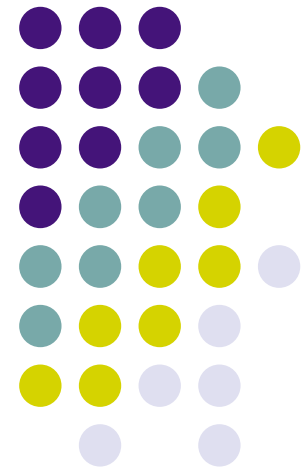
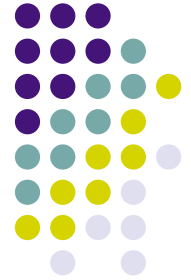


# Mix Design for HMA Recycling

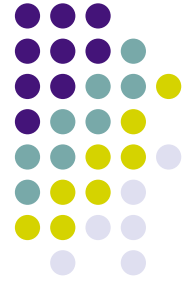
Rebecca McDaniel  
North Central Superpave Center  
ISAP Short Course on Recycling  
Fortaleza, Brazil  
September 30, 2012





# What is RAP?

- Reclaimed Asphalt Pavement (RAP)
- Existing pavements removed and reused
- Produced by
  - Milling -- Upper pavement layers removed and replaced with new pavement
  - Full-Depth Removal -- Pavement completely removed and reprocessed



# RAP from Milling

- Removes old/distressed pavement
- Improves smoothness
- Eliminates costly shoulder work
- Maintains drainage features, curbs, clearance
- Valuable rehabilitation option







**What to do with the RAP?**



# Composite Sources

- Usually chunks and slabs from full depth pavement removal
- Plant cleanout
- Reject material or excess returned from jobs
- Excavation
- Other sources



Composite RAP is reprocessed (i.e. crushed, screened, stockpiled and QC tested)

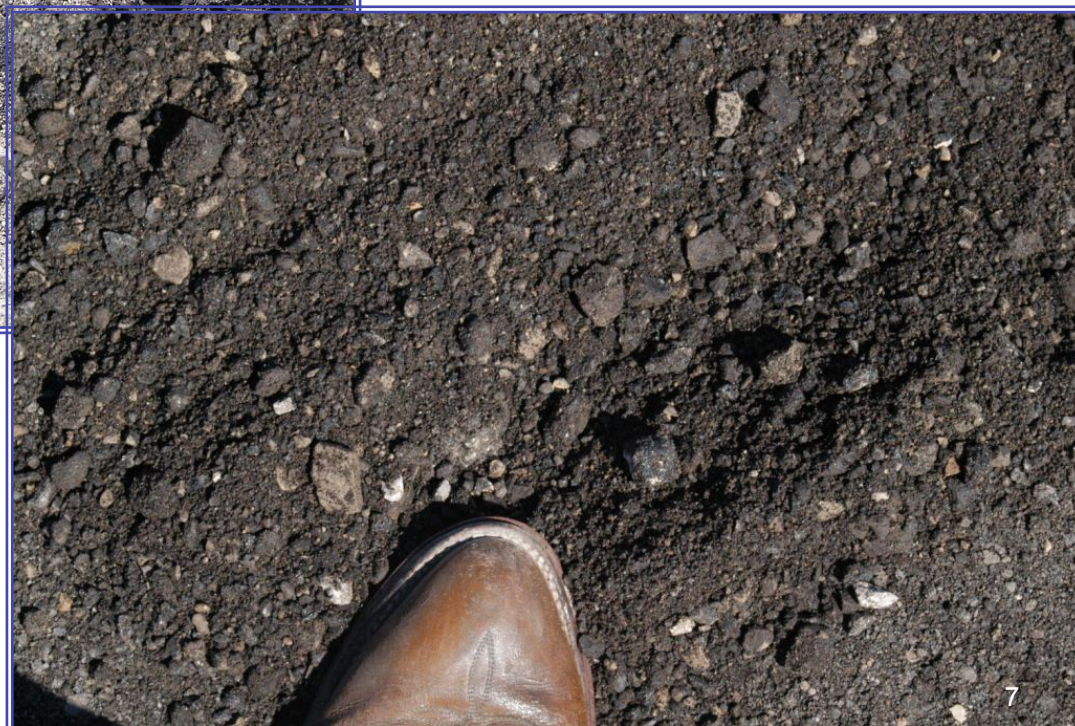




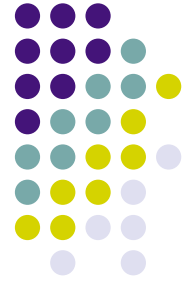


***In Composite  
Pile***

***After  
Processing***







The reprocessed products are very consistent components





# RAP is just another component of HMA







# History of RAP Use

- First used in 1915 (!)
- Major emphasis started in 1970's
  - Oil embargo and increased oil prices
  - Improved milling machines
  - Counterflow drum plants
- Became routine in many states
  - Necessary to be competitive (lower bid prices)
  - RAP contents of 15-20% common



# Today



- Strong incentives to increase RAP use
  - Increased material and energy costs
  - Material supply issues
  - Growing environmental concerns
- Growing demand to
  - Use RAP in more mixes (i.e. surfaces)
  - Use higher RAP quantities (30% or more)



# Why?



- Valuable resource – reduced material costs
  - Cost savings – avoid disposal costs
  - Competitive edge – lower bid prices
  - It is the right thing to do
  - It works!
- 
- *Produce a recycled mix that performs as well as, or better than, the original mix.*



# Typical Asphalt Mix

- 95% aggregate (approx. 30% of cost)
- 5% asphalt binder (approx. 70% of cost)

*RAP can be treated as another component of the mix.*







# Uses of RAP

- RAP can be used for
  - Base
  - Fill
  - Shoulders
  - Alleys
- But, the highest and best use of RAP is back into new asphalt mixtures.
  - Most beneficial
  - Most cost effective

# Where Can RAP be Used?



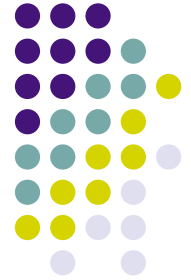
- Virtually any mix – following best practices
- Base and intermediate
  - Potential to use higher amounts
- Surface mixes
  - Tendency to allow lower amounts
  - Friction and cracking are potential concerns
  - Increased resistance to rutting





## Note

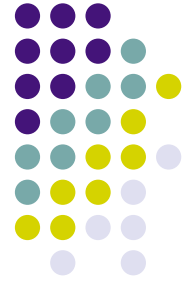
- Cold and hot in-place recycling can reuse essentially 100% of the material
- Focus here is on hot mix asphalt for high type pavements



## Another Note

- Examples and properties tested in this presentation are based on Superpave mix design practices.
- Similar steps and procedures are appropriate for Marshall mix designs as well.
  - Similar aggregate requirements.
  - Use viscosity instead of Performance Graded binder properties for blending chart.





# Possible Effects of RAP

- At low RAP contents, little aged binder and RAP aggregate to affect properties of blend
- At higher RAP contents, the hardened RAP binder may stiffen the mix
  - Good for rutting, not so good for cracking
- The aggregate in the RAP may affect structure and stability of the mix

# How can we ensure performance?



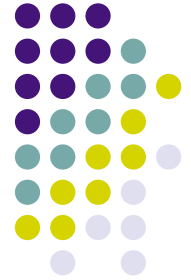
- Account for the RAP aggregate and binder in the mix design
  - Adjust design as necessary
  - Tiered system
- Control variability
  - Treat the RAP like another stockpile
  - Practice good stockpile management
  - Process the RAP, if needed





# Evaluation of RAP

- Asphalt Content
- Aggregate Gradation
- Aggregate Properties
- Binder Properties – for high RAP contents
  - RAP binder stiffness influences how much RAP can be used with minimal testing



# RAP Mix Design Basics

## Aggregate Considerations

- Include RAP aggregate in determinations of:
  - Specific gravity
  - Gradation
  - Fine aggregate angularity
  - Coarse aggregate angularity
  - Flat and elongated content
  - Other tests required by agency

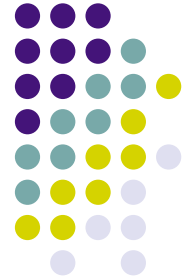


# RAP Aggregate Evaluation



- Extract and test
  - Gradation
  - Coarse aggregate angularity
  - Fine aggregate angularity
  - Flat and elongated particles
  - Aggregate specific gravity (one option)
- Include in evaluation of consensus properties of trial blends
  - Evaluate sand equivalent on virgin agg only

# RAP Specific Gravity



1. Measure RAP agg specific gravity after solvent extraction
  2. Use RAP agg effective specific gravity, or
  3. Backcalculate bulk s.g. from Rice density and assumed or known absorption.
- Agency discretion.



# Recommendations for the Characterization of RAP Aggregate Properties Using Traditional Testing & Mixture Volumetric

**Elie Y. Hajj, Peter E. Sebaaly, Randy West, Nathan Morian,  
Luis Loria**

**87<sup>th</sup> AAPT Annual Meeting**  
**April 1 – 4, 2012 Austin, Texas**





# Research Approach

Extract lab-produced RAP aggregates using:

**Centrifuge (TCE)**

**Reflux (TCE)**

**Ignition oven**





# Research Approach

- Tested extracted RAP aggregates & compared results to virgin aggregate properties.
- SG of RAP & virgin aggregates is required for volumetric calculation.
  - BSG of each aggregate stockpile, including RAP aggregate needs to be determined for the calculation of BSG of combined aggregates.
- Assessed the impact on VMA calculation for various RAP contents

# Conclusions/Recommendations

## Based on Evaluated Aggregates



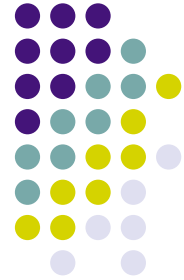
## RAP Asphalt Content

- Ignition method appears to give the most accurate results for asphalt content of RAP.
- Solvent extraction methods do not appear to remove all of the aged binder from RAP



# Conclusions/Recommendations

## Based on Evaluated Aggregates

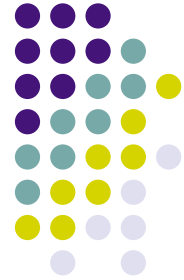


### RAP Aggregate SG

- For high RAP content mix designs:
  - Best method is to use a solvent extraction method to recover the aggregate & then test the coarse & fine parts of recovered aggregate.
  - Ignition furnace may also be used to recover RAP aggregate except for some aggregate types which undergo significant changes in SG when subjected to the extreme temperatures used in ignition method.
  - As RAP contents approach 50%, the net effect may be an error in the VMA determination of +/- 0.4%.

# Conclusions/Recommendations

## Based on Evaluated Aggregates



### RAP Aggregate SG (cont'd)

- (NCHRP Report 452) – *Method B*
  - Correct the  $G_{se}$  to an estimated  $G_{sb}$  using an assumed value for RAP asphalt absorption.
  - Correction is only reliable when asphalt absorption can be *assumed with confidence*.
  - Correction is very sensitive to the assumed asphalt absorption value & can lead to errors in VMA that are 0.5% or more.

# Conclusions/Recommendations

## Based on Evaluated Aggregates



## RAP Aggregate SG (cont'd)

- (NCHRP Report 452) – *Method C*
  - Although some agencies use the  $G_{se}$  for the RAP aggregate in the calculation of VMA, the authors strongly advise against this practice.

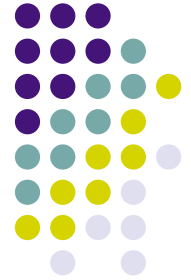




# RAP Mix Design Basics

## Binder Considerations

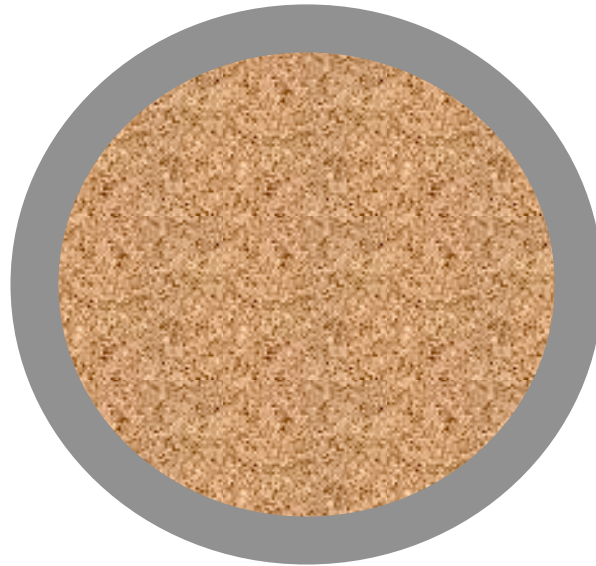
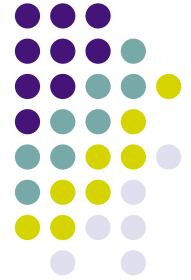
- Reduce added binder to account for RAP binder
- For higher RAP contents, use softer virgin binder grade to blend with and “soften” the hardened RAP binder
  - Cost and construction (compaction) implications



# Conventional Wisdom

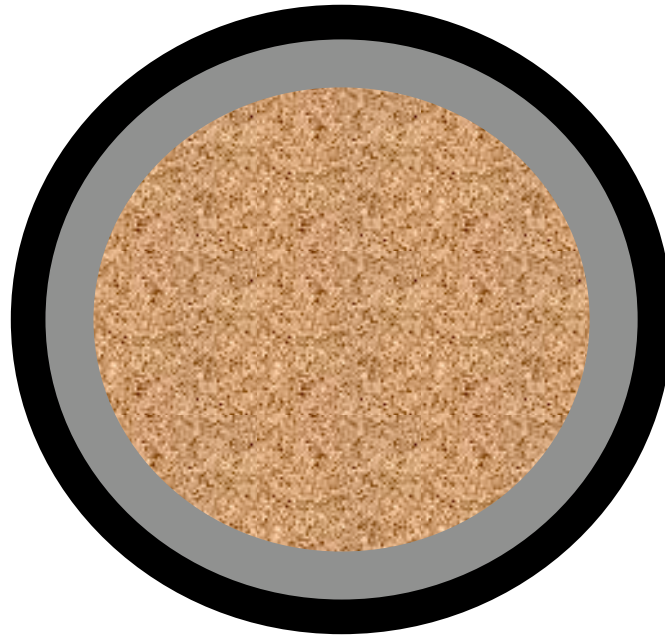
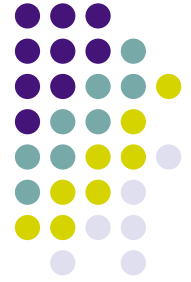
- RAP contains old, hardened binder that will stiffen the mix
- This will help reduce rutting
- May increase cracking tendencies
- There is research and experience to support conventional wisdom
  - And some that doesn't.

# Possible Effects of RAP Binder



RAP aggregate  
with oxidized  
binder film

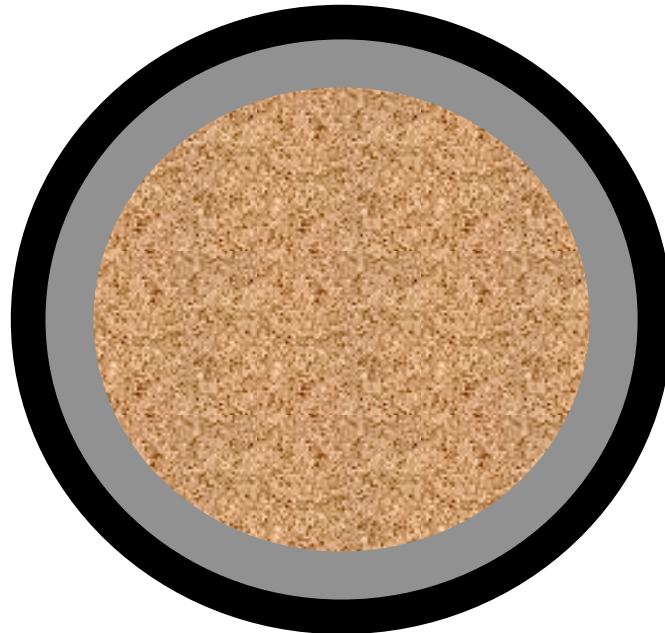
# Possible Effects of RAP Binder



RAP aggregate  
with oxidized  
binder film  
plus virgin  
binder film

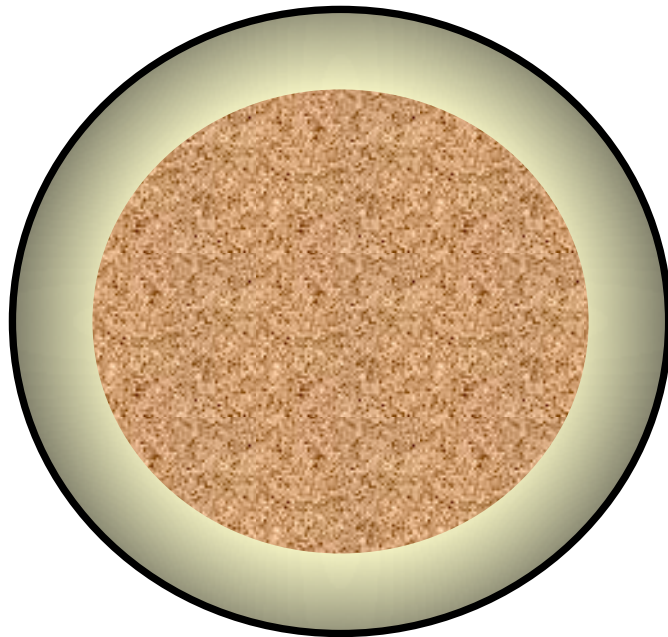


# Possible Effects of RAP Binder

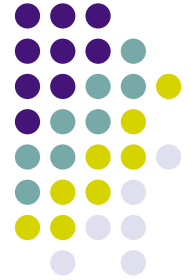


If RAP and virgin binders do not blend, effective binder properties will be those of the virgin binder only.

# Possible Effects of RAP Binder



If RAP and virgin binders blend or merge, effective binder properties will be determined by the amount of blending that occurs.



# Does blending happen?

- With many materials and plants, significant (nearly complete) blending does occur.
  - Evaluation of blending by looking at mixture and binder stiffness
  - But, we may be able to go to higher RAP binder contents before changing grades
- In other cases -- especially with very hard binders (shingles), high RAP contents or ???-- complete blending may not occur.
  - Temperature, Time, Compatibility, Plant



## Current US Tiers

- Based on weight of RAP in mix
- Up to 15% RAP, no change in binder grade.
- 16-25% RAP, lower binder grade by one increment.
- More than 25%, create blending charts.
  - Extract, recover and test RAP binder
- Some states have established higher limits based on knowing their materials and research.

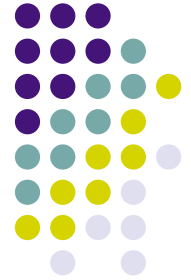


# RAP Binder Replacement



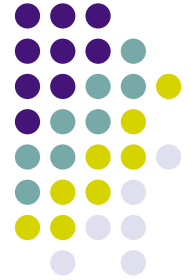
$$\frac{(A \times B) + (C \times D)}{E} \times 100\%$$

where A = binder content in RAP, %  
B = RAP content in mixture, %  
C = binder content in shingles, %  
D = shingle content in mixture, %  
E = total binder content in mixture, %



# RAP Binder Evaluation

- *Only necessary if using high percentages of RAP*
- Extract and recover binder
- Determine high, intermediate and low critical temperatures for recovered RAP binder.
  - Or use viscosities or penetration at specification temperature.



# Constructing a Blending Chart

- Use critical temperatures
- Determine Appropriate Grade of New Binder (Method A), or
- Determine Maximum and Minimum Amounts of RAP (Method B)

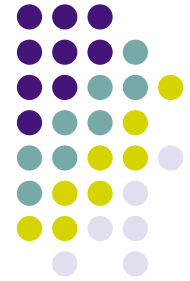
# Data Needed for Blending Chart



- Target PG Grade
- Critical high, intermediate and low temperatures of recovered RAP binder
- And either
  - Critical high, intermediate and low temperatures of new (virgin) binder, or
  - Desired RAP content

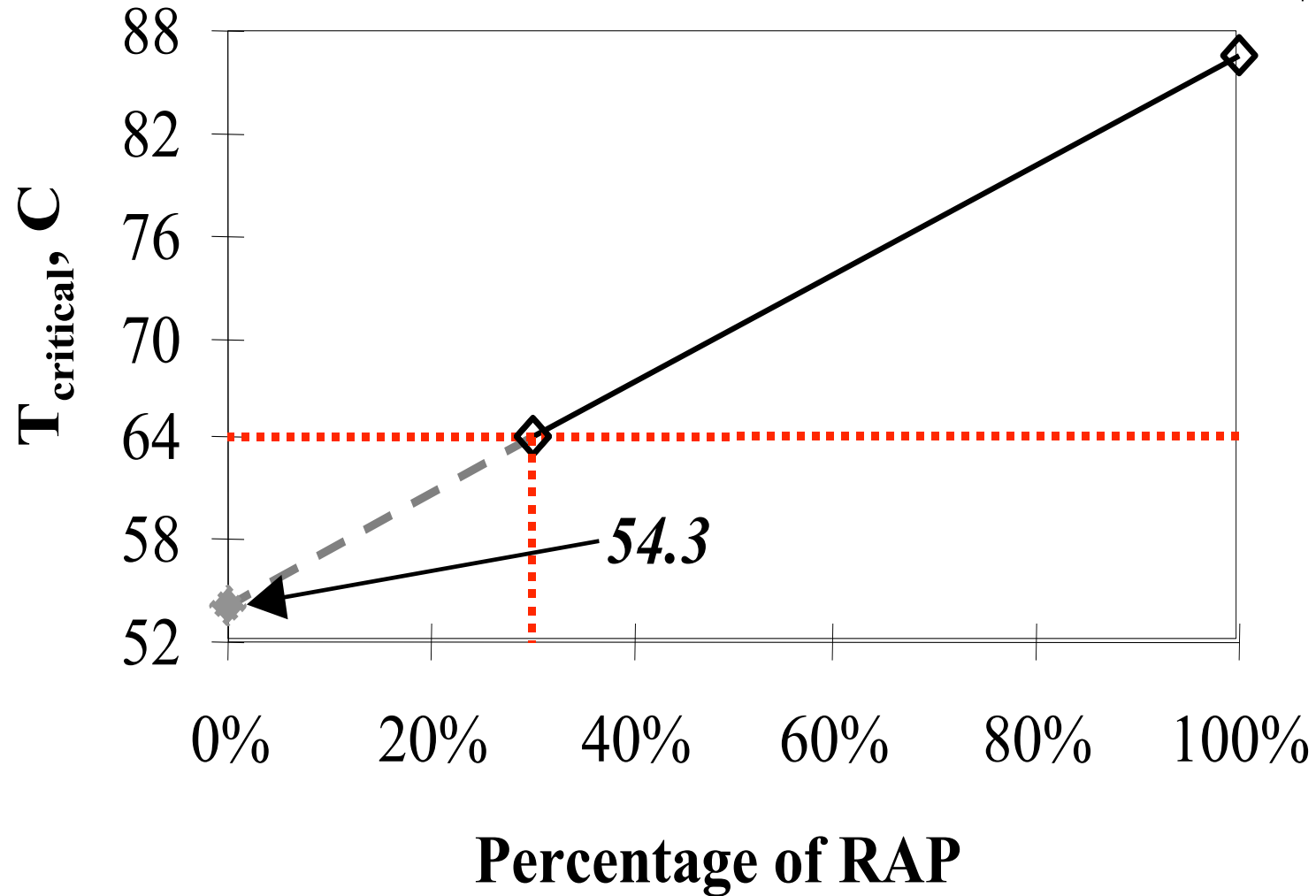


# Example of Method A - Blending at Known RAP Content

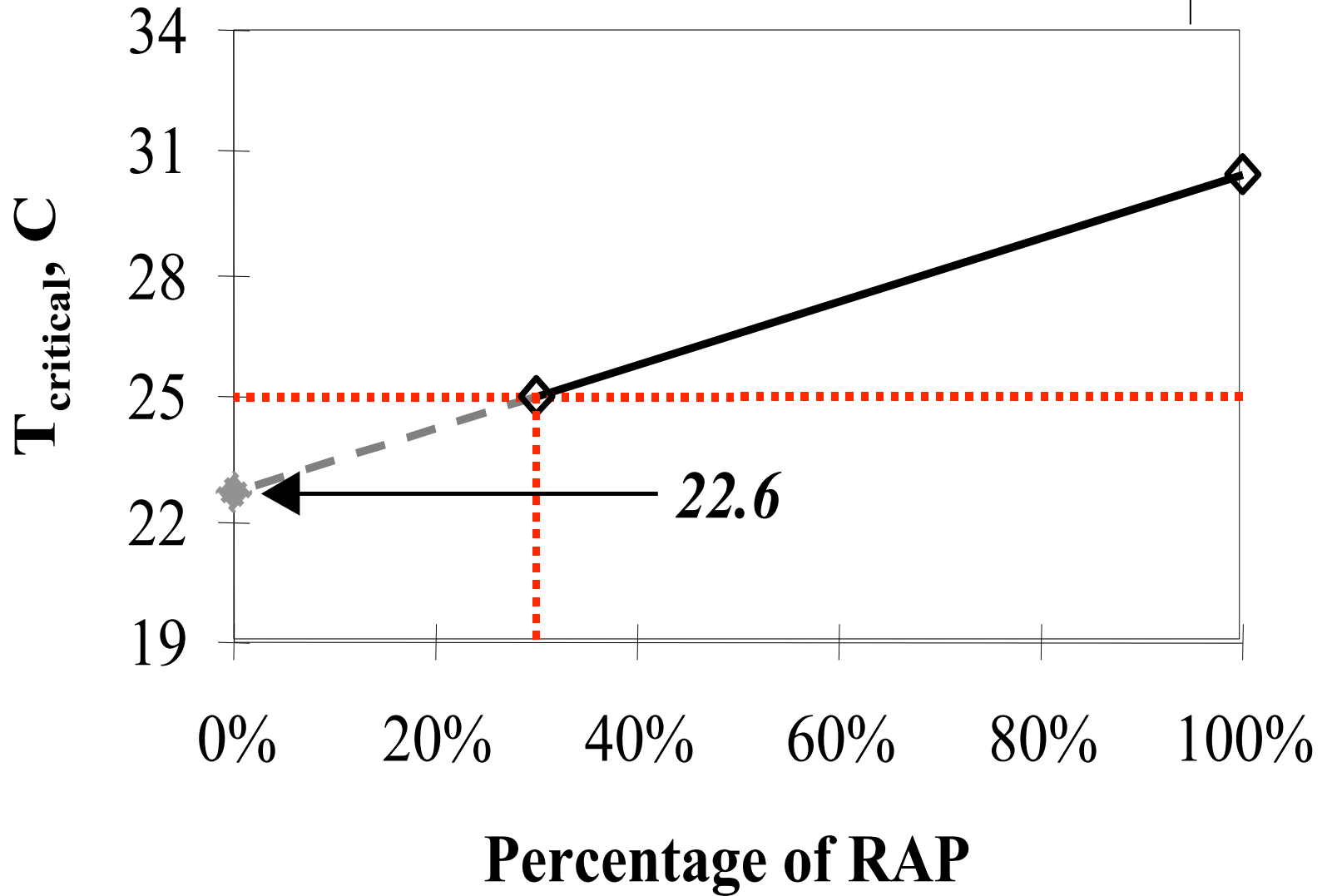


- Desired Final Binder Grade = PG64-22 or better
- Desired RAP Content = 30%
- Recovered RAP Properties Measured

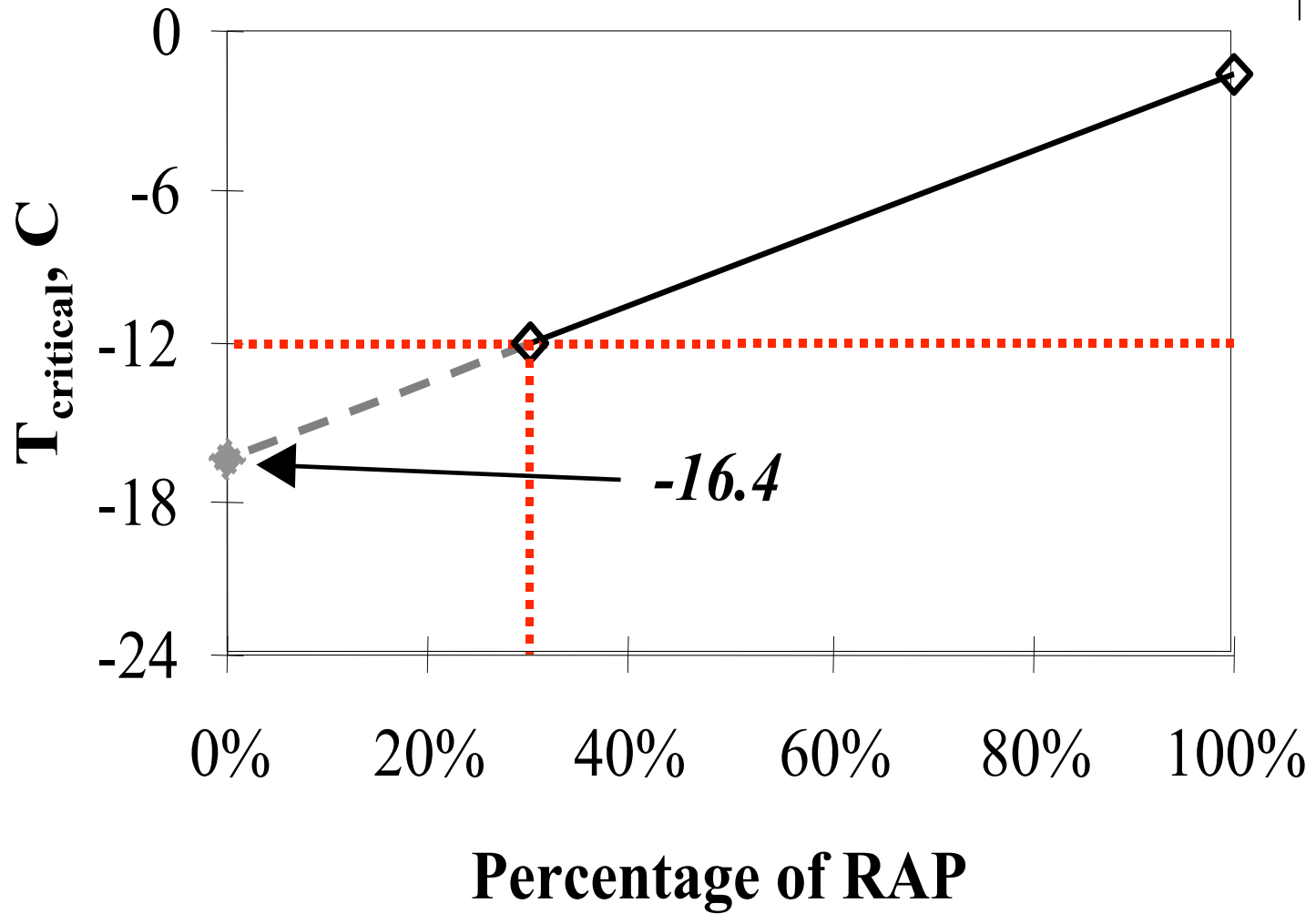
# High Temperature Blending Chart, Method A



# Intermediate Temperature Blending Chart, Method A

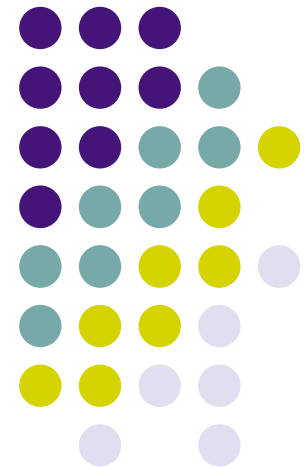


# Low Temperature Blending Chart, Method A



**Use PG58-28  
for the virgin binder**

---



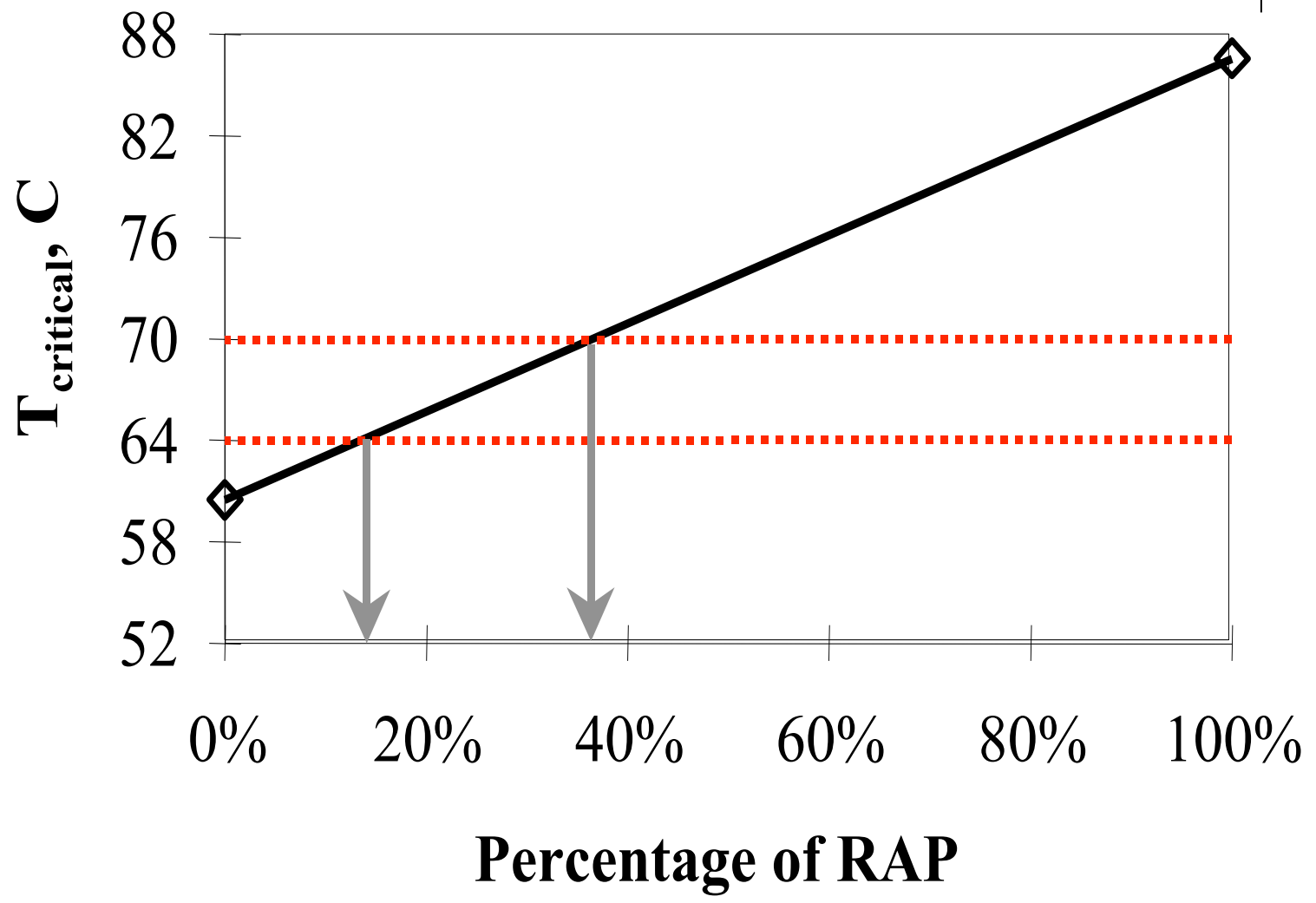
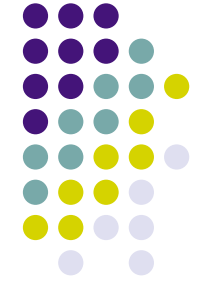


# Example of Method B - Blending with Known Virgin Binder

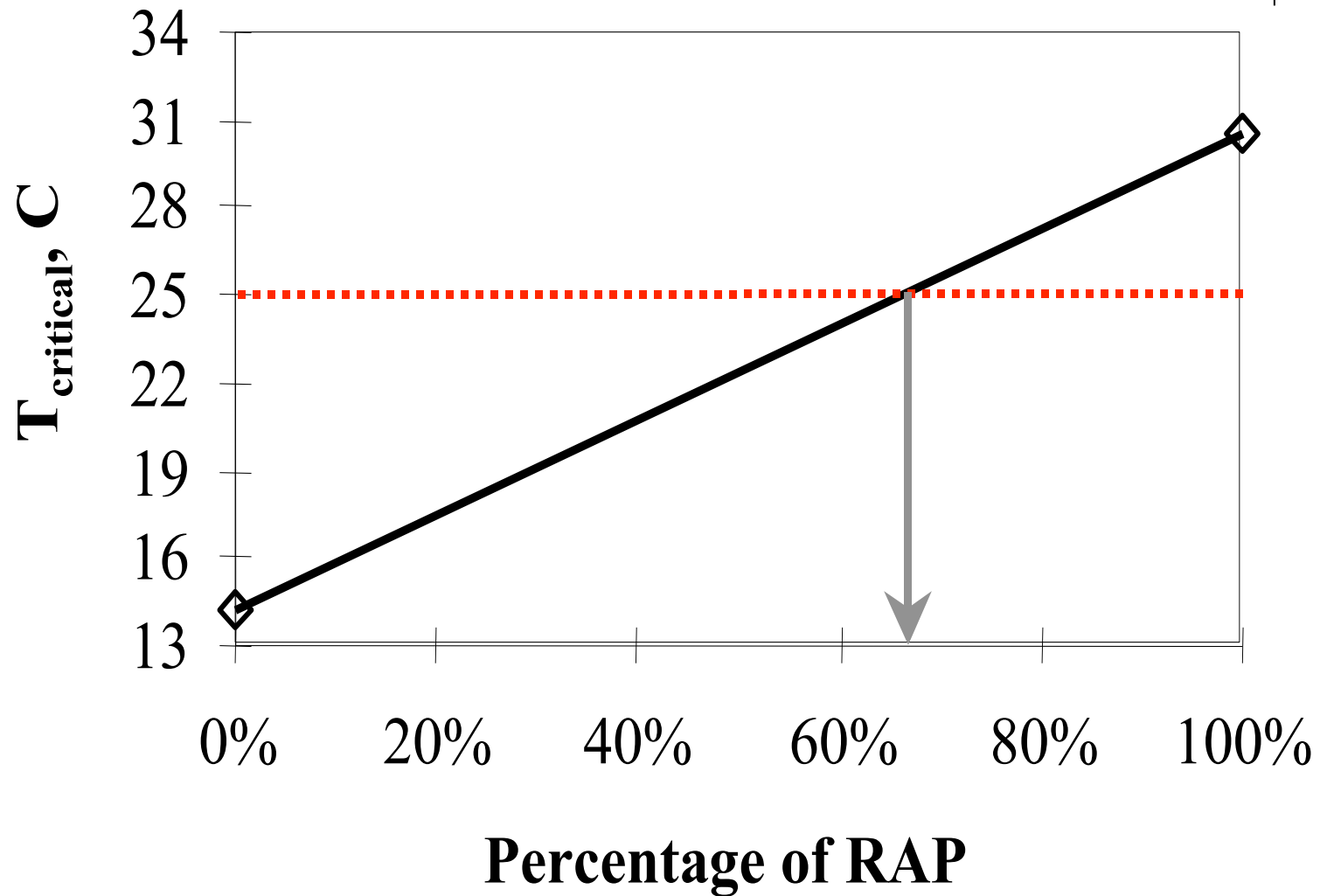
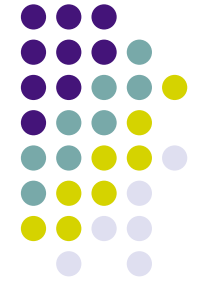


- Desired Final Binder Grade = PG64-22 or better
- Virgin binder grade is PG58-28
- Recovered RAP is a PG82-10
- Critical temperatures of virgin and RAP binders are determined.

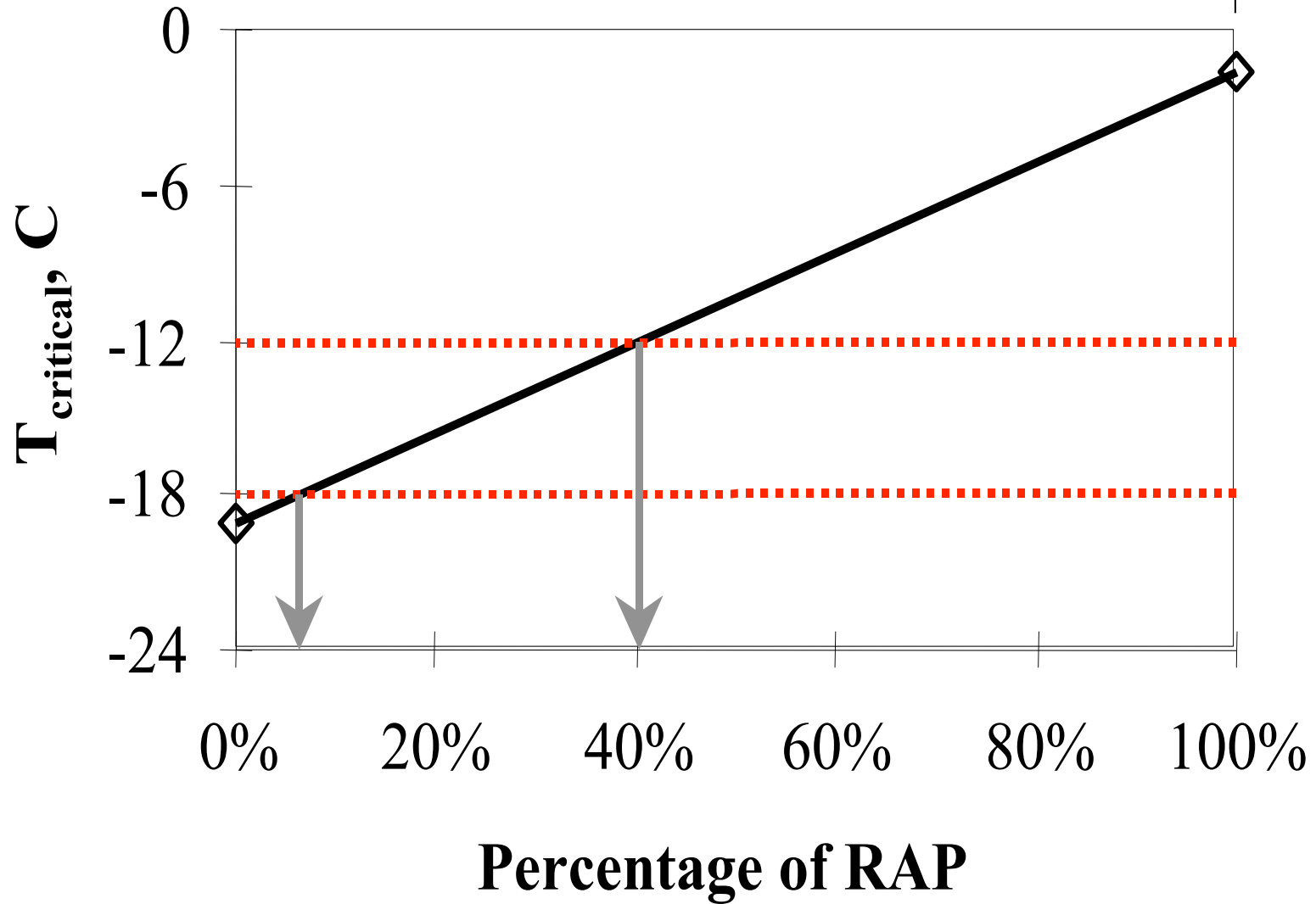
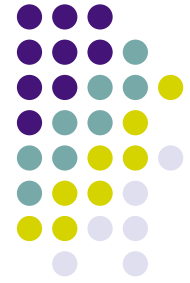
# High Temperature Blending Chart, Method B



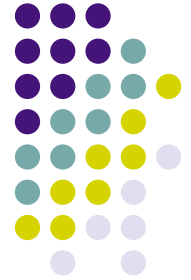
# Intermediate Temperature Blending Chart, Method B



# Low Temperature Blending Chart, Method B

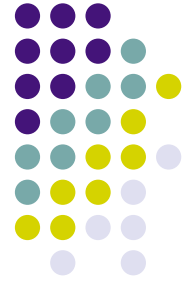


# RAP Content



- To achieve PG64-22, use between 14 and 36% RAP.





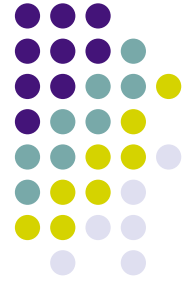
# Rejuvenators

- Many on the market, especially for pavement preservation
- Some can be used with RAP mixes
- Add maltenes to bring the oxidized asphalt “back to life”
- Most US states just use softer binder grades
- If using a rejuvenator, use mixture tests to ensure it is working as intended.



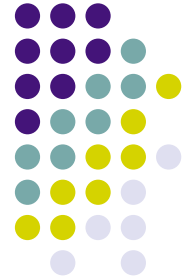
## Handling RAP in the Lab

- Heat it gently just enough to heat it through
- Recommend 110°C for no more than 2 hours
- Heat virgin aggregate about 10°C above the mixing temperature
- Then mix, condition and compact as usual.



# Summary

- Include RAP aggregate in gradation and determination of consensus properties of trial and final blends.
- Evaluate RAP binder properties if RAP is very hard or high percentages are used.
- Adjust virgin binder grade by decreasing grade or constructing blending charts, depending on RAP stiffness and content.
- Reheat RAP gently and slightly overheat virgin aggregate, then proceed as usual.



## More info:

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