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Dynamic triaxial test research on the effect of water content on the dynamic characteristics of rubber-sand particles

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ABSTRACT: *In order to understand the effect of moisture content on the dynamic characteristics of rubber-sand particles (Rubber-Soil Mixture, RSM), a dynamic triaxial test was carried out. Before the test, the rubber particles and sand were mixed according to the rubber volume ratio of 0%, 25%, 30%, 40%, 50%, 75%, and 100%, and the water content was 0%, 5%, and 10%. The confining pressure control of the triaxial test is 50, 100, 200, a total of 63 groups of tests. In the test, the effects of dynamic triaxial confining pressure, rubber particle content and moisture content on RSM were investigated respectively. The test results show that: (1) under the same rubber particle content, the dynamic shear modulus of the RSM sample increases with the increase of the confining pressure; (2) with the increase of the rubber particle content, the dynamic shear modulus of the RSM sample increases. The shear modulus decreased significantly; (3) The change of water content did not cause significant changes in the dynamic shear modulus of RSM samples. The test results can be used as a reference for the engineering application of RSM seismic isolation technology in the future.*

KEY WORDS: Rubber-sand particles; confining pressure; rubber particle content; moisture content; dynamic triaxial test

INTRODUCTION

As of 2022, the number of cars in the world is 1.446 billion, of which the number of cars in China exceeds 312 million. Accounting for 22% of the world's total, ranking first in the world. A large number of cars are scrapped over time, resulting in a continuous accumulation of used tires. However, its low recycling rate leads to the waste of tire rubber resources. How to effectively recycle waste tire rubber to alleviate the pressure brought by environmental problems will be a problem worth exploring. Mixing waste tire fragments or particles into asphalt, cement, sand and clay and other substances as a new type of geotechnical material has become an ideal recycling method for turning waste tires into treasures, while relieving environmental pressure. , It also broadens the way to deal with waste tires, and can provide high-quality and low-cost geotechnical materials.

The mixture of rubber particles and sand has been widely used in slope, retaining wall, roadbed and runway backfill, but its application in building foundation isolation is relatively rare. Rubber-sand particles have many advantages such as light weight, durability, economy, good shock absorption and

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isolation effects, and convenient construction. They have attracted the attention of many scholars at home and abroad and conducted a series of research [1–5]. Liu Fangcheng et al [6–8] conducted a series of experimental studies on the composite blocks formed by filling the cavity of the concrete hollow block with rubber sand, and the results showed that the composite blocks with rubber sand core have good shock isolation effect. Yao Fei et al. [9,10] conducted low-cycle repeated load tests on the steel-asphalt composite isolation layer, and studied the influence of the shear stiffness and horizontal force-displacement curve of the isolation layer on the seismic response. Lu Huaxi et al. [11,12] established a two-dimensional finite element calculation model of the subgrade-raised terrain under the action of trains, and studied the influence of the width, shape, aspect ratio and foundation soil properties of the raised terrain on the vibration of the railway environment. For more studies, see references [13–21].

With the increasing application of rubber-sand particles in engineering, it is foreseeable that this mixture will receive more attention and research. The application of rubber particle-sand mixture will promote the development of the waste tire recycling industry, and will also provide more references for shock absorption and isolation in the economically backward villages and towns.

1. dynamic triaxial test

The dynamic shear modulus and damping ratio of soil are the two most basic and important parameters in the calculation and analysis of soil dynamics, and they are also indispensable parameters in the evaluation of site seismic safety and the analysis of soil seismic response. This test uses a vibrating triaxial instrument to adopt the test method of consolidation without drainage (considering that the earthquake time is short and the pore water pressure generated by the earthquake is too late to dissipate), the vibration form of bidirectional vibration and the consolidation method of equal pressure consolidation , and the dynamic load is applied according to the preset dynamic shear stress ratio after the consolidation is completed. Then, in the case of seven different mixture ratios of 0%, 25%, 30%, 40%, 50%, 75%, and 100%, the moisture content of the rubber-sand particle mixture at 0%, 5%, and 10% is measured. And the dynamic shear modulus under 50, 100, 200kPa consolidation pressure, and obtain its dynamic shear modulus-strain curve under different water content, different mixture ratio and different consolidation pressure, and finally analyze and summarize The effect of various factors on the dynamic shear modulus of the rubber-sand particle mixture was obtained.

2. Trial Design and Operation

2.1. Rubber-sand particle mixture material

Rubber-sand granular material, as the name suggests, is a mixture made by mixing rubber particles and sand in a certain proportion. Because of its special mechanical properties and environmental friendliness (it can consume a large amount of waste tires and other waste rubber products, which can alleviate the environmental pollution caused by incineration, landfill and accumulation), and its light-weight properties as a lightweight filler, many scholars have studied it Were studied. Moreover, as a rock-soil isolation cushion material, its mechanical (including static and dynamic) properties have also been studied to a certain extent. However, these studies are basically based on the assumption of dryness or dryness (0% moisture content), which cannot reflect the real environment in actual engineering applications.) was buried 1m below the outdoor floor. After three months of natural environment influence, the moisture content was finally measured to be 5.15%. Therefore, different moisture content conditions should be set up for test analysis.

Although the rubber particles come from waste tires or other rubber products, because these waste products are mixed with other substances, they will interfere with the analysis of the test, so they need to be "purified" in advance, that is, after removing the internal fiber reinforcement The remaining pure rubber is broken into particles with a particle size of 3~5mm by ordinary mechanical devices. The relative density of rubber is 1.08, and the bulk density is 0.53g/ml. The sand is ordinary quartz sand with a particle size of 3~5mm, a relative density of 2.55, and a bulk density of 1.38g/ml, as shown.

Figure 1 Rubber particles and quartz sand

2.2. Dynamic triaxial instrument

The dynamic triaxial test adopts the DDS-70 microcomputer-controlled electromagnetic vibration triaxial instrument produced by Beijing Binda Yingchuang Technology Co., Ltd., as shown in Figure 2. Its working principle is to place a cylindrical soil sample between the upper and lower pistons in a triaxial chamber filled with anaerobic water. The axial and lateral static pressure is applied to the sample by gas pressure. The vibration exciter and power amplifier convert the electrical signal of a certain frequency and amplitude provided by the microcomputer system into an axial excitation force, which is applied to the soil sample through the lower piston. The measurement system records the force, displacement and pore water pressure values during the vibration process, processes the measurement data through the microcomputer system, and draws curves. The system consists of electromagnetic drive system, triaxial chamber, electrical control, static pressure control and data acquisition and processing system, and has control functions such as static and dynamic axial force, confining pressure and pore water pressure, and axial loading program.

Figure 2 DDS-70 Microcomputer Control Electromagnetic Vibration Triaxial Instrument

Because the sine wave load can make the soil withstand more cyclic vibrations, the dynamic triaxial test generally adopts sine wave loading. In addition, although the seismic spectrum has a relatively high frequency, the influence of the frequency is not very significant, so the frequency is generally taken as 1 Hz, and the amplitude is taken as the equivalent average value. In the test, the pore water pressure does not rise within 5 minutes after closing the drain valve as the standard for isotropic consolidation stability, while the standard for vibration failure is that the full-amplitude axial strain reaches 5% of the axial height.

2.3. Test Conditions and Operation

The rubber particle-sand soil mixture is the sandy foundation soil backfill material, and its working environment can be divided into dry and wet, so the simulated dry and wet environments are used to make samples. The average particle size of rubber particles is 2~5 mm, the relative density is 1.08, and the density is 0.54 g/mm^2, cut and screen with a sieve with an aperture of 5mm, and air-dry for later use. The average particle size of ordinary quartz sand is 2~5 mm, the relative density is 2.55, and the density is 1.41 g/mm^2, the sample particles pass through a sieve with an aperture of 5 mm, and two samples that are sufficient for the test under the sieve are taken, air-dried, and put into a plastic bag for later use.

(1) Take the sand and rubber particles after air-drying for 24 hours, according to the volume ratio of rubber particles to the mixture, 0% (pure sand), 25%, 30%, 40%, 50%, 75%, 100% (pure rubber particles) mixed with sand evenly. Prepared mixture forD_k （k =0, 25, 30, 40, 50, 75, 100 represent 0%, 25%, 30%, 40%, 50%, 75%, 100% of the rubber particle volume ratio) respectively). Measure the air-dried moisture content of the mixture under each proportioning ratio, and put them into plastic bags separately according to the proportioning ratio for storage as a material in a dry environment.
(2) Take 1000g of dry material and spread it on a non-absorbent tray and use pure water calculated according to the formula (calculate the water consumption according to the moisture content of 5% and 10%), stir quickly and fully to mix the particles evenly, and put them into a non-absorbent tray Cover the container tightly, and let it stand for 24 hours to make the water fully infiltrate evenly, and use it as a material in a humid environment for later use.

$$\omega_0 = \left(\frac{m}{m_d} - 1\right) \times 100\% \qquad (1)$$

In the formula:m— wet mass of sample (g);
m_d- Dry mass of sample (g).

Figure 3 Samples with different proportions

The working conditions of the dynamic triaxial test are divided into 63 (3 × 7 × 3), that is, under the condition of 3 kinds of water content, the dynamic elastic model test under 3 kinds of confining pressure is carried out for the mixed materials of 7 kinds of mix proportions, and the test conditions are shown in Table 1. Under each set of working conditions, the program will automatically output data such as waveform curves, dynamic elastic modulus calculation data, stress paths, and trial calculation damping ratios.

Table 1 Dynamic triaxial test conditions

moisture content	Mixing ratio of rubber particles-sand mixture	Confining pressure (kPa)
0%、5%、10%	0%、25%、30%、 40%、50%、75%、100%	50、100、200

2.4. Dynamic Behavior of Rubber-Sand Particle Mixture

Soil is composed of a soil skeleton composed of soil particles and water and air in pore water. Due to the weak connection between soil particles, the soil skeleton structure is unstable. Under the action of external load, the soil particles tend to move to a new and more stable position, and the soil deforms accordingly. For saturated soil, when the soil skeleton is deformed and the pores are reduced, the excess water will be squeezed out; for unsaturated soil, the gas in the pores is compressed first, and then the excess gas and pore water are squeezed out. Due to the friction between the soil skeleton and pore water, the discharge of pore water and gas is hindered, so that the deformation of the soil is delayed, so the stress change and deformation of the soil are functions of time. Under the action of dynamic load, soil not only has elastic-plastic characteristics, but also has viscosity characteristics. Soil can be regarded as a viscoelastic-plastic body with elastic, plastic and viscous properties.

2.5. Dynamic shear modulus

The performance of soil after stress can abstract three basic mechanical elements: elastic element, plastic element and viscous element, and the combination of these three elements can be used to approximate the mechanical properties of soil. The back-and-forth dynamic stress acting on the mechanical element isσ_d：

$$\sigma_d = \sigma_a sin\omega t \tag{2}$$

In the formula:σ_a——Amplitude of reciprocating dynamic stress;
ω- circular frequency;
t--time.

In a dynamic triaxial test, an axial dynamic stress is appliedσ_d, to measure the axial dynamic strainε_dWhen , the hysteresis curve of each cycle can also be drawn. Change different dynamic stresses, by the maximum value of stress-strain$\sigma_m$andε_m, can also make the backbone curve. Axial dynamic strain by dynamic triaxial test$\varepsilon_d$dynamic shear strainγ_d, from the resulting compressive modulus of elasticityAND_dThe dynamic shear modulus of elasticity can be obtainedG_d. The conversion relationship between the two is as follows:

$$\gamma_d = \varepsilon_d(1 + m) \tag{3}$$

$$G_d = \frac{AND_d}{2\,(1+m)}$$

3. Test Results and Analysis

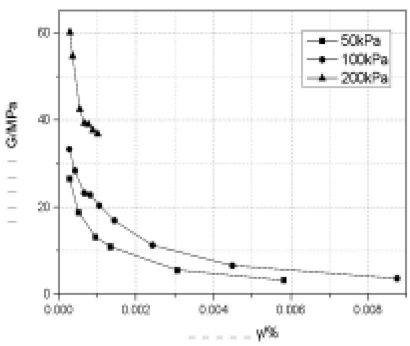
In the dynamic triaxial test, the axial dynamic stress acting on the sample starts from a small amplitude, and then increases step by step for vibration test. When the strain waveform is obviously asymmetrical or the pore pressure increases obviously, the test is terminated. Record the dynamic stress and dynamic strain of each load during the test, or directly record the stress-strain hysteresis curve to determine the dynamic modulus of each dynamic strain. According to the data obtained from the test, the dynamic shear strain (γ_d), dynamic shear stress (τ_d)value. Since the soil is regarded as a viscoelastic body, its equivalent dynamic shear modulus can be expressed by the secant modulus, that is, the dynamic shear stress and dynamic shear strain of the line connecting the vertices of the hysteretic loop. The calculation of the dynamic shear modulus The formula is expressed as:

$$G_d = \frac{\tau_d}{\gamma_d} \tag{5}$$

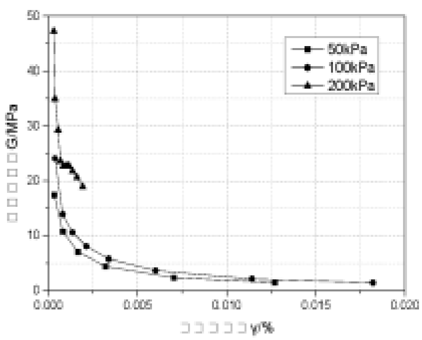
in: G_d—— is the dynamic shear modulus (MPa);
τ_d—— is the dynamic shear stress (kPa);
γ_d —— is the dynamic shear strain.

3.1. Effect of confining pressure on dynamic shear modulus of RSM mixture

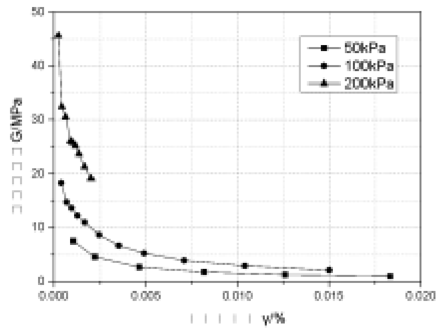
Fig. 10 is the relationship curve of the dynamic shear modulus of the RSM sample as a function of the dynamic shear strain under the same rubber particle content and different confining pressure under the condition of 0% moisture content of the mixture. It can be seen from the figure that the dynamic shear modulus of RSM mixture and pure sand increases with the increase of confining pressure. Among them, when the confining pressure is 200kPa, the dynamic shear modulus of the sample is much higher than that of the confining pressure of 50kPa and 100kPa, and the difference between the dynamic shear modulus value of the confining pressure between 50kPa and 100kPa is larger. Much smaller than the difference between 200kPa and 50kPa and 100kPa confining pressure. It can also be found from the graph that with the increase of confining pressure, the dynamic shear strain of the sample also decreases greatly. The dynamic shear strain value with the largest difference reaches 10 times. The above law shows that under the action of confining pressure, the pores between the particles of the mixture are reduced, and the contact between particles is closer, so the ability to resist deformation becomes stronger. And with the increase of external confining pressure, this change shows a rising trend.



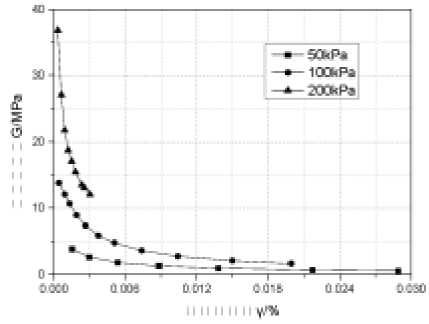
(a) Rubber particle content 0%



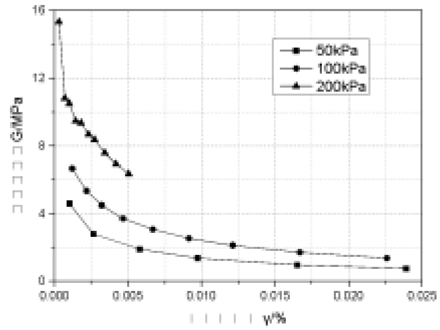
(b) Rubber particle content 25%



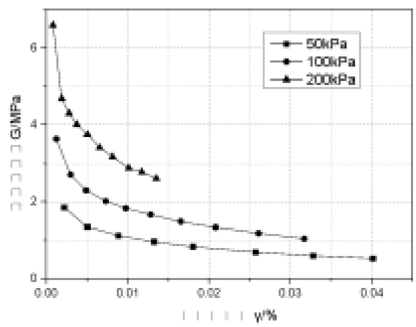
(c) 30% rubber particle content



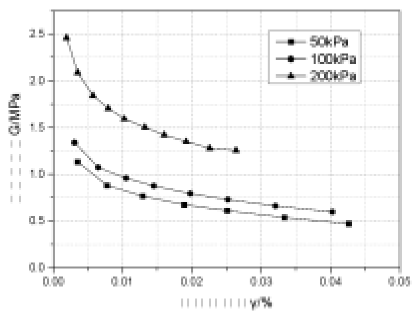
(d) Rubber particle content 40%



(e) Rubber particle content 50%



(f) Rubber particle content 75%



(g) rubber particle content 100%

Fig. 10 Relationship between dynamic shear modulus and dynamic strain under different confining pressure at 0% moisture content

In Figure 10, it can also be seen that as the rubber particle content increases, the differences in dynamic shear modulus and strain between mixtures with different rubber particle ratios brought about by the confining pressure gradually decrease. The maximum value of dynamic shear modulus decreases from 2.4 times of 0% rubber particle ratio to 1.4 times of 100% rubber particle ratio, and the reduction rate is 42%. It can be seen that when the ratio of rubber particles in the mixture sample exceeds 75%, the dynamic shear modulus-dynamic shear strain curves under the three confining pressures gradually become the same. When the ratio of rubber particles is 100%, the dynamic shear modulus-dynamic shear strain curves of the mixtures under the three confining pressures are more gentle than those of other ratios. This is due to the elastic properties of the rubber particles. With the increase of the rubber particle content in the mixture, the dynamic shear modulus attenuation curve

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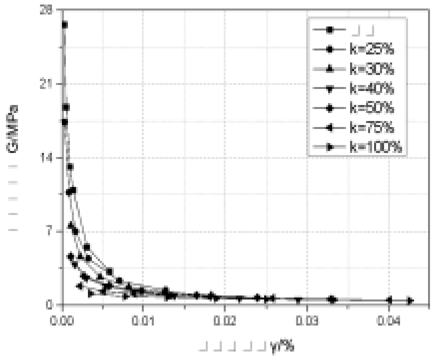
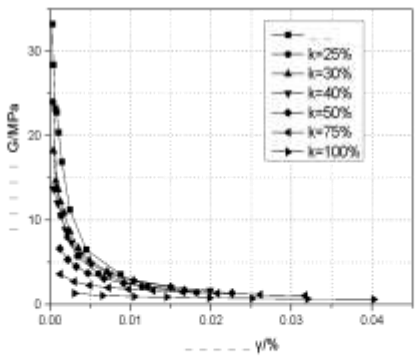
of the mixture weakens nonlinearly.

3.2. Effect of Rubber Particle Content on Dynamic Shear Modulus of RSM Mixtures

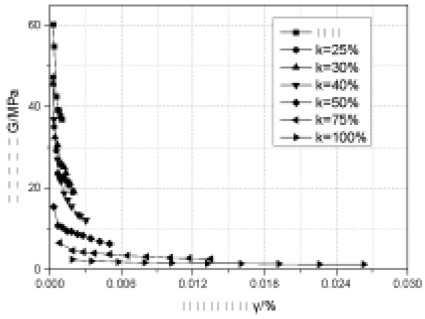
Fig. 11 is the relationship curve of dynamic shear modulus and dynamic shear strain of mixture samples with different rubber particle contents under fixed confining pressure when the water content is 0%. It can be seen from the figure that the dynamic shear modulus of the seven RSM samples with different ratios gradually decreases with the increase of the ratio of rubber particles in RSM. With the increase of the ratio of rubber particles in RSM, the dynamic shear strain of each sample also increases gradually. The dynamic shear modulus and dynamic shear strain of RSM samples with different rubber particle ratios have opposite characteristics, and the dynamic shear strain is smaller when the dynamic shear modulus is larger. As the dynamic shear strain increases, the dynamic shear modulus decreases continuously. And the smaller the dynamic shear modulus, the faster the dynamic shear modulus decreases, that is, the steeper the dynamic shear modulus-dynamic shear strain curve. This is due to the large deformation capacity and low elastic modulus of rubber particles, which cause the sample to produce shear deformation under the action of load.



(a) Confining pressure 50kPa



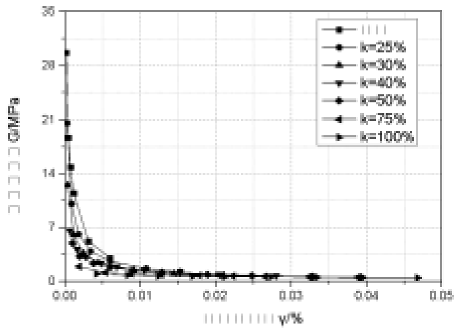
(b) Confining pressure 100kPa



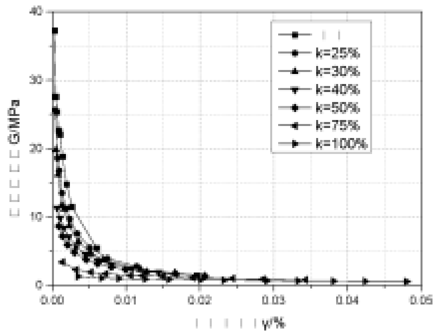
(c) Confining pressure 200kPa

Fig. 11 Relationship between dynamic shear modulus and dynamic strain with different rubber particle contents at 0% moisture content

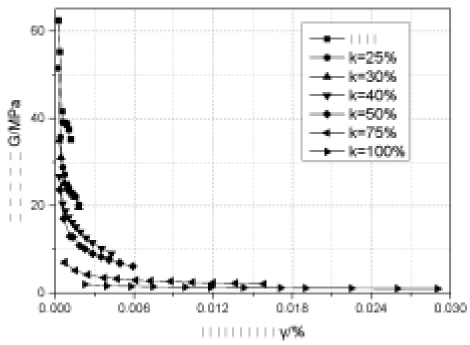
Figure 12 and Figure 13 are the dynamic shear modulus-dynamic strain relationship curves of RSM samples with 7 different ratios of rubber particle content under fixed confining pressure when the water content is 5% and 10%, respectively. Compared with the curve in Figure 11, it can be seen that when the moisture content of each RSM sample is 5% and 10%, the influence of rubber particle content on the dynamic shear modulus-dynamic shear strain curve is the same as that of the moisture content of 0%. the law.



(a) Confining pressure 50kPa

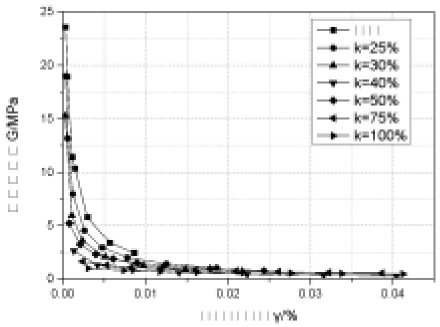


(b) Confining pressure 100kPa

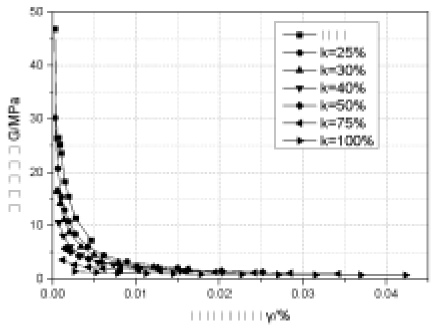


(c) Confining pressure 200kPa

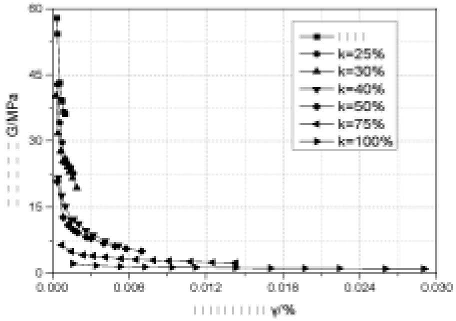
Fig. 12 Relationship between dynamic shear modulus and dynamic strain under different rubber particle contents at 5% water content



(a) Confining pressure 50kPa

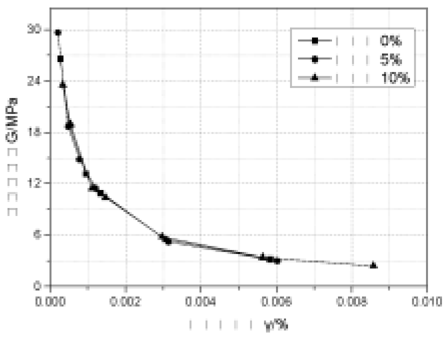


(b) Confining pressure 100kPa

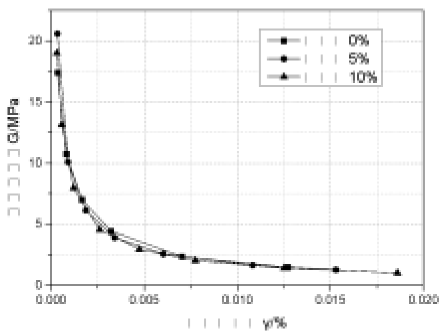


(c) Confining pressure 200kPa

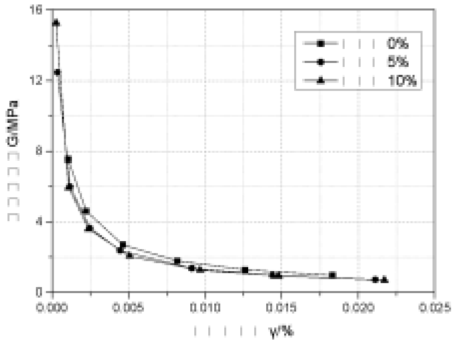
Fig. 13 Relationship between dynamic shear modulus and dynamic strain with different rubber particle contents when moisture content is 10%



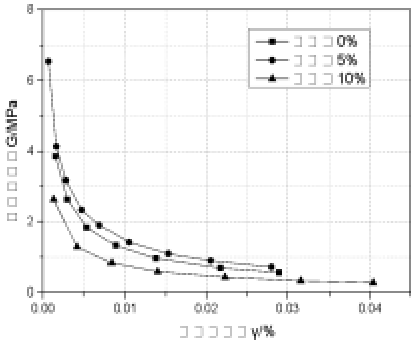
(a) Rubber particle content 0%



(b) Rubber particle content 25%



(c) 30% rubber particle content



(d) Rubber particle content 40%

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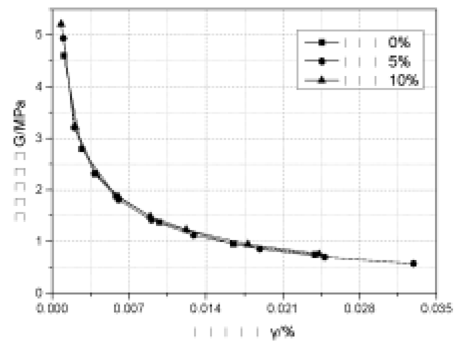
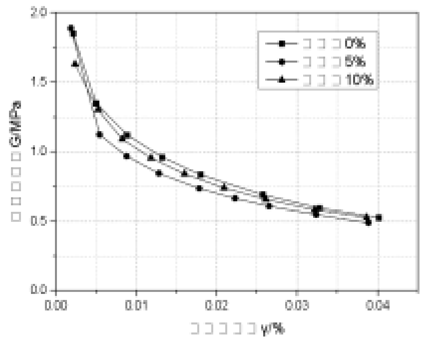
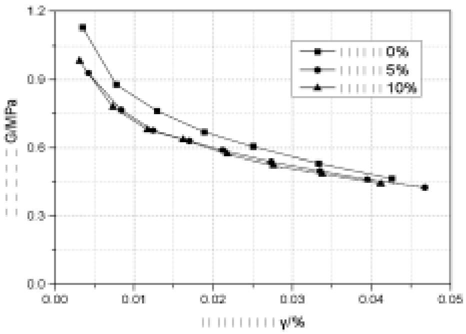


(e) Rubber particle content 50%

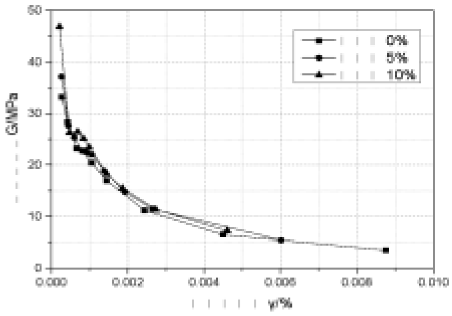


(f) Rubber particle content 75%

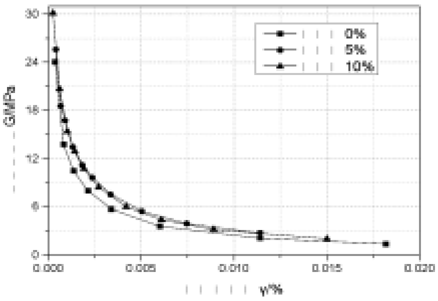


(g) rubber particle content 100%

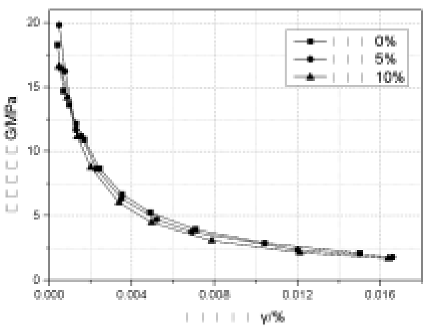
Fig. 14 Relationship between dynamic shear modulus and dynamic strain at different water contents at confining pressure of 50kPa

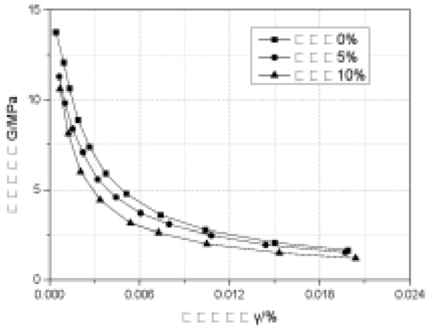


(a) Rubber particle content 0%



(b) Rubber particle content 25%





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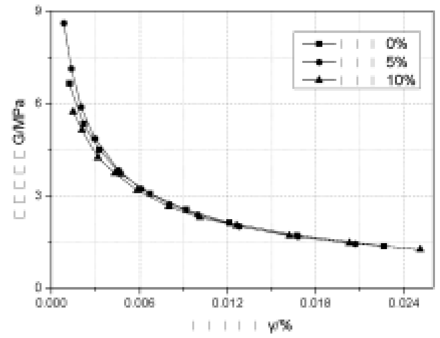
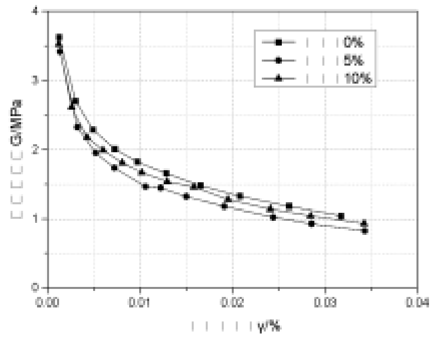
(c) 30% rubber particle content

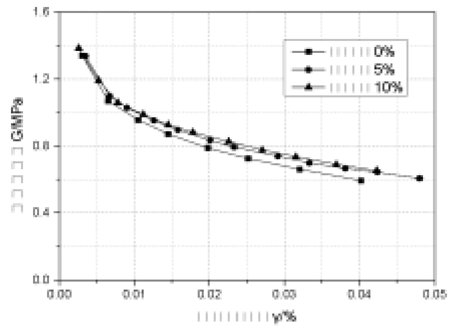
(d) Rubber particle content 40%





(e) Rubber particle content 50%

(f) Rubber particle content 75%



(g) rubber particle content 100%

Fig. 15 Relationship between dynamic shear modulus and dynamic strain at different water contents at confining pressure of 100kPa

3.3. Effect of Moisture Content on Dynamic Shear Modulus of RSM Mixtures

Fig. 14 and Fig. 15 are the relationship curves of dynamic shear modulus and dynamic shear strain of RSM samples with fixed confining pressure and different water contents under the same rubber particle content. It can be seen from the figure that the dynamic shear modulus of the RSM sample decreases with the increase of the shear strain; and the dynamic shear modulus-dynamic strain curves are close to coincide under each water content condition. This shows that the mixture does not affect the value of its dynamic shear modulus under a small change in water content.

4. in conclusion

By changing the three different conditions of confining pressure, rubber particle content and water content, the RSM dynamic triaxial test was carried out respectively, and finally the following conclusions were drawn from the comparative analysis of the test results:

(1) The rubber particle content and confining pressure are the main factors affecting the dynamic shear modulus of the rubber particle-sand mixture, and the dynamic shear modulus value of the mixture will not be significantly affected by the change of the lower water content. Under the condition of the same rubber particle content, the dynamic shear modulus of the RSM sample increases with the increase of the confining pressure.

(2) As the content of rubber particles increases, the dynamic shear modulus of the RSM sample decreases significantly, so it can better exert its advantages of shock absorption and isolation, so that the rubber-sand particle mixture vibration isolation cushion is used as the base isolation system is possible.

(3) The change of water content did not cause significant changes in the dynamic shear modulus of the RSM sample, which indicates that the impact of lower water content on the dynamic shear modulus of the RSM sample is negligible, that is, In practical engineering applications, RSM samples do not need to consider the change of moisture content.

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