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THE LINK BETWEEN THE ADVANCED ASH FUSION TEST CURVE AND FACTSAGE MODELLING

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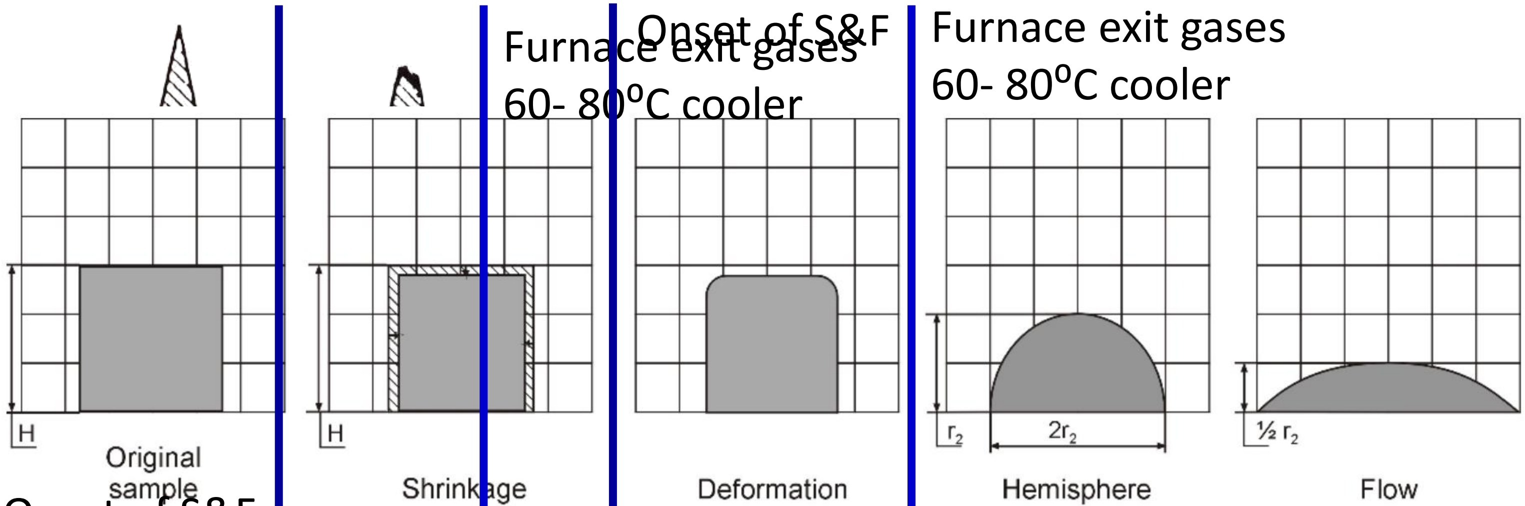
Conventional Ash Fusion Test (AFT)

- What is it used for?
- How does it work?

- Deformation temperature of ashes
- Using characteristic temperatures



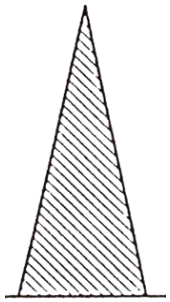
Onset of S&F

Furnace exit gases 60- 80°C cooler

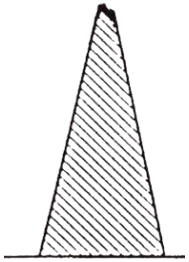
Onset of S&F

Furnace exit gases 60- 80°C cooler

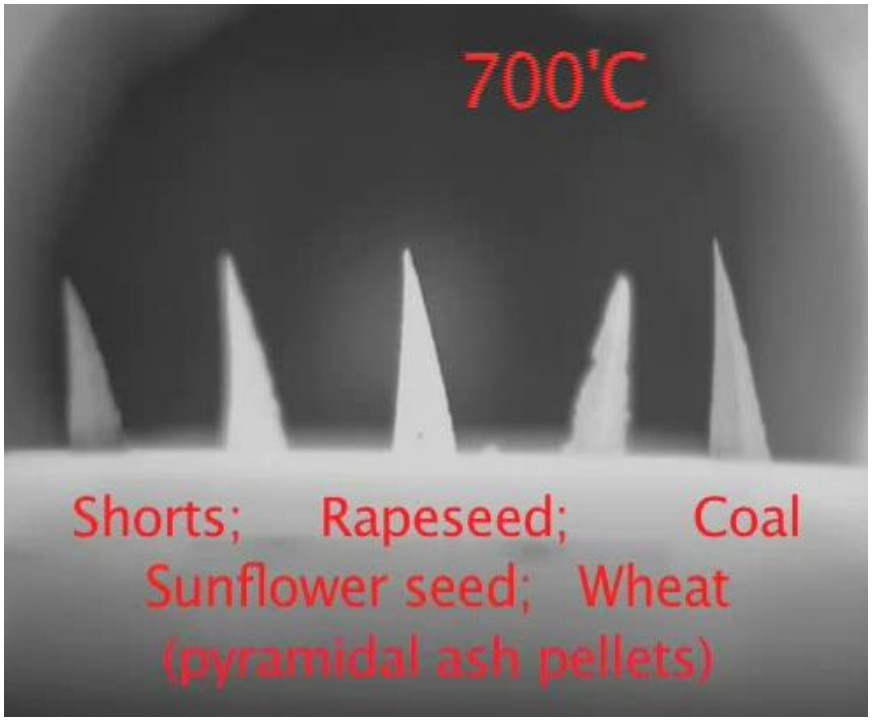
Conventional Ash Fusion Test (AFT): Problems

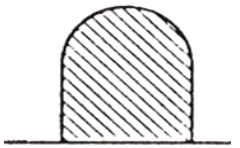


Original specimen



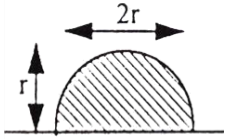
Initial deformation temperature (IDT)





Softening temperature

(ST)



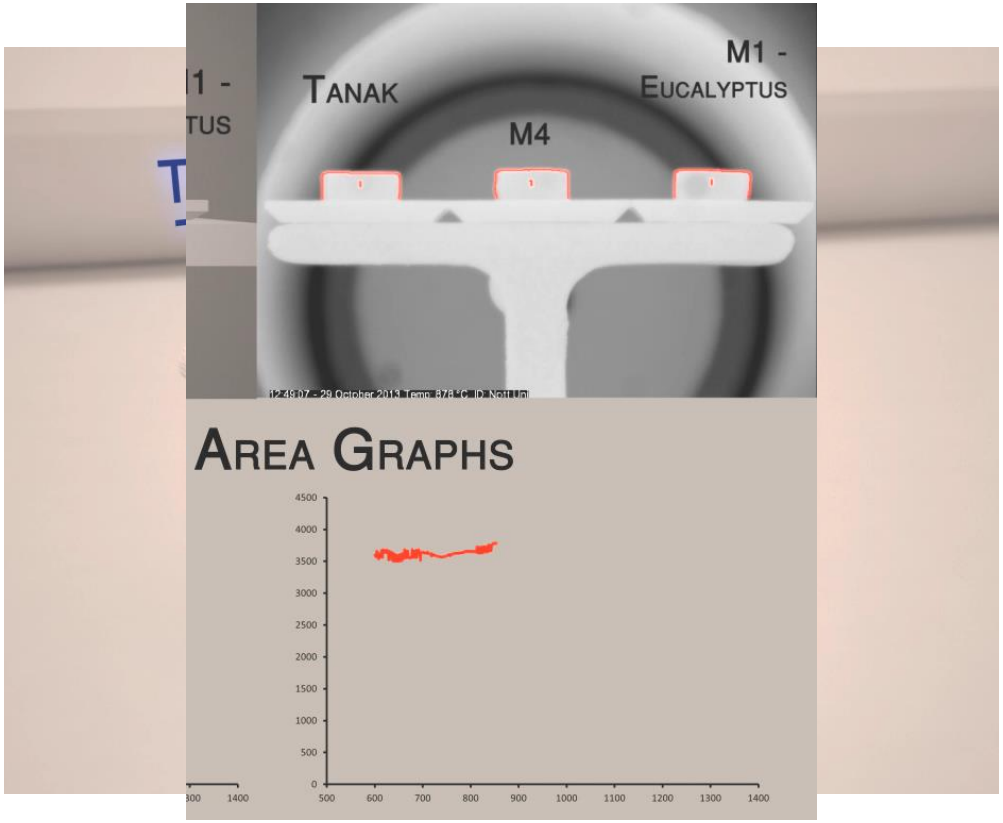
Hemispherical temperature

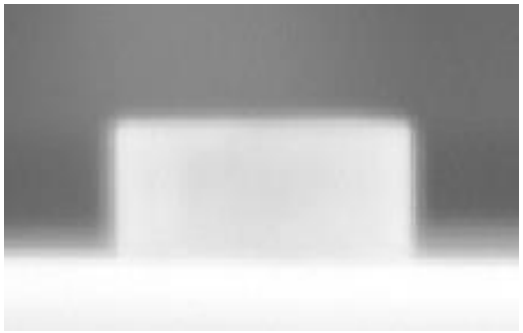
(HT)

Flow temperature

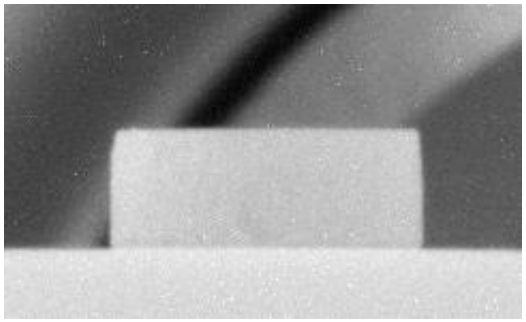
(FT)

Analysis Furnace





Old Image



New Image

Summary of Optimised AAFT

- The AAFT process has been optimised
  - 5mm machine made pellet
  - ± 5°C repeatability (from ± 40 °C)
  - Earliest possible trigger of melting
  - Crisp profile
- The AAFT Curve has been optimised
  - Combination of Area, Perimeter, aspect ratio and eccentricity (for IDT trigger).

Optimising the AAFT

Step 1: Pelleting

Shape/standard	Diagram
COAL: CONE MOULD WITH DEXTRIN	
BIOMASS: CARBOLITES CUSTOM CYLINDRICAL PELLET PRESS	
MACHINE PRESSED CYLINDRICAL PELLET	

Step 2: Curve

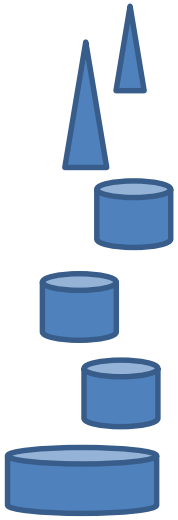
- SST Analysis:
  $A_P^{(1/5)}*(4P_P)^2$
- The initial deformation:
  $A_P*ECC*AXR$
- The curve profile:
  $A_{P0}*AR$

Optimising the AAFT : Step 1

1. Pellet type
    a. Cone
    b. Cylinder(with without dextrin)
    c. Pressurised cylinder
2. Voidage
    1. Particle size (post ashing)
    2. A range of pressures for pressurised pellets
3. Heat Ramp
4. Ashing temperature

Optimising the AAFT : Step 1

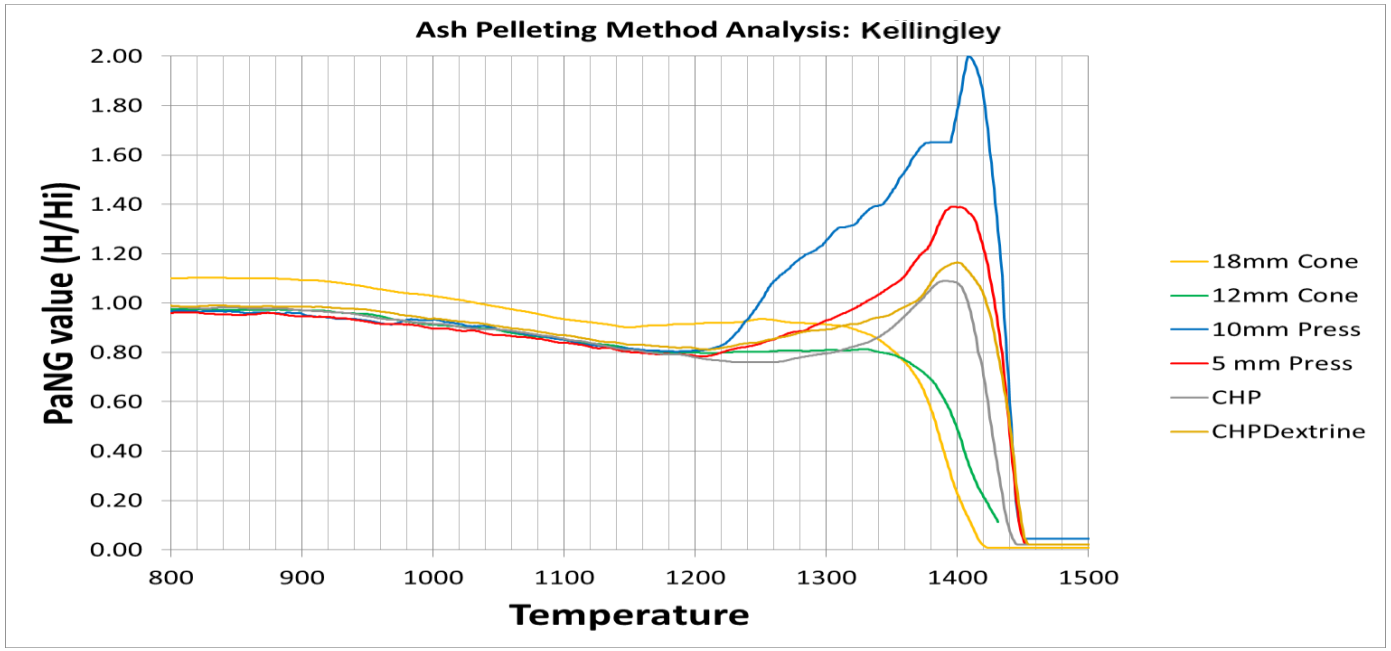
1. Pellet type



Sample	IDT (°C)	Repeatability (°C)
Standard Cone w/dextrin (12mm)	1320	± 50
Standard Cone w/dextrin (18mm)	1256	± 40
Carbolite Hand Press (5mm)	1260	± 10
Carbolite Hand Press w/dextrin (5mm)	1220	± 20
Tensometer Press 5000psi (5mm)	1204	± <10
Tensometer Press 5000psi (10mm)	1207	± <5

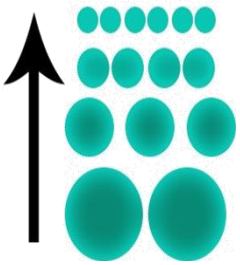
Optimising the AAFT : Step 1

1. Pellet type



Optimising the AAFT : Step 1

2. Particle size (post ashing)



Sample	IDT
36/38-µm (No. na/400) PaNG	1180
150-µm (No. 100)	1220
212-µm (No.65) BS Standard	1220
250-µm (No. 60) ASME	1220

Optimising the AAFT : Step 1

3. A range of pressures for pressurised pellets

	IDT (C)	
Standard Press (for reference)	1220	
Sample	10mm Die	5mm Die
2500 psi	1227	1223
3750 psi	1224	1220
5000 psi	1205	1210
6250 psi	1199	1200
7500 psi	1193	1190

Optimising the AAFT : Step 1

4. Heat Ramp and Ashing Temperature

Heating Rate (°C/min)	IDT (°C)
4	1185
7	1192
10	1198

Ashing Temperature (°C)	IDT (°C)
500	1195
750	1215
815	1215

Optimising the AAFT : Step 1

1. The cones and the hand press performed poorly

2. Machined pellets: excellent repeatability, accuracy, crisp profile.

3. Only maximum particle size of 36 µm reduced IDT.

4. Higher pressure pellet reduces the IDT for both pellets sizes
   - ~34^{o}C decrease.

5. A reduced ashing temperature resulted in lower IDT, and greater FT.

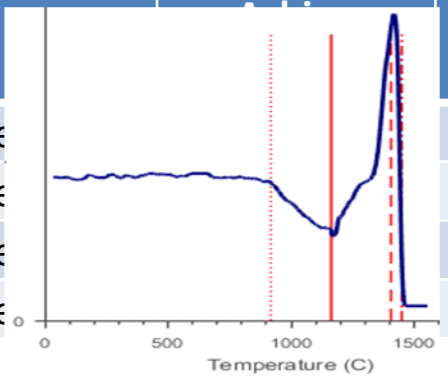
Optimising the AAFT : Step 1

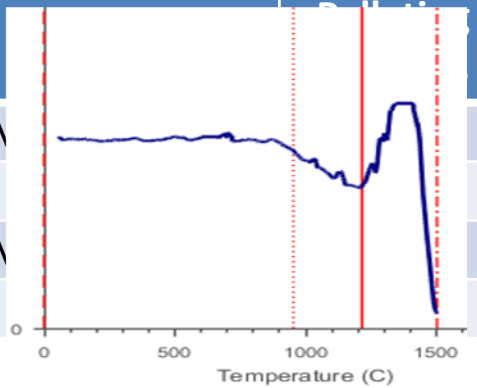
Milled

Un-milled

Sample		Heating rate
1	Ke	4 °C/min
2	Ke	10°C/min
3	Ke	4 °C/min
4	Ke	10°C/min

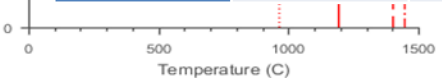
500C





815C

Sample	SST	IDT	ST	FT
1	921*	1168	1411	1455
2	957	1220	0 (1375)	1508
3	965	1194	1403	1448
4	972	1238	1342	1424



Optimising the AAFT : Step 1

- An optimised advanced ash fusion test (OAAFT) process includes:
  - The selected fuel milled to below 250 µm
  - Ashed at 500/815 ^{o}C (TBC)
  - Ash milled to below 76 µm (if any particles do not pass include them in the sample
  - 0.100g of ash (+- 0.05g) compressed into 5mm pellet at 7500psi
  - Ash fusion test run at 7 ^{o}C/min from room temp (or 300 ^{o}C for consecutive tests) to 1600 ^{o}C/completion of the test (or capacity of the furnace)

Optimising the AAFT : Step 2

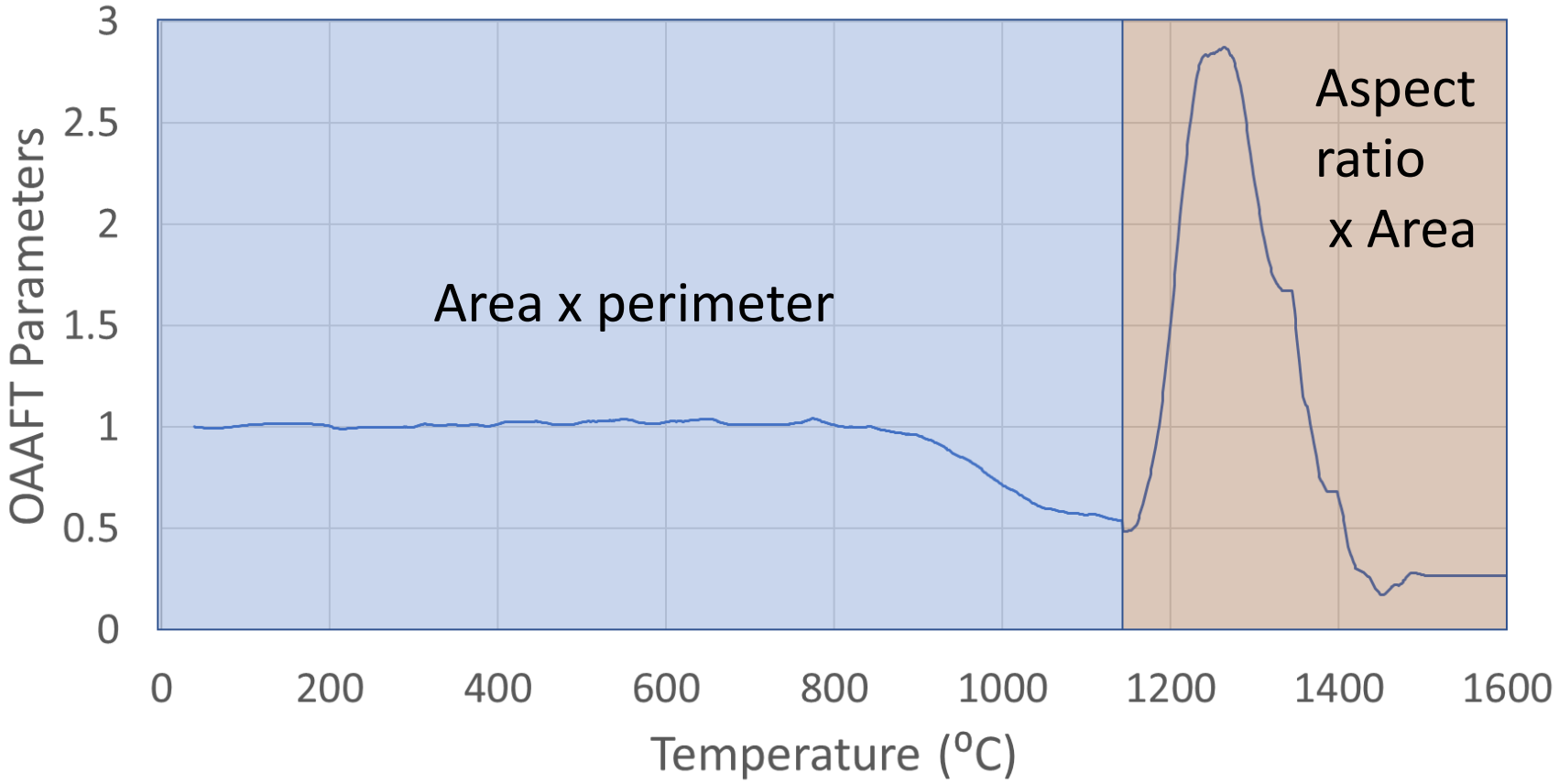
1. Clustering Variables
2. Formulating curve equation

Symbol	Definition
H	Height of the bounding box
W	Width of the bounding box
Ap	Area of the particle
Ach	Area of the convex hull
Pp	Perimeter of the particle
Cen	Centroid
AXmax	Length (in pixels) of the major axis of the ellipse that has the same normalized second central moments as the region.
AXmin	Length (in pixels) of the minor axis of the ellipse that has the same normalized second central moments as the region.
Fmax	Maximum Feret Diameter, or longest internal line segment of the particle
De	Diameter of equivalent area circle (Heywood diameter) computed as sqrt(4*Ap/pi)

Optimising the AAFT : Step 2

Shape Parameter	Inclusion	Link	Cluster Group	Parameter Type
PaNG	H/Hi	Height	1	Size
Area	Ap	Area	1	Size
Convex Area	Ach	Area	1	Size
Height to weight ratio (AR)	H/W	Height & width	1	Shape
Perimeter	Pp	Perimeter	1	Size & shape links
Eccentricity	ECC*	Ellipse height & width	1	Shape
Roundness	4A/(pi*Dmaxferet^2)	Area, Perimeter, Fmax	2	Shape
1/Rectangularity	Pp/(2H+2W)	Perimeter, height, width	4	Shape

Optimised AAFT Parameters



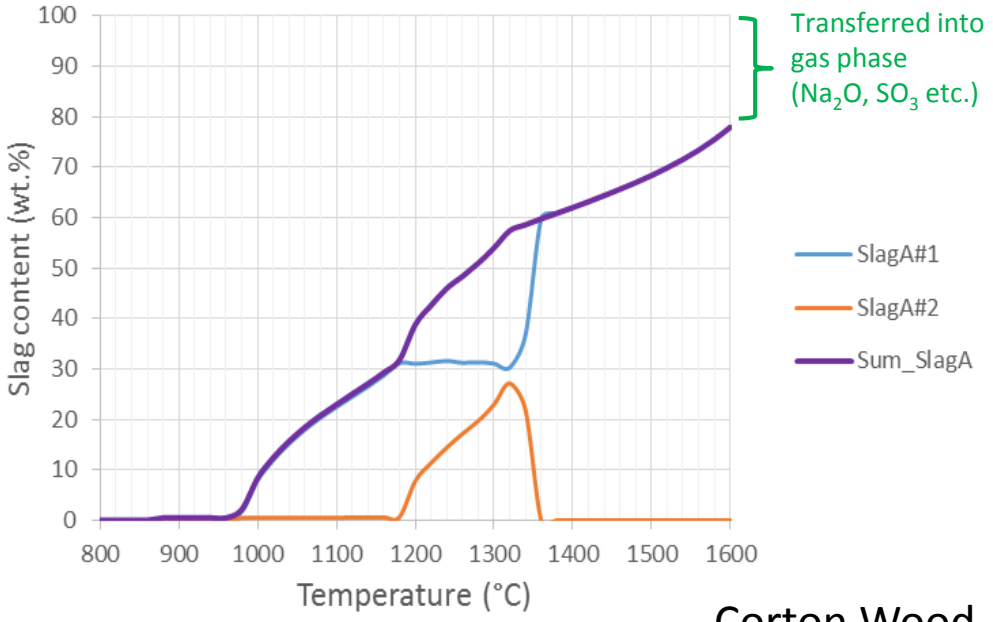
FactSage Analysis intro

- FactSage version 7.2
- Data bases: FToxid, FTmisc, FTsalt and FactPS
- Solution species comparable to literature [1]
- Input data:
  - Ash composition (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, K_2O, P_2O_5 and SO_3)
  - Air (N_2, O_2, Ar)

[1] Fuel 202 (2017) 641-649.

FactSage Analysis intro

- Analysis:
  - Slag content (SlagA with two potentially immiscible phases) vs. temperature

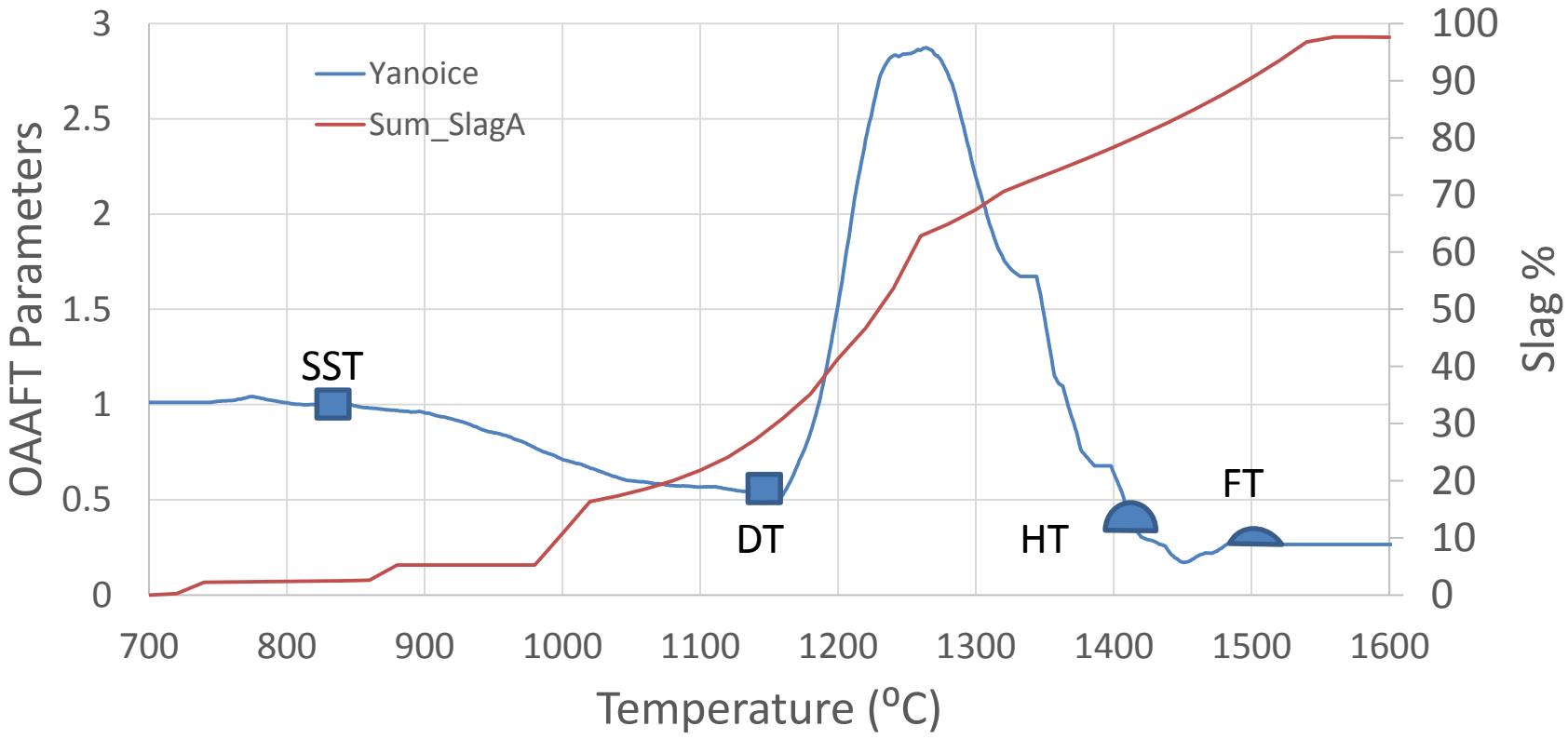


Corton Wood

In the Study

- 20 BF2RA coal bank and international coals & 11 Biomasses
- Identify links in the slag % to curve shape
- Further validate both fact sage analysis and OAAFT
- Create large database for coals and biomass

Slag % vs OAAFT Example Curve



Slag % vs OAAFT Curve

	Average Slag %			
	SST	IDT	HT	FT
Coal	7.3	45.7	86.1	90.9
Biomass	48.6	70.1	86.4	86.1

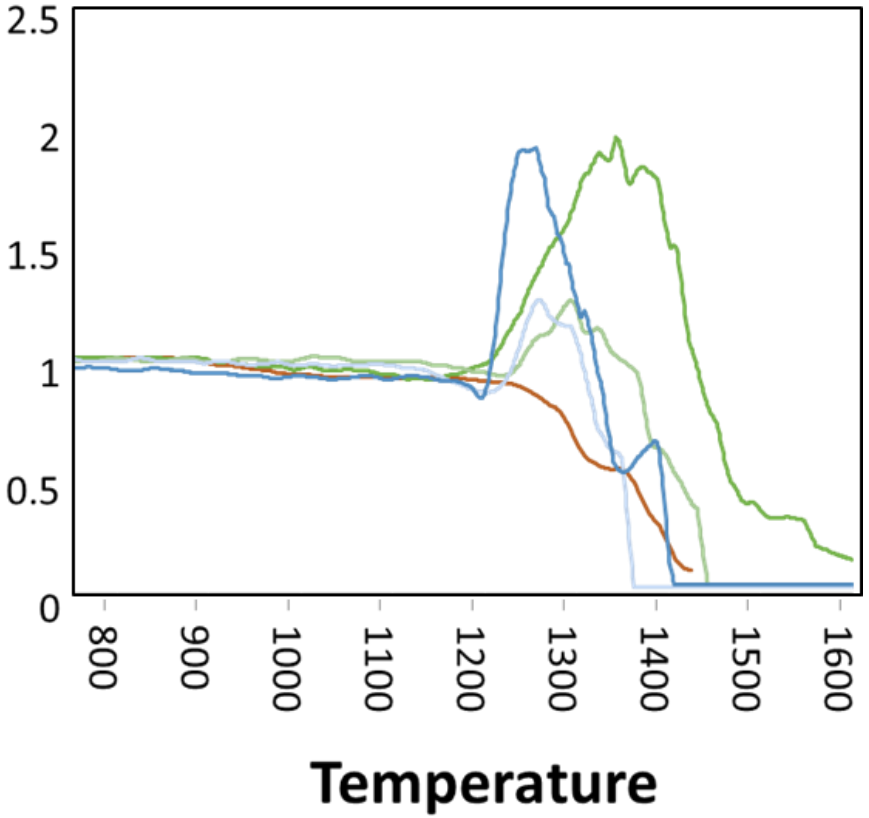
- Coal shows good relationship to the OAAFT curve
  - Indicates that slagging phases are already present at SST and IDT
- Biomass samples do not correlate to curve shape

Slag % vs OAAFT Curve

- The modelling suggests that on average 45% of the coal ash is in a slag phase at IDT.
  - Max 68%
  - Min 27%
- The term ‘initial’ deformation may be misleading
  - Redefine the term as ‘critical’ deformation

OAAFT Database Grouping

- Individual, repeatable characteristic profile generated
- No of general trend of shape in relation to components in ash
- Potentially insufficient sample variation



Summary

- AFT improved using an Optimised Advanced Ash Fusion Test.
- Coal ash displays good relationship between OAAFT and Factsage slag prediction
  - Biomass requires alternative database
- Characteristic curve generated for large database of coals and biomass
- Inconclusive outcome of curve shape significance to S+F

Further Work

- Investigate the impact of coal-biomass blends on curve shape
- Identify alternative database for biomass slag prediction
- Add more industrial and global fuels to OAAFT database

Acknowledgements

Supervisors:

- Prof. Ed Lester
- Dr. Chengheng Pang
- Dr. Mark Flower
- Dr Orla Williams

Co-contributor:

- Dr. rer. nat. Markus Reinmöller

Thank you

Any Questions?

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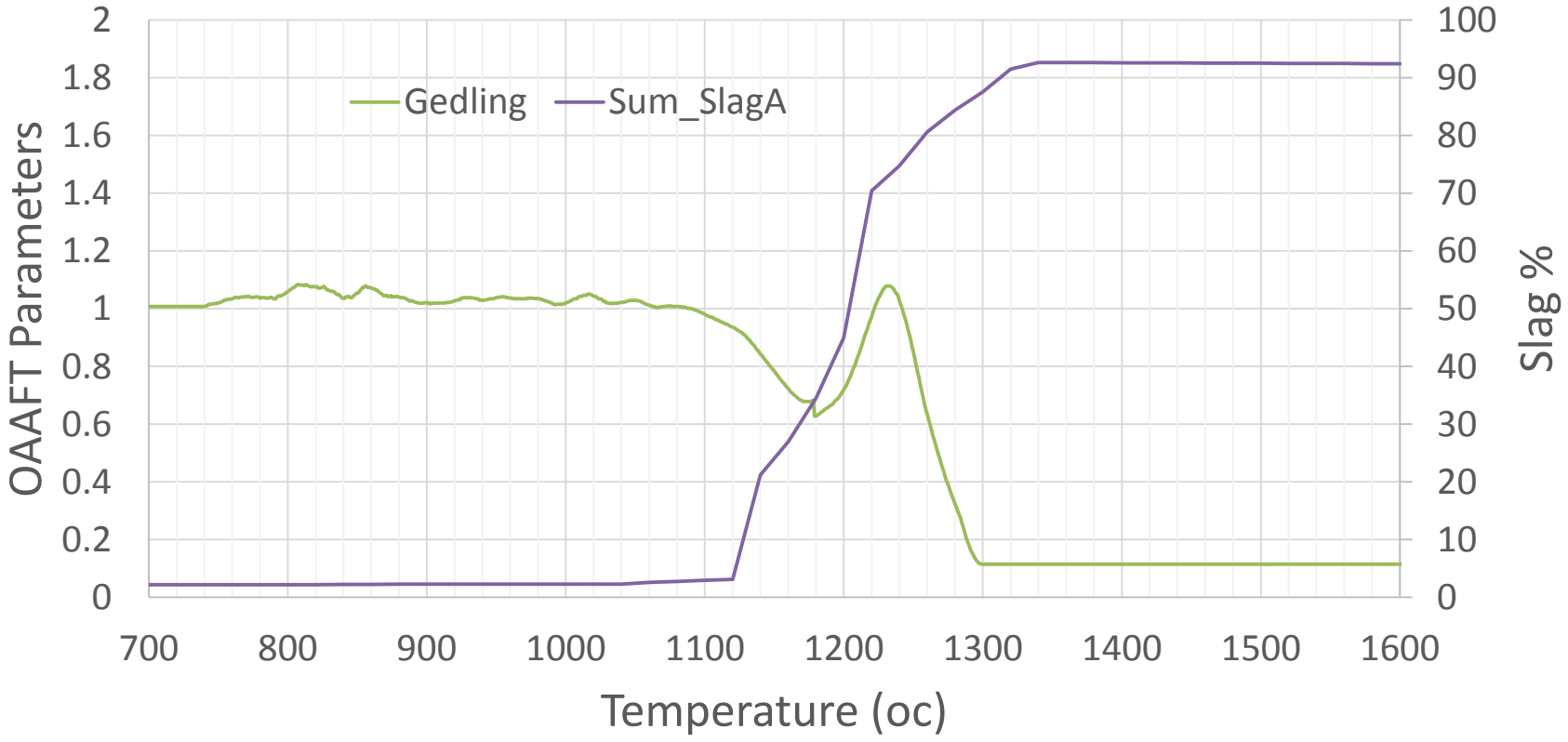
Coals

Slag % vs OAAFT Curve



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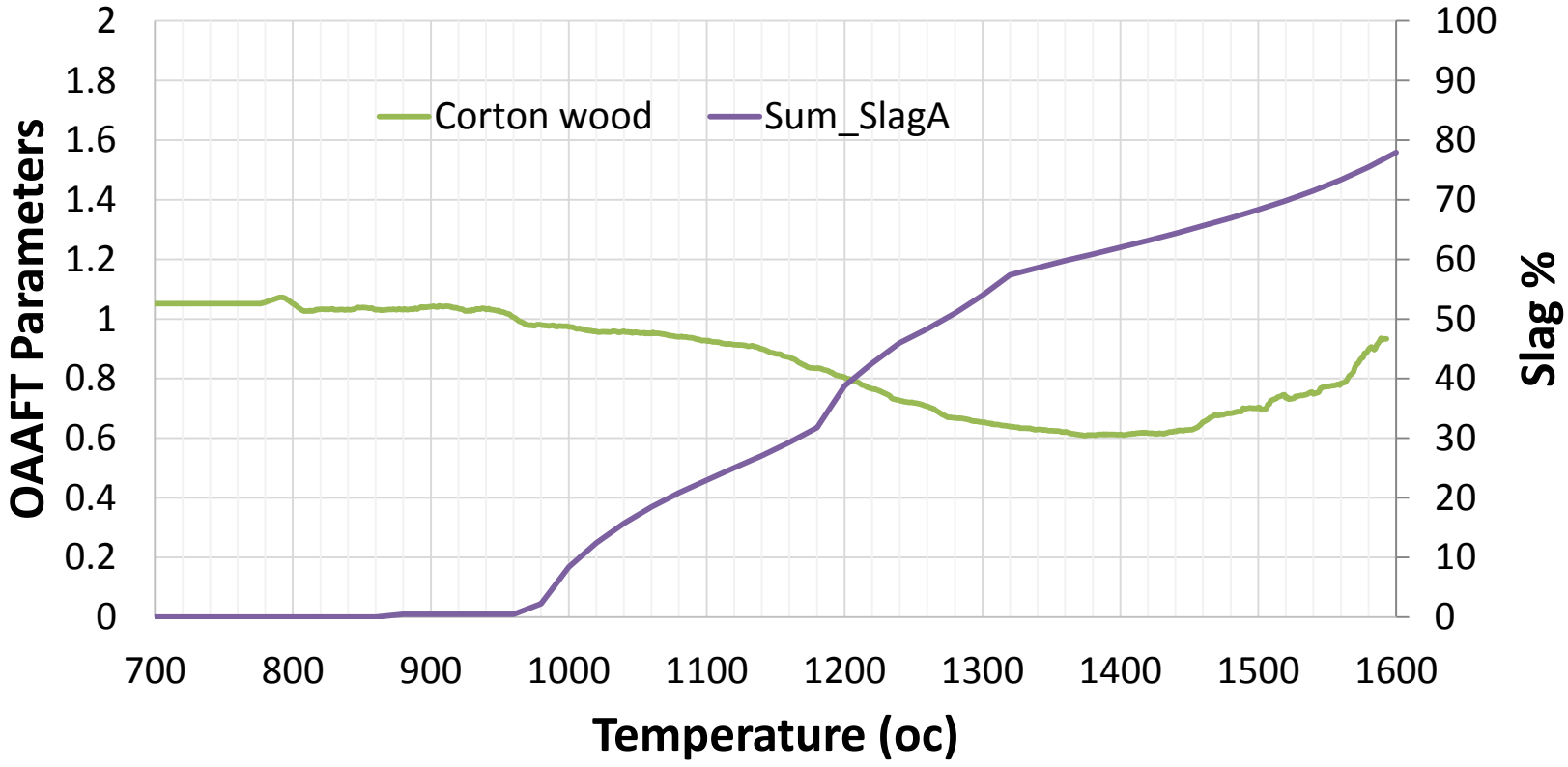

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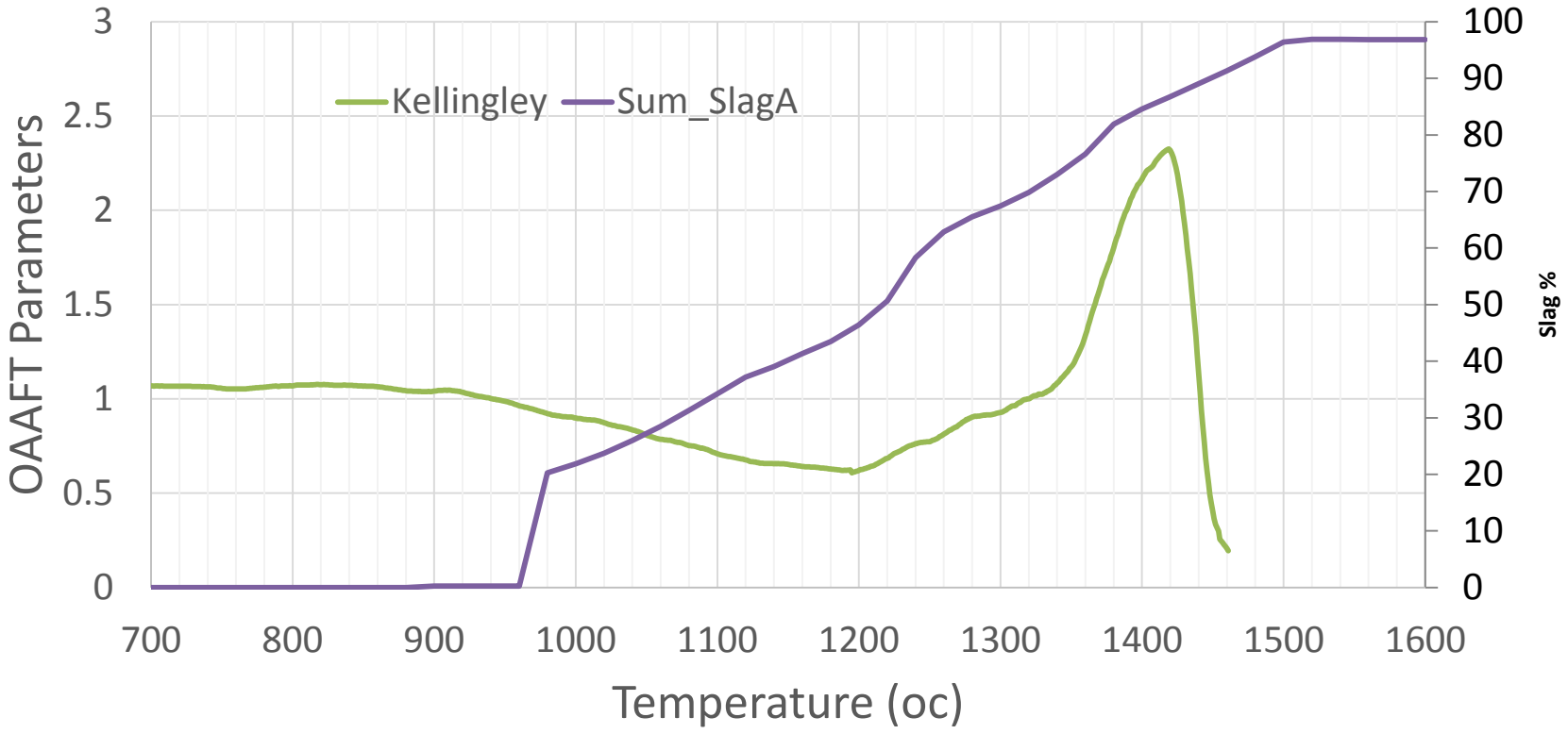

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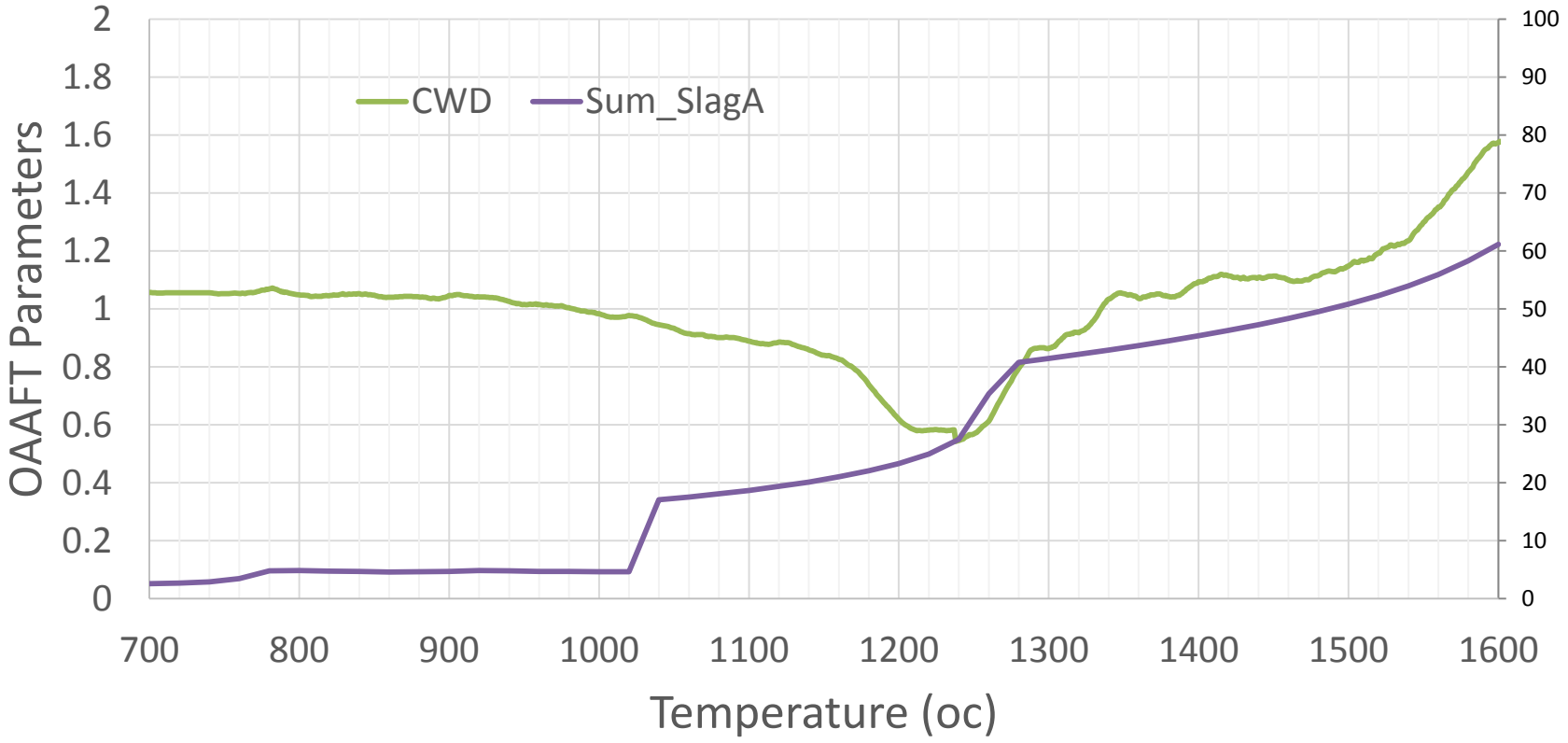

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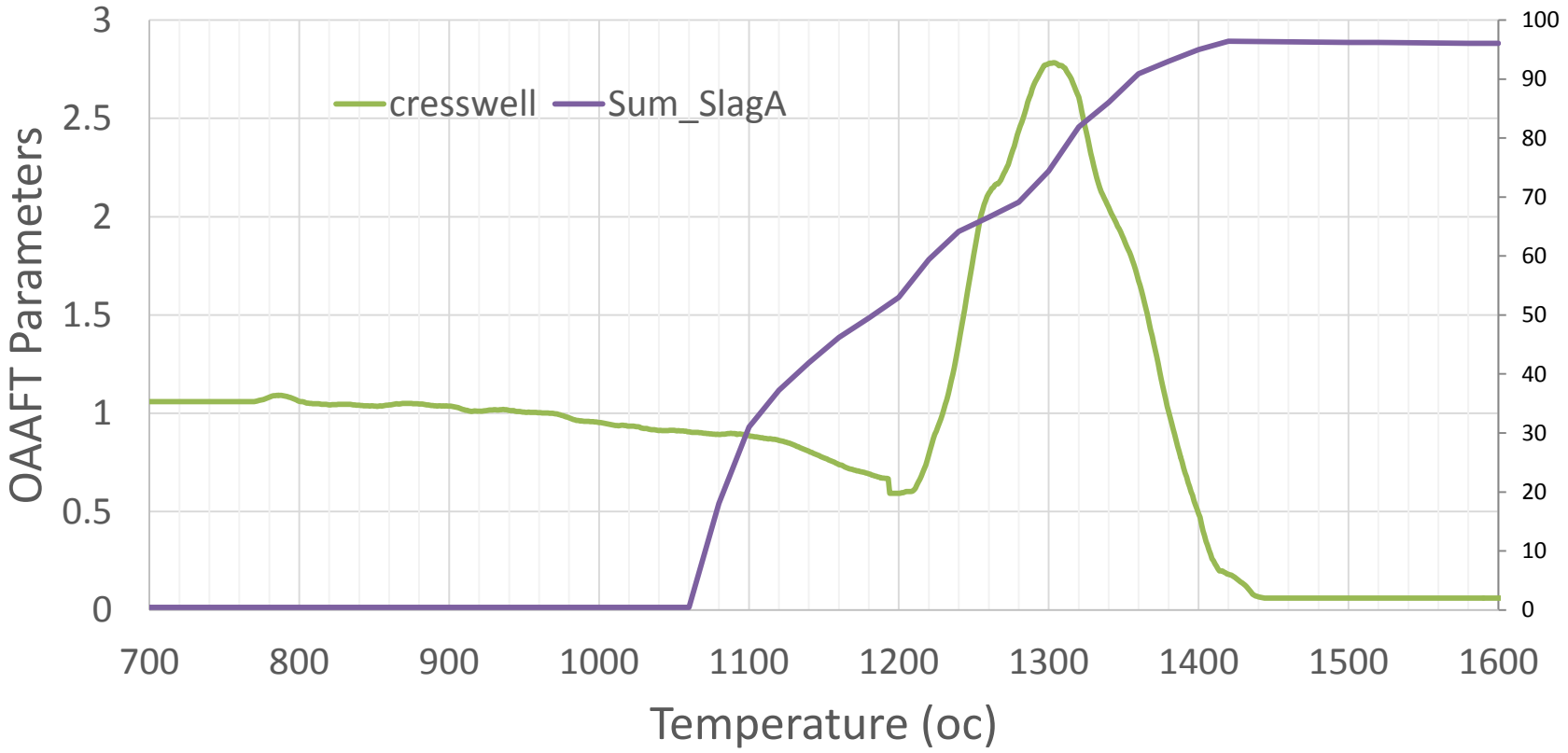

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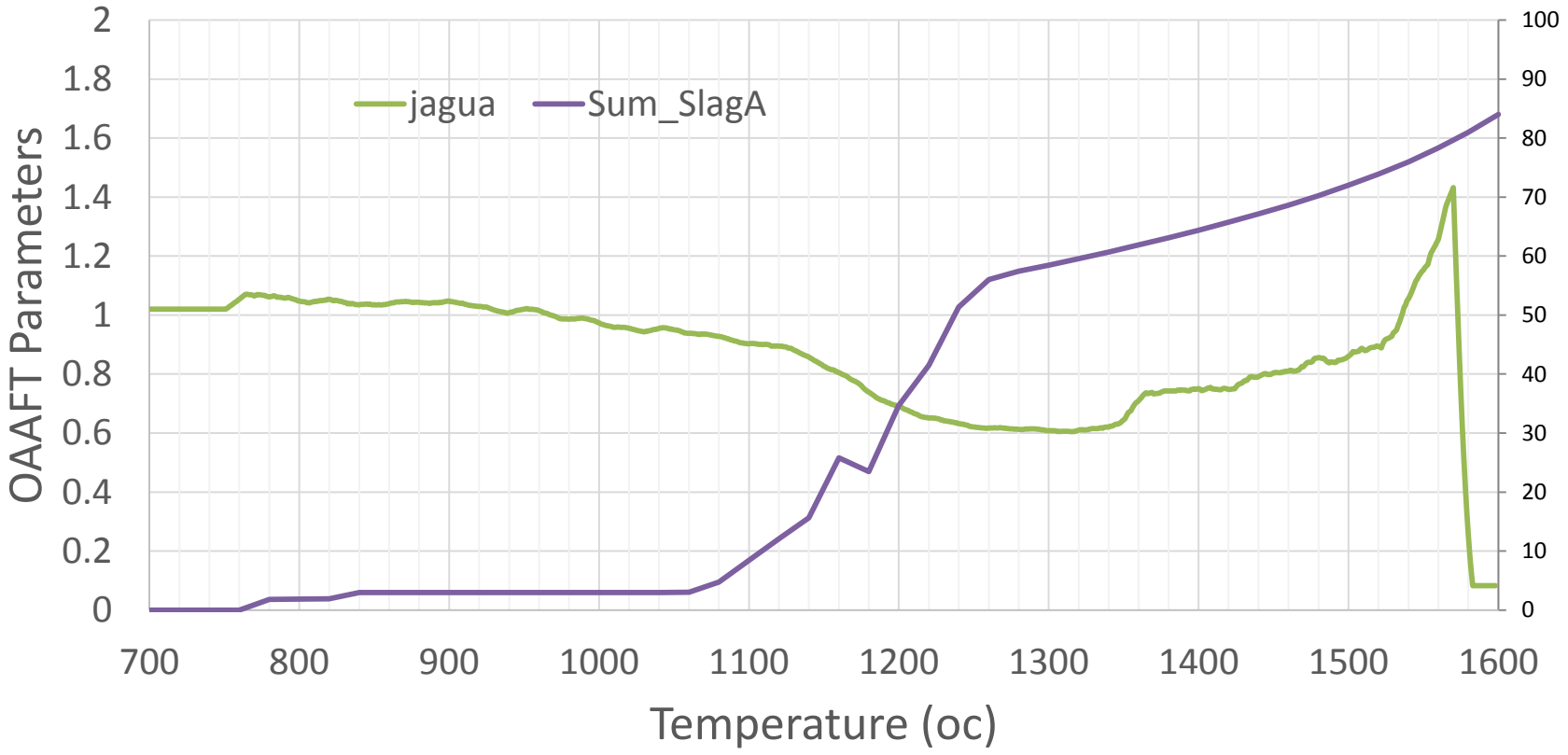

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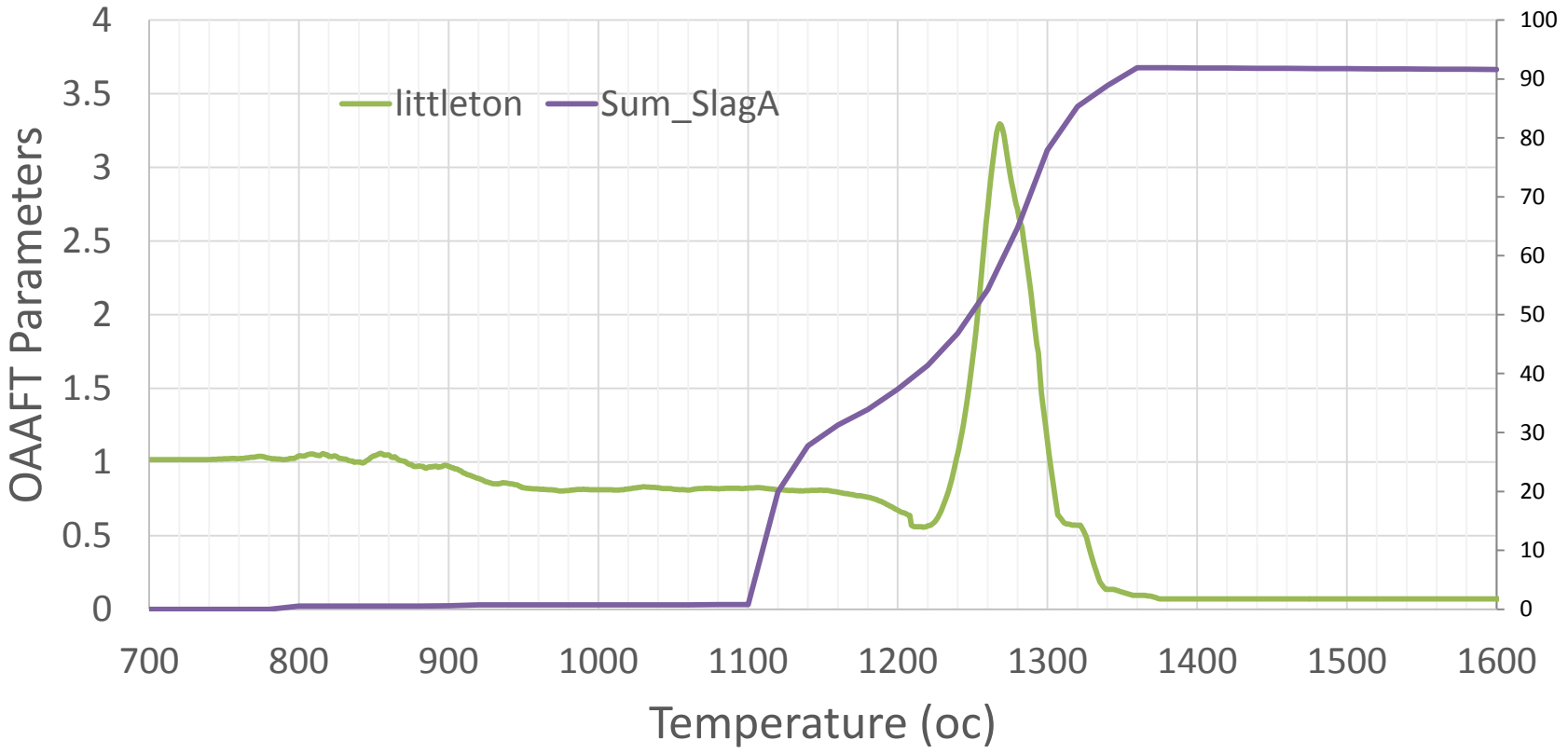

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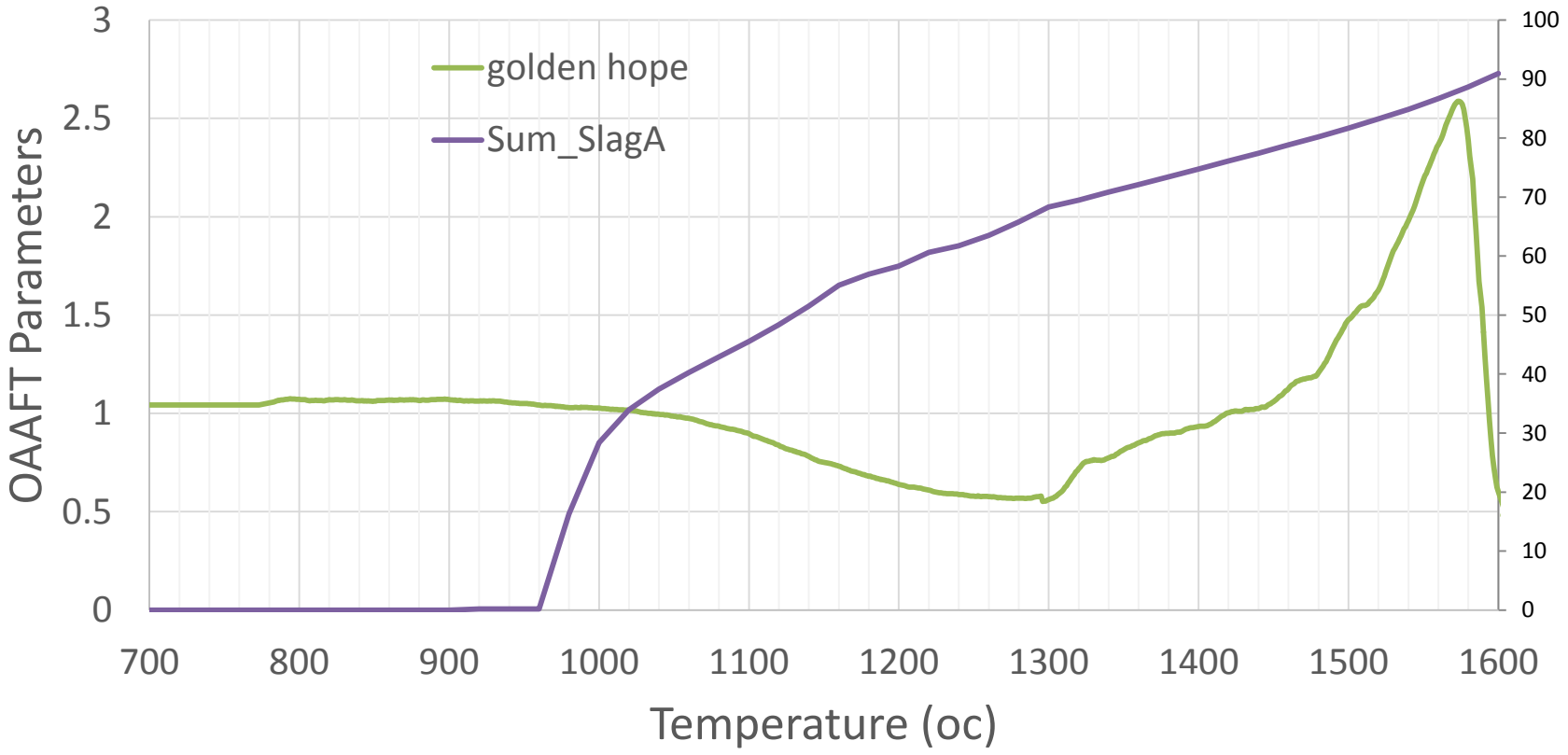

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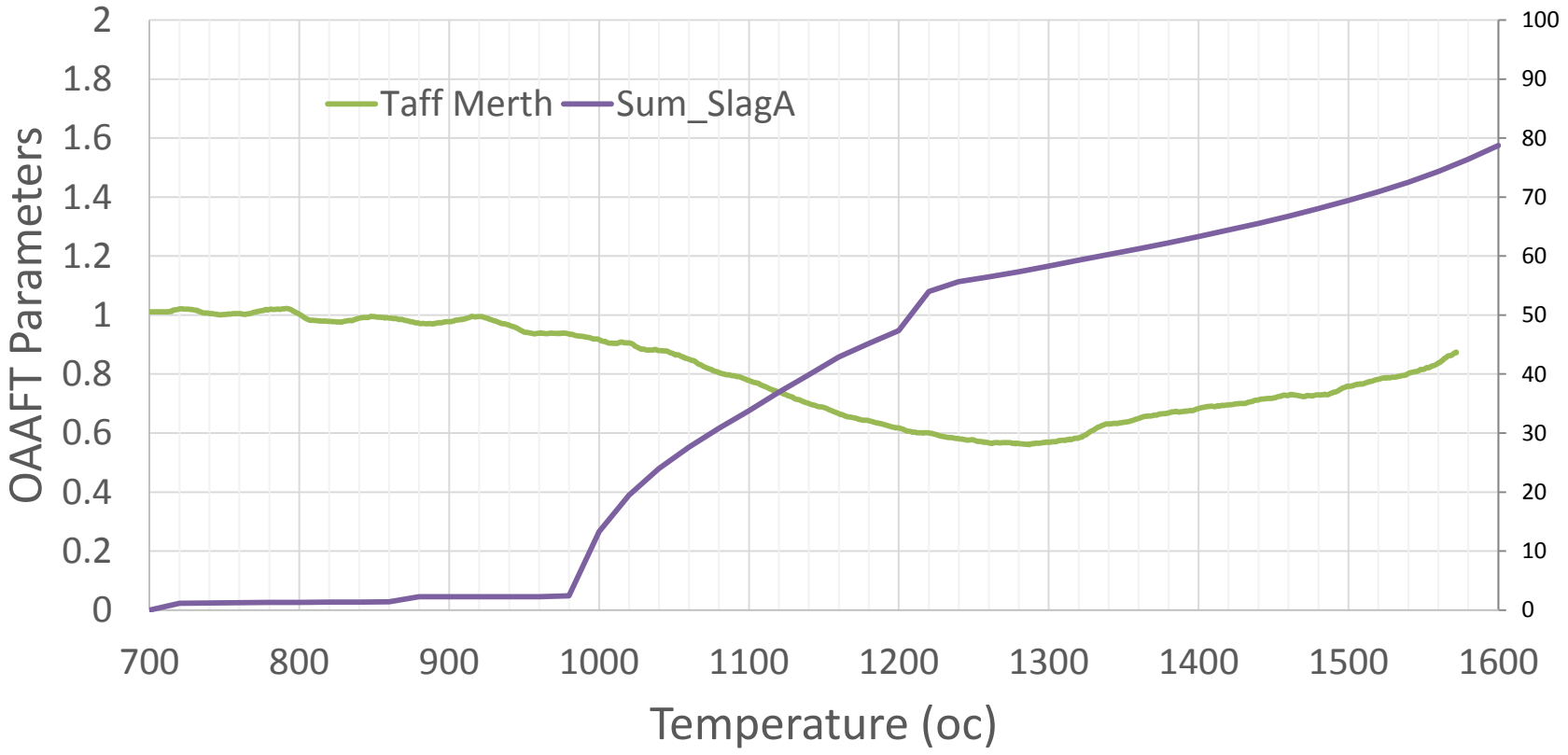

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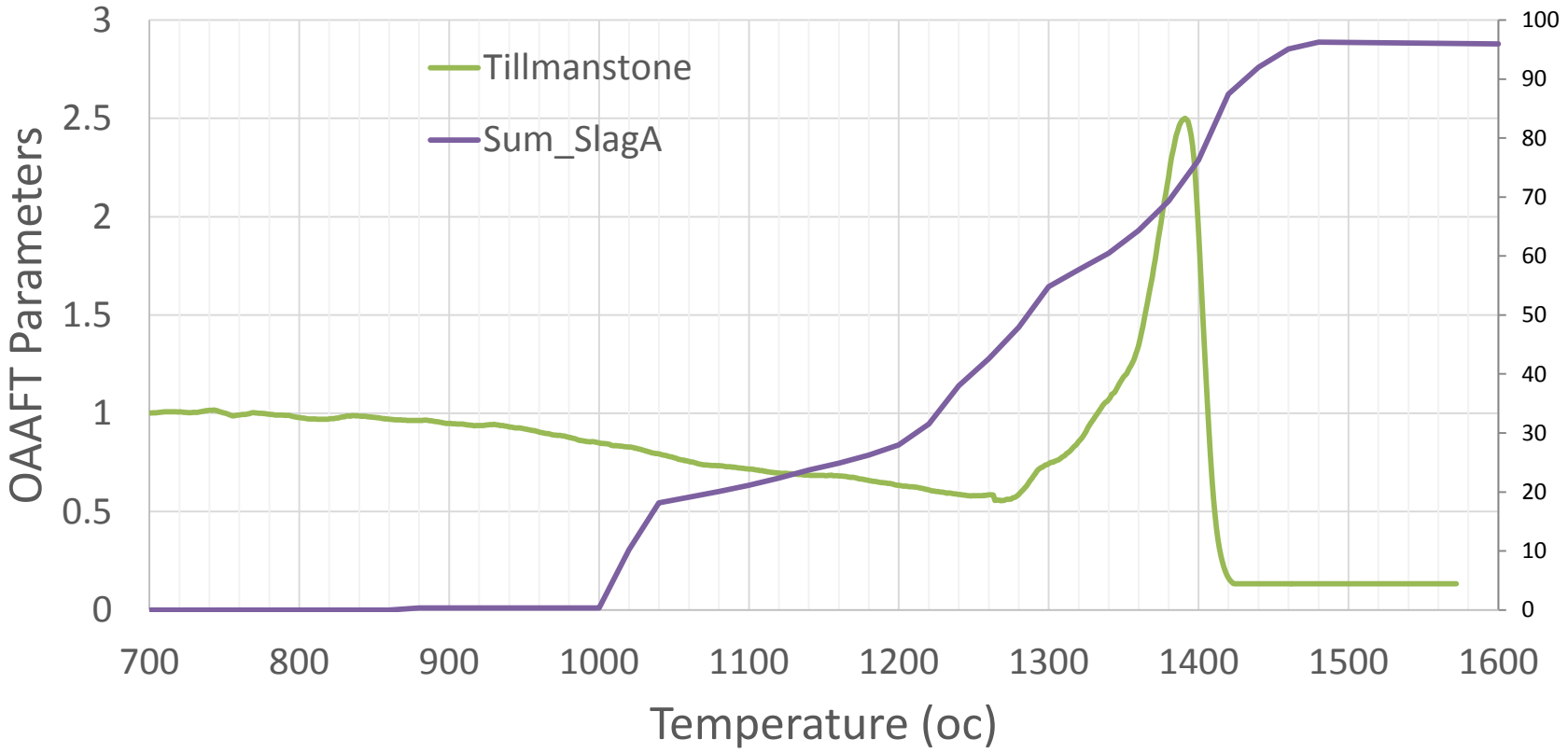

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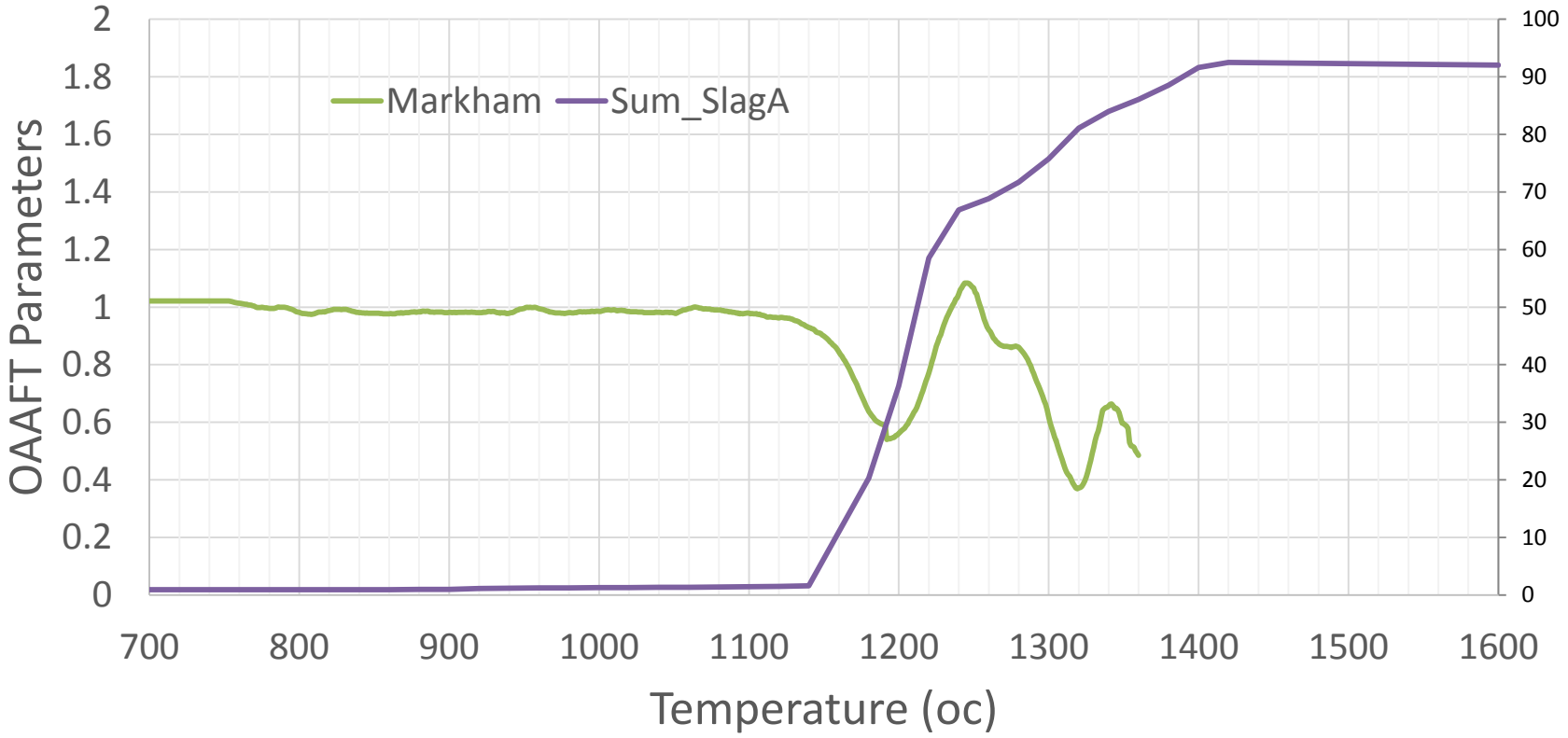

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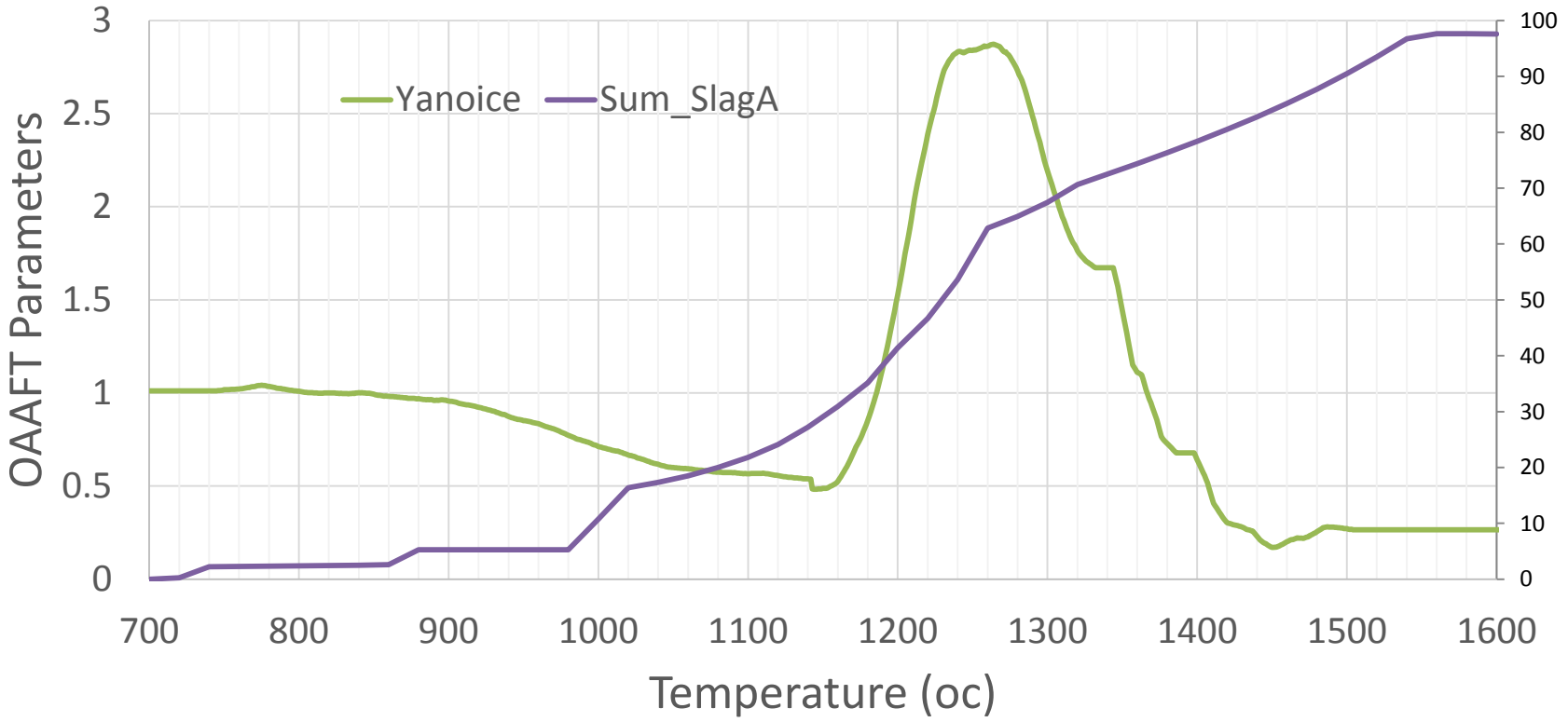

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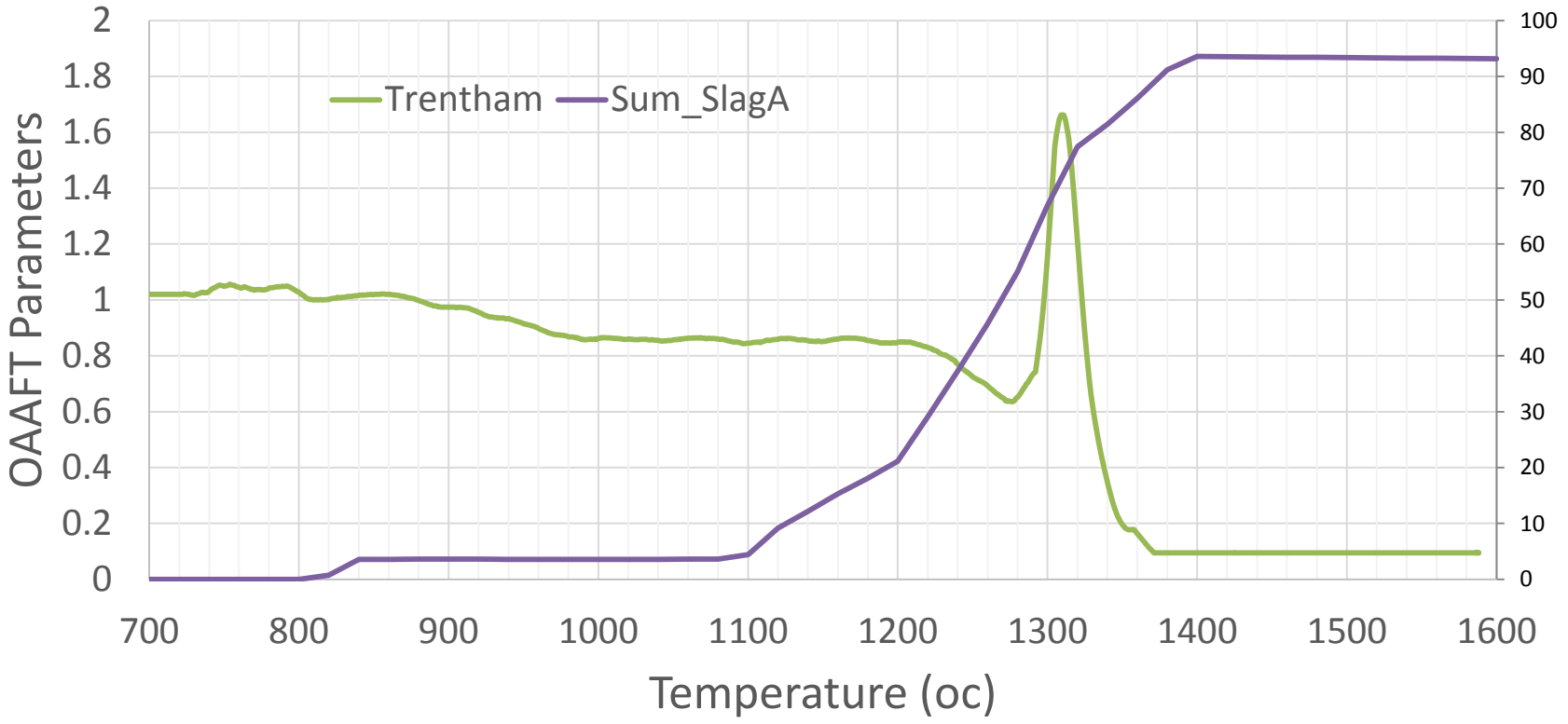

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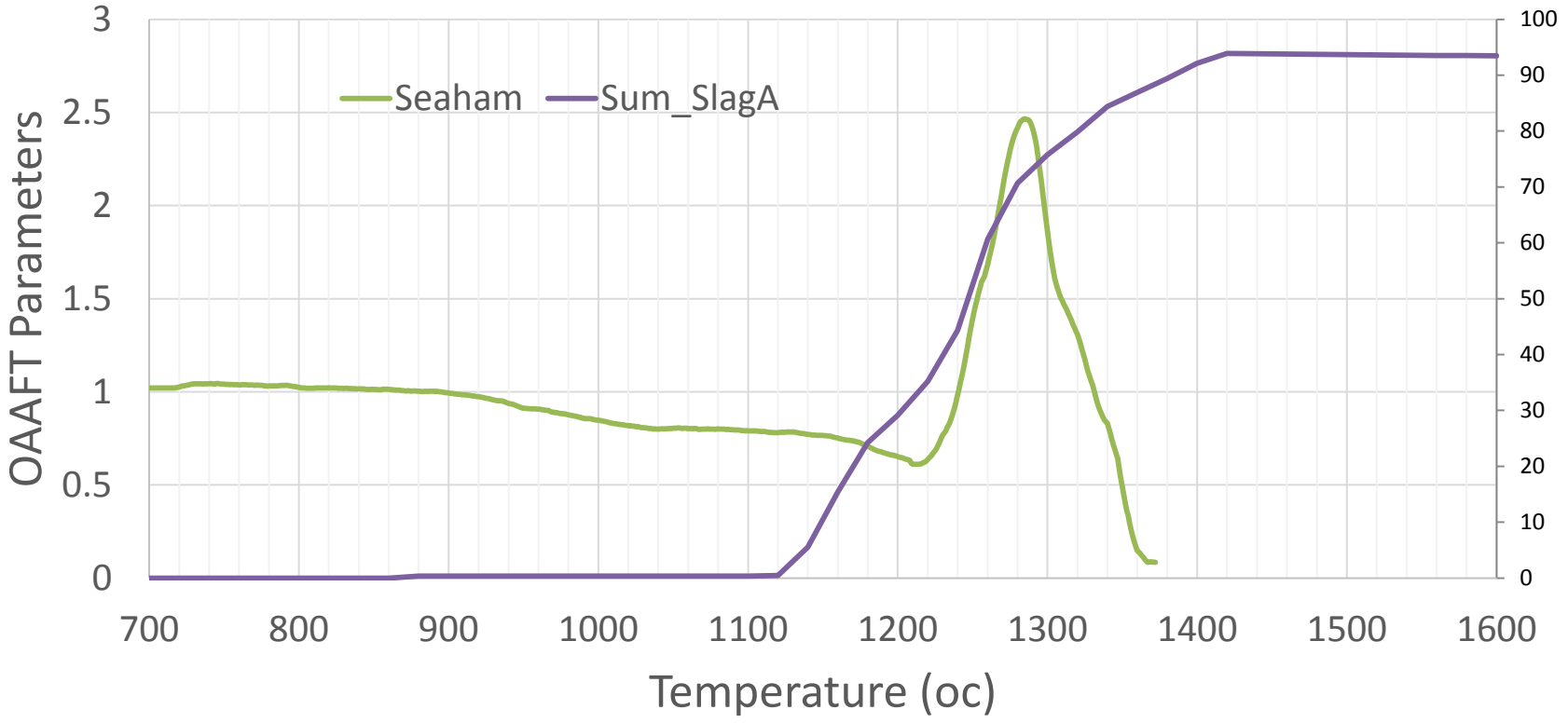

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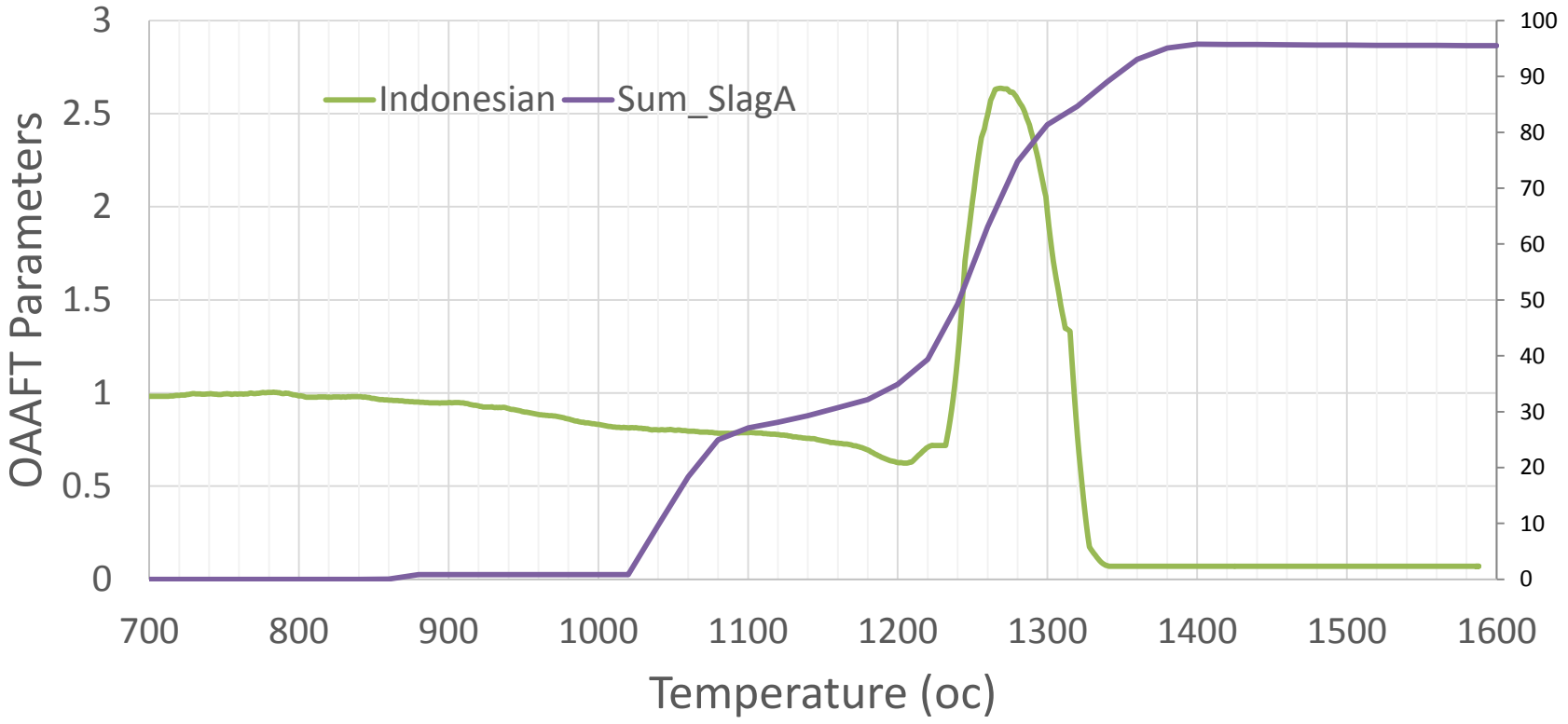

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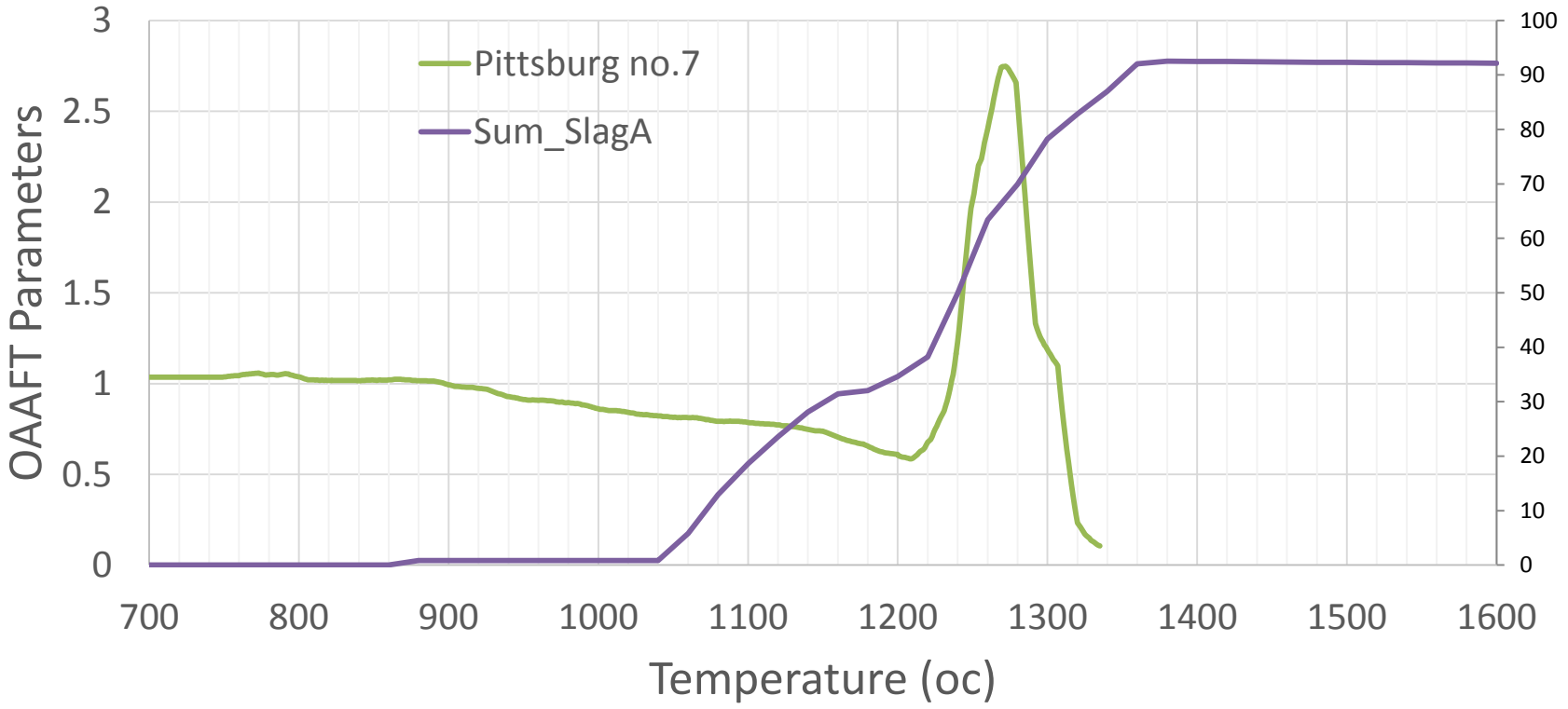

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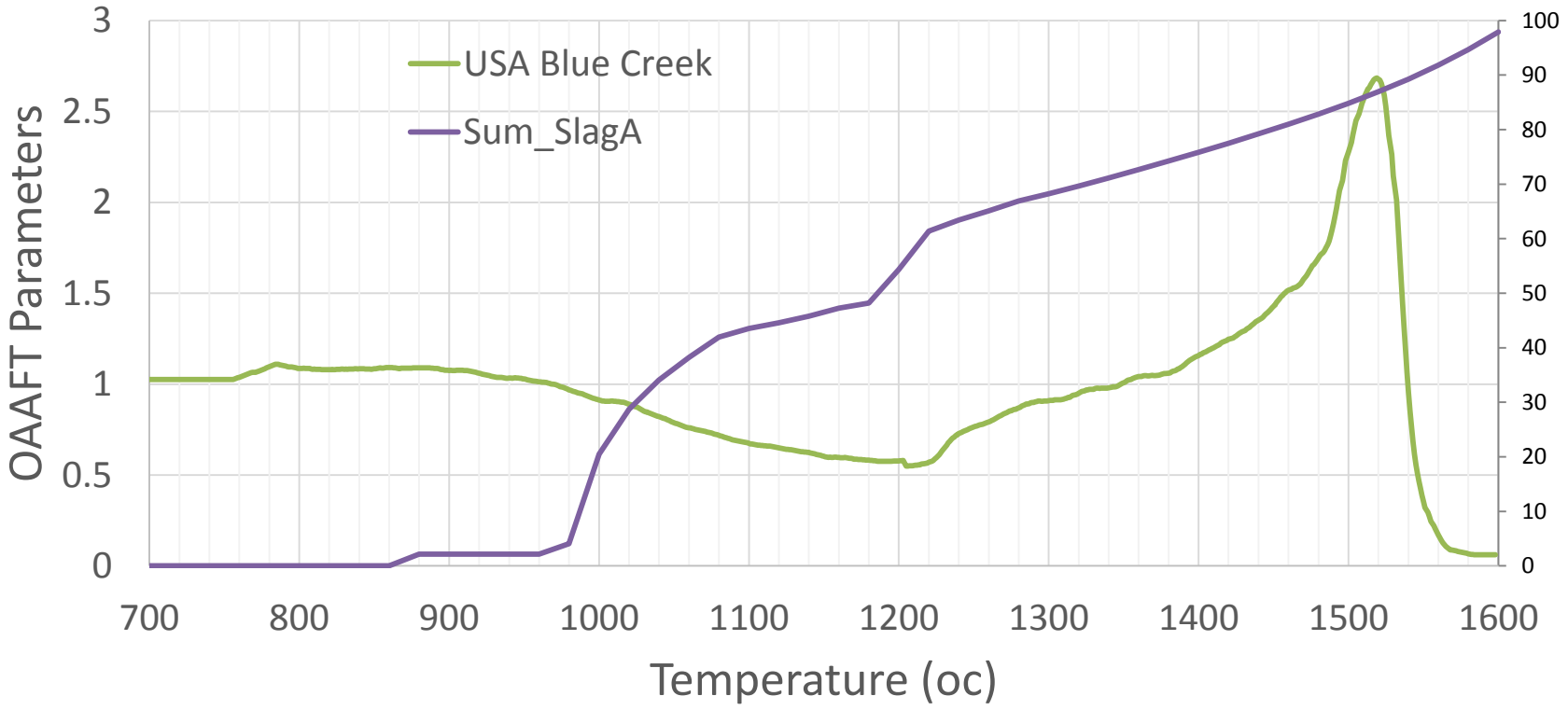

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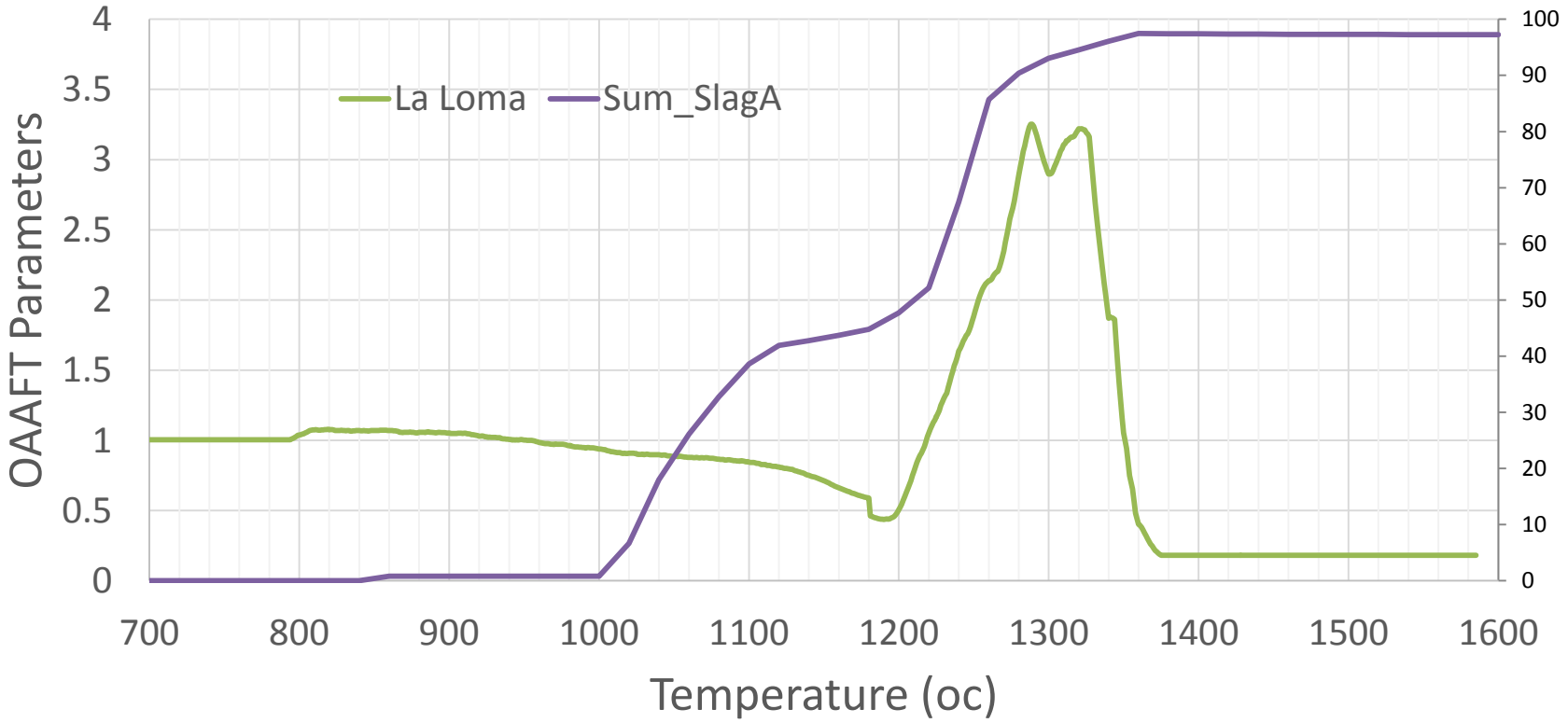

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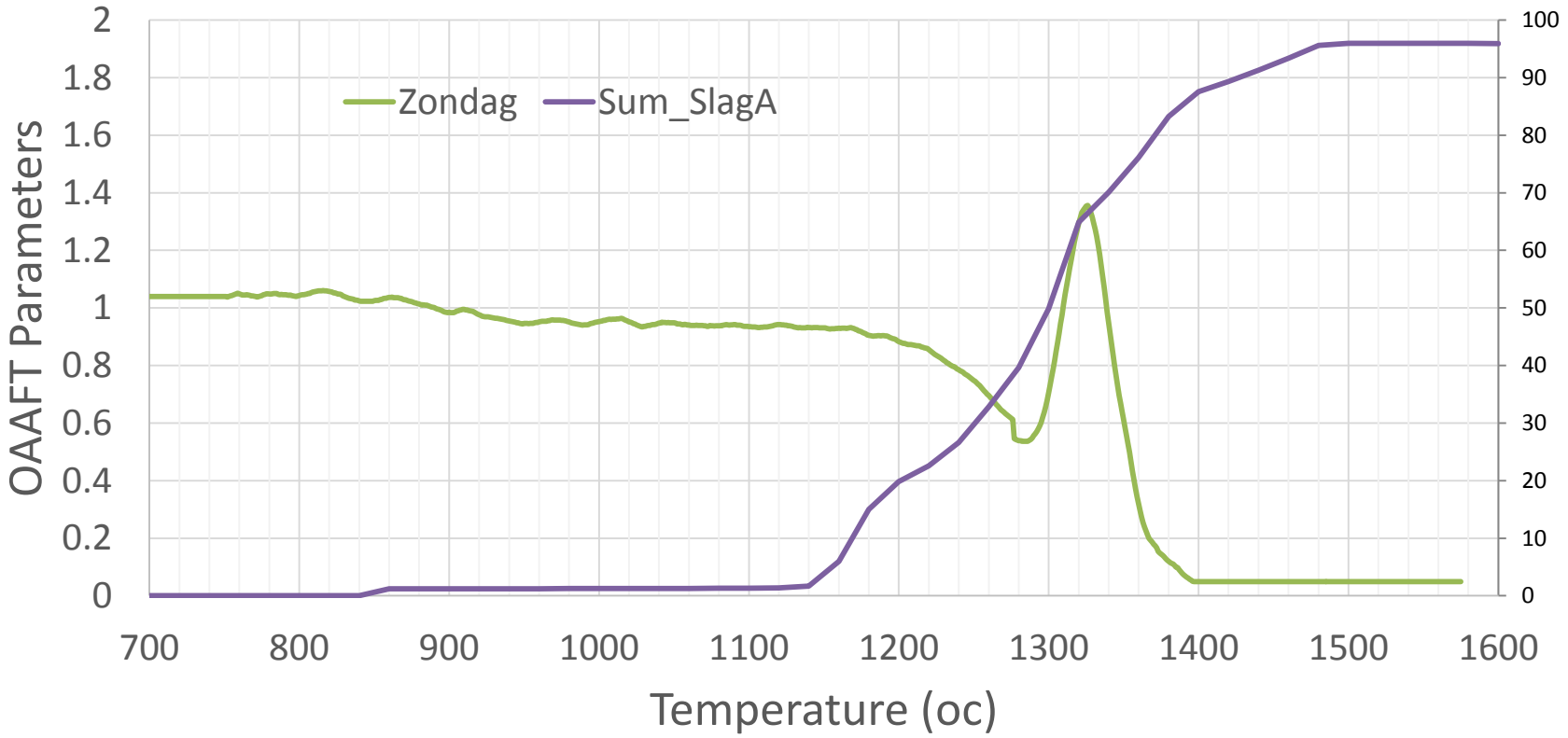

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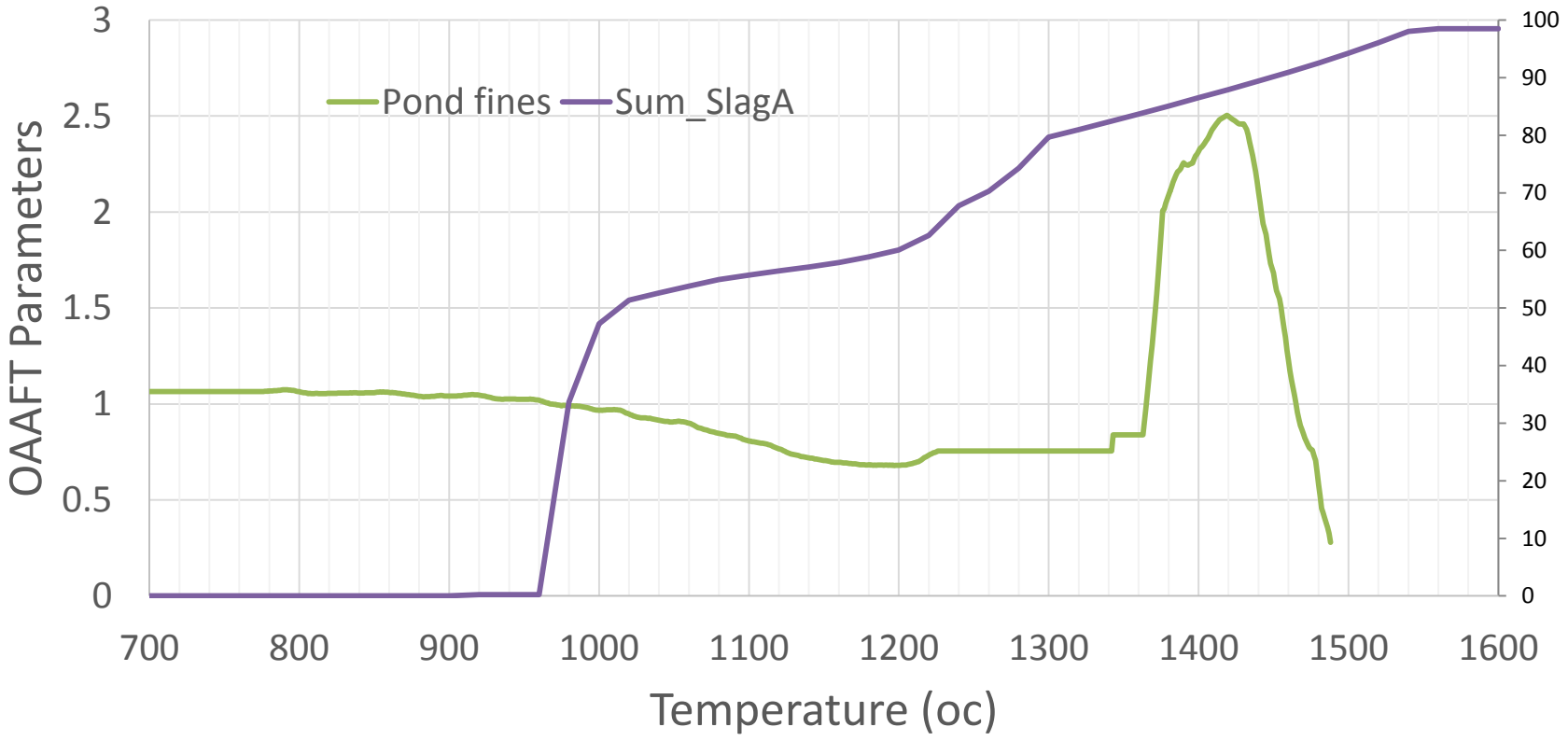
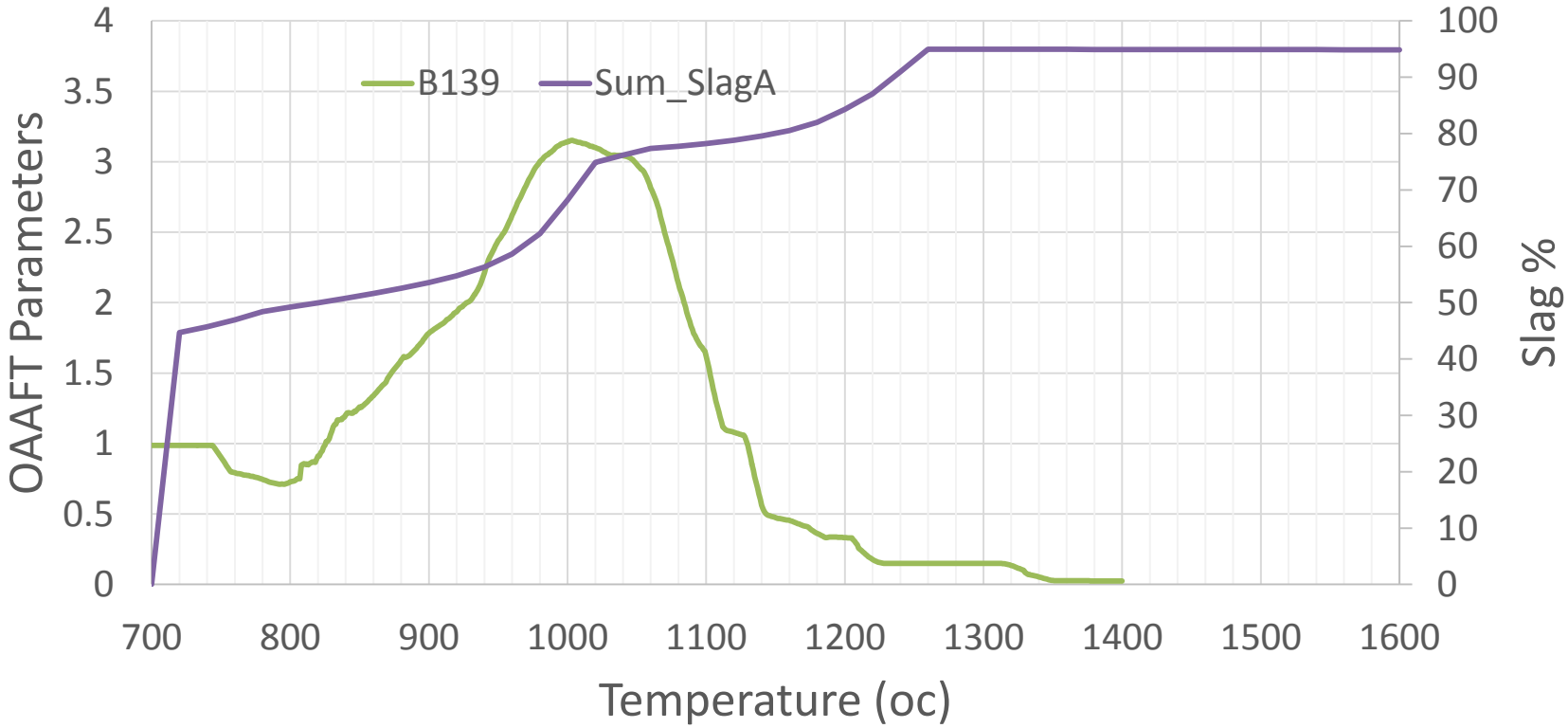


Biomasses

Slag % vs OAAFT Curve



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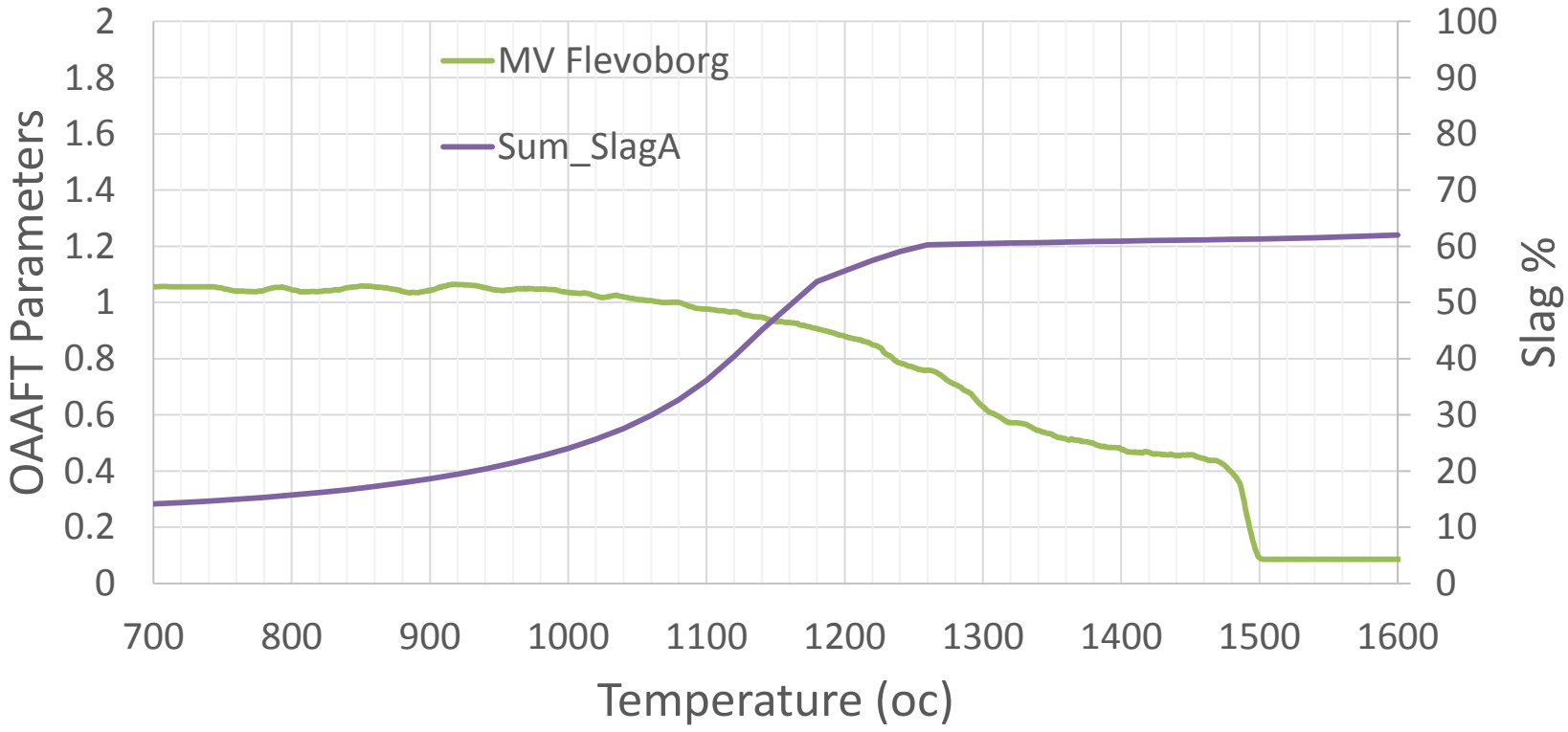
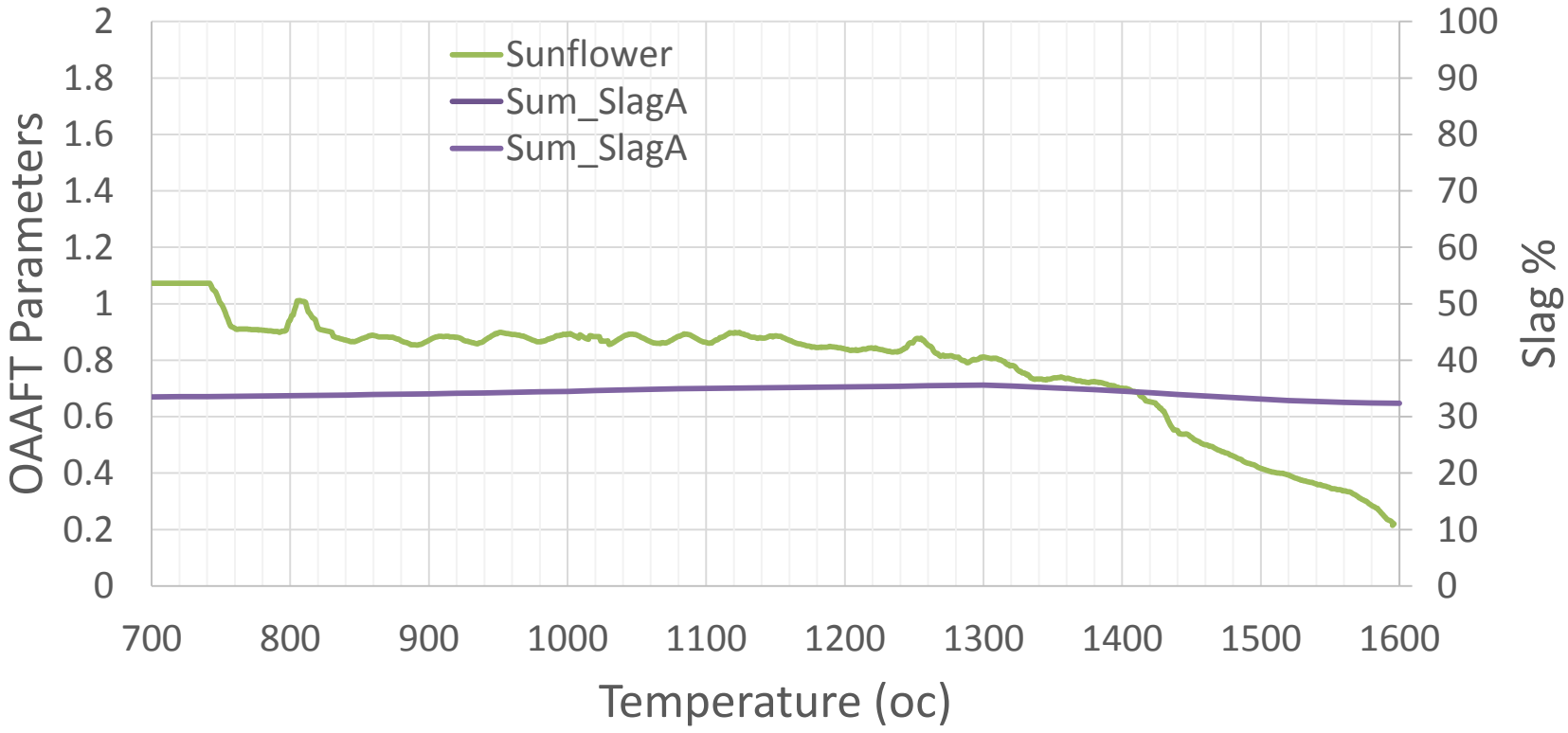
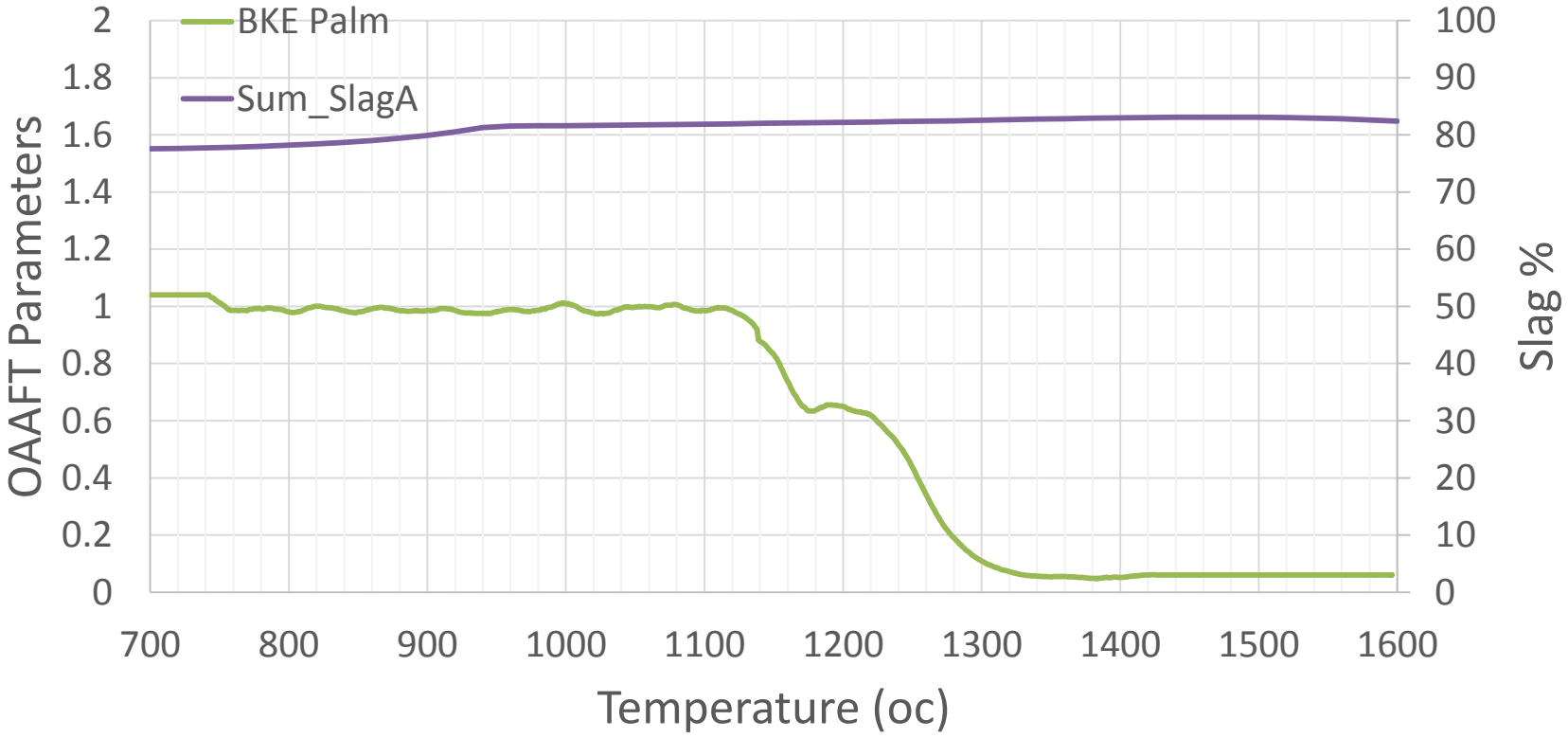


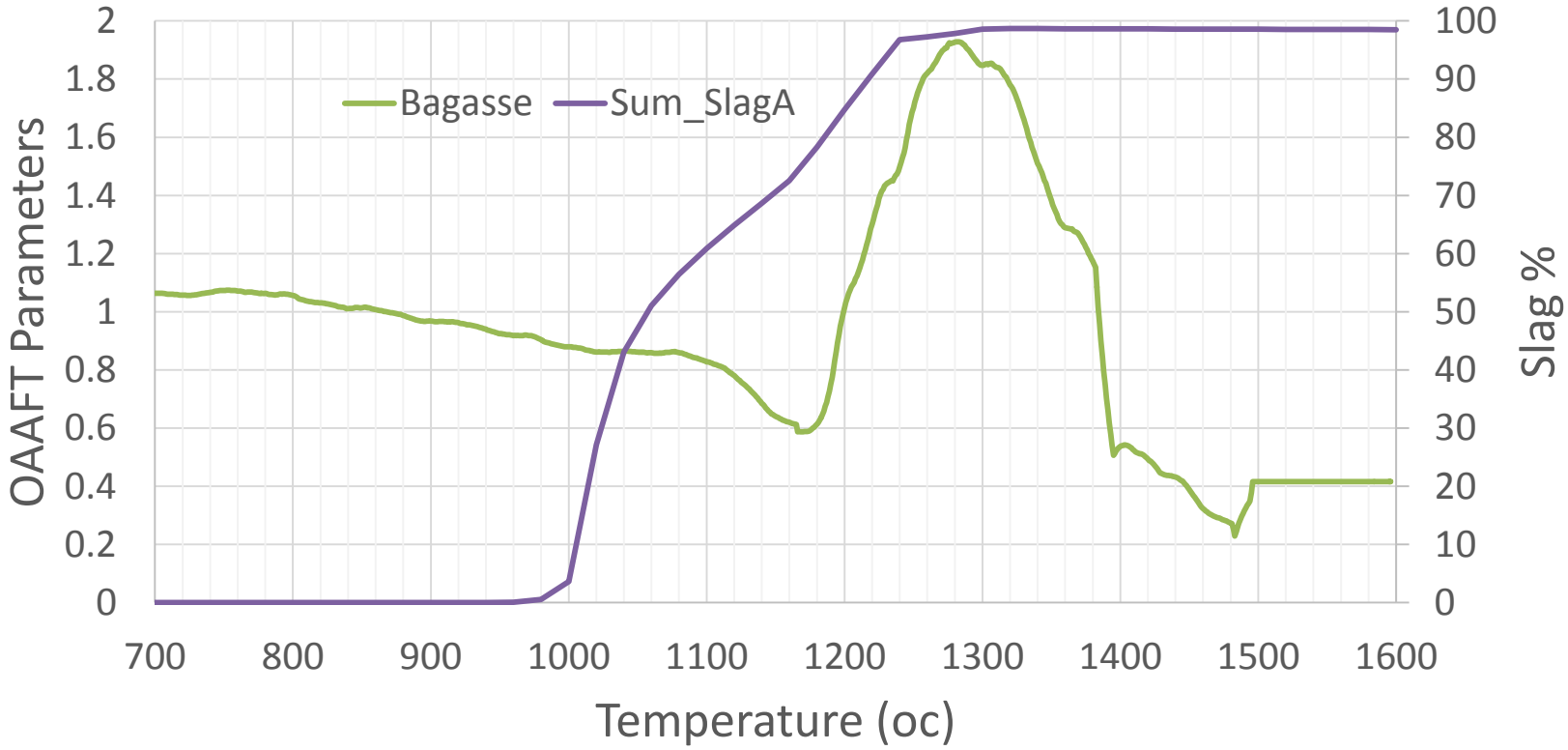
Slag % vs OAAFT Curve



Slag % vs OAAFT Curve



Slag % vs OAAFT Curve



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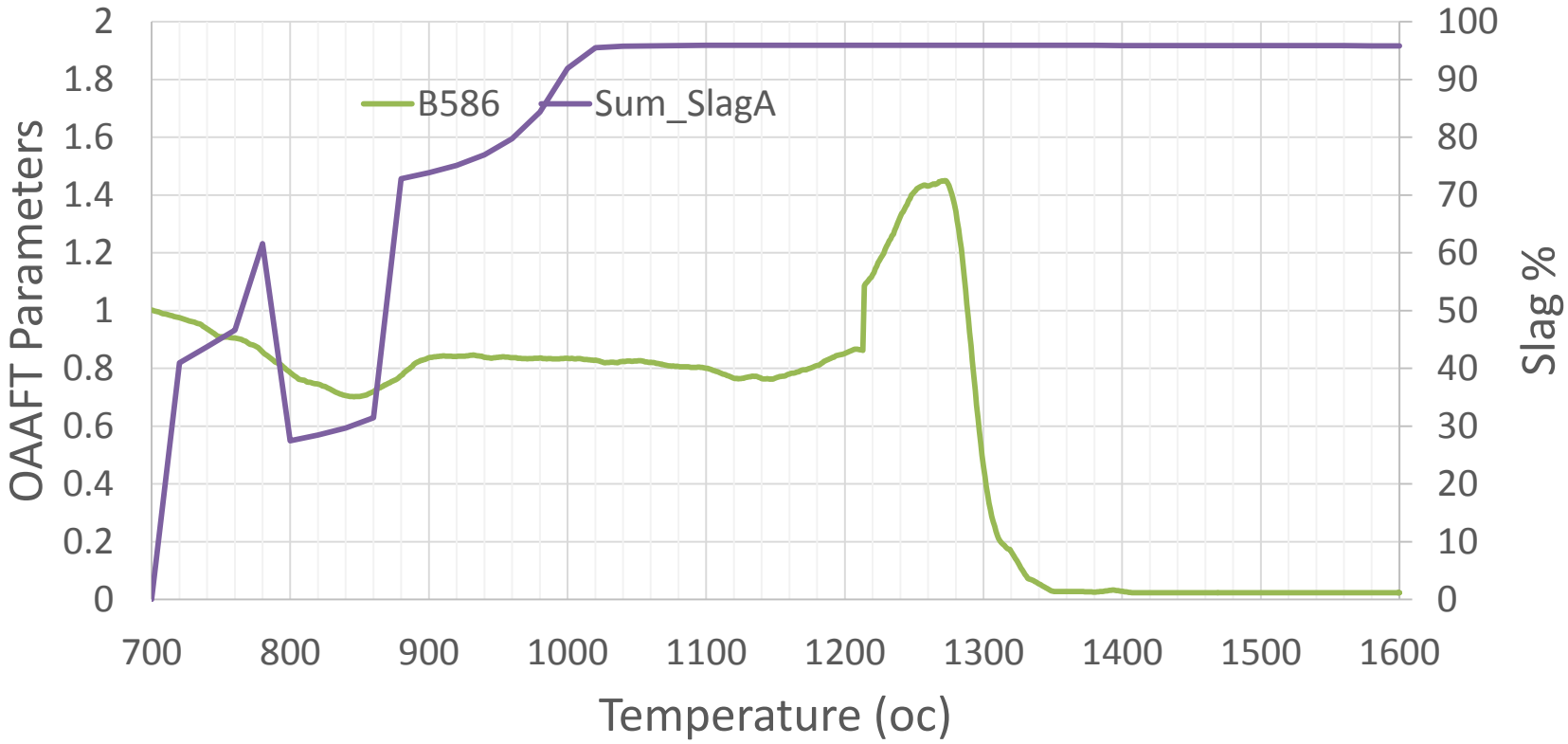
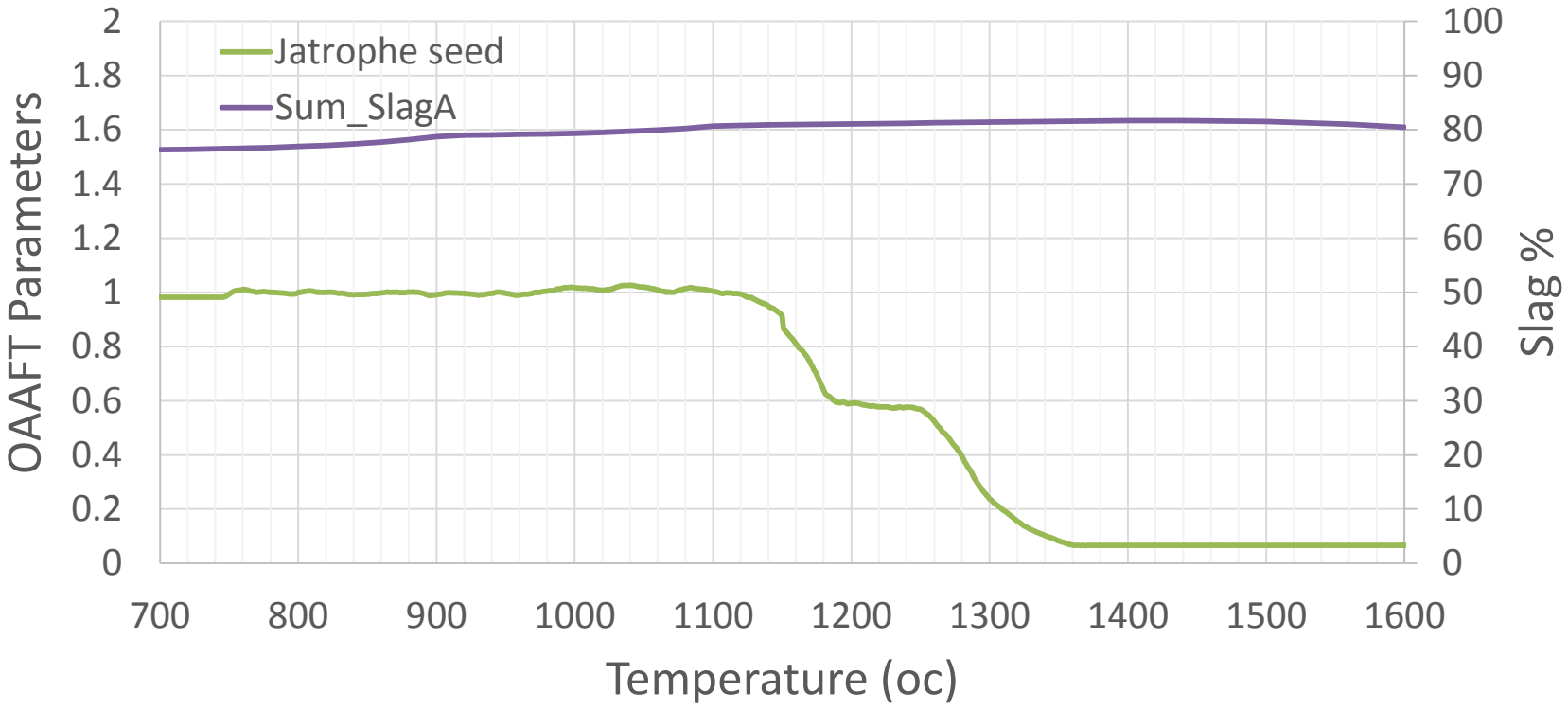


Slag % vs OAAFT Curve



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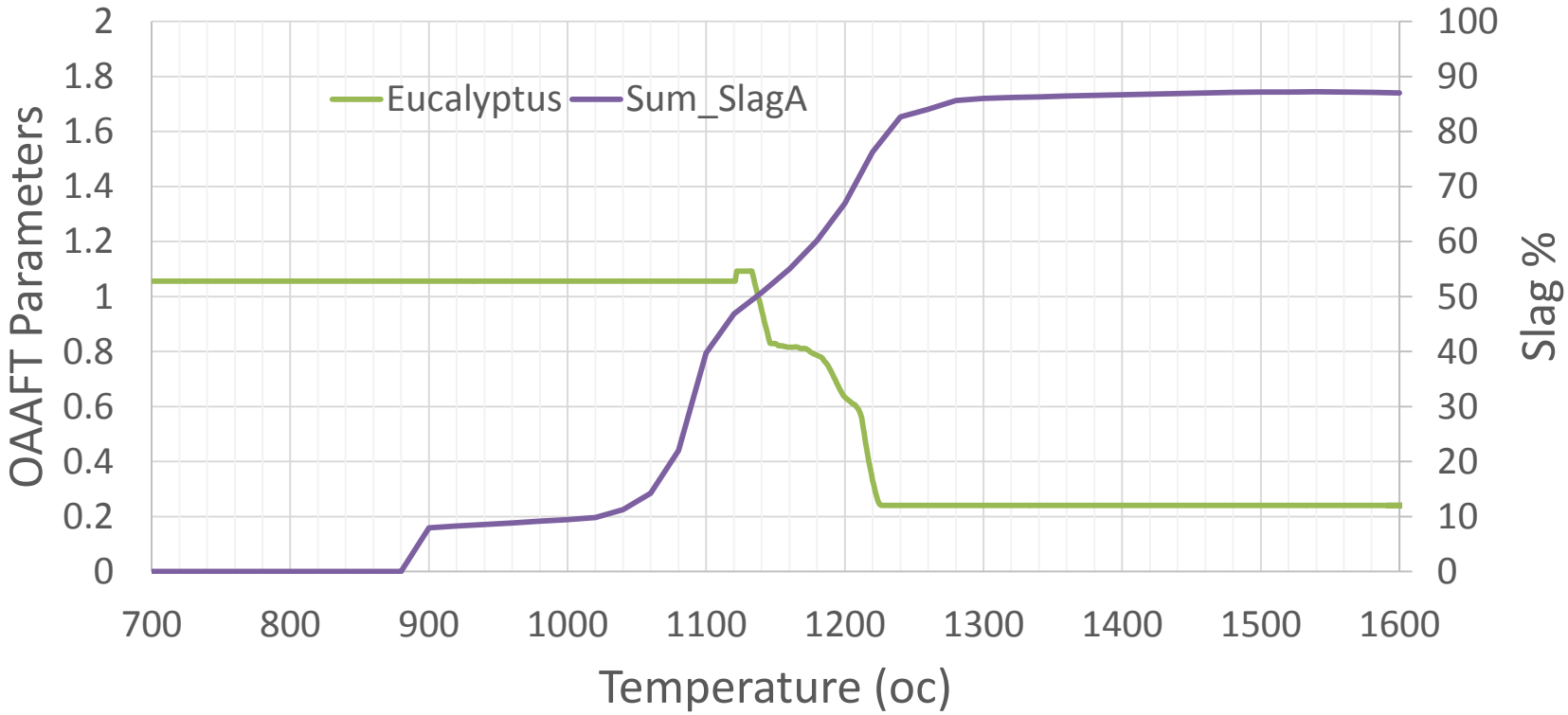

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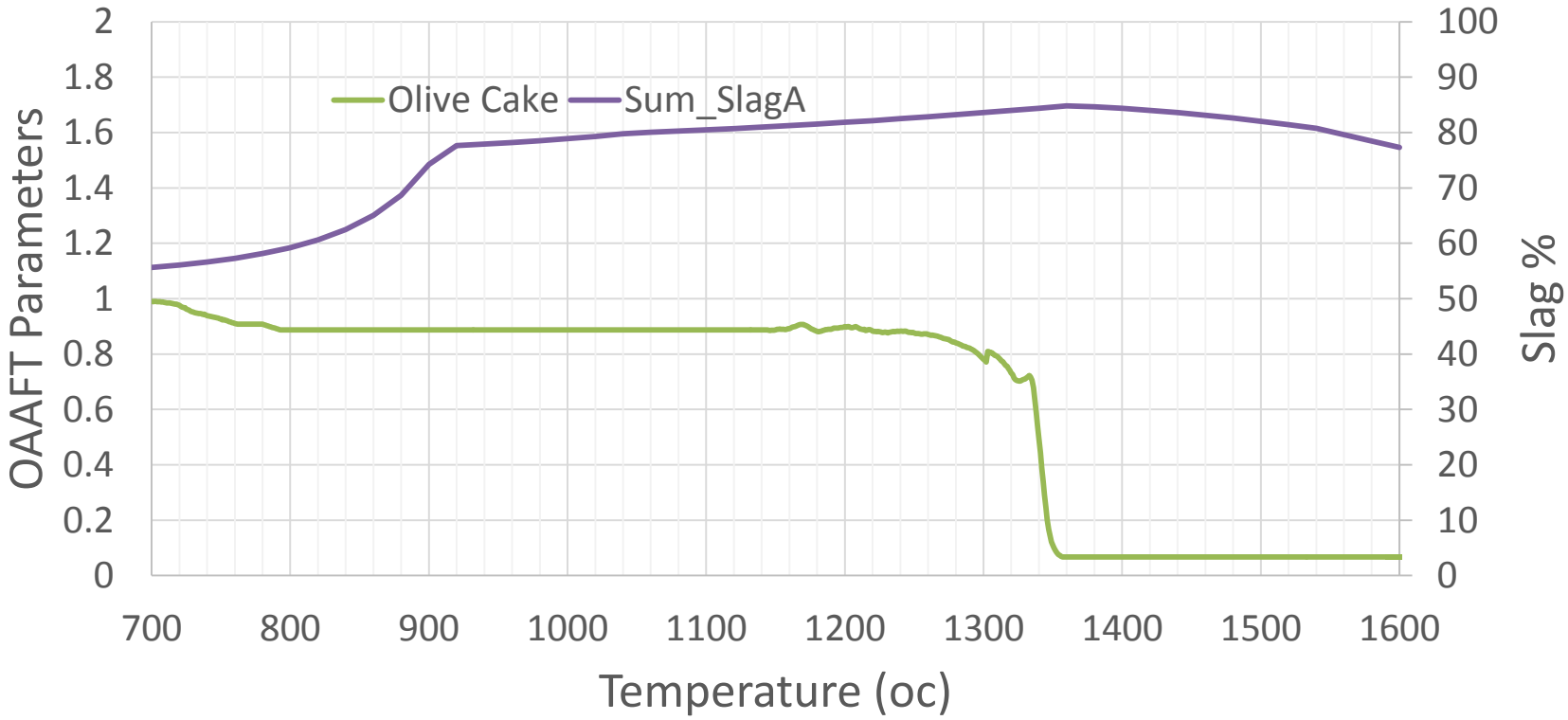

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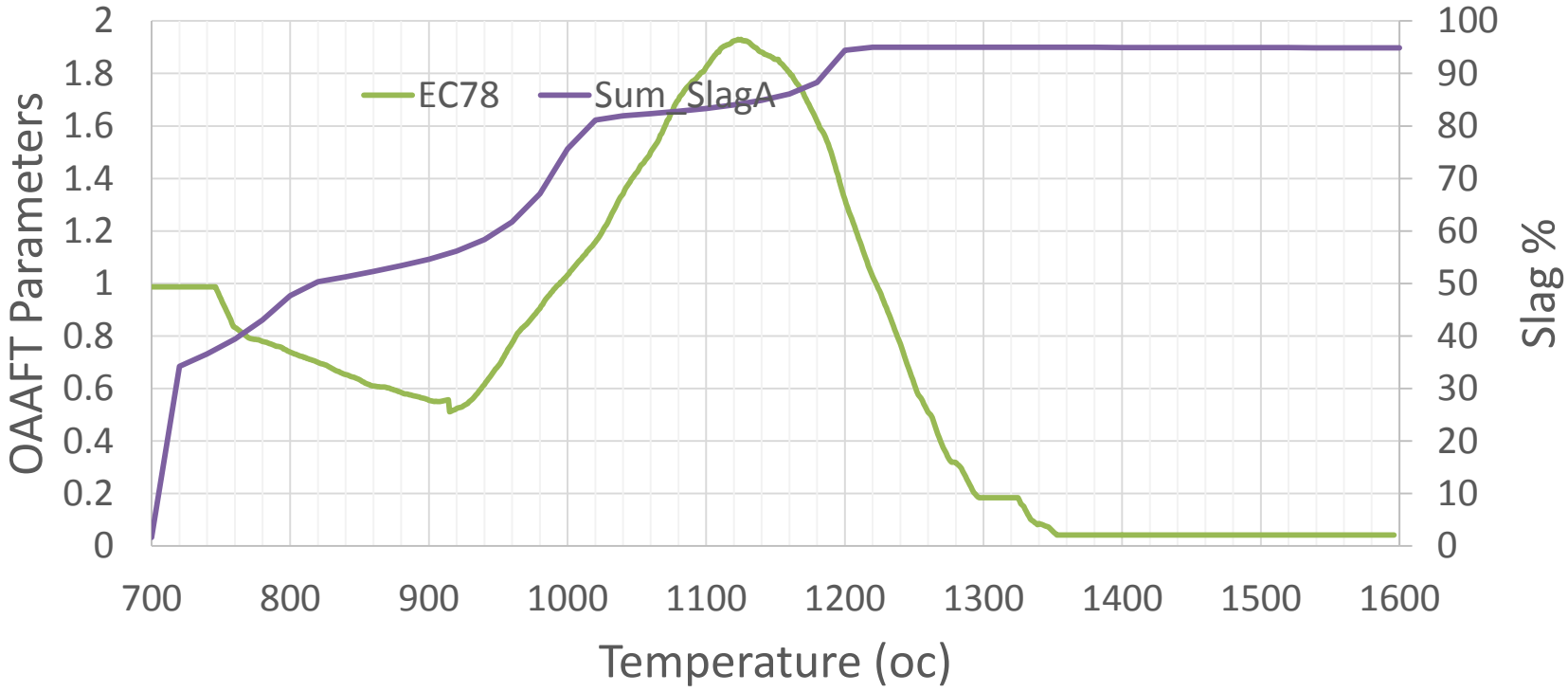

Slag % vs OAAFT Curve