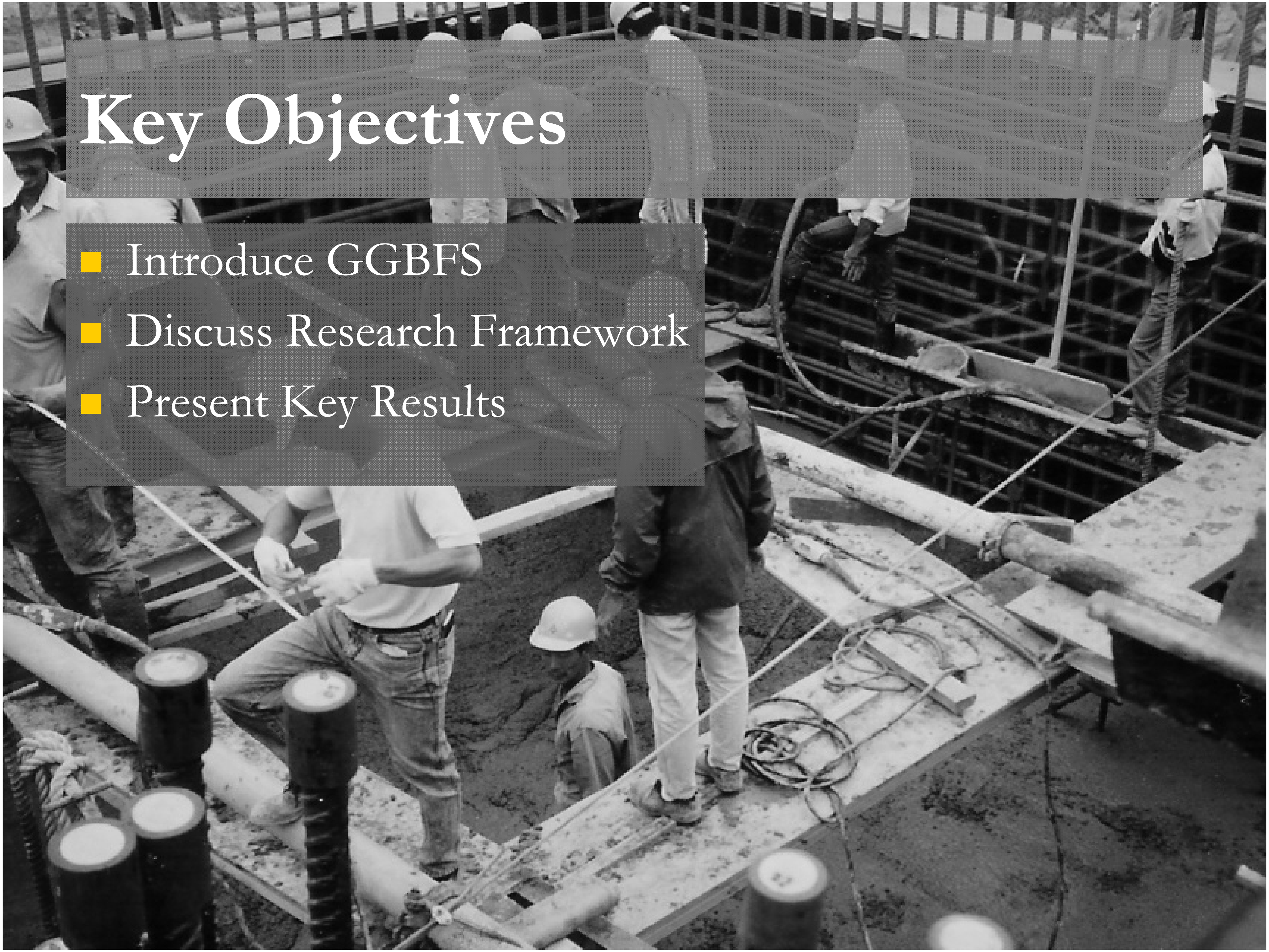
Blast Furnace Slag: Concrete Benefits

Sponsored By

K Wah Construction Materials (Hong Kong) Ltd

Key Objectives

- Introduce GGBFS
- Discuss Research Framework
- Present Key Results

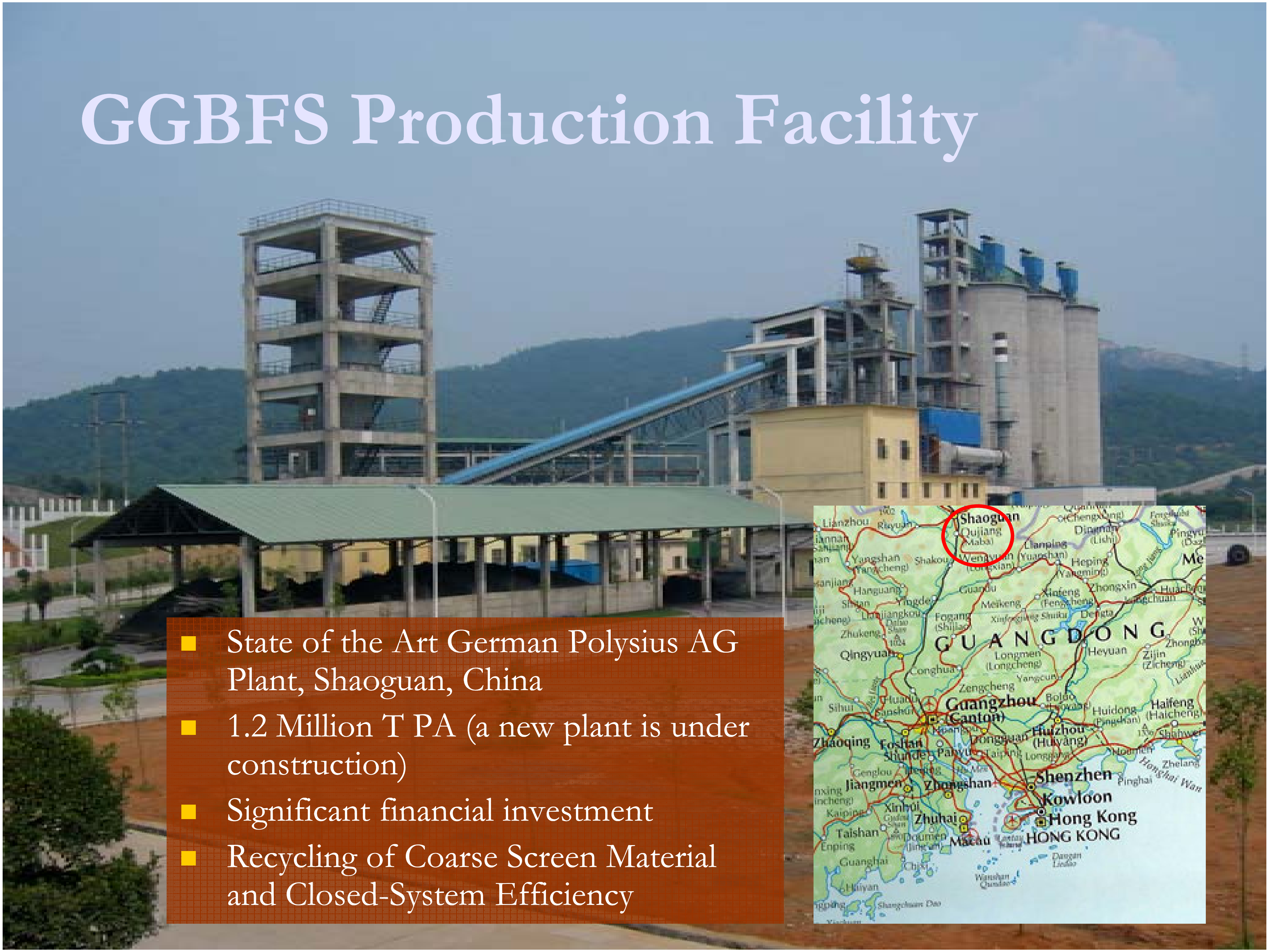


Slag - GGBFS

- By product of steel industry
- Typical Composition
  - Silica (S 30-40%)
  - Lime (C 35-45%),
  - Alumina (A 10-20%)

- Benefits:
  - Environmentally friendly energy by-product
  - Enhances concrete durability
  - Continued strength gain
  - Reduces heat in concrete
  - Typically replaces 60-70% of cement (compared to 25-40% PFA) and can replace up to 90%.

GGBFS Production Facility



- State of the Art German Polysius AG Plant, Shaoguan, China
- 1.2 Million T PA (a new plant is under construction)
- Significant financial investment
- Recycling of Coarse Screen Material and Closed-System Efficiency

Processing

Plant Management

QA/QC and Testing

The Raw Product

- **Consistency of medium to fine sand, gritty texture, pale brown colour.**

The Final Product

- Consistency of fine talcum powder, off-white colour, very fine GGBFS.

Typical Chemistry Comparisons

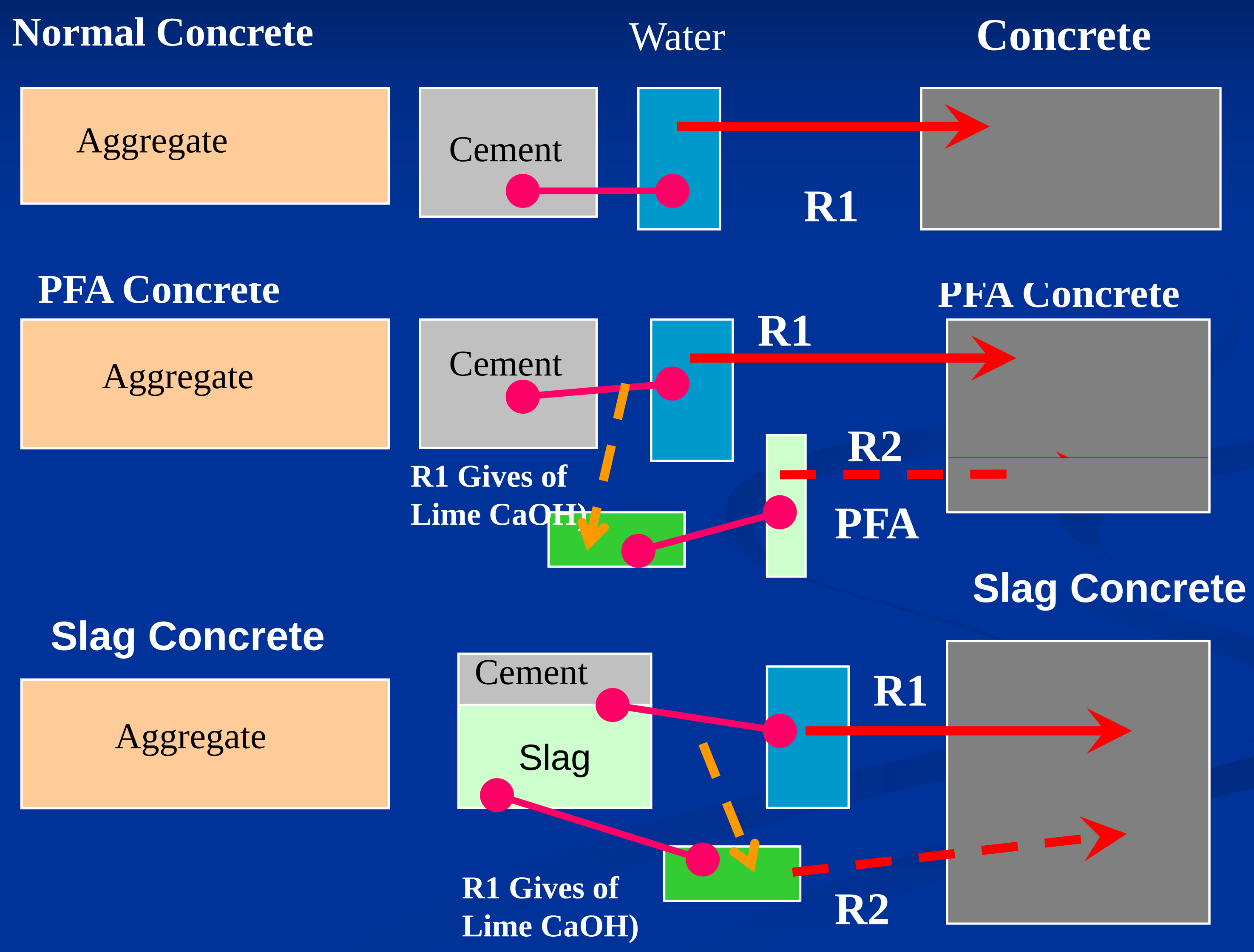
Material	C%	S%	A%
OPC	65	22	5
PFA	2-10	35-50	18-25
Slag	35-45	30-40	10-20
Silica Fume		85-97	

- Complies with BS 6699: 1992 Requirements C1.9 to 9.7
- Calcium Oxide Content (CaO): 36.1%
- Silica Content: (SiO_2) 34.1%
- Alumina (Al_2O_3): 15.9%
- Magnesia Content (MgO): 12.3% (<14%)
- Insoluble Residue 0.76% (<1.5%)
- Chemical Moduli: (CaO+Mg)/SiO_2) 1.5 (>1)
- & CaO/ SiO_2 1.1% <1.4%
- Acid Soluble Alkali Content (Eq. Na_2O) 0.69%

GGBFS in HK 1992

- 120 Year Design Life
- Triple Blend: OPC, GGBFS, CSF for harsh marine exposure conditions
- Over 100 intrinsic and inferred performance criteria for concrete.
- Lower heat than OPC triple blend
- Better chloride diffusion resistance
- In 100 years this will be a Historical Structure

How Does Slag Work?



GGBFS Trials : Key Objectives

- Quality and Consistency
- Strength Development
- Thermal Properties
- Durability

Laboratory Trials

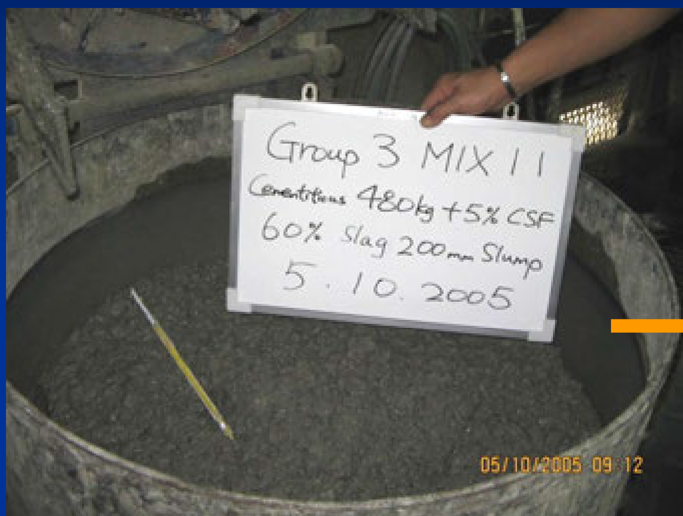
3 Main Groups:

Group 1: Normal 30MPa Concrete (0.58 W/B Ratio)

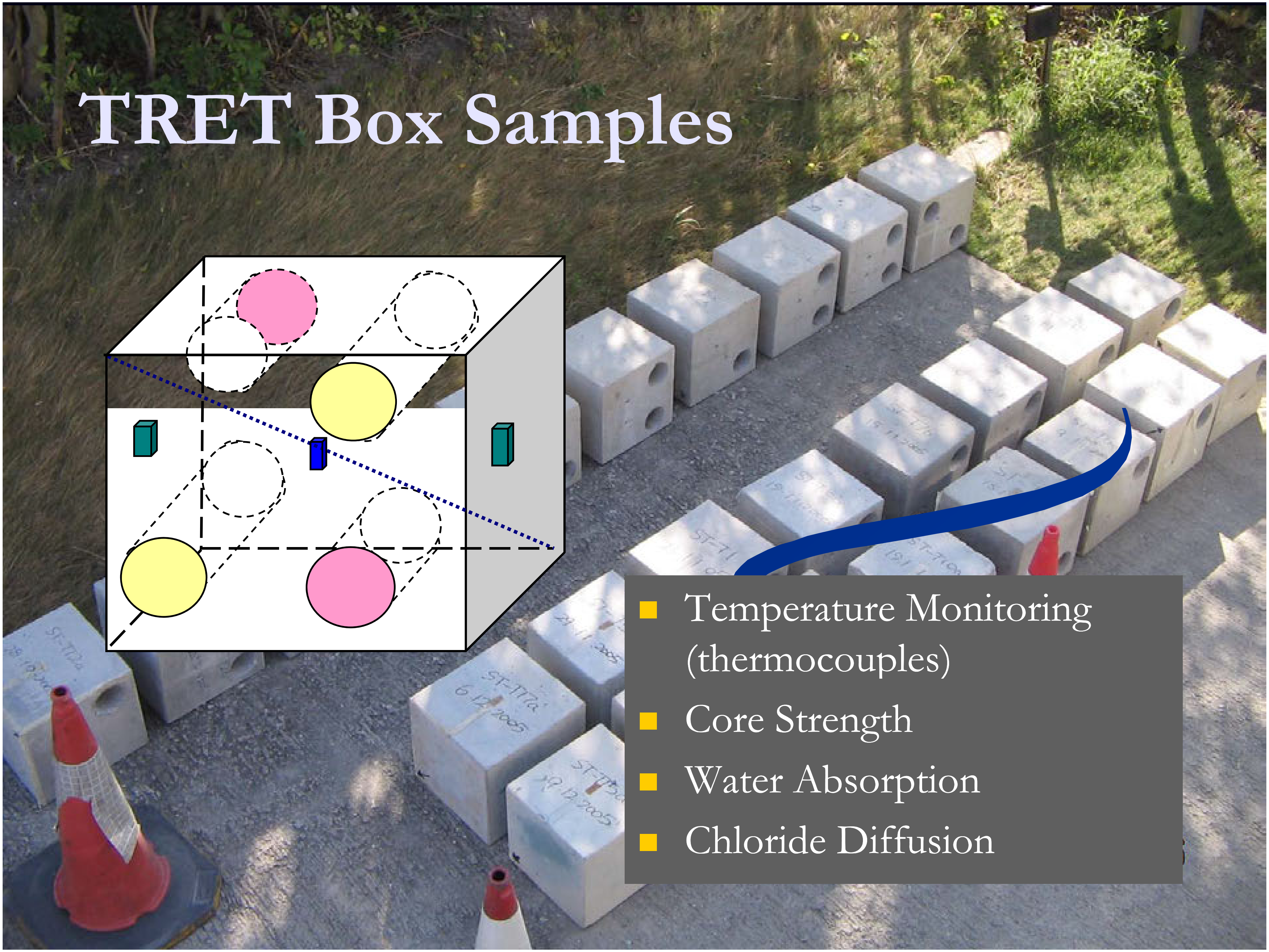
Group 2: Marine Concrete (0.38 W/B Ratio)

Group 3: High Performance Concrete (0.3 and 0.34 W/B Ratio)

Laboratory Trial Procedure

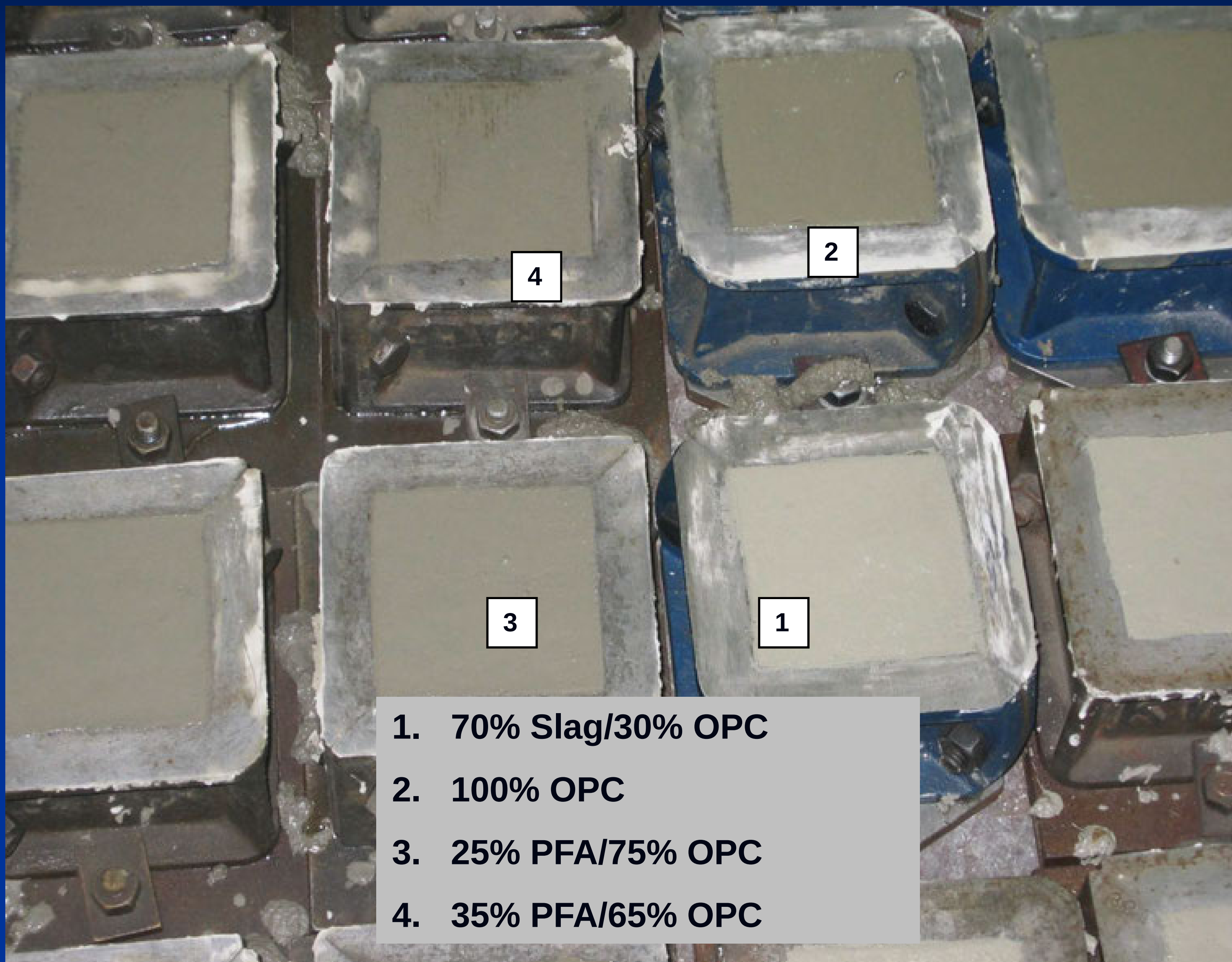


TRET Box Samples



- Temperature Monitoring (thermocouples)
- Core Strength
- Water Absorption
- Chloride Diffusion

Colour Differences & Benefits



1. 70% Slag/30% OPC
2. 100% OPC
3. 25% PFA/75% OPC
4. 35% PFA/65% OPC

Group 1 and Group 2 Mixes

GROUP 1 MIX NO.	CEMENT (Kg)	W/B	ADMIX (Lt) WRD A889
1 (25% PFA)	360	0.58	2.16
2 (35% PFA)	360	0.58	2.16
3 (60% GGBFS)	360	0.58	2.16
4 (70% GGBFS)	360	0.58	2.16
5 (100% OPC)	360	0.58	2.16
16 (30% GGBFS)	360	0.58	2.16
18 (100% GGBFS)	360	0.58	2.16
15b (90% GGBFS Grade 30 Concrete)	380	0.55	2.28

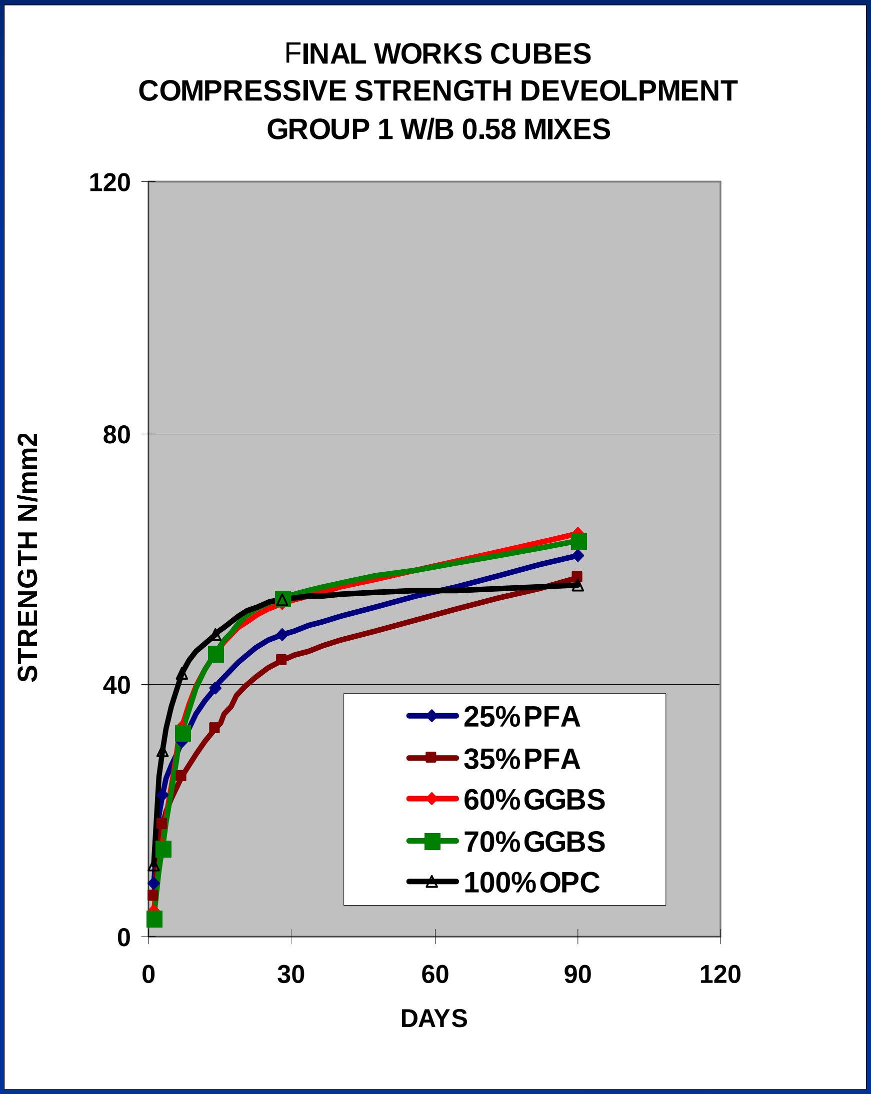
GROUP 2 MIX NO.	CEMENT (Kg)	W/B	ADMIXTURE (Lt) Super 20		
			Init	Add	Tot
6 (25% PFA)	450	0.38	4.0	2.25	6.3
7 (35% PFA)	450	0.38	4.0	2.00	6.0
8c (60% GGBFS)	450	0.38	4.0	2.00	6.0
9b (70% GGBFS)	450	0.38	4.0	1.88	5.9
10 (100% OPC)	450	0.38	4.0	3.50	7.5
17 (40% GGBFS)	450	0.38	4.0	2.00	6.0
19 (100% GGBFS)	450	0.38	4.0	3.50	7.5
20 (80% GGBFS)	450	0.38	4.0	1.60	5.6
21 (90% GGBFS)	450	0.38	4.0	1.40	5.4

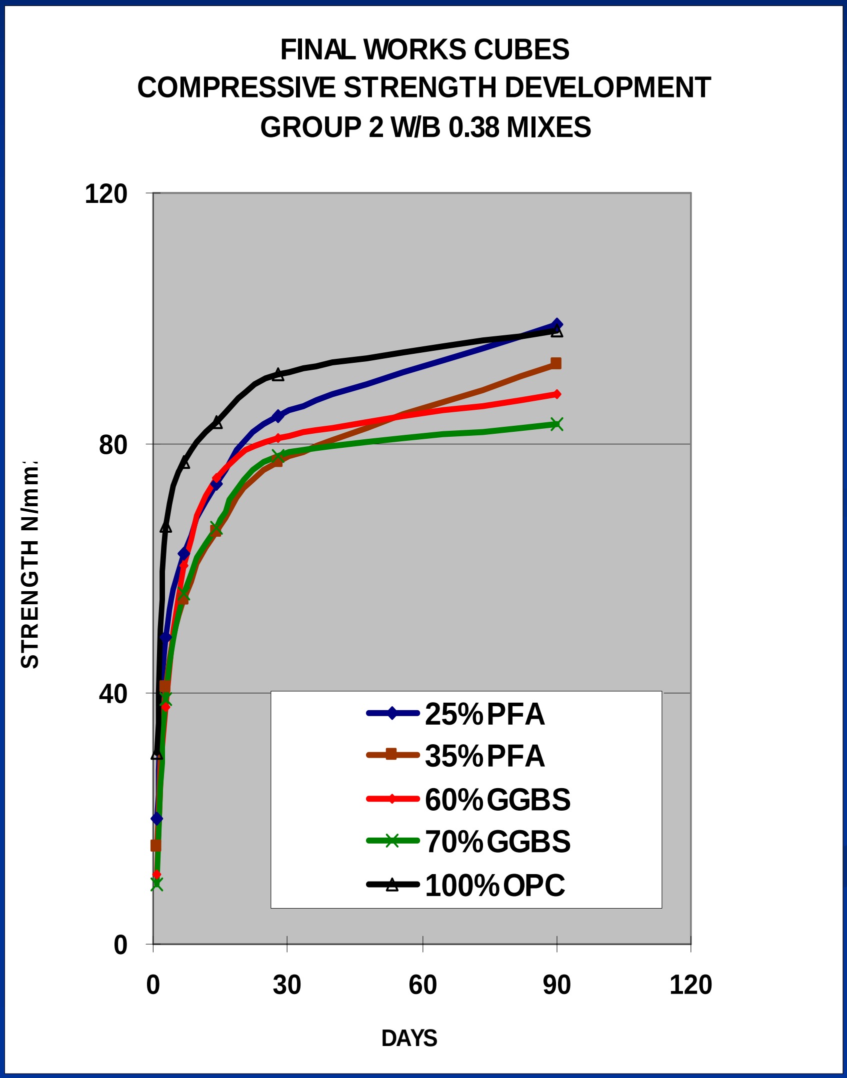
Group 3 Mixes

MIX NO.	CEMENT (Kg)	WATER (Kg)	W/B	CEMENT (Kg)						ADMIXTURE (Lt)		
				Slump	OPC	PFA	SLAG	SF		Adva109		
										Init	Add	Tot
11 (60% GGBFS & 5% SF)	480	113 (Plus 24 Lt from SF Slurry)	0.30	200	168	0	288	24		7.00	1.38	8.4
12 (70% GGBFS & 5% SF)	480	113 (Plus 24 Lt from SF Slurry)	0.30	200	120	0	336	24		7.00	1.00	8.0
13 (60% GGBFS)	450	148	0.34	200	180	0	270	0		5.00	1.00	6.0
14 (70% GGBFS)	450	148	0.34	200	135	0	315	0		5.00	0.80	5.8

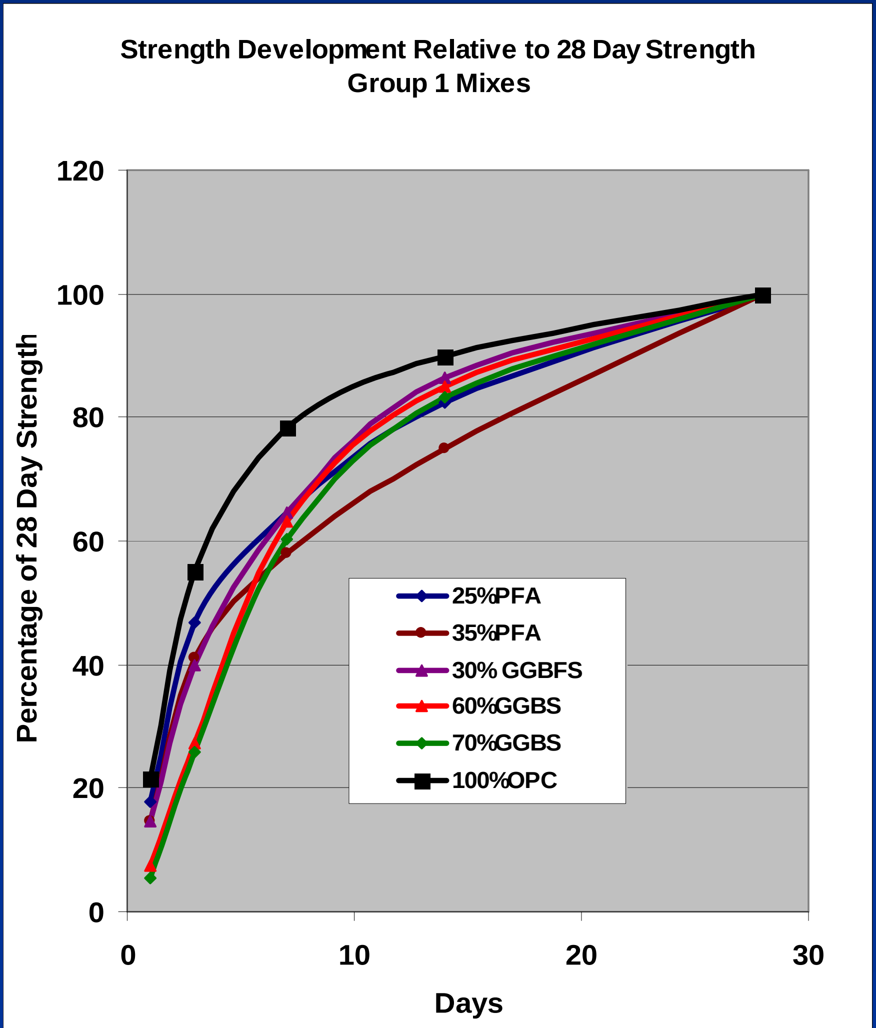
Cement-Free Concrete?
100% Slag

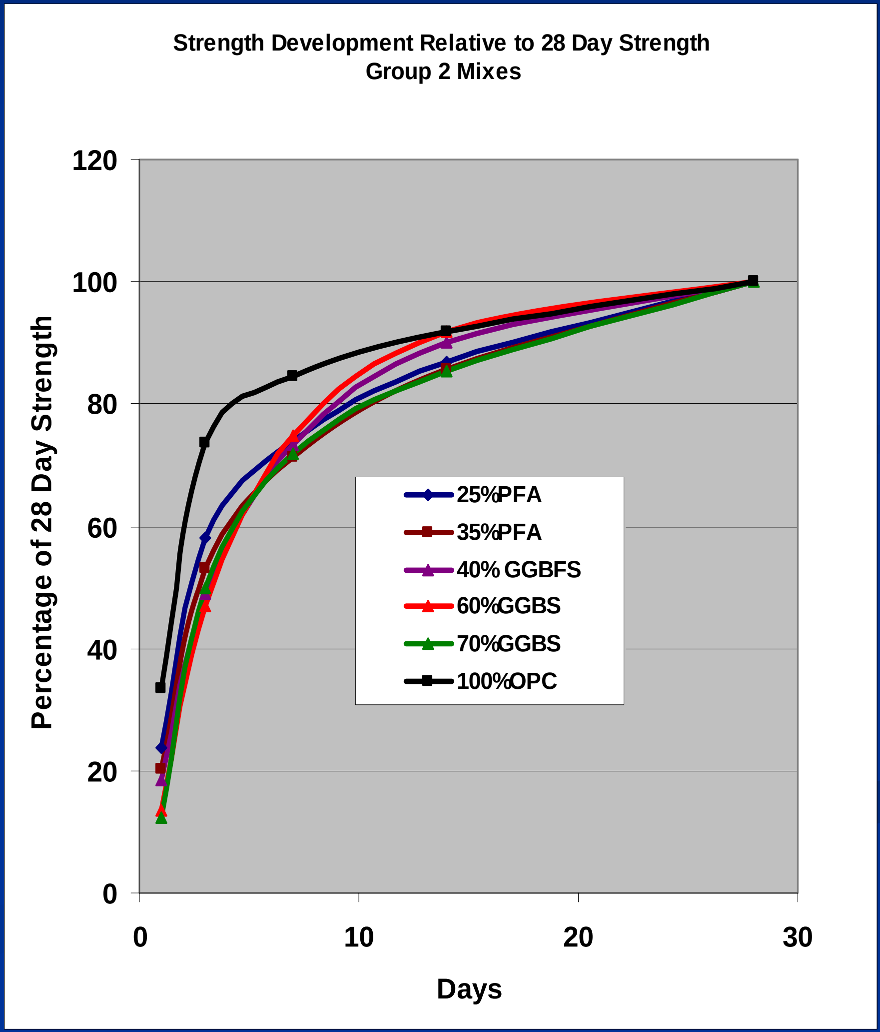
Compressive Strength Development
Group 1 and Group 2 Mixes



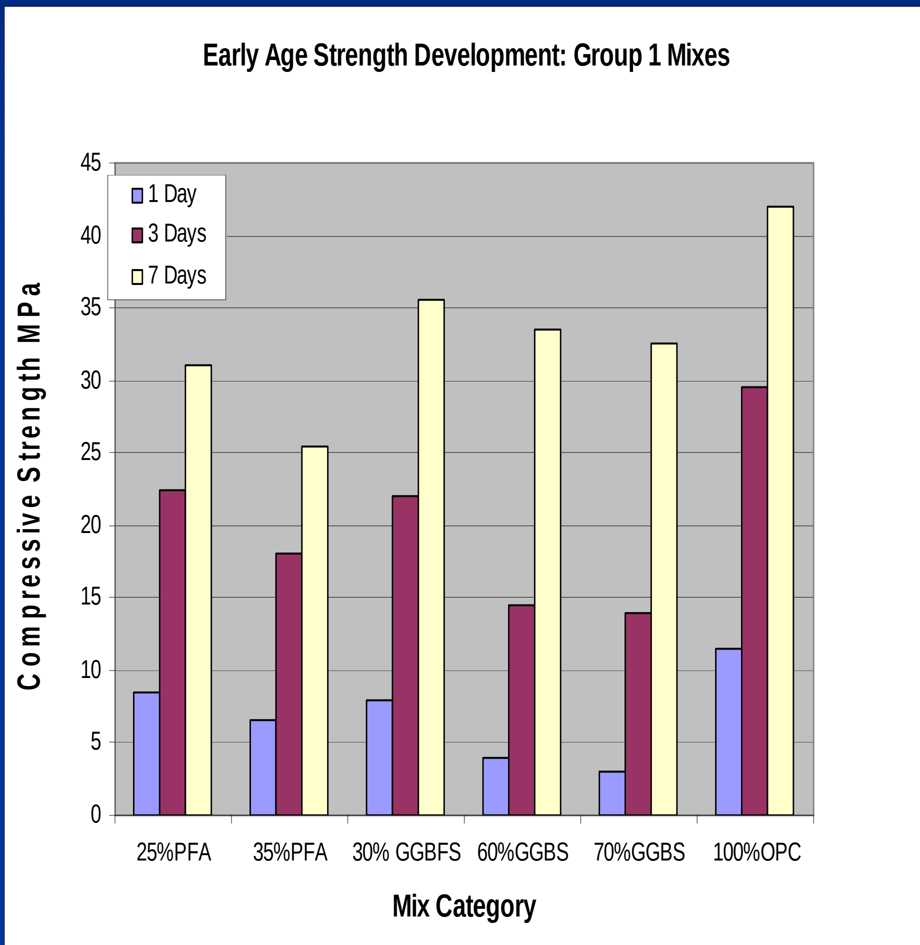


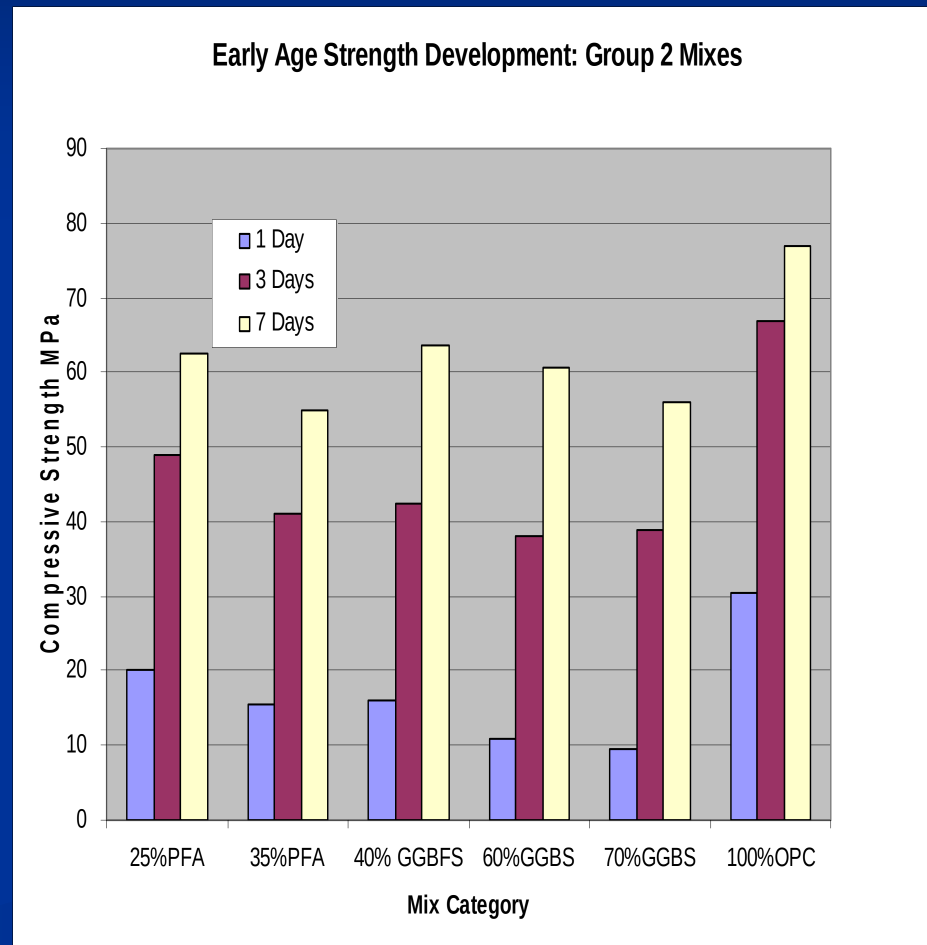
Relative Strength Development
Group 1 & 2 Mixes for 28 Days



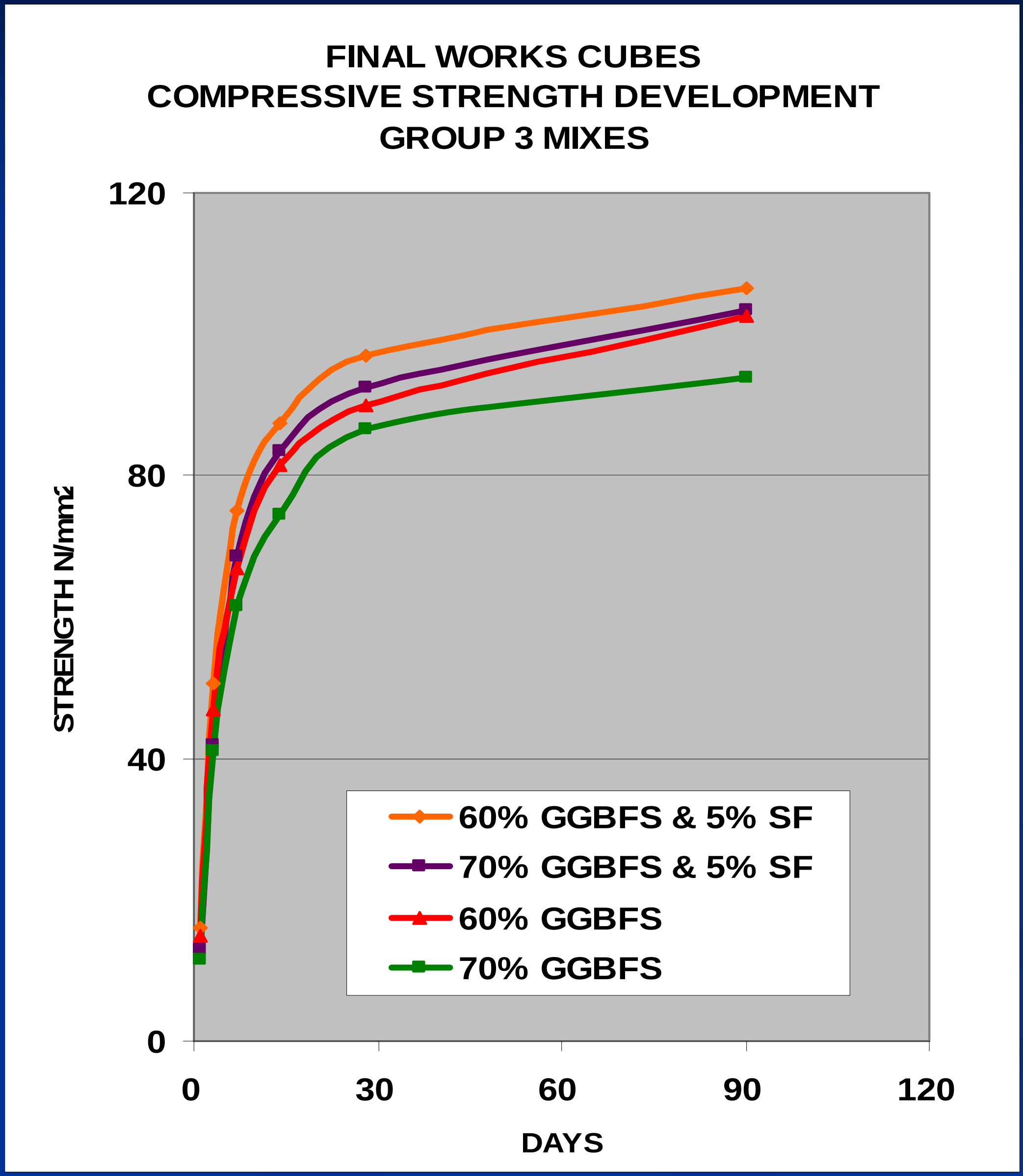


Early Age Strength Development
Group 1 & 2 Mixes

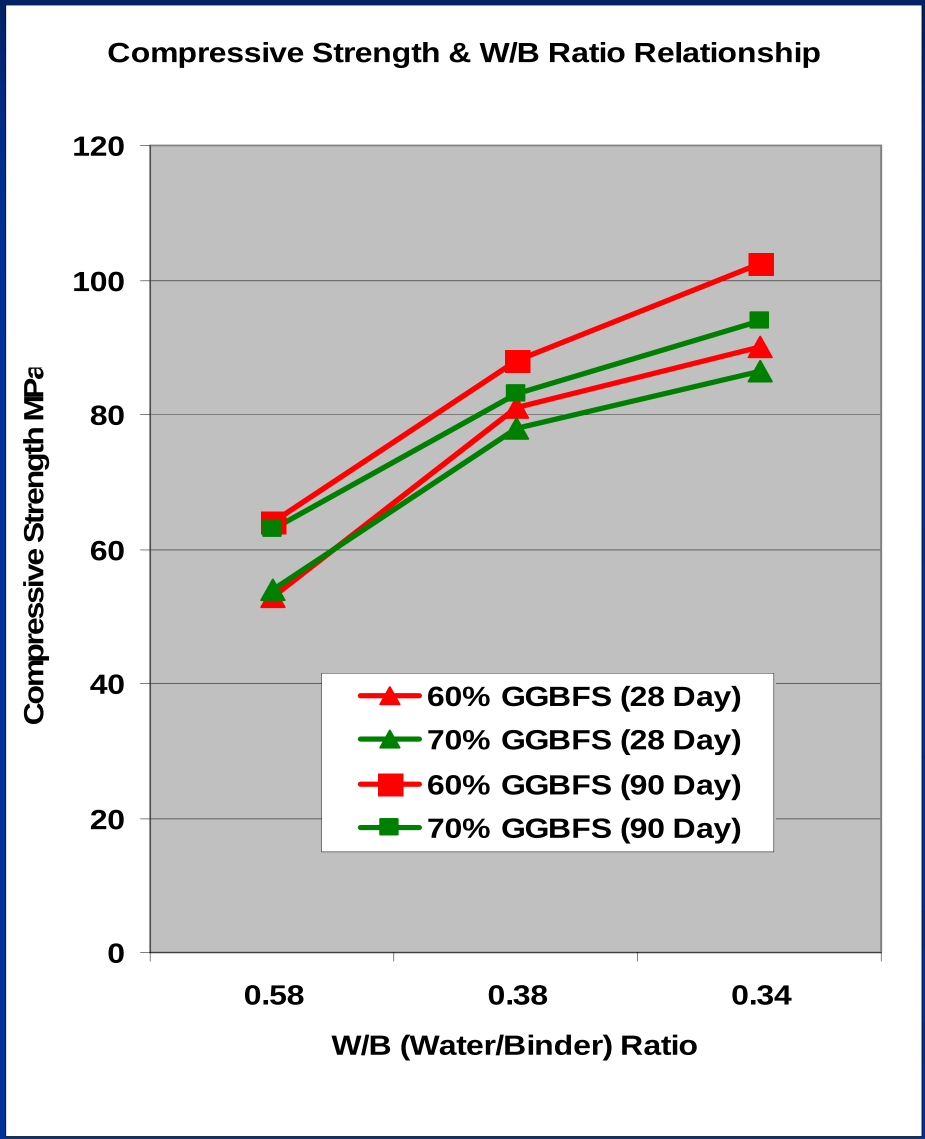




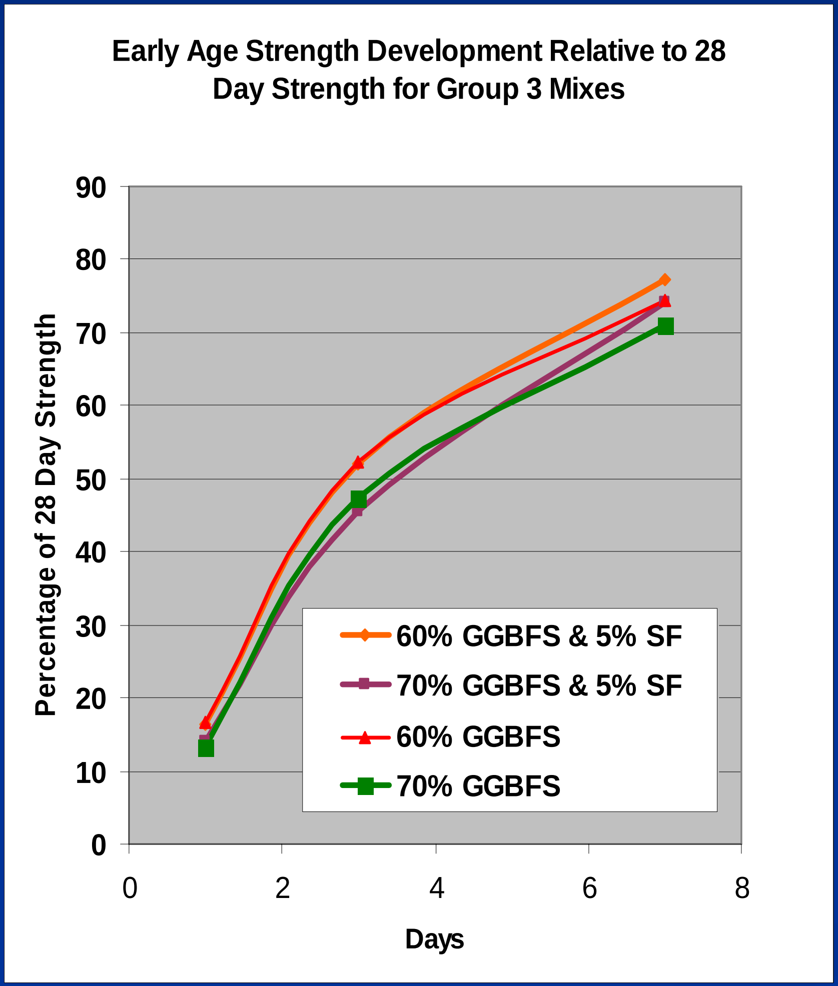
Compressive Strength Development

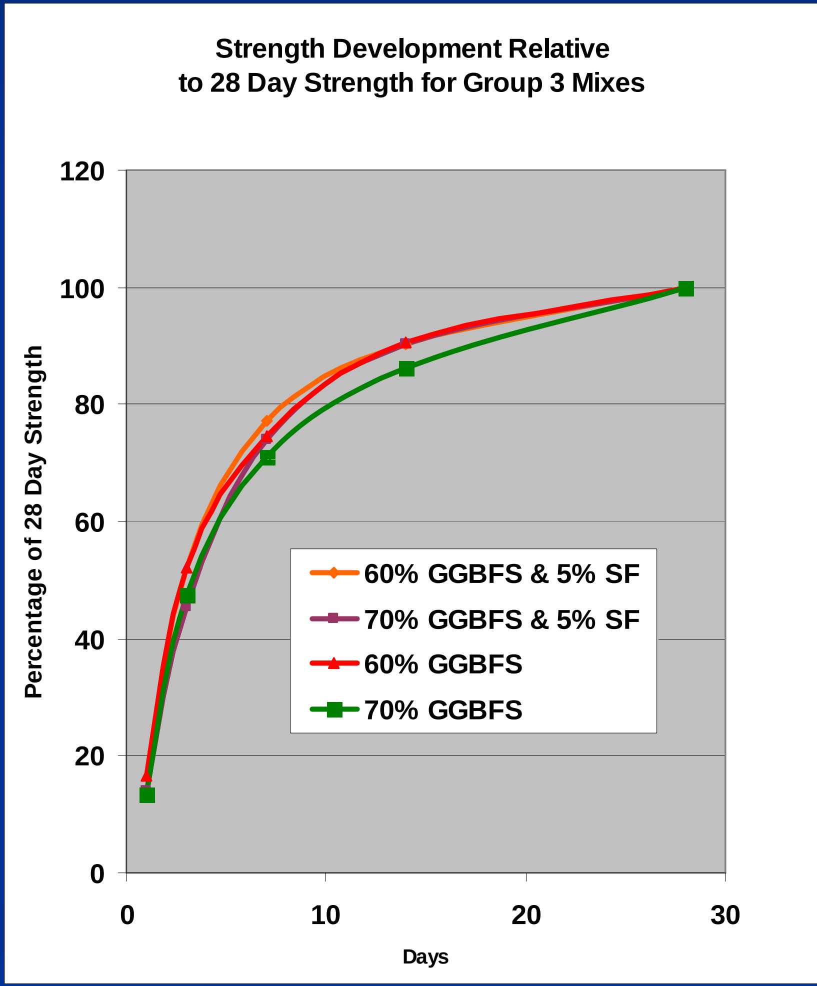


Compressive Strength & W/B Ratio

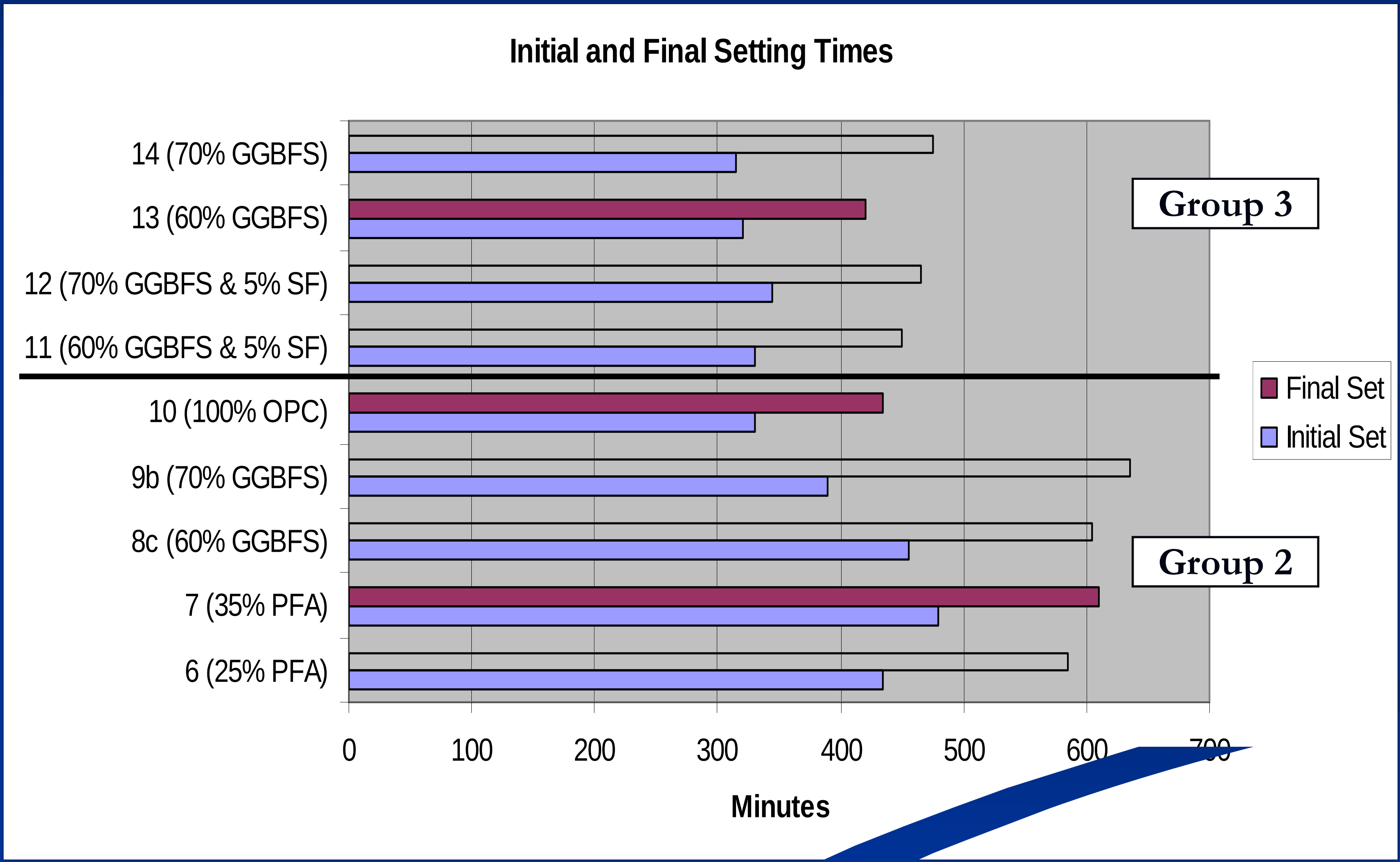


Early Age Strength Development
Group 3 Mixes

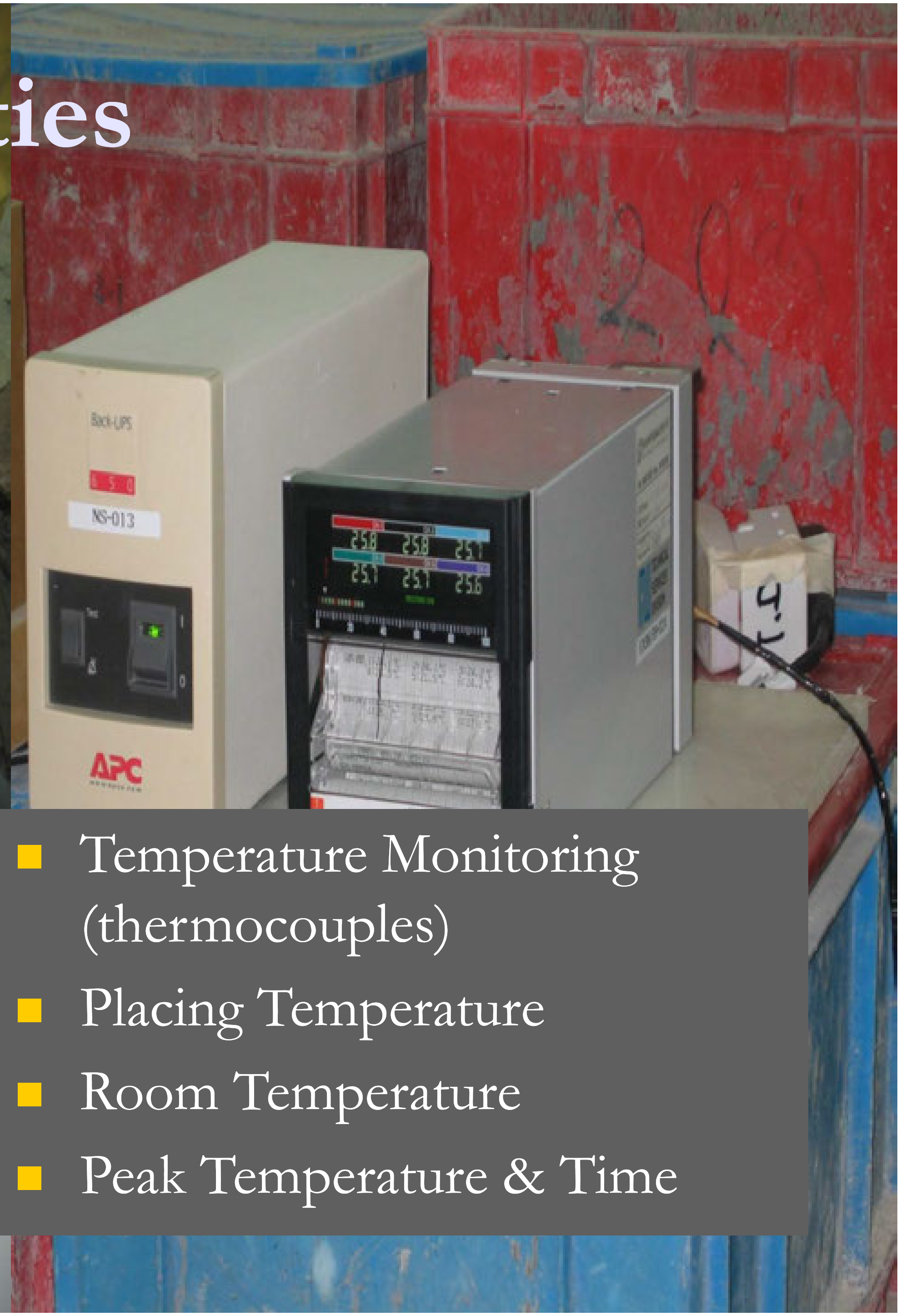




Initial and Final Set
Group 2 and Group 3 Mixes

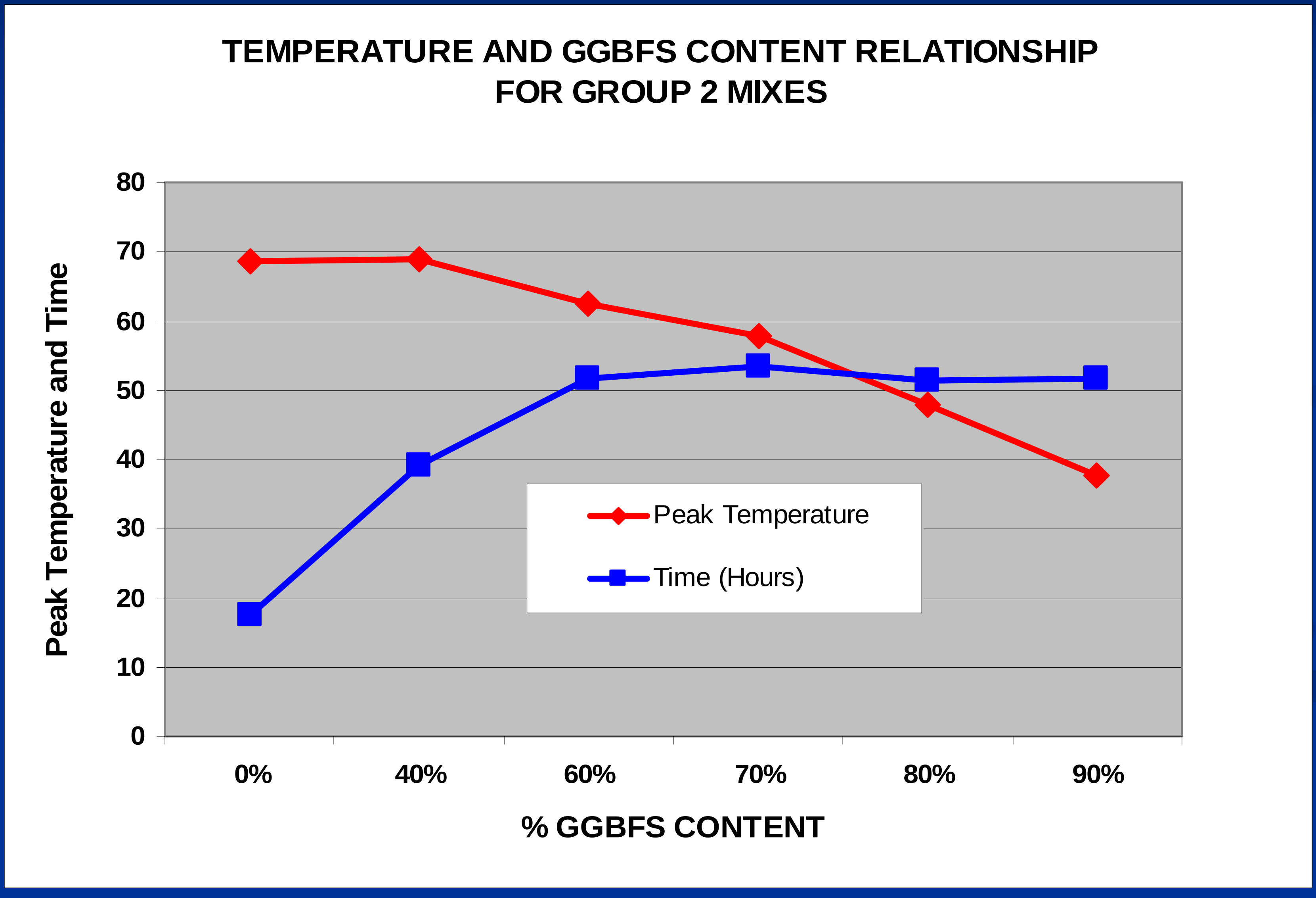


Thermal Properties

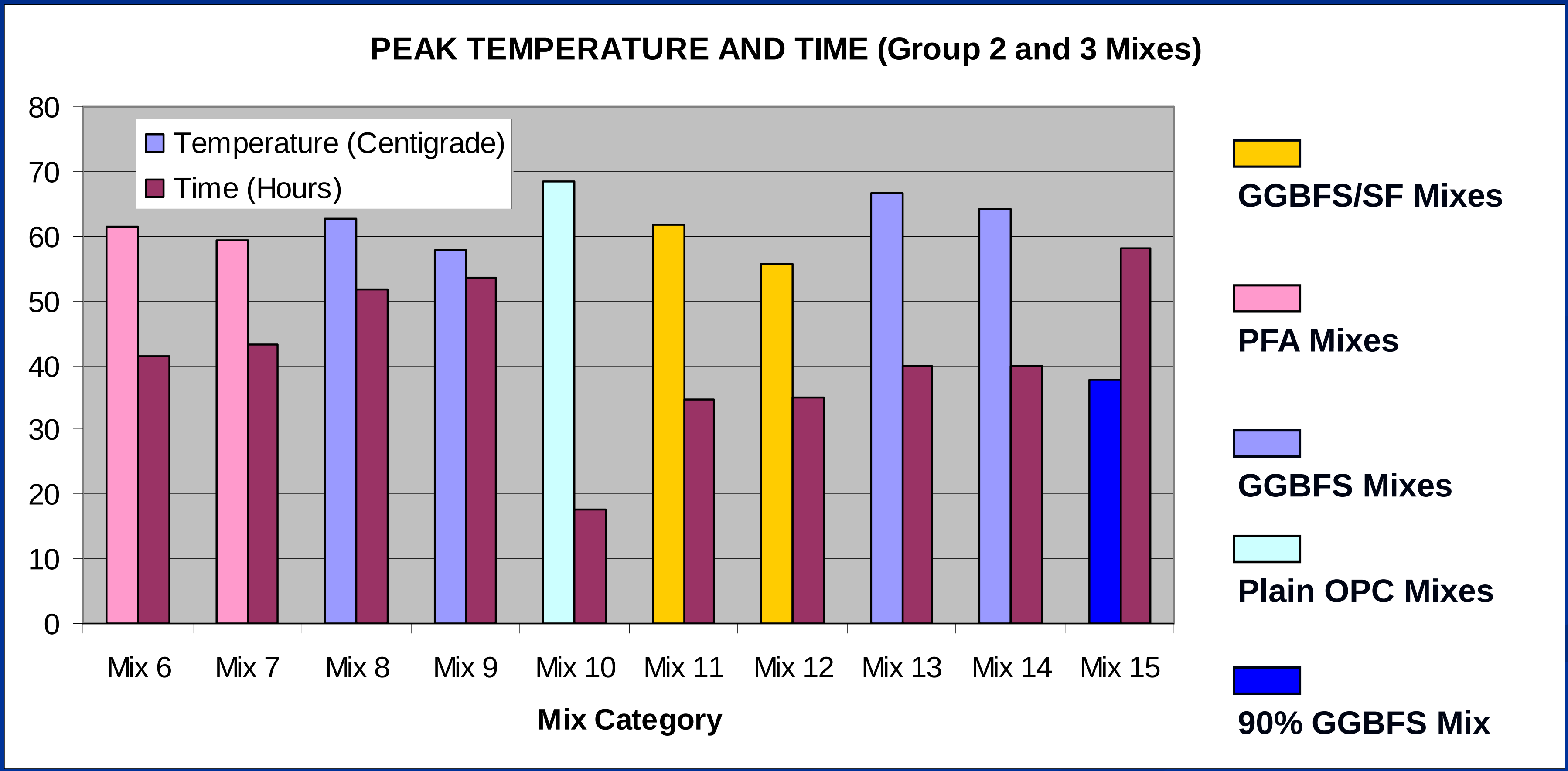


- Temperature Monitoring (thermocouples)
- Placing Temperature
- Room Temperature
- Peak Temperature & Time

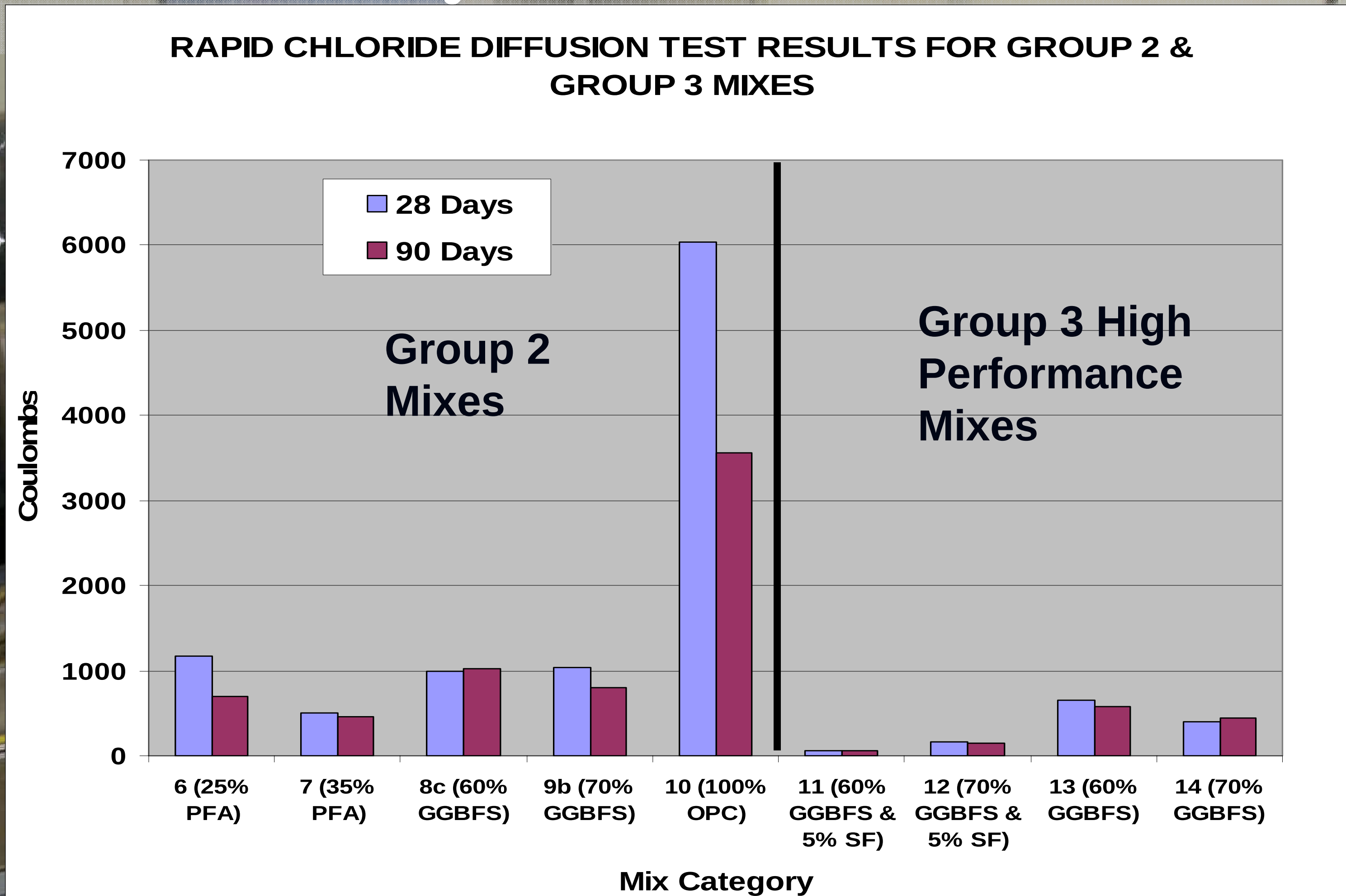
Thermal Properties
GGBFS Content & Temperature Reduction



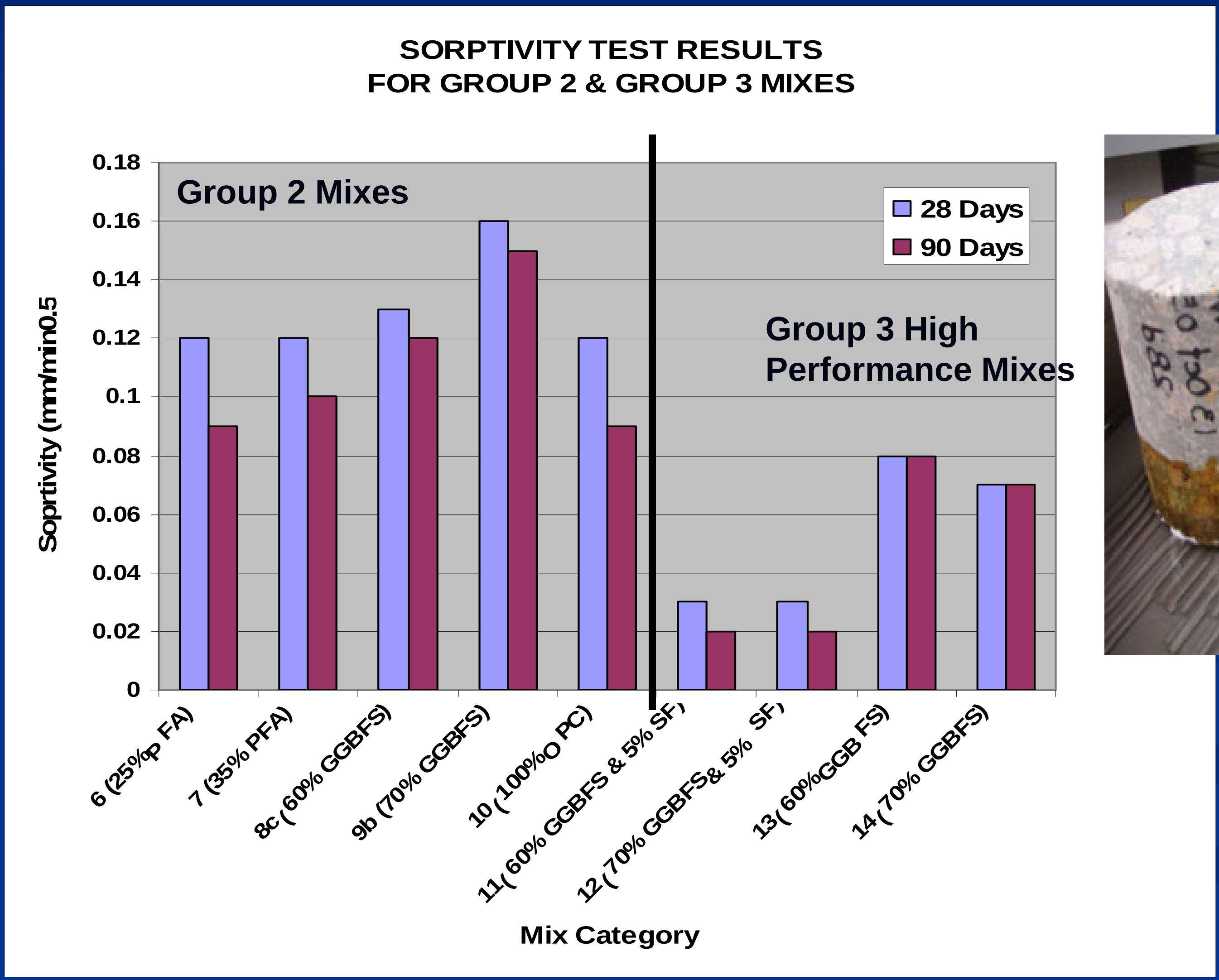
Thermal Properties
Group 2 and 3 Mixes



Durability: Chloride Diffusion



Durability: Sorptivity



Experience CSPC Project

- US$4.3 Billion CSPC Project in Shenzhen (CNOOC, Shell Petroleum Corporation)
- > 800,000 Cubic Metres of Concrete (All Slag Concrete)
- 65% Slag Content
- Slag all from Shaoguan Plant
- Beijing and Shanghai

Environmental Credit

- Greatly Reduced Cement Content.
- 1 Tonne Cement = 0.8 Tonne CO_2.
- In 2005 China Cement trade released 0.867 billion Tonnes of CO_2. This accounted for 22.8% of total CO_2 emission in China
- GGBFS is produced anyway. Additional energy input is only for grinding and processing.
- Use of this valuable construction material is an environmental credit for HK and the Mainland as a whole.
- Provides alternative to PFA and is more compatible with renewable energy source objectives.

Key Benefits of GGBFS

- Very Cost Effective: Similar market price to PFA per tonne, but twice as much GGBFS is used.
- Green Perspective: Significantly Reduces Cement (OPC) and CO_2
- Properties comparable to PFA: Thermal, Durability, Strength.
- Colour
- Introduces a Broader Range of Materials & Greater Flexibility
- Extensive Experience on Prestigious Projects Exist

Thank You

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(Hong Kong) Ltd

- ALL OF THE SLIDES THAT FOLLOW SHOW ADDITIONAL DATA

Group 1 Mix Trials

W/B Ratio 0.58: Grade 30 Concrete

MIX NO.	CEM (Kg)	WAT (Kg)	W/B	CEMENT (Kg)					AGG (Kg)			ADMIX (Lt)
				Slump	OPC	PFA	SLAG	SF	20	10	CRF	WRDA88
1 (25% PFA)	360	207	0.58	100	270	90	0	0	690	295	780	2.16
2 (35% PFA)	360	207	0.58	100	234	126	0	0	690	295	780	2.16
3 (60% GGBFS)	360	207	0.58	100	144	0	216	0	690	295	780	2.16
4 (70% GGBFS)	360	207	0.58	100	108	0	252	0	690	295	780	2.16
5 (OPC 100%)	360	207	0.58	100	360	0	0	0	690	295	780	2.16
16 (30% GGBFS)	360	209	0.58	100	252	0	108	0	690	295	780	2.16
18 (100% GGBFS)	360	207	0.58	100	0	0	360	0	690	295	780	2.16
15b (90% GGBFS)	380	208	0.55	100	38	0	342	0	650	275	760	2.28

Group 2 Mix Trials

Marine Concrete (0.38 W/B Ratio)

		WAT	W/B	CEMENT (Kg)					AGG (Kg)			Admix (Lt)		
MIX	CEM	(Kg)		Slump	OPC	PFA	SLAG	SF				Super 20		
NO.	(Kg)								20	10	CRF	Init	Add	Tot
6 (25% PFA)	450	167	0.38	175	338	112	0	0	640	290	800	4.0	2.25	6.3
7 (35% PFA)	450	167	0.38	175	293	157	0	0	640	290	800	4.0	2.00	6.0
8c (60% GGBFS)	450	167	0.38	175	180	0	270	0	640	290	800	4.0	2.00	6.0
9b (70% GGBFS)	450	167	0.38	175	135	0	315	0	640	290	800	4.0	1.88	5.9
10 (100% OPC)	450	167	0.38	175	450	0	0	0	640	290	800	4.0	3.50	7.5
17 (40% GGBFS)	450	167	0.38	175	270	0	180	0	640	290	800	4.0	2.00	6.0
19 (100% GGBFS)	450	167	0.38	175	0	0	450	0	640	290	800	4.0	3.50	7.5
20 (80% GGBFS)	450	167	0.38	175	90	0	360	0	640	290	800	4.0	1.60	5.6
21 (90% GGBFS)	450	167	0.38	175	45	0	405	0	640	290	800	4.0	1.40	5.4

Group 3
High Performance Mixes

MIX NO.	CEM (Kg)	WAT (Kg)	W/B	CEMENT (Kg)					AGG (Kg)			ADMIX (Lt) Adva109		
				Slump	OPC	PFA	Slag	SF	20	10	CRF	In	Ad	T
11 (60% GGBFS & 5% SF)	480	113	0.30	200	168	0	288	24	600	290	850	7	1.4	8.4
12 (70% GGBFS & 5% SF)	480	113	0.30	200	120	0	336	24	600	290	850	7	1.0	8.0
13 (60% GGBFS)	450	148	0.34	200	180	0	270	0	620	295	845	5	1.0	6.0
14 (70% GGBFS)	450	148	0.34	200	135	0	315	0	620	295	845	5	0.8	5.8

Final Works Cubes: Strength

Mix No.			Slump (mm)	Flow (mm)			Mean Cube Compressive strength (N/mm2)					
							1d	3d	7d	14d	28d	90d
1 (25% PFA)			110	-	-		8.5	22.5	31.0	39.5	48.0	60.5
2 (35% PFA)			110	-	-		6.5	18.0	25.5	33.0	44.0	57.0
3 (60% GGBFS)			95	-	-		4.0	14.5	33.5	45.0	53.0	64.0
4 (70% GGBFS)			95	-	-		3.0	14.0	32.5	45.0	54.0	63.0
5 (OPC 100%)			95	-	-		11.5	29.5	42.0	48.0	53.5	56.0
6 (25% PFA)			160	470	480		20.0	49.0	62.5	73.5	84.5	99.0
7 (35% PFA)			150	450	450		15.5	41.0	55.0	66.0	77.0	92.5
8c (60% GGBFS)			165	480	490		11.0	38.0	60.5	74.5	84.5	88.0
9b (70% GGBFS)			210	570	575		9.5	39.0	56.0	66.5	78.0	83.0
10 (100% OPC)			180	550	570		30.5	67.0	77.0	83.5	91.0	98.0
11 (60% GGBFS & 5% SF)			195	460	445		16.0	50.5	75.0	87.5	97.0	106.5
12 (70% GGBFS & 5% SF)			210	500	490		13.0	42.0	68.5	83.5	92.5	103.5
13 (60% GGBFS)			205	510	520		15.0	47.0	67.0	81.5	90.0	102.5
14 (70% GGBFS)			210	500	530		11.5	41.0	61.5	74.5	86.5	94.0
15b (90% GGBFS Grade 30 Concrete)			110	-	-		1.5	10.0	23.5	31.0	37.0	43.5
16 (30% GGBFS)			100	-	-		8.0	22.0	35.5	47.5	55.0	59.5
17 (40% GGBFS)			190	510	520		16.0	42.5	63.5	78.0	86.5	92.0

Durability Performance

Group 2 and Group 3 Mixes

Mix No.	Mean Rapid Chloride Diffusion (Coulombs)				Sorptivity (mm/min0.5)	
	28d		90d		28d	90d
6 (25% PFA)	1171/1161	Low	659/699	Very Low	0.12/0.12	0.09/0.09
7 (35% PFA)	505/470	Very Low	345/459	Very Low	0.12/0.11	0.10/0.09
8c (60% GGBFS)	898/987	Very Low	851/1027	Very Low	0.13/0.13	0.10/0.12
9b (70% GGBFS)	995/1034	Very Low	797/753	Very Low	0.15/0.16	0.13/0.15
10 (100% OPC)	6035/6023	High	3560/3427	Moderate	0.12/0.12	0.09/0.09
11 (60% GGBFS & 5% SF)	60/56	Negligible	56/51	Negligible	0.03/0.03	0.02/0.02
12 (70% GGBFS & 5% SF)	156/162	Very Low	142/154	Very Low	0.03/0.03	0.03/0.03
13 (60% GGBFS)	650/623	Very Low	543/578	Very Low	0.08/0.07	0.08/0.08
14 (70% GGBFS)	402/406	Very Low	394/445	Very Low	0.07/0.06	0.04/0.07

Madagascar


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68°10'51.75" E
Streaming |||||||||| 100%
Eye alt 8330.43 mi

Power Station: Francoise the Gladiator

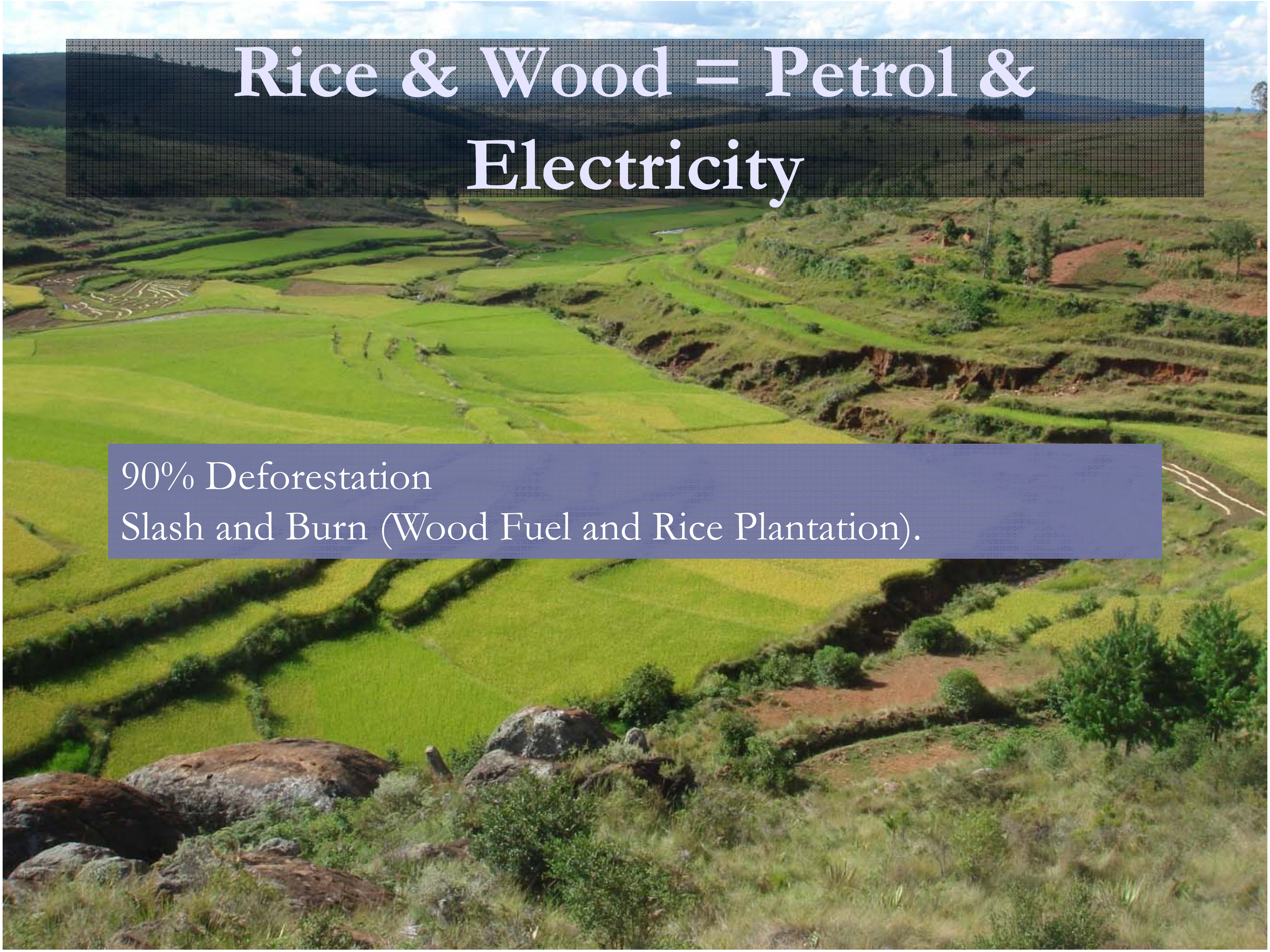
Mobile Crushers: Lalatiana, Ruth and Rija

Dredge Units: Madame Rasoazanany and Claude

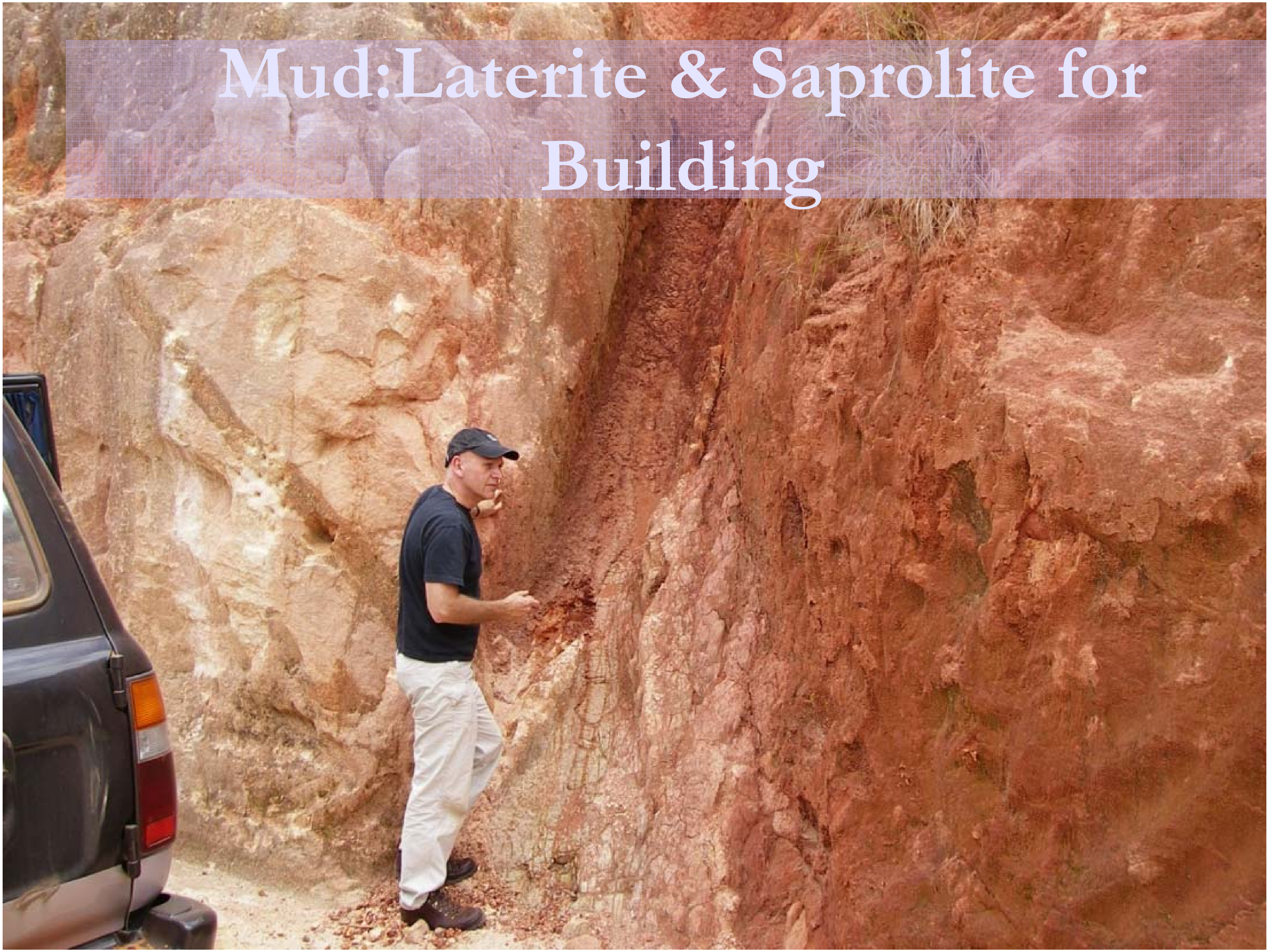
Rice & Wood = Petrol & Electricity

90% Deforestation

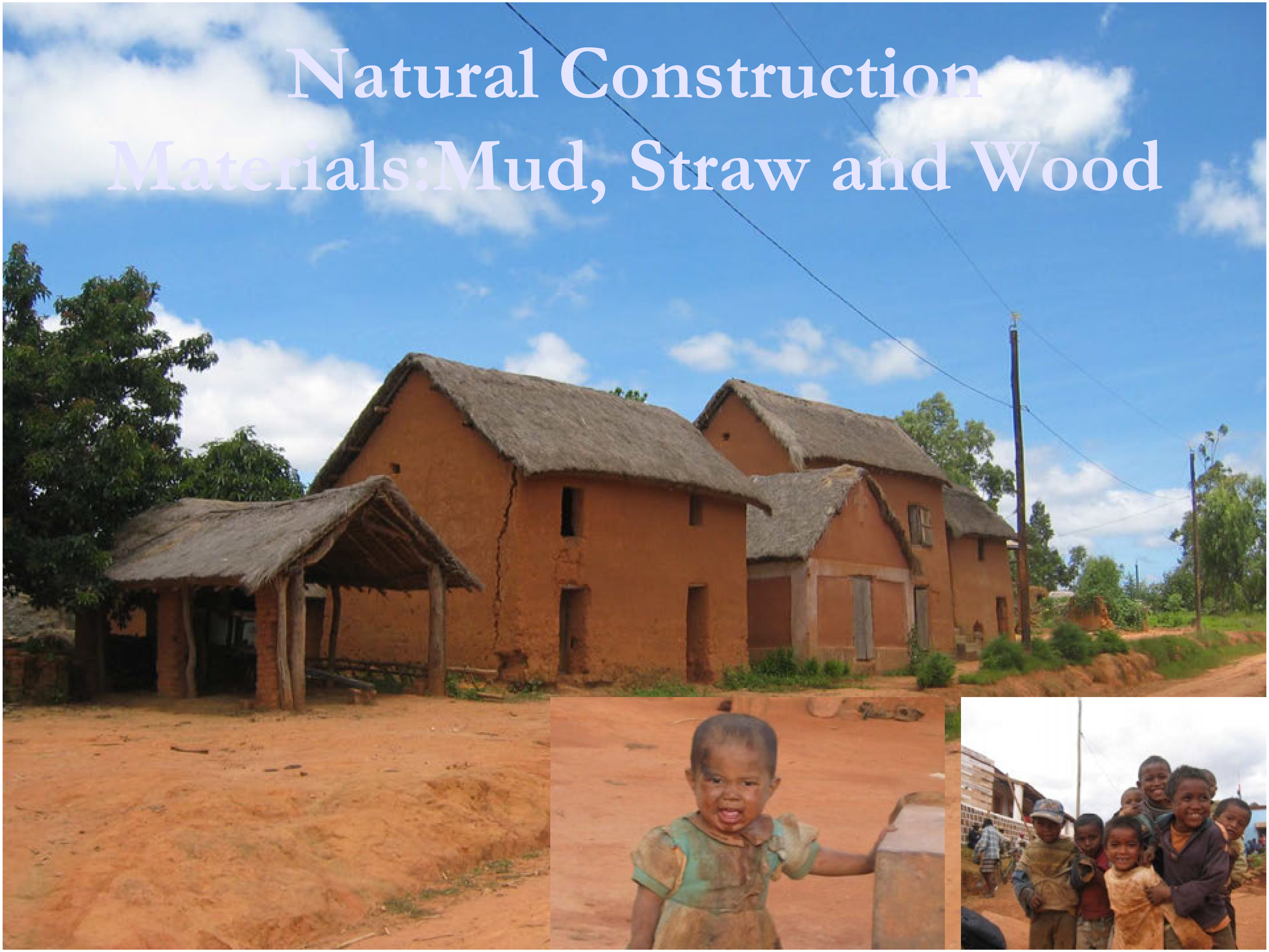
Slash and Burn (Wood Fuel and Rice Plantation).



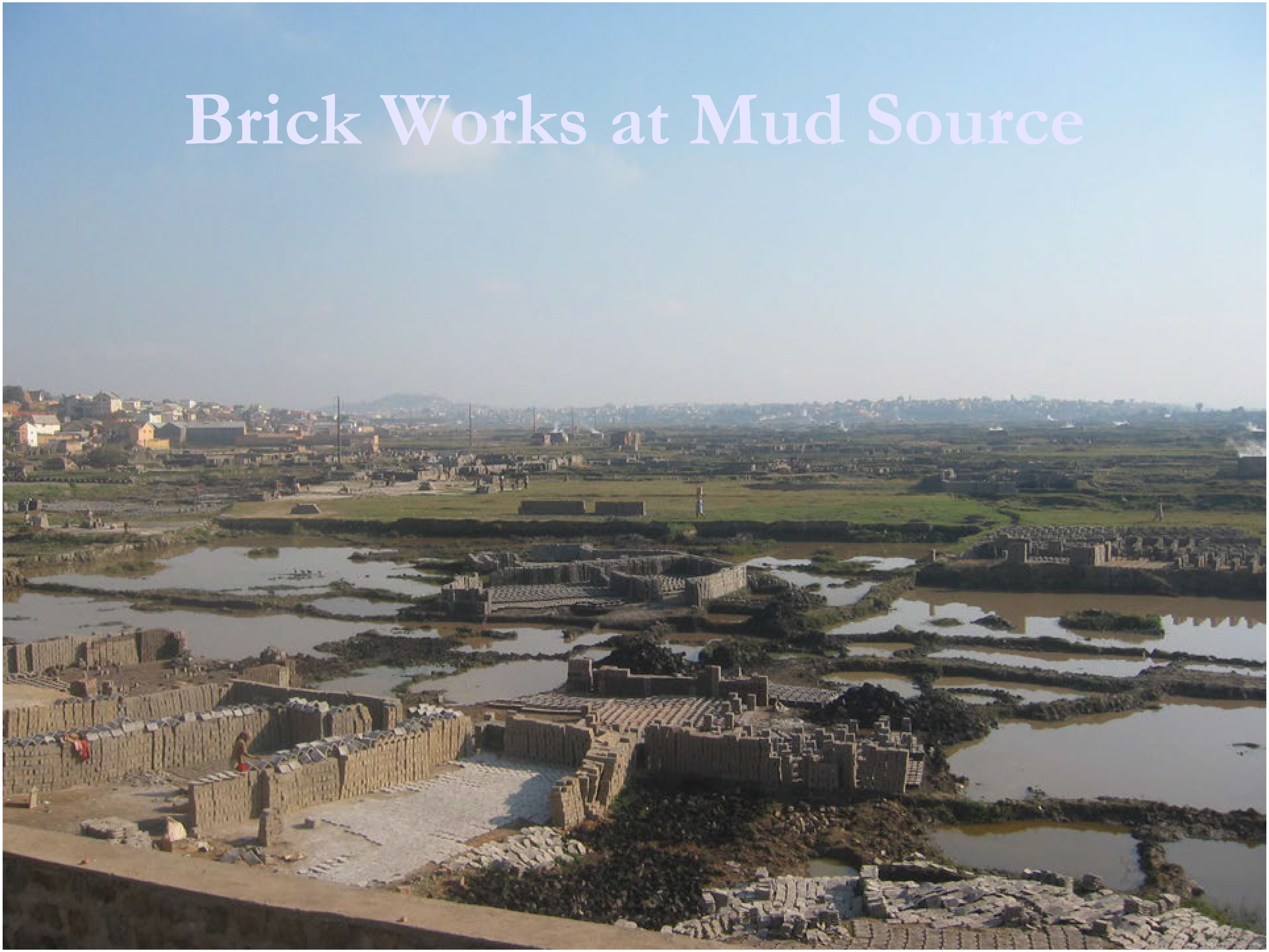
Mud:Laterite & Saprolite for Building



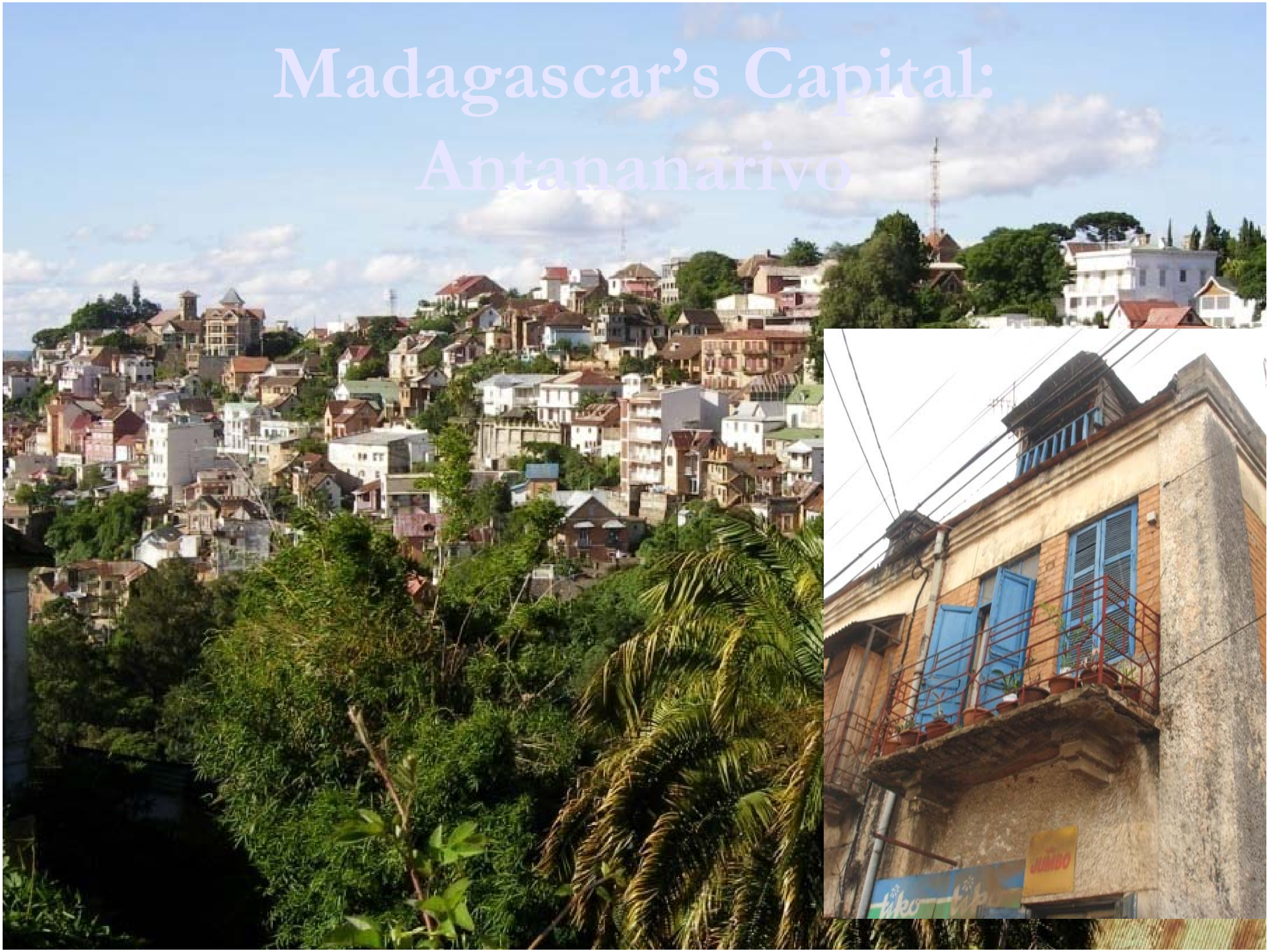
Natural Construction Materials:Mud, Straw and Wood



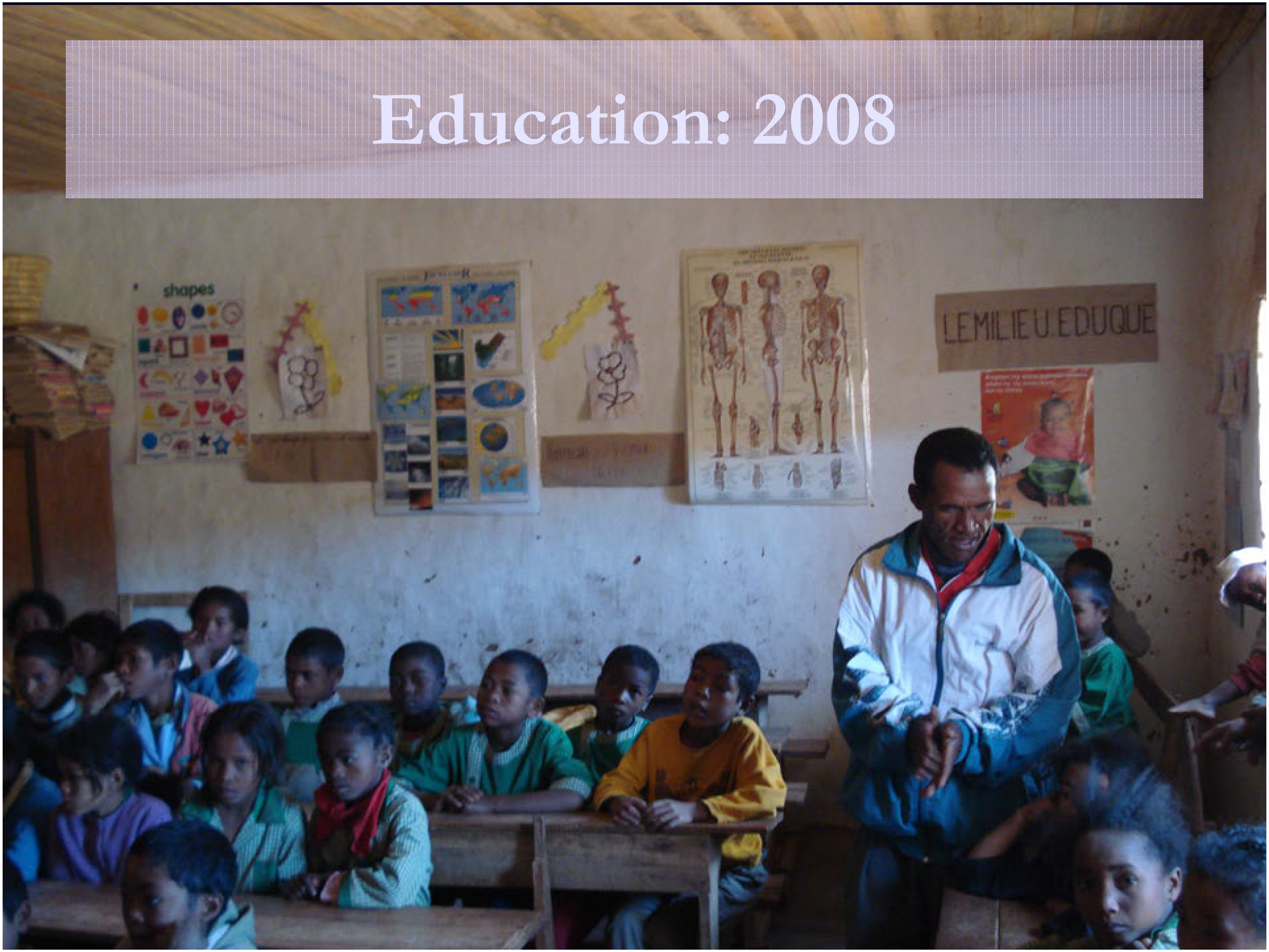
Mud Bricks: 100% Recycled Material


Brick Works at Mud Source

Madagascar's Capital: Antananarivo



Education: 2008




Education & Social Cement
The Best Concrete Ever Made

Global Citizens & Engineers

Construction Sustainability

- Re: Reuse, Recycling, Regeneration, Rehabilitation: Efficiency. E.g 75% can be reused.
- L: Lifespan. 1 year, 10 years, 50 Years, 100 Years.
- O: Optimal Balance (Consumption, Risk, Safety, Technology). E.g can we produce 40MPa concrete with 30% of the standard cement content we use now. Yes, easily. Solution: time and materials. Do we really need 40 Mpa at 28 days: why not 90 days?
- Social Context, Value and Usage. Is a bridge more valuable than a wall or a school or building or a nuclear power station. Material resources are limited. We should use them wisely.

- Concrete lost technology for 1200 years or so.
- Scottish buildings stones taken from old churches etc over the centuries and re-used.