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The damage of unconfined granite edge due to the impact of varying stiffness projectiles

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ABSTRACT

A rectangular box shaped granite specimen was subjected to varying stiffness projectile impacts on its unconfined edge to investigate the rock damage. Three kinds of projectiles were used, namely chrome steel, copper 102 and pure lead. In comparison to high constraint impact, unconfined edge impact of varying projectile stiffness for brittle targets has not been reported in the literature. Steel, copper and lead projectile impacts revealed that the extent of damage varied depending on the projectile materials. Larger damage on impacted granite's edge was observed due to copper projectile in comparison to steel and lead projectiles. The experimental results were compared to numerical simulations by using Smooth Particle Hydrodynamics (SPH) available in commercial software LS-DYNA as a finite element tool and they were in good agreement. The SPH model of granite provided good description that double-layer crater was formed as a result of unconfined edge projectile impact which matched the experimental findings well. Threshold value of projectile stiffness was proposed to remain significant factor in damaging unconfined granite's edge.

1. Introduction

Dynamic crack propagation in rocks is a very haphazard process. Granite itself was the most commonly used building stone for structural buildings in Britain and most world cities during nineteenth and twentieth century [1]. This fact suggests the essence of further studying granite's behaviour in particular related to impact and blast engineering. As a brittle material, granite rock consists of various relatively low-temperature minerals, mainly feldspar and quartz [2]. The weakest area in granite was identified by using scanning electron microscope (SEM) imaging technique to be feldspar mineral followed by the bonding between quartz grains [3]. Nevertheless, the presence of microcracks together with their orientation influences the fracture toughness value more significantly compared to the factor of same dimension of grain size and the orientation [4].

Though granite exhibits variation of characteristics as those other types of rocks, nevertheless it has less properties variation than the rest [1]. Due to less variation in inhomogeneous granite's material behaviour especially the rock's fracture makes the granite to be among popular choices for construction buildings. Rock fracture is defined as the formation of planes of separation within the rock as the cohesion between particles is broken and new surfaces are formed. Shear stress failure is considered as the most common and important type of failure where one face of surface slips from another [5]. The failure via shear faulting was addressed to be the most fundamental in rock damage [6]. On the other hand, the importance of tensile fracturing was also emphasized in the development of shear zone [7].

Cracked chevron notched Brazilian disc method was used to show that the propagation fracture toughness is consistently larger than dynamic fracture initiation toughness on Laurentian granite [8]. Contrary to static loading condition, fracture toughness of Fangshan gabbro and Fangshan marble which in the heating state were investigated to be greater during dynamic (stress wave) loading [9]. This finding suggests the effect of temperature rise during impact. Longer crack extension was found to be developed at lower stress-loading rates because stresses released at adjacent cracks were reduced [10]. The above mentioned discovery gave quite adequate explanation for this project's experimental result given later in this report.

Combination of experimental, analytical and simulation were conducted to study the penetration of limestone targets impacted by steel projectiles at oblique angles (15° and 30° from normal line), where the research focused on projectile position after penetration of oblique impact [11]. A research was further performed to show the impacting angle factor is more significant than impacting energy in fragmentation of foliated rocks, within certain threshold

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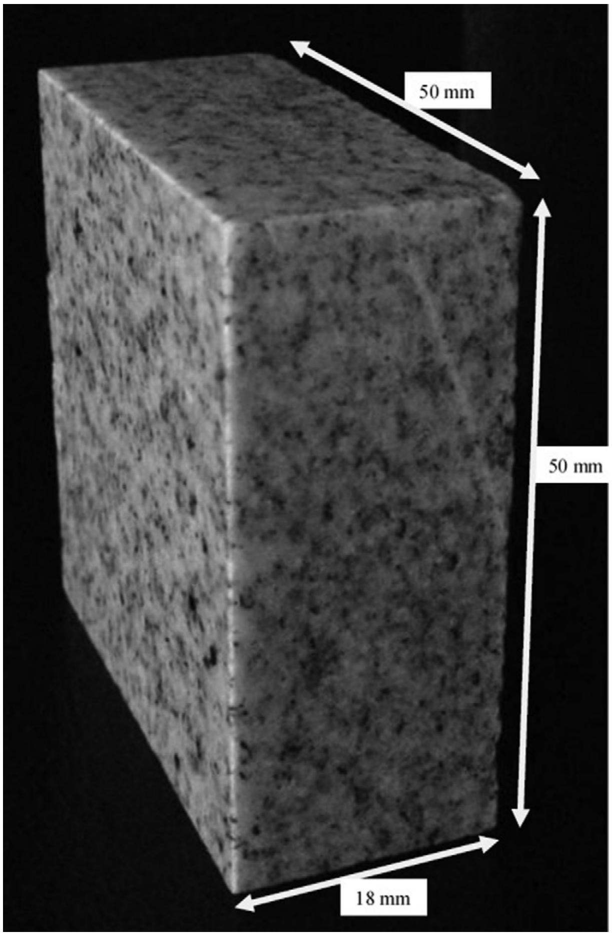

Fig. 1. 50 × 50 × 18 mm Barre granite target used in impact tests.

value of impacting energy [12]. Cylindrical steel projectile was utilized to perform edge-on impacts on crinoidal and Beaucaire limestones, where the higher predominant factor on rock fragmentation, namely Weibull modulus of rock was found to lead to numerous cracks occurrence and higher crack density [13].

Impact resistance of plain concrete with mixture of coarse granite aggregate was enhanced in terms of reduction of crack diameter and propagation as well as the penetration depth. Nevertheless, granite specimen itself exhibits better impact resistance even while compared to high-strength concrete [14]. This outcome can be seen as preference of using granite compared to high-strength concrete with coarse granite aggregate. Uni-axial compression strengths (UCS) of cubic and cylindrical granite samples were explored in laboratory test with suggestion that UCS of cubic granite sample to be greater than the latter attributed to its larger aspect ratio leading to reduced strength [15].

Numerous numerical methods were utilized ranging from discrete element method [7,16,17] to solid element [13] for rock modelling. Solid element coupled with Arbitrary Lagrange-Euler (ALE) method also can be effectively used for anisotropic brittle continuum damage model for rock mass [18] especially for large deformation zone near the charge. Nevertheless, this method requires high resources and computing time thus becomes unfavourable unless for blasting simulation. Another method for rock loadings is mesh-free Smooth Particle Hydrodynamics (SPH) model which gave good correlation with experimental results in terms of perforation hole and spallation zones left in the SPH rock target [19]. This SPH method was chosen for modelling the granite rock in the current work.

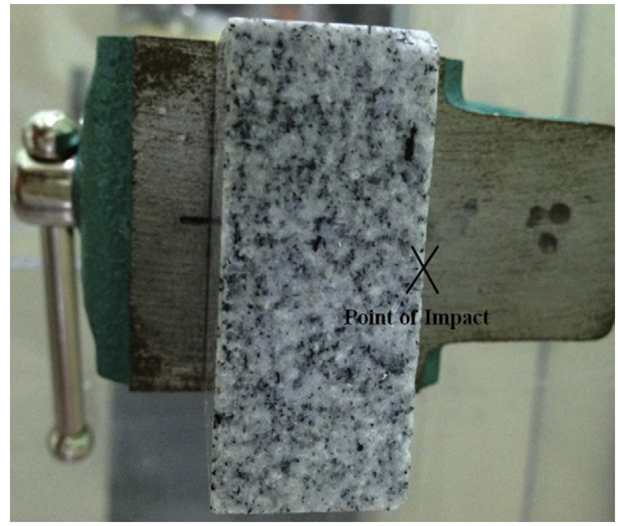

Fig. 2. Frontal view of clamped granite's position with its point of impact on the unconfined edge.

From various projectile impact tests on rock targets, most of the researches focus on high constraint surface impact, while some on edge of target [13]. Nonetheless, no research work was performed to impact orthogonal edge of cuboid target perpendicularly with varying projectile types. In the present work, the focus is on the unconfined edge of granite was subjected to varying projectile stiffness. The objective of the present project was to study the localized and extended craters formed at the impacted edge. Another objective was to determine suitability of modelling rock target with SPH.

2. Experimental work

Three (3) types of spherical projectiles -which are labelled as chrome steel, copper and pure lead, were used to impact unconfined edge granite target. A cuboid granite sample with dimension of 50 × 50 × 18 mm is shown in Fig. 1 while all spherical projectiles, regardless of the materials, have a common diameter of 9.5 mm. The unconfined edge of brittle granite target was subjected to a 9.5 mm spherical ductile projectile impact by using air gun with projectile's velocity at impact is shown in Table 1 for each test. Fig. 2 shows the granite target that was rigidly clamped at the end for every set of impact test and the clamped distance is shown in Fig. 3.

Table 1
Projectile types, material models and velocities in LS-DYNA.

Projectile types	Material model used in LS-DYNA	Shot #1 (m/s)	Shot #2 (m/s)	Shot #3 (m/s)	Average speed (m/s)
Chrome Steel	*MAT_020_RIGID	97	99	98	98
Copper 102	*MAT_018_POWER_LAW_PLASTICITY	94	95	93	94
Pure Lead	Nil	88	88	88	88