Development of Lightweight Self-compacting Concrete (LWSCC)

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Production Requirements of SCC

- Higher powder content (cement + filler) and/or viscosity- modifying admixture
- Better quality control on grading of aggregates
- More accurate control of total moisture
- Higher cost for powder and new type of superplasticiser

Impact on Conventional Precasting Operation

- **New types moulds – lighter and without form vibrators**
- **Smaller footprints – using vertical casting for elements**
- **Greater flexibility in finishes – both faces of element**
- **Higher flexibility in design – complex bar arrangement**

Lightweight Concrete

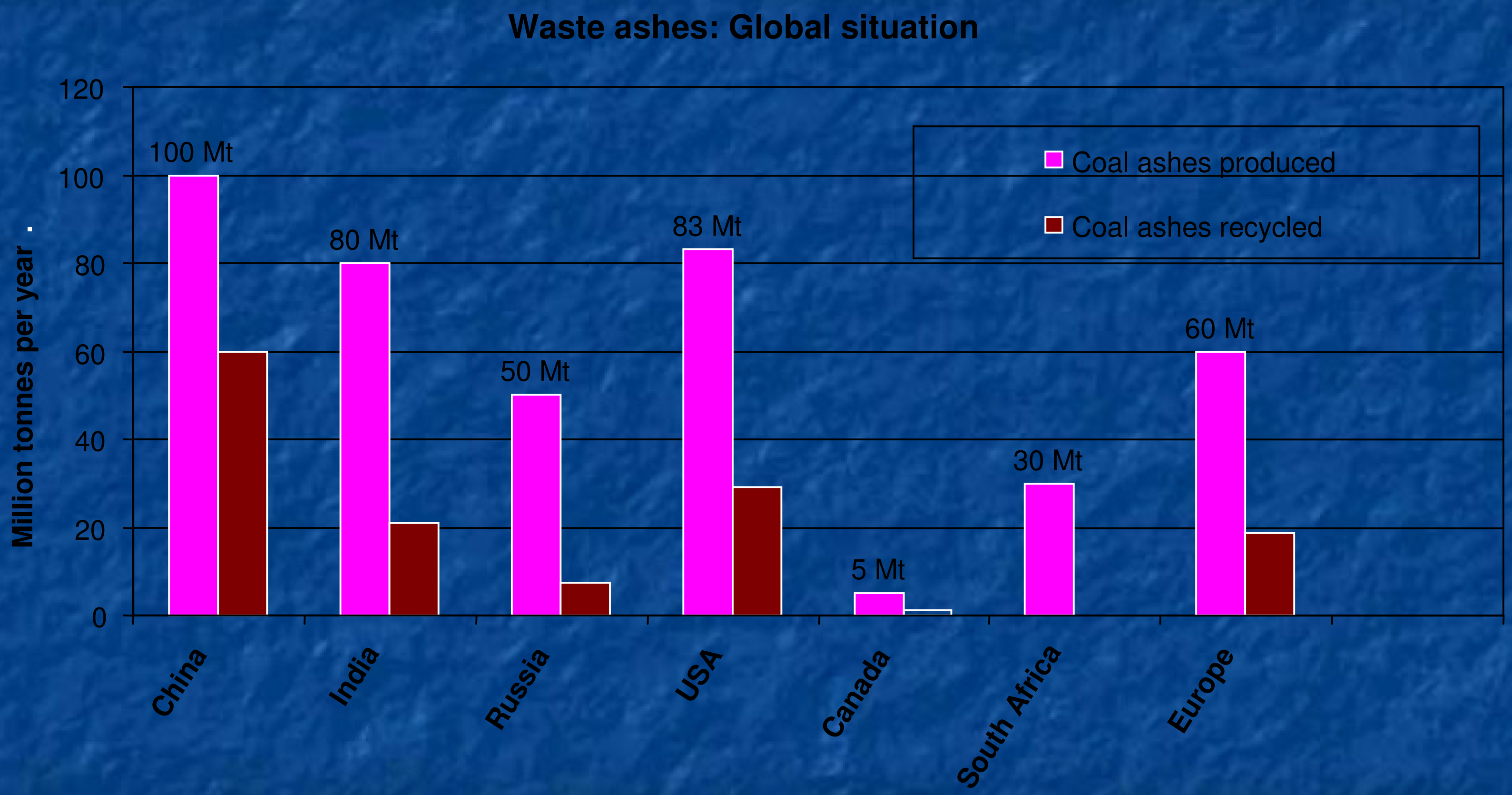
- Lower dead weight
- Easier transportation
- Larger precast elements for same tower crane capacity
- Better insulation

Concern of the use of Lightweight Concrete

- Mechanical properties
- Durability (permeability, carbonation)
- Cost

Worldwide coal ash production:

~ 500 Mt of ash produced per annum and this is expected to increase



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Hong Kong - Coal Fired Power Plant

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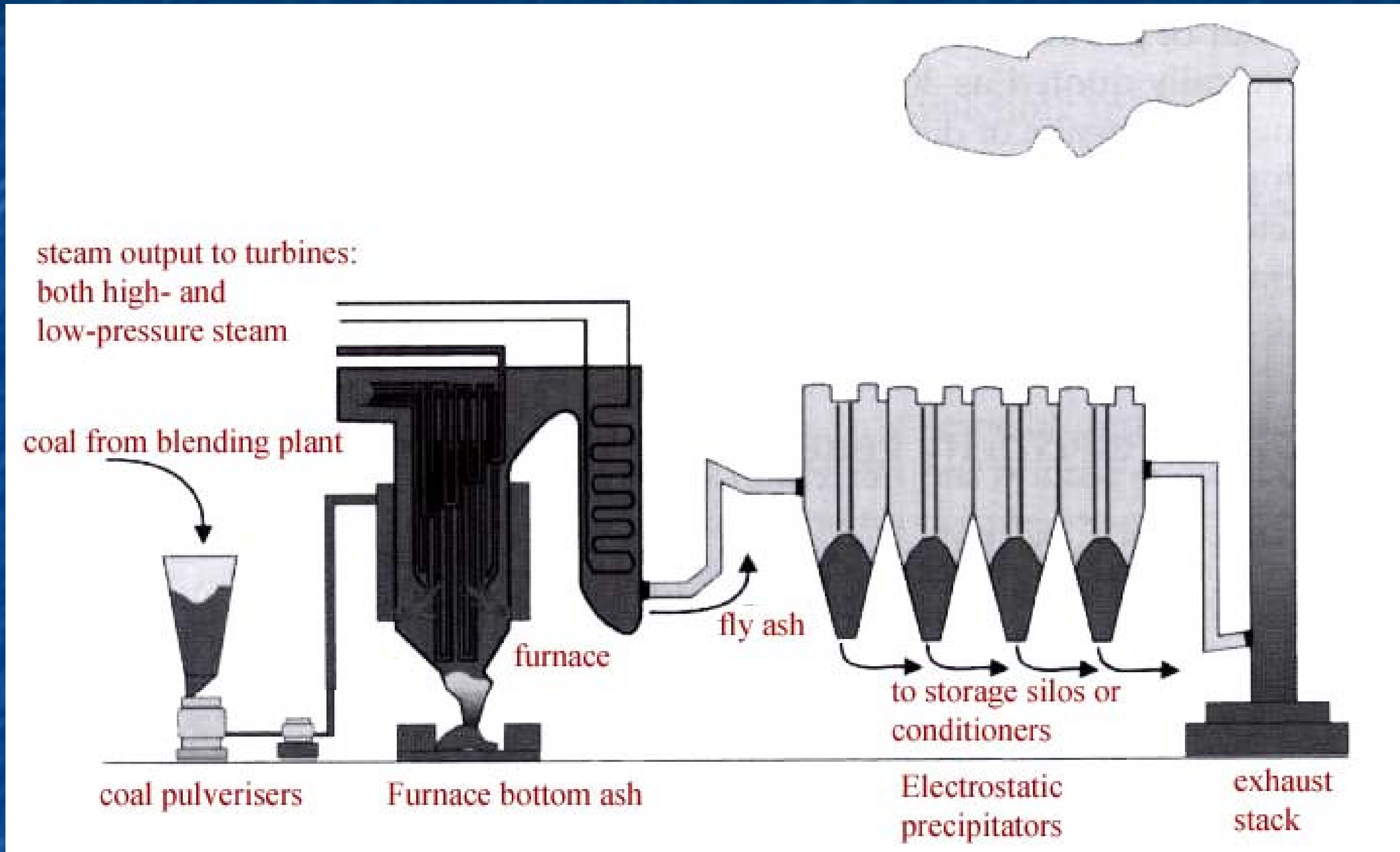
Pulverized Fuel Ash (PFA)



Castle Peak pulverised fuel ash

PFA collected in precipitators → Ash Classification Plant (ACP).

Classified PFA (CPFA) has a fineness value where no more than 12.5% is retained on the 45 micron sieve

Conforms to British Standard 3892 Part 1-1982 for the production of structural concrete

Used as a cement substitute in concrete and building blocks

Reject Ash - oversized material from ACP is not used for structural concrete

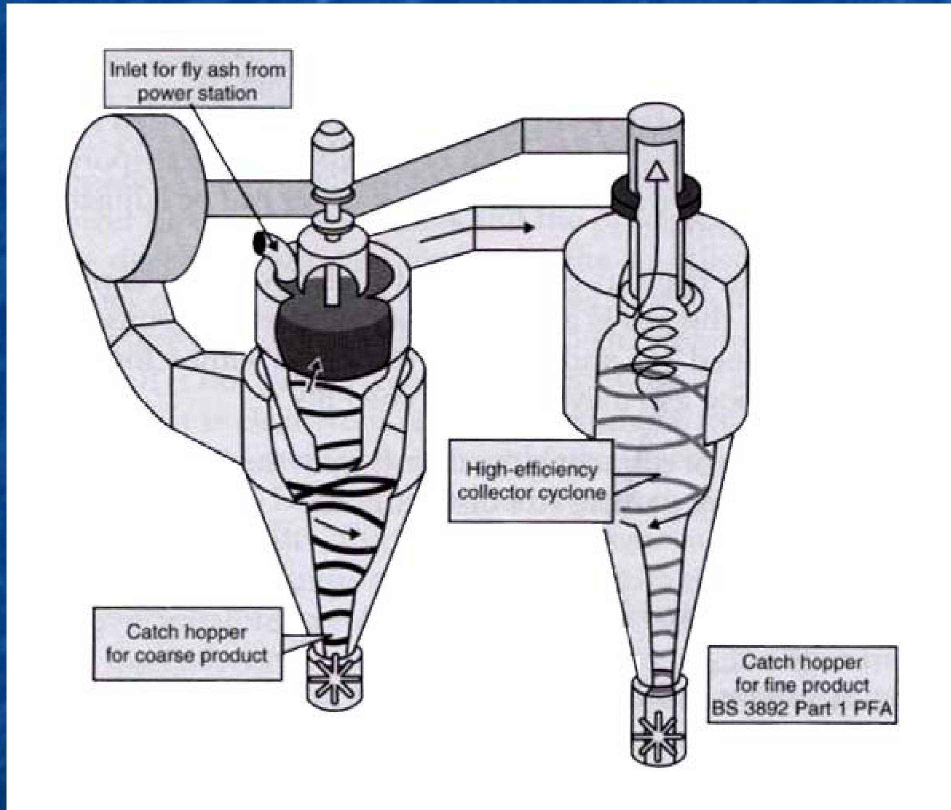
Pumped through pipelines to a lagoon, 5.5 kilometres north of the station

Classification of PFA

PFA

45μm< → Rejected and kept no use

<45μm → Used for building and S/S materials



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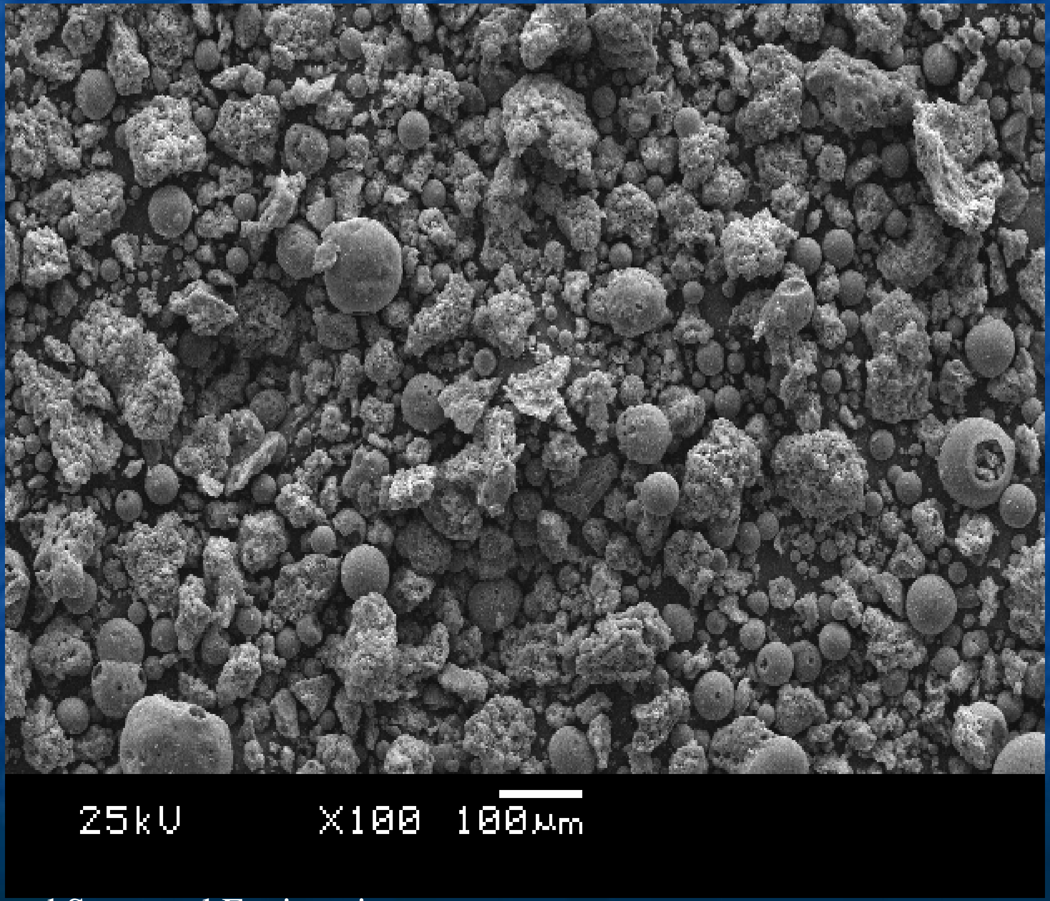
Pulverized Fuel Ash (PFA)

- By-product from burn-out of pulverized coal in power stations
- Fine alumino-silicate powder
- Glassy spheres, together with crystalline matter and unburned carbon



Particles of Fly Ashes

Spherical shapes of f-FA particles

Irregular shapes of r-FA particles

Furnace Bottom Ash (FBA)

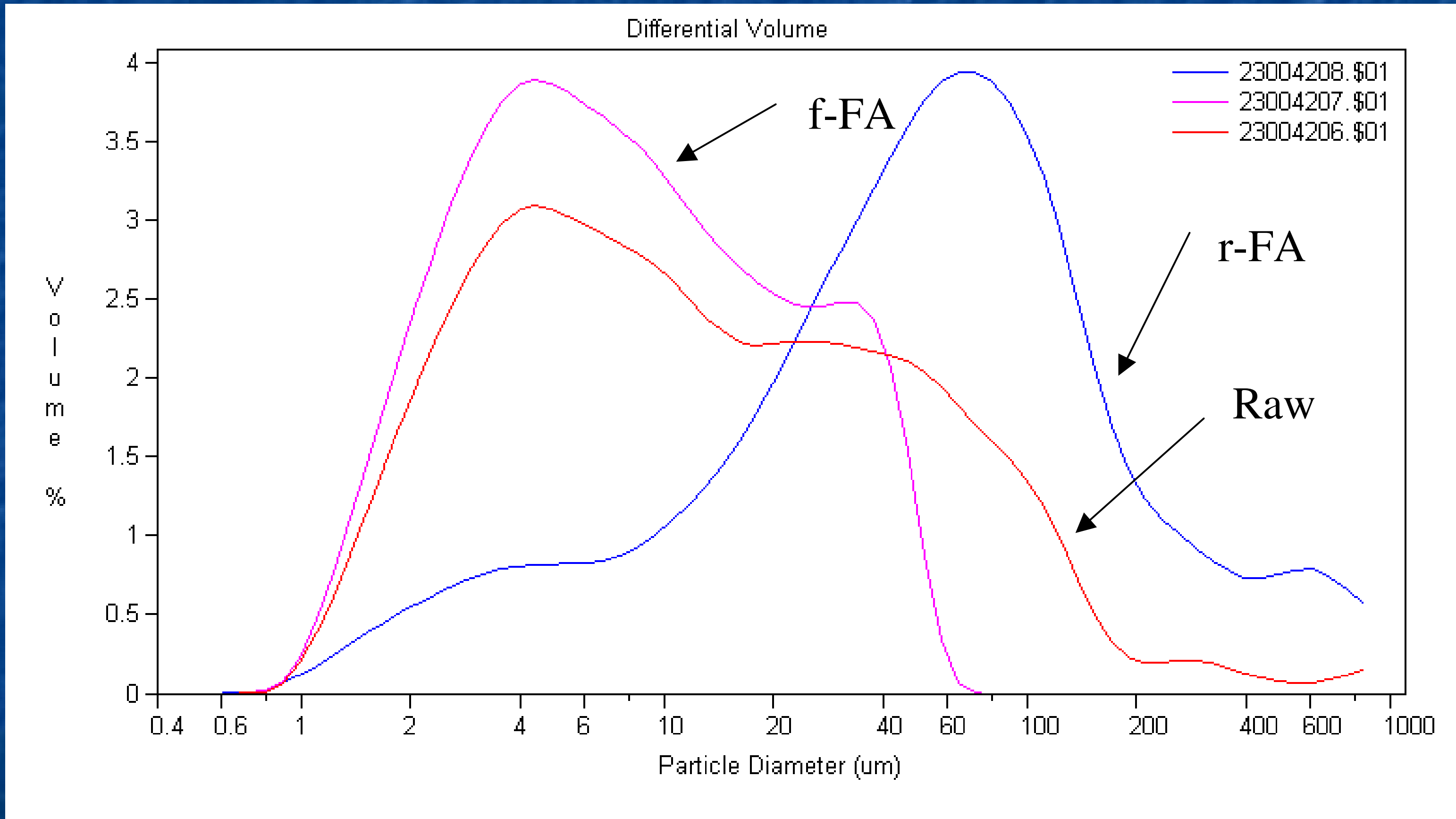
Objectives of Research

- To use r-FA as a replacement of viscosity agent in normal and lightweight SCC mixtures
- To investigate the influences of r-FA on the fresh and hardened properties of <u>NORMAL WEIGHT</u> SCC mixtures
- To investigate the influences of r-FA and FBA on the fresh and hardened properties of <u>LIGHTWEIGHT</u> SCC mixtures

Chemical Composition of Fly Ashes

Type	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	LOI	Fineness (m^2/kg)	Density (kg/m^3)
r-FA	47.2	8.4	24.5	1.0	8.3	8.1	119.0	2.19
f-FA	47.6	7.4	27.4	1.2	8.1	0.9	399.6	2.28

Size Distribution of r-FA



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Benefits of Using r-FA

- Pozzolanic properties of fly ashes
- Replacement of limestone fillers and mineral powders
- Replacement of viscosity agent
- By-product in electricity generation
- Additional benefits of economy

Requirements of SCC Mixtures

- Initial slump flow = 650 mm
- Slump flow value of 650 mm to be maintained over a period of 2 hours
- A minimum blocking ratio of 0.75 measured using the L-box apparatus
- Segregation ratio between 5 % and 15 %

Normal Weight SCC

Mix Proportions for Normal Weight SCC Mixtures

Mix	OPC (kg/m³)	f-FA (kg/m³)	r-FA (kg/m³)	Aggregate (kg/m³)	Sand (kg/m³)	Water (kg/m³)	w/b	w/p	SP (%)
1*	375	125	0	400	860	200	0.4	0.4	1.7
2	375	125	100	400	740	200	0.4	0.34	1.6
3	375	125	150	400	680	200	0.4	0.32	1.8
4	375	125	200	400	620	200	0.4	0.30	1.7
5	375	125	250	400	560	200	0.4	0.28	2.1

increase

* Viscosity agent of 1.1 % by weight of binder (OPC+f-FA) was added

Fresh Properties

- **Slump flow**
- **L-box**
- **Wet density**
- **Segregation**

SCC with Lightweight Aggregates

Hardened properties

- **Compressive strength (1, 4, 7, 28 and 90 days)**
- **Tensile strength (28 days)**
- **E-value (28 days)**
- **Wet and oven dry densities**

Durability

- Chloride permeability
- Drying shrinkage

Fresh properties of Normal Weight SCC with r-FA

Mix	Slump flow (mm)				L-box		Wet density (kg/m^3)	Air content (%)	Segregation degree (%)
	Immediately after mixing		2 hours after mixing		Final time (s)	Blocking ratio			
	Time (s)	Flow (mm)	Time (s)	Flow (mm)					
1	36	690	40	688	23	0.82	2180	5.9	8.1
2	41	760	40	705	31	0.72	2280	2.5	7.4
3	44	755	41	710	36	0.72	2260	3.5	5.3
4	49	835	28	765	22	0.88	2200	3.0	9.9
5	35	718	40	685	40	0.60	2220	3.6	9.2

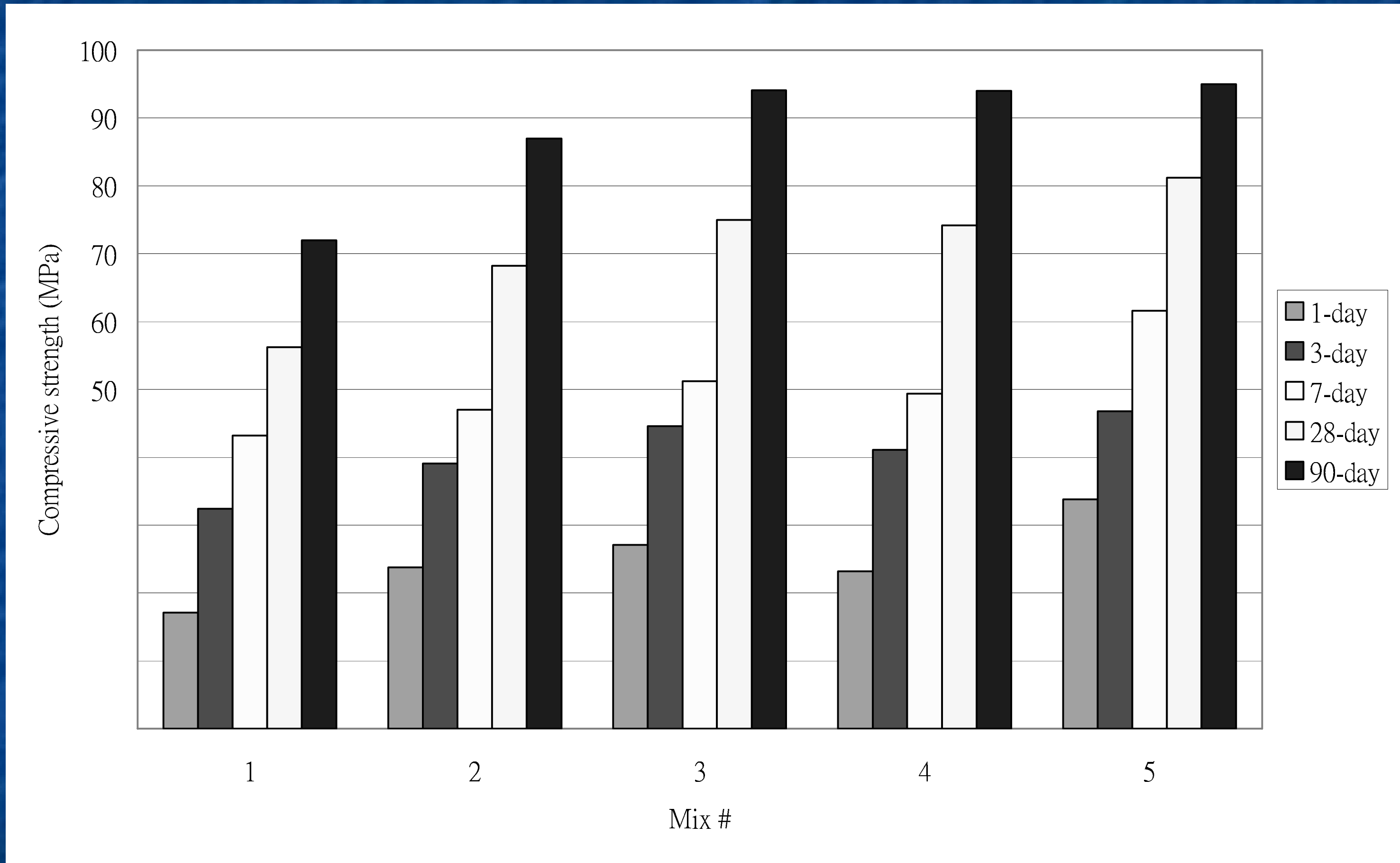
Fresh Properties of Normal Weight SCC with r-FA

- Slump flow values of the SCC mixtures were acceptable ($\geq$650 mm).
- The addition of r-FA could cause a reduction in the blocking ratio.
- Segregation ratio was satisfactory
- r-FA could be used as a replacement of viscosity agent

Tests for Hardened Properties

- Compressive strength
- Elastic modulus
- Chloride ion penetration (ASTM C1202)

Compressive Strength



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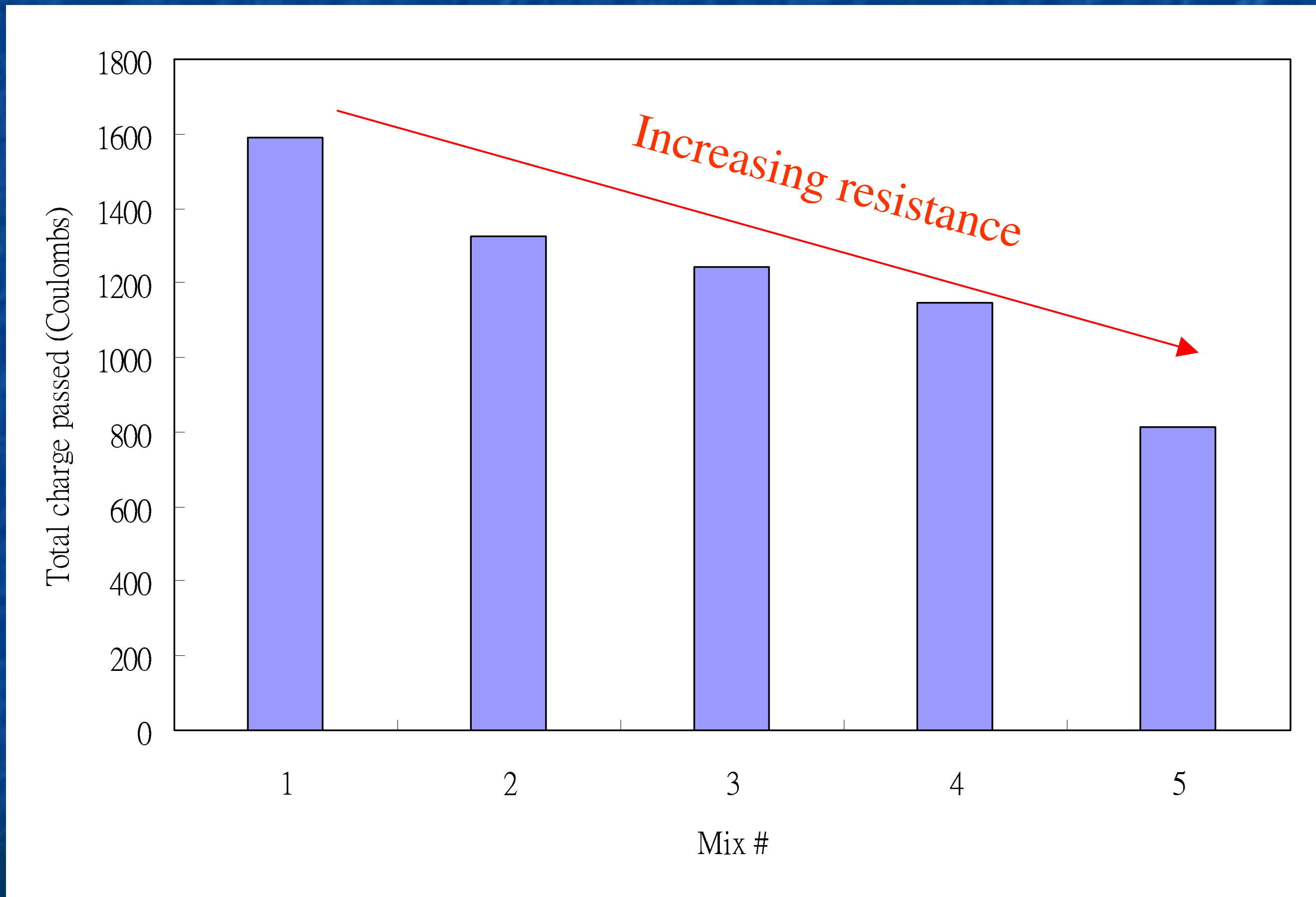
Compressive Strength

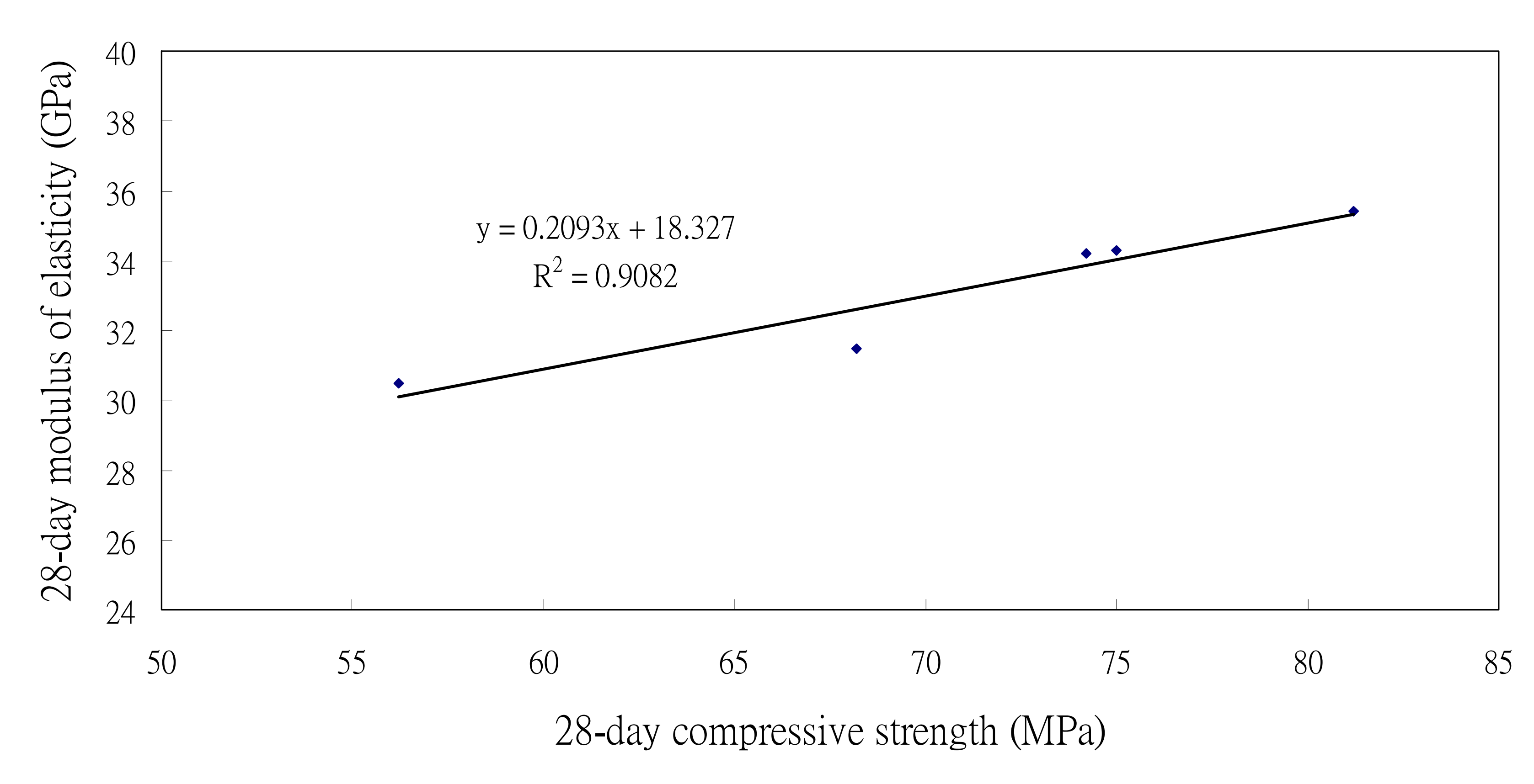
- Control mixture had the lowest strength at all ages.
- Mix #5, which contained the highest amount of r-FA, had the highest strength at all ages.
- The strength increased as the r-FA content increased.
- The increased strength was due to the pozzolanic effect of r-FA and the improved packing within the concrete matrix.

Elastic Modulus

Chloride Ion Penetration



Relationship between Strength and Elastic Modulus



Hardened Properties

- Elastic modulus increased with an increase in the r-FA content.
- A 15 % increase in elastic modulus was observed when r-FA content increased from 0 to 250 kg/m^3.
- Resistance to chloride ion penetration improved as the r-FA content increased.
- A good correlation existed between strength and elastic modulus.

Lightweight SCC

Lightweight Aggregates

Aggregate Properties

	Lightweight Aggregate (Leca)	Sand	FBA
Water absorption (%)	25.0	0.9	17.0
SSD density (kg/m^3)	1355	2620	2190
Drying shrinkage (%)	<0.05%	-	-
TFV (kN)	106	-	-
Fineness modulus (FM)	5.70	2.28	2.22

Mix Proportions

	OPC (kg)	PFA (kg)	r-FA (kg)	LWA (kg)	Sand (kg)	Water (kg)	w/b	SP (L/m^3)	VMA (L/m^3)
r-FA-0	400	100	0	615	450	168	0.34	6.0	2.9
r-FA-150	400	100	150	580	450	168	0.34	6.0	-
r-FA-180	400	100	180	560	450	168	0.34	6.0	-

	OPC (kg)	PFA (kg)	r-FA (kg)	LWA (kg)	Sand (kg)	FBA (kg)	Water (kg)	w/b	SP (L/m^3)
FBA-30	400	100	150	580	300	110	168	0.34	6.0
FBA-50	400	100	150	580	215	180	168	0.34	6.0
FBA-70	400	100	150	580	108	270	168	0.34	6.0
FBA-100	400	100	150	580	-	365	168	0.34	6.0

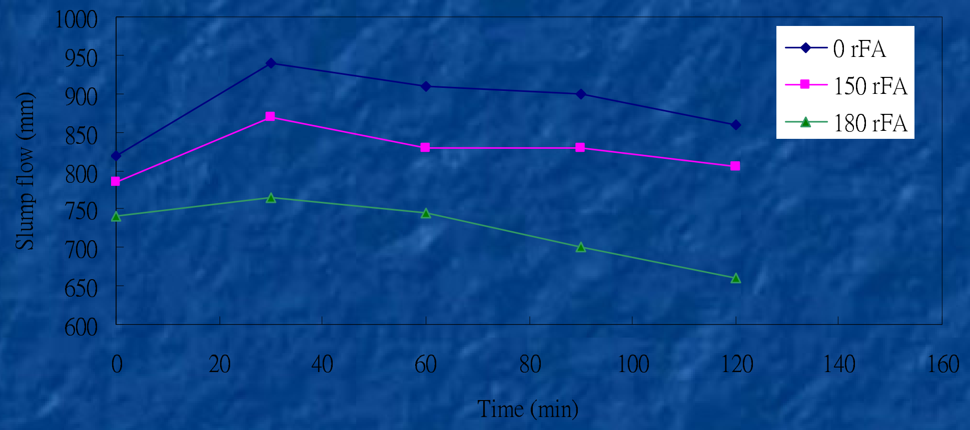
Fresh Properties

	L-box ratio (%)	Segregation ratio (%)	Wet density (kg/m^3)	Slump flow (After2 hours) (mm)
Series I				
r-FA-0	90.6	10.3	1740	860
r-FA-150	90.4	7.1	1860	805
r-FA-180	86.7	10.2	1880	660
Series II				
FBA-30	83.3	8.5	1810	715
FBA-50	93.8	8.3	1740	730
FBA-70	87.5	9.2	1730	735
FBA-100	93.8	11.0	1720	670

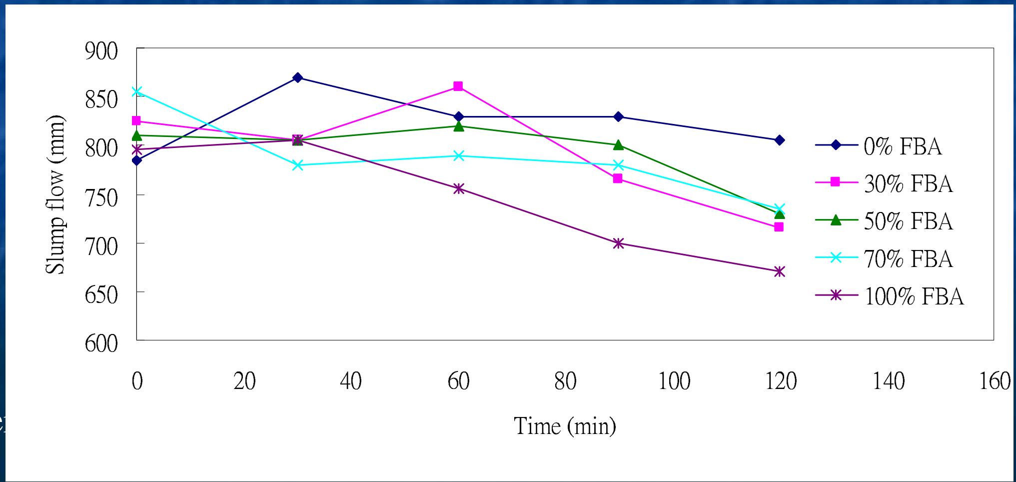
Shrinkage, Permeability and Density

	Shrinkage (112 days) ($x10^{-6}$)	Chloride permeability (C)	Oven-dry density (kg/m^3)	Saturated density (kg/m^3)
Series I				
r-FA-0	462	1308	1715	1921
r-FA-150	680	1396	1692	1890
r-FA-180	409	1439	1865	1937
Series II				
FBA-30	619	1129	1694	1909
FBA-50	510	1569	1644	1845
FBA-70	472	1143	1614	1805
FBA-100	723	1818	1557	1820

Slump flow

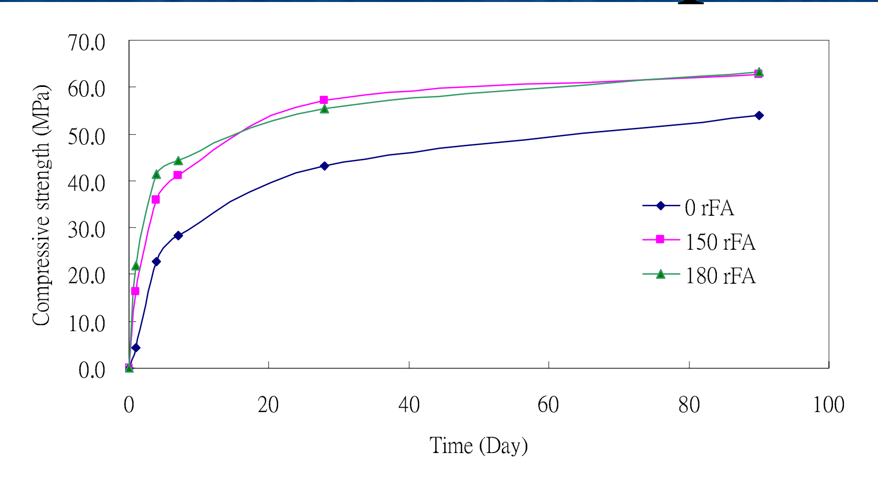


1000
950
900
850
800
750
700
650
600
Slump flow (mm)
0
20
40
60
80
100
120
140
160
Time (min)
0 rFA
150 rFA
180 rFA

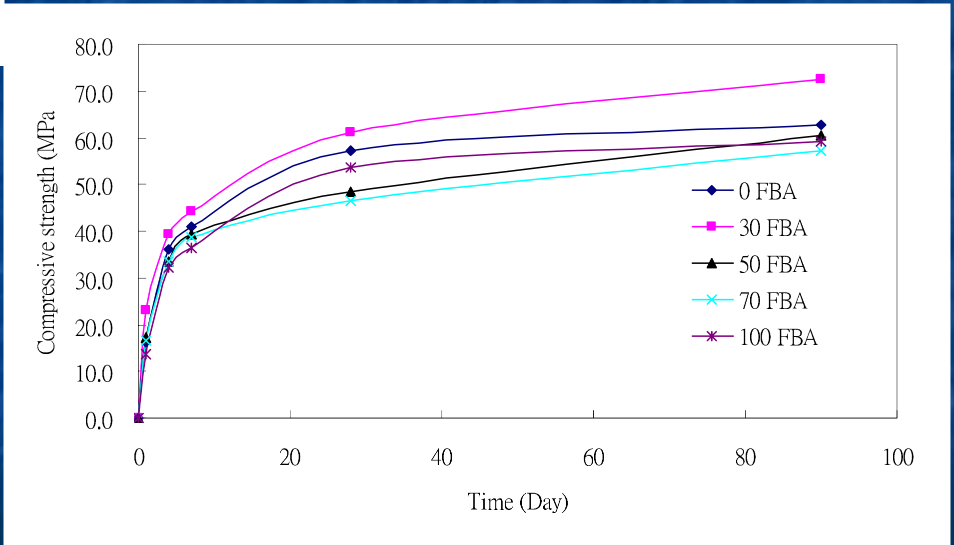


900
850
800
750
700
650
600
Slump flow (mm)
0
20
40
60
80
100
120
140
160
Time (min)
0% FBA
30% FBA
50% FBA
70% FBA
100% FBA

Compressive strength



150 and 180 rFA mixes show similar compressive strength but higher than that without rFA



Highest compressive strength→30% FBA replacement

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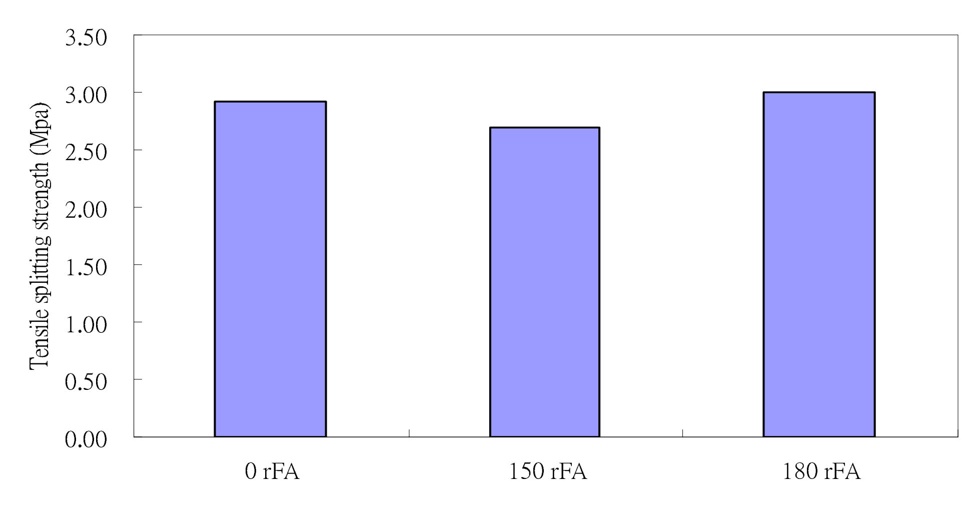
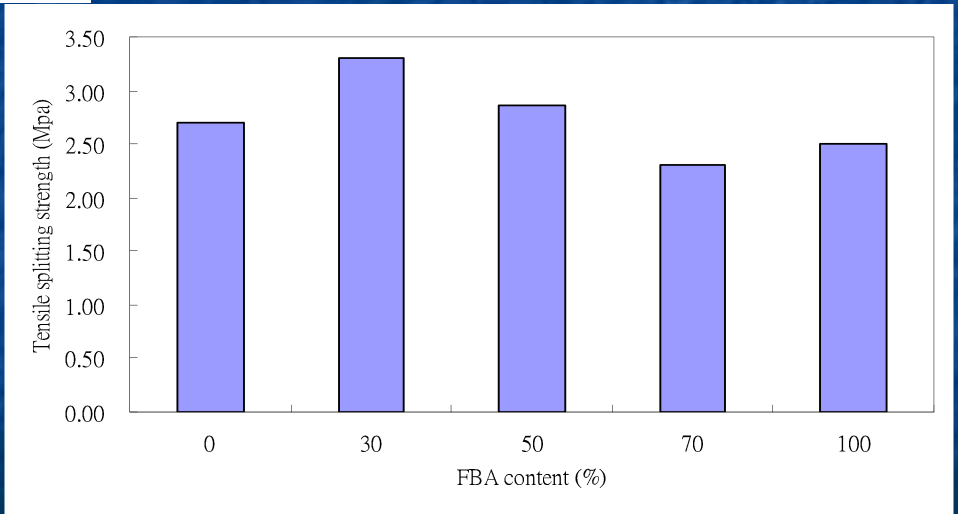
Tensile splitting Strength





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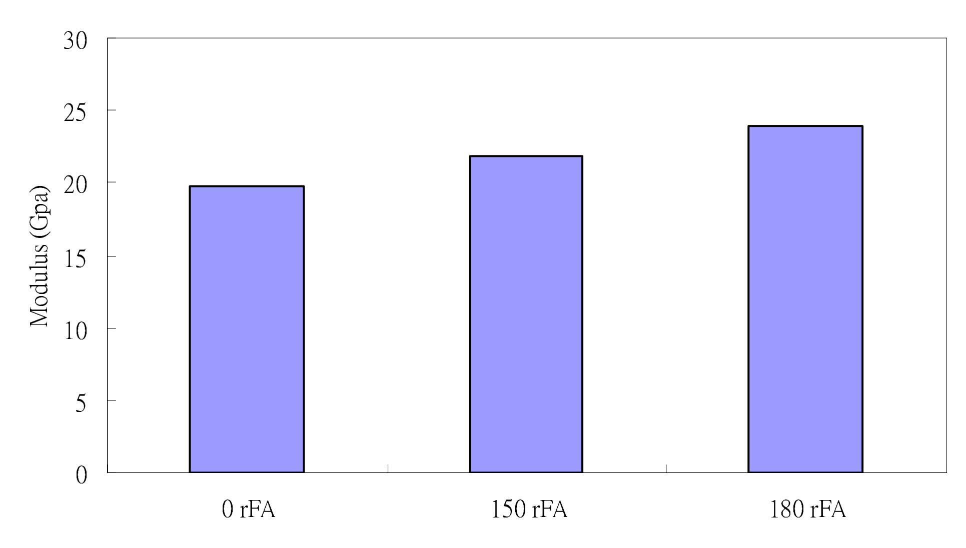
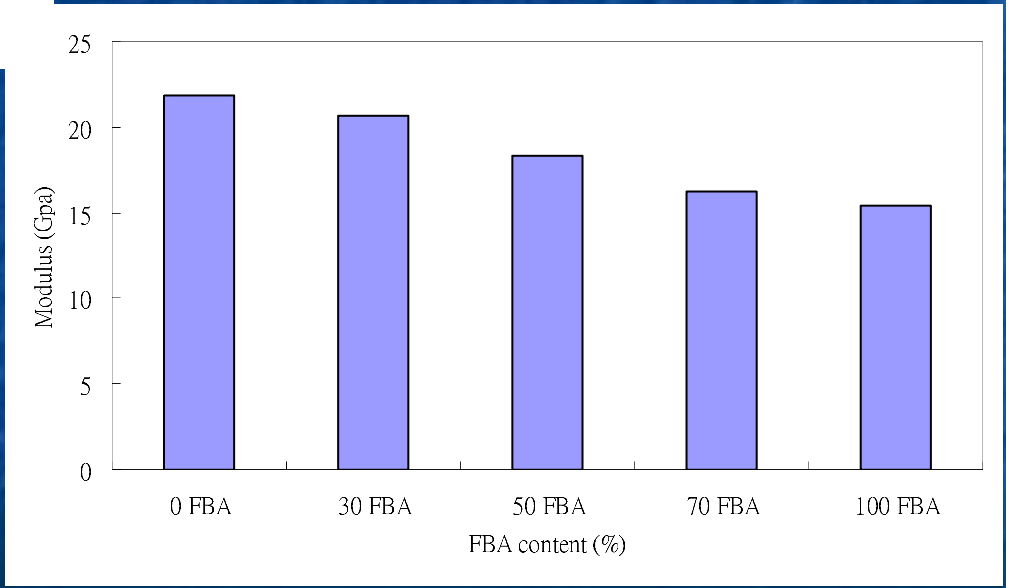
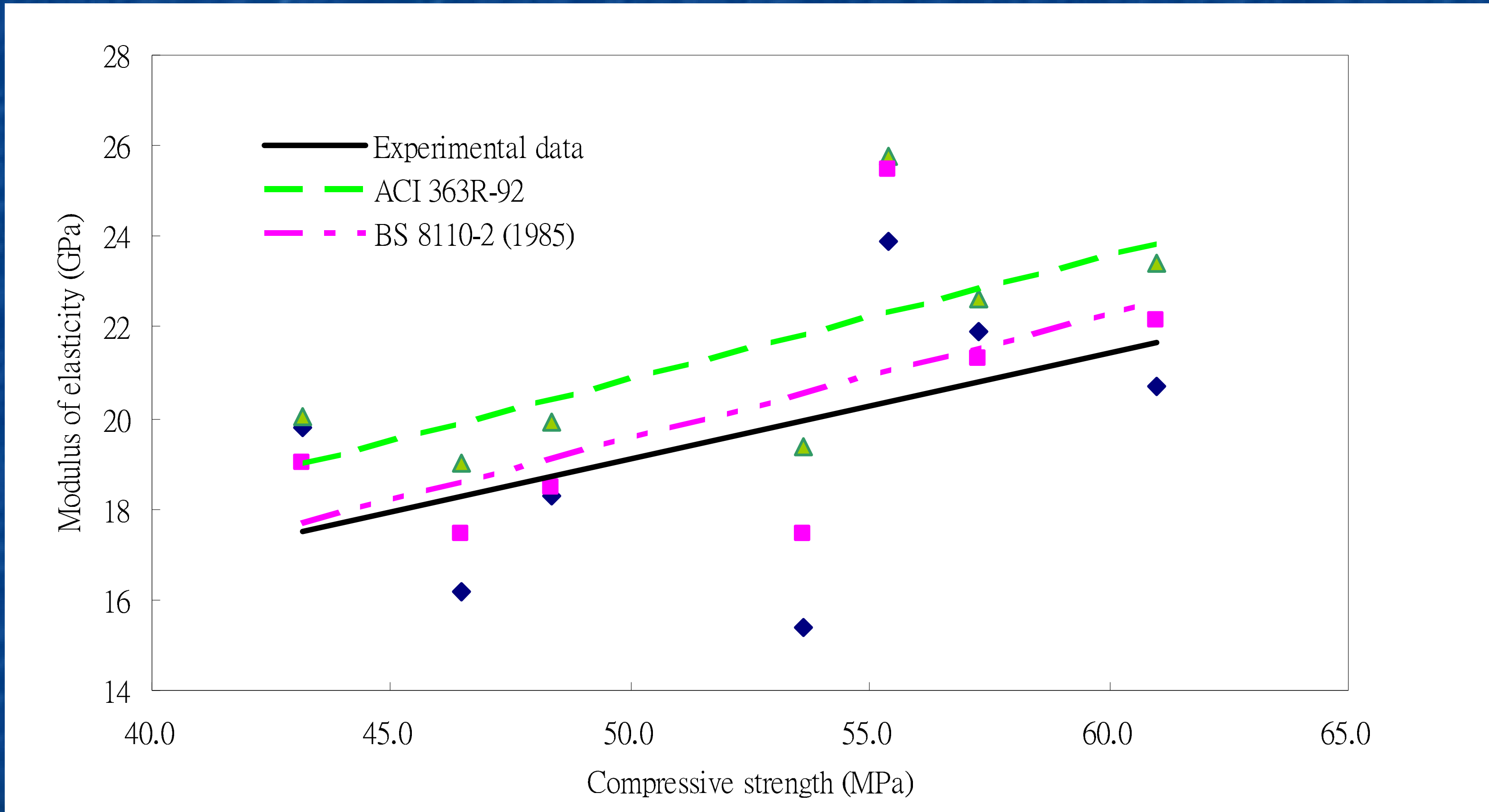
E-values


30
25
20
15
10
5
0
Modulus (Gpa)
0 rFA
150 rFA
180 rFA


25
20
15
10
5
0
Modulus (Gpa)
0 FBA
30 FBA
50 FBA
70 FBA
100 FBA
FBA content (%)

E-value vs Compressive strength



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Compressive Strength

- The use of r-FA increased the compressive strength.
- Low 1-day strength (4.5 MPa) without the use of r-FA.
- The 1-day strengths were 16 and 21 MPa for mixtures with 150 and 180 kg/m^3 of r-FA respectively.

Conclusions: I

Normal weight SCC

- r-FA could be used as a replacement of viscosity agent.
- The fresh properties of SCC with r-FA were satisfactory.
- The compressive strength of SCC increased with an increase in r-FA content.

Conclusions: II

- Elastic modulus also increased with an increase with an increase in r-FA content.
- Resistance to chloride ion penetration was improved as the r-FA content increased.
- A good correlation between strength and elastic modulus.

Conclusions: III

Lightweight SCC

- R-FA and FBA can be used to produce lightweight SCC
- The fresh properties of lightweight SCC was satisfactory.
- It was found that slump flow reached the maximum 30 minutes after mixing.
- The oven dried density of lightweight SCC was about 1650 kg/m^3.

Conclusions: IV

- The addition of r-FA significantly increased the compressive strength of LWSCC.
- The incorporation of r-FA significantly improved the 1-day compressive strength.
- Mix with 30 FBA achieved the highest strength

Thank you for your attention !