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Effect of geometric heterogeneity on macroscopic behavior and microcracking in granite using UDEC-BBM

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1 INTRODUCTION

Understanding the rock failure process, especially for brittle rock, is important for the application of rock mechanics in mining and civil engineering (Chung et al. 2019, Wang et al. 2022). Previous research has shown that the intrinsic microstructural heterogeneity of rock will affect both macroscopic mechanical response and microcracking behavior (Peng et al. 2017, Wang et al. 2022, He et al. 2022, Gao et al. 2016). This heterogeneity is contributed by three key factors: mineral geometry, contact geometry, and elastic properties (Lan et al. 2010, Li & Bahrani, 2021).

In this study, the effect of geometric heterogeneity on numerically simulated uniaxial and triaxial compression tests was analyzed using a series of *UDEC* (Itasca 2019) models, mainly focusing on the effect resulting from grain shape (circularity in 2D) and grain size. A new geometry generation method was introduced, allowing for the direct importation of 2D geometries from Neper (an open-source polycrystal generation tool) into *UDEC*. The Mohr-Coulomb strain softening constitutive model was employed to represent breakable minerals, and the behaviors of mineral boundary, such as separation and slippage, were captured using the Coulomb-slip model with residual strength. An analysis of macroscopic mechanical properties and fractures was provided based on the results.

2 DESIGN AND ANALYSIS

A series of laboratory-scale models were established using the combination of Neper, Rhino, and *UDEC*. The 2D geometry was generated using Neper according to results from X-ray diffraction (XRD) analysis and thin section microscopic observation. Both mineral size and circularity obey the normal distribution. In previous methods, 3D Neper geometry was imported into 3DEC, and sections were sliced and reintroduced into *UDEC*, with mineral types randomly assigned to each block after importation. By the new method, 2D Neper geometries were converted to a DXF file using Rhino, enabling direct importation into *UDEC*. Additionally, the blocks were assigned different mineral types using FISH language, based on the Neper results. Compared to the previous one, the advantages of this method include the following:

- Straightforward quantification of geometric parameters such as circularity (or sphericity in 3D).
- Direct recognition and assignment of mineral types according to Neper statistical outputs.

With two platens positioned at both the top and bottom of the generated geometry, the bottom platen was constrained in both x- and y-directions after being imported into *UDEC*. A constant velocity of 0.1 m/s was applied to the upper platen (Gao et al. 2016, Wang & Cai 2019). Since *UDEC* can automatically adjust the mechanical time step to a small value, the model maintains quasi-static state. The model was calibrated against the unpublished experimental results from compression tests on granite under 0 to 30 MPa confining pressures. 'Local damping' with a high damping value was employed (Sinha & Walton 2020). The deformation parameters of blocks were sourced from the literature as shown in Table 1 (Park et al. 2017, Wang et al. 2021, Staněk et al. 2013), and the calibrated microparameters are listed in Table 2.

Table 1. Deformation Parameters of Blocks.

Parameters	Quartz	Feldspar	Mica
Density (kg/m^3)	2650	2620	3050
Young's Modulus (GPa)	35	18.4	20
Poisson's Ratio	0.2	0.24	0.18

Table 2. Calibrated Strength Parameters for Blocks and Contacts in *UDEC*.

Block Parameters		Contact Parameters	
Peak Cohesive Strength (MPa)	80	Peak Cohesive Strength (MPa)	38
Residual Cohesive Strength (MPa)	5	Residual Cohesive Strength (MPa)	0
Peak Friction Angle (°)	65	Peak Friction Angle (°)	50
Residual Friction Angle (°)	30	Residual Friction Angle (°)	32
Peak Tensile Strength (MPa)	30	Peak Tensile Strength (MPa)	8
Residual Tensile Strength (MPa)	0	Residual Tensile Strength (MPa)	0
Peak Dilation Angle (°)	25		
Residual Dilation Angle (°)	10		
Plastic Strain	0.05		

These calibrated microparameters were applied to 56 laboratory-scale models, each varying in grain circularity, mean grain size, and confining pressures. This application aimed to analyze their effects on the macroscopic mechanical properties and the normalized number of intergranular cracks at peak strength.

3 RESULTS AND DISCUSSION

In all models, the values for Young's modulus and Poisson's ratio remained relatively stable across different geometries, with fluctuations not surpassing 2%.

It is worth noting that since '1-circularity' was utilized in the Neper script in the current study. Therefore, as the mean grain circularity increases, the likelihood of grains being hexagons decreases, and the macroscopic cohesive strength exhibits a roughly linear decline as depicted in Figure 1. The most significant observed variance in macroscopic cohesive strength was approximately 51% compared to the calibrated model results. However, there is no noticeable trend for macroscopic friction angle. Variation in the standard deviation of grain circularity had only a minor effect on the results. Notably, the macroscopic cohesive strength increases with increasing grain size, with the maximum differential reaching 26%.

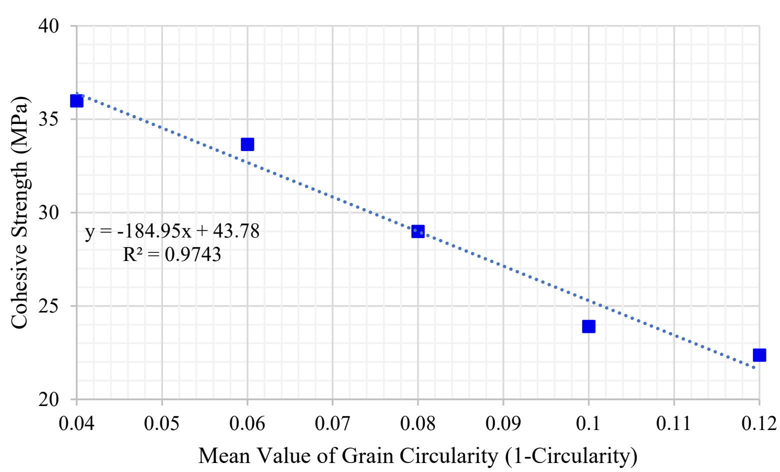

Figure 1. Effect of mean value of grain circularity on macroscopic cohesive strength.

From the fracturing perspective, all the models show a similar trend for normalized tensile and shear intergranular cracks at the peak strength with increasing confining pressures. The results for models with various mean values of grain circularity have been shown in Figure 2 as an example.

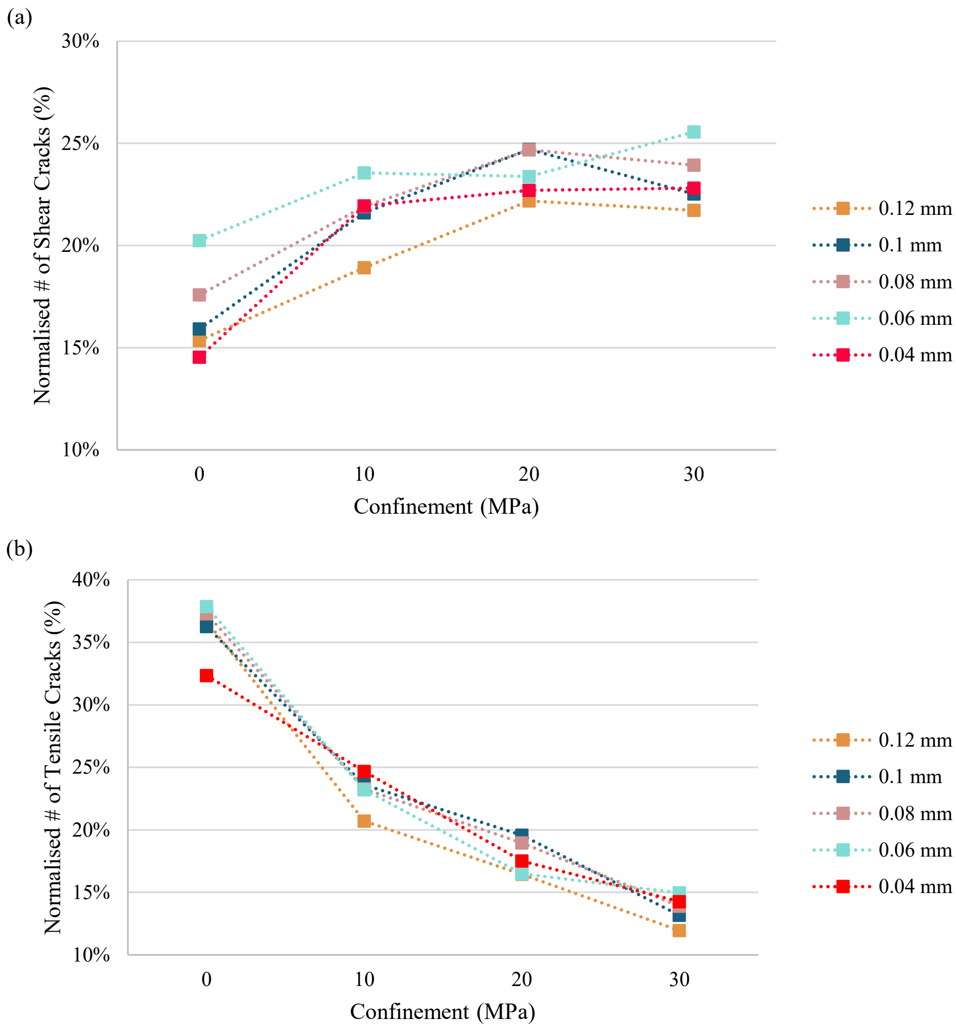

Figure 2. Effect of mean value of grain circularity on (a) shear and (b) tensile cracks under various confinement.

4 CONCLUSIONS

Both grain circularity and size are crucial microstructural parameters that affect the rock failure process and macroscopic mechanical response. The UDEC-BBM numerical results in the current study show that the Young's modulus and Poisson's ratio almost remain unchanged with all different geometries. Both grain circularity and size affect the macroscopic cohesive strength, while they only have a minor effect on macroscopic friction angle. In the view of microcracking, the normalized number of intergranular cracks that failed in shear increases with increasing confinement, while the intergranular cracks that failed in tension shows an opposite trend. Additionally, these trends persist, regardless of microstructures.

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