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Development of limestone calcined clay cement concrete in South China and its bond behavior with steel reinforcement

Key words:

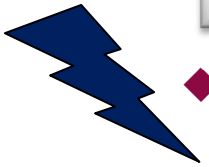
Limestone calcined clay cement; Hydration; Bond-slip; MIP; SEM; Bond strength

1. Introduction



- Global cement grows by 3% annually.
- Global cement production is expected to be about 2.2 billion tons, growing at a rate close to the world economy.
- For every 20 tonnes of man-made CO2 that enter the atmosphere, one comes from the kilns of cement factories.

Emissions in cement production are threefold



- Use electrical energy to grind the raw materials and clinker;
- Heat the raw materials in a kiln to 1450°C to form clinker, crush and blend with gypsum to make cement;
- Process emissions: heat the limestone to change into lime. These emissions of CO2 represent 60 to 65% of total emissions linked to cement production.

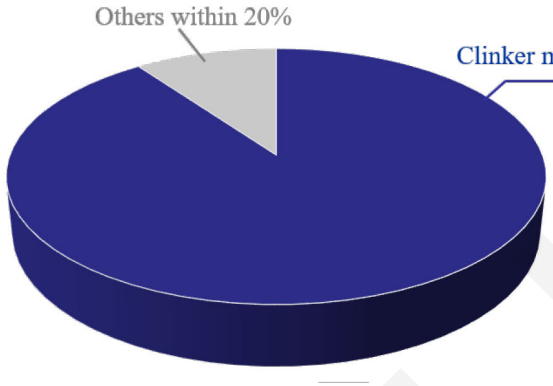




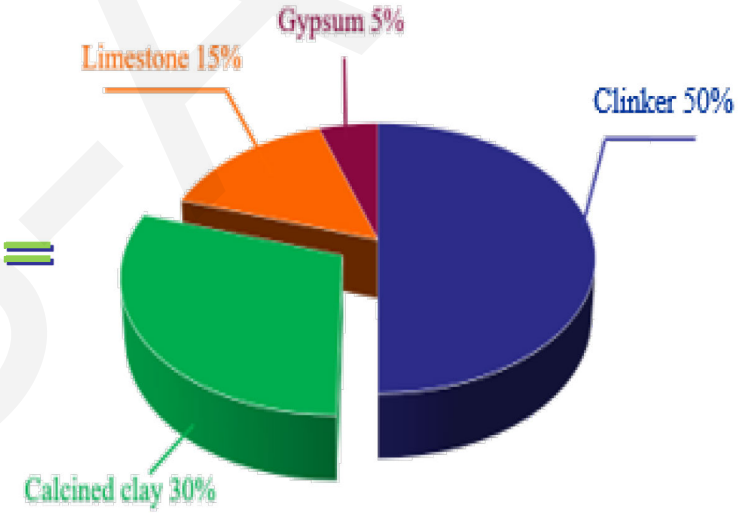
What is LC^3?

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OPC =



LC^3 =



Limestone + **C**alcined **C**lay + **C**ement = LC^3

metakaolin

Karen Scrivener, Fernando Martiren, Shashank Bishnoi, Soumen Maity. Calcined clay limestone cements (LC3). Cement Concrete Res,114:49-56 (2018).

Why LC^3?

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Reducing the amount of clinker in cement, reduces the amount of CO2 in the atmosphere.

Now, the amount of clinker is reduced by half in LC^3.

LC^3 Advantages:

Environmental friendly

Emissions of LC^3 are estimated to be 20-30% lower than OPC because:

- Reduced clinker content leads to less process emissions from the decarbonation of limestone in clinker and less emissions from heating limestone to form clinker;



Economic

- Grinding limestone takes less energy than heating it;



Practical

- Calcination of clay takes place at 800°C and uses roughly 55% of the energy needed for clinkerisation at 1450°C.



- 50% less clinker
- 30% less CO_2
- Similar strength
- Better chloride resistance
- ASR resistant

2. Development of LC^3 concrete

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Oxides	Calcined Clay (%)	Gypsum (%)	Limestone (%)	OPC (%)
SiO_2	52.70	3.09	0.30	22.37
Al_2O_3	36.90	1.34	0.10	4.36
K_2O	3.49	0.05	-	-
Fe_2O_3	1.99	0.36	0.08	3.38
MgO	0.28	1.31	0.64	2.43
TiO_2	0.18	-	-	-
SO_3	0.12	40.87	-	2.45
CaO	0.04	30.51	81.13	61.08
Rb_2O	0.03	-	-	-
SrO	-	-	0.02	-
Others	4.27	23.26	17.73	2.71

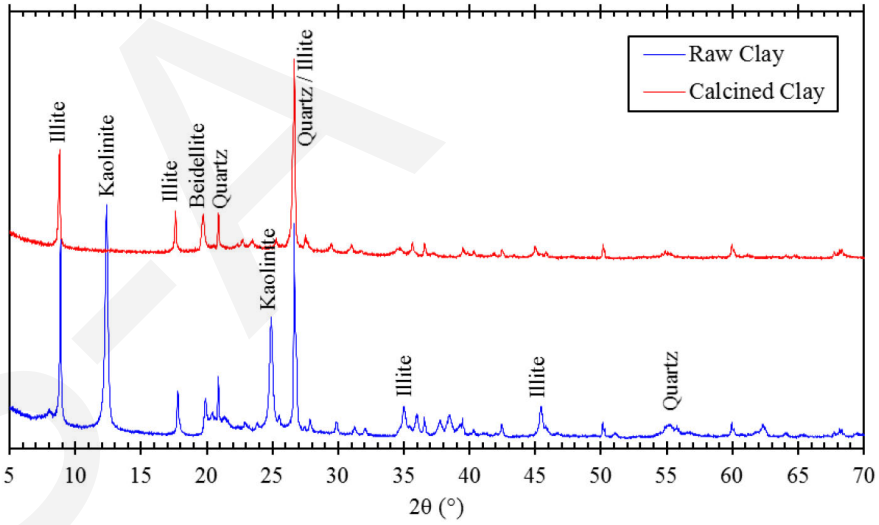


Fig. 2 XRD of raw clay and calcined clay

Mixture	W/B	OPC	CC	LS	GYP	Sand	CAgg	SP(%)	Slump /flow(mm)	Remark
OPM-0.5	0.5	1	-	-	-	3	-	-	230	OPC mortar
OPM-0.45	0.45	1	-	-	-	3	-	-	200	
OPM-0.4	0.4	1	-	-	-	3	-	0.27	190	
OPM-0.35	0.35	1	-	-	-	3	-	0.47	185	
LCM-0.5	0.5	0.523	0.3	0.15	0.027	3	-	0.37	220	LC3 mortar
LCM-0.45	0.45	0.523	0.3	0.15	0.027	3	-	0.52	200	
LCM-0.4	0.4	0.523	0.3	0.15	0.027	3	-	0.73	180	
LCM-0.35	0.35	0.523	0.3	0.15	0.027	3	-	1.15	180	
OC-0.5	0.5	1	-	-	-	1.43	2.21	-	190	OPC concrete
OC-0.4	0.4	1	-	-	-	1.43	2.21	0.32	70	
LCC-0.5	0.5	0.523	0.3	0.15	0.027	1.43	2.21	0.32	175	LC3 concrete
LCC-0.4	0.4	0.523	0.3	0.15	0.027	1.43	2.21	0.57	90	

Properties of concrete

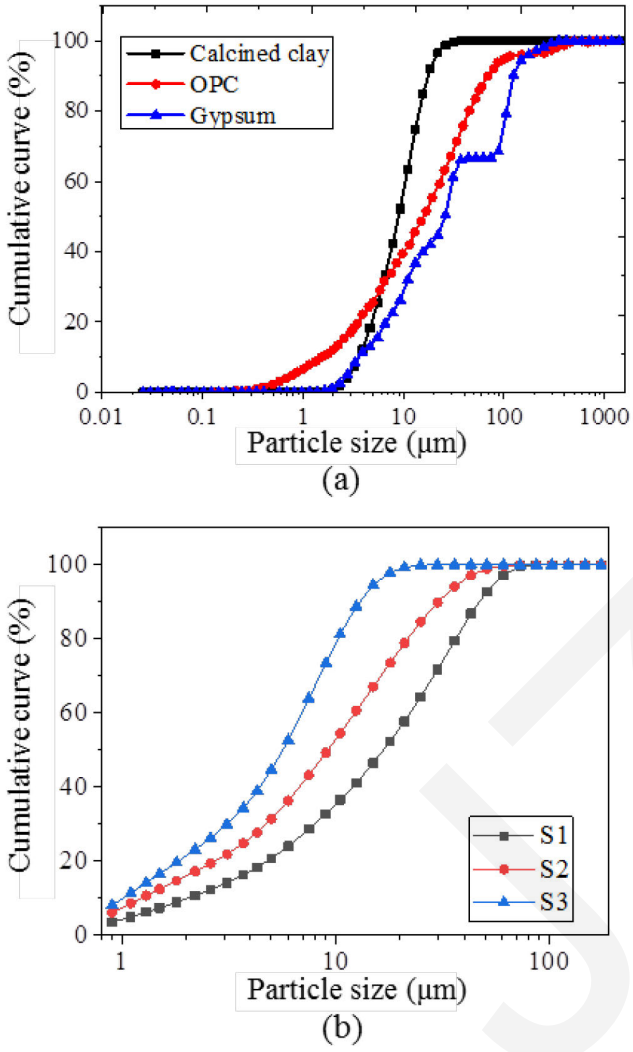


Fig. 3 Particle size distributions of raw materials: (a) Calcined clay, OPC and gypsum; (b) Limestone

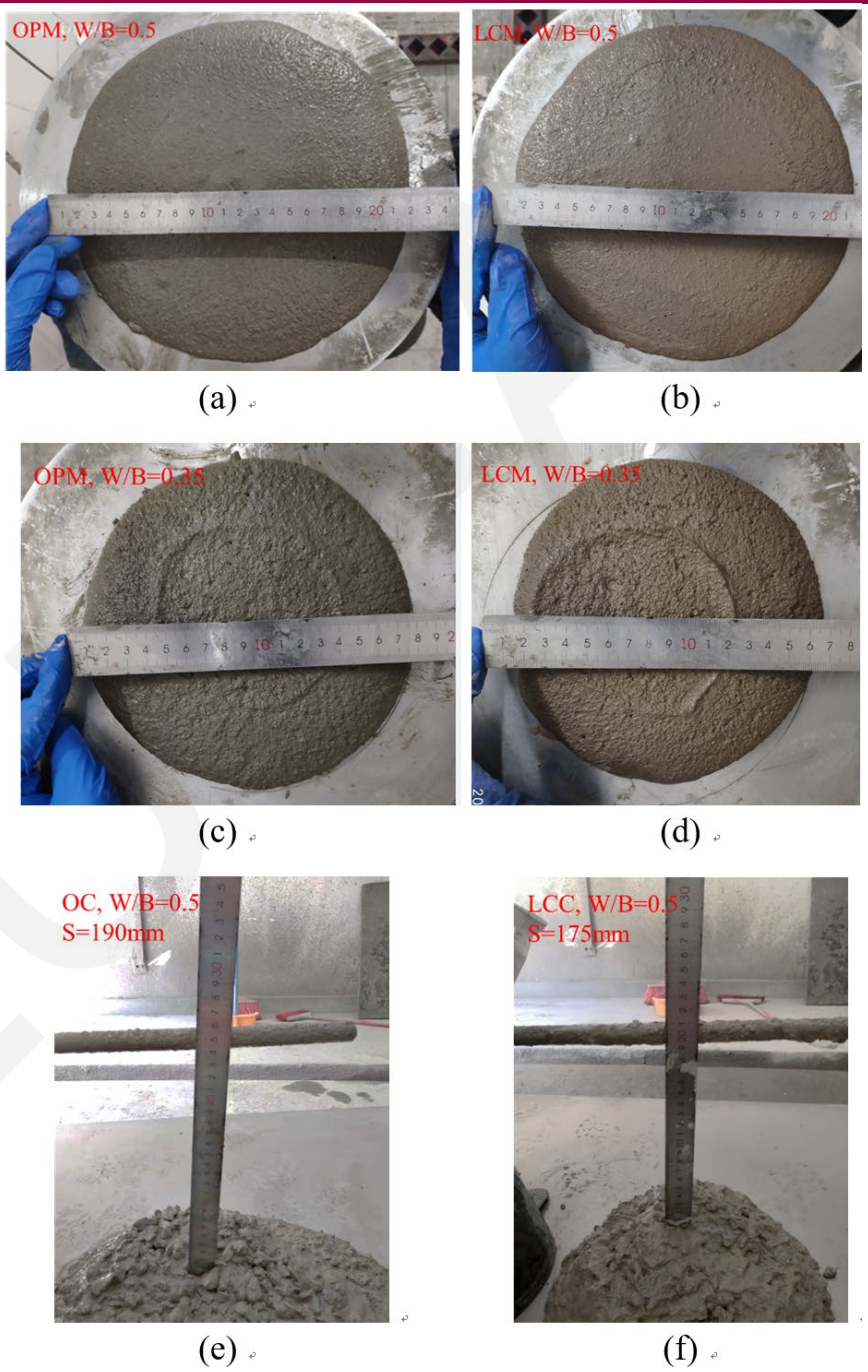
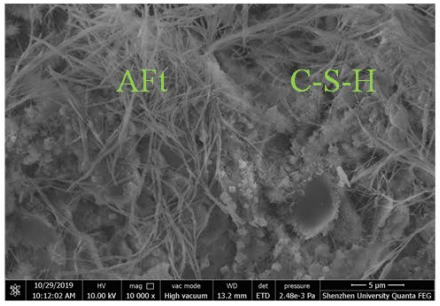
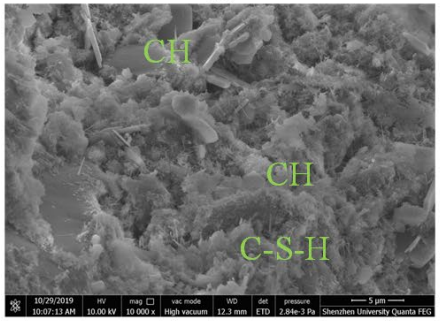


Fig. 4 Flow and slump test of OPC and LC3 mortar and concrete: (a) OPM-0.5, (b) LCM-0.5, (c) OPM-0.35, (d) LCM-0.35, (e) OC-0.5, (f) LCC-0.5

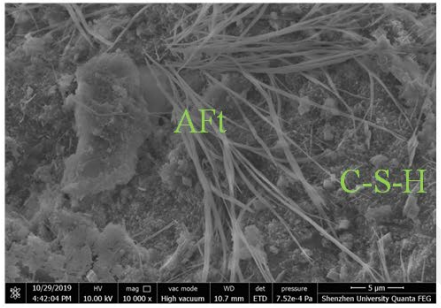
SEM analysis and Pore size analysis



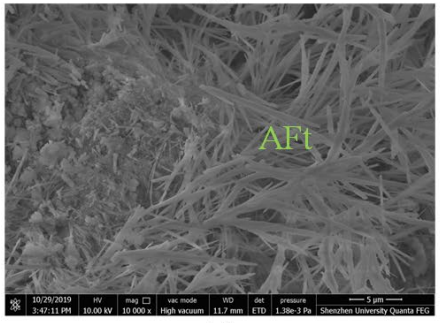
(a)



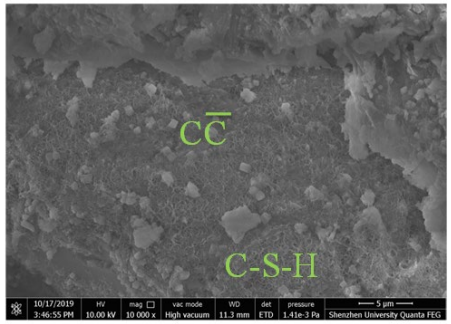
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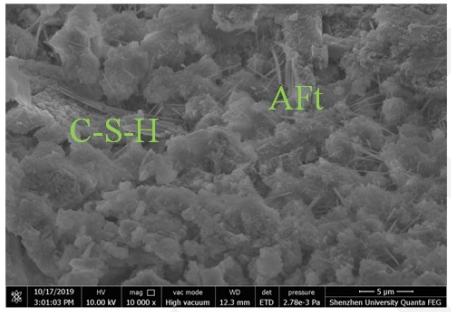
(c)



(d)

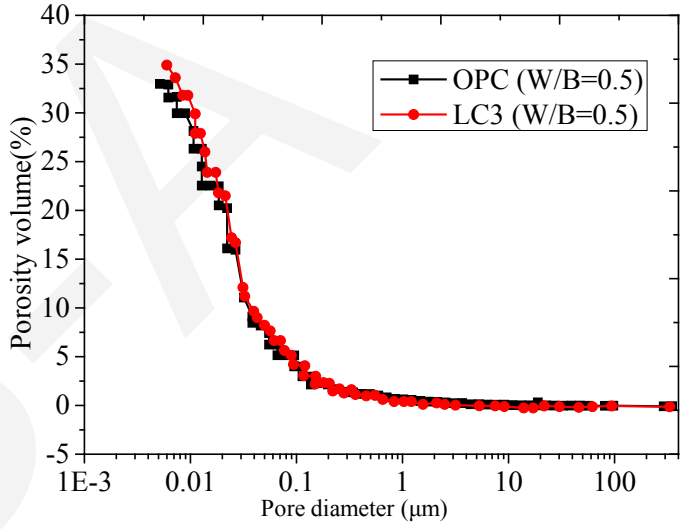


(e)



(f)

Fig. 7 SEM image of OPC and LC3 pastes under different curing ages: (a) LC3-Day 1, (b) OPC-Day 1, (c) LC3-Day 3, (d) OPC-Day 3, (e) LC3-Day 28, (f) OPC-Day 28



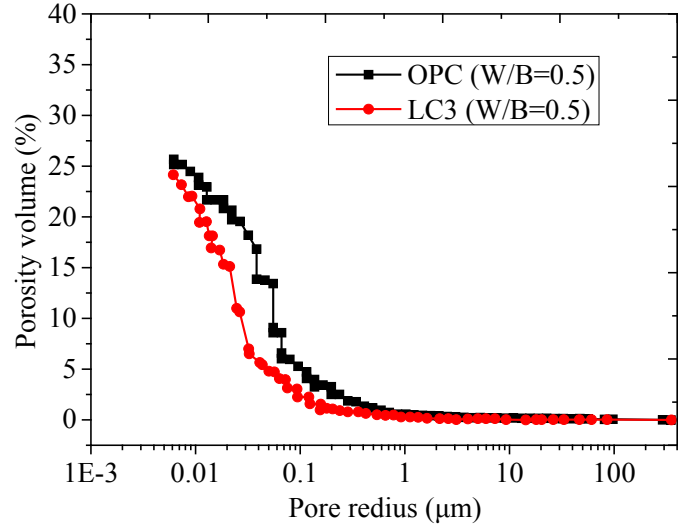


Fig. 8 Cumulative porosity curves: (a) Day 3; (b) Day 28

◆ Mechanical properties

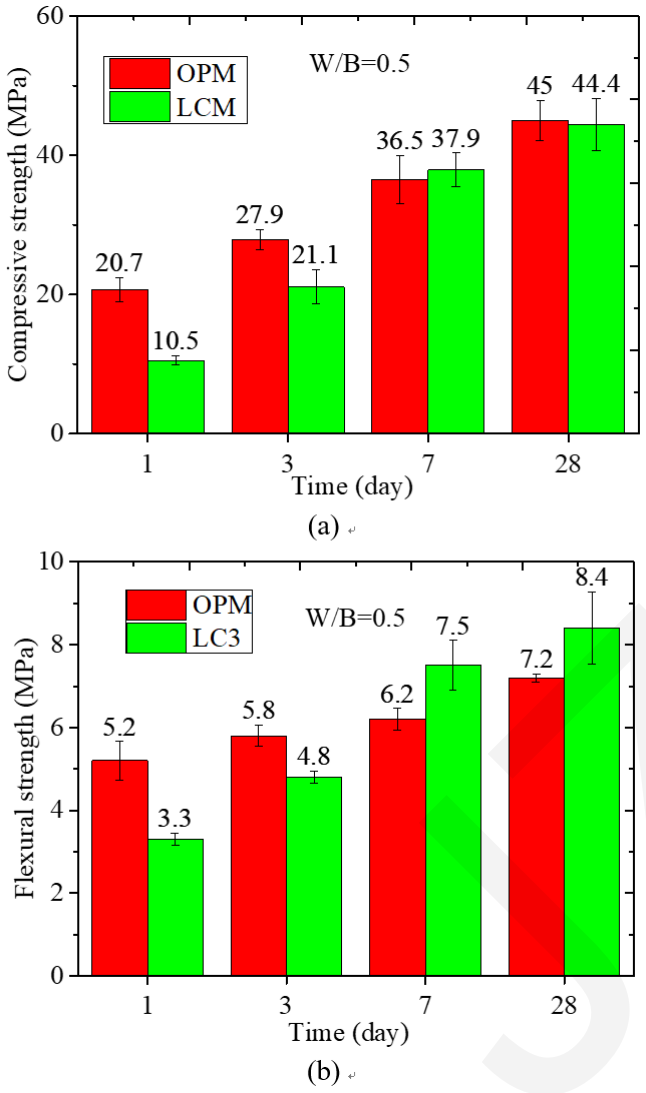


Fig. 9 Compressive strengths of OPC and LC^3 mortars: (a) Compressive strength; (b) Flexural strength

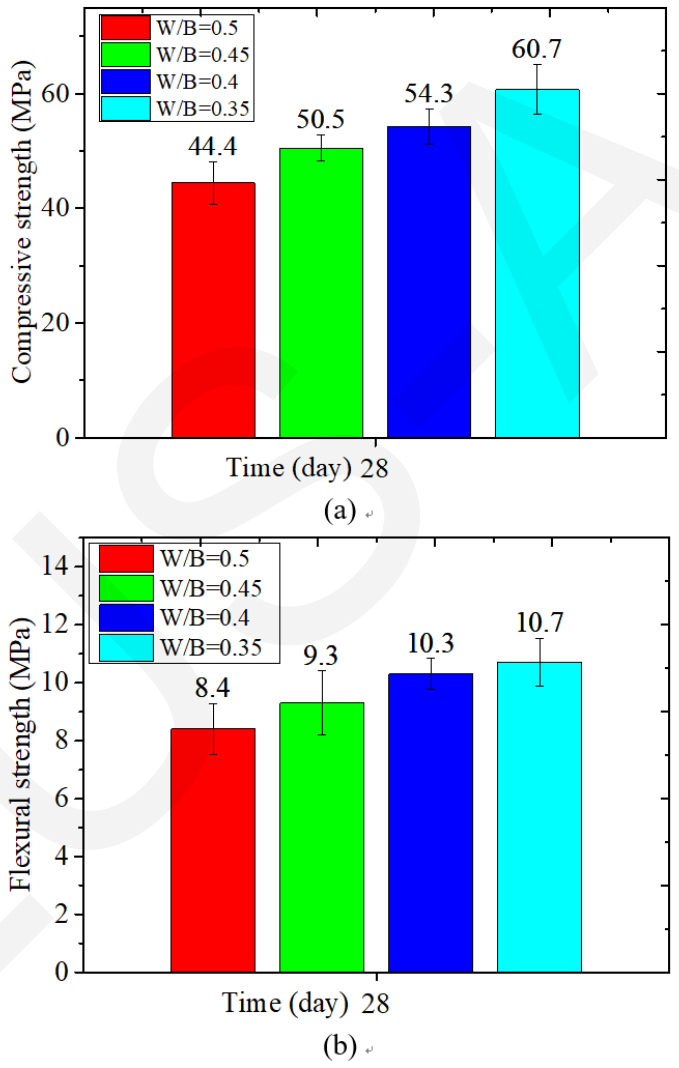


Fig. 10 Effect of W/B ratio on 28-day compressive and flexural strength of LC^3 mortar: (a) Compressive strength; (b) Flexural strength

Given comparable compressive strengths, LC3-based materials tend to have higher flexural or splitting tensile strength and are thus potentially tougher than their OPC counterparts.

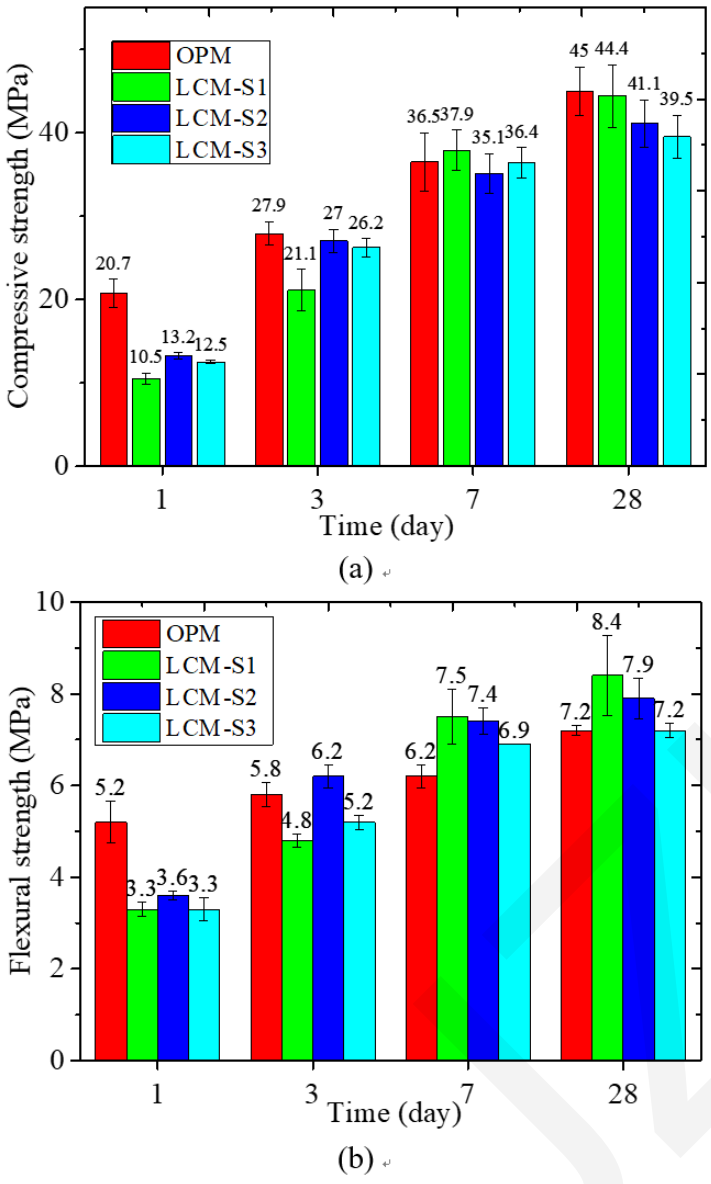


Fig. 11 Effect of fineness of limestone on compressive and flexural strength: (a) Compressive strength; (b) Flexural strength

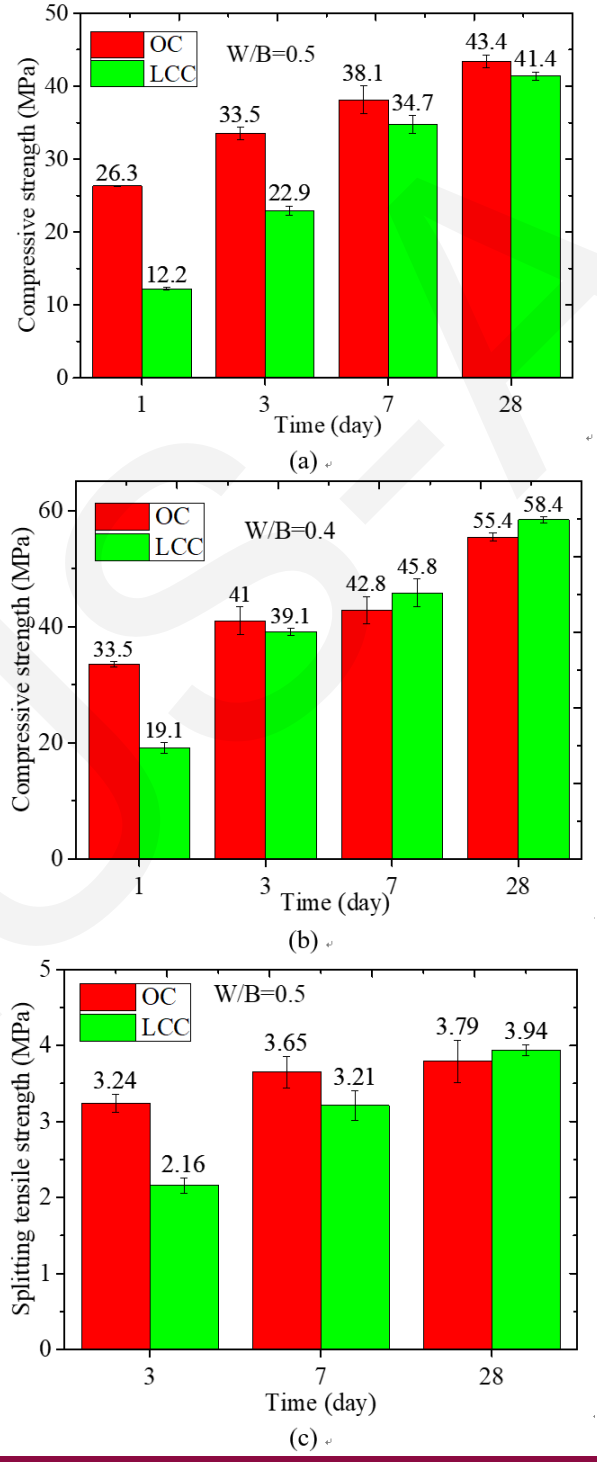
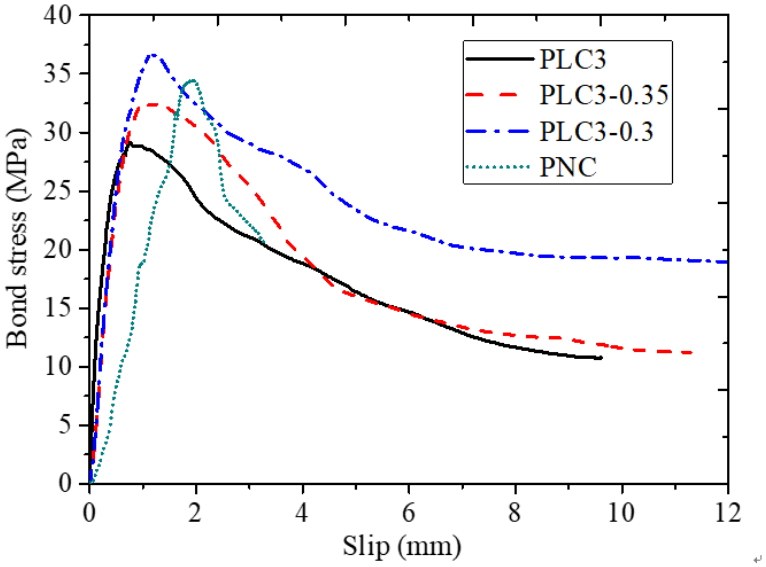


Fig. 12 Compressive and tensile strength of concrete: (a) Compressive strength with W/B of 0.5; (b) Compressive strength with W/B of 0.4; (c) Splitting tensile strength with W/B of 0.5

3. Bond-slip relationship





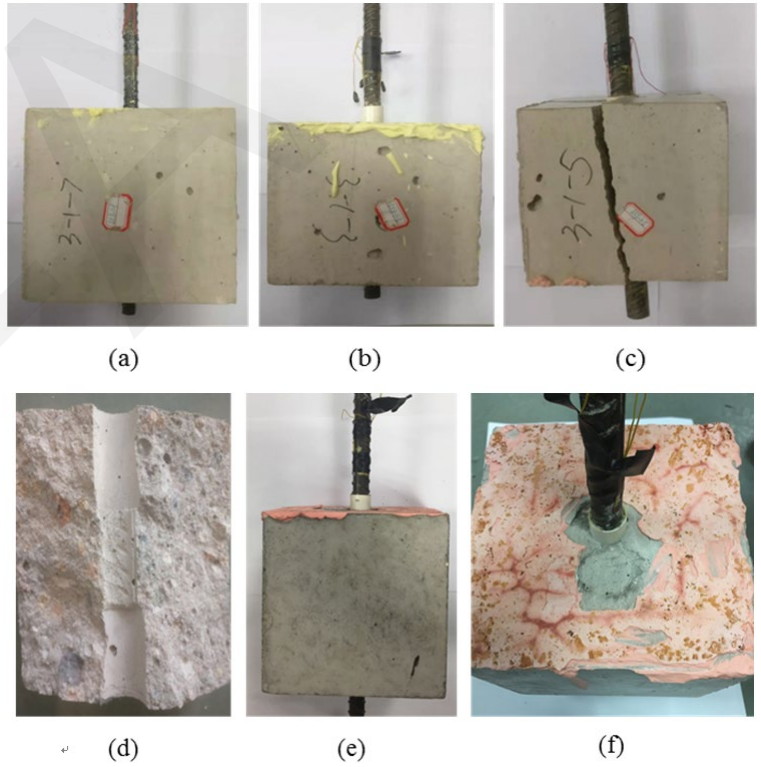


Fig. 14 Failure mode of the pull-out tests: (a) PLC3-D12 (d=12 mm, pull-out failure); (b) PLC3 (d=16 mm, pull-out failure); (c) PLC3-D22 (d=22 mm, concrete splitting failure); (d) Failure profile in PLC3-D22; (e) OPC group; (f) Rebar pull out

The failure mode is generally identical to that of the OPC group. Two failure modes, namely, pull-out of rebar from the concrete substrate and concrete splitting, were observed in the tests. Given the same grade of compressive strength, the bond strength of LC^3 concrete is comparable to that of OPC concrete; however, its bond-slip stiffness is greater than that of its OPC counterpart.