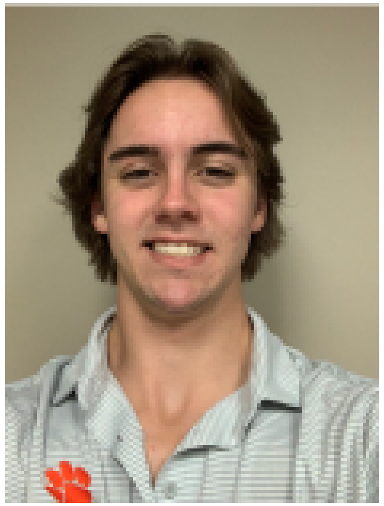
October 17th, 2023
ICRI 2023 Fall Convention

Influence of Ambient Environmental Condition on Performance of Pre-Blended Patching Materials



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Background – Bridge Conditions

- Bridge Conditions – SC
  - Good: 3525 (42.37%)
  - Fair: 4018 (48.3%)
  - Poor: 776 (9.33%)
    - 48% of bridges by count were built from the 1960's-70's.
    - 40% of concrete bridges are near or have already exceeded their original design service life of 50 years.

- Bridge Conditions – US
  - Over 220,000 bridges (36%) need repair.
  - 45,000 remain "Structurally Deficient" and are in poor condition.
  - 295,000 bridges (48%) are in fair condition.
  - Estimated cost to repair ~ $41.8 billion.

Background – Bridge Deck Deterioration

- **On a bridge structure, the decks are the most vulnerable to deterioration over time.**
- Deck directly bears traffic loads
- High surface area to volume ratio
- Environmental Factors:
  - Freeze thaw
  - Aggressive Agents
  - Poor Curing conditions
- Physical/Chemical Factors:
  - Overloading
  - Poor design/compatibility
  - Corrosion of steel reinforcement
  - Poor construction practices

Early Age Impacts
&
Often Overlooked

Need for study

- Material Selection:
  - Wide variety of available materials
  - Very limited requirements for material implementation
    - Generally, strength gain is the most important factor
  - Majority of manufactured materials components are kept proprietary.
  - Engineers are forced to make a cost-efficient solution without proper knowledge of performance or compatibility.

"Often times, the design for repair and rehabilitation is executed by a staff with limited skill and experience in the field of durability, corrosion and repair"

- P.H. Emmons, A.M. Vaysburd

Purpose of study

- Better understand how early-age factors (temperature) affect long term durability.
- Provide engineers with insight into how materials react to external stimuli and how they interact with substrates as a composite.

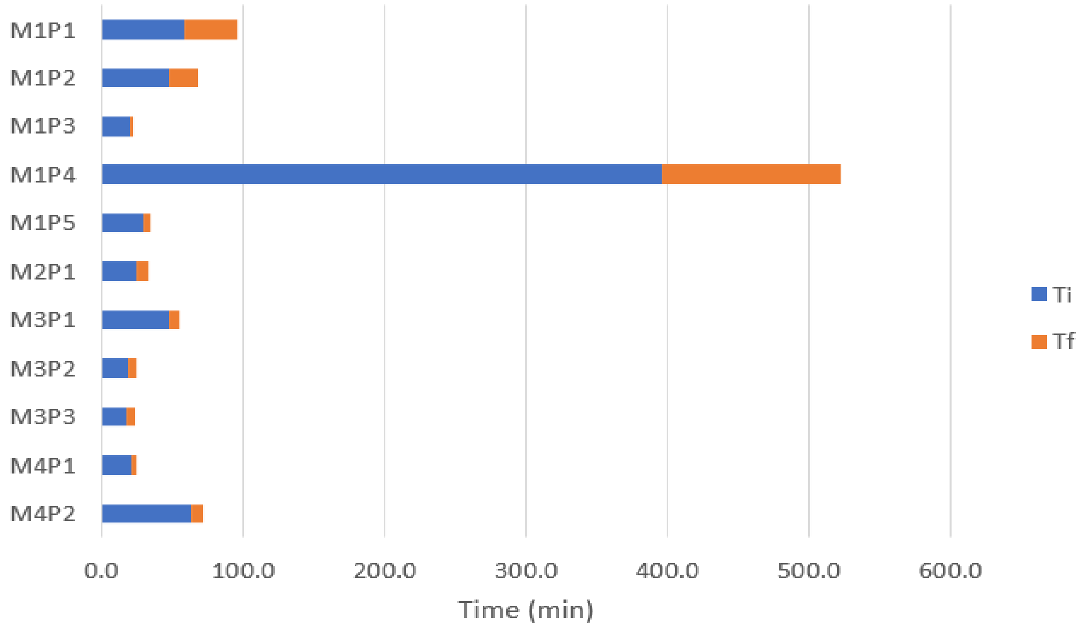
Overview

- Experimental Testing – All samples conditioned and tested at 10, 23 & 40°C.
  - VICAT Setting Time Test
    - Determination of initial & final setting time of patching materials sieved at 4.75 mm.
  - Ultrasonic Pulse Velocity (UPV)
    - Measures the rate of crystalline micro-structural development over first 24 hours of curing.
  - Isothermal Calorimetry
    - Measurement of the exothermic heat production resulting from hydration reactions, for first 7 days.
  - Compressive Strength
    - Samples cured in temperature-controlled chamber before compressive testing at 0.25, 0.5, 1, 3 & 7 days.

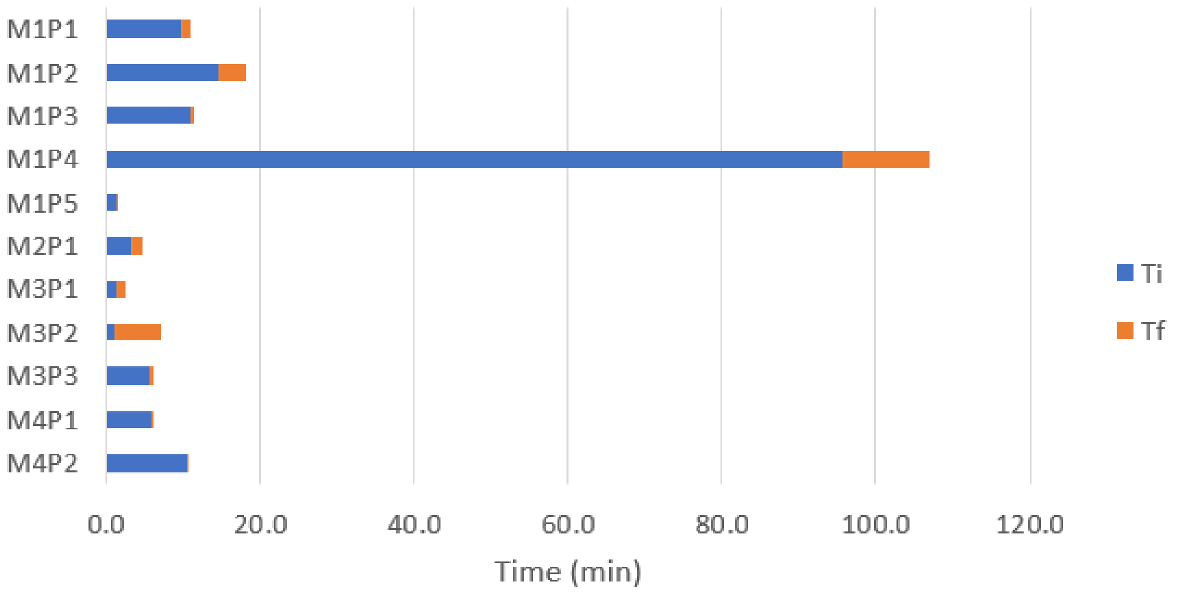
VICAT Setting Time Test

- ASTM C191-21/C807-21
- Directly compare setting behavior at 10, 23 & 40°C
- Increased temperatures causes rapid loss of workability

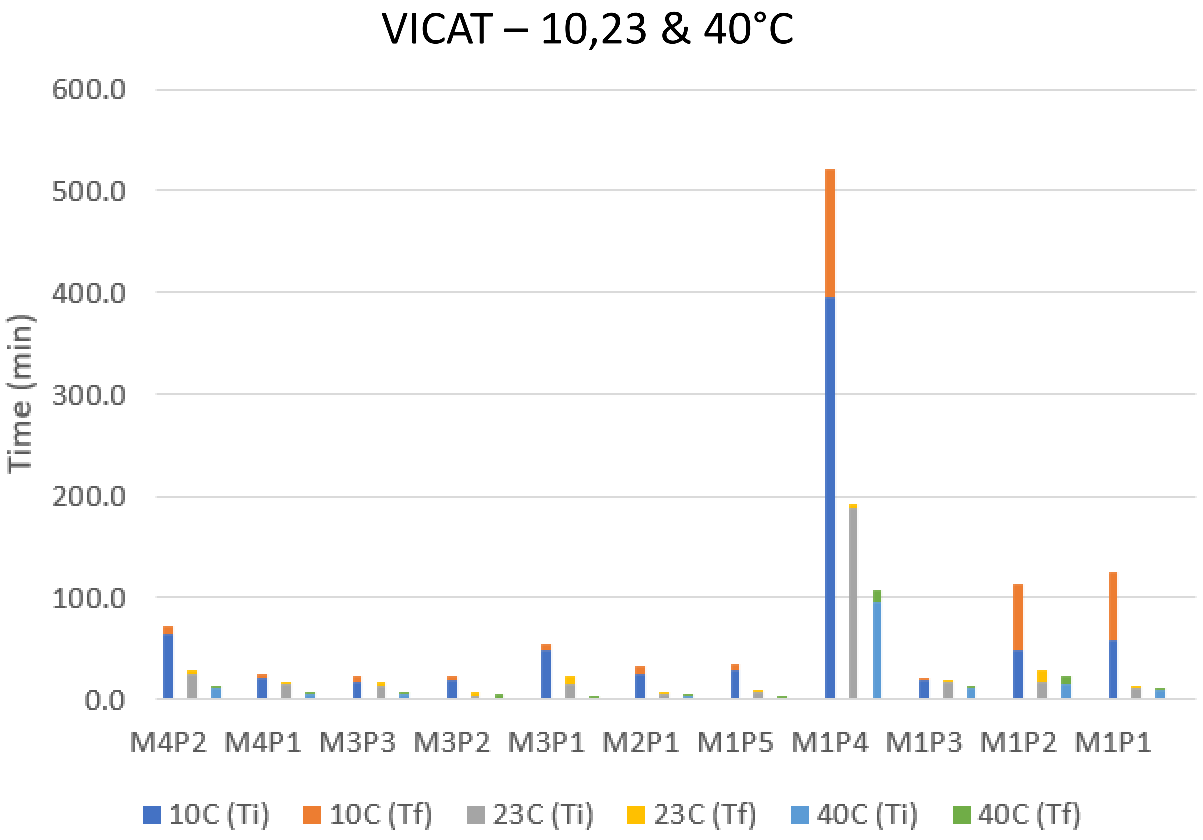
VICAT 10°C

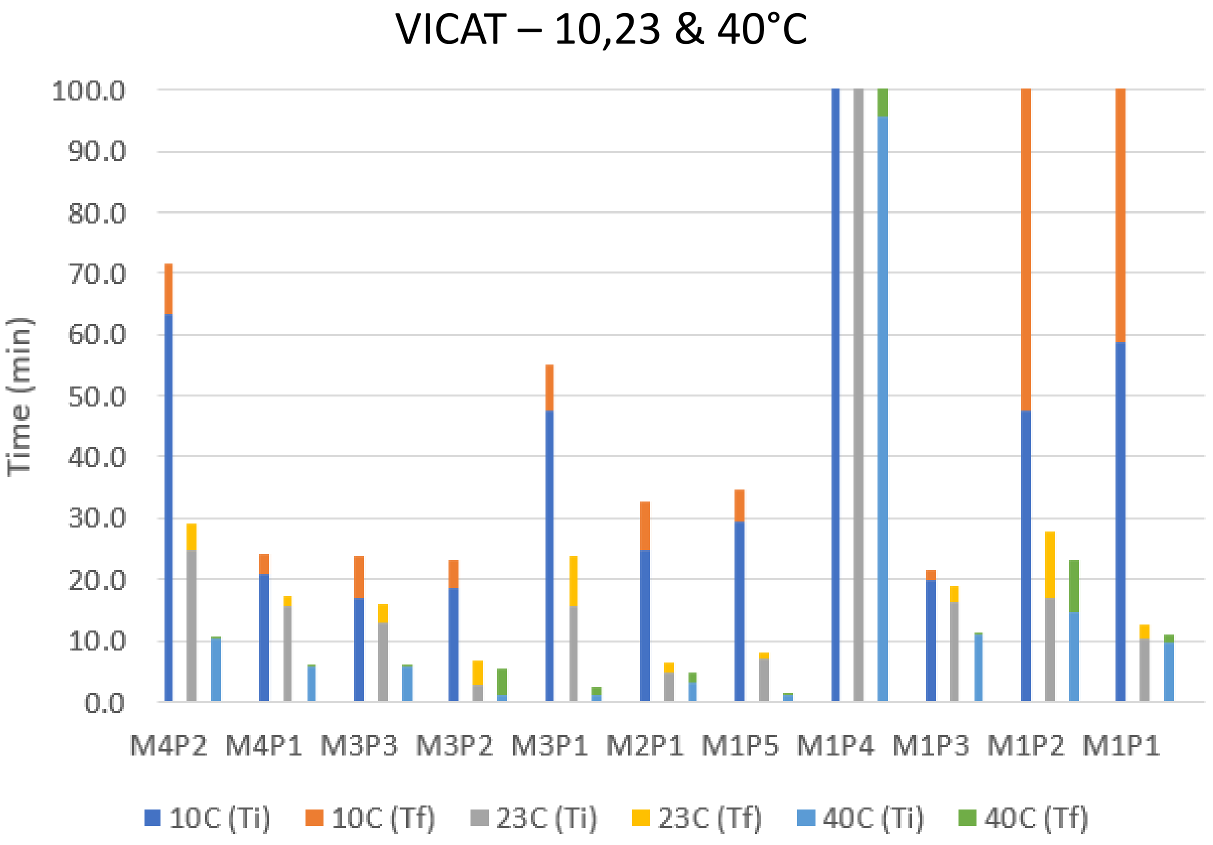


VICAT 40°C



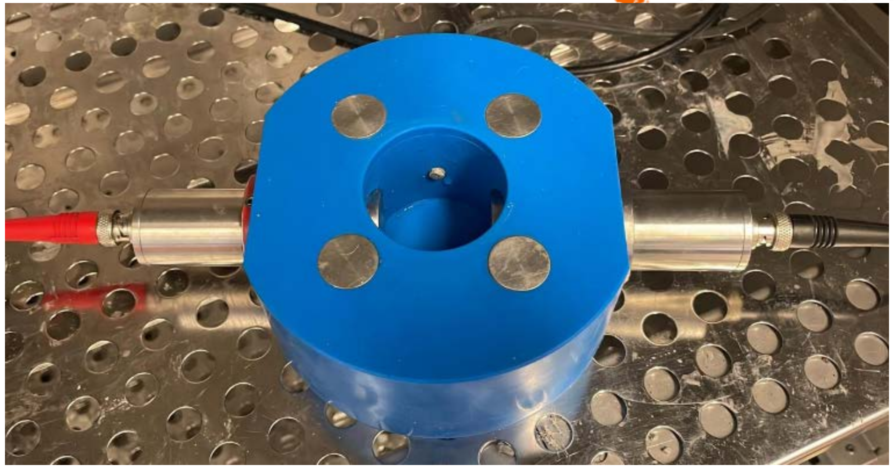
VICAT Setting Time Test



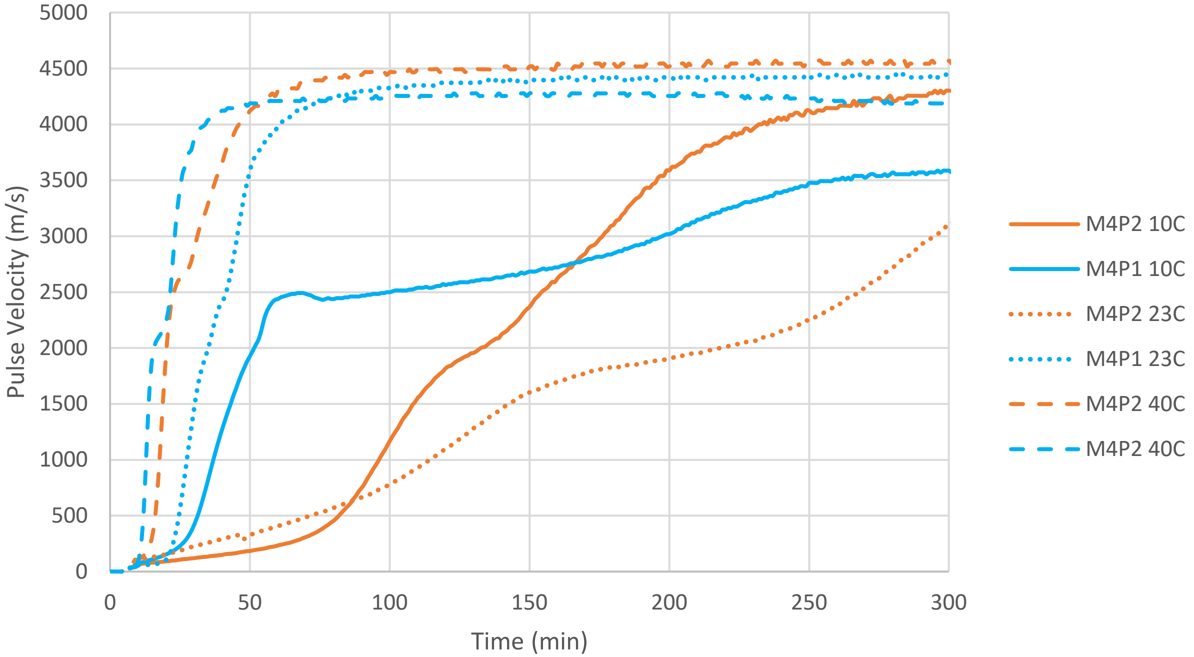


Ultrasonic-Pulse Velocity (UPV)

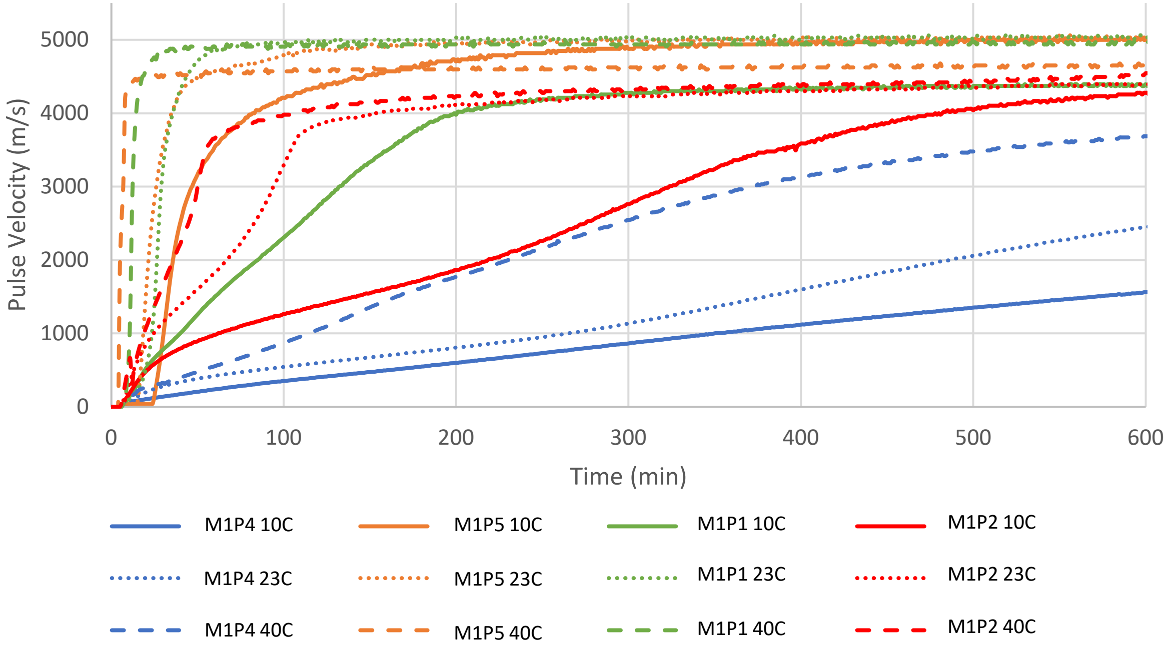
- Measuring micro-structural development
- Decreasing temperature dampens the rate of binder stiffening & hardening phases

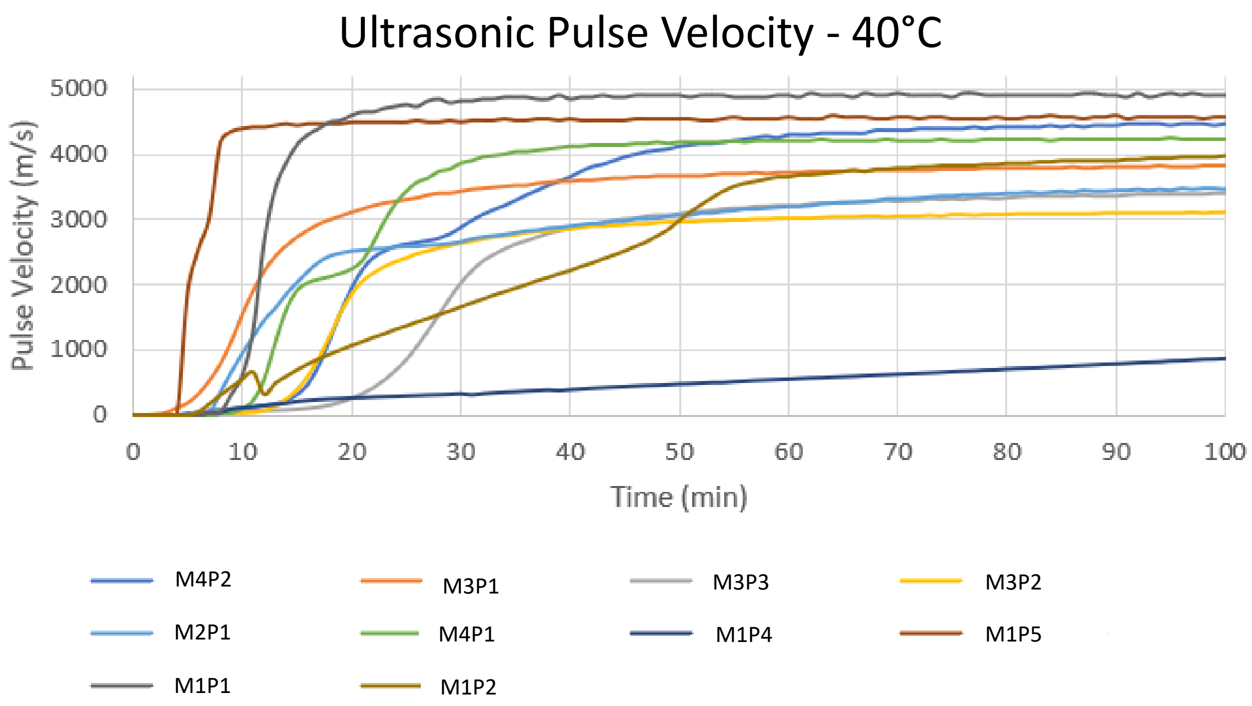


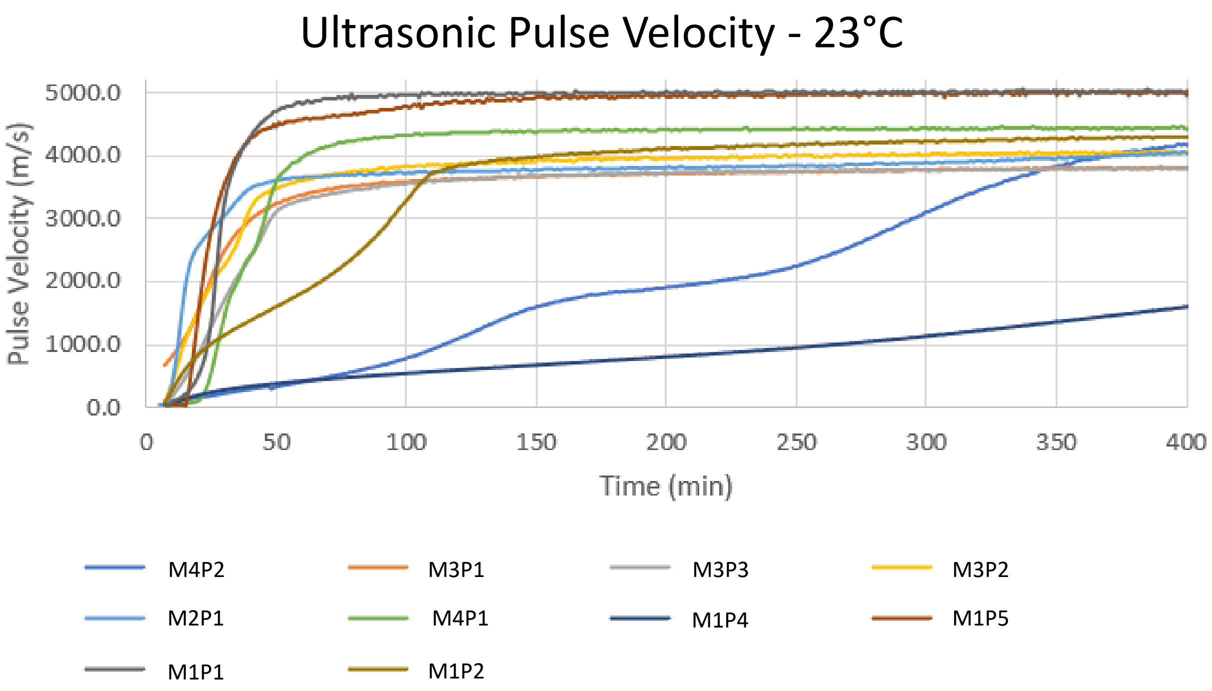
M2 UPV – 10,23 & 40°C

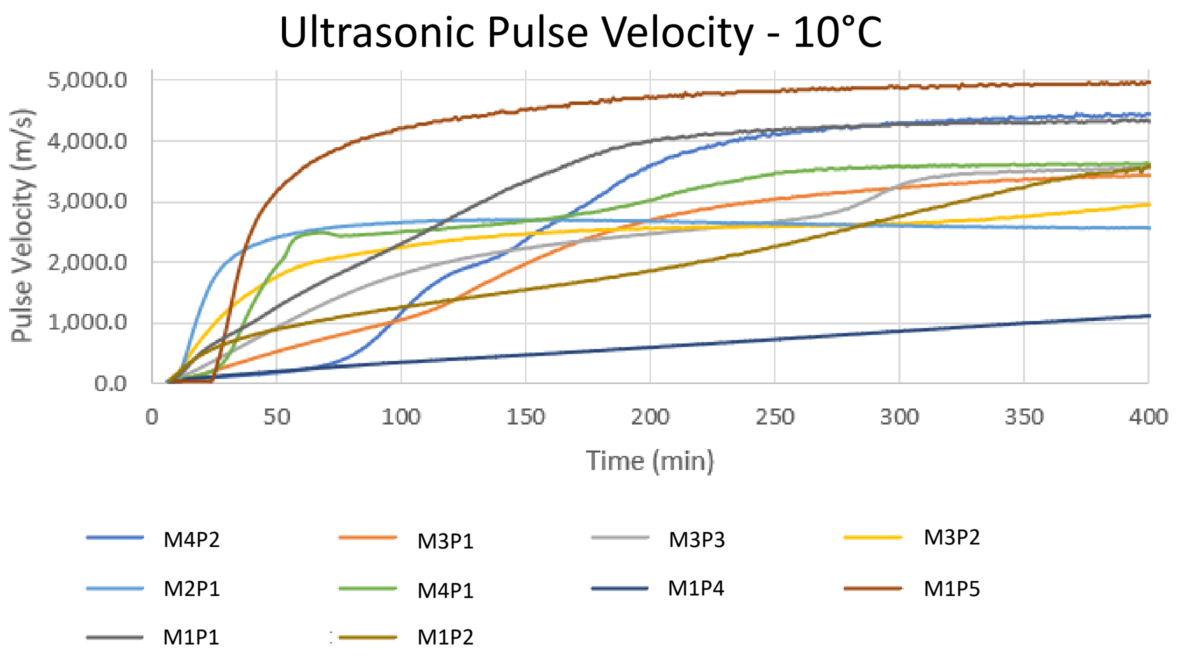


M1 UPV – 10,23 & 40°C

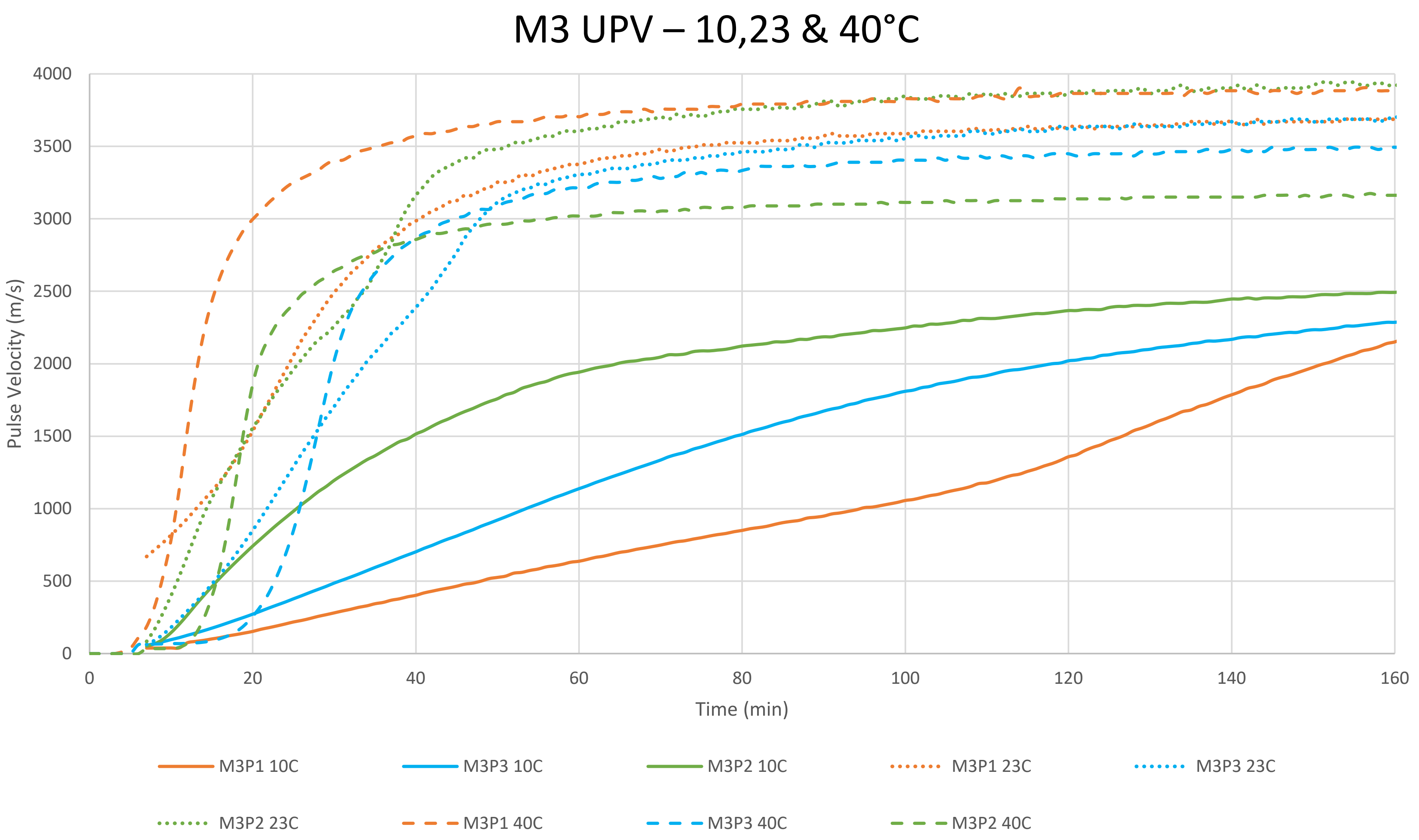



Ultrasonic Pulse Velocity - 40°C
Pulse Velocity (m/s)
Time (min)
0
1000
2000
3000
4000
5000
0
10
20
30
40
50
60
70
80
90
100
M4P2
M3P1
M3P3
M3P2
M2P1
M4P1
M1P4
M1P5
M1P1
M1P2


Ultrasonic Pulse Velocity - 23°C
Pulse Velocity (m/s)
Time (min)
0.0
1000.0
2000.0
3000.0
4000.0
5000.0
0
50
100
150
200
250
300
350
400
M4P2
M3P1
M3P3
M3P2
M2P1
M4P1
M1P4
M1P5
M1P1
M1P2

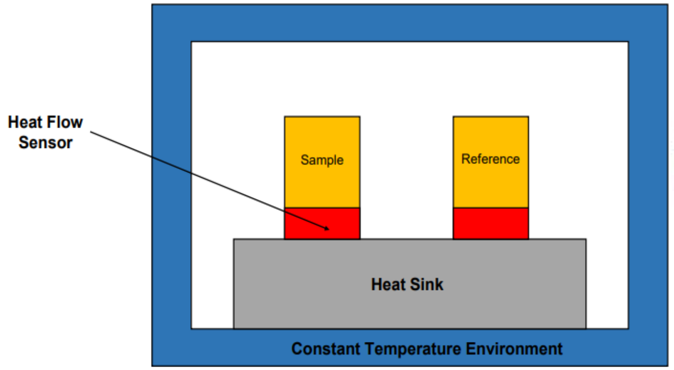

Ultrasonic Pulse Velocity - 10°C
Pulse Velocity (m/s)
Time (min)
0.0
1,000.0
2,000.0
3,000.0
4,000.0
5,000.0
0
50
100
150
200
250
300
350
400
M4P2
M3P1
M3P3
M3P2
M2P1
M4P1
M1P4
M1P5
M1P1
M1P2

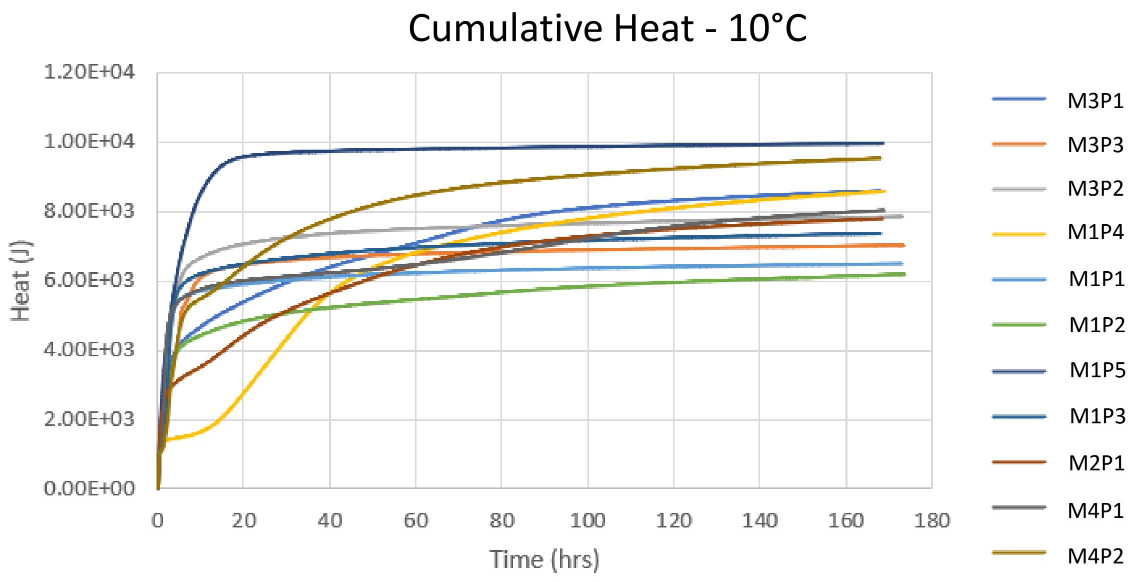
Ultrasonic-Pulse Velocity (UPV)

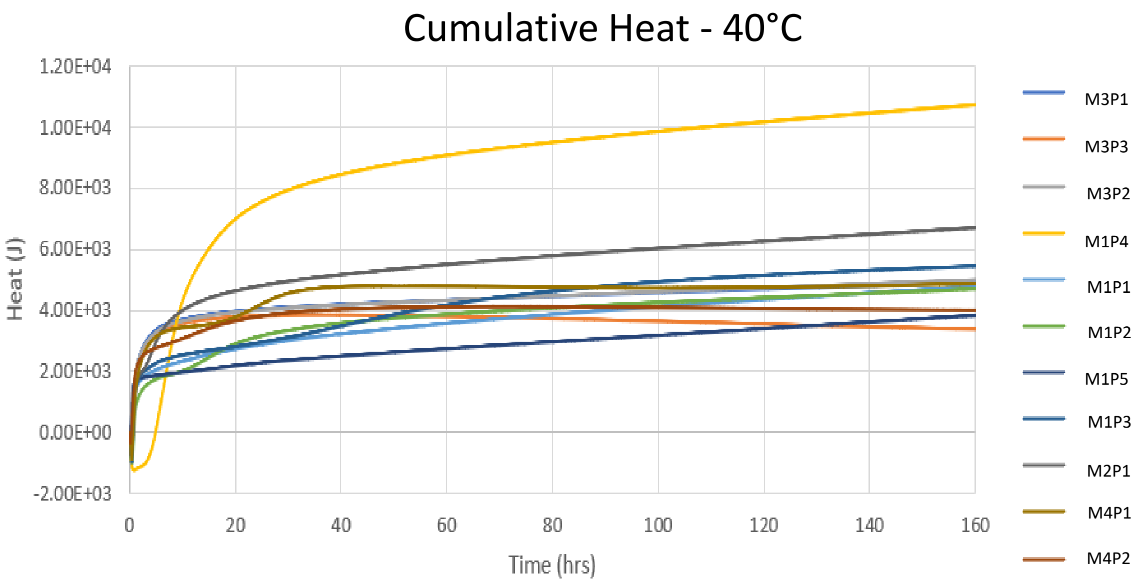


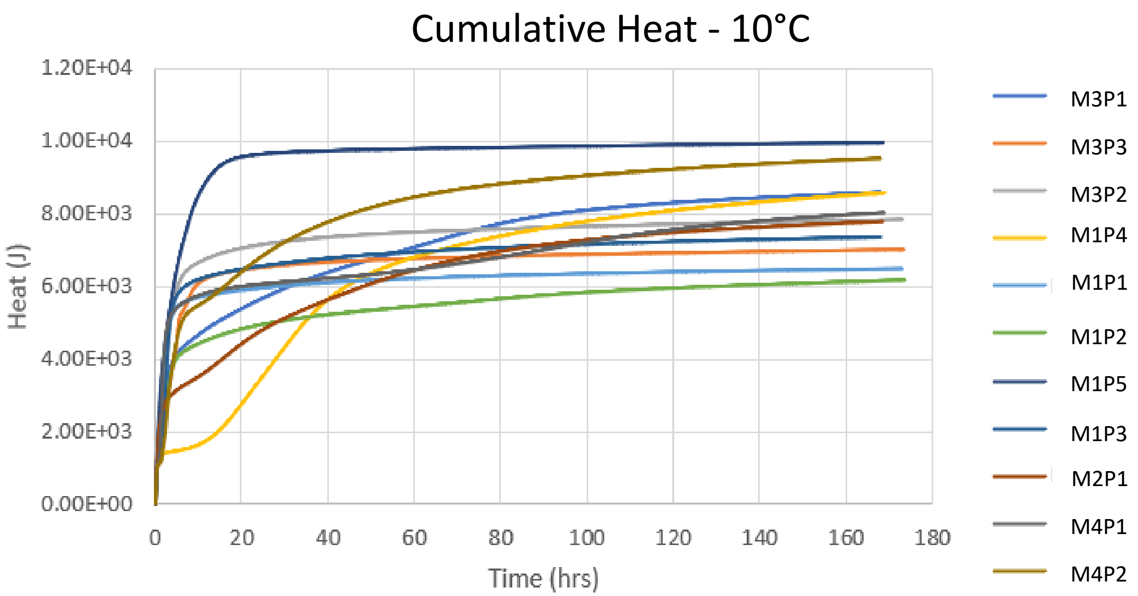
Isothermal Calorimetry

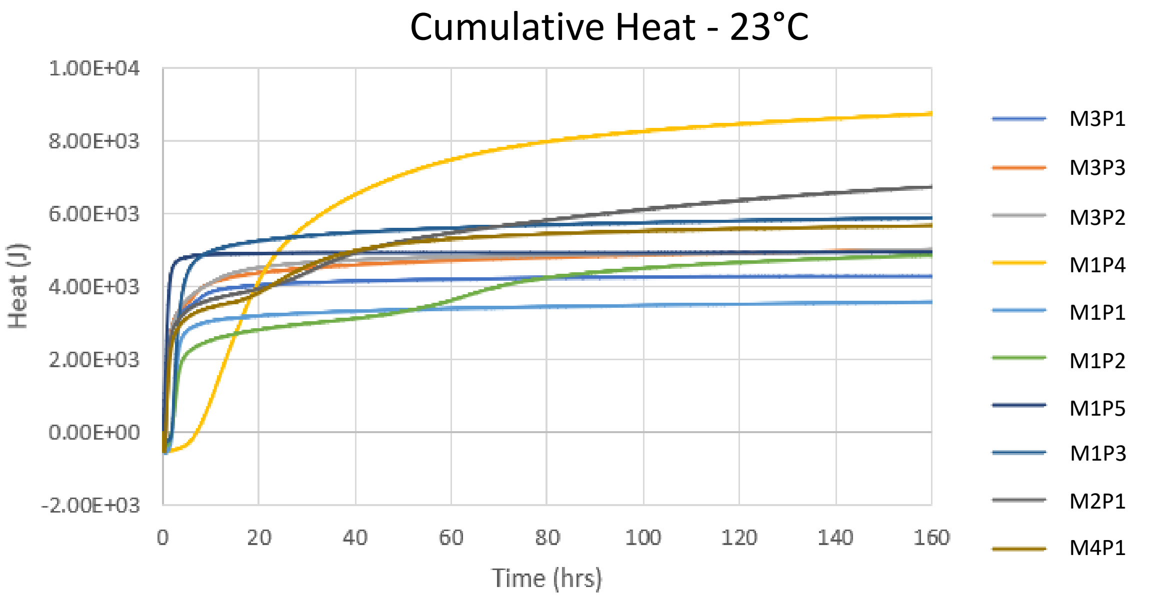
- Measure of materials exothermic heat production
- Useful to observe how ambient temperature affects hydration reactions
- Lower temperatures can decrease overall reactivity

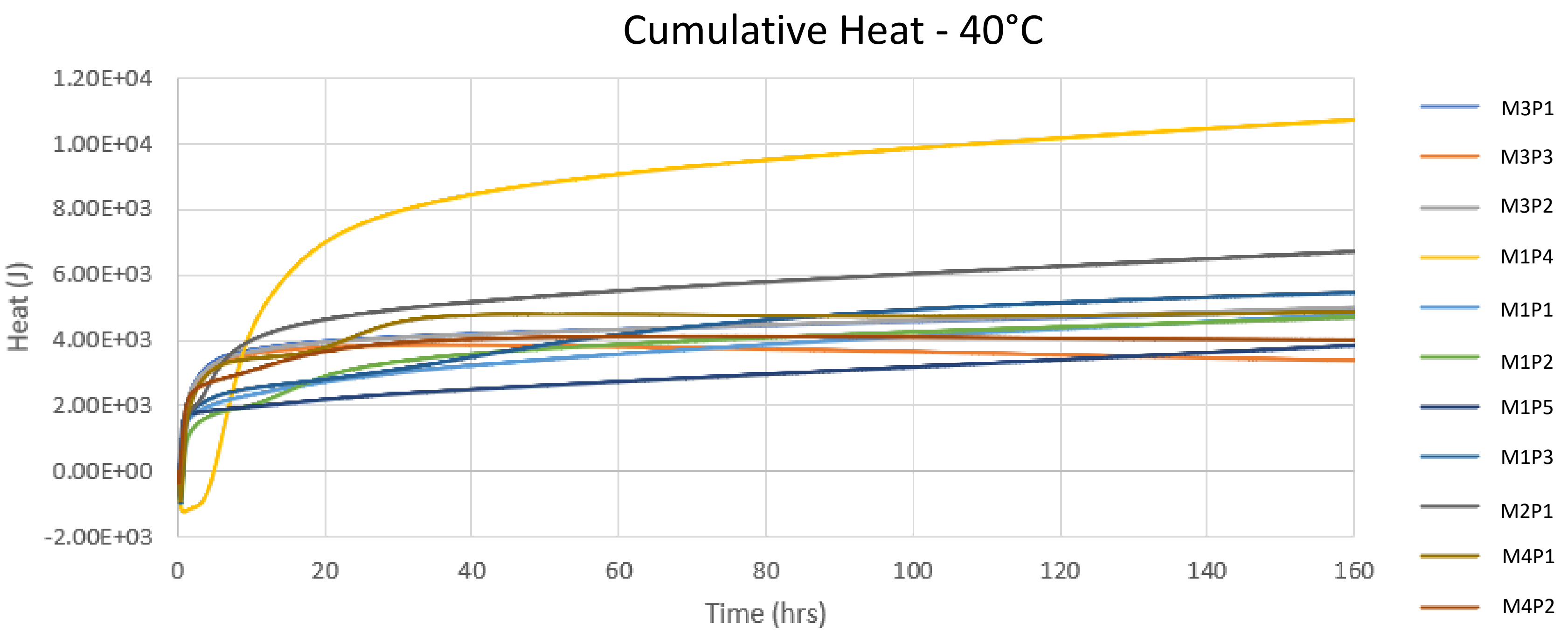




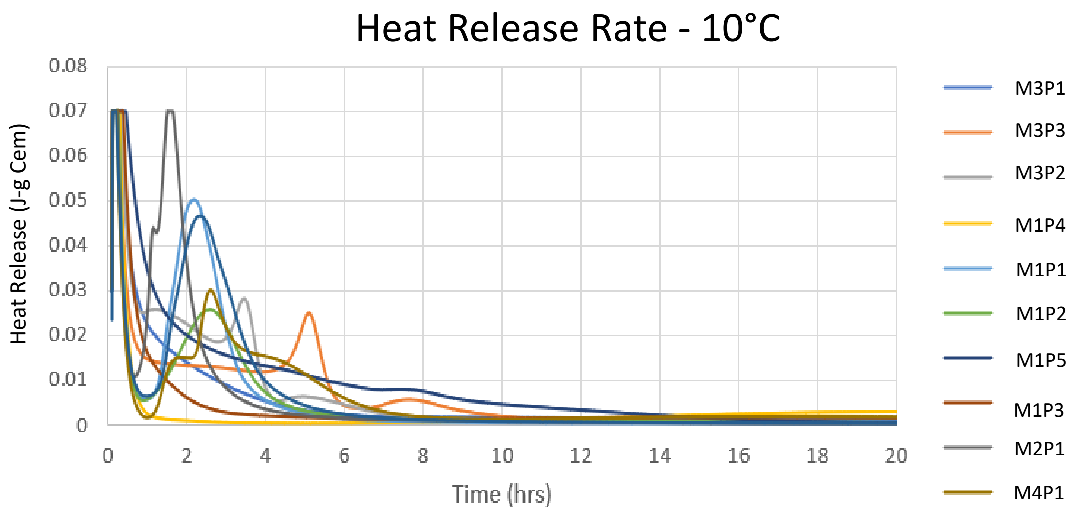


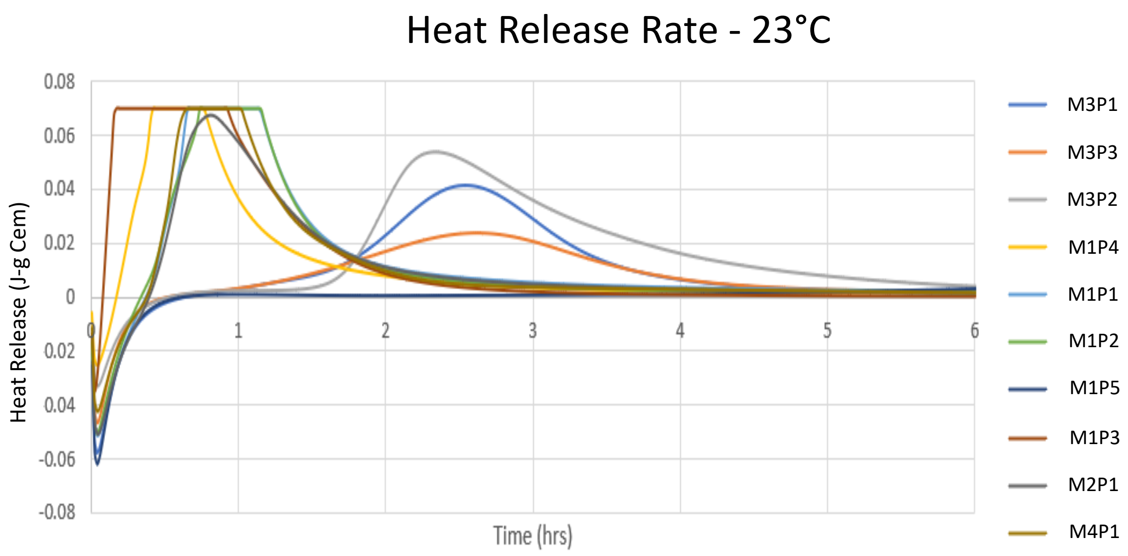

Cumulative Heat - 10°C
1.20E+04
1.00E+04
8.00E+03
6.00E+03
4.00E+03
2.00E+03
0.00E+00
Heat (J)
0
20
40
60
80
100
120
140
160
180
Time (hrs)
M3P1
M3P3
M3P2
M1P4
M1P1
M1P2
M1P5
M1P3
M2P1
M4P1
M4P2

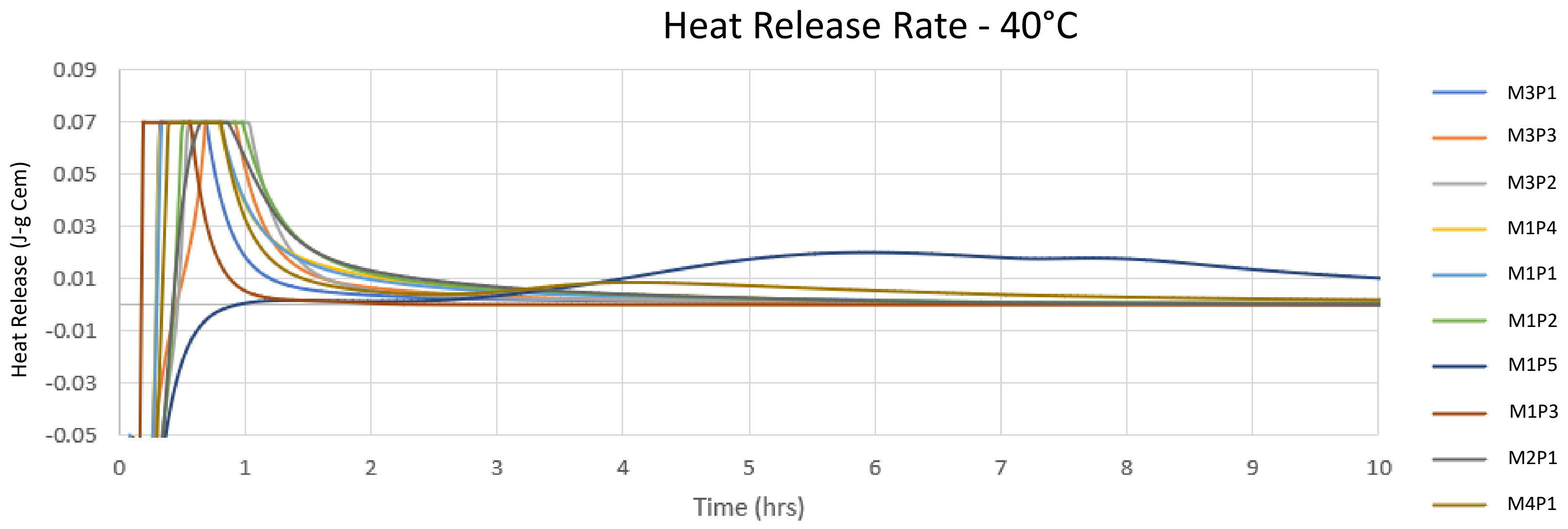

Cumulative Heat - 23°C
1.00E+04
8.00E+03
6.00E+03
4.00E+03
2.00E+03
0.00E+00
-2.00E+03
Heat (J)
0
20
40
60
80
100
120
140
160
Time (hrs)
M3P1
M3P3
M3P2
M1P4
M1P1
M1P2
M1P5
M1P3
M2P1
M4P1


Cumulative Heat - 40°C
1.20E+04
1.00E+04
8.00E+03
6.00E+03
4.00E+03
2.00E+03
0.00E+00
-2.00E+03
Heat (J)
0
20
40
60
80
100
120
140
160
Time (hrs)
M3P1
M3P3
M3P2
M1P4
M1P1
M1P2
M1P5
M1P3
M2P1
M4P1
M4P2

Isothermal Calorimetry

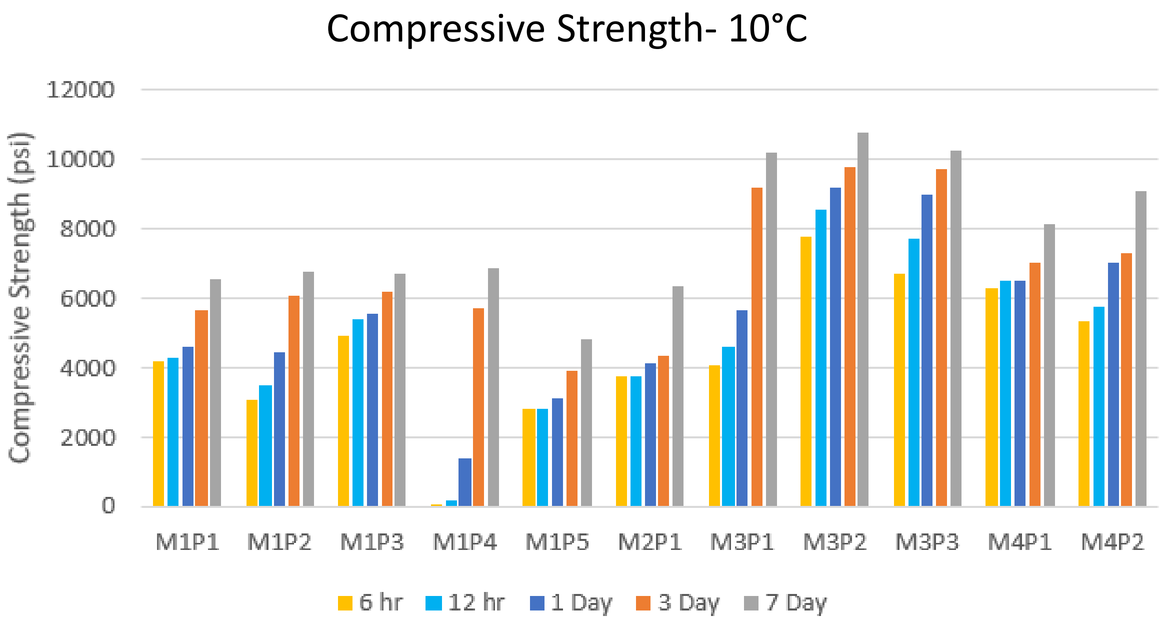


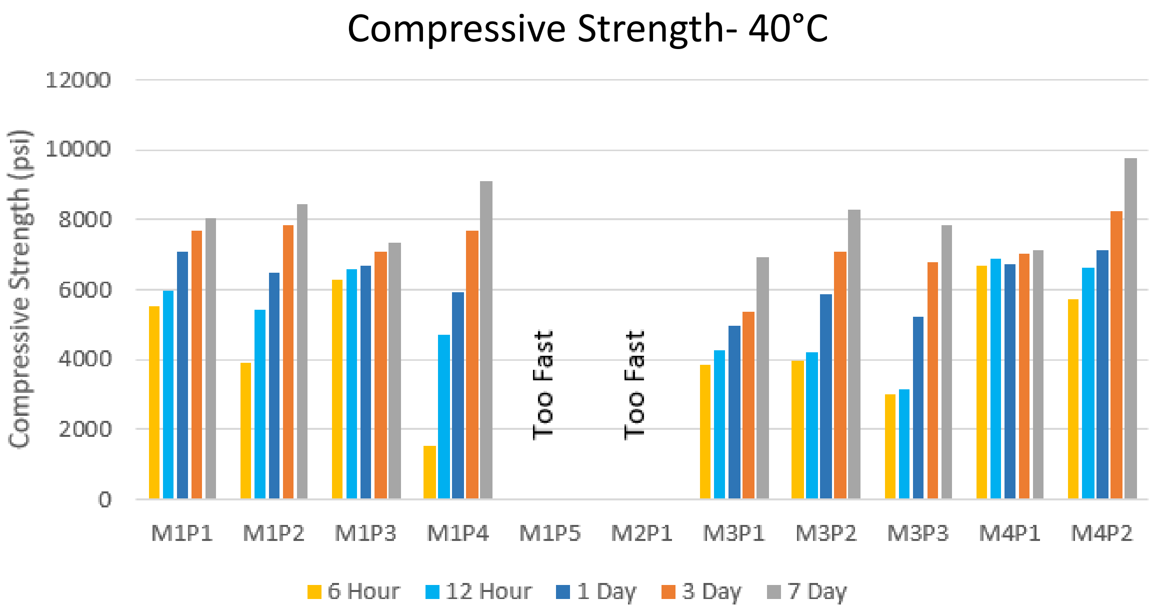




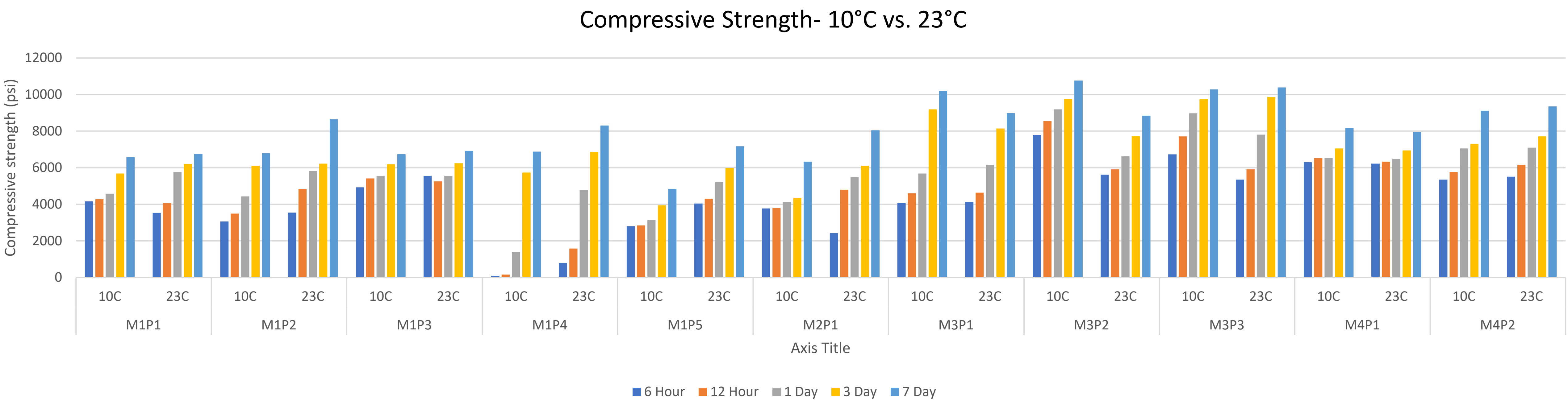
Compressive Strength

- 3 in. x 6in. cylinder Samples
- Strength testing at 0.25, 0.5, 1, 3 & 7 days
- High temperatures made some materials un-workable

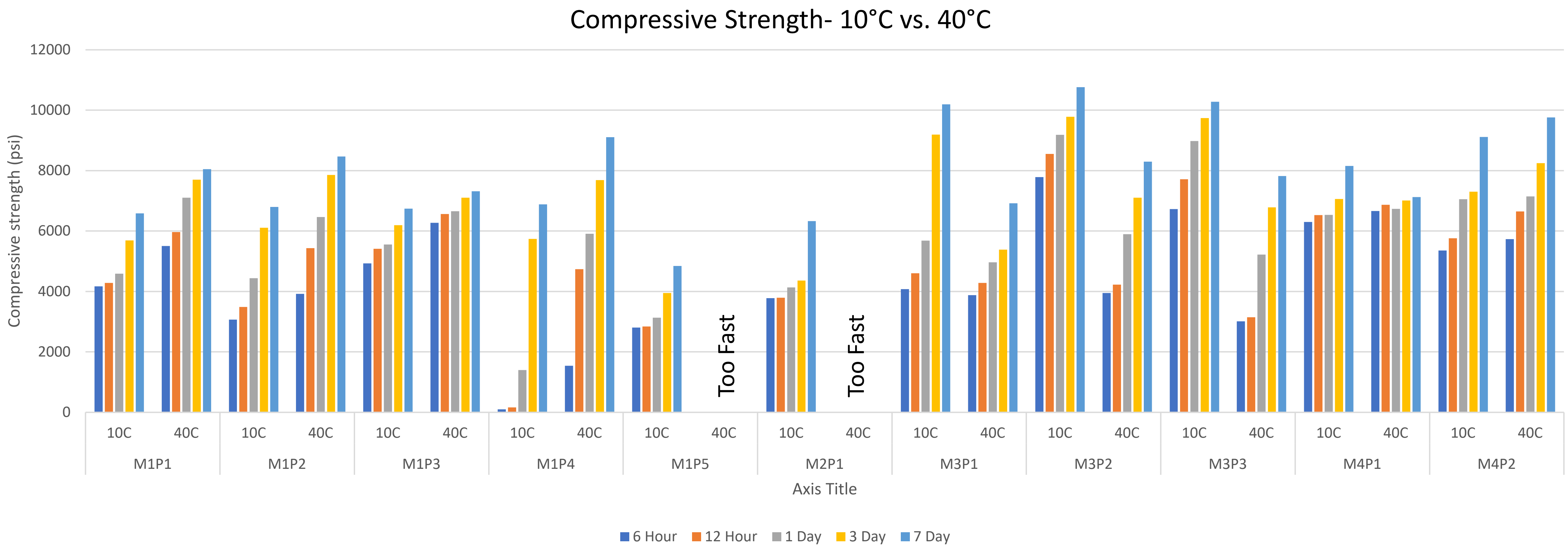




Compressive Strength



Compressive Strength



Conclusions

- Ambient temperature extremes have significant impacts on setting behavior and long-term mechanical performance & properties of patching materials.
- Certain materials are more susceptible to being impacted by temperature fluctuations than others.
- VICAT testing shows extreme loss in workability at 40°C. Certain materials setup almost immediately, which could lead to poor consolidation in-situ.
- UPV testing displays how lower temperatures can heavily delay micro-structural development thus affecting setting time and strength gain, however some materials showed minimal impact.
- High temperature exposure during setting can rapidly increase the rate of exothermic heat production, but it can decrease the overall heat produced over time.
- Alterations in material properties due to ambient temperatures can impact both short- and long-term repair performance and compatibility with substrate concrete.
- For engineers to make the proper material selections and implementation recommendations, they need a thorough understanding of how these materials can be affected by the environment.

Questions?

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