same mixture ratio is the highest at 20°C, and the ultimate stress gradually decreases when the temperature continues to rise or fall. At the same temperature, the ultimate stress of polyurethane cement specimens with different proportions is also different. The ultimate stress of group B (polyurethane: cement =1:1.25) is the largest, while that of group C (polyurethane: cement =1.25:1) is the smallest. Compared with group C, the ultimate stress of group B specimens increases by 19.2% at -70°C, 17.0% at 20°C, and 8.3% at 70°C.

**Table 3.** Comparison of ultimate stress of specimens at different temperatures

| **Temperature (℃)** | **Ultimate stress (MPa)** | | |
|---|---|---|---|
| | Group A | Group B | Group C |
| -70 | 30.5 | 33.5 | 28.1 |
| -60 | 33.1 | 35.7 | 29.7 |
| 20 | 33.1 | 36.1 | 31.5 |
| 60 | 29.8 | 31.3 | 27.2 |
| 70 | 24.3 | 26.1 | 24.1 |

Figures 7 and 8 are failure patterns of specimens at 60 and 70°C respectively. At high temperatures, the failure mode of polyurethane cement specimens is mainly that the strain increases sharply, the stress remains unchanged, and the specimen does not fracture, but a large number of "V" shaped cracks appear at the edge. The higher temperature can bring more obvious phenomena. Because the loading point is under the dual action of axial tension and high temperature, the mobility and resistance to crack propagation of polyurethane components are enhanced. The full play of its cementation effectively prevents the brittle fracture of the specimen at the weak point and increases its tensile strength.

However, other temperature conditions are quite different from the high-temperature conditions. Under the condition of extremely low temperatures, the tensile strain of the specimens is smaller. And, brittle fracture is happened and accompanied by sound when loaded to a certain extent. At room temperature, a small “V” shape crack appears in the middle of the specimen and expand gradually. Finally, the specimens fracture directly and are accompanied by sound.

**Figure 7.** Failure mode of the specimen at 60℃

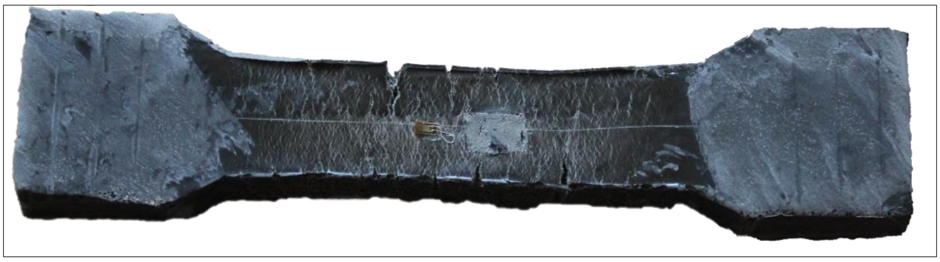
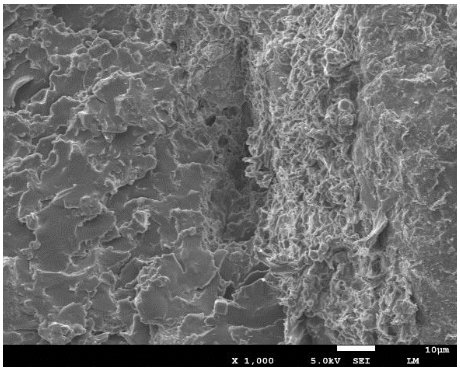


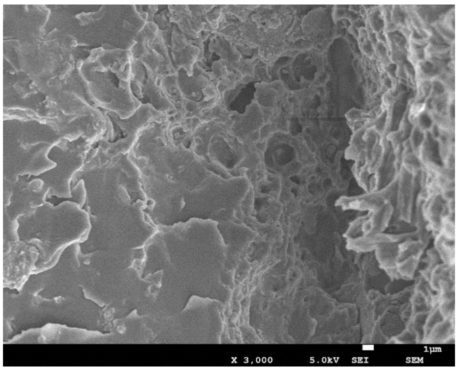
**Figure 8.** Failure mode of the specimen at 70℃

The following figure shows the microscopic scanning electron microscope image of polyurethane cement specimens. At room temperature (20$^{o}$C), the main failure mode of the specimens is that a small “V” ‘crack first appears in the middle of the specimen and expands gradually. Eventually, specimens are directly destroyed and are accompanied by sound. The specimen (20$^{o}$C) at the microscopic level can be seen in Figure 9. In the figure, it can be observed obvious cracks that have more stubble on the surface and rough fractures that have more honeycomb holes. This indicates that the bearing capacity is weak at this part. At high temperature (70$^{o}$C), the specimen is mainly characterized by no fracture but a large number of “V” shaped cracks at the edge. Figure 10 shows the microscopic view of the specimen at 70$^{o}$C. At this temperature, the specimen had a tendency to change to a high elastic state. The molecular fluidity of the specimen is enhanced. The structural surface of the specimen is dense. In the center of the specimen, there is a large range of membrane material produced by tensile fiber material, but the fiber did not break.

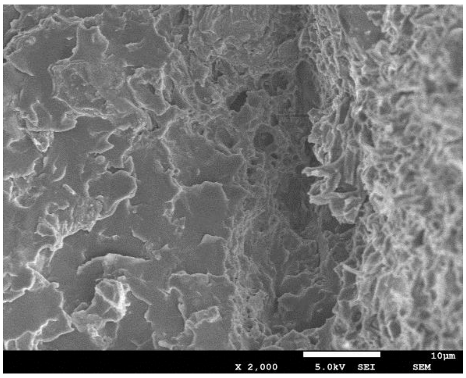
In addition, it can be seen from the scanning electron microscope that the polyurethane cement specimen has less void and high structural density, which is due to the small order of magnitude of polyurethane polymer, cement structure can play a gap-filling role, resulting in poor connectivity of pore structure network of polyurethane cement. Thus, the pore structure of cement mortar is improved and the ability to resist liquid and gas penetration is enhanced Therefore, the durability of polyurethane has been greatly improved.



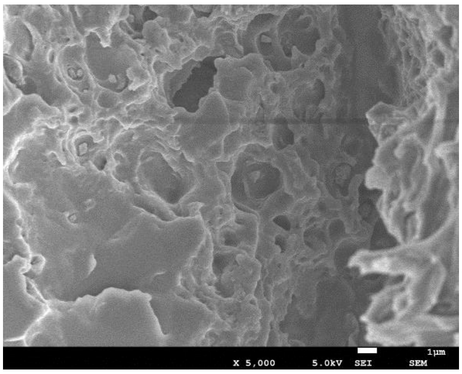
(a) Scanning image at 1000 multiples



(b) Scanning image at 2000 multiples

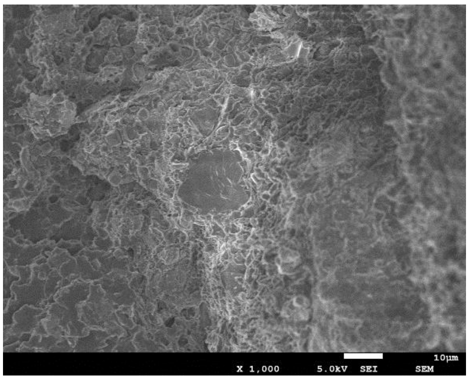


(c) Scanning image at 3000 multiples

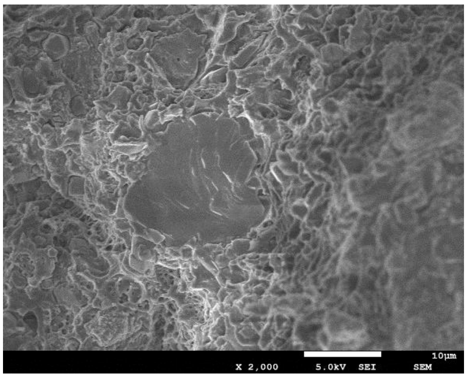


(d) Scanning image at 5000 multiples

**Figure 9.** Microstructure photos of polyurethane cement fracture (20℃) at the loading point



(a) Scanning image at 1000 multiples



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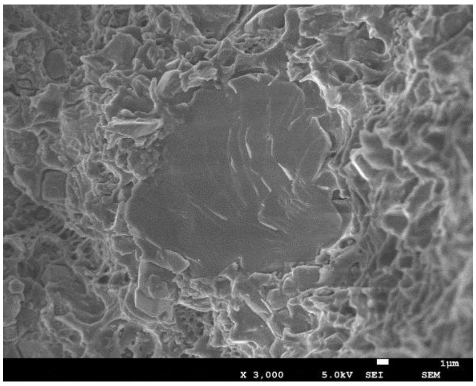
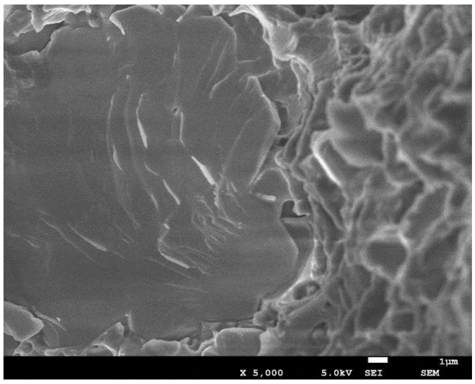


(c) Scanning image at 3000 multiples



(d) Scanning image at 5000 multiples

**Figure 10.** Morphology photos of polyurethane cement fracture (70$^{o}$C) at the loading point

**Acknowledgments:** Financial support for this research provided by the 2021 Liaoning Province Doctoral Research Start-Up Fund Project (2021-BS-168) is greatly appreciated.

## 4. Conclusions

In this paper, through the axial tensile test of materials at different ambient temperatures, the mechanical properties are compared and analyzed. Thus, the influence law of ambient temperature on material constitutive relation is obtained, and the following conclusions are drawn:

- the stress-strain curves of polyurethane cement with different proportions are roughly similar at -40°C~40°C. As the temperature increases or decreases, the strength of the material will change. After 40°C, with the rise of temperature, the elastic modulus and tensile strength of polyurethane cement specimens will decrease obviously, and the limit strain will increase. When the temperature is below -40°C, the ultimate strain and tensile strength of polyurethane cement specimens decrease obviously with the decline of temperature;
- the limit stress of polyurethane cement (different proportions) is not the same. Group B (polyurethane: cement =1:1.25) has the largest elastic modulus, followed by Group A (polyurethane: cement =1:1) and group C (polyurethane: cement =1.25:1);
- with the increase of temperature, the modulus of elasticity of specimen will decrease gradually. The modulus of elasticity of polyurethane cement specimens (different proportions) at the same temperature is also different. Group C (urethane: cement =1:1.25) has the largest elastic modulus, followed by Group A (urethane: cement =1:1) and Group B (urethane: cement =1.25:1);
- due to the dual action of axial tension and high temperature at the loading point, the fluidity of polyurethane components is enhanced, which can effectively prevent the brittle fracture of specimens. The failure mode of polyurethane cement specimen shows that the strain increases sharply and the stress remains unchanged. The specimen does not fracture, but a large number of "V" shaped cracks appear at the edge. The higher temperature can bring a more obvious situation;
- scanning electron microscopy analysis showed that at room temperature, the component fractured in a weak place with more pores, rough fracture, and more stubble on the surface. At high temperature, the polyurethane cementation is fully reflected in the specimen, and the unbroken polymer fibers are seriously stretched and deformed.

**References**

1.TYRRELL, H.G., *History of bridge engineering*, Chicago: The author, 1911.
2.BENNETT, D., The history and aesthetic development of bridges, *ICE Manual of Bridge Engineering: Second Edition. ICE Publishing*, 2008, 1-21.
3.PODOLNY, J. W., FLEMING, J. F., Historical development of cable-stayed bridges, *Journal of the Structural Division*, 98(9),1972, 2079-2095.
4.FANG, R., YANG, X., Cause and countermeasure of structure disease of bridge, *ICTIS 2013: Improving Multimodal Transportation Systems-Information, Safety, and Integration*. 2013, 470-475.
5.DIAO, Y., STONE, ARCH, BRIDGE, DISEASE, DETECTION, AND EVALUATION, Applied Mechanics and Materials, *Trans Tech Publications Ltd*, 501, 2014, 1332-1335.
6.ZHONGQIU, F., GUYU, S., TONG, S., JIE, X., Research on fatigue diseases evaluation of steel bridge deck based on fuzzy comprehensive method. *Industrial Construction*, 2017.
7.XIANFENG, H., HUI, P., JIE, L., Engineering Application and Evaluation of the Bridge Structure Strengthened with Prestressed CFRP Plate. *China Railway Science* 28.2 (2007), 139-144.
8.WENZHONG, Z., FUXIONG, W., SHIGUANG, L., Experimental research of fire performance on reinforced concrete slabs strengthened with CFRP sheets bonded with inorganic adhesive. *Journal of Building Structures*, 2010, 31(10), 89-97.
9.GUOQIANG, L., RUNDE, L., ZEQI, L., A Practicability Analysis for Reinforce Technique of Air-Defence Shelter Front by Inside Sticking Steel-Plates. *Chinese Quarterly of Mechanics* 3 (2000).

10.SIYU, S., Comparison of the Method of Sticking Steel Plate and Sticking CFRP in Reinforcing the Framework of the Reinforced Concrete. *Science Technology and Engineering* (2007).
11.KEXIN, Z., TIANYU, Q., ZHIMIN, Z., XINGWEI, X., XINYUAN, S., Strengthening of a Reinforced Concrete Bridge with a Composite of Prestressed Steel Wire Ropes Embedded in Poly-urethane Cement. *Journal of Performance of Constructed Facilities*, 35(5), 04021063.
12.HALEEM, K., HUSSAIN., LIANZHEN, Z., GUIWEI, LIU., An experimental study on strengthening reinforced concrete T-beams using new material poly-urethane-cement (PUC). *Construction and Building Materails*, 2013, 40, 104-117.
13. KEXIN, Z., TIANYU, Q., ZHIMIN, Z., XINGWEI, X., Study on reinforcement of fabricated hollow slab bridge by polyurethane-cement composite (PUC). *Stavební obzor-Civil Engineering Journal*, 30(2).
14. CHUNWEI, L., QUANSHENG, S., YANCHENG, L., Study on static load test of simply supported hollow slab bridge flexural strengthened with polyurethane-cement composite. *International Journal of Structural Integrity* (2021).
15. KEXIN, Z., QUANSHENG, S., The use of Wire Mesh-Polyurethane Cement (WM-PUC) composite to strengthen RC T-beams under flexure. *Journal of Building Engineering* 15 (2018), 122-136.
16.HUSSAIN., HALEEM, K., GUIWEI, L., YUWEN, Y., Experimental study to investigate mechanical properties of new material polyurethane-cement composite (PUC). *Construction and Building Materials* 50 (2014), 200-208.
17. KEXIN, Z., QUANSHENG, S., Bending fatigue properities research of polyurethane cement (PUC), *Civil Engineering Journal* 2 (2019).
18.HONGSHUAI, G., YAQIAO, D., KEXING, Z., HONGBO, L., Study on mechanical properties of lightweight and high strength polyurethane cement composite (PUC). *In Journal of Physics: Conference Series (Vol. 1965, No. 1, p. 012075). IOP Publishing*.
19.H, O., GUIWEI, L., A foundational study on static mechanical characteristics of the super light weight and high strength material using fly-ash. *Journal of the Society of Materials Science*. 2006, 55 (8), 738-745.
20.JIAN, S., WEIDONG, W., Experiment on mechanical properties of resin matrix composites laminates under various temperatures. *Journal of Aerospace Power*, 2016, 031(004),1006-1018.
21.HAIYAN, Z., LIANG, C., BO, W. U., Tensile and bond properties and strength degradation mechanism of geopolymer mortar after exposure to elevated temperatures. *Journal of Harbin Institute of Technology*, 2016.
22.JIE, C., HUAJUN, D., JUN, W., BO, Z., Effect of polyol composed with PAPP and PPG on the mechanical properties of rigid polyurethane. *Thermosetting Resin*, 2018

Manuscript received: 19.09.2022