REPORT DOCUMENTATION PAGE

2

Form Approved OMB NO. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
31-08-2014	MS Thesis	-

4. TITLE AND SUBTITLE
Microstructure, Quasi-Static, and High Strain Rate Dynamic Characterization of Metakaolin and Fly Ash Bsed Geopolymers for Structural Applications

5a. CONTRACT NUMBER
W911NF-11-2-0043

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
611104

6. AUTHORS
Damian Stoddard

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES AND ADDRESSES
North Carolina A&T State University
1601 East Market Street

Greensboro, NC 27411 -0001

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES)
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSOR/MONITOR'S ACRONYM(S)
ARO

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
59544-MA-PIR.12

12. DISTRIBUTION AVAILIBILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT
The concrete community has significant interest on additives for concrete that can drastically change the strength, tensile, compressive, flexural properties, workability, rate of cure of cement. Defense applications require new blast, impact, and ballistic mitigation materials. This work focused on the characterization of the mechanical properties and microstructure of metakaolin geopolymer, obtain the static properties of metakaolin geopolymer for high strain rate Hopkinson Bar comparsons.

15. SUBJECT TERMS
Metakaolin, fly ash, geopolymer, characterization, high strain rate

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Ram Mohan
UU	UU	UU	UU		19b. TELEPHONE NUMBER 336-285-2867

Report Title

Microstructure, Quasi-Static, and High Strain Rate Dynamic Characterization of Metakaolin and Fly Ash Bsed Geopolymers for Structural Applications

ABSTRACT

The concrete community has significant interest on additives for concrete that can drastically change the strength, tensile, compressive, flexural properties, workability, rate of cure of cement. Defense applications require new blast, impact, and ballistic mitigation materials. This work focused on the characterization of the mechanical properties and microstructure of metakaolin geopolymer, obtain the static properties of metakaolin geopolymer for high strain rate Hopkinson Bar comparsons.

Characterization of a Metakaolin-Based Geopolymer

Damian Stoddard[1], Paul G. Allison[2], Robert D. Moser[2], Wayne Hodo[2]

[1]University of Mississippi, Department of Mechanical Engineering; [2]US Army Corps of Engineers, Engineer Research And Development Center

Motivation

- Research on additive for concrete that can drastically change the strength, tensile properties, compressive properties, flexural properties, rate of cure, work ability, etc.
- Research on new blast, impact, and ballistic mitigation materials
- Research on microstructure characterization methods
- Provide comparable data for future high strain rate testing of geopolymers

Objectives

- Perform research on the characterization of the mechanical properties and microstructure of metakaolin geopolymer
- Acquire static properties of metakaolin geopolymer for high strain rate Hopkinson Bar result comparison
- Become familiar with microstructure characterization methods

Metakaolin

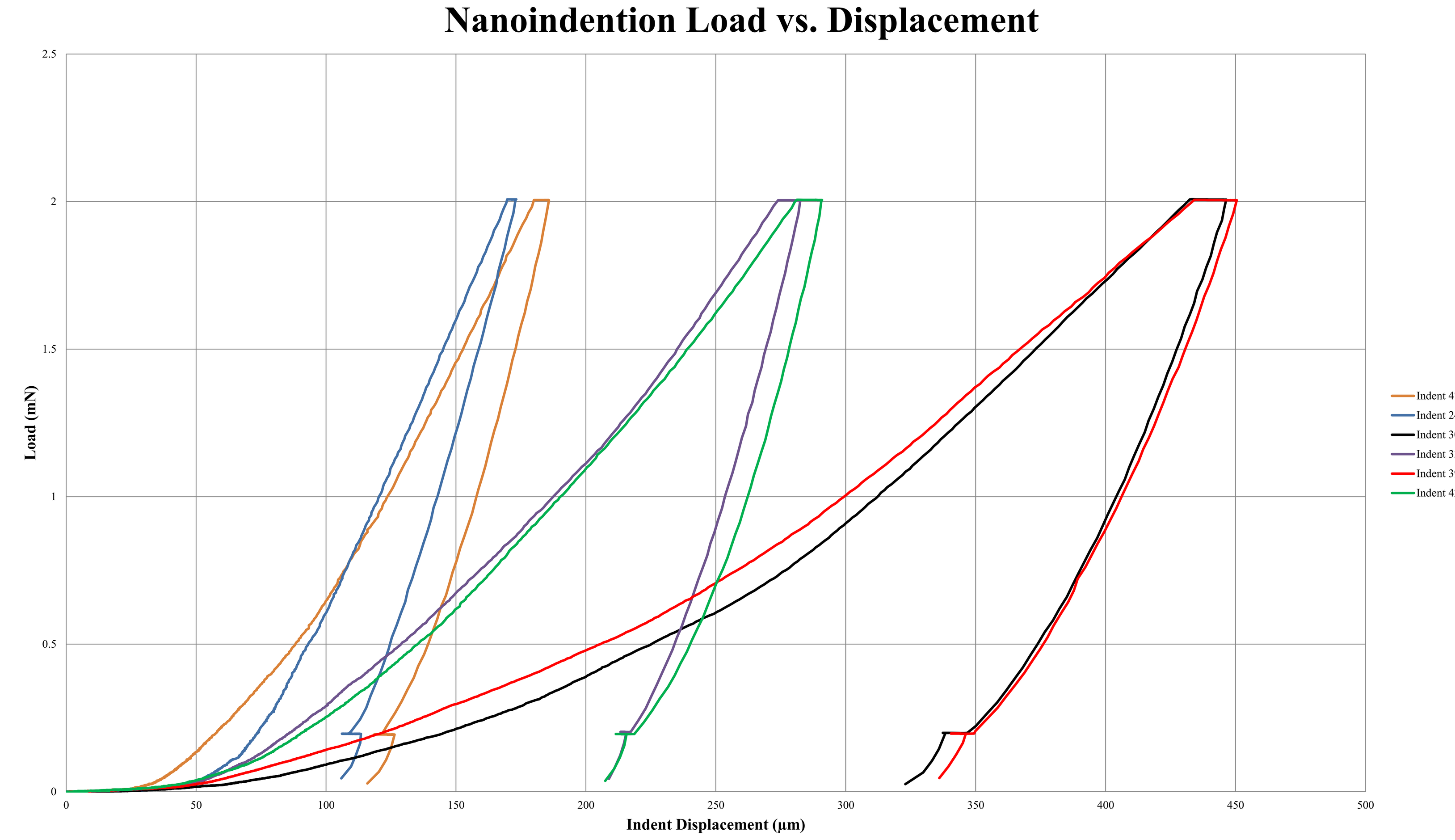
- Prepared from thermal conditioning (calcining) of Kaolinite
- Aluminosiliceous material along with Fe
- Increases strength and chemical resistance of concrete
- Reduces permeability of concrete
- Workability enhancement of concrete

Figure 1. Metakaolin Powder(a), Cured Metakaolin Geopolymer(b)

Methodology

- Optical Microscope/Scanning Electron Microscope
  - Optical microscope and scanning electron microscope images used to explore topography
- Compressive Strength
  - Tinius Olsen material testing machine used to determine quasi static ultimate compressive strength of Metakaolin geopolymer
- Nanoindentation
  - -50 x 10 grid with 10µm horizontal spacing and 20µm vertical spacing were done at a maximum load of 2mN with a 5 sec dwell time at maximum load using a Berkovich tip
  - Used to calculate elastic modulus and hardness values
- X-Ray Diffraction/Energy Dispersive Spectroscopy
  - X-Ray diffraction used to determine the mineralogy
  - Energy dispersive spectroscopy used to determine chemical composition for specific microstructure components
- Thermogravimetric Analysis
  - Thermo gravimetric analysis used to determine the water (chemically- and physically-adsorbed) as well as other phases.

Mechanical Characterization



Nanoindentation Load vs. Displacement

- Nanoindentation data demonstrated the load vs. displacement of 3 different components of the metakaolin-based geopolymer.
- Modulus of the 3 components were experimentally found to be 11GPa, 25GPa, and 50GPa, representing various geopolymerization reaction products.
- Compression test utilized to determine strength.

Table 1. Metakaolin Ultimate Strength

Maximum Load (lbs)	Strength (psi)
1028.9	2176.8
942.0	1982.6
1534.4	3130.7

Figure 2. Tested Sample

SEM Imaging

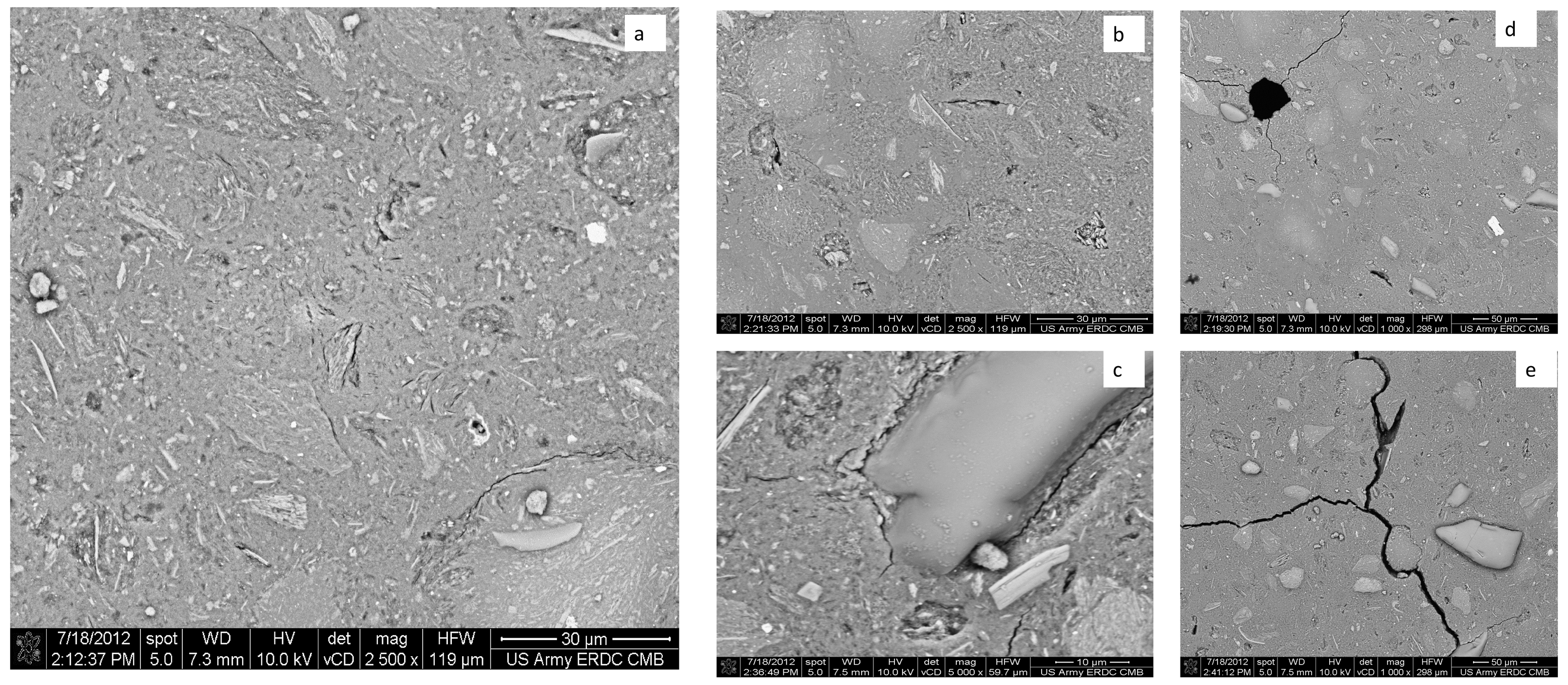
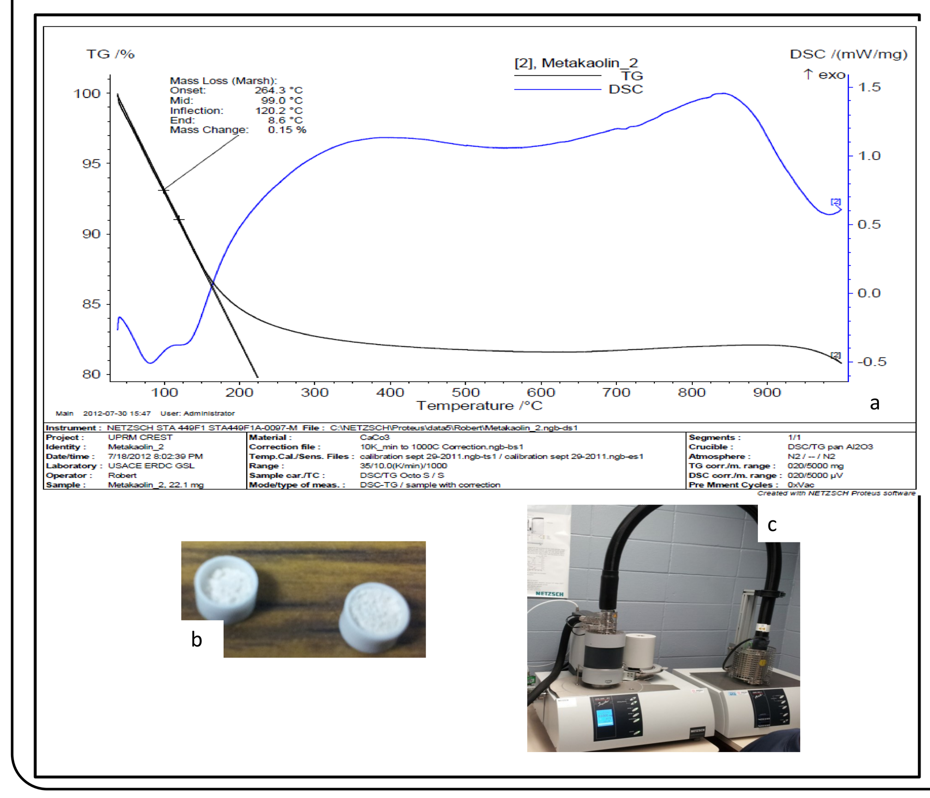


Figure 3: SEM images of Metakaolin-Based Geopolymer (a),(b), Cracks Propagating from Voids (c), Crack Around non-reacted Metakaolin (d), Cracks Propagation Through Matrix (e)

- SEM images displayed homogenous material
- Micro cracks found in various location of geopolymer micro structure
- Cracks found to resonate from voids and also follow a path around areas of non-reacted Metakaolin

Thermogravimetric Analysis



- Thermogravimetric Analysis showed that Metakaolin geopolymer contains physisorbed water.
- Thermogravimetric graph shows that the geopolymer is homogenous and relatively pure in reaction product phase

Figure 4: Thermogravimetric Analysis of Metakaolin Geopolymer (a), Thermogravimetric Analysis Samples(b), Thermogravimetric Analysis Apparatus(c)

Chemical Characterization (EDS/XRD)

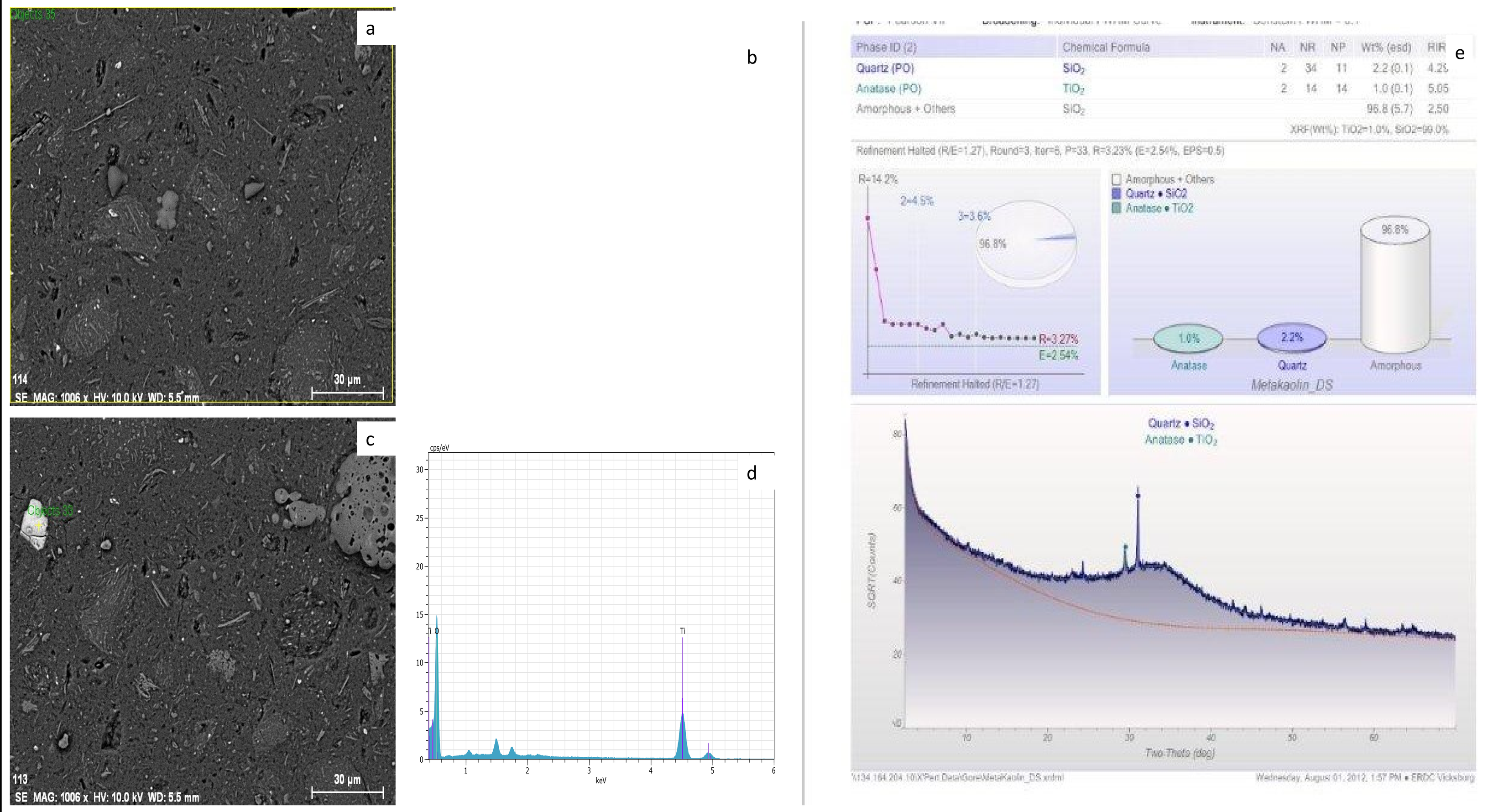


Figure 7: EDS Analysis Locations (a) Large Area Map, (b) Analysis Graph, (c) Anatase Particle(d) Anatase Analysis Graph, (e) X-ray Diffraction Analysis

- EDS graphs showed the presence of Oxygen, Sodium, Aluminum, Silicon, and Titanium

Conclusions and Future Work

- Experimental data shows that Metakaolin-based geopolymer has an approximate ultimate strength of 2400psi and an approximate modulus of 11GPa
- Analysis of the chemical components of Metakaolin revealed the presence of Oxygen, Sodium, Aluminum, Silicon, and Titanium.
- Future research will be conducted on tensile properties, shear properties, low impact properties, high strain rate properties in both compression and tension, ballistic characterization, and blast simulation.

Acknowledgements

Want to thank Dr. Robert Moser, and Dr. Paul Allison from the Geotechnical and Structures Laboratory. DOD HBCU PIRT program summer internship support (Dr. Joseph Myers, PM) is acknowledged. University PIRT Principal Investigators: Dr. Ram Mohan, North Carolina A&T State University and Dr. A. M. Rajendran, University of Mississippi are thanked and acknowledged.