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Fracture Propagation in Mortar Models with Rough Non-Persistent Joints

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ABSTRACT: This paper describes a series of tests on mortar specimen models of rock masses with non-persistent rough joints. In the test program, the influence of roughness on the initiation fracture angle, coalescence path and peak strength and displacements will be analyzed. The specimens containing, flat (*JRC* = 0), slightly rough (*JRC* = 4) and moderately rough (*JRC* = 8) non-persistent joints were loaded in a biaxial frame. The way how to obtain joints reproducing rough surfaces by using polyester films will be described. In all cases, joints were inclined at 30° with respect to the major principal stress direction. The experiments indicate that the initiation fracture angle decreases when *JRC* increases. Also, the results show that the degree of roughness affects the fracture propagation pattern, being different for the three types of specimens. Relationships between strength and *JRC* and peak displacements and *JRC* are nonlinear.

1. INTRODUCTION

Rock mass behavior is complex mainly due to the present of discontinuities, which can be both persistent and non-persistent. There are many recent research work about non-persistent joints. Among those, Jamil (1992) tested several mortar blocks with smooth flat joints, subjected to biaxial loading, investigating the influence of joint orientation, confining stress, degree of persistency and relative joint density. Four different failure modes were found: 1)Failure with coalescence along joint planes; 2) stepping failure; 3) combination of 1 and 2; 4)failure along intact material, with no influence of joints.

Bobet & Einstein (1998) carried out uniaxial and biaxial tests on gypsum specimens with two inclined, open or closed, non-coplanar joints. They observed that two types of fracture propagation take place: wing tensile fracture, and coplanar secondary fractures, caused by shear displacements along the joint plane. They concluded that joint friction contributes significantly for the specimen strength, and for the decrease of the fracture initiation angle.

This paper reports the results of biaxial tests on mortar specimens containing 15 artificial non-persistent joints. Different degrees of roughness were tested in order to investigate the influence of the joint friction and dilation on fracture coalescence and peak specimen strength.

2. SPECIMEN GEOMETRY

Twelve prismatic blocks (600x300x132 mm) were made with mortar with cement:sand:water mix 1:5:0.65 and unconfined compressive strength σ_c=14.86 MPa. Joints were created by inserting a polyester film in the fresh mortar. The process to fabricate the specimens is described by Chong (1998). Fifteen joints were placed in each specimen, as shown in Figure 1, with the following space arrangement: joint thickness s = 0.05 mm, angle between joints and the direction of minor principal (confining) stress β = 60°, joint spacing d = 25 mm, joint and rock bridge lengths $L_j = L_r$ = 50 mm. In order to investigate the influence of dilatancy and friction on the fracture initiation and propagation, all the values mentioned above were kept constant in all tests, varying only the joint roughness. In order to duplicate roughness of natural rock joint surfaces, polyester films were pressed against granite blocks, heated at 89 °C, with natural roughness. A phaneritic sample of split granite with uniform grain size was used for roughness equivalent to *JRC* = 4. For *JRC* = 8, another sample from split granite was used (phaneritic, non-uniform grain size). The polyester film is left for two minutes pressed against the heated granite blocks.

3. LOADING AND DATA ACQUISITION SYSYTEM

The same loading system, previously used by Jamil (1992), Mughieda (1997), Aguiar (1998) e Chong (1998), was used in order to allow free movement of the loaded surface keeping load distribution uniform. This system is composed by a stack of three layers of metallic triangular pieces supported on two other smaller triangles from the next layer. It transmits the load from the ram to the specimen faces, as shown in Figure 1. The confining stress was applied in the vertical direction and kept constant at σ_2=0,2MPa in all the tests. The horizontal ram, with displacement control, loads the specimen at a rate of 0.35 mm/min. This stage proceeds until peak load is reached. After that, the unloading stage starts with a displacement rate of 0.5 mm/min. A data acquisition system collects ram displacement and force every 0.15 sec. A SVHS camera records images during the test. The complete image analysis to obtain relative displacement is still underway. The test arrangement is shown in Figure 1. Stress–strain curves for three values of *JRC* are shown in Figure 2.

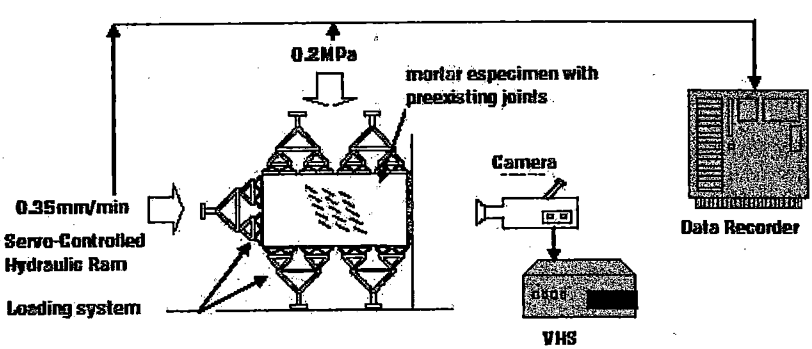


Figure 1. Schematic diagram of loading and data acquisition system

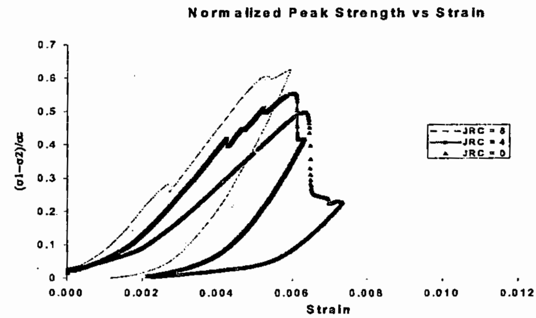


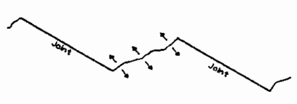
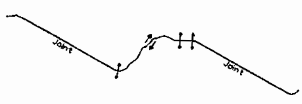
Figure 2. Normalized peak strength vs Strain curves for different values of *JRC*

4. EXPERIMENTAL OBSERVATIONS

4.1 *Direction of initial fracture propagation and coalescence*

For flat joints, the angle of initial fracture propagation η was approximately 65° with respect to the joint direction. Wing tensile crack are initially created at the initial joint tips. Their orientation leads to the direction of the maximum principal load. In this case, tension controls the process throughout coalescence. For joints with *JRC* = 4, η varied in the range of 40° to 48°. Decrease of η with increasing joint roughness was also observed by Wong & Chau (1998) and Bobet & Einstein (1998), and it is due dilation increasing tension (mode I propagation) at the joint tips. Initial fracture propagation is controlled by tension at the joint tips, but at the end of the coalescence process shearing mechanism dominates. This was concluded by observing slickensides on the fracture surfaces. For joints with *JRC* = 8, the propagation path was different, but the mechanisms were essentially the same ones described for *JRC*=4. The average value for η was 5° at one tip and 20° at the other. Stepping failure took place in all the tests, but the internal mechanisms were different, depending on *JRC*, as shown in Table 1.

Table 1. Summary of test results

Specimen	Initial Angle (η)		Schematic path of coalescence	Description of Coalescence	Mode of coalescence
	Left	Right			
JRC=0	64°	65°		Initial wing cracks from preexisting joint tips. Final rough surface	Tension
JRC=4	40°	48°		Initial wing cracks from preexisting joint tips. Final surface with rough and crushed mortar.	Tension + Shearing
JRC= 8	5°	20°		Initial wing cracks from preexisting joint tips. Final sheared surface with crushed mortar.	Tension + Shearing

4.1 *Variation of strength and peak displacements with JRC*

Figure 3 shows results of strength and peak displacements for different values of *JRC*. Dimensionless strength results (ratio between deviator stresses, $\sigma_1-\sigma_2$, and unconfined compressive strength σ_c) are shown in Figure 3a. Each value presented is the average obtained from four tests. The lower bound strength of persistent joints calculated according to Barton & Choubey (1977) is also shown. The upper bound strength of intact material is not shown and corresponds to a straight line with constant values close to 1.0. It is interesting to notice that the strength increase, corresponding to *JRC* varying from 4 to 8 is larger for non-persistent than for persistent joints. This is due to the additional normal stress on the joint generated by dilation counteracted by the rock bridges. Figure 3b shows total specimen displacements for different values of *JRC*, decreasing for rougher joints.

a) b)

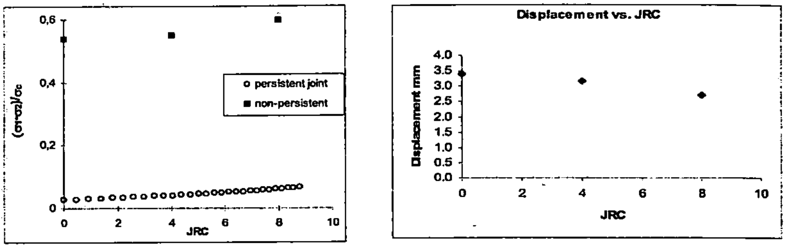


Figure 3. a) Normalized peak stress vs *JRC*. b) Peak displacements vs. *JRC*.

5. CONCLUSIONS

The influence of roughness on the coalescence process of non-persistent joints was experimentally observed. For flat surfaces, wing cracks initiate the process and tensile fracturing dominates throughout failure. For rougher surfaces, shear mode dominates the final stage of failure.

The variation of the fracture initiation angle with roughness was also observed. It decreases with increasing roughness due to dilation. The rate of strength increase with roughness is higher for non-persistent than those for persistent joints. This is also due to the action of rock bridges counteracting dilation, thus increasing normal stress on the joint surface.

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