Prediction of Virgin Aggregate Temperature in Asphalt Plant Using Thermodynamics

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Presentation Outline

- Research Need
- Field Data Collection
- Prediction of Virgin Aggregate Temperature
- Validation of Thermodynamics Model
- Recommended Future Study

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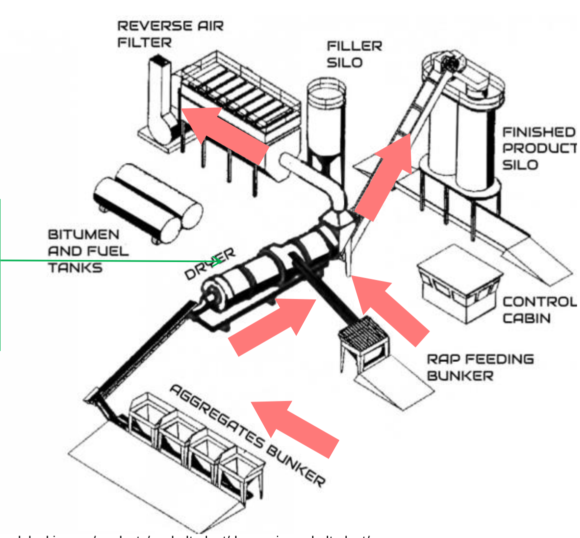
Research Need

HMA Mix Plant: Drum Plant

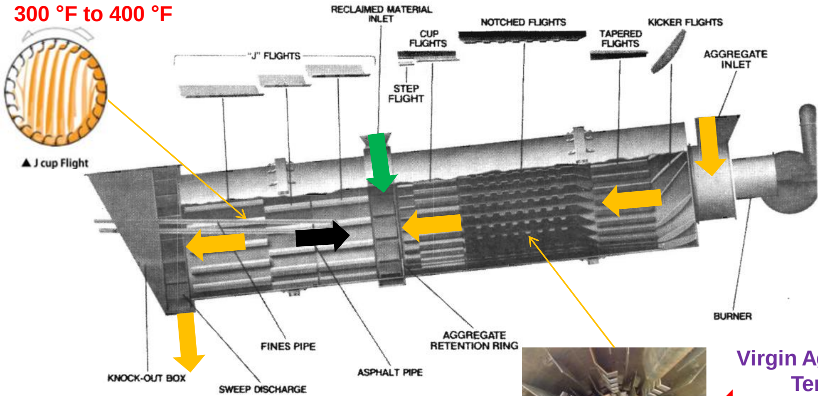
Aggregate, RAP and Binder Mixing Time: 45-60 sec

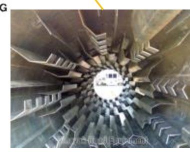


Source: http://eu.anadoluekip.com/products/asphalt-plant/drum-mix-asphalt-plant/

Inside of a Drum: Parallel Flow Aggregate

HMA Mix Temp.
300 °F to 400 °F





Virgin Aggregate Temp.
300 °F to 500 °F

Lay Down and Compaction Temp.
250 °F to 300 °F

Source: Kennedy et. al. (1986)

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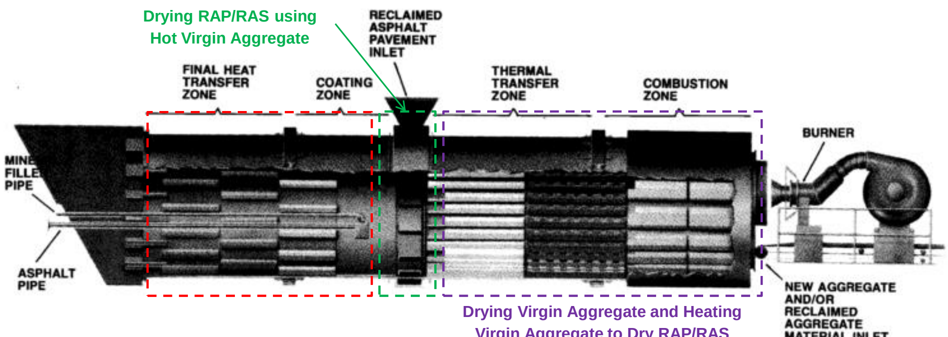
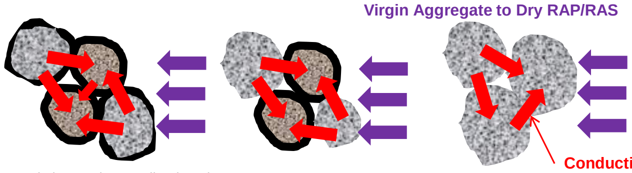
Thermodynamics and Heat Transfer inside a Drum: Parallel Flow Aggregate





Source: Asphalt Hot-Mix Recycling (1986)

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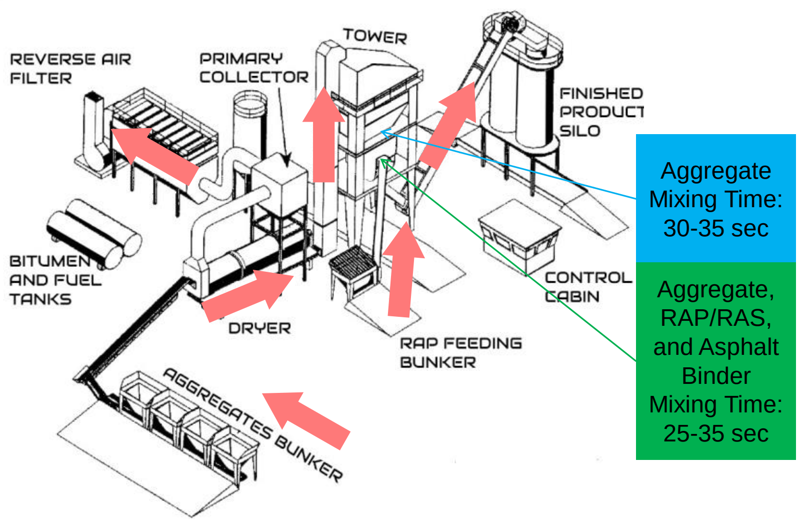
Factors Influencing HMA Production

- Size of plant
  - Diameter of drum
  - Length of drum
- **Moisture content in virgin aggregate**
- **Moisture content in RAP/RAS**
- **Amount of RAP/RAS**
- **HMA mix temperature**
- Exhaust gas temperature
- Bag house temperature

Virgin Aggregate Temperature: Batch Plant

- The **Asphalt Institute (AI)** reported the virgin aggregate variations due to change in RAP moisture content and HMA mix discharge temperature in the book titled "***Asphalt Hot-Mix Recycling***" published in **1986**
- Tabular values are given for % of RAP ranging from 10% to 50% mixing with 90% to 50% of virgin aggregate respectively
- The data is given for **batch plant only**
- The tabulated values are plotted in Excel to see the variations in virgin aggregate temperature

HMA Mix Plant: Batch Plant



Source: http://eu.anadoluekip.com/products/asphalt-plant/drum-mix-asphalt-plant/

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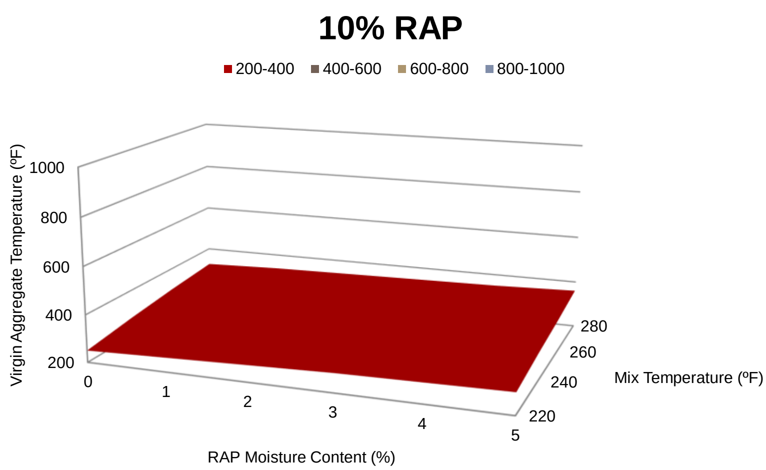
Batch Plant: Virgin Aggregate Temperature



Source: Asphalt Hot-Mix Recycling (1986)

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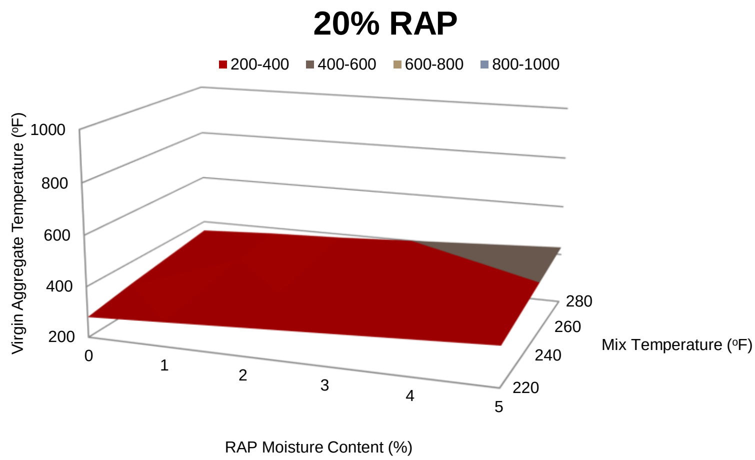
Batch Plant: Virgin Aggregate Temperature



Source: Asphalt Hot-Mix Recycling (1986)

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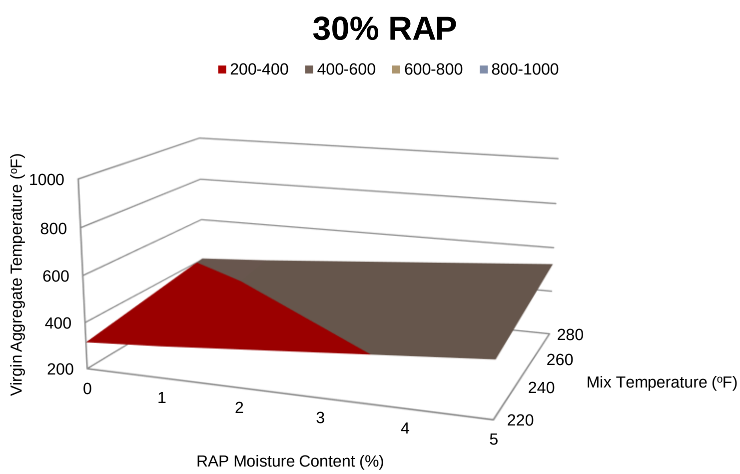
Batch Plant: Virgin Aggregate Temperature



Source: Asphalt Hot-Mix Recycling (1986)

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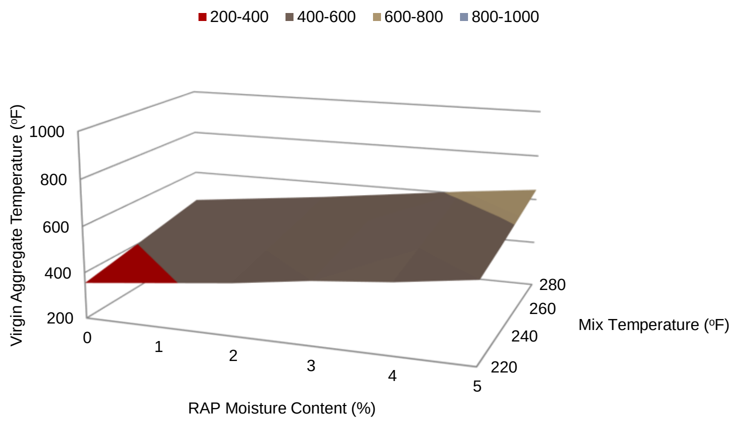
Batch Plant: Virgin Aggregate Temperature

40% RAP



Source: Asphalt Hot-Mix Recycling (1986)

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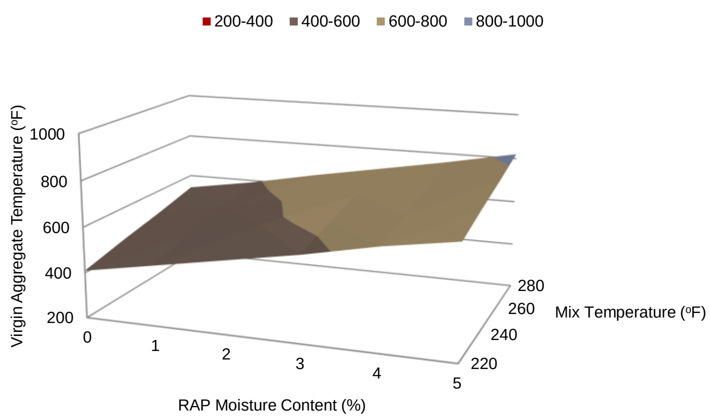
Batch Plant: Virgin Aggregate Temperature

50% RAP



Source: Asphalt Hot-Mix Recycling (1986)

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Field Data Collection

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Moisture Content in the Plant Aggregates

- Materials are collected in 2015
  - April (4/16, 4/22, 4/28)
  - May (5/7, 5/13, 5/19, 5/27)
  - June (6/2, 6/11, 6/19)
- Weather data are collected for three days:
  - Precipitation (1 hr, 3 hr, and 6 hr)
  - Maximum relative humidity
  - Minimum average temperature
  - Maximum average temperature
- HMA Plant Location
  - Peoria, IL

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Moisture Content in the HMA Plant Aggregate: April, 2015

16-Apr	Time:	~ 8:00 am					
Aggregate Type	Moisture Content (%)	Cumulative Precipitation (in.)			Max RH (24 hr)	Min Avg Temp (F) (24 hr)	Max Avg Temp (F) (24 hr)
		1 hr	3 hr	6 hr			
CA11	1.74%	0	0	0	78%	58.75	69.25
CA13	3.23%						
CA16	2.76%						
CA16	3.57%						
FA01	4.58%						
FA01	4.74%						
FA04	3.38%						
FA20	4.94%						
FA20	**5.49%**						
-3/8 FRAP	**4.99%**						
-3/8 RAS	**6.43%**						

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Moisture Content in the HMA Plant Aggregate: May, 2015

27-May	Time:	~ 8:00 am					
Aggregate Type	Moisture Content (%)	Cumulative Precipitation (in.)			Max RH (24 hr)	Min Avg Temp (F) (24 hr)	Max Avg Temp (F) (24 hr)
		1 hr	3 hr	6 hr			
CA11	2.48%	**0.95**	**0.52**	**0.95**	87%	67.75	79
CA13	2.18%						
CA16	3.25%						
CA16	1.24%						
FA01	4.52%						
FA01	4.46%						
FA04	2.45%						
FA20	4.99%						
FA20	**5.92%**						
-3/8 FRAP	**5.37%**						
-3/8 RAS	**6.22%**						

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Moisture Content in the HMA Plant Aggregates: June, 2015

19-June	Time:	~ 8:30 am					
Aggregate Type	Moisture Content (%)	Cumulative Precipitation (in.)			Max RH (24 hr)	Min Avg Temp (F) (24 hr)	Max Avg Temp (F) (24 hr)
		1 hr	3 hr	6 hr			
CA11	2.48%	0.17	0.02	1.03	88%	70.25	78.5
CA13	2.84%						
CA16	4.13%						
CA16	2.69%						
FA01	4.98%						
FA01	3.63%						
FA04	4.25%						
FA20	**6.60%**						
FA20	**6.54%**						
-3/8 FRAP	**5.60%**						
-3/8 RAS	**9.04%**						

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Prediction of Virgin Aggregate Temperature

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Heat Transfer and Energy Requirements

- Heat transfer and energy require to prepare a mix has broken down into **Three** stages:
  - Energy requires for heating and drying virgin aggregates
  - Energy requires for heating and drying RAP/RAS
  - Heat transfers while mixing hot virgin aggregates, hot RAP/RAS, and hot binder
- Exit temperature represents partial equilibrium of heat transfer among virgin aggregates, RAP/RAS, and binder
- Final temperature equilibrium is achieved inside the silo

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Heating and Drying of Virgin Aggregates

- Energy requires to remove moisture from virgin aggregates **(Q_1)**
  - Energy requires to increase temperature from ambient condition to 212 °F **(Q_{1-1})**
  - Energy requires to evaporate water at 212 °F **(Q_{1-2})**

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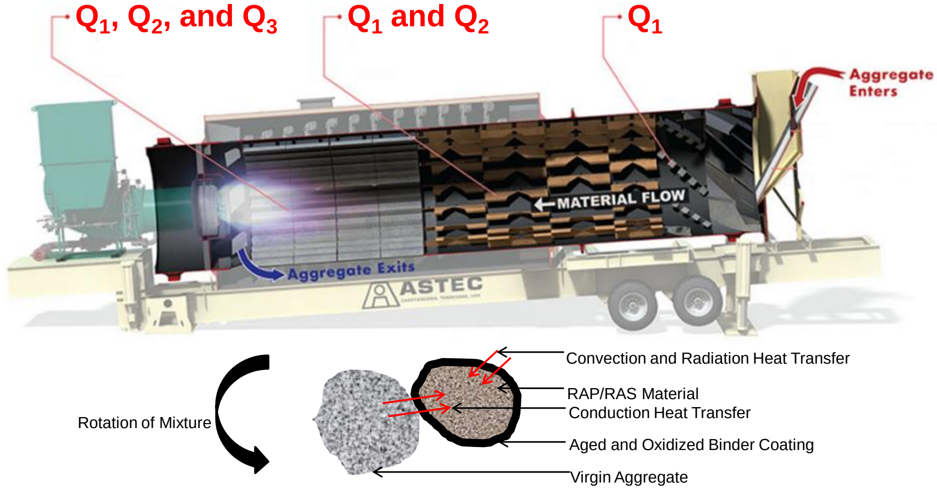
Heating and Drying of RAP/RAS

- Energy requires to remove moisture from RAP/RAS **(Q_2)**
  - Energy requires to increase temperature from ambient condition to 212 °F **($Q_{2\text{-}1}$)**
  - Energy requires to evaporate water at 212 °F **($Q_{2\text{-}2}$)**

Mixing Aggregates with Binder

- Energy requires to achieve exit temperature **(Q_3)**
  - Energy requires for additional heating of virgin aggregates to achieve exit temperature after partial equilibrium of heat transfer **($Q_{3\text{-}1}$)**
    - If virgin aggregates temperature is higher than the binder and mixing temperature than virgin aggregates transfer heat to binder and partial equilibrium of exit temperature is achieved
    - If virgin aggregates temperature is lower than the binder and mixing temperature than additional energy requires for heating virgin aggregates to achieve mixing temperature **($Q_{3\text{-}2}$)**

Thermodynamics and Heat Transfer: Double Barrel Drum



Source: Modified from ASTEC (2015)

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Example: Virgin Aggregates Drying and Heating

- Step 1:
  - Total 100 ton aggregates are considered
  - Different percentages of virgin aggregates (i.e. 90% to 50%) and RAP (i.e. 10% to 50%) are considered
  - Different percentages of moisture content in virgin aggregates (i.e. 1% to 5%) and RAP (i.e. 1% to 5%) are considered
- Step 2:
  - $Q_{1\text{-}1}$ and $Q_{1\text{-}2}$ are calculated for virgin aggregates.
  - $Q_{2\text{-}1}$ and $Q_{2\text{-}2}$ are calculated for RAP

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Example: Virgin Aggregates Drying and Heating

- Step 3:
  - Physical properties of the drum are considered from available literature
    - Rotational speed of drum = 7 rpm
    - Drum radius = 1.5 m
    - Drum length = 6.1 m
  - Virgin aggregates drying and heating time = 30 sec

Example: Virgin Aggregates Drying and Heating

- Step 4:
  - Percentage of **conduction**, **convection**, and **radiation** are calculated
    - Consider **"one virgin aggregate"** rotates on the drum wall as well in contact with the neighboring aggregates and climb on the flight (**i.e. conduction**) and travel half of the perimeter of the drum and then drops freely (**i.e. convection**) while it reaches at the top of the drum
    - Calculate the time the "one virgin aggregate" is in contact with the drum wall as well as with the other aggregates (**time of conduction**) and the time requires to free fall (**time of convection**) while it reaches at the top of the drum
    - **Assume "time of radiation" is 5% of the total time**
    - Other 95% time is for "time of conduction" and "time of convection"
  - This three times are considered as percent contribution of heat transfer in virgin aggregates

Example: Virgin Aggregates Drying and Heating

- Step 5:
  - Determine heat transfer equations parameters
- Step 6:
  - As per Step 4:
    - **83% Conduction; 12% Convection; 5% Radiation is calculated**
  - Assume spherical shape aggregates
  - Calculate mass of virgin aggregates by considering density of virgin aggregates
  - Calculate total number of virgin aggregates
  - Calculate T_{hot} for conduction, convection, and radiation separately
  - Take average of T_{hot}

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Example: Virgin Aggregates Drying and Heating

- Step 7:
  - Case 1 or Case 2:
    - Check if average T_{hot} is smaller or greater than mix temperature
  - If T_{hot}<Mix temperature
    - Calculate the energy required to achieve the exit temperature and add that energy in the virgin aggregate drying and heating calculation
  - If T_{hot}>Mix temperature
    - Keep the T_{hot} temperature

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Example: Virgin Aggregates Temperature

VA%	RAP%	VA Moisture %	RAP Moisture %	T_{hot} Average (F)
90	10	1	1	340
			2	356
			3	371
			4	386
			5	400

VA%	RAP%	VA Moisture %	RAP Moisture %	T_{hot} Average (F)
70	30	2	1	509
			2	560
			3	610
			4	659
			5	707

VA%	RAP%	VA Moisture %	RAP Moisture %	T_{hot} Average (F)
50	50	5	1	912
			2	1020
			3	1127
			4	1232
			5	1337

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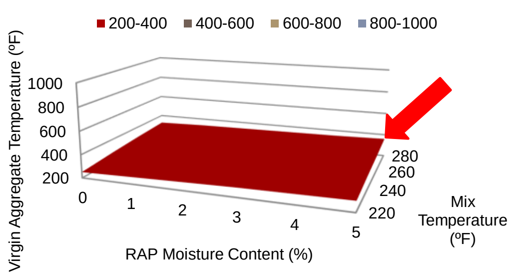
Compare: Drum Vs. Batch Plant

VA%	RAP%	VA Moisture %	RAP Moisture %	T_{hot} Average (F)
90	10	1	1	340
			2	356
			3	371
			4	386
			5	400

10% RAP



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Verification of Thermodynamics Model

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Plant Visit

- A plant located in Joliet, IL is visited on June 24th, 2015 to record virgin aggregates temperature at the time of mixing
  - The **double barrel counter flow drum** plant has a **temperature recorder that records virgin aggregates temperature** when the aggregates drop in to the outer barrel
  - Binder temperature, **mix temperature**, and outer drum wall temperature were also recorded
  - One fine aggregate mix was preparing while taking the temperature record

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Plant Visit: Double Barrel Counter Flow Drum

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Plant Visit: Temperature Recording

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Drum Information

- Drum capacity: 500 tons/hr
- Drum inside radius: 10 ft
- Drum length: 49.8 ft
- RAP entrance from top: 44 ft from the entrance of the drum
- Drum rotation: 6 rpm
- Drum is preheated for 30-45 min

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Mix Information

- Fine Aggregate mix
  - 33% FM02
    - Moisture content **5.1%**
  - 67% FM20
    - Moisture content **6.3%**
- 31% RAP
  - Moisture content **6.9%**
- 4.75% RAS
  - Moisture content **15.2%**
- 7.8% Binder
  - PG 70-28, Polymer modified
  - Binder temperature varies from 278 °F to 289 °F
- Heating time of aggregate: 140 sec
- Binder mixing time: 40 sec

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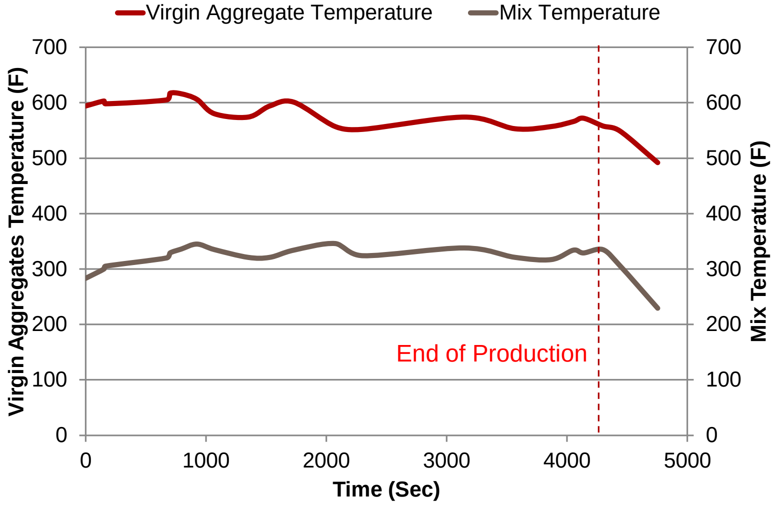
Virgin Aggregates and Mix Temperature



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Virgin Aggregate (FM02) Temperatures Required to Dry and Heat RAP/RAS

Sieve Size	T_{Hot} Average (F)
#4	586
#8	219
#16	179
#30	156
#50	136
#100	145
#200	183
Mineral Filler	149

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Virgin Aggregate (FM20) Temperatures Required to Dry and Heat RAP/RAS

Sieve Size	T_{Hot} Average (F)
#4	**515**
#8	203
#16	168
#30	154
#50	139
#100	125
#200	116
Mineral Filler	121

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Recommended Future Studies

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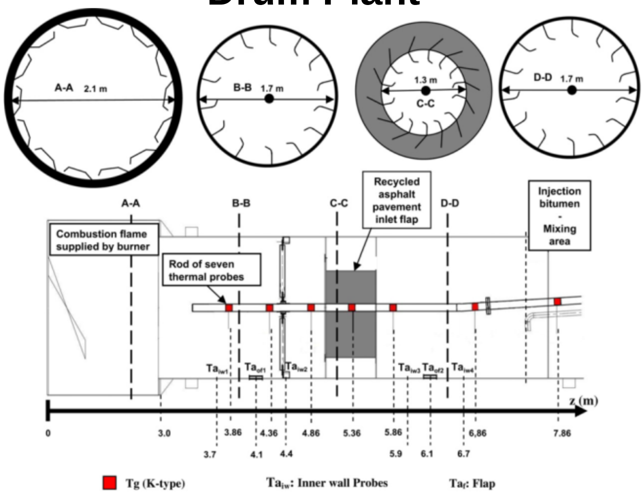
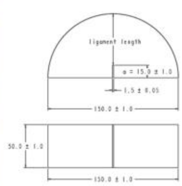
Extensive Temperature Data Collection from the Drum Plant

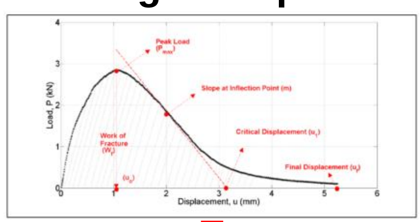


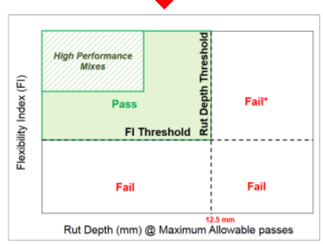
Source: Le Guen et al. 2013

Correlate Illinois Flexible Index Test (I-FIT) with Plant Mix that is Exposed to High Temperature



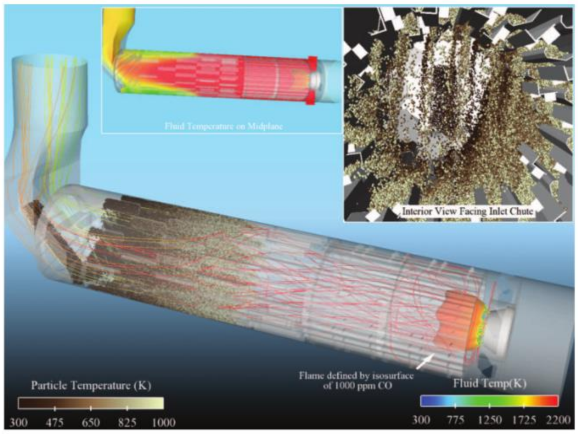
Source: Al-Qadi et al. 2015





*This mix can be used as a thin, highly flexible interlayer to control reflective cracking

Numerical Computation such as Computational Fluid Dynamics (CFD) to Predict Virgin Aggregate Temperature



Source: Hobbs 2009

Acknowledgement

- Dr. Imad Al-Qadi, Founder Professor of Engineering, UIUC, and Director, ICT
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- Robert Flemming, District-4, IDOT

Questions?

Thank You!

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