ACI CONCRETE CONVENTION

REAL TIME PLASTIC VISCOSITY PREDICTION THROUGH VIDEO RECOGNITION

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Outline

- ❑ Why monitor plastic viscosity of concrete
- ❑ Case study of plastic viscosity assessment via video
  - Mixture design
  - Mixing procedure
  - Experimental results
  - Training ad testing results of deep learning.
- ❑ Conclusions

☐ Why monitor plastic viscosity of concrete?

- Plastic viscosity influence properties of concrete.
  - ✓ Workability
  - ✓ Pumpability
  - ✓ Extrudability
  - ✓ Fiber distribution
  - ✓ Aggregate segregation

➡

- ✓ Productivity
- ✓ Quality
- ✓ Mechanical properties
- ✓ Durability

Aggregate Segregation of SCC

Non-buildable 3D printing
Fabian B Rodriguez (2022)

Fiber segregation

◻ Plastic viscosity influences 3D printed concrete

- Plastic viscosity influence the stability of 3D printed concrete.
  - ✓ Low viscosity – low buildability
  - ✓ High viscosity – low extrudability (hard to be pumped)
  - ✓ Optimum plastic viscosity is requirement.

Low viscosity

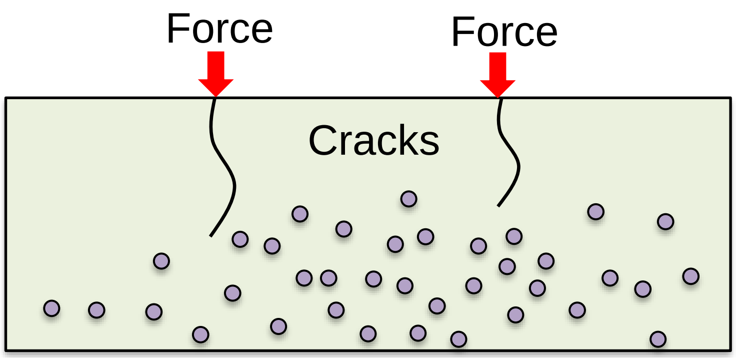
Optimum viscosity

Reference:
[1] Weng, Y., Lu, B., Li, M., Liu, Z., Tan, M.J. and Qian, S., 2018. Empirical models to predict rheological properties of fiber reinforced cementitious composites for 3D printing. Construction and Building Materials, 189, pp.676-685.

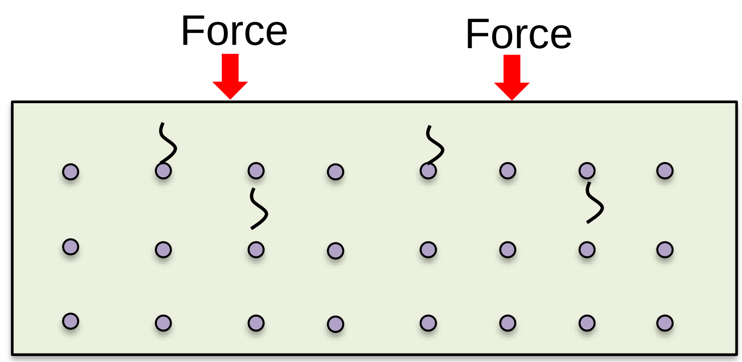
☐ Plastic viscosity influences fiber distribution

- Low plastic viscosity
  - ✓ Fiber segregation
  - ✓ Bad fiber orientation
  - ✓ Large crack opening

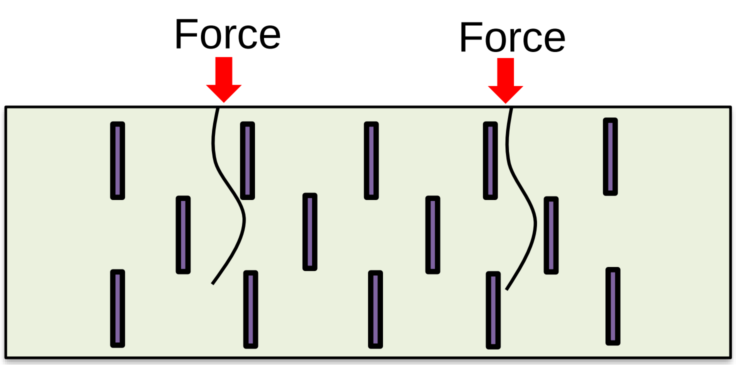
- Proper plastic viscosity
  - ✓ Uniformly-dispersed fibers
  - ✓ Well-oriented fiber
  - ✓ More chance to bridge cracks



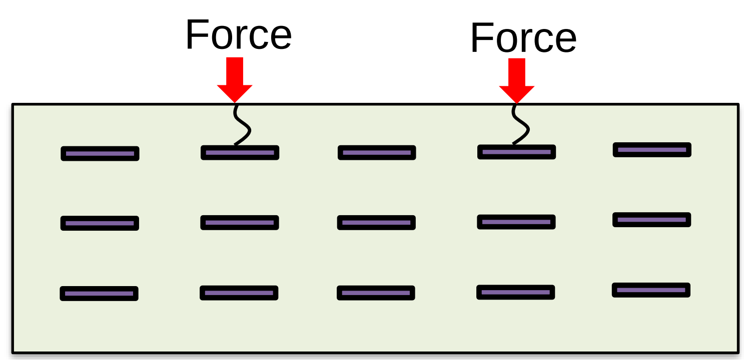
Poor fiber dispersion



Uniformly-dispersed fibers



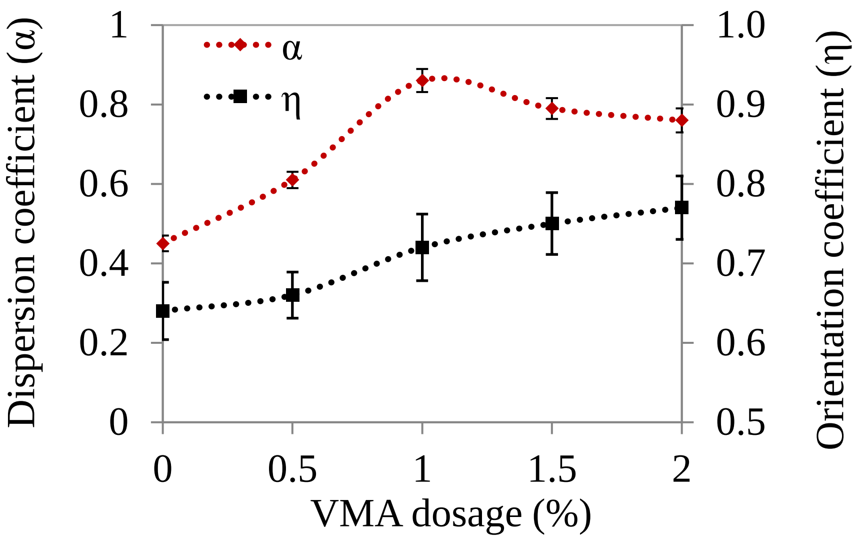
Poor fiber orientation

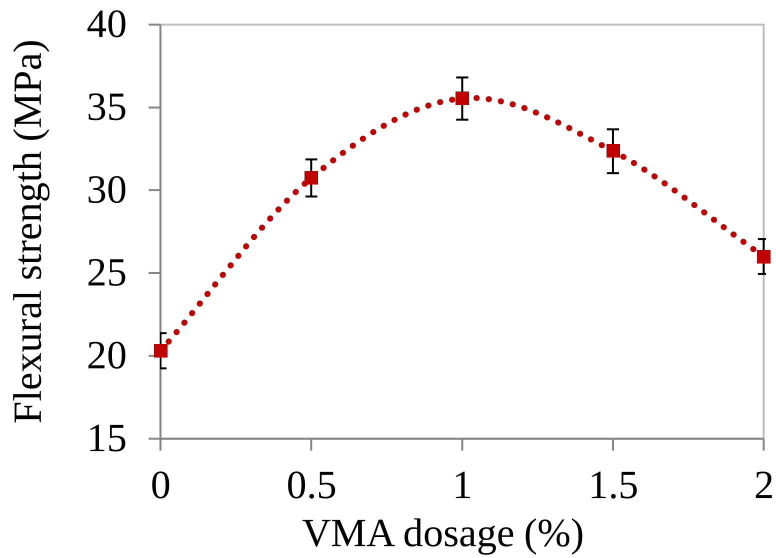


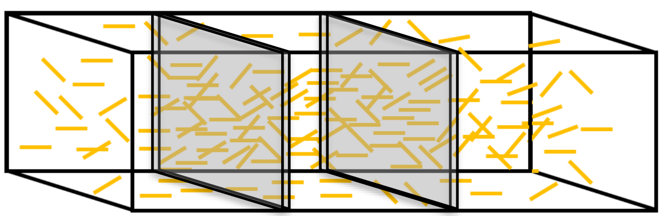
Well-oriented fiber

Effect of plastic viscosity on flexural properties

- Control plastic viscosity to optimize flexural properties







Fiber distribution (orientation and dispersion)

Flexural properties (ASTM C1609)

Reference:

[1] Meng, W. and Khayat, K.H., 2017. Improving flexural performance of ultra-high-performance concrete by rheology control of suspending mortar. Composites Part B: Engineering, 117, pp.26-34.

☐ Equipment test plastic viscosity

- Rheometer/viscometer – test plastic viscosity
- Limitations:
  - ✓ Time consuming (20~30 mins).
  - ✓ High cost.
  - ✓ Most of them are not applicable for field application.

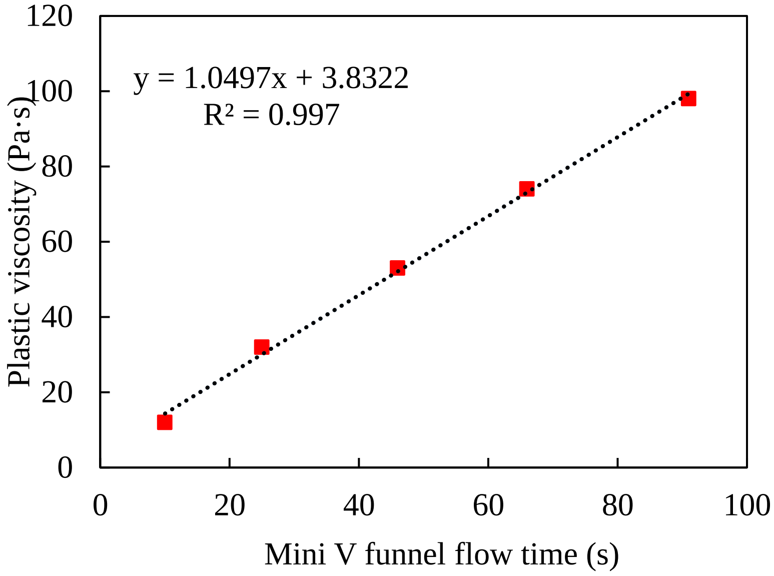
ConTech 5 viscometer [1]

ICAR Rheometer [2]

Reference:
[1] Meng, W. and Khayat, K.H., 2017. Improving flexural performance of ultra-high-performance concrete by rheology control of suspending mortar. Composites Part B: Engineering, 117, pp.26-34.
[2] https://www.germann.org/TestSystems/ICAR%20Rheometer/ICAR%20Rheometer.pdf.

◻ Simplified method to test plastic viscosity

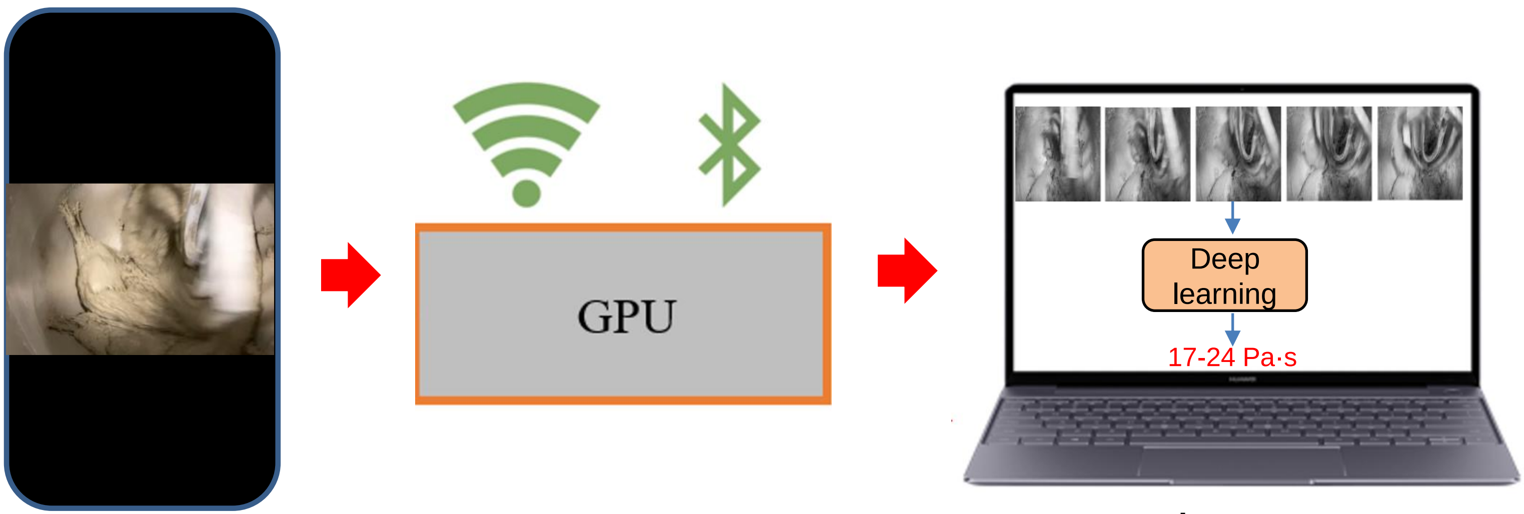
- Flow time method [1].
  - ✓ Plastic viscosity has strong linear relationship with flow time of mortar.
  - ✓ Flow time method is more applicable for field applications.
  - ✓ Limitation:
    - ○ Interfere the concrete mixing process.



Reference:
[1] Meng, W. and Khayat, K.H., 2017. Improving flexural performance of ultra-high-performance concrete by rheology control of suspending mortar. Composites Part B: Engineering, 117, pp.26-34.

☐ Goal

- This study aims to propose a method for the in-situ assessment plastic viscosity of UHPC:
  - ✓ In real-time
  - ✓ Automatically
  - ✓ Cost-effective
  - ✓ Not interfere the concrete mixing
  - ✓ More feasible for actual application

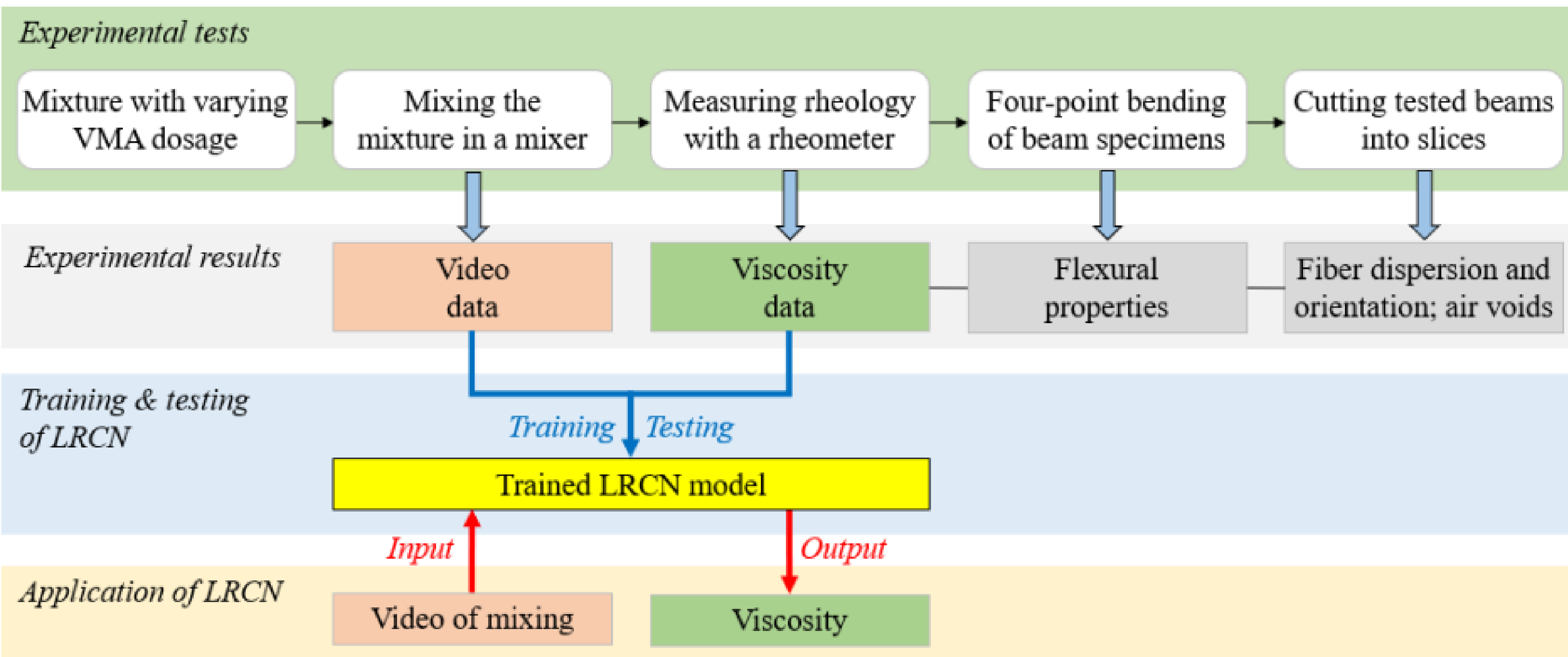


Phone (Input-videos)

Laptop (Output-plastic viscosity)

◻ Case study of plastic viscosity assessment by videos

- Experimental tests
- Training and testing of LRCN
- Experimental Results
- Application of LRCN



◻ Mix design

- Assessed plastic viscosity of ultra-high-performance concrete (UHPC) suspending mortar before adding fibers.
- 5 UHPC mixtures were investigated
- VMA dosage was varied to obtain different plastic viscosity.

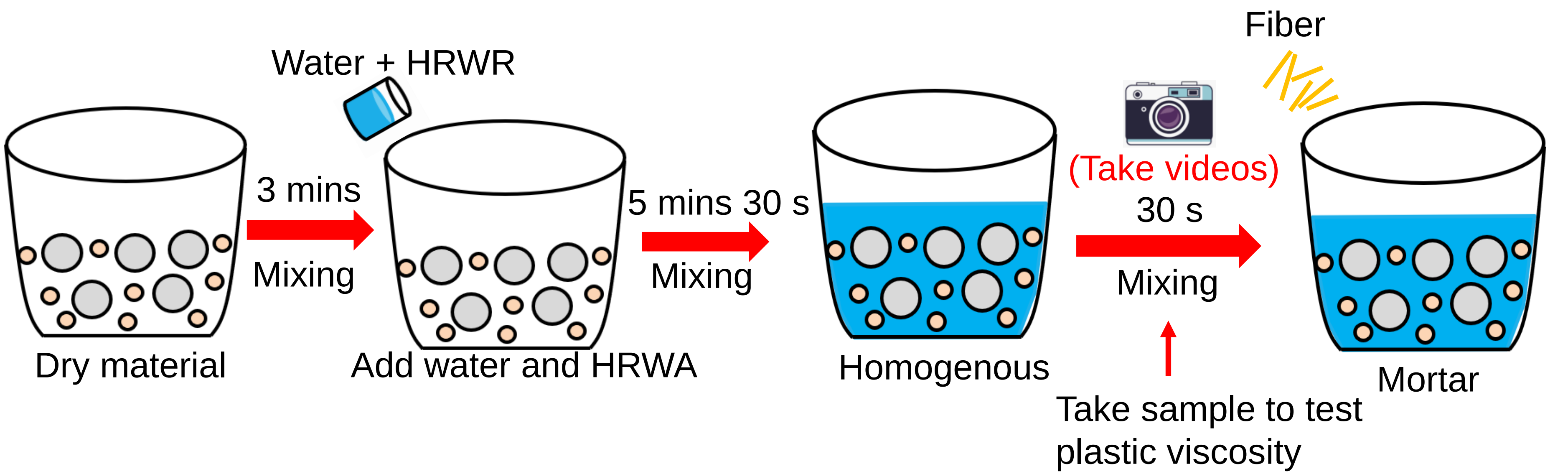
Table 1. Ingredient proportioning of the investigated mixtures

Mixture	Cement	Slag	LWS	MS	RS	HRWR	VMA	Water
VMA0	459.0	633.9	163.9	287.4	432.8	7.0	0	246.1
VMA0.5	459.0	633.9	163.9	287.4	432.8	7.0	5.5	240.9
VMA1.0	459.0	633.9	163.9	287.4	432.8	7.0	10.9	235.7
VMA1.5	459.0	633.9	163.9	287.4	432.8	7.0	16.4	230.5
VMA2.0	459.0	633.9	163.9	287.4	432.8	7.0	21.9	225.3

Notes: LWS: lightweight sand; MS: masonry sand; RS: river sand; HRWR: high range water reducer; VMA: viscosity modifying agent.

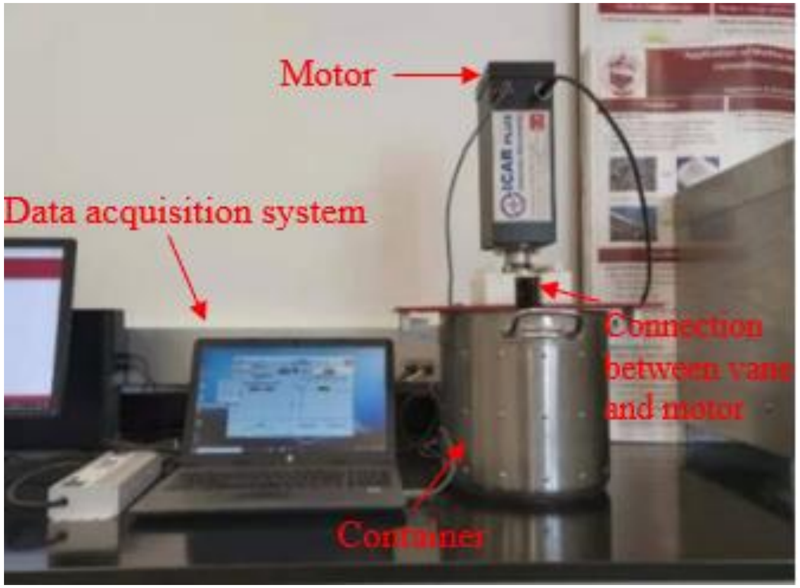
Taking video during mixing

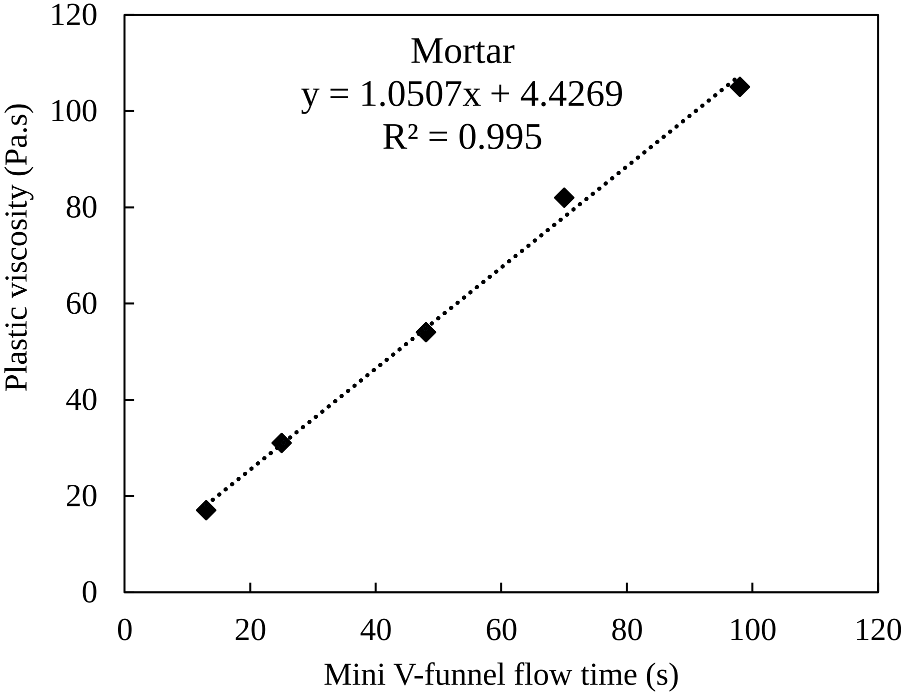
- Mixing procedure:
  - ✓ Dry mixing – 3 mins
  - ✓ Add 90% water and HRWR– 3 mins
  - ✓ Rest of 10% water and HRWR – 2 mins 30 s
  - ✓ Videos were taken (30 s) and plastic viscosity was measured after the mortar was homogenous
  - ✓ Add fibers – 2 mins



☐ Experimentally establish the relationship between Flow time and plastic viscosity

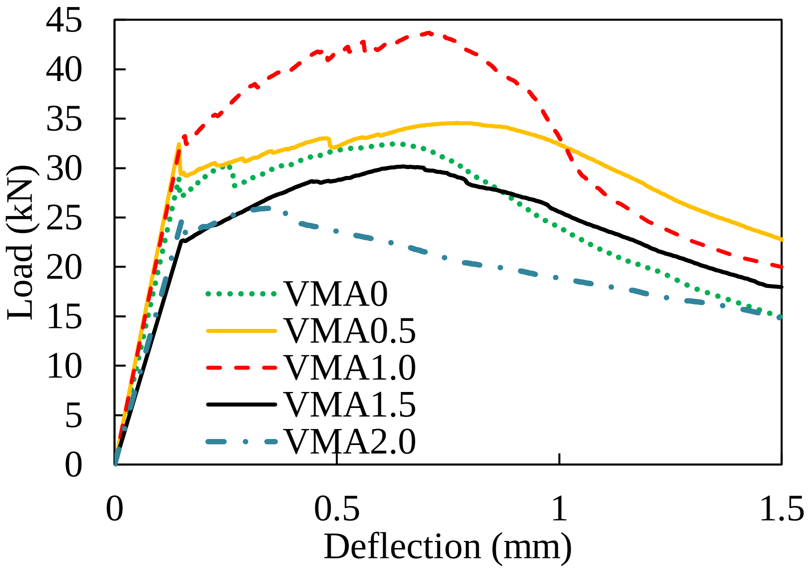
- Plastic viscosity of mortar – ICAR rheometer
- Strong correlation between flow time and plastic viscosity

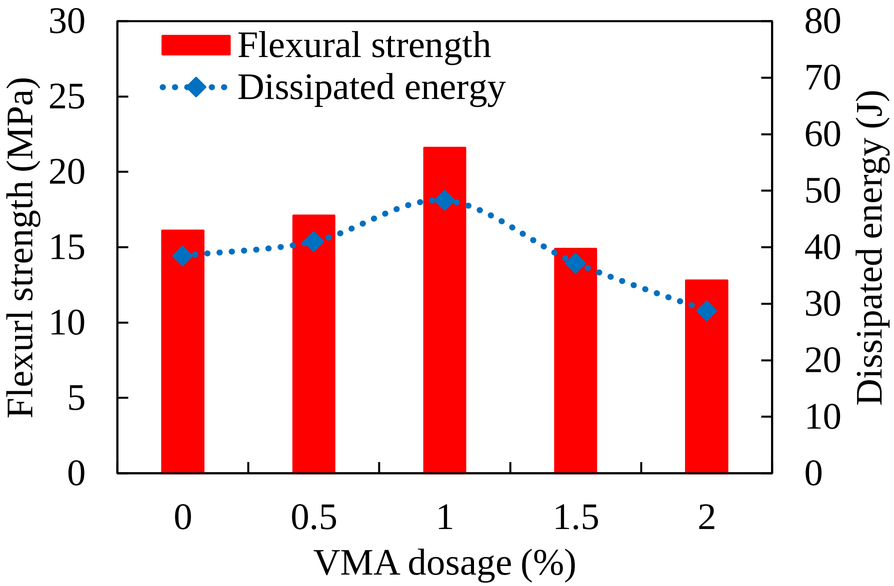




Flexural performance

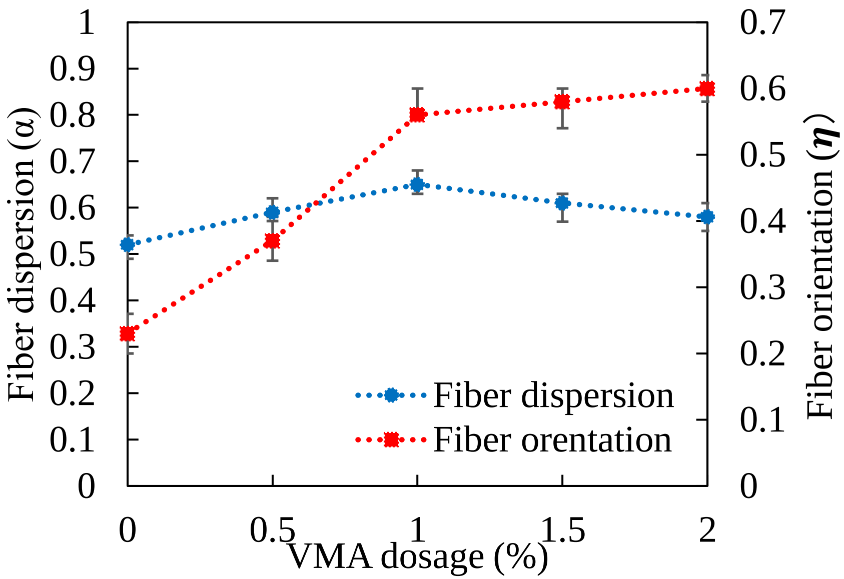
- Flexural behavior
  - ✓ VMA dosage from 0 to 1%:
    - Maximum bending load: increase
    - Flexural strength: increase
    - Dissipated energy: increase
  - ✓ VMA dosage from 1 to 2%:
    - Maximum bending load: decrease
    - Flexural strength: decrease
    - Dissipated energy: decrease

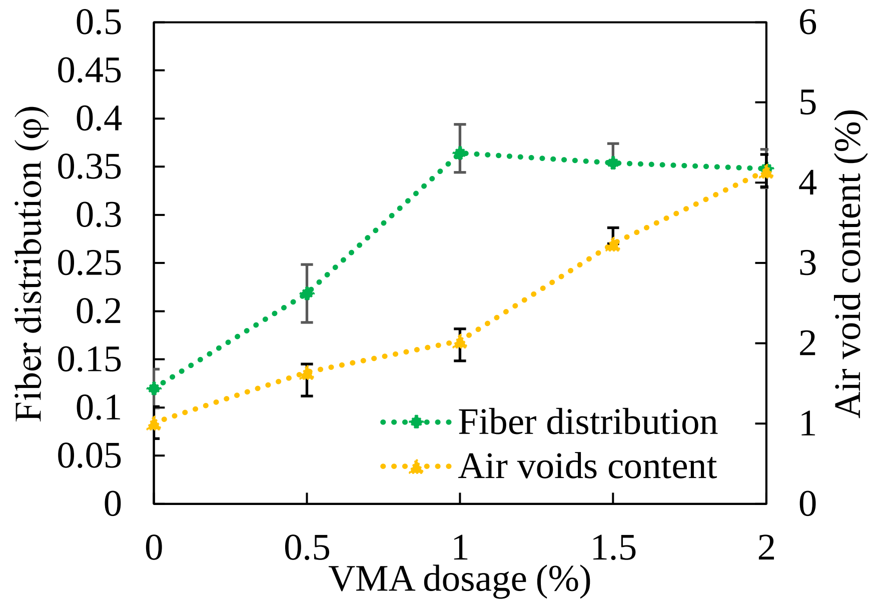




◻ Experimental results on fiber activity and air voids

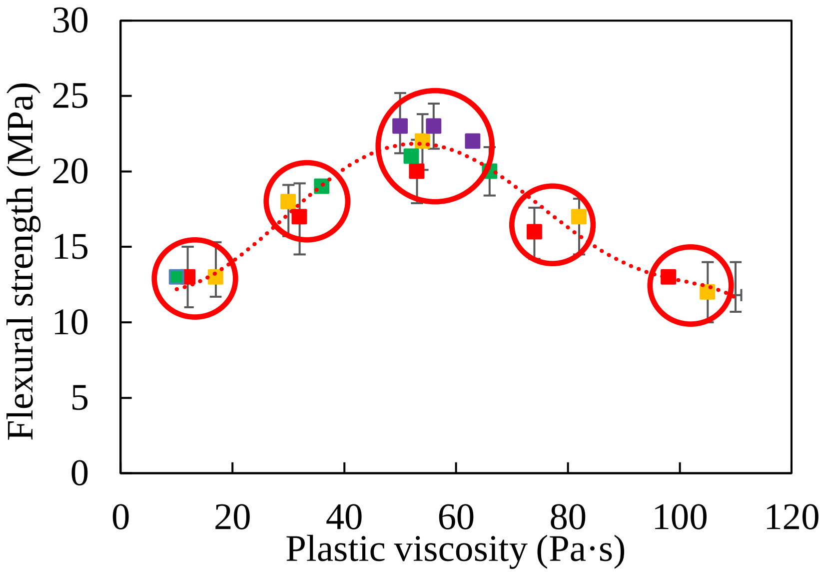
- Fiber behaviors and hardened air voids:
  - ✓ VMA dosage from 0 to 1%:
    - Fiber dispersion: increase
    - Fiber orientation: increase
    - Fiber distribution: increase
    - Air voids: increase
  - ✓ VMA dosage from 1 to 2%:
    - Fiber dispersion: increase
    - Fiber orientation: decrease
    - Fiber distribution: decrease
    - Air voids: increase





☐ Determine the ranges of plastic viscosity

- Range of plastic viscosity
  - ✓ Flexural strength - 5 groups
  - ✓ Different flexural strength intervals – plastic viscosity range



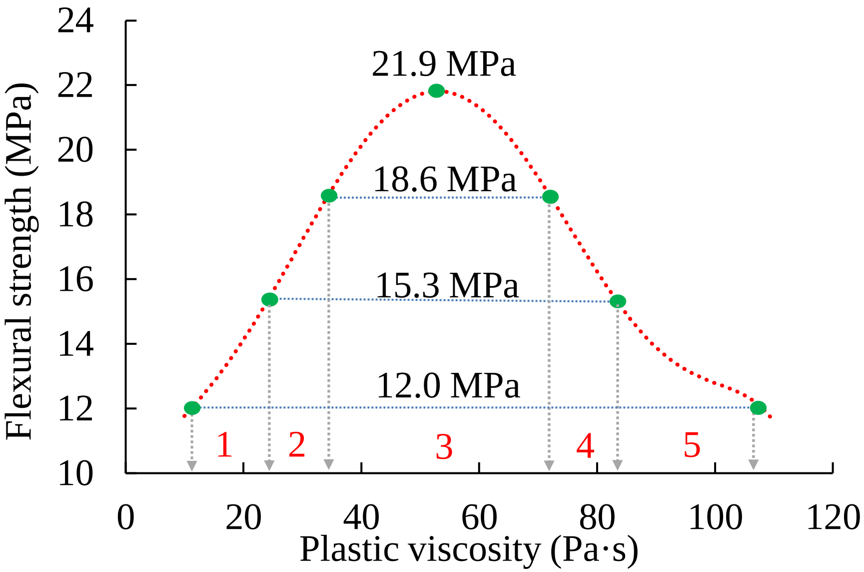
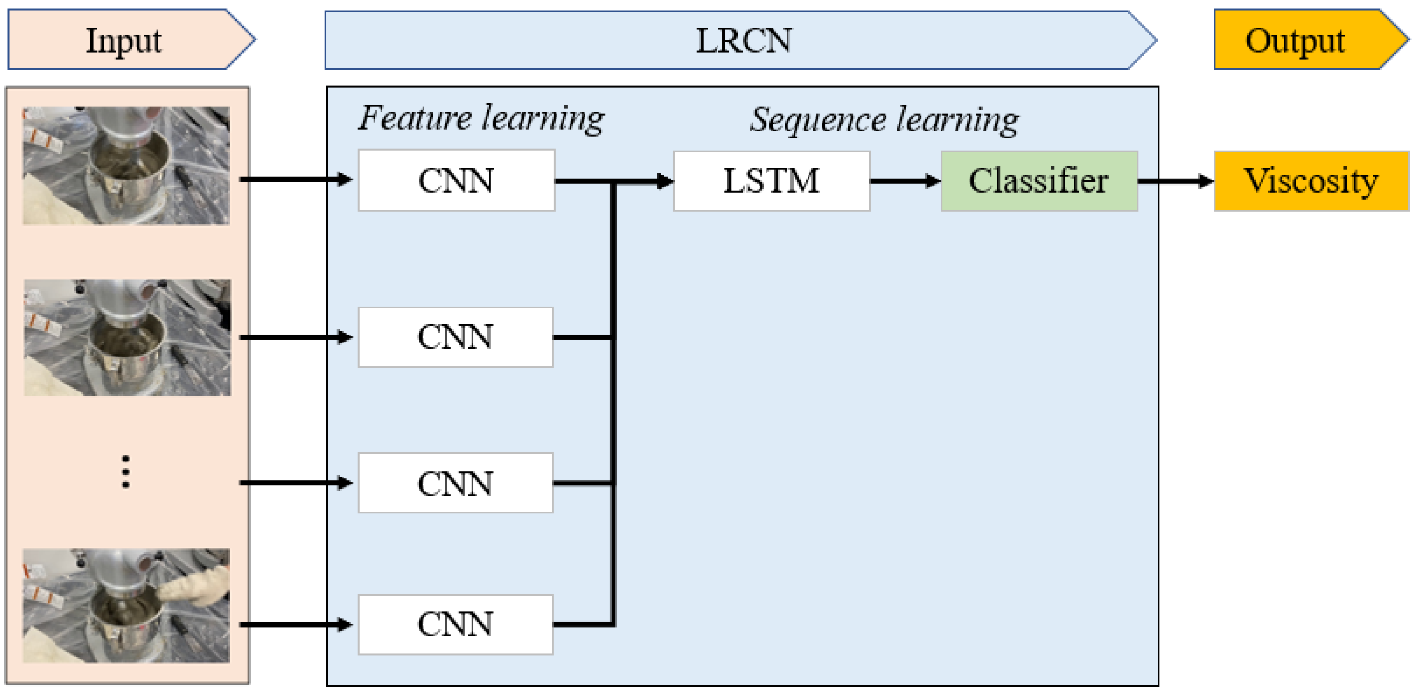


Table 3. Determination of the ranges of plastic viscosity

Class	Range 1	Range 2	Range 3	Range 4	Range 5
Plastic viscosity (Pa·s)	10-24	25-34	35-72	73-83	84-106
Designation	1	2	3	4	5

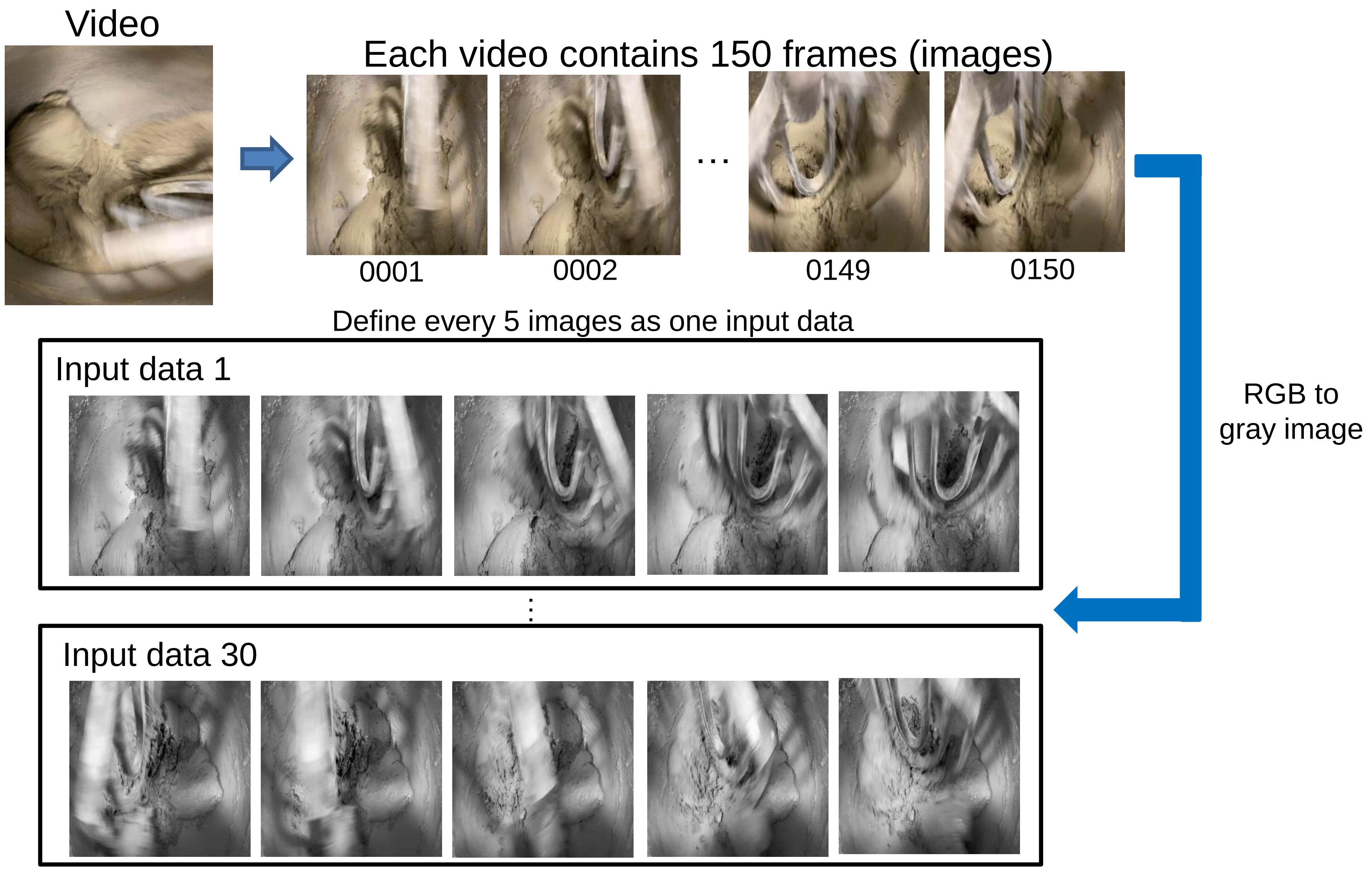
☐ Deep learning for plastic viscosity prediction

- Long-term recurrent convolutional network (LRCN) is proposed to estimate the plastic viscosity.
  - ✓ Input: video during mixing.
  - ✓ Output: plastic viscosity.



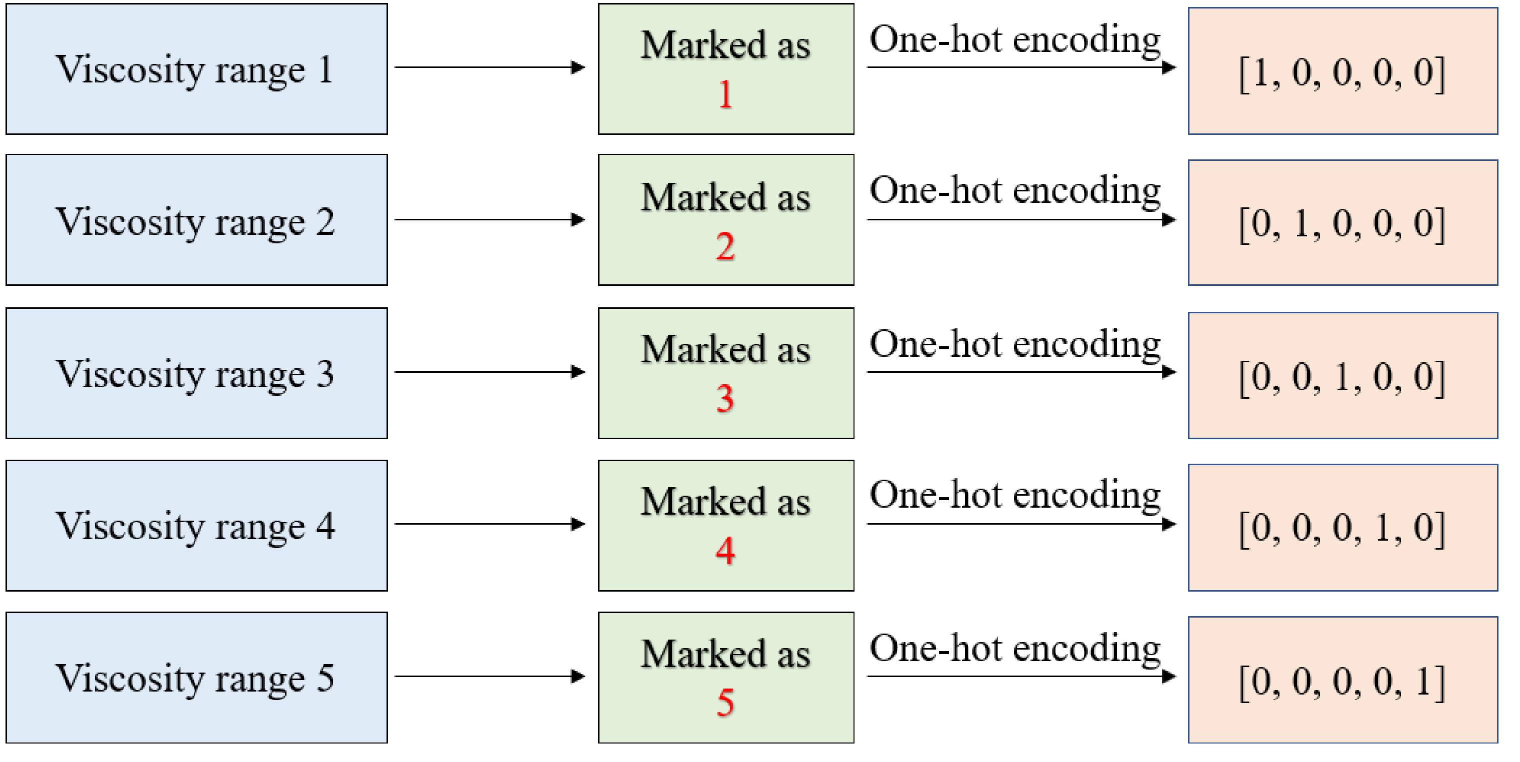
☐ Data Preprocessing

- Video is converted into a series of image to train LRCN.



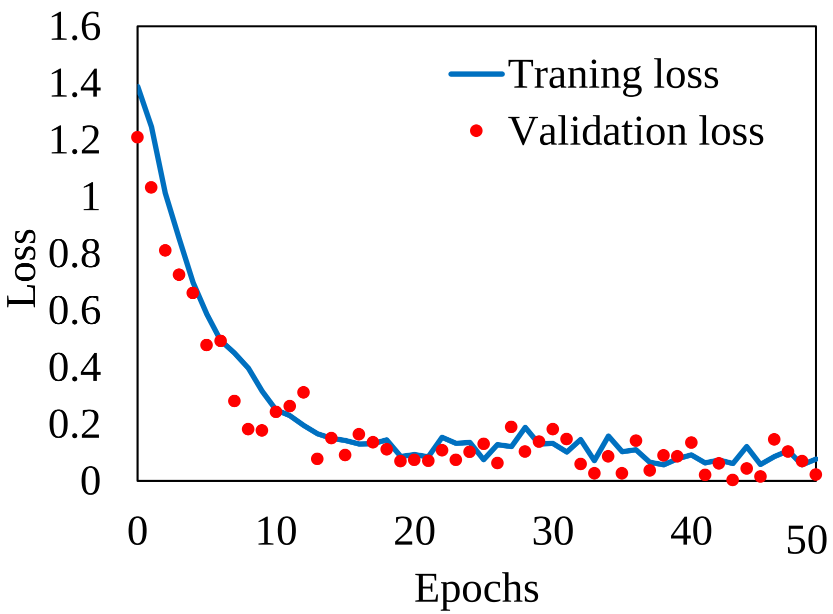
Output format of plastic viscosity for deep Learning algorithm

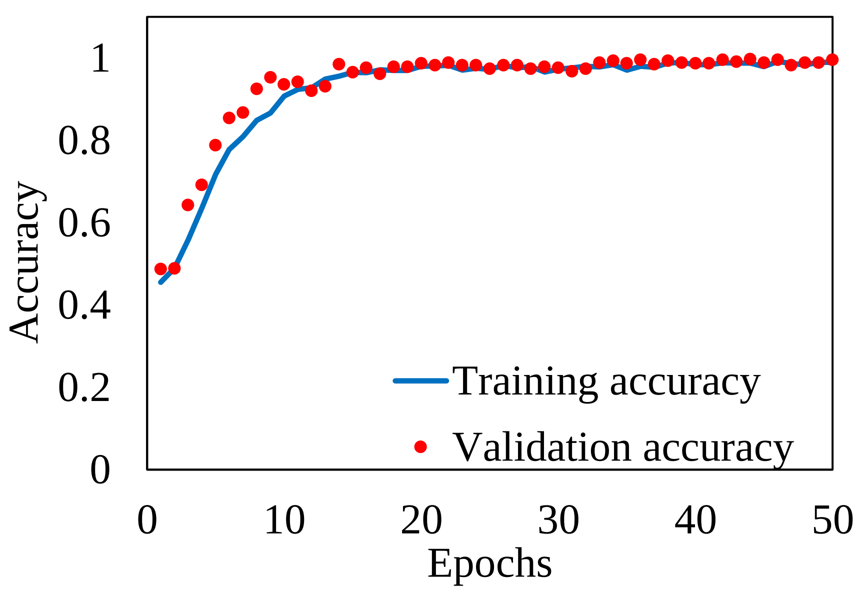
- The viscosity range are converted into one-hot code to be identified by deep learning method. The plastic viscosity range after one-hot encoding is used as output of LRCN.



□ Data description and training results

- In this study, a total of 78 videos were captured and used to generate 2340 data samples.
- The dataset is divided into 80% of training and 20% of validation data.
- The model is converged, and the validation accuracy is up to 1.





☐ Testing results

Sequence images (5 images)	Prediction		Actual
	Encode	(1, 0, 0, 0, 0)	17 Pa·s
	Class	0	
	Viscosity	10-24 Pa·s	
	Encode	(0, 0, 0, 0, 1)	98 Pa·s
	Class	4	
	Viscosity	84-106 Pa·s	
	Encode	(0, 0, 0, 1, 0)	80 Pa·s
	Class	3	
	Viscosity	73-83 Pa·s	
	Encode	(0, 1, 0, 0, 0)	33 Pa·s
	Class	1	
	Viscosity	25-34 Pa·s	
	Encode	(0, 0, 1, 0, 0)	54 Pa·s
	Class	2	
	Viscosity	35-72 Pa·s	

Predicted value	(1,0,0,0,0)	(0,0,0,0,1)	(0,0,0,1,0)	(0,1,0,0,0)	(0,0,1,0,0)
Designation	0	4	3	1	2
Plastic viscosity (Pa·s)	10-24	84-106	73-83	25-34	35-72
Measured (Pa·s)	17	98	80	33	54

Conclusions

1. The accuracy of the trained LRCN model for assessing the plastic viscosity of UHPC suspending mortar was higher than 0.990.
2. With a common laptop configuration, the assessment time for the plastic viscosity was shorter than 1 s, enabling real-time assessment of in-site viscosity.

Method	Time	Human action
Measurement using rheometer	10-30 min	Need manual operation
Measurement using mini V-funnel	10 min	Need manual operation
The proposed method	< 1 s	Without human intervention

◻ Acknowledgment

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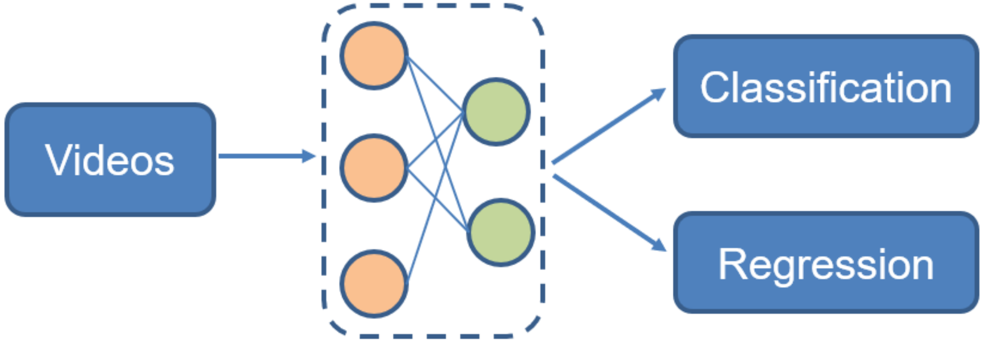
Advanced Concrete Technology (ACT) Lab

- The ACT lab in Stevens is capable of fabricating, testing, and characterizing concrete materials and structures.

◻ Limitations

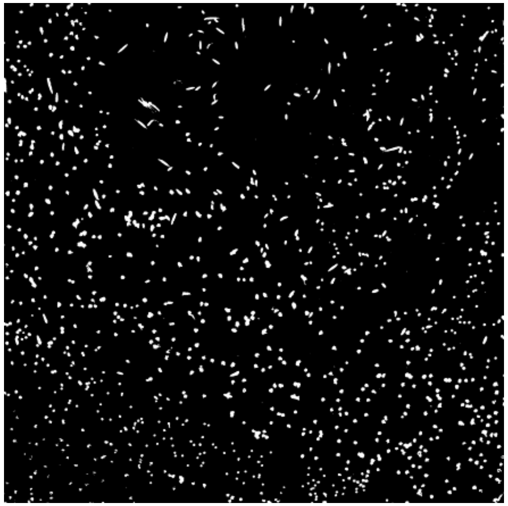
- Limitation: due to limited dataset, the proposed work can only predict the plastic viscosity range, rather than a accurate value.



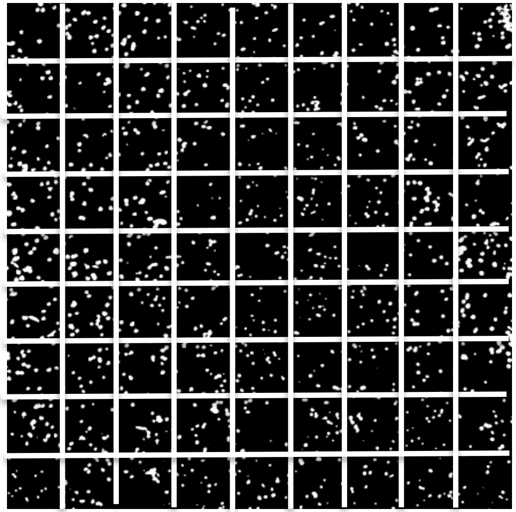
- This research only employs one type of mixer for mixtures.
  - ✓ Different mixing kinetic
  - ✓ Different flow state of mixture during mixing.

☐ Image analysis for fiber dispersion and orientation

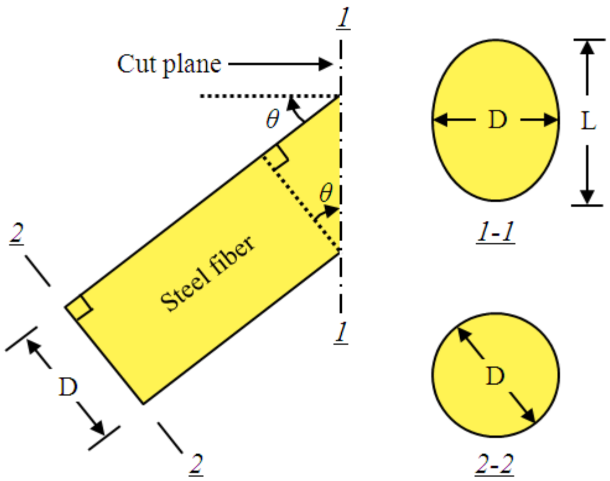
- Binary images of the cross sections of beam specimens



VMA-0



VMA-1.0



Fiber orientation coefficient (η):
η = 1, fibers aligned perpendicular to cross section

Fiber dispersion coefficient (α):
α = 1, fibers uniformly dispersed

$$\theta = \arccos\left(\frac{D}{L}\right)$$

$$\eta = \int_{\theta_{min}}^{\theta_{max}} p(\theta)\cos^2\theta \, d\theta$$

$$\alpha = \exp\left[-\frac{1}{x_0}\sqrt{\frac{\sum(x_i - x_0)^2}{n}}\right]$$