Experimental Study of Impact Cratering Formed on Simulated Icy Crust Including Soil: Image Analyses of Ejecta Velocity

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Abstract We performed impact experiments onto H_2O ice–rock powder mixture target, with changing projectile velocity and rock content rate. We found that the tensile strength of the target derived from the size and velocity of spalls based on the model of Melosh (1983) does not vary with rock concentrate for targets with lower rock content. We derived the relation between crater volume and kinetic energy,and late-stage effective energy proposed by Mizutani et al.(1990).

1. Introduction

object	small ← crater diameter → large	
Moon and Mercury	bowl shaped crater ←	→ central peak crater
Icy satellites	bowl shaped crater ←	→ central pit crater
Mars	bowl shaped crater ←	→ (central peak crater / central pit crater)

Origin and formation mechanism of central pit crater …
unknown(contribution of volatiles?)

Purpose of this study:
1)experimental study for the contribution of volatile to impact cratering.
2)estimation of target strength from ejecta velocity and size based on the model of Melosh (1983) and derivation of a scaling law of crater volume including the strength.

2. Model

Melosh(1983) derived the following equation:

$$\boxed{z \approx \left(\frac{\sigma}{\rho c_L}\right)\frac{d}{\upsilon_e}} \quad (1)$$

- z : spall thickness
- σ : tensile strength of target
- c_L : sound velocity
- υ_e : ejection velocity of spall
- d : depth of equivalent center of shock wave propagation
- ρ : target density

This equation is applicable for the spalls except for those from very near the impact site having high ejection velocities.

3. Experiments

● Experiments were performed at Institute of Low Temperature Science, Hokkaido University(263～253K).

	Oct.24 and 25, 2002	Sep.4 and 6, 2003
Projectile	H_2O ice (Diameter=15mm, Height= 10mm, Mass≒1.6g)	Nylon (Diameter=1.0 and 2.0mm, Height = 2.5mm, Mass≒7mg)
Impact velocity	350, 450, 550, 650m/s using gas gun	1480～3670m/s using two stage light gas gun
Target*	shape: cylinder, Diameter=20 or 27 or 30cm, Height = 5 or 6cm Rock content = 12.5, 25, 37.5wt%	shape: truncated cone Diameter=1.0 and 2.0mm, Height = 2.5mm Rock content = 0, 12.5, 25, 37.5, 50wt%
Framing rate	2000 frame/sec	4000 frame/sec

*In order to make uniform targets, the targets were made by adding water into rock powder and natural snow mixture in the room at the temperature of 250K

image analysis:
From the high-speed video images, we selected the fragments which can be measured their thickness. Then we derived the ejection velocities from their moving distances.

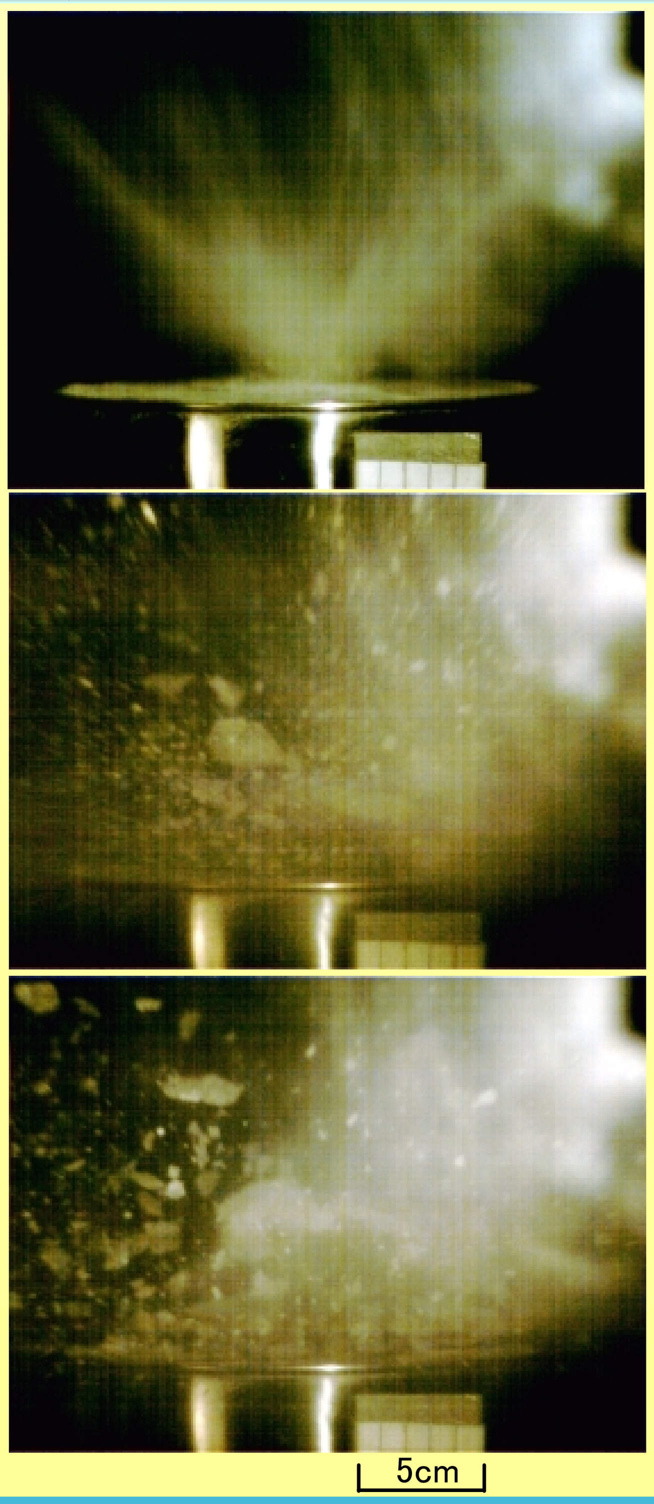

Fig.1
Taking a picture from every 10 frames. Projectile was impacted on a target of 37.5 wt% rock content in vertical direction. The impact velocity was 569m/s.

4. Results

● Crater volume V determined from total mass of ejecta

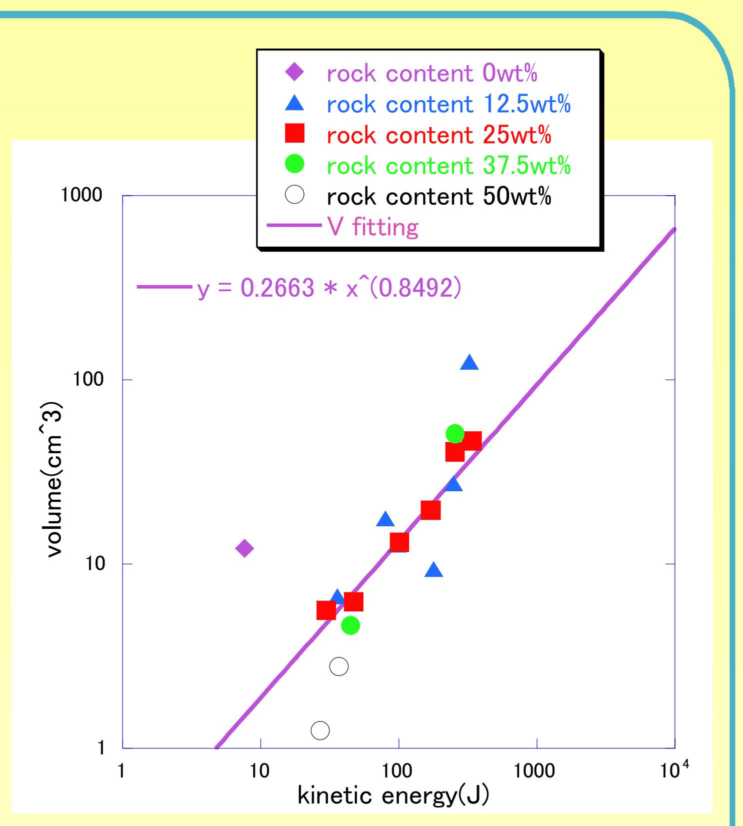

Fig.2
Crater volume V versus projectile kinetic energy E_k

$$V \propto E_k^{0.849}$$

● Target tensile strength σ estimated from Eq.(1)

There is no big difference in the tensile strength of 12.5wt% target and 25wt% target, and this tendency is also found in crater volume shown in Fig. 2.

Tensile strength appears to increase with rock content for targets of rock content more than 37.5wt%.

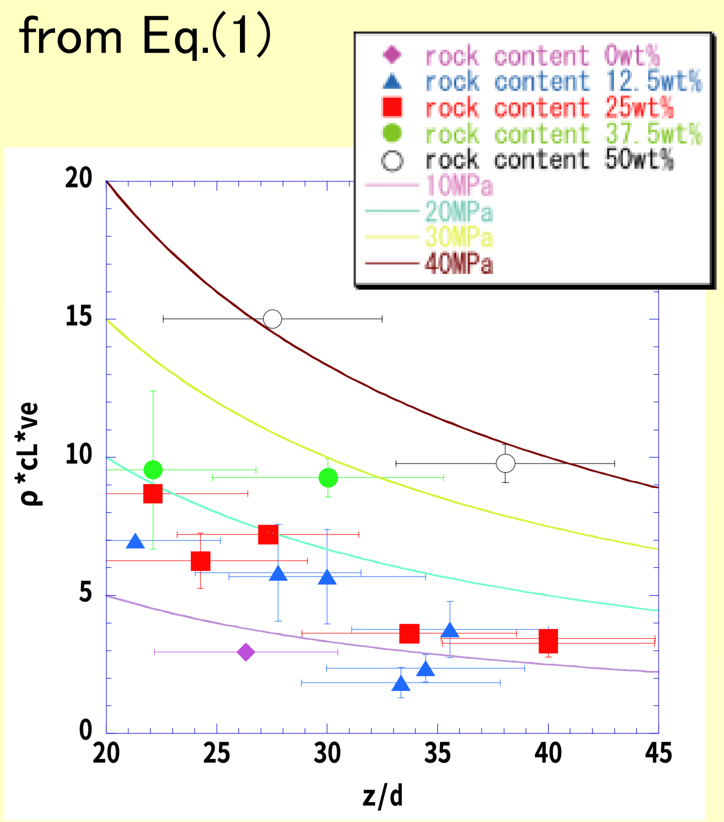

Fig.3
Tensile strength estimated from Melosh`s model. X axis is z/d, Y axis is $\rho c_L v_e$. (see Eq.(1))

5. Discussion

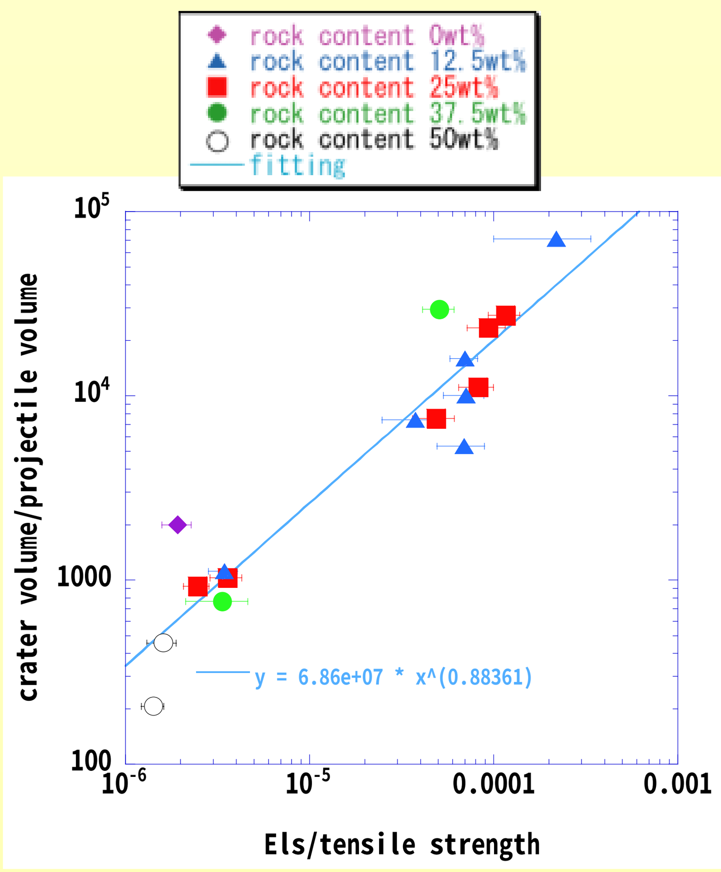

Fig.4
late-stage effective energy/ tensile strength versus Crater volume V/projectile volume V_p

We derived 'late-stage effective energy' E_{ls} proposed by Mizutani et al.(Eq (16), 1990):

$$E_{LS} = P_0 V_p$$

where V_p is projectile volume and P_0 is the initial peak pressure. Crater volume is proportional to a power of E_{ls}. We found

$$\frac{V_p}{V} \propto \left(\frac{E_{LS}}{\sigma}\right)^{0.883}$$

The gap around (E_{ls} / σ)=10^{-5} should be made up by further experiments.

6. Summary

● In our experiments, we found

$$V \propto E_k^{0.849}$$

● Target strength σ calculated from Melosh`s model has no big difference between between targets of rock content 12.5wt% and 25wt%.

● The relation between E_{ls} and V is

$$\frac{V_p}{V} \propto \left(\frac{E_{LS}}{\sigma}\right)^{0.883}$$

● The process of image analyses should be semi-automated.