Japan Geoscience Union Meeting 2015
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Experimental study on the oblique collisional disruption on porous gypsum target

MATSUE, Kazuma[1*] ; TAKANO, Shota[1] ; ARAKAWA, Masahiko[1] ; YASUI, Minami[1]

[1]Graduate School of Science, Kobe University, Japan

Introduction

High-velocity impact among small bodies in the solar system could originate asteroidal bodies and EKBOs and so on through collisional disruptions. Then, the collisional disruption is one of the most important physical processes to clarify the formation and evolution of the small solar system bodies. The degree of collisional disruption is quantitatively defined by an impact strength, and it has been studied for various materials, then it is found that it depends on a porosity. Because the shock wave rapidly attenuates in a porous target, so the impact damage is well concentrated near the impact point (Arakawa et al.2009). Recently, many porous asteroids were found by the explorations, then it is important to understand the impact phenomenon for the porous asteroids. Okamoto and Arakawa (2009) conducted high-velocity impact experiments on porous gypsum targets, but they carried out them only for a head-on impact. However, oblique impacts would be dominant in the collisions among solar system bodies. Therefore, we conducted high-velocity oblique impacts for porous targets and examined the effect of impact angles on the collisional disruption.

Experimental method

The impact cratering experiments were conducted by using a two-stage light-gas gun at Kobe University. We used a polycarbonate sphere with the diameter of 4.75mm and the density of 1.2g/cm^3 for a projectile. A spherical gypsum target was prepared and it has the diameter of 70mm, the porosity of 61%, the tensile stress of 1.0MPa and the bulk sound speed of 1.19km/s. The impact velocity, V_i, was 4.0km/s and 7.0km/s. The impact angle, θ, was changed from 15 to 90-degree, where the head-on impact was defied as the impact angle 90-degree. The impact fragments during the disruption process were observed by a high-speed video camera to measure the ejection velocity of these fragments. In addition, we recovered impact fragments after the shot and measured the mass of each fragment to construct the mass distribution of these fragments.

Result

In order to study the degree of the collisional disruption quantitatively, we studied the relationship between the mass of the largest fragment normalized by the original target mass (m_l/M_t) and the energy density, Q_t = $1/2V_i{}^2m_p/M_t$, where m_p, M_t are the mass of the projectile and target respectively. Our result for a head-on collision (θ=90) was almost consistent with a previous study for porous gypsum targets (Okamoto and Arakawa 2009). While, it was surprised that m_l/M_t did not change or was almost constant when the impact angle was changed from 90-degree of a head-on collision to 45-degree of a oblique collision. However, ml/Mt was significantly changed to be almost for θ of 15,30-degree at 4km/s and θ of 15-degree at 7km/s because an impact crater was formed instead of the catastrophic disruption.

In the case of oblique impacts, the kinetic energy effectively used for the impact disruption could be that originated from the normal velocity component of the projectile. Thus, we could calculate the effective energy density defined as Q_c = $1/2V_i{}^2m_p\sin^2\theta/M_t$ and found that our result at the impact angle θ from 90 to 45-degree was not inconsistent with the previous study (Okamoto and Arakawa 2009). Therefore, the normal velocity component might be important for oblique impacts in these angles. However, Q_c did not work well at the impact angle smaller than 45-degree at 4km/s an 30-degree at 7km/s. This result indicates that not only normal component of the impact velocity but also the tangential component of the impact velocity might affect the impact disruption.

Keywords: collisional disruption, oblique impact, porosity

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Granular convection and its application to asteroidal resurfacing timescale

YAMADA, Tomoya[1*] ; KOUSUKE, Ando[1] ; MOROTA, Tomokatsu[1] ; KATSURAGI, Hiroaki[1]

[1]Graduate School of Environmental Studies, Nagoya University

Recently, planetary explorations by space probe have observed various surface geomorphologies that are covered with regolith and boulders on the asteroids. In particular, landforms resulting from the regolith fluidization and sorting by impact-induced global seismic shaking were found on the asteroid Itokawa [1]. As a possible mechanism for the regolith fluidization, granular convection was proposed [1]. In addition, the regolith migration and resurfacing resulting from the granular convection might be consistent with the relatively young surface age (1 ? 8 Myr) of Itokawa [2, 3]. In fact, when the granular matter such as regolith is subjected to the vertical vibration, the granular convection can be readily generated (e. g. [4]). Although the gravity dependence of the convective velocity has to be investigated to discuss the possibility of regolith convection under the microgravity condition such as asteroid Itokawa, only a few researches concerning this problem have been performed so far [5].

We performed systematical experiments of the granular convection with glass beads under the steady vertical vibration. Although the direct control of gravity is quite difficult in laboratory experiments, we instead employ the scaling approach to figure out the gravity dependence of the granular convective velocity. As a result, we found that the granular convective velocity is almost proportional to the gravitational acceleration [6]. This experimental result suggests that the convective velocity would be very low under the microgravity condition. The low convective velocity would result in the long timescale of regolith migration. In order to examine the feasibility of the regolith convection on Itokawa, the resurfacing timescale induced by regolith convection should be compared with the surface age or the lifetime of Itokawa. In this study, we aim at developing a model of resurfacing process induced by granular convection. The model allows us to estimate the resurfacing timescale not only Itokawa but also on the general asteroids covered with regolith.

In the model, we divide the resurfacing process into three phases as follows:
1. Impact phase: An impactor intermittently collides with a target asteroid.
2. Vibration phase: The collision results in a global seismic shaking.
3. Convection phase: The global seismic shaking induces the regolith convection on the asteroid.

For the impact phase, we estimate the frequency of impact events per year by using the model of impactors' population in the main belt asteroids (MBA) [7]. To compute the vibration strength induced by each impact, we utilize the global seismic shaking model [8] for the vibration phase. For the convection phase 3, we use the scaling of the granular convective velocity [6] in order to relate the vibration strength and the regolith convective velocity. Combining these three phases, we compute the resurfacing timescale T as a function of the diameter of target asteroid D_a.

We assume the specific parameter values based on previous work [1, 7, 8] to compute T. As a result, we find T= 9 Myr for the Itokawa-sized asteroid, and this value is comparable to the surface age of Itokwa measured by the returned sample (1 ? 8 Myr) [2, 3]. In addition, T= 9 Myr is much shorter than the mean collisional lifetime of Itokawa (about 170 Myr [7]). This indicates that the regolith convection is able to resurface the asteroid almost within its lifetime.

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Keywords: granular convection, regolith fluidization, asteroid, resurface

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Granular flow field around an obstacle and clogging at a bottleneck outlet

ENDO, Keita[1*] ; KATSURAGI, Hiroaki[1]

[1]Graduate School of Environmental Studies, Nagoya University

Granular materials in the flowing state can form an arch structure at the bottleneck. Due to the arch formation, particles suddenly clog to arrest the flow. It has been empirically known that the clogging phenomenon cannot occur when the size of bottleneck is larger than approximately six times of diameter of particles [1]. Even in this flowing state without clogging, the flow rate would not be steady but vary depending on various parameters. In addition, the occurrence frequency of clogging could be decreased by inserting obstacles into the flow fields. Therefore, the effect of obstacles in the flow field must be an important key for the better understanding of granular clogging phenomenon. Furthermore, it is expected that the understanding of these phenomena will be helpful for structural design of buildings to control the flow of evacuating people. In this case, the flow of evacuating people can be regarded as a kind of granular flow. The nonlinear behaviors of granular matter such as the sudden clogging and arch formation could also relate to various geophysical phenomena, e.g., landsliding and avalanching.

In this study, we performed a simple experiment of gravity-driven granular flow controlled by the outlet and obstacle. First, we insert a disk-like obstacle into a two-dimensional cell, and fill the cell with stainless balls in diameter of 6.35 mm. Then, a small outlet is opened at the center of the bottom in the cell to create the granular flow toward the outlet. Granular flow field and the flow rate as well as the drag force exerted on the obstacle are measured using a high-speed camera and load cells. In particular, we experimentally examine how the flow field and flow rate are influenced by the parameters such as the size of outlet and the position of obstacle.

From the images of the granular flow acquired by the high-speed camera, we observe that the alternate flow, i.e., non-uniform (asymmetric) flow field, is generated by inserting the obstacle. On the other hand, the net flow rate at the outlet is found to be approximately steady. We further analyze the granular flow movie by Particle Tracking Velocimetry (PTV) method. Using PTV method, tracks of flowing particles can be measured. We divide the cell into three parts: an area right above the outlet and two sides (left and right) around the obstacle. Then, we calculate the flow field and packing fraction for each area. Besides, we also compute Mean Square Displacement (MSD) from the paths of the individual particle, on the basis of PTV data.

We discuss the relation between these values and physical quantities such as granular flow rate and drag force exerted on the obstacle, and then, we clarify how obstacles influence the granular flow fields through these parameter dependency.

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Keywords: granular flow, clogging, obstacle, particle tracking velocimetry, mean square displacement

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Feasibility Study of Morphological Characterization to Comminuted Particles by A Particle Characterization Approach

SASAKURA, Daisuke[1*] ; HAYAUCHI, Aiko[1] ; KUWANO, Osamu[2]

[1]Malvern instruments A division of Spectris Co., Ltd., [2]Japan Agency for Marine-Earth Science and Technology

1.introduction

A faults zone contains fine rock powders called gouge that have been ground up by past fault motions. Particle size distribution and particle shape of gouge particles may affect the frictional properties of the fault and reflect the comminution process by the past fault motions. It is well known that particle size distribution (PSD) of fault gouge show power-law distributions. Exponent of this power law, called fractal dimension, is considered to reflect the style and amount of deformation. This report will be discussed for relationship between the particle morphology and a style and a degree of comminution of model particles by automated particle image analysis and laser diffraction as a particle characterization method.

2.Method

As an automated particle image analysis, Morphologi G3-SE (Malvern Instruments) was used for evaluation of particle size and shape. The observation mode was diascopic mode (Transmittance mode) and a magnification was choose to sufficient to cover 1 to 1,000um. The sample was dispersed with SDU (Sample Dispersion Unit) which attached Morphologi G3-SE. Number of measured particles was over than ten thousand and a parameter filter function on software was used based on shape and pixel number of particle image. As a laser diffraction instruments with dry dispersion methods , Mastersizer3000 with Aero unit (Malvern Instruments) was used for evaluation of particle size in less than 1um as fine particles.

Keywords: Fault gouge, Particle size, Particls Shape, Comminution, Fractal Distributions

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Shape, propagation style and velocity of a buoyancy-driven crack : a parameter study

TAKEGUCHI, Izumi[1*] ; SUMITA, Ikuro[1]

[1]Kanazawa University

Introduction: Magma is considered to ascend in the form of a diapir by deforming the host rock in the asthenosphere whereas it ascends as a dyke by brittle fracturing in the lithosphere (Rubin, 1995). How does the magma ascend in the transitional regime? We have been studying the ascent mechanism in the transitional regime by model experiments using a viscoelastic agar and widely varying its stiffness (Sumita and Ota, 2011). Here we report the results of experiments which focus on the effect of fluid viscosity on the magma migration in a viscoelastic medium.

Experimental method: We conducted (1) rheology measurement of an agar and (2) fluid injection experiments. We inject magma (CsCl solution to which a thickener is added) using a syringe from the top of a cylindrical acrylic tank (height of 250 and 500 mm). The fluid has a volume of 1ml, a density difference with the agar of 0.580 and 0.770 g/ml, and is injected at a constant rate of 1 ml/s. We vary the agar concentration(C) in the range of C = 0.06-0.5 wt% and the fluid viscosity(η) in the range of η = 10ˆ-3 - 1300 Pas. As we increase the agar concentration in this range, the yield stress and the rigidity of the agar increases by 3 and 2 orders of magnitude, respectively. From creep test conducted under a constant shear stress, we find that the agar can be approximated by a Voigt model to which a spring is connected in series for C › 0.1wt%, and a Burgers model for C ‹ 0.1wt%. The experiments are recorded using video cameras from two sides and from the bottom of the tank.

Result: From the crack shape, propagation style and velocity, we classified the experiments into the following 3 regimes. Regime Ⅰ: The crack has a 2D(blade-like) shape, a straight trajectory and stops propagating in a short distance. We fit the distance(z) vs time(t) data to a power-law(z$\propto$tˆn) relation, and find that the power law exponent is n$\sim$1/5. The migration velocity depends on viscosity as $\sim$ 1/n. Regime Ⅱ: The crack shape transforms from 2D to 3D(i.e. , having a bulged head) and its trajectory is curved or meanders. The power-law exponent varies as n=1/3-1. We find that as the fluid viscosity increases, the amplitude of the meandering becomes smaller and transforms to a straight path. The same transformation was observed when the fluid density becomes smaller (Sumita and Ota, 2011). The migration velocity is intermediate from those of regimes Ⅰ and Ⅲ. Regime Ⅲ: The crack shape is 3D, the trajectory is straight and the propagation distance is long. The power-law exponent is n$\sim$1. The dependence of migration velocity on viscosity is small.

Discussion: The condition for the regime Ⅰ-Ⅱ transition can be approximately described using the dimensionless buoyancy B=△ρgVˆ1/3/G(△ρ: density difference, g: gravity, V: crack volume)as B$\sim$1. However in detail, we find that the B value becomes larger for a high viscosity fluid. This is because when the propagation velocity is small, a larger fraction of the fluid is left along the crack tail such that the crack head volume become smaller, which results in a smaller effective B value . The migration velocity was found to be comparable to or smaller than the channel flow velocity(n=1/3:Taisne et al. (2011)) in regime Ⅰ and comparable to the Stokes settling velocity(n=1) and shear wave velocity in regime Ⅲ. This suggests that the propagation velocity is also rate-limited by rupture velocity. We indeed confirmed that the propagation becomes faster when there is a preexisting crack. We find that the meandering of regime Ⅱ no longer occurs under a large viscosity. This suggests that in addition to B$\sim$1, there is a critical velocity, or a critical Reynolds number required for meandering to occur.

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Keywords: magma ascent, crack propagation, viscoelasticity, fluid viscosity, bouyancy

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Measurements of elastic wave velocity of Aji granite on triaxial compression fracture test

ZAIMA, Kanta[1*] ; KATAYAMA, Ikuo[1]

[1]Department of Earth and Planetary Systems Science, Hiroshima university

Elastic wave velocity is one of the important physical properties to understand underground mechanics. Especially, in geothermal generation, it has an important part to play in estimating geothermal fluid reservoir. In addition, it is imperative in estimating artificial geothermal reservoir which is formed by hydraulic fracturing. Elastic wave velocity varies in different situations, for example, porosity, shape of crack, distribution of crack, with or without fluid and so on. Many experimental results have been reported until now, for example, velocity change against confining pressure (Nur and Simmons, 1969), velocity change in fracture process (Bonner, 1974). At laboratory, examining these change lead to interpreting underground mechanics which means that estimating geothermal reservoir or artificial one. This study is intended to examine the velocity change in fracture process existing pore pressure and lead to interpreting artificial reservoir in hydraulic fracturing. In this graduation work, we improved the system of measurement of elastic wave velocity using inter-vessel deformation fluid-flow apparatus at Hiroshima University and examined change of elastic wave velocity of dry rock in fracture process.

We used Aji granite which is formed into cylindrical shape as a specimen and tried three measurement systems. First method is pulse reflection method which place piezoelectric device on the top of specimen. Second method is transmission method (σ1 direction) which place piezoelectric device on the top and bottom of specimen. Third method is transmission method (σ3 direction) which place piezoelectric device on the lateral face of specimen directly. We measured elastic wave velocity under the confining pressure 10 to 200MPa using these methods. In all methods, we could find increase of elastic wave velocity due to compaction through increasing confining pressure. However, in pulse reflection method and transmission method (σ1 direction), we could'nt calculate the velocity under low confining pressure in which porosity is high and in long specimen because of attenuation of pulse. So these two methods are not well-suited on the purpose of measurement in fracturing process which use specimen of 40mm long. On the other hand, in transmission method (σ3 direction), although we cannot reuse piezoelectric device because it is attached directly, it is possible to minimalize the pulse attenuation.

From the results mentioned above, We used the transmission method (σ3 direction) and measured elastic wave velocity of Aji granite in fracture process. This experiment is conducted under confining pressure 20MPa and displacement rate 0.01mm/min using loading system by servo control of inter-vessel deformation fluid-flow apparatus. Specimen is Aji granite which is prepared into a cylindrical shape, which diameter and lengths is 20mm and 40mm, and also which is processed to attach the piezoelectric device.

Increasing of elastic wave velocity was observed until about one-fifth of fracture stress, and then over one-third of it increasing shifted to decreasing. Firstly, increasing of the velocity means closure of micro-cracks in existence. Then gradually, the changes of the velocity start to decrease due to formation of new cracks in the specimen. This effect of formation of crack is more strengthen and the velocity decreases rapidly. Therefore it is possible to explain this decreasing of the velocity by dilatancy effect. Increasing of Vs is affected strongly by closure of cracks extended to σ3 direction because direction of vibration of S-wave is normal to maximum compressional axis in this experiment.

Keywords: elastic wave velocity, geothermal fluid reservoir, hydraulic fracturing, dilatancy

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Rheological weakening due to phase mixing of olivine + orthopyroxene

TASAKA, Miki[1*] ; ZIMMERMAN, Mark[1] ; KOHLSTEDT, David[1]

[1]University of Minnesota

The formation of well-mixed, fine-grained, poly-phase rocks may lead to strain localization and play a key role in the development of the lithosphere asthenosphere boundary (LAB). To understand the mixing process in the olivine + orthopyroxene rocks, we have conducted torsion experiments on samples of iron-rich olivine + orthopyroxene aggregates at a temperature of 1200 ℃ and a pressure of 300MPa. We fabricated the samples with grain sizes significantly larger than the steady state grain size. The samples were deformed to total shear strains up to γ = 17. We conducted two series of torsion experiments, the first at fixed strain rate to different strains and the second at different strain rates to the same strain.

The stress exponent of $n \approx 3$ and grain size exponent of $p \approx 1$ were determined from a least-squares fit to the strain rate, stress and grain size data using a power-law creep equation; these values of n and p indicate that our samples deformed by dislocation-accommodated grain boundary sliding. Dynamic recrystallization occurred with significant grain size reduction of both phases in deformed samples. Well-mixed microstructures develop in samples deformed to higher strains at faster strain rates, whereas elongated olivine and pyroxene grains without a mixed texture are observed at lower strain and strain rate. Mixing of the olivine and orthopyroxene phases occurs due to a contribution of interface-reaction-limited diffusion (IRLD) creep [Sundberg and Cooper, 2008]. This IRDL creep process involves diffusion of metal oxides along phase boundaries oriented perpendicular to σ_1 to boundaries parallel to σ_1 resulting in the formation of new pyroxene grains along boundaries perpendicular to σ_1 and olivine grains along boundaries parallel to σ_1. Grain size reduction due to dynamic recrystallization of olivine and orthopyroxene enhance the rate of this process.

Keywords: olivine, opx, deformation, mixing process

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Technical developments on acoustic emissions monitoring at high pressures

OHUCHI, Tomohiro[1*] ; LEI, Xinglin[2] ; HIGO, Yuji[3] ; TANGE, Yoshinori[3] ; IRIFUNE, Tetsuo[1]

[1]Geodynamics Research Center, Ehime University, [2]National Institute of Advanced Industrial Science and Technology, [3]Japan Synchrotron Radiation Institute

The subduction zone produces a major fraction of the Earth's seismic activity. Intermediate-depth earthquakes within the subducting slab form a double seismic zone. The cause of intraslab seismicity have been attributed to dehydration of hydrous minerals (e.g., Peacock, 2001). Brittle fracture associating dilatancy is difficult at high pressures (i.e., depths at which intermediate-depth and deep-focus earthquakes occur), although dilatancy prior to failure usually occurs in the case of shallow-depth earthquakes.

At deeper depths, dehydration embrittlement (i.e., hydrofracturing) is expected to play an important role in failure of rocks because the overall volume change of the dehydration reaction is positive and thus pore pressure can be increased (e.g., Raleigh and Paterson, 1965). However, experimental results on dehydration embrittlement of antigorite are controversial. Dobson et al. (2002) conducted a series of experiments on dehydration of antigorite, and they reported that dehydration of antigorite associates acoustic emission (AE) when the dehydration reaction is positive. Even though the volume change becomes strongly negative above 2 GPa, Jung et al. (2004) reported that brittle failure of antigorite occurs at pressures up to 6 GPa. Recently, Gasc et al. (2011) reported that no detectable AEs through dehydration of antigorite-rich serpentinite. Therefore, the cause of intermediate-depth earthquakes is still unclear.

In some of subduction zones, a significant activity of deep-focus earthquakes has been reported (e.g., Kirby et al., 1996). It has been proposed that deep-focus earthquakes are triggered by an instability faulting caused by olivine phase transformations (Kirby et al., 1991; Green et al., 1992). Schubnel et al. (2013) conducted deformation experiments on germanium olivine (Mg2GeO4) at 2-5 GPa and 1000-1250 K, and they observed many AEs generated in the sample. Schubnel et al. (2013) discussed that fractures nucleated at the onset of the olivine-to-spinel transition.

To investigate the brittle properties of rocks, determination of AE source is critical. In the community of high-pressure rock physics, Green et al. (1992) conducted AE monitoring by using a Griggs apparatus combined with an AE sensor. Dobson et al. (2002, 2004) and Jung et al. (2006) adopted 2 or 4 AE sensors to a multianvil apparatus. However, the position of AE source has not been determined in the experiments because of not enough number of sensors used in the experiments. De Ronde et al. (2007) adopted 8 AE sensors to a multianvil apparatus and they succeeded to determine the position of AE sources. Recently, Gasc et al. (2011) succeeded to develop an experimental setup that allows determining the position of AE source by using DIA-type multianvil apparatus combined with 6 AE sensors. Schubnel et al. (2013) adopted the experimental setup reported by Gasc et al. (2011) to a D-DIA apparatus installed at a synchrotron facility, and they succeeded to measure strain and stress of the sample and AE signals. We have developed an experimental setup that is optimized for the determination of the position of AE source in a synchrotron D-DIA apparatus. We will report some preliminary experimental results on AE monitoring under the upper mantle conditions.

Keywords: acoustic emission, high pressure, earthquake

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Study of rock deformation mechanism using neutron diffraction technique and AE signal measurement

ABE, Jun[1*] ; SEKINE, Kotaro[2] ; HARJO, Stefanus[3] ; GONG, Wu[3] ; AIZAWA, Kazuya[3]

[1]CROSS-Tokai, [2]JOGMEC, [3]JAEA

Acoustic emission (AE) is defined as a transient elastic wave generated by the rapid release of energy within a material. Crack initiation and slipping generated inside rock materials are all detectable with the measurement of AE signals, and therefore such measurement helps to research the underlying mechanism of macroscopic deformation. On the other hand, strain gauge is commonly used to measure strain in rock. In recent years, diffraction techniques for investigating strain in engineering materials have been developed. Strain measurements using diffraction technique are based on Bragg's law. Strain value can be estimated from the changes of lattice parameter.

Accumulation of macro strain in rock samples is generally caused by lattice strain as well as grain boundary shearing and pore collapse generated inside the rock, which would be detectable as AE events. Therefore, simultaneous using of neutron diffraction technique and AE signal measurements should provide us with new insight into rock deformation and fracturing mechanism. In order to study deformation mechanism of geological materials under uni-axial compression, neutron diffraction patterns and AE signal have been measured simultaneously.

Berea sandstone and calcarenite are used as a specimen. Main composed mineral of Berea sandstone is quartz (SiO2), and that of calcarenite is calcite (CaCO3) with minor apatite. Berea sandstone was compressed uniaxially up to 35.6 MPa with two-cycle compression. Calcite was compressed until the specimen fractured at 16.4 MPa. Lattice strain measurements using neutron diffraction technique were performed at the Engineering Materials Diffractometer "TAKUMI" in J-PARC/MLF. The diffractometer have been designed to investigate the stress-strain state of engineering materials (e.g. steel) using a pulsed neutron beam. Macroscopic strain was recorded using a strain gauge attached to the rock specimen surface. AE signal measurements were conducted using USB AE NODE (PHYSICAL ACOUSTIC CORP.) with a miniature AE sensor (Micro30) attached to a compression jig.

Macroscopic strain of both rock materials was greater than lattice strain. Inside rock specimens, mineral grain slip and pore collapse might be generated under compression. These changes would induce macroscopic deformation of the rock specimens. In addition, AE signals which might be derived from these changes in the internal structure of the rock specimens were detected. Parameters of AE signals might be a function of the amount of grain-boundary shear and/or the degree of resistance to deformation. And the frequency characteristics of AE signals depend on rock type. This difference between rock types might be related to the deformation mechanism of the rock specimens.

Keywords: neutron diffraction, lattice strain, AE, uxi-axial compression, rock deformation

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High-pressure deformation experiments on olivine-orthopyroxene aggregates under hydrothermal conditions

FUKUSHIMA, Kumi[1*] ; HIRAUCHI, Ken-ichi[1] ; KIDO, Masanori[2] ; MUTO, Jun[2]

[1]Department of Geosciences, Graduate School of Science, Shizuoka University, [2]Department of Earth Sciences, Tohoku University

For plate tectonics to operate on a terrestrial planet, the strength of faults within the oceanic lithosphere must be low, with the coefficient of friction below 0.05. However, standard strength profile using olivine flow law far exceeds this threshold value, particularly at depths of 20 to 40 km, where fluids passed through the faults may interact with peridotites to form hydrous minerals (e.g., serpentine). Here, we conducted deformation experiments on harzburgitic olivine-orthopyroxene aggregates under hydrothermal conditions, at a temperature of 500 ℃, a confining pressure of 1.0 GPa, and shear strain rates of 5.9 x 10^{-5} to 4.3 x 10^{-6} s^{-1}. All experiments showed a peak shear strength (about 400 MPa) at shear strains of 0.7, followed by a large stress drop (up to 150 MPa), after which steady-state sliding was observed until significant strain weakening started to occur at shear strains of 1.5. The drop in shear stress was initially caused by unstable slip, which resulted from the development of localized shear planes (Riedel or boundary shears) after yielding. The strain weakening after shear strains of 1.5 is related to shearing of newly formed talc along the shear planes. Talc may form from preferential dissolution of orthopyroxene rather than olivine. The final shear strength (down to 30 MPa) decreased with decreasing shear strain rates, reflecting widening of the talc layer along the shear planes. These results suggest that hydrothermal alteration of peridotites along the deep faults play an important role in forming the extremely weak zone for subduction initiation.

Keywords: olivine, orthopyroxene, talc, hydration reaction, strength weakening, subduction initiation