Experimental analysis of heat transfer behavior during vulcanization of elastomer blends

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1. INTRODUCTION

Vulcanization is a highly exothermic process in which the temperature evolution inside the elastomer compound strongly influences the final properties. Non-uniform heat transfer may lead to temperature gradients, affecting cross-linking rate and product quality.

Real-time monitoring at different depths inside the compound enables better understanding and control of the curing process.

2. AIM OF WORK

To monitor and analyze the heat transfer behavior during vulcanization of elastomer blends using distributed temperature sensing and infrared thermography, and to correlate the temperature evolution with rheological behavior.

3. MATERIALS

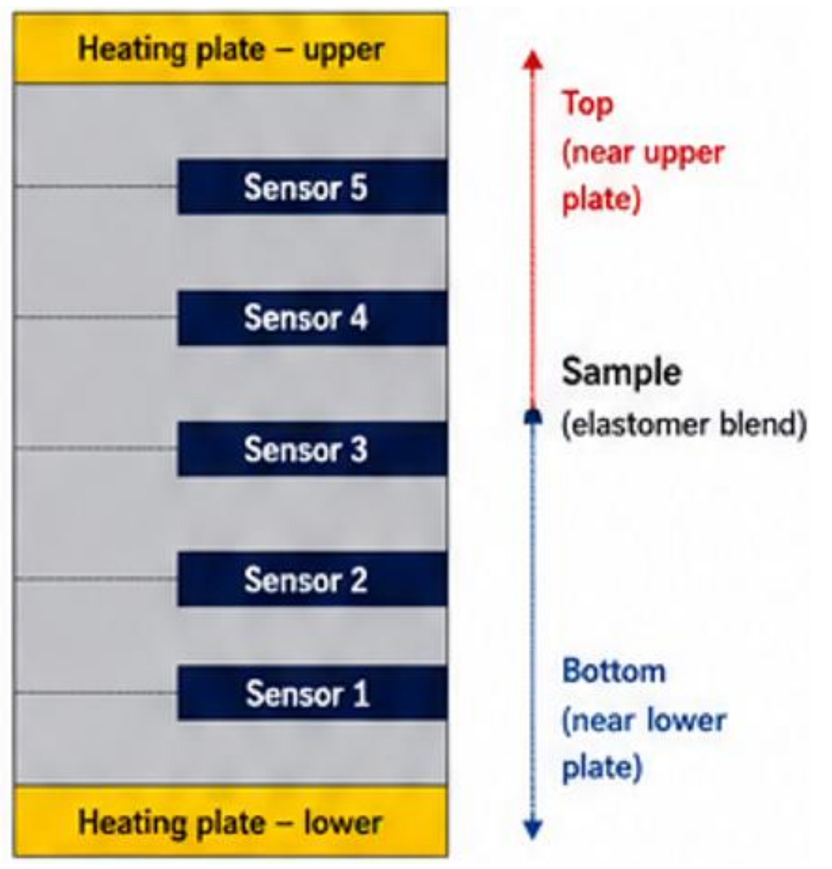
NR based elastomer blend filled with carbon black N330 and standard curing system.

Formulation (phr)

Ingredient	Content (phr)
SMR 10	100
ZnO	3
SA	2
Filler*	40
TBBS	1.5
Sulfur	2

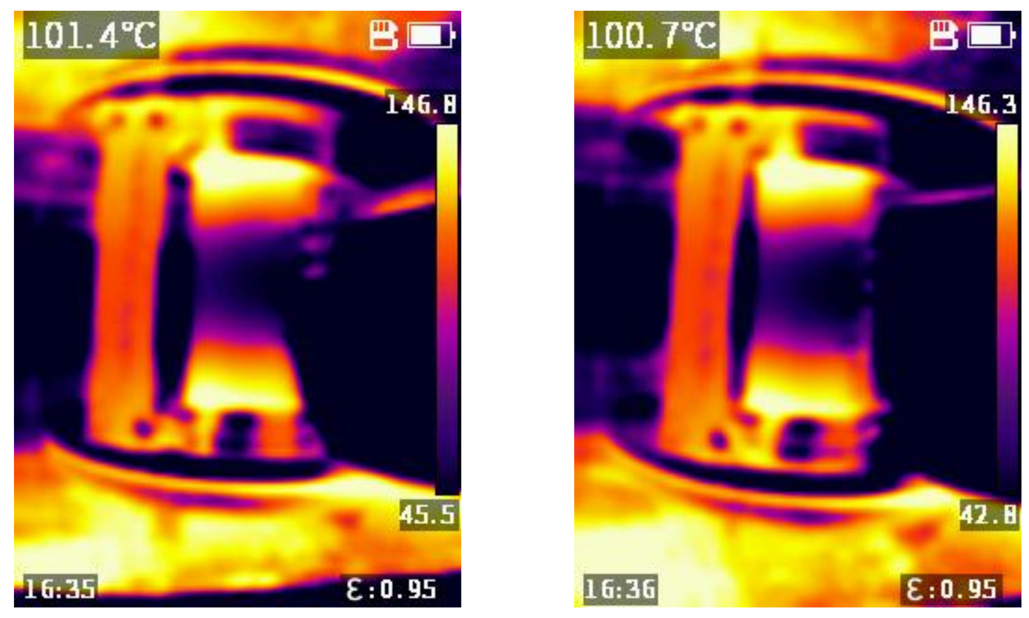
* Filler types: CEL, $CaCO_3$, SILICA, CB

4. SENSOR ARRAGEMENT



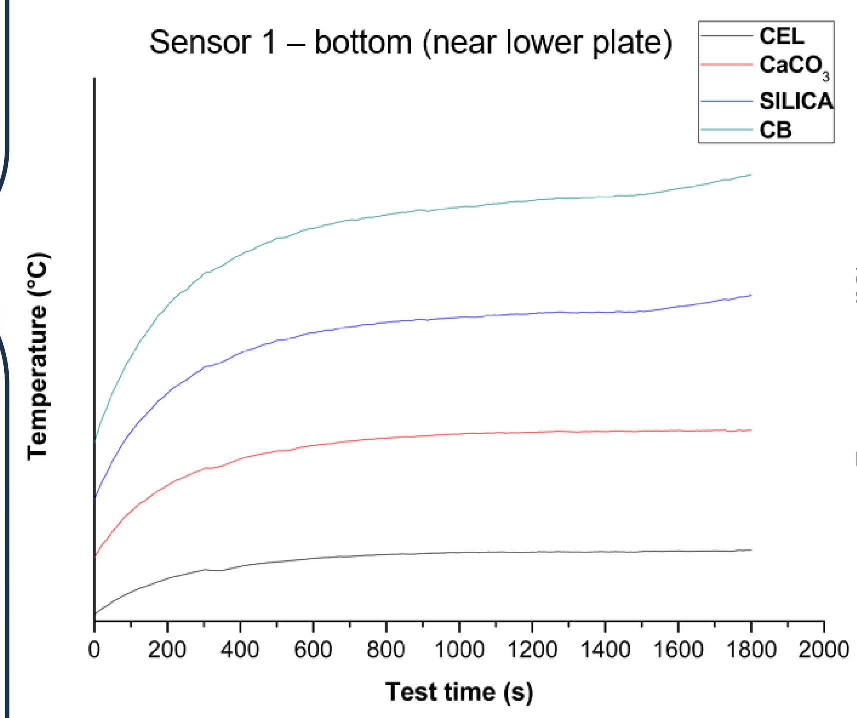
5. INFRARED THERMOGRAPHY

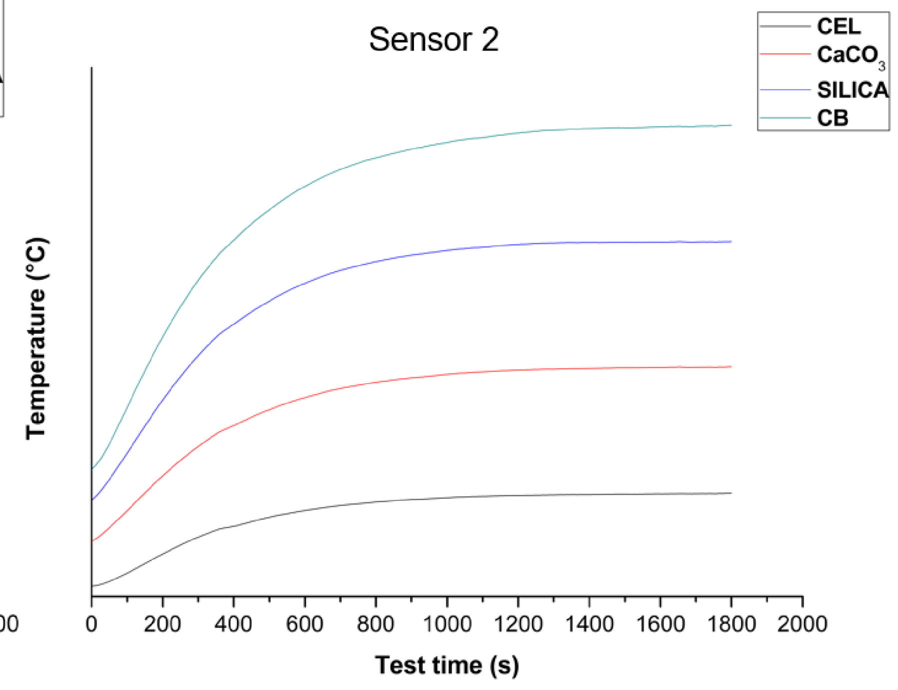
(a) Initial heating stage (b) Temperature evolution

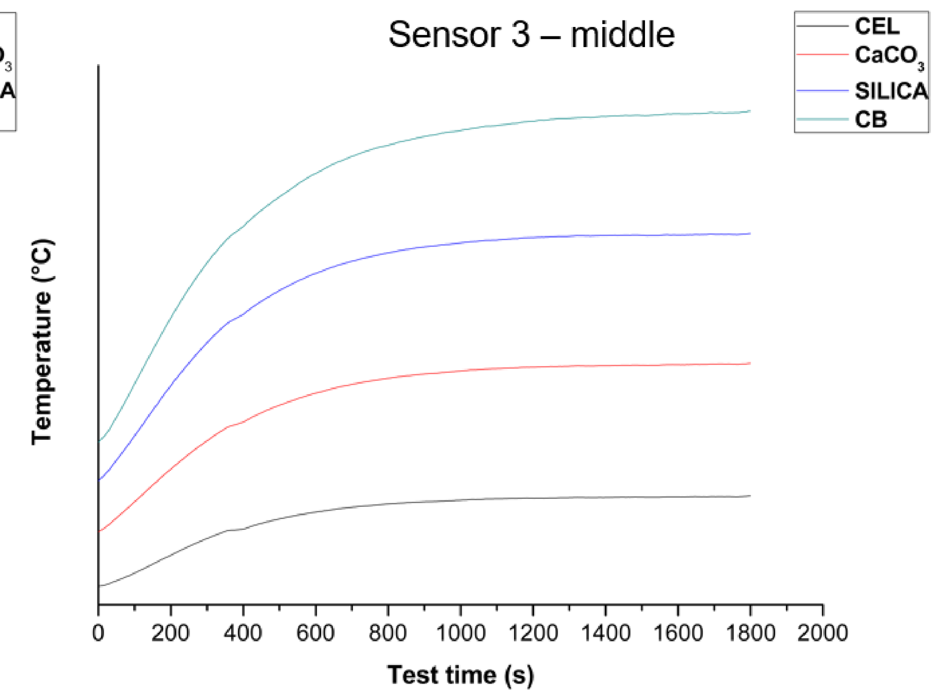


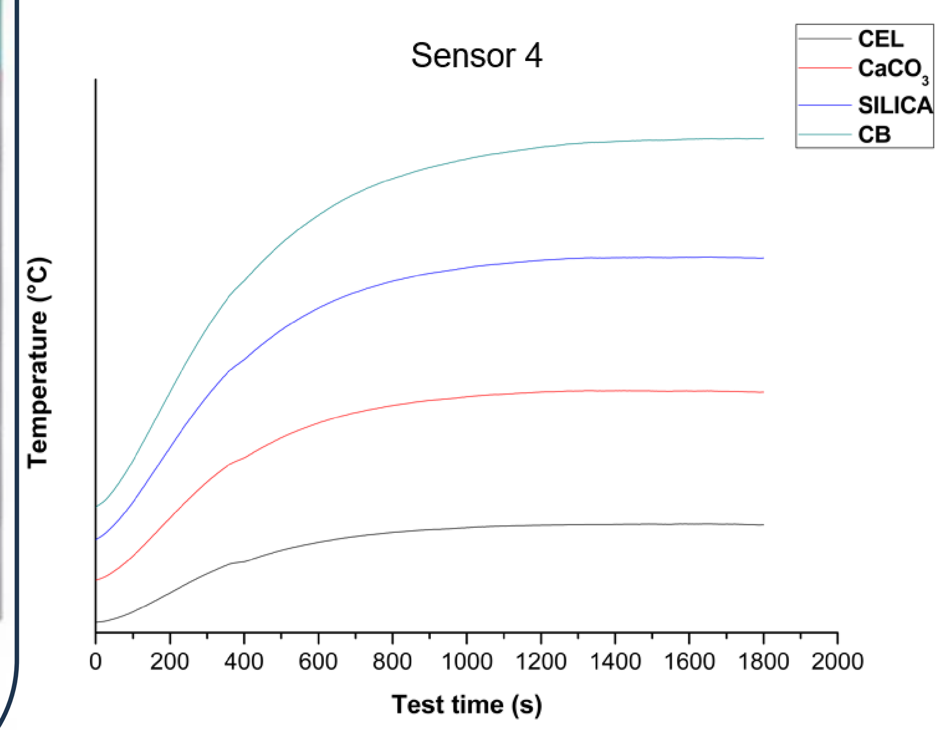
IR thermography confirmed non-uniform temperature propagation during heating.

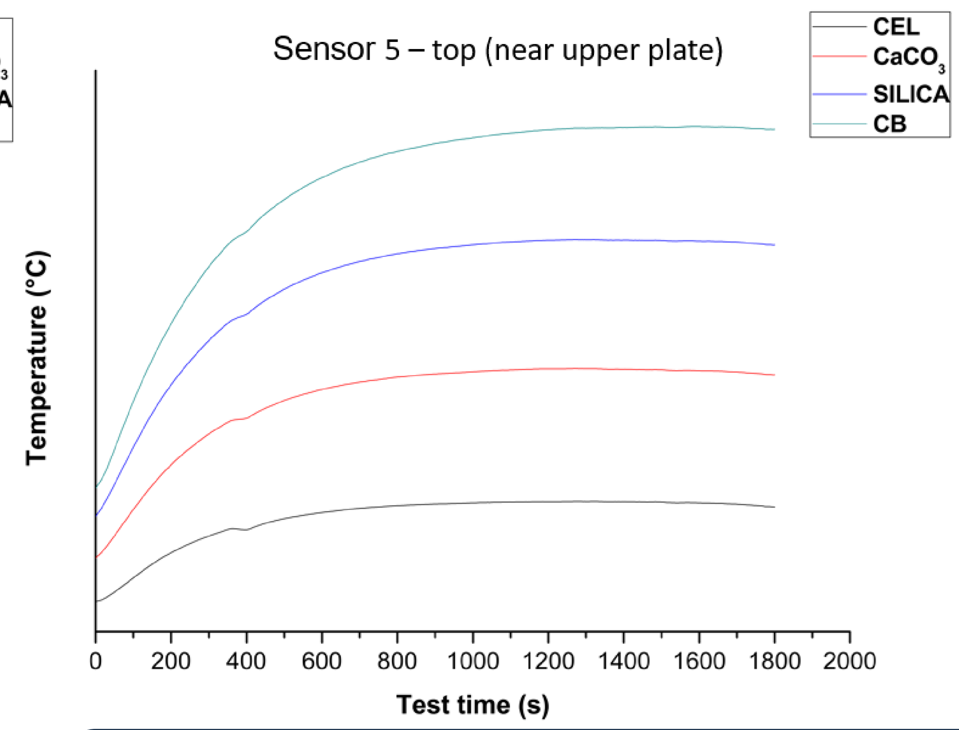
6. TEMPERATURE EVOLUTION DURING VULCANIZATION AT DIFFERENT DEPTHS







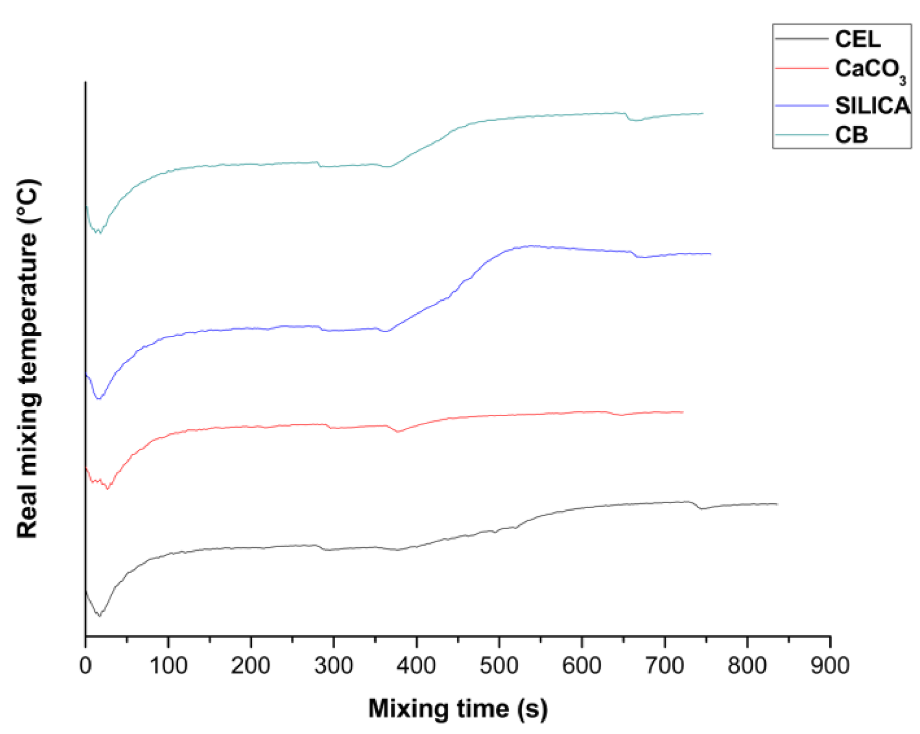




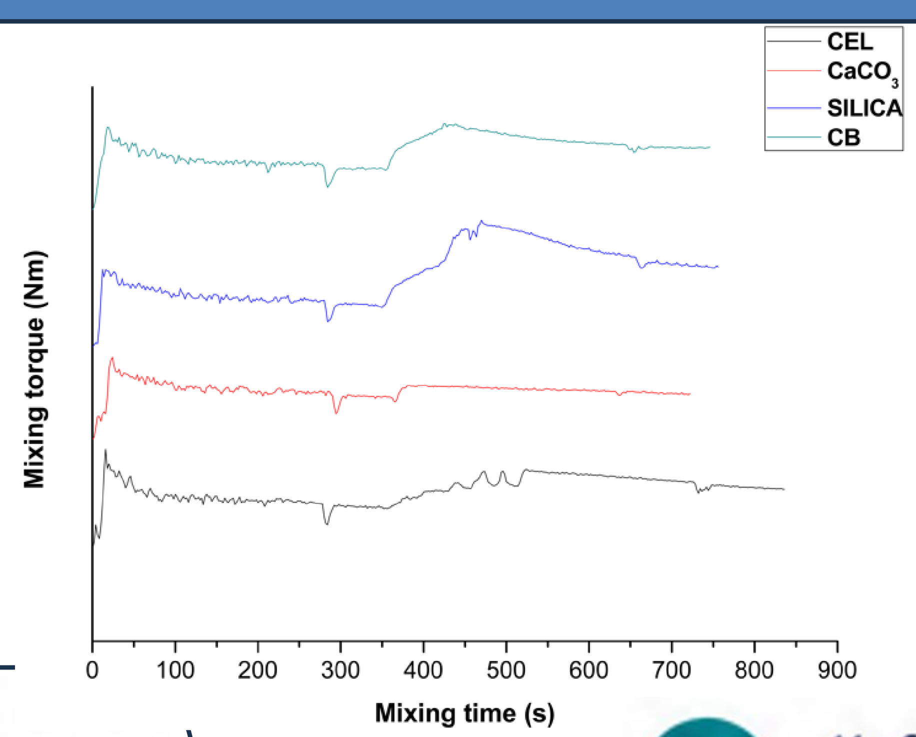
- Near the upper plate, temperature rises faster and reaches higher values.
- Sensors in the middle show delayed response.
- Near the lower plate, temperature increase is slower and final values are lower.

Significant temperature gradients develop between the upper and lower part of the sample during vulcanization. Filler type strongly influences the temperature evolution.

7. INTERNAL MIXING – REAL MIXING TEMPERATURE



8. INTERNAL MIXING – TORQUE



9. VULCANIZATION CHARACTERISTICS (RHEOMETER)

Filler type	M_L (dN·m)	M_H (dN·m)	t_{c02} (min)	t_{c90} (min)
CEL	2.20	30.06	4.82	7.82
$CaCO_3$	2.18	20.46	6.19	9.63
SILICA	6.36	32.72	3.31	7.68
CB	3.54	30.41	1.70	4.35

10. KEY FINDINGS

- Filler type significantly affects temperature evolution during vulcanization.
- Carbon black (CB) filled compounds exhibit the highest temperature increase and the shortest curing time (t_{c90} = 4.35 min).
- Clear temperature gradients develop between the upper and lower regions of the sample.
- Internal mixing curves show differences in temperature and torque response depending on filler type.
- Distributed temperature sensing enables real-time monitoring of thermal behavior inside the elastomer blend.
- IR thermography confirms non-uniform heat transfer during heating.

11. CONCLUSIONS

- The combination of distributed temperature sensing and IR thermography provides comprehensive insight into the heat transfer behavior during vulcanization.
- Understanding heat transfer helps to optimize curing conditions and improve product quality and consistency.
- The developed monitoring approach can be applied for process control and advanced material development.

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