

ASABE 2023 Annual International Meeting

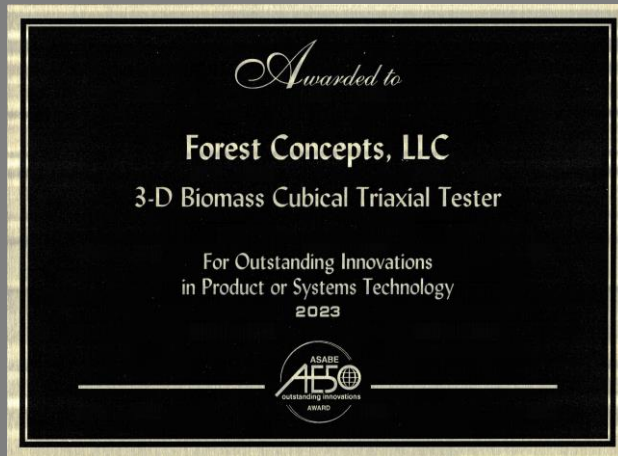
Meeting Date: July 9-12, 2023

Project Title:

Improved biomass feedstock materials handling and feeding engineering data sets, design methods, and modeling/simulation tools

Award Number: DE-EE0008254

WBS: 3.1.1.002



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Presenter: Chris Lanning, PE

forestconcepts™

Auburn, Washington

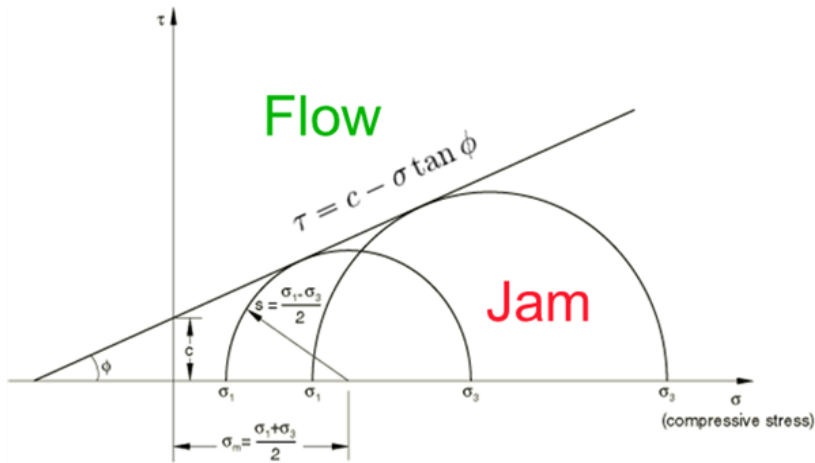
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Introduction to Flowability Modeling

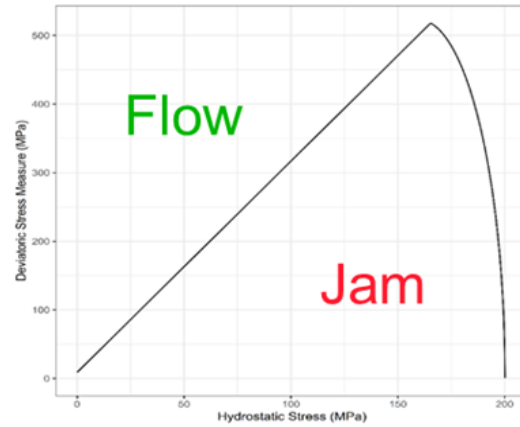
- Flow modeling and simulation tools need to be good enough to reliably design biomass equipment.
- Biomass lab methods and equipment are even for modestly flowable materials inadequate to measure coefficients needed for flowability models.
- Current test results may only be valid at temperature or moisture levels used during testing. These results cannot be normalized or extrapolated.
- Given this set of challenges how can we improve the testing we need to do to make a new material perform in our existing or designed handling systems?



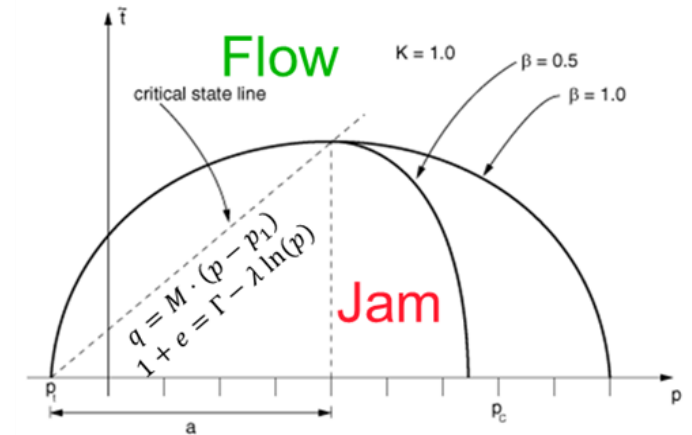
Model Formulations



Mohr-Coulomb



Drucker-Prager/Cap



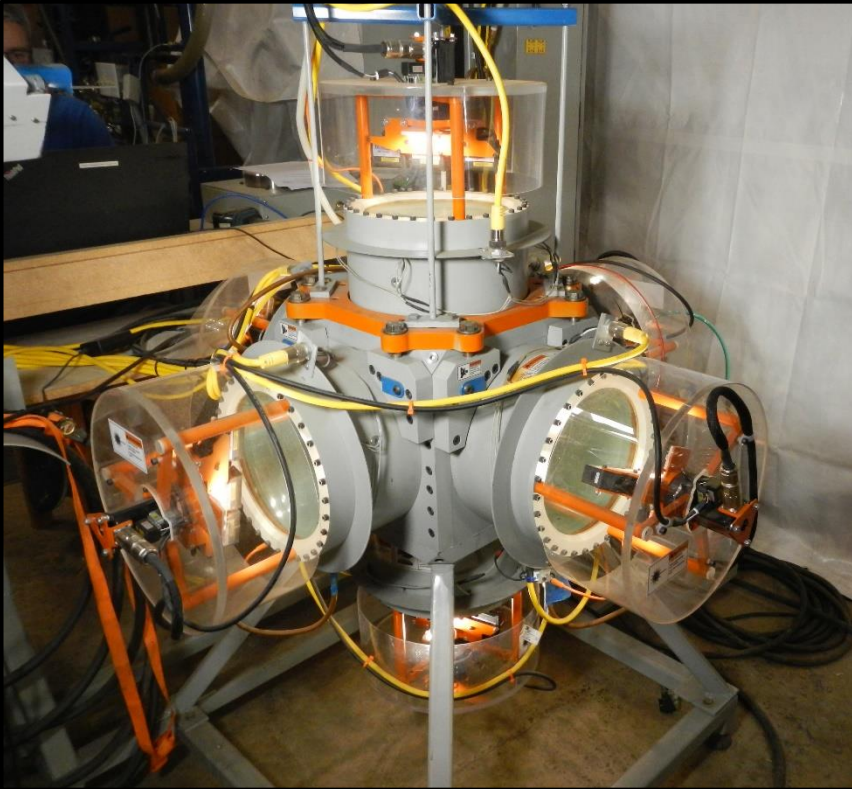
Modified Cam-Clay

Characterization of Mechanical Properties

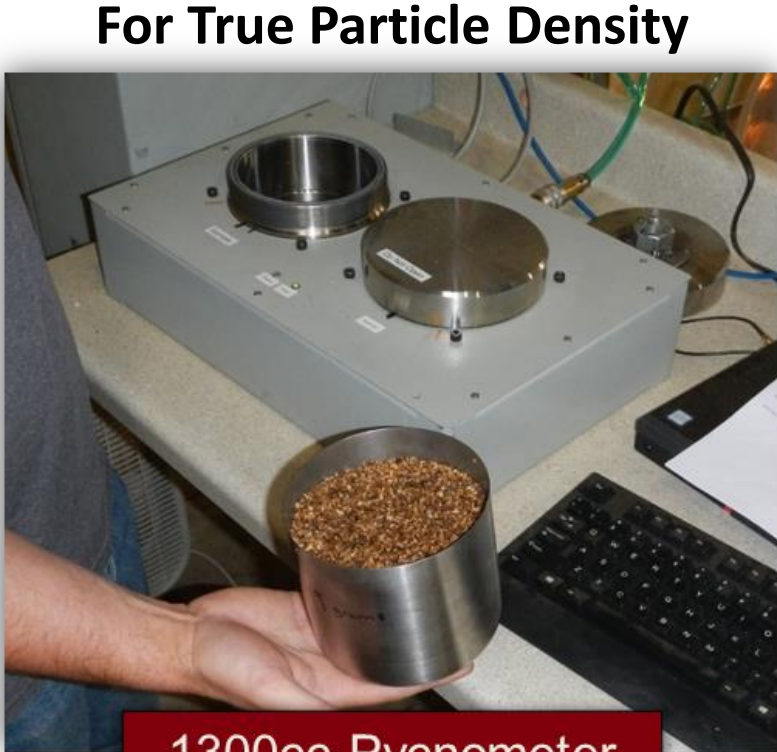
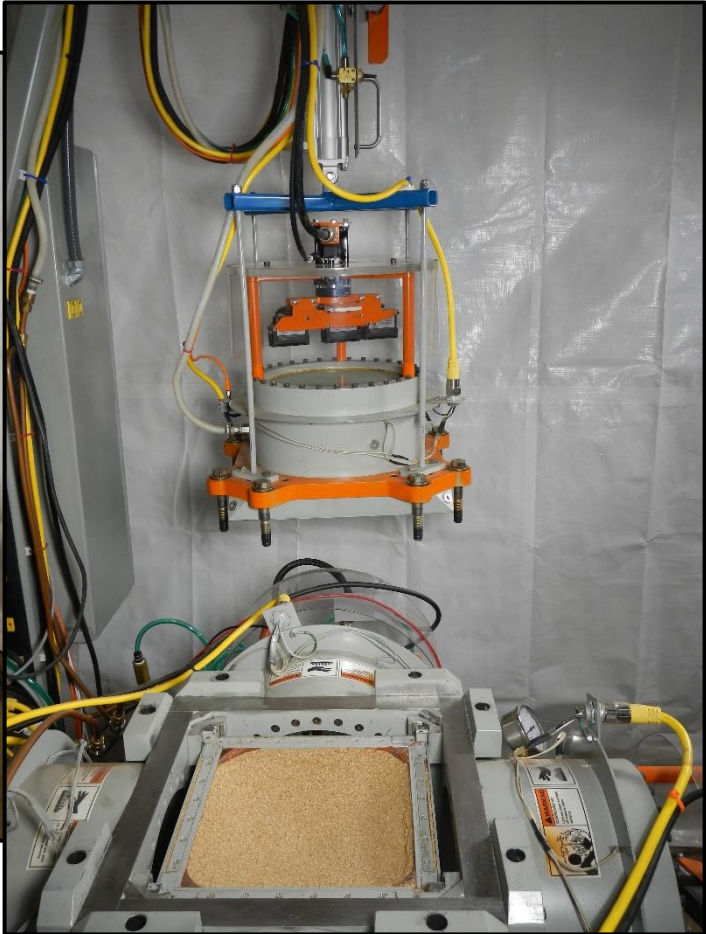
- Determination of Constitutive Biomass Flow Model Parameters
- Efforts are continued to automate the determination of listed parameters

Constitutive Biomass Flow Model	Model Parameters from Hydrostatic Compression Triaxial Tests	Model Parameters from Conventional Compression Triaxial Tests
Mohr-Coulomb model	NONE	C (Coefficient of Cohesion) ϕ (Angle of Internal Friction)
Drucker-Prager/Cap model	p_c (Hydrostatic Yield Stress) $\varepsilon_{vol}^{plastic}$ (Corresponding Volumetric Plastic Strain)	d (Coefficient of Cohesion on $j_1 - \sqrt{j_2}$ plane) β (Angle of friction on $j_1 - \sqrt{j_2}$ plane) R (Cap eccentricity parameter) $\varepsilon_{vol,0}^{initial}$ (initial cap yield surface position) α (Transition surface radius parameter) K (tensile/compression yield stress ratio)
modified-Cam/Clay model	K (Bulk modulus) λ (Compression index) p_c (Hydrostatic Yield Stress) $\varepsilon_{vol}^{plastic}$ (Corresponding Volumetric Plastic Strain)	M (Critical State Slope) $\varepsilon_{vol,0}^{plastic}$ (initial plastic volumetric strain) β (tensile/compression yield coefficient), K (tensile/compression yield stress ratio)

Cubical Triaxial Tester (CTT) and Pycnometer



Bulk Flow Model Parameters



1300cc Pycnometer



CTT Output

Woody Biomass

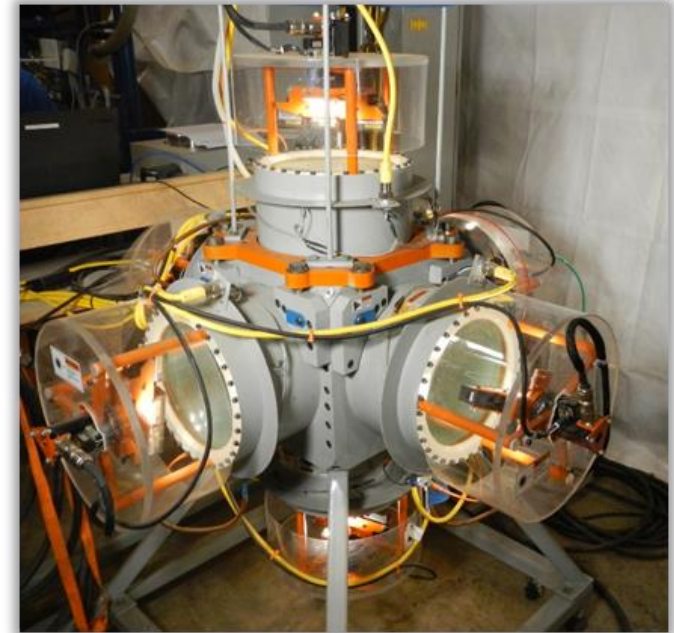


Corn Stover



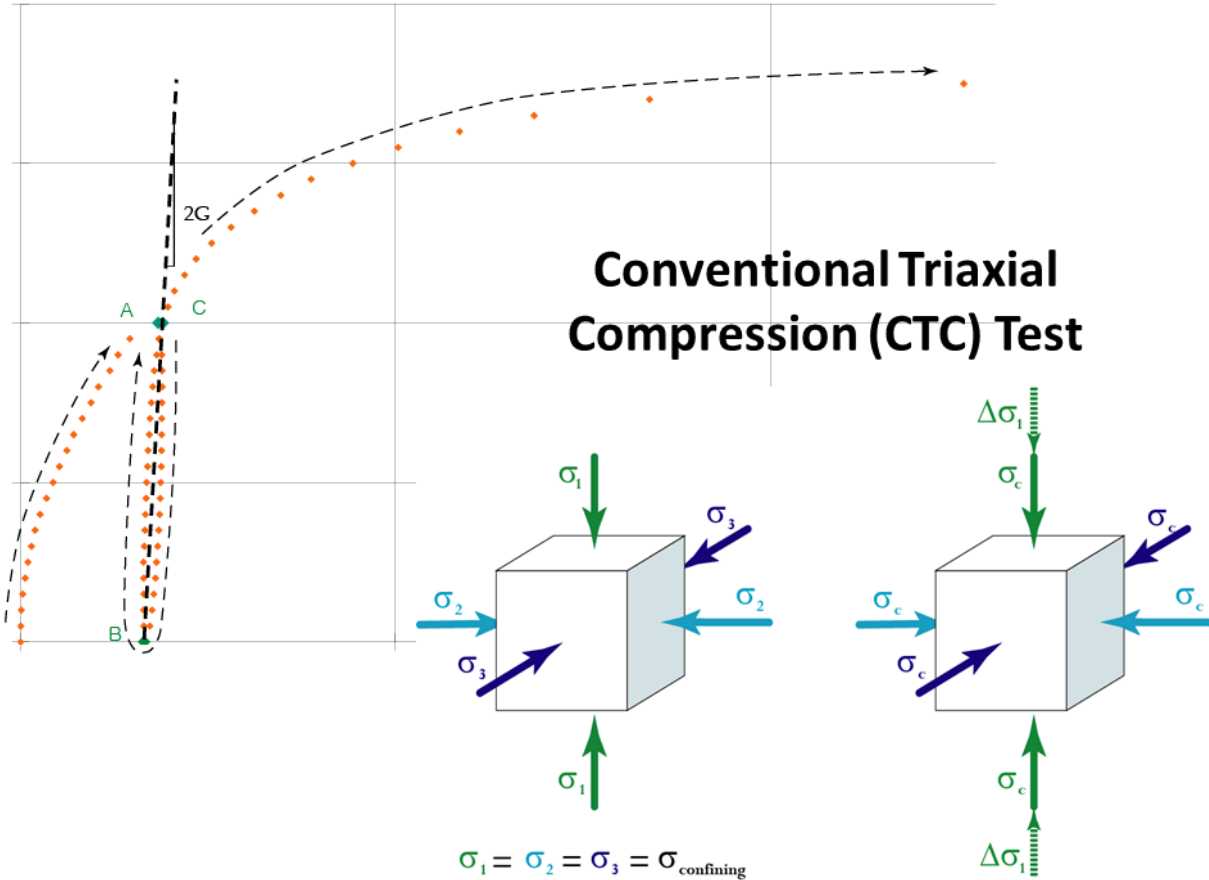
Cubical Triaxial Tester (CTT) for Biomass Scale Materials

- Improved material modeling without confounding effect of die-wall friction
- Measurement of the pressures and displacements in three orthogonal directions
- More suitable for biomass scale materials relative to scale of existing CTT and soils devices
- CTT optimized for biomass material

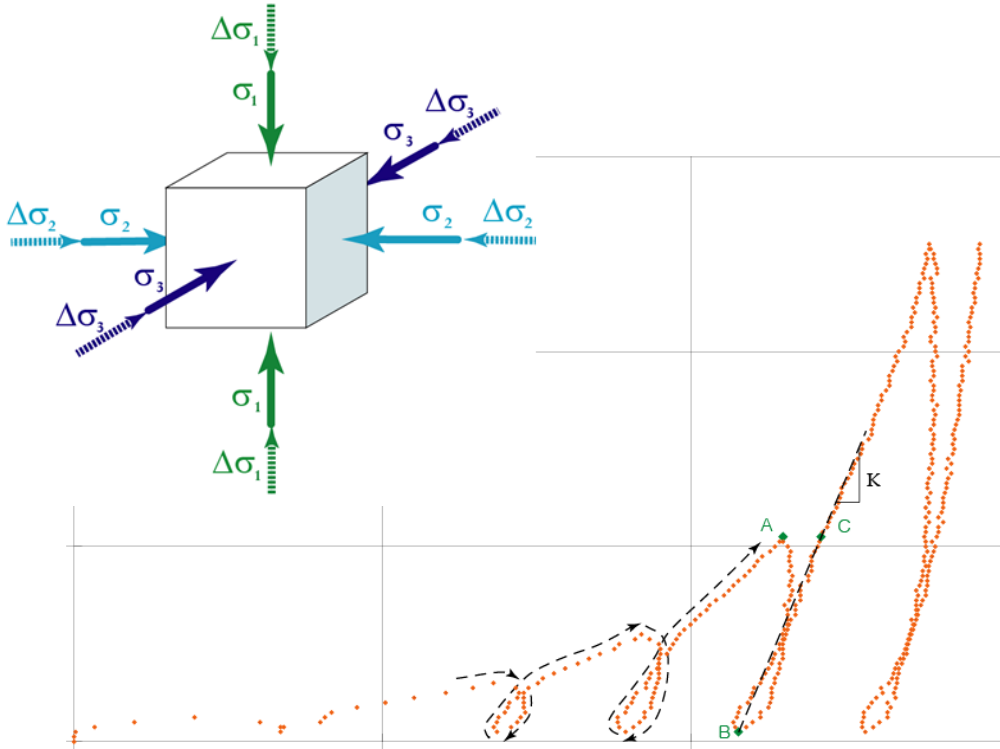


CTT Stress Paths

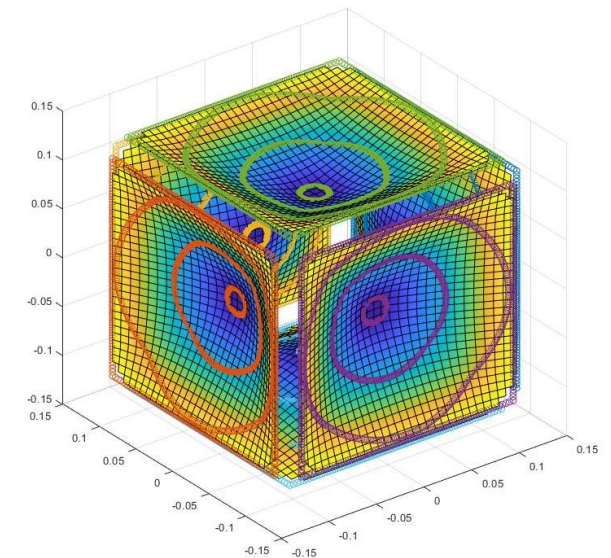
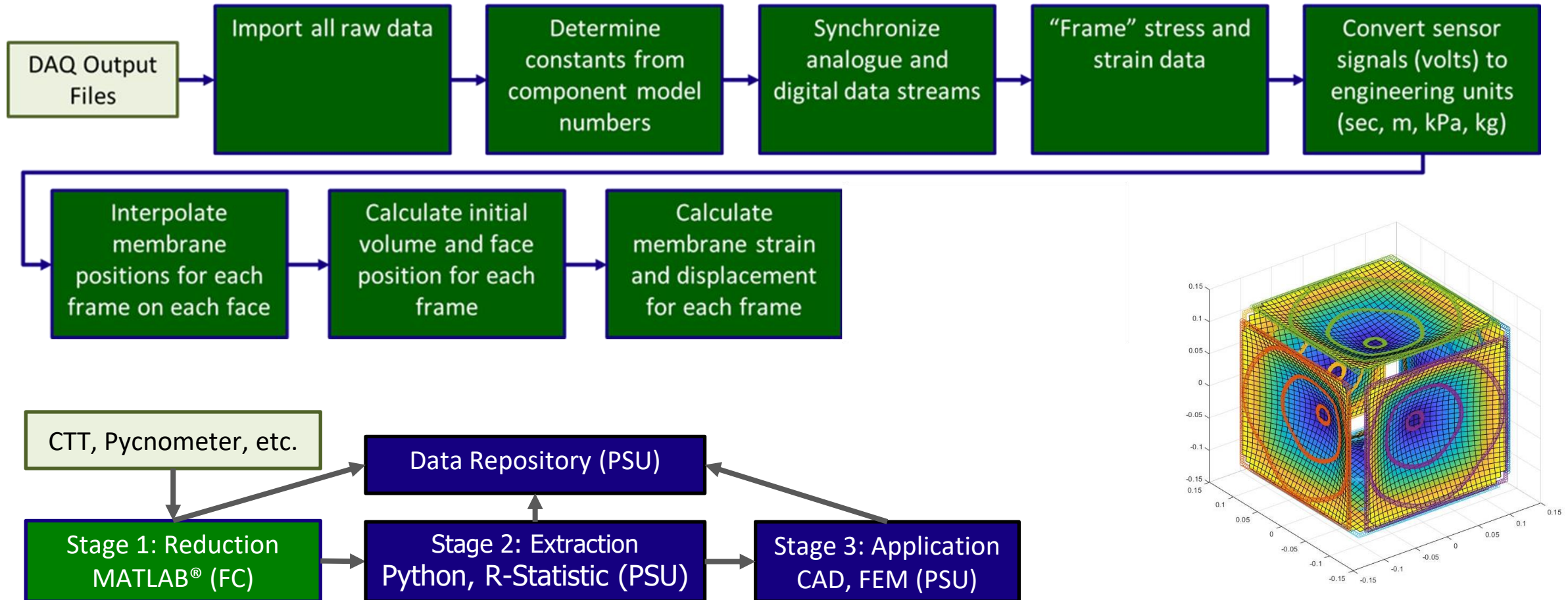
Conventional Triaxial Compression (CTC) Test



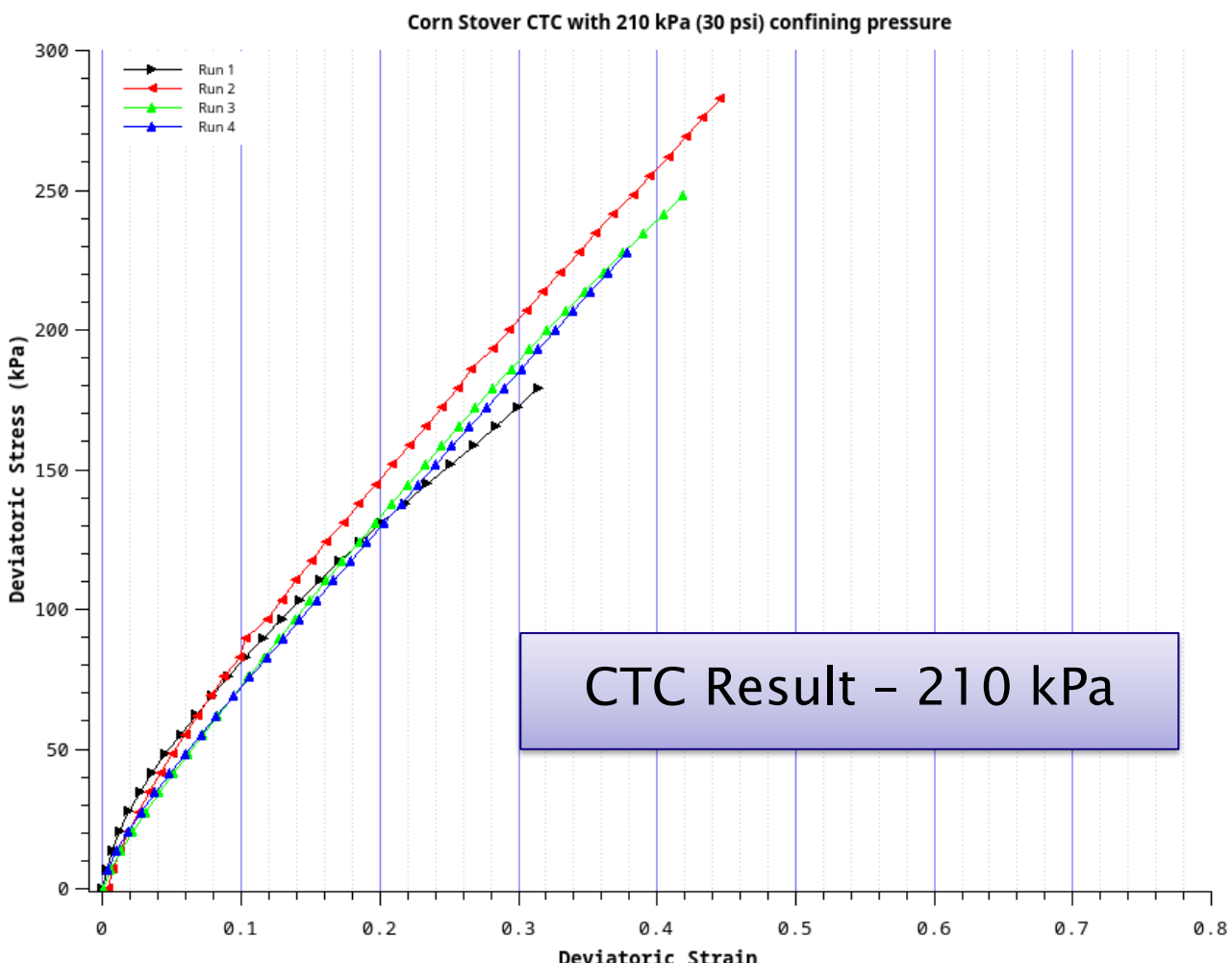
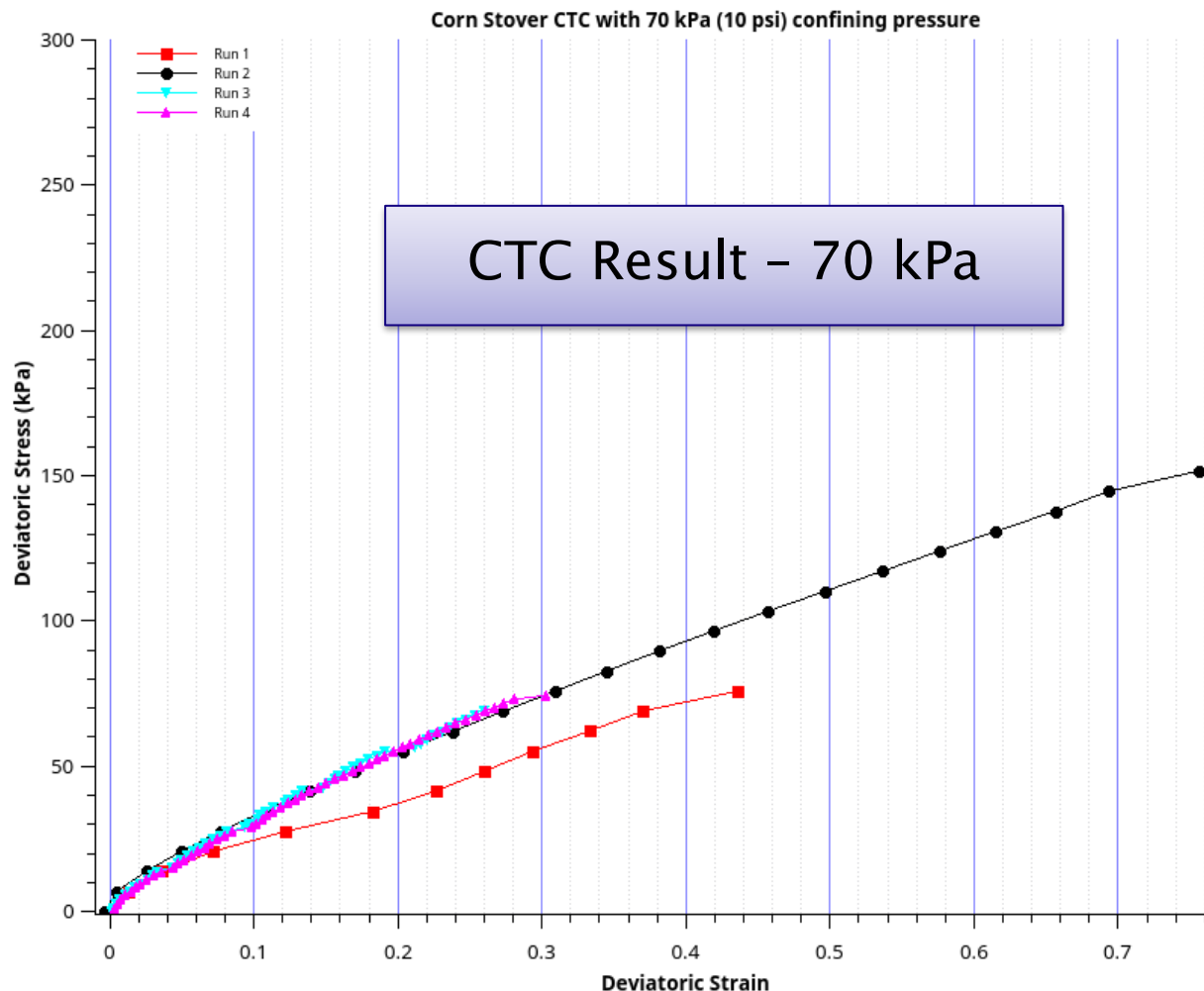
Hydrostatic Triaxial Compression (HTC) Test



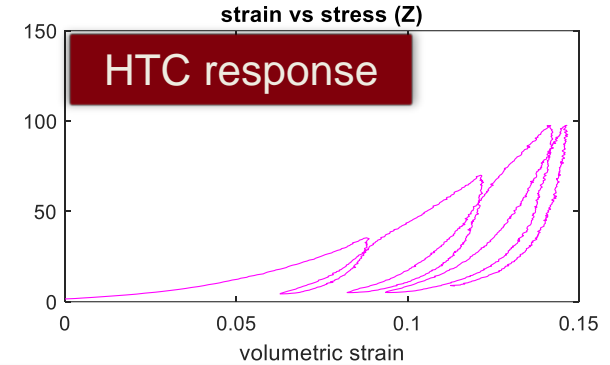
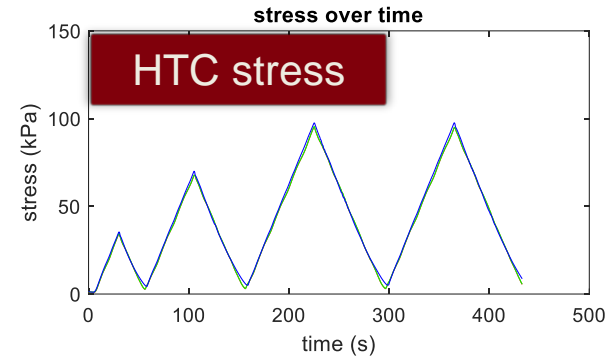
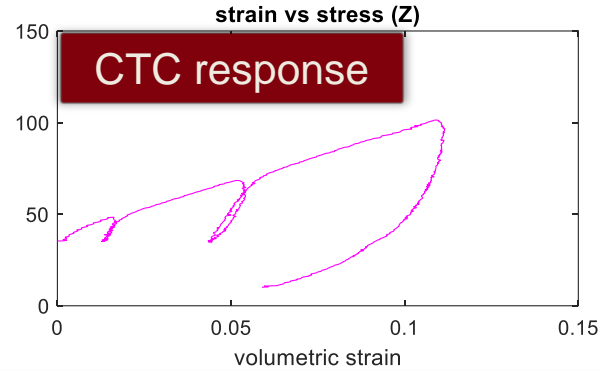
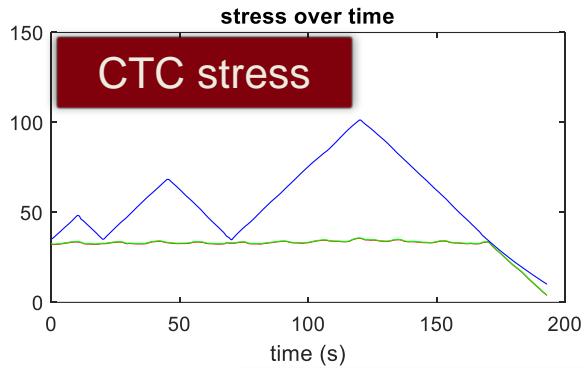
Data Reduction and Analysis



Data Repeatability

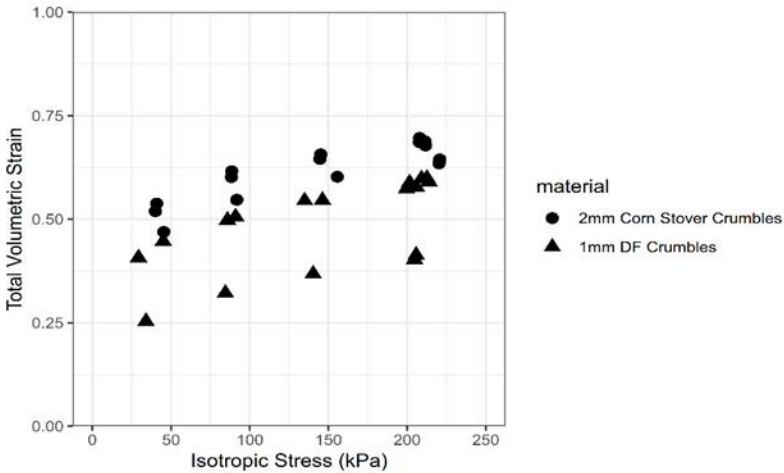


Stress Path Data

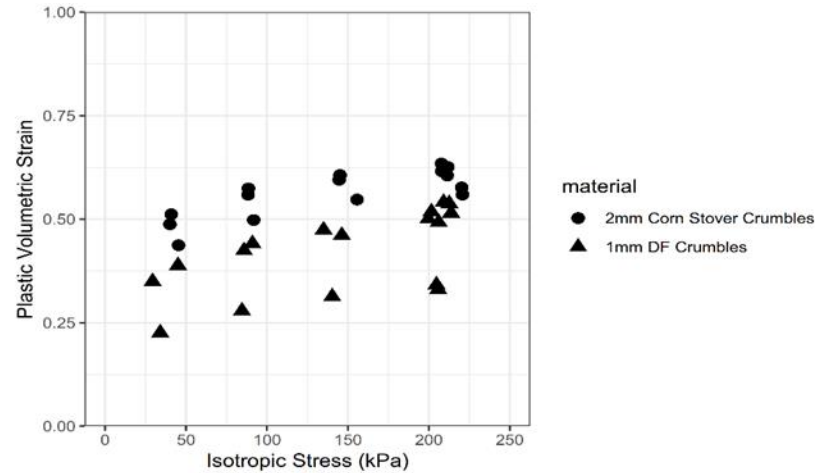


Coefficients for all three models can be determined from CTT data

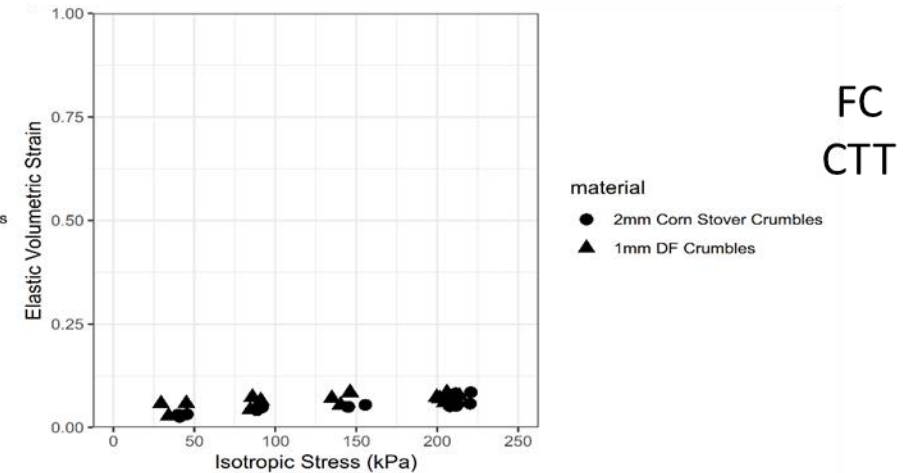
Total Volumetric Strain



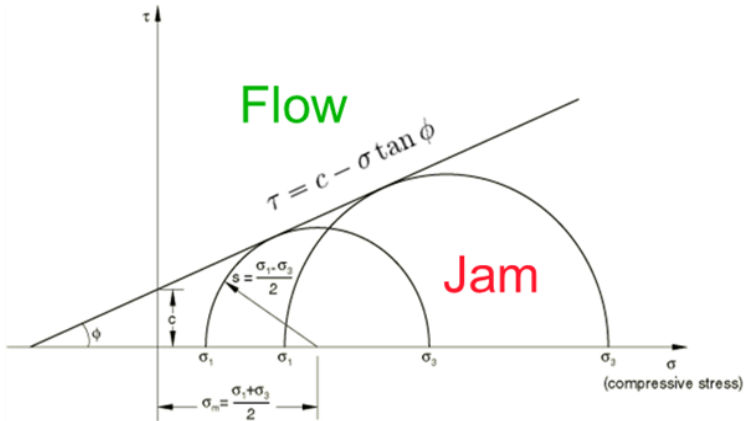
Plastic Volumetric Strain



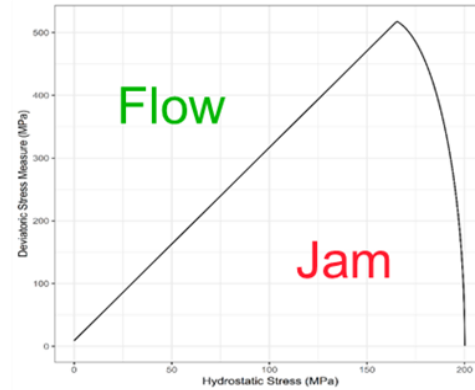
Elastic Volumetric Strain



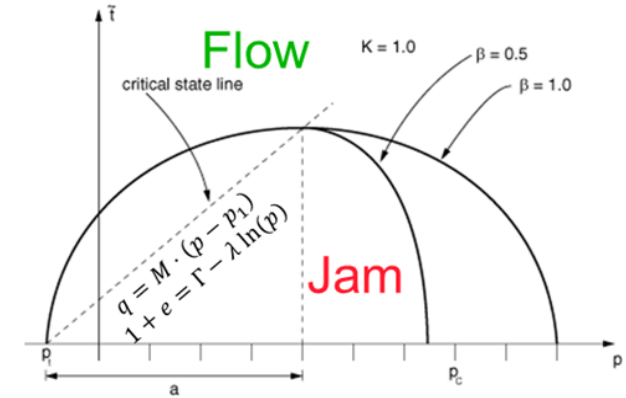
Model Parameters



Mohr-Coulomb



Drucker-Prager/Cap



Modified Cam-Clay

A series of HTC and CTC test results are reduced to a set of model parameters

Corn Stover Example Results			Drucker-Prager/Cap							
Description	%wb	Temperature	$\epsilon 1$	p_c (kPa)	d (kPa)	β (degree)	R (approximated)	$\epsilon 2$	α (assumed)	K (assumed)
CS C2mm	10	Ambient	0.01	1.0	6.9	8.7	0.020	0.01	1.0	1.0
CS C2mm	25	Ambient	0.01	1.0	3.0	11.5	0.030	0.01	1.0	1.0
CS C2mm	50	Ambient	0.01	1.0	3.4	10.1	0.001	0.01	1.0	1.0

Model Parameters Cont.

Corn Stover Example Results

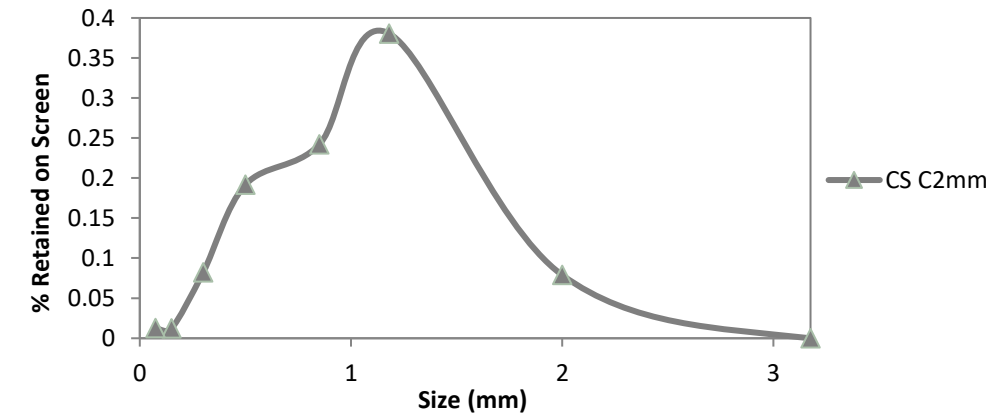
			Mohr-Coulomb			
Description	MC	Temperature	C (kPa)	$stdev$	ϕ (degree)	$stdev$
CS C2mm	10	Ambient	3.8	3.5	34	3
CS C2mm	25	Ambient	1.6	1.0	36	1
CS C2mm	50	Ambient	1.9	1.1	35	1

			Modified-Cam/Clay									
Description	MC	Temperature	K (kPa)	λ	κ	p_c (kPa)	ϵ_1	M (kPa)	G (kPa)	ϵ_3	β (assumed)	K
CS C2mm	10	Ambient	649	2.57	0.39	1	0.01	22	826.2461381	0.01	1	1
CS C2mm	25	Ambient	1042	2.23	0.19	1	0.01	29	666.9231158	0.01	1	1
CS C2mm	50	Ambient	654	1.63	0.28	1	0.01	25	496.7521062	0.01	1	1

CS C2mm*						
PYC	HTC	CTC	Target ODMC (%wb)	Loose BD	Tapped BD	Hausner Ratio
1250	164	111	12	130	161	1.2
1294	190	100	21	115	148	1.3
1189	243	110	35	127	170	1.3
1166	337	137	50	169	229	1.4

* Xgm = 1.23mm

Sieve Size Distribution of CS C2mm



IBR Project
Control Number: 1689-1534
Award Number: DE-EE0008254

Thank You



PI: Jim Dooley, Ph.D., PE
Presenter: Chris Lanning, PE

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Auburn, Washington

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Thank you

Related Work

- Dooley et. al. (2020) Overview of DOE Flowability Measurements and Modeling Project. ASABE paper 200080
- Yi et. al. (2020) Effects of Moisture on the Fundamental Mechanical Properties of Biomass Flow Models. ASABE Poster number 2000060
- Yi et. al. (2020) Finite Element Modeling of Biomass Hopper Flow. ASABE paper 2000059.
- Yi et. al. (2020) Biomass Flow Mechanical Properties Characterizations. ASABE paper 2000058
- Yi et. al. (2019). Computational modeling of continuum scale constitutive equations to improve biomass feedstock material handling and conveying systems. ASABE paper number 19000929
- Yi et. al. (2018). Computational modeling of continuum scale constitutive equations to improve biomass feedstock material handling and conveying systems. ASABE paper number 1800867.

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