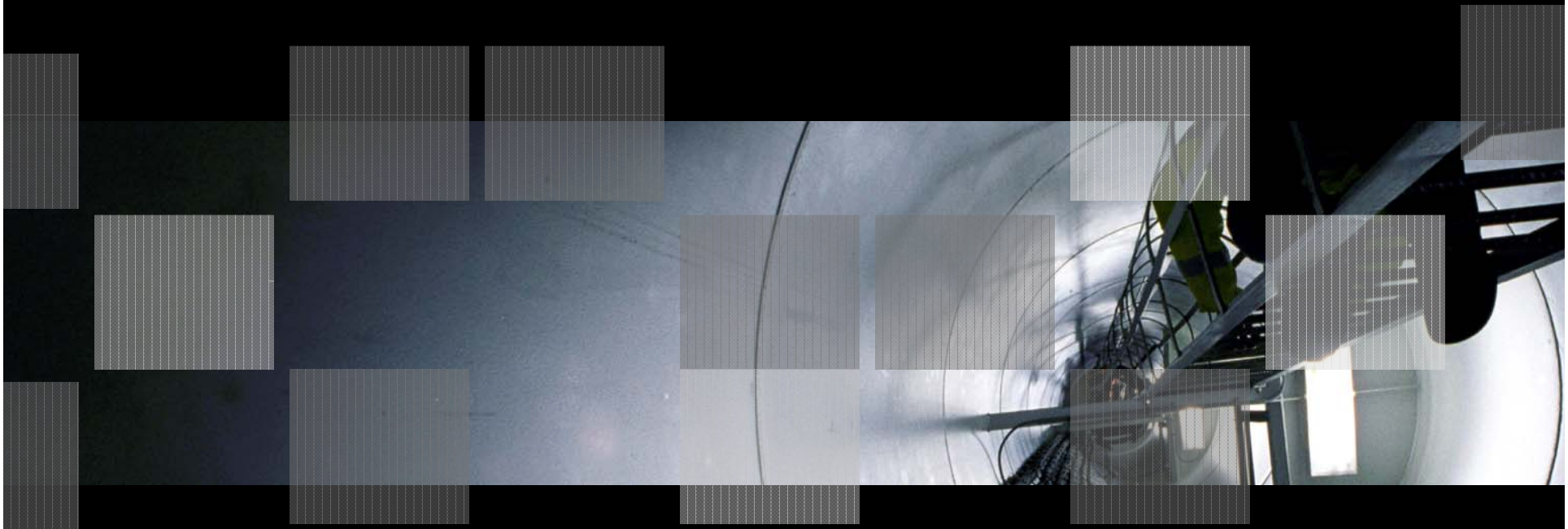
Metakaolin Used in Fibre Reinforced Centrifugal Placed Concrete in Mine in Western Canada

Anna Maria Workshop X, Holmes Beach, FL November 4-6, 2009



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Introduction to Metakaolin (MK)

- Mined from natural Kaolin (aluminum silicate), calcinated at high temperature (800^{o}C) through a dry process.
- Type N Supplementary Cementing Material (SCM) in ASTM C618 and CSA A3001-03
- Product research was conducted by AMEC including trial mix, compressive strength testing, shrinkage testing, rapid chloride penetration testing, freeze-thaw testing, and AAR testing.

Introduction to MK– Chemical properties

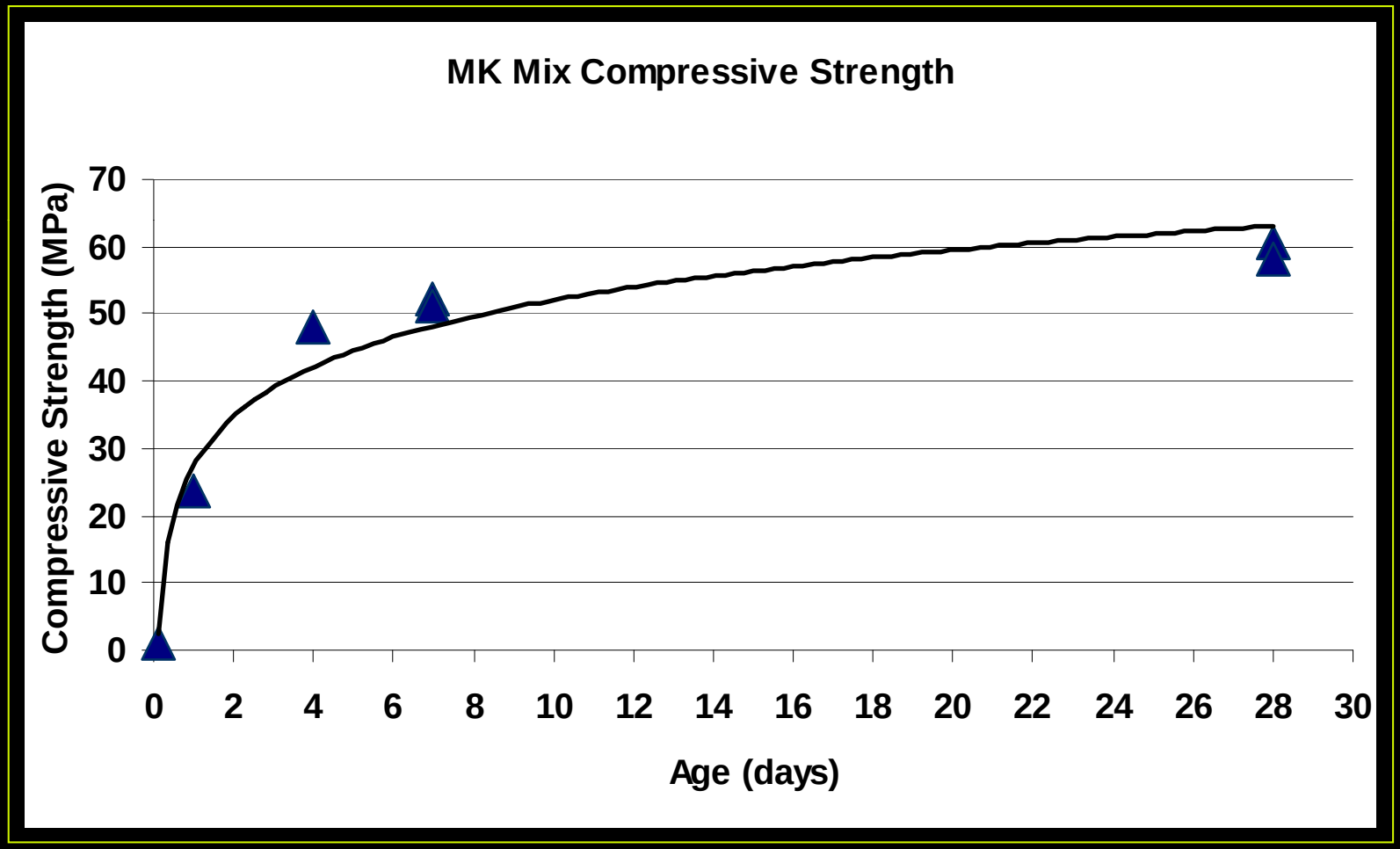
Chemical Properties			Requirements	
			CSA	ASTM/AASHTO
SO_3	0.06	%	3% Max	4% Max
Sum (SiO_2, Al_2O_3, Fe_2O_3)	93.6	%		70% Min
Total Alkalis as Na2O	1.4	%		
Moisture Content	0.2	%		3% Max
Loss On Ignition - 800 C	1	%	10% Max	10% / 5% Max
Available Alkalis as Na2O	0.22	%		- / 1.5% Max
Physical Properties				
Fineness (45 um % retained)	3	%	34% Max	34% Max
Density	2.56	g/cc		
Autoclave expansion	0.02	%	0.8% Max	0.8% Max
Water Requirement	105	% of Control		115% Max
Strength Activity Index				
7 day	121	% of Control	75% Min	75% Min
28 day	116	% of Control	75% Min	75% Min
Uniformity Requirements				
Density	1	% Variation from Ave.		5% Max
Fineness (45 um % retained)	0.4	Variation from Ave.		5% Max

Fibre Reinforced CPC Mix Designs

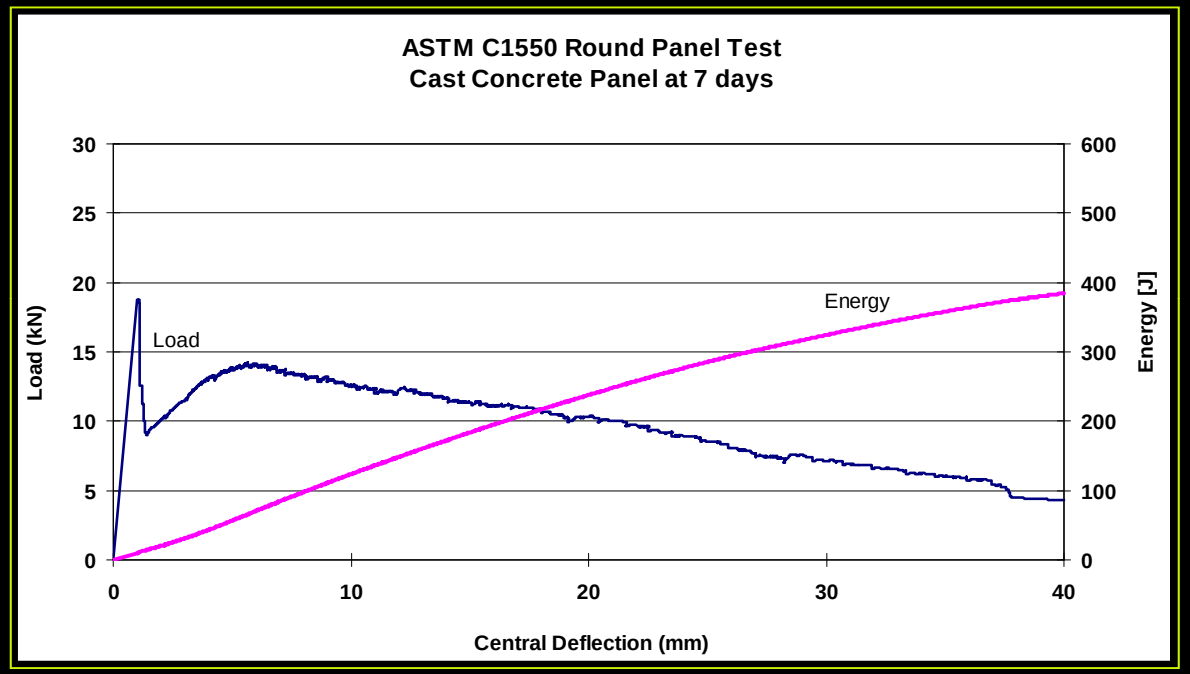
Material [kg/m^3]	Mix A: Natural Pozzolan (30%)	Mix B: Silica Fume (10%)	Mix C: Metakaolin (20%)	Mix D: Metakaolin /Silica Fume
Cement Type GU	386	430	418	420
Natural Pozzolan	119			
Silica Fume		44		21
Metakaolin			85	85
Fine Aggregate (SSD)	1516	1655	1630	1630
Water	227	200	193	210
Macro-Synthetic Fibre	6	6	6	6

Metakaolin Mix – Laboratory Hand Cast Trial

Metakaolin Mix
Laboratory Hand Cast Trial Results: Compressive Strength



Metakaolin FRS
Laboratory Hand Cast Trial Results: Flexural Toughness



Property	At centre point deflection of				
	7 mm	10 mm	20 mm	30 mm	40 mm
Corrected Load [kN]	13.7	12.6	10.3	7.2	4.3
Load vs. First Peak Load	73%	67%	55%	38%	23%
Corrected Energy [J]	85	124	238	324	385

Peak Load = 18.7 kN

Panel broken into three pieces with typical Y yield line failure pattern

Metakaolin Mix
Centrifugal Placed Concrete (CPC) Mock-up

- Centrifugal placement
- Compressed air used to rotate spinner head at 4000-5000 rpm
- No accelerator added
- Slump: 150 mm at the end of hose at spinner head

Metakaolin CPC Field Application

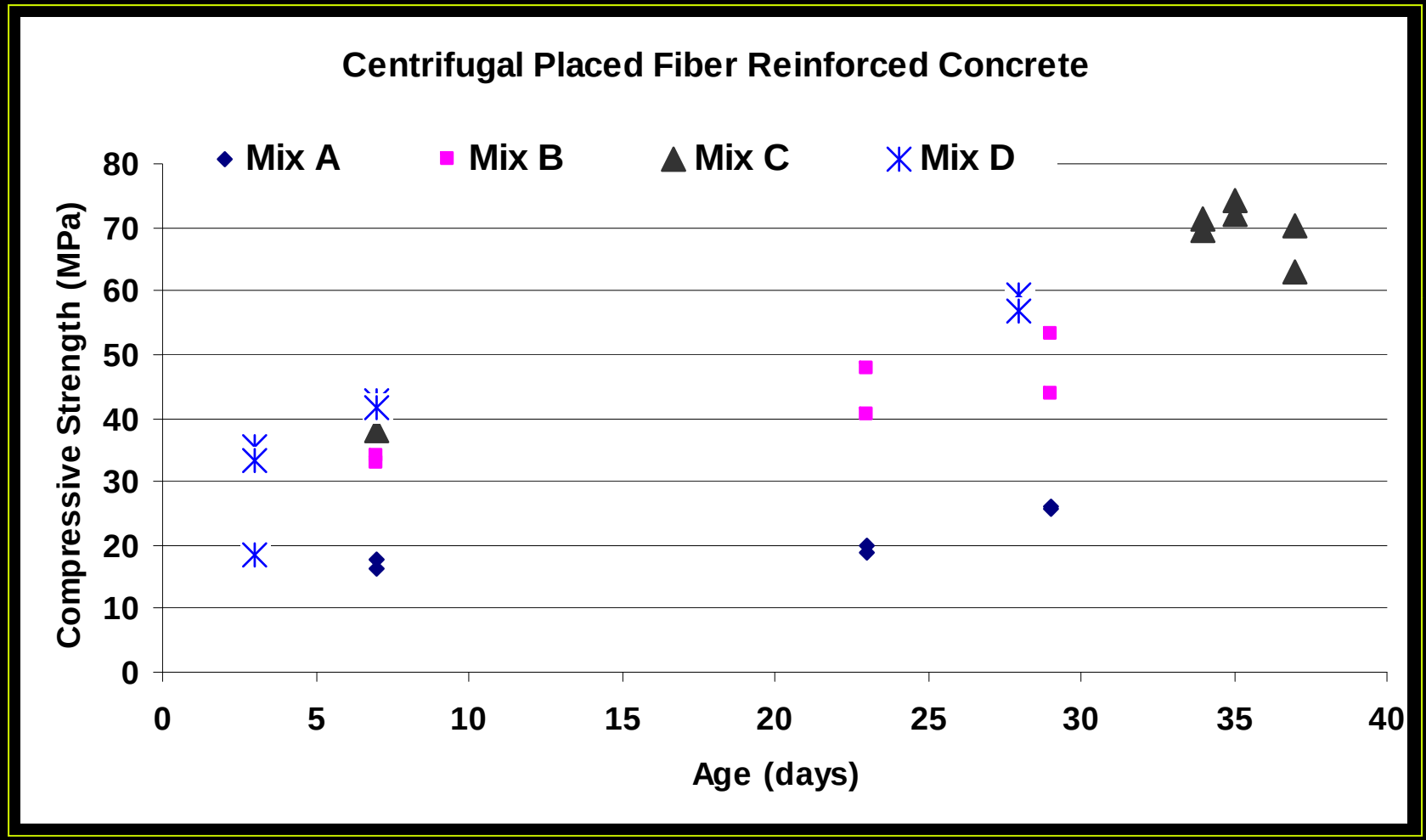
- Underground Mine Raise Bore Shaft in British Columbia, Canada
- 11.5 ft (3.5m) in diameter, 951 ft (290 m) deep
- CPC applied 2 in (50 mm) thick
- Mine set up a batch plant for batching CPC
- Time of placement : June, 2009

CPC Field Application

- Plastic concrete: 150 mm slump at the end of hose, air content 2% as shot
- Low rebound
- Two test panels (800 mm diameter, 75 mm thick) were produced every day and tested at 3 and 7 days.
- Fiber dosage 5 kg/m^3

CPC test panel production

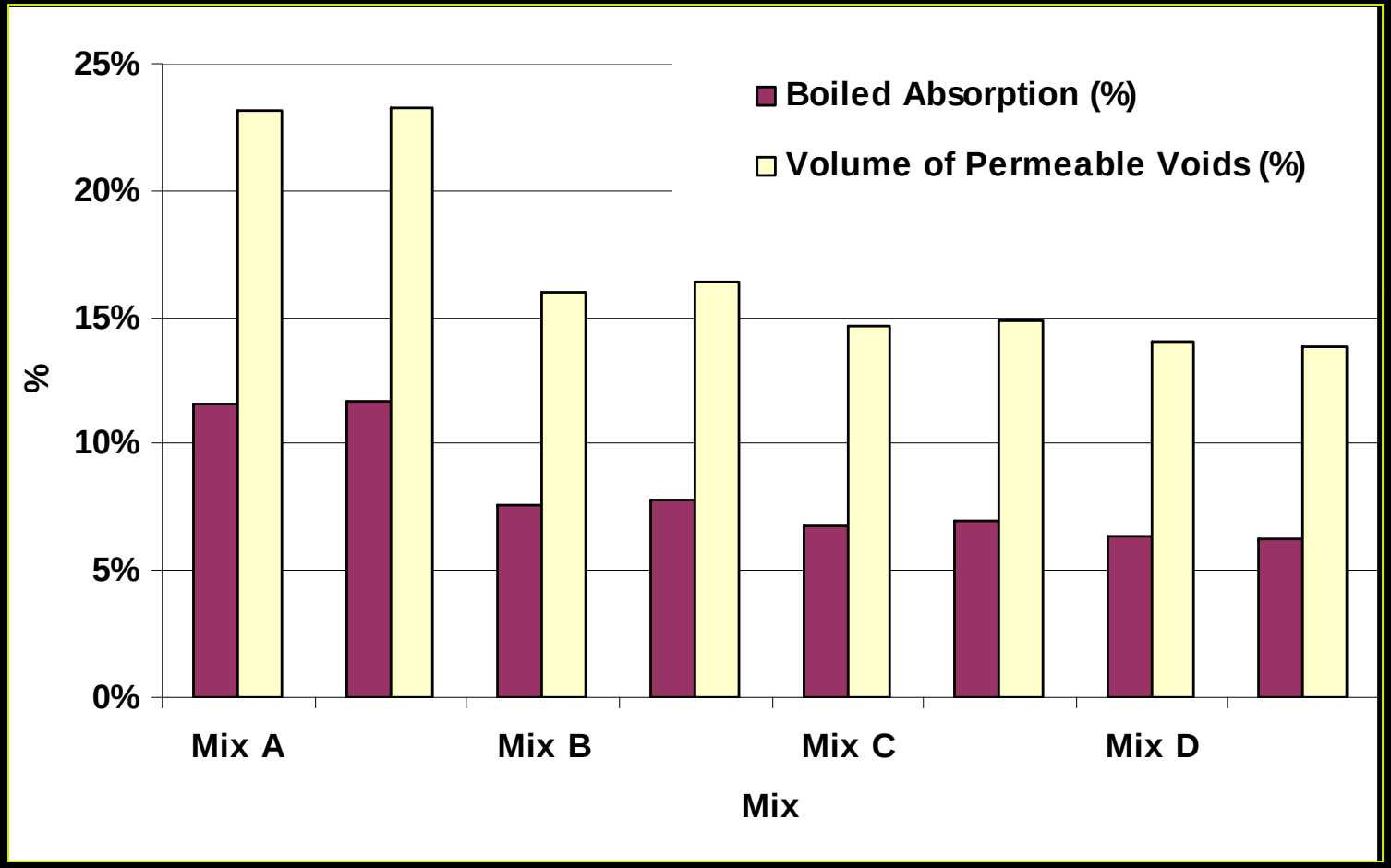
CPC Performance – Compressive Strength



Performance Requirement:
Compressive strength minimum 30 MPa at 7 days, 40 MPa at 28 days

Mix A: Natuaral Pozzolan Mix B: Silica Fume Mix C: Metakaolin Mix D: Metakaolin + Silica Fume

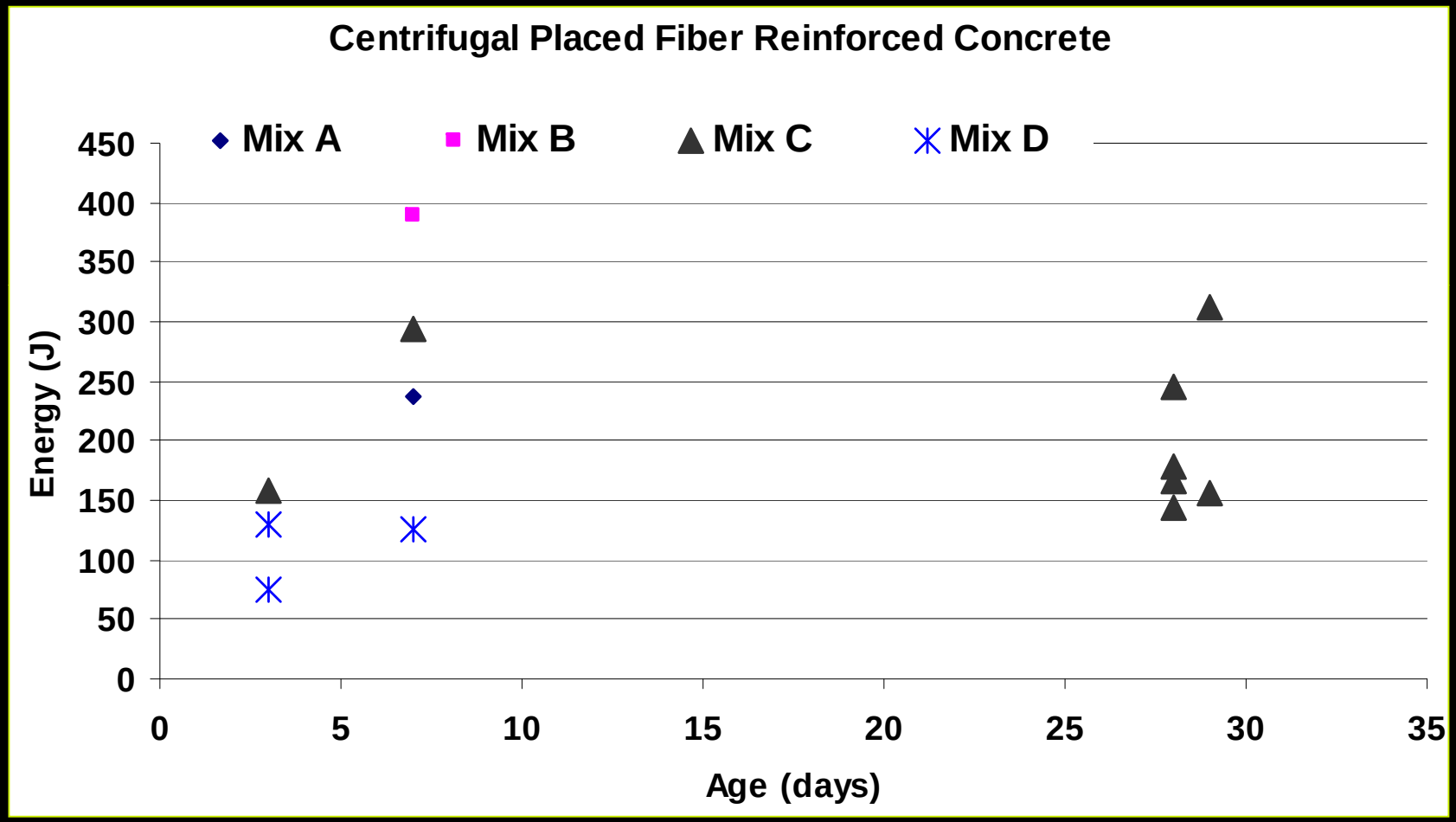
CPC Performance
- Volume of Permeable Voids & Boiled Absorption (ASTM C642)



Performance Requirement:
Maximum Value of Boiled Absorption 8%; Maximum Value of Permeable Voids 17%

Mix A: Natuaral Pozzolan Mix B: Silica Fume Mix C: Metakaolin Mix D: Metakaolin + Silica Fume

CPC Performance – Energy (ASTM C1550)



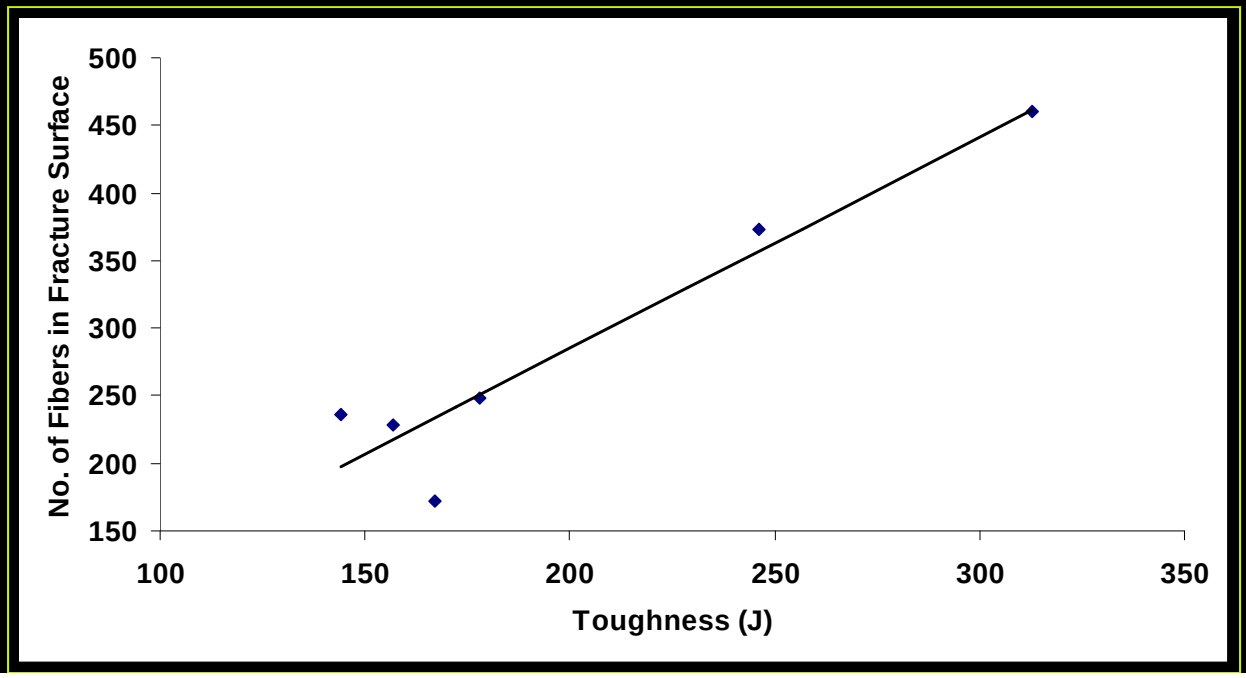
Performance requirement:
Flexural toughness 320 J at 28 days

Mix A: Natuaral Pozzolan Mix B: Silica Fume Mix C: Metakaolin Mix D: Metakaolin + Silica Fume

Metakaolin CPC Performance
Flexural Toughness vs. Number of Fibers

Date Cast/Shot	Panel #	Mix Designation	Test Age (days)	Compressive Strength (MPa)	RDP Corrected First Crack Load (kN)	RDP Corrected Energy (J)	No. of Fibers in Fracture Surface
10-Jun-09	1	Mix C	37	62.9	27.1	313	460
	2		37	70.2	26.0	157	228
13-Jun-09	1	Mix C	35	71.9	24.4	144	236
	2(1)		35	74.1	26.1	167	172
14-Jun-09	2(2)	Mix C	34	71.2	19.5	178	248

(1) Broken into two pieces
(2) Not a Y type failure



Metakaolin CPC Performance

MK CPC

- 20% replacement of cement used in both trial mixes and large mine project
- Higher compressive strength than natural pozzolan concrete
- Good workability, good compaction with low values of boiled absorption & volume of permeable voids
- Performed well with macro synthetic fiber reinforcement

Centrifugal Placed Concrete (CPC) Method

- Cost effective: completed in 10 days (much shorter than previously used: conventional robotically placed dry-mix steel fiber reinforced shotcrete lining completed in 6 weeks)
- First time used in North America (D.R. Morgan., Centrifugal Placed Concrete for Lining Horizontal Pipes, Culverts, and Vertical shafts, 3rd International Conference/Engineering Developments in Shotcrete. Queenstown, New Zealand 2010 March)
- Now to be used for lining several more raise bore shafts in mines in North America

Metakaolin in Concrete – Sustainability

- MK is a SCM
- MK concrete has high compressive strength, and good durability
- LEED New Construction MR 4.1 & 4.2:
- Cement Reduction (%) = 2x(cement in base mix-cement in SCM mix)/(cement in base mix)
- MK replaces 20% cement by mass; LEED equates this to a 40% cement reduction

Metakaolin in Concrete – LEED Compliance

- LEED New Construction, MR 4.1 & 4.2:
- 1 point for 7.5% (post-consumer + ½ post-industrial)
- 2 points for 15% (post-consumer + ½ post-indsutrial)
- LEED specifies post-consumer recycled content and post-industrial content, such as fly ash, slag, silica fume, incinerator ashes, GS-CEM.
- Calcining kaolin at 800 ^{0}C generates 55% less GHG vs. cement production.
- Calculation of CO_2 emitted for 1 ton cement production (1 ton) vs. 1 ton metakaolin production (to be determined)

Metakaolin in Concrete – LEED Compliance

- MRc5 Regional Materials
- MRc8 Durable Building (LEED Canada NC 1.0)
- MRc2 Environmentally Preferable Products (LEED Canada for Homes 2009)

AMEC's Leading Role in Industry

- 1976 Converted ready mix concrete producers in Western Canada into routine use of fly ash in everyday concretes
- 1983 first time use of silica fume in shotcrete in North America
- 1998 founding member of America Shotcrete Association
- 2000 Full characterization Teck Commico ground metallergical slag cementing material, later become integral hardener with brand name of "Hard Cem"
- 2002-2008 use of high volume fly ash (up to 48%) in Little Mountain Reservoir and Seymour Capilano Filtration Plan projects in Vancouver
- 2005 Full characterization of use of calcined metakaolin in concrete
- 2008/9 Dow Jones Sustainability Index