Performance of concrete containing water-hyacinth ash (WHA) as cement replacement – resistance to elevated temperature and seawater exposures

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المركز القومى لبحوث المياه

American Concrete Institute

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Outline

- Introduction
- WHA
  - —Production
  - —Properties
  - —Strength-activity index (SAI)
- Concrete mix design
- Compressive and tensile strengths
- **Effect of high temperatures on cube F_{cu} of WHA concrete**
- **Resistance of WHA concrete to seawater**
- Conclusions

1- Introduction

Cement industry → ***5-8% of global CO_2 emission***

Traditional SCM FA, Slag, .. → ***Coal-based power plants are being shut down all over the world***

Alternative Supplementary Cementitious Materials

(ASCM)

By-products, waste, bio-based

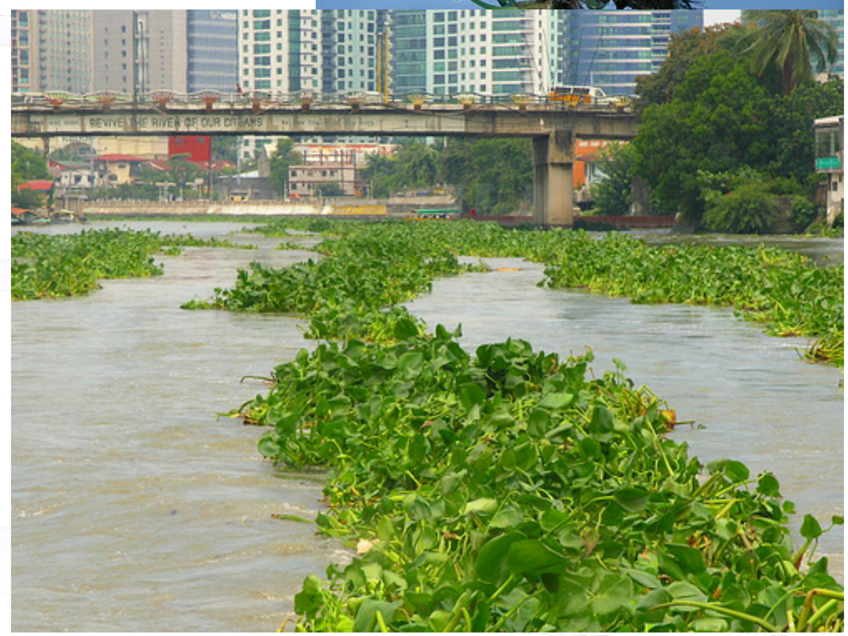
2- WH plants

Origin :

- Lives in fresh water (rivers) in warm regions
- Native to Latin America, Introduced to USA in 19th (Louisiana), then moved to central states

Problematic :

- Fast growing rate (2 plants produce 30 plants in 23 days and 1200 plants in 4 months)
- Block water ways ➔ increase water level in main & branch drainages and flood agricultural land
- Damage canal walls
- Increase water evaporation
- Decrease oxygen in water ➔ 1-acre WH = 40 persons
- Enhance mosquito production



WH

- Growth & decomposition of WH cause organic pollution and costly $$$
- Collecting & burning in open air ➔ air pollution

Cement

- Shortage in:
  - resources of raw materials
  - energy needed for manufacture
- CO_2 emission

What about using WH as ASCM ?

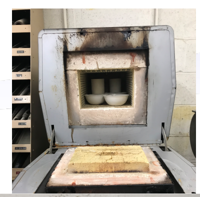
WHA production

WH plants in fresh case

Collection of WH plants from watercourses

WH plants after drying for 2-3 weeks

Furnace



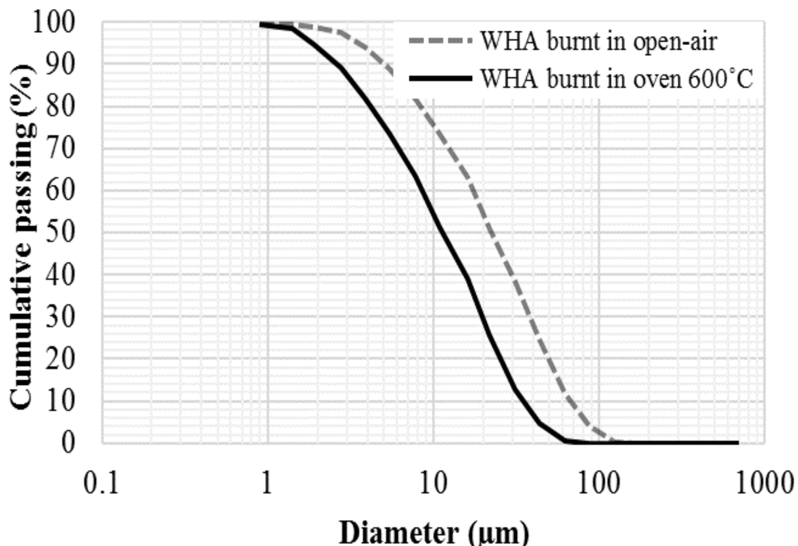
Oven burning at 600˚C *[1112°F]*

Open-air burning

Los – Angles (LA) apparatus for grinding

Sieving WHA on sieve # 200

Physio-chemical analysis of WHA



	Open-air burning	Oven burning at 600ºC [1112° F]
% wt. of WHA/dried plant	27.65	25.85
D_{50} (µm)	23	12
Specific gravity	2.52	2.65
Color	Dark gray	Light brown

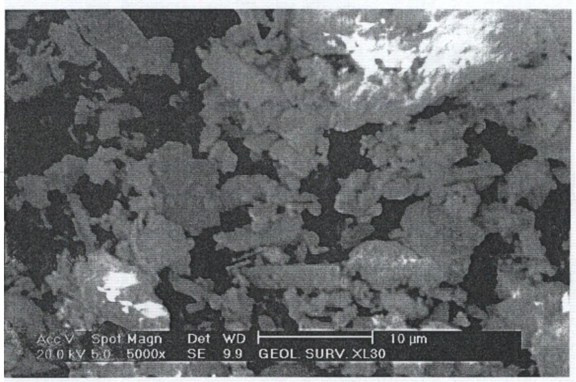
∑ 3 oxides ≈ 50% (as fly and rice-husk ash)

Large LOI due to organic materials

Constituent	%	
	Open-air burning	Oven burning at 600°C [1112°F]
SiO_2	33.89	34.50
Ti_2O_3	0.75	0.78
Al_2O_3	6.77	6.95
Fe_2O_3	5.77	6.02
MgO	5.40	5.93
CaO	10.08	11.46
Na_2O	1.26	1.41
K_2O	9.83	10.98
MnO	0.66	0.73
P_2O_5	1.04	1.13
Cl^-	3.82	4.02
SO_4^{--}	2.37	3.74
LOI	17.93	11.91

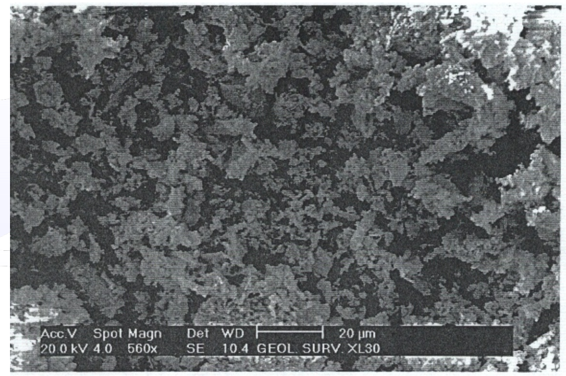
SEM of WHA

(a): At 1500 x

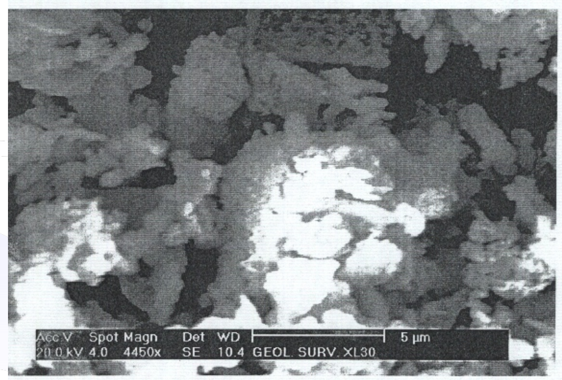


(b): At 5000x

(A) WHA burnt in open air



(a): At 560 x



(b) At 4450 x

(B) WHA burnt in oven 950ºC

WHA is porous and mainly contain angular particles of irregular shape and rough textures, with few spherical particles of smooth surfaces

Strength-Activity Index (SAI) of WHA

Mortar mixtures

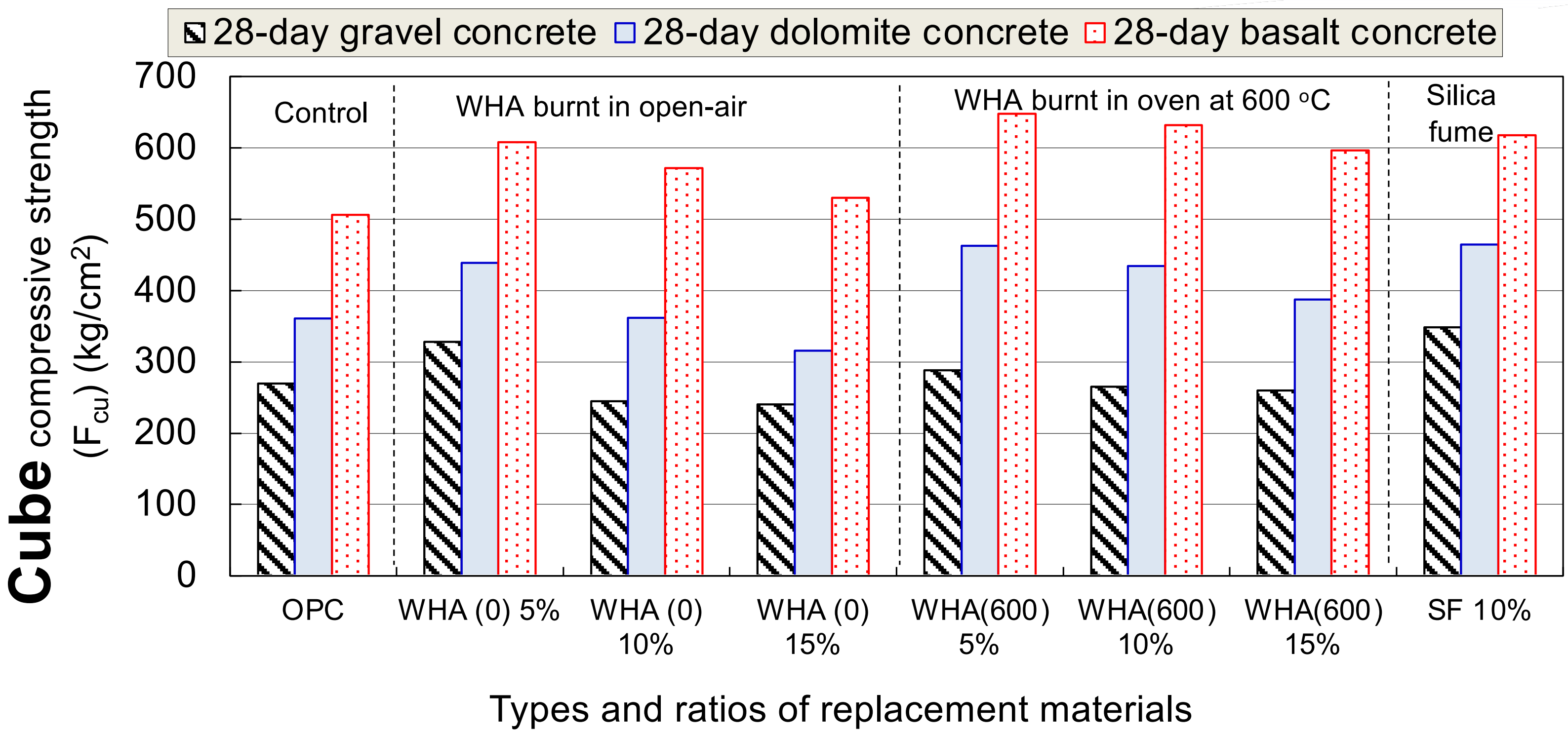
Materials	Replacement ratio	Pozzolanic activity index	
		7 days	28 days
Pure OPC	0%	1.00	1.00
WHA burnt in open air, $WHA_{(0)}$	5%	1.26	1.18
	10%	1.31	1.15
	15%	1.26	1.10
WHA burnt in oven at 600ºC, $WHA_{(600)}$	5%	1.42	1.25
	10%	1.16	0.87
	15%	0.68	0.60
S.F.	10%	1.34	1.18

According to **ASTM C 618**, SAI ≥ 0.75 ➔ pozzolanic materials

3- Concrete mix design

Mix	Mix proportions (kg/m³)							Rep/Cement
	Cement	Water	sand	Coarse aggregates **1- Gravel** **2- Dolomite** **3- Basalt**	Replacement (Rep)			
					$WHA_{(0)}$	$WHA_{(600)}$	Silica fume	
OPC	300	150	638	1276	—	—	—	—
$WHA_{(0)}$5%	285	150	637	1274	15	—	—	5%
$WHA_{(0)}$10%	270	150	636	1272	30	—	—	10%
$WHA_{(0)}$15%	255	150	635	1270	45	—	—	15%
$WHA_{(600)}$5%	285	150	637	1274	—	15	—	5%
$WHA_{(600)}$10%	270	150	637	1273	—	30	—	10%
$WHA_{(600)}$15%	255	150	635	1271	—	45	—	15%
SF 10%	270	150	635	1269	—	—	30	10%

4- Compressive strength



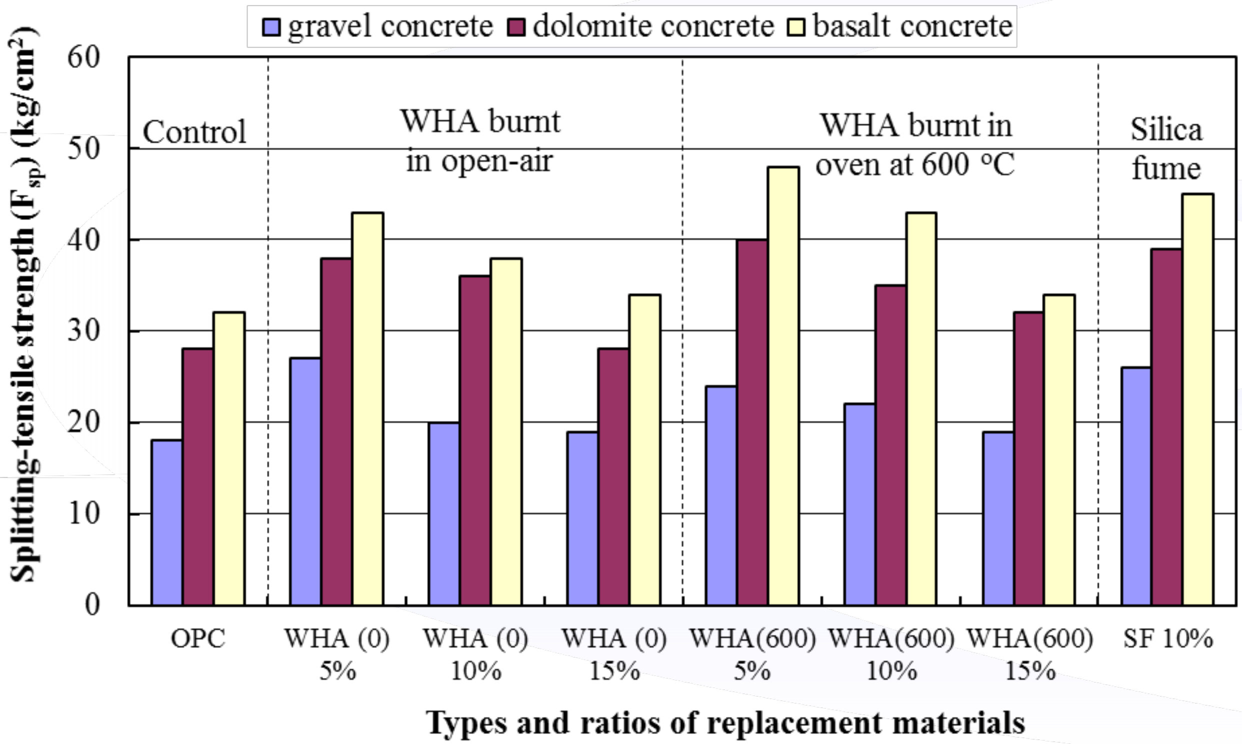
Cubes

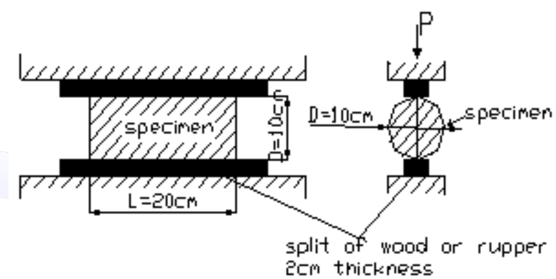
Strength increase was due to pozzolanic reactivity & filling effect of WHA

Burning method had no clear effect on strength

4- Splitting-tensile strength

After 28 days of curing





Cylinders

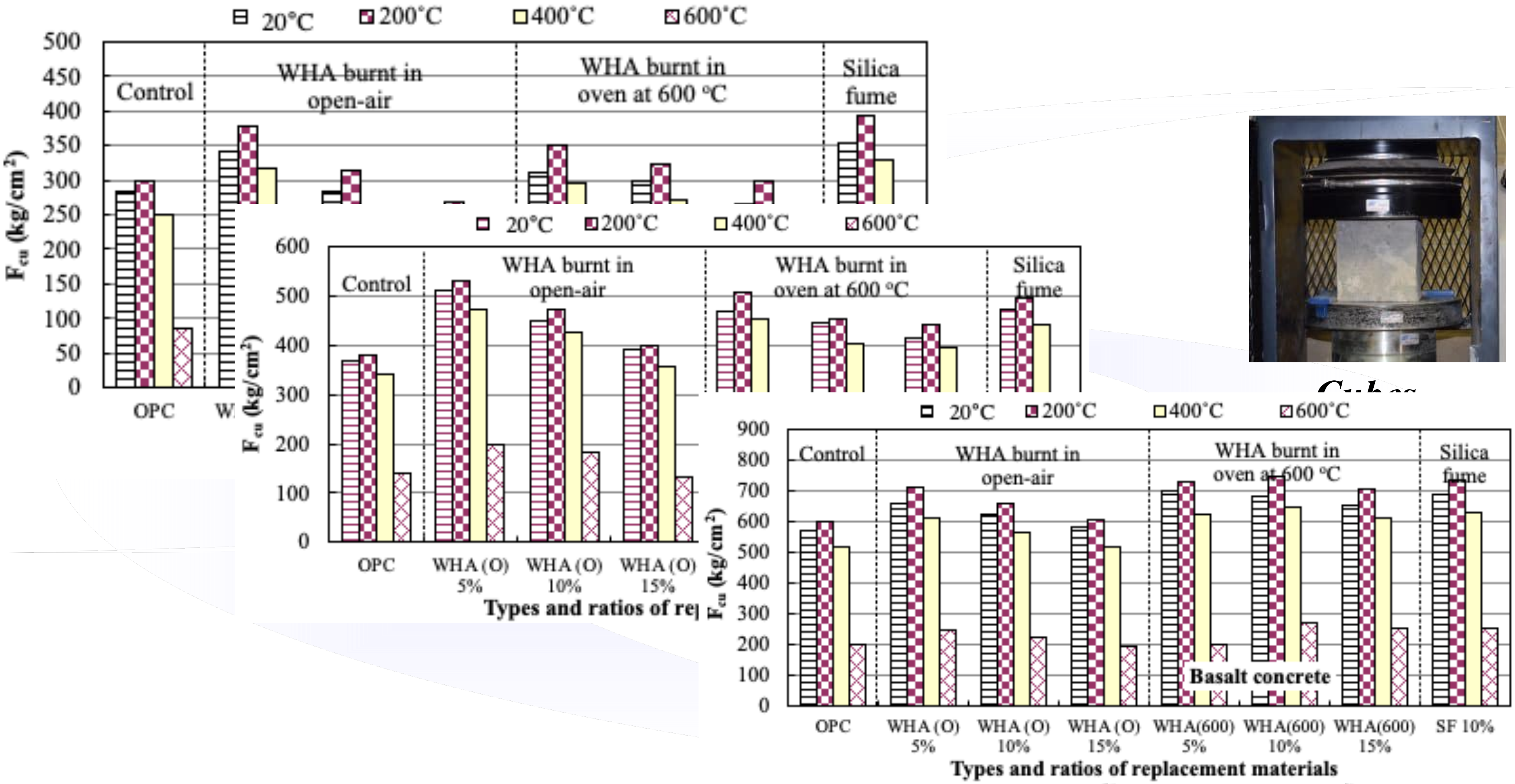
Pozzolanic reactivity, filling effect of WHA, and enhancing transition zone

5- Effect of high temperatures on cube F_{cu} of WHA concrete

- 1-28 days, moisture curing (lime-water path at 23°C)
- 28-91 days, lab atmosphere (23^{o}C, 50% RH)
- Oven drying at 105±5ºC for 24 hrs
- Furnace heating to 200, 400, 600°C (73, 392, 752, 1112°F) for **3 hrs**
- Cooling to lab temperature before testing

➢ *Concrete at lab atmosphere (23^{o}C, 50% RH) – served as a* ***reference***

Furnace


20°C
200°C
400°C
600°C
Control
WHA burnt in open-air
WHA burnt in oven at 600 °C
Silica fume
F_{cu} (kg/cm²)
OPC
WHA (O) 5%
WHA (O) 10%
WHA (O) 15%
WHA(600) 5%
WHA(600) 10%
WHA(600) 15%
SF 10%
Basalt concrete
Types and ratios of replacement materials

1- Cement paste unstable

Thermal treatments started at age of 3 months,

5-10%WHA was enough to react with ALL Ettringite, and convert it to CSH of higher thermal stability & binding forces

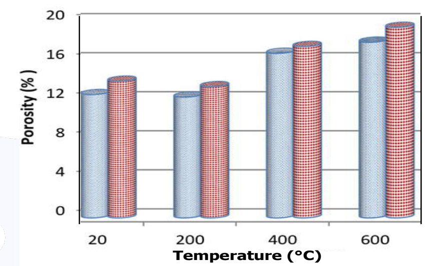
Extra WHA (10-15%) remains un-reacted (filler) as there is NO more Ettringite

100-300°C Heat causes internal moisture removal as faster rate, steam (so-called: internal autoclaving)

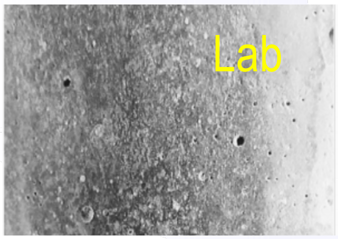
- internal pressure ↑
- porosity ↑
- transform any un-hydrated cement grains to Ettringite

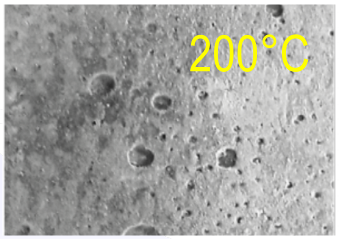
weak if system contains only cement,

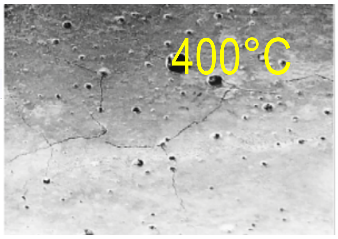
strong if pozzolanic material exists as transforms it to CSH

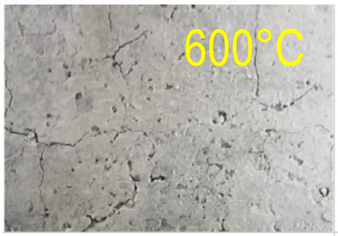


400-600°C, structure disruption and crack propagation









2- Aggregate more stable

Reduction in F'_{cu} α thermal stability of aggregates (dolomite < gravel < dolomite)

6- Resistance of WHA concrete to seawater

Why seawater?

Sodium Na^+	Chloride Cl^-	Magnesium Mg^{++}	Sulfate SO_4^{--}
participate in alkali-aggregate reaction	promote steel corrosion	attack most constituents of hardened portland cement paste, especially aluminate constituent	
12,000 mg/l	21,000 mg/l	1500 mg/l	2600 mg/l

Curing Conditions:

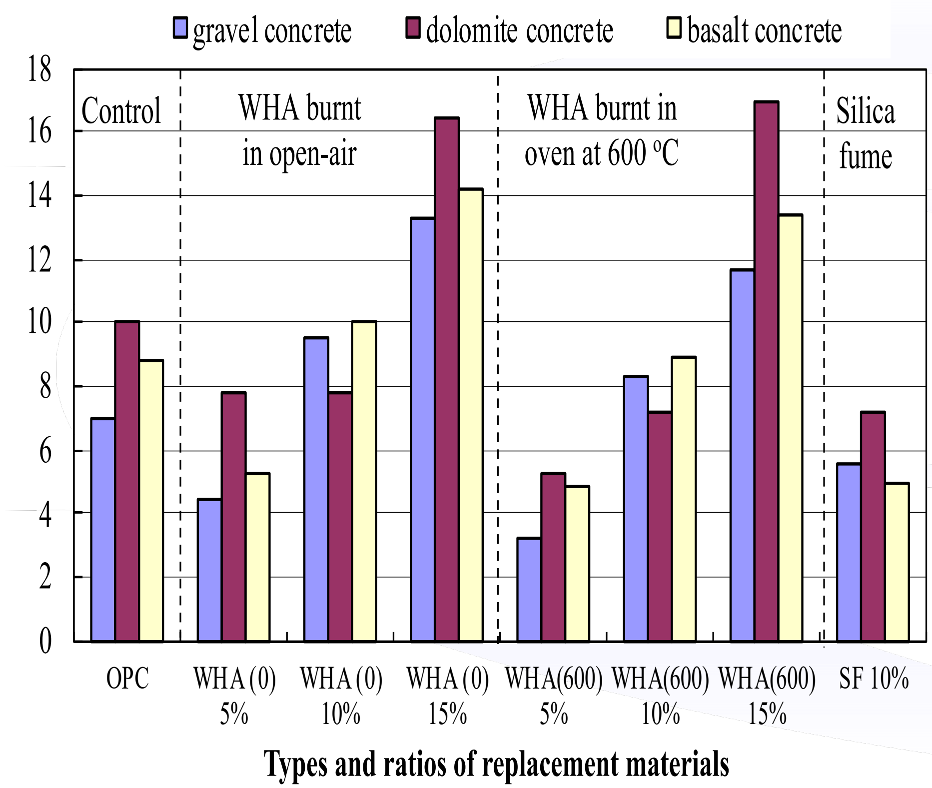
1-28 days, moisture curing (lime-water path at 23°C)

28-58 days, lab atmosphere (23°C, 50% RH)

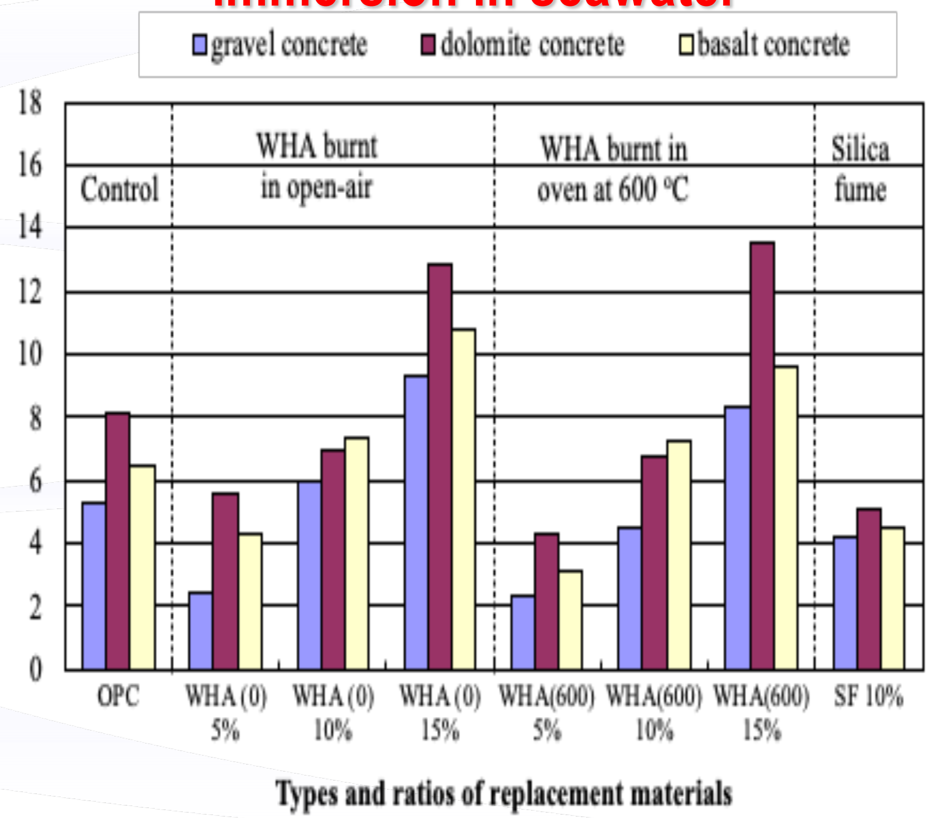
32 days of special curing (age 58-90 days)

1. lab atmosphere (23°C, 50% RH) -- served as **control**
2. stored in seawater path for the entire period
3. dry-wet cycles: 1-day at lab atmosphere & 1-day in seawater path

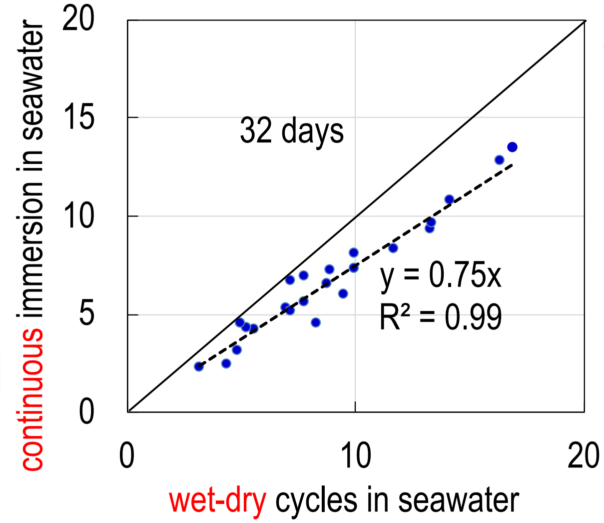
% decrease in cube F'_{cu} (relative to lab atmosphere, control) - wet-dry cycles



% decrease in cube F'_{cu} (relative to lab atmosphere, control) - continuous immersion in seawater



- Wet-dry cycles more severe > continuous projection to seawater ➔ due to change in volume and uniformity of water
- Densified microstructure (less porosity & permeability) of concrete containing WHA ➔ prevent entry of ions
- Reduction of Ettringite (pozzolanic reactivity) that may deteriorate when reacts with SO_4^{--}
- Presence of more Al_2O_3 in WHA ➔ it may act as expansive cement which recommended by ASTM C845 for marine structures (shrinkage compensation)



- Resistance of WHA_{600} > WHA_0 due to fineness
- Resistance of Gravel > Basalt > Dolomite, due to abrasion & surface texture

Conclusions

Using WHA as an ASCM in concrete mixes: adds a value to a waste material, contributes to green environment, cost saving of cement manufacture, and saves materials resources

Burning WH plants in closed ovens produces ash with no effect on environment and with high silica content than burning in open air

Concrete with 5-10% WHA has higher strength

➔ in normal curing conditions, subjected to elevated temperatures, or when contact chlorides and sulfates of seawater

Because adding WHA to ordinary concrete:

➔ reacts with ettringite [Ca(OH)] from cement hydration and forms more C-S-H (pozzolanic reactivity) of stronger binding forces and higher thermal stability

➔ densifies microstructure and enhances transition zone

➔ lowers porosity and permeability

Thank you!