Asphalt Mixture Characteristics Affecting Durability Cracking

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- Kentucky Department of Highways
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- Member Companies of the Asphalt Institute

Durability

- NCHRP Report 673, "A Manual for Design of Hot Mix Asphalt with Commentary"
  - Resistance of asphalt mixture to disintegration due to the combined effects of weathering and traffic
    - Surface (wearing) mixes have most severe exposure
  - The most durable mixes have…
    - Good fatigue resistance
    - Low permeability to air and water

Importance of Air Voids

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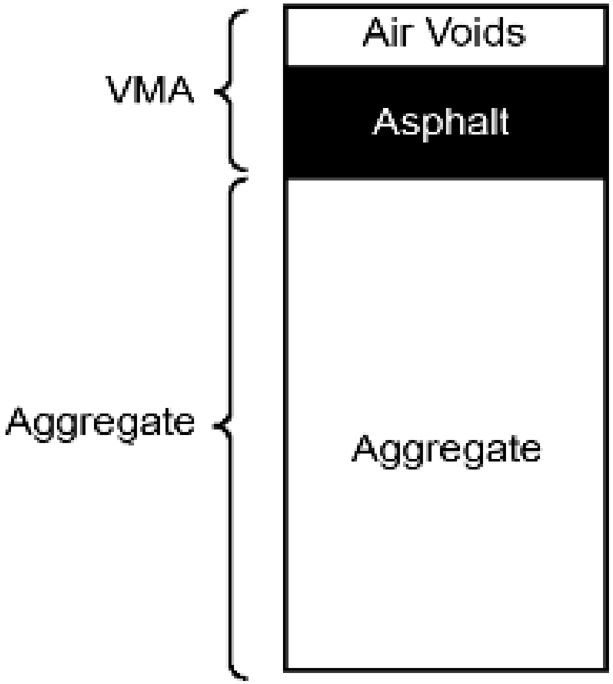
- Field performance has shown that typical mixtures designed with low air voids (maybe < 2%) are susceptible to rutting and shoving

- Mixtures designed over about 5% air voids are susceptible to raveling, oxidation and a general lack of durability

- 4% air void design is an empirically derived target that allows for thermal expansion of the binder along with a cushion for future compaction

Importance of VMA

- VMA is the volume of the voids in a compacted aggregate sample to accommodate asphalt and air.
  - Assure sufficient binder coating
  - Maintain 4% Air voids



Durability

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  - Resistance of asphalt mixture to disintegration due to the combined effects of weathering and traffic
    - Surface (wearing) mixes have most severe exposure
  - The most durable mixes have…
    - Good fatigue resistance
    - Low permeability to air and water
  - To accomplish this…
    - High binder content
    - Reasonable amount of fine material
  - …and most importantly…
    - Well-compacted during construction

NCHRP Report 673

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Table 6-1. Effect of mixture composition on performance.

Typical Effects of Increasing Given Factor within Normal Specification Limits
While Other Factors Are Held Constant within Normal Specification Limits

Component	Factor	Resistance to Rutting and Permanent Deformation	Resistance to Fatigue Cracking	Resistance to Low Temperature Cracking	Resistance to Moisture Damage	Durability/ Resistance to Penetration by Water and Air
Asphalt Binder	Increasing High Temperature Binder Grade	↑↑↑				
	Increasing Low Temperature Binder Grade			↓↓↓		
	Increasing Intermediate Temperature Binder Stiffness		↑↓			
Aggregates	Increasing Aggregate Angularity	↑↑				
	Increasing Proportion of Flat and Elongated Particles					
	Increasing Nominal Maximum Aggregate Size		↓	↓		↓
	Increasing Mineral Filler Content and/or Dust/Binder Ratio	↑↑				↑
	Increasing Clay Content				↓	
Volumetric Properties	Increasing Design Compaction Level	↑↑	↑↑			
	Increasing Design Air Void Content	↑↑				
	Increasing Design VMA and/or Design Binder Content	↓↓	↑	↓		
	Increasing Field Air Void Content	↓↓	↓↓	↓	↓↓	↓↓↓

NCHRP Report 673

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	Increasing Design Air Void Content	↑↑				
	Increasing Design VMA and/or Design Binder Content	↓↓	↑	↓		
	Increasing Field Air Void Content	↓↓	↓↓	↓	↓↓	↓↓↓

- Effect of Mix Variables on Fatigue Life
  - For every 1% increase in in-place air voids, relative fatigue life decreases by a nearly constant amount of about 22%.
    - An increase in in-place air voids of 2% will decrease fatigue resistance by nearly 50%.
    - Probably understates the importance of in-place air voids to fatigue life because it neglects the effect of changes in air voids on permeability and age hardening.
  - Other analytical studies (Linden et al.) showed a predicted 10% to 30% reduction in fatigue life for every 1% increase in in-place air voids
    - General rule of thumb is 10% overall reduction in performance for every 1% increase in in-place air void content.

- Effect of Mix Variables on Fatigue Life
  - Relationships exist between the fatigue resistance of asphalt mixtures and volumetric composition
    - Fatigue resistance increases with increasing volume of effective binder (VBE)
      - assuming no change in design compaction, design air voids and in-place air voids.
    - Fatigue resistance increases with increasing Ndesign
      - assuming no change in VBE, design air voids and in-place air voids.
    - Fatigue resistance increases with decreasing in-place air voids (increasing compaction)
      - Assuming no change in VBE, design air void content, and Ndesign.

NCHRP Report 567:

Volumetric Requirements for Superpave Mix Design

- Effect of Mix Variables on Fatigue Life
  - "Although an in-depth study of the effect of in-place air voids on pavement performance is outside the scope of this research, successful implementation of the results of this research will depend in part on achieving proper field compaction of mixtures designed according to the recommendations put forth in this report."

- Effect of Mix Variables on Age Hardening
  - Results partly confirmed a relationship between permeability and age hardening, in that the amount of age hardening clearly increased with increasing air voids.
  - The extent of age hardening also depended strongly on the specific aggregate and binder used in a mixture.

- Effect of Mix Variables on Age Hardening
  - Mixture age hardening increases with increasing air voids and decreasing aggregate specific surface.
    - Indicated by complex modulus
    - Age-hardening ratios decrease 2% to 7% for each 1% increase in FM300
    - Age-hardening ratios increase 5% to 14% for each 1% increase in field air voids at a MAAT of 15.6°C.
    - Combined effect of high air voids and low aggregate specific surface can increase age hardening by 50% or more.
  - Also strongly dependent upon the specific binder used and the MAAT.

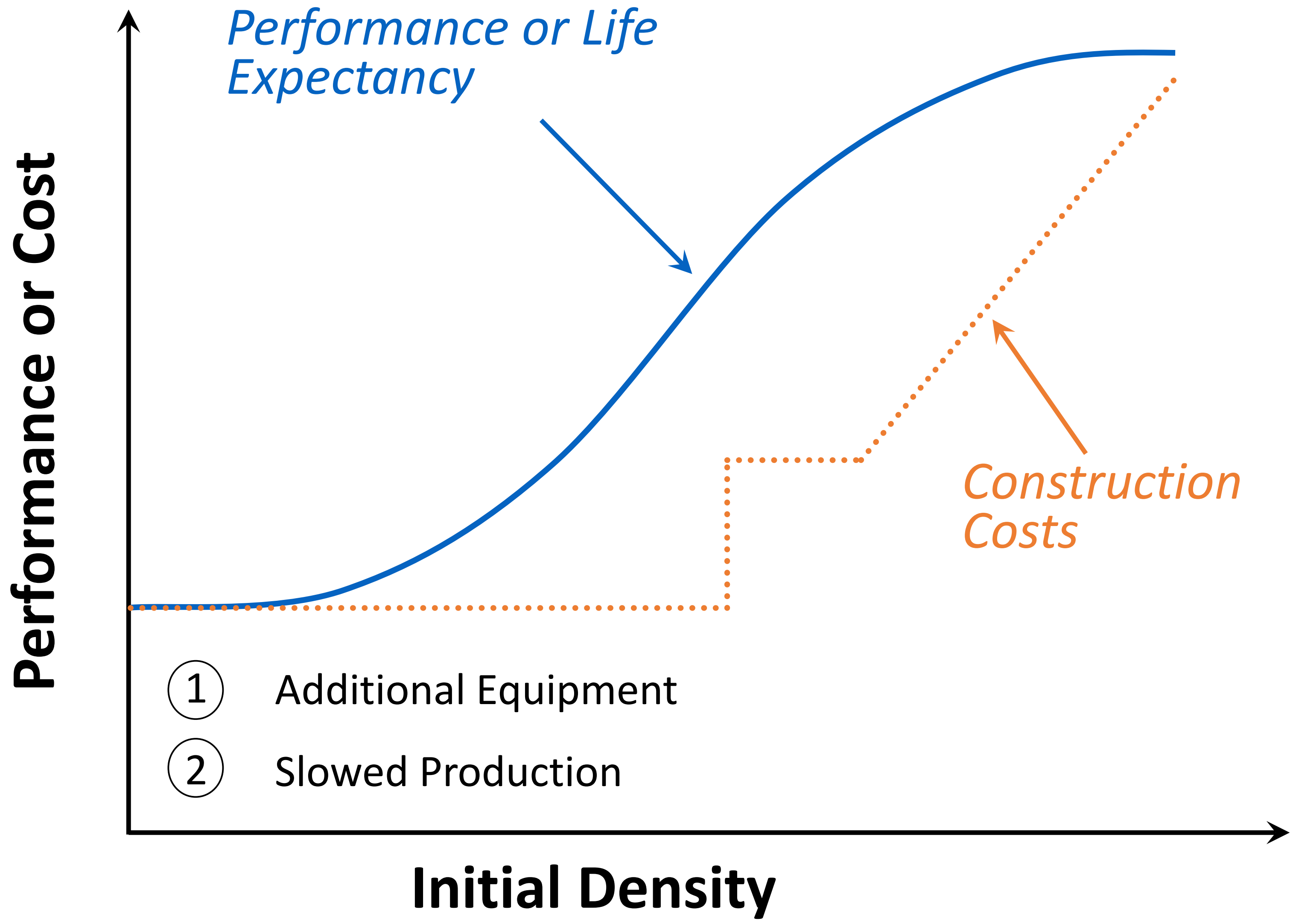
NCHRP Report 567:
Volumetric Requirements for Superpave Mix Design

- Effect of Mix Variables on Age Hardening
  - Increasing in-place air voids by 2%...
    - Increases age hardening by a factor of 2 at an MAAT of 15.6°C (60°F)
    - Increases age hardening by a factor of 3 at an MAAT of 23.9°C (75°F).
    - Comparable with the effect of decreasing FM300 by 5%.
      - Careful control of aggregate specific surface should help maintain good resistance to age hardening
  - "The very high binder viscosities that can potentially exist in aged pavements could contribute significantly to surface cracking by preventing any healing from occurring at the pavement surface during hot summer weather."

NCHRP Problem #2005-D-21

"The missing link in successful long-term performance of pavements is the construction of that pavement. …even a 10% greater success ratio for the pavements being built each year would represent a savings of millions of dollars to the states and other public agencies."

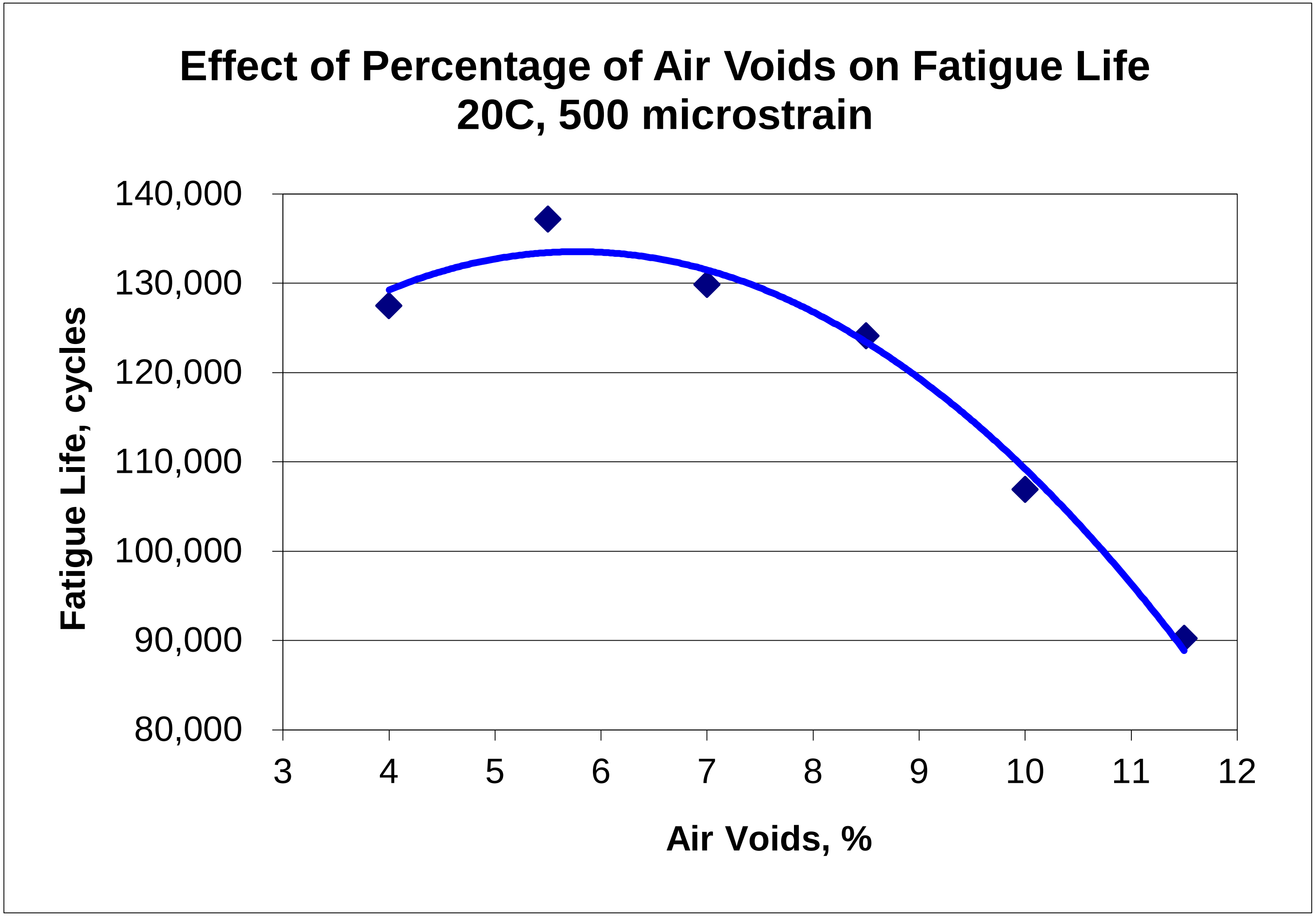
Effect of Density on Performance



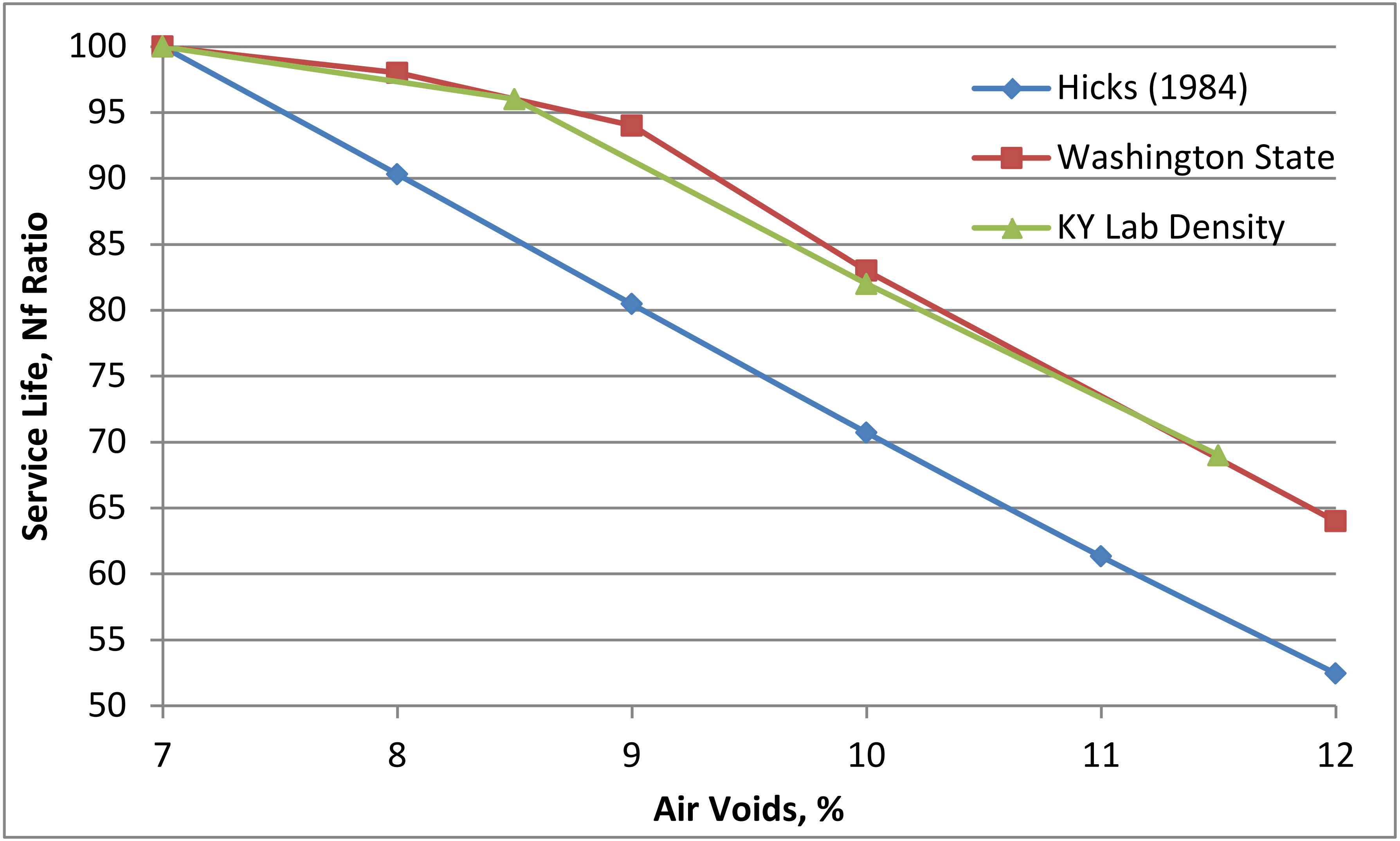
Kentucky Density Effects Study

- 12.5-mm Mixture
  - Crushed Limestone (80-90%) and Natural Sand (10-20%)
  - PG 76-22 asphalt binder
    - Typical asphalt binder for interstate applications in Kentucky
  - Three Asphalt Binder Contents
    - Optimum (4.8%)
    - Low (4.3%)
    - High (5.3%)

Kentucky Density Effects Study



Effect of Voids on Service Life, Nf



Kentucky Density Effects Study

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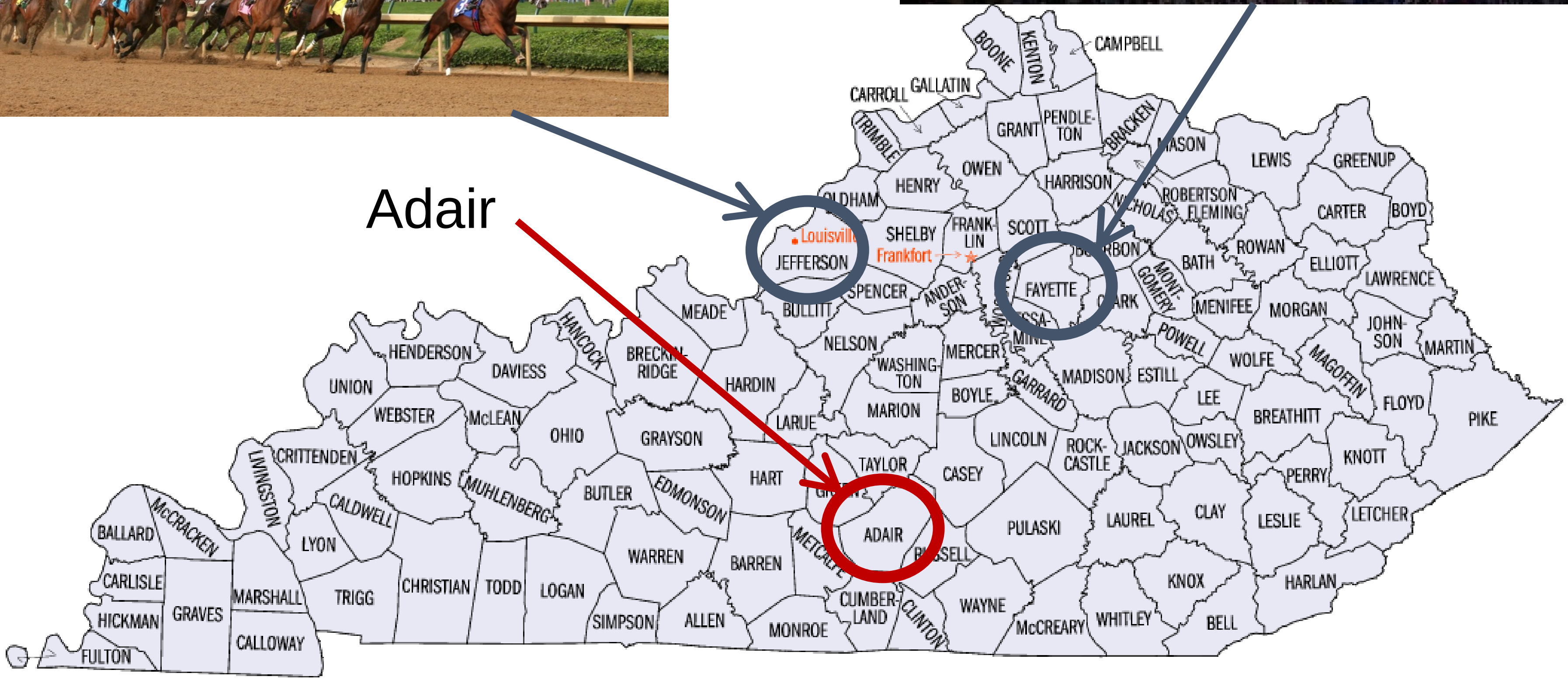
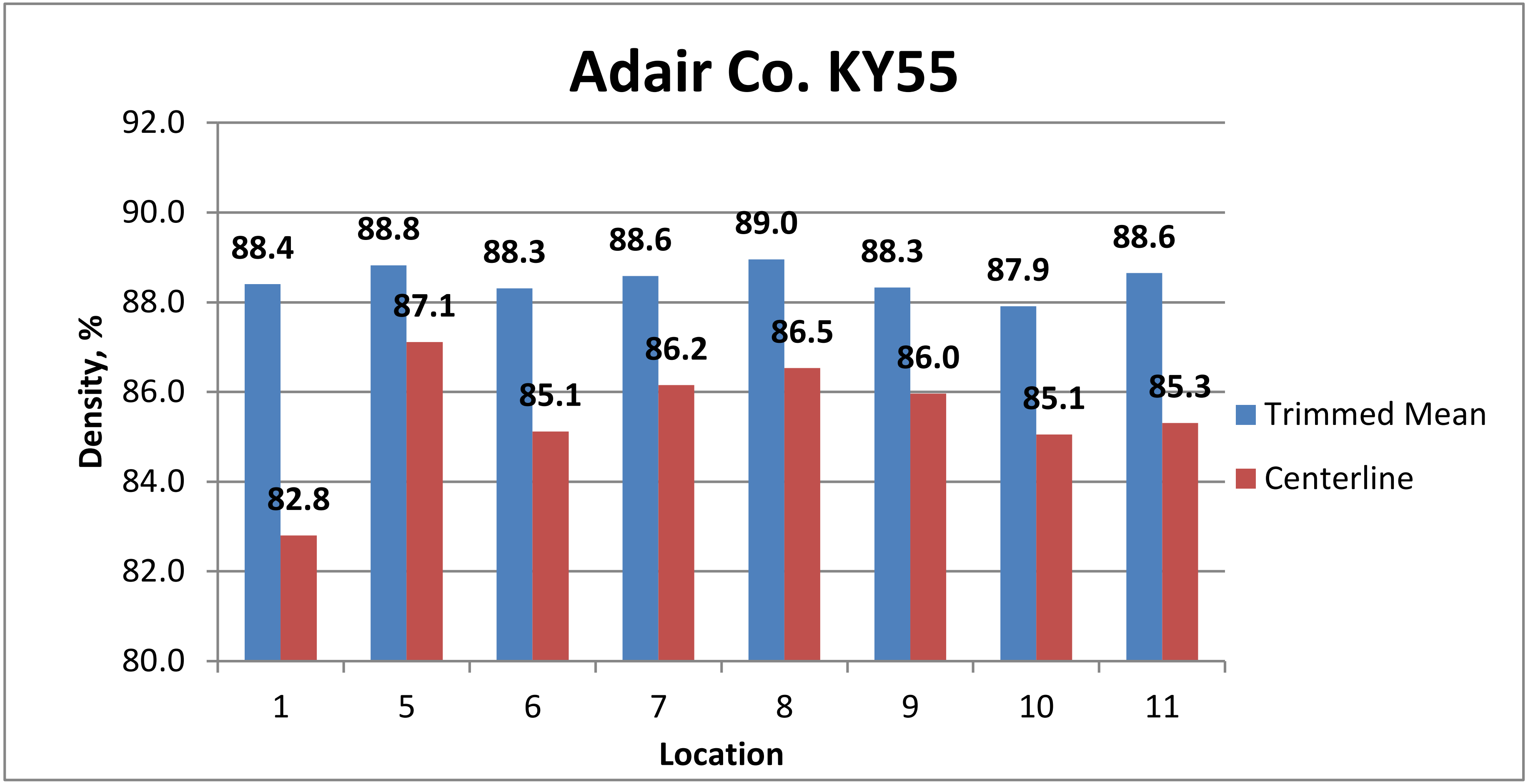
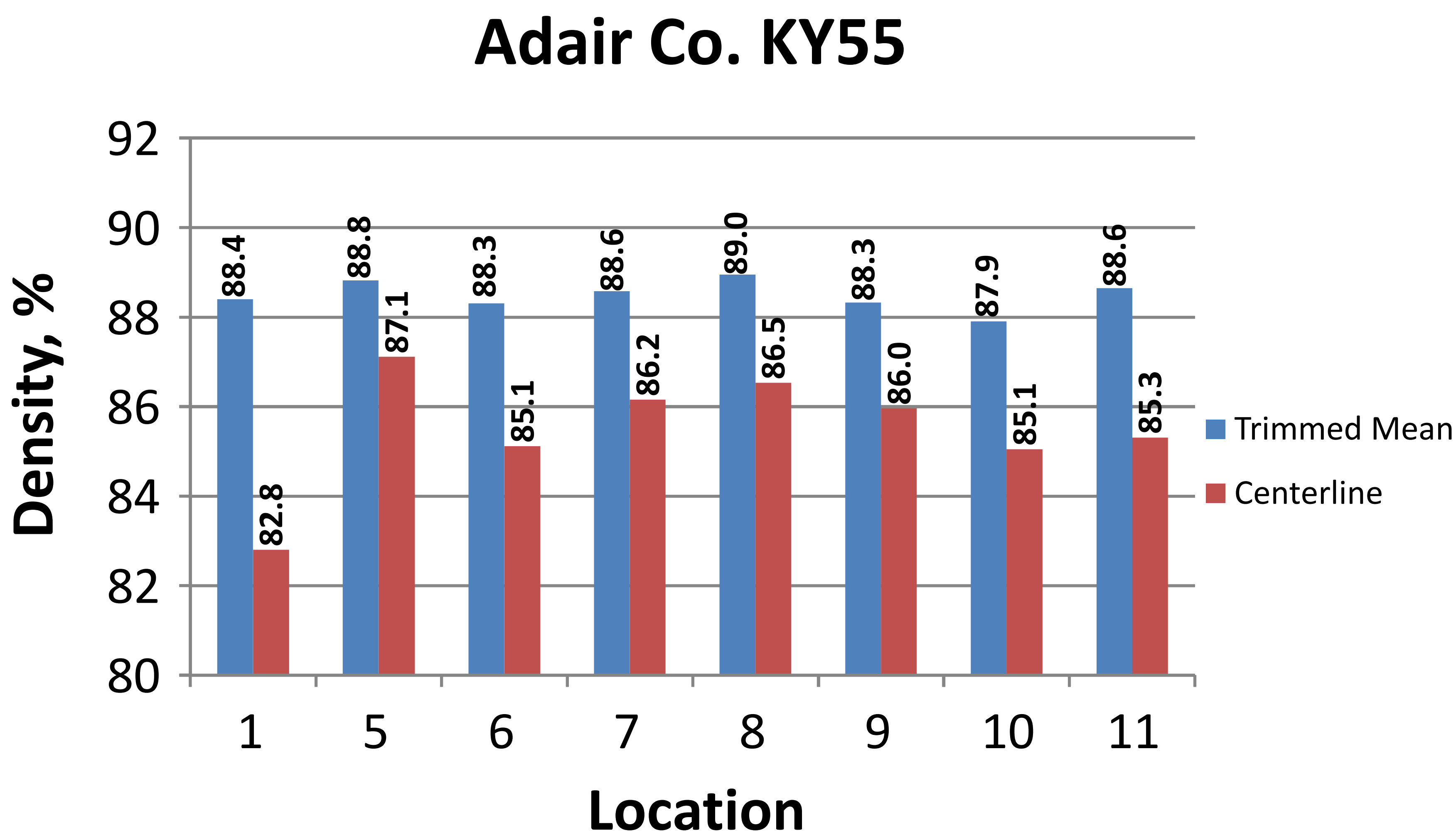
Adair



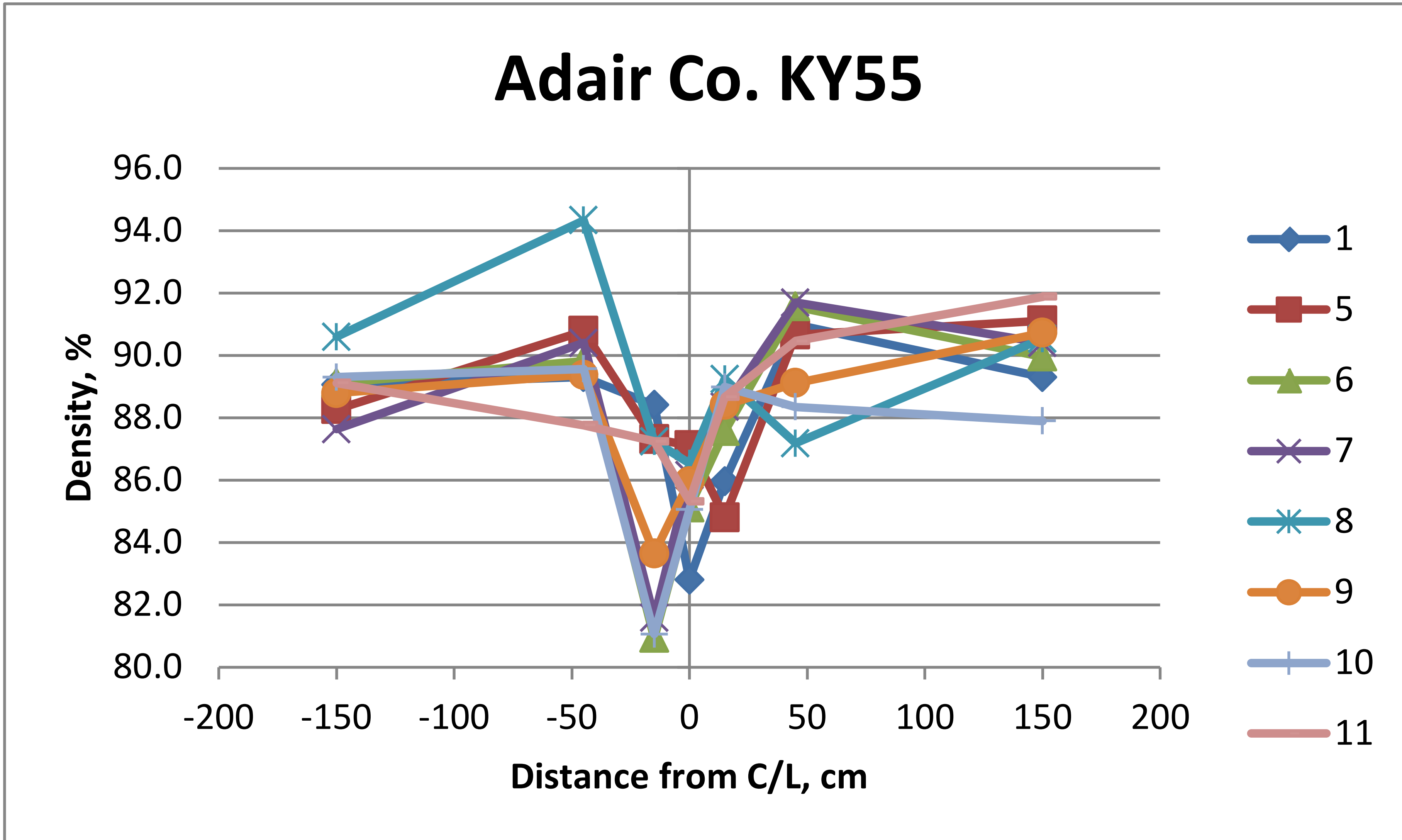
Kentucky Density Effects Study



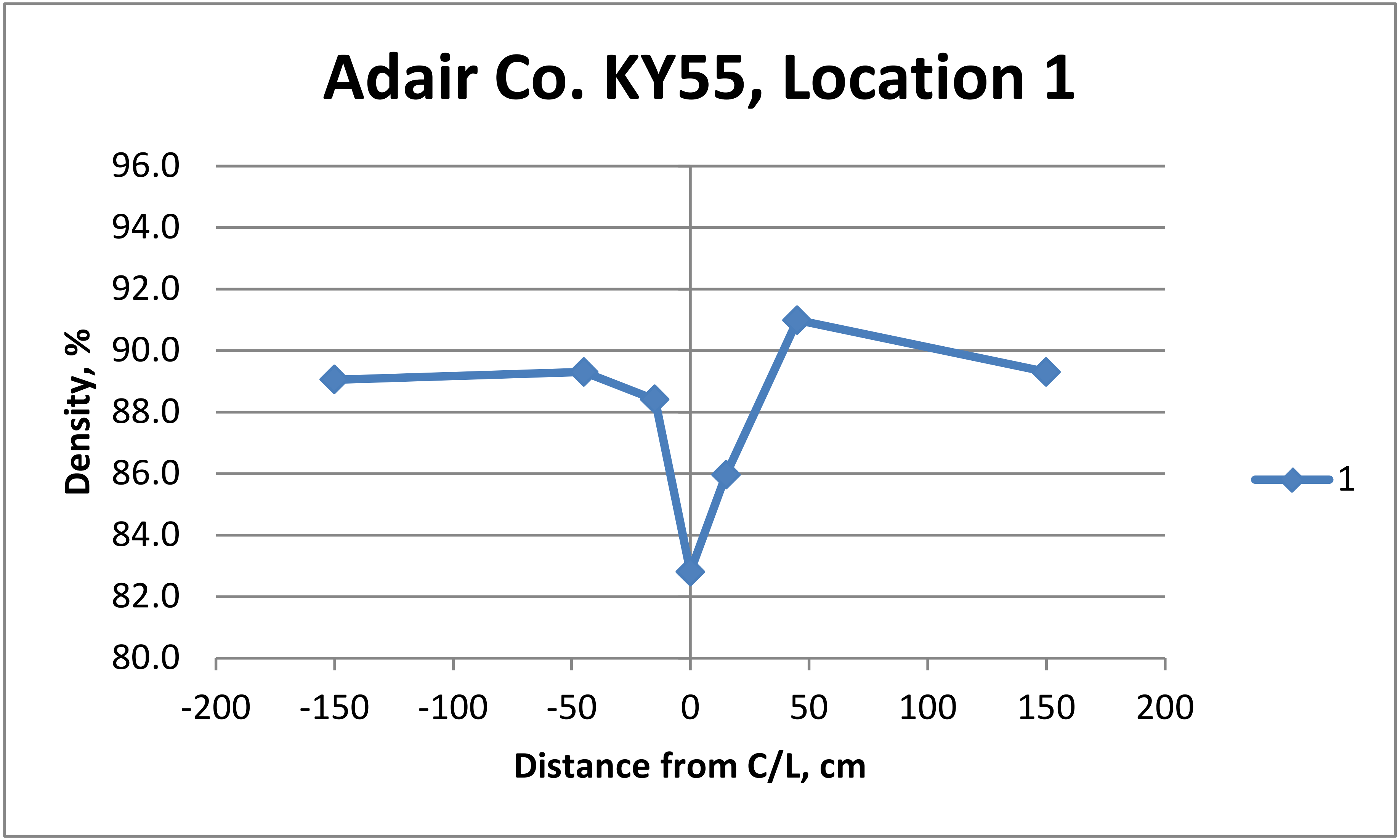
Kentucky Density Effects Study



Kentucky Density Effects Study



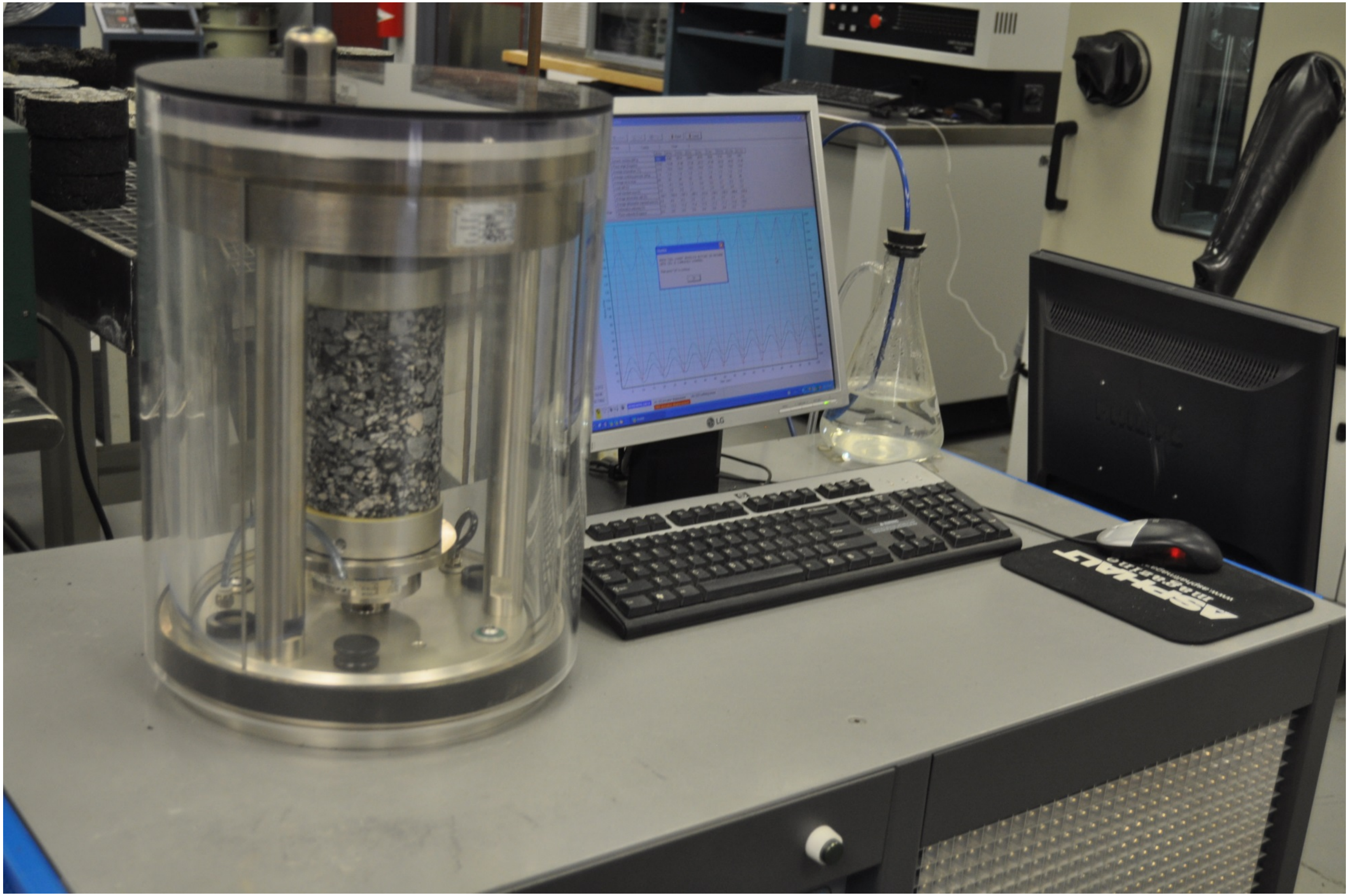
Kentucky Density Effects Study



Kentucky Density Effects Study

- Testing of Field Mix Samples
  - Assume any given sample represented the entire project
    - BIG assumption, but better than sampling and testing at every location
  - Compact specimens in lab (SGC) to 92% density (8% air voids) and air voids representing average project density
    - average of trimmed mean at each sampling location
  - Conduct rutting, fatigue, low temperature cracking tests on each mix

AMPT – Flow Number



AMPT Flow Number Results

(Figure from NCHRP Report 673)

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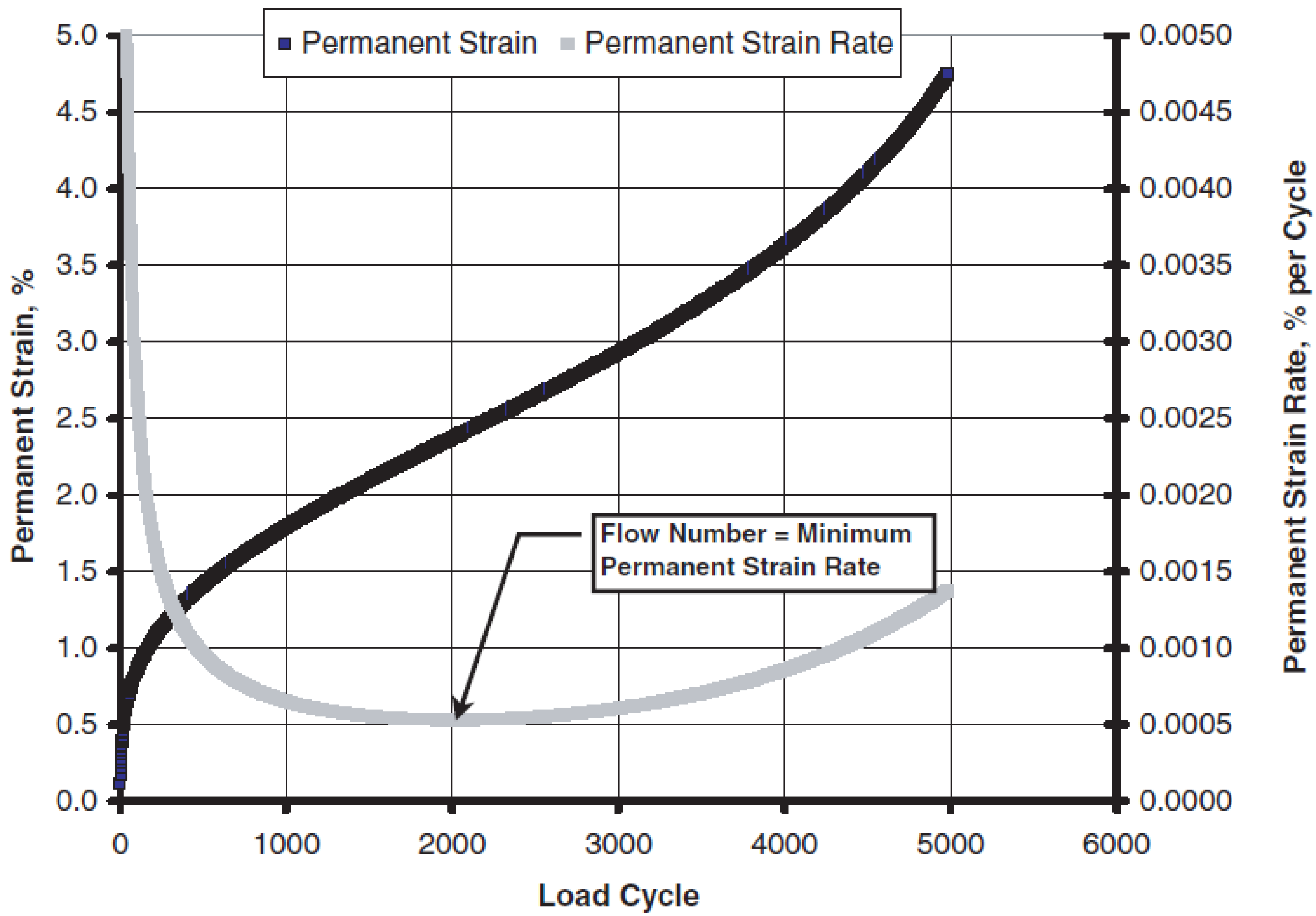

Figure 6-2. Typical data from the flow number test.

AMPT Flow Number

- Established standard test conditions
  - Unconfined
  - 600 kPa axial stress
  - 0.1-second pulse loading, 0.9-second rest period
  - 10,000 cycles maximum
  - 100 mm diameter by 150 mm height specimens
  - 7.0% air voids (mix design)
  - Test temperature equal to the average 7-day maximum pavement temperature at a depth of 20 millimeters for the project location (the “50% Reliability” temperature in LTPPBind software Version 3.1)

AMPT Flow Number: Recommended Criteria

- Recommended criteria from NCHRP Report 673
  - Uses calculated Flow Number

Traffic (ESAL)	Flow Number, cycles
<3	n/a
3 to <10	≥ 53
10 to <30	≥ 190
≥30	≥ 740

Kentucky Density Effects Study: Flow Number (Rutting)

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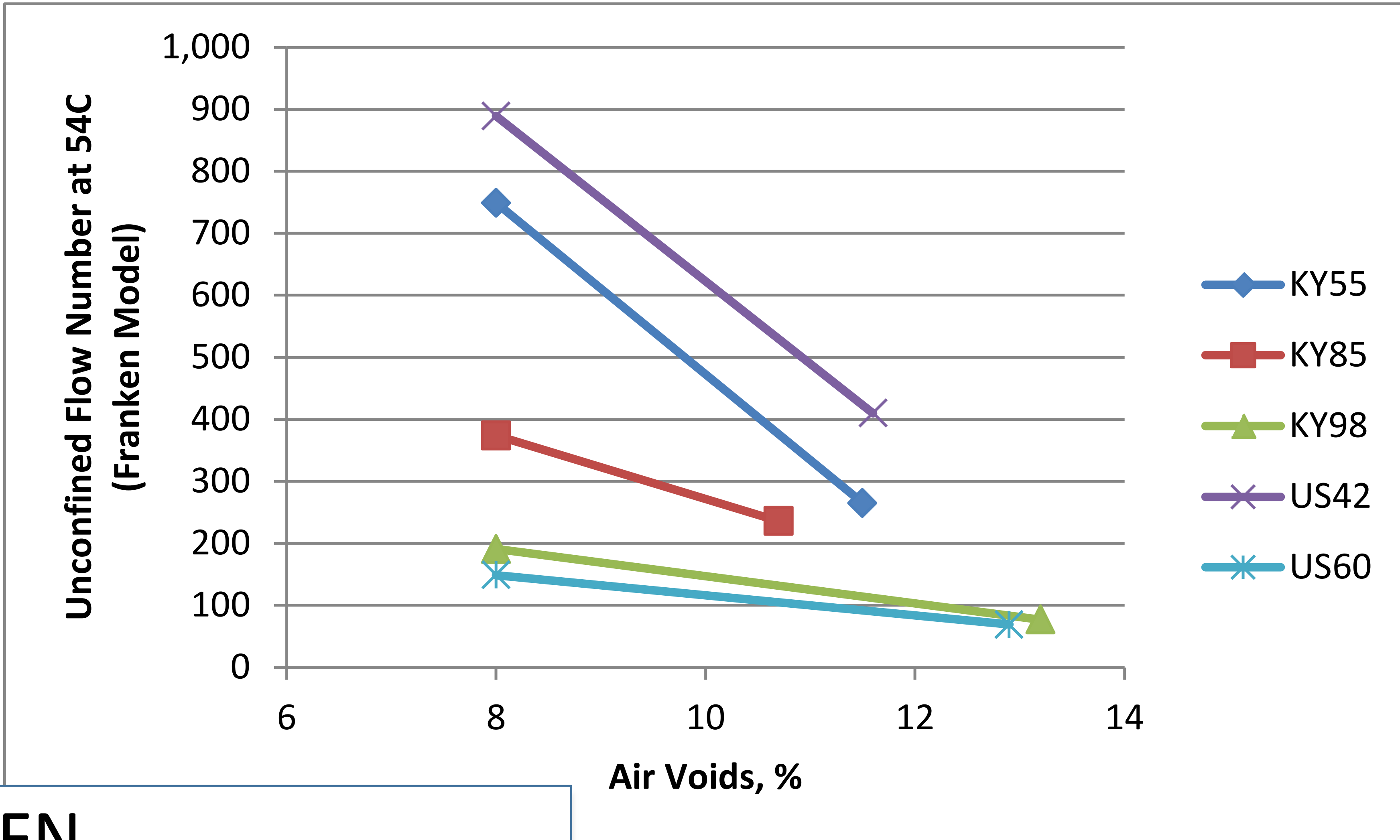

$$\frac{FN_{Project}}{FN_8} \approx 0.46$$

Flexural Beam Fatigue (IPC)

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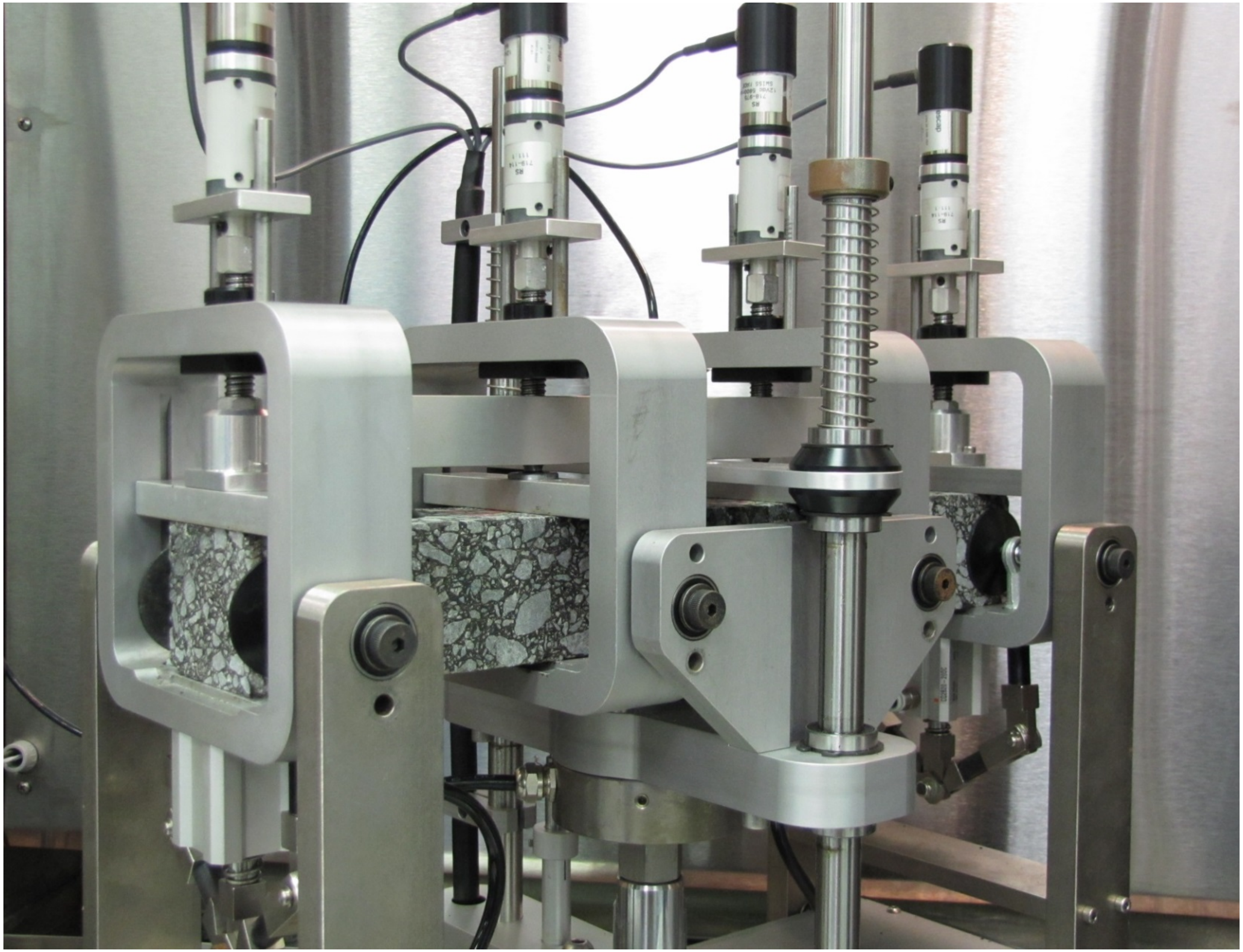
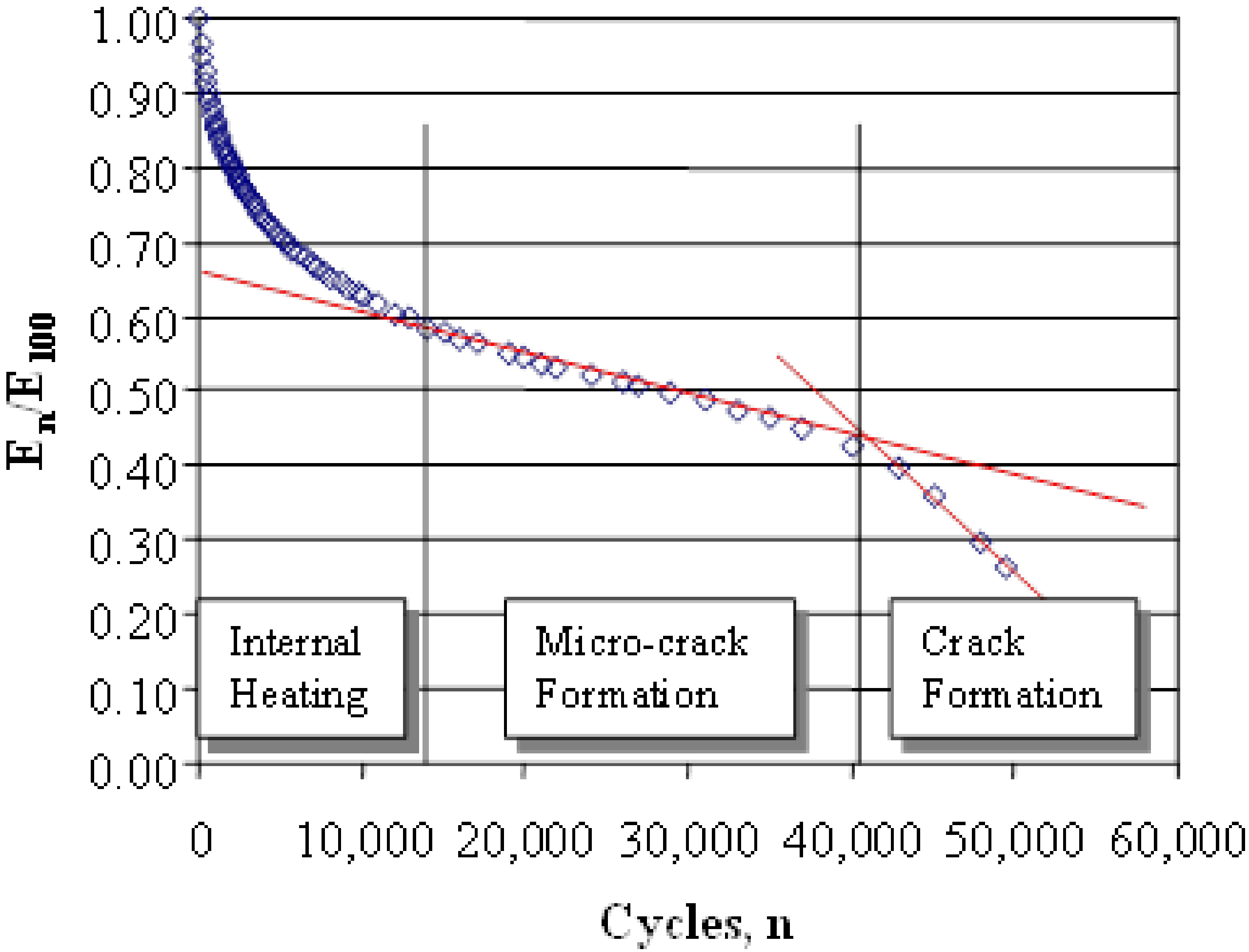
Fatigue Testing



Flexural Beam Fatigue Test



Fatigue Testing

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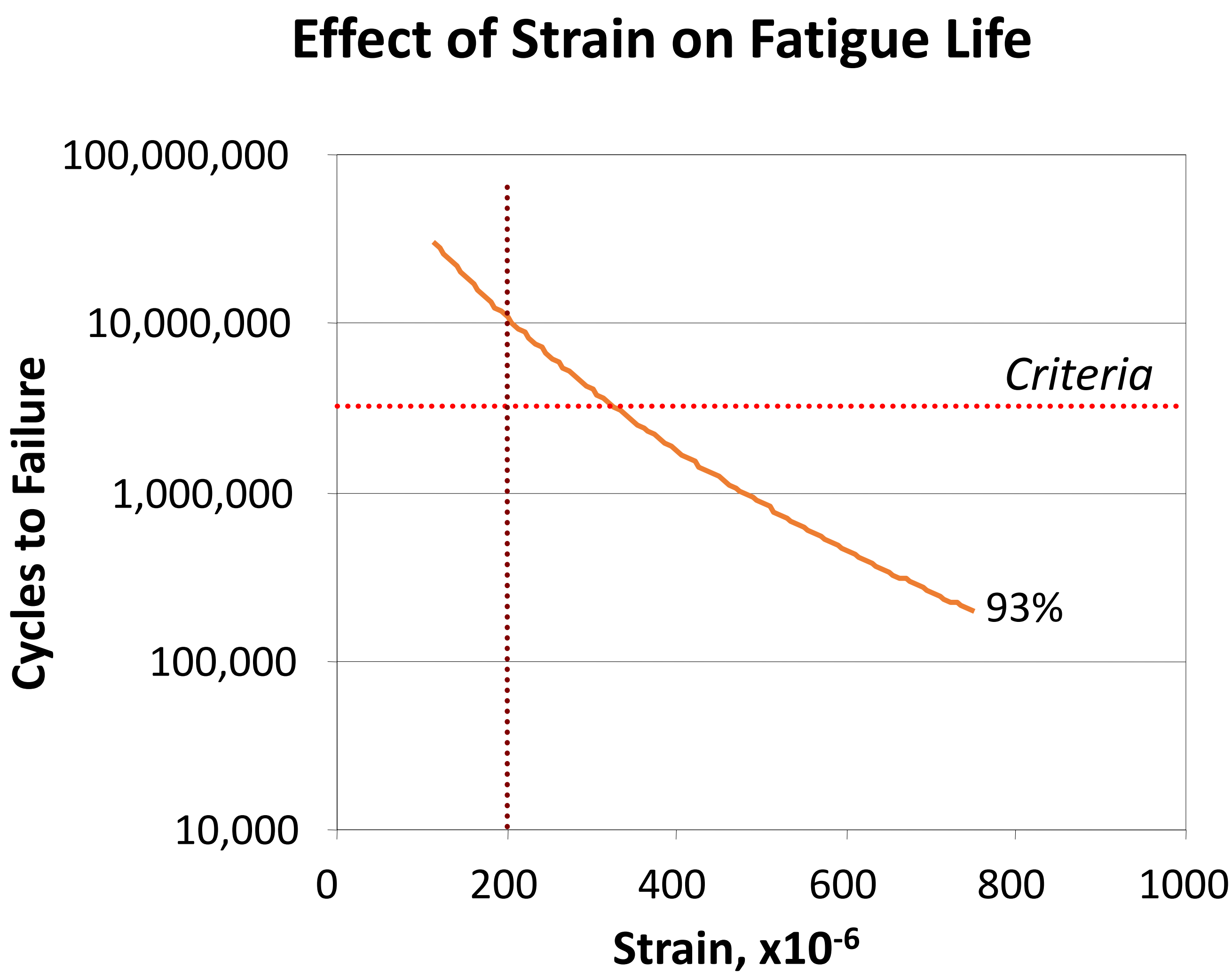
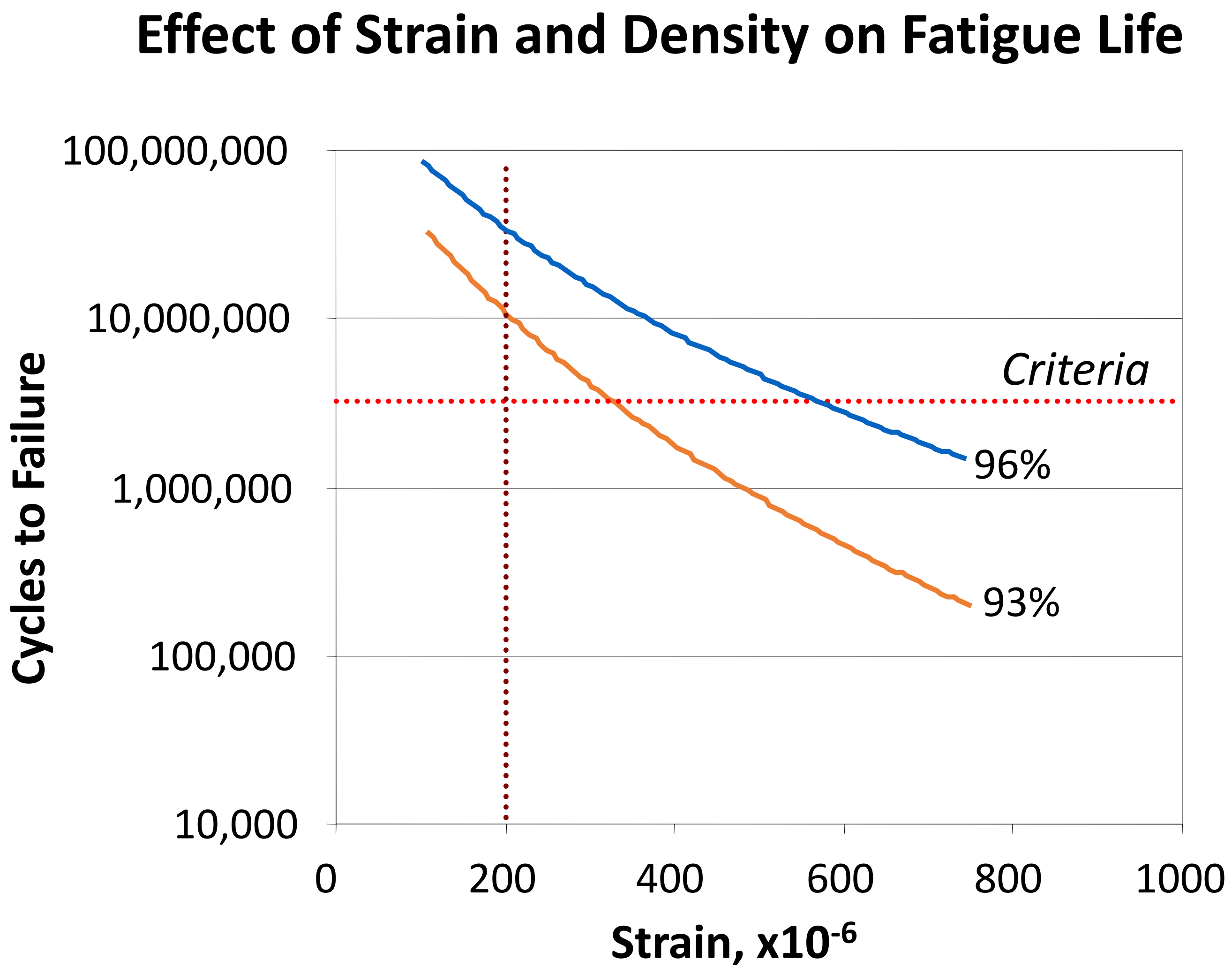
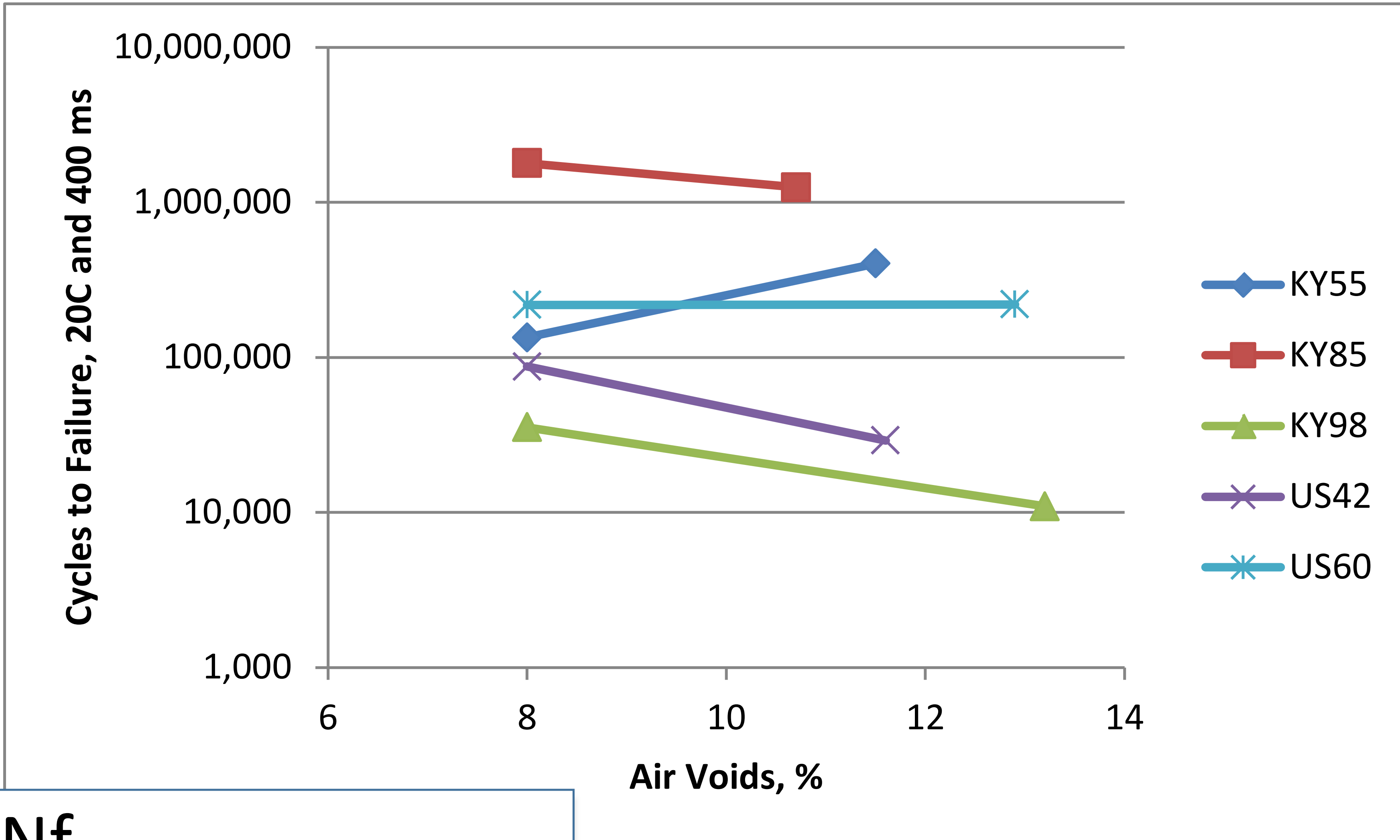


Fatigue Testing



Kentucky Density Effects Study: Fatigue Cycles to Failure (Cracking)



$$\frac{Nf_{Project}}{Nf_{8}} \approx 0.59$$

Range from 30%-100%

Disk-Shaped Compact Tension Test: DC(T)

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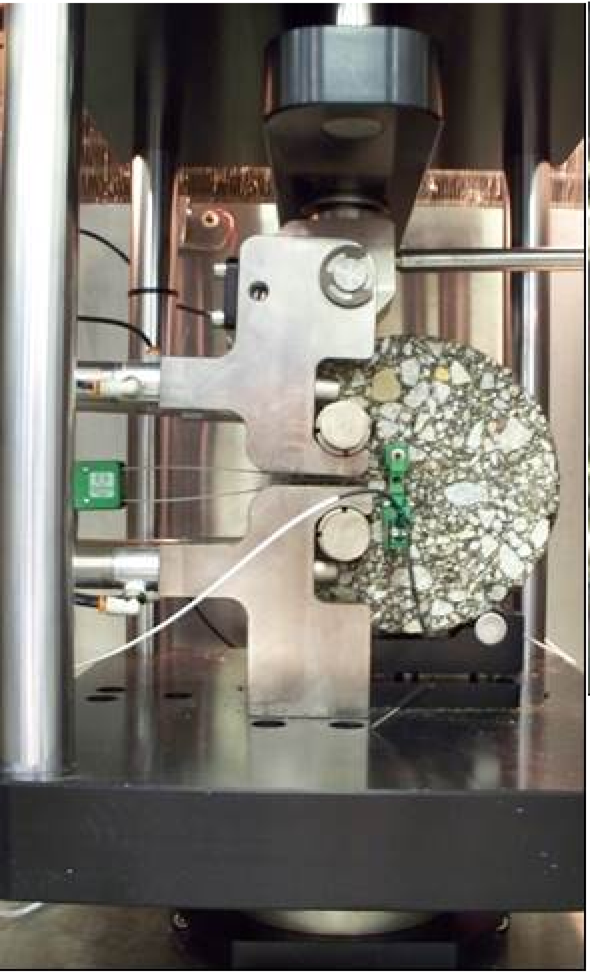
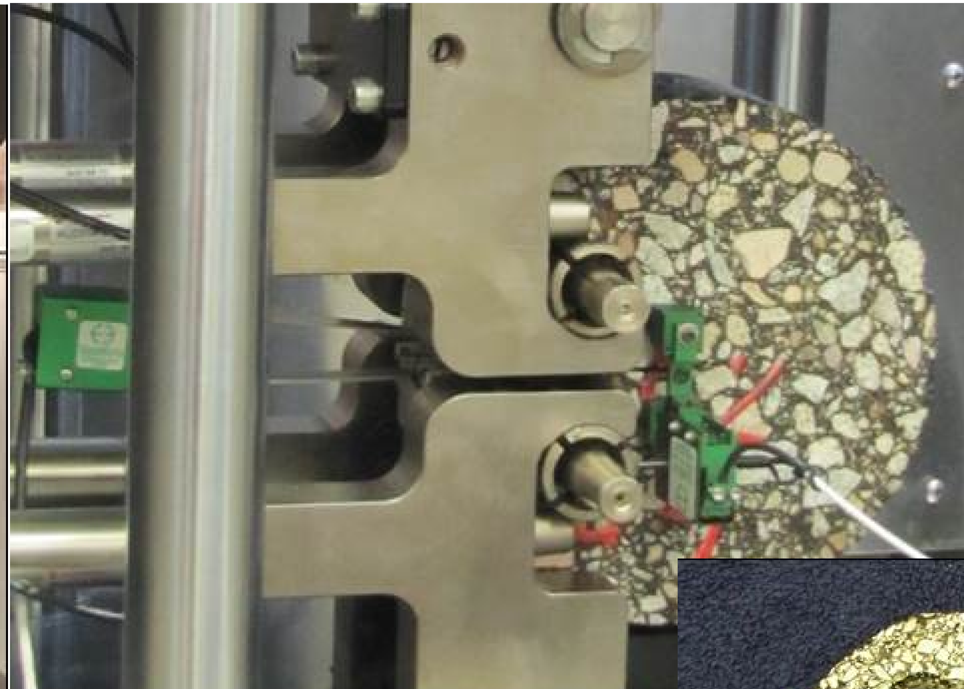
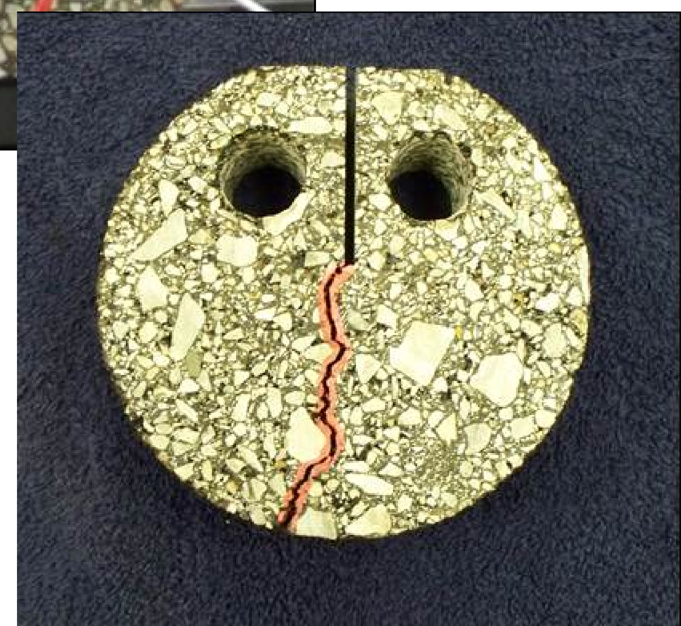
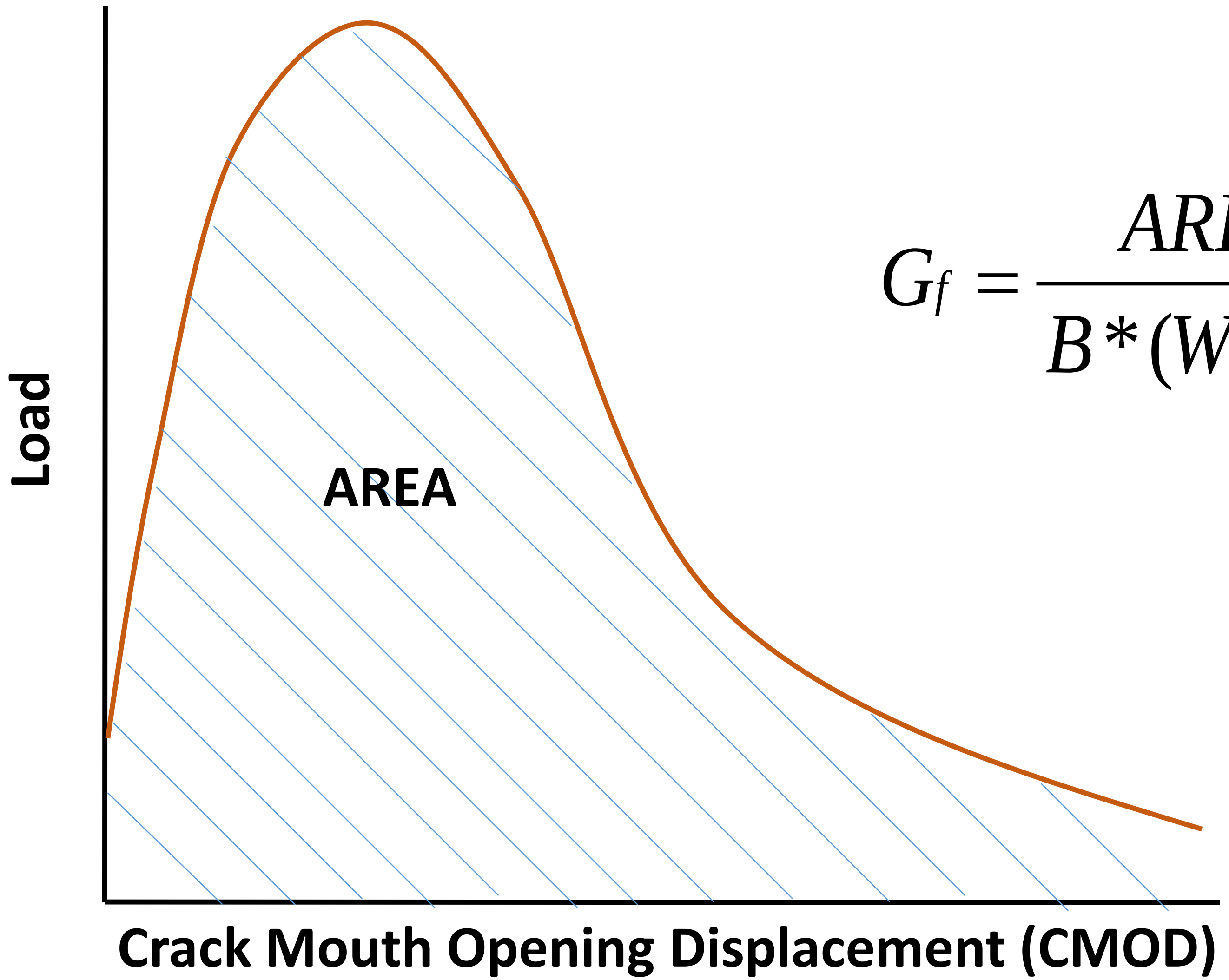




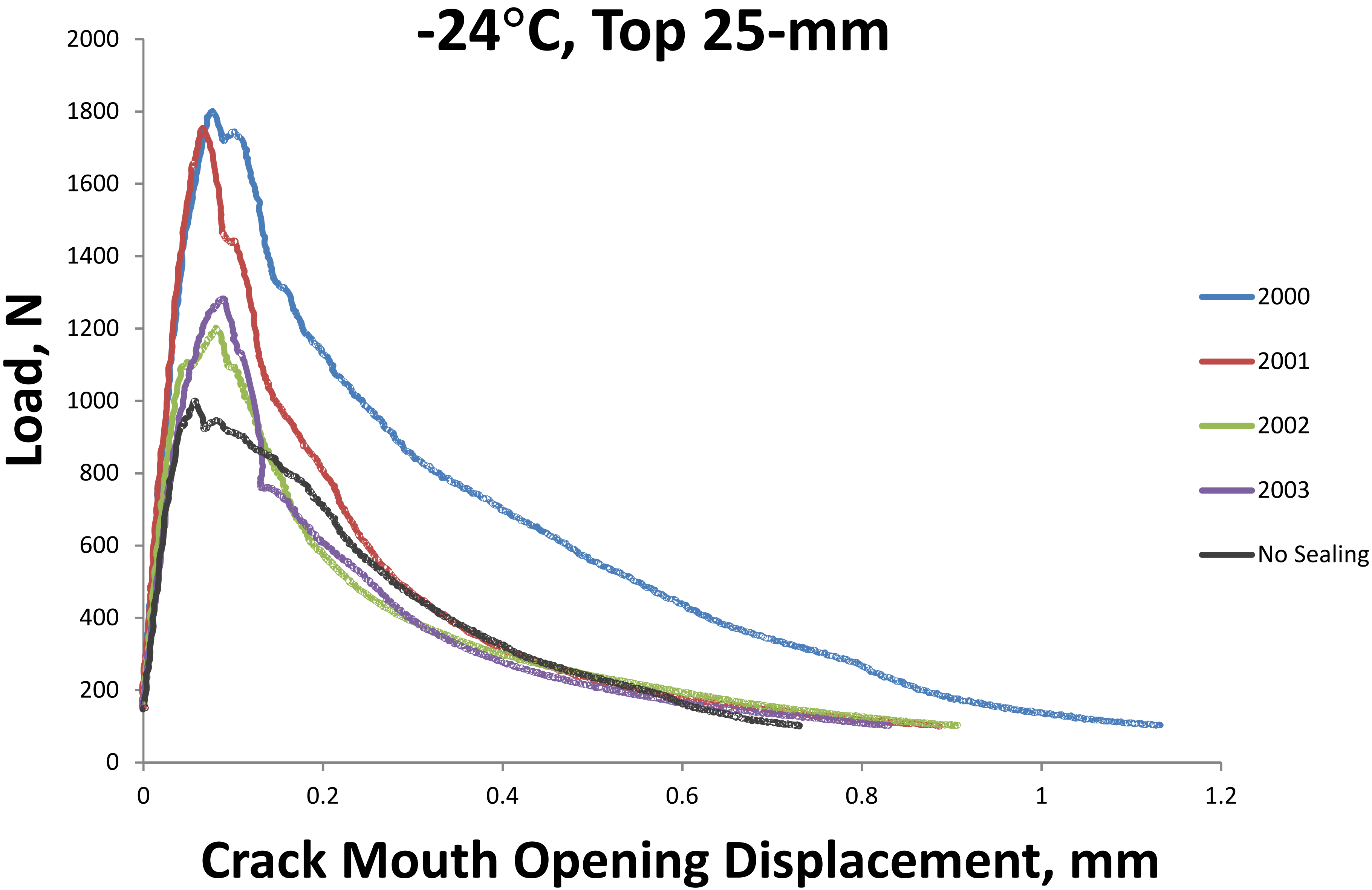


DC(T) Output

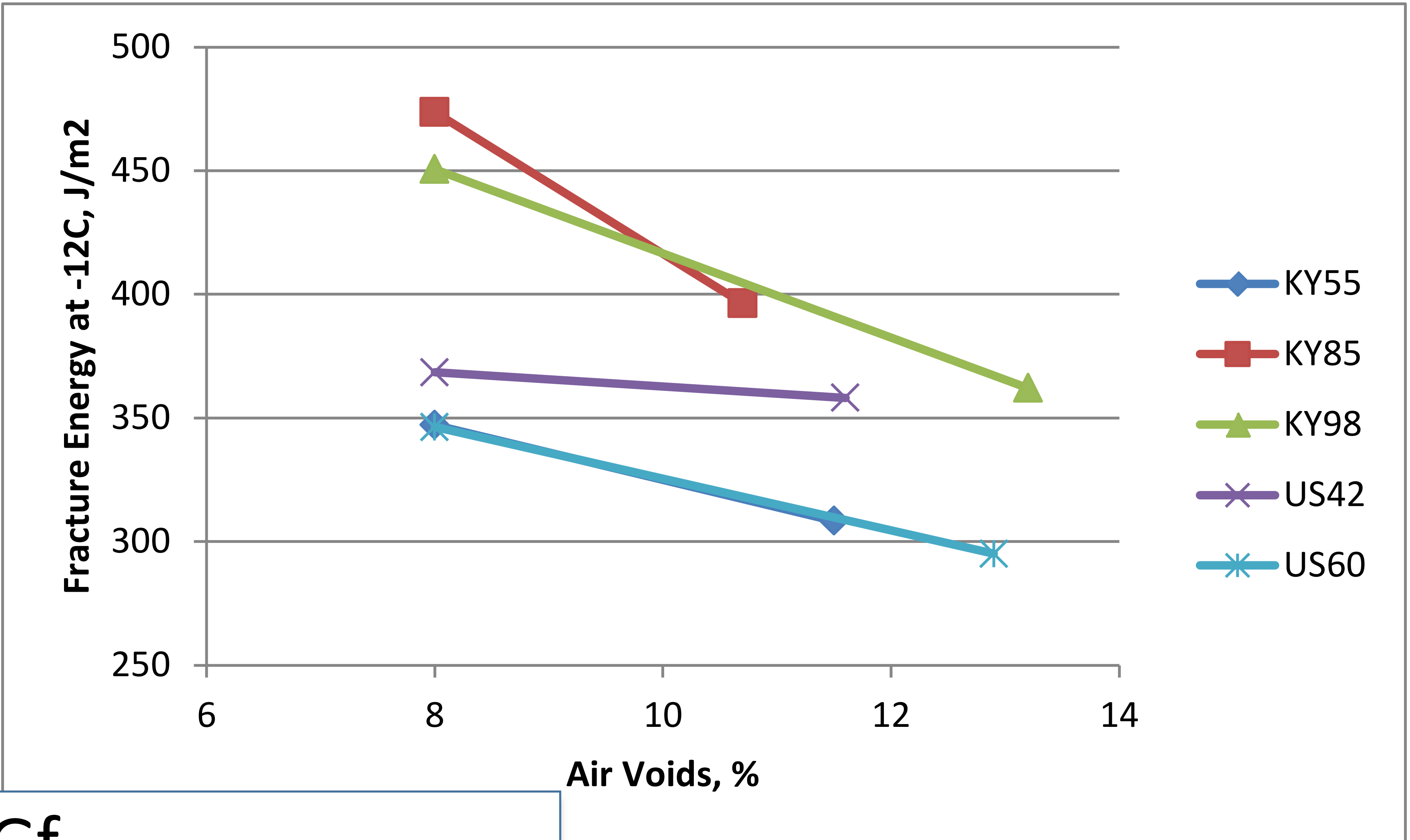


$$G_f = \frac{AREA}{B*(W-a)}$$

DC(T) Results: MN TH-56

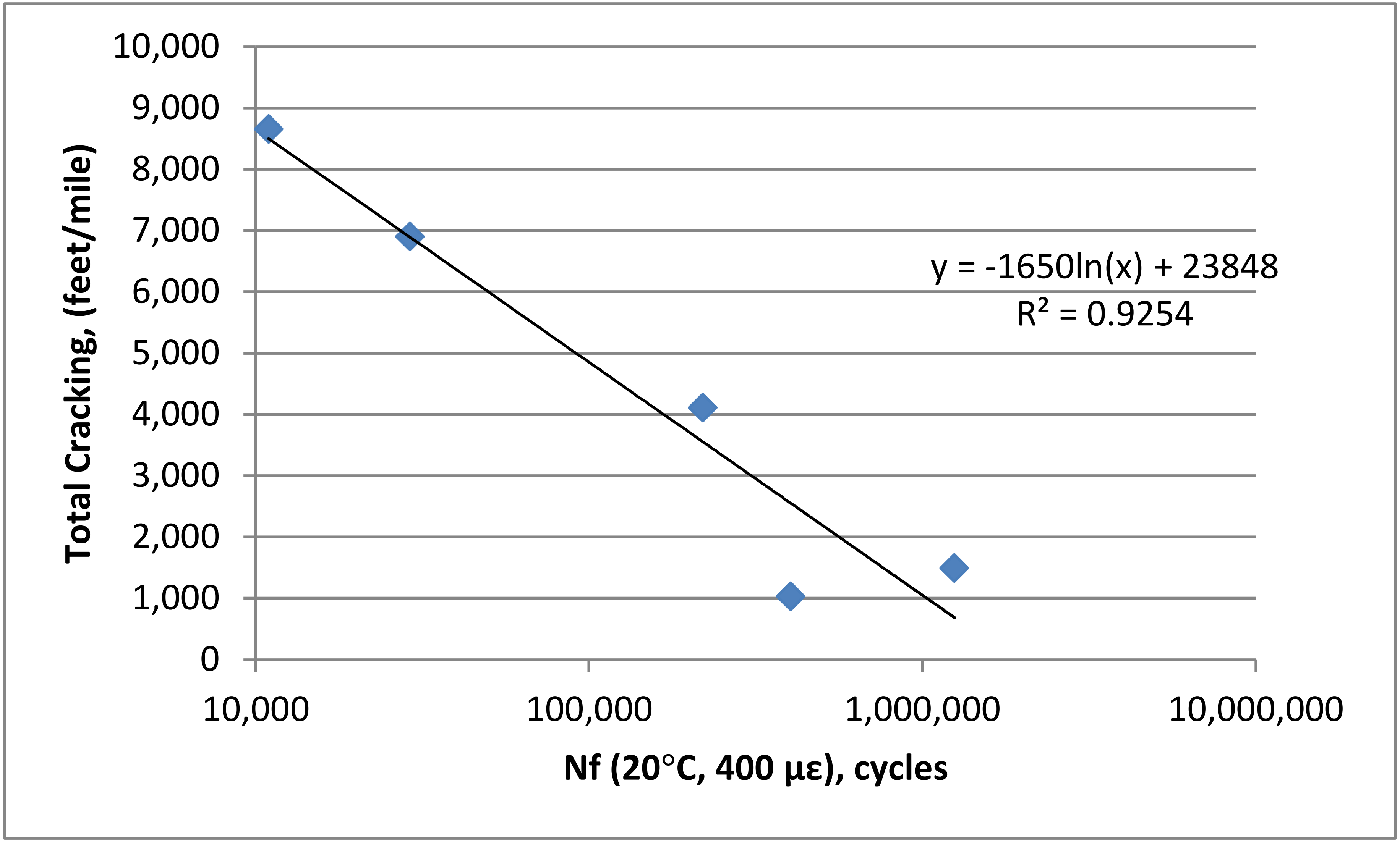


Kentucky Density Effects Study: Fracture Energy (Cracking)



$$\frac{Gf_{Project}}{Gf_8} \approx 0.87$$

Kentucky Density Effects Study



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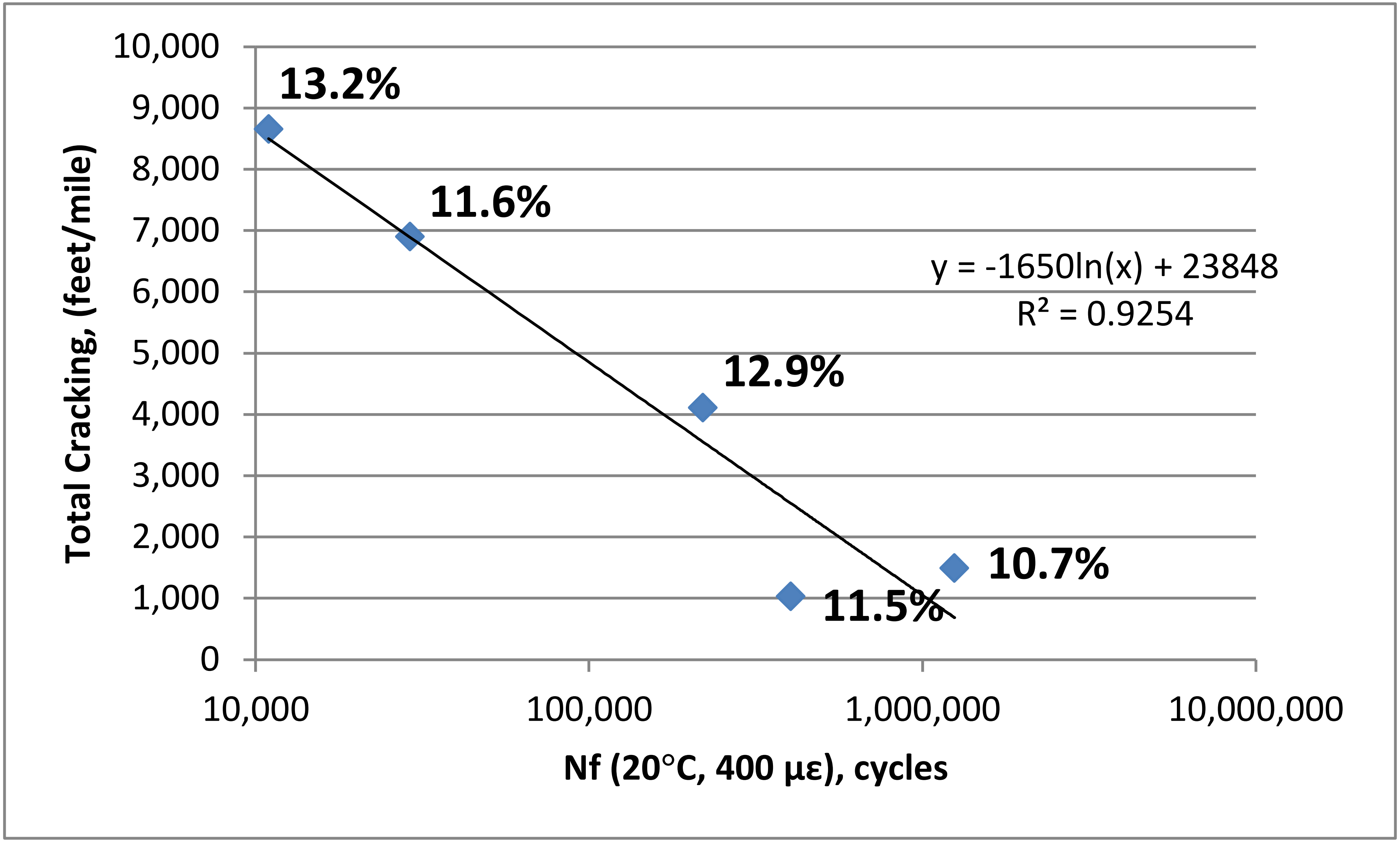

Durability and Recycled Materials

- A few words about durability and recycled materials (e.g., RAP and RAS)…
  - Understand effects of materials
    - Adding age-hardened asphalt binder with reduced relaxation to mix in some proportion
    - "The very high binder viscosities that can potentially exist in aged pavements could contribute significantly to surface cracking by preventing any healing from occurring at the pavement surface during hot summer weather." ~ NCHRP Report 567

Durability and Recycled Materials

- A few words about durability and recycled materials (e.g., RAP and RAS)…
  - Understand effects of materials
    - Properly account for amount of recycled binder that is available for use by the mix (i.e., how well is it actively blended?)
      - Can lead to under-asphalted mixes
    - If using premium asphalt binders, consider impact of added aged binder
      - Reduction in polymer loading?
  - Mix performance testing

Fatigue Study: Effect of Modifier Concentration

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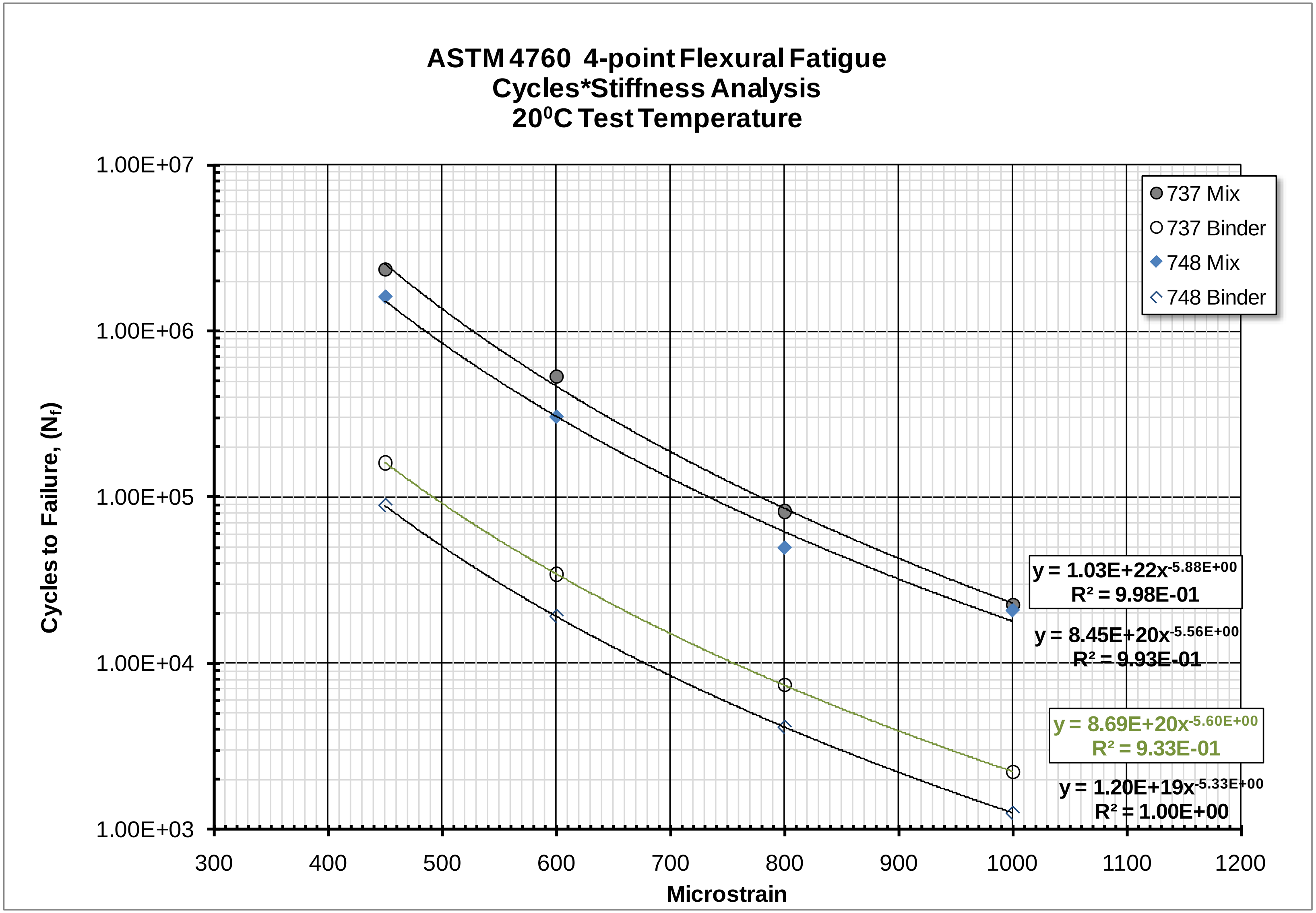

Fatigue Study: Effect of Modifier Concentration

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	N_f			
	Binder Strain (E-06)			
Binder	22,500	30,000	40,000	50,000
737	1.61E+05	3.45E+04	7.37E+03	2.23E+03
748	8.86E+04	1.91E+04	4.13E+03	1.26E+03
Ratio 748/737	55%	56%	56%	57%

	N_f			
	Mix Strain (E-06)			
Mixture	450	600	800	1000
737	2.33E+06	5.35E+05	8.19E+04	2.25E+04
748	1.61E+06	3.05E+05	4.98E+04	2.09E+04
Ratio 748/737	69%	57%	61%	93%

Summary

- Mixture Durability
  - Proper materials
    - Asphalt binder, aggregate, recycled materials
  - Proper design volumetric properties (air voids, VMA)
    - Appropriate (sufficient!) design asphalt binder content
    - Gradation to minimize permeability
  - Proper as-produced properties
    - Volumetric properties
    - Asphalt binder content
    - Gradation
  - Proper construction
    - Well-compacted

Thanks!

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