Colloidal Silicas
What you need to know

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Acknowledgements

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Warning

If you produce, use, or plan to use colloidal silica then at some point during this talk might get upset.

Warning

If you produce, use, or plan to use colloidal silica then at some point during this talk might get upset.

Hold your horses because a few slides later you may be happy.

Warning

This cycle of being upset and then happy may continue throughout the presentation.

Warning

If you say, “That doesn’t match my experience.”

There may be a good reason for this that I will talk about at the end.

If you find yourself saying…

Did you try….

Why didn’t you test…

What happens if…

What is really going on…

How does this apply to…

If you find yourself saying…

Did you try….

You are in good company.

What is really going on…

How does this apply to…

What is colloidal silica?

What is colloidal **silica**?

Silica fume

Silica fume has been a widely used additive to reduce the permeability and increase the strength of concrete.

Silica fume reacts with calcium hydroxide to produce more CSH.

Silica fume

Silica fume is about 30x smaller than portland cement.

As you make particles smaller, this typically makes them more reactive.

Colloidal Silica

Colloidal silica is similar in chemistry to silica fume, and it reacts with calcium hydroxide to form more CSH.

Colloidal silica is 3000x smaller than a cement grain

This is 100x smaller than silica fume

Colloidal Silica

Because the particles are so small, the colloidal silica particles are even more reactive.

History of colloidal silica

Colloidal silica is not new.

It was first used in concrete in the 1940s.

It is most widely used as a floor hardener for industrial floor slabs.

What are the uses of colloidal silica?

Added during mixing

Spray on the surface

Why would you use colloidal silica?

Reduce permeability

Increase strength/hardness

Reduce cracking?

Make my surface concrete more workable?

What could you do if this is true?

Reduce my curing requirements

Reduce cement

Extend the service life of my concrete

How did this start?

Oklahoma DOT wanted to build a bridge deck with each span using a different concrete mixture:

- Light weight aggregate
- Conventional concrete
- Colloidal silica admixtures

How did this start?

They wanted Oklahoma State to “develop” the concrete mixtures and measure the benefits of these materials.

What was done

- Lab work – Develop Mixture Design
- Field work – Build a bridge with light weight, colloidal silica, conventional concrete
- Evaluate the construction and early age performance.

What colloidal silica admixtures were used?

What colloidal silica admixtures were used?

Materials were used from three different companies.

All of these materials are used commercially.

		(1)	(2)
Colloidal Silica	**Specific Gravity**	**Solids Content (%)**	**Manufacturer Recommended Dosage (oz/cwt)**
A1	1.14	22.6	4
A2	1.14	22.6	8
B	1.16	25.6	20.6
C	1.1	17.5	20.6

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These are from the same manufacturer and are recommended to be used together

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		(1)	(2)	(1) x (2)
Colloidal Silica	**Specific Gravity**	**Solids Content (%)**	**Manufacturer Recommended Dosage (oz/cwt)**	**Suspended Solids (oz/cwt)**
A1	1.14	22.6	4	0.9
A2	1.14	22.6	8	1.8
B	1.16	25.6	20.6	5.3
C	1.1	17.5	20.6	3.6

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Most active ingredient ←

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Least active ingredient

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There may be a reason for this

How much does this represent of the cementitious content?

		(1)	(2)	(1) x (2)	
Colloidal Silica	**Specific Gravity**	**Solids Content (%)**	**Manufacturer Recommended Dosage (oz/cwt)**	**Suspended Solids (oz/cwt)**	**Percentage of the cementitious (%)**
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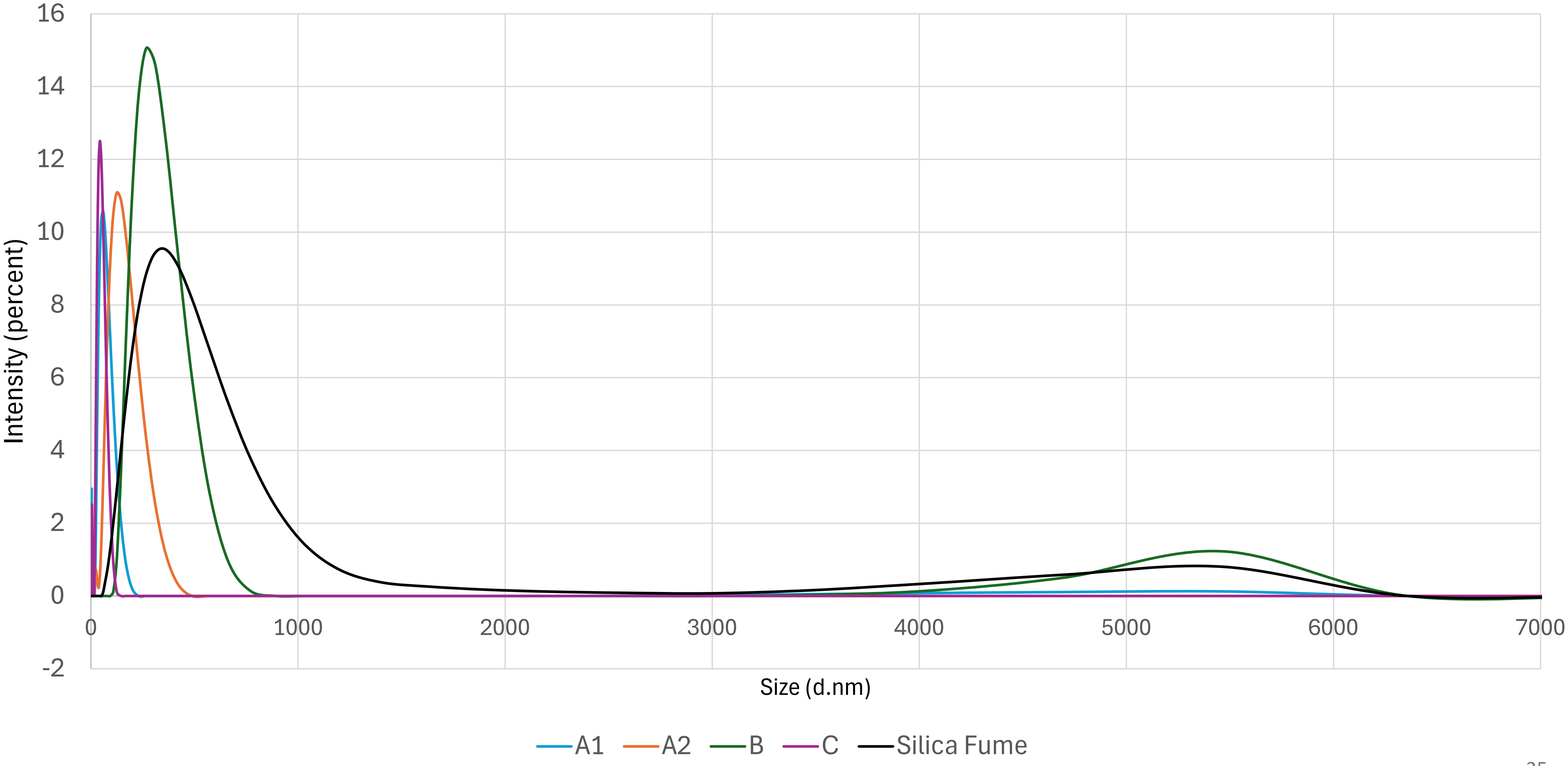
A2	1.14	22.6	8	1.8	0.6
B	1.16	25.6	20.6	5.3	1.5
C	1.1	17.5	20.6	3.6	1.0
				Silica Fume	5.0

Discussion

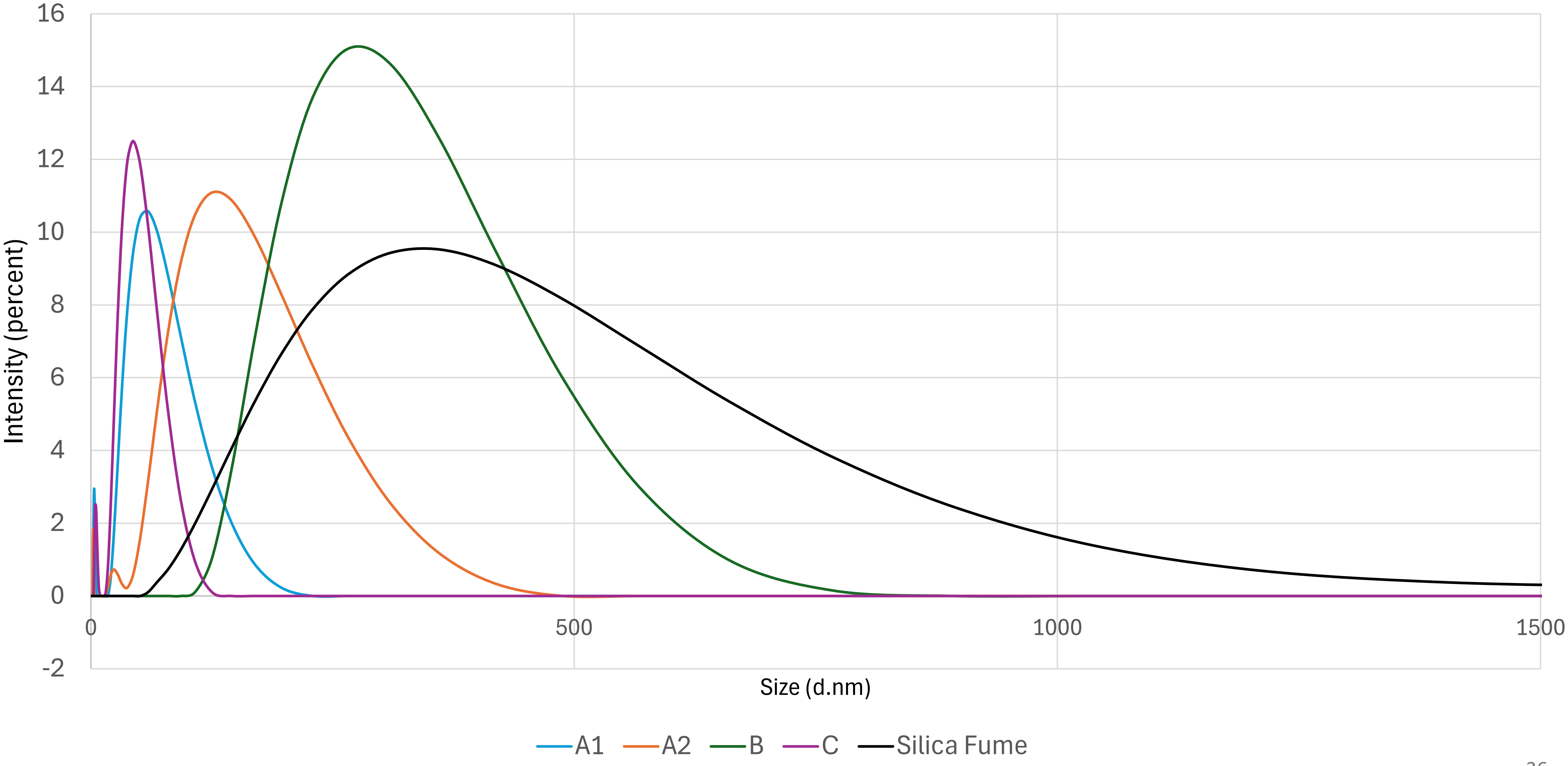
- At the Manufacturer's Recommended Dosage there are differences in the active solids content.
- Different active solids contents may be used because the solids could have different reactivity levels.
- The particle size distribution may tell us more about this.

Laser Diffraction Analysis
Sizes from 0.3 nm to 10 µm

Particle size distribution



Particle size distribution



		(1)	(2)	(1) x (2)	
Colloidal Silica	**Specific Gravity**	**Solids Content (%)**	**Manufacturer Recommended Dosage (oz/cwt)**	**Suspended Solids (oz/cwt)**	**D50 (nm)**
A1	1.14	22.6	4	0.9	50
A2	1.14	22.6	8	1.8	125
B	1.16	25.6	20.6	5.3	267
C	1.1	17.5	20.6	3.6	37

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Silica fume is 310 nm

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Finer particles may be more reactive

Bridge Deck Concrete Mixtures

Material	Mass
#57	1890 lbs
Sand	1290 lbs
Cement	611 lbs
Water	275 lbs

0.45 w/cm

6.5 sack

No fly ash available

Cement and Admixture Combinations

1L cement + midrange (lignosulfonate)

Cement and Admixture Combinations

1L cement + midrange (lignosulfonate)

1L cement + high range (polycarboxylate)

Cement and Admixture Combinations

1L cement + midrange (lignosulfonate)

1L cement + high range (polycarboxylate)

I/II cement + high range (polycarboxylate)

Testing

1. Slump, unit weight, and air content
2. w/cm with the Phoenix
3. Calorimetry (24 hours)
4. Compressive strength at 7, 28, and 56 days
5. Resistivity at 7, 28, and 56 days
6. Shrinkage test
7. Diffusion Coefficient (130 days)

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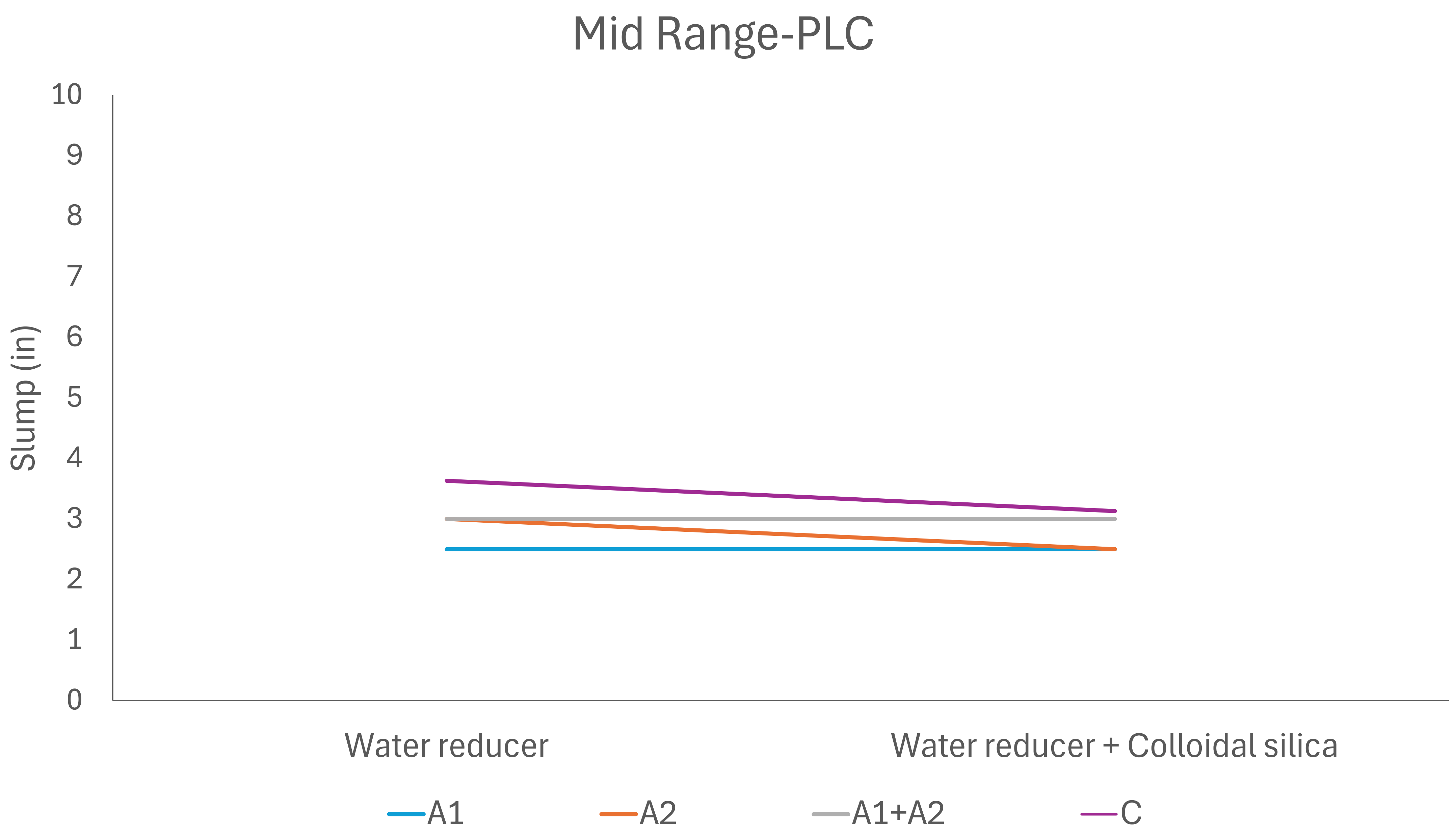
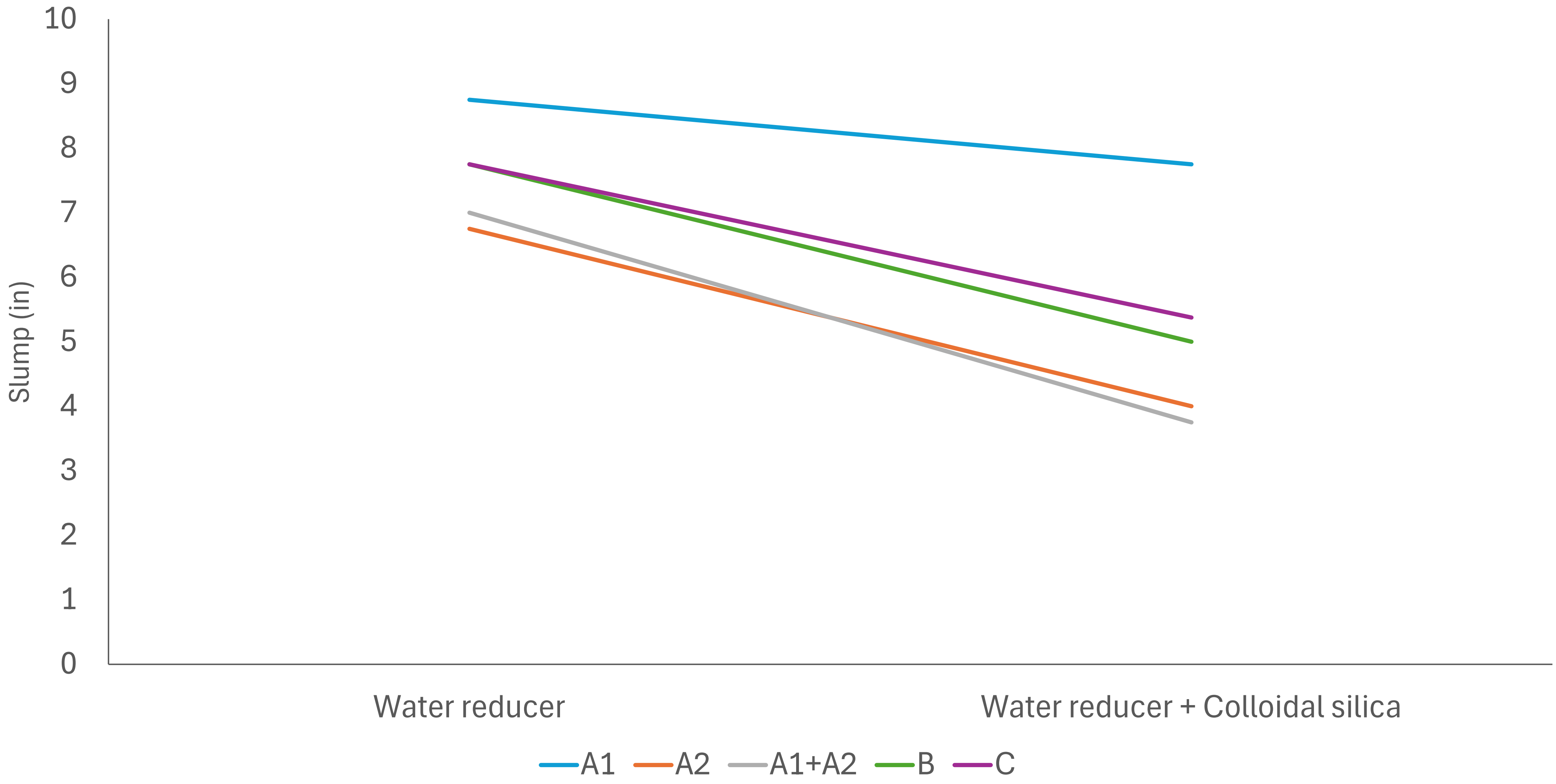
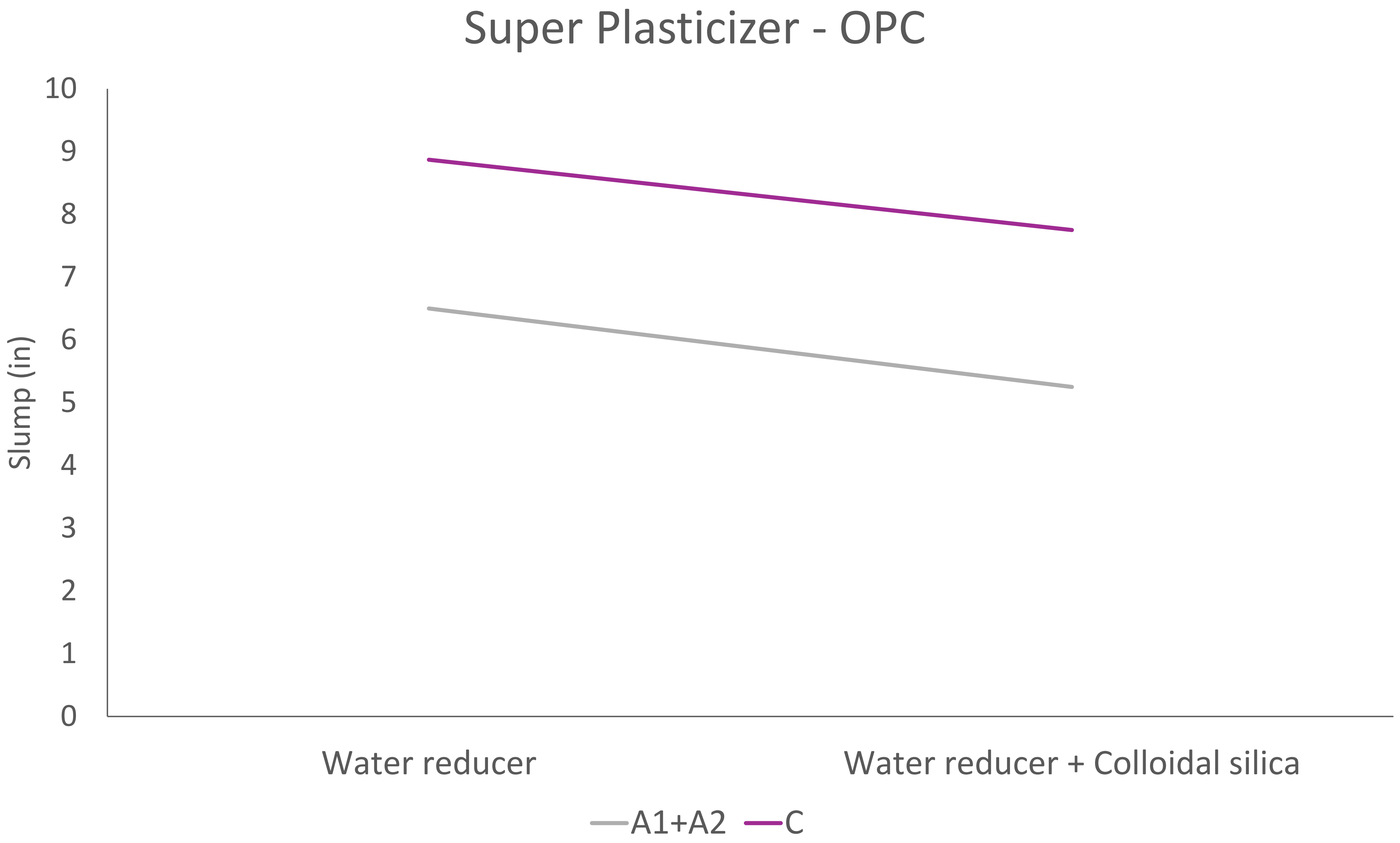
Mixing sequence

1. Add rock and sand and 50% of water and mix 2 min
2. Add cement and 50% of water and mix 3 min
3. Scrape the mixer 2 min
4. Add water reducer and mix 3 min
   (measure 1st slump)
5. Add colloidal silica admixture and mix 3 min
   (measure 2nd slump)


Mid Range-PLC
Slump (in)
10
9
8
7
6
5
4
3
2
1
0
Water reducer
Water reducer + Colloidal silica
A1
A2
A1+A2
C

Super Plasticizer-PLC

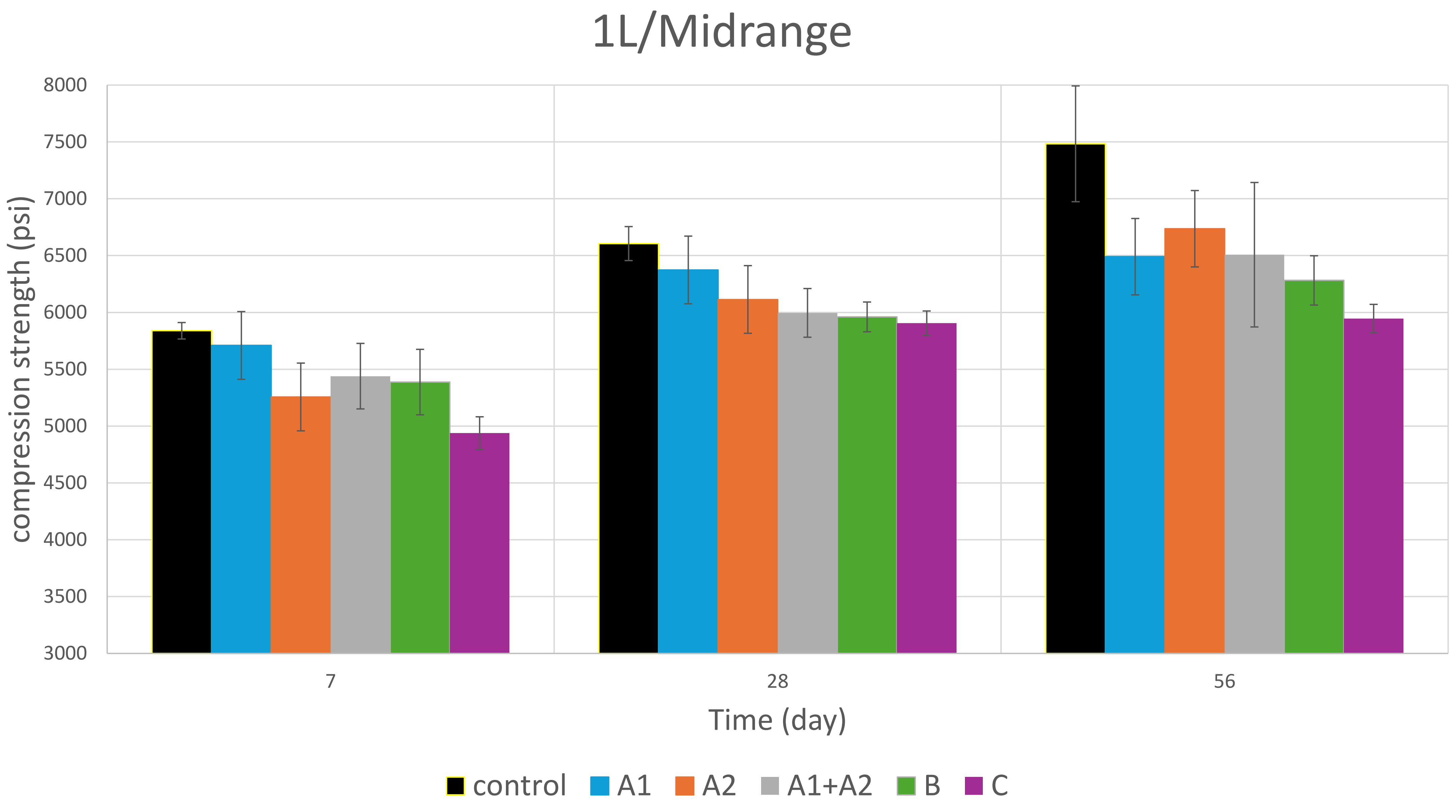


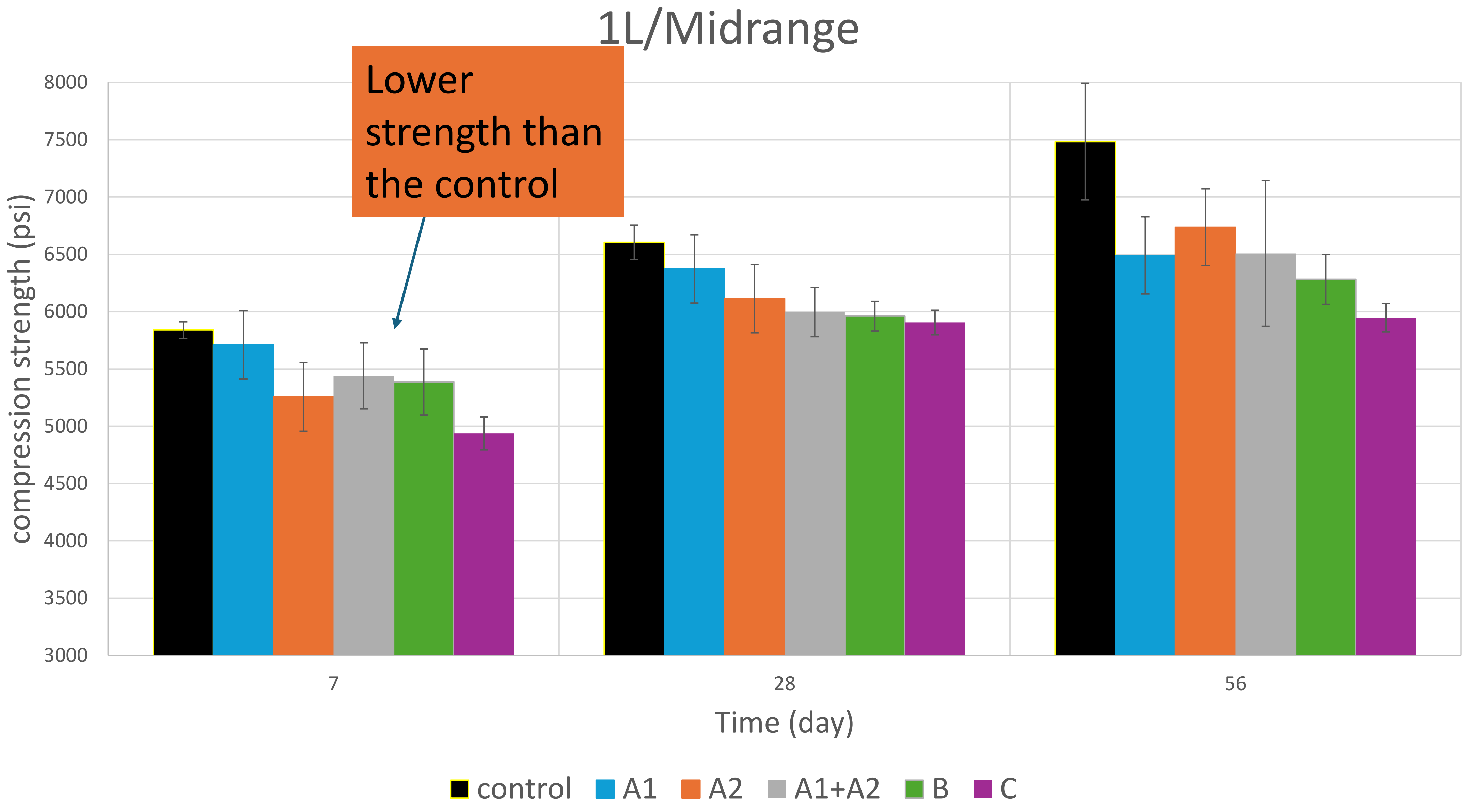


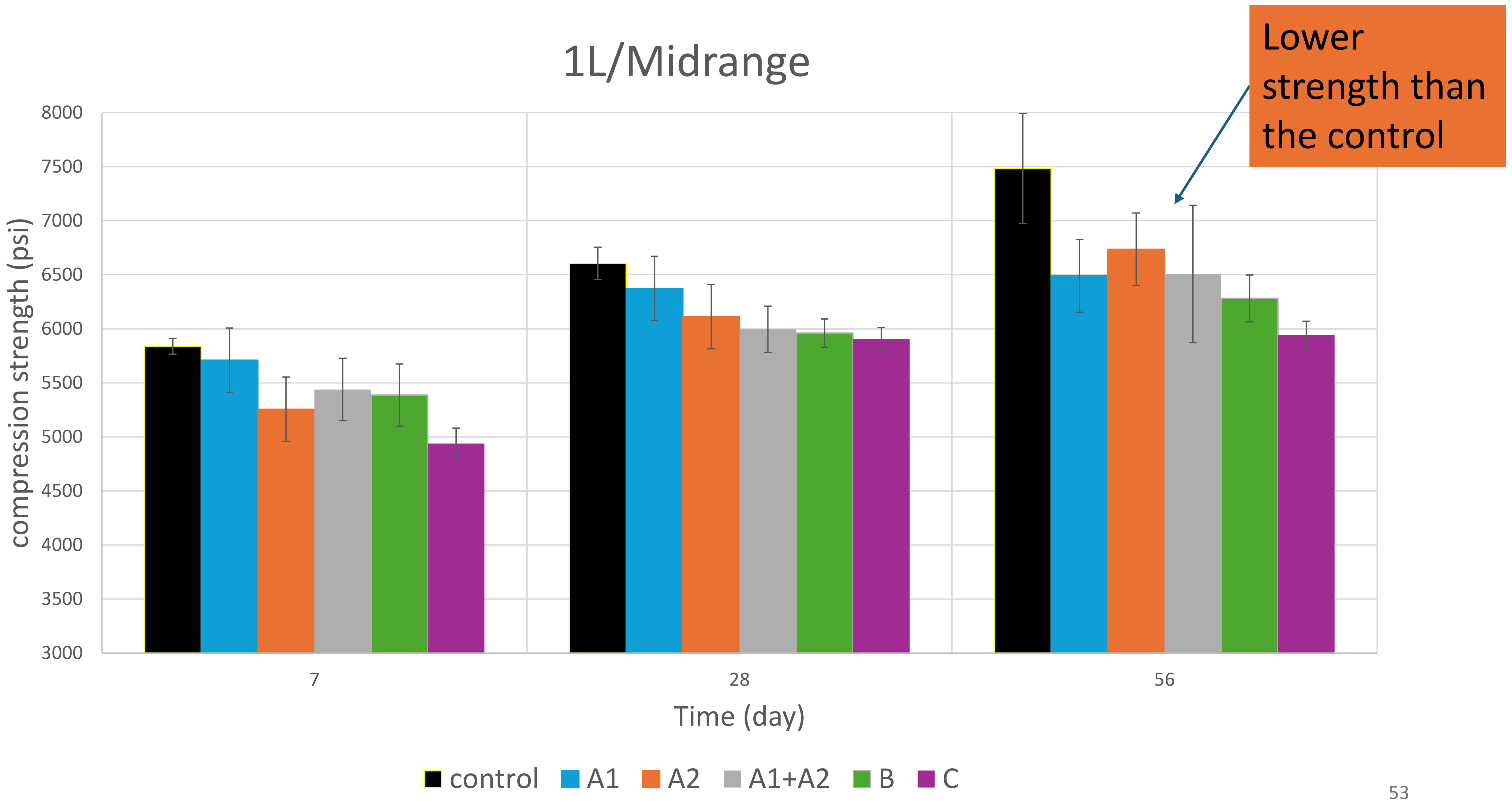
Super Plasticizer - OPC
10
9
8
7
6
5
4
3
2
1
0
Slump (in)
Water reducer
Water reducer + Colloidal silica
A1+A2
C

Discussion

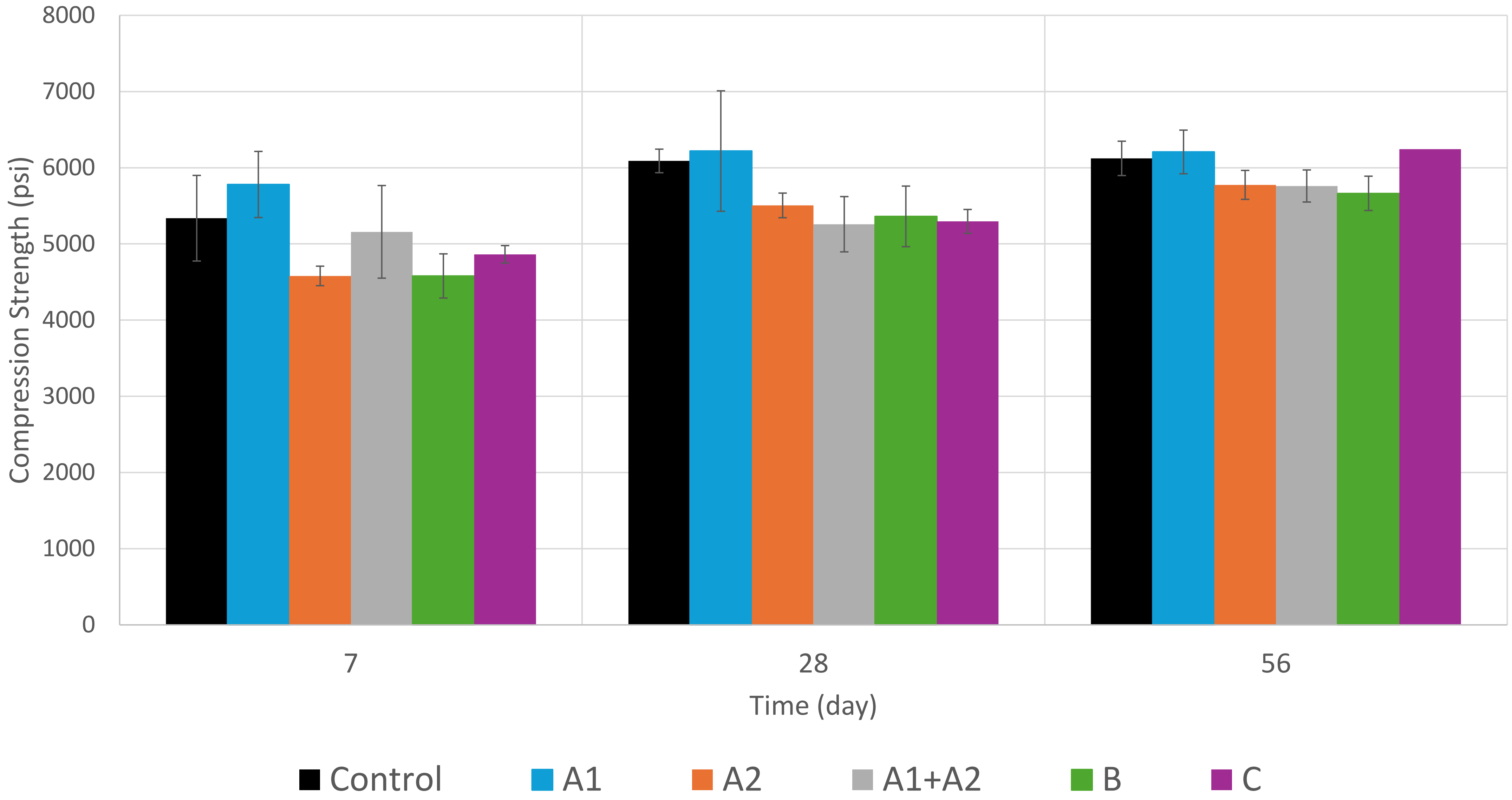
- There is minimal change in slump (< 0.5”) when the colloidal silica is added to the 1L/midrange mixture
- There is a significant reduction in slump (> 2”) when the colloidal silica is added to the 1L/highrange and I/II/highrange.


1L/Midrange
compression strength (psi)
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
7
28
56
Time (day)
control
A1
A2
A1+A2
B
C

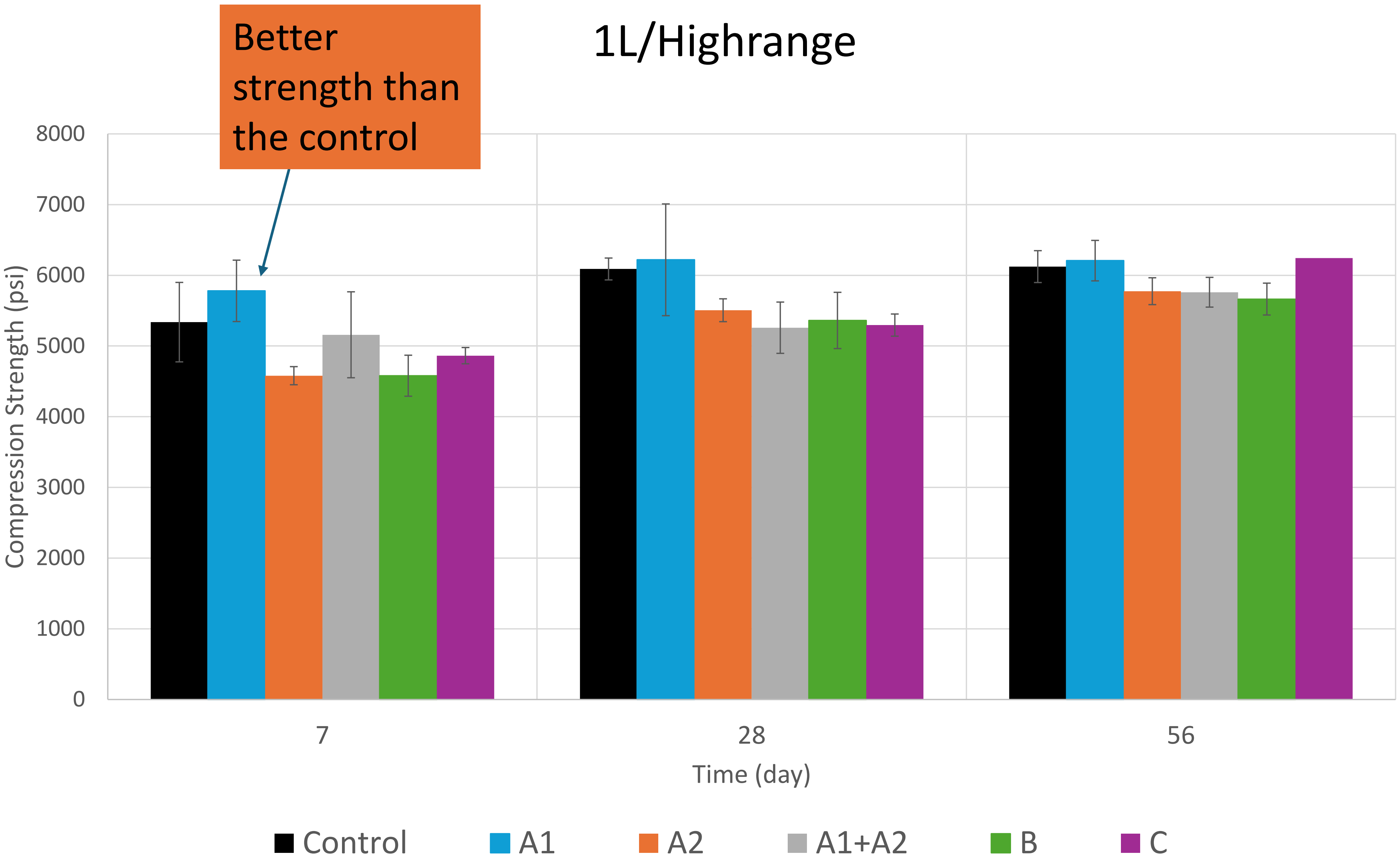

1L/Midrange
Lower strength than the control
compression strength (psi)
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
7
28
56
Time (day)
control
A1
A2
A1+A2
B
C


1L/Midrange
Lower strength than the control
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
compression strength (psi)
7
28
56
Time (day)
control
A1
A2
A1+A2
B
C

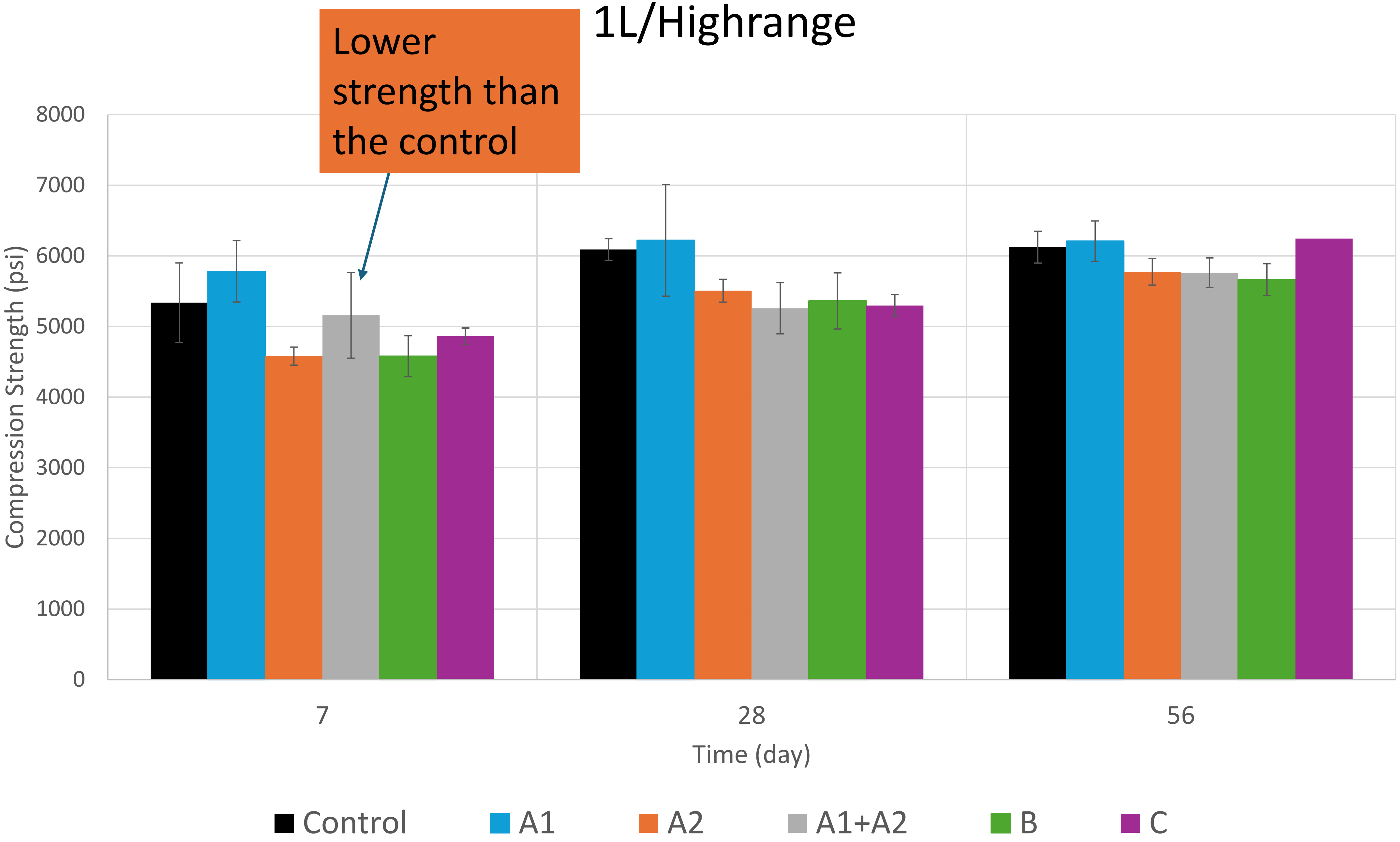
1L/Highrange



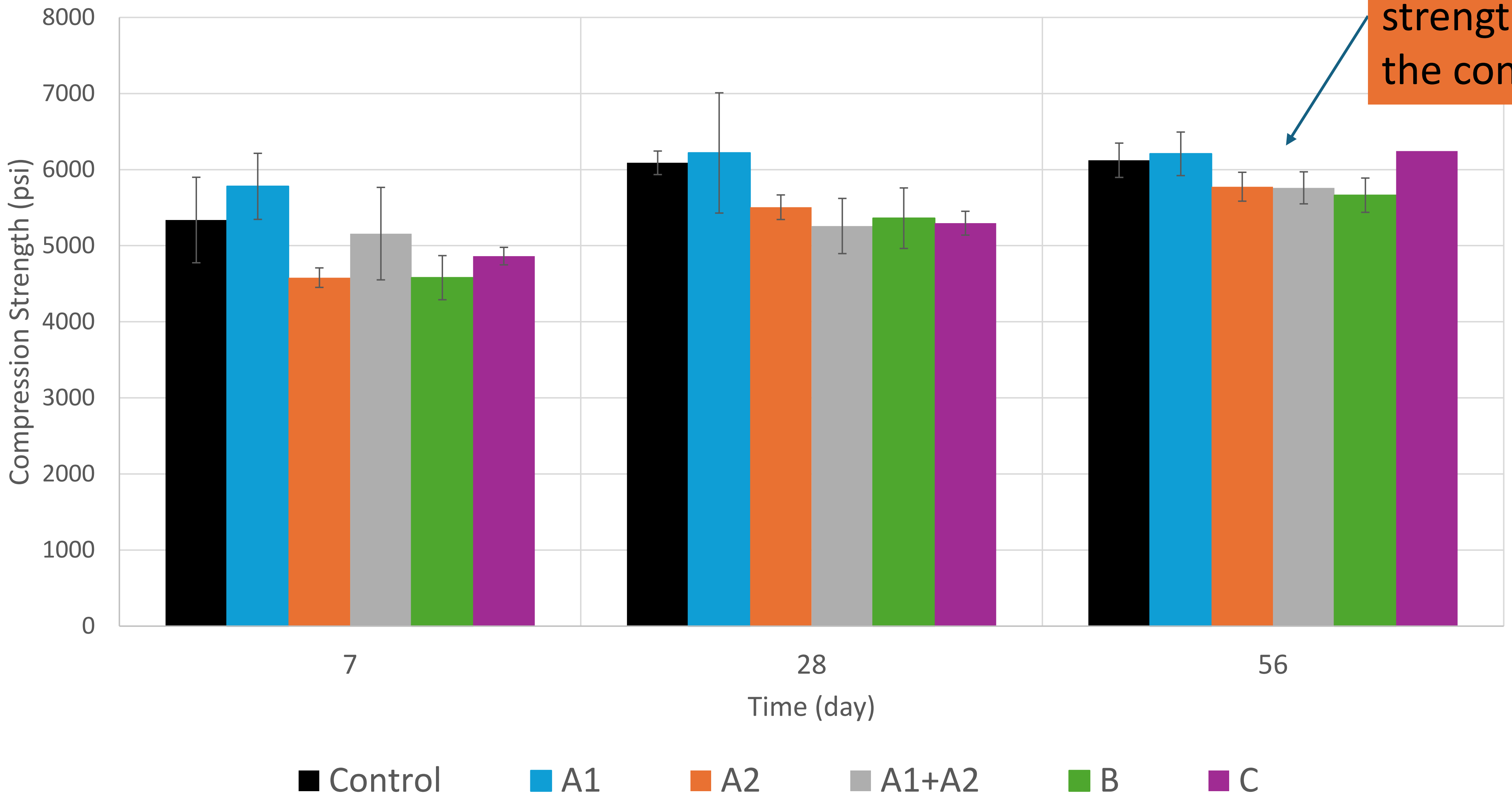
1L/Highrange



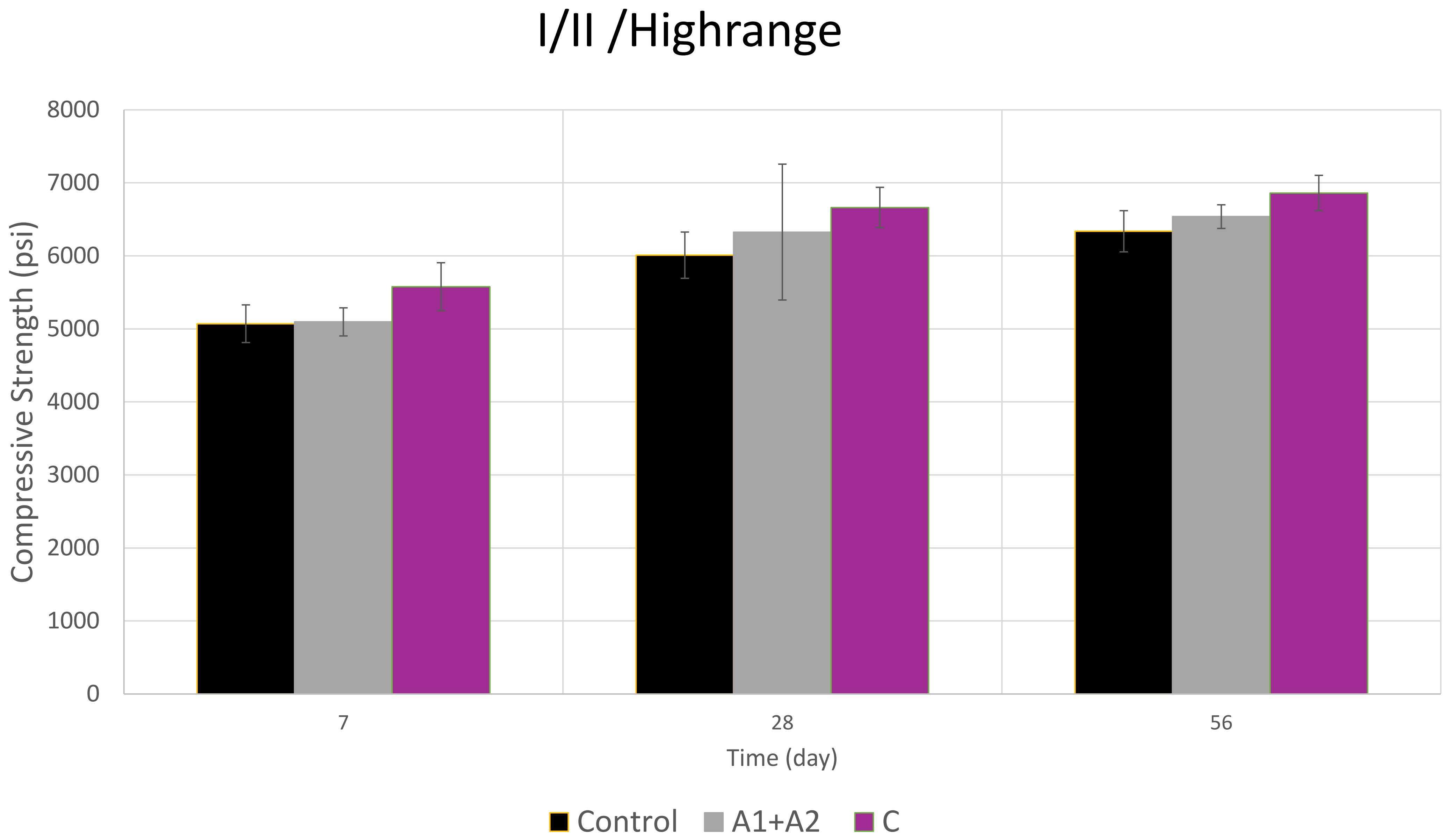
1L/Highrange

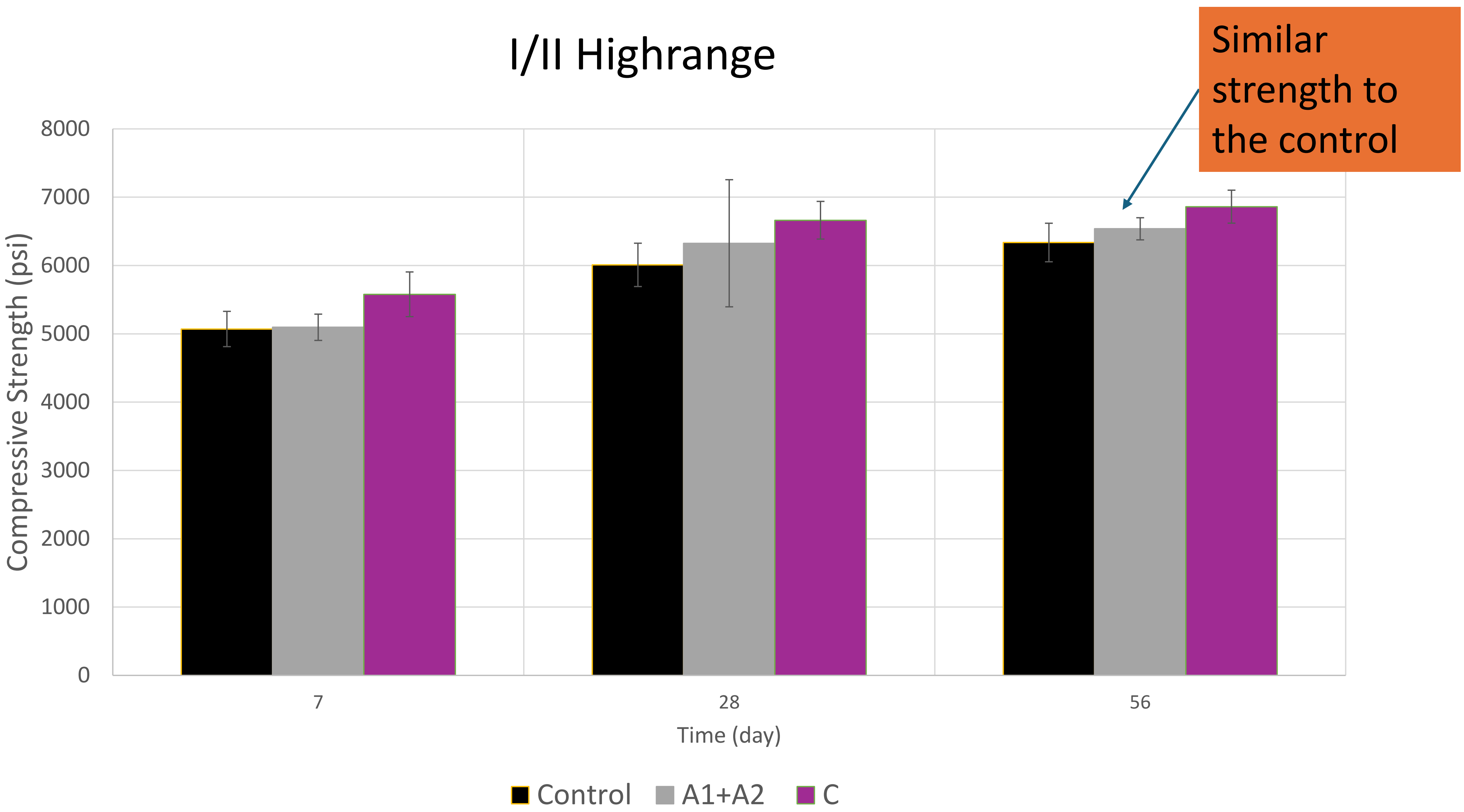


1L/Highrange



Similar strength to the control


I/II /Highrange
8000
7000
6000
5000
4000
3000
2000
1000
0
Compressive Strength (psi)
7
28
56
Time (day)
Control
A1+A2
C


I/II Highrange
Similar strength to the control
Compressive Strength (psi)
8000
7000
6000
5000
4000
3000
2000
1000
0
7
28
56
Time (day)
Control
A1+A2
C

Discussion

1L/ Midrange – Lower strength than the control at all ages

1L/ Highrange – Lower strength at 7 days
Similar strength at 56 days

I/II Highrange – Similar to 500 psi higher

Resistivity

WARNING!

Resistivity $\neq$ Permeability

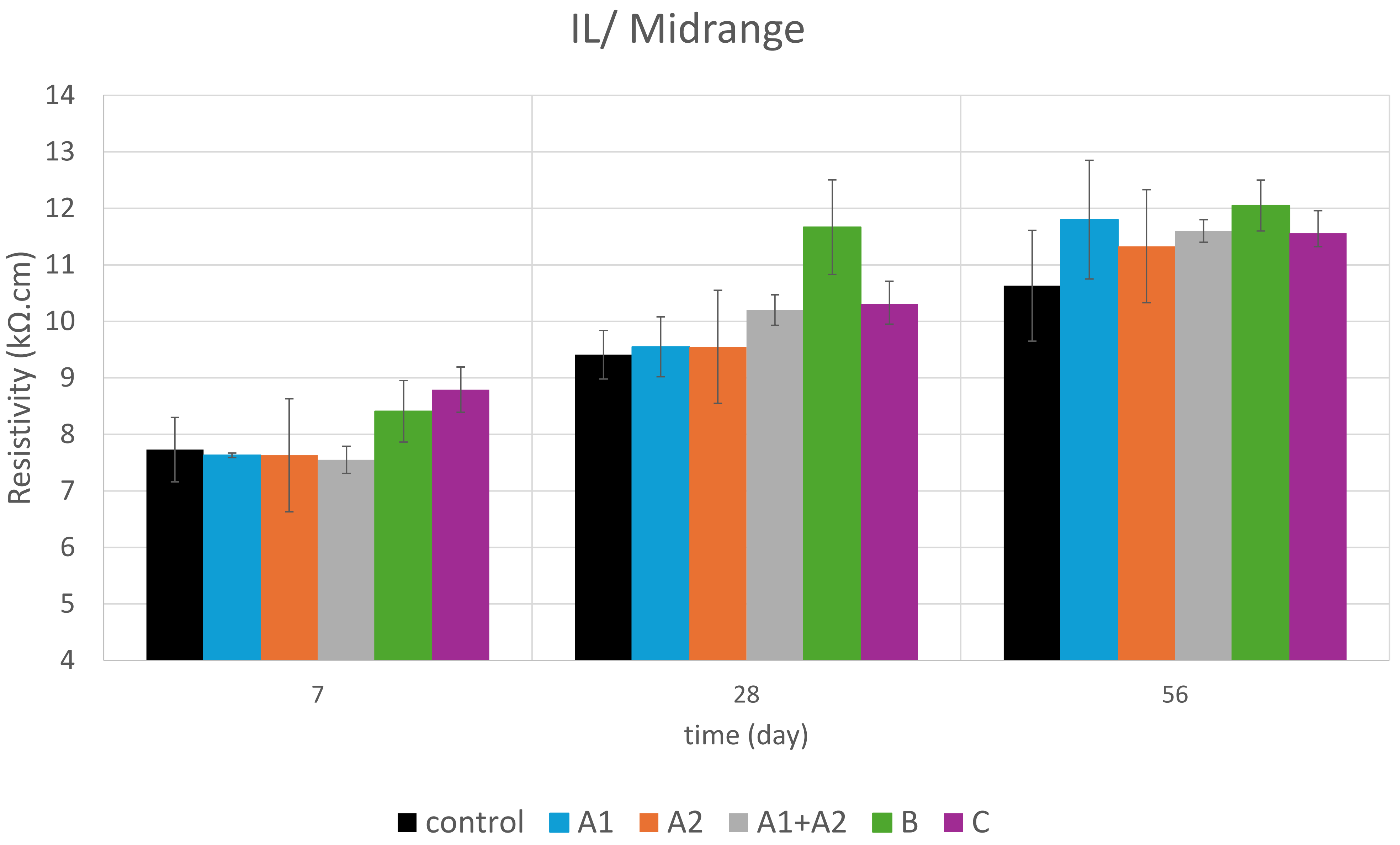
Resistivity measures how electrons flow.

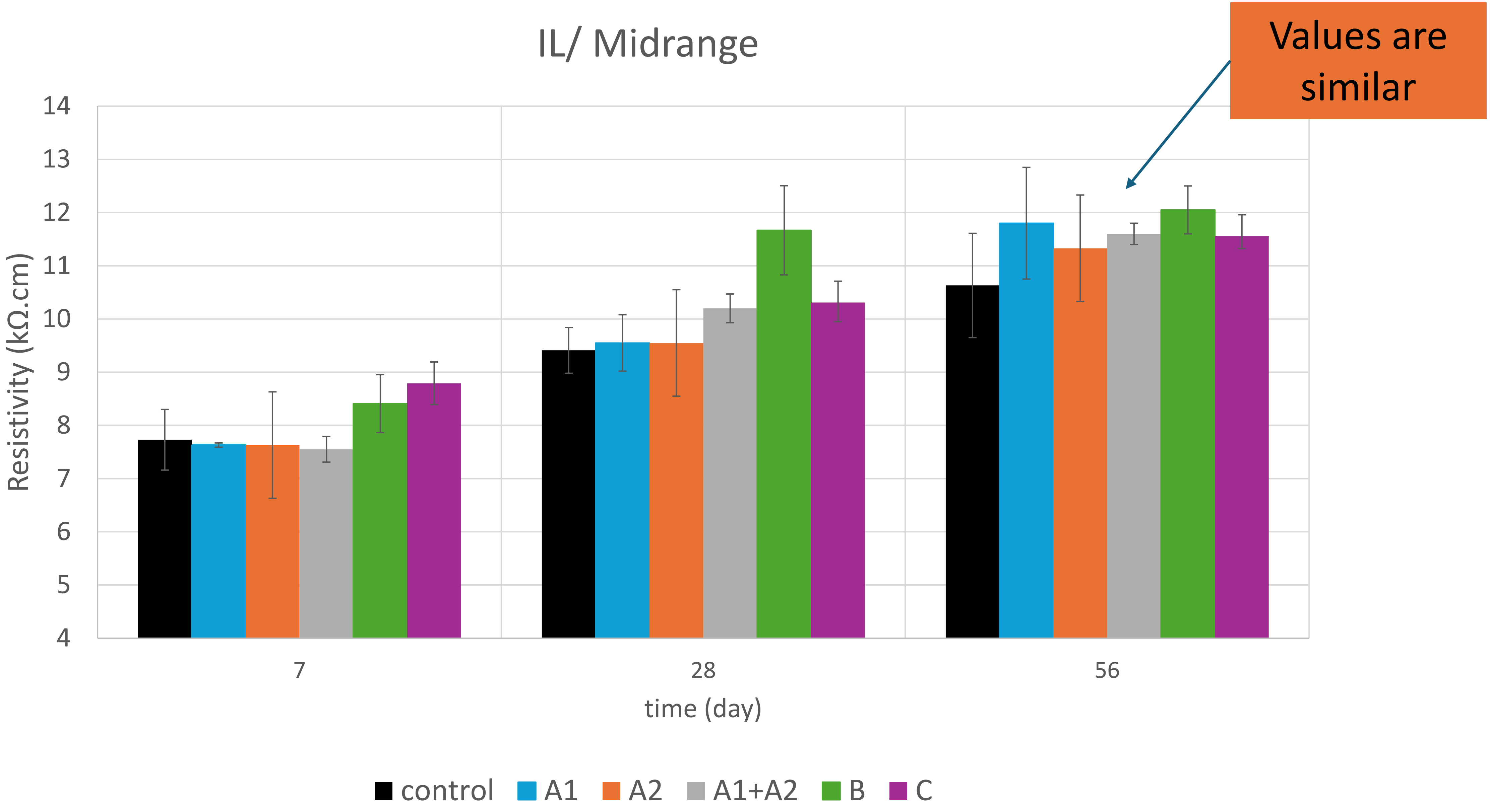
If an additive changes the chemistry of the pore solution, the resistivity may change but not the permeability.

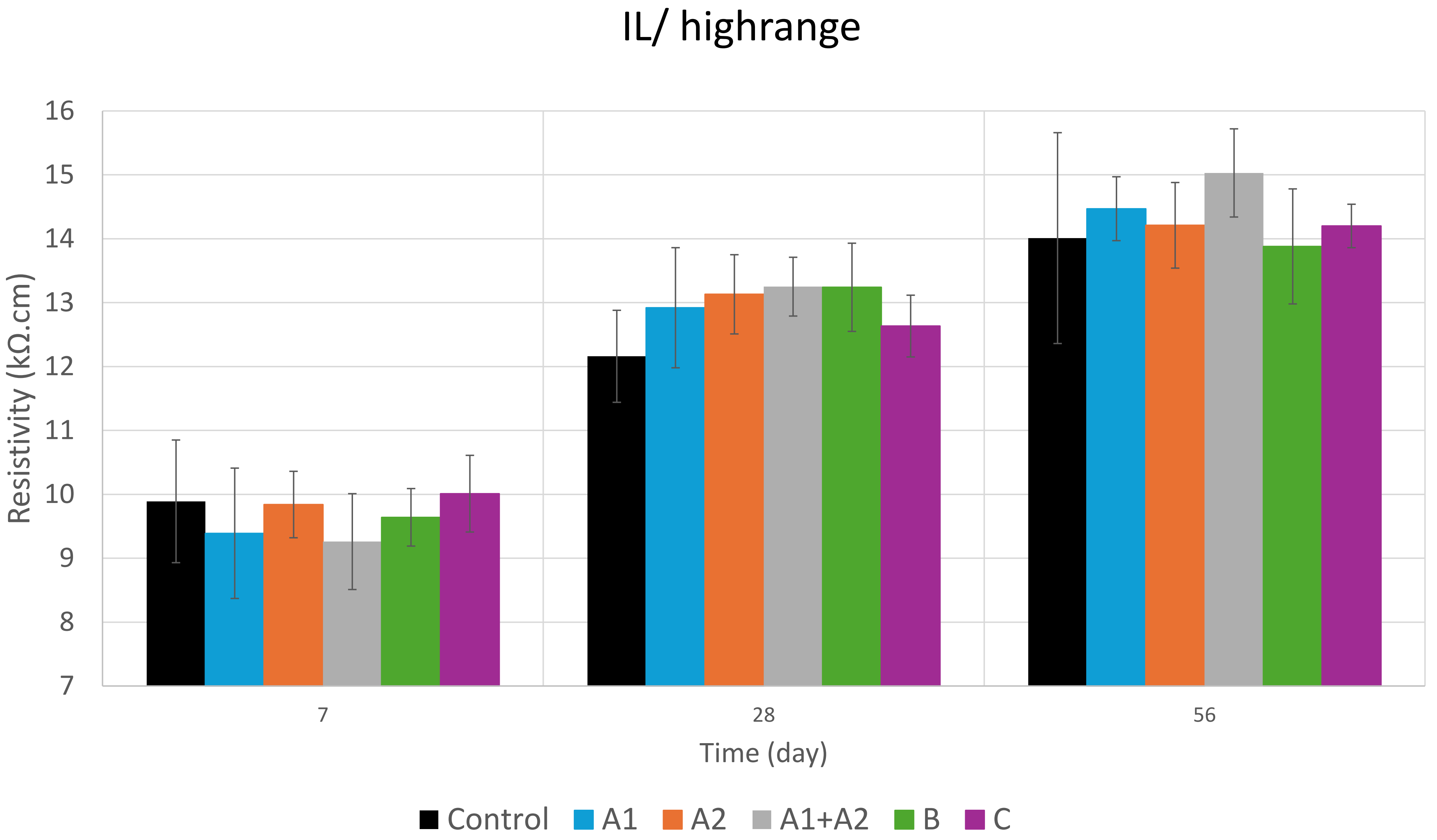
WARNING!

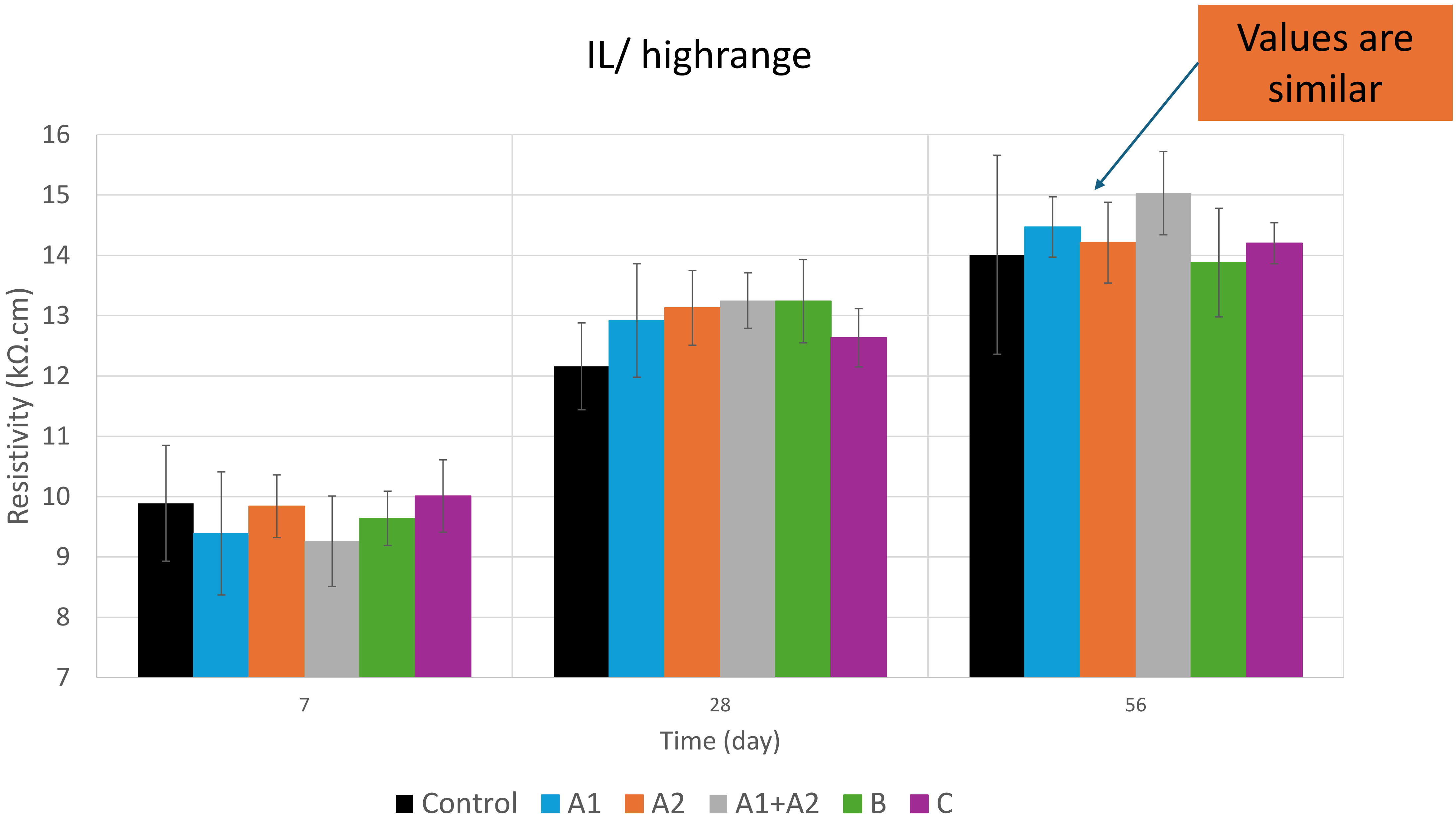
Resistivity $\neq$ Permeability

Sometimes resistivity and permeability agree and sometimes they do not. This depends on the combination of materials that you are using.


IL/ Midrange
Resistivity (kΩ.cm)
14
13
12
11
10
9
8
7
6
5
4
7
28
56
time (day)
control
A1
A2
A1+A2
B
C

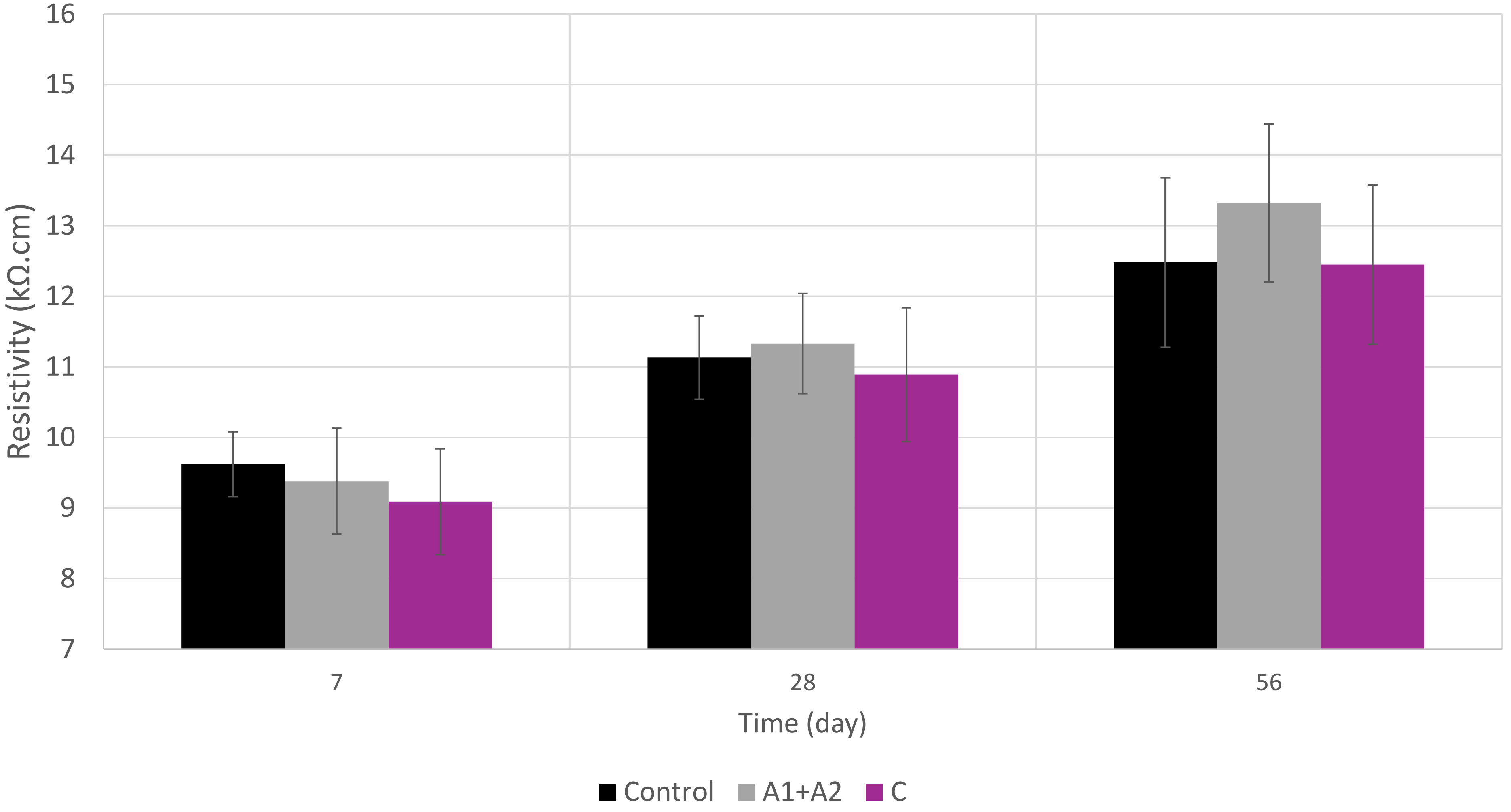

IL/ Midrange
Values are similar
Resistivity (kΩ.cm)
14
13
12
11
10
9
8
7
6
5
4
7
28
56
time (day)
control
A1
A2
A1+A2
B
C


IL/ highrange
Resistivity (kΩ.cm)
16
15
14
13
12
11
10
9
8
7
7
28
56
Time (day)
Control
A1
A2
A1+A2
B
C

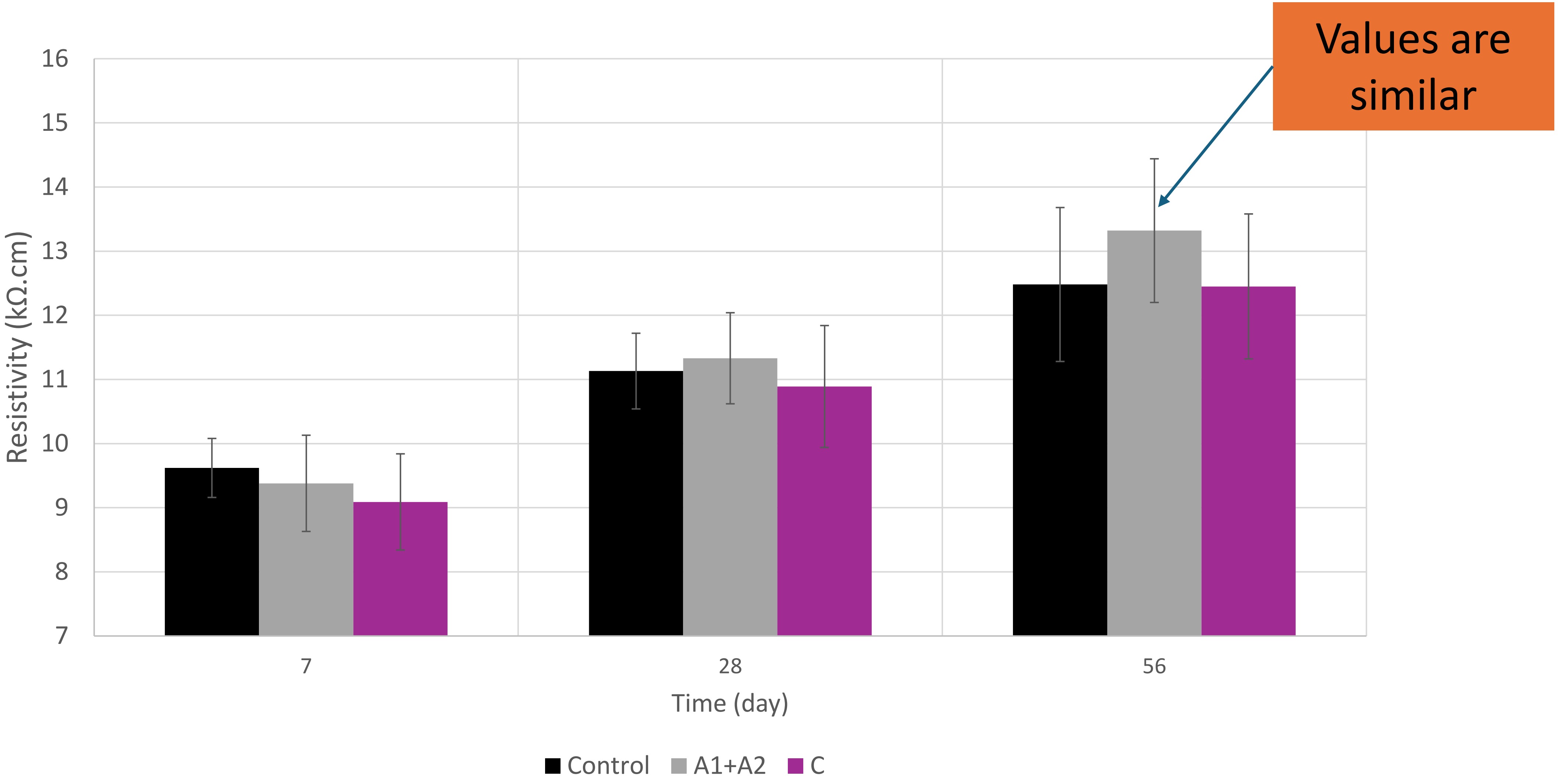


Values are similar
IL/ highrange
16
15
14
13
12
11
10
9
8
7
Resistivity (kΩ.cm)
7
28
56
Time (day)
Control
A1
A2
A1+A2
B
C

I/II Highrange



I/II Highrange



Discussion

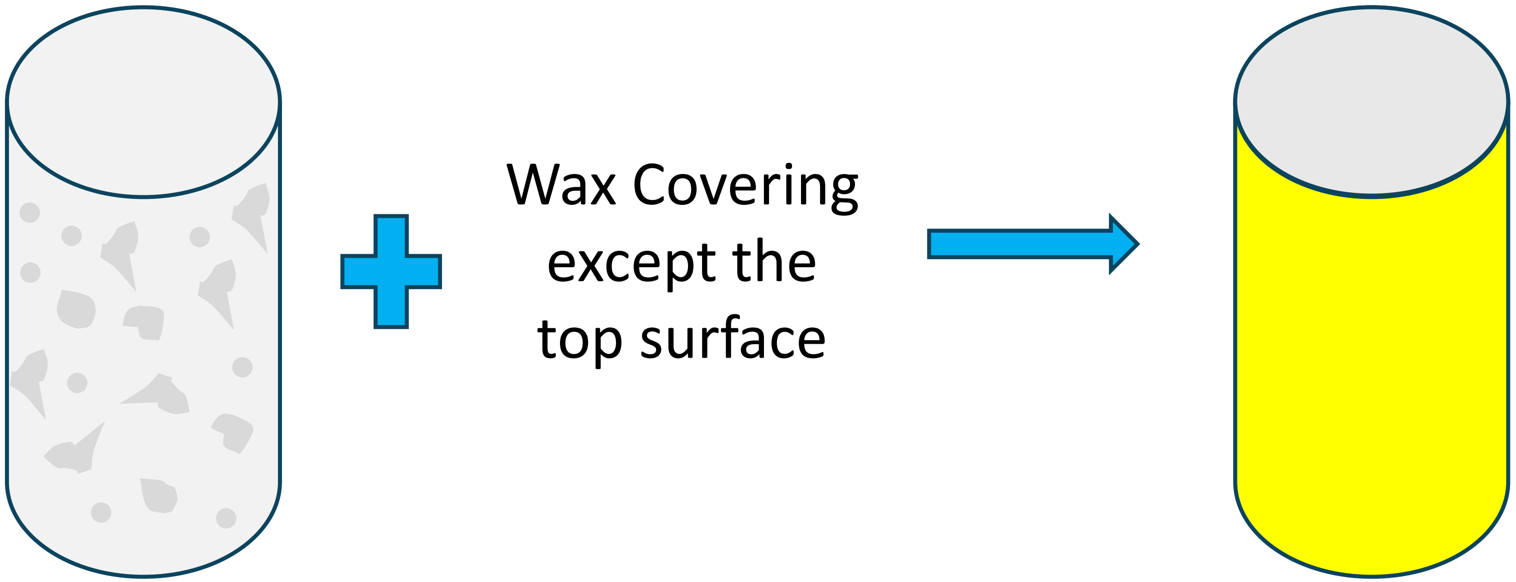
- There is minimal difference in the resistivity measurements of the control and the mixtures with colloidal silica.

Resistivity ≠ Permeability

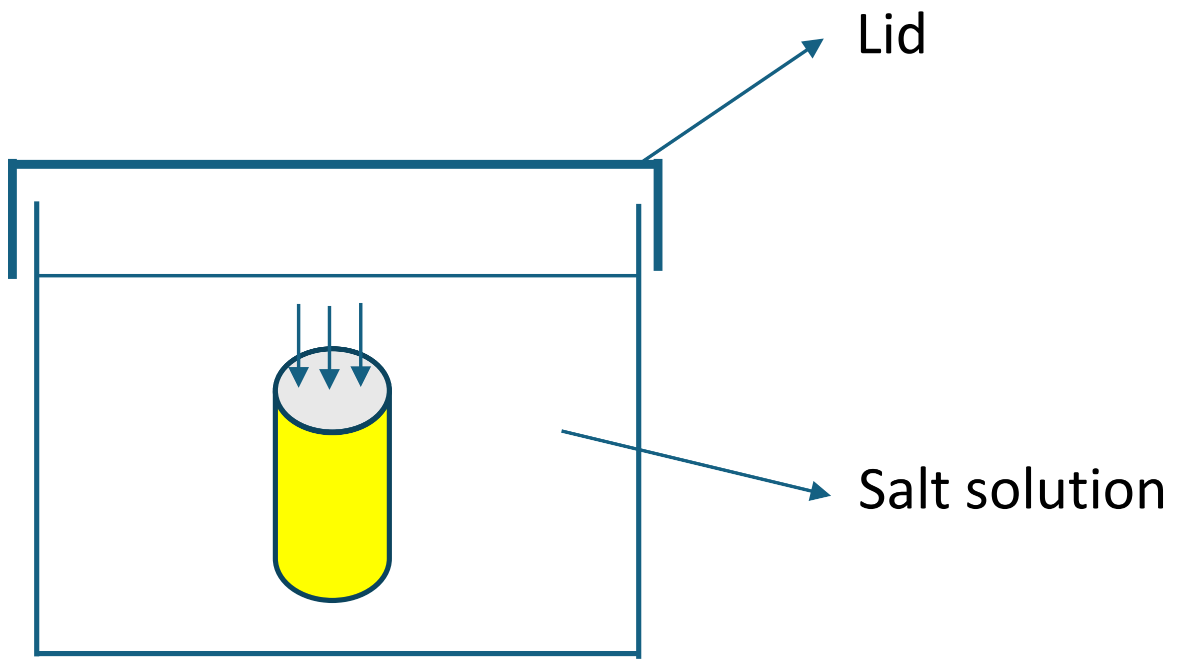
Permeability

We measured the permeability with a modified ASTM C1152.

Test setup



Test setup



The liquid penetrate just from top of the sample

Permeability

Next, you measure the concentration of salts in the concrete over the depth.

We do this with X-rays with no grinding.

You can also do this with grinding and titrations to the powder.

Permeability

Next, you measure the concentration of salts in the concrete over the depth.

We do this with X-rays with no grinding.

You can also do this with grinding.

Permeability

From this concentration you calculate a term called the diffusion coefficient.

The diffusion coefficient can be used to calculate the life of a concrete structure.

Permeability

This is more work than resistivity, but it tells you how the salts penetrate the concrete which is really what we need.

Remember!

Resistivity ≠ Permeability

Remember!

Resistivity ≠ Permeability

Permeability = Permeability

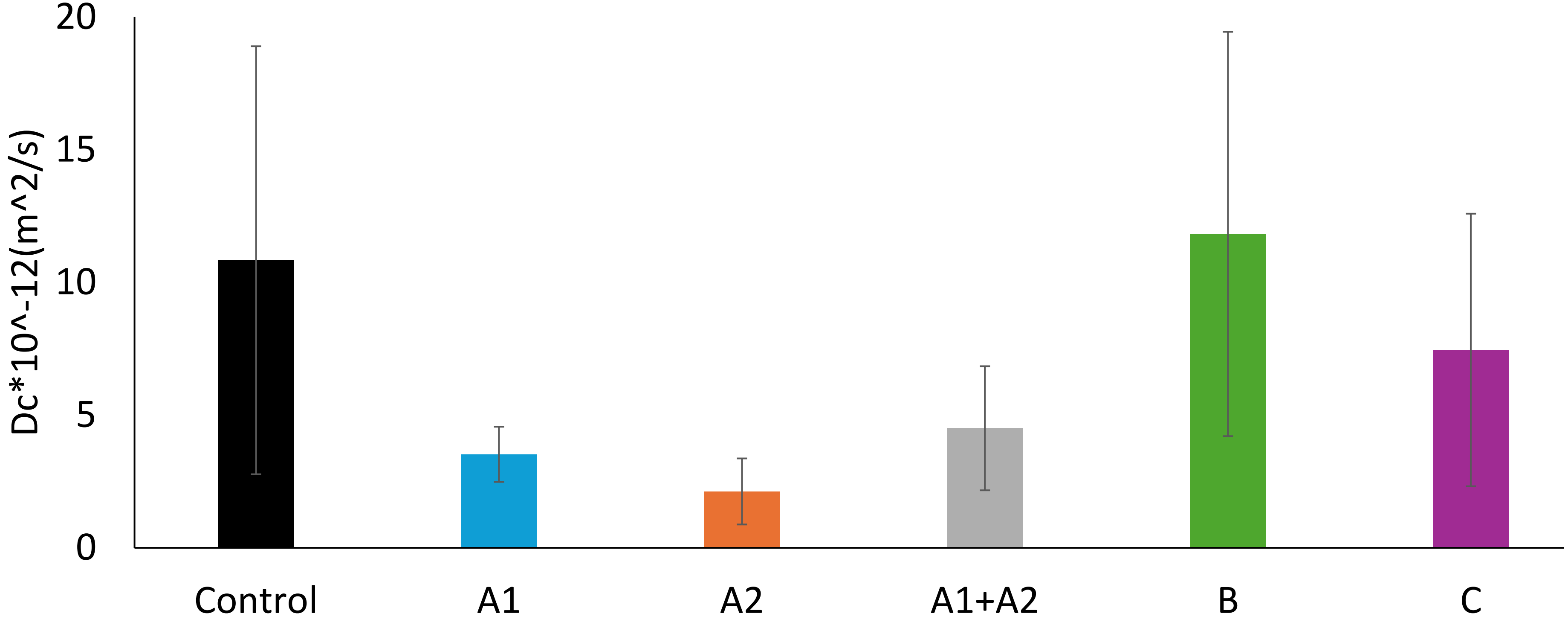
Curing

Concrete was cast in cylinders and sealed with a lid in a temperature controlled room for 130 d

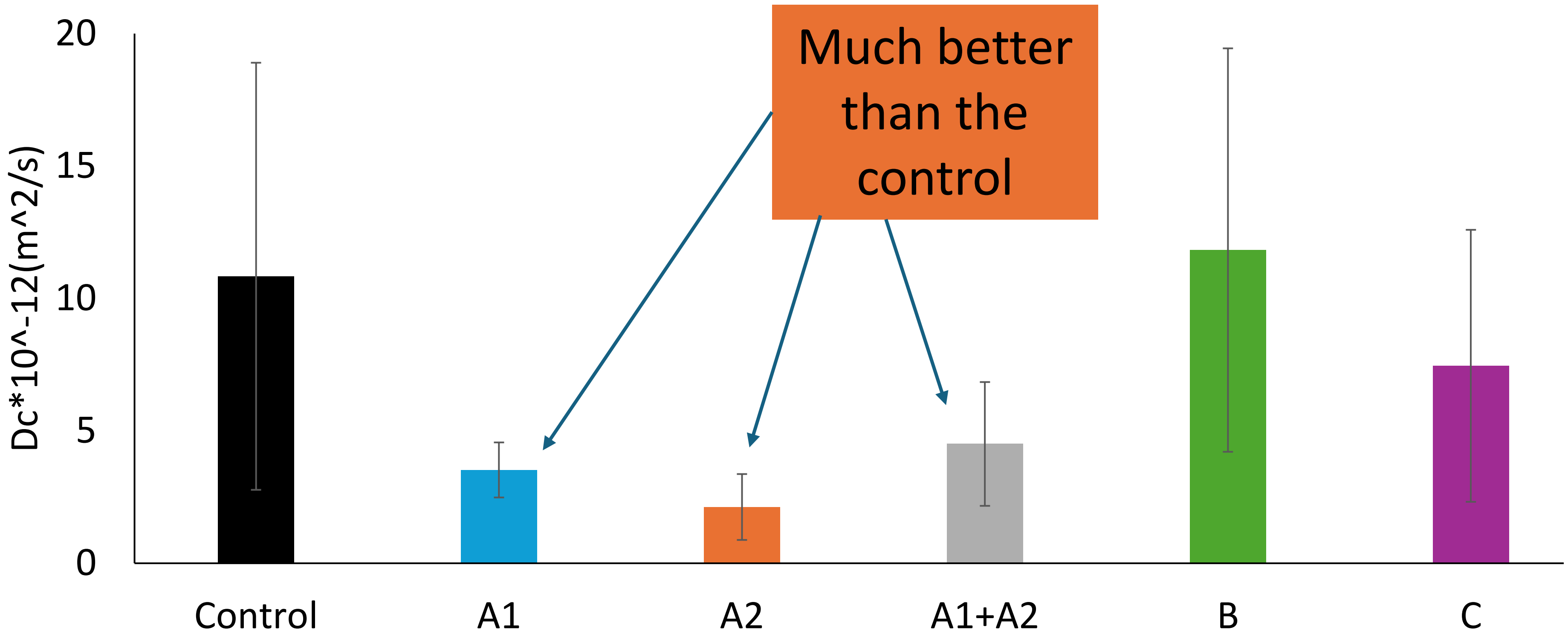
We stored the samples in molds to be consistent

We also did this to give the materials a long time to react

1L/ Mid-Range

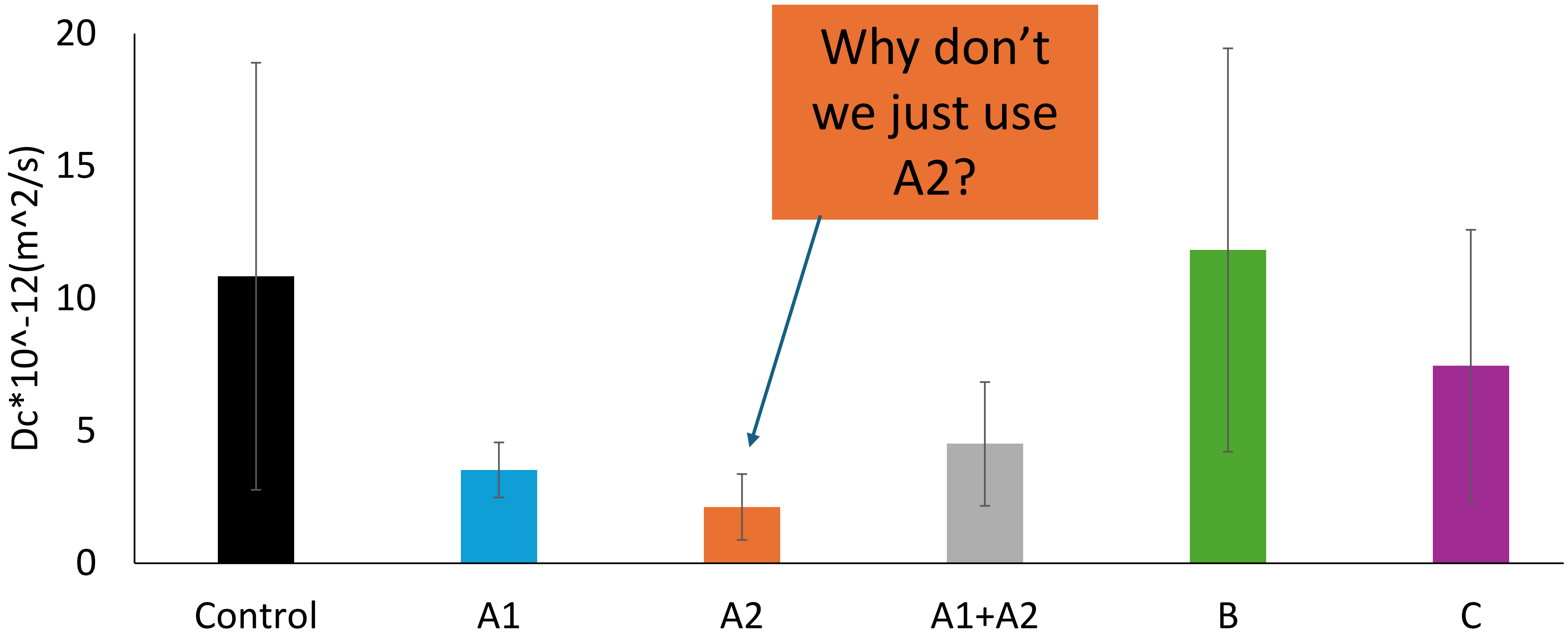


1L/ Mid-Range



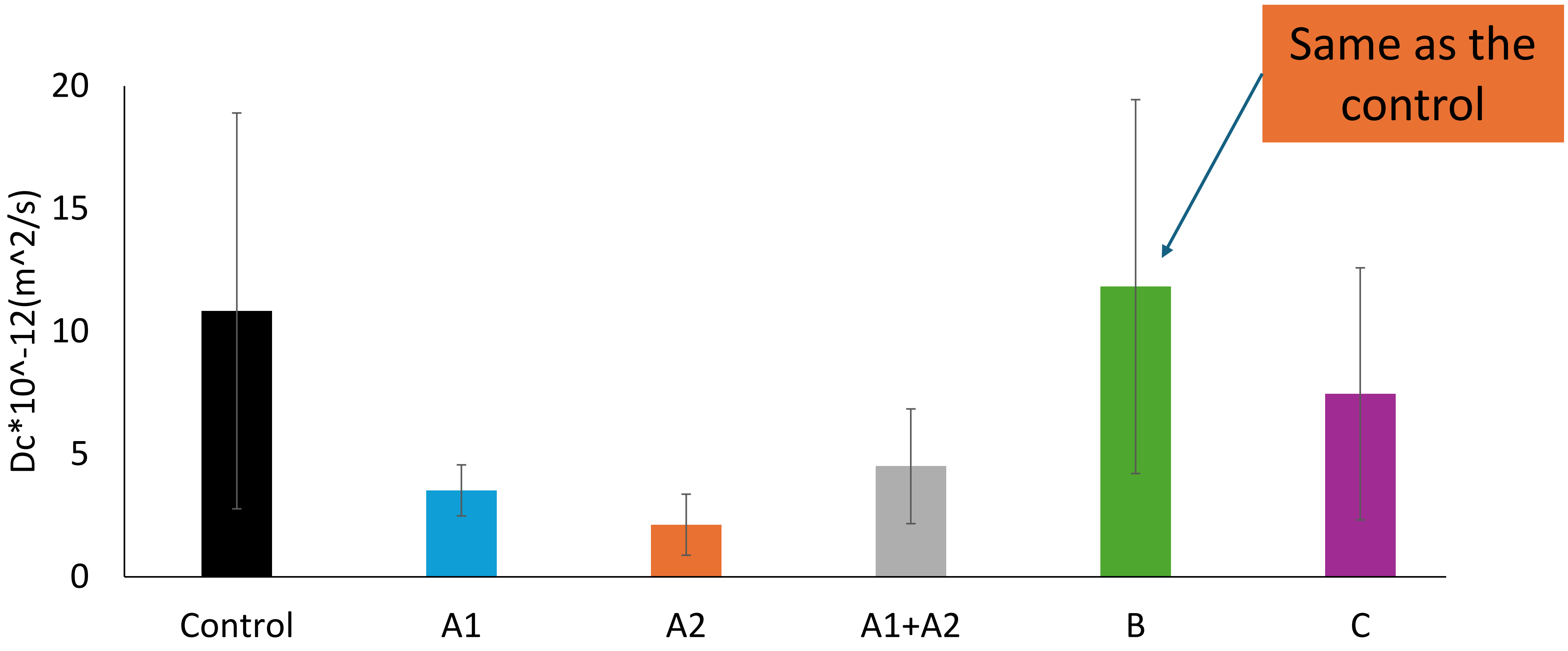
Much better than the control
20
15
10
5
0
Dc*10^-12(m^2/s)
Control
A1
A2
A1+A2
B
C

1L/ Mid-Range



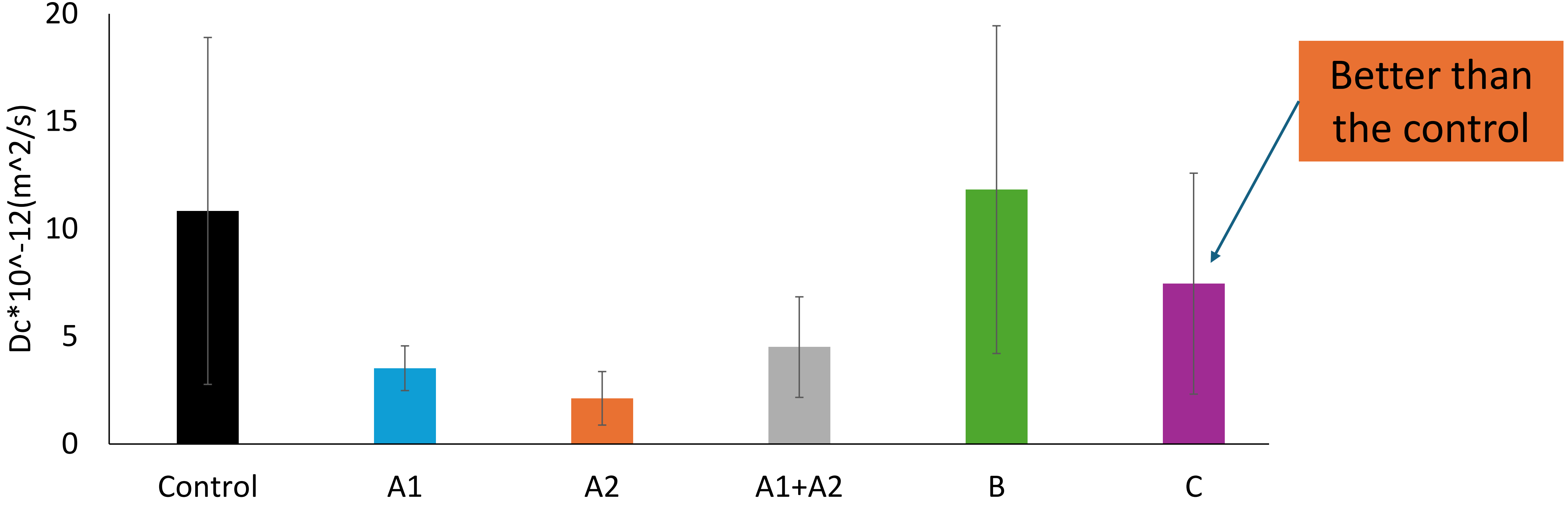
Why don't we just use A2?
Dc*10^-12(m^2/s)
20
15
10
5
0
Control
A1
A2
A1+A2
B
C

1L/ Mid-Range



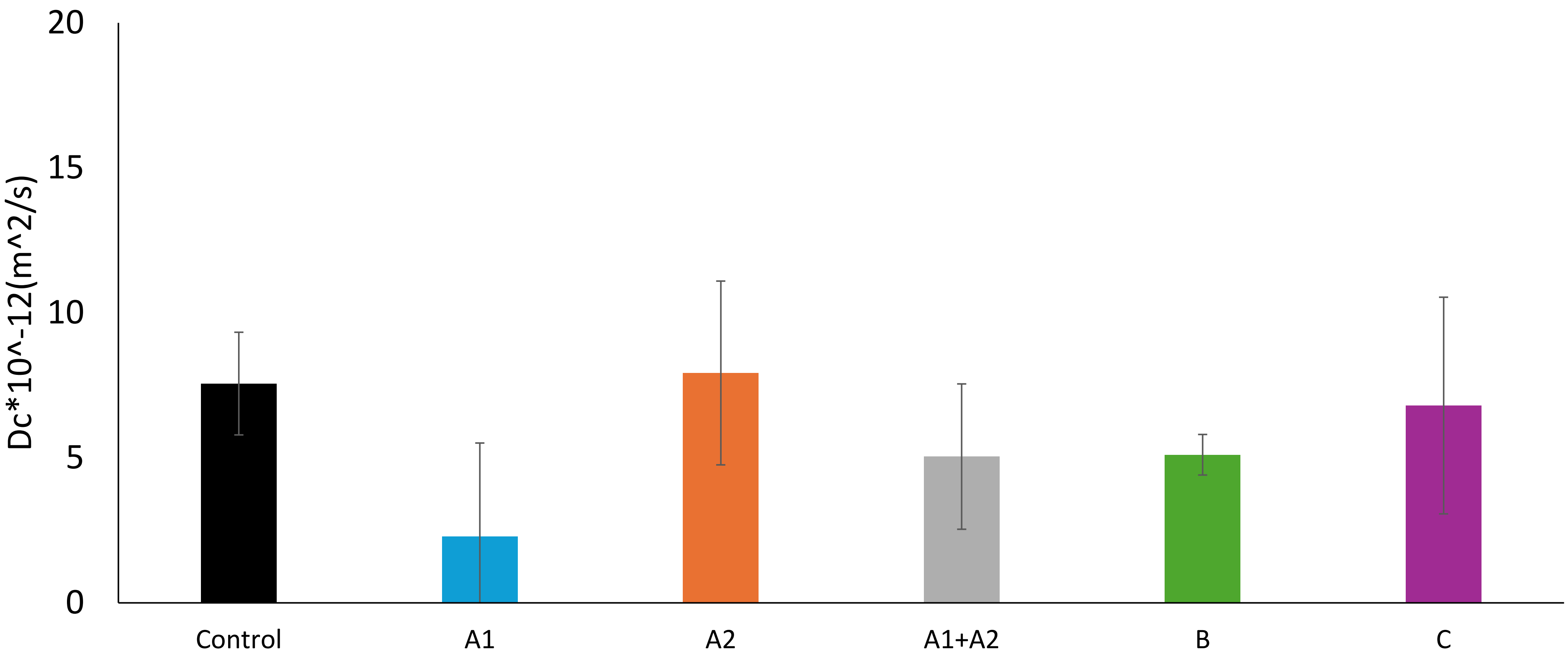
Same as the control
Dc*10^-12(m^2/s)
20
15
10
5
0
Control
A1
A2
A1+A2
B
C

1L/ Mid-Range

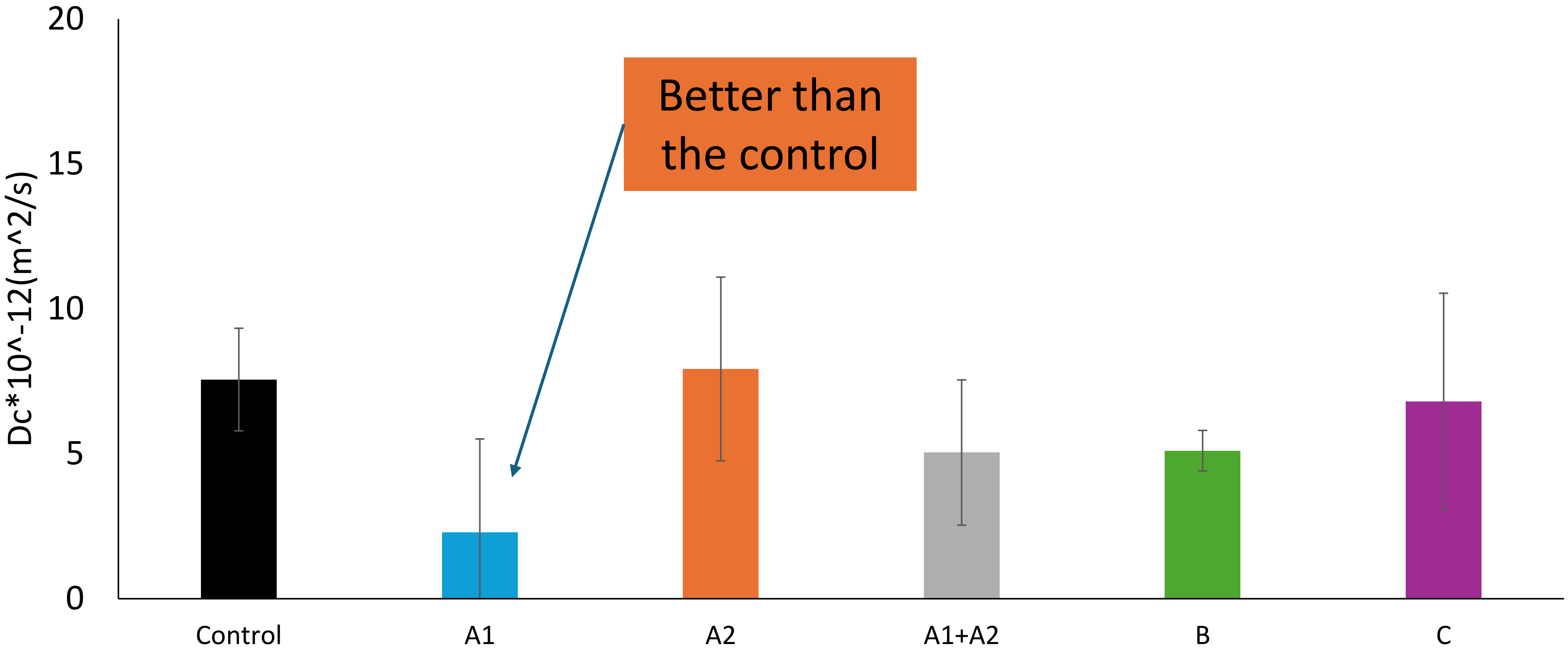


20
15
10
5
0
Dc*10^-12(m^2/s)
Control
A1
A2
A1+A2
B
C
Better than the control

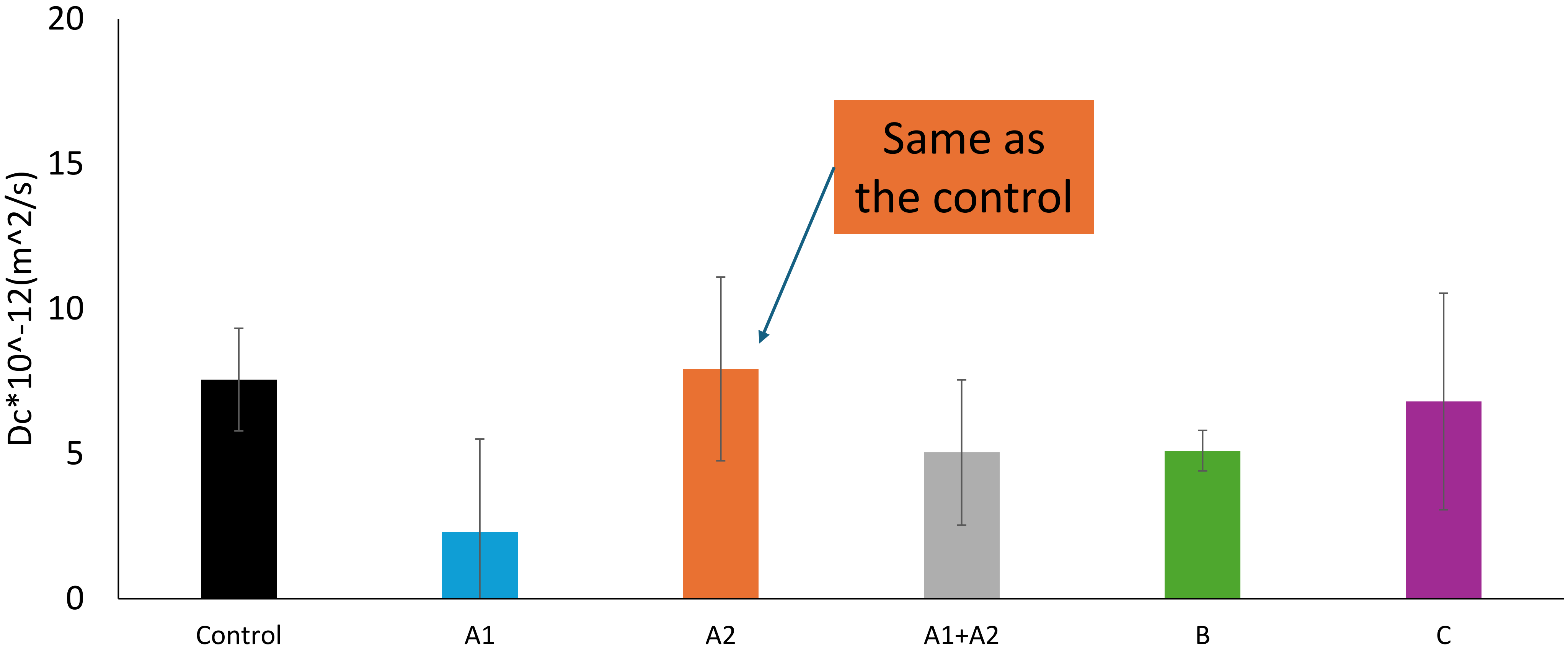
1L / Highrange



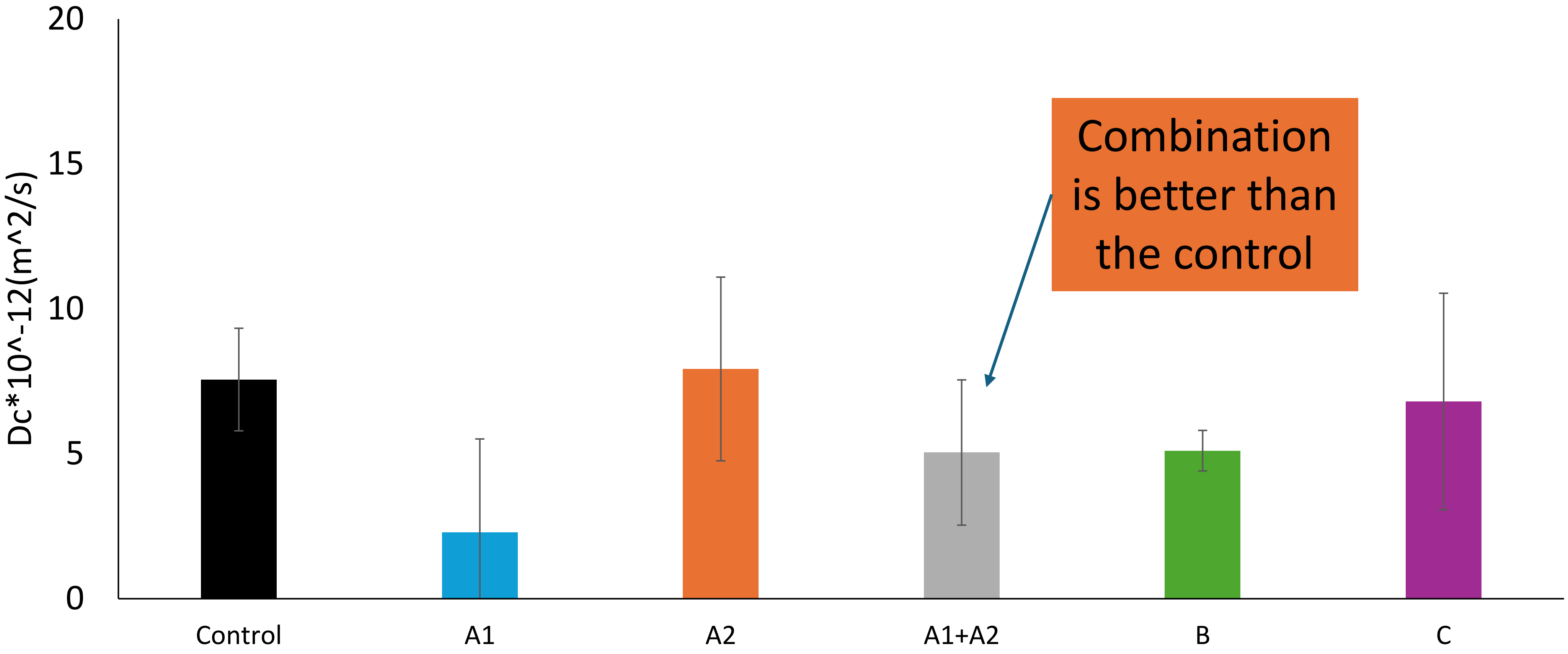
1L / Highrange



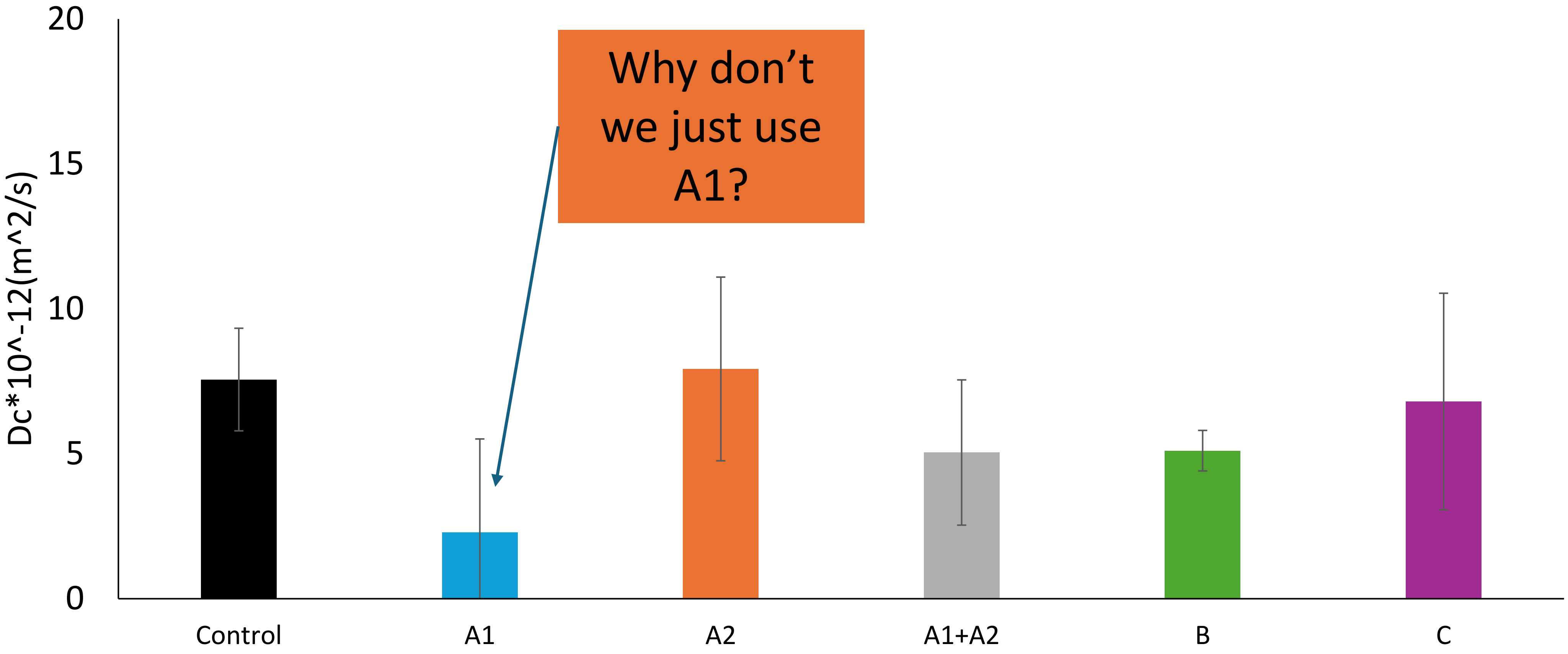
1L / Highrange



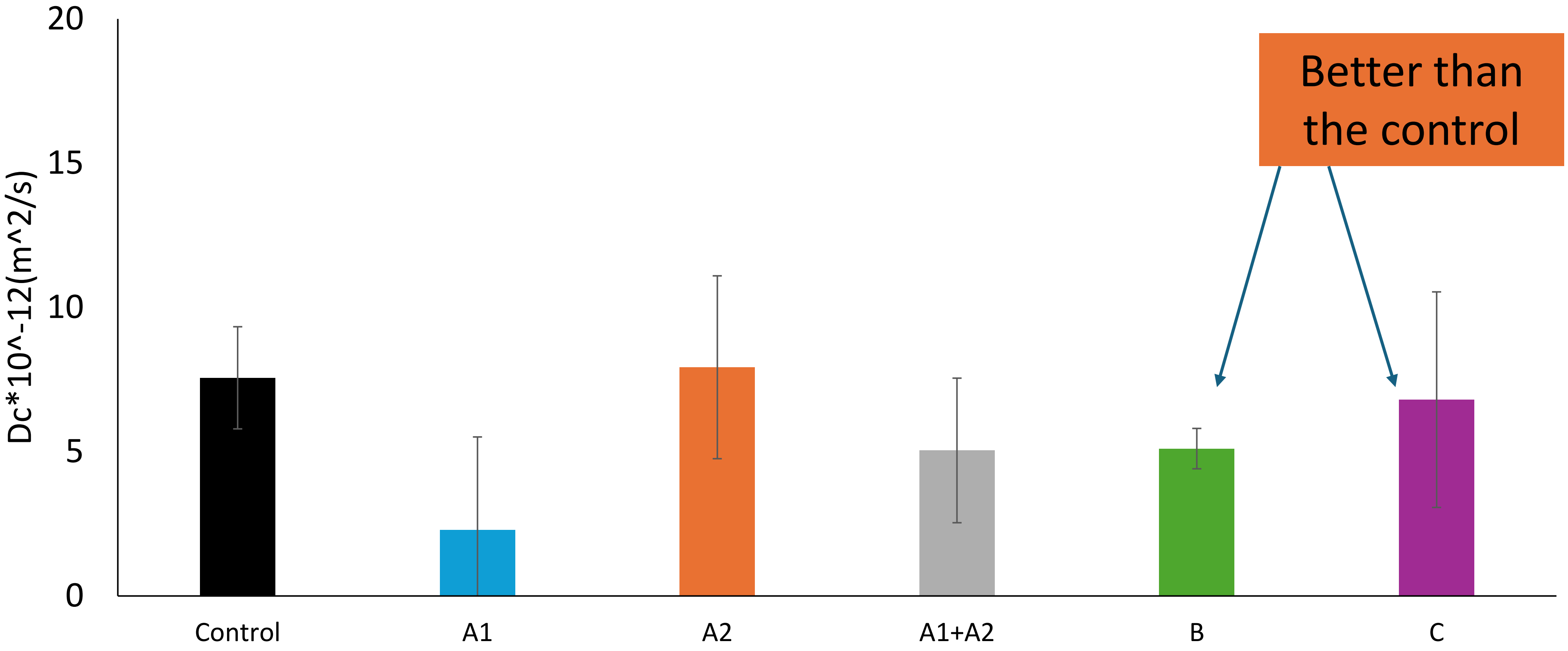
1L / Highrange



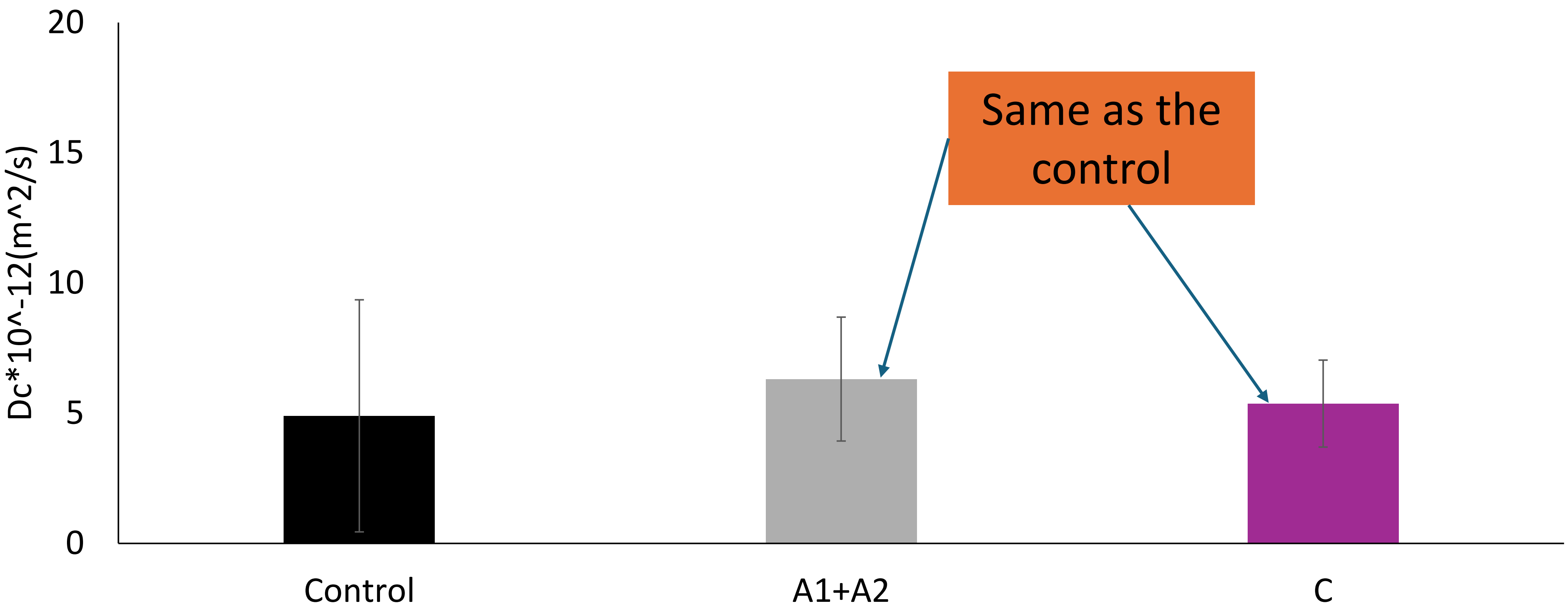
1L / Highrange



1L / Highrange



I/II Highrange



Discussion

- We get different results with commercial colloidal silicas depending on the combination of the cement and the water reducer used.

- Sometimes there is no improvement.

- Sometimes there is significant improvement.

Discussion

When a product has variable performance, it is hard to rely on the performance.

Shrinkage

ASTM C 157 - A strain gauge was cast in a shrinkage beam

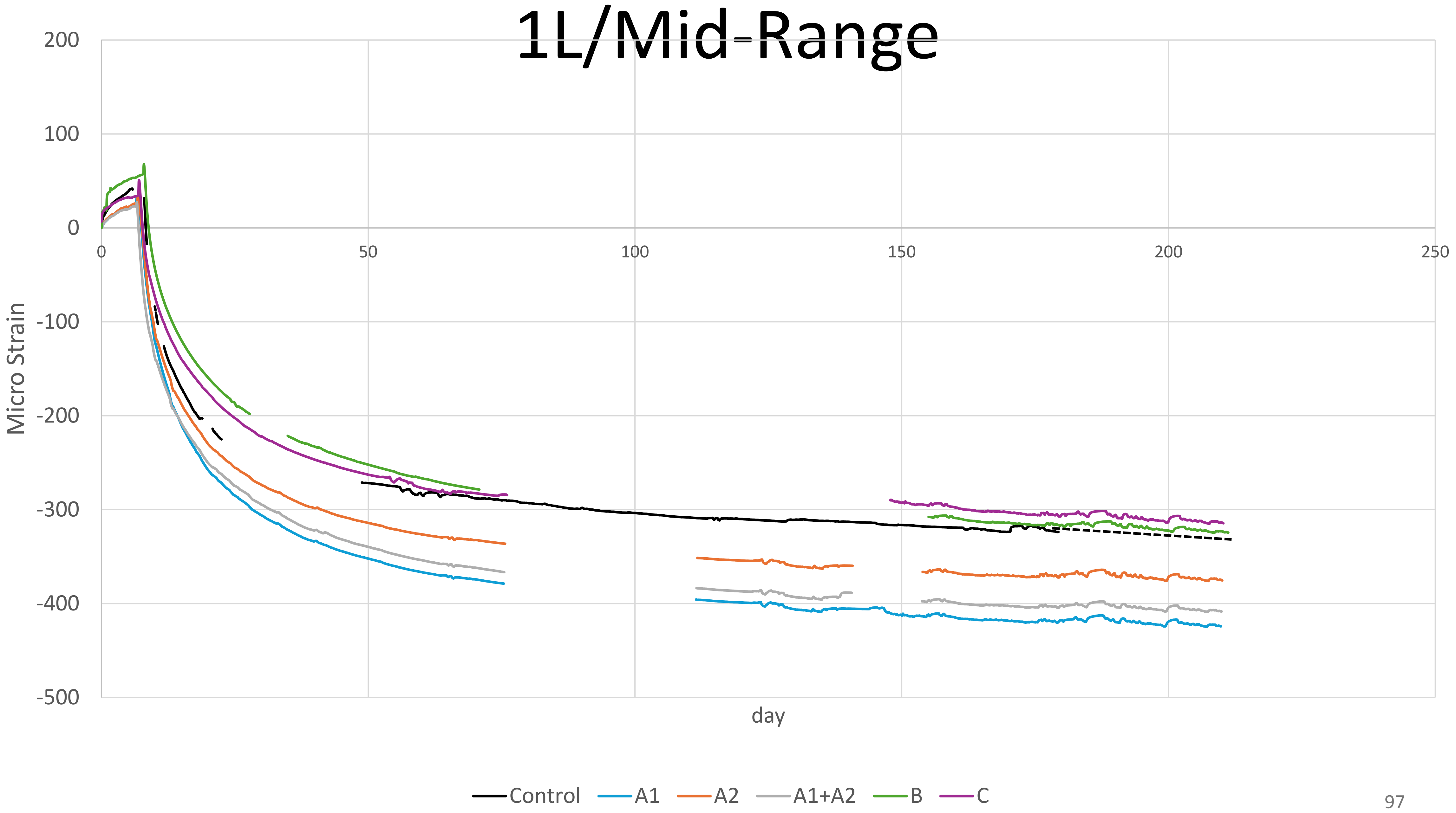
This allows a continuous measurement of the strain over the life of the concrete.

Concrete was wet cured for 7 days and then stored in 50% relative humidity and 73^{o}F.

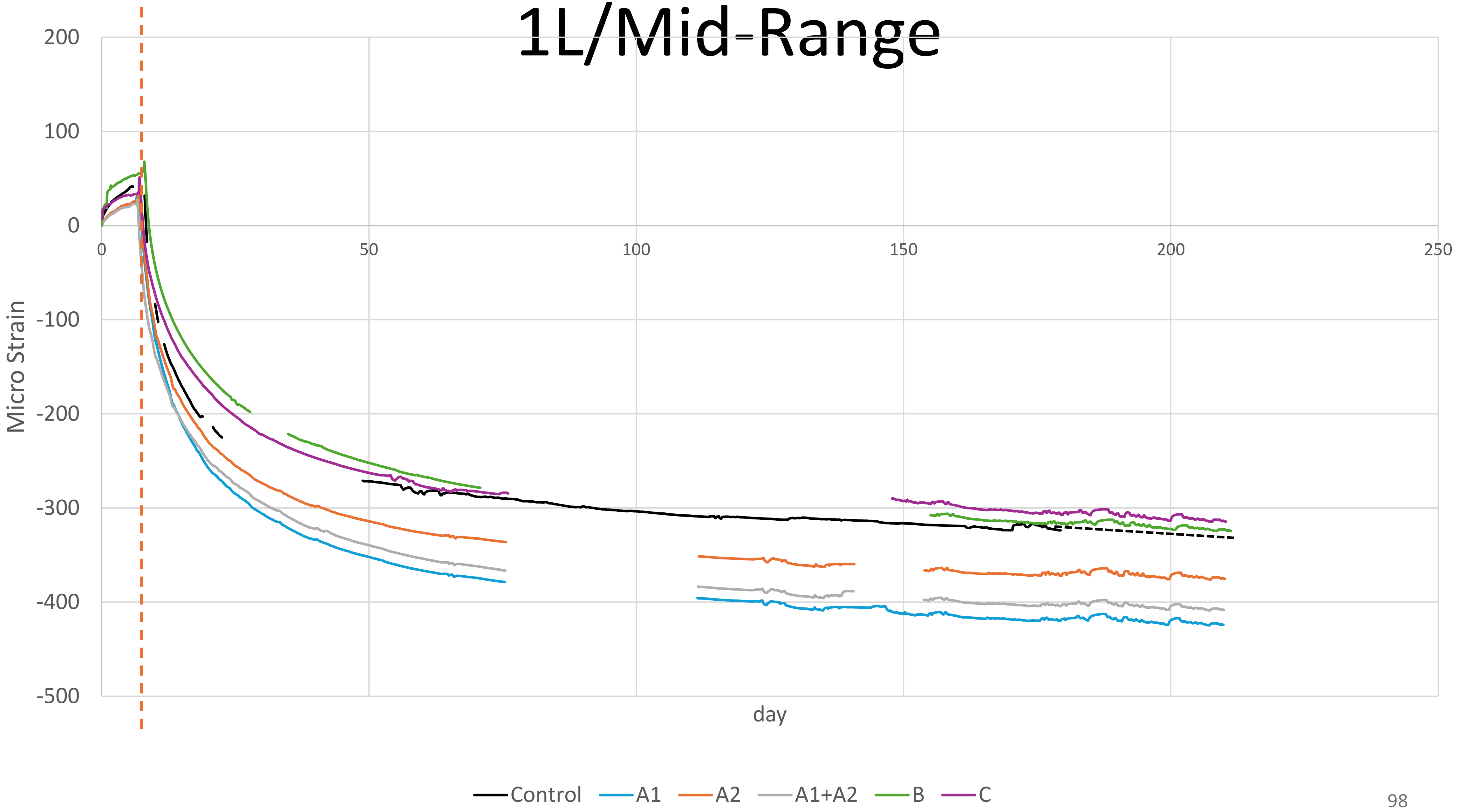
Shrinkage

Concrete was wet cured for 7 days and then stored in 50% relative humidity and 73^{o}F.

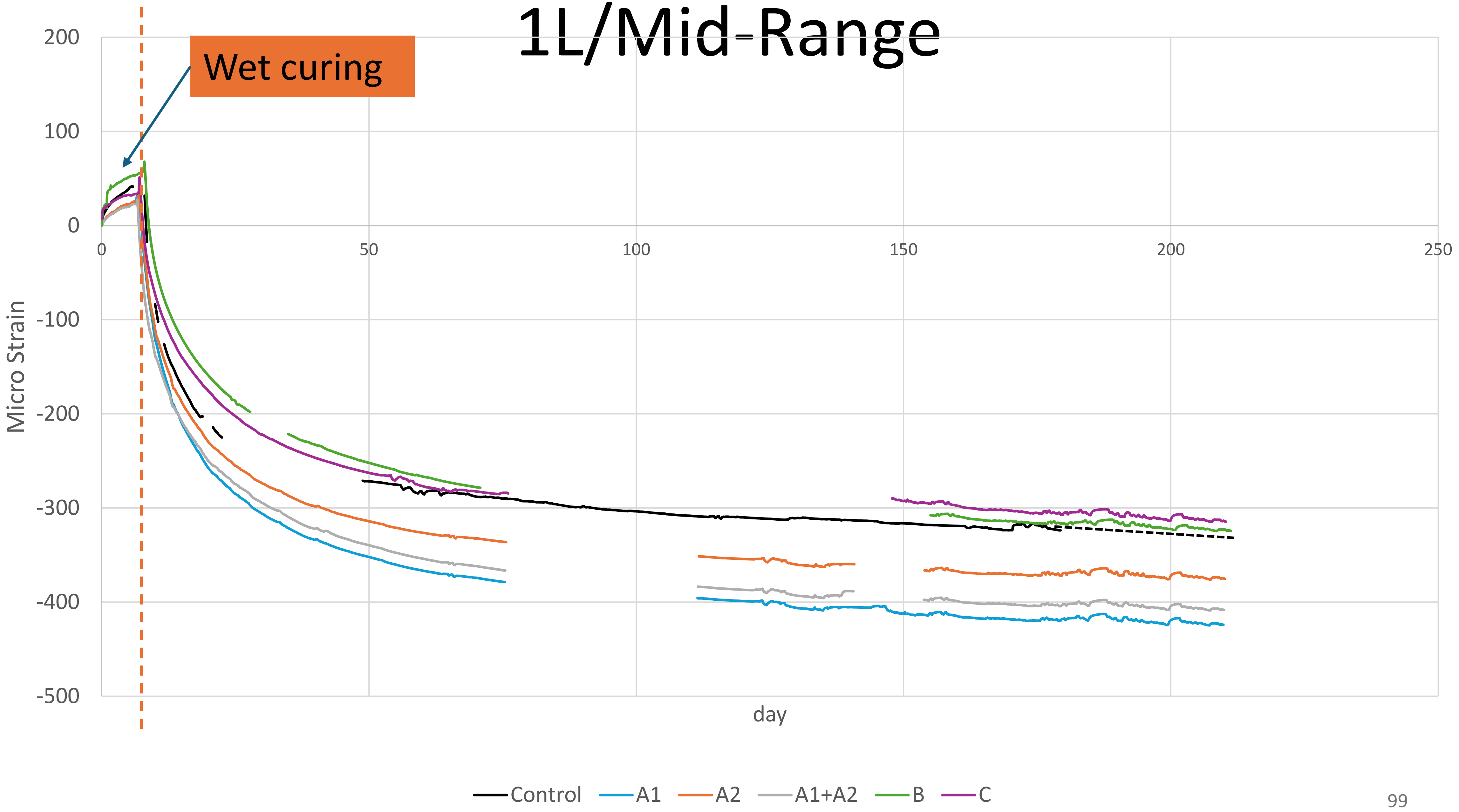
We only had funds to do this with the 1L / midrange


1L/Mid-Range
200
100
0
-100
-200
-300
-400
-500
Micro Strain
0
50
100
150
200
250
day
Control
A1
A2
A1+A2
B
C

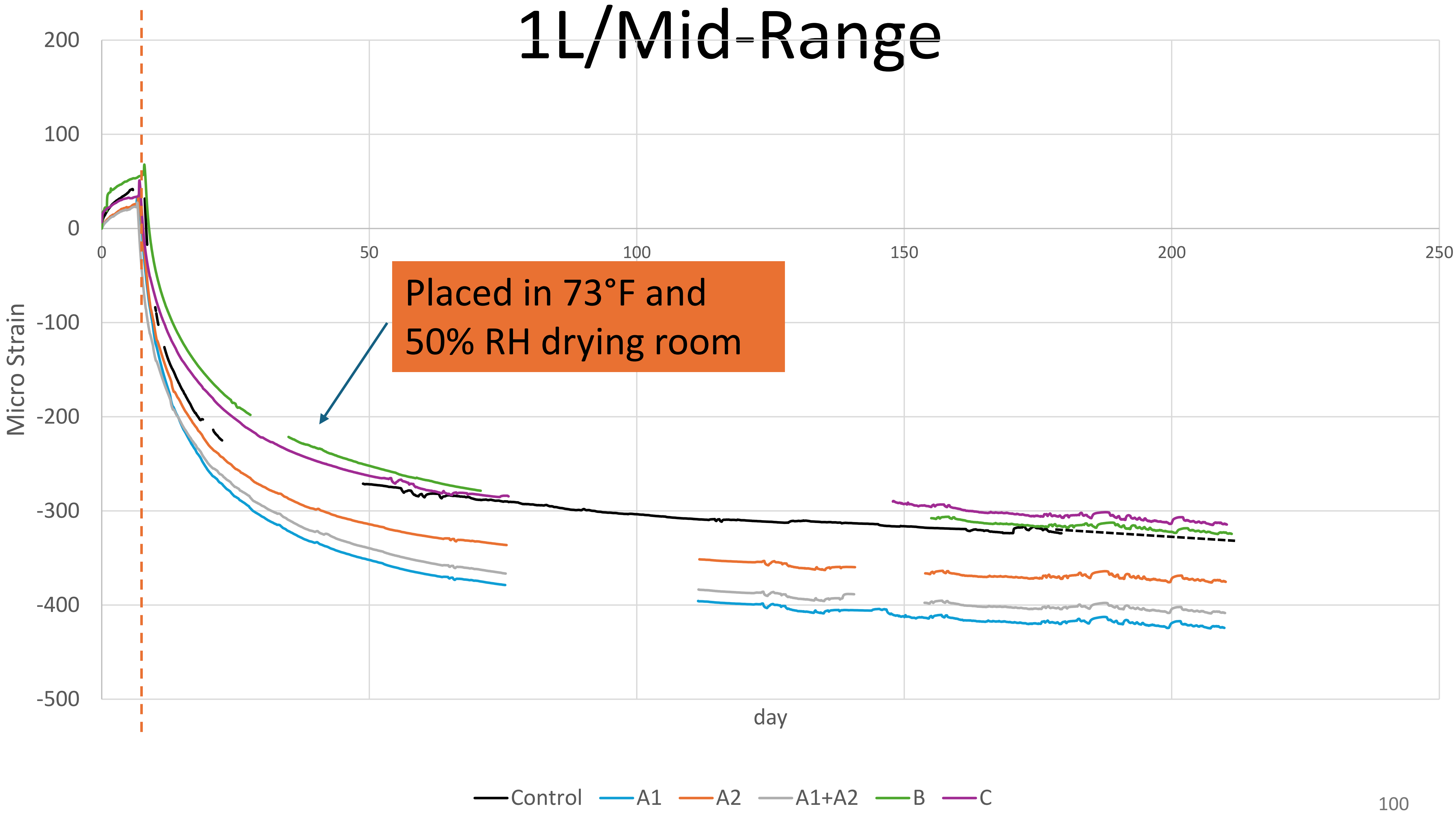
1L/Mid-Range


200
100
0
-100
-200
-300
-400
-500
Micro Strain
0
50
100
150
200
250
day
Control
A1
A2
A1+A2
B
C

1L/Mid-Range

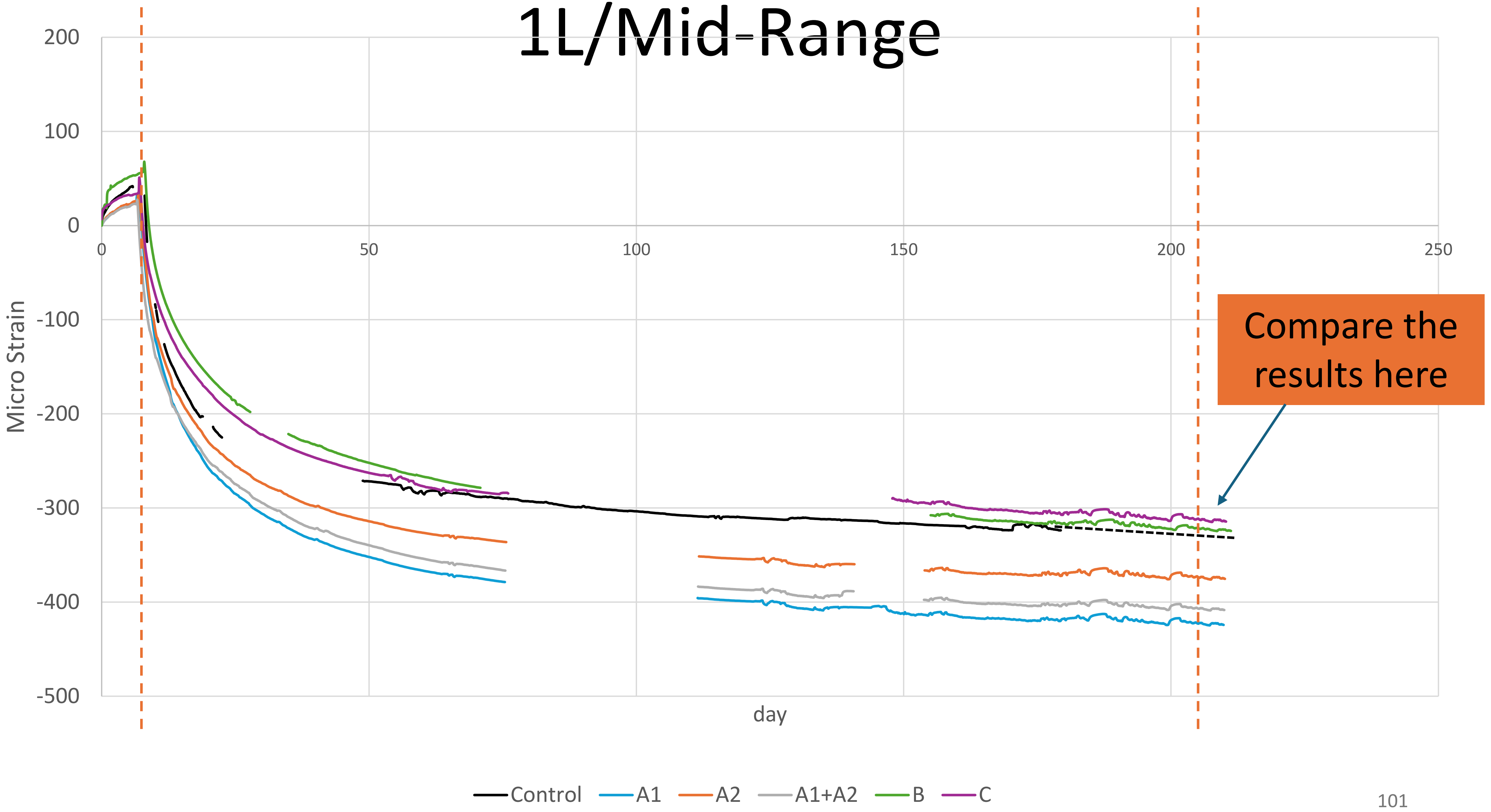


Wet curing
Micro Strain
200
100
0
-100
-200
-300
-400
-500
0
50
100
150
200
250
day
Control
A1
A2
A1+A2
B
C



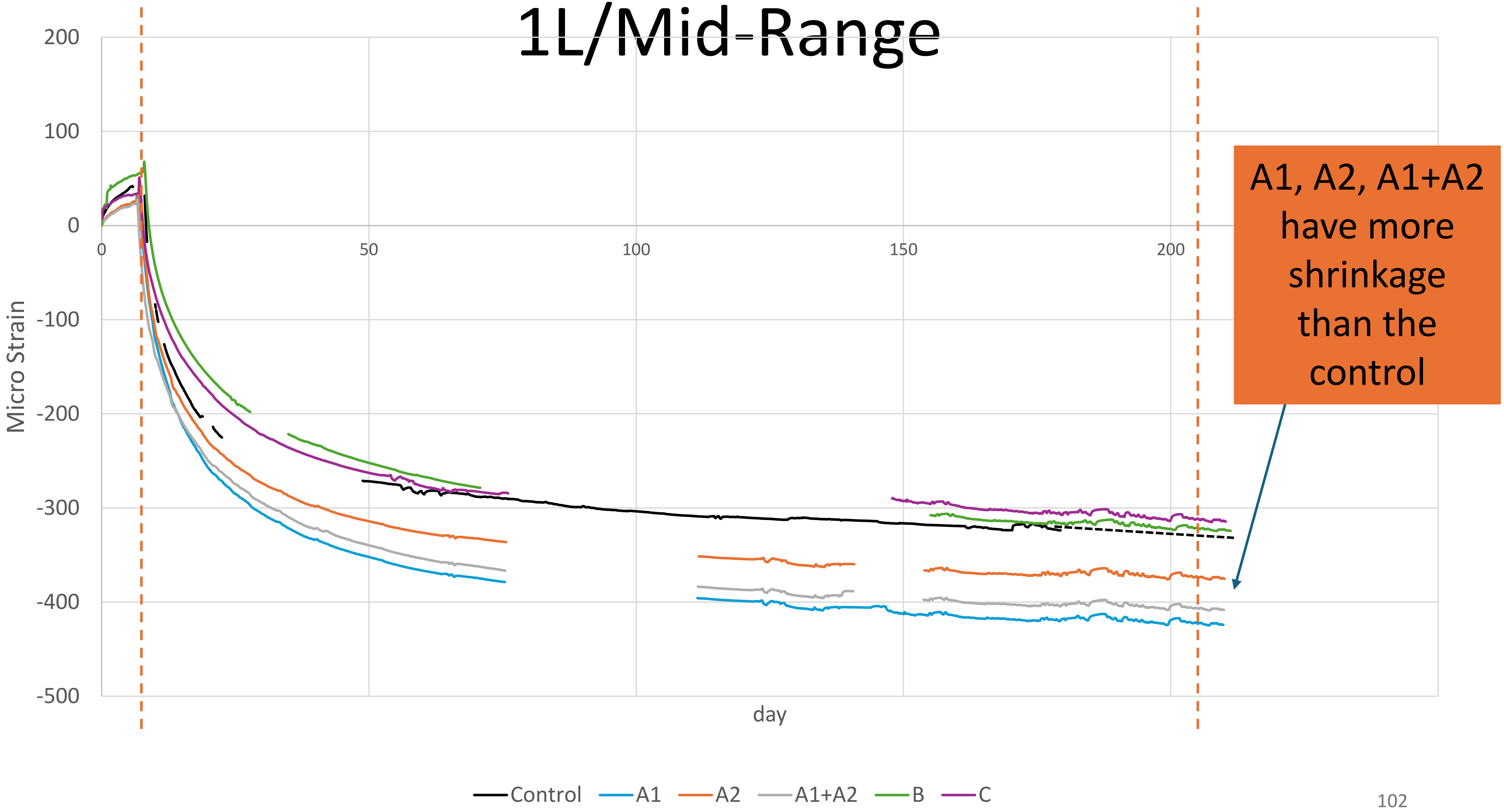
1L/Mid-Range
Micro Strain
200
100
0
-100
-200
-300
-400
-500
0
50
100
150
200
250
day
Placed in 73°F and
50% RH drying room
Control
A1
A2
A1+A2
B
C

1L/Mid-Range



200
100
0
-100
-200
-300
-400
-500
Micro Strain
0
50
100
150
200
250
day
Compare the results here
Control
A1
A2
A1+A2
B
C

1L/Mid-Range



200
100
0
-100
-200
-300
-400
-500
Micro Strain
0
50
100
150
200
day
Control
A1
A2
A1+A2
B
C
A1, A2, A1+A2 have more shrinkage than the control

Mix	Shrinkage Strain at 250 days (microstrain)	Percent difference compared to the control
Control	-340.9	
A1	-440.8	29
A2	-388.6	14
A1+A2	-425.4	25
B	-333.9	-2
C	-315.5	-7

Mix	Shrinkage Strain at 250 days (microstrain)	Percent difference compared to the control
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A1+A2 have 25% more shrinkage than the control.

Mix	Shrinkage Strain at 250 days (microstrain)	Percent difference compared to the control
Control	-340.9	
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A2	-388.6	14
A1+A2	-425.4	25
B	-333.9	-2
C	-315.5	-7

A1+A2 have 25% more shrinkage than the control.

This could lead to increased cracking in the field. **(Remember this for the field project)**

Discussion

A1, A2, A1+A2 showed an increase in shrinkage of the concrete.

B and C had minimal impact on the shrinkage.

Bridge Deck Construction

Three span bridge on Hwy 94 near Guymon, Oklahoma

This is a hot and dry environment

Bridge Deck Construction

Span 1 – Light weight aggregate

Span 2 – Control

Span 3 – Colloidal Silica (A1 + A2)

Bridge Deck Construction

The 1L / midrange mixture was used for the colloidal silica mixture

A technical rep for the colloidal silica was on site for the construction.

All spans were wet cured.

Bridge Deck Survey

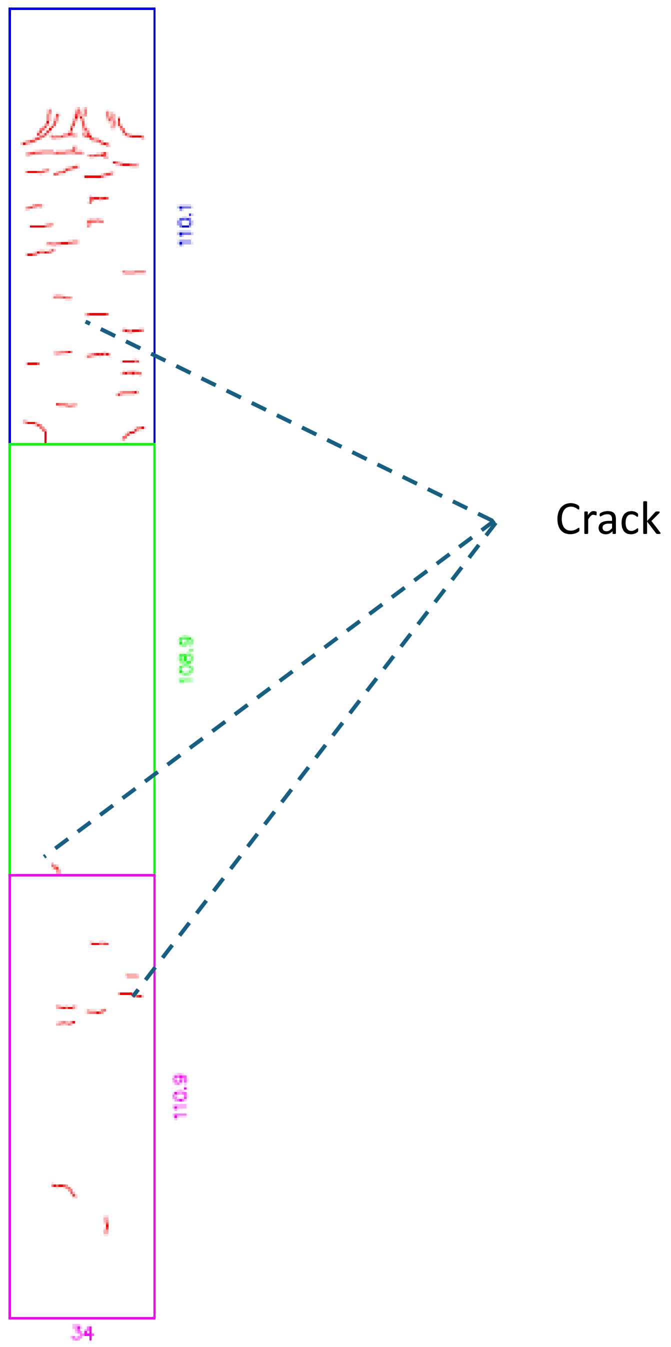
A crack survey was done 120 days after casting.

A drone survey was used to capture the length and location of cracks > 0.02”.

Span 3
Colloidal Silica
A1 + A2

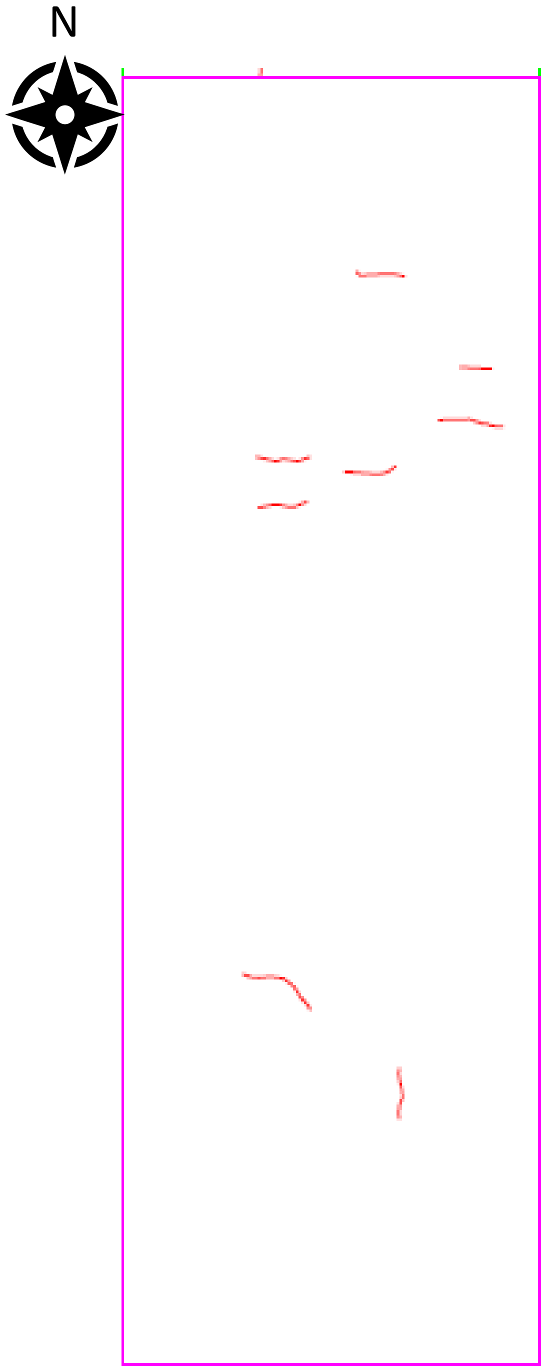
Span 2
Control

Span 1
LWA



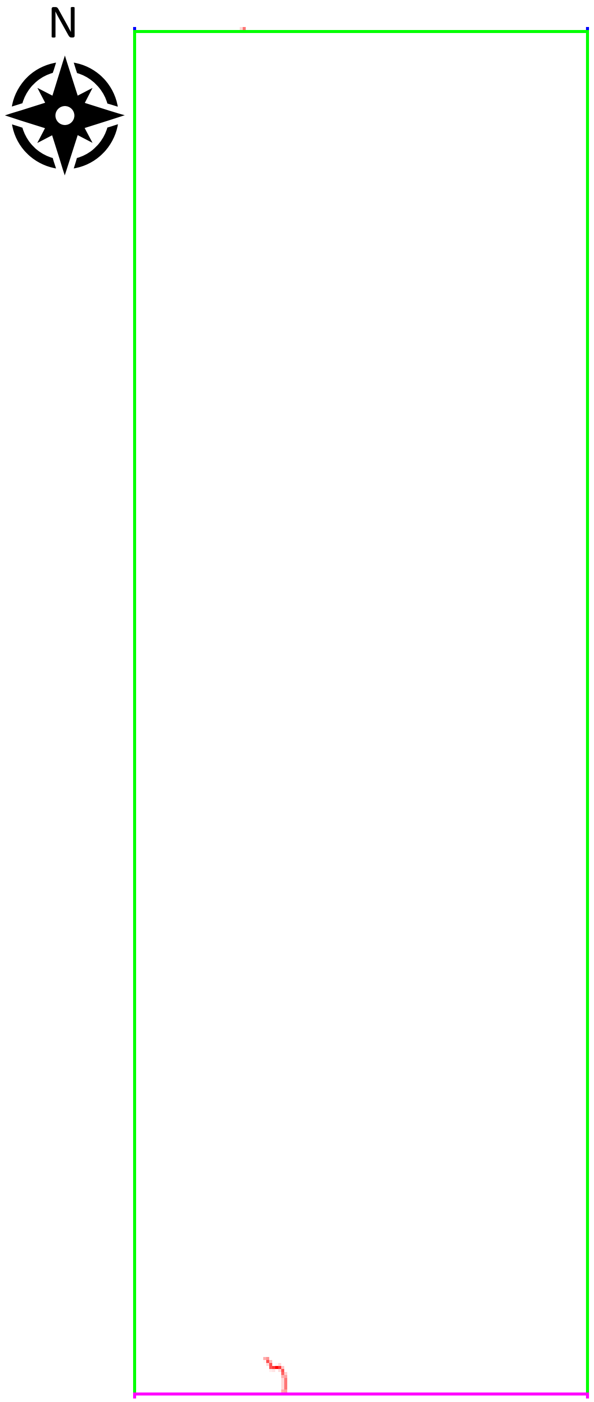
Span 1 - LWA

Span	Avg Crack Length (ft)	Total Cracks Length (ft)	Total number of cracks
1	4.8	38.45	8



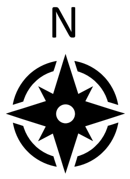
Span 2 - Control

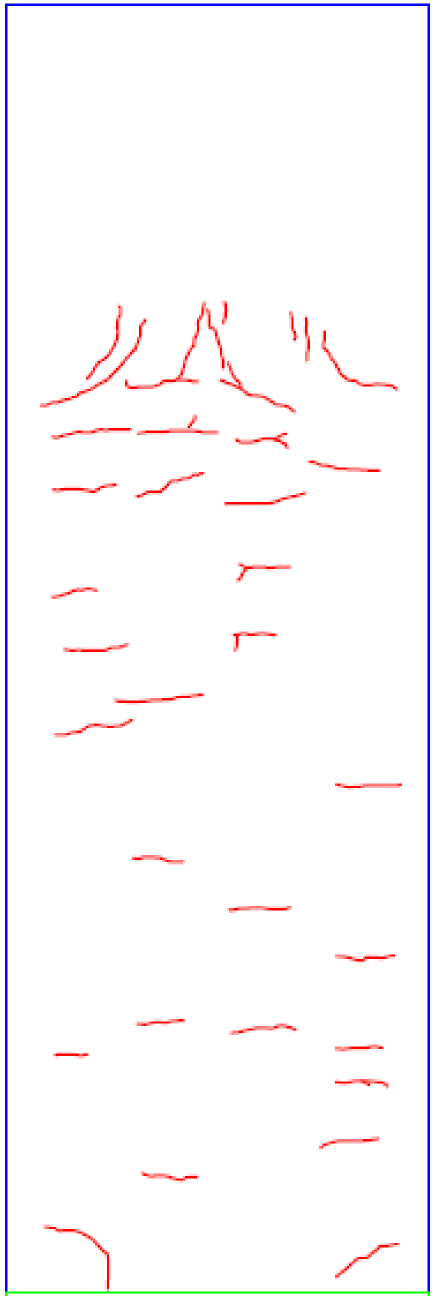
Span	Avg Crack Length (ft)	Total Cracks Length (ft)	Total number of cracks
2 (Control)	3.9	3.9	1



Span 3 – A1 + A2

Span	Avg Crack Length (ft)	Total Cracks Length (ft)	Total number of cracks
3	4.8	212.2	44





Span 3 – A1 + A2

Span	Avg Crack Length (ft)	Total Cracks Length (ft)	Total number of cracks
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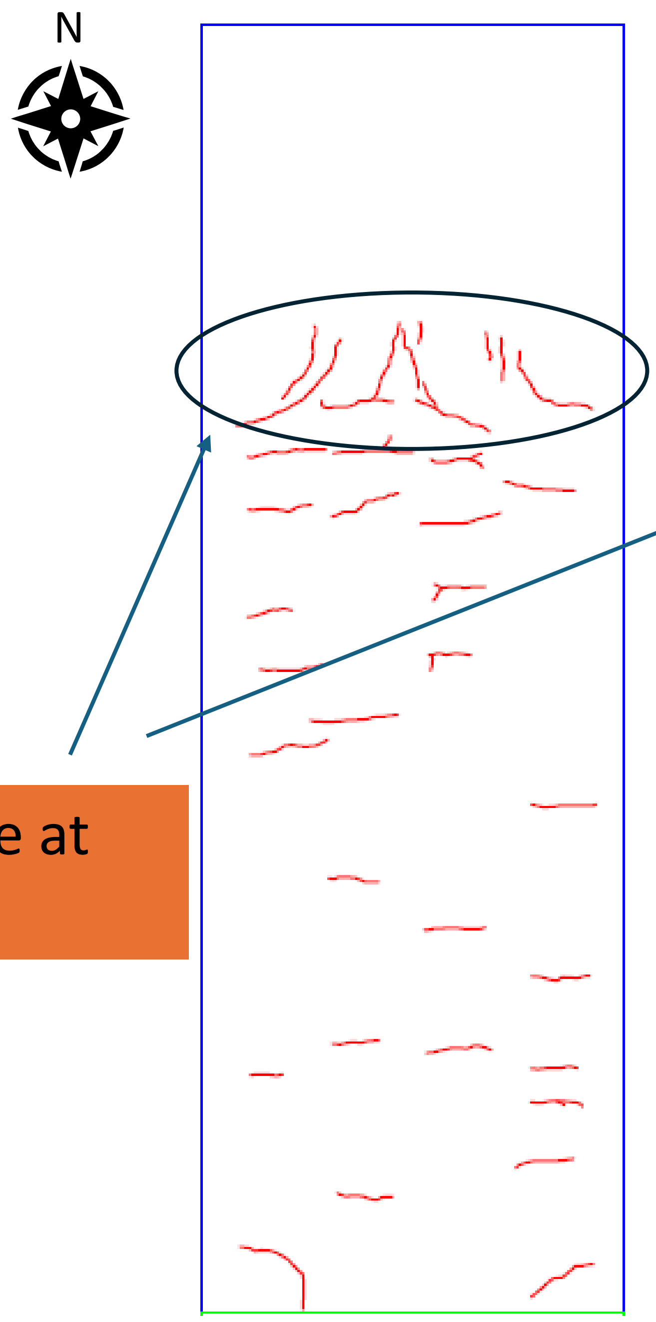
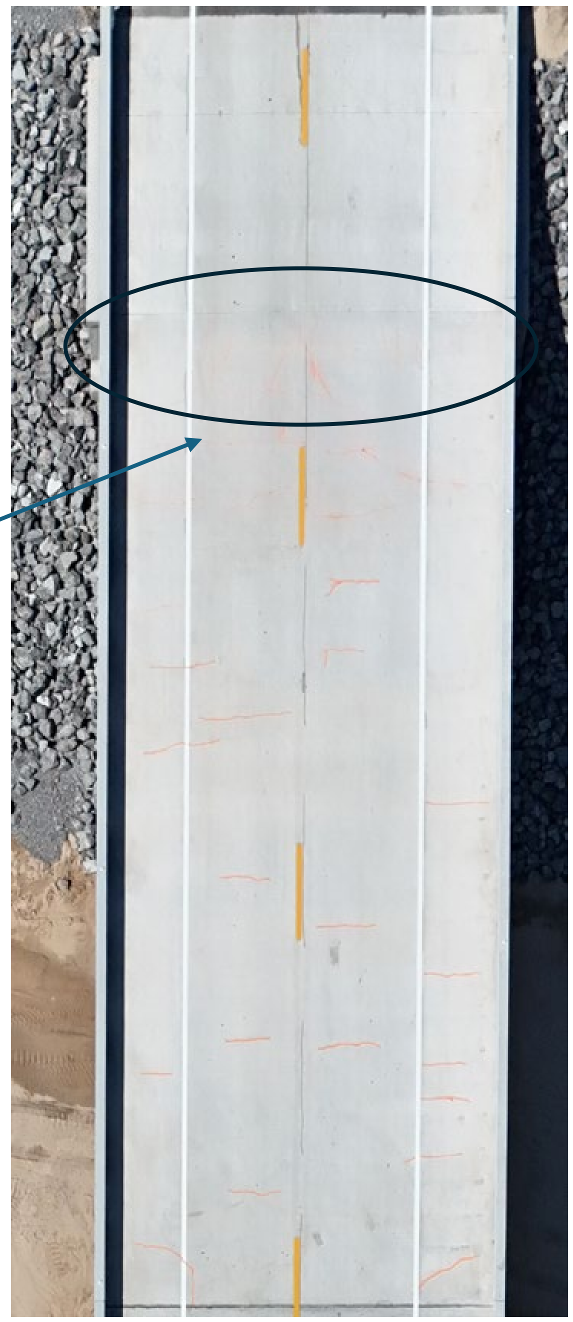


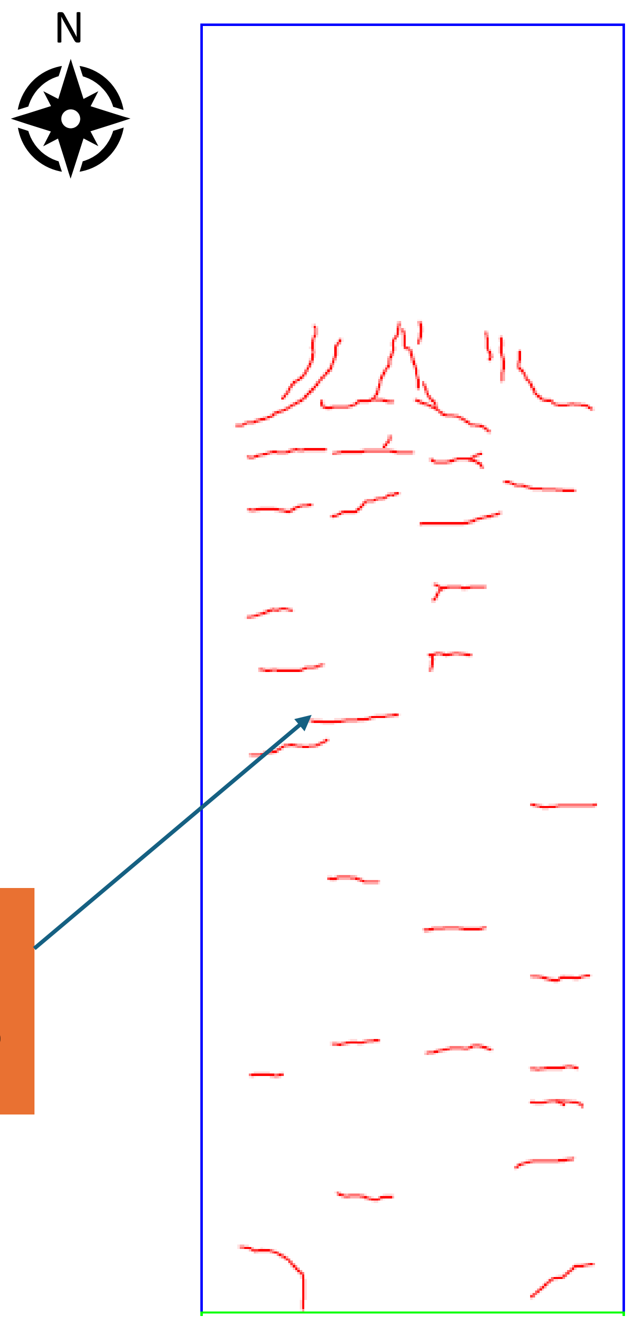


These cracks are at the abutment.

Span 3 – A1 + A2

Span	Avg Crack Length (ft)	Total Cracks Length (ft)	Total number of cracks
3	4.8	212.2	44

Why are there so many cracks?



Span 3 – A1 + A2

Span	Avg Len
3	4.8

It might be influenced by the shrinkage.

Why are there so many cracks?

Discussion

- The span with the A1 + A2 had the most cracking; however, there are some unusual cracking at the abutment that needs more investigation.

- The increase in shrinkage from A1+A2 may contribute to this.

On going work

- We have taken cores and are measuring permeability of the concrete.
- We are still analyzing the data from the field project.

What does this mean?

All colloidal silica admixtures show potential to improve the permeability of the concrete.

What does this mean?

All colloidal silica admixtures show potential to improve the permeability of the concrete.

Some colloidal silicas caused an increase in the concrete shrinkage.

What does this mean?

The colloidal silica admixtures were sensitive to the type of cement and water reducer used.

This made their performance variable.

Permeability is a critical parameter in concrete

If I am relying on an admixture to reduce my permeability it should be reliable with the materials that you are using.

If I am relying on an admixture to reduce my permeability it should be reliable with the materials that you are using.

This admixture should also not increase cracking.

What do I think?

If you are relying on something that is variable for the permeability of your concrete then you are setting yourself up for challenges with the materials that I studied.

Your enemy is the **unexpected change**.

What do I think?

I do not recommend changing your construction practices or materials design and relying on the colloidal silica admixtures that I tested to reduce permeability.

What do I think?

I would not change my curing practices because of colloidal silica.

I would not increase my w/cm because of colloidal silica.

I would not decrease my SCM dosage because of colloidal silica.

Do I think colloidal silica should be used?

I think you should use any tool that helps you make better concrete.

Colloidal silica can do this in some cases.

Do I think colloidal silica should be used?

Sometimes colloidal silica shows promise.

I think this needs to be proved by trial batching and permeability measurements that are not electrical based. (I would not use resistivity or RCPT)

But my data shows product XYZ is great!

That is possible. I don’t think we understand how colloidal silica interacts with other cements, water reducers, and SCMs.

You should trial batch and test with the materials that you are using.

Why did this product work on project A and not work on project B?

I don’t think we understand how colloidal silica interacts with other cements, water reducers, and SCMs.

You should trial batch and test with the materials that you are using.

Your enemy is the **unexpected change**.

Summary

For one cement and and water reducer combination colloidal silica lowered the permeability and for the others it had no effect.

This variable performance occurred in all investigated commercial products.

Summary

Trial batching is the only way to understand how these materials will behave.

<u>If you don’t want to require a trial batch then I would recommend that you do not use them.</u>

www.youtube.com/tylerley

www.concretefreaks.com

Questions?

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