

UPDATE on Study of Impact of Loose
Mix Aging Time and Temperature on
the Mechanistic Performance of Hot
and Warm Bituminous Mixtures
MTE SERVICES, INC

WARM MIX TECHNICAL WORKING GROUP MEETING
DECEMBER 15-16, 2009
SEATTLE, WA

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OVERVIEW OF LAB STUDY-1

1. HOT MIX PRODUCED WITH 0% & 20% RAP USING PG 58-28 BINDER
2. MIXED & CURED AT 275°F
3. LOOSE MIX CURED FOR 0.5, 2 AND 4 HRS
4. HAMBURG RUT PILLS FOR DRY & WET TESTING PRODUCED
5. AMPT PILLS PRODUCED FOR E* AND FLOWNUMBER TESTING

OVERVIEW OF LAB STUDY-2

1. WARM MIX PRODUCED WITH 0% & 20% RAP USING PG 58-28 BINDER
2. USED 0.5% EVOTHERM 3G IN BINDER
3. MIXED @ 230°F & CURED AT 220°F
4. LOOSE MIX CURED FOR 2, 4 AND 8 HRS
5. HAMBURG RUT PILLS FOR DRY & WET TESTING PRODUCED
6. AMPT PILLS PRODUCED FOR E* AND FLOWNUMBER TESTING

OVERVIEW OF LAB STUDY-3

1. BINDER EXTRACTED FROM DRY HAMBURG RUT PILLS, RECOVERED, PG GRADED
2. ADDITIONAL SPECIMENS PRODUCED WARM AT 4 HRS CURING TIME USING
 - a) WATER ONLY (250°F, 235°F)
 - b) WAX (220°F)
 - c) HAMBURG TESTING @ 58°C DRY
 - d) BINDER RECOVERED, $G^*/\text{SIN}(\delta)$, J_{nr}

OVERVIEW OF LAB STUDY-4

1. **ADDITIONAL STUDIES USING 64-22 FOLLOWING ABOVE TESTING PROGRAM BEING CONDUCTED BY PARAGON TECHNICAL SERVICES AND THE ASPHALT INSTITUTE**
 - a) **Limited data available from work done by AI**
 - b) **HMA & WMA mixes produced with virgin aggregate**
 - c) **Different mix aging periods**
 - d) **Dry Hamburg rut testing performed at MTE**

GOALS OF STUDY EFFORT

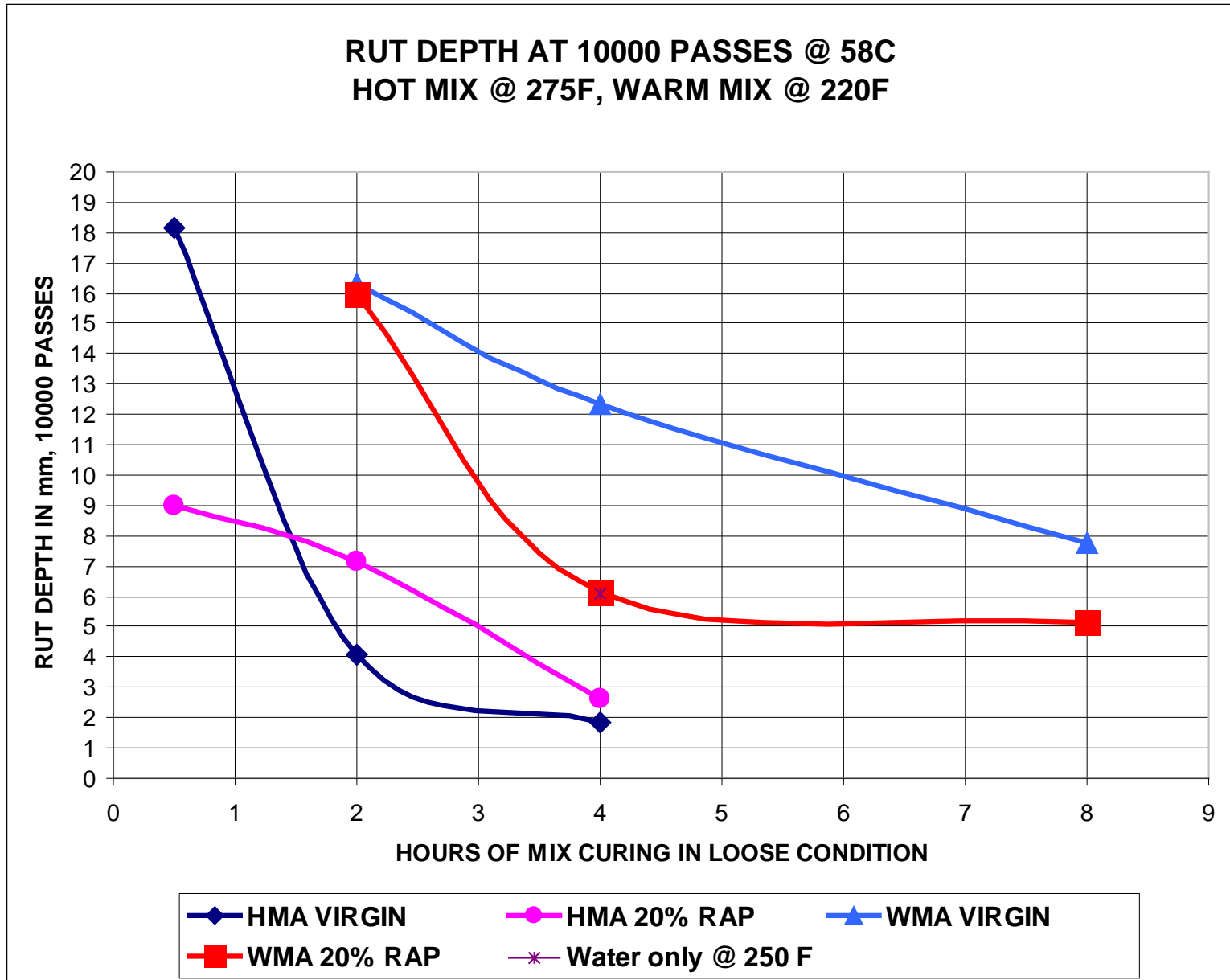
- 1. ATTEMPT TO ARRIVE AT MIX CONDITIONING TIMES FOR WMA THAT MATCHES HMA CONDITIONING AT 2 HRS**
- 2. EVALUATE THE IMPACT OF RAP ON WARM MIX PERFORMANCE**
 - a) TO WHAT EXTENT DOES WARM MIX MITIGATE THE STIFFNESS OF THE RAP IN THE MIX**
 - b) WHAT EVIDENCE IS THERE FOR THE ACTIVATION OF RAP AT WARM MIX TEMPERATURES**

**ALL MIXES RUN WITHOUT ADDITIONAL BINDER THROUGH
MATHY BATCH PLANT AT CONDITIONS SHOWN
PICTURE COURTESY OF ROGER OLSON**



Warm temp 220°F 24% RAP, High temp 300°F 24% RAP and High temp 300°F 10% RAP

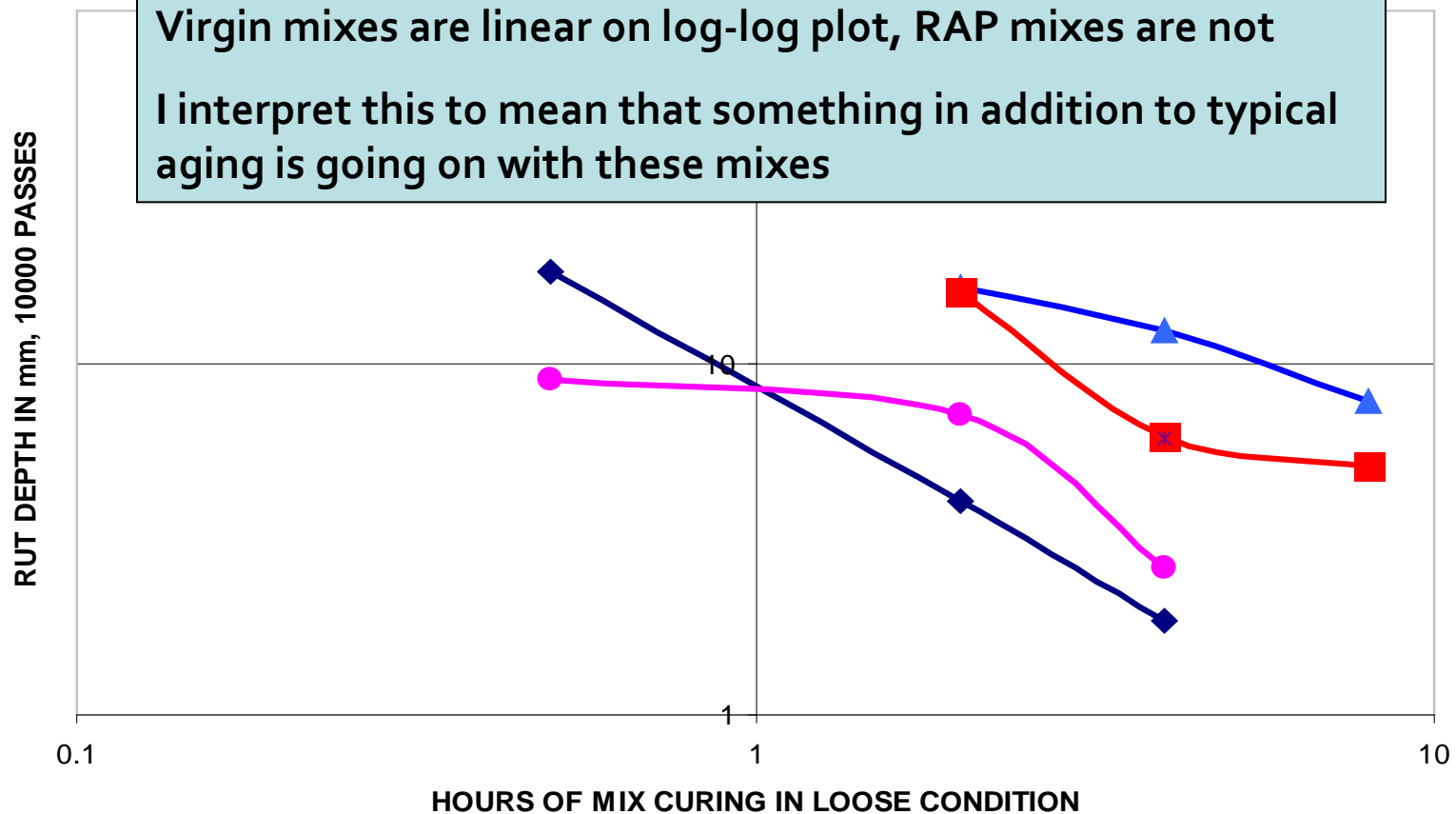
LINEAR SCALE PLOT OF RUT DEPTH VERSUS LOOSE MIX CURE TIME



LOG-LOG PLOT OF RUT DEPTH VERSUS LOOSE MIX CURE TIME

RUT DEPTH AT 10000 PASSES @ 58C
HOT MIX @ 275F, WARM MIX @ 220F

Virgin mixes are linear on log-log plot, RAP mixes are not
I interpret this to mean that something in addition to typical aging is going on with these mixes

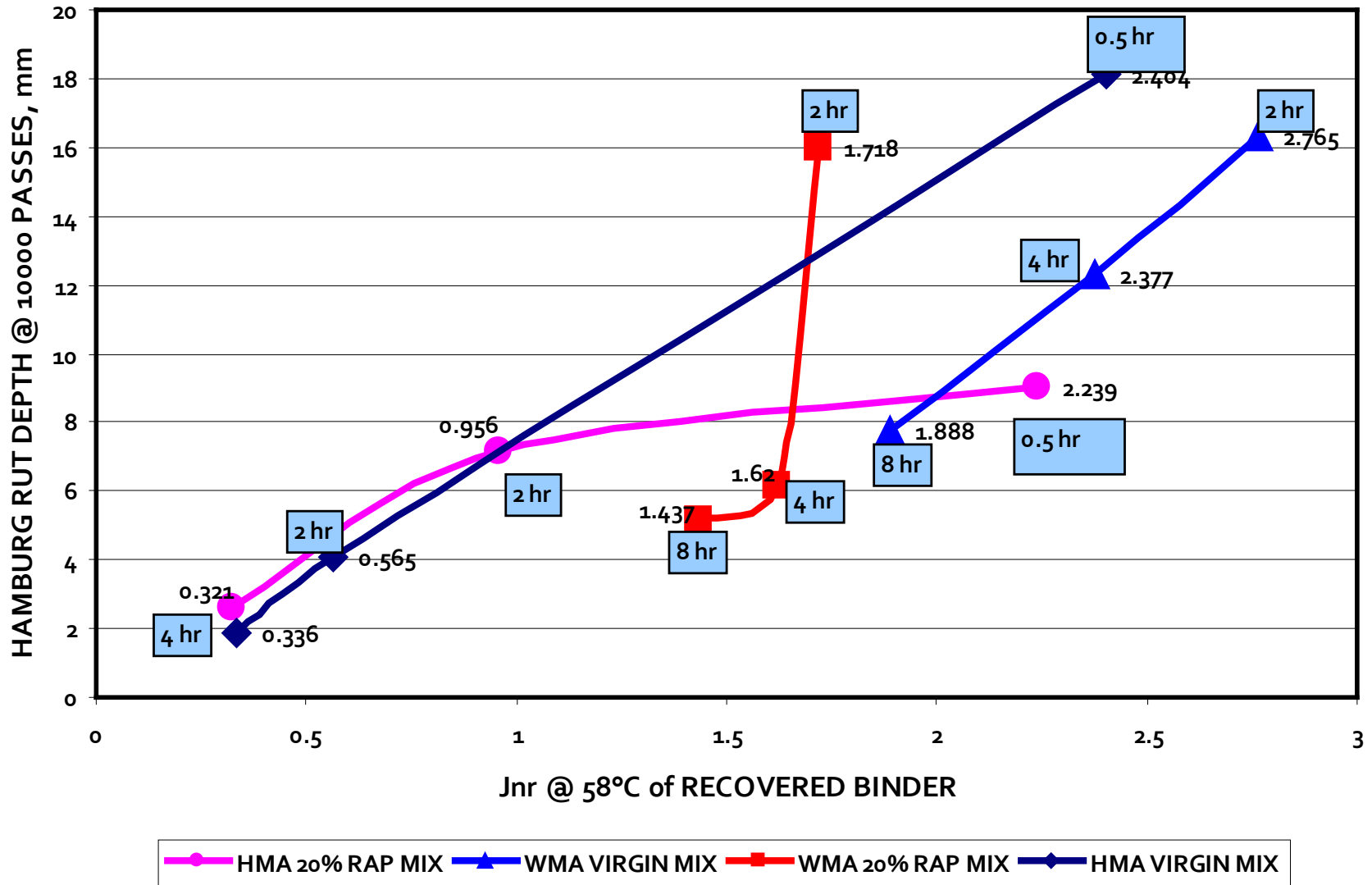


- ◆ HMA VIRGIN
- HMA 20% RAP
- ▲ WMA VIRGIN
- WMA 20% RAP
- * Water only @ 250 F

PLOT OF RUT DEPTH @ 10000 PASSES VERSUS Jnr OF RECOVERED BINDERS

RUT DEPTH @ 10000 PASSES @ 58°C HMA @ 275°F, WMA @ 220°F

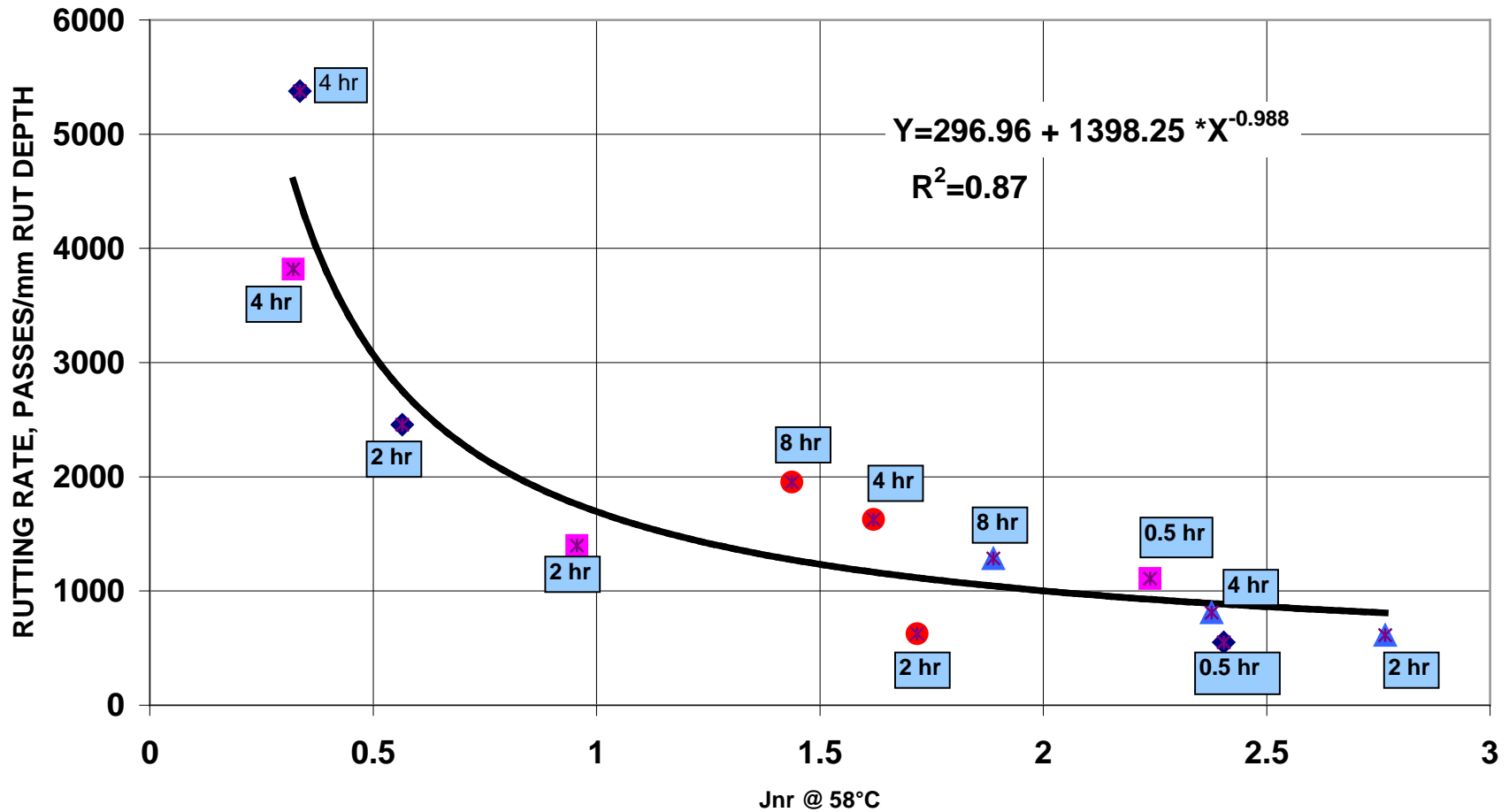
X hr= LOOSE MIX CURING TIME AT EITHER 275°F OR 220°F



HAMBURG RUTTING RATE AS A FUNCTION OF Jnr @ 58°C

PLOT OF RUTTING RATE (PASSES/mm RUT DEPTH) VS. Jnr @ 58°C

X hr= LOOSE MIX CURING TIME AT EITHER 275°F OR 220°F

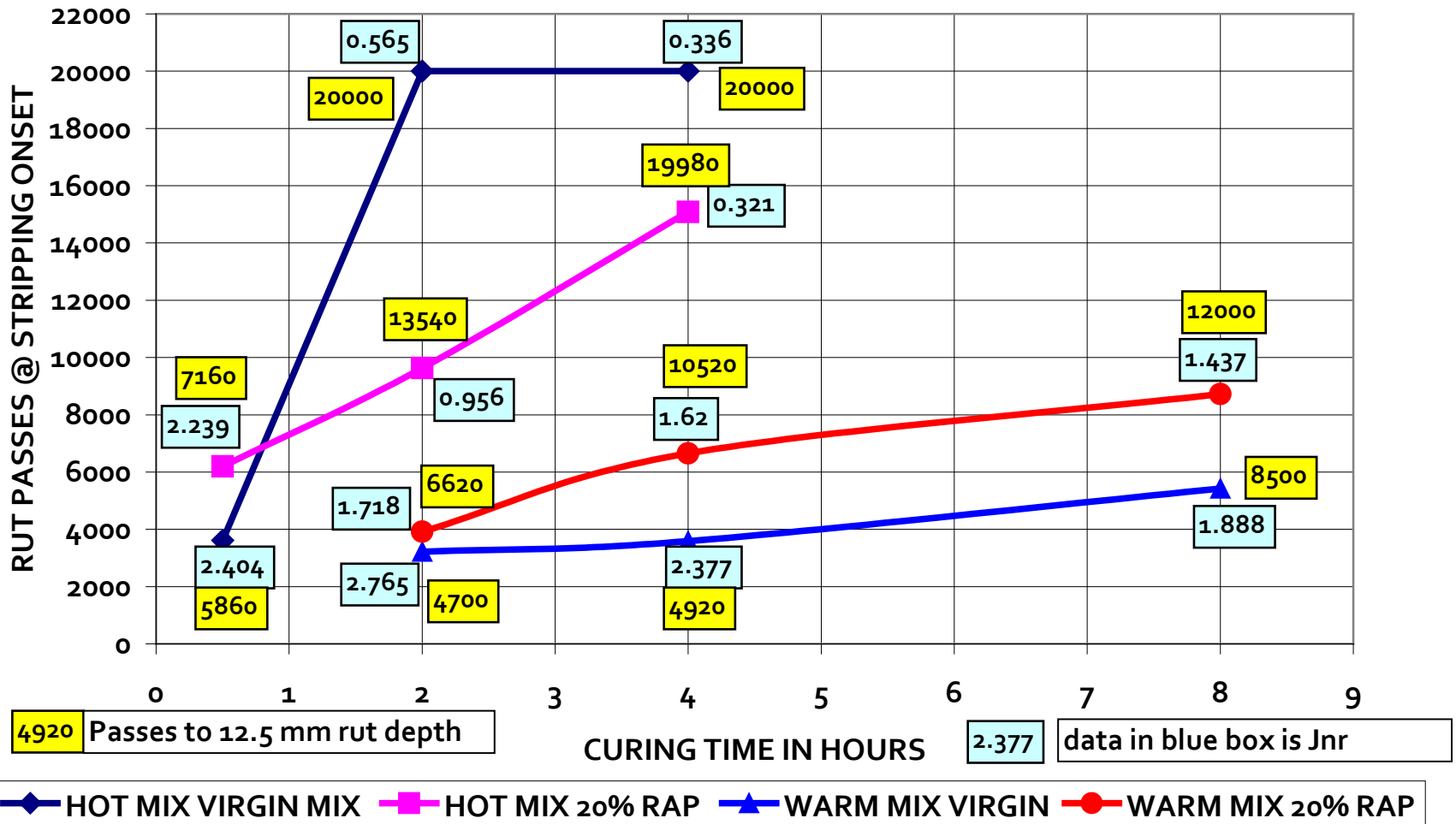


- ◆ HMA VIRGIN MIX
- HMA RAP MIX
- ▲ WMA VIRGIN MIX
- WMA RAP MIX
- ✱ HMA & WMA ALL MIXES
- TRENDLINE ALL DATA

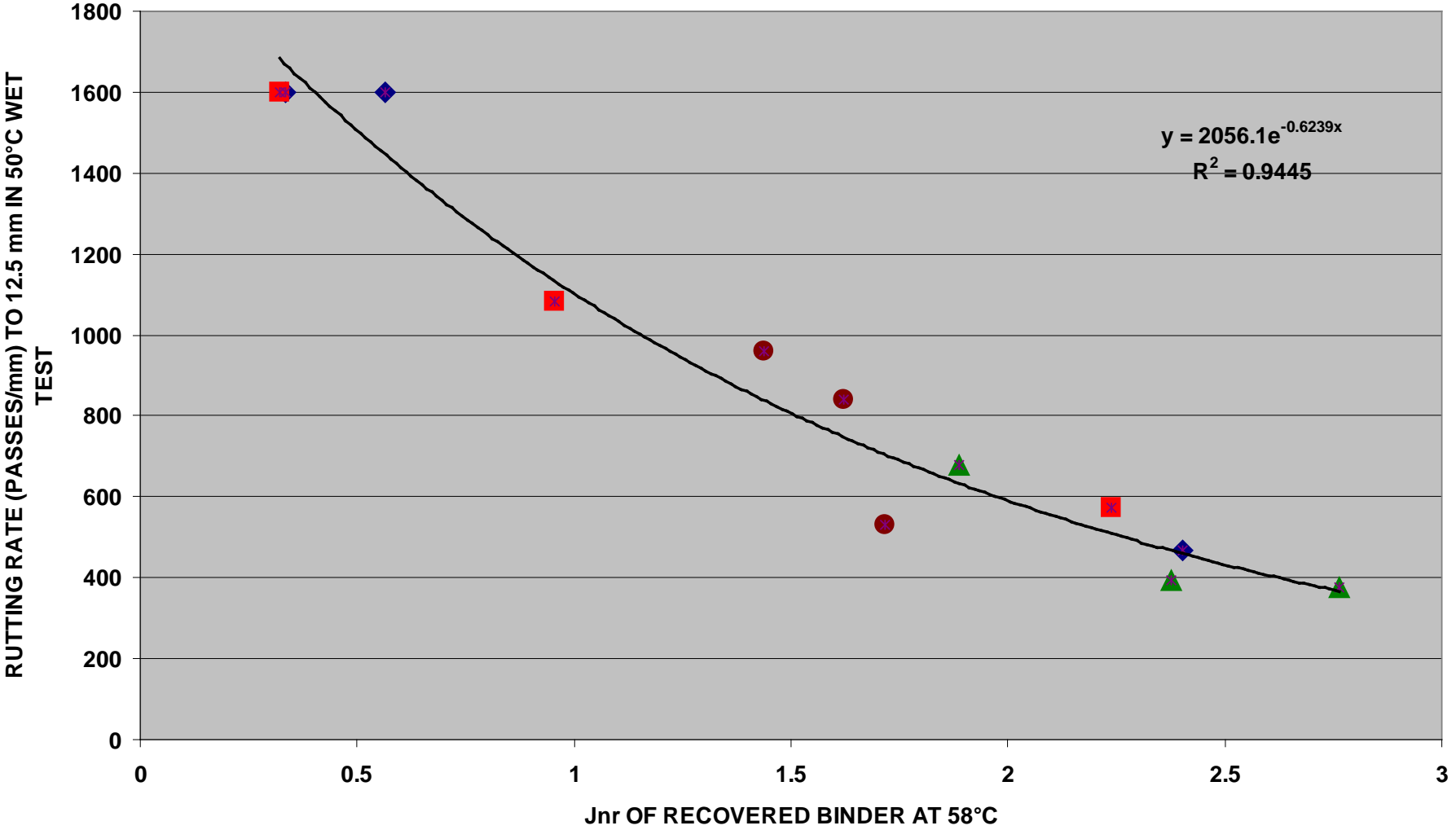
WET HAMBURG RESULTS @ 50°C-RUT PASSES TO STRIPPING ONSET

Jnr values of recovered binders rut passes to 12.5 mm of rutting shown adjacent to each rutting result as indicated in the key

RUT PASSES TO STRIPPING ONSET @ 50C [HOT MIX @ 275F, WARM MIX @ 220F]

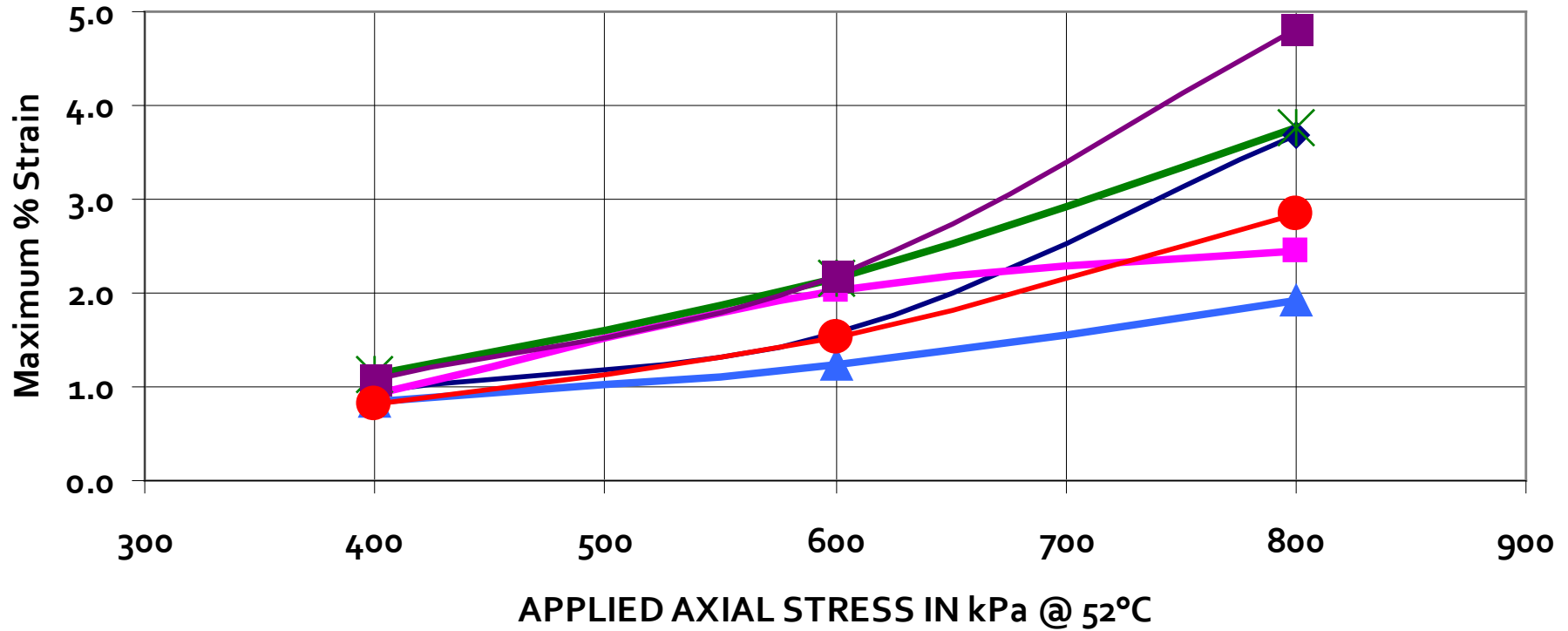


PLOT OF RUTTING RATE FOR WET HAMBURG TEST AS FUNCTION OF Jnr



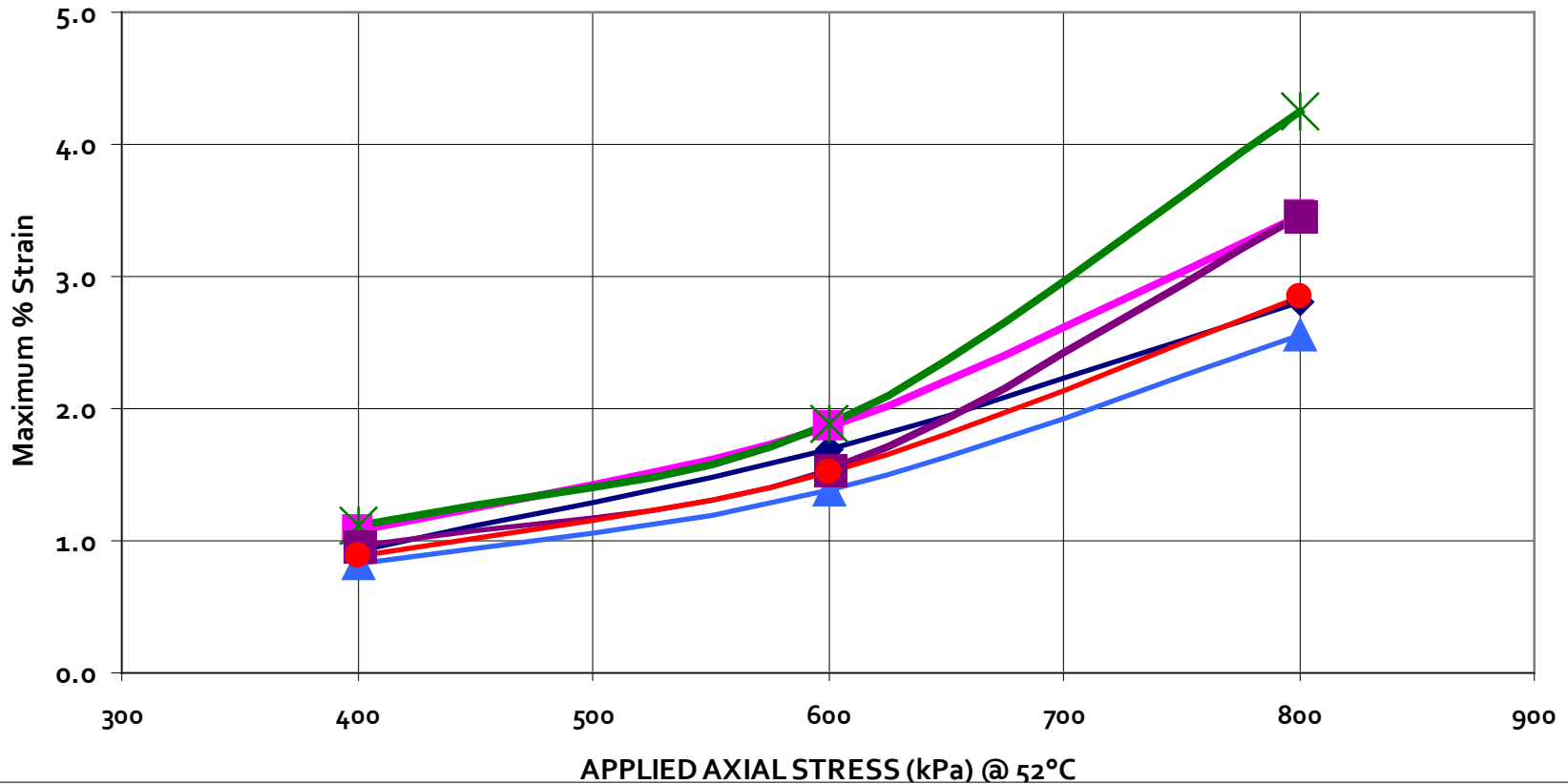
◆ HMA VIRGIN MIXES ■ HMA RAP MIXES ▲ WMA VIRGIN MIXES ● WMA RAP MIXES * Series5 — Expon. (Series5)

**MAXIMUM % STRAIN IN FLOWNUMBER TEST @ 52°C FOR VIRGIN MIXES
69 kPa (10 PSI) CONFINING STRESS**



Examining the stress sensitivity of virgin HMA and WMA shows that at low axial stress of 400 kPa all mixes have similar and low strain. At 600 kPa the 2 and 4 hr aged WMA is deviating from the HMA, but the 8 hr aged WMA is similar to 0.5 and 2 hr aged HMA.

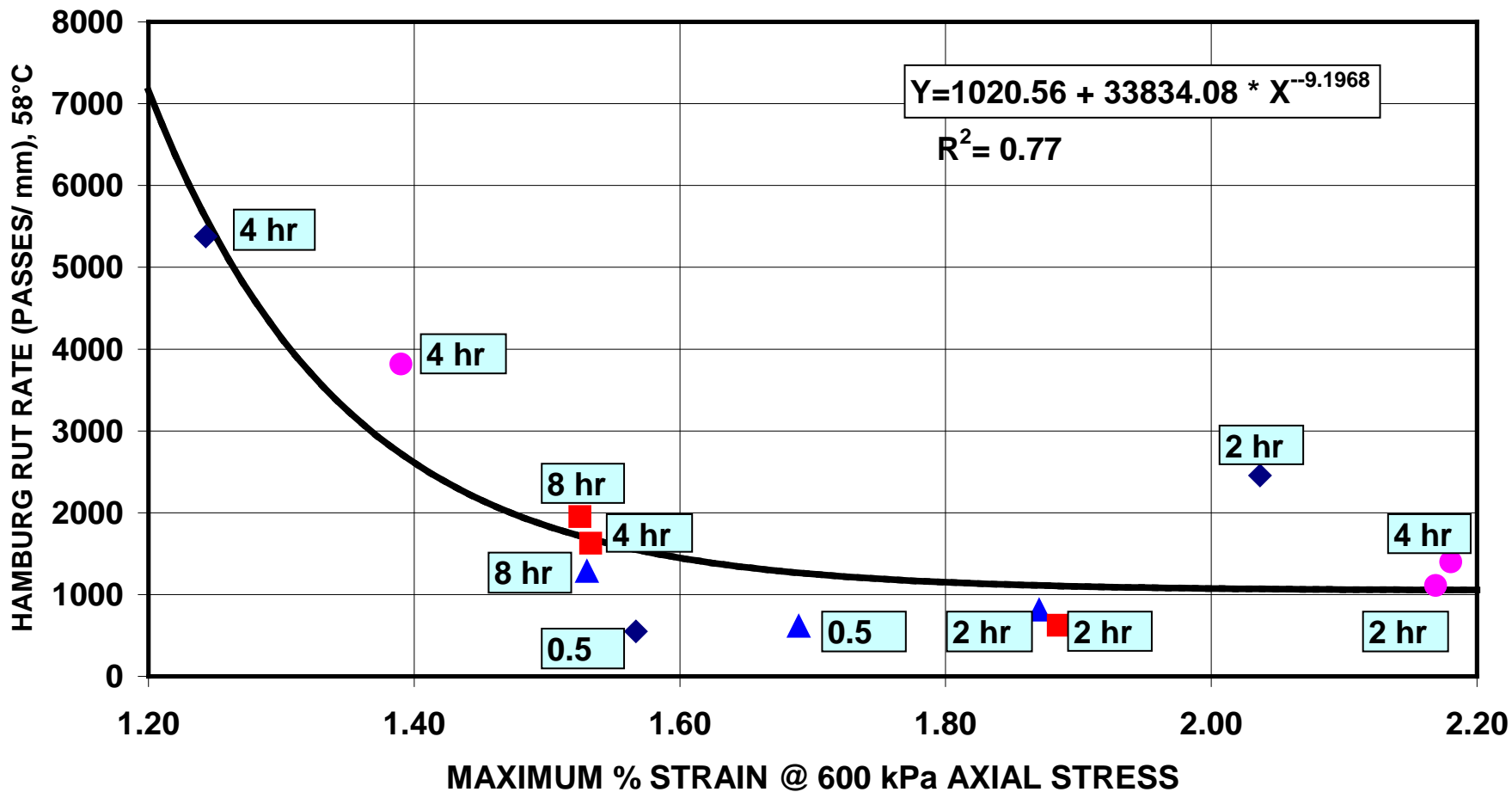
**MAXIMUM % STRAIN IN FLOWNUMBER TEST @ 52°C FOR 20% RAP MIXES
69 kPa (10 PSI) CONFINING STRESS**



◆ HMA, RAP, 1/2 hr cure ■ HMA, RAP, 2 hr cure ▲ HMA, RAP, 4 hr cure
✱ WMA, RAP, 2 hr cure ■ WMA, RAP, 4 hr cure ● WMA, RAP, 8 hr cure

For RAP mixes both WMA and HMA have very similar strains at 400 and 600 kPa, but exhibit differences as the axial stress moves to 800 kPa. 8 hr cures WMA is comparable to the 4 hr cured HMA. As with the rut test samples the 2 hr cured RAP HMA seems to be out of sequence compared to the other mixes. The AMPT specimens were prepared on different days than were the rut test specimens, which I think would eliminate an error in preparing the mix.

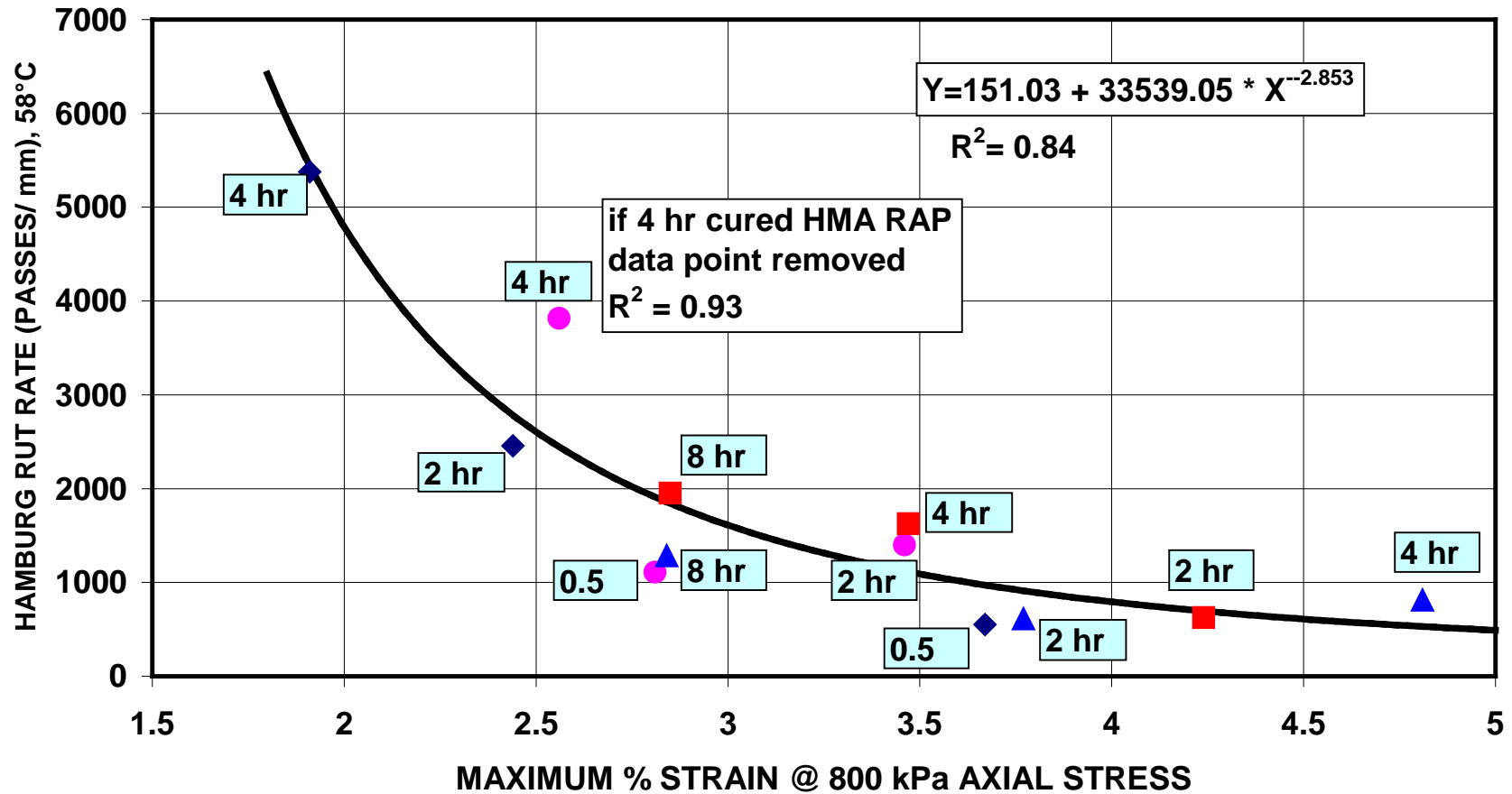
RUT RATE (PASSES/mm) @ 58°C VS % STRAIN @ 600 kPa STRESS



- ◆ HMA VIRGIN MIX
- HMA 20% RAP MIX
- ▲ WMA VIRGIN MIX
- WMA 20% RAP MIX
- TRENDLINE FOR ALL DATA

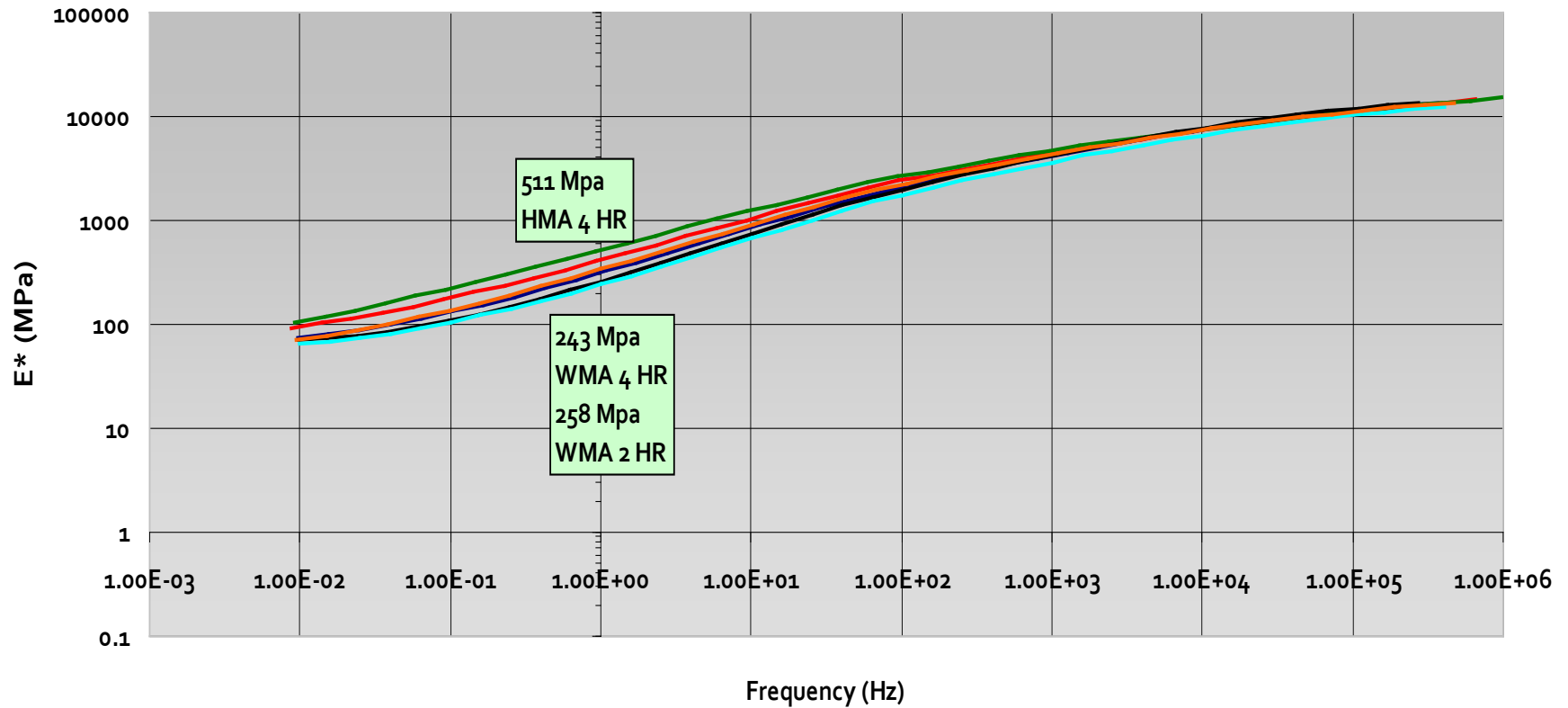
HAMBURG RUT RATE AS A FUNCTION OF STRAIN @ 800 kPa STRESS

RUT RATE (PASSES/mm) @ 58°C VS % STRAIN @ 800 kPa STRESS



- ◆ HMA VIRGIN MIX
- HMA 20% RAP MIX
- ▲ WMA VIRGIN MIX
- WMA 20% RAP MIX
- TRENDLINE FOR ALL DATA

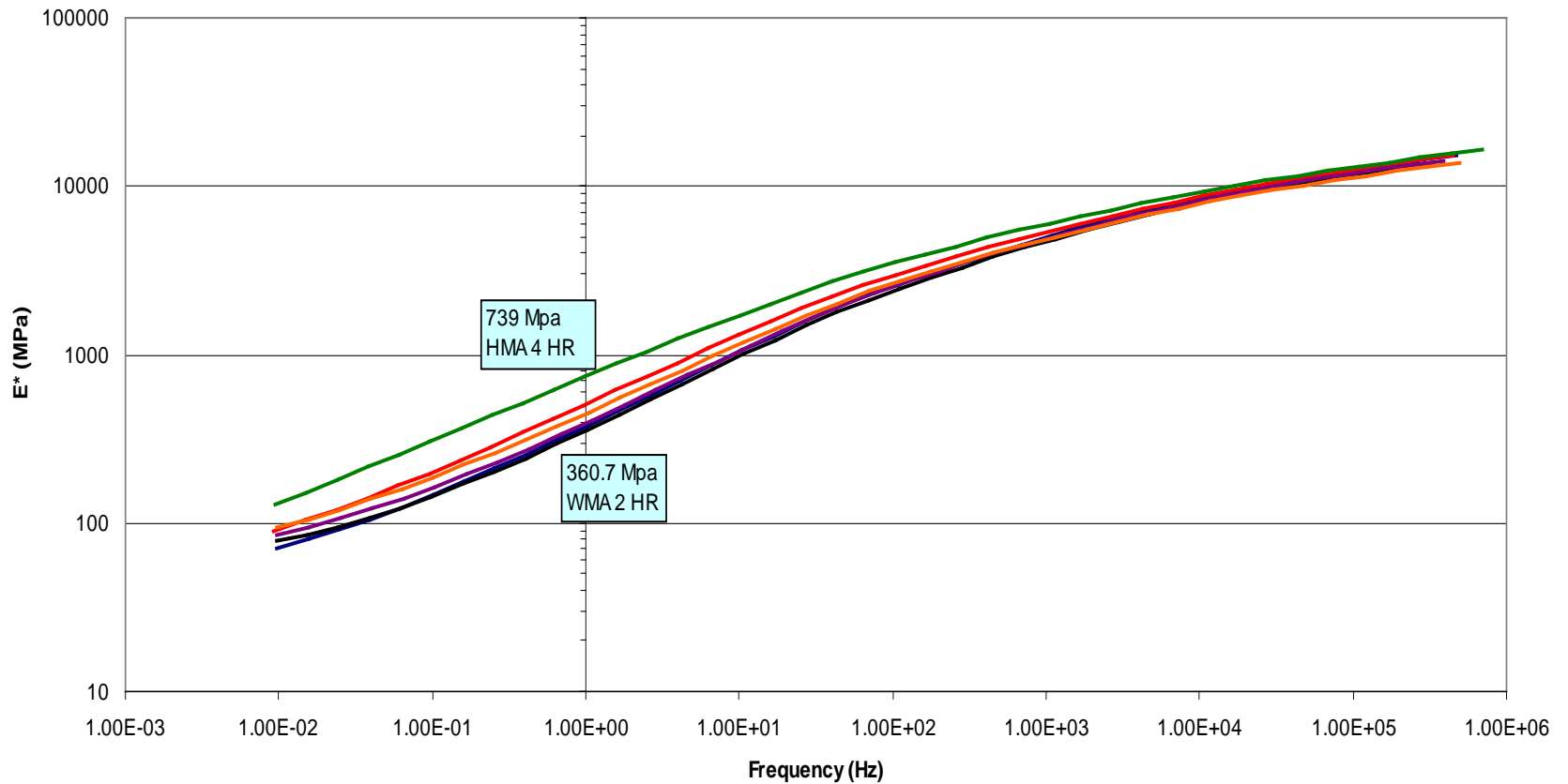
Comparison of Stiffness Mastercurves of Virgin Hot & Warm Mixes at $T_r=40^{\circ}\text{C}$



— Virgin hot mix, 0.5 hr — Virgin hot mix, 2 hr — Virgin hot mix, 4 hr — Virgin warm mix, 2 hr
— Virgin warm mix, 4 hr — Virgin warm mix, 8 hr

Mix complex modulus (E^*) for the HMA and WMA at 1 Hz has a maximum range of 511 to ~250 MPa. This covers the range of the greatest amount of aging time for HMA (4 hrs) and the least amount of aging time for WMA (2 hrs).

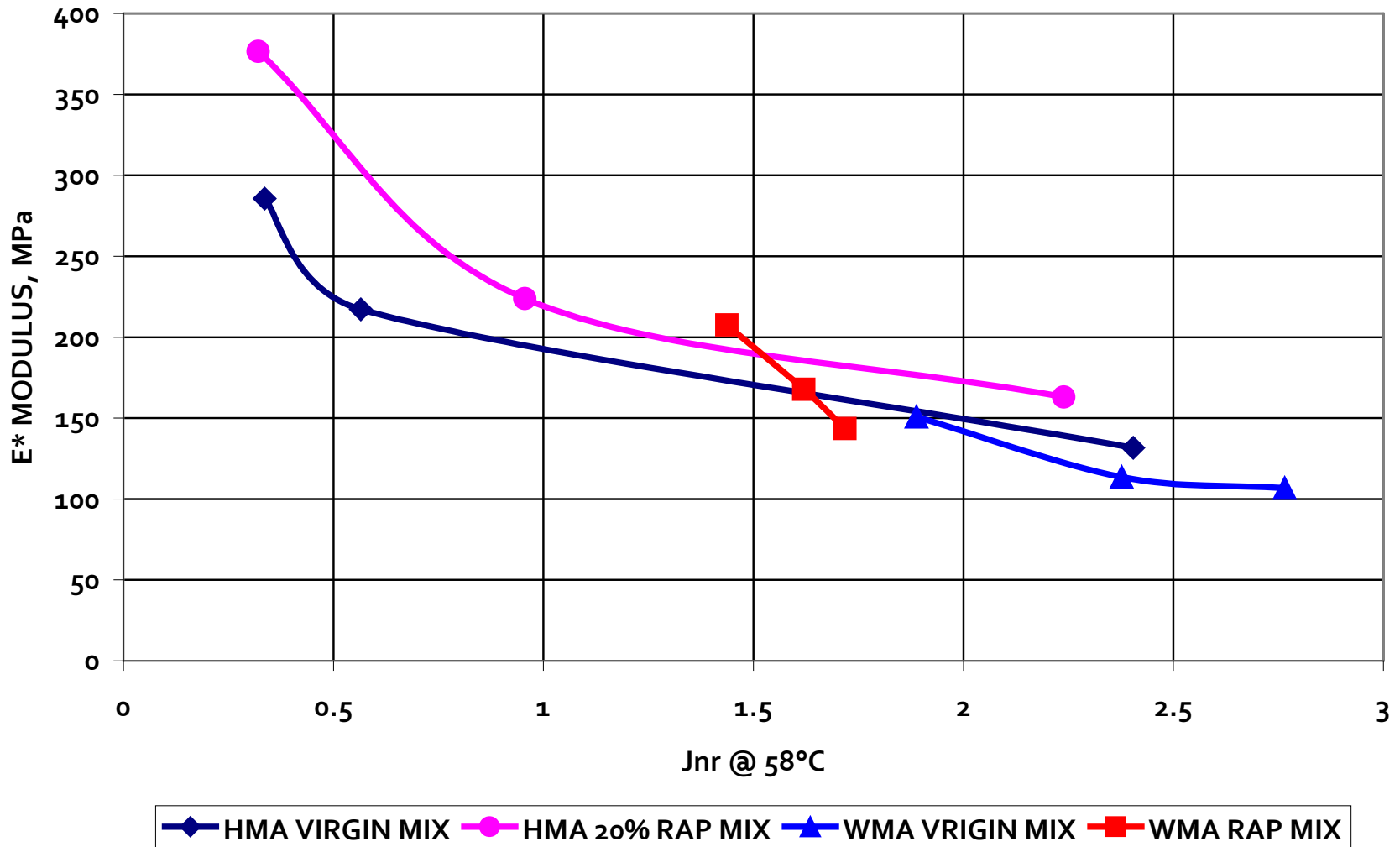
Stiffness Comparison at $T_r=40^\circ\text{C}$



— RAP hot mix, 0.5 hr — RAP hot mix, 2 hr — RAP hot mix, 4 hr — RAP warm mix, 2 hr
— RAP warm mix, 4 hr — RAP warm mix, 8 hr

Comparison of E^* for RAP HMA and WMA mixes shows approximately a doubling of modulus from 4 hr aged HMA to 2 hr aged WMA. Also examination of the data shows that HMA RAP mix aged at 2 hrs exhibits nearly the same stiffness as 8 hr aged WMA RAP mix.

E* MODULUS @ 0.001 Hz FROM 20°C MASTERCURVE VS Jnr @ 58°C

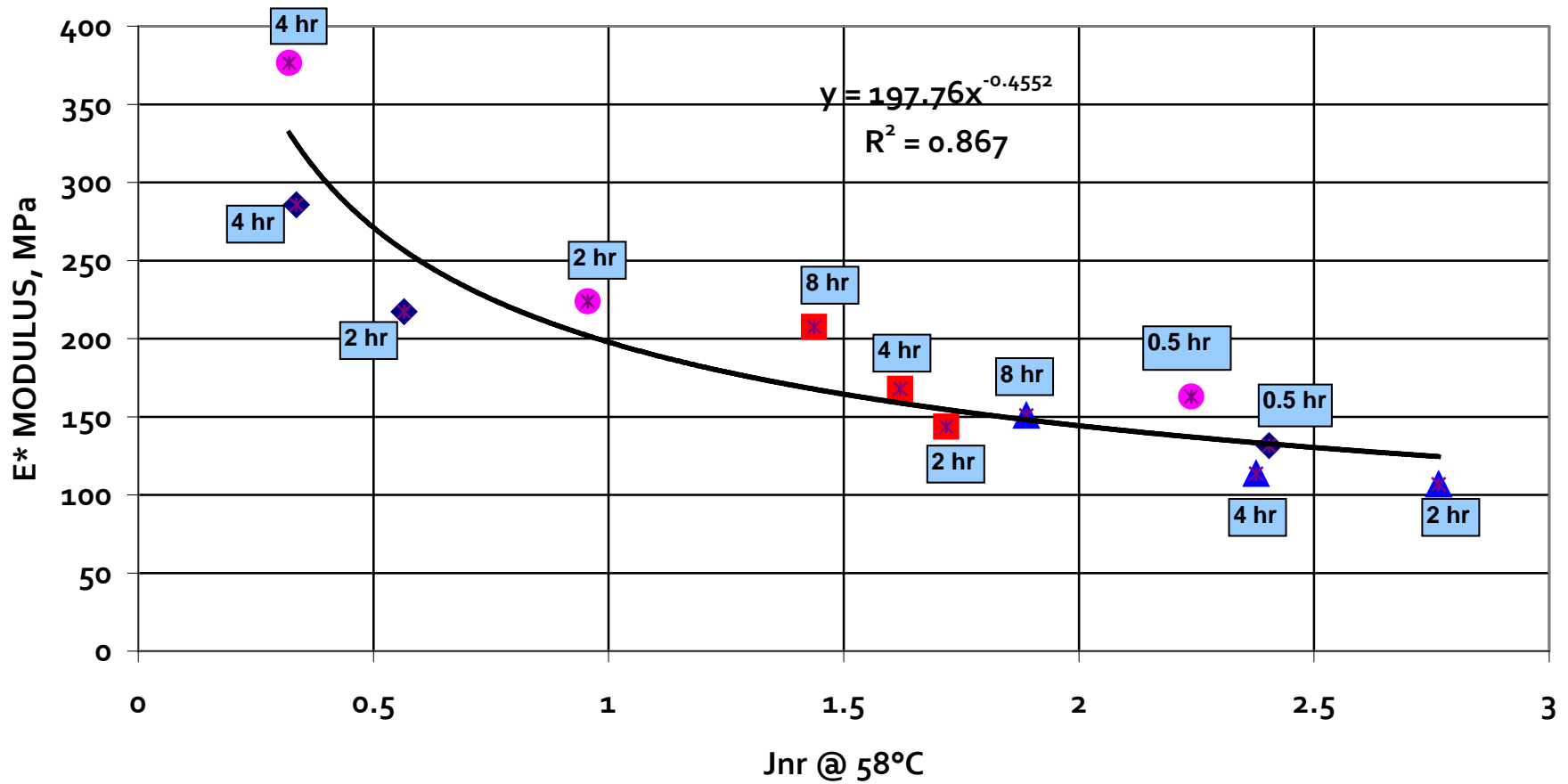


In this plot of E* versus Jnr it appears as though the E* data is one continuous function of Jnr for the virgin mixes. That is explored in the next plot.

E* MODULUS FOR BOTH HMA & WMA MIXES AS A FUNCTION OF Jnr E* @ 0.001 Hz FROM 20°C MASTERCURVE

E* MODULUS @ 0.001 Hz FROM 20°C MASTERCURVE VS Jnr @ 58°C

X hr= LOOSE MIX CURING TIME AT EITHER 275°F OR 220°F



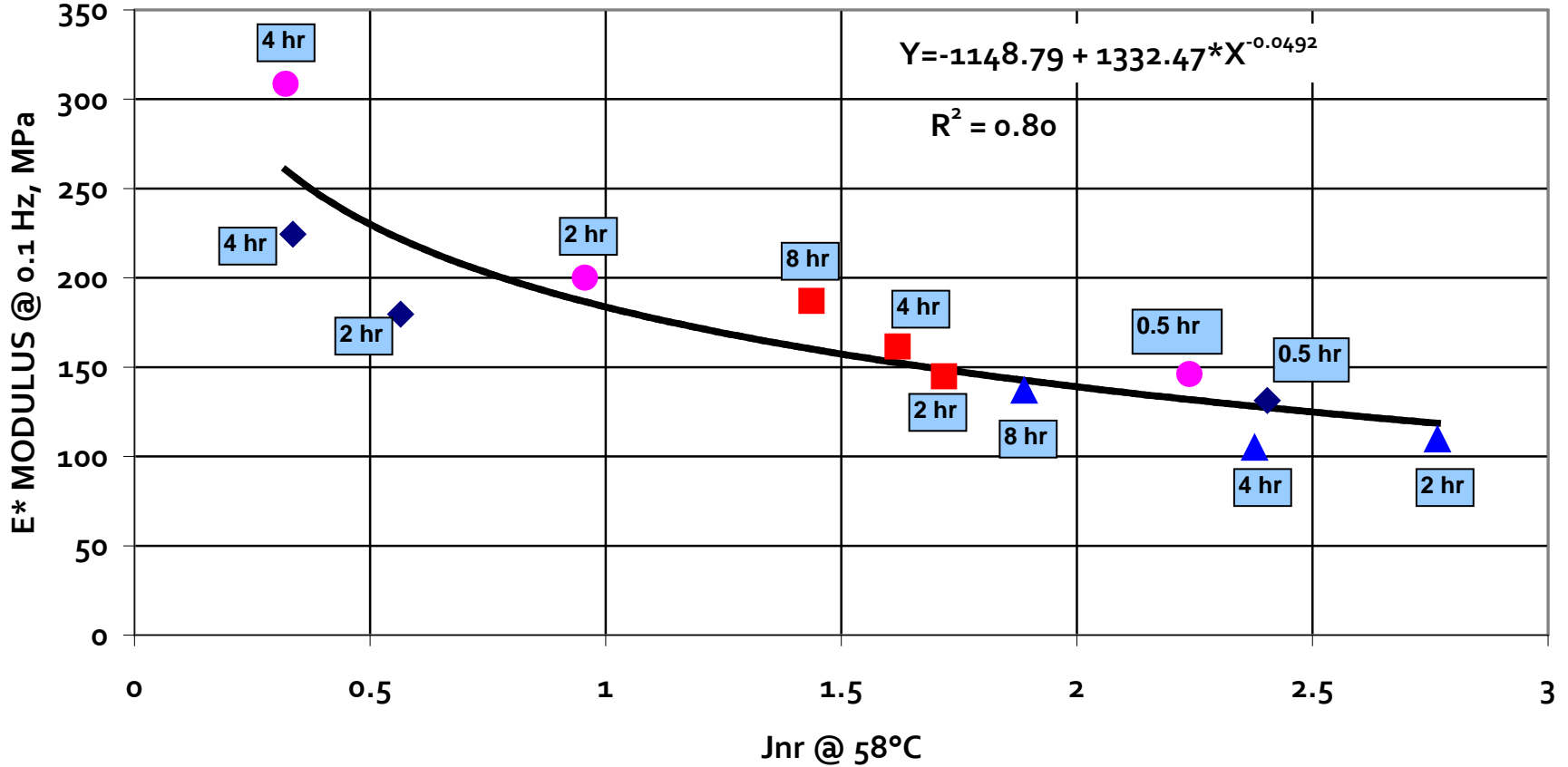
- ◆ HMA VIRGIN MIX
- ▲ WMA VIRGIN MIX
- ✱ All HMA & WMA Mix Data
- HMA 20% RAP MIX
- WMA RAP MIX
- Power (All HMA & WMA Mix Data)

E* MODULUS FOR BOTH HMA & WMA MIXES AS A FUNCTION OF Jnr

E* @ 0.1 Hz FROM 40°C MASTERCURVE

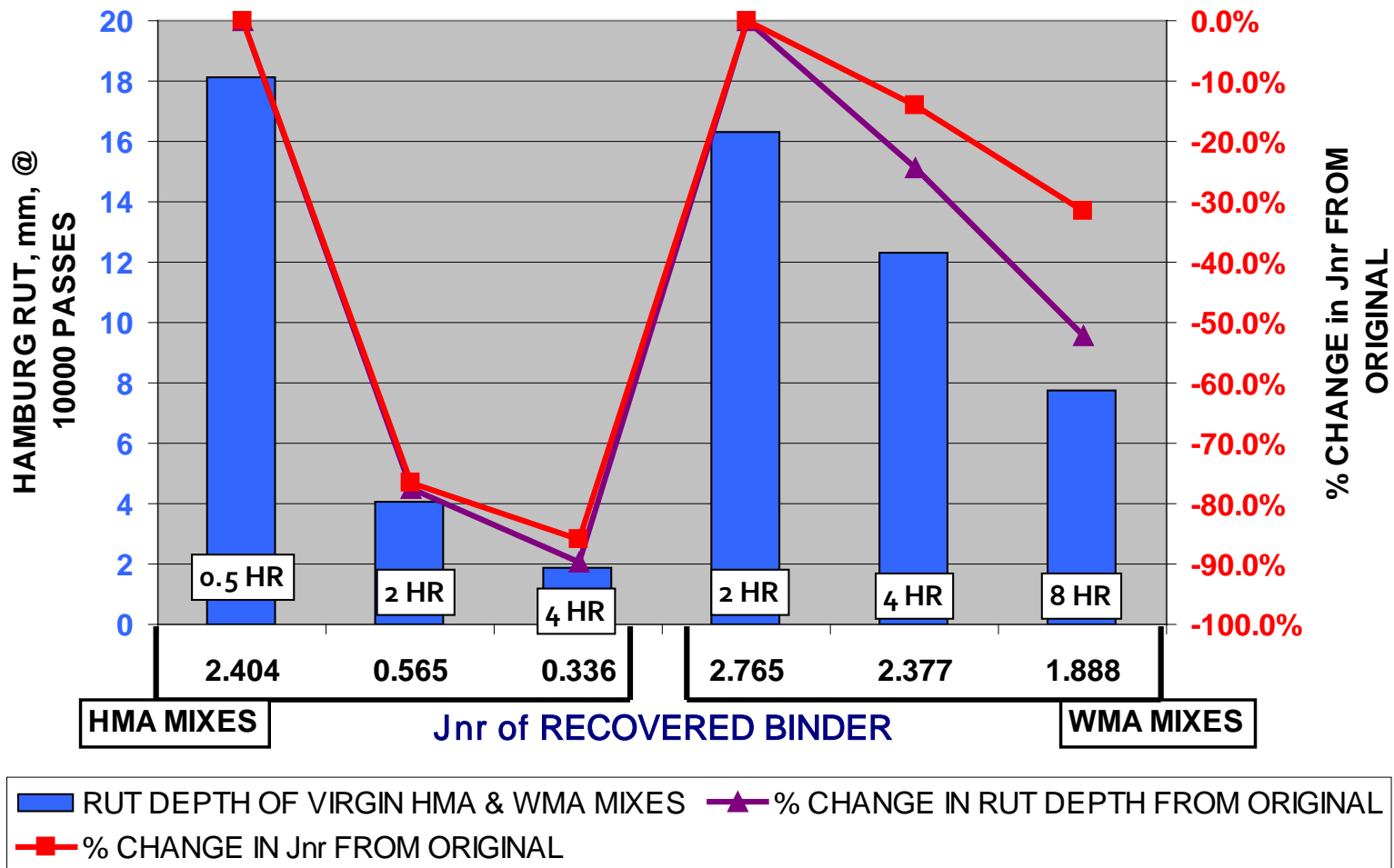
E* MODULUS @ 0.1 Hz FROM 40°C MASTERCURVES VS Jnr @ 58°C

X hr= LOOSE MIX CURING TIME AT EITHER 275°F OR 220°F



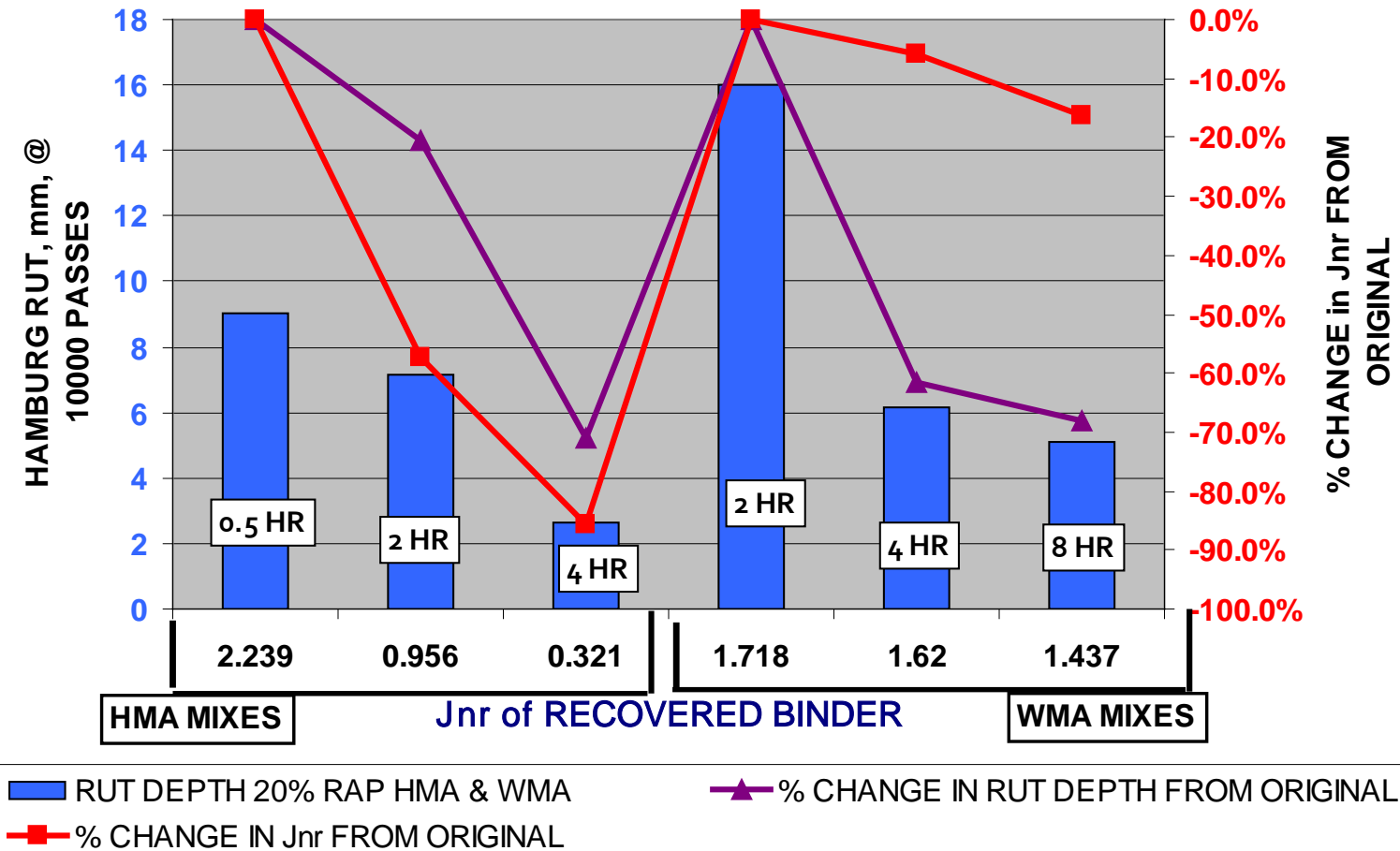
- ◆ HMA VIRGIN MIX
- ▲ WMA VIRGIN MIX
- HMA & WMA ALL MIXES TRENDLINE
- HMA 20% RAP MIX
- WMA RAP MIX

EXAMINATION OF RUT DEPTH, CHANGE IN Jnr and CHANGE IN RUT DEPTH FOR VIRGIN MIXES



COMMENT: For virgin mixes (both hot and warm) mix conditioning time drives Jnr of recovered binder. For the HMA the percent reduction in Jnr and rut depth at 2 and 4 hrs as compared to 0.5 hrs is very similar. For the WMA the rut depth is being reduced at a faster rate than the Jnr value and this difference is increasing with aging time. This work should be repeated and extended to longer periods; because, if confirmed, we would have some basis for concluding that even though the binder is not aging as rapidly, there is something else happening within the binder/aggregate interaction that is improving rutting resistance besides binder aging.

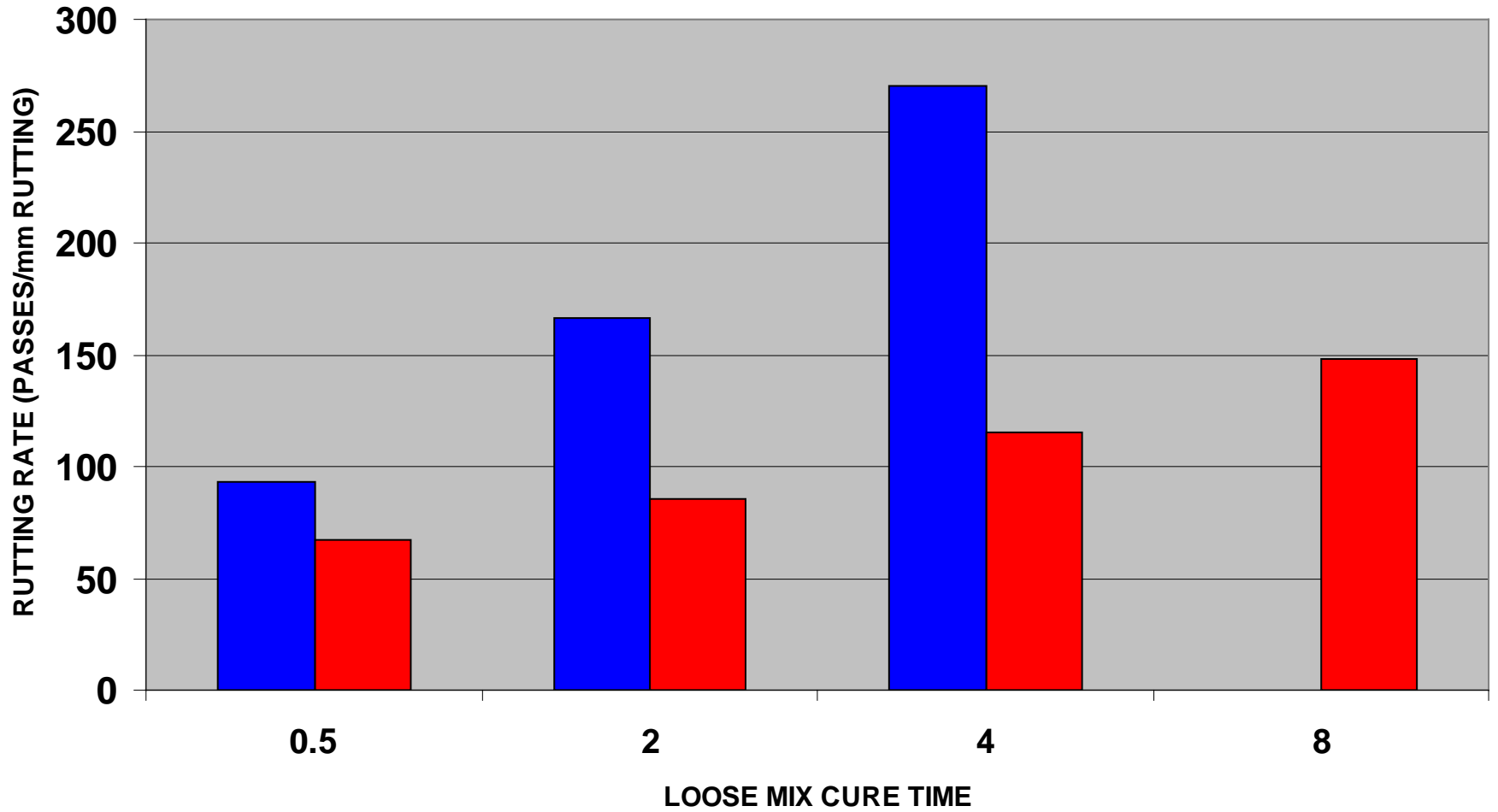
EXAMINATION OF RUT DEPTH, CHANGE IN Jnr and CHANGE IN RUT DEPTH FOR RAP MIXES



COMMENT: For the RAP HMA conditioning time drives Jnr. For the 0.5 hr aged mix there can be minor aging and the Jnr is a product of the extraction and homogenization of the RAP and virgin binders. Even though there is a large change in Jnr at 2 hrs there is only a modest change in rut depth because of relatively low rut value of the 0.5 hr mix. Is this low value due to an asphalt deficient mix since at 0.5 hrs there would be little opportunity for interaction? For the WMA mixes the 2 hr aged mix has a lower Jnr than the 0.5 hr HMA and yet a much greater rut depth. Some binder aging and comingling has occurred and perhaps the mobilized binder is greater than in the 0.5 hr HMA. For the 4 and 8 hr aged WMA the Jnr decreases very little as a percent of the 2 hr value, but the rut depths decrease substantially. Once again we have to consider the mechanism that enables the rut depth to decrease with relatively modest changes in the recovered Jnr value

COMPARE RUTTING RATE @ 64°C FOR HMA VS WMA

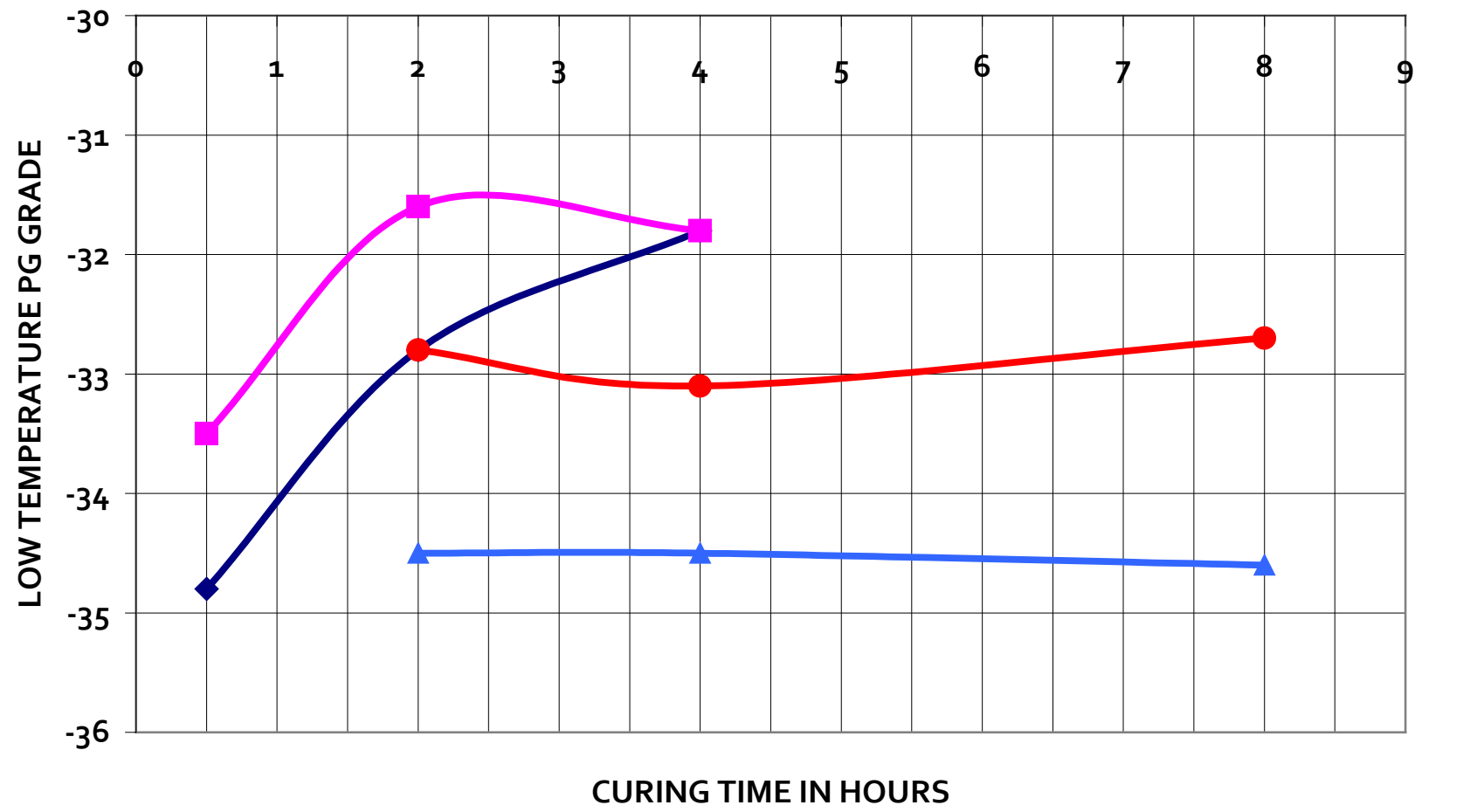
MIX PRODUCED BY ASPHALT INSTITUTE-PG 64-22 BINDER



■ HMA MIXES ■ WMA CURED MIXES

LOW TEMPERATURE PG GRADE RECOVERED BINDER VERSUS MIX CURE TIME IN HOURS

LOW TEMPERATURE PG GRADE VS MIX CURE TIME [HOT MIX @ 275F, WARM MIX @ 220F]



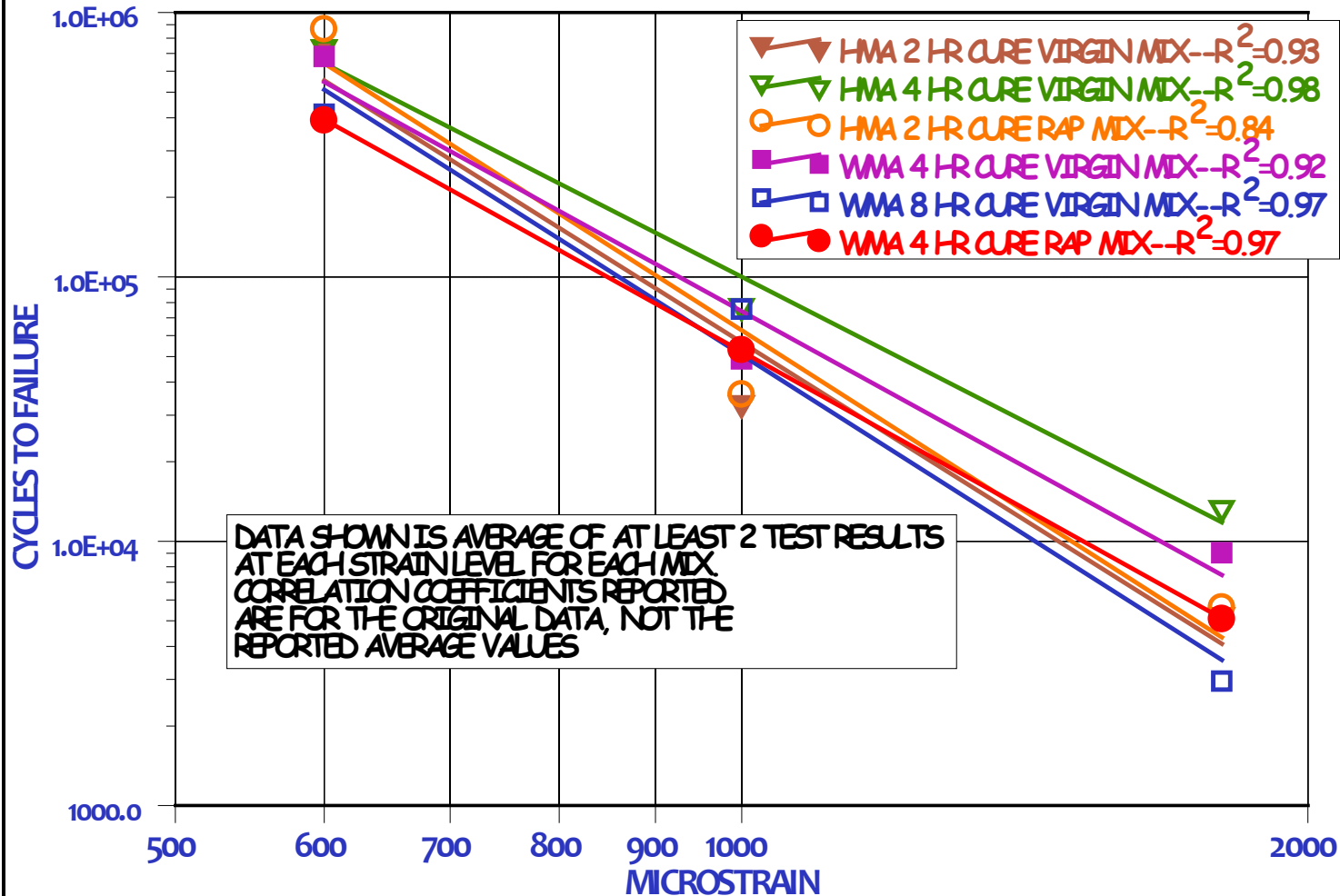
◆ HOT MIX VIRGIN MIX ■ HOT MIX 20% RAP ▲ WARM MIX VIRGIN ● WARM MIX 20% RAP

MIX CYLINDER OF MIX PASSING 4.75 mm SIEVE FOR TORSIONAL FATIGUE TESTING



FATIGUE RESULTS CYCLES TO FAILURE AS A FUNCTION OF MICROSTRAIN

FAILURE DETERMINED WHERE $G^* = 30\%$ OF INITIAL G^*





CONCLUSIONS

THESE ARE RELEVANT FOR THIS MIX AND MORE SPECIFICALLY FOR THE NON-MODIFIED BINDER USED IN THIS STUDY

1. MECHANISTIC RESULTS DRIVEN BY AGING TEMPERATURE AND AGING TIME FOR VIRGIN MIXES
2. 4 HOURS AGING AT 220°F WITH RAP WAS ROUGHLY SIMILAR TO 2 HOURS AGING AT 275°F WITH RAP
 - a) Takes twice as long at warm mix vs. hot mix temperature to activate RAP???

CONCLUSIONS

3. **50°F REDUCTION IN CONDITIONING TEMPERATURE RESULTED IN:**
 - a) **~11°C INCREASE IN HIGH TEMPERATURE PG GRADE WHEN CONDITIONING AT 275°F FROM 0.5, 2, TO 4 HOURS**
 - b) **~2°C INCREASE IN HIGH TEMPERATURE PG GRADE WHEN CONDITIONING AT 220°F FROM 2, 4, TO 8 HOURS**

CONCLUSIONS

4. 50°F REDUCTION IN CONDITIONING TEMPERATURE RESULTED IN:

- a) ~3°C INCREASE IN LOW TEMPERATURE PG GRADE WHEN CONDITIONING AT 275°F FROM 0.5, 2, TO 4 HOURS FOR VIRGIN MIX
- b) ~2.5°C INCREASE IN LOW TEMPERATURE PG GRADE WHEN CONDITIONING AT 275°F FROM 0.5, 2, TO 4 HOURS
- c) ~0°C INCREASE IN LOW TEMPERATURE PG GRADE WHEN CONDITIONING AT 220°F FROM 2, 4, TO 8 HOURS

CONCLUSIONS

5. 4 HOURS OF 220°C AGING OF RAP MIX PRODUCES RUTTING RESULTS SIMILAR TO 2 HOURS OF AGING OF HMA RAP MIX AT 275°F
6. FLOWNUMBER STRAIN RESULTS WITH 10 PSI CONFINING PRESSURE SHOW THAT 8 HOURS OF WARM MIX CONDITIONING TIME IS EQUIVALENT TO 2 TO 4 HOURS OF HOT MIX CONDITIONING FOR VIRGIN BINDER MIXES AT 600 & 800 kPa AXIAL STRESS LEVELS
7. BASED ON THE COMBINATION PLOT OF E^* AS A FUNCTION OF J_{nr} FOR ALL VIRGIN MIXES IT APPEARS AS THOUGH E^* IS A FUNCTION OF BINDER STIFFNESS FOR A GIVEN MIX AND (AT LEAST) FOR A NON-MODIFIED BINDER

CONCLUSIONS

8. FOR 20% RAP MIXES BOTH HMA & WMA HAVE SIMILAR MAXIMUM STRAIN RESULTS BASED ON THE FLOWNUMBER TEST WITH 10 PSI CONFINING PRESSURE AT 600 kPa AXIAL STRESS,
9. AT 800 kPa AXIAL STRESS BOTH THE 2 & 4 HR CURED WARM MIXES AND 2 HR CURED HOT MIX SHOW STRESS SENSITIVITY COMPARABLE TO THE 8 HR CURED WARM MIX AND THE 4 HR CURED HMA MIX
10. FLOWNUMBER STRAIN RESULTS WITH 10 PSI CONFINING PRESSURE SHOW THAT AT AXIAL STRESS LEVEL OF 400 kPa BOTH HMA & WMA HAVE SIMILAR RESULTS FOR BOTH VIRGIN BINDER MIXES AND 20% RAP MIXES

CONCLUSIONS

- 11. Based on evaluation of % change in Jnr compared to % change in rut depth for WMA RAP mixes it appears as though some other mechanism besides just binder aging is responsible for improved resistance to rutting**
 - a) There is a need to further investigate this**

- **QUESTIONS**
- **COMMENTS**
- **SUGGESTIONS**

