

Concrete for Automated Digital Fabrication

Accelerating the early age properties of Low Carbon Cements for Digital Fabrication

Background

The primary challenges (3DCP) mix design are the overreliance on Portland cement content in mortars (typically > 800kg/m³). Increasing the use of cement replacement materials and optimizing mixture are two ways of reducing the clinker factor and therefore the embodied carbon CO₂. This necessitates the use of accelerators to compensate for the slow reactivity of SCMs. This study is investigating the interaction of calcium sulfo-aluminate cement as an accelerator. However, the rheology, hydration, and microstructure development in composite cements containing high SCMs and calcium aluminate cements is complex.

- Working towards **net-zero** by lowering clinker factor in cement binders and ensuring durability
- Working towards **industry 4.0** by implementing 3DCP as a potential low carbon concrete technology



Recent interests on limestone addition in ternary binders makes it critical to develop an understanding of their early age and long term performance and their suitability to extrusion based 3D concrete printing.

Research Questions

- How do the early age properties of binary slag compare with their limestone ternary forms?
- To what extent does limestone have benefits on the performance of the binary and ternary blends?
- How does the calcium aluminate sulphate cement acting as an accelerator alter the early age properties of the novel SCMs mortars?

Materials and Methodology

Binder Formulations (wt.%) of components used

Mix ID	CEM1	GGBS	Limestone	Anhydrite	Plasticizer	Admixture
C	100	-	-	-	-	-
C-A	100	-	-	-	0.3	3.5*
C-AR	100	-	-	-	0.3	3.5* + 0.73°
CS	30	67.5	-	3.5	-	-
CS-A	30	67.5	-	3.5	0.3	3.5*
CS-AR	30	67.5	-	3.5	0.3	3.5* + 0.73°
CSL	30	54	13.5	2.5	-	-
CSL-A	30	54	13.5	2.5	0.3	3.5*
CSL-AR	30	54	13.5	2.5	0.3	3.5* + 0.73°

Note: * is calcium sulfoaluminate activator and ° is citric acid retarder

- A target of 70% replacement of CEM1 is pursued for the composite binders – high volume replacement
- Anhydrite blended with composite binders to adjust sulphate content

Mortar mixing, curing and preconditions

- Mortar prepared in accordance with BS EN 196-3:2016.
- Water: binder ratio = 0.4.
- Mortar for compressive strength testing cured in moist room until testing age
- Specimens for isothermal calorimetry prepared in accordance with BS EN 196-1: 2016 using 9g of paste and observed over 4 days.

Experimental Flow Chart

Literature Review identified Calcium sulfo-aluminate as potential accelerator for ultra-low clinker cements

Initial **scoping study** to determined w/b ratio to be between 0.3 and 0.35, being greater in ternary cement. 0.4 w/b ratio plus 0.3%wt of binder as plasticizer content

Fresh state testing:
Shape stability, flowability
Setting time

Hard state testing:
Compressive strength and
heat evolution

Results

Evaluation of Printability

- Flowability and shape retention are important parameters that govern the printability of cementitious materials. The flow table test provides an indirect means for evaluating these and can be used as a buildability indicator

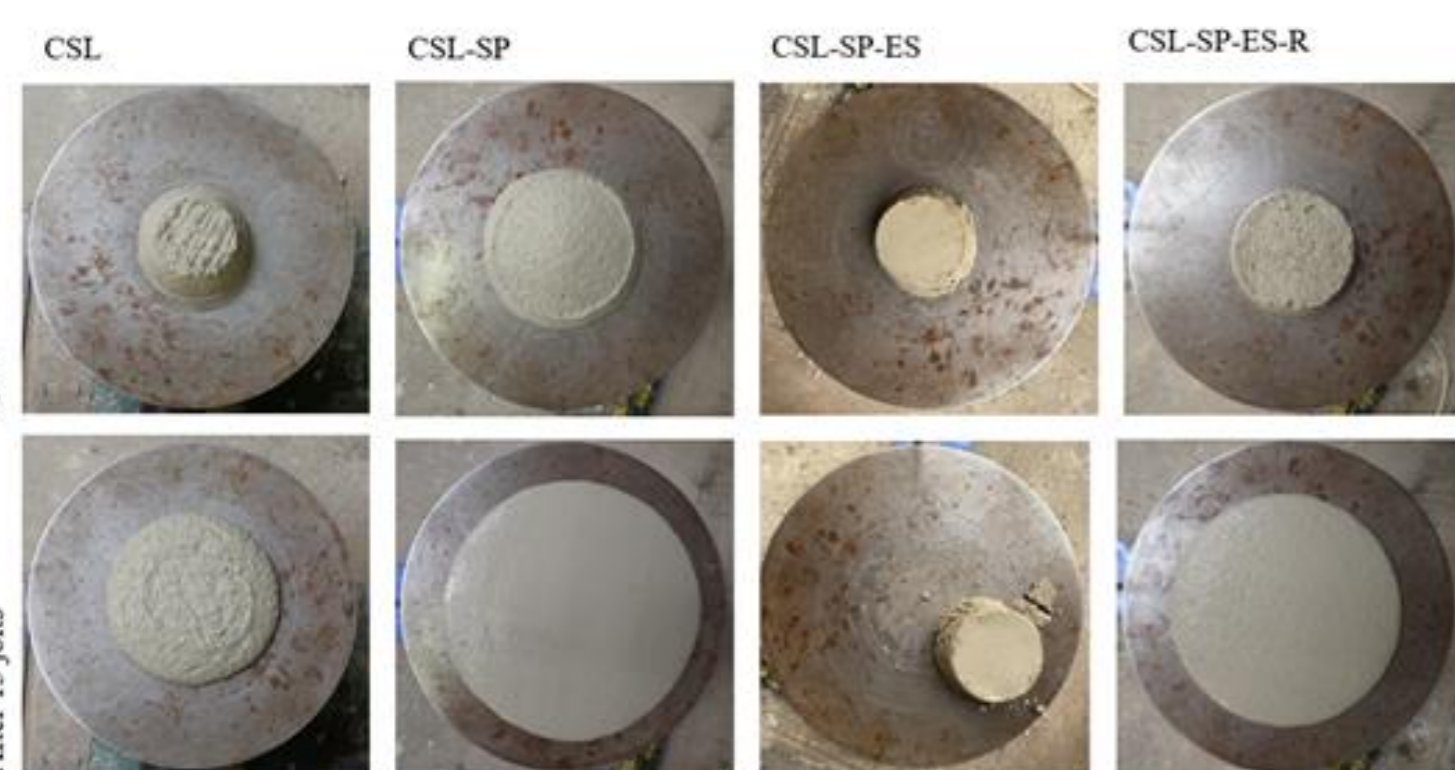


Figure A . Representative photographs of fresh mortars immediately after removing the conical moulds (i.e. 0 jolts) and 15 jolts .

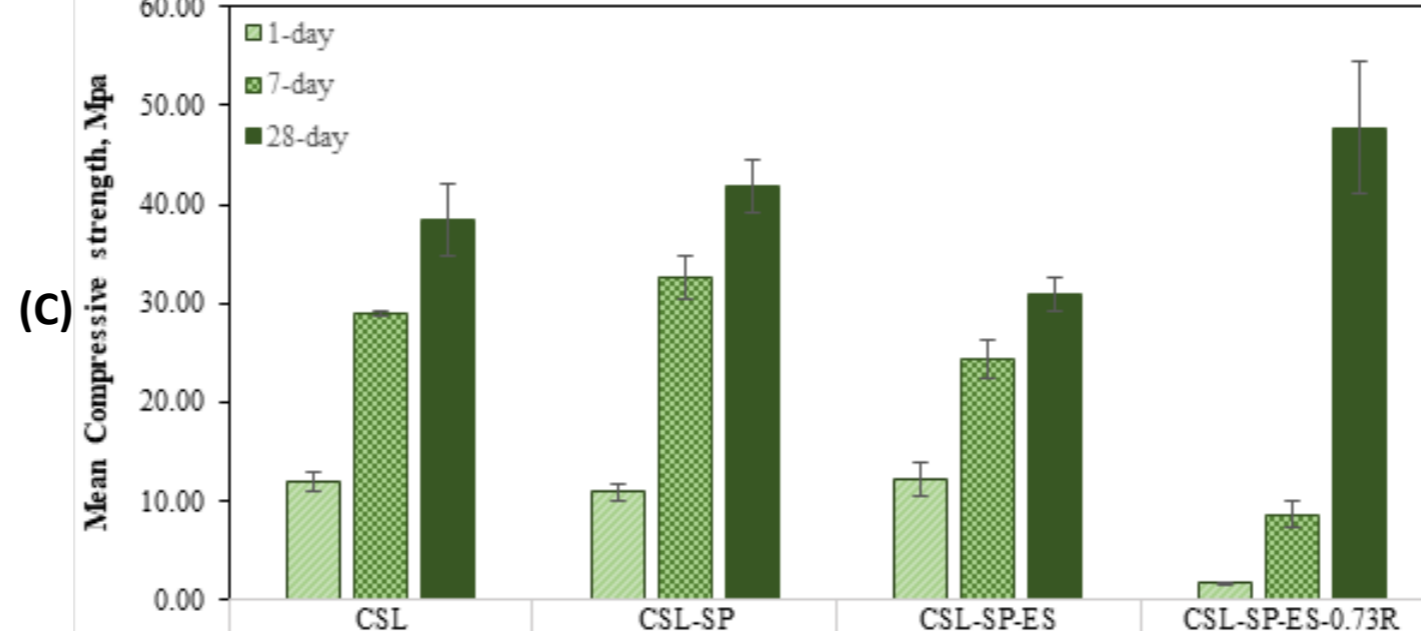
(A) Shape retention

- For the ternary blend (CSL), accelerators improved the initial and final shape retention compared to the plain mortar. Significant spread was noticed upon jolting with the retarder.

Evaluation of Structural evolution

- Setting time, Isothermal calorimetry and compressive strength provide an evaluation of the structuration, hydration and the microstructure of mortar.
- For 3DCP, rapid structuration and early age strength are required in order to support additional layers placed during printing while maintain plastic viscosity

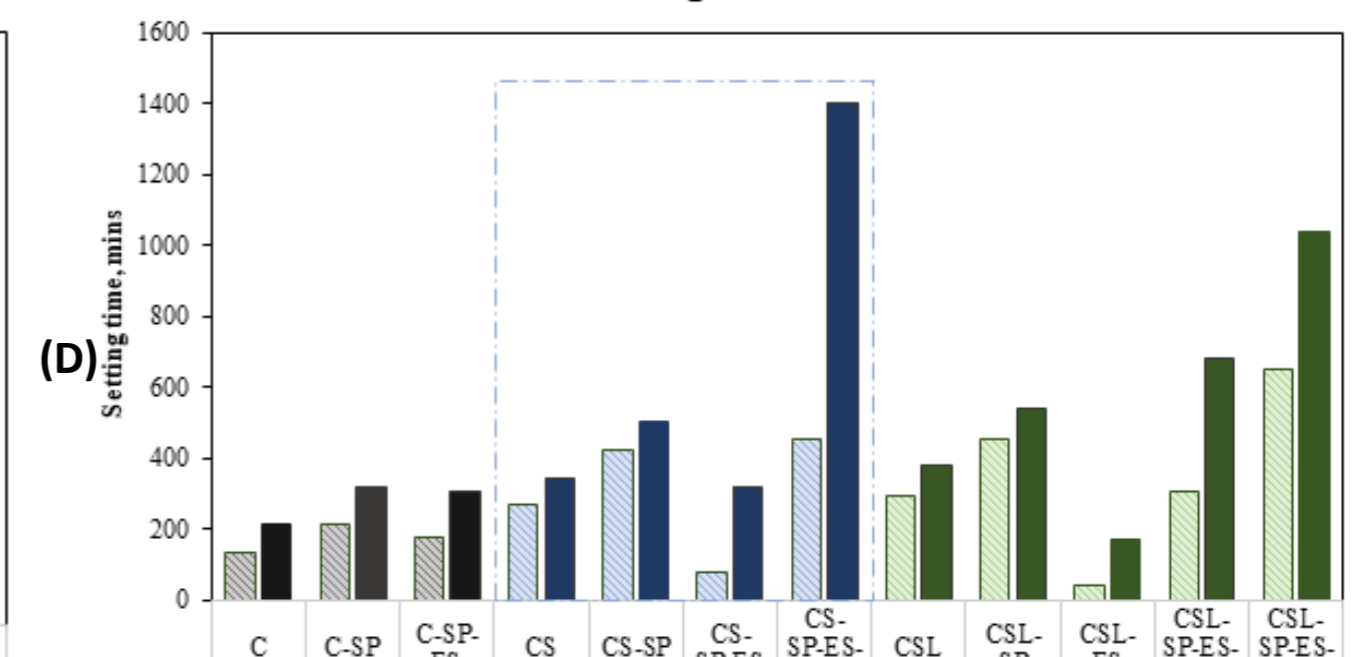
Compressive strength of CSL based Mortars



(E) Compressive strength

- For the ternary cement, the accelerator+ retarder combination significantly reduced early age strength development (1,7 days) and accelerated 7-28day strength development.

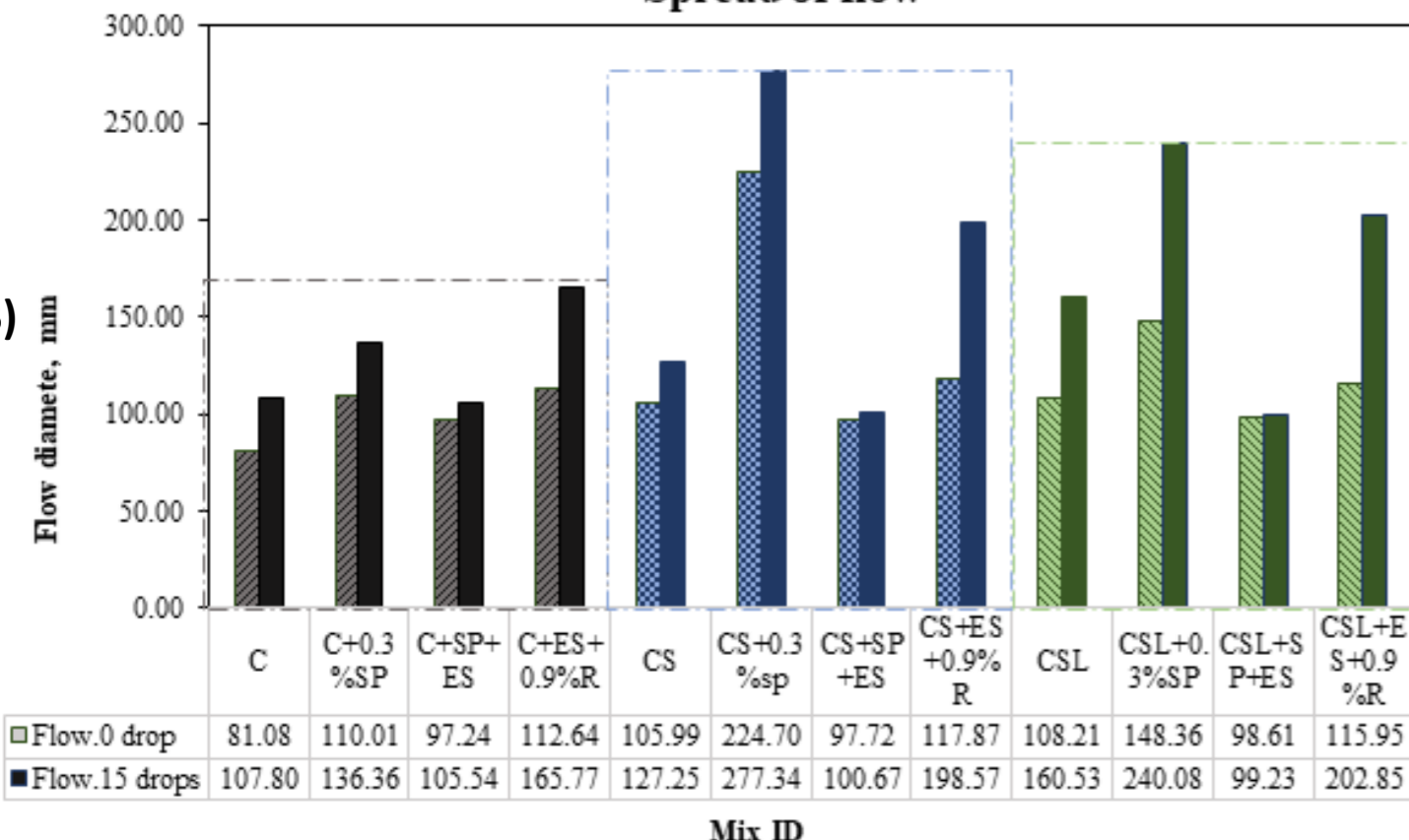
Setting time



(C) Setting time

- For all cements, addition of accelerator caused rapid structural build up as rapid initial/final setting time implying enhanced structuration.

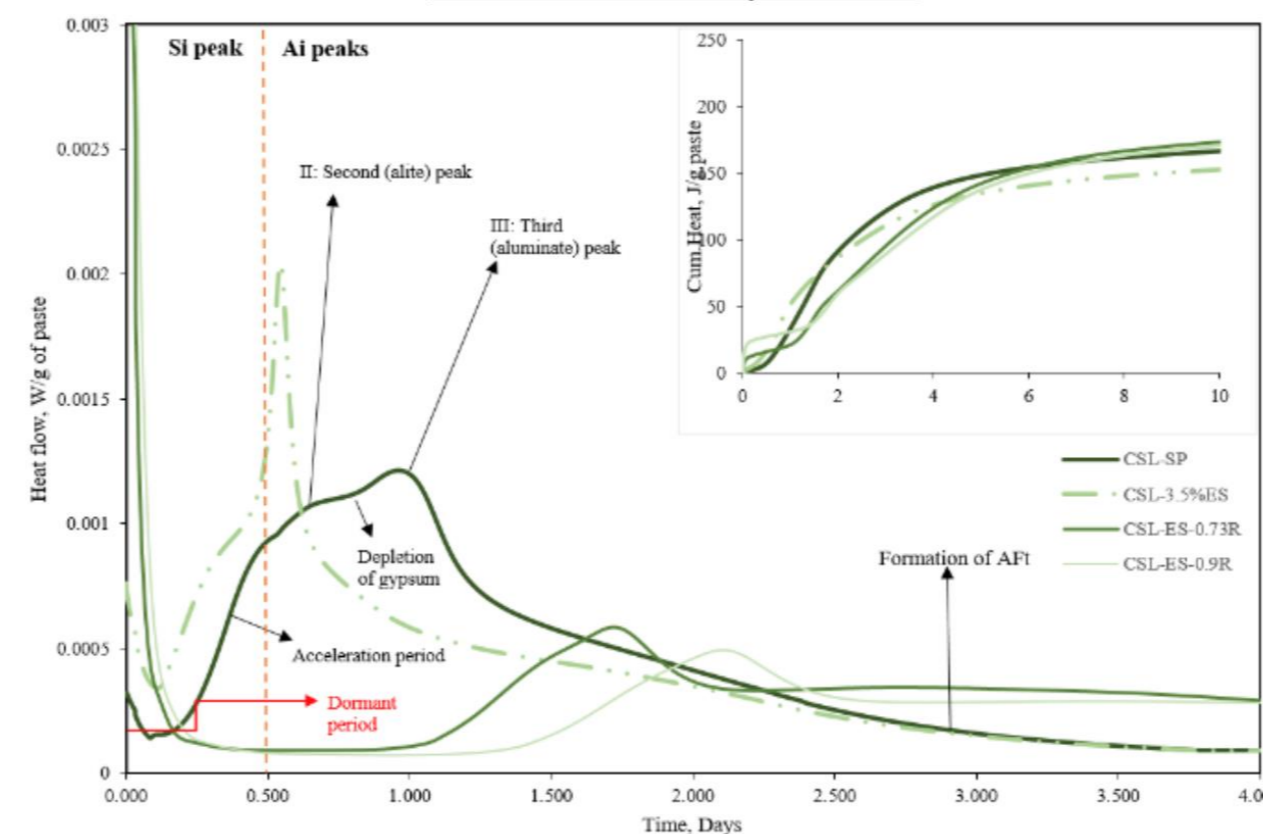
Spread of flow



(B) Workability

- For the Ternary cement, flow resistance was greater in the calcium sulfo-aluminate mix than the mix with retarders.

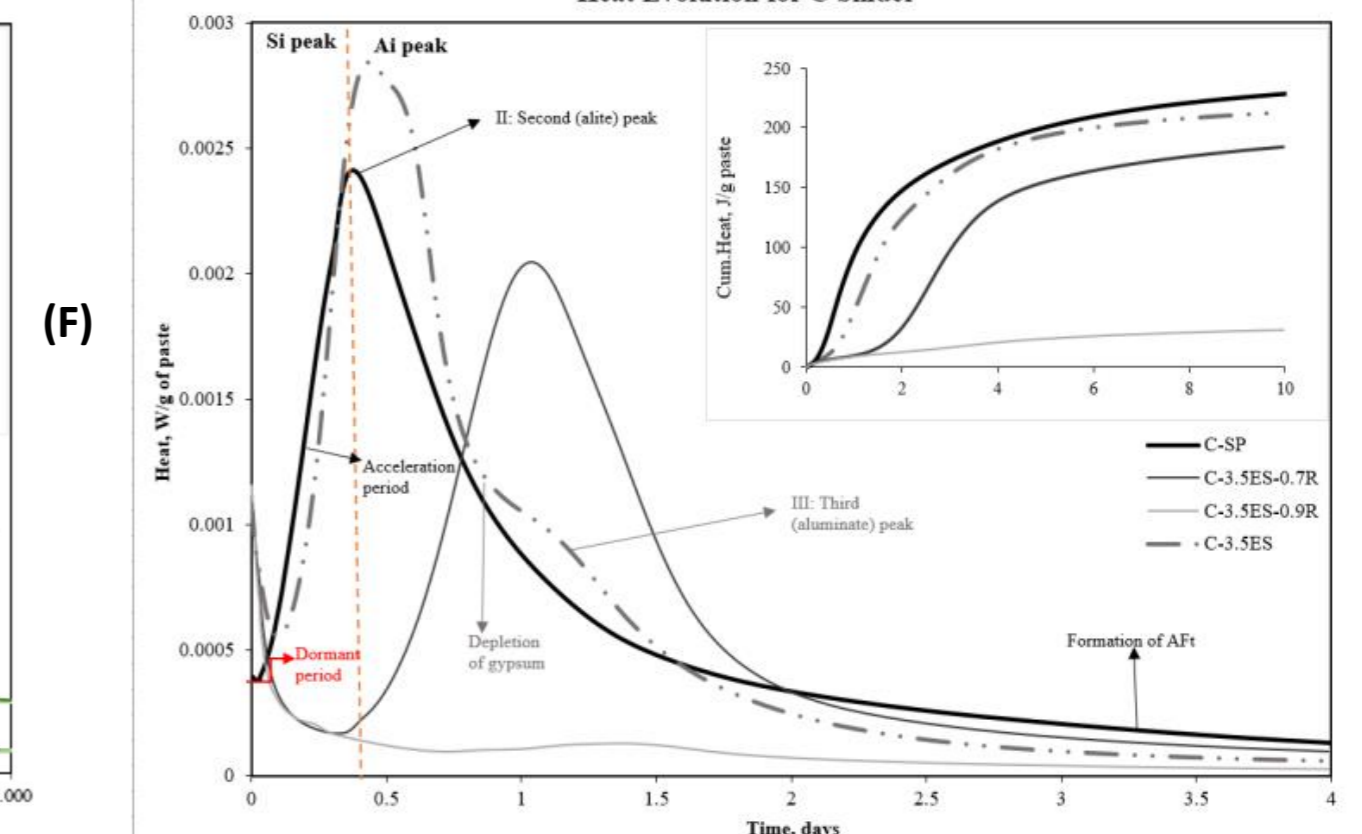
Heat evolution for ternary CSL binder



(E) Heat evolution

- Compared to the ternary cement (e), more heat was generated in the neat OPC (F) mixes, implying faster structuration.
- The sulfo-aluminate accelerated the silicate and aluminate peaks (dotted line) in the ternary cement profoundly, however the accelerated hydration led to lower cumulative heat and so accelerated mixed have lower hydration rates

Heat Evolution for C binder



Conclusions

- The compressive strength, flowability and setting time of the ternary binder are comparable with the binary binder however still slightly less than the neat Portland cement binder.
- Results indicate there is scope for low carbon cement for digital fabrication however, more work is needed to understand the effect of the accelerator on the binary and ternary cement binder, especially in the presence of both the accelerator and retarder .