Effect of thixotropic UHPC on interfacial properties as an overlay

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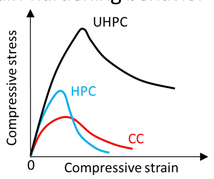
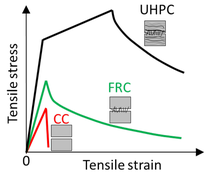
Sponsor(s): FHWA and NJDOT (Bridge Resource Program (BRP))

Advantages of UHPC

- High particle packing density, low w/b, and high fiber volume
- High mechanical strengths
  - ✓ Compressive strength (28 days): ≥ 120 MPa
  - ✓ Tensile strength (28 days): ≥ 7 MPa
- Strain-hardening behavior

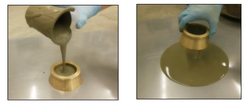




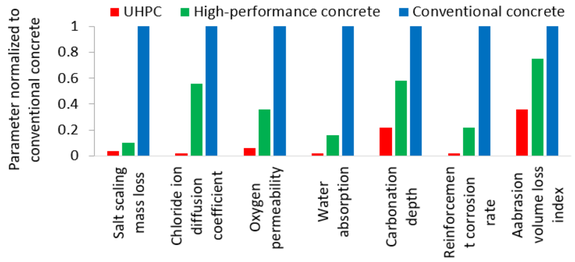
UHPC: ultra-high performance concrete
HPC: high-performance concrete

FRC: fiber-reinforced concrete
CC: conventional concrete

- Super workability (self-consolidating)
  - ✓ Low construction energy (no mechanical vibration for consolidation)
  - ✓ High construction quality



- Sustainability
  - ✓ Low life-cycle cost
  - ✓ Excellent durability



Durability properties (the lowest values are desired)

Mixture Design of UHPC

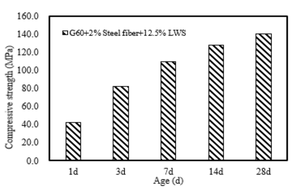
1. Mixture design of developed cost-effective UHPC

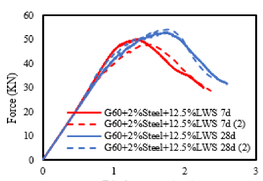
UHPC mixture design unit (kg/m³):
(1 kg/m³ =0.0624 pounds/ cubic feet)

Cement	Slag	RS	LWS	HRWR	Water	SF
469.5	648.4	864	83.8	9.2	228.7	156

Note: RS: River sand; LWS: Lightweight sand; HRWR: High-range water reducer; SF: Steel fiber

2. Performance of developed cost-effective UHPC



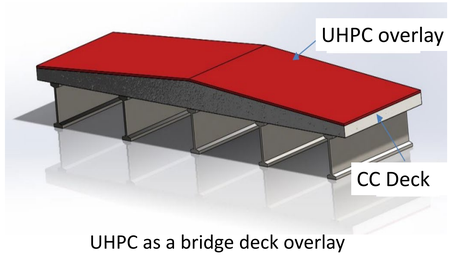


Five mixtures with different content of nanoclay:
0% Nanoclay (Reference),
0.05% Nanoclay, 0.10% Nanoclay, 0.15% Nanoclay, 0.20% Nanoclay

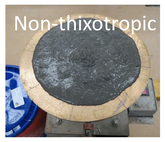
Three ambient temperatures are considered:
10 ℃, 25 ℃, and 35 ℃.

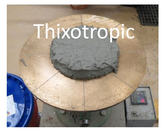
Introduction of Thixotropic UHPC

1. Non-thixotropic UHPC



UHPC as a bridge deck overlay





Problems:

✓ Non-thixotropic UHPC mixture can flow on the crown, when it applies as an overlay. Therefore, a large number of formworks are required for this construction.

2. Thixotropic UHPC

Thixotropy is a time-dependent shear thinning property of the non-Newtonian fluid that behaves as the solid under the static condition and changes to the fluid by agitating or vibrating.

Advantages

- ✓ Fast construction of overlay
- ✓ Removal of formworks
- ✓ Quality control

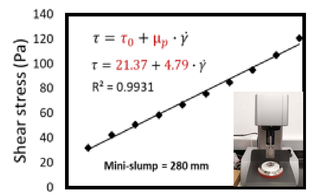
3. Impact factors of thixotropy

- ✓ Nanoclay addition
- ✓ Ambient temperature

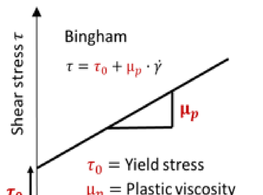
Thixotropic UHPC is easy to cast and can hold its shape when cast is done

Experimental Methods

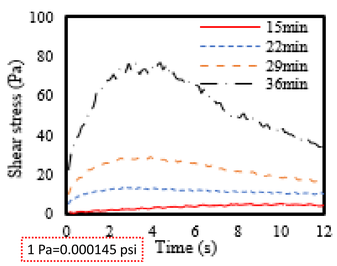
1. Use Bingham Model to determine dynamic yield stress



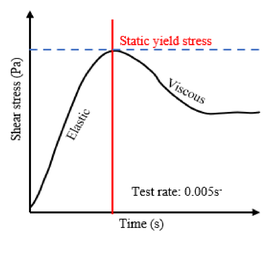
1 Pa=0.000145 psi



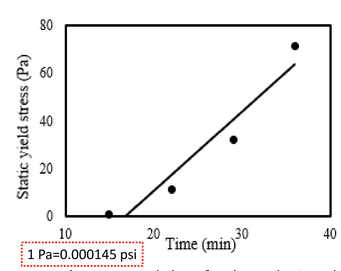
2. Use shear-rate-control protocol to determine static yield stress



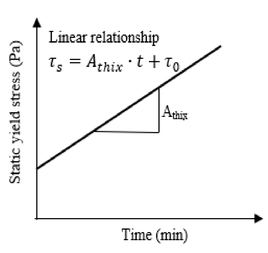
1 Pa=0.000145 psi



3. Use growth of static yield stress to determine thixotropy

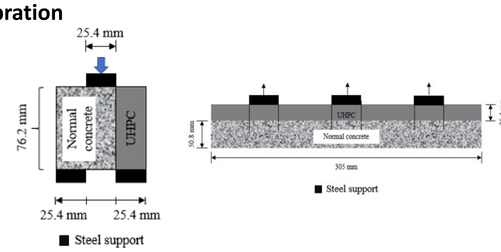


1 Pa=0.000145 psi



- Using linear model to fit the relationship between static yield stress and time so that the slope of the fitting straight line reflects thixotropy

4. Use bonding strength to evaluate effect of thixotropy and vibration

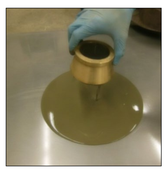


Direct shear strength

Pull-off strength

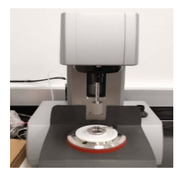
- Introduce three different vibration energy (i.e. non-vibrated, middle-frequency vibrated, and high-frequency vibrated) in casting period
- Vibration benefits the bonding strength between thixotropic UHPC and its substrate.

5. Establish relations of workability, yield stress, thixotropy, and bonding strength



Mini-slump diameter

Linear relationship



1. Dynamic yield stress
2. Thixotropy

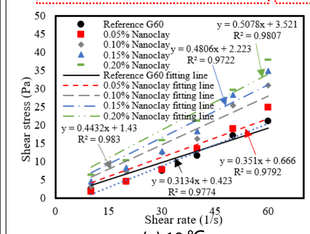
1. Optimal thixotropy range at 10 ℃
2. Optimal thixotropy range at 25 ℃
3. Optimal thixotropy range at 35 ℃

- Optimal thixotropic range will be determined based on bonding strength and workability

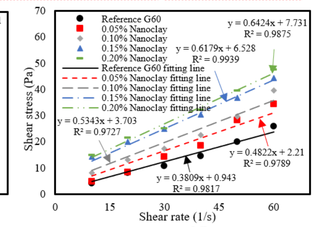
Performance of Thixotropic UHPC

1. Effect of nanoclay addition and temperature on rheology of UHPC paste

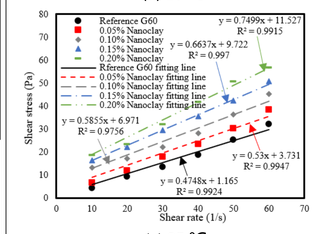
1 kN to pounds = 224.80894 pounds | 1 mm = 0.0393700787 inch | 1 MPa = 0.14503 ksi



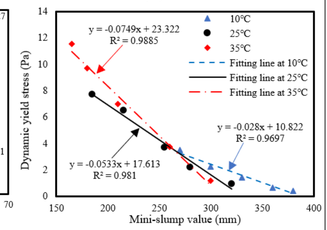
(a) 10 ℃



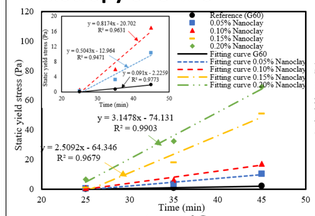
(b) 25 ℃



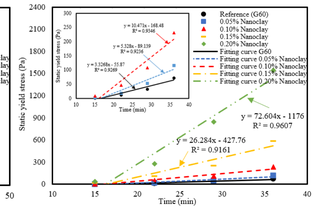
(c) 35 ℃



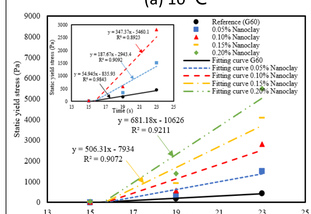
2. Effect of nanoclay addition and temperature on the thixotropy of UHPC



(a) 10 ℃



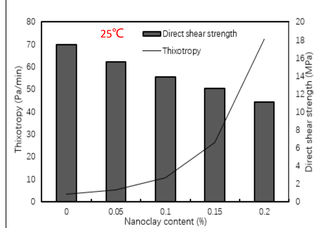
(b) 25 ℃

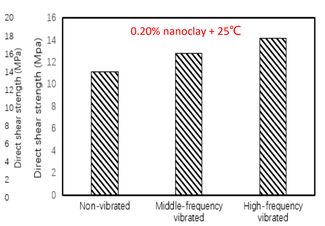


(c) 35 ℃

Temperature	UHPC paste	Thixotropy (Pa/min)	Normalized value
10℃	Reference G60	0.091	0.027
	0.05% nanoclay	0.504	0.151
	0.10% nanoclay	0.817	0.246
	0.15% nanoclay	2.509	0.754
	0.20% nanoclay	3.147	0.946
25℃	Reference G60	3.327	1.000
	0.05% nanoclay	5.328	1.601
	0.10% nanoclay	10.471	3.147
	0.15% nanoclay	26.284	7.900
	0.20% nanoclay	72.604	21.823
35℃	Reference G60	54.945	16.515
	0.05% nanoclay	187.672	56.409
	0.10% nanoclay	347.371	104.410
	0.15% nanoclay	506.311	152.182
	0.20% nanoclay	681.183	204.744

3. Effect of thixotropy and vibration on bonding strength





Conclusions

1. The nanoclay addition and increase of ambient temperatures can increase the thixotropy of UHPC.
2. Vibration benefits the bonding strength between thixotropic UHPC and its substrate.