Mitigating plastic shrinkage of 3D printed concrete using Super Absorbent Polymers

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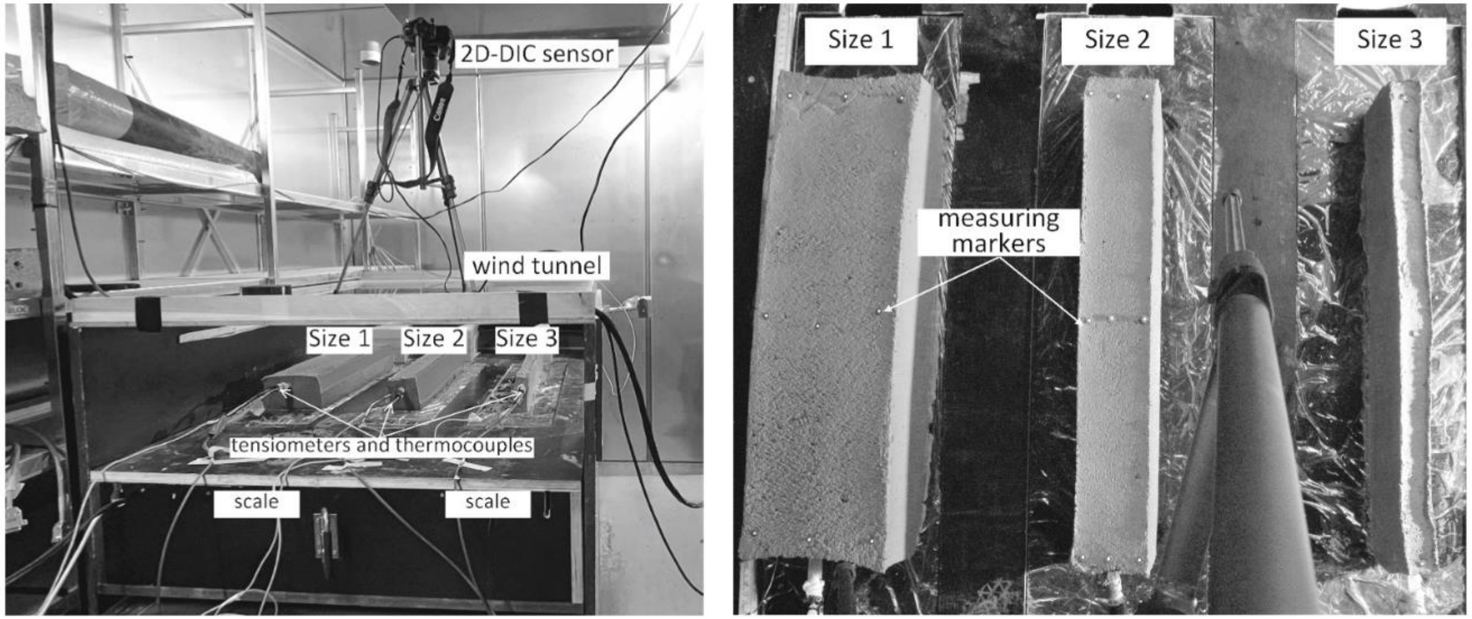
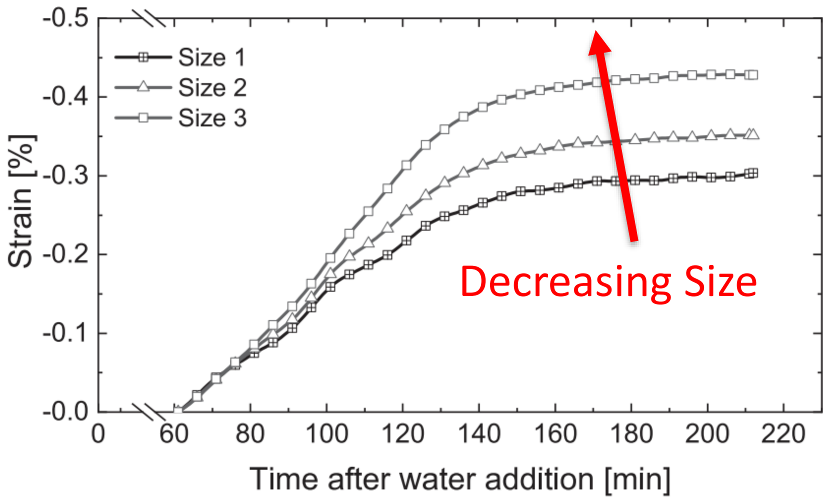
The Problem

Markin et al, 2024

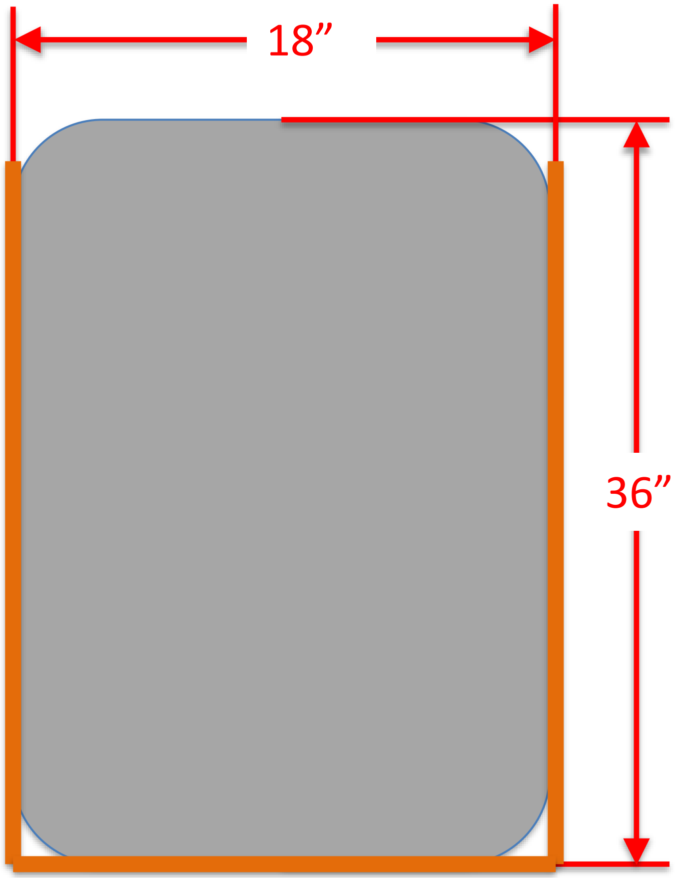


(a) (b)

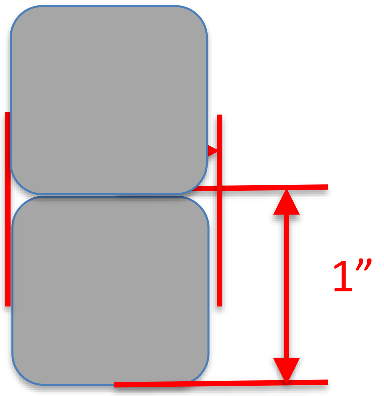


The Problem

Typical RC Beam



3D Printed Concrete Filament



Surface Area Ratio (SAR)

$$SAR = \frac{Exposed\ Surface\ Area}{Volume}$$

$$SAR = \frac{Exposed\ Perimeter\ Length}{Cross\ Sectional\ Area}$$

$$SAR_{beam} = \frac{18+36+36+18}{18*36} = 0.167$$

$$SAR_{3DPC} = \frac{1+1+1}{1*1} = 3$$

A 3D printed concrete filament is 18 times more exposed!!

What Drives Shrinkage

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- Chemical: cement reaction products smaller than reactants

- Autogenous: water loss due to formation of solid cement reaction products, drying pores and resulting in capillary suction

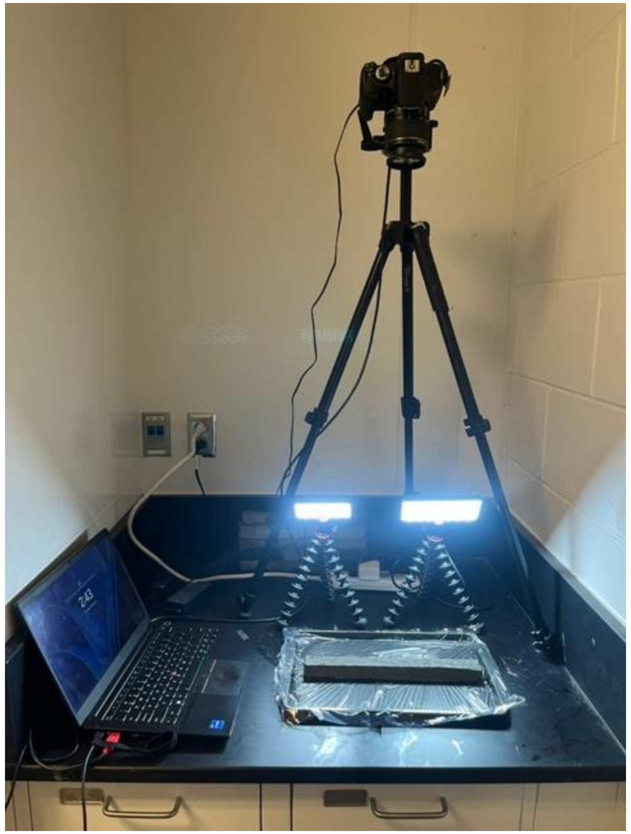
- External: water loss to the environment and resulting capillary suction

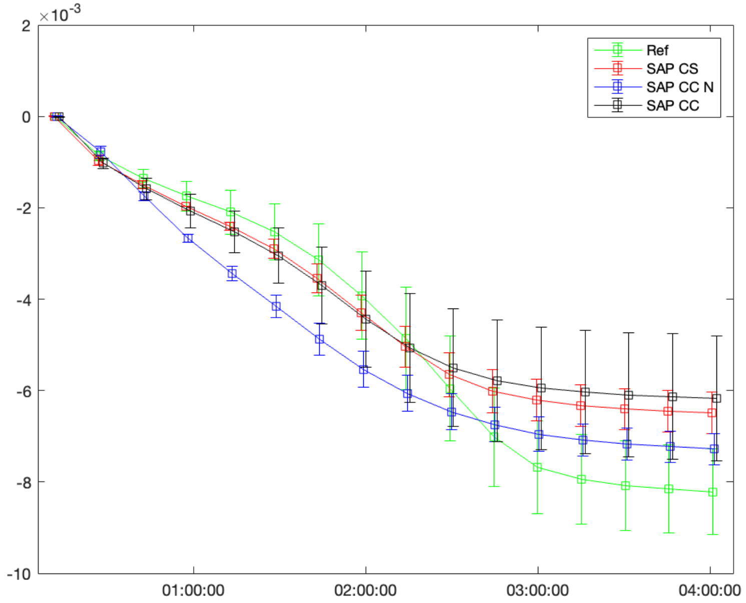
The Answer?

- Super Absorbent Polymers (SAP) are covalently cross-linked flexible polymers
- Absorb up to 1000x their mass in Water
- Effective solution at preventing autogenous and drying shrinkage[1]
- Promising for preventing plastic shrinkage and related problems[2,3,4]

1. Erk, et al., FHWA/IN/JTRP-2022/04 Report, 2022
2. Boshoff et al, 2020
3. Van Der Putten et al, 2022
4. Molech et al, 2022

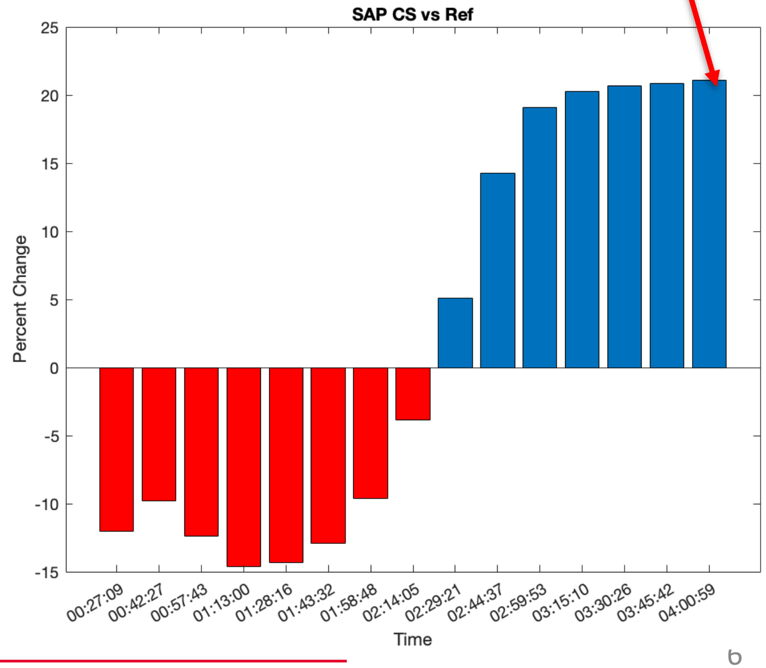
Previous RIP Presentation





SAP CS vs Ref

~21%



Test Matrix

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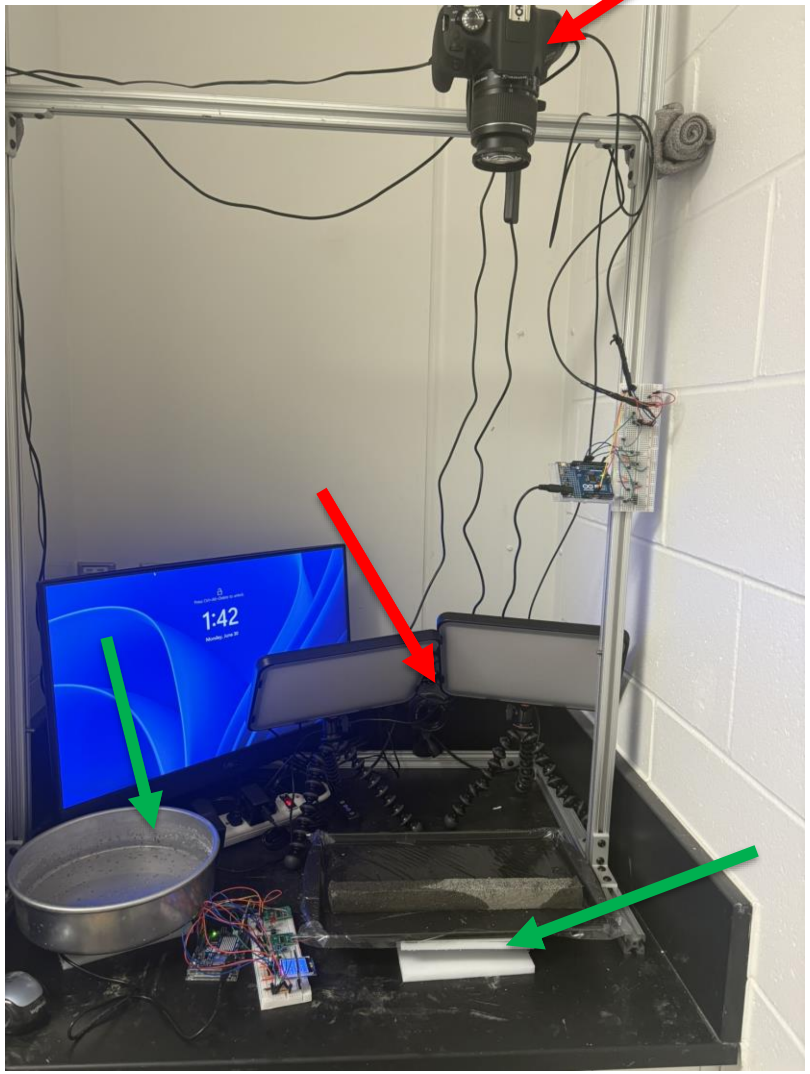
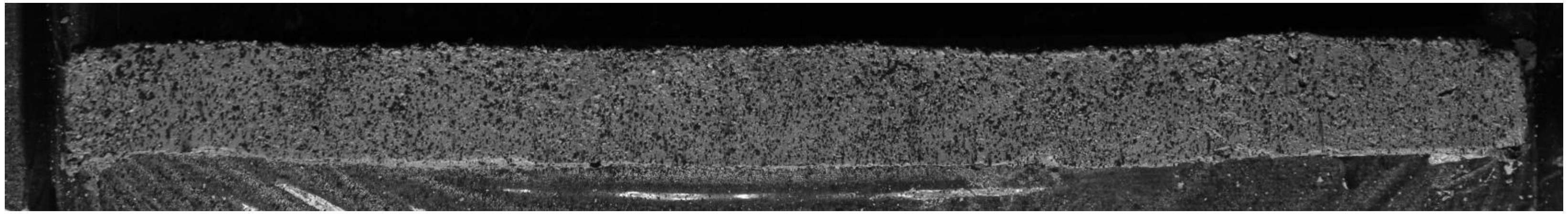
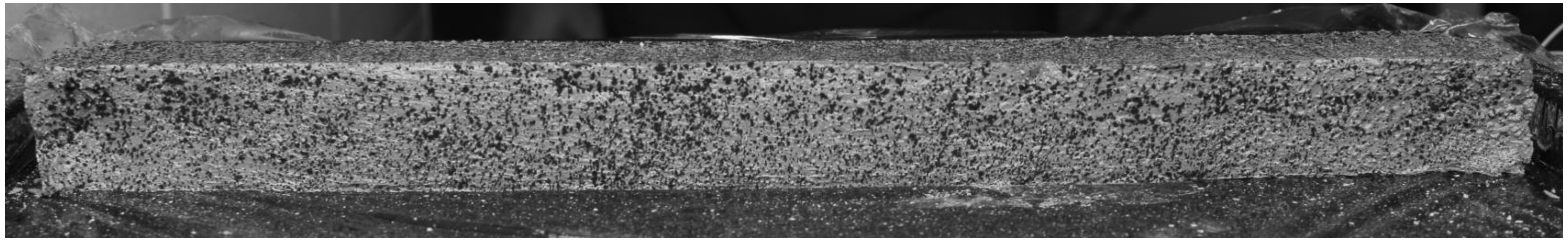
Name	Cement (g)	Nano-Clay (g)	Water (g)	SAP (g)	+ Water (g)
Ref	400	1	120	0	0
SAP CS*	400	1	120	1	20
0.3 SAP CS NW	400	1	120	0.3	0
0.5 SAP CS NW	400	1	120	0.5	0
0.3 SAP CS HW	400	1	120	0.3	10
0.5 SAP CS HW	400	1	120	0.5	10
0.3 SAP CS W	400	1	120	0.3	20
0.5 SAP CS W	400	1	120	0.5	20
SAP CS HW	400	1	120	1	10

*SNF Floset 127 CS
Crosslinked polyacrylamide (30% anionic)

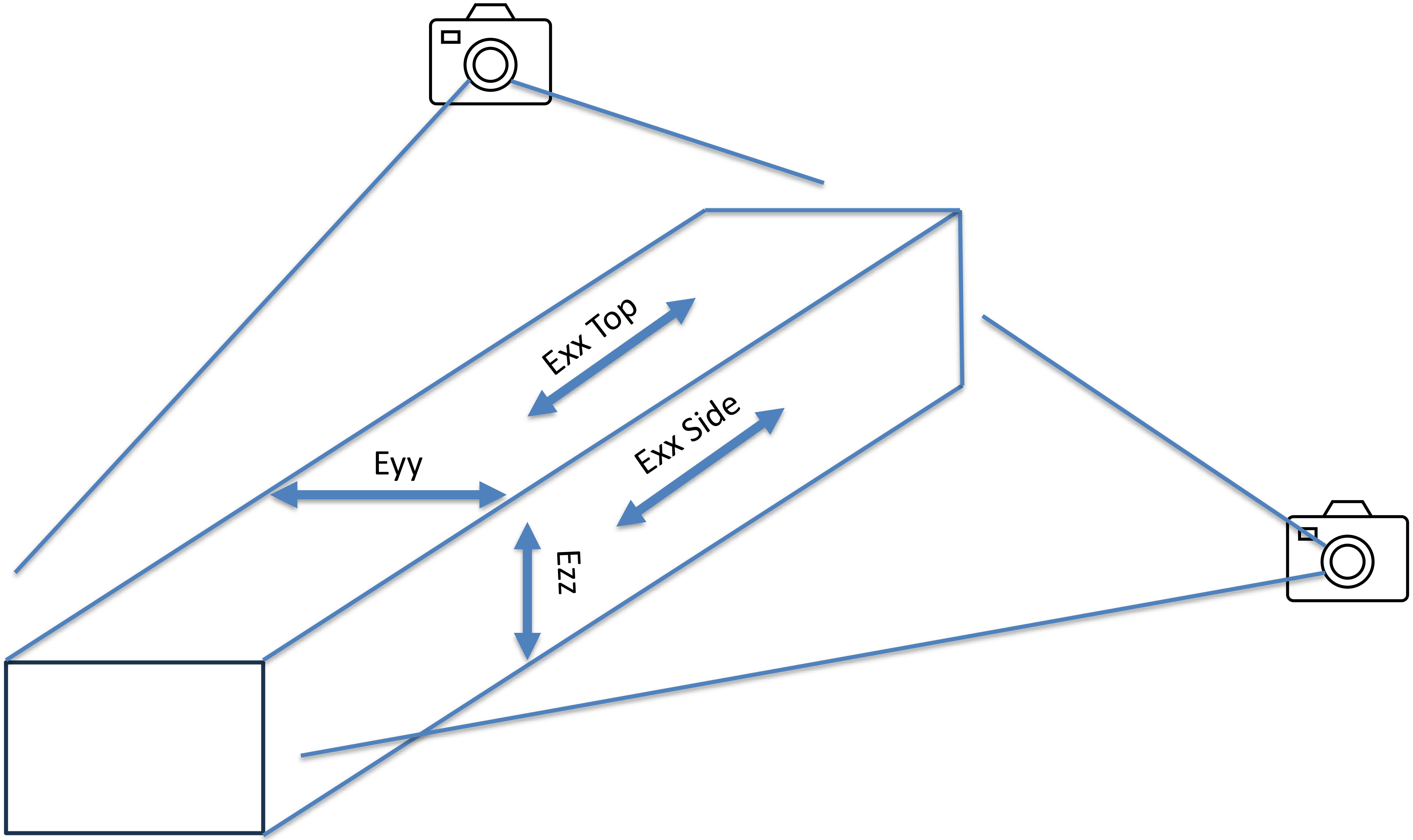
Set-up Updates



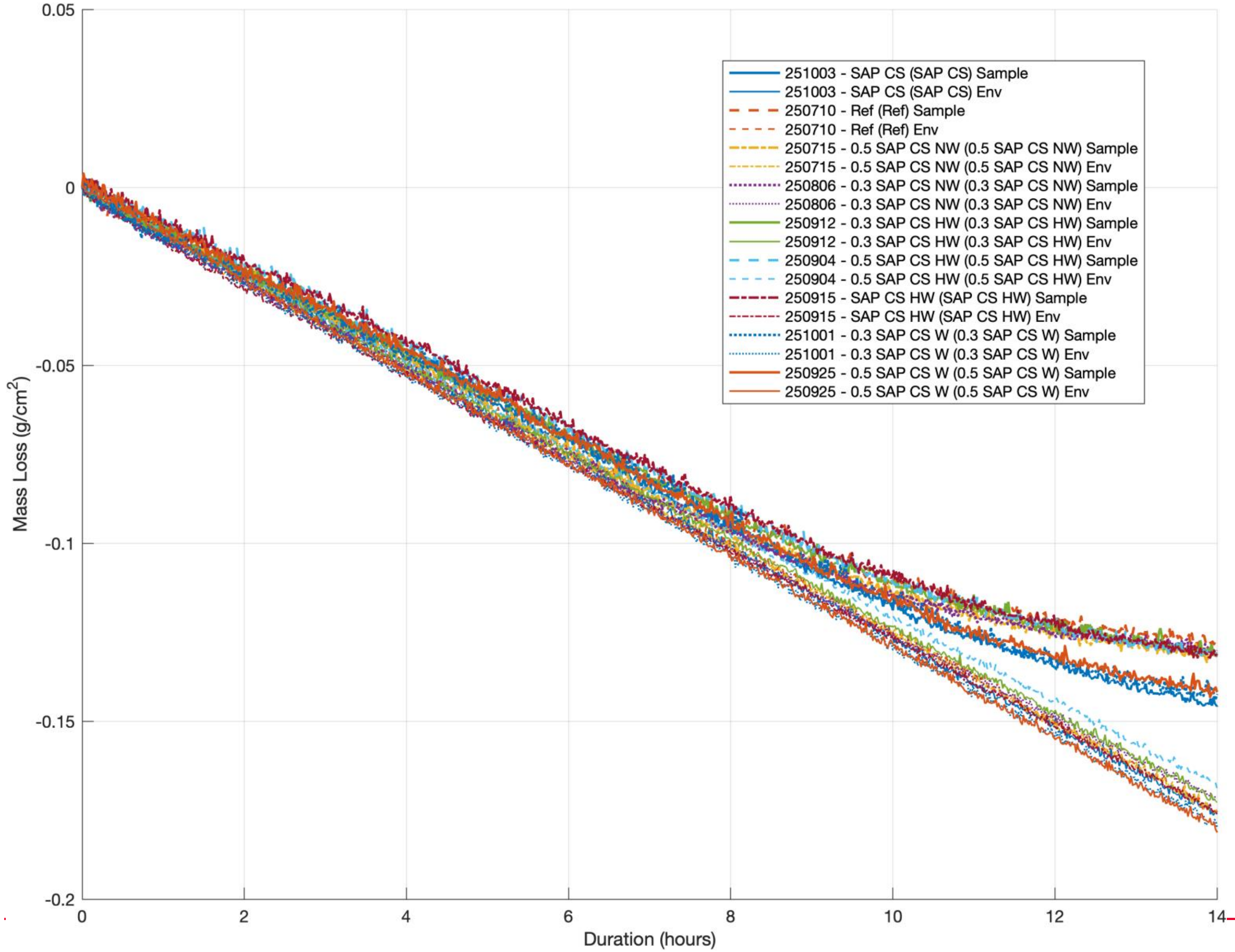




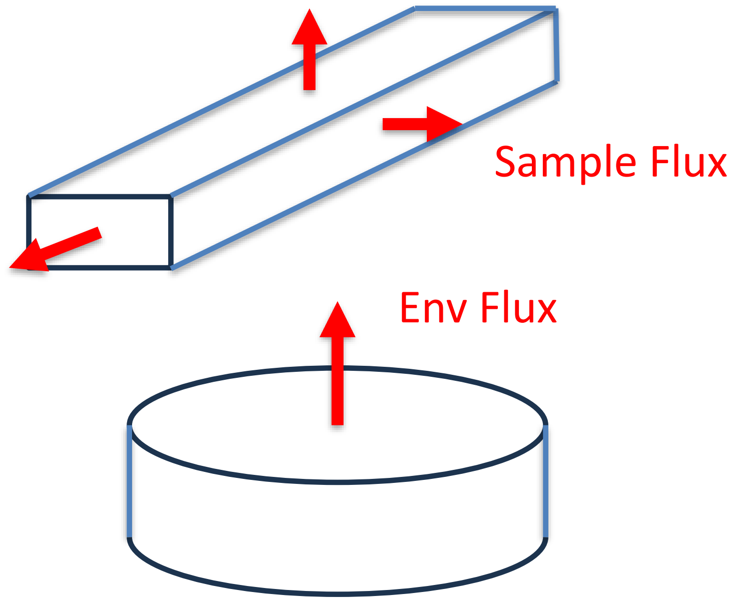
Sign Conventions



Drying “Flux”

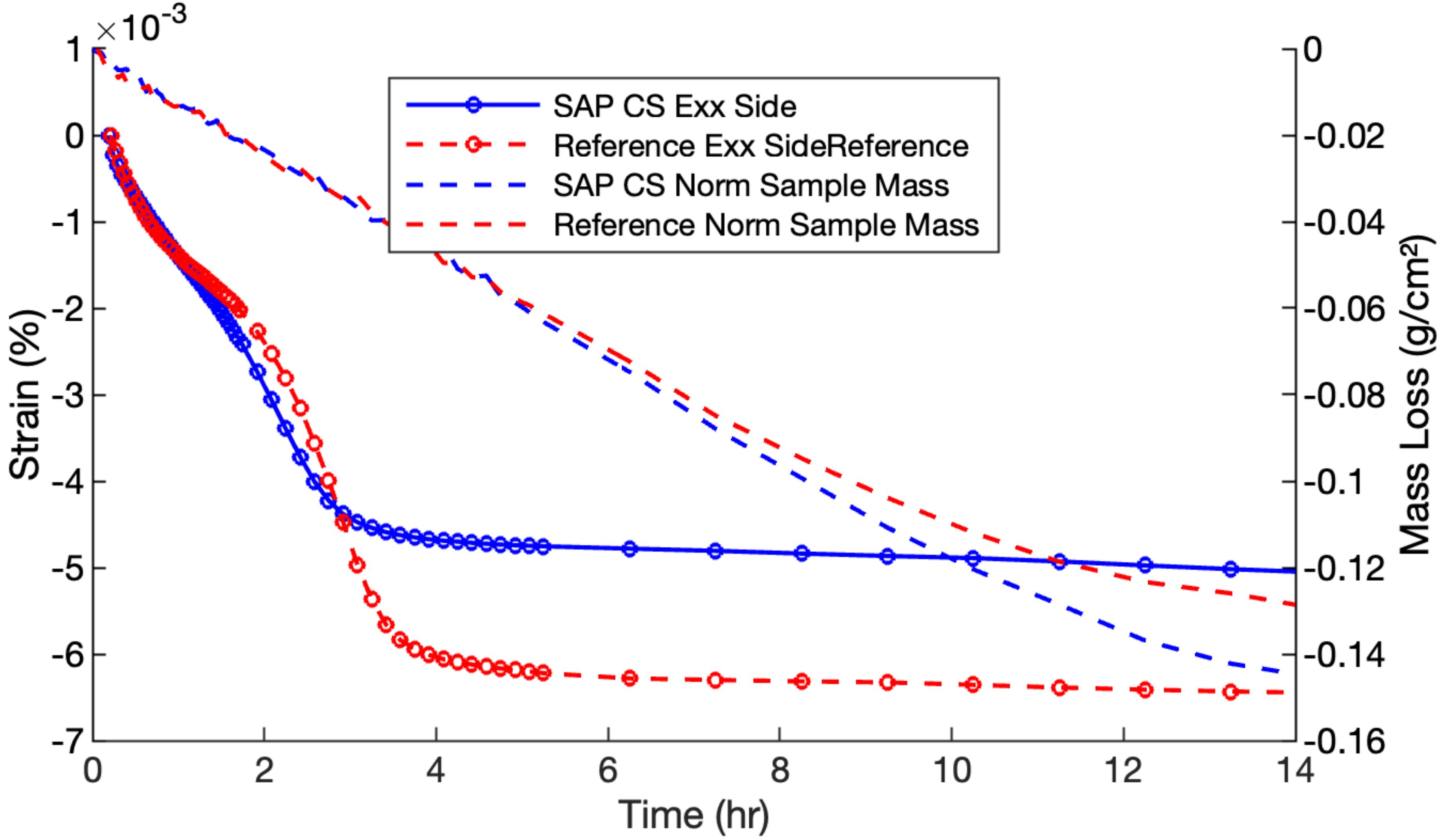


0.05
0
-0.05
-0.1
-0.15
-0.2
Mass Loss (g/cm^2)
0
2
4
6
8
10
12
14
Duration (hours)
251003 - SAP CS (SAP CS) Sample
251003 - SAP CS (SAP CS) Env
250710 - Ref (Ref) Sample
250710 - Ref (Ref) Env
250715 - 0.5 SAP CS NW (0.5 SAP CS NW) Sample
250715 - 0.5 SAP CS NW (0.5 SAP CS NW) Env
250806 - 0.3 SAP CS NW (0.3 SAP CS NW) Sample
250806 - 0.3 SAP CS NW (0.3 SAP CS NW) Env
250912 - 0.3 SAP CS HW (0.3 SAP CS HW) Sample
250912 - 0.3 SAP CS HW (0.3 SAP CS HW) Env
250904 - 0.5 SAP CS HW (0.5 SAP CS HW) Sample
250904 - 0.5 SAP CS HW (0.5 SAP CS HW) Env
250915 - SAP CS HW (SAP CS HW) Sample
250915 - SAP CS HW (SAP CS HW) Env
251001 - 0.3 SAP CS W (0.3 SAP CS W) Sample
251001 - 0.3 SAP CS W (0.3 SAP CS W) Env
250925 - 0.5 SAP CS W (0.5 SAP CS W) Sample
250925 - 0.5 SAP CS W (0.5 SAP CS W) Env

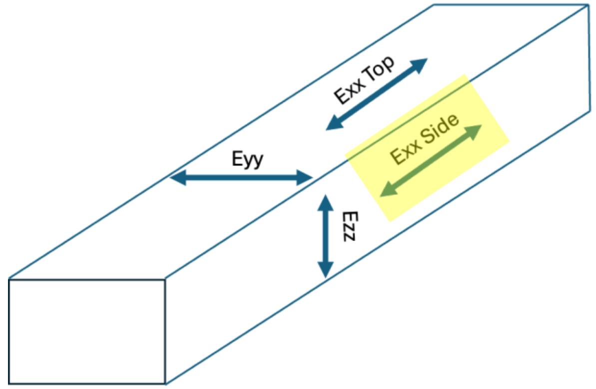


Sample Flux
Env Flux

The Dilemma

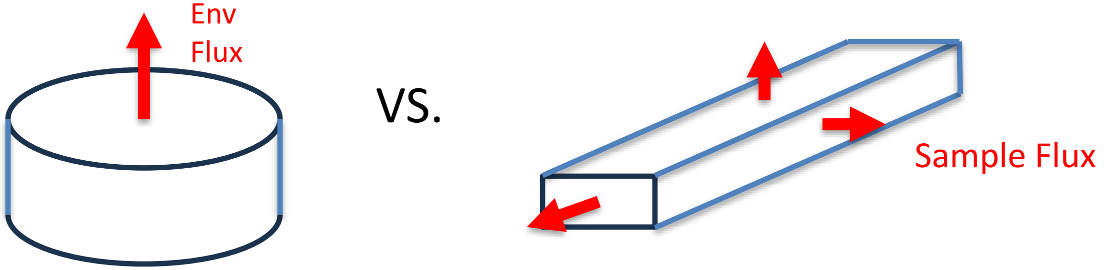


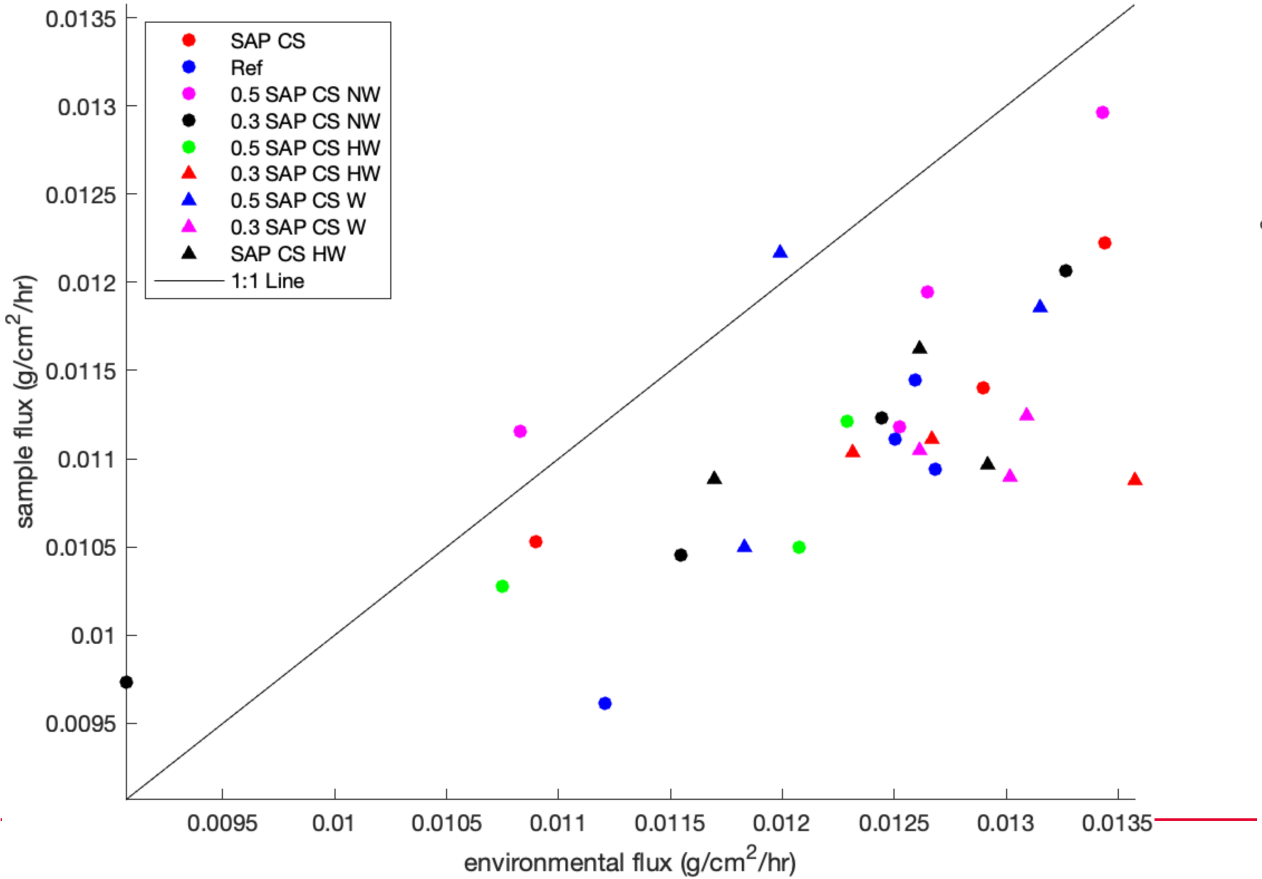
$\times 10^{-3}$
SAP CS Exx Side
Reference Exx SideReference
SAP CS Norm Sample Mass
Reference Norm Sample Mass
Strain (%)
Mass Loss (g/cm²)
Time (hr)

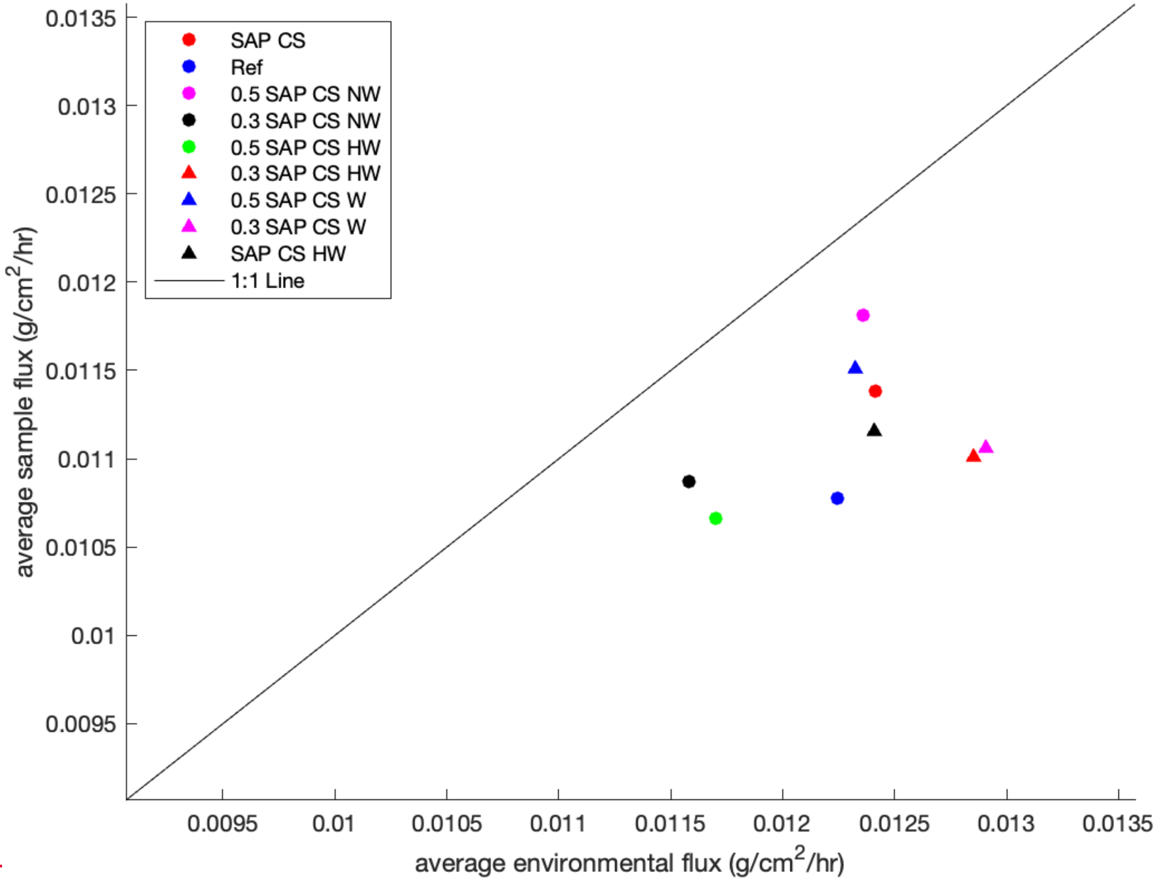


Exx Top
Exx Side
Eyy
Ezz

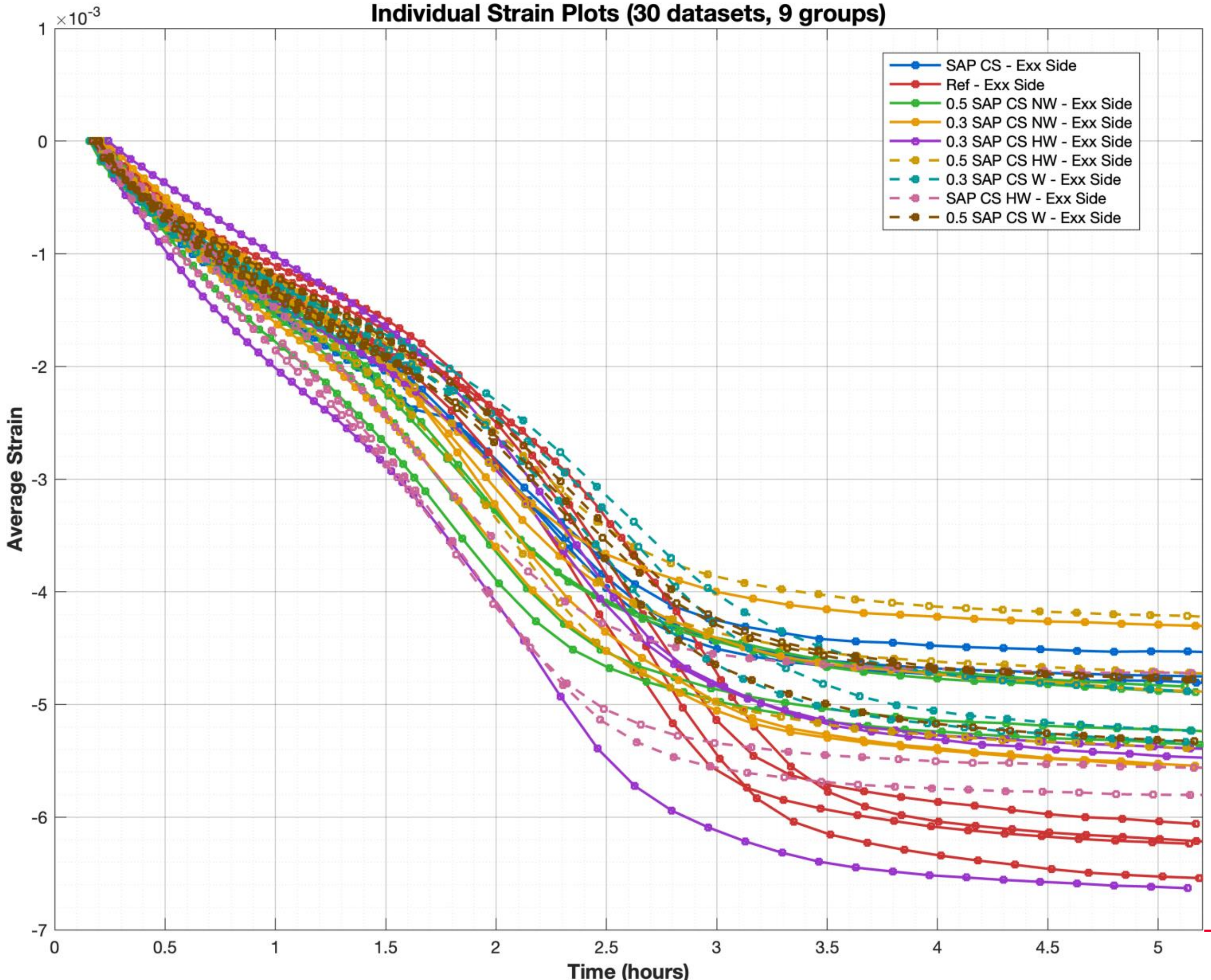
Environmental vs. Sample Flux

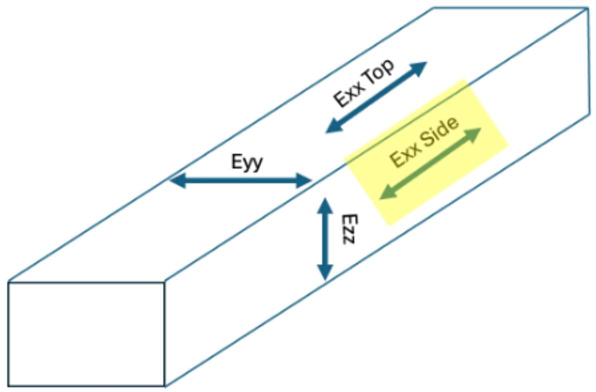




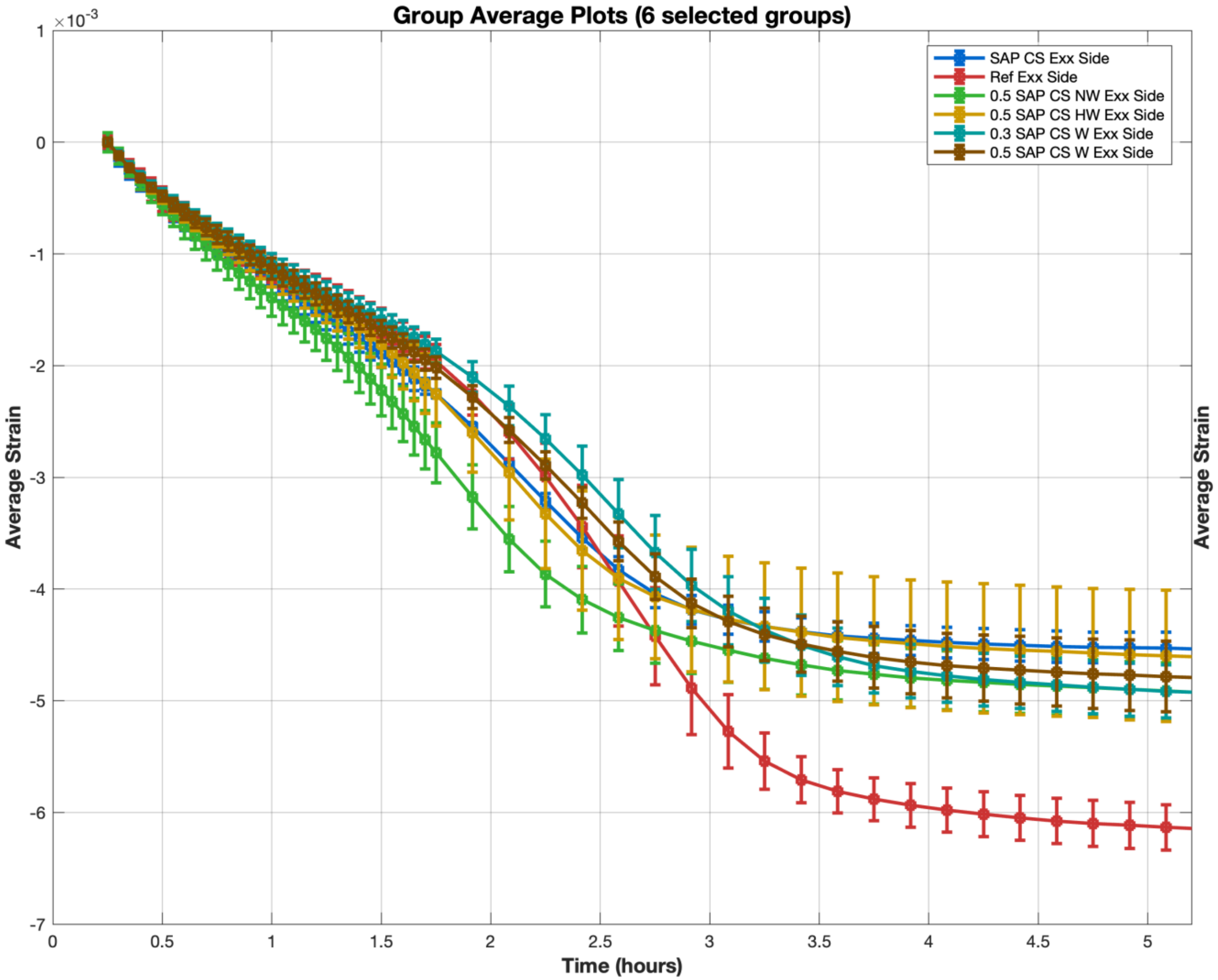


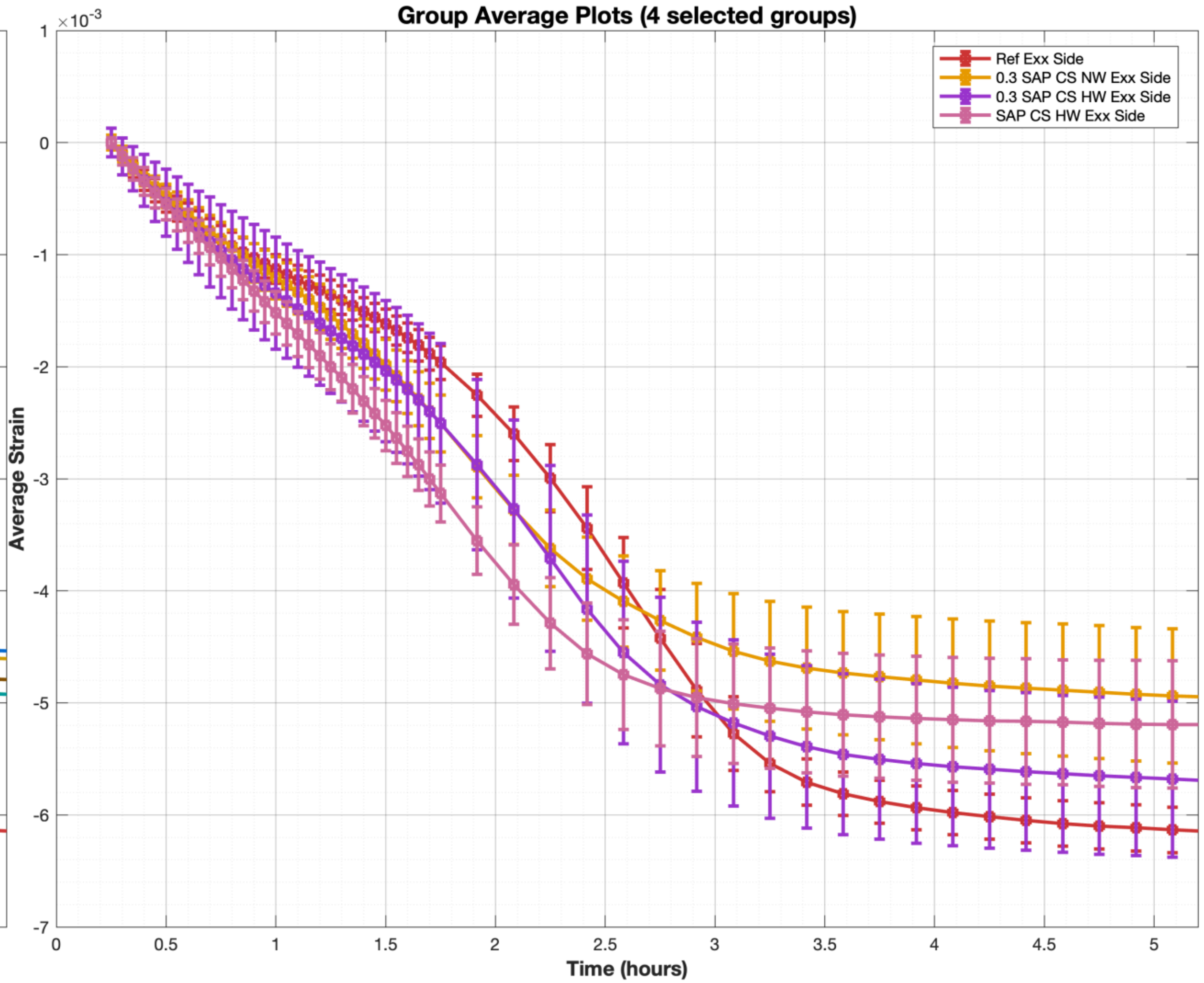
All Exx Side Data



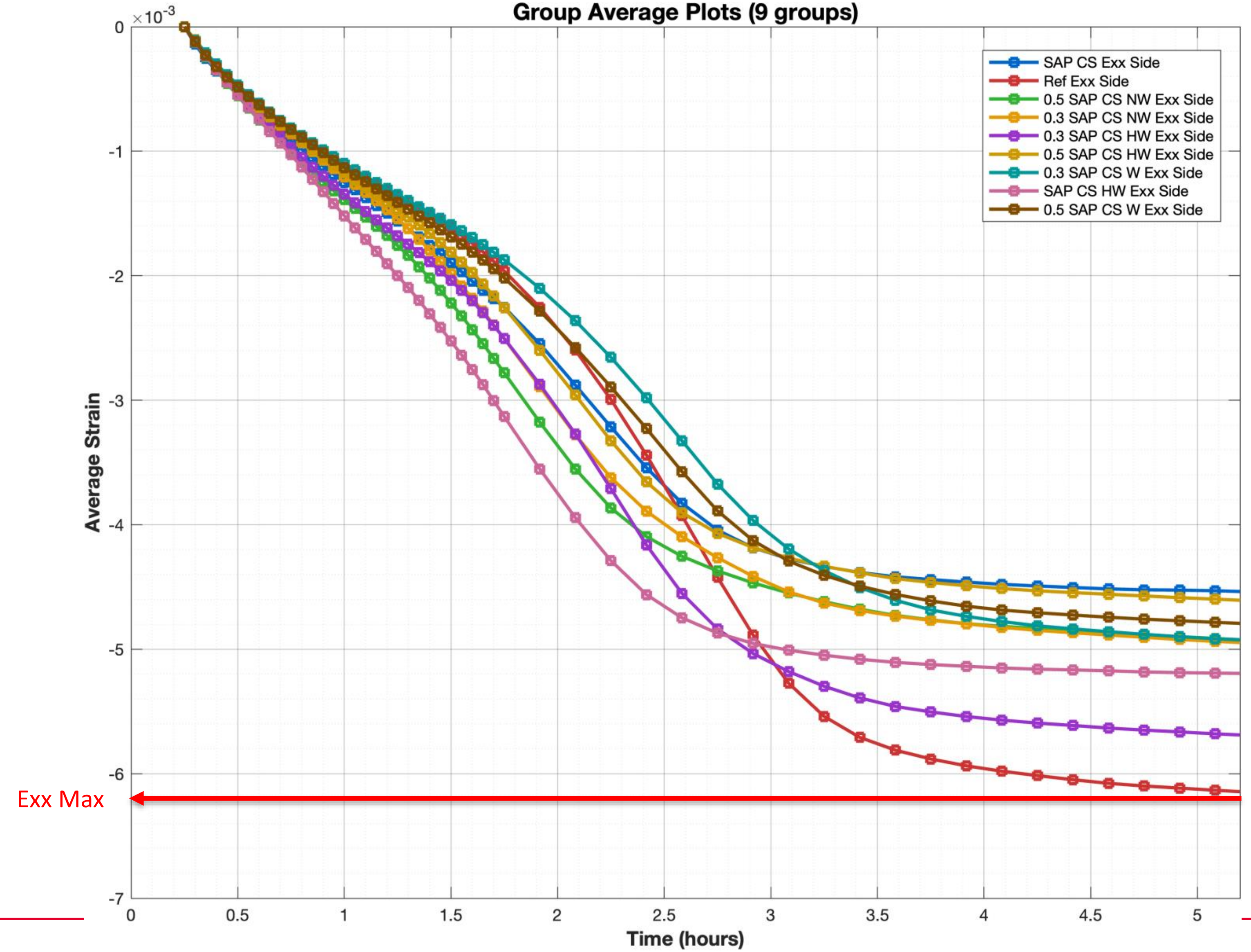


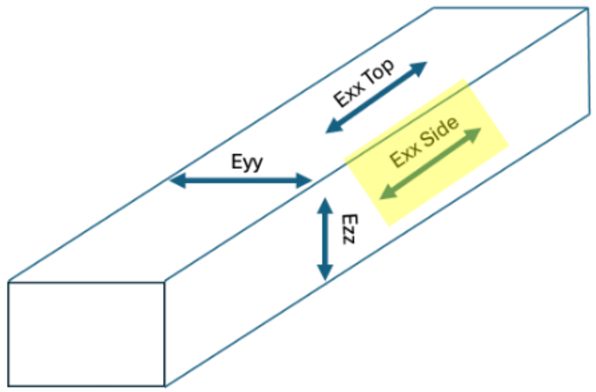
Averages


Group Average Plots (6 selected groups)
×10^-3
SAP CS Exx Side
Ref Exx Side
0.5 SAP CS NW Exx Side
0.5 SAP CS HW Exx Side
0.3 SAP CS W Exx Side
0.5 SAP CS W Exx Side
Average Strain
Time (hours)
1
0
-1
-2
-3
-4
-5
-6
-7
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

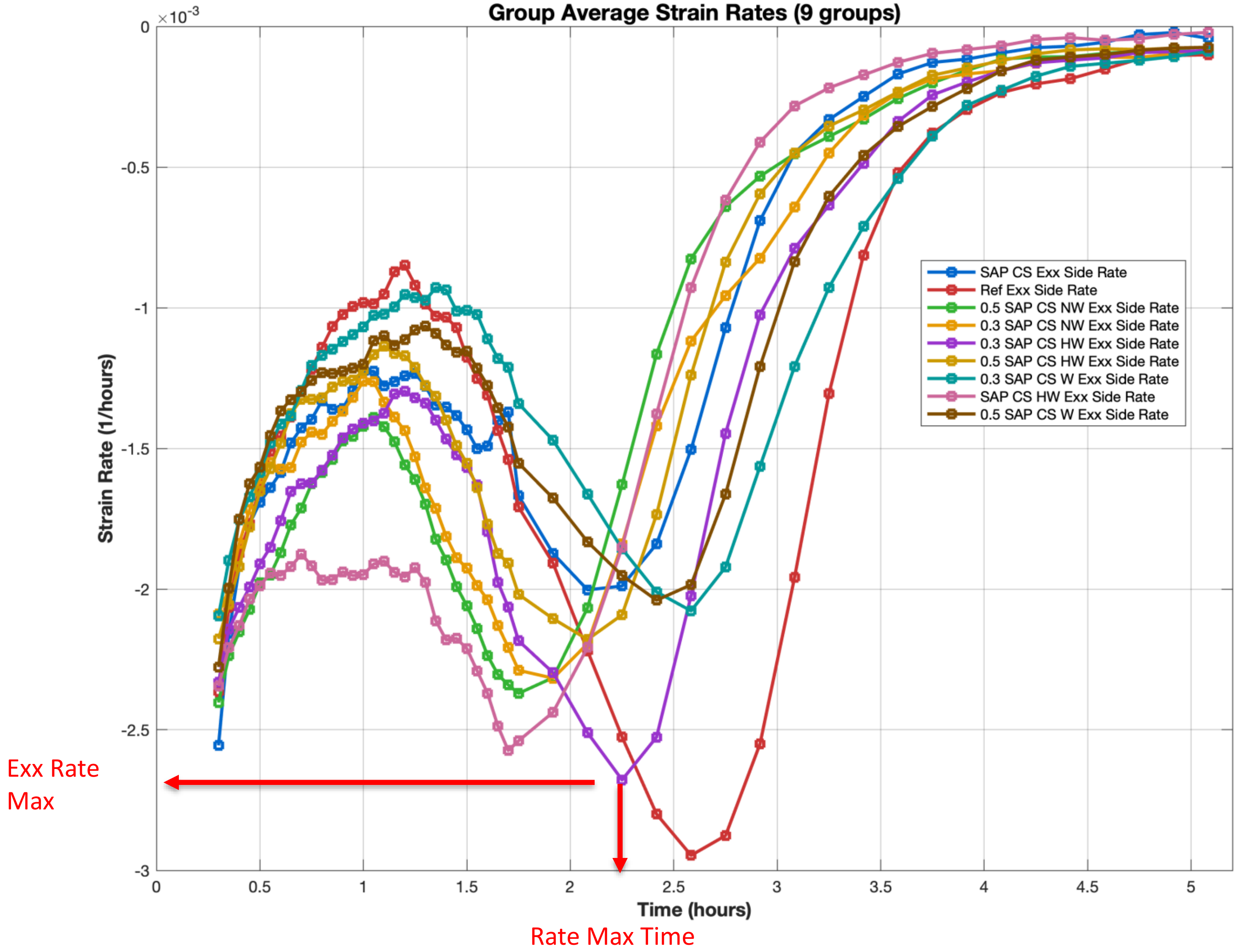

Group Average Plots (4 selected groups)
×10^-3
Ref Exx Side
0.3 SAP CS NW Exx Side
0.3 SAP CS HW Exx Side
SAP CS HW Exx Side
Average Strain
Time (hours)
1
0
-1
-2
-3
-4
-5
-6
-7
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

Longitudinal Shrinkage



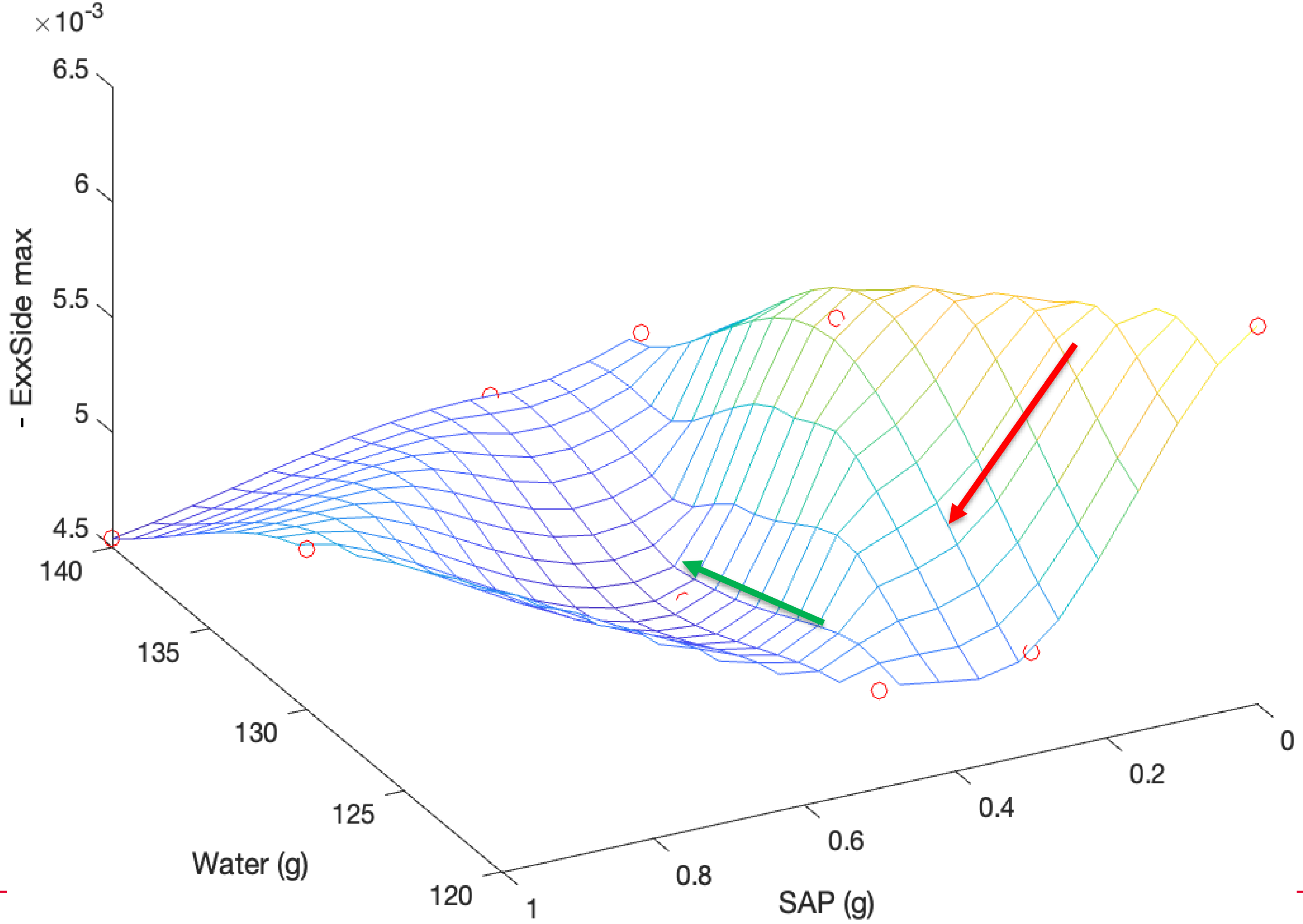


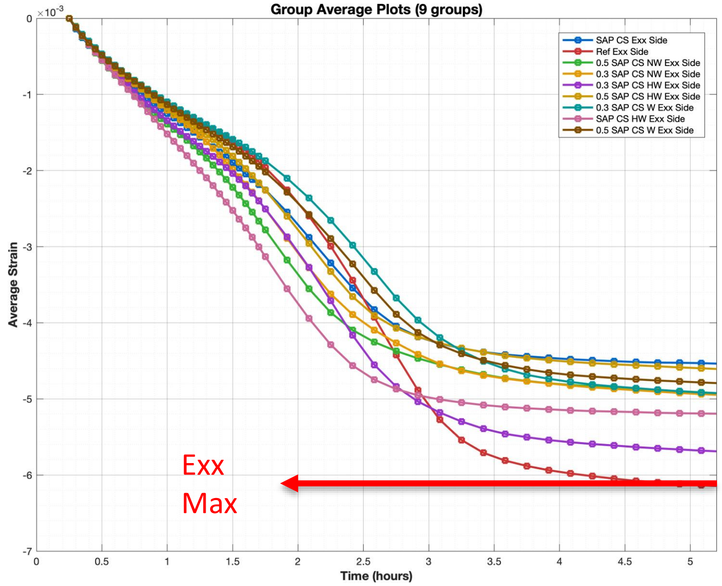
Rates



Group Average Strain Rates (9 groups)
$\times 10^{-3}$
Strain Rate (1/hours)
Time (hours)
0
-0.5
-1
-1.5
-2
-2.5
-3
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
SAP CS Exx Side Rate
Ref Exx Side Rate
0.5 SAP CS NW Exx Side Rate
0.3 SAP CS NW Exx Side Rate
0.3 SAP CS HW Exx Side Rate
0.5 SAP CS HW Exx Side Rate
0.3 SAP CS W Exx Side Rate
SAP CS HW Exx Side Rate
0.5 SAP CS W Exx Side Rate
Exx Rate Max
Rate Max Time

Exx Max

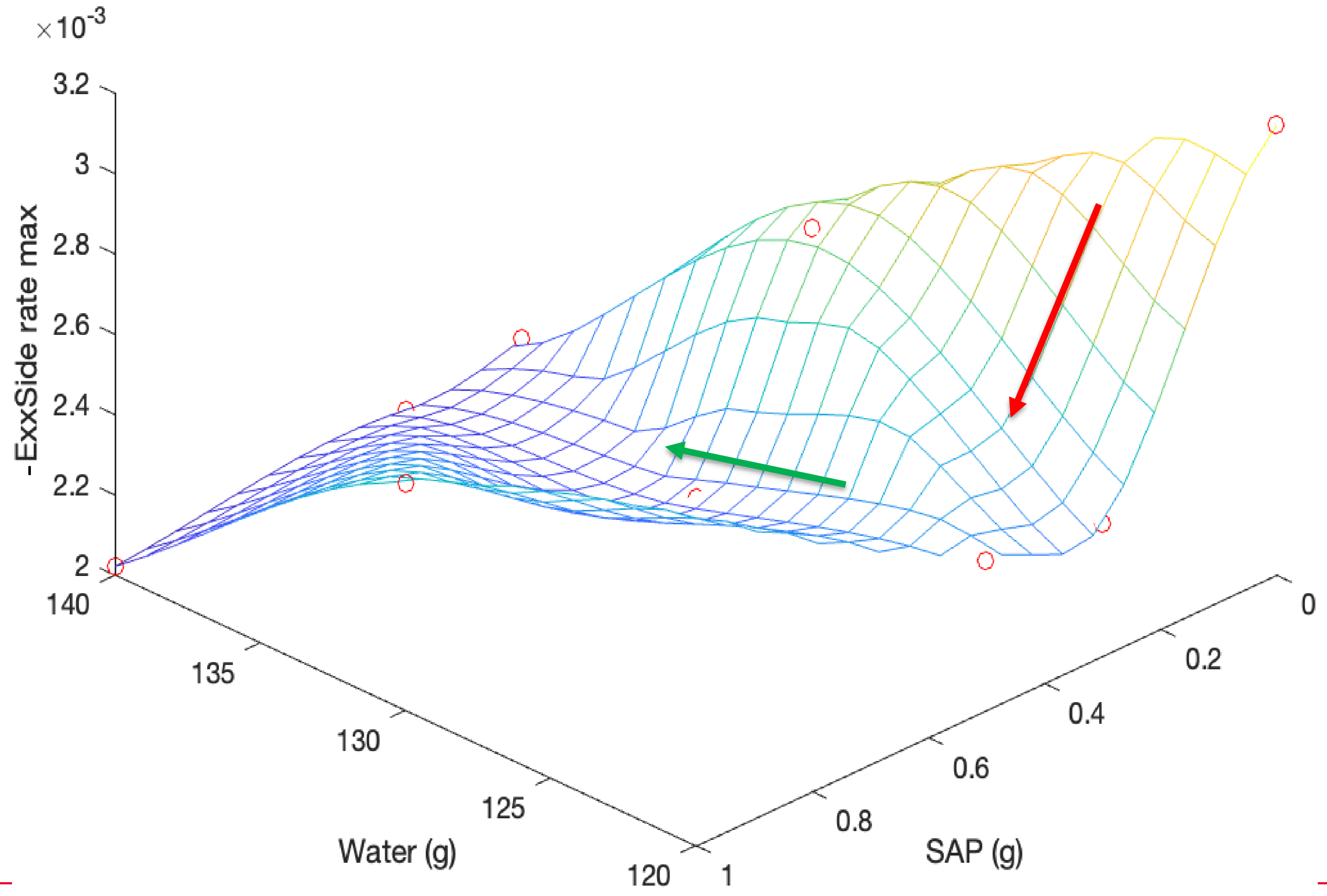


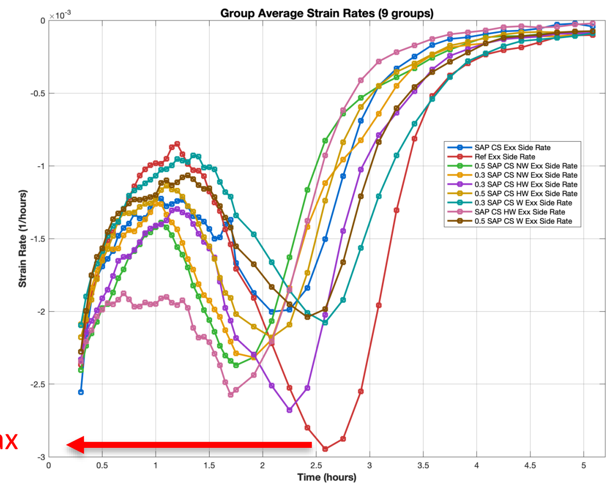


Increasing SAP

Increasing Water

Rates



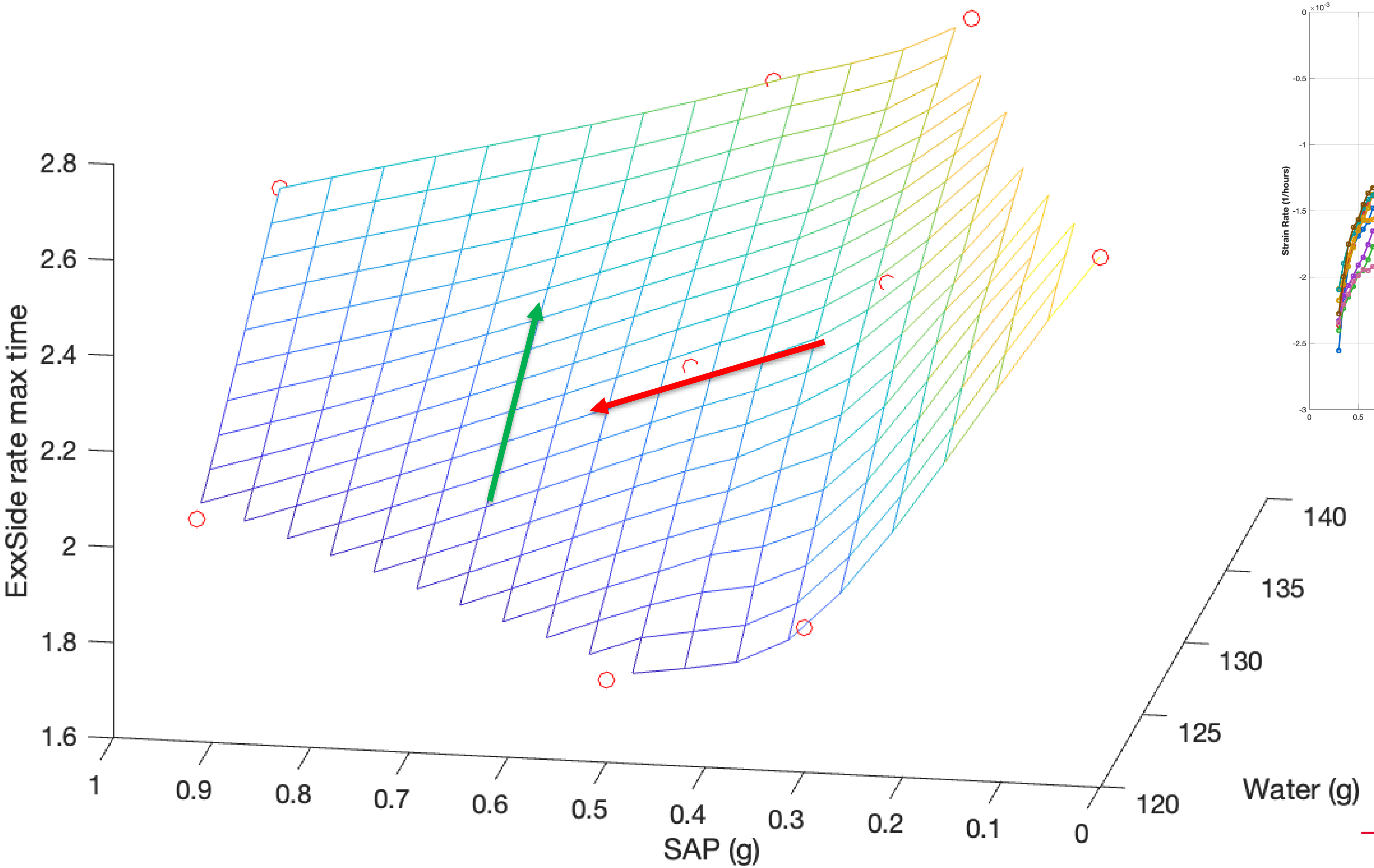


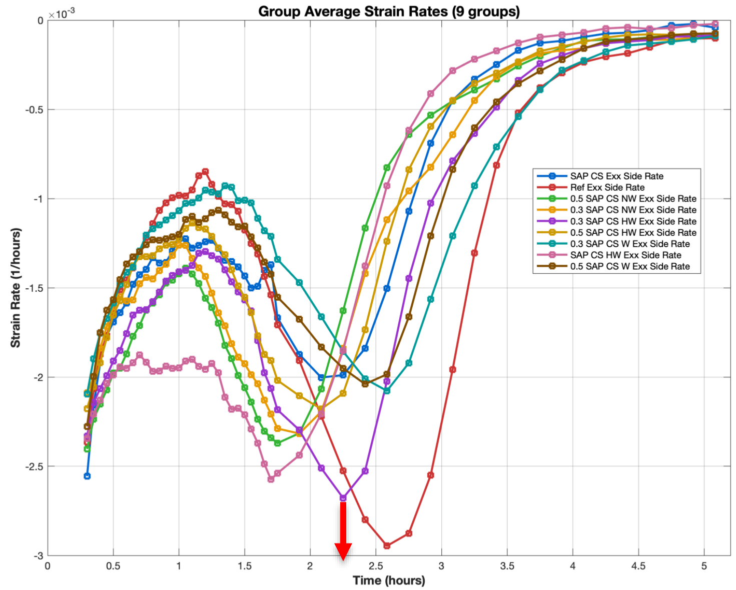
Exx Rate Max

Increasing SAP

Increasing Water

Rates





Rate Max Time

Increasing SAP

Increasing Water

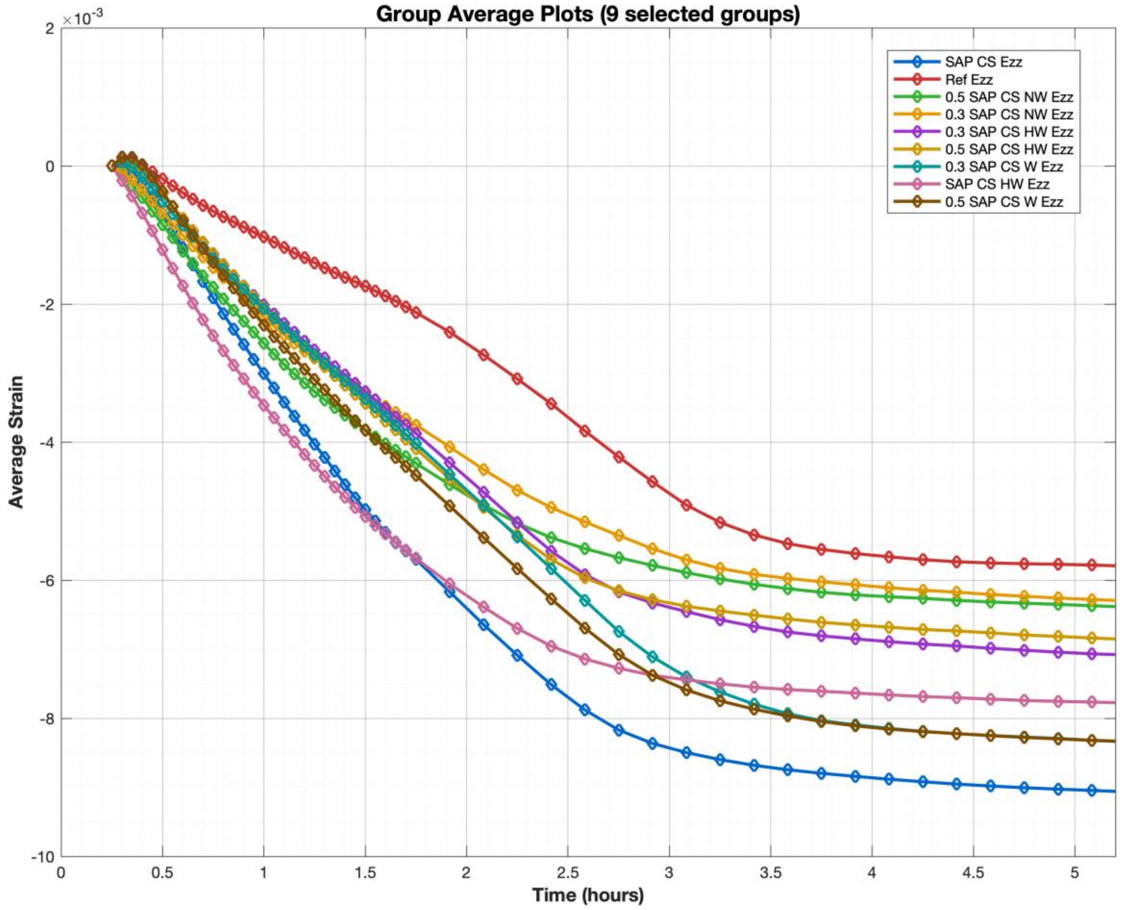
Conclusions and Next Steps

1. Modest improvement in terms of Longitudinal Strain
2. Modest max rate reduction
3. Generally sped up time to peak rate

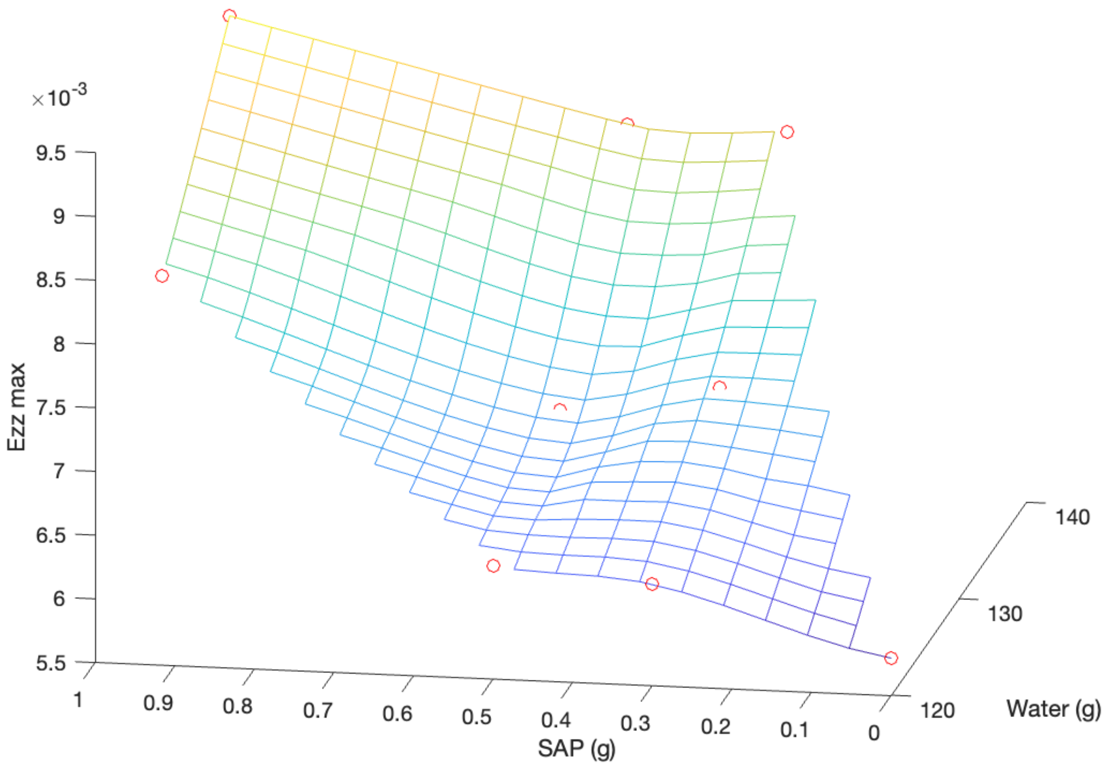
1. Quantify reaction rate
2. Relationship between free-shrinkage and cracking
3. Different SAP and mix proportions

Thanks!

Ezz

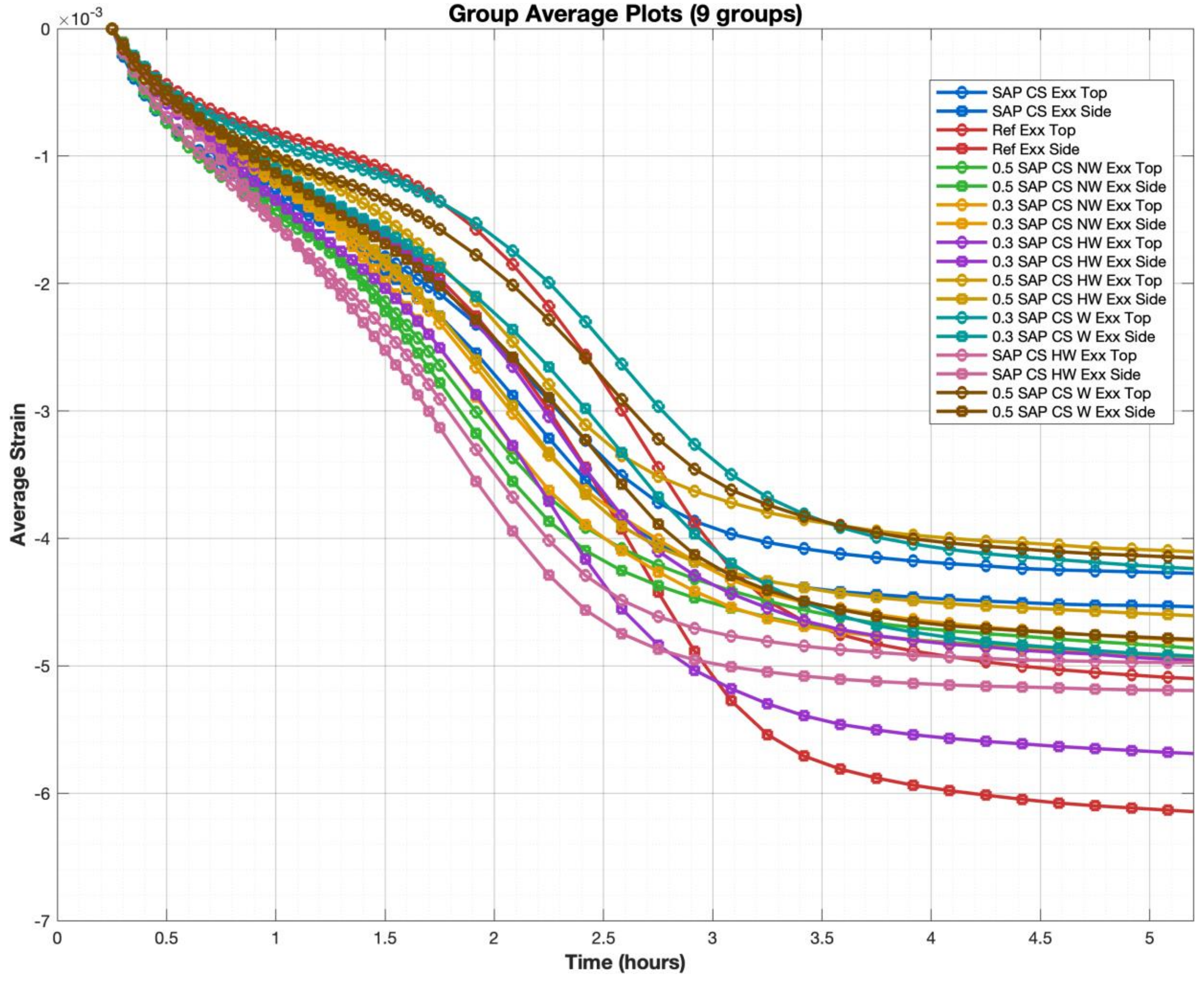


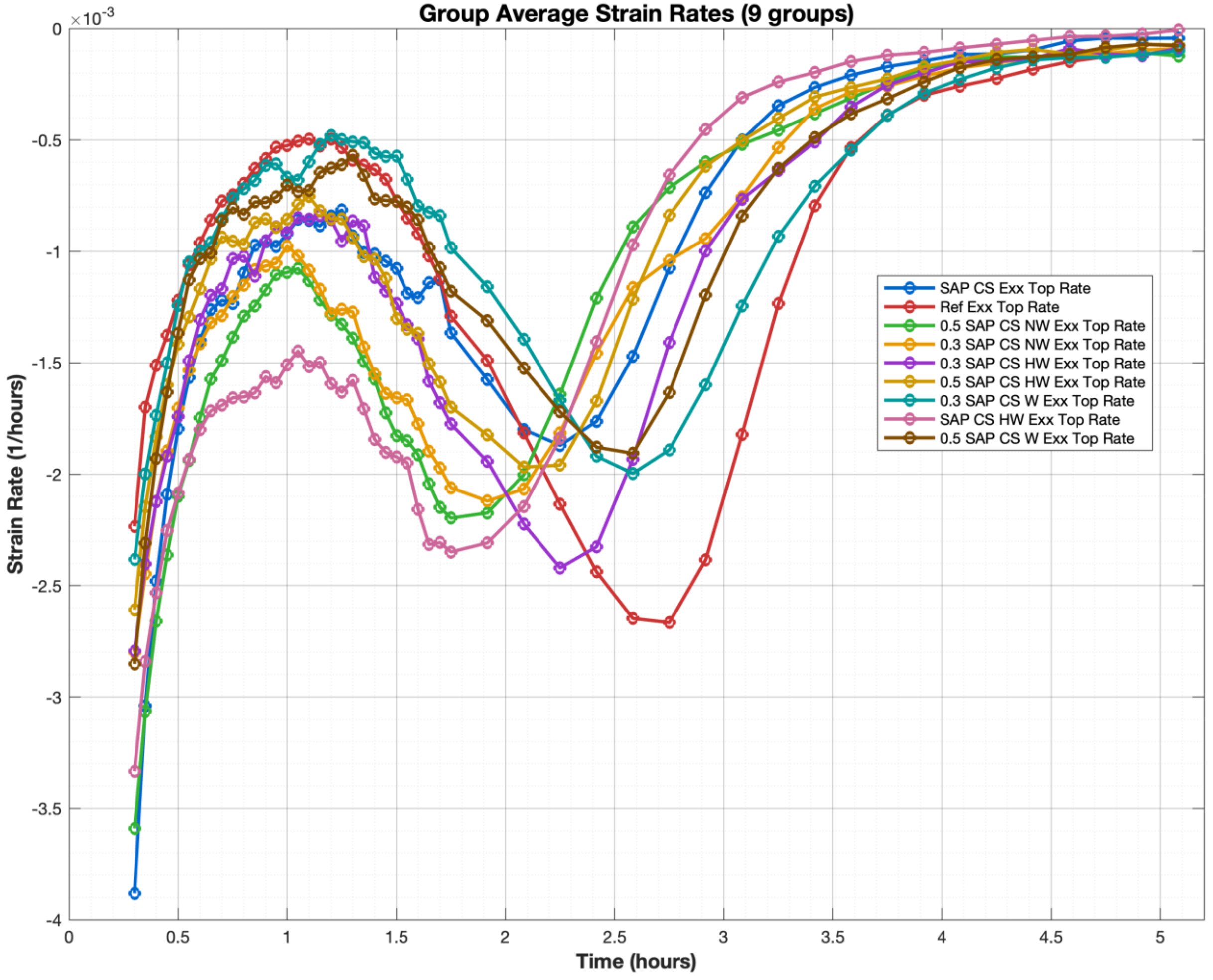
Group Average Plots (9 selected groups)
×10^-3
Average Strain
Time (hours)
SAP CS Ezz
Ref Ezz
0.5 SAP CS NW Ezz
0.3 SAP CS NW Ezz
0.3 SAP CS HW Ezz
0.5 SAP CS HW Ezz
0.3 SAP CS W Ezz
SAP CS HW Ezz
0.5 SAP CS W Ezz



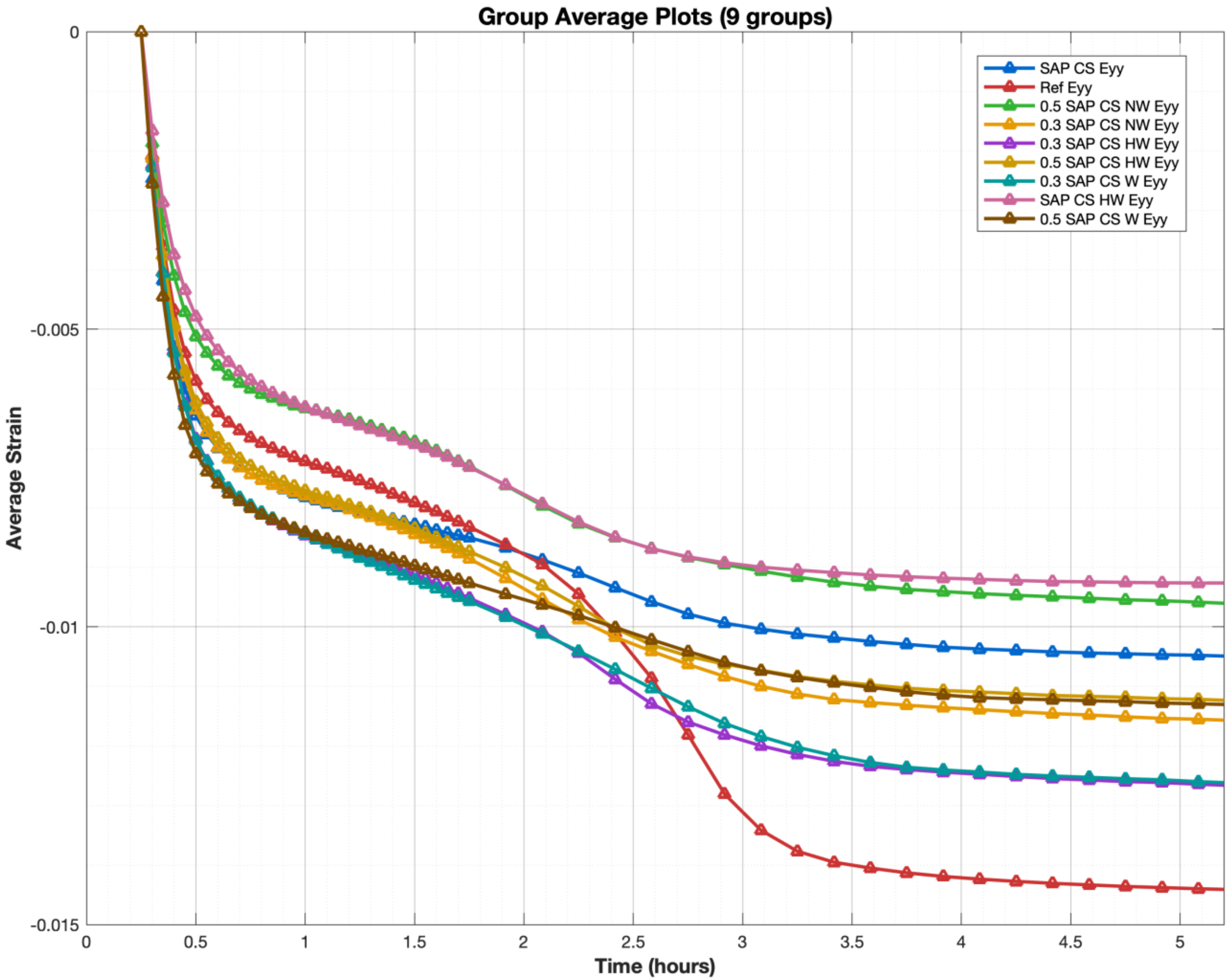
×10^-3
Ezz max
SAP (g)
Water (g)

Exx Top

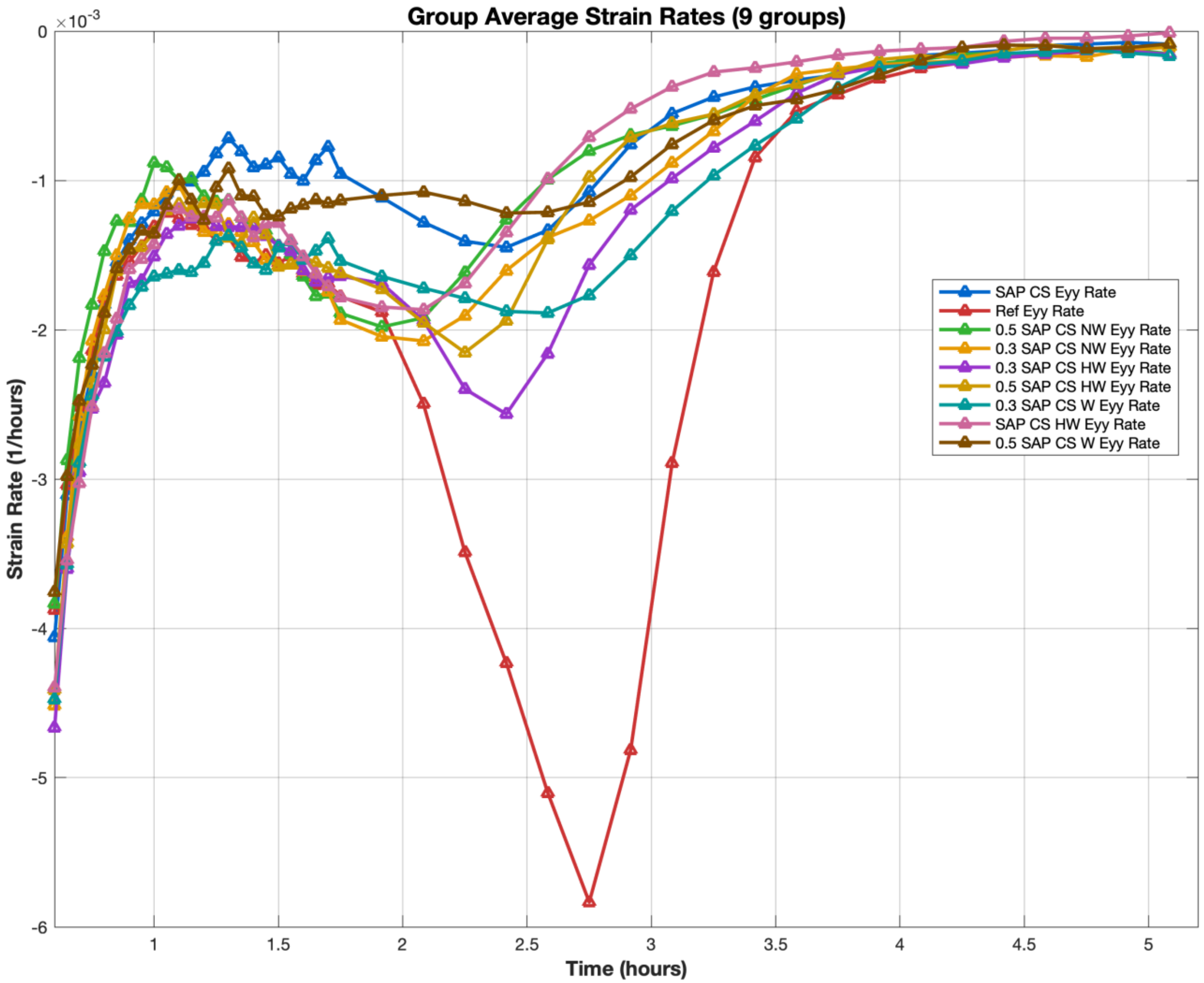

Group Average Plots (9 groups)
×10^-3
Average Strain
Time (hours)
SAP CS Exx Top
SAP CS Exx Side
Ref Exx Top
Ref Exx Side
0.5 SAP CS NW Exx Top
0.5 SAP CS NW Exx Side
0.3 SAP CS NW Exx Top
0.3 SAP CS NW Exx Side
0.3 SAP CS HW Exx Top
0.3 SAP CS HW Exx Side
0.5 SAP CS HW Exx Top
0.5 SAP CS HW Exx Side
0.3 SAP CS W Exx Top
0.3 SAP CS W Exx Side
SAP CS HW Exx Top
SAP CS HW Exx Side
0.5 SAP CS W Exx Top
0.5 SAP CS W Exx Side


Group Average Strain Rates (9 groups)
×10^-3
Strain Rate (1/hours)
Time (hours)
SAP CS Exx Top Rate
Ref Exx Top Rate
0.5 SAP CS NW Exx Top Rate
0.3 SAP CS NW Exx Top Rate
0.3 SAP CS HW Exx Top Rate
0.5 SAP CS HW Exx Top Rate
0.3 SAP CS W Exx Top Rate
SAP CS HW Exx Top Rate
0.5 SAP CS W Exx Top Rate

Eyy

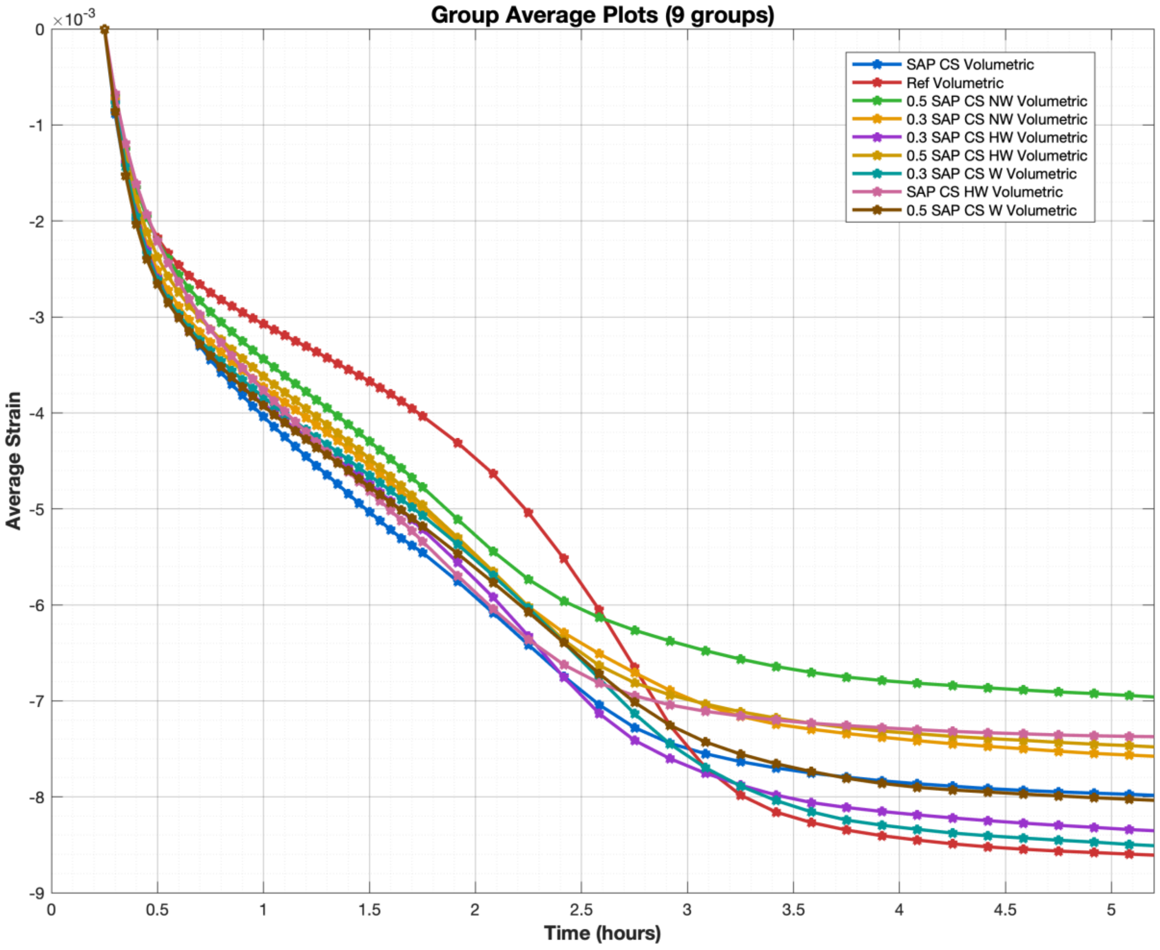


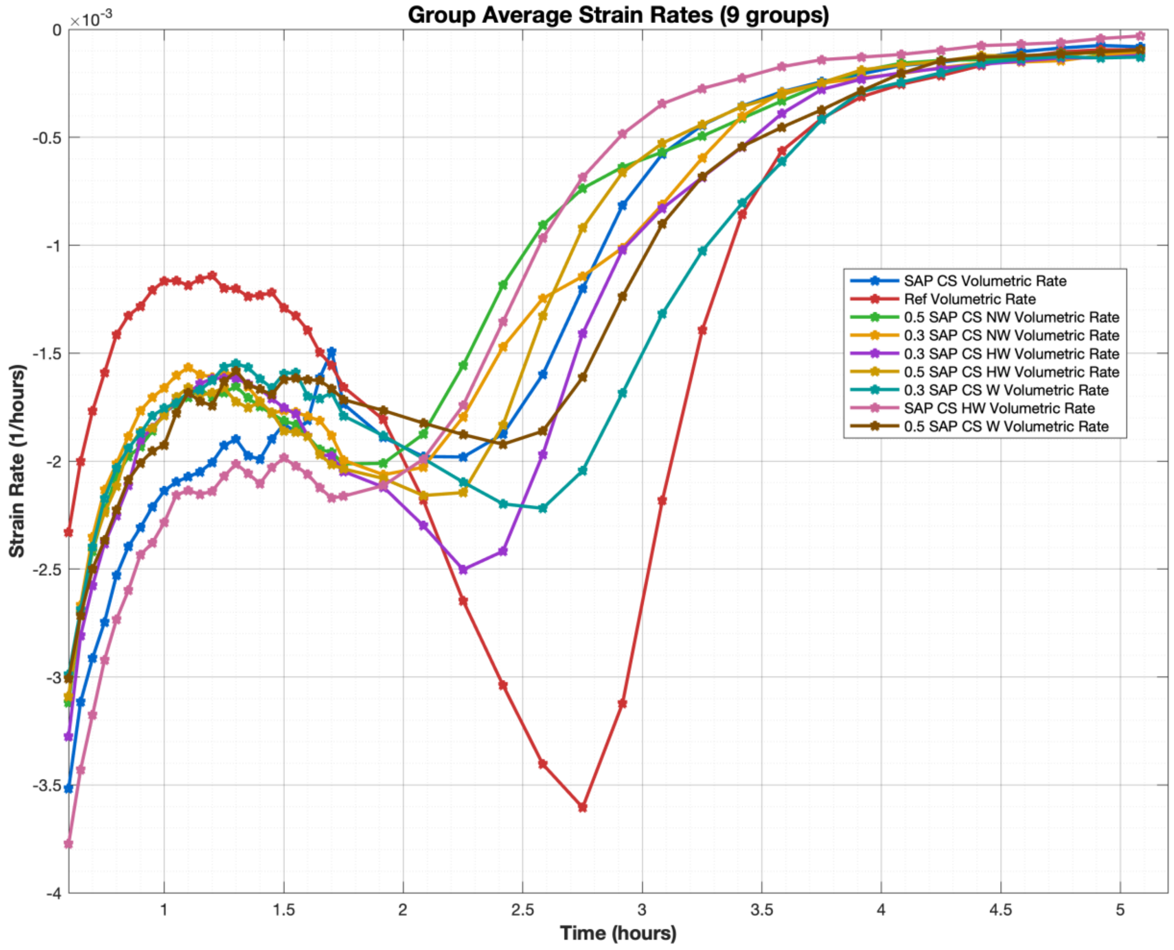
Group Average Plots (9 groups)
Average Strain
Time (hours)
0
-0.005
-0.01
-0.015
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
SAP CS Eyy
Ref Eyy
0.5 SAP CS NW Eyy
0.3 SAP CS NW Eyy
0.3 SAP CS HW Eyy
0.5 SAP CS HW Eyy
0.3 SAP CS W Eyy
SAP CS HW Eyy
0.5 SAP CS W Eyy



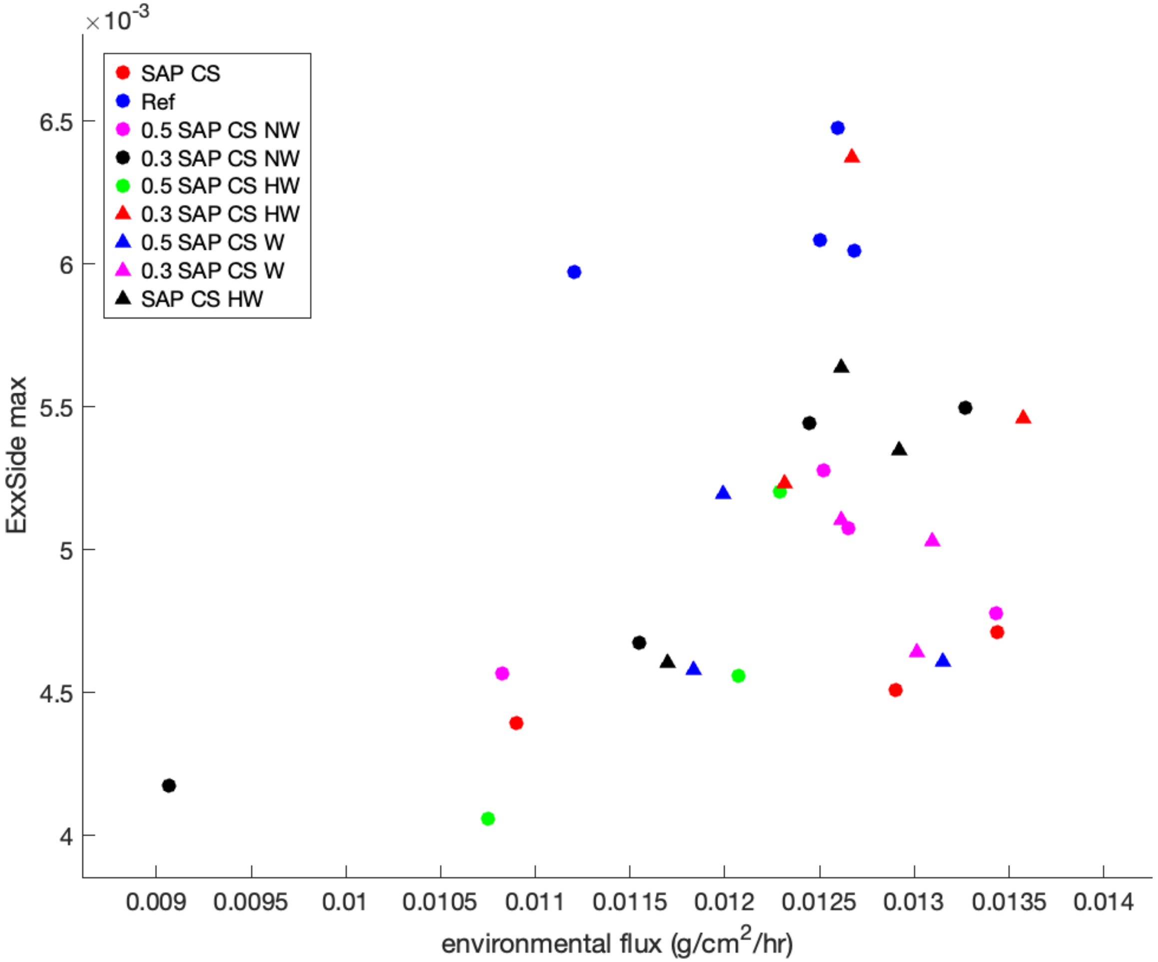
Group Average Strain Rates (9 groups)
$\times 10^{-3}$
Strain Rate (1/hours)
Time (hours)
0
-1
-2
-3
-4
-5
-6
1
1.5
2
2.5
3
3.5
4
4.5
5
SAP CS Eyy Rate
Ref Eyy Rate
0.5 SAP CS NW Eyy Rate
0.3 SAP CS NW Eyy Rate
0.3 SAP CS HW Eyy Rate
0.5 SAP CS HW Eyy Rate
0.3 SAP CS W Eyy Rate
SAP CS HW Eyy Rate
0.5 SAP CS W Eyy Rate

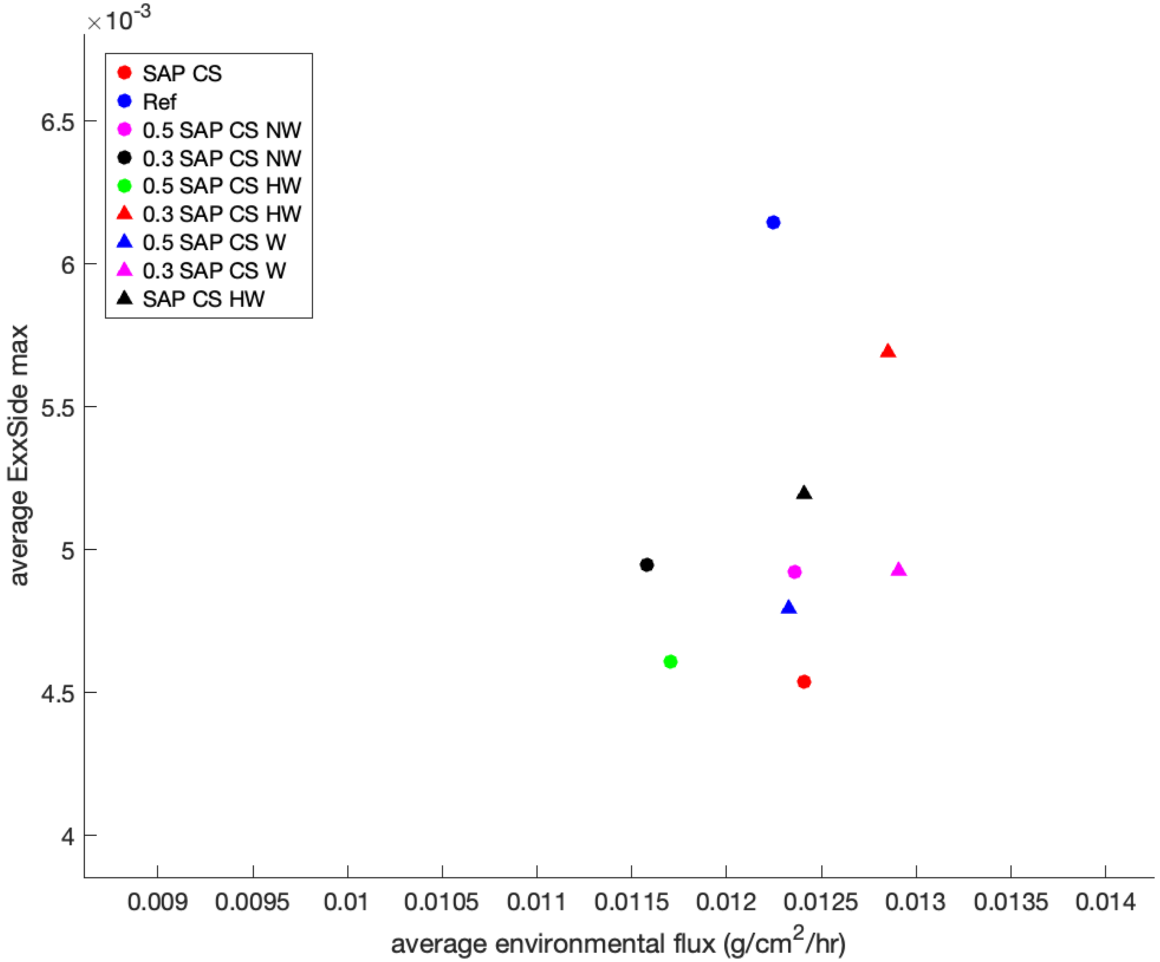
Ev


Group Average Plots (9 groups)
Average Strain
Time (hours)
×10⁻³
SAP CS Volumetric
Ref Volumetric
0.5 SAP CS NW Volumetric
0.3 SAP CS NW Volumetric
0.3 SAP CS HW Volumetric
0.5 SAP CS HW Volumetric
0.3 SAP CS W Volumetric
SAP CS HW Volumetric
0.5 SAP CS W Volumetric

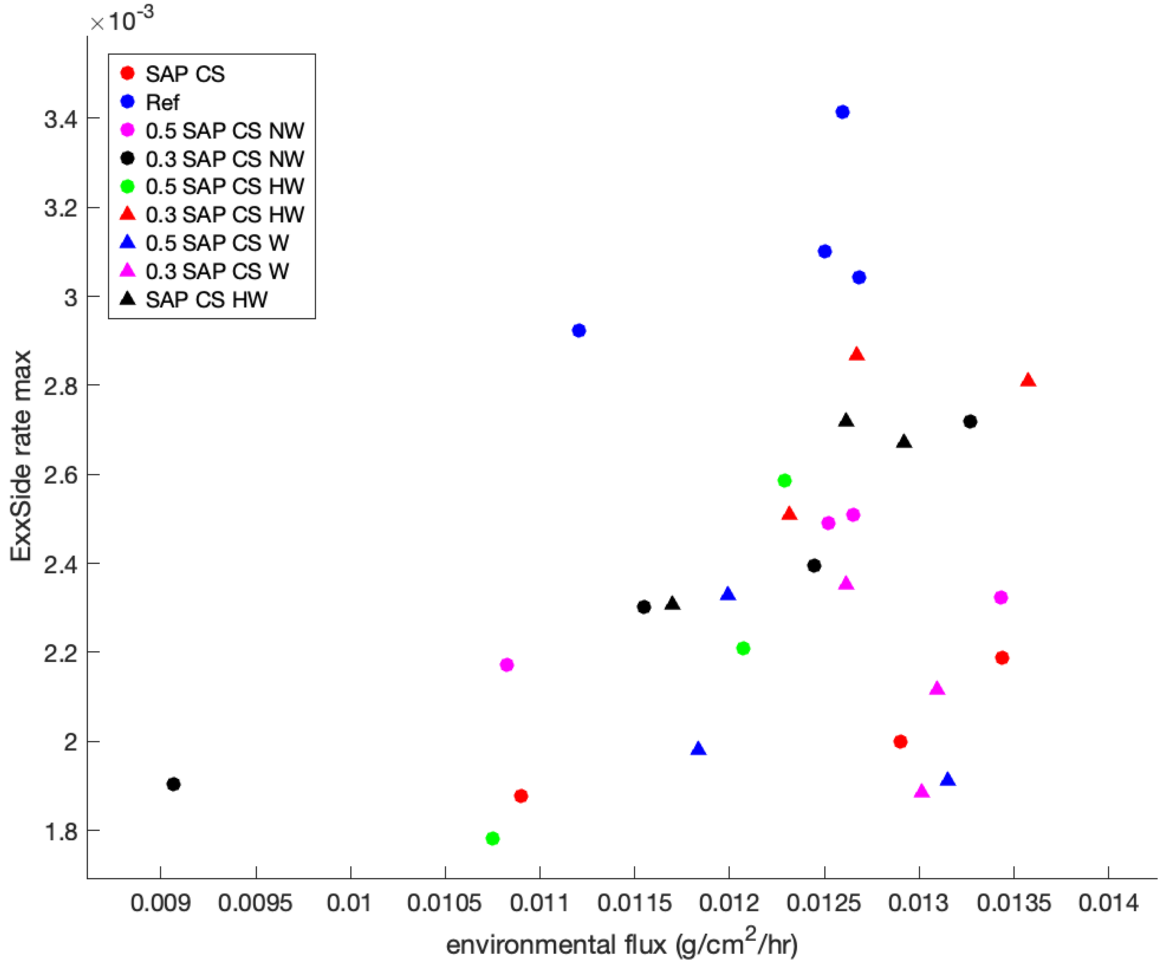

Group Average Strain Rates (9 groups)
Strain Rate (1/hours)
Time (hours)
×10⁻³
SAP CS Volumetric Rate
Ref Volumetric Rate
0.5 SAP CS NW Volumetric Rate
0.3 SAP CS NW Volumetric Rate
0.3 SAP CS HW Volumetric Rate
0.5 SAP CS HW Volumetric Rate
0.3 SAP CS W Volumetric Rate
SAP CS HW Volumetric Rate
0.5 SAP CS W Volumetric Rate

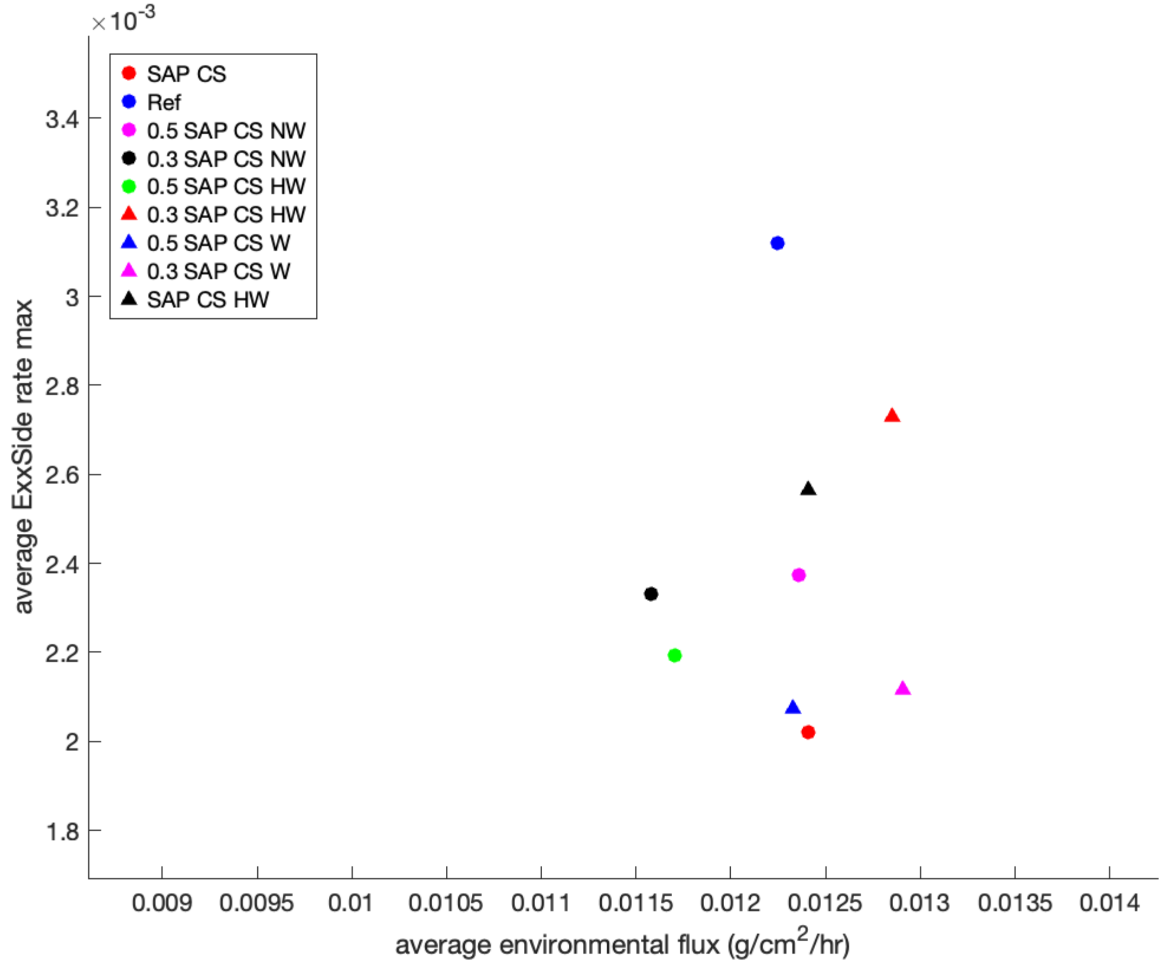
Flux vs. Strain



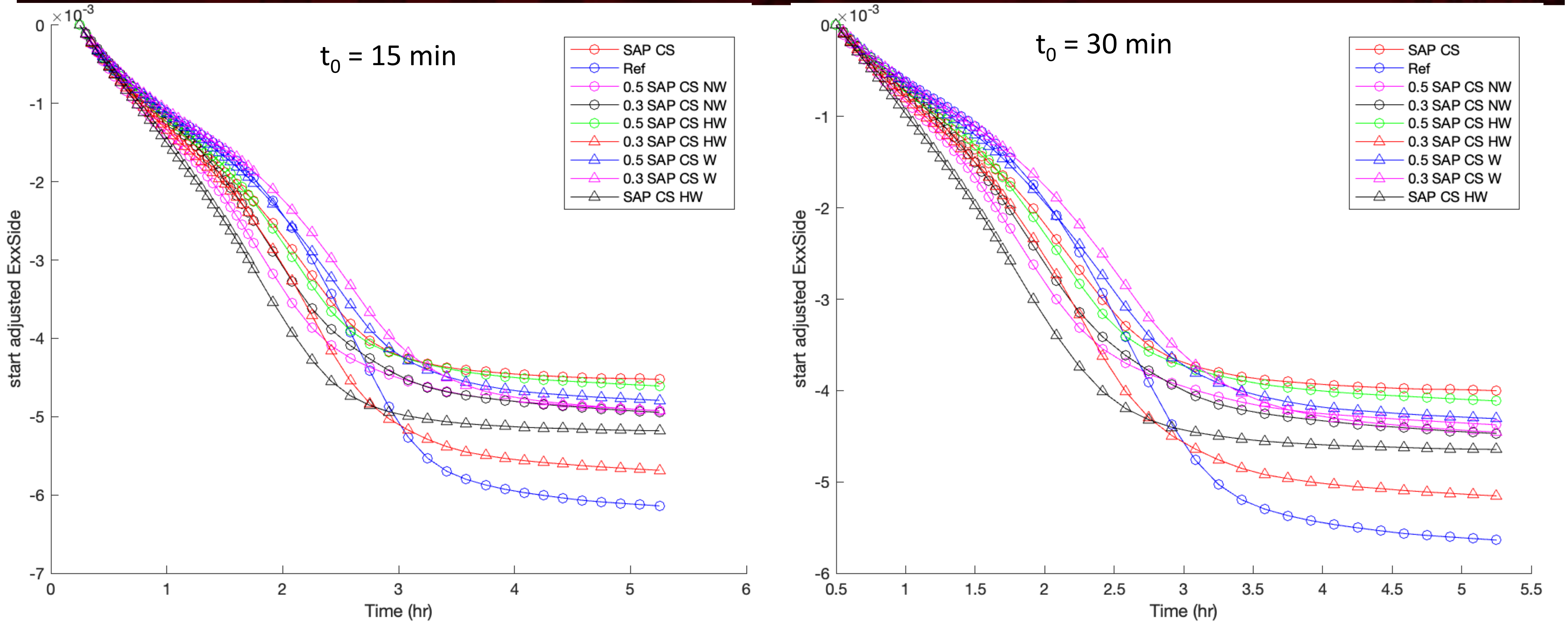


Flux vs. Strain Rate Peak





Adjusted Start Time



Adjusted Start Time