Utilizing Stress Transmissions in Bonded Granular Materials to Determine Grain Contact Stiffness in Sandstone

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Abstract—**An experimental investigation of stress transmission through bonded particulate structures with visible stress pattern and stress-strain data from rock matrix akin to the problem of rock fracturing remains a challenge and this is addressed in the present work. The stress transmission through sandstone under mechanical loading is analyzed experimentally by applying a thin coating of birefringent material. The retardation of the light components that reflect from the surface of the birefringent on sandstone samples was measured. By using a reflection type optical tomography, the maximum shear stress under the external loading indicates stressed point on the surface of the sample which was related to grain displacement. The strain induced birefringence occurs due to the anisotropy within the grains in the sandstone which result isochromatic fringes. Hence the shear stress map on the surface of the sandstone sample was visualized. This information is used further to evaluate modulus at micro scale and the yield strength. The stress measurement made from photo-stress experimental techniques was compared with the ultrasound sensors, strain gauges and bulk strength devices. Analogous to this experiment, simulations using Discrete Element Modeling (DEM) were performed using the measured grain-scale parameters as inputs. The boundary and initial conditions for the experimental conditions were used to simulate force distribution for sandstone under compression. The stiffness ratio associated with the grain-to-grain cementation in experiment agrees excellently with the simulations. This makes it possible to visualize and understand how micro-scale behavior contributes to the bulk strength characteristics of cementations in materials even when they are opaque.**

Index Terms—**Bonded particles, granular assembly, anisotropy, birefringence, stiffness ratio**

I. Introduction

QUALITATIVE approaches to probing strength characteristics of strongly bonded (rock-like) particulate materials has been attempted in the past; [1], [2] and [3]. However the concept of accounting grain scale interactions within grains bonded with cement-like structure such as rock and concrete is not sufficiently developed for formulating contact models for the materials. Therefore, a more significant step to understand the behavior of strength of sandstone is presented in this work where the stress distribution on opaque sandstone under mechanical loading using photo stress analysis tomography (PSAT) was obtained. In this, stress-sensitive thin coating was initially applied on the sandstone which is sufficiently free of residual-stress and adherent on rock surface. Using reflective type PSAT [4], shear stress distribution on the sample can be visualized during external loading. From this, examinations are performed to derive the contact stiffness parameters suitable for feeding into their DEM simulations. Further the contact parameter was validated with the P-wave and S-wave data using ultrasound probes. The Qua ibo sandstone (with grain size 80-100 microns) was used in this study.

The particle flow code have been employed to obtain the macro-parameters of rock by first defining calibration as micro parameters. Micro properties of sandstone can be made to interact to produce corresponding macro properties of the material. Further the macro properties are then synthesized to produce the material behavior under stress. The work of [5] have shown that the choice of appropriate micro parameters depends largely on the material behavior. The particles are simulated as bonded together with cement called parallel bond where they closely interact by contact forces occurring in every particle to particle contact point. The degree of closeness of the particles makes the packing properties cohesive but the bonded particles are connected by parallel bond. The bond is a finite dimensionally equal to the particle diameter [6]. It possesses both tensile and shears strength, the stiffness of both normal and tangential strength. The external application of load leads to stress transmission in the material, when either of the strength are exceeded, the parallel bond breaks and forms micro-cracks inside the rock mass between the particles. Coalescence of the micro-cracks occurs as the loading weight increases which are seen as cracks which divide the rock mass into separate clusters. The location of this failure point can be tracked from the onset by accurate evaluation of both contact and parallel bond existing in the microstructure of the material. In this work the micro-mechanical properties are estimated experimentally and simulated and are presented for the evaluation and determination of deformability of rock material.

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