Sensing Mechanical Properties of Rocks and Beams using Photo Stress Analysis

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Abstract. In this work, we applied photo stress analysis to study the stress distribution characteristics on the surface of opaque rock and concrete beams with a birefringent coating, subjected to mechanical loading. By analysing the components of the retarded light vectors from the surface of the samples, we provide new insights on the distribution of maximum shear stress at both local and global scales. We also provide the direction map of the major principal stress in the beam sample. The results were also compared with computer simulations where feasible (though not included here) and a good level of agreements were obtained. Overall the study provides a novel experimental pathway for understanding the links between the stress distribution characteristics of such opaque materials from point scale to bulk scale.

Introduction

Fundamental level understandings on the stress distribution characteristics of discrete powders and strongly bonded granular materials such as rocks and beams are sought in several engineering sectors including petroleum energy, chemical, civil, geotechnical, mechanical and space exploration. The macroscopic mechanical properties strongly depend on the individual grain-scale properties of all constituent elements in the bulk assemblies [1]. Previous experimental studies report advancements on the multi-scale behaviours of materials under external loading. In these, the experimental measurements of strain (/stress) distributions on engineering materials are usually done using strain gauges, photoelasticity and more recently, using thermography and digital image correlation techniques [2-5]. Each technique has its advantages and disadvantages. However photoelastic analysis has been reported often using the transmission type polariscope [5-8], for which initially a birefringent model needs to be fabricated [5]. However, the reflective polariscope offers the opportunity to evaluate the stress distribution on opaque materials [5]. The applications of this to different engineering problems is relatively limited in the literature – this aspect is addressed in the present work.

Experiments

The specific details of the reflective photostress experimental methodology used here can be found from our previous publication [6], and details of the theoretical background is explained earlier [9]. Here we map out the stress distribution characteristics for two cases of practical relevance using (i) V-notch sandstone rock sample (180x115x40 mm, notch angle=50°, maximum width of notch =75mm) subjected to point loading at the notch tip and (ii) a concrete beam (160x40x40mm) subjected to the three-point bending test [5]. A birefringent coating of average thickness 300 µm (strain optic coefficient is 0.06 m/m/(m/m) i.e., in retardation/thickness/strain) was used in this study.

Results and discussion

Figure 1 shows the maximum shear stress distribution at the verge of failure of the sample. The physical location of the crack is also presented separately. We can observe a strong correlation between the progressive fronts of the maximum shear stress contours and the physical crack line. Other studies have also reported an intense temperature variation along the regions of the crack front at the verge of failure [10]. Figure 2 shows a similar profile for the concrete beam sample studied here. The results suggests the usefulness of tracking the maximum shear stress contours in loaded samples to determine their strength characteristics and fracture.

Conclusion

Photostress analysis has been efficient in revealing the stress distribution characteristics of even opaque materials under mechanical loading. Further studies are required (on-going) to relate the characteristics of the stress distribution profiles reported here to suitable descriptions of macroscopic strength parameters of opaque materials in different engineering applications.

References

Figure 1: (a) The variation of maximum shear stress in the V-notch sandstone rock sample at the verge of failure load is presented here (b) for the same sample, the visual crack path is provided.

Figure 2: (a) The variation of maximum shear stress on the surface of a typical concrete beam at the verge of failure load (b) for the same sample, the direction of the major principal stress is presented. The crack line is also indicated in dotted lines where discontinuities in the features of maximum shear stress is evident.