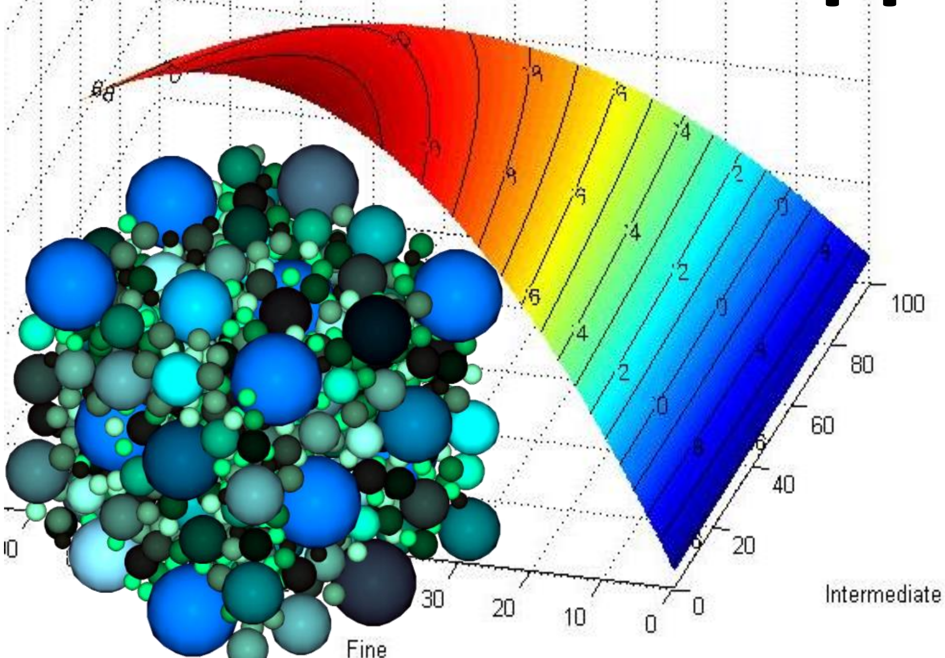
ACI Fall Convention, Washington, DC

October 26, 2014

"The Best Aggregate Blends for DOT Applications"



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Dr. Konstantin Sobolev
Dr. Ismael Flores-Vivian

Outline

- Aggregate Properties and Characterization
- Experimental Packing vs. Regression Model
- Experimental Packing vs. Theoretical Models
- What is the Best Packing/Blend for Concrete Mixtures?
- Results and Discussion

Problem Statement

<u>**WisDOT**</u> is interested in reduced cementitious materials content than meet the specs:

- ✓ 470 lb/yd^3 (279 kg/m^3) vs. standard 517 to 565 lb/yd^3 (306 to 335 kg/m^3)

<u>**Specs:**</u>

- ✓ 2-4 in slump
- ✓ 3 days to open for traffic (3000 psi / 20 MPa)
- ✓ F/T Durability ASTM 666
- ✓ RCP Durability AASHTO T 277 or ASTM 1202

<u>Previous research:</u> concrete with reduced cementitious materials content had an adequate durability; however, these mixes frequently demonstrated <u>poor workability</u> and <u>strength</u>.

<u>Current WisDOT</u> practice does not address the use of optimized aggregates gradation.

<u>Therefore, a research</u> on aggregate optimization is needed to support the development of specifications including best aggregate combination for a sustainable concrete paving mixtures.

Goals and Scope

Goals:

- Optimization of aggregate combination for DOT applications.

Scope:

- Measure the experimental packing degree of aggregate blends and compare with corresponding model for binary and ternary mixes.
- Calculate theoretical packing degree based on Modified Toufar-Aim model for binary mixes.
- Compare theoretical packing models with experimental data for binary mixes.
- Compare PSD of the optimal blends vs. power curves.
- Compare the optimal aggregate blends from model/experiments with optimal concrete mixes.

Materials and Experiments

- Cement Type I, 470 lb/yd^3 (280 kg/m^3)
- 2 types of aggregates from WI (Southern C1, I1, F1 and Northern – C2, I2, F2)
- Each aggregate set was tested for up to 40 combinations for Compacted and Loose Packing degree using VeBe Apparatus (45 seconds):

  Fine aggregates: 0-100%

  Intermediate aggregates: 0-100%

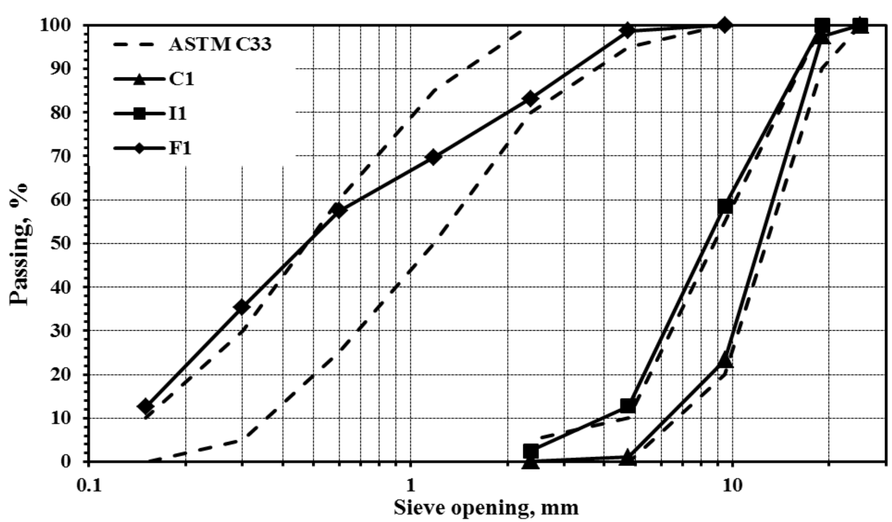
  Coarse aggregates: 0-100%

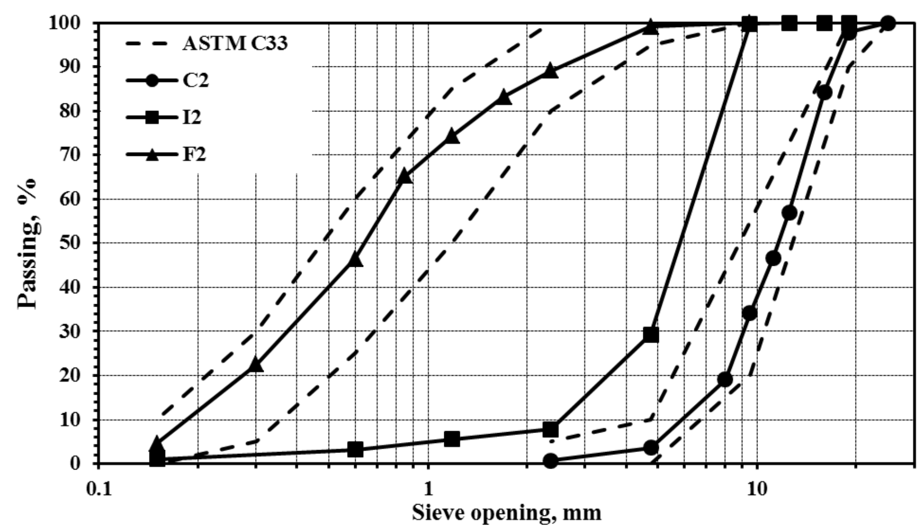
  Reference packings for each aggregate

- Experimental packing vs. regression and theoretical models
- Fresh and hardened properties of concrete

Aggregate's Properties

	ID	Type	Specific Gravity		Density, kg/m^3		W Abs., %	< 75μm, %
			(OD)	(SSD)	(OD)	(SSD)		
Southern	C1	Limestone	2.730	2.765	1638.2	1659.3	1.290	0.776
	I1	Limestone	2.684	2.734	1605.2	1634.8	1.840	0.791
	F1	Torpedo Sand	2.566	2.637	1868.3	1919.9	2.766	1.185
Northern	C2	Glacial Gravel	2.706	2.741	1674.7	1696.0	1.272	0.811
	I2	Glacial Gravel	2.659	2.715	1610.6	1644.2	2.085	0.938
	F2	Igneous Sand	2.560	2.62	1797.3	1836.8	2.200	0.779





Experimental Packing Degree

VeBe Test :

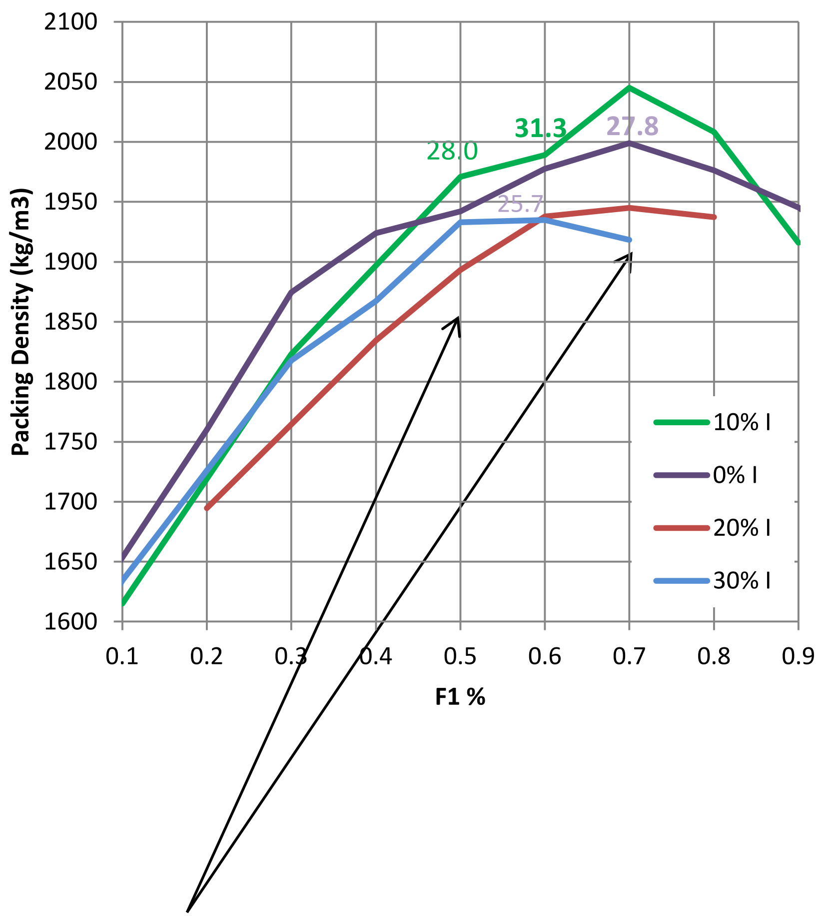
- Is previously used to measure the consistency of RCC and low-slump concrete (ASTM C1170):
    - Filling container
    - Striking with rod
    - Vibration
    - Vibration + Compaction

- Different Methods are proposed by researchers for <u>Dry Packing Density</u> of aggregates with different compaction index for experimental packing of aggregates.

- VeBe Apparatus is used for as a standard tool to measure packing density of 40 different aggregate combinations in 2 states:
    - Pouring <u>(Loose)</u>
    - Vibration (45s) + Compaction <u>(Compacted)</u>

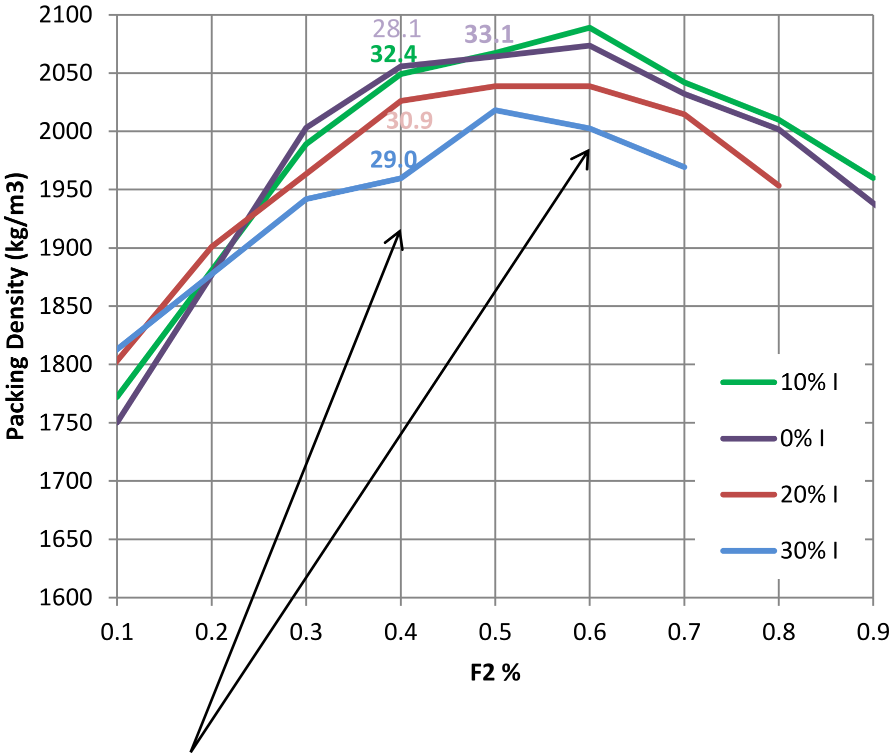
Experimental Packing Degree

Exp. Packing for C1, F1, I1 Blends:



- The max. packing occurs at 70% F1.
- The practical limitations impose 50% F1.

Exp. Packing for C2, F2, I2 Blends:



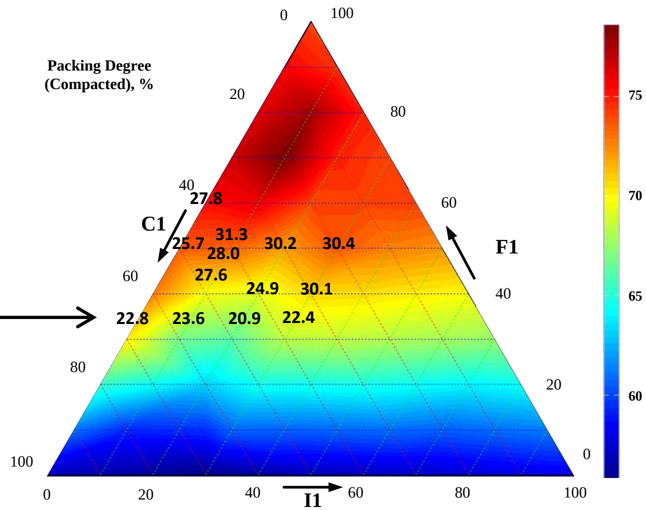
- The max. packing occurs at 60% F1.
- The practical limitations impose 40% F1.

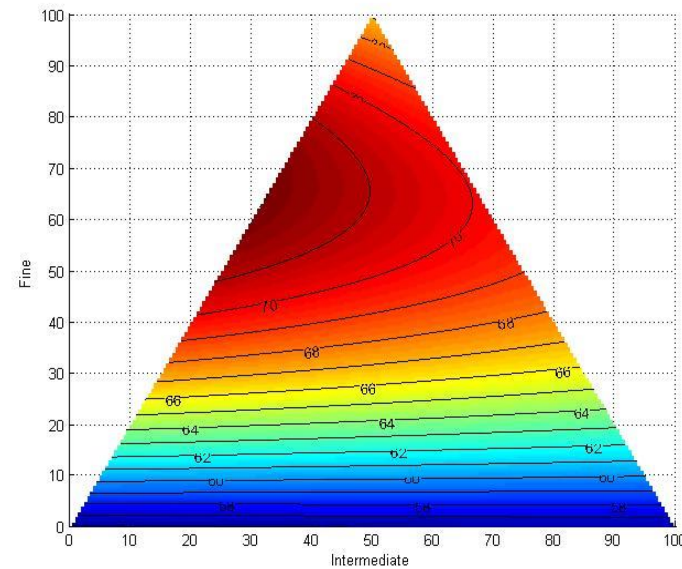
Experimental packing degree vs. Model

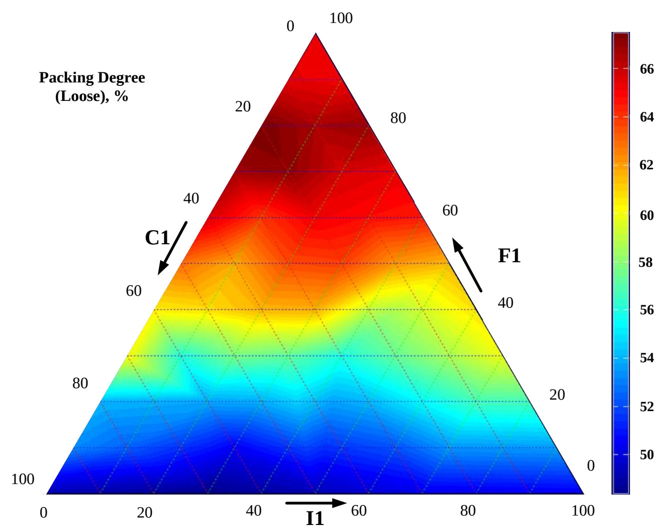
Experimental Results and Regression Model Response for C1, F1, I1:

28 C.S.

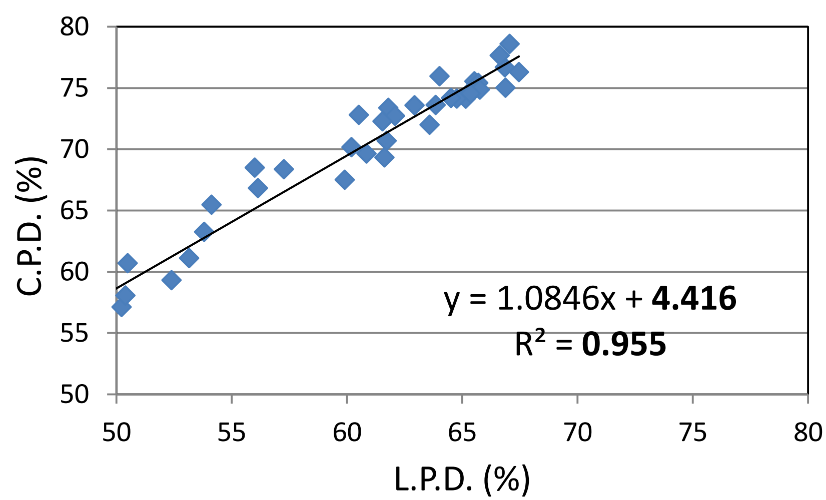
7 C.S. had similar trend.





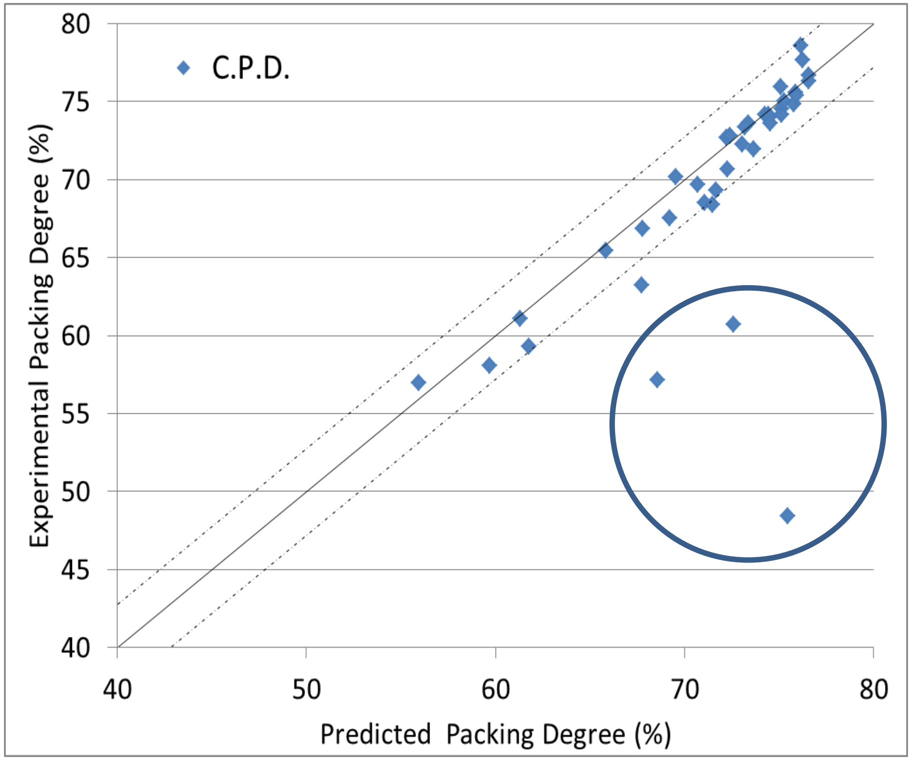


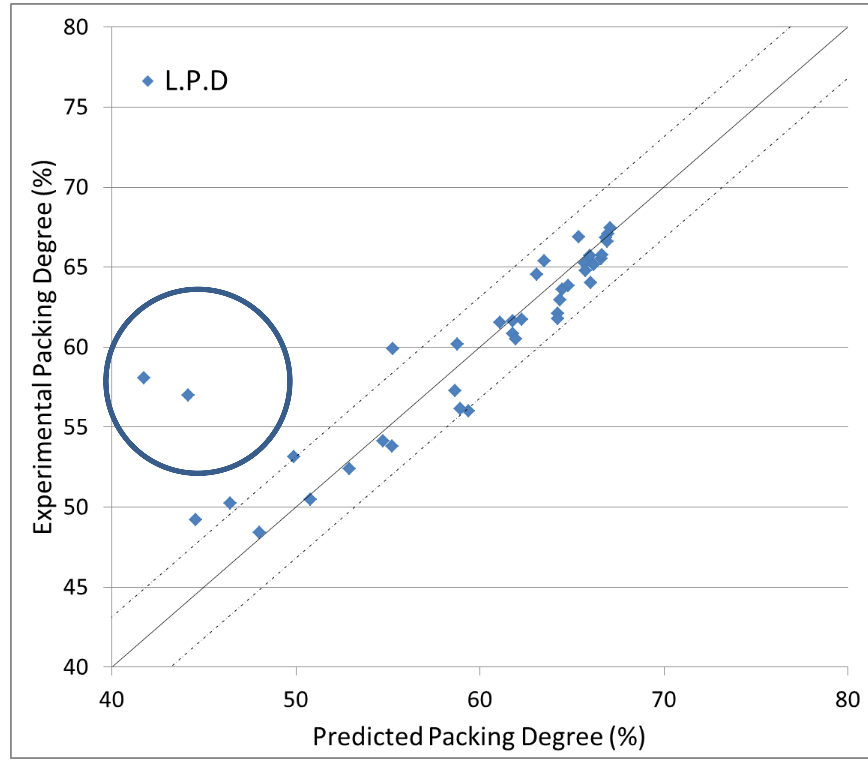
Loose vs. Compacted:



Experimental Packing vs. Model

Experimental Results and Linear Regression Coefficient Model Response for C1, F1, I1:





	C.P.D.	L.P.D.
Sum Error	108.6	81.3
Mean Error	2.786	2.085
St. Dev.	7.236	3.160
R^2	0.988	0.996
MSE	60.11	14.33
MAPE	6.047	3.604

Classical Models

Aim Model:

- Model suggested in 1967 takes into account:

i. Takes into account the interaction of larger particles on packing of smaller particles based on **Furnas** model - wall effect (F>>C)

ii. Describes the packing degree as:

$$\phi = \frac{\phi_2}{1 - y_1}, \qquad \text{for F dominant} \qquad y_1 < y^* \ (1)$$

$$\phi = \frac{1}{[\frac{y_1}{\phi_1} + (1 - y_1) \times (1 + 0.9 * \frac{d_1}{d_2})]},$$

$$\text{for C dominant} \quad y_1 > y^* \qquad (2)$$

Toufar Model:

- Model suggested in 1976 [5] is based on **Furnas** model and takes into account:

i. Diameter ratio ($\mathrm{k_d}$)
ii. probability of the number of interstices between coarse particles ($\mathrm{k_s}$)
iii. Describes the packing degree as:

$$\alpha_t = \frac{1}{\frac{r_1}{\alpha_1} + \frac{r_2}{\alpha_2} - r_2(\frac{1}{\alpha_2} - 1)k_d k_s}$$

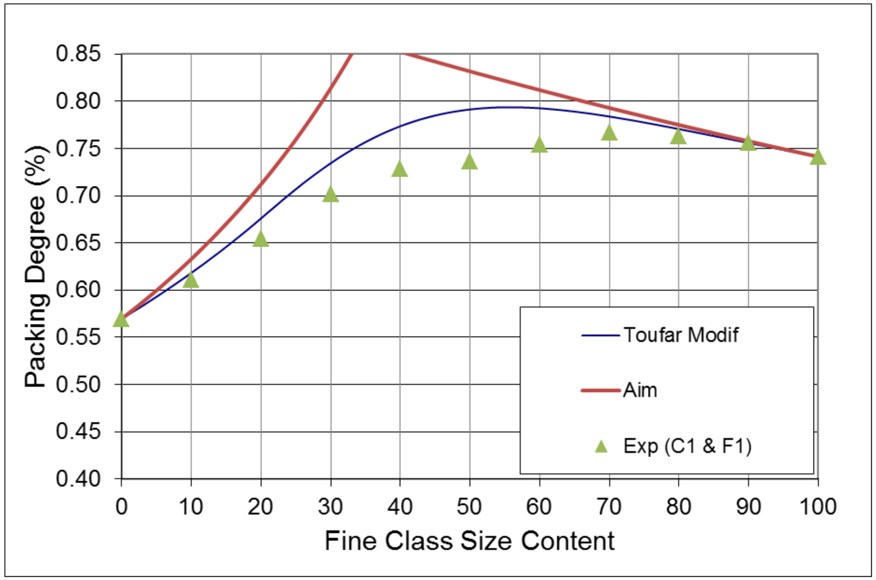
- Uses three experimental values as :
    - Characteristic Diameter
    - Eigenpacking Degree
    - Grain Density

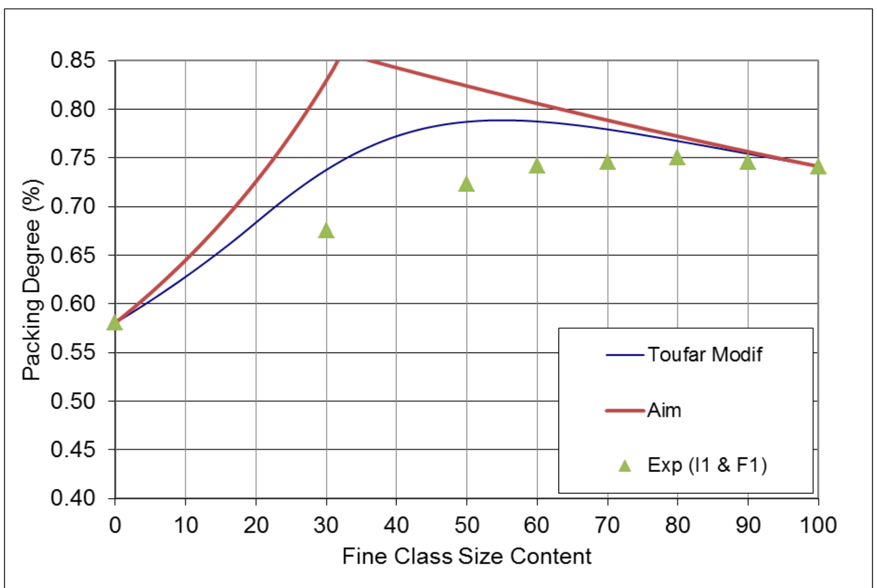
Modified Toufar Model:

- Modified Toufar Model suggested in 1997 and corrects the ($\mathrm{k_s}$)

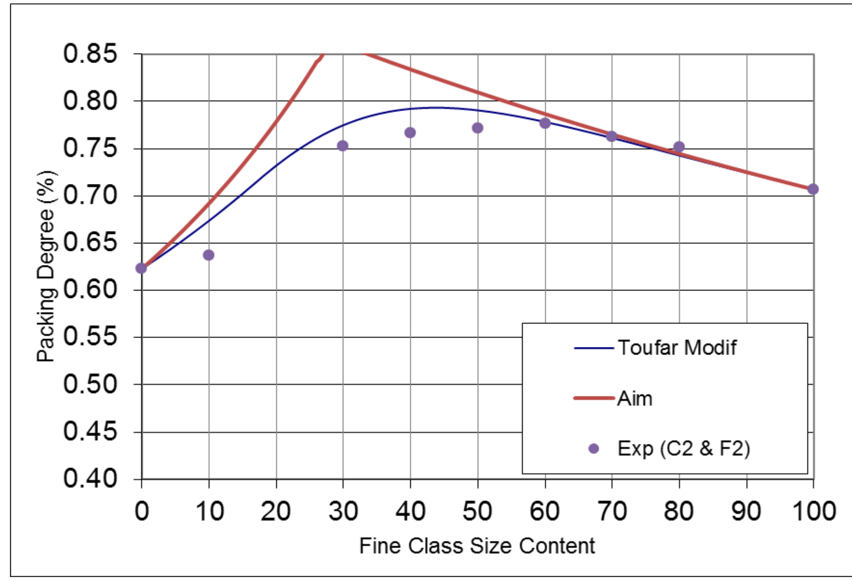
Experimental Packing vs. Models

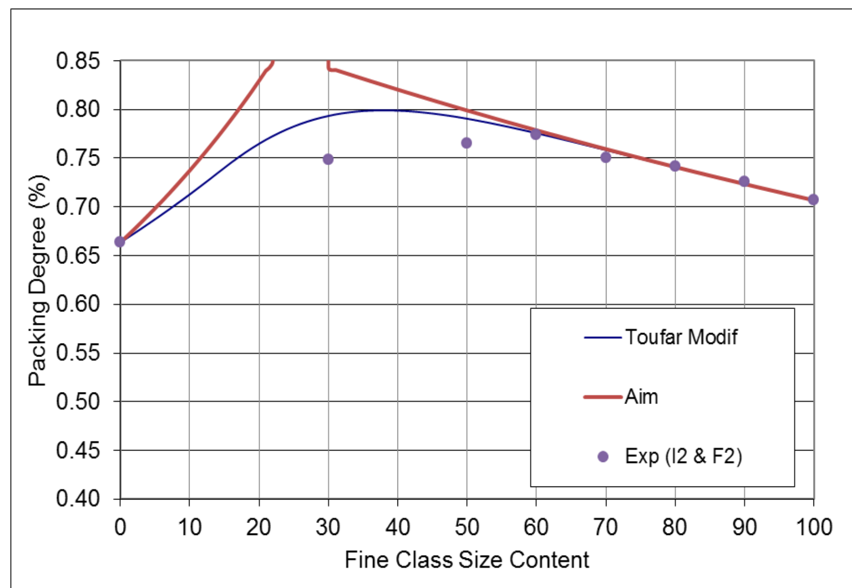
Model Response for C1, F1, I1 Blends:



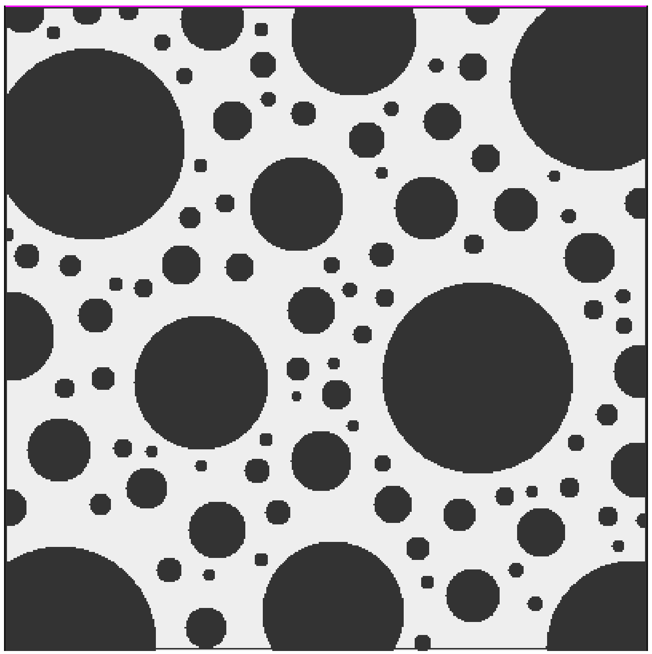


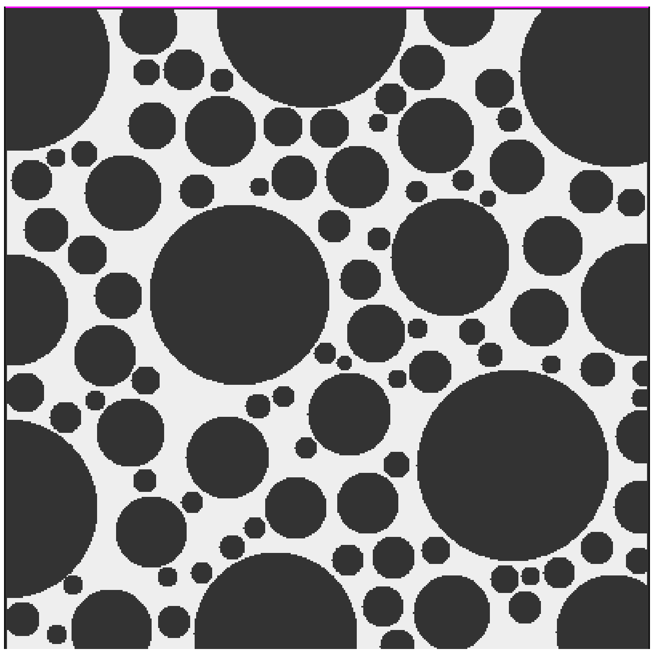
Model Response for C2, F2, I2 Blends:





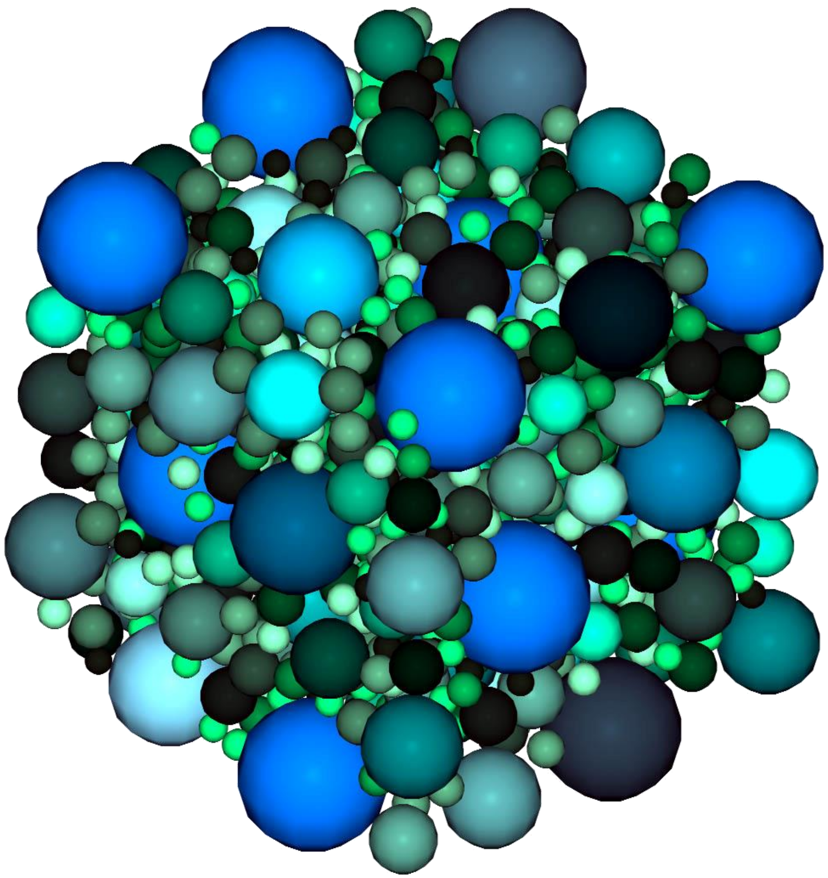
Virtual Aggregate Packing

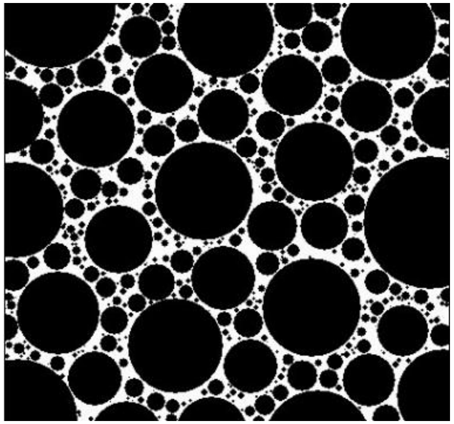




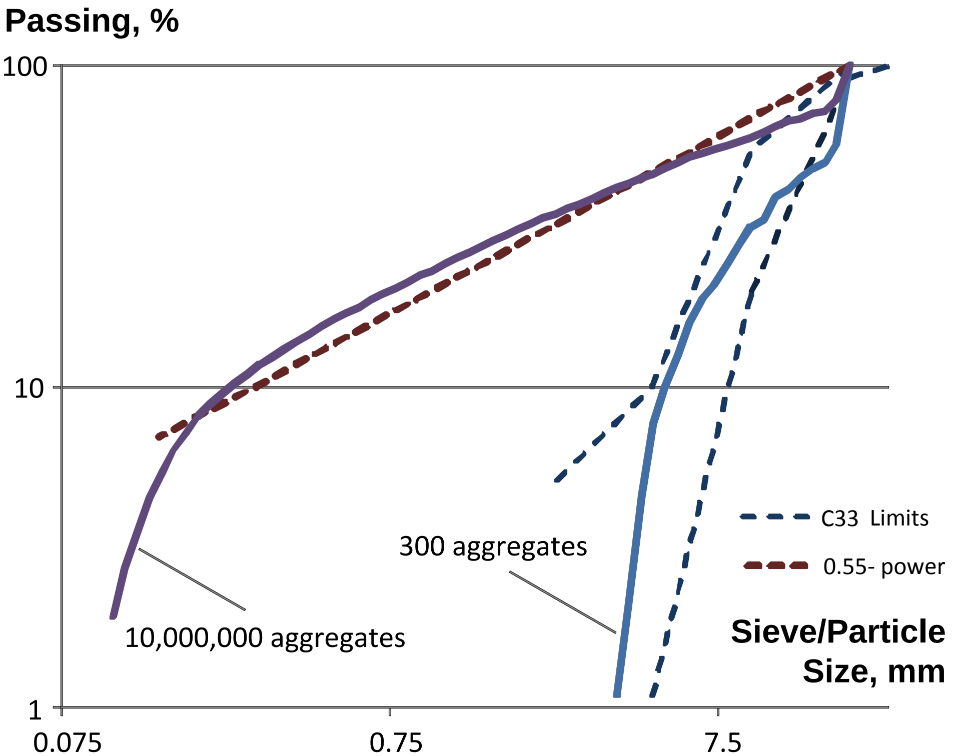
The results of two-dimensional packing (to illustrate the algorithm) with K= -1 (L) and K= -3 (R)

Virtual Aggregate Packing





- 86% packing
- 500 disks
- N=10
- Kr=1.005
- Ks= 10
- Sr = 1.025

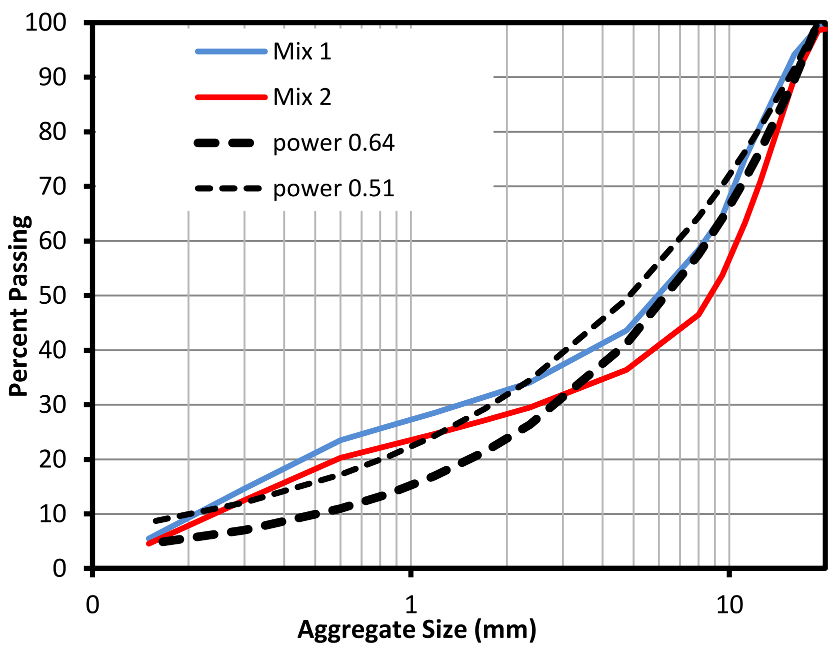


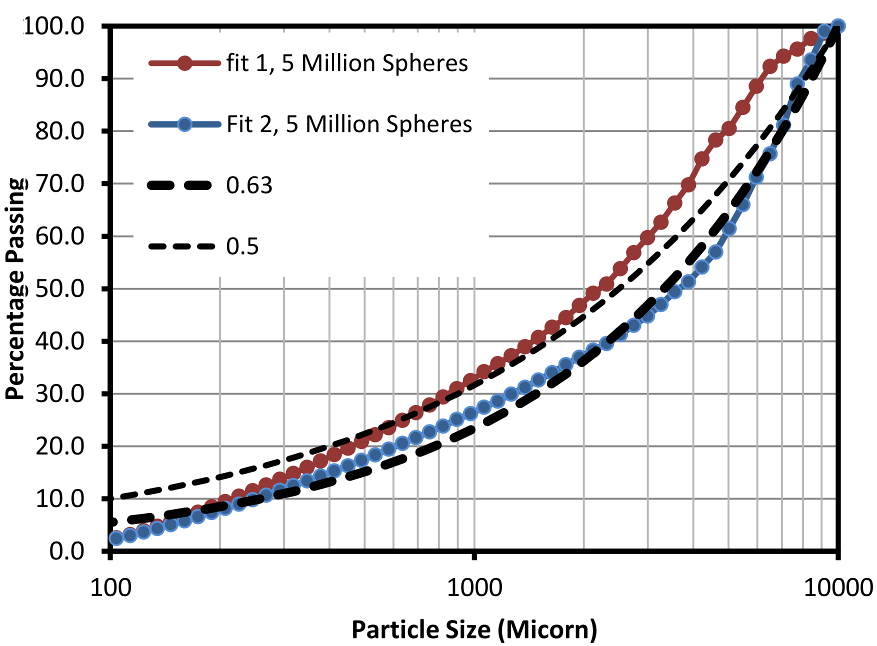
- 50.39% Packing
- 1000 Spheres
- N= 100k
- Kr= 1.001
- Ks= 1.5
- Sr= 1.001

Experimental Packing vs. Models

Mix ID	Compacted Packing Degree (PD_C)	Loose Packing Degree (PD_L)	F1, %	I1, %	C1, %	Slump (mm)	Bulk Density (kg/m3)	Air Content (%)	C.S. MPa (7days)	C.S. MPa (28days)	Best Fit n	St. Dev.
1	**70.7**	61.7	40	30	30	146	2457	1.1	23.4	30.8	0.44	404
2	**68.3**	58.8	35	10	55	205	2479	0.9	16.5	23.6	0.64	694

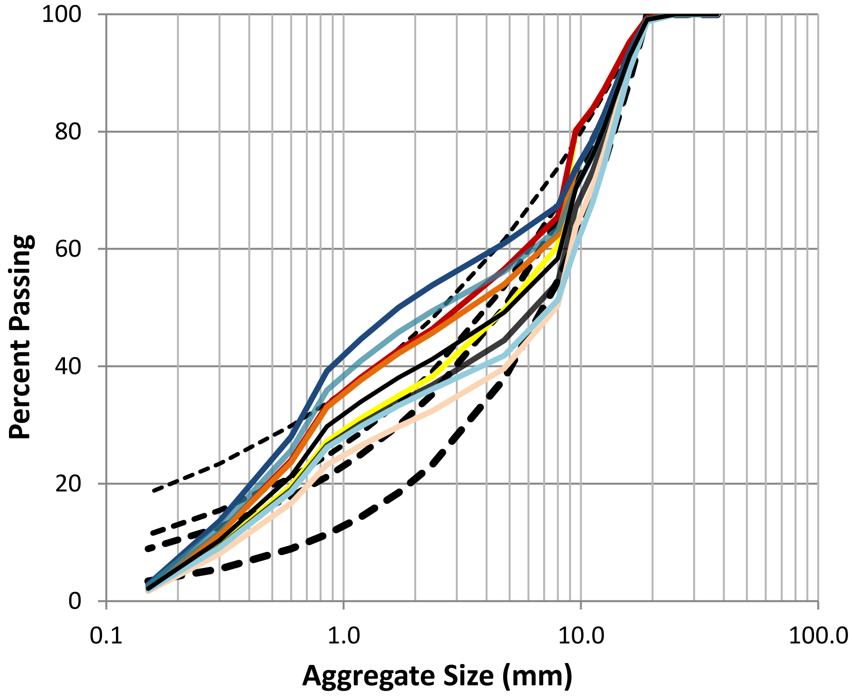
	Input					Output			
	# of Spheres	Red. Coef. (K red..)	Sep. Coef. (k.)	Step Sep. (S..)	# of Trials	P.D.	St dev.	Best fit n	St. dev.
fit 1	5 Million	1.01	5	1.025	10	**78.80**	2924	0.50	2182
fit 2	5 Million	1.01	10	1.025	10	**74.52**	964	0.63	447



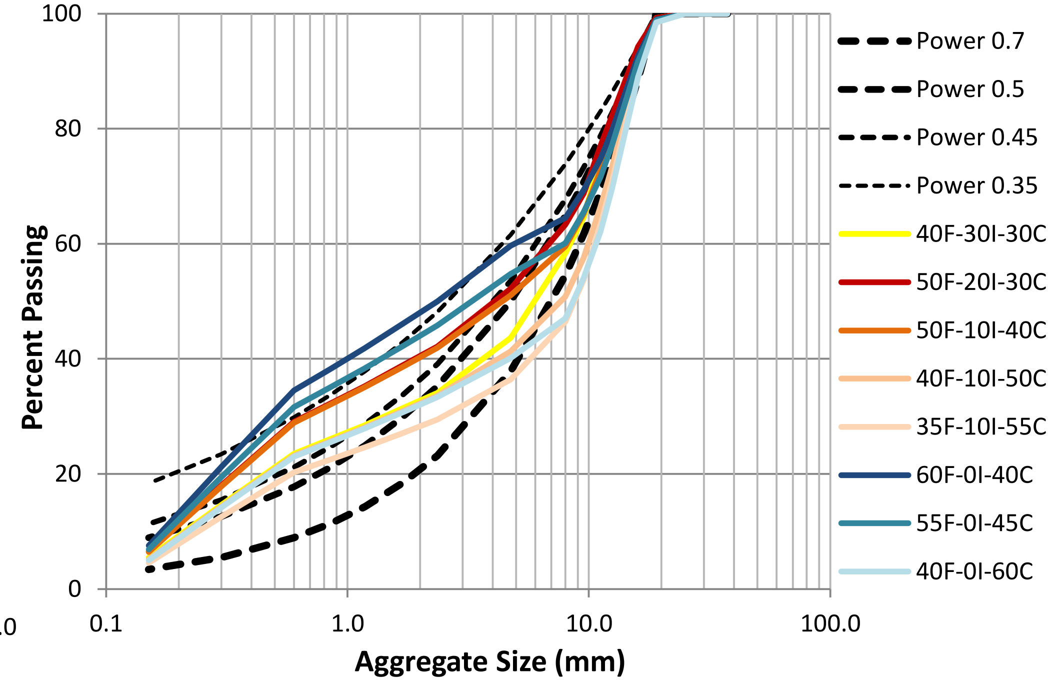


Aggregate Blends vs. Power Curves

Northern Aggregates:
C1, F1, I1



Southern Aggregates:
C2, F2, I2



Concrete Mixtures

- Concrete mixtures tested for different aggregate combinations
- The performance of concrete was investigated for fresh and hardened properties

W/C = 0.6
Agg. Vol. = 0.692

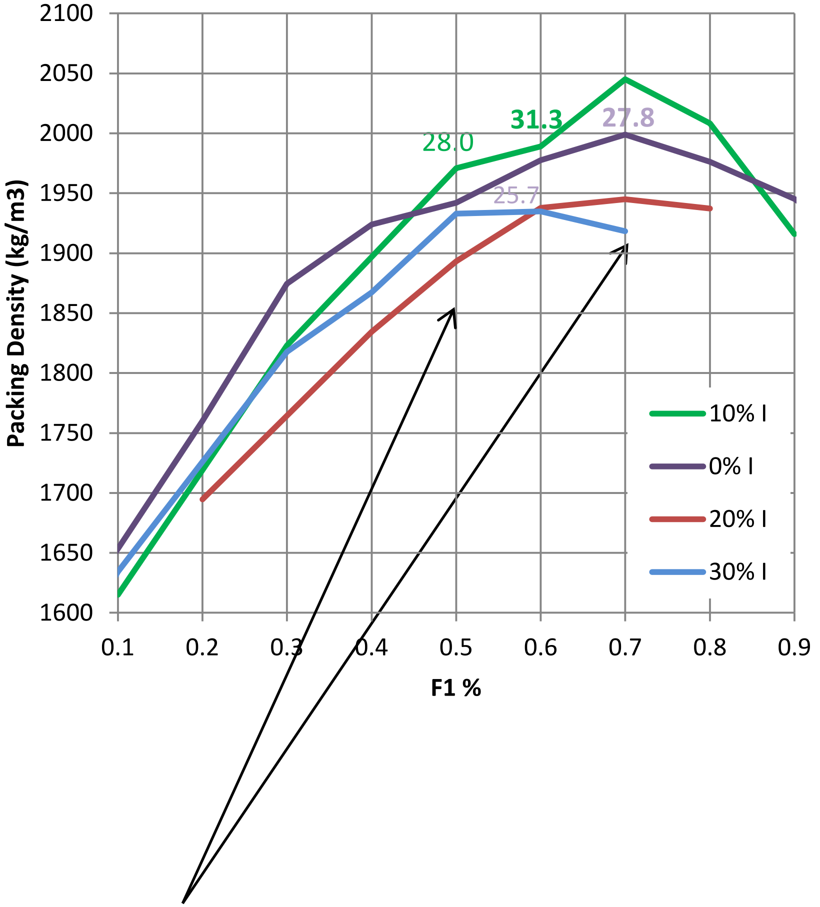
	Agg. Combinations				Results					
Mix ID	Aggs.	Coarse	Interm.	Fines	Slump	Air (Pressure)	Bulk density	Yield	C.S.	
	kg/m^3	%	%	%	mm	%	kg/m^3	m^3	7 days	28 days
S1	1850	65	0	35	76	1.0	2480	0.953	15.6	22.8
S2	1844	60	0	40	70	0.8	2477	0.952	20.2	25.5
S3	1838	55	0	45	191	1.0	2463	0.956	20.4	25.8
S4	1833	50	0	50	191	1.3	2435	0.965	21.2	25.7
S5	1821	40	0	60	165	2.2	2406	0.972	23.0	27.8
S6	1846	55	10	35	205	0.9	2480	0.950	16.5	23.6
S7	1835	45	10	45	191	1.2	2449	0.960	20.3	27.6
S8	1829	40	10	50	191	1.2	2435	0.960	22.4	28.0
S9	1826	37.5	10	52.5	191	1.3	2446	0.957	23.0	31.3
S10	1824	35	10	55	171	1.8	2446	0.956	22.5	30.8
S11	1843	45	20	35	181	0.9	2469	0.952	17.7	20.9
S12	1837	40	20	40	175	0.9	2460	0.954	17.9	24.9
S13	1826	30	20	50	156	1.2	2463	0.949	23.5	30.2
S14	1840	35	30	35	166	0.9	2483	0.945	17.7	22.4
S15	1834	30	30	40	146	1.1	2457	0.953	22.9	30.1
S16	1823	20	30	50	165	1.3	2443	0.955	21.6	30.4

W/C = 0.53
Agg. Vol. = 0.745

Mix ID	Aggs.	Coarse	Interm.	Fines	Slump	Air (Pressure)	Bulk density	Yield	C.S.	
	kg/m^3	%	%	%	mm	%	kg/m^3	m^3	7 days	28 days
N1	1991	65	0	35	32	0.75	2544	0.963	19.4	29.5
N2	1985	60	0	40	93	0.8	2525	0.968	21.7	28.0
N3	1973	50	0	50	70	2.2	2473	0.984	21.5	33.1
N4	1961	40	0	60	20	2.8	2410	1.005	17.4	27.7
N5	1988	55	10	35	36	1	2502	0.978	20.2	31.6
N6	1982	50	10	40	43	1.3	2524	0.968	24.8	32.4
N7	1976	45	10	45	70	0.8	2486	0.980	23.8	30.2
N8	1978	40	20	40	33	1.6	2477	0.985	21.9	30.9
N9	1966	30	20	50	30	3	2476	0.981	21.1	26.7
N10	1975	30	30	40	44	1.8	2490	0.979	20.9	29.0

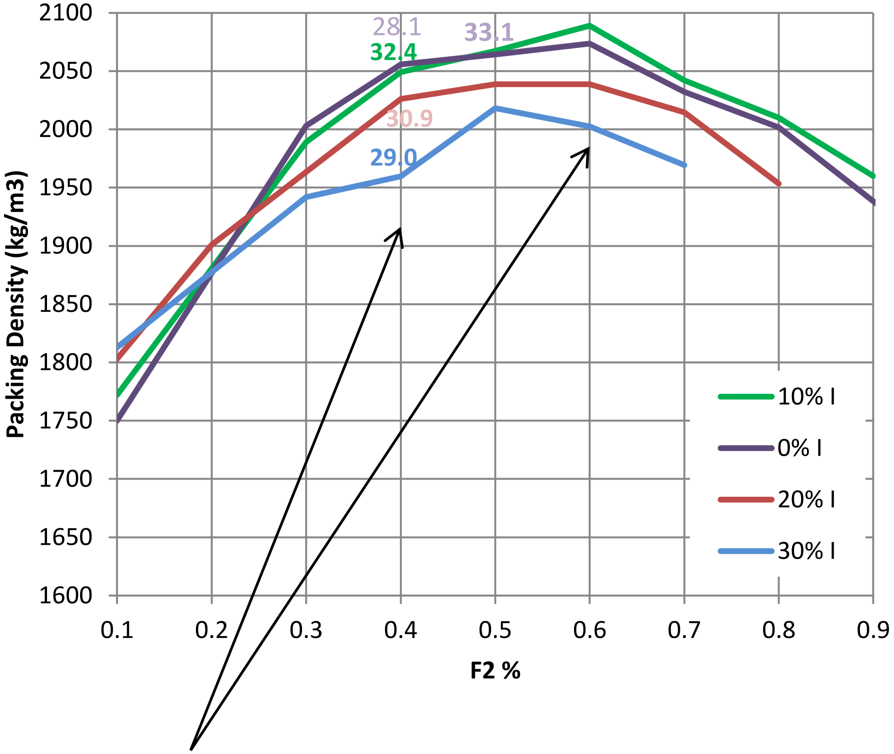
Experimental Packing Degree

Exp. Packing for C1, F1, I1 Blends:



- The max. packing occurs at 70% F1.
- The practical limitations impose 50% F1.

Exp. Packing for C2, F2, I2 Blends:



- The max. packing occurs at 60% F1.
- The practical limitations impose 40% F1.

Conclusions and Recommendations

- The early age strength of concrete can be increased by up to 15% using optimization of aggregate proportions, particularly, incorporating intermediate aggregates (up to 30%).
- The aggregate optimization for concrete with cementitious content of less than 300 kg/m^3 may require using higher proportions of sand in the aggregate blend (vs. DOT spec), up to 50%.
- Aggregate packing can be used as an effective criteria for aggregates optimization and selection of the best blend for low-slump concrete.
- Toufar model can be used to find the proximity of the maximal packing of the blend. However, for binary mixes this model has about 15% deviation from the experimental packing density values.
- The closest practical combinations to the maximal packing and minimal sand content can be used in concrete.
- The power curves can be used as an additional criteria to select the best aggregate combination. Based on the experimental results, the power curve based on the level of workability should be selected for optimizing the best blend.

References

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Experimental Methods: Educational Module

https://pantherfile.uwm.edu/sobolev/www/V_LAB/

VIRTUAL AGGREGATE TESTING

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PURPOSE

This laboratory module is designed to teach how use the computer software for modeling of aggregates.

This procedure will help to visualize the packing of particulate materials and help to determine how to achieve the best packing of aggregates.

OBJECTIVES

-

The main objectives of this laboratory module include:

1) Determine which parameters create the best packing of aggregates
2) Learn to use computer software for aggregate packing
3) Visualize the aggregate's packing by 3-D and 2-D models

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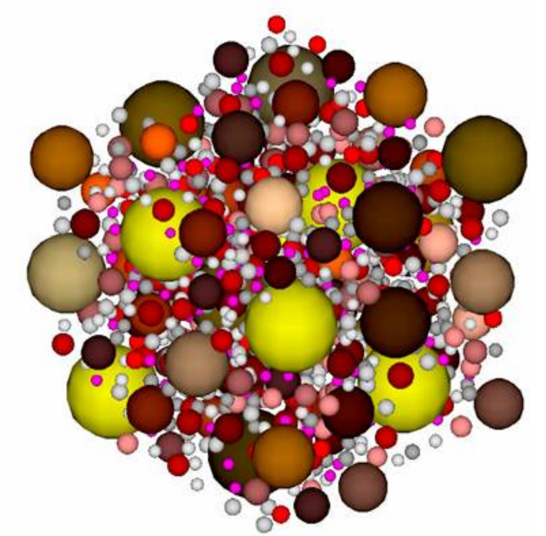
QUIZ



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NICOM symposia were instituted to exchange ideas and results in the field of nanotechnology for construction materials. These events facilitated the integration of scientific research obtained in laboratories and in field applications from around the world.

The world's leading researchers in the field of nanotechnology in construction will be brought together by NICOM5. This offers a special opportunity for participants to gain exposure to many of the top investigators in the field and the cutting-edge research conducted in Europe, the U.S., and other countries.

Attendance of engineers, scientists, and students from different countries is vital for the success of NICOM5 symposium: it will bring research results to the world community and allow engineers and scientists to evaluate the results of investigations performed elsewhere. These global connections are likely to lead to new ideas, active collaborations, and greater interactions.

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