Arabian Journal of Geosciences (2022) 15: 885
https://doi.org/10.1007/s12517-022-10205-3

ORIGINAL PAPER

Determination of basic friction angle of three planar rock joints

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Received: 15 September 2021 / Accepted: 11 April 2022 / Published online: 29 April 2022

Abstract

Basic friction angle is an important input parameter in many peak shear strength criteria of rock joint. Reliable estimation of joint basic friction angle is essential for accurate determination of the corresponding peak shear strength. In this study, the basic friction angles of planar joint surface of three rocks (i.e., granite, marble, and sandstone) are studied using two commonly used methods, including tilt test and direct shear test. Although the basic friction angles determined from tilt test are about 4 to 5° smaller than those determined from direct shear test, the marble is found to have the largest basic friction angle in both tilt test and direct shear test. In direct shear test, there is about 2° difference of basic friction angles determined under low and high normal stress conditions, which is mainly associated with the shearing mechanism of joint surface. Friction generally occurs under low normal stress. On the other hand, shear-off is observed when the applied normal stress is high. To obtain a reliable basic friction angle using direct shear test, the test data under low normal stresses are suggested to be used. It is also seen from the results that the shear strength of planar joint surface is negligibly influenced by the cyclic shearing when the applied normal stress is low. The data in this study replenish the test data of basic friction angle of different rock types and are useful for establishing a database for the estimation of basic friction angle in future.

Keywords Basic friction angle · Tilt test · Direct shear test · Planar joint surface · Cyclic shearing

Introduction

Rock mass is in nature composed of rock matrix and discontinuities at different scales, ranging from large-scale faults, fractures, joints, bedding planes, weak layers, to small-scale micro-cracks (Kranz 1983). The mechanical properties of these discontinuities, especially the shear strength, significantly affects the stability of engineering structures constructed in jointed rock mass, such as high slopes, deep tunnels, boreholes for oil or gas production, wells for injection of carbon dioxides, and underground caverns for storage of radioactive waste. Therefore, it is of vital importance to comprehensively investigate the shear strength of discontinuities at different scales.

In the past several decades, many shear strength criteria have been proposed to characterize the peak shear strength of rock joints including empirical ones and theoretical ones (Patton 1966; Ladanyi and Archambault 1969; Barton and Choubey 1977; Kulatilake et al. 1995; Zhao 1997; Grasselli and Egger 2003; Xia et al. 2014; Jang and Jang 2015; Ban et al. 2020; Li et al. 2020; Tang et al. 2021). Basic friction angle is an important input parameter in these models to estimate the shear strength of joints. Basic friction is the frictional component of shear strength for a planar joint, which is considered as an intrinsic property of the material (Barton and Choubey 1977). This aspect is usually independent of shear strength component contributing from joint roughness, which causes dilation during shear. In general, two methods are commonly used to estimate the joint basic friction angle, namely, tilt test and direct shear test (Alejano

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Responsible Editor: Zeynal Abiddin Erguler

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et al. 2012; Behnia and Nateghpour 2020). Both tests should be conducted on well-prepared planar joint surface.

Tilt test is a simple and effective method to estimate the basic friction angle of rock joint. In general, different tilt-test arrangements can be used according to the type of contact, such as surface contact using rectangular-based specimen or lengthwise-cut-core specimen and linear contact using three cores or two cores (Alejano et al. 2012). A large number of laboratory tests have been conducted to determine the basic friction angle of rock joint using tilt tests (Stimpson 1981; Cruden and Hu 1988; Alejano et al. 2012; González et al. 2014; Hencher and Richards 2015; Pe´rez-Rey et al. 2015; Ulusay and Karakul 2016; Jang et al. 2018; Li et al. 2019; Muralha et al. 2019; Behnia and Nateghpour 2020; Tang et al. 2020). The results from these studies showed that the basic friction angle determined from tilt test varied in a large range from 10 to 40° for different rock types. In addition, the basic friction angle was affected by many factors including wet and dry condition, wear production, repetition, surface size, specimen shape, mineralogy, grain size, slip distance, tilting speed, polishing degree, and testing setup. Recently, a laboratory method for determining the basic friction angle of unfilled planar rock joint using tilt test was suggested by International Society of Rock Mechanics and Rock Engineering (ISRM) (Alejano et al. 2018).

Although direct shear test is more difficult to perform when compared with tilt test, it is generally believed that the direct shear test on planar joint surface yields more accurate basic friction angle (Barton and Choubey 1977; Jang et al. 2018; Tang et al. 2020). In recent years, many scholars have used direct shear test to study the basic friction angle of planar joint surface of different brittle materials (Atapour and Moosavi 2014; Bahaaddini et al. 2016; Dang et al. 2016; Jang et al. 2018; Cui 2019; Behnia and Nateghpour 2020). In these studies, the direct shear tests are generally conducted under low normal stresses (i.e., ≤ 4 MPa). Whether the high normal stress affects the determination of basic friction angle or not is rarely discussed. In addition, more test data on real rocks should be conducted to establish a database for estimating joint basic friction angle in future.

Generally, the basic friction angle is considered to reflect the friction behavior of rock joint under the low stress level. However, planar rock joint would be sheared under high normal stress level. Under the condition, the basic friction angle under the high normal stress level would be more reasonable (as the tests performed in this study). In the literature, most of the above-mentioned experiments are performed under the low normal stress level. To better understand the tribological properties of rock joint under a broad of normal stress level, tilt test and direct shear test are conducted on planar joint surface of three rocks (i.e., granite, marble, and sandstone) and the basic friction angles of the three rocks are examined and compared. The purpose of the present study is to add more basic friction angle test data of real rock to the database, which is useful for establishing a guideline for the estimation of basic friction angle of different rock types within the range from low to high normal stress level. More importantly, the effect of high normal stress on the determination of basic friction angle using direct shear test is discussed.

Experimental setup

Specimen preparation

Basic friction angles of planar joint surfaces prepared from three rock types (i.e., granite, marble, and sandstone) are examined in this study. To ensure homogeneity of the tested rock specimen, all specimens of each rock type are collected from the same massive rock block. A cuboid specimen with a dimension of length of 200 mm, width of 100 mm, and height of 100 mm is first extracted from the rock block. The cuboid specimen is then cut to two blocks from the middle height using a diamond saw (see Fig. 1a). Each half block has a dimension of 200 mm in length, 100 mm in width, and 50 mm in height. At last, the joint surfaces are carefully polished using #100 grinding powder till the smoothness of the surfaces meets the specifications suggested by Alejano et al. (2018). Essentially, the basic friction angle of rock joint reflects the adhesion of two contact surfaces, and hence, ideally smooth surfaces should be used (Li et al. 2019). However, the measurement cannot be done and also not necessary from the perspective of engineering practice. The basic friction angle measured on slightly rough surfaces could be considered as a material parameter (Li et al. 2019), due to the widespread small-scale asperities randomly distributed on "real" rock surfaces. From a scientific point of view, as long as the surface finish is consistent on all tested rock specimens, the results can be used to analyze (Tang et al. 2020).

The granite is collected from Yichang of Hubei province, China. It is a massive structure featured by gold ephedra. It is composed of feldspar, quartz, and biotite with a medium-grain texture with grain sizes ranging from 1 to 3 mm (see Fig. 1b). The marble is retrieved from Suizhou of Hubei province, China. As shown in Fig. 1c, it is mainly composed of calcite accounting for 95% of its total volume. The rock has a coarse-grained texture, with grain size in the range of 2 to 4 mm. The sandstone is also collected from Yichang of Hubei province, China. It is predominantly composed of feldspar and quartz with a fine-grain texture. The rock has a brick red color (see Fig. 1d). The grains are angular and cemented with calcium carbonate.

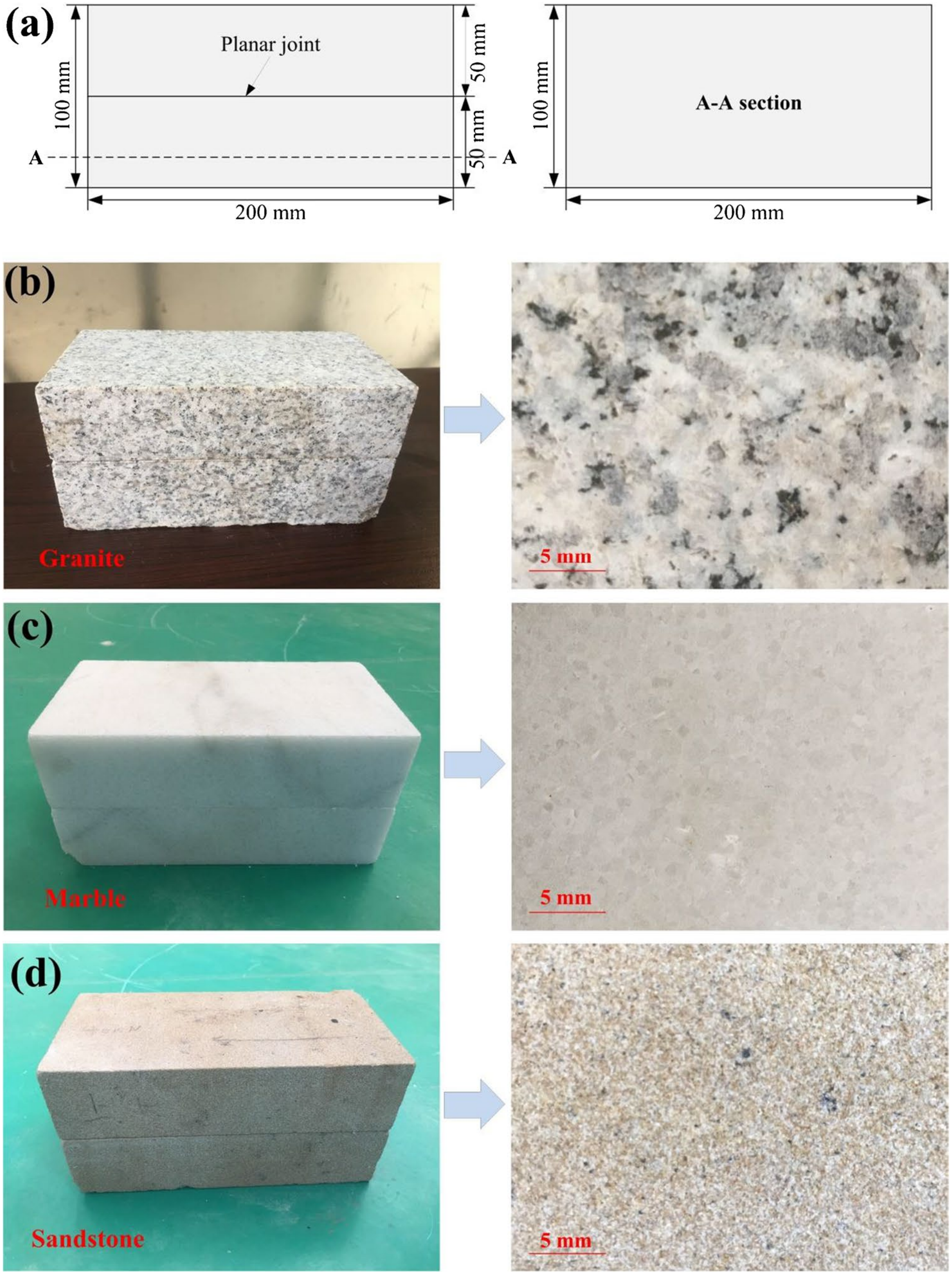

Fig. 1 Prepared planar rock joints. **a** Procedures for joint surface preparation, **b** granite joint, **c** marble joint, and **d** sandstone joint

Testing procedure

Tilt test is an easy and simple method to estimate the basic friction angle of rock joint. A tilting apparatus is used to measure the basic friction angle of planar rock surfaces (Tang et al. 2020). The apparatus is connected to a free downloadable digital slope meter (Max Protractor) with an accuracy of 0.1°. The device consists of a rigid frame supporting a hinged platform and a manually-rotated arm with a screw feed, which can rotate the platform from 0 to about 80°. A metal holder is mounted in front of the platform to prevent the movement of the lower specimens during the process of tilting.

The procedures of ISRM suggested method (Alejano et al. 2018) are used to perform the tilt tests. Prior to each test, the horizontality of the tilting platform is confirmed using an electrolytic bubble. The surfaces of the specimens are carefully cleaned to remove dust and rock powder using a soft paintbrush. The lower rock block is first placed upon the platform horizontally with the front touching the metal holder tightly. The upper block is then placed on the lower one to ensure the two surfaces completely contact with each other. The tilting platform is steadily rotated at a rate of about 24°/min (see Fig. 2a). When the sliding displacement of the upper block is about 10% of the specimen length, the angle is recorded as the basic friction angle for the present test. In our study, three planar surfaces are tested for each rock type and each specimen is tested five times.

Direct shear test is also used to determine the basic friction angle of joint surfaces. In this study, the direct shear tests are performed using a servo-controlled shear testing apparatus (Yang et al. 2016). The normal and shear forces are applied by hydraulic jacks. The loading capacities of the jacks are 1000 kN for the normal force and 600 kN for the shear force, respectively. The shear and normal displacements are measured by two Dial indicators, with an accuracy of 0.001 mm. The force is measured by the pressure sensors installed in the hydraulic jacks. The forces and displacements during the test are recorded automatically by a PC with a data acquisition system.

As presented in Fig. 2b, the lower block is fixed stationary in the shear box during the direct shear tests. Both shear stress and normal stress are applied on the upper rock block. The normal load is applied with a loading velocity of 0.1 kN/min. In this study, the applied normal loads range from 10 to 400 kN. After the specimen is consolidated under the desired normal force, the shear force is applied with a loading velocity of 0.5 mm/min. The test will be stopped when the shear displacement reaches a steady post-peak stage. For the cyclic shear test, the rock blocks are first taken out from the shear box and the surfaces are carefully cleaned to remove the dust and abraded rock particles generated during the shearing process using compressed air at the end of each test. The rock blocks are then put back to the initial position in the shear box for another shear process.

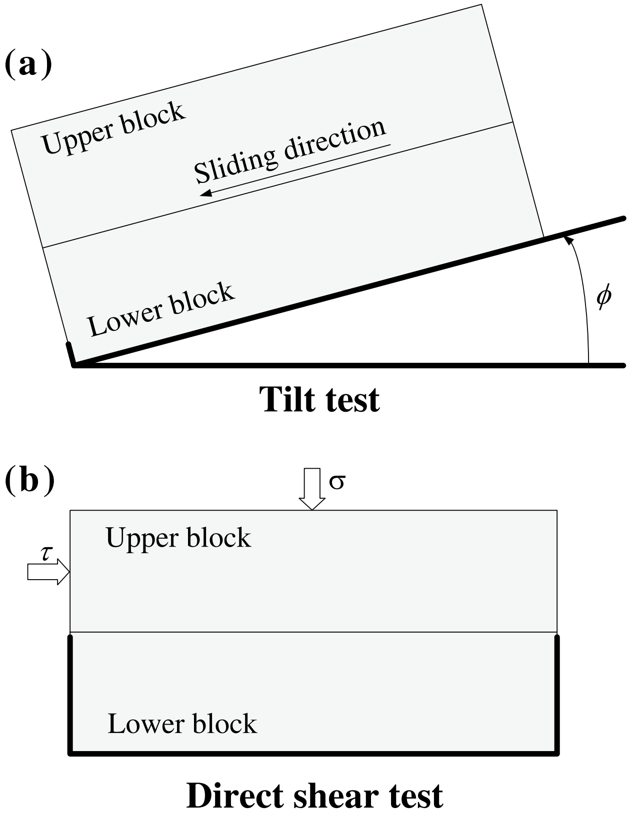

Fig. 2 Illustrations showing the test setup for **a** tilt test and **b** direct shear test

Experimental results

Tilt test

The results of tilt test on planar surfaces of three rock types are summarized in Table 1. The average value and standard deviation of basic friction angle of each specimen can be obtained. It is found that the standard deviation of each specimen is generally smaller than 3°, indicating that the obtained basic friction angle is convergent (Ulusay and Karakul 2016). In general, the marble has the largest standard deviation (from 1.1 to 2.5 with an average of 1.7) and the standard deviation of sandstone is smallest (from 0.3 to 0.7 with an average of 0.5).

The basic friction angle of planar surfaces of three rock types is presented in Fig. 3. The results show that the marble has the largest basic friction angle and the basic friction angle of sandstone is smallest. The determined basic friction angle of marble ranges from 37.8 to 38.1, and the average value is 38.0. The basic friction angle of granite ranges from 32.0 to 33.4 with an average of 32.5. The basic friction angle of sandstone is in the range from 26.2 to 27.0, and the average value is 26.7. Alejano et al. (2012) found that the basic friction angle of sedimentary rock was lower than that of other types of rocks, which is in a good agreement with the results in this study.

In principle, tilt test is similar to the shear test under the normal stress level of self-weight of upper rock block. The main influencing factor would be the micro-roughness of sliding surface, which is fabricated by the cutting tool, such as the diamond drill bit (Li et al. 2019). Another one would be the mineral composition and its distribution (Ulusay and Karakul 2016). According to experimental results (Horn and Deere 1962; Hu et al. 2018), the friction coefficients of minerals could have a significant impact on the fracture basic friction angle. However, quantitative study of the two factors on the friction behavior would be very complex, and related results are rare in the literature.

Table 1 Summary of tilt test results on planar surfaces of three rock types

Rock type	Specimen No	Tested basic friction angle (°)						
		1	2	3	4	5	Average	Std
Granite	G-1	32.6	32.9	31.0	35.8	34.9	33.4	1.7
	G-2	31.5	31.0	32.0	32.9	32.8	32.0	0.7
	G-3	32.1	32.9	32.9	32.9	29.9	32.1	1.2
Marble	M-1	37.4	36.1	39.4	38.0	38.1	37.8	1.1
	M-2	38.1	38.5	35.0	38.5	39.7	38.0	1.6
	M-3	34.5	37.4	36.9	40.9	40.8	38.1	2.5
Sandstone	S-1	28.2	26.8	26.2	26.7	26.6	26.9	0.7
	S-2	26.1	26.1	26.8	25.9	26.2	26.2	0.3
	S-3	26.2	27.0	27.5	26.7	27.8	27.0	0.6

Std standard deviation

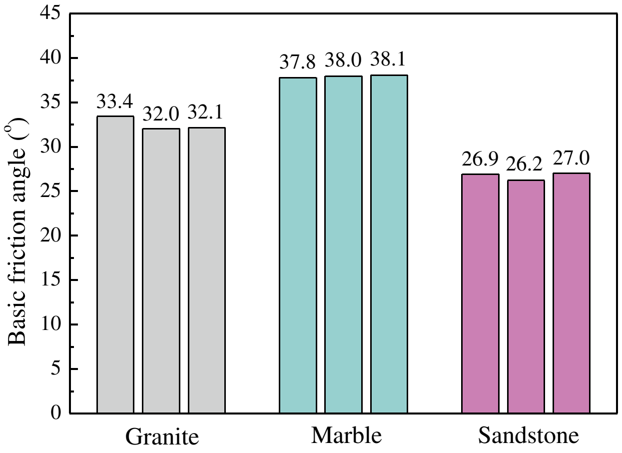

Fig. 3 Comparison of basic friction angles of three rock types determined from tilt test

Direct shear test

The direct shear test results in terms of shear stress versus shear displacement for different rock types are presented in Fig. 4. The associated normal stress ranges from 0.5 to 20 MPa. The shear stress is found to first increase generally linearly with increasing shear displacement under various normal stresses. The slope of the shear stress versus shear displacement curve then gradually decreases and reaches a constant value (i.e., near zero) in the residual stage. The results are in a good agreement with previous laboratory test results of planar rock joints (Bahaaddini et al. 2016; Dang et al. 2016; Jang et al. 2018; Behnia and Nateghpour 2020). The shear stress is also found to increase with the increase in the normal stress. This is because the micro-scale asperities randomly distributed on the joint surface interlock tightly as the normal stress gradually increases.

In this study, the shear stress, at which the slope of shear stress–shear displacement curve begins to stabilize or slightly decrease, is identified as the peak shear stress of the joint (Lee and Chang 2015). Figure 5 shows the relations between peak shear stress and normal stress for various rock types. The results show that the peak shear stress generally increases linearly with increasing normal stress. The relation between the normal stress and the peak shear stress for planar joint surface is usually described using the Mohr–Coulomb failure criterion with zero cohesion, which is expressed as

$$\tau = \sigma_{\mathrm{n}} \tan\phi_b \tag{1}$$

where σ_n and τ are the normal stress and the peak shear stress applied on the joint surface, respectively, and ϕ_b is the friction angle.

In previous laboratory tests, the peak shear stresses under low normal stresses (i.e., $\sigma_n \leq 4$ MPa) are generally used to fit the basic friction angle of planar rock surface (Bahaaddini et al. 2016; Dang et al. 2016; Jang et al. 2018; Behnia and Nateghpour 2020). From literature review, it is found that there is no specification on the magnitude of normal stress for the fitting of basic friction angle using direct shear test data. This is probably due to the fact that the test data under low normal stress are easily obtained when compared with those under high normal stress. The basic friction angles fitted using test data under low normal stress are presented in Fig. 5a. The obtained basic friction angles for granite, marble, and sandstone are 36.88, 43.06, and 40.30, respectively. The marble also has the largest basic friction angle, which is consistent with the results of tilt test.

Figure 5b shows the fitting results of basic friction angle of different rock types when the test data under high normal stress are included. It is seen that the fitted basic friction angles for granite, marble, and sandstone are 38.69, 41.64, and 38.34, respectively. The results show that the basic friction angle of marble is largest, which is in a good agreement with the results of tilt test. It is also indicated that the obtained basic friction angles under high normal stress have a difference about 2° when compared with those under low normal stress. In general, the basic friction angle of granite increases under high

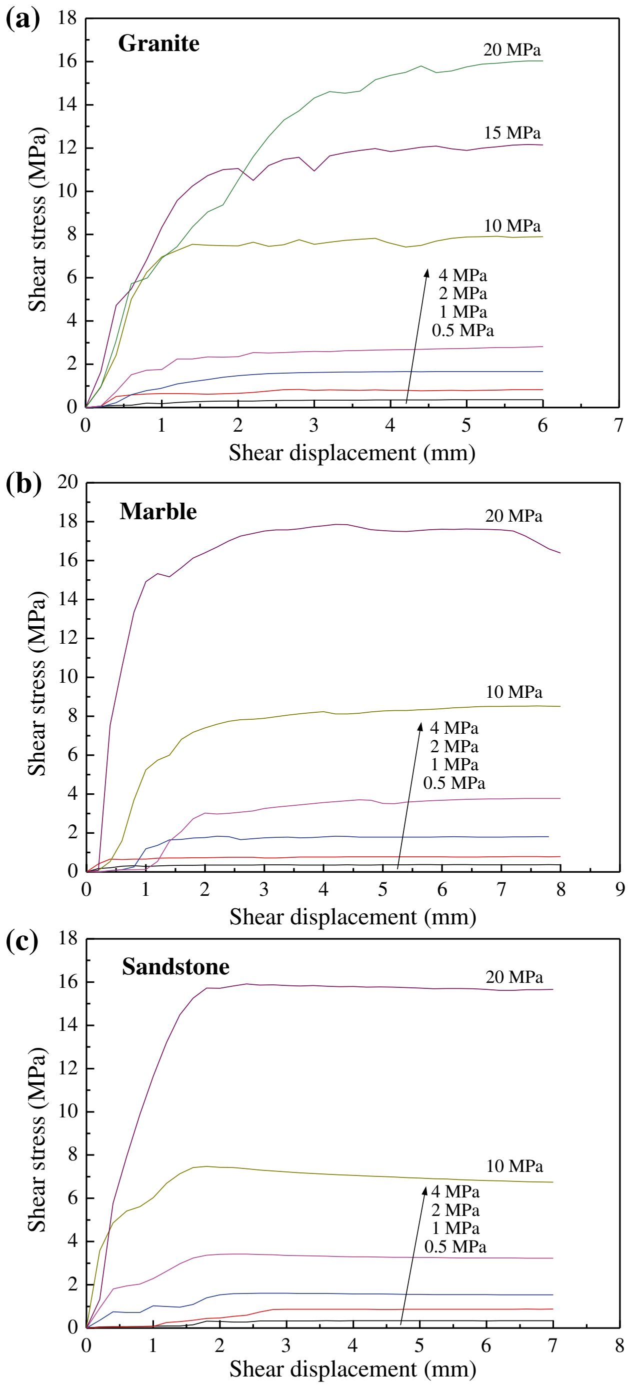

Fig. 4 Relations between shear stress and shear displacement in direct shear under various normal stresses for planar surfaces of different rock types. **a** Granite, **b** marble, and **c** sandstone

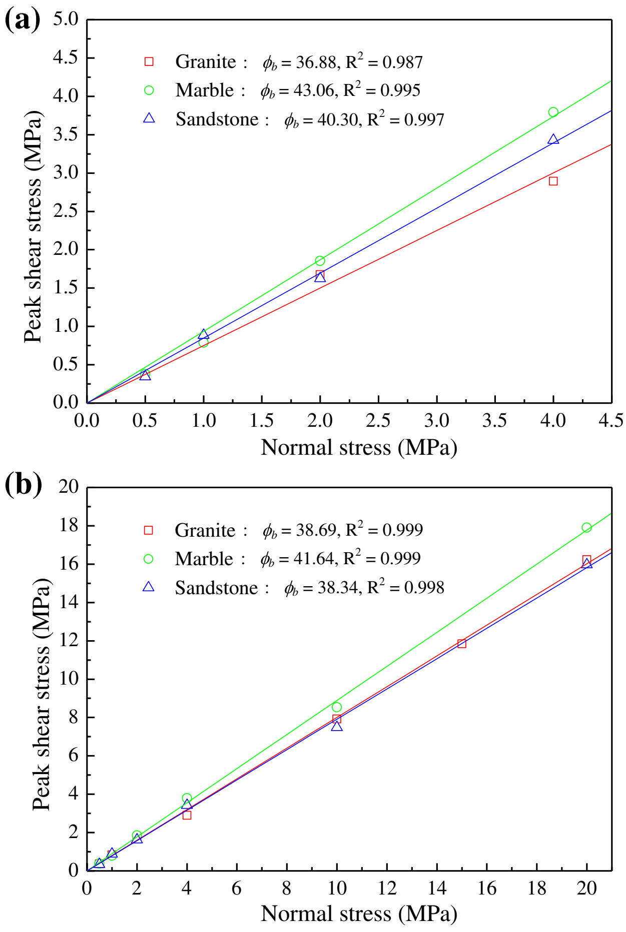

Fig. 5 Determination of basic friction angles for different rock types under **a** low normal stress condition and **b** high normal stress condition

normal stress condition, while the basic friction angles of marble and sandstone decrease. This phenomenon is mainly associated with the difference in strength of various rock types. The strength of granite is high, and the micro-scale asperities on the granite joint surface can hardly be sheared off under high normal stress. Due to tightly interlocked asperities, the shear resistance of granite will be large under high normal stress condition. On the other hand, the strength of marble and sandstone is much lower when compared with that of granite. The micro-scale asperities will be sheared off when the applied normal stress is high. The abraded particles will play a rolling effect during shear, which will greatly lower the basic friction angle of marble and sandstone.

The patterns of joint surfaces after shearing for different rock types are presented in Fig. 6. The results reveal that the shearing patterns of the joint surface are quite different under low normal stress and high normal stress. In general, the shearing is stable when the applied normal stress is low. The joint surface is basically intact and obvious striation can be observed after shearing. The area of shearing striation generally increases with the increase of normal stress, especially for marble and sandstone, indicating that more area in the joint surface is in contact when a higher normal stress is applied. The shear mode of rock joint under low normal stress would be dominated by friction. On the other hand, shear-off can generally be observed after shearing of

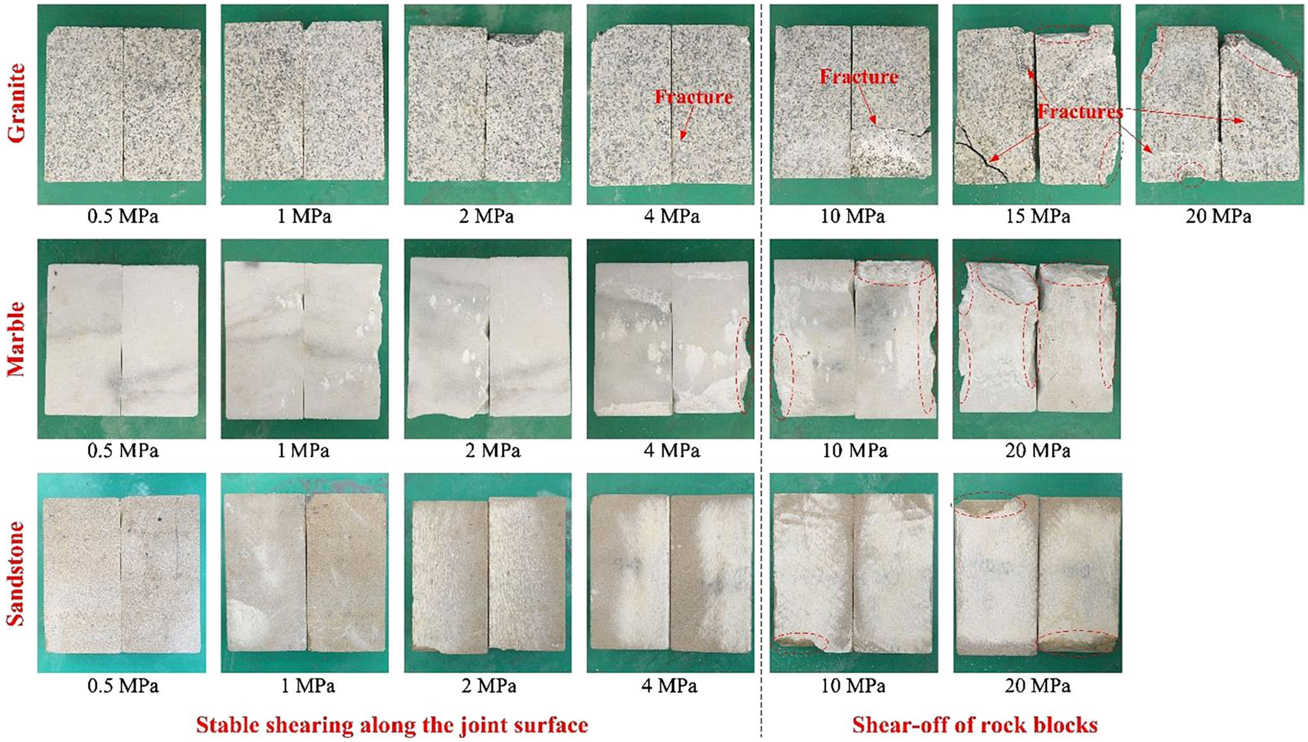

Fig. 6 Shearing patterns of joint surfaces of different rock types under various normal stresses

joint surface when the normal stress is high (see red dashed circle in Fig. 6). This is because the applied normal stress may exceed the strength or fracture toughness of the rock block, resulting in a shear-off when a high normal stress is applied. In addition, the shear-off is more violent in granite and marble than in sandstone, which indicates that the granite and marble are more brittle than sandstone.

The results from the above discussion reveal that the mechanism in shearing or failure of joint surface is quite different under low normal stress and high normal stress. Friction occurs under low normal stress while shear-off happens under high normal stress. This is probably why there is about 2° difference in the obtained basic friction angle under low normal stress condition when compared with that under high normal stress condition. To obtain a rational basic friction angle, test data in a same shearing pattern (i.e., friction) should be used. Recall that the basic friction angle is defined as the frictional component of shear strength of a planar joint surface. If the shear-off happens during shearing of a planar rock joint, the pattern of shear failure is not only associated with the joint frictional strength, but also related to the rock strength or other properties of different rock types. Hence, the test data under high normal stress are not representative any more to determine to pure frictional property of rock joint. This is probably why test data under low normal stress are generally used to fit the basic friction angle in previous studies.

The factors influencing the friction behaviors under direct shear would be more complicated when compared to the tilt test. Besides the micro-roughness and mineral composition of rock surface, the mechanical property of rock material would also cause great effect on the shear strength (i.e., compressive strength, and tensile strength). In addition, the number of contacts among micro-asperities randomly distributed on the rock surface will increase under the external normal loading, and even existing tightly interlocked asperities under the high normal stress level. As such, the basic friction angle by direct shear test is usually higher than the one by tilt test (as shown in this study).

Discussion

Cyclic shearing effect on shear behavior

The effect of cyclic shearing on the shear behavior of planar rock joint is discussed in this section. Because the shear of sandstone under low normal stress is generally stable, the cyclic shearing effects of sandstone under low normal stresses are discussed. The variation of peak shear stress with the number in shearing is presented in Fig. 7. When the applied normal stress is 0.5 MPa, the peak shear stress is basically not influenced by the number in shearing. When the applied normal stress is 2 MPa, the number in shearing also has a negligible effect on the peak shear stress, expect the data point in the fourth shearing. Because there is no

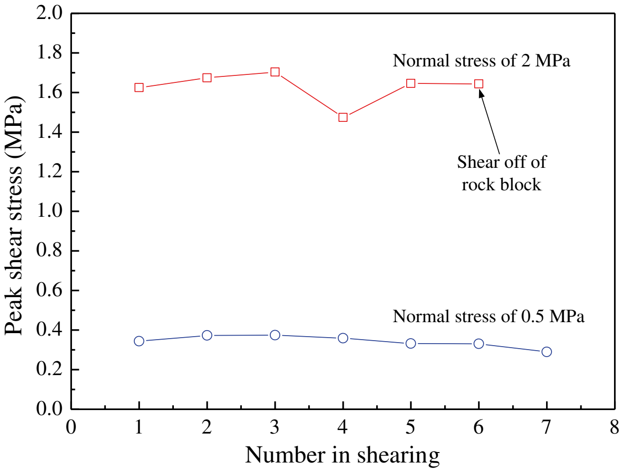

Fig. 7 Variation of peak shear stress with number in shearing of specimen

prominent asperity degradation in the direct shear of planar rock surface, the influence of cyclic shearing on the shear behavior is negligible under low normal stress condition. If a rough rock joint is sheared, the joint asperity can be greatly degraded during each shearing process and the peak shear stress will experience a large decrease with increasing shear number (Jing et al. 1993; Lee et al. 2001; Hou et al. 2016). The effect of cyclic shearing on shear behavior of planar rock joint is quite different from that of rough rock joint.

On the other hand, the rock block is sheared off in the sixth shearing under a normal stress of 2 MPa. However, the specimen will not be sheared off after experiencing seven repetitive shearing when a normal stress of 0.5 MPa is applied. It is indicated from the results that more damage is accumulated inside the specimen during shearing under a higher normal stress, which is more likely to result in shear-off of the rock blocks.

Basic friction angle of different materials

In this study, the basic friction angles of planar joint surface of three rocks are studied using two methods, i.e., tilt test and direct shear test. The results show that the basic friction angles determined from tilt test are generally about 4 to 5° smaller than those determined from direct shear test under low normal stress condition. Although the tilt test is easy to conduct, many factors are found to affect the test results, such as testing setup, moisture condition, surface size, specimen shape, tilting speed, and polishing degree (Behnia and Nateghpour 2020). The factors are sometimes different among previous laboratory studies and the determined basic friction angle for different rock types using tilt test varies in a quite large range (i.e., 10 to 40°). Hence, the basic friction angle determined from tilt test can hardly be generalized.

On the other hand, although the test setup for direct shear test is more complex than that of tilt test, the determined basic friction angle is found to be more reliable (Barton and Choubey 1977). Table 2 summarizes the basic friction angles determined from direct shear test for different rock types. Many test data are extracted from the publication in Barton and Choubey (1977). It is seen that the basic friction angles for various rocks are in a much narrower range (i.e., 25 to 43°) when compared with the results of tilt test. In addition, the determined basic friction angle for the same rock type is generally comparable in different studies.

The obtained basic friction angle varies for the three rock types in this study. Although the joint surface is generally planar in a macro scale, many micro-scale asperities can be observed on the "apparent" planar joint (see Fig. 8a). Figure 8b presents an example of micro-scale asperities of a planar granite joint observed from scanning electron microscopy (SEM) (Tang et al. 2020). It is seen that the "apparent" planar joint is rough in a micro-scale viewpoint. The micro-scale asperities are mainly associated with the exfoliation of minerals in the surface cutting and polishing. The marble examined in this study is composed of mainly one mineral (i.e., calcite), while the granite and sandstone are composed of several minerals (i.e., quartz and feldspar). Because the grain size of different minerals varies to a certain extent, the marble is much more homogeneous when compared with granite and sandstone, resulting in much rougher micro-scale asperities. The rougher micro-scale asperities account for a higher frictional strength, which corresponds to a larger basic friction angle. Therefore, the marble studied in the present study has the largest basic friction angle.

For the direct shear test, the results in the present study show that the test data under low normal stresses are suggested to be used to fit the basic friction angle. This is because the rock blocks are generally sheared off under high normal stress, which is quite different from the shear pattern (i.e., pure shear) under low normal stress. The data in this study replenish the test data of basic friction angle of different rock types and are useful for establishing a database for the estimation of basic friction angle in future.

Conclusions

This paper studies an important strength parameter (i.e., basic friction angle) of rock joint. Tilt test and direct shear test are conducted on planar joint surface of three rocks and basic friction angles obtained from both tests are compared and discussed. The results show that the marble has the largest basic friction angle in both tilt test and direct shear test. The basic friction angles determined from tilt test are about 4 to 5° smaller than those determined from direct shear test. In direct shear test, there is about 2° difference of basic friction angles under low and high normal stress conditions. This is because the shear mechanism of joint surface is different under low normal stress and high normal stress.

Table 2 Summary of basic friction angle of different rock types

Classification	Rock type	Basic friction angle (°)	Reference
Rock-like material	Plaster	39.2	Atapour and Moosavi (2014)
	Concrete	30.6	Atapour and Moosavi (2014)
	Concrete	36.2	Bahaaddini et al. (2016)
	Concrete	39.2	Dang et al. (2016)
	Plaster	38.0	Cui (2019)
Igneous rock	Porphyry	31.0*	Barton (1971)
	Basalt	35.0–38.0*	Coulson (1972)
	Granite	31.0–35.0*	Coulson (1972)
	Dolerite	36.0*	Richards (1975)
	Granite	29.2	Jang et al. (2018)
	Granite	36.9	*This study*
Metamorphic rock	Amphibolite	32.0*	Wallace et al. (1970)
	Slate	25.0–30.0*	Barton (1971)
	Gneiss	26.0–29.0*	Coulson (1972)
	Slate	30.0*	Richards (1975)
	Marble	43.1	*This study*
Sedimentary rock	Sandstone	26.0–35.0*	Patton (1966)
	Sandstone	31.0–33.0*	Krsmanovic (1967)
	Conglomerate	35.0*	Krsmanovic (1967)
	Sandstone	32.0–34.0*	Coulson (1972)
	Siltstone	31.0–33.0*	Coulson (1972)
	Limestone	31.0–37.0*	Coulson (1972)
	Sandstone	35.1	Jang et al. (2018)
	Limestone	34.4–37.8	Behnia and Nateghpour (2020)
	Sandstone	40.3	*This study*

*The data are sourced fromBarton and Choubey (1977)

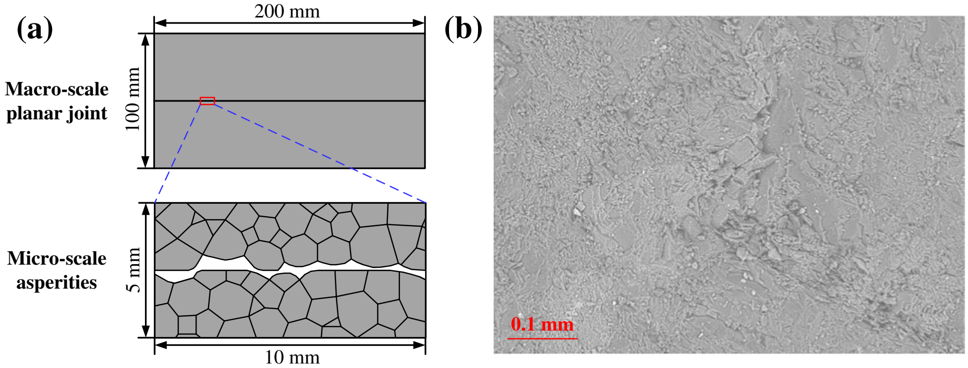

Fig. 8 Micro-scale asperities of planar joint surface. **a** A schematic diagram showing the rough micro-scale asperities associated with exfoliation of minerals in the joint surface, and **b** SEM observation of a planar granite joint (image sourced from Tang et al. (2020))

Friction occurs under low normal stress, while shear-off happens under high normal stress. To obtain a reliable basic friction angle using direct shear test, the test data under low normal stresses are suggested to be used. It is also found that the cyclic shearing has a negligible influence on the shear strength of planar joint surface under low normal stress.

Funding The research work presented in this paper is in part supported by the Natural Science Foundation of China (grant no. 51609178), the Natural Science Foundation of Hubei Province (grant no. 2018CFB593), Natural Science Foundation of Anhui Province (grant no. 2008085QE221), the China Postdoctoral Science Foundation (grant nos. 2015M582273 and 2018T110800), the Open-end Research Fund of the State Key Laboratory for GeoMechanics and Deep Underground Engineering (Grant no. SKLGDUEK1709), and Key project of Higher Education Department of Anhui Province (grant no. KJ2020A0235).

Declarations

Conflict of interest The authors declare no competing interests.

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