Effect of saturation on mechanical behavior of cement mortar based on 8-type tensile test

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Abstract. Based on the purpose of revealing the effect of saturation on static tensile mechanical behaviour of cement mortar, the single-axis static tensile test was carried out for 8-type cement mortar specimens with the saturation of 0%, 50%, and 100% respectively. The WDW-20 microcomputer controlled electronic universal testing machine was used in this paper. The date obtained from test indicates that the stress-strain curves of different saturation cement mortar are similar, stress with strain increases, the stress growth rate increases gradually. With the increase of saturation, the static tensile strength of cement mortar gradually decreases, and the stiffness of cement mortar gradually decreases, and the deformation performance gradually improves, and the maximum tensile strain increases gradually. Compared with dry cement mortar specimens, the tensile strength of saturated cement mortar specimens is decreased by 23.36%; the maximum tensile strain of semi-saturated and saturated cement mortar specimens is increased by 4.79% and 23.43% respectively. The elastic modulus of the dry and the semi-saturated cement mortar specimens are similar, when they are under pulled, and are larger than the elastic modulus of saturation cement mortar specimens.

1. Introduction
Concrete is one of the most widely used building materials in civil engineering. In practical application, many concrete buildings, such as bridge foundations, dams, piers and abutments, have been in water environment and saturated for a long time. These concrete structures are different from those in conventional environment. Because of the influence of pore water pressure and external water pressure, their mechanical properties will change. Therefore, it is necessary to study the mechanical properties of concrete in water environment. At present, scholars at home and abroad have done a lot of research on the mechanical properties of concrete in water environment. Yaman[1] et al. found that under certain conditions, the active porosity and moisture content of concrete were directly proportional to the elastic modulus of concrete and inversely correlated with the strength. Wegen[2] et al. found that the strength of concrete did not increase under the action of lateral water pressure, and when the water pressure was greater than the compressive strength of concrete, its strength decreased with the increase of water pressure. Huang changling[3] et al. found that when water pressure exists around concrete specimens, the compressive strength of saturated concrete increases. Peng gang[4] et al. found that the compressive resistance of saturated concrete is weaker than that of natural dry concrete. Deng yousheng[5] et al. found that the ultimate compressive strength of concrete is affected by the age, and at the age of 15d, the ultimate compressive strength is directly proportional to the water content. At the age of 28d, its water content has little influence on its ultimate compressive strength and the overall growth rate is small. At the age of 40d, the ultimate strength of concrete is
inversely proportional to the moisture content. Ding ning[6] et al. found that the young's elastic modulus of cement mortar first increased and then decreased with the increase of water content. With the entry of free water, the dynamic young's elastic modulus of cement mortar decreased from 56.75GPa when dry to 43.62GPa when saturated, which decreased by 23%. Most of these literatures take concrete as the research material to study its compressive properties. However, in practical engineering, the structure is mostly concrete tensile failure, and cement mortar is the weak layer of concrete, failure cracks appear in cement mortar, therefore, the study of mechanical properties of cement mortar in water, especially tensile properties, has certain significance for practical engineering.

In this paper, with saturation as a variable, 8-type cement mortar specimen is adopted to carry out uni-axial static tensile test through wdw-20 microcomputer controlled electronic universal testing machine. The variation rules of tensile strength, stiffness, maximum tensile strain and elastic modulus of cement mortar under three saturations are analyzed, and the action mechanism of free water in cement mortar is analyzed. The results provide a certain experimental basis for further research on the tensile properties of concrete in water.

2. Test scheme

2.1 Raw materials and dimensions of specimens
Cement: qinling brand 42.5R P·O cement, yaoxian county, shanxi province, whose 28d compressive strength is 48.6MPa. Sand: bahe medium sand, fine modulus is 2.8. Water: drink tap water.

The size of the specimen: the 8-character specimen of 78mm × 22.5mm × 22.2mm (length × middle width × height), as shown in figure 1. The 8-shaped specimen is easy to make, and can ensure the axial stress of the specimen, so that the stress is evenly distributed along the length of the specimen, the test results can reflect the tensile properties of cement mortar.

![Figure 1. The 8-type cement mortar specimens](image)

2.2 Specimen preparation
In this paper, the influence of saturation on the mechanical properties of cement mortar was studied by using 15 8-shaped cement mortar specimens with 5 pieces in each group and 3 groups. Mix proportion is prepared according to the ratio of lime sand of cement mortar with strength grade M15[7], as shown in table 1. According to the mixing ratio, the cement and sand were put into the blender and stirred for 1min, then water was poured into the blender and stirred for 2min. Finally the mixed cement mortar was poured into the 8-type mold and vibrated on the vibration table for 2min. The specimen is maintained in the maintenance pool, the mold is removed after 24h, and then the specimen is put into the maintenance box for 28d.

| Number | Strength grade of cement mortar | Mix proportion (kg/m³) | Lime sand ratio | Water cement ratio |
|--------|--------------------------------|------------------------|----------------|-------------------|
|        | M15                            | Cement 646.2 Water 290.8 Sand 298.2 | 0.224 | 0.45 |
The preparation methods of cement mortar specimens with different saturation are as follows:

① In order to obtain the specimens with saturation of 0%, the cured cement mortar specimens were put into the oven and dried completely. Rapid evaporation of water will lead to a decrease in the strength of cement mortar. Based on the precaution against this situation, the specimen is first baked at 30°C for 2 days, then adjusted to 50°C, baked for 2 days, and finally baked at 70°C for 4 days. During the baking process, the quality of cement mortar is measured by electronic scale every 1 day. When the quality does not change, it is considered that water mud and mortar reached the dry state, and then every hour the oven temperature was lowered by 10 until room temperature. After taking out the samples, the samples were wrapped in plastic film.

② In order to obtain 100% saturation specimens, the cured specimens were immersed in a pool for 28 days.

③ In order to obtain the specimen with 50% saturation, the sample is dried according to the above steps, and the mass of the sample is measured by electronic scale when it is completely dried. After the measurement, the sample is immersed in a pool for 28 days, and the mass at saturation is measured. Then the saturated specimen is dried in an oven at 50°C. During the drying process, every 3 samples are dried. The required mass is calculated by formula (1). When the measured mass reaches the desired mass (i.e., the cement mortar is considered to have reached the semi-saturated state, the drying is stopped and the specimen is wrapped in plastic film.

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K = \frac{M_x - M_G}{M_B - M_G} \times 100\% \tag{1}
\]

In the formula: \( K \) is the pore water saturation of cement mortar; \( M_x \) is the mass of cement mortar specimens in kg; \( M_G \) is the mass of cement mortar specimens in kg when they are dried to constant weight; \( M_B \) is the mass in kg when the pore water of cement mortar is saturated.

Cement mortar specimens with three saturation degrees are recorded as M0, M50 and M100 respectively.

2.3 Test equipment and procedures.

The direct tensile test method [8], which can truly reflect the tensile strength of cement mortar, is adopted in this test. WDW-20 microcomputer controlled electronic universal testing machine is selected. Two semi-circular steel rings are used to clamp the 8-shaped specimen to ensure uniaxial tension and uniform tension stress on the section of the specimen. The test device and fixture are shown in Fig. 2.

Three types of 8-shaped cement mortar specimens with different saturation were put into the fixture of universal testing machine, and the initial strain loading rate was set at (5 ± 1) mm/min. The uniaxial static tension test was carried out to record the stress-strain values during the experiment.
3. Test results and analysis

3.1 Stress-strain curves of specimens.

Figure 3. Stress-strain curves of three kinds of saturation cement mortar specimens

Tensile stress-strain curves of three kinds of saturation cement mortar specimens are shown in Fig. 3. Fig. 3 shows that the stress-strain curves of three kinds of cement mortar specimens with different saturation have similar trend. The stress increases with the increase of strain, the tangent slope of the points on the curve increases gradually, and the stress growth rate increases gradually. When the strain is 0.02, the stresses of curve M0-1 to M0-5 are 0.9889 MPa, 0.7854 MPa, 1.1729 MPa, 1.3774 MPa and 0.9784 MPa under dry condition, and the mean square deviation is 0.2239 MPa; under semi-saturated condition, the stresses of curve M50-1 to M50-5 are 1.2153 MPa, 0.7892 MPa, 0.8764 MPa, 0.5795 MPa and 1.8274 MPa, respectively. The variance is 0.4876 MPa, and the stress of curves M0-1 to M0-5 is 1.0241 MPa, 0.3540 MPa, 0.4872 MPa, 1.0609 MPa and 0.9873 MPa under saturation, respectively. The mean square deviation is 0.3349 MPa. It can be seen that in the three states, the test results under dry state are more accurate than those under semi-saturated state and saturated state. The reasons for this phenomenon are as follows.

When drying in oven, the surrounding environment conditions are the same, and the test results are more accurate. In the process of controlling the saturation, the semi-saturated specimens are dried completely in oven and then immersed in water. This process may damage the cement-based materials and affect the mechanical properties. The results show that the accuracy of the test is relatively low. When the saturated specimens are immersed in the pool, although the surrounding environmental conditions are the same, the porosity of the specimens is different, and the moisture content of the specimens will be deviated, which will affect the test results.
Figure 4. Representative stress-strain curves of three kinds of saturation cement mortar specimens

The representative stress-strain curves of the three saturation degrees are plotted in Fig. 4. Fig. 4 shows that the stress of cement mortar specimen increases slowly with the increase of strain. When the strain is about 0.01, the stress-strain curve appears inflection point and the stress increases rapidly. When the strain is less than 0.01, the cement mortar is in the elastic stage, and the deformation is recoverable elastic deformation. When the strain is greater than 0.01, the stress-strain curve increases rapidly. With the increase of stress, the proportion of plastic strain in total strain increases gradually, and the deformation can not be restored, and the curve rises rapidly.

3.2 Stress-strain curves of specimens.

Table 2. Static tensile test result of three kinds of saturation cement mortar specimens

| Specimen status         | Tensile strength (MPa) | Maximum tensile strain |
|-------------------------|-----------------------|------------------------|
| Dry (M0-2)              | 3.81                  | 0.03975                |
| Semi saturated (M50-4)  | 3.01                  | 0.0416                 |
| Saturated (M100-2)      | 2.92                  | 0.049                  |

Figure 5. Tensile strength of three kinds of saturated cement specimens

The tensile strength of three kinds of cement mortar specimens with different saturation is plotted in Fig. 5. According to Fig. 5 and Table 2, the tensile strength of three kinds of saturated cement mortar specimens are 3.81 MPa, 3.01 MPa and 2.92 MPa, respectively. The tensile strength of semi-saturated cement mortar specimens is 21.00% lower than that of dry cement mortar specimens; the tensile strength of saturated cement mortar specimens is 21.00% lower than that of semi-saturated cement mortar specimens. The tensile strength of mortar specimens decreased by 2.99%. It can be seen that when the saturation is less than 50%, with the increase of the saturation, the decrease of the tensile strength of cement mortar specimens is larger; when the saturation is more than 50%, with the increase of the saturation, the decrease of the tensile strength of cement mortar specimens is smaller. The tensile strength of saturated cement mortar specimens is 23.36% lower than that of dry cement mortar specimens. It can be seen that the saturation has a significant impact on the tensile strength of cement mortar specimens. When the saturation increases, the tensile strength of cement mortar decreases.
From the analysis of meso-damage mechanism, cement mortar is a kind of multi-phase composite material with a large number of pores and internal cracks. There are many micro-pores and internal cracks in the cement mortar. With the increase of specimen saturation, the free water entering the pores and internal cracks will gradually increase. On the one hand, when the specimen is stretched long, the middle section of the 8-shaped specimen shrinks, and the pore water increases the compressive stress from the opposite direction to the outside of the pore, which makes the pore easier to connect and form cracks; on the other hand, due to the wedging effect [9], the free water entering the crack tip increases, resulting in the decrease of cohesion at the crack tip and the absence of micro-cracks. With the extension of fracture, the specimen is more likely to break. This reduces the load required for crack development of cement mortar, so the static tensile strength of saturated cement mortar is lower than that of dry cement mortar.

### 3.3 Effect of Saturation on Deformation Characteristics of Cement Mortar

![Figure 6. Maximum tensile strength of three kinds of saturated cement specimens](image)

From Fig. 4, it can be seen that the stress-strain curves of dry and semi-saturated cement mortar specimens differ slightly in the range of strain 0-0.01, and the original tangent slope of both specimens is larger than that of saturated specimens. It can be seen that the elastic modulus of dry and semi-saturated cement mortar specimens under tension is larger than that of saturated specimens. The difference is small and greater than the elastic modulus of saturated state, which is different from that of reference [10] in the case of ordinary concrete. When the stress increases from 0 to 2.0 MPa, the strain of dry specimens increases by 0.0306, that of semi-saturated specimens increases by 0.0338 and that of saturated specimens increases by 0.0406. Obviously, under the same stress, the deformation in saturated state is the largest, the deformation in semi-saturated state is the second, and the deformation in dry state is the smallest. Therefore, the deformation capacity of saturated state is the best, the stiffness is the smallest, the deformation performance of dry state is the worst, and the stiffness is the largest. The maximum tensile strain of three kinds of saturated cement mortar specimens is shown in Table 2 and drawn in Figure 6. As can be seen from Fig. 6, the maximum tensile strain values of semi-saturated and saturated cement mortar specimens increased by 4.79% and 23.43% respectively, compared with the maximum tensile strain values of dry cement mortar specimens 0.0397. Obviously, the saturation has a significant effect on the maximum tensile strain of cement mortar specimens. When the saturation increases, the maximum tensile strain of cement mortar specimens increases. The reason for this phenomenon may be that the "softening effect" of cement mortar in the dry state is small. That is, the stiffness of cement mortar decreases less under this state. There is no aggregate in the cement mortar, the particles of cement mortar are relatively small and evenly distributed, so there is no obstacle of aggregate when the free water enters the force and moves. Finally, with the increase of saturation, the stiffness gradually decreases, the deformation capacity gradually improves, and the maximum tensile strain gradually increases.
4. Conclusion
In this experiment, the uniaxial static tension test of three kinds of saturated 8-shaped cement mortar specimens was carried out by WDW-20 computer controlled electronic universal testing machine. The main conclusions are as follows.

1. The stress-strain curves of cement mortar with different saturation are similar. The stress increases with the increase of strain, and the stress growth rate increases gradually.

2. The static tensile strength of cement mortar decreases with the increase of saturation. When the saturation is less than 50%, the tensile strength of cement mortar specimens decreases greatly with the increase of saturation. When the saturation is more than 50%, the decrease of the tensile strength of cement mortar specimens is smaller with the increase of saturation. The tensile strength of saturated cement mortar specimens is 23.36% lower than that of dry cement mortar specimens.

3. The difference of elastic modulus between dry and semi-saturated cement mortar specimens under tension is small, and both of them are larger than that under saturated condition.

4. With the increase of saturation, the stiffness of cement mortar decreases gradually, the deformation ability improves gradually, and the maximum tensile strain increases gradually. Compared with the dry cement mortar specimens, the maximum tensile strain of semi-saturated and saturated cement mortar specimens increases by 4.79% and 23.43%, respectively.

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