



Proceedings of  
**International Symposium on  
Earth Science  
and Technology 2019**

**December 5 - 6, 2019**

**Shiiki Hall**

**Kyushu University, Fukuoka, Japan**

Organized by  
Cooperative International Network for Earth Science and Technology (CINEST)

Sponsored by  
MITSUI MATSUSHIMA CO.,LTD.  
KAJIMA FOUNDATION  
YASHIMA ENVIRONMENT TECHNOLOGY FOUNDATION  
ASSOCIATION FOR DISASTER PREVENTION RESEARCH

Assisted by  
 The Mining and Materials Processing Institute of Japan

Supported by  
Mining and Materials Processing Institute of Japan (MMIJ) Kyushu Branch  
MMIJ-Division of Coal Mining Technology



## Contents

Paper No.	Paper Title	Authors	Page
Prenary I	Underground Coal Gasification Development in Japan	Ken-ichi Itakura	1
Prenary II	Acid Mine Drainage Mitigation Using Industrial Byproducts	Amde M. Amde	5
A-01	Three-Dimensional Gravity Modeling for Imaging the Geothermal Reservoir Border in Eburru Geothermal Field, Kenya	Justus Maithya, Yasuhiro Fujimitsu, Jun Nishijima	13
A-02	Optimization of geothermal Binary Unit by Energy, Exergy and Sustainability Index: Comparative study of Olkaria Geothermal Field in Kenya and Chiweta Geothermal field in Malawi	Alvin Kiprono Bett, Dyson Moses, Saeid Jalilinasrabad	19
A-03	Multi-dimensional Resistivity Imaging from Magnetotellurics Data and its Geological Interpretation in Kiejo-Mbaka Geothermal Field, South-West Tanzania.	Tumbu Lucas Boniface, Hideki Mizunaga	25
A-04	Numerical Simulation of Thermosiphon's Sustainability for Estimating Energy and Cost with Closed-Loop Geothermal Power Generation Using SCCO <sub>2</sub>	Zhenyu Ma, Masaatsu Aichi	32
A-05	Geochemistry and origin of the host rocks of Mbesa Cu-Ni-PGE prospect, Southern Tanzania	Hidaya HASSAN, Kotaro YONEZU, Akira IMAI, Thomas TINDELL, Koichiro WATANABE	36
A-06	Mineralogy and mineral associations of platinum group elements in the ultramafic cumulates of Molopo Farms Complex at the Tubane area, southern Botswana	Jacob KAAVERA, Akira IMAI, Kotaro YONEZU, Thomas TINDELL, Kenzo SANEMATSU, Koichiro WATANABE	42
A-07	Characteristics of ore-forming fluids at the Hakurei Site, Izena Hole, middle Okinawa Trough	Yushi Sekiya, Nobuhiro Mukae, Kotaro Yonezu, Thomas Tindell, Jun-ichiro Ishibushi, Tatsuo Nozaki, Akira Imai	47
A-08	Petrography and mineralogy of tin pegmatite deposit in the Yamon-Kazat area, southern Myanmar	Hiroki Kinoshita, Kyaw Thu Htun, Kotaro Yonezu, Akira Imai	51

A-09	Relation between concentration of Sc and Ni and bedrock in Ni laterite deposit, Berong in Palawan Island, Philippines	T. Yamada, K. Yonezu, Jillian Aira S. Gabo-Ratio, R. A. Santos, Marc Raymond L. Zamora	55
A-10	Mineralogical study of chimney and mound sulfide ore at the Gondo hydrothermal field in the Okinawa Trough	Yuuki Tada, Kotaro Yonezu, Thomas Tindell, Shu-hei Totsuka, Akira Miyamoto, Jun-ichiro Ishibashi, Junichi Miyazaki, Ryo Okumura, Yuto Inuma, Koichi Takamiya	59
A-11	Geochemistry, Mineralization and Fluid Inclusion Study of The Bayan-Uul Porphyry Cu-Au-Mo Deposit, Central Mongolia	Bilegsaikhan Bolor-Erdene, Kotaro Yonezu, Akira Imai, Thomas Tindell, Jargalan Sereenen	63
A-12	Mineralization and Fluid Inclusion Microthermometry in EE3 Gold Prospect, Sagaing Region, Northern Myanmar	Htet Sandar Aung, Kotaro Yonezu, Akira Imai, Thomas Tindell, Koichiro Watanabe, May Thwe Aye	67
A-13	MINERALOGY AND GEOCHEMISTRY OF TAGUN -KHIN-DAN GOLD MINERALIZATION AREA IN SLATE BELT OF CENTRAL MYANMAR	Sai PYAE SONE, Kotaro YONEZU, AKIRA IMAI, Koichiro WATANABE, Kenzo SANEMATSU	72
A-14	Environmental impact of amino acids on the stability of layered double hydroxides bearing $^{79}\text{SeO}_2^{-4}$	Mengmeng WANG, Keiko SASAKI	78
A-15	Novel ultrasonic-assisted modulated hydrothermal synthesis of Zr-fumarate framework (MOF-801) for adsorption of antimonate in aqueous solutions: A comparison study with conventional solvothermally synthetic methods	Shunsuke Imamura, Radheshyam Rama Pawar, Keiko Sasaki	82
A-16	Suppression of anionic pollutants released from fly ash by different Ca additives and its application to cement.	Shingo NAKAMA, Keiko SASAKI, Ryoichi TAKAGI, Tadahiro KAWAHARA	85
A-17	Characterization and Flotation Separation of Bitumen from Indonesian Asbuton	Aldiyansyah, Bonita Dilasari, Ismi Handayani	89
A-18	Strontium ion ( $\text{Sr}^{2+}$ ) separation from water using nanoscale zero valent iron-zeolite composite	Tamer SHUBAIR, Osama ELJAMAL	95
A-19	Experimental Study on Correlation Between Spontaneous Combustion and Surface $\text{CO}_2$ Flux in Abandoned Coal Mine Goaf	Yongjun WANG, Xinoming ZHANG, Hemeng ZHANG, Wei DONG, Kyuro SASAKI	97

A-20	"Leave the Carbon in the Ground": in-situ combustion by injecting air into abandoned shale reservoirs	Kazuki Sawayama, Kewen Li, Roland Horne	103
A-21	Study of Models of Hydration Force to Calculate the Wettability of CO <sub>2</sub> /Brine/Mineral System	Masushige Shiga, Masaatsu Aichi, Masao Sorai, Hiromi Honda	109
A-22	The influence of polymorphs of CaCO <sub>3</sub> on CO <sub>2</sub> mineralization	Yutian Zhang, Takeshi Tsuji, Fei Jiang	115
A-23	Numerical Study of the Effects of Interfacial Tension on Production of Foamy Oil by CO <sub>2</sub> -gas Foaming	Sovanborey MEAKH, Chanmoly OR	118
A-24	In-Situ Gelation, Characterization and Pore Blocking Performance In Heterogeneous Reservoir	Sammeang Chea, Sasaki Kyuro, Ronald Nguete, Sugai Yuichi	124
A-25	Nanofluid Flooding for Enhanced Oil Recovery: Study on Ion Tracking of Produced Fluid	Tola Sreu, Kyuro Sasaki, Ronald Nguete, Yuchi Sugai	129
A-26	Alteration of Physical Properties of Heavy Crude oil in High Temperature Range by Adding Fine Particles	Vitana Mom, Kyuro Sasaki, Ronald Nguete, Yuichi Sugai	132
B-01	Performance of Open Fly Ash Channel: Result of Laboratory Study	Sendy Dwiki, Rudy Sayoga Gautama, Ginting Jalu Kusuma, Mohammad Salman Said	136
B-02	Study of Wetland for Management of Acid Mine Drainage on the Porphyry Copper-Gold Mine in Indonesia	Waterman Sulistyana Bargawa, Untung Sukanto, Muhammad Nurcholis, Maharani Rindu Widara, Agus Parica Adi Sucahyo	142
B-03	Geochemical Characterization of Rare Earth Elements (REE) in Acid Mine Drainage from Coal Mine	Abie Badhurahman, Rudy Sayoga Gautama, Ginting Jalu Kusuma	148
B-04	Application of Isotope Methods for Identifying Groundwater Flow Paths into Closed Mine Sites in Japan	S. Matsumoto, M. Ono, I. Machida	152
B-05	Analysis on the Geological Factors and Countermeasures of Geological Risk Events in Mountain Tunnel	Yoshio UDAGAWA	156
B-06	Study of Ground Reaction Curve (GRC) In Non-Circular Shallow Twin Tunnels Using Finite Element Methods and Convergent Measurement Results	Ali Husain TAHERDITO, Nuhindro Priagung WIDODO, Simon Heru PRASETYA, Budi SULISTIANTO, Made Astawa RAI	162

B-07	Stability Analysis of Sill Pillar on Underground Mining Sublevel Stopping with Analytical Methods	Calvin Leonard, Simon Heru Prasetyo, Ganda Maribot Simangunsong	168
B-08	Designing a Drill-and-Blast Tunnel Excavation Method to Minimize Vibration Impact on the Surrounding Structures	Ganda M. Simangunsong, Simon H. Prasetyo, Jordi Fatah	174
B-09	Subsidence Calculation Model of Different Zone after Mining Based on Optical Fiber Sensor	Meng Fanfei, Takashi Sasaoka, Hideki Shimada, Akihiro Hamanaka, Sugeng Wahyudi, Piao Chunde	178
B-10	Geochemistry and Petrography Characteristics of Magmatic Rare Earth Elements Deposit in Belitung Island with Special Reference to S-type Tanjungpandan Granite	Muhammad Dzulfikar Faruqi, Faishal Arkhanuddin, Natalia Aritonang, Angga Widya Yogatama, Sutarto	183
B-11	First Step of Gold Mining Exploration To Discovery: Determining Area of Prospect by Intersection of GIS & Geology Information	Bella Wijdani Sakina, Zulfahmi Roskha, Trifatama Rahmalia, Abdul Bari, Bronto Sutopo	191
B-12	Characteristic of Gold Mineralization of the Santoy Vein, Sangilo Mine, Baguio Mineral District, Philippines	Naoto Kugizaki, Kotaro Yonezu, Akira Imai, Jillian Aira S. Gabo-Ratio, Eric S. Andal	197
B-13	Geometry of Paleovolcanic Area Groundwater Basin System Based On Geoelectric & Geological Data in Wediombo beach and Surrounding, Gunungkidul Regency, Yogyakarta Province	Arhananta, Avellyn Shinthya Sari, Aditya Rizky Wibowo, Agung Prayoga, Suko Prakoso, Abdul Aziz Makarim, Haikal Fadhil Pamungkas, Anggita Mahyudani Rkt, Favian AvilaRestiko	201
B-14	Analysis of Physical and Mechanical Rock Properties Based on Geological Domain in the Nickel Laterite Zones at PT Antam Tbk Site Pomalaa, Southeast Sulawesi	Febrianti Tricahyani, Riko Ardiansyah, Barlian Dwinagara	205
B-15	An Evaluation of Excavatability Criteria for Sedimentary Rocks: A Correlation from Mechanical Properties	Oktarian W. Lusantono, Prasodo D. Prabandaru, Shefa R. Haq, Barlian Dwinagara	210
B-16	PROBABILISTIC OF PLANE FAILURE USING MONTE CARLO SIMULATION IN SLOPE STABILITY ANALYSIS WITH LIMIT EQUILIBRIUM METHOD	Muhammad Alfiza Farhan, Made Astawa Rai	216

B-17	Overburden Dump Stability in Coal Open Pit Mine with Weak Coal-Bearing Strata	Tri Karian, Budi Sulistianto, Ginting Jalu Kusuma	222
B-18	Effect of Firing Pattern on the Size Distribution of Rock Fragmentation in Open Pit Mine	Takahiro SHIOMORI, Takashi SASAOKA, Sugeng WAHYUDI, Akihiro HAMANAKA, Hideki SHIMADA	228
B-19	Fundamental Study on Recycling of Returned Concrete as Ground Materials: Strength Properties of Modified Soils Produced from Returned Concrete	Ryota ICHINOHE, Tomoaki SATOMI, Hiroshi TAKAHASHI	233
B-20	Experimental Evaluation of Shear Strength Parameters of Fiber-Cement-Stabilized Soil	Kazumi RYUO, Haruka KUBOTA, Tomoaki SATOMI, Hiroshi TAKAHASHI	238
B-21	Study on Soft Soil Reinforcement by Liquefied Stabilized Soil Method using Paper Sludge Ash based Geopolymer	Vu Minh CHIEN, Tomoaki SATOMI, Hiroshi TAKAHASHI	244
B-22	Experimental Investigation of Effect of Gravel Content on Soil Failure Process and Excavating Force during Soil Excavation by Bucket	Kobei SHIOTA, Tomoaki SATOMI, Hiroshi TAKAHASHI	250
B-23	Quality improvement of Cambodian ceramic using Kandal clay incorporating with rock dust for ceramic brick	Chea Monyneath, Bun Kim Ngun	255
B-24	Revisiting the Method of Groundwater Flux Estimation from Underground Temperature Profile Considering the Joule-Thomson Effect and Gravitational Potential Energy Dissipation	Kento Akitaya, Masaatsu Aichi	261
B-25	Spatial-Temporal Analysis of Landscape Ecological Connectivity Changes in Makassar City	Nurul Masyiah Rani HARUSI, Yasuhiro MITANI, Yuki OKAJIMA, Hisatoshi TANIGUCHI	266
B-26	Relationship between land use changes during 1900-2014 and Kyushu heavy rain disaster in 2017	Lu TIAN, Yasuhiro MITANI, Yuki OKAJIMA, Satoru KIMURA, Taiga TABUCHI	273
C-01	Comparison on the Catalytic Mechanism of Activated Carbon in Bioleaching of Chalcopyrite and Enargite	Keishi Oyama, Kyohei Takamatsu, Hajime Miki, Keiko Sasaki, Naoko Okibe	280
C-02	Synergistic effects of biogenic manganese oxide and Mn(II)-oxidizing bacteria on the oxidation of arsenite	Ryohei NISHI, Santisak KITJANUKIT, Kohei Nonaka, Naoko OKIBE	282

C-03	Importance of sulfur oxidizing microorganisms for chalcopyrite bioleaching with saline water	Haruki NOGUCHI, Naoko OKIBE	284
C-04	Sequential Bio-treatment of Carbonaceous Silver Ore	Diego M. Mendoza Flores, Kojo T. Konadu, Ryotaro Sakai and Keiko Sasaki	286
C-05	Environmental Impact of Au Artisanal Mining on Plampang River, Yogyakarta, Indonesia	Dewi Ayu Kusumaningsih, Barlian Dwinagara, Shofa Rijalul Haq	290
C-06	Heavy metal removal from aqueous solution using Na <sub>2</sub> S treated sheep wool at different concentration	Solongo Enkhzaya, Koichiro Shiomori, Bolormaa Oyuntsetseg	297
C-07	How Does Organizational Culture Support Company Safety Performance, Evidence from Indonesia	Yosep Irsana, Yoshiyuki Matsuura	301
C-08	Outliers Treatment in the Grade Determination for Economic Feasibility (Case Study: Limestone Mining)	Hidayatullah Sidiq, Akliq Ardian, Shofa Rijalul Haq	307
C-09	Economic Valuation of Mining Project Using Fuzzy Real Option Method: Case Study of Underground Gold Mine	Fadhila Achmadi ROSYID, Arjo Prawoto Wibowo, Sari Uly SIBARANI, Lilik Eko WIDODO, Mohamad Nur HERIAWAN	312
C-10	Automatic Interpretation of Nankai Trough Seismic Data Using Convolutional Neural Networks (CNNs)	Ahmad.B Ahmad, Takeshi Tsuji	318
C-11	SLOPE CONSERVATION IN GUCI GEOTHERMAL AREA, SLAMET MOUNTAIN, CENTRAL JAVA, INDONESIA BASED ON GEOLOGY AND GEOPHYSICAL DATA	Avellyn Shintfya Sari, Arhananta, Anggita Mahyudani Rki, Sari Bahugiarti Kusumayudha	322
C-12	Development of Magnetotelluric 1-D Sparse Inversion	Yosuke Kiyomoto, Hideki Mizumaga, Toshiaki Tanaka	328
C-13	The research on the application of Hilbert-Huang Transformation to time series magnetotelluric data	Hao Chen, Hideki Mizumaga, Toshiaki Tanaka	332
C-14	Potential Assessment of Gas hydrate and Free gas reservoir in Kumano Basin, Japan	Hiroki Matsui, Takeshi Tsuji	336
C-15	Fault detection using pre-trained Convolutional Neural Networks by synthetic seismic data	Lin Yuhua, Takeshi Tsuji	340
C-16	Development of quasi-real time monitoring system of spatial seismic velocity variation on Kyushu Island using ambient noise	Fernando Lawrens Hutapea, Takeshi Tsuji, and Tatsunori Ikeda	346

C-17	Analysis of Seismic Waves from Continuous and Controlled Seismic Signal System in Kyushu Area	Ryosuke Matsuura, Tatsunori Ikeda, Takeshi Tsuji	350
C-18	Impact of Seasonal Rainfall on Crustal Pore Pressure: Insight from Monitoring of Seismic Velocity Changes	Rezkiia Dewi Andajani, Takeshi Tsuji, Tatsunori Ikeda, Fernando Lawrens Hutapea	354
C-19	Water content delineation using Ground-Penetrating Radar Q Tomography	Wahyudi W. Parnadi, Djoko Santoso, Warsa Warsa	358
C-20	Comparison of the Deformation Characteristics of Lowwall on Pit C2 and Pit 7 West Based On Radar Monitoring Data – PT Berau Coal	Nurbaiti Melistia Akhmadi, Ridho Kresna Wattimena	362
C-21	An Analysis of Materials Adhesivity Level on Excavator's Bucket in Open Pit Coal Mining	Prasodo D. Prabandaru, Tubagus Hendarto, Oktarian W. Lusantono, *Barlian Dwinagara, Shofa Rijalul Haq	368
C-22	Analyses of Seasonal Temperature Difference in Underground Surrounding Rocks - Field Verifications	Jianwei Cheng	374
C-23	Visible-Shortwave Infrared Reflectance Spectroscopy Features of Samples from Mamuju, Indonesia Containing Radioactive Minerals	Arie Naftali Hawu Hede, Yogi Priamata, Syafrizal, Mohamad Nur Heriawan, Heri Syaeful	380
P-01	Coal Geology and Coal Depositional Environmental of Keban Area, Lahat Sub-District, South Sumatera, Indonesia	Basuki RAHMAD, Sugeng RAHARJO, EDIYANTO, Fadhil ZUHDI, Indra DARMAWAN	384
P-02	The Affect Coal Facies to the Adsorption of Methane Gas in Coal of Tanjung Formation at Arangalus Area, South Kalimantan Province, Indonesia	Sugeng, Sari BAHAGIARTI, Heru SIGIT PURWANTO, Basuki RAHMAD	389
P-03	Numerical Analysis on Retained – GOAF Side – Gate Road in a Weak Rock Properties of Longwall Coal Mine	Harry KUSUMA, Takashi SASAOKA, Hideki SHIMADA, Akihiro HAMANAKA, Pisith MAO, Sugeng WAHYUDI	394
P-04	Preliminary Study of Mine Closure for Underground Mines in Myanmar	Cho Thae Oo, Takashi SASAOKA, Hideki SHIMADA, Akihiro HAMAKA, Sugeng WAHYUDI, Tun Naing	400



P-05	Investigation on Slope Stability of Internal Dump of the "Baganuur" Open Pit Mine in Mongolia	Bilguun Enkhbold, Hideki Shimada, Takashi Sasaoka, Akihiro Hamanaka, Sugeng Wahyudi	404
P-06	Numerical Study on Rock-Breaking Effect of Shield Hob in Contact Surface of Upper Soft and Lower Hard Strata	Cheng-long Guo, Xin Zhou, Qing Yu, Hideki Shimada	407
P-07	Design of Contiguous Pile Wall and Lateral Supporting System for Deep Excavation at Chroy Changva Region, Phnom Penh City, Cambodia	Tongsan LANN, Chandoeun ENG, Vuthy HORNG	413
P-08	Upgrading the quality of Cambodian ceramic using Kampong Cham clay incorporating with rock dust for ceramic roof tile	Idol PHANN, BUN Kim Ngun	419
P-09	Gas Production Characteristics and Plasma-Desulfurization in Hybrid Underground Coal Gasification (H-UCG) System	Kazuhiro TAKAHASHI, Ken-ichi ITAKURA, Akihiro HAMANAKA, Gota DEGUCHI, Jun-ichi KODAMA	425
P-10	Oil Migration Counteracting Against Chemical Osmosis in Stagnant Pores: A Potential Mechanism of Low Salinity Waterflooding	Mikio Takeda, Mitsuo Manaka, Yoshito Nakashima	427
P-11	Strategies and problems of groundwater monitoring in radioactive waste disposals	Kazumasa Ito	431
P-12	Characterization and acid leaching behavior of spent Mo/Co-catalyst	Yu TANAKA, Naoko OKIBE	435
P-13	Recovery of Ilmenite from Sand Using Wet High-Intensity Magnetic Separator (WHIMS)	Lytheng THORNG, Nallis KRY, Somsak SAISINCHAI	437
P-14	Study of selective flotation of copper sulfide and As containing copper minerals	Yuta Orii, Gde Pandhe Wisnu Suryantara, Hajime Miki, Keiko Sasaki, Tsuyoshi Hirajima, Shigeto Kuroiwa, Yuji Aoki	443
P-15	Decontamination of zinc leach residues by recovering lead and zinc: An approach of concurrent dissolution and cementation using chloride solution and aluminum powder	Marthias SILWAMBA, Ryota HASHIZUME, Ilwan PARK, Sanghee JEON, Meki CHIRWA, Kawawa BANDA, Imasiku NYAMBE, Carlito Baltazar TABELIN, Mayumi ITO, Naoki HIROYOSHI	445

P-16	The effects of co-existing metal ions on the recovery of gold from ammonium thiosulfate solutions using aluminum and activated carbon	Sanghee Jeon, Sharrydon Bright, Ilhwan Park, Mayumi Ito, Naoki Hiroyoshi	449
P-17	Selective coating for improving MoS <sub>2</sub> /CuFeS <sub>2</sub> Flotation	Ilhwan Park, Seunggwon Hong, Mayumi Ito, Naoki Hiroyoshi	452
P-18	Polymerization state of silicic acid adsorbed on anion exchange resin <sup>29</sup> Si MAS NMR relaxation time	Takaaki Chuuman, Kinnosuke Eguchi, Marina Akinaga, Daisuke Kawamoto, Kotaro Yonezu, Koichiro Watanabe, Takushi Yokoyama	455
P-19	Landsat 8 and Airborne Geophysical Data Interpretations to Investigate the Radioactivity Hazards at El Gilf El Kiber Area, South Western Desert, Egypt	Tamer Farag, Nehal Soliman, Atef El Shayat, Hidaki Mizunaga	458
P-20	A study on detection of anomalous groundwater level using Machine Learning	Soshi KAMITAKI, Yasuhiro FUJIMITSU, Jun NISHIJIMA, Tatsuya WAKAYAMA	462
P-21	The Understanding of Volcanoclastics Model in Tebing Breksi Geotourism By Digital Outcrop Model	Muchamad Ocky Bayu NUGROHO, Muhamad SYAIFUDIN, Bambang YUWONO, Basuki RAHMAD	466
P-22	Identification of Characteristics Tsunami Pacitan Bay, East Java Province, Indonesia Based on Surface and Subsurface Data	Dissa Firlina Aya Chania, Alviani Permatasari, Arhananta, Aditya Rizky Wibowo, Yuli Wibowo	470
P-23	Structural Control of Gunungsewu Karst Landform Based on Geomorphological Aspect Guide	Favian Tiko, Nazwa Khoiratun Hisan, Arhananta, Bambang Kuncoro Prasongko	476
P-24	Tectonic history in Hidaka-oki basin and Sanriku-oki basin estimated by sedimentation rates using 3D seismic reflection data	Kosuke Takahashi, Takeshi Tsuji	480
P-25	An Enhanced Edge Detection Technique for Potential Field Data; Case Study of Western USA	Mohammad SHEHATA, Hideki MIZUNAGA	484
P-26	Resistivity measurement technique using capacitor electrodes	Soichiro Hashimoto, Toshiaki Tanaka, Hideki Mizunaga	488
P-27	Subsurface Void Investigation using Ground Penetrating Radar in the Garuda Wisnu Kencana (GWK) Bali	Warsa Warsa, Jeoreinhard Munandar, IB Suandana Yogi	492

P-28	Non-linear inversion study for long grounded wire TDEM Data	Warsa Warsa, Rai Sudha Prabawa	496
P-29	Study on elucidation of hydrothermal system around Shishimuta caldera	Ryo TODA, Yasuhiro FUJIMITSU, Jun NISHIJIMA	501
P-30	Research on improving accuracy of heat discharge estimation system by observing fumarolic gas	Tetsuya YAMAMOTO, Yasuhiro FUJIMITSU, Jun NISHIJIMA	504
P-31	Subsurface structure analysis in Beppu area by gravity survey to clarify of hot spring eruption mechanism	Ryosuke TSUTSUI, Jun NISHIJIMA, Yasuhiro FUJIMITSU	508
P-32	Monitoring geothermal reservoir by measuring gravity change in Ogiri geothermal area	Kentaro SHIMODA, Jun NISHIJIMA, Yasuhiro FUJIMITSU	512
P-33	Geothermal Structure in the Western Part of Kirishima Volcano	Hiroki SHIMADA, Yasuhiro FUJIMITSU, Jun NISHIJIMA	516
P-34	Aluminum Species in Acidic and Neutral pH Geothermal Water	Sachi MASUNAGA, Kotaro YONEZU, Koichiro WATANABE, Takushi YOKOYAMA	520
P-35	GEOHERMAL MANIFESTATION IDENTIFICATION IN ARJOSARI SUBDISTRICT PACITAN REGENCY, EAST JAVA PROVINCE, INDONESIA BASED ON SURFACE AND SUBSURFACE DATA	Anggita Mahyudani Rkt, Dinantina Ahyani W, Aditya Rizky Wibowo, Arhananta, Avellyn Shintya Sari	525
P-36	Geological Mapping and Interpretation of Wild Boar Prospect Area in Ratanakiri Province, Cambodia	Chantra CHHORN, Chandoeun ENG	531
P-37	Geology and fluid inclusion studies on the Shwetagan gold mineralization at Yamethin Township, Mandalay Region, central Myanmar	Myo Kyaw HLAING, Kotaro YONEZU, May Thiwe AYE, Day Wa AUNG, Koichiro WATANABE	537
P-38	Physicochemical Condition of Gold Mineralization in the Masara Mine, Southeastern Mindanao, Philippines	Ryota Kokubu, Akira Imai, Kotaro Yonezu, Thomas Tindell	542
P-39	Study on Applicability of Sealing Material with Low Specific Gravity for Suction Mining of Rare-Earth Rich Mud	Yoshihiro TAGASHIRA, Takashi SASAOKA, Akibiro HAMANAKA, Hideki SHIMADA, Keisuke TAKAHASHI	546

P-40	Study of Critical Concentration on Coal Dust-Air Explosion in 10 L and 20 L Closed Chambers	Nuhindro Priagung Widodo, Ahmad Ihsan, Anggraini Widiya Astuti, Raden Muhammad Imam K., Alan Gassadesna Arisandi, Budi Sulistianto, Sugeng Wahyudi	549
P-41	Cost Estimation Model for Open-pit Nickel Mining in Indonesia	Lidana Erfiandri, Sri Marlana, Aldin Ardian, Oktarian W Lusantonu, Barlian Dwingara, Shofa Rijalul Haq	555
P-42	Mineralogical and Geochemistry Characteristic of Hydrothermally Altered Rock at Guci Geothermal Fields, Tegal, Central Java	Abdul Aziz Makarim, Dwi Fitri Yudiantoro, Iwan Setiawan, dan Andrie Al Kausar	562
P-43	LANDSLIDE SUCEPTIBILITY INDEX OF BRONDONG AREA AND SURROUNDINGS, KECAMATAN BRUNO, PURWOREJO DISTRICT, CENTRAL JAVA	Suko Prakoso, Arhananta, Aditya Rizky Wibowo, Anggita Mahyudani Rkt, Prod. Dr. Ir. Sari Bahagiarti K. M.Sc, Dr. Ir. Heru Sigit Purwanto	569

## An Analysis of Materials Adhesivity Level on Excavator's Bucket in Open Pit Coal Mining

Prasodo D. Prabandaru<sup>1</sup>, Tubagus Hendarto<sup>1</sup>, Oktarian W. Lusantono<sup>2</sup>, Barlian Dwinagara<sup>2</sup>, Shofa Rijalul Haq<sup>1</sup>

<sup>1</sup>PT. Studio Mineral Batubara (Mining Consultant)

<sup>2</sup>Mining Engineering Department University of Pembangunan Nasional "Veteran" Yogyakarta

### ABSTRACT

This paper investigated materials adhesivity as one of the equipment productivities factors in an open-pit coal mining operation. The parameters of adhesivity investigated in this study were obtained from physical and mechanical properties of soil. The parameters were cohesion ( $C$ ), density ( $\gamma$ ), grain size (% clay and % sand), moisture contents ( $w$ ), plasticity index ( $PI$ ), and liquid limit ( $LL$ ). The data was measured from extensive laboratory testing on disposal materials, composed of clay-sized grains with the moisture content of 8.06 – 47.98%. The materials were also classified as a very plastic material (Plasticity Index > 17%). The relationship of several parameters as materials adhesivity level ( $a$ ) was formulated using multivariate regression analysis, used as a prediction of adhesivity levels on disposal materials. Therefore, actual adhesivity was also analyzed using physical models modified from the direct shear test as a verification. The result was quite similar with a standard deviation of 0.007, suggesting that the estimation value would be applicable in open pit coal mining operation.

**Keywords:** Adhesivity, Soil Properties, Multi-Variate Regression, Physical Models, Open Pit

### INTRODUCTION

Mining, especially in open pit systems, includes excavation and overburden (i.e., soil and weak rock material) removal activities which the digging equipment affects the productivity and the energy consumed. Soil and rock materials potentially stick on the digging bucket reducing the productivity level since the equipment may be difficult to operate. Adhesiveness is not only related to the tensile force between the soil material and the digging material bucket forming material, but also the tensile force between the material itself (cohesion) causing the sticky material to become thicker.

Kooistra (1998) suggested a theory that adhesion affects contact between the soil and other material. Adhesion is explained through Mohr Coulomb's sheath behavior with an approach that is almost the same as the approach used on soil shear strength. According to Hendrick and Bailey (1982), the soil adhesive properties (the normal force parameters and the adhesive shear angle) greatly affect the ability of the soil to slip on a surface of another material plane. Decreasing the level of adhesivity to below the value of cohesion and shear angle in the soil may affect the reduced level of soil adhesiveness.

The adhesiveness of the material is closely related to the physical and mechanical properties of the excavated material encountered, especially parameters such as material composition, moisture content, plasticity index, liquid limit, plastic limit, and material adhesivity. Therefore, this study determined key parameters affecting adhesiveness which is the ideal material disposal conditions, so that adhesiveness can be minimized.

### METHODOLOGY

The parameters of adhesivity in this study was obtained from physical and mechanical properties of soil. The parameters were cohesion ( $C$ ), density ( $\gamma$ ), grain size (% clay and % sand), moisture contents ( $w$ ), plasticity index ( $PI$ ), and liquid limit ( $LL$ ).

Through a similar approach to the concept of the Mohr Coulomb, the methodology for testing adhesive in the laboratory was conducted with a direct shear testing.

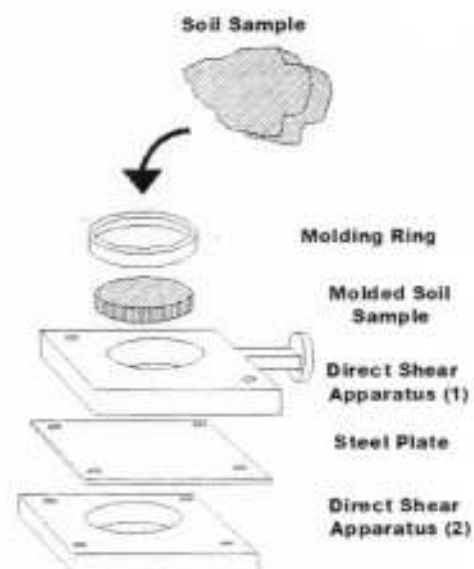


Figure 1. Illustration of Adhesivity Testing Through Direct Shear Test

The laboratory testing methodology was adjusted to the direct shear test, but an adjustment was made to the friction plane of the shear tool, which originally in the

form of soil material replaced by a steel plate. Accordingly, the results of the initial parameters in the form of cohesion was replaced by the value of adhesion, namely friction between the ground and the surface of the steel plate. Illustration of adhesivity testing is shown in Figure 1.

Through this test, the parameter adhesion value was obtained which the friction force between the soil sample and the surface of the steel plate replaced the cohesion value in the direct shear test. As an interpretation of the difference in outcome parameters in direct shear testing, the test method was described as shown in Figure 2.

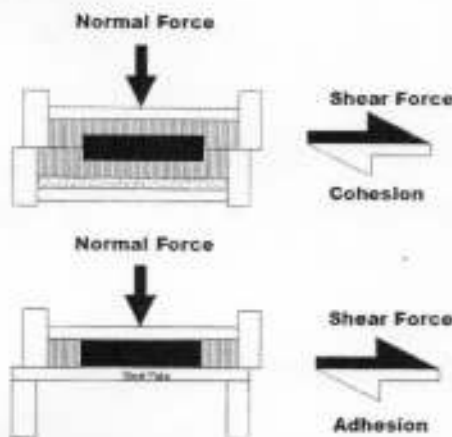


Figure 2. Cohesion and Adhesion Parameters in Direct Shear Testing

## RESULTS AND DISCUSSION

Based on the natural weight and dry density data group of laboratory tests on material disposal at the study site, showed that the weight of the original content (natural density) of material disposal at the study site ranged from 16.19 to 23.20 kN/m<sup>3</sup> with an average value of 19.25 kN/m<sup>3</sup>. The value of the original weight in the data (mode) was 20 kN/m<sup>3</sup>. The original weighted data group had a standard deviation of 1.47 kN/m<sup>3</sup>. The natural moisture content was 8.06% to 47.98% with an average value of 21.97%. Material disposal had an average porosity of 40.55% with a range between 22.79 - 57.34%.

The great percentage of pores in a soil aggregate stated that the soil is looser because of the amount of space between the soil grains. This caused the aggregate volume of the soil to have less weight in each volume unit, which is defined by the weight value of the contents. These soil characteristics were proved in Figure 3, stating the influence of porosity on the value of the weight content at disposal research site. The graph shows that the porosity percentage on the soil has a negative influence on the value of the original soil density. the higher porosity in the soil aggregate actually indicates a decrease in the value of the weight of the contents. The relationship between these two parameters is illustrated through a non-linear

regression approach on 55 physical properties testing data with a high coefficient of determination, 0.90.

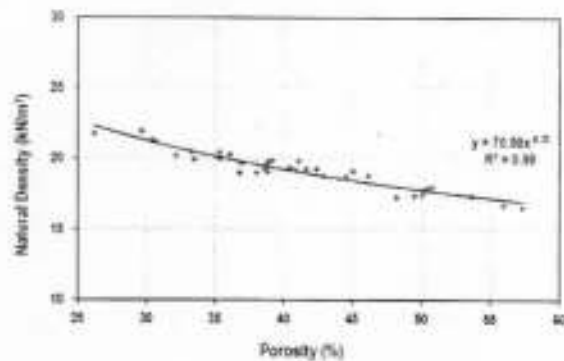


Figure 3. Graph of Porosity Effect on the Disposal Natural Density

In addition to analyzing the influence of porosity with the weight value of contents, also analyzed the effect of porosity on the original moisture content contained in the soil. Figure 4 shows a graphic interpretation of the relationship between porosity and original water content in disposal is presented. The graph shows that there is a correlative relationship between porosity and original water content contained in the material disposal at the study site. The relationship shown in the graph is a positive relationship graph, in the form of linear regression. This confirms that the greater the value of the water content in the soil. This correlative relationship is caused by the porosity representing the percentage of pores or space between the grains in a soil aggregate, so that the greater the space between grains also defines the greater space provided by soil aggregates in storing water and air. The correlative relationship produces a relatively strong coefficient of determination that is equal to 0.903.

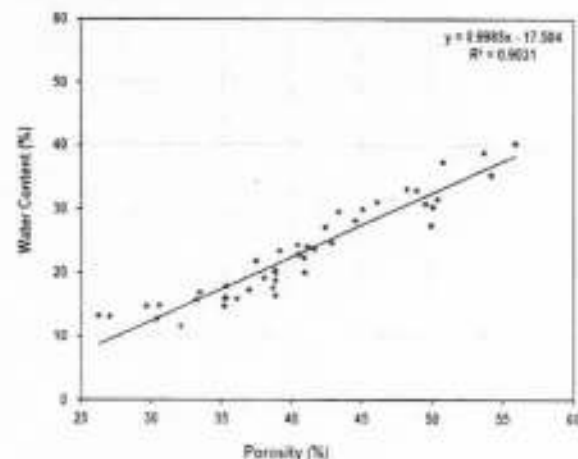


Figure 4. Graph of Porosity Effect on Original Disposal Water Content

Disposal material at this research is dominated by material with a very plasticity level with a percentage of 66.23% (Figure 5). Material with a very plasticity level is represented by material with a plasticity index value greater than 17%. In the medium plasticity group, which have plasticity index value is at 7-17%, shows a

smaller amount of data compared to very plastic material, which is at a percentage of 34%. Material with low plasticity level was not found in the test results at the study site, so it can be concluded that the majority material at of research sites has a high plasticity level or very plastic.



Figure 5. Percentage of Disposal Plasticity Level at Research Site

The percentage values of the disposal grain size distribution are shown in Table 1 shows that overall material disposal at the research site is dominated by clay grain material, while the grains of sand are valued at the lowest.

Table 1. Disposal Grain Size Distribution for Each Depth

No	Depth Range (m)	Average Grain Size Distribution		
		Clay (%)	Silt (%)	Sand (%)
1	0,00 - 10,00	39,63	46,36	13,74
2	10,00 - 20,00	38,36	46,02	14,42
3	20,00 - 30,00	41,23	40,05	18,72
4	30,00 - 40,00	40,03	37,08	22,89
5	40,00 - 50,00	46,80	34,57	18,61
6	> 50,00	51,98	39,95	8,08

In Figure 6, there can be seen that the correlative relationship between the percentage of grain size and the plasticity index is illustrated through linear regression. The relationship curve for the size of the sand grains explains that the greater the percentage of sand content in the soil, the plasticity index formed in the soil actually decreases, in contrast to the curve in the size of clay grains, which defines a correlative relationship positive, where an increase in the percentage of the amount of clay content will cause an

increase in the soil plasticity index. The coefficient of determination shown on the graph gives the influence of the clay grain size distribution is 0.700 to the plasticity index, while that of the sand grains is only 0.500.

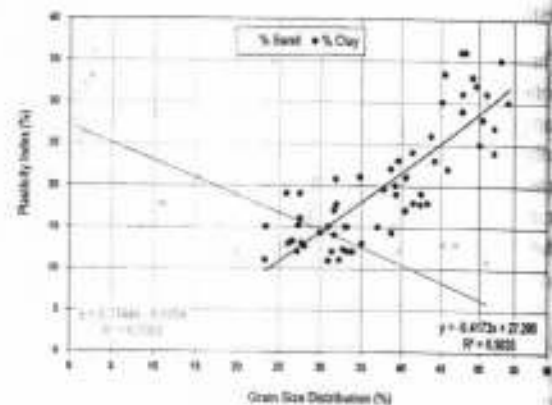


Figure 6. Percentage of Disposal Plasticity Level at Research Location

Furthermore, laboratory testing is carried out in more detail on two types of samples with different constituent materials. Sample 1 (S1) is a sample with a dominant constituent material in the form of clay and sample 2 (S2) is a material with a dominant constituent material in the form of sand. The composition of the constituent grains of both types of samples can be seen through the following test results.

Table 2. Disposal Grain Size Distribution for Each Depth

Sample Code	Grain Size Distribution			
	Clay (%)	Silt (%)	Sand (%)	Gravel (%)
S1	47,28	47,22	5,50	0
S2	21,86	31,14	47,00	0

The results shown in the table above show that the sample group S1 is dominated by clay compilers, with a percentage of 47.28%, while the aggregate percentage with grains of sand is only 5.50%. Unlike the case with the aggregate grains compiling the S2 sample group, the percentage of sand is more dominant with a percentage of 47%, while the clay is only 21.86%.

Based on the cohesion parameters and the internal friction angle shown in Table 3, it can be concluded that the cohesion value in the S1 sample group is relatively greater than the sample disposal groups S2. Cohesion values in the S1 sample group were in the range of 0.19 - 0.46 kg / cm<sup>2</sup>. In the sample group S2 with aggregate-dominated material the size of the sand grain residual cohesion values obtained in the range of

values 0.15 - 0.36 kg / cm<sup>2</sup>.

**Table 3.** Recapitulation of Direct Shear Test Results

Sample	Sample Code	Water Content %	Cohesion kg/cm <sup>2</sup>	Internal Friction Angle °
Disposal (Clay Dominant)	S1_A	21,87	0,37	31,01
	S1_B	25,25	0,43	21,85
	S1_C	27,60	0,37	21,85
	S1_D	34,71	0,19	16,70
	S1_E	19,08	0,46	31,01
Disposal (Sand)	S2_A	20,00	0,36	35,07
	S2_B	22,65	0,33	31,01
	S2_C	24,77	0,23	31,01
	S2_D	29,41	0,28	31,01
	S2_E	35,80	0,15	31,01

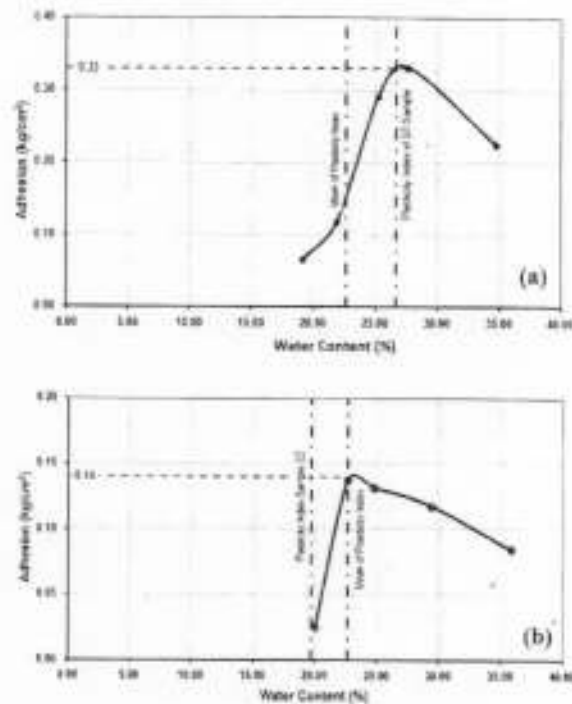
Adhesivity testing has been carried out to obtain the disposal adhesivity parameters. In this study, testing only takes into account the adhesion parameters produced between the disposal material and steel as the material representing the surface of the excavator's bucket.

**Table 4.** Recapitulation of Adhesivity Direct Shear Test

Sample	Kode Sample	Kadar air %	Adhesi kg/cm <sup>2</sup>	Sudut Geser Dalam °
Disposal (Clay Dominant)	S1_A	21,87	0,12	21,85
	S1_B	25,25	0,29	21,85
	S1_C	27,60	0,33	21,85
	S1_D	34,71	0,23	26,61
	S1_E	19,08	0,07	21,85
Disposal (Sand Dominant)	S2_A	20,00	0,03	26,61
	S2_B	22,65	0,14	21,85
	S2_C	24,77	0,13	21,85
	S2_D	29,41	0,12	16,70
	S2_E	35,80	0,09	21,85

The recapitulation of the test results shown in **Table 4** shows that in the sample group S1 the adhesion value was in the range of values 0.07 - 0.33 kg / cm<sup>2</sup> with a moisture content between 19.08 - 34.71%. In the S2 sample group the range of adhesion values was

between 0.03 - 0.14% for variations in water content between 20.00 - 35.80%.



**Figure 7.** Effect of Moisture Graph on Adhesion of Sample Disposal (a) Sample S1 and (b) Sample S2

The effect of the water content value contained in the disposal on the adhesion value in each sample group is depicted as illustrated in **Figure 7**. It is explaining that the adhesion value in each sample group has a peak phase and a decrease phase. The peak phase of general adhesion values in all test groups is in the range of 22-30% moisture content. In the range of values, the adhesion value increased until the maximum value then dropped again. In the sample groups S1 and S2, the maximum value of disposal adhesion is close to the average plasticity index value of the soil, both as a whole and the sample group itself. This can be a validation of previous studies that stated same things.

Based on the results obtained, it was concluded that a correlative relationship between water content and disposal adhesion value at the study site in **Figure 8**. On the same graph, the maximum adhesion value in each sample group is at a relatively different water content. Sample S1 group showed a peak adhesion value of 0.33 kg / cm<sup>2</sup> at a water content value of 29.21%, while in the sample group S2 a peak adhesion value of 0.14 kg / cm<sup>2</sup> was at a water content value of 28.73%. The value of water content at the time of peak adhesion conditions in the sample group S2 explains that the material with the sand constituent material has a peak phase with less water content compared to clay. Soil material dominated by sand compilers also shows much smaller adhesion value compared to clay.



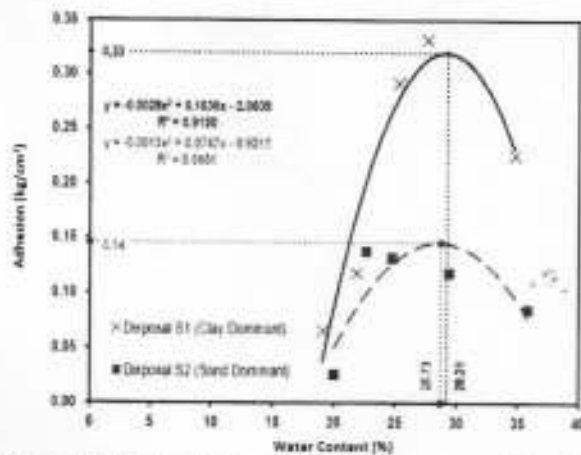


Figure 8. Graph Effect of Water Content on Disposal Adhesion at Research Sites

As a comprehensive analysis of the relationship on each related parameter, a multiple regression analysis is then performed to assess the relationship of water content, plastic limit, liquid limit, plasticity index, cohesion, percentage of clay grains, percentage of grains of sand, and weight of contents to adhesion so that it can be determined an Regression equation from the values of the test parameters that have been obtained. The analysis was conducted with a confidence level of 95% and a real level of 5%. The results of the analysis are summarized in Table 5

Table 5. Results of Beta Coefficients of Statistical Regression Analysis

Parameter	Coefficients	Standard Error
Intercept	74,6671	17,0908
Water Content	-0,0169	0,0073
Plastic Limit	0	0
Liquid Limit	0,0112	0,0063
Plasticity Index	0,0084	0,0101
Cohesion	0,0091	0,1387
%Clay	-1,4908	0,3420
%Sand	-0,9167	0,2099
Natural Density	0,7092	0,3826
Multiple R		0,93
R Square		0,84

In Table 5 it is stated that the adhesion parameter is influenced by several test parameters as mentioned above and has a fairly strong influence relationship. This is indicated by the coefficient of determination ( $R^2$ ) of 0.84. Similar to the value of compound R (multiple R) which states the relationship between the dependent variable (adhesion) with all independent variables (test parameters such as water content, weight weights, consistency limits, cohesion, and grain size distribution) as a compound, that is equal to 0.92. Because of that case, it can be concluded that the test parameters which become the input parameters in the analysis have a significant influence on the adhesion value so that the relationship can be stated in a statement function whose coefficients are determined in Table 5. In this table, each test parameter has a

coefficient value with varying standard error values. Then the regression equation can be written as follows:

$$a = 74,67 - 0,0169w + 0,0112(LL) + 0,0084 (IP) + 0,0091C - 1,4908(\%Cl) - 0,9167 (\%Sd) + 0,7092\gamma \dots \dots \dots \text{(Equation 1)}$$

which:

- a = Adhesion (kg/cm<sup>2</sup>)
- w = Water Content (%)
- LL = Liquid Limit (%)
- IP = Plasticity Index (%)
- C = Cohesion ((kg/cm<sup>2</sup>)
- %Cl = Percent Grain of Clay (%)
- %Sd = Percent Grain of Sand (%)
- γ = Natural Density (g/cm<sup>3</sup>)

The regression is then validated in the analysis, this is done in order to determine the difference between the original adhesion value and the predicted adhesion value. This difference value is referred to as the residual value in . Based on the residual values shown in the 15 data, it was concluded that the deviation between the original adhesion value and the predicted value was relatively small, amounting to 0.0074.

Table 6. Validation of Predicted Adhesion Value

Sample Code	Adhesion	Predicted Adhesion	Residual
S1_A	0,12	0,1733	-0,0533
S1_B	0,29	0,2629	0,0270
S1_C	0,33	0,2652	0,0647
S1_D	0,23	0,2571	-0,0271
S1_E	0,07	0,0812	-0,0112
S2_A	0,03	0,0323	-0,0023
S2_B	0,14	0,0969	0,0430
S2_C	0,13	0,1134	0,0165
S2_D	0,12	0,1615	-0,0415
S2_E	0,09	0,1057	-0,0157
Mean			0,0074

**CONCLUSION**

Based on the results discussed in this study, several conclusions are summarized as follows:

1. Disposal at the research site has a natural water content of 21.97%, porosity value of 40.55%. Characteristics of the dominant constituent grains in the form of clay with a very plastic material category and a peak adhesion value of 0.15 - 0.33 kg/cm<sup>2</sup> at moisture content of 28.73 - 29.21%. It shows that the actual material disposal at the research location is at the maximum adhesiveness phase.
2. The greater the sand material as the size of the constituent disposal reduces the plasticity index on the material that can affect the stickiness level.
3. The maximum phase of stickiness (adhesion

value) is close to the plasticity index value.

4. Relationship between water content parameters ( $w$ ), natural density ( $\gamma$ ), grain size distribution of clay (% Cl), sand (% Sd), cohesion ( $C$ ), liquid limit (LL), and Plasticity Index (IP) with adhesion values ( $a$ ) can be stated in the equation :
- $$a = 74,67 - 0,0169w + 0,0112(LL) + 0,0084 (IP) + 0,0091C - 1,4908(\%Cl) - 0,9167 (\%Sd) + 0,7092\gamma$$

#### ACKNOWLEDGEMENTS

This study is directed by PT Studio Mineral Batubara. We would to thank Universitas Pembangunan Nasional "Veteran" Yogyakarta and PT Bukit Asam Tbk for research supports.

#### REFERENCES

- Ali Hassan, Omar S., 1980, Modelling of The Soil Mechanical Properties to Soil Moisture Condition and Their Application to Study the Traction Developed by Lugged Tires, Department of Agricultural Engineering MacDonald College of McGill University Sainte Anne de Bellevue, Quebec.
- Azadegan, B., dan Massah, J., 2012, Effect of Temperature On Adhesion of Clay Soil to Steel, *Cercetari Agronomice in Moldova* Vol. XLV No. 2 (150), page 21 – 27.
- Bravo, E.L., dkk., 2012, Determination of Basic Mechanical Properties In A Tropical Clay As A Function of Dry Bulk Density and Moisture, *Revista Ciencias Técnicas Agropecuarias*, ISSN -1010-2760, RNPS-0111, Vol. 21, No. 3, Julio-Septiembre, Cuba, page. 5-11.
- Birch, R.A., Ekwue, E.I., dan Phillip C.J., 2016, Soil-Metal Sliding Resistance Forces of Some Trinidadian Soils at High Water Contents, *The West Indian Journal of Engineering* Vol.38 No.2, page 52-58.
- Combe, T.A.A., dan Miedema, S.A., 2015, Influence of Adhesion on Cutting Processes in Dredging, *Proceedings of Western Dredging Association and Texas A&M University Center for Dredging Studies*.
- Das, B.M., 2012, *Soil Mechanics Laboratory Manual* 8th Edition, Oxford University Press, NY
- Dumbleton, M. J., dan West. G., 1966, Some Factors Affecting The Relation Between The Clay Minerals In Soils And Their Plasticity, *Clay Minerals* 6, 179.
- Harsono, S.S., 2011, Tillage Implement Effects On Wet Sticky Soil, *Research Journal of Agricultural Science*, 43 (4), page 86 – 94.
- Fontaine, E.R., 1954, Investigations into The Mechanism of Soil Adhesion, *Journal of Soil Science*, Vol. 5, page 251 – 263.
- Hendrick J.G., dan Bailey A.C, 1992, Determining Component of Soil-Metal Sliding Resistance, *Transactions of the ASABE*. 25 (4)
- Ijaz, A. et al, 2014, Effects of Soil and Air Drying Methods on Soil Plasticity of Different Class of Pakistan, *Int. Journal Research and Applications* Vol. 4 Issue 12 (Part 3), page 49 – 53.
- Jancsecz, S., 1991, Definition Geotechnischer Parameter Fur Den Einsatz Von Schildvortriebsmaschinen Mit Suspensionsgestutzter Ortsbrust. Proc. STUVA '91, Dusseldorf.
- Kooistra, A., dkk, 1998, Appraisal of Stickiness of Natural Clays of Laboratory Test, Faculty of Civil Engineering and Geosciences, Delft University of Technology.
- Sutono, S, dkk., 2006, *Sifat Fisik dan Metode Analisisnya : Penetapan Plastisitas Tanah*, Balai Besar Penelitian dan Pengembangan Pertanian, Departemen Pertanian, Jakarta.
- Tagar, A.A., et al, 2013, Soil Failure Patterns and Draft as Influenced by Consistency Limit, *Soil and Tillage Research* 137, page 58 -66.
- Ukiman, 2009, Karakteristik Indeks Plastisitas Tanah Terhadap Tegangan Geser dan Regangan Geser, *Wahana Tenik Sipil* Vol. 14 No. 1 April 2009, 29-37.
- Ramadhani, T., dkk, 2015, Hubungan Batas Cair dan Plastisitas Indeks Tanah Lempung yang Disubstitusi Pasir Terhadap Nilai Kohesi Tanah Pada Uji Direct Shear, *JRSDD Edisi Juni 2015* Vol. 3 No. 2, Hal. 291-302.
- Russell, E.R., Mickle, J.L., 1970, Liquid Limit Values of Soil Moisture Tension, *Journal of Soil Mechanics and Foundations Divisions* 96, 967-987.
- Vilde, A. Dan Tanas, W., 2005, Determination of The Soil Friction Coefficient and Specific Adhesion, *TEKA Kom. Mot. Energ. Rohn*, page 212 – 216.
- Watson, K., dan Pennock, D., 2016, *Field Handbook for The Soils of Western Canada Section 3 : Soil Profile Description*, NRC Research Press, Ottawa.
- Yusu, Y., dan Dechao, Z., 1990, Investigation Of The Relationship Between Soil-Metal Friction and Sliding Speed, *Journal of Terramechanics*, Vol. 27, No. 4, page 283-290.