WARRIP

WESTERN AUSTRALIAN ROAD RESEARCH & INNOVATION PROGRAM

2020-005, 2022-006, 2024-001: Digestion of crumb rubber in bitumen

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Acknowledgement of Country

I begin today by acknowledging the Traditional Custodians of the land on which we meet today and pay my respects to their Elders past and present. I extend that respect to Aboriginal and Torres Strait Islander peoples here today.

WARRIP

Welcome

About WARRIP

The Western Australian Road Research and Innovation Program is a joint initiative between Main Roads Western Australia and the National Transport Research Organisation.

The program has a strategic commitment to the delivery of collaborative research and development that positively contributes to the design, construction and maintenance of safe, sustainable transport infrastructure in Western Australia.

Overview

- Background
- Project scope and objectives
- Crumb rubber digestion
- Materials
- Experimental methods
- Key results

Background

- **Historic use of crumb rubber-modified binders (CRMBs) in WA**
  - sprayed seals (approximately 15 wt.%)
  - waterproofing (approximately 15 wt.%)
- **WARRIP 2016-012 → MRWA Specification 516 *Crumb rubber open graded asphalt***
- **WARRIP 2019-002 → MRWA Specification 517 *Crumb rubber gap graded asphalt***

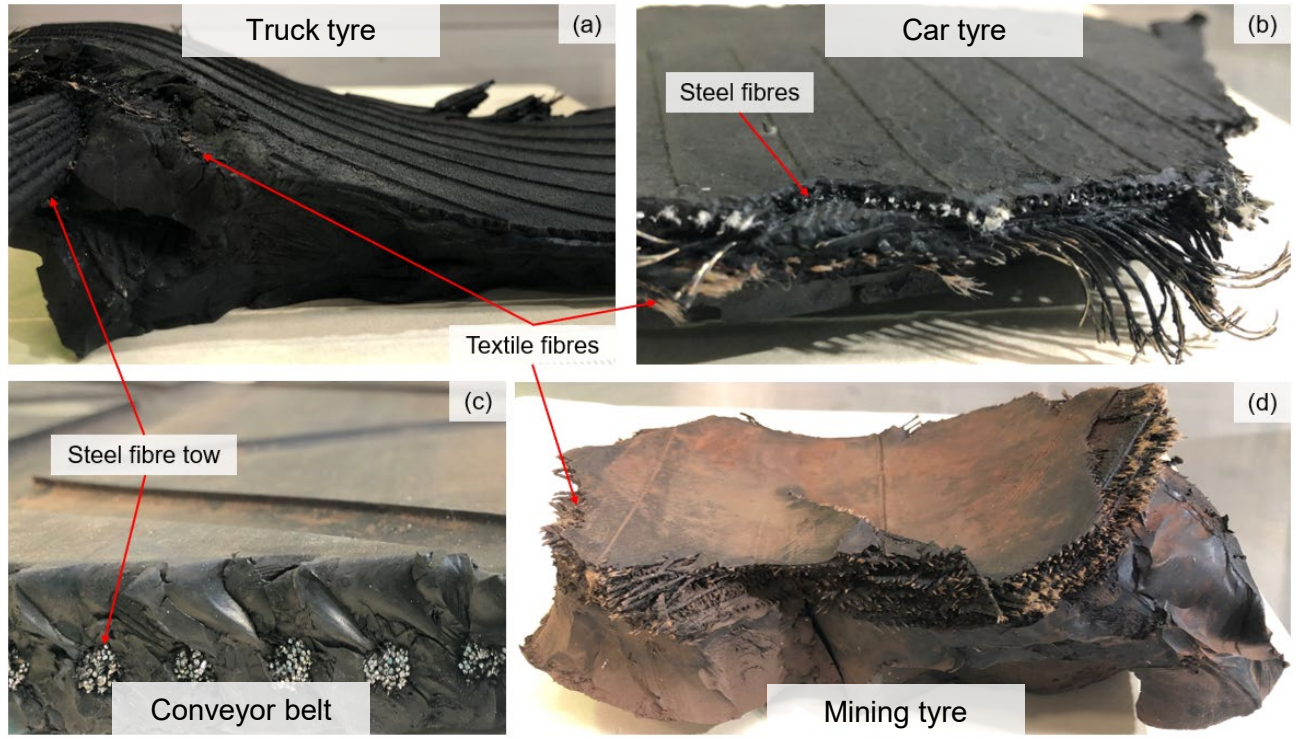
- **Established use of truck tyre-derived crumb rubber**
  - other end-of-life rubber products may also be suitable

Project scope and objectives

- **Research objectives:**
  - Understand combination of parameters that result in optimum binder performance
- **In this research:**
  - Truck tyre-, car tyre- and conveyor belt-derived binders were found to be comparable despite differences in the crumb rubber composition
  - Results for mining tyre-derived binders were variable and so need to be investigated further

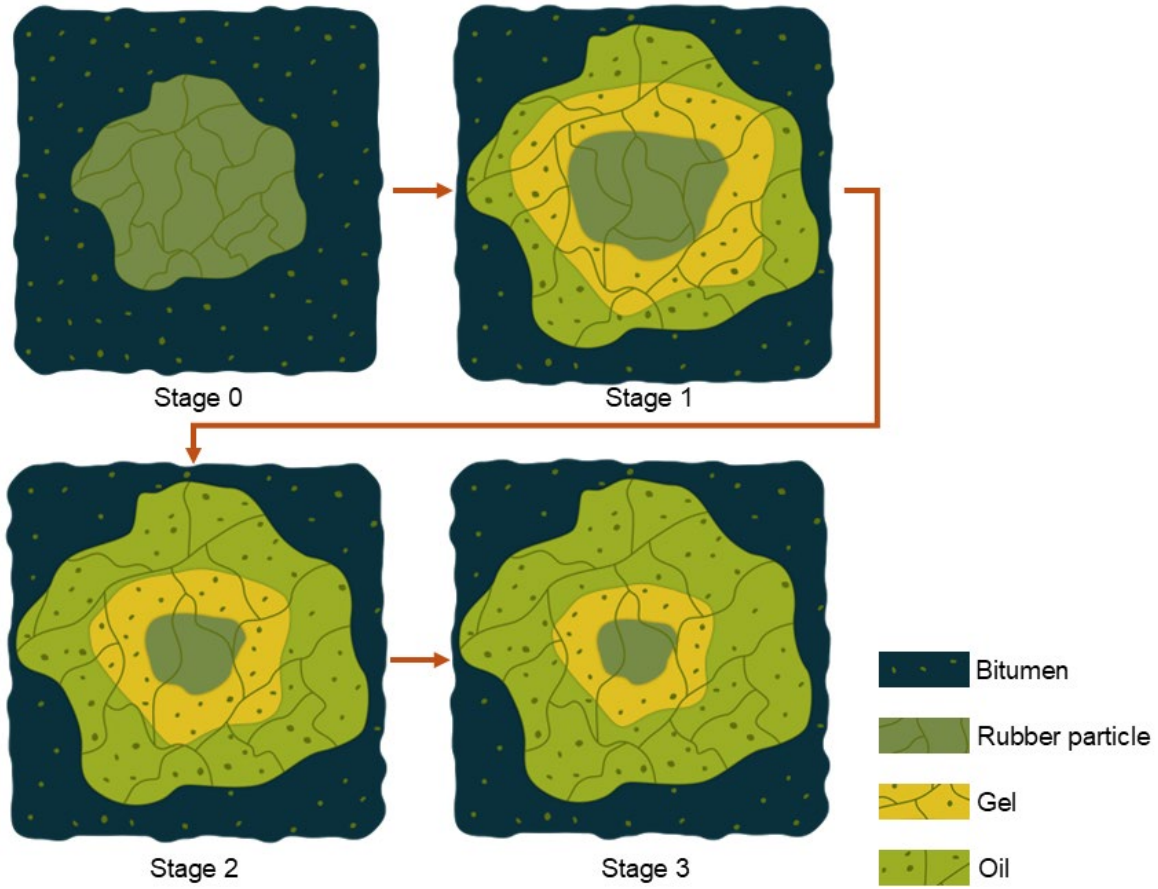
Project scope and objectives

- **Investigate impacts of:**
  - crumb rubber (CR) type
    - truck tyre (TR), car tyre (CT), conveyor belt (CB) - OTR, mining tyre (MT) - OTR
  - CR size
    - size 30 (S30), size 16 (S16)
  - blending temperature
    - 165 and 190°C
  - blending time
    - 1, 2, 4, 11, 24 and 36 hours



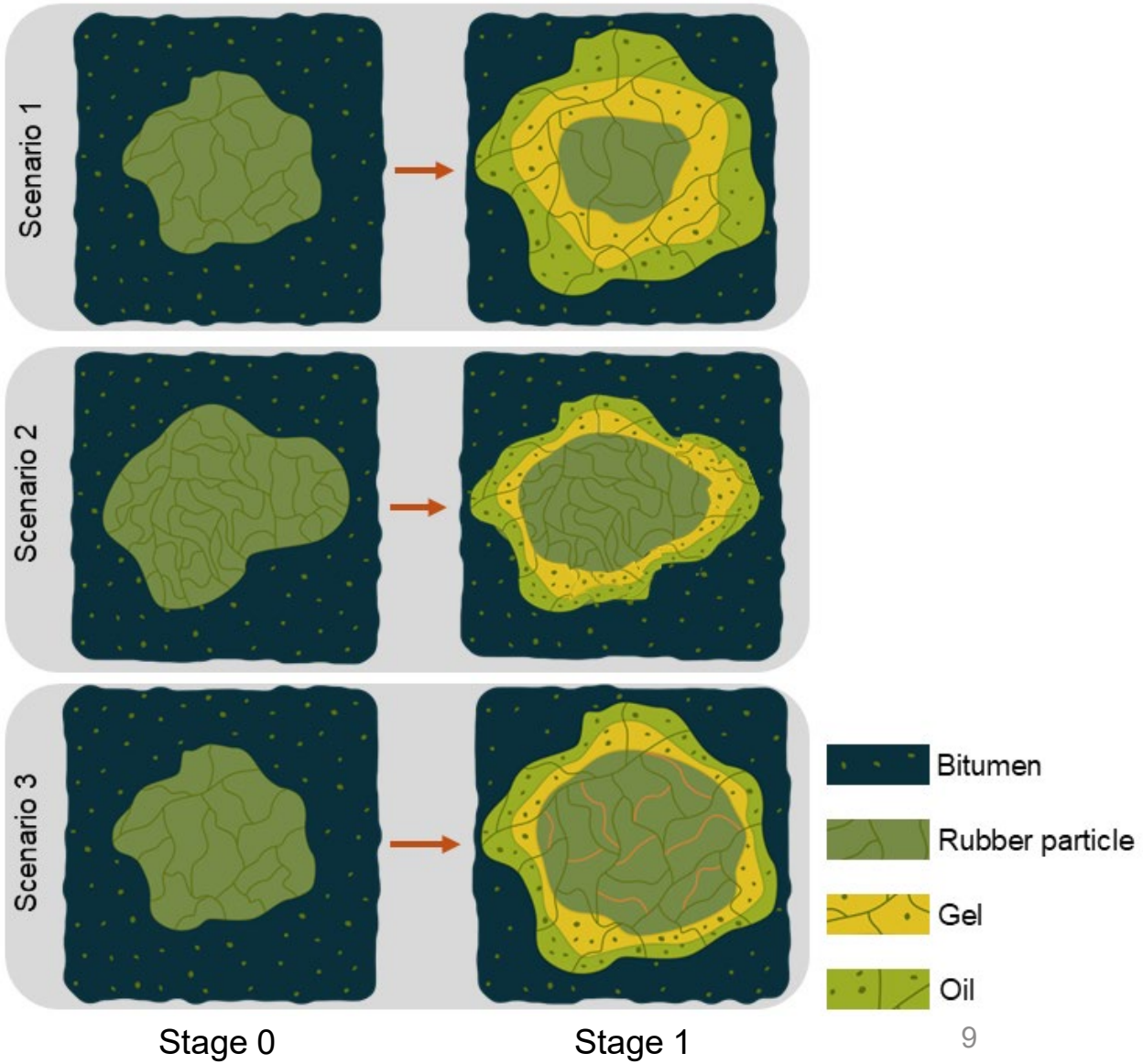
Crumb rubber digestion

- **CR particles absorb bitumen light fractions**
  - CR swelling
- **CR components are digested by bitumen**
  - mainly light oils and natural rubber
  - synthetic rubber may be digested at elevated temperatures
- **Process affected by:**
  - CR gradation
  - CR source and composition
  - CR content
  - bitumen source
  - blending temperature
  - blending time



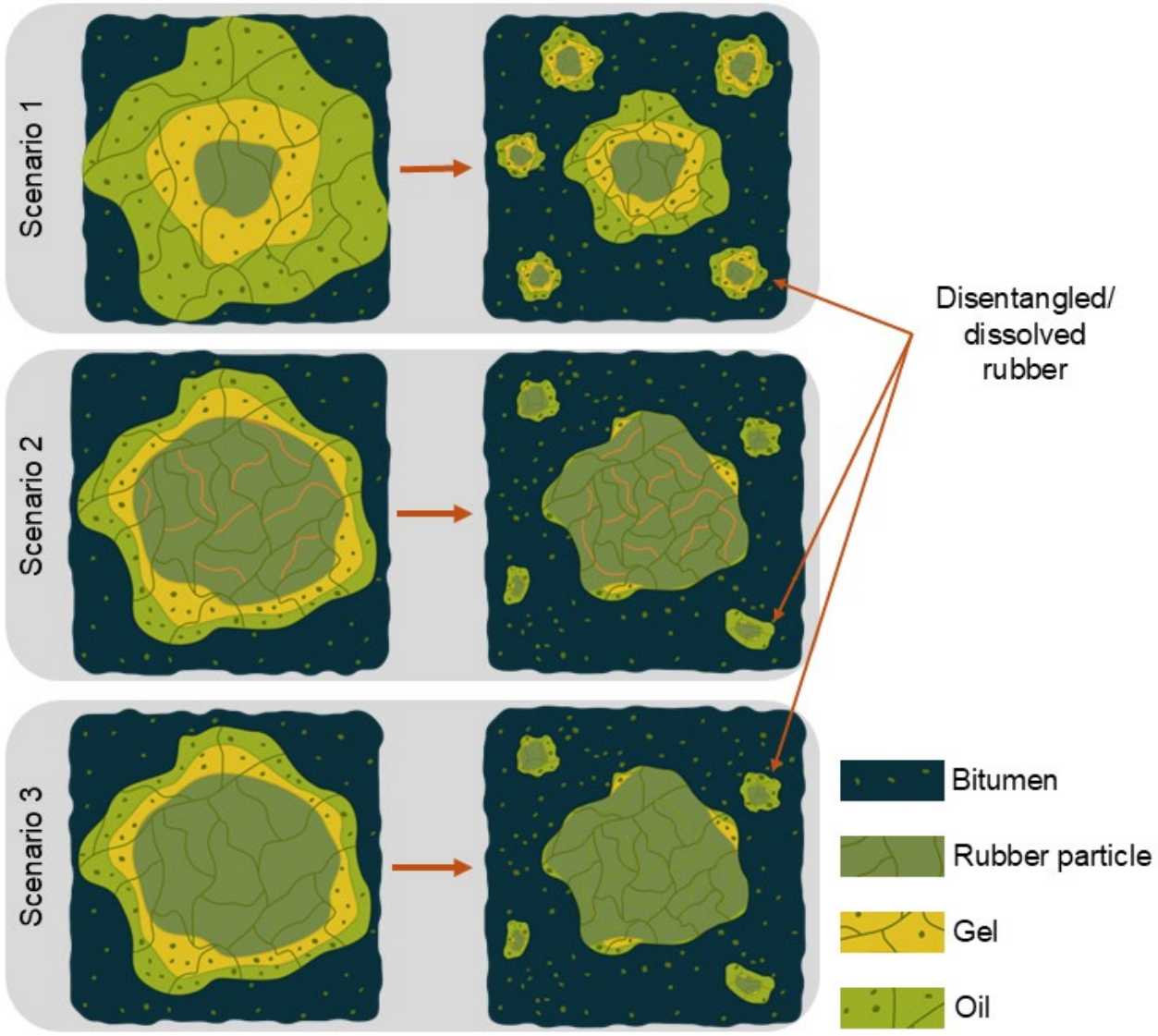
Crumb rubber digestion

- **Scenario 1**
  - relatively greater free volume and upon exposure to bitumen at elevated temperatures it swells
- **Scenario 2**
  - comparatively greater number of cross-links
- **Scenario 3**
  - relatively sparce molecular structure initially, but cross-links upon exposure to elevated temperatures



Crumb rubber digestion

- **Scenario 1**
  - dissolution after extensive exposure to bitumen at elevated temperatures
- **Scenario 2**
  - dissolution after prolonged exposure for rubber that cross-links or has low free volume
- **Scenario 3**
  - dissolution after short exposure time at relatively high temperature



Materials
Bitumen

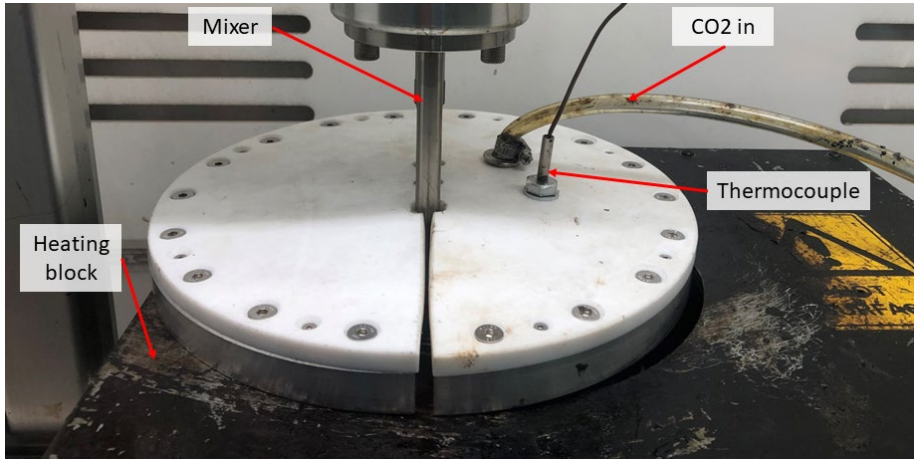
Property	Test method	C170 results	Main Roads Specification 511
Viscosity at 60 °C (Pa.s)	AS/NZS 2341.2	178	160-230
Viscosity at 135 °C (Pa.s)	AGPT/T111	0.36	0.30-0.50
Penetration at 25 °C (pu)	AS 2341.12	66	55-78
Percentage increase in viscosity at 60 °C after rolling thin film oven (RTFO) treatment (%)	AS/NZS 2341.10 and AS/NZS 2341.2	199	300 max.

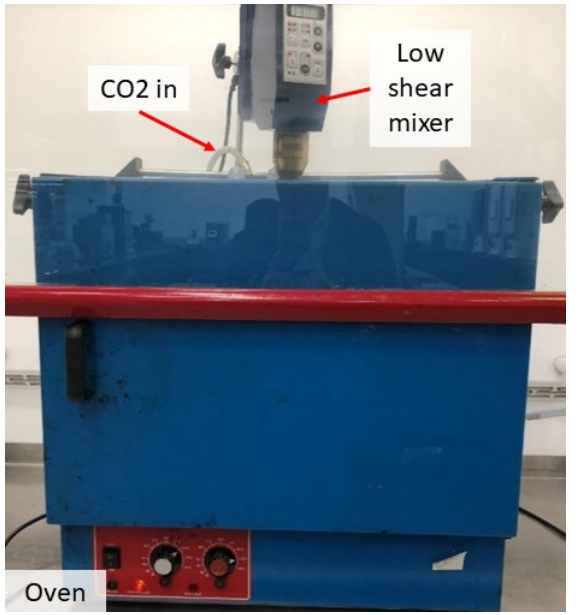
Materials
Crumb rubber

Property	Test method	Truck tyre rubber (TR)	Car tyre rubber (CT)	Conveyor belt rubber (CB)	Mining tyre rubber (MT)	Main Roads Specification 511	ATS 3110
S30							
Particle size distribution	AGPT/T143						
passing 2.36 (mm)		100.0	100.0	100.0	100.0	**100**	**100**
passing 1.18 (mm)		100.0	100.0	100.0	100.0	**100**	**100**
passing 0.6 (mm)		69.0	71.0	66.0	64.0	**60 – 100**	**60 min.**
passing 0.3 (mm)		14.0	16.0	16.0	17.0	**0 – 22**	**20 max.**
passing 0.15 (mm)		0.0	1.0	3.0	2.9	**-**	**-**
passing 0.075 (mm)		0.0	0.0	0.0	0.0	**0 – 2**	**-**
Particle length (mm)	AGPT/T143	0.5	0.5	0.5	0.5	**3 max.**	**3 max.**
Bulk density (kg/m^3)	AGPT/T144	349	347	327	294	**< 350**	**Report**
Water content (%)	AGPT/T143	0.5	0.5	1.0	0.5	**1 max.**	**1 max.**
Foreign materials – other than iron (%)	AGPT/T143	0.00	0.06	0.05	0.01	**0.1 max.**	**0.1 max.**
Foreign materials – metallic iron (%)	AGPT/T143	0.05	0.04	0.00	0.02	**0**	**0.1 max**
S16							
Particle size distribution	AGPT/T143						
passing 2.36 (mm)		100.0	100.0	100.0	100.0	**-**	**100**
passing 1.18 (mm)		87.0	88.0	90.0	89.9	**-**	**80 min.**
passing 0.6 (mm)		5.0	4.0	6.4	6.9	**-**	**10 max.**
passing 0.3 (mm)		1.0	0.0	1.2	1.5	**-**	**-**
Particle length (mm)	AGPT/T143	2.0	0.5	0.5	1.0	**-**	**3 max.**
Bulk density (kg/m^3)	AGPT/T144	332	402	357	417	**-**	**Report**
Water content (%)	AGPT/T143	0.7	0.0	1.0	0.4	**-**	**1 max.**
Foreign materials – other than iron (%)	AGPT/T143	0.01	0.05	0.08	0.00	**-**	**0.1 max.**
Foreign materials – metallic iron (%)	AGPT/T143	0.04	0.01	0.10	0.01	**-**	**0.1 max**

Sample preparation
Binder blending

- **1st hour of blending**
  - 4 L tin in air forced oven at 150°C until C170 free-flowing
  - 4 L tin placed in heating block with CO2 blanket (5 L/min)
  - condition C170 to blending temperature (165 or 190°C)
  - gradually added 18 wt.% CR
  - low shear mixing at 1300 rpm
- **Remaining blending in different oven**



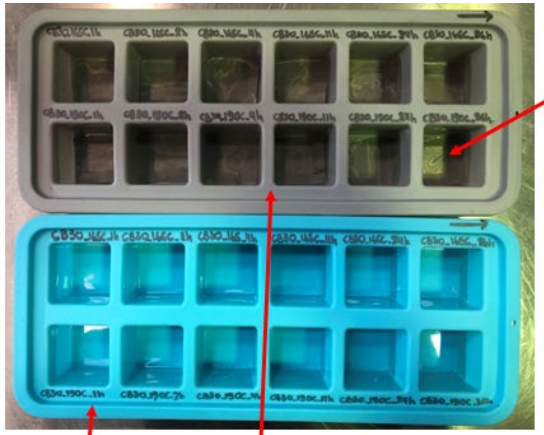


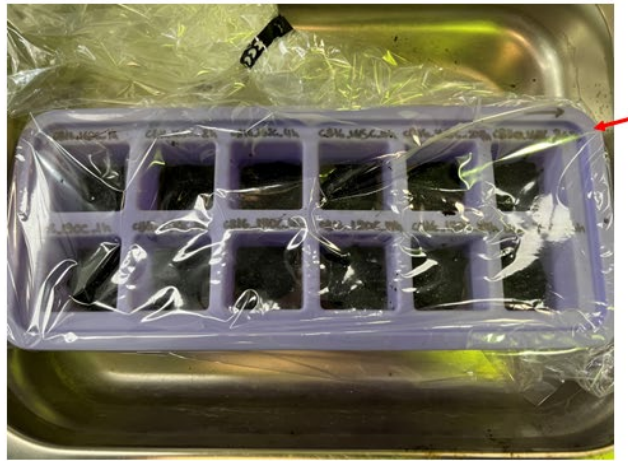
Sample preparation
Soxhlet extraction

- **Extract the solid phase of binder**
- **In toluene for 48 hours as per WA 238.1:2022**
- **AGPT/T142:2020**
  - CR recovery factor
  - mass before and after

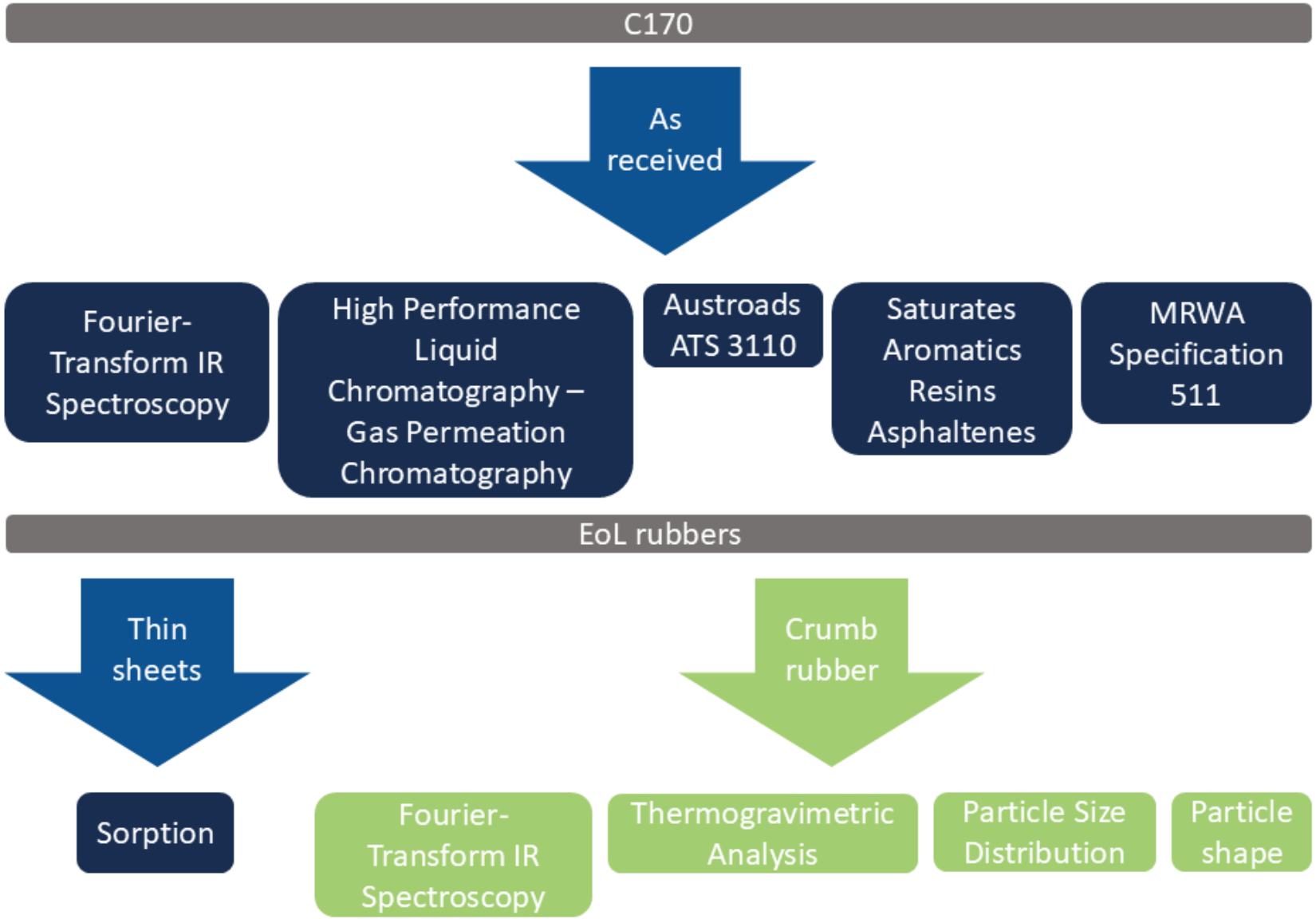
Sample preparation
Melt extraction

- Extract the liquid phase of binder
- Air forced oven at 165°C for 30 minutes
- Removed and placed in a refrigerator for rapid cooling

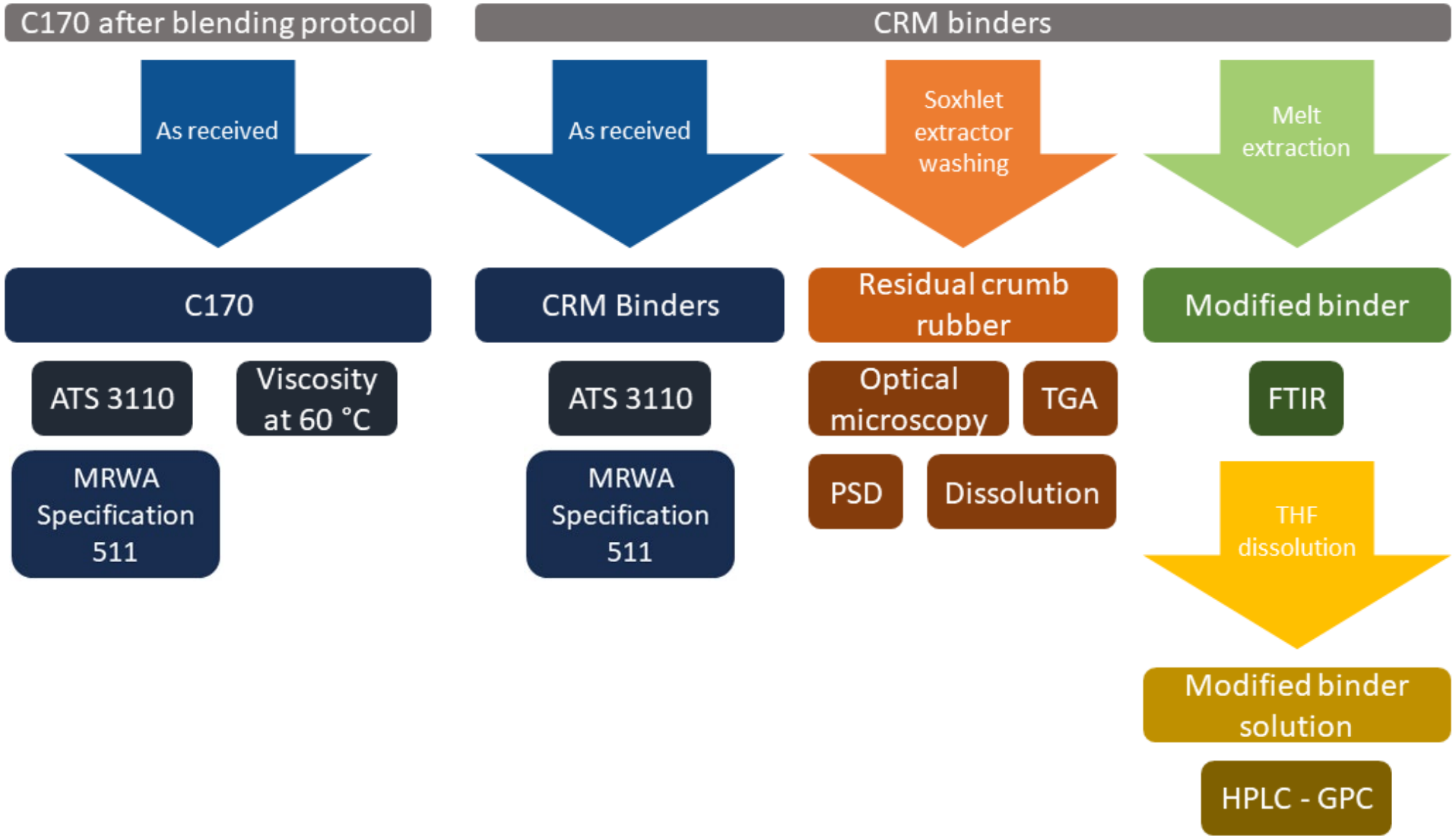




Experimental methods:
Bitumen and crumb rubber



Experimental methods
CRMBs and constituents following digestion



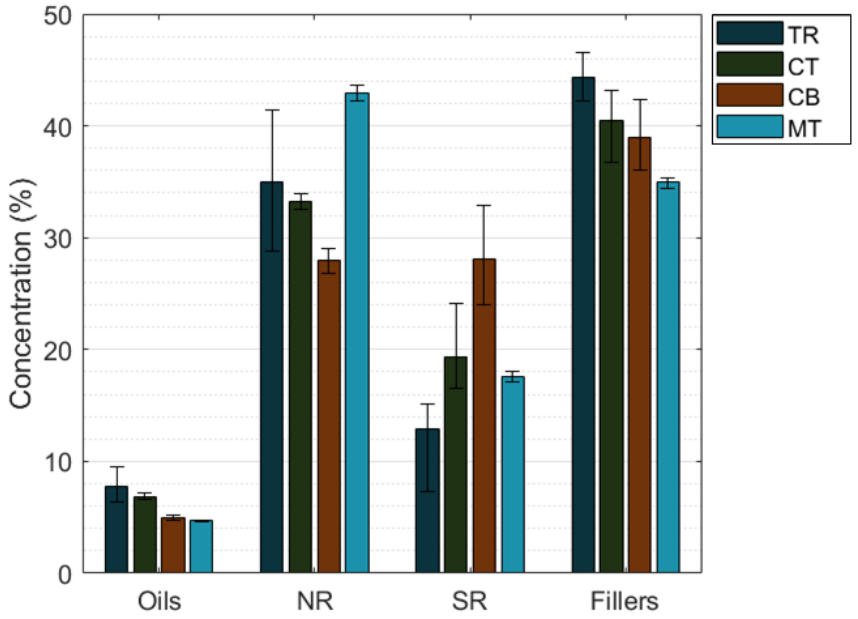
Questions?

Results
Viscosity at 60°C

- AS/NZS 2341.2
- C170 before and after blending

Samples	Digestion time						
	0h	1h	2h	4h	11h	24h	36h
C170	178	-	-	-	-	-	-
C170_165C_	-	186	-	-	-	-	957
C170_190C_	-	187	198	333	246	569	19,136

Results
Thermogravimetric analysis

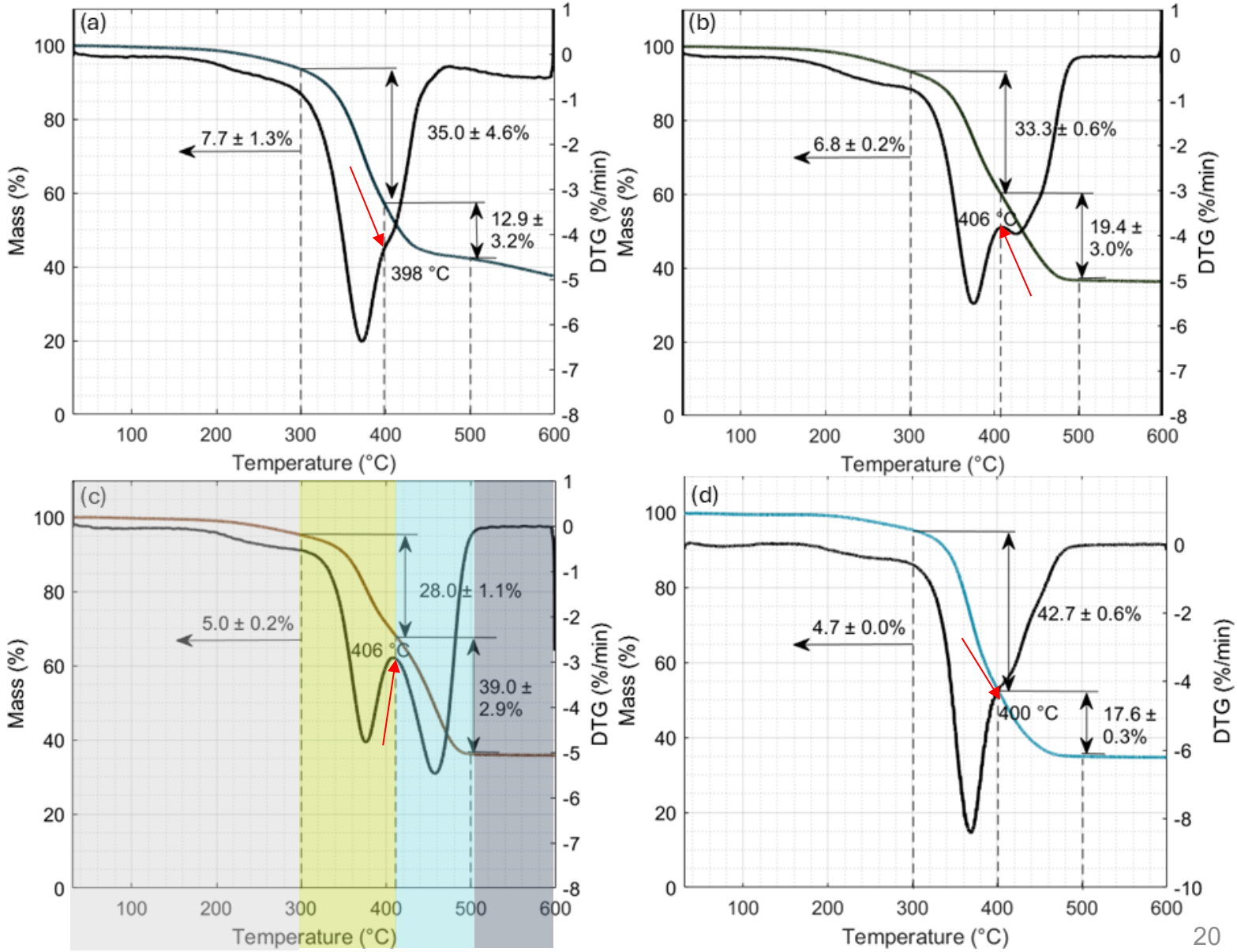


(a) Truck tyre-derived CR

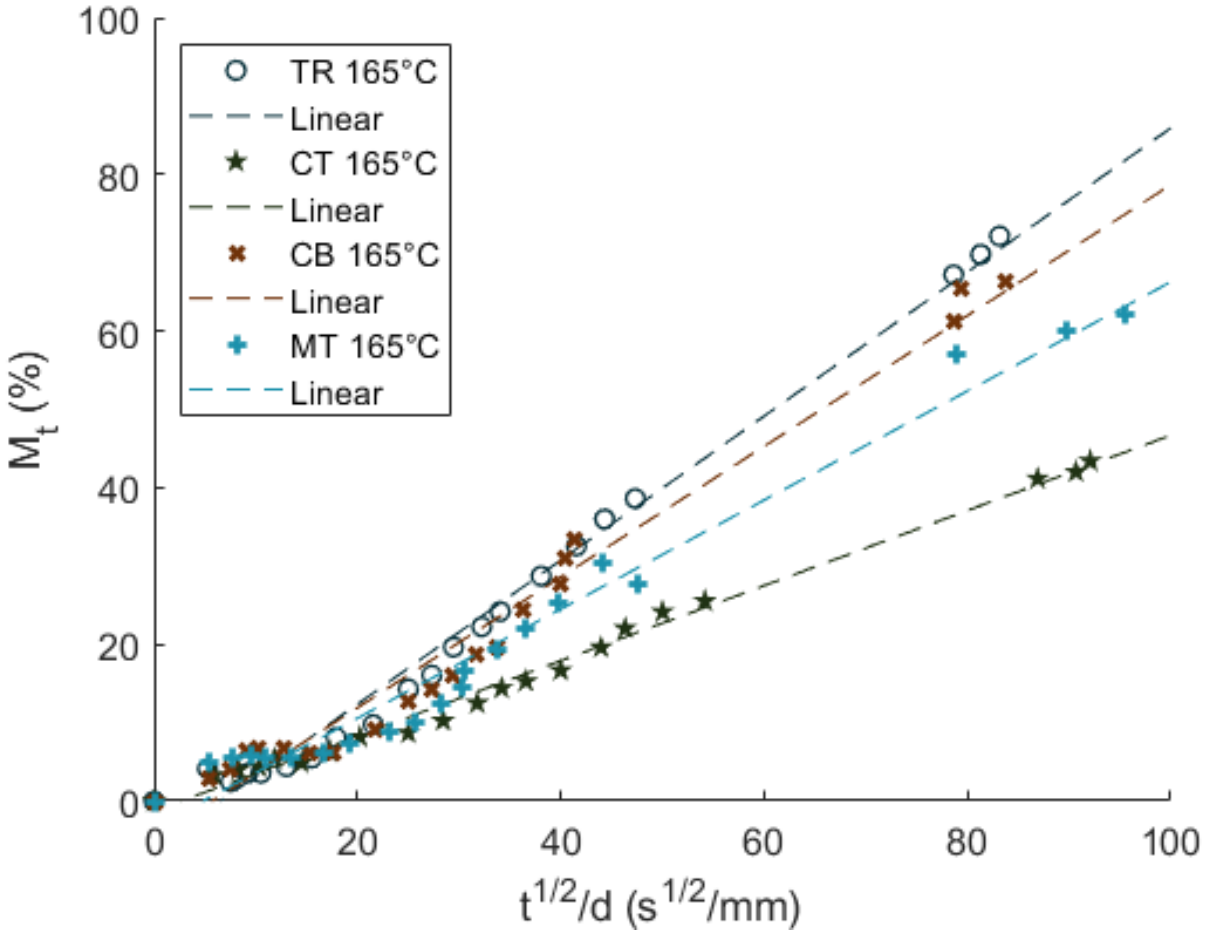
(b) Car tyre-derived CR

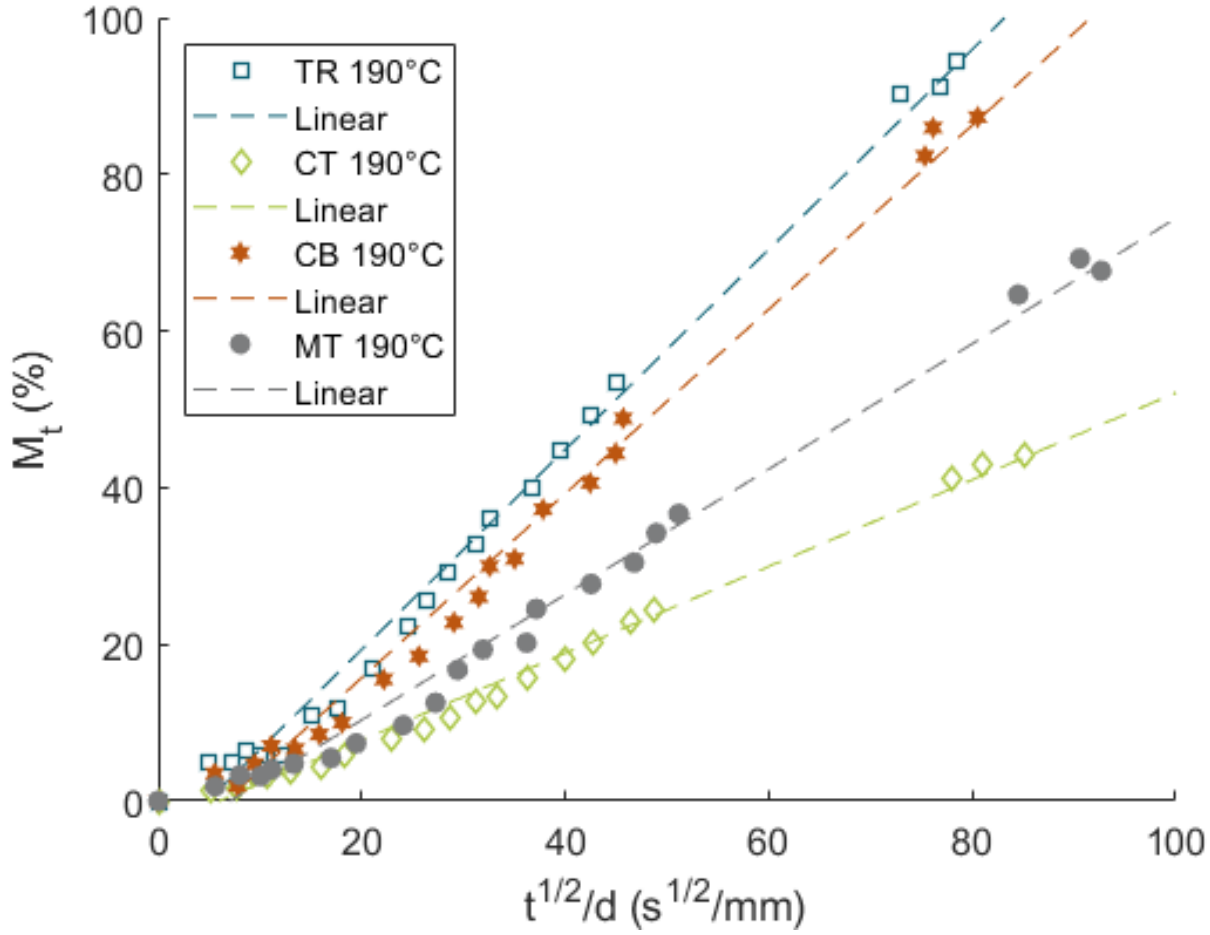
(c) Conveyor belt-derived CR

(d) Mining tyre-derived CR



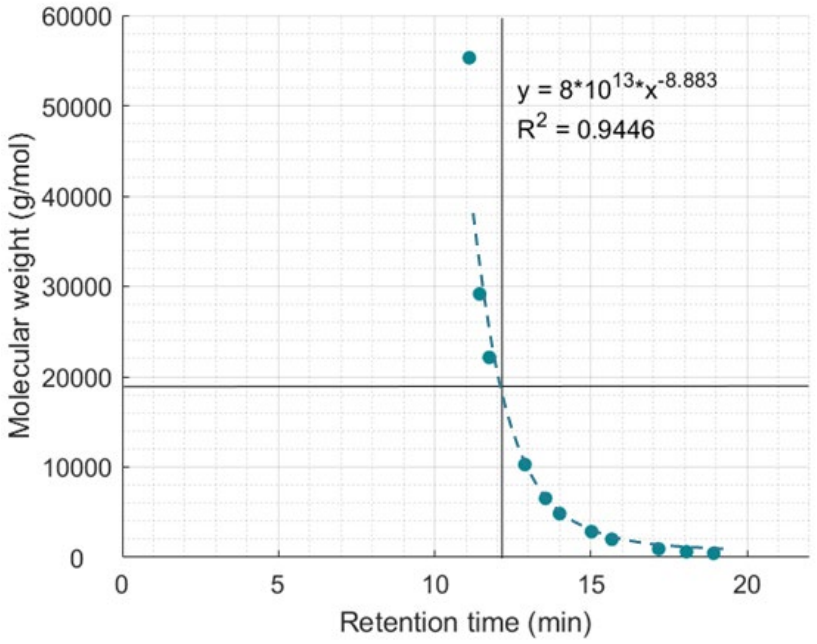
Results
Sorption

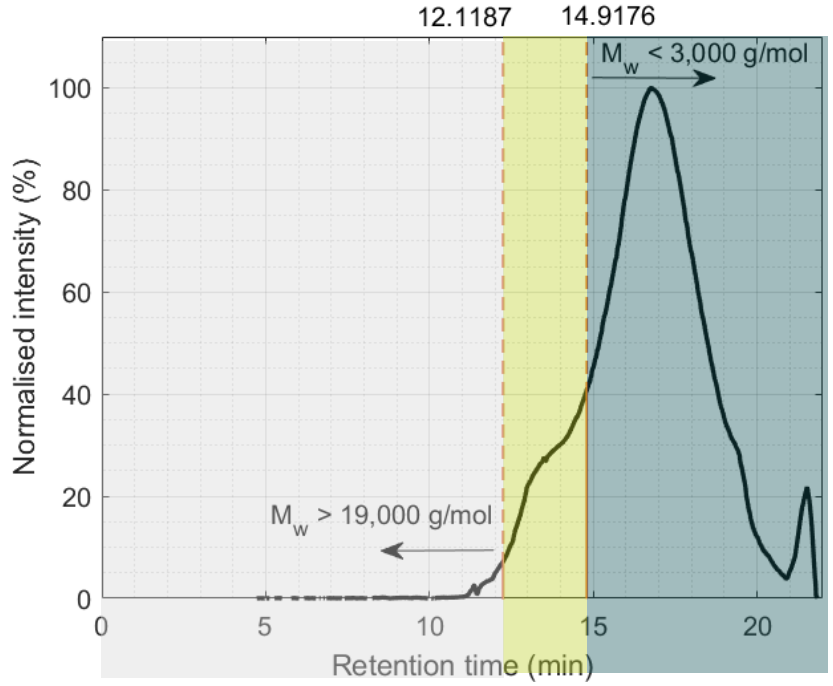




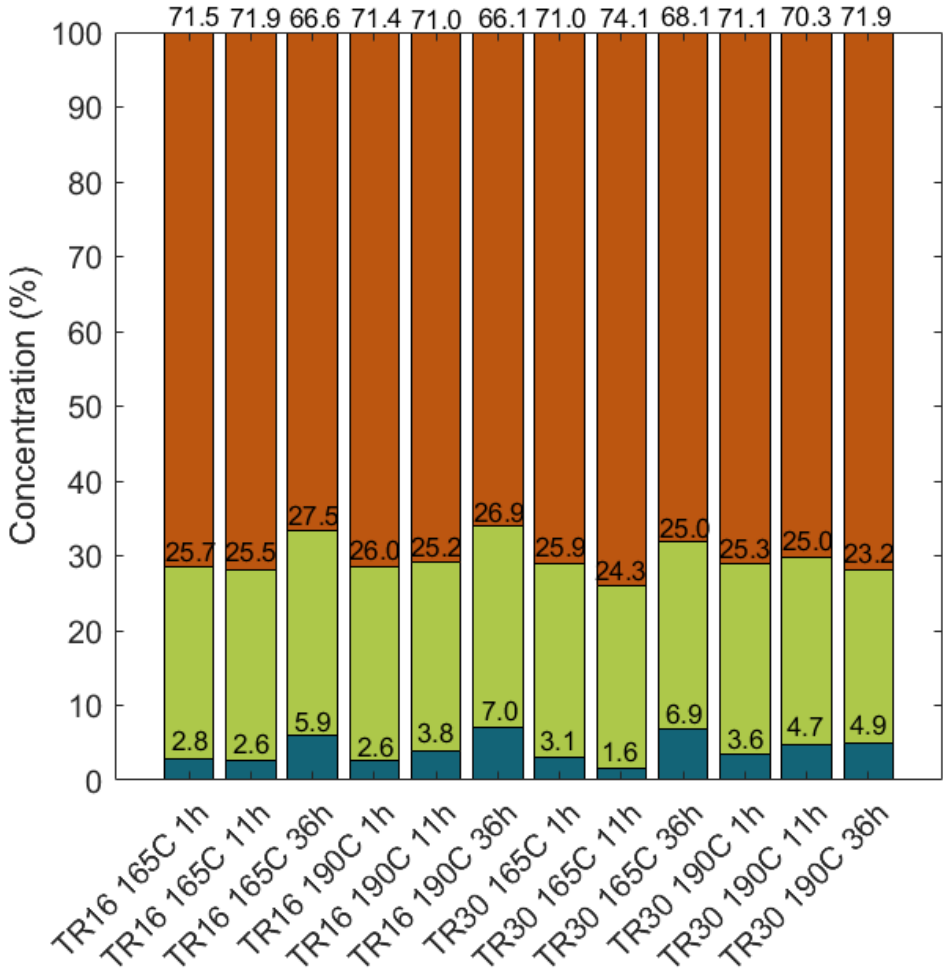
Results
High performance liquid chromatography – gas permeation chromatography

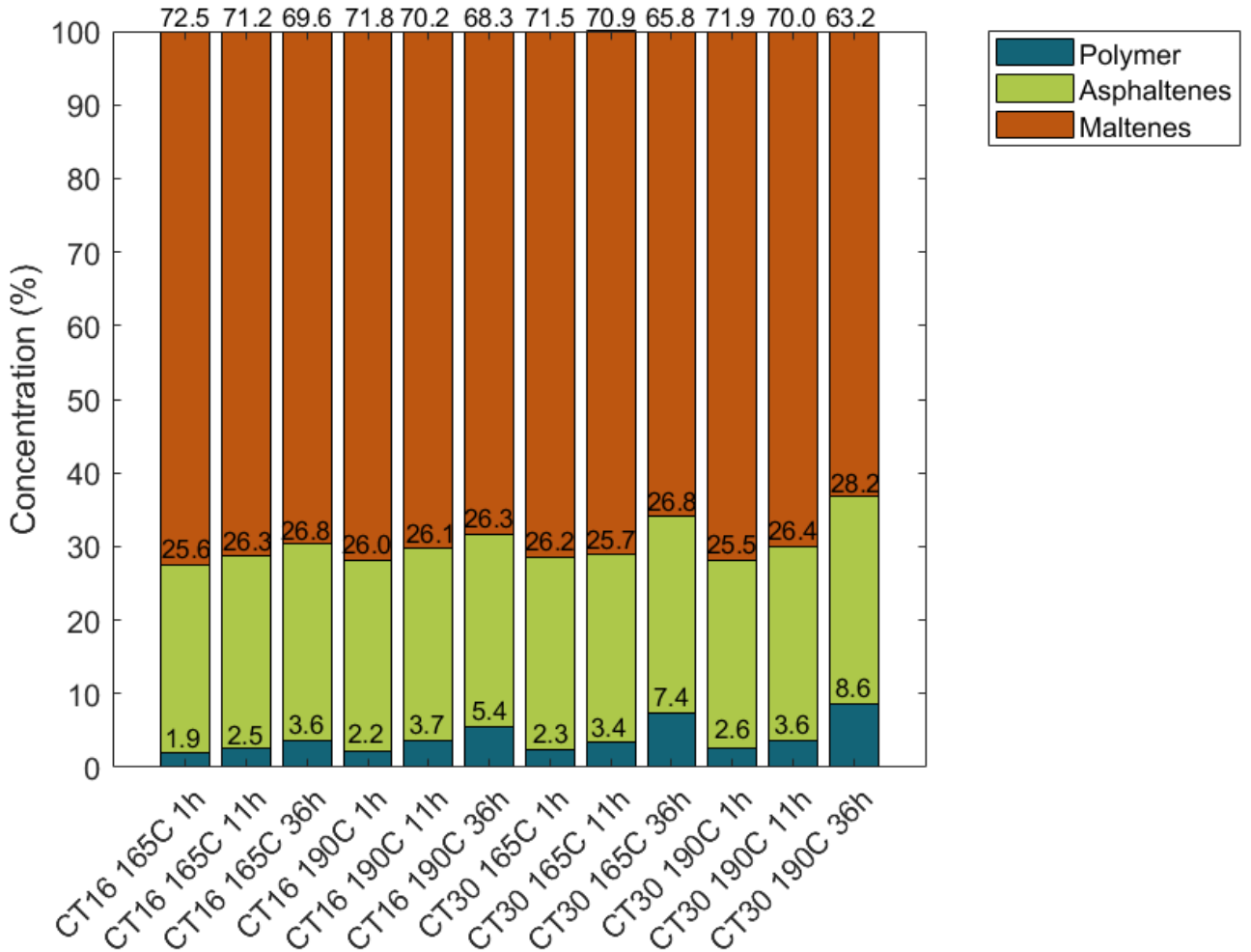
- Mw > 19,000 g/mol = polymer content
- Mw < 3,000 g/mol = maltenes
- 19,000 g/mol < Mw < 3,000 g/mol = asphaltenes



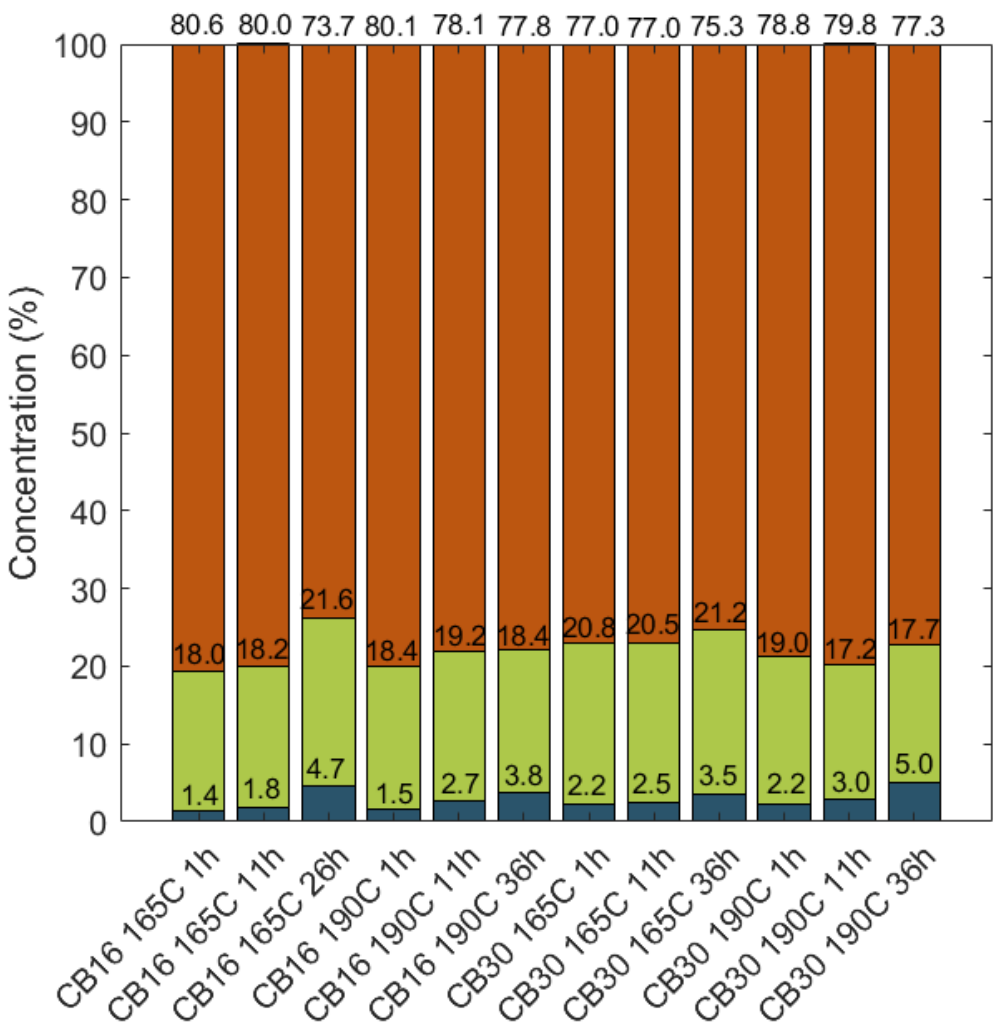


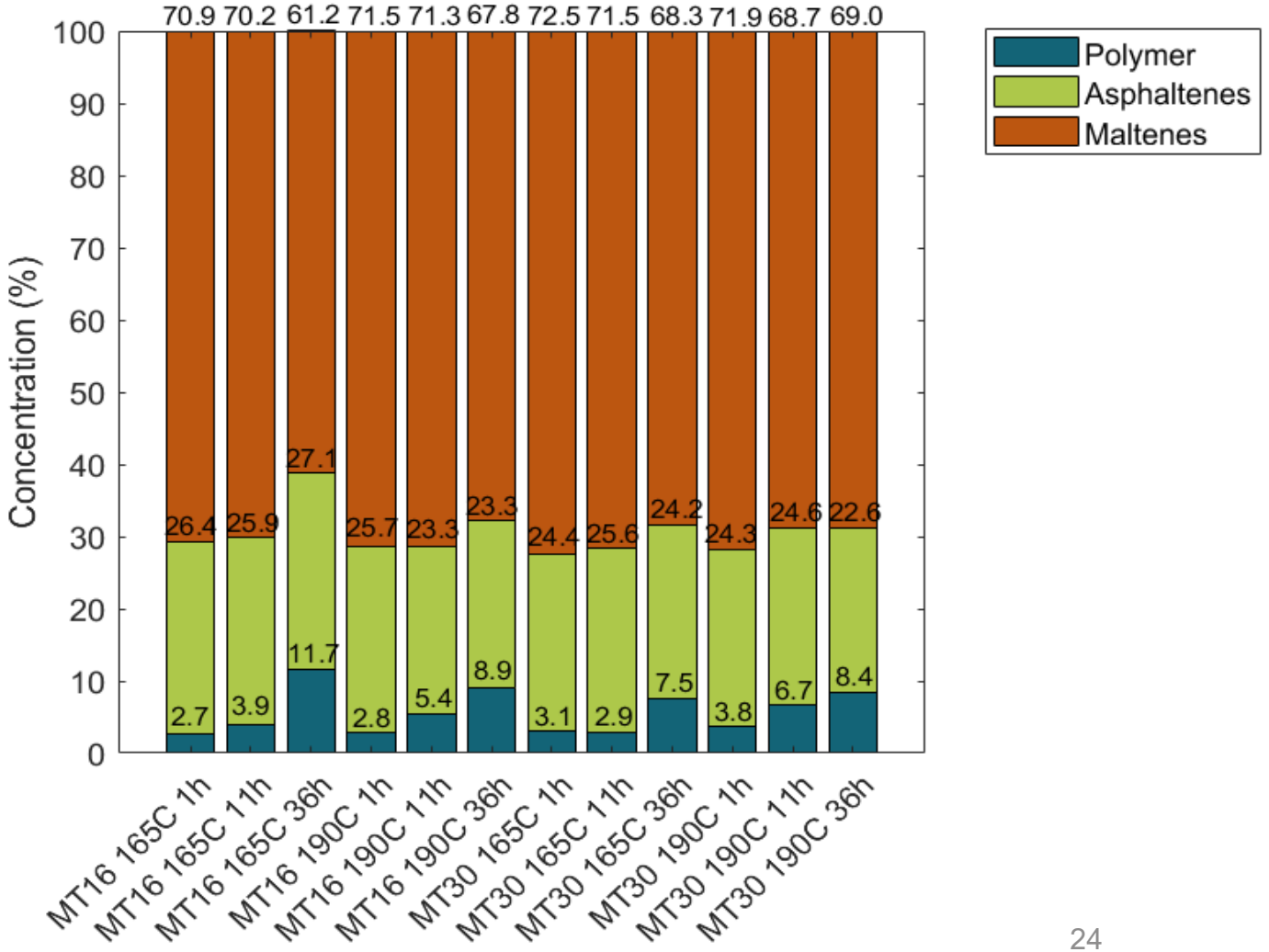
Results
High performance liquid chromatography – gas permeation chromatography





Results
High performance liquid chromatography – gas permeation chromatography



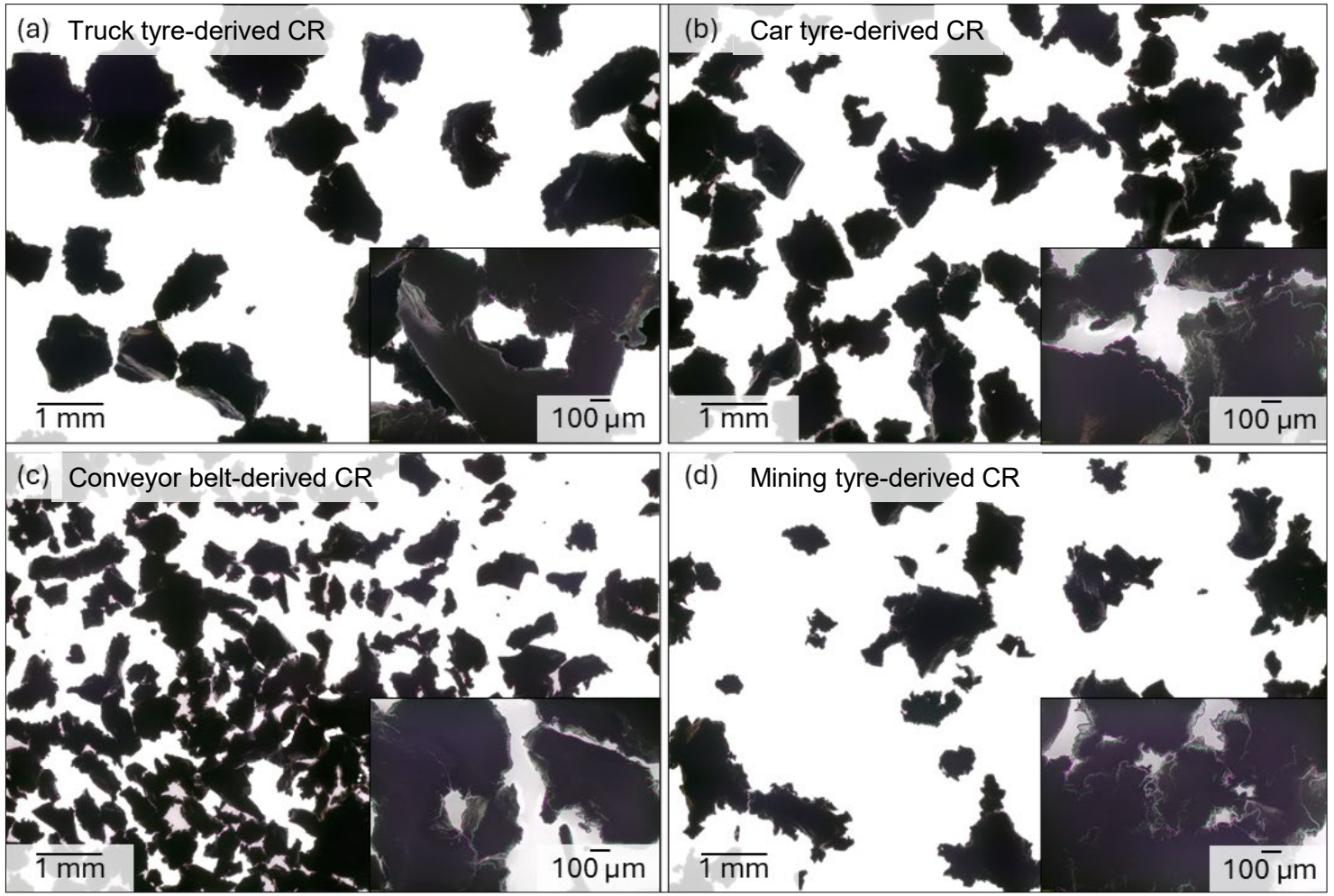


Results
CRMB characteristics, handling and performance properties

- **Characteristics**
  - ATM-132: 2022 - Compressive limit at 70 °C
- **Handling properties**
  - ATM-111:2022 - Viscosity and 165 and 175 °C
  - ATM-103:2022 - Loss on heating
- **Elasticity**
  - ATM-122:2022 - Torsional recovery at 25 °C
  - ASTM D3229-20 - Resilience at 25 °C
- **Rutting resistance**
  - AGPT-T131:2006 - Softening point
  - AGPT-T121:2014 - Consistency 6% at 60 °C
- **Fatigue life**
  - AGPT-T125:2018 - stress ratio 10 °C

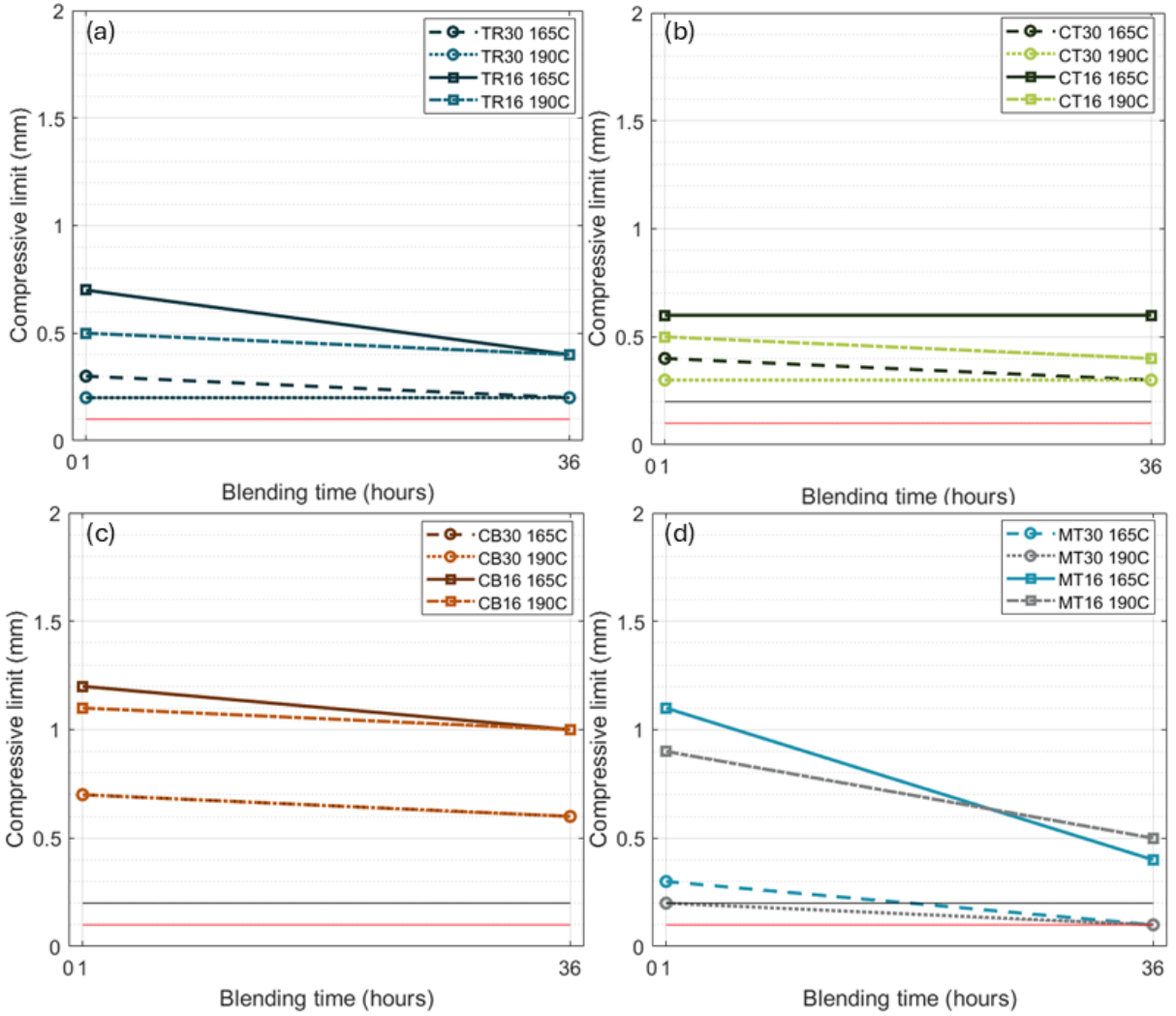
Results
Reporting

- **Test report values in tabulated format**
- **Test report values plotted**
  - MRWA Specification 511
  - ATS 3110
- **ANOVA in table, $p < 0.05$**
- **Main effect plots**
- **Interaction plots**

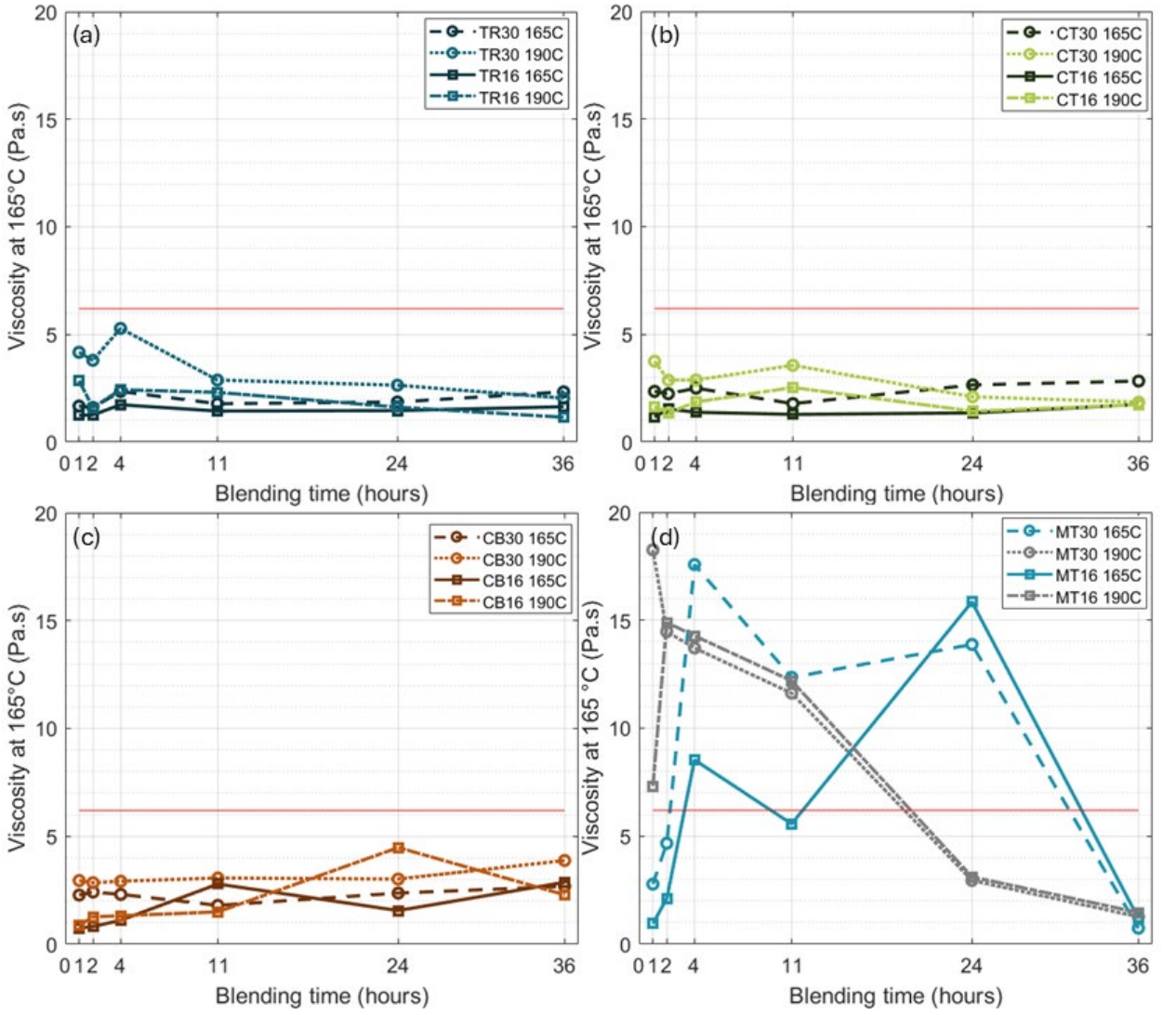


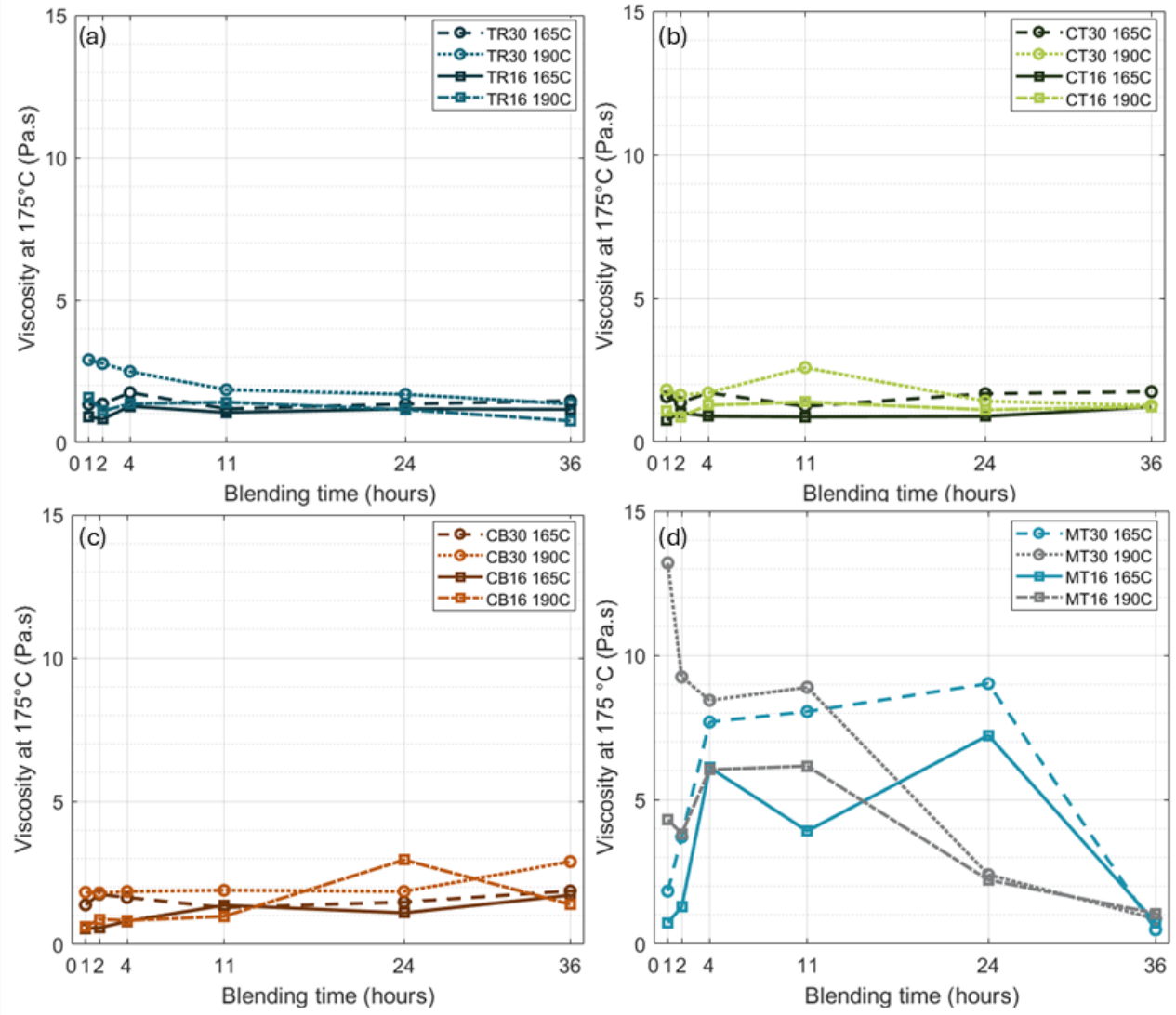
Results
Characteristics: Compressive limit at 70°C

- S30 MT-derived CRMBs blended for 36 hours were below the MRWA Specification 511:2025 limit
- All CRMBs met the limit in ATS 3110:2023



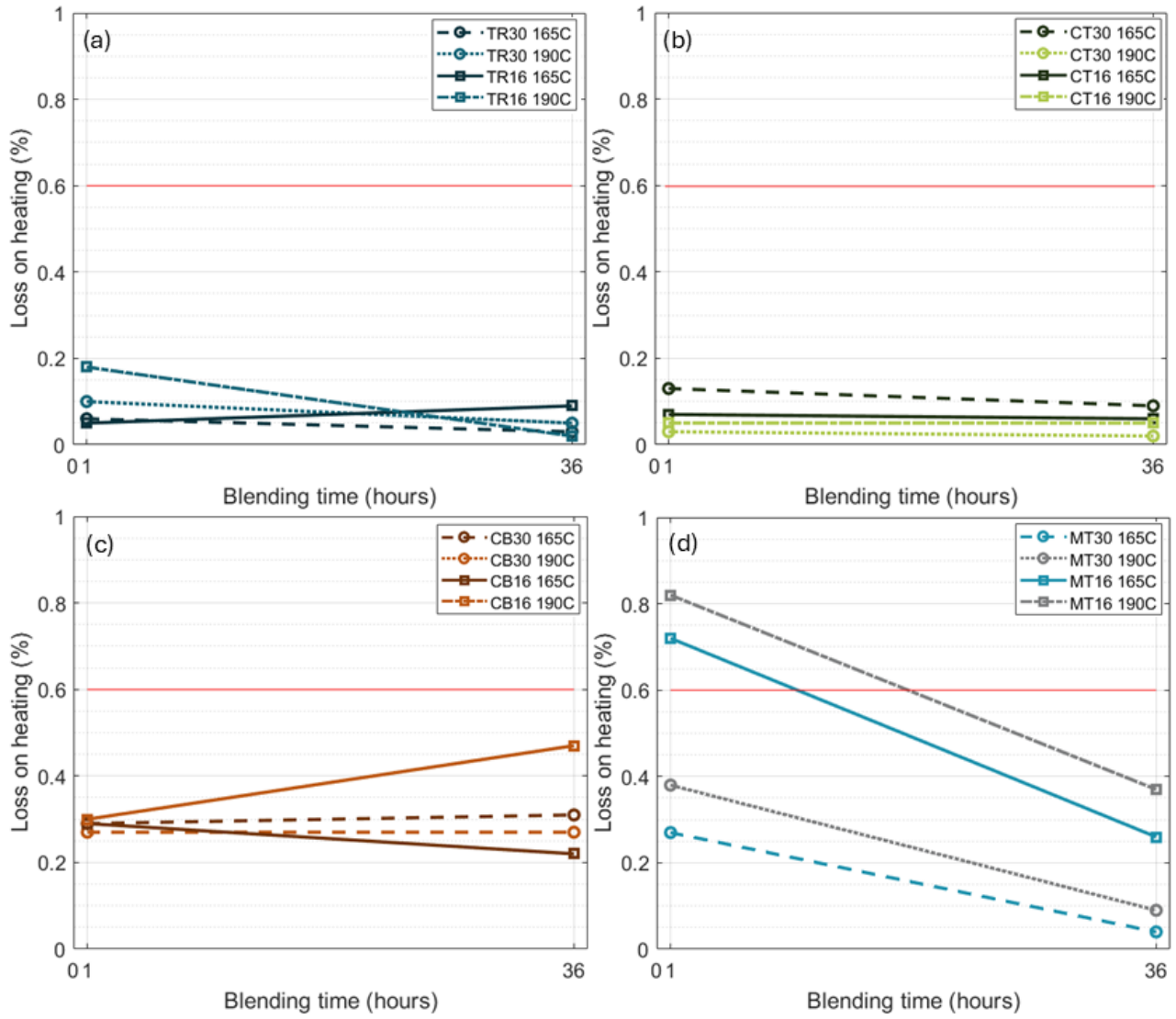
Results
Handling: Viscosity 165 and 175°C



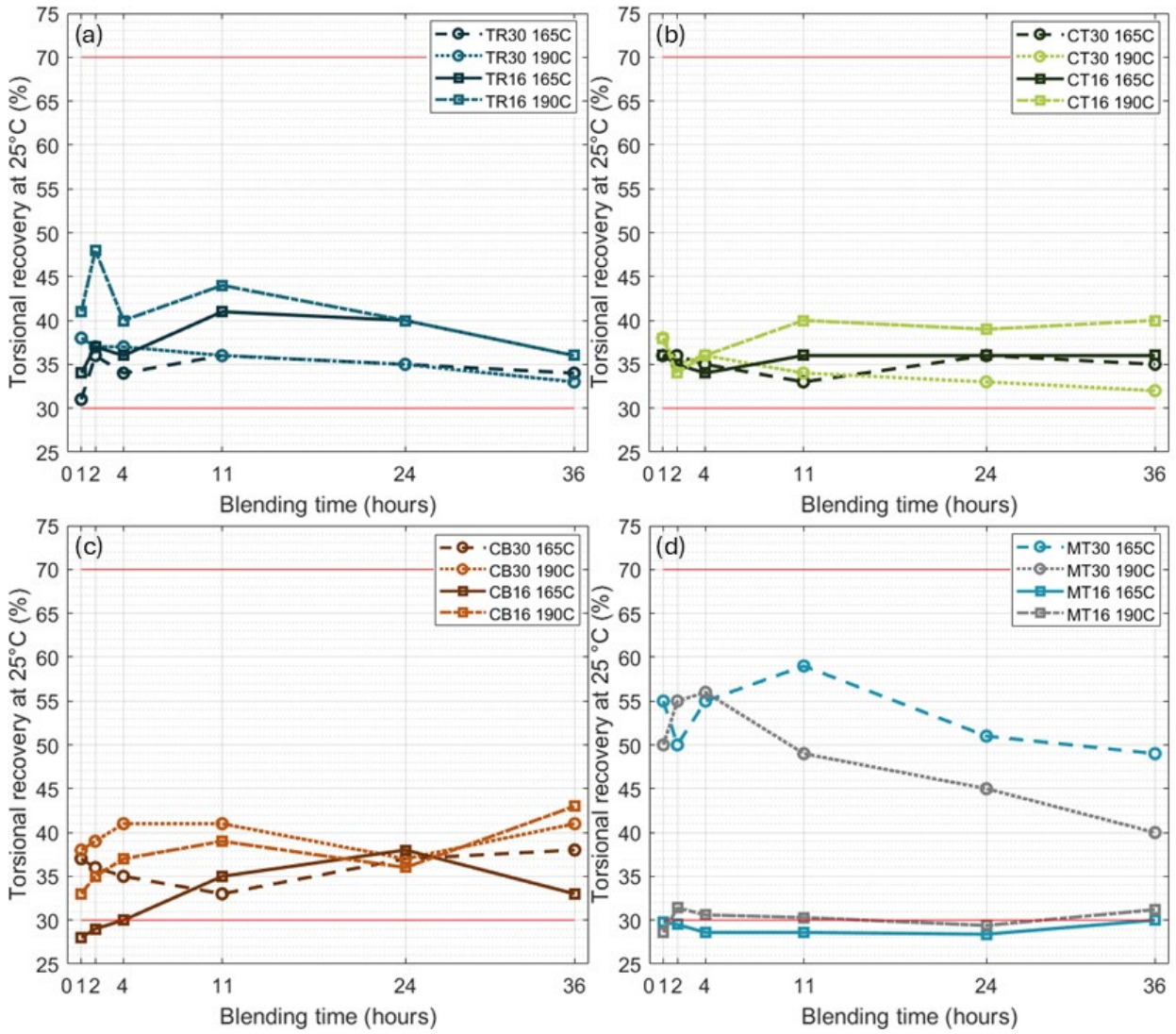


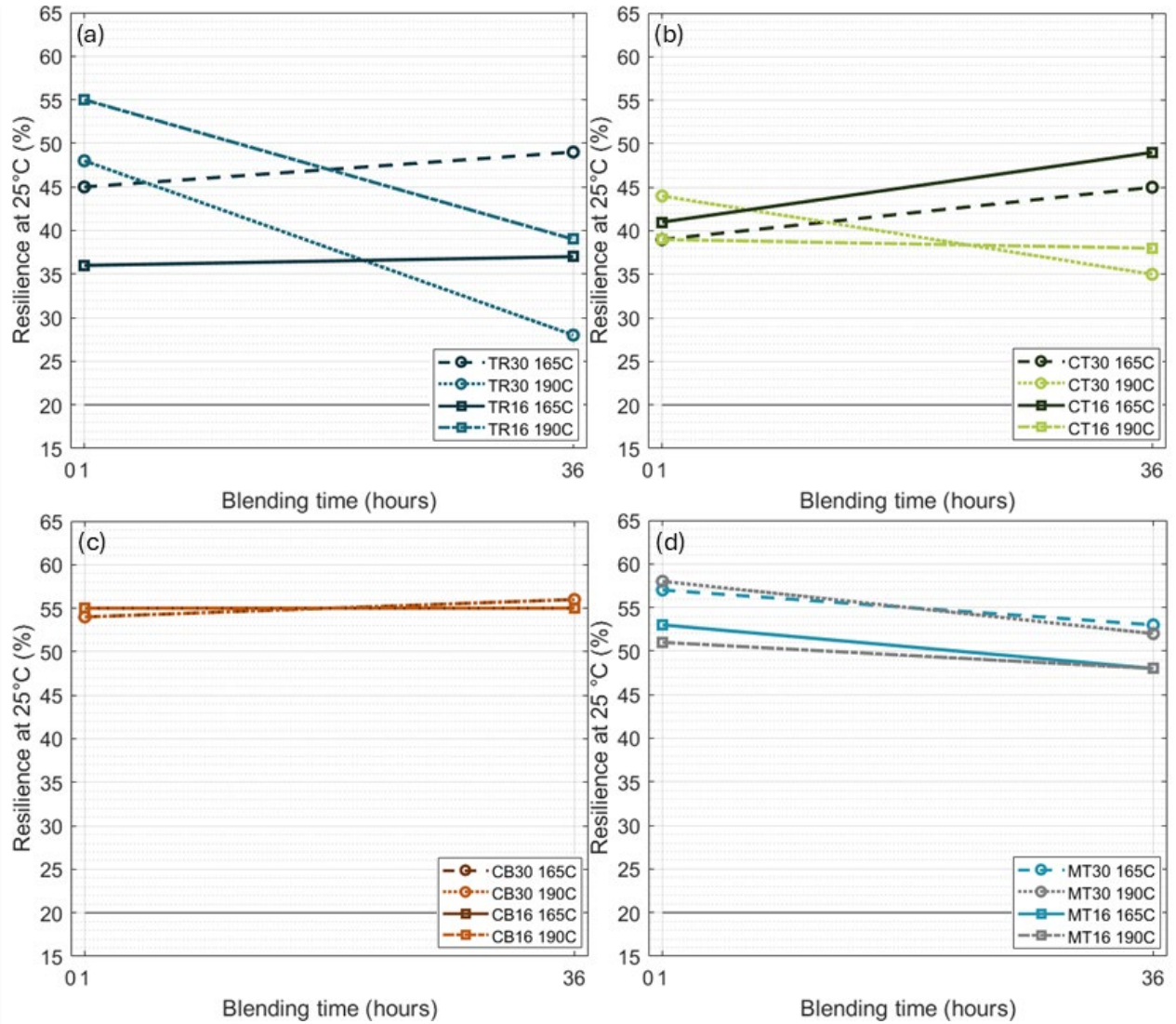
Results
Handling: Loss on heating

- **All CRMBs met the limit in ATS 3110:2023 except:**
  - MT16_165C_1h
  - MT16_190C_1h



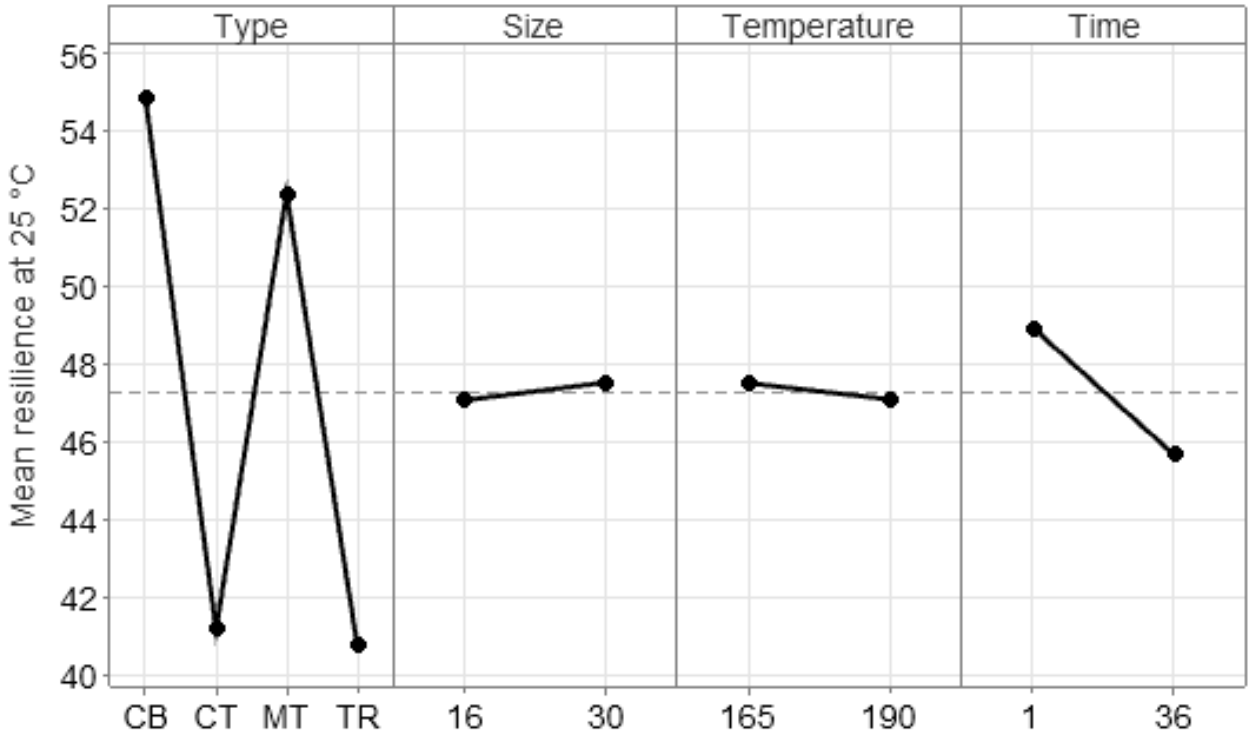
Results
Elasticity





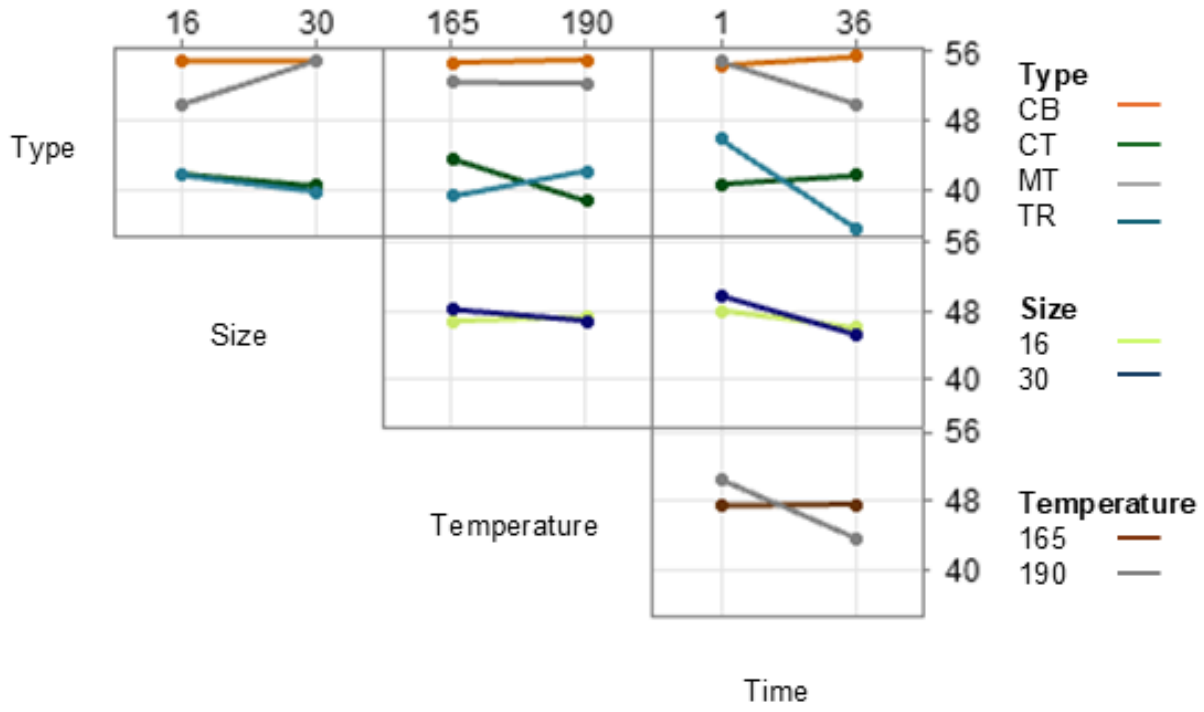
Results
Elasticity: Resilience at 25°C

Source	DF	Adj SS	Adj MS	F-value	P-value
Type	3	2609.71	869.903	39.31	0.000
Size	1	3.38	3.376	0.15	0.698
Temperature	1	2.85	2.848	0.13	0.721
Time	1	170.63	170.629	7.71	0.007
Error	57	1261.52	22.132		
Lack-of-fit	25	1256.81	50.272	341.19	0.000
Pure error	32	4.71	0.147		
Total	63	4048.09			



Results
Elasticity: Resilience at 25°C

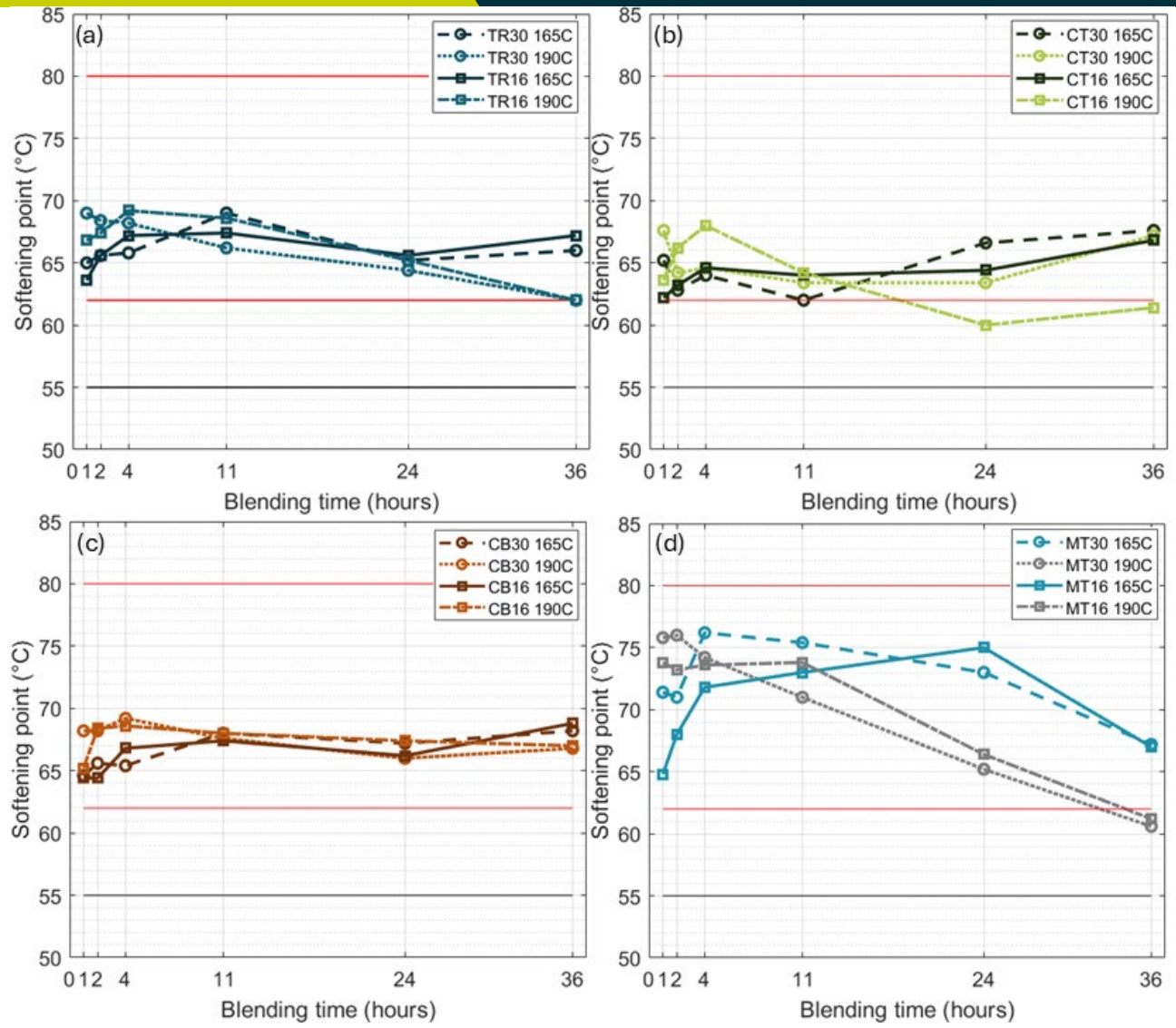
- Torsional recovery at 25°C and resilience at 25°C both relate to elasticity
- Greatest elasticity according to torsional recovery at 25°C results for sample MT30_190C_11h
- Greatest elasticity according to resilience at 25°C results for sample CB30_165C_1h



Results
Rutting resistance: Softening point

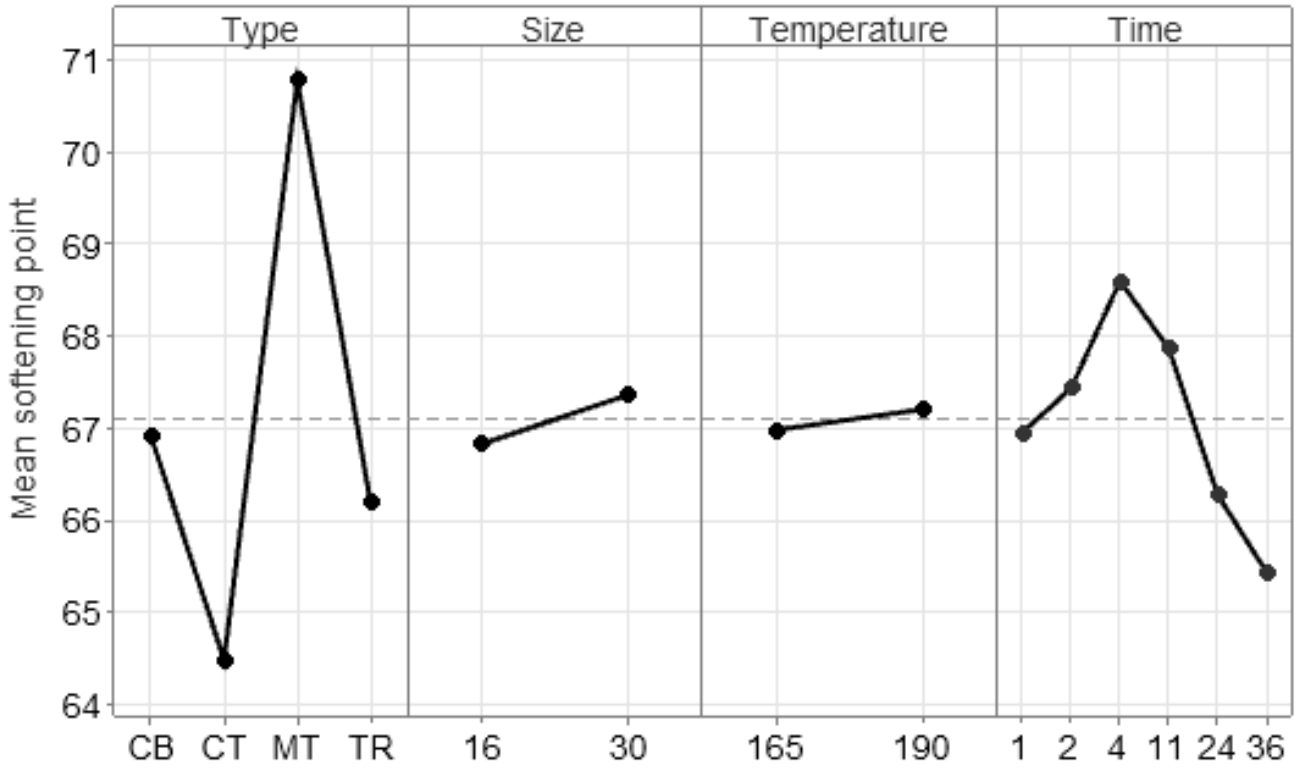
- All CRMBs within MRWA Specification 511:2025 limits
- 4 CRMBs below ATS 3110:2023 limits
- Impact of oxidation

Samples	Digestion time						
	0h	1h	2h	4h	11h	24h	36h
C170	49.0	-	-	-	-	-	-
C170_165C	-	48.2	-	-	-	-	58.6
C170_190C	-	49.0	49.8	51.6	49.2	55.6	74.2



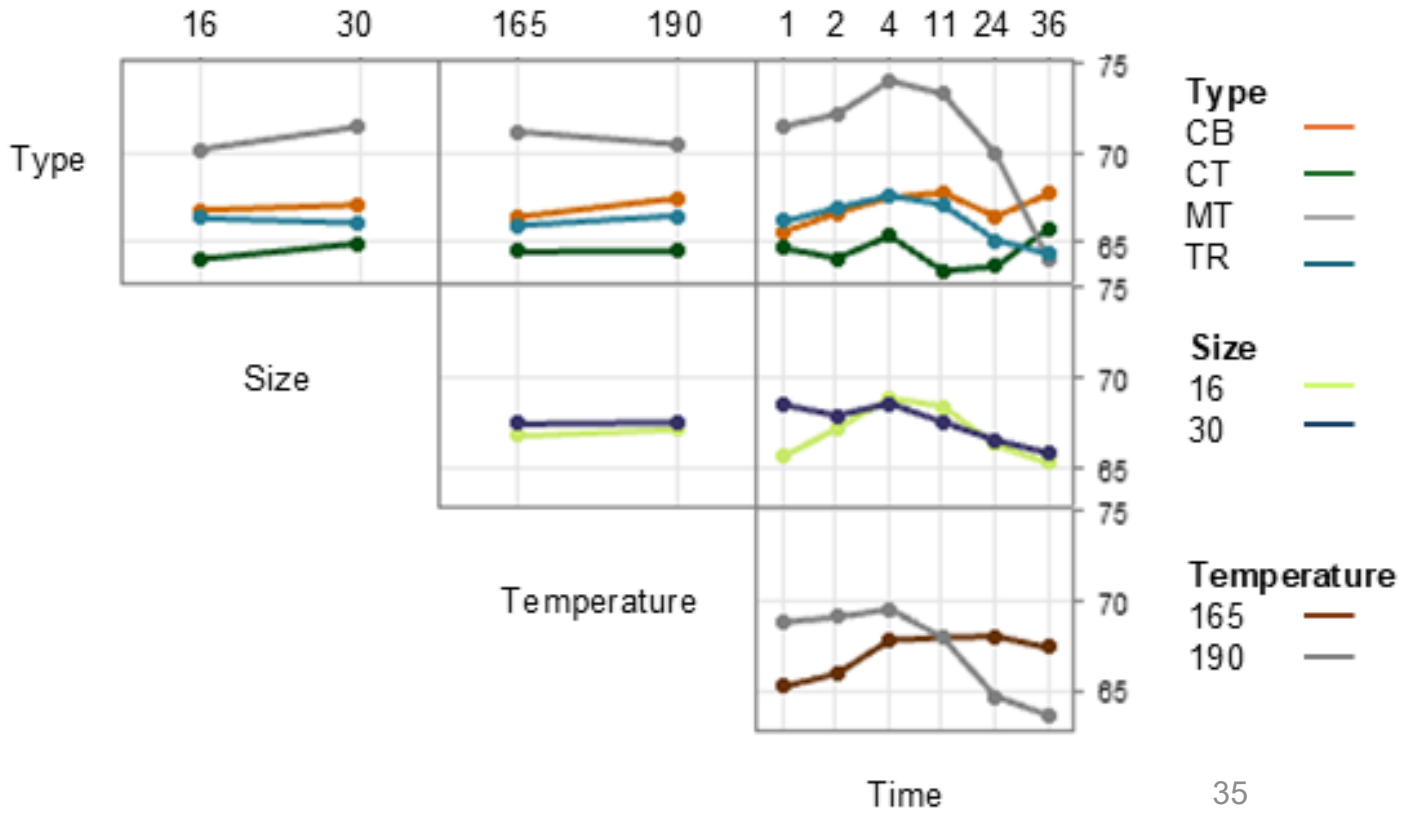
Results
Rutting resistance: Softening point

Source	DF	Adj SS	Adj MS	F-value	P-value
Type	3	1022.41	340.804	49.85	0.000
Size	1	13.95	13.954	2.04	0.155
Temperature	1	2.44	2.444	0.36	0.551
Time	1	205.78	41.155	6.02	0.000
Error	181	1237.49	6.837		
Lack-of-fit	85	1234.43	14.523	456.68	0.000
Pure error	96	3.05	0.032		
Total	191	2482.07			



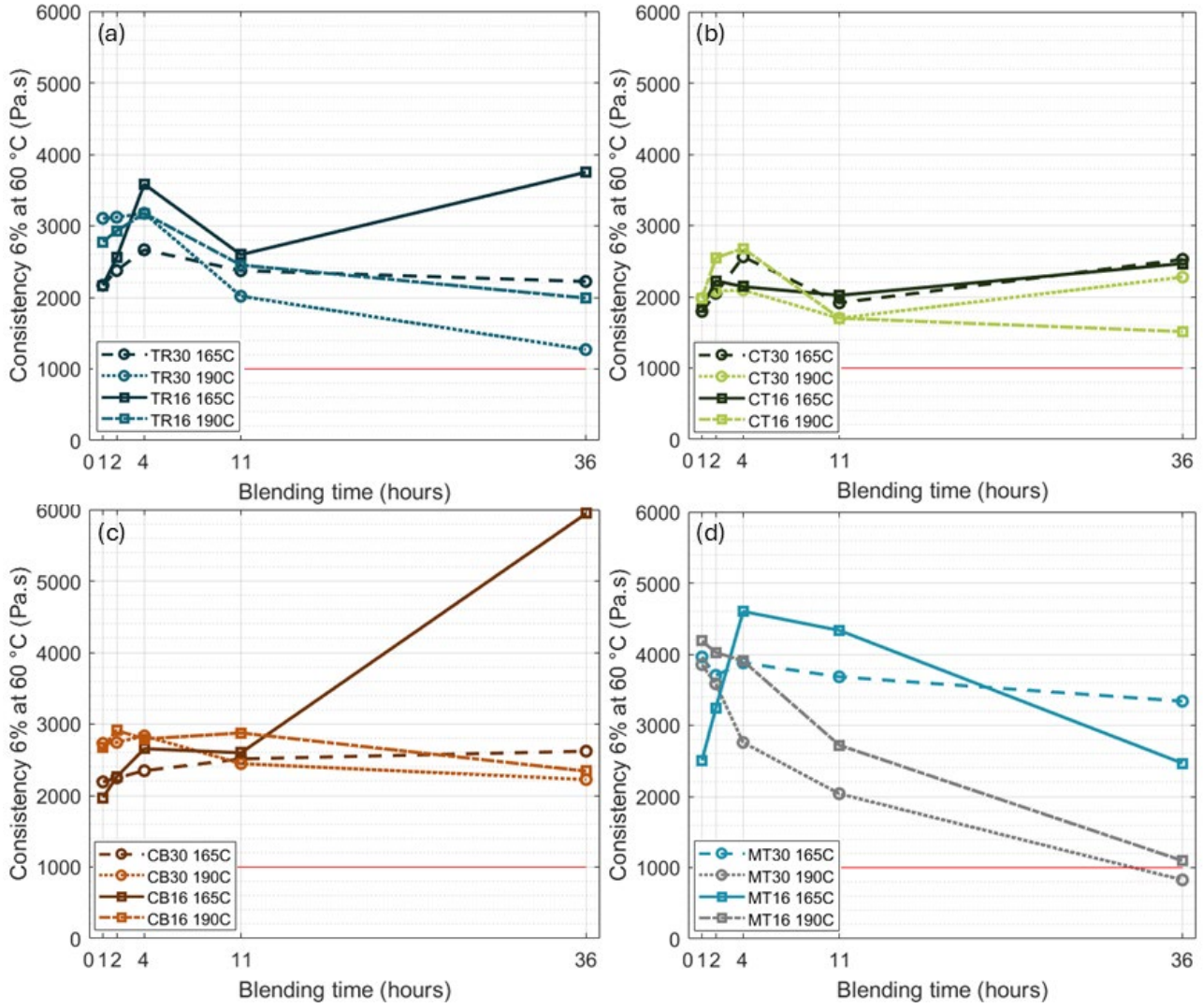
Results
Rutting resistance: Softening point

- **Interactions between all parameters with CR size and blending temperature**



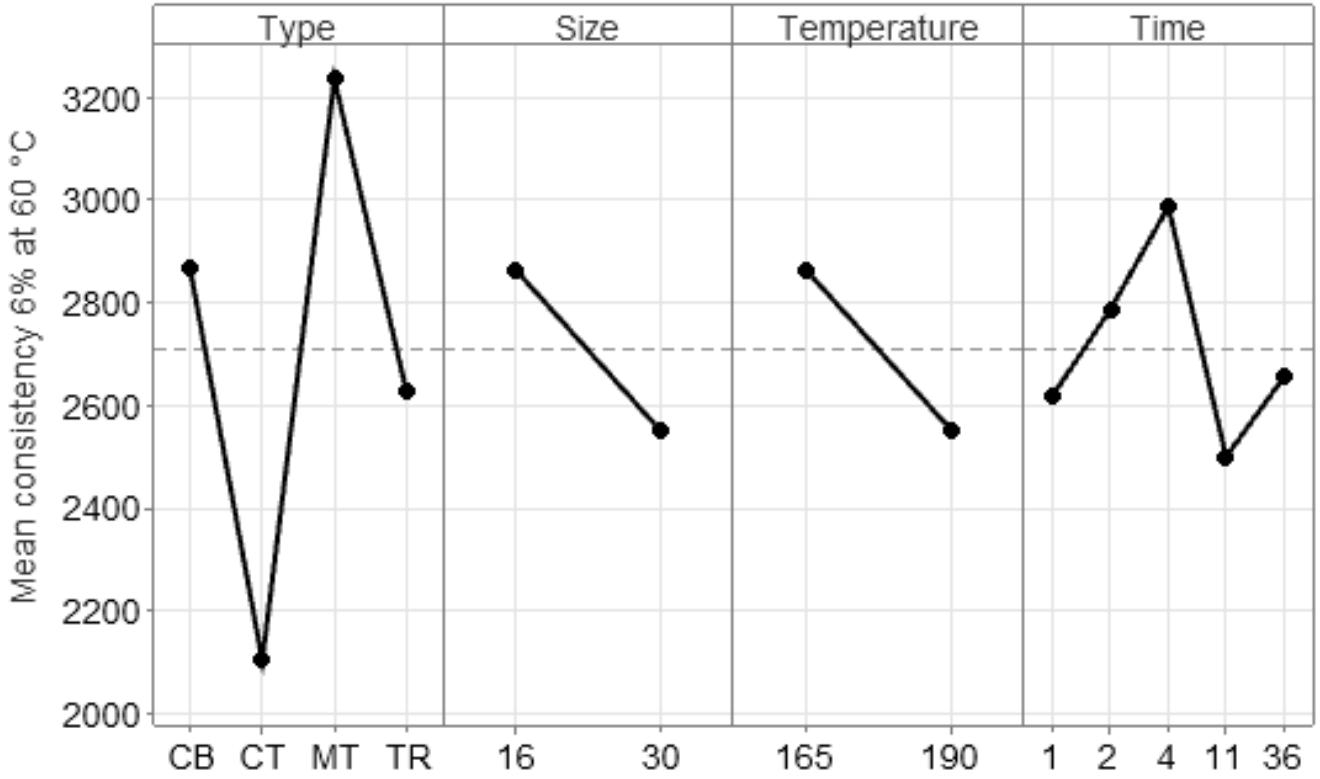
Results
Rutting resistance: Consistency 6% at 60°C

- All CRMBs except MT30_190C_36h were above the ATS 3110:2023 minimum specified limit



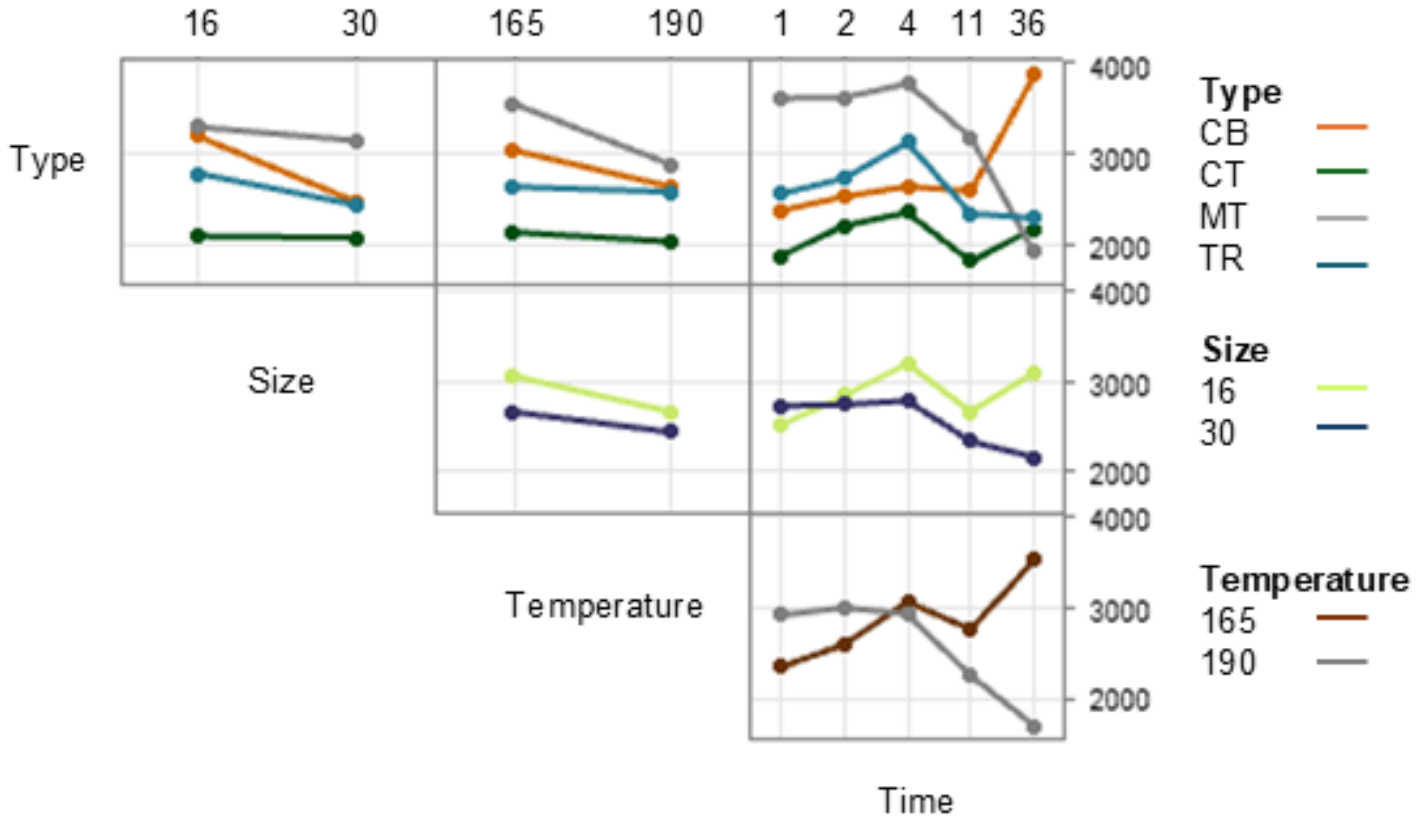
Results
Rutting resistance: Consistency 6% at 60°C

Source	DF	Adj SS	Adj MS	F-value	P-value
Type	3	26953680	8984560	14.41	0.000
Size	1	3872725	3872725	6.21	0.014
Temperature	1	3809157	3809157	6.11	0.015
Time	1	4557391	1139348	1.83	0.126
Error	152	94767278	623469		
Lack-of-fit	70	94484544	1349779	391.47	0.000
Pure error	82	282735	3448		
Total	161	134109251			



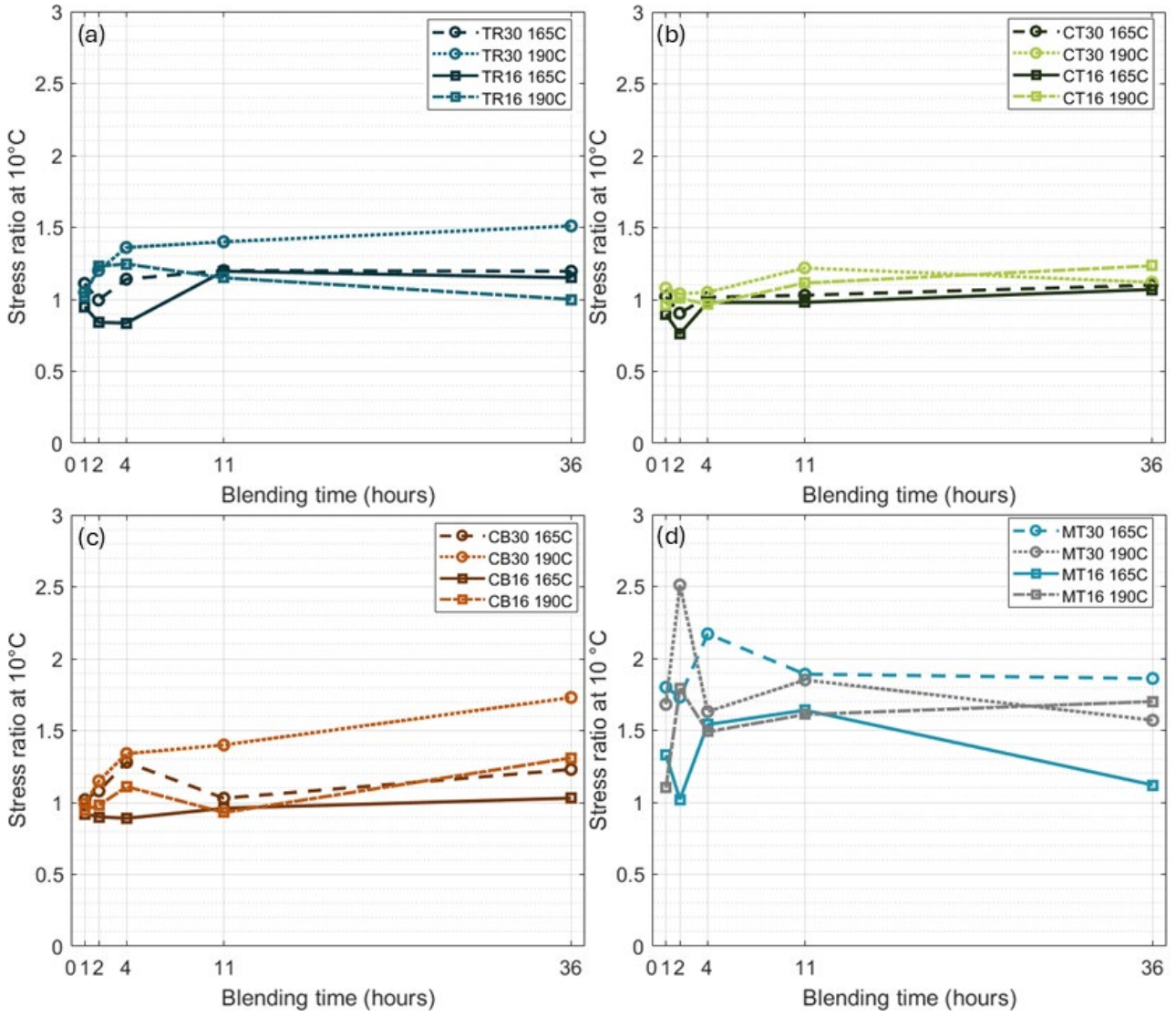
Results
Rutting resistance: Consistency 6% at 60°C

- **Blending time interacted with all parameters**

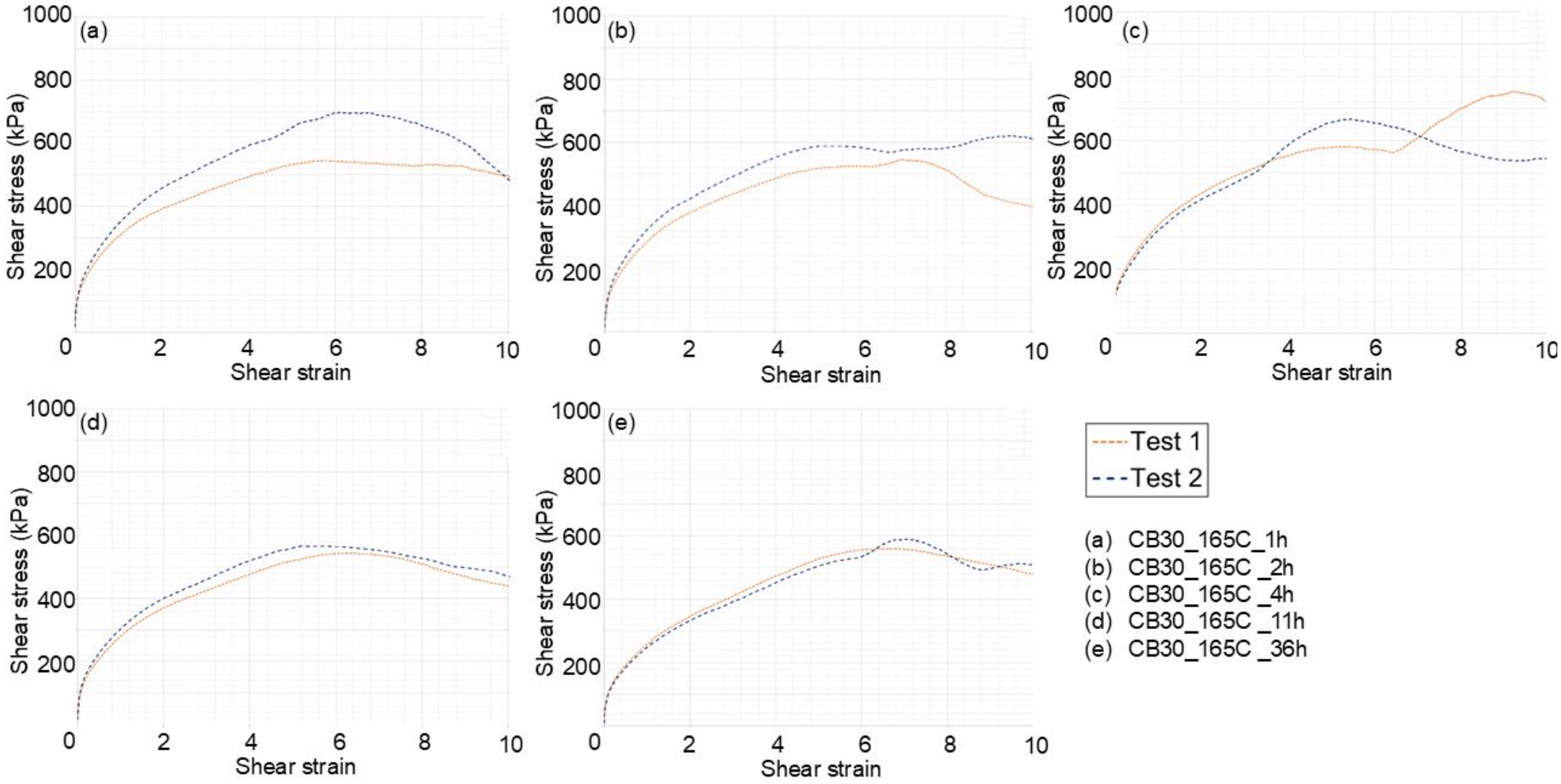


Results
Fatigue life: Stress ratio at 10°C

- Greatest deviations observed within mining tyre-derived crumb rubber-modified binders



Results
Fatigue life: Stress ratio at 10°C



Conclusions and future work

- **Truck tyre-, car tyre-, and conveyor belt-derived crumb rubber could be used as direct replacement to each other**
- **Mining tyre-derived crumb rubber-modified binders in this research demonstrated varied results**
  - Further research including great variability of mining tyre sources would be valuable
- **Understanding of how any observed differences may impact asphalt performance**

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Questions?