Concrete Mixes of the Future

Dr Peter Taylor, PE (IL)

National Concrete Pavement Technology Center

IOWA STATE UNIVERSITY

An Emphasis on Durability

- What do I want?
- What is in it and so what?
- How do I get what I want with what I have?
- How do I know?

What is Concrete?

- Versatile

What is Concrete?

- Versatile

What Do We Want?

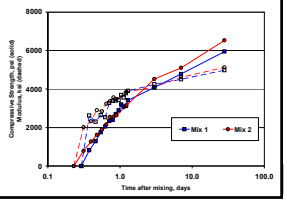
- The Owner wants:
  - ✓Strong enough
  - ✓Crack free
  - ✓Ability to resist the environment
  - ✓Safety
  - ✓Cost effective

How Does Concrete Fail

- Overload / Fatigue
  - ✓*Strength*
  - ✓*Support*
  - ✓*Thickness*
  - ✓*Drainage*
- *Polishing / Abrasion*

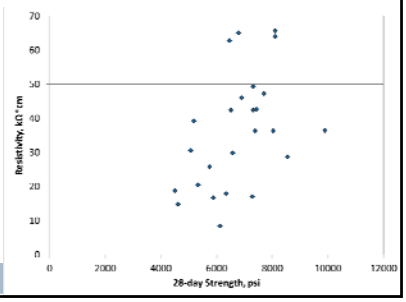
Strength

- Strong enough
  - ✓Controlled by w/cm
- Stiffness?
  - ✓High stiffness = small deflections
  - ✓Low stiffness = high cracking risk



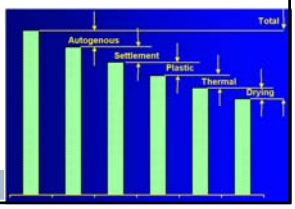
Strength

- Strength is not a surrogate for other properties



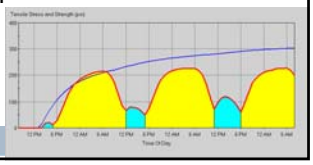
Cracking

- Concrete always cracks
  - ✓Control size and spacing
- Concrete moves over time:
  - ✓Chemical changes
  - ✓Moisture changes
  - ✓Temperature changes
  - ✓Loading



Cracking

- Stress depends on
  - ✓Contraction
  - ✓Stiffness
  - ✓Creep
  - ✓Load
- Cracking depends on
  - ✓Stress
  - ✓Strength



How Does Concrete Fail

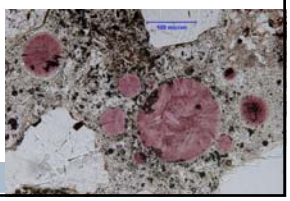
- Internal Expansion
  - ✓*AAR*
  - ✓*D-Cracking*
  - ✓*Steel Corrosion*
  - ✓*Choose aggregates*
  - ✓*Reduce permeability*

How Does Concrete Fail

- Cold Weather
  - ✓*Freeze Thaw Cycling*
  - ✓*Salt Crystallization*
  - ✓*Air*
  - ✓*Permeability*

How Does Concrete Fail

- Chemical Attack
  - ✓*Soft Water / Acid*
  - ✓*Sulfates*
  - ✓*De-icing Salts*
  - ✓*Permeability*

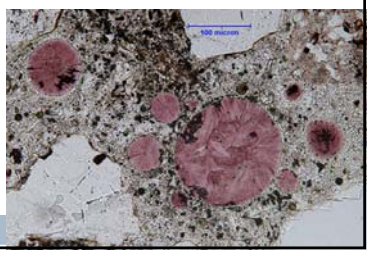


Salts

- Provide chlorides
  - ✓Corrosion
- Increase saturation
  - ✓Freeze thaw

Salts

- React with paste
  - ✓Calcium oxychloride
  - ✓Friedel's Salt – Calcium-chloro-aluminate
  - ✓Ettringite
  - ✓Potasium acetate



What Do We Want?

- The Contractor wants:
  - ✓The right workability for his machine (water content, agg gradation)
  - ✓Control of the setting time (SCM type)
  - ✓Cost effective

What is concrete?

- Aggregates
- Cement
- Supplementary cementitious materials
- Water
- Admixtures

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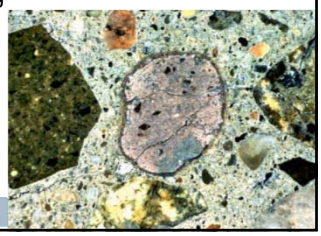
Aggregates

- Most of the volume of a mixture
- Influence:
  - ✓Workability
  - ✓Durability
    - ➢D-Cracking
    - ➢ASR



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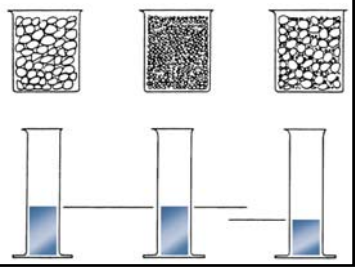
Aggregate Gradation

- Control combined grading to increase amount of aggregate in the mix
  - ✓ = Reduced paste (shrinkage, heat, cost)



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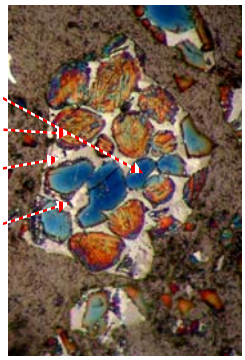
Portland Cement

- C_3S – The hare (alite)
- C_2S – The tortoise (belite)
- C_3A – The fox (calcium aluminate)
- C_4AF – … (ferrite)

ASTM C 150, Type I or II



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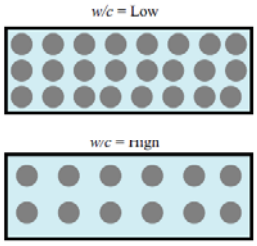
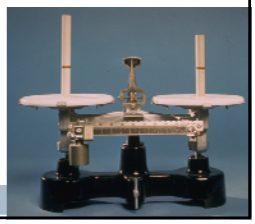
Permeability

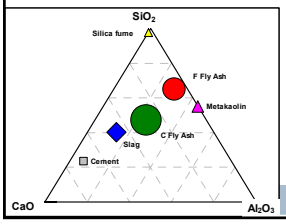
- More water – means more space between cement grains

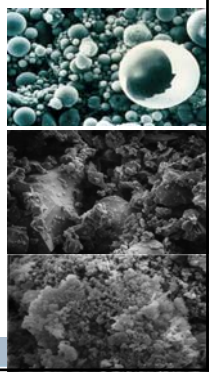




Supplementary Cementitious Materials

- Fly ash
- Slag
- Silica fume





How Do SCMs Work?

Cement + Water = C-S-H

+

SCM + Water + CH = more C-S-H

So What Do they Do?

- Fresh
  - Reduce water requirement
  - Reduce heat
  - Retard setting
  - Slow initial strength gain

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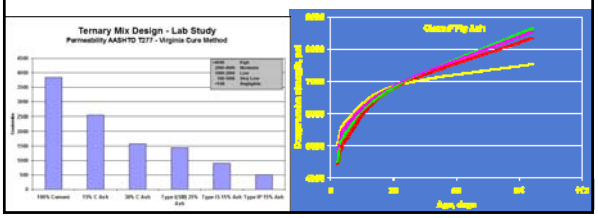
So What Do they Do?

- Hardened
  - Reduce permeability
  - Reduce ASR expansion
  - Higher long term strength



How Much?

- Class F fly ash: 15% - 25%
- Class C fly ash: 15% - 40%
- Slag: 25% - 50%

Too little – no benefit
Too much – slow setting, slow strength gain, cracking risk

Blended at the concrete batch plant, or blended or interground at the cement plant

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Blended or Interground Cements - ASTM C 595

- IS (x) Slag cement
- IP (x) Pozzolan (e.g. fly ash)
- IT (Ax)(By) Ternary*
- IL(x) Limestone

* e.g. IT (S25)(P15) = 25% slag,15% fly ash & 60% portland cement

Effects of Extra Water on Concrete

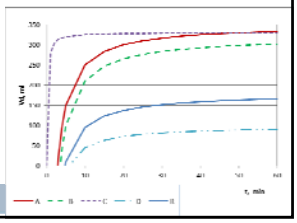
- Adding 1 gallon / yd3
- Increases workability ~1”
- Lowers strength ~200 psi
- Increases drying shrinkage ~10%
- Increases permeability ~ 50%

Air Entraining Admixtures

- Provide resistance to freezing and thawing
- Improved workability, reduced water, and reduced segregation
- Reduces strength
- Inexpensive
- ASTM C 260

Air Entrainers

- Vinsol / Rosin / Tall Oil
- Synthetics
  - ✓ Bubble size
  - ✓ Stability
  - ✓ Effects of WRA



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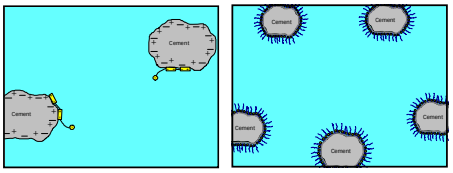
(IMCP—page 58)

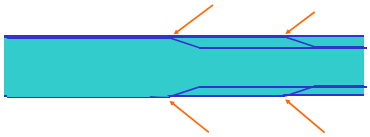
Water Reducers

- Reduce water required about 5% (12%)
- ASTM C 494 Type A (or F)
- Lignin (polycarboxylate)
- May retard setting (affect air-entrainment)



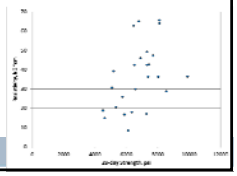
Shrinkage Reducing Admixtures

- Menisci set up forces as air / water interface penetrates from surface
- SRAs change angle of contact inside capillaries



Common Misconceptions

- More cement means stronger concrete
- Supplementary cementitious materials are dilutants
- Stronger concrete is more brittle & that is bad
- Strength and workability are correlated
- Strength and durability are correlated

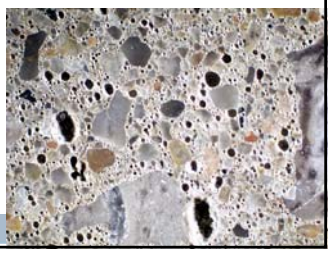


Putting It All Together

- w/cm
  - ✓ Concrete exposed to the weather = 0.38 to 0.42
  - ✓ Interior = 0.45 to 0.50
  - ✓ Don't care = >0.50

Putting It All Together

- Air Void System
  - ✓Spacing factor <0.008 inch
  - ✓Air content >5% behind the paver



Putting It All Together

- Fly Ash Type
  - ✓Class F is slower, good for durability
  - ✓Class C is faster, OK durability, rare incompatibility issues
- Fly Ash Dose
  - ✓Maximum depends on weather and set time

Putting It All Together

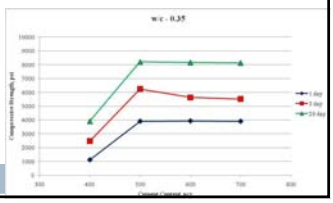
- Slag Cement Dose
  - ✓Maximum depends on scaling

Putting It All Together

- Ternary Mixtures
  - ✓Test for properties
  - ✓Good for sustainability
  - ✓Reduced permeability

Putting It All Together

- Cementitious Content
  - ✓Enough, and not much more
  - ✓Depends on aggregate gradation and workability



Putting It All Together

- Aggregate Contents
  - ✓Target good combined gradation
- Aggregate Quality
  - ✓D-Cracking
  - ✓ASR – AASHTO protocol – use blended cements)
  - ✓Use DOT approved sources

Putting It All Together

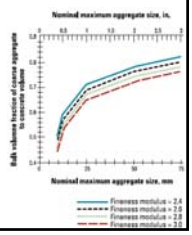
- Admixtures
  - ✓Will vary depending on weather
  - ✓Do not specify dosage
  - ✓Compare with manufacturers' guidelines

Current Proportioning Technologies

- Developed
  - ✓Before water reducers
  - ✓Before supplementary cementitious materials
- Primarily focused on structural concrete
  - ✓100 mm (4") slump
  - ✓30 MPa (~4000 psi)
- ACI 211 last revised in 1991

Absolute Volume Approach

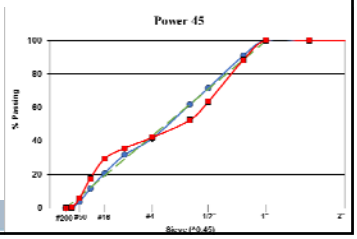
- Paste volume based on coarse aggregate size
- Coarse aggregate volume based on subtracting the fineness modulus (FM) of sand from a fudge factor
- Fill the remaining volume with sand



Proposed Mixture Proportioning Procedure

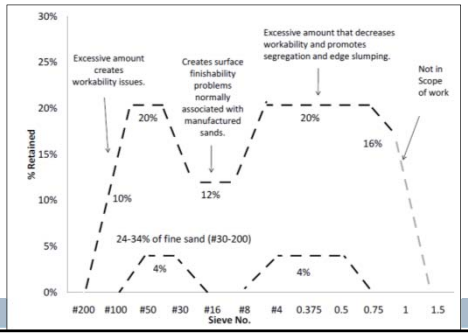
<u>Choose the Aggregate System</u>

- Combined gradation
- Determine void ratio



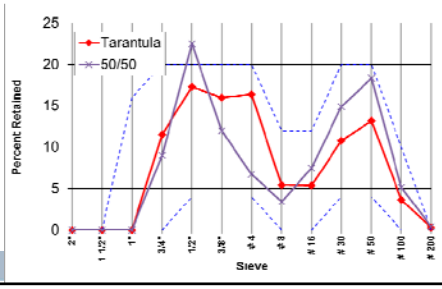
Aggregate System

- Tarantula Curve (Ley)



Aggregate System

- 50/50 – void ratio 25.3%
- Tarantula – void ratio 27.1%



Proposed Mixture Proportioning Procedure

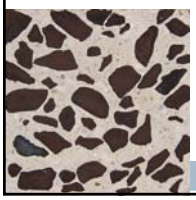
<u>Choose a Paste System for Performance</u>

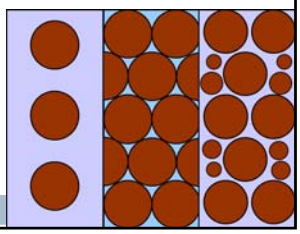
- Cementitious blend
- W/Cm
- Air content
- Chemical admixtures

Proposed Mixture Proportioning Procedure

<u>Choose Paste Volume</u>

- All voids must be filled with paste
- And a bit more to coat the particles for workability

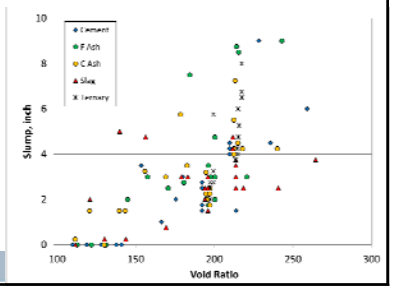




Proposed Mixture Proportioning Procedure

Choose Paste Volume

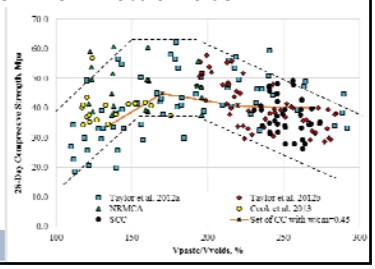
- Need enough paste for base workability



Proposed Mixture Proportioning Procedure

Choose Paste Volume

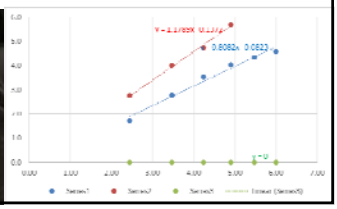
- Need enough paste for mechanical properties ~125 - 175% of voids



Proposed Mixture Proportioning Procedure

Put it all together

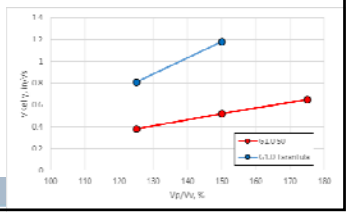
- Measuring workability



Proposed Mixture Proportioning Procedure

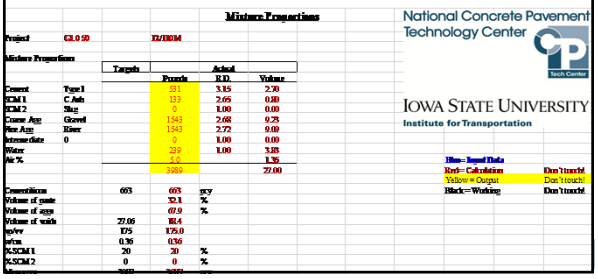
Put it all together

	Tarantula		50/50		
Void ratio	125	150	125	150	175
Cementitious	427	505	424	500	543



Proposed Mixture Proportioning Procedure

Its not that complicated



What do we measure now?

- Slump
- Strength
- Air
- Thickness

What do we measure now?

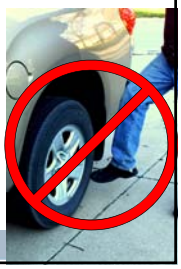
- How are these related to potential distress?
  - ✓And tougher environments
  - ✓And new materials
  - ✓And new practices

What do we want to measure?

- Critical Properties at design / proportioning stage
- Uniformity at delivery
  - ✓Testing
  - ✓3'rd party records

AASHTO Guide Specification

- Based on existing specs
- Add new thinking
- Take out some stuff



Materials

- Cement – M85, M240
- Slag cement – M302
- Fly ash – M295 (ASTM C 1709)
- Admixtures – M154, M194 (others?)

Materials

- Aggregates
  - ✓M80 for contaminants
  - ✓PP65 for ASR
  - ✓?? For d-cracking
  - ✓Continue with current individual fraction gradation
  - ✓Address combined gradation in proportioning
  - ✓ASTM C 1761 for IC

Prescriptive

Property	Value	AASHTO Test Method	When Test Must be Conducted*
Combined Aggregate Gradation	Within Tarantula Curve	T27	All
	#8 - #30 >15%		
	24% < #30 - #200 < 34%		
Cementitious content	400 lb/yd^3, minimum	Batch records	Mixture design
	658 lb/yd^3, maximum	Batch records	Mixture design
Portland cement content	50% of cementitious, minimum	Batch records	Mixture design
Class C Fly Ash**	30% maximum cement replacement	Batch records	Mixture design
Class F Fly Ash**	25% maximum cement replacement	Batch records	Mixture design
GGBFS**	50% maximum cement replacement	Batch records	Mixture design
w/cm ratio	[0.42] […] maximum	Batch records	All
Entrained air	4% after placement, and	T 152, T 196M/T 196,or T 199	All
	0.2 SAM number	Super-air-meter	All
	2% maximum loss during placement	T 152, T 196M/T 196,or T 199	All

Performance

Property	Value	AASHTO Test Method	When Test Must be Conducted
Electrical Resistivity	[27] […] kΩ-cm minimum at [28] […] days	TP 95	All
Compressive strength	[4000] [3500] […] psi minimum at [28] [90] days	T 22	All
Freeze thaw resistance	RDM > [80] […] %	C666	Mixture design
Shrinkage	Crack free at [14] […] days	ASTM C 1581 Ring	Mixture design
	<0.06 %	ASTM C 157 mod**	Mixture design

Report

Property	AASHTO Test Method
Modulus of elasticity at 28 days	ASTM C 469
Drying shrinkage	ASTM C 157
Coefficient of thermal expansion	T 336
Rate of strength development to 90 days	T 22
Rate of development of electrical resistivity	TP 95
Unit weight	T 121
Slump	T119

QC

Property	AASHTO Test Method	When Test Must be Conduc
Air void system	Foam Drainage	Mixture design
Slump	Within 1" of design mix	T 119M/T 119
Unit weight	Within 3 pcf of design mix	T 121
Calorimetry	Adiacal	Construction
Maturity	ASTM C 1074	Construction
Strength development	T 22	Construction
Resistivity Development	TP 95	Construction

Closing

- Did you get what you thought you paid for?
- Did you measure what you really want?
- Concrete can last a long time…


Chicago Sun Times

Discussion…