Impact of Hydrated Cement Paste Quality and Entrained Air-Void System on the Durability of Concrete

Sponsored by Michigan DOT

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Background

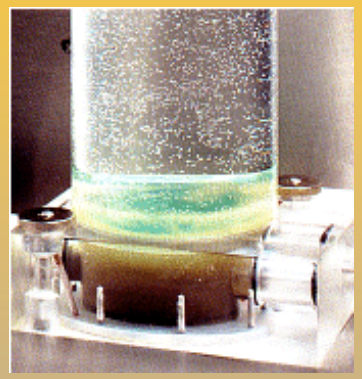
- Concrete mixtures have undergone numerous changes in recent years
- As the mixtures have changed, the research linking air-void system parameters to performance has not been updated
- Changes that have occurred (e.g. lower *w/cm*, use of SCMs, synthetic AEAs) affect not only the quality of the hydrated cement paste but also the characteristics of the entrained air-void system

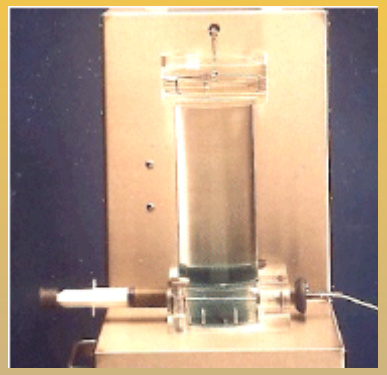
Objective

- Examine how the durability of concrete is affected by the quality of the hydrated cement paste and the presence of a properly entrained air-void system
  - Focus on the use of SCMs and “synthetic” air entrainers
  - Review emerging laboratory test equipment and protocols for application in practice

Approach

- *Emerging Methods to Evaluate*
  - AVA
  - Calorimetry
  - Cementometer
  - Microwave Water Content





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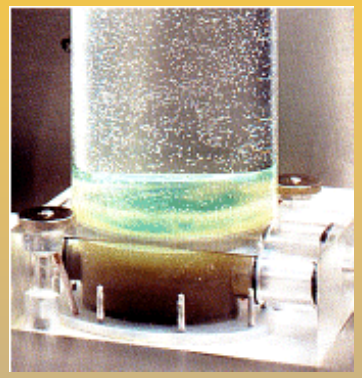

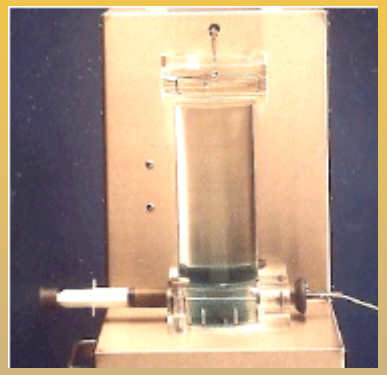

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Approach

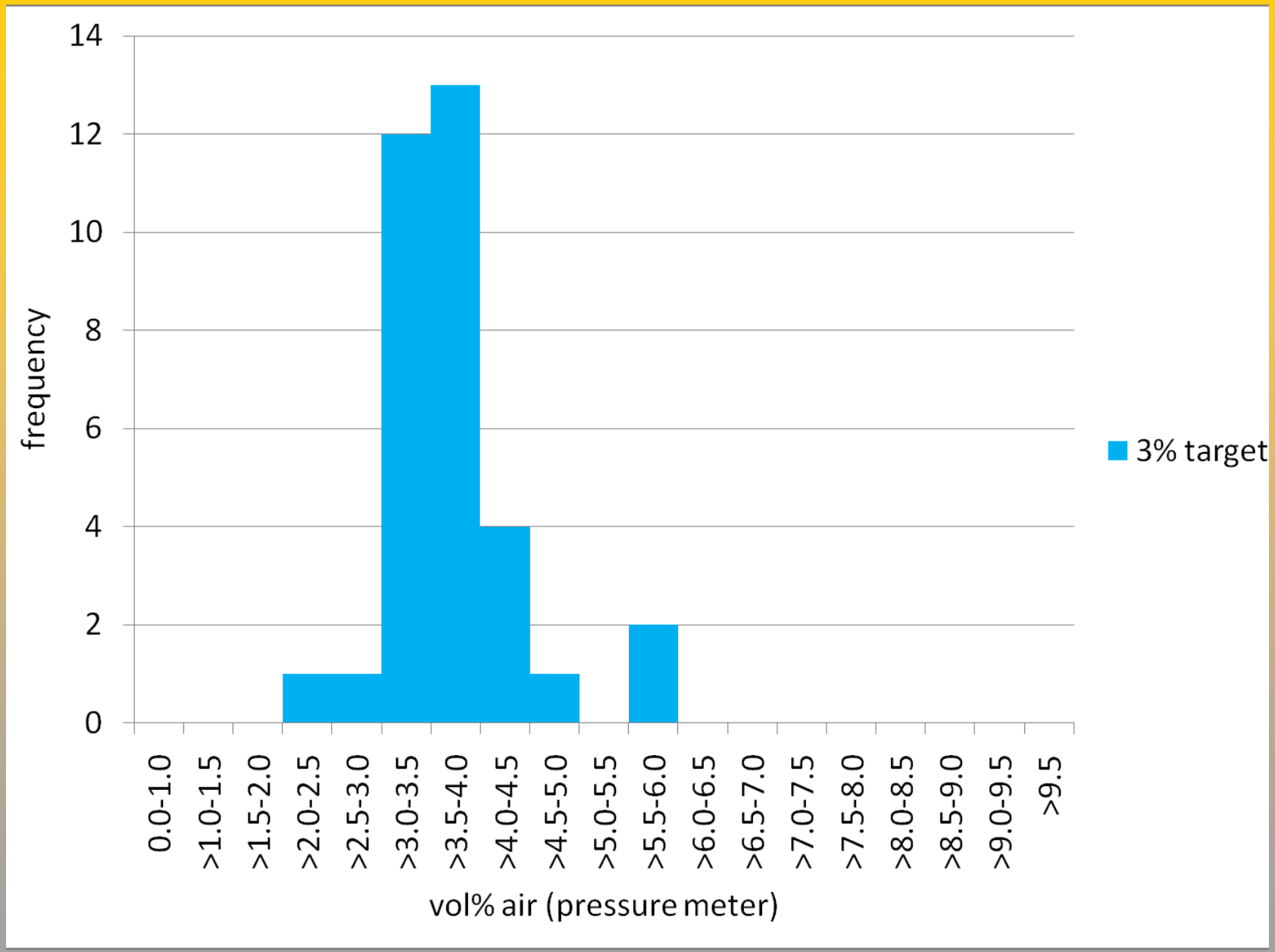
- *Phase II Experiment: Combined Full- and Partial- Factorial*
  - Cement type: ASTM Type I/II
  - Cement factors: 564 lb/yd^3, 517 lb/yd^3, and 470 lb/yd^3
  - SCMs: none, Class C fly ash, and Grade 100 ground blast furnace slag
  - AEAs: one vinsol resin and one synthetic
  - Coarse aggregate: a durable carbonate
  - Aggregate gradings: gap gradation and optimized
  - Fine aggregate volume altered to adjust yield with changes in *w/cm*
  - *w/cm*: 0.45, 0.50, and 0.52.
  - Two target air contents: 3% and 6%

Approach

- *Testing to assess fresh concrete properties*
  - Slump (ASTM C143)
  - Determination of air content using the pressure (ASTM C231), volumetric (ASTM C173) and gravimetric method (ASTM C138)
  - Air-void system parameters using the AVA
  - Unit weight and yield (ASTM C138)
  - Calorimetry to determine heat signatures of concrete
  - Maturity (ASTM C1074)
  - Water content by microwave method (AASHTO T 318) and Cementometer

Approach

- *Testing to assess hardened concrete properties*
  - Compressive strength (ASTM C39) at 1, 3, 7, and 28 days.
  - Determination of air-void system parameters using ASTM C457 calculations – flatbed scanner
  - Sorptivity after 56 days (ASTM C1585)
  - F-T durability (ASTM C666)
  - Limited analysis of thin sections to estimate *w/cm* content of concrete



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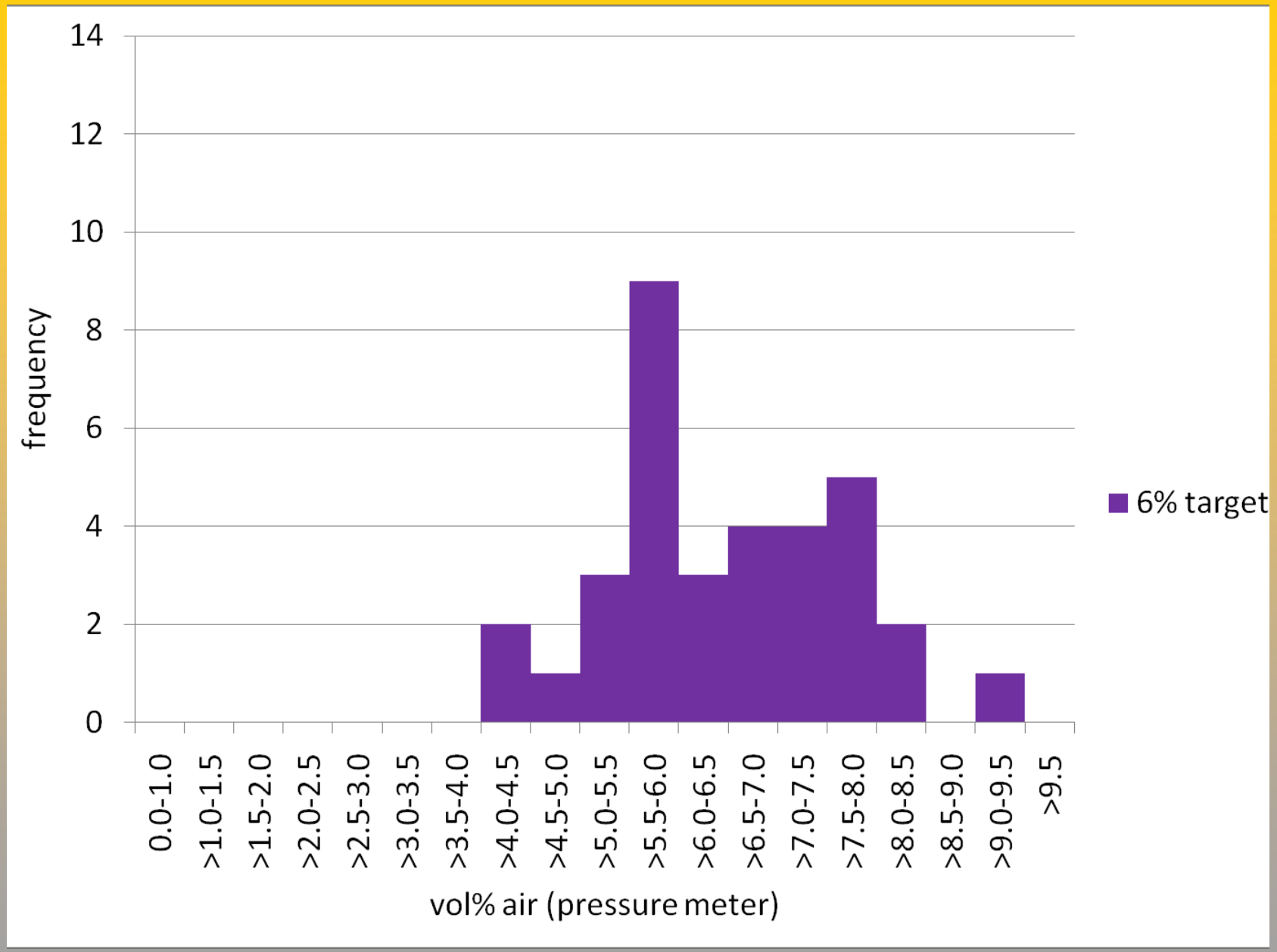

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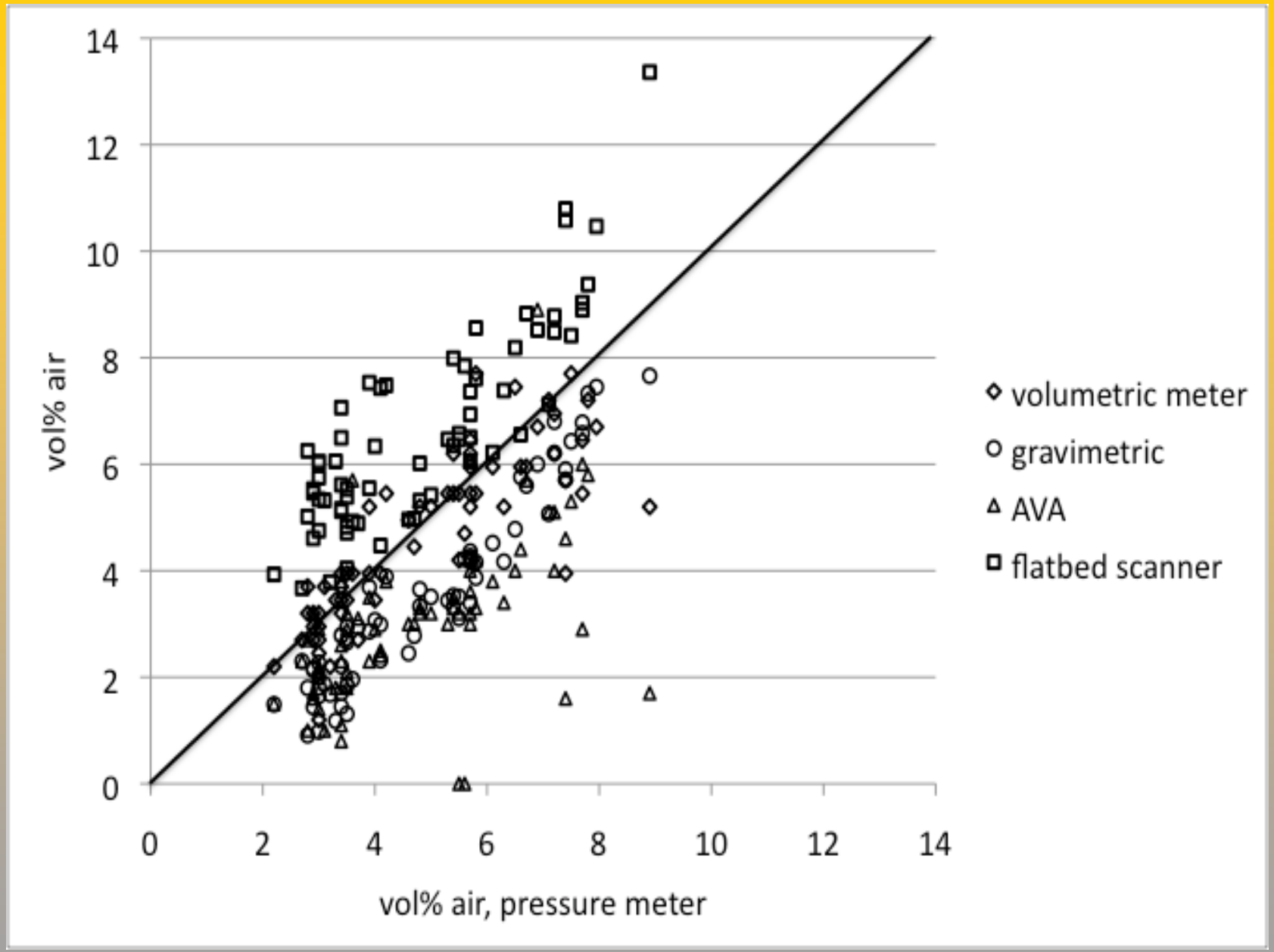

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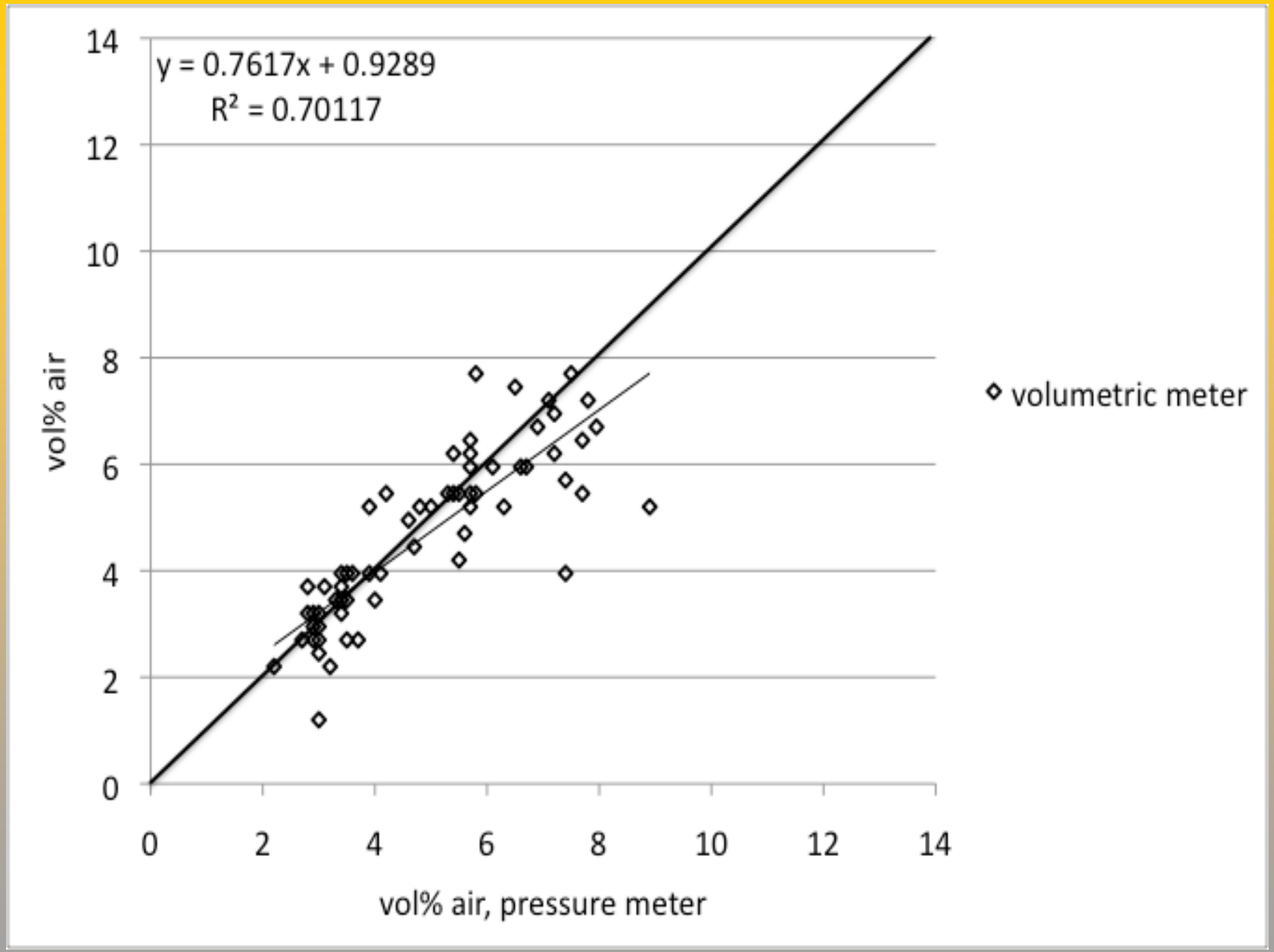

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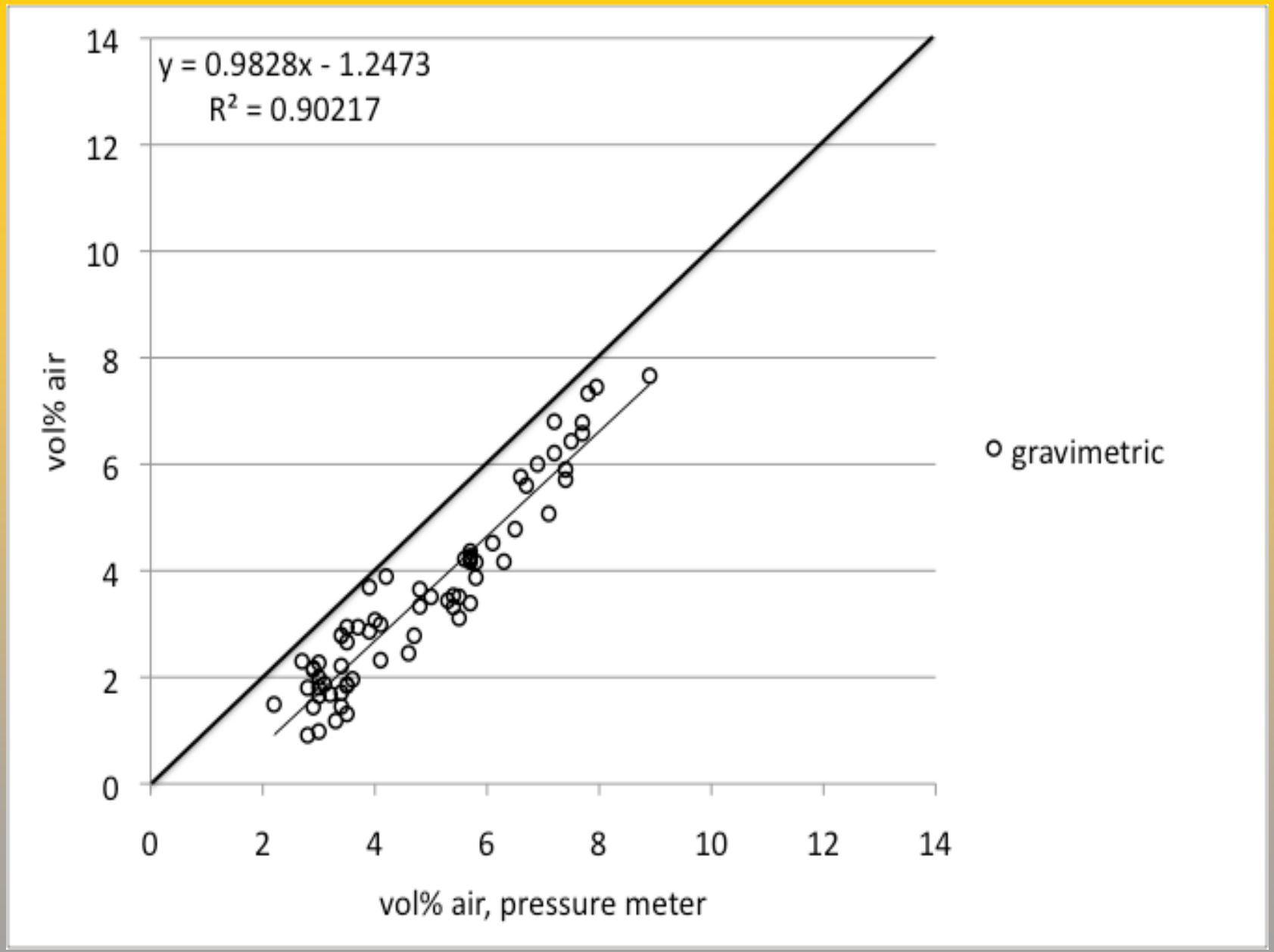

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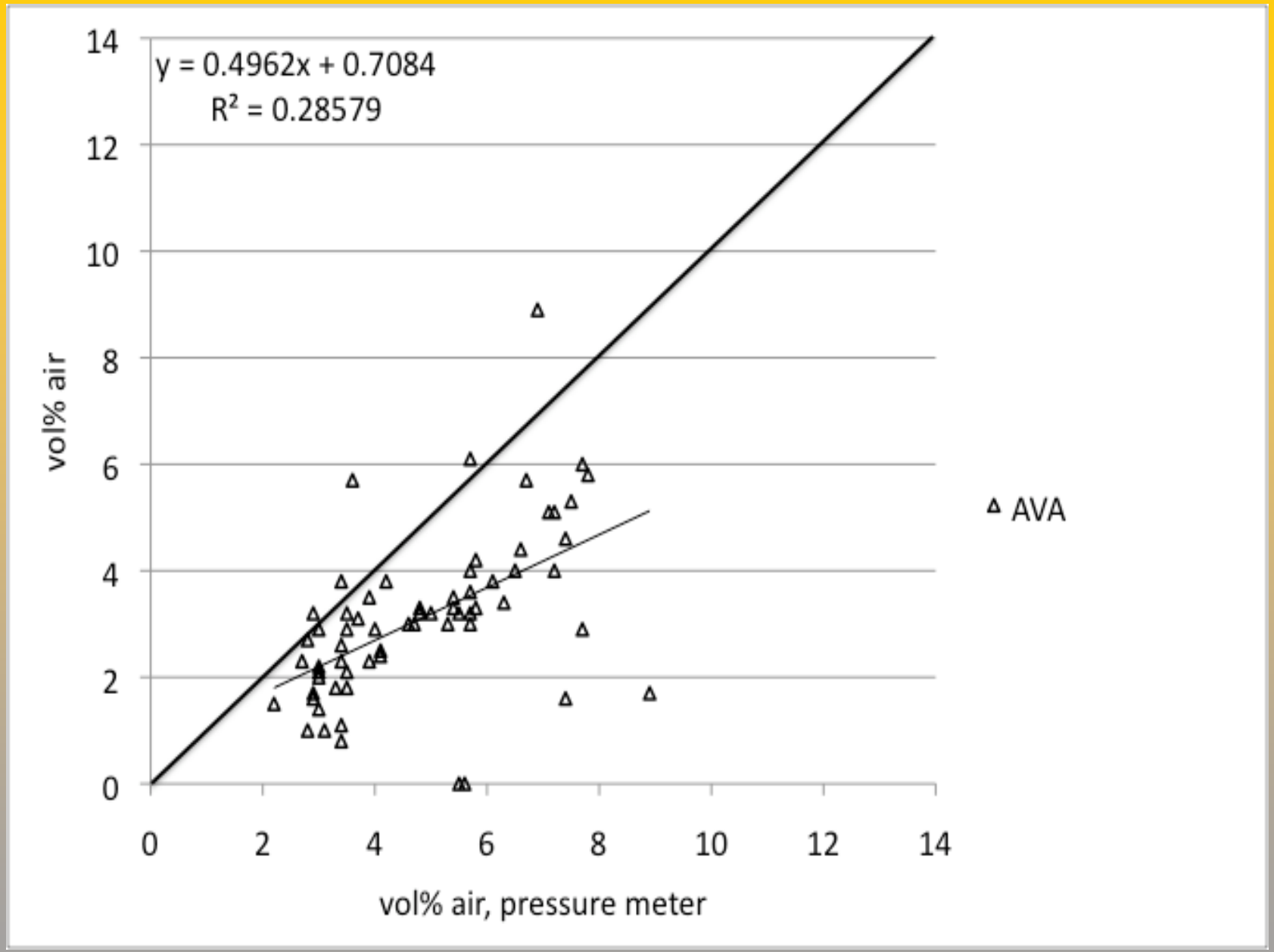

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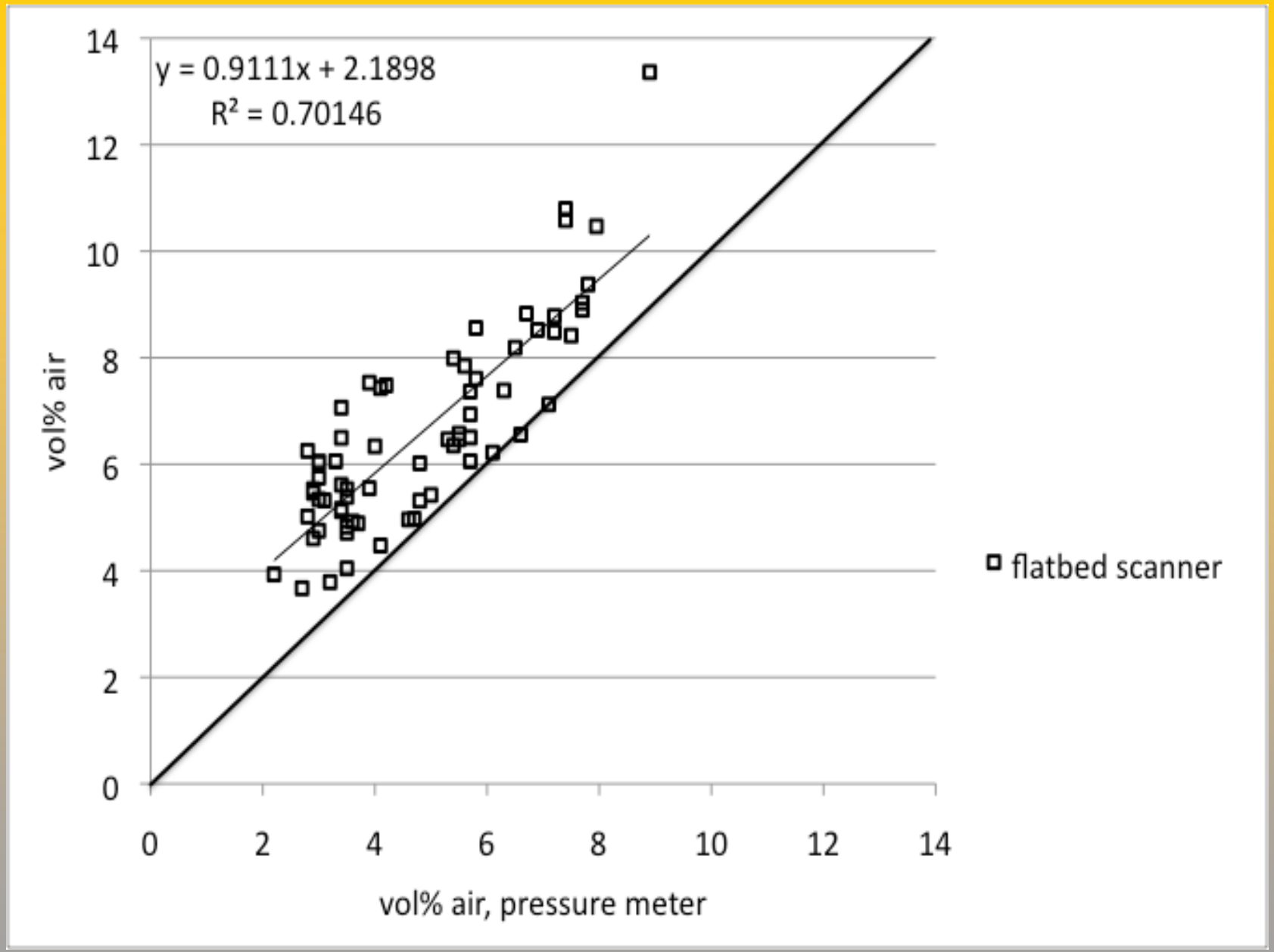

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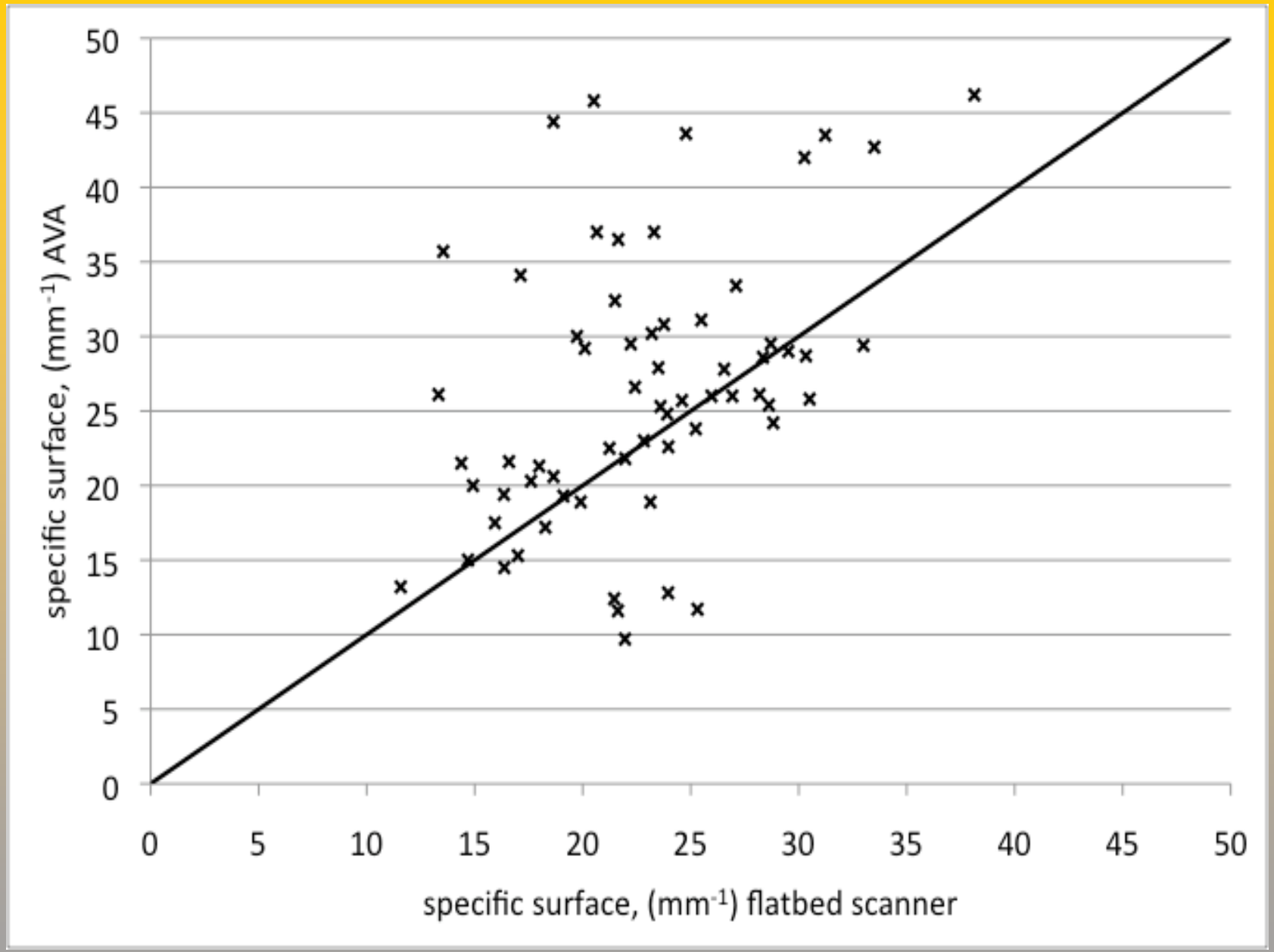

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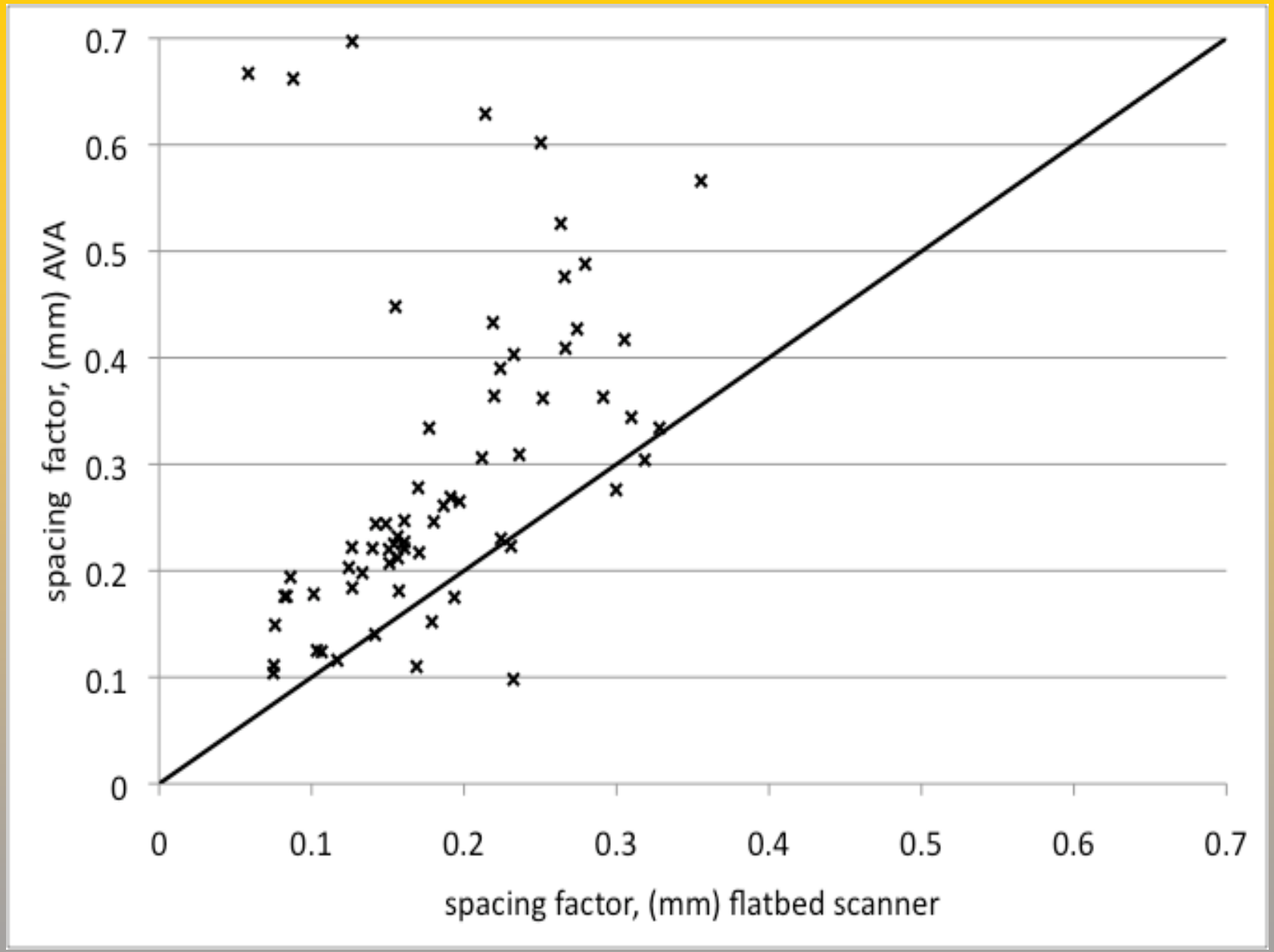

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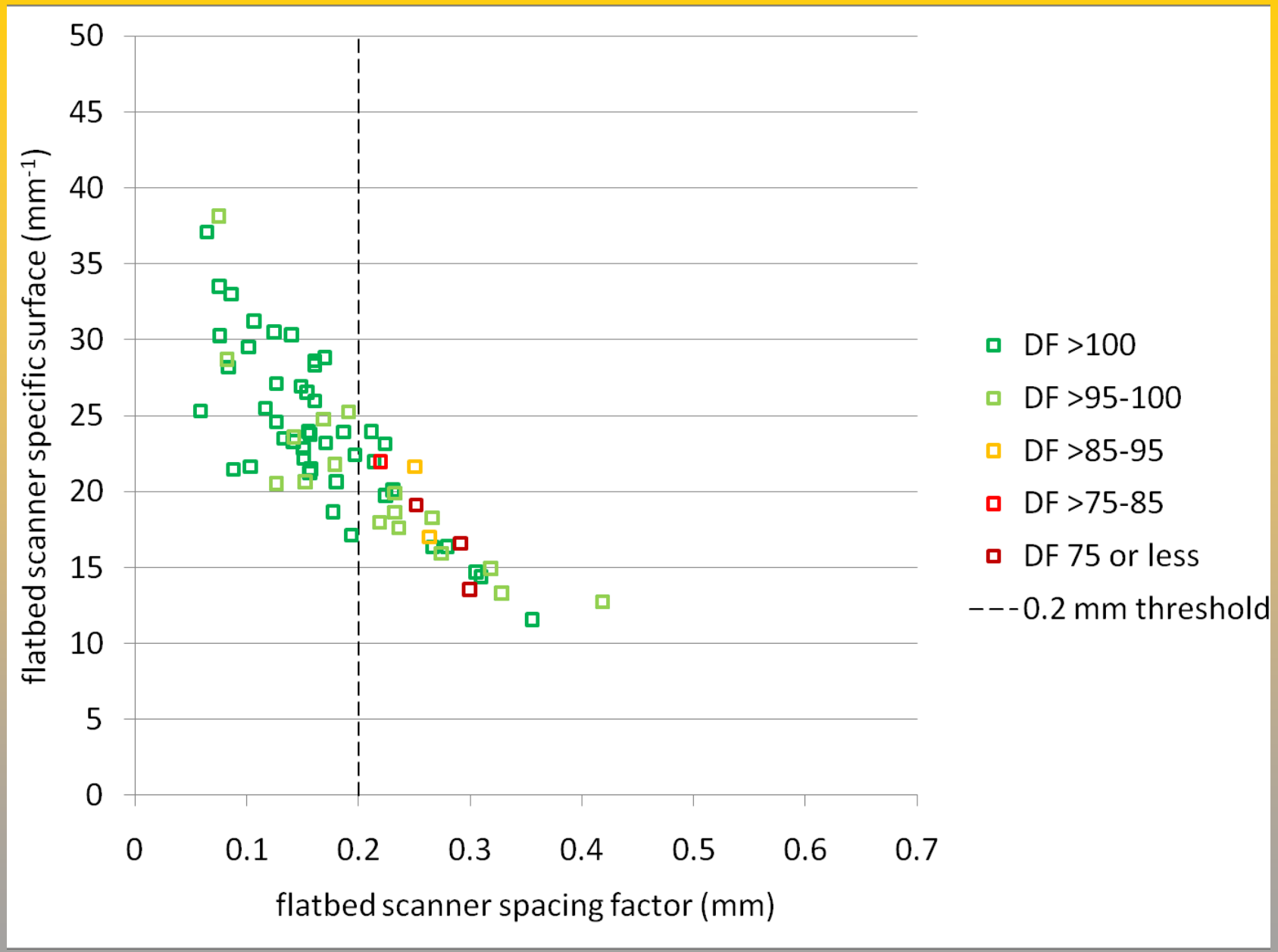

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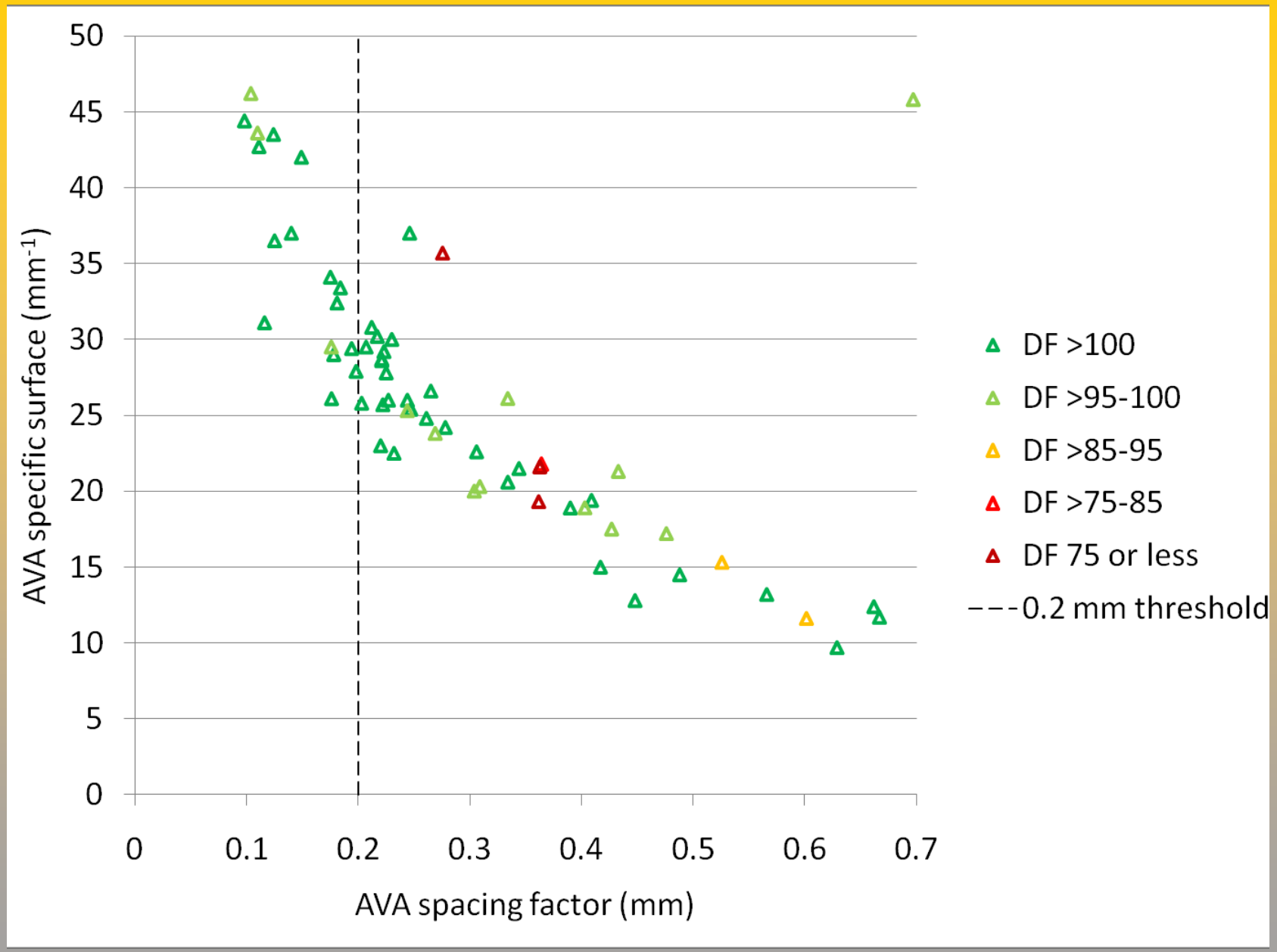

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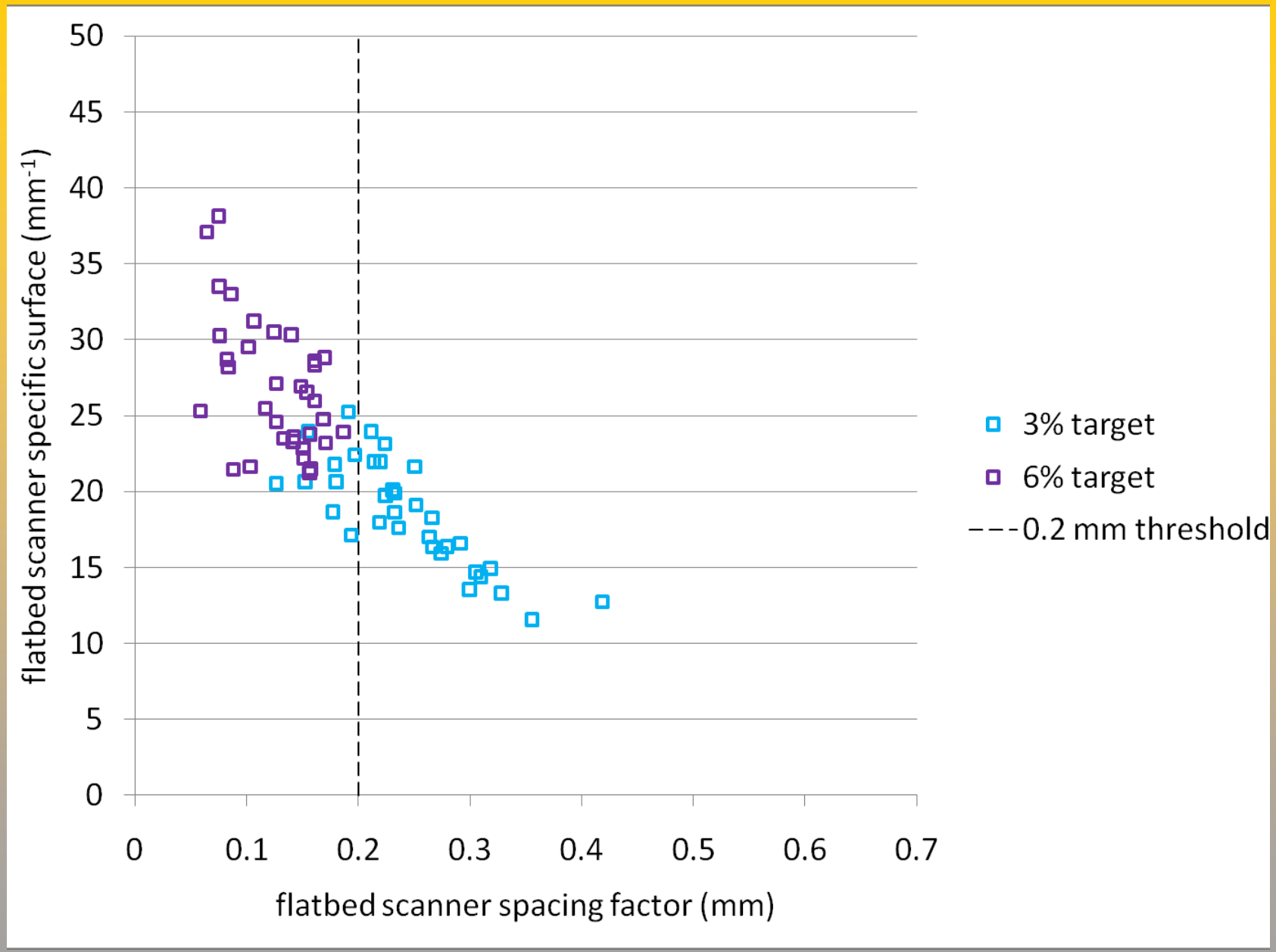

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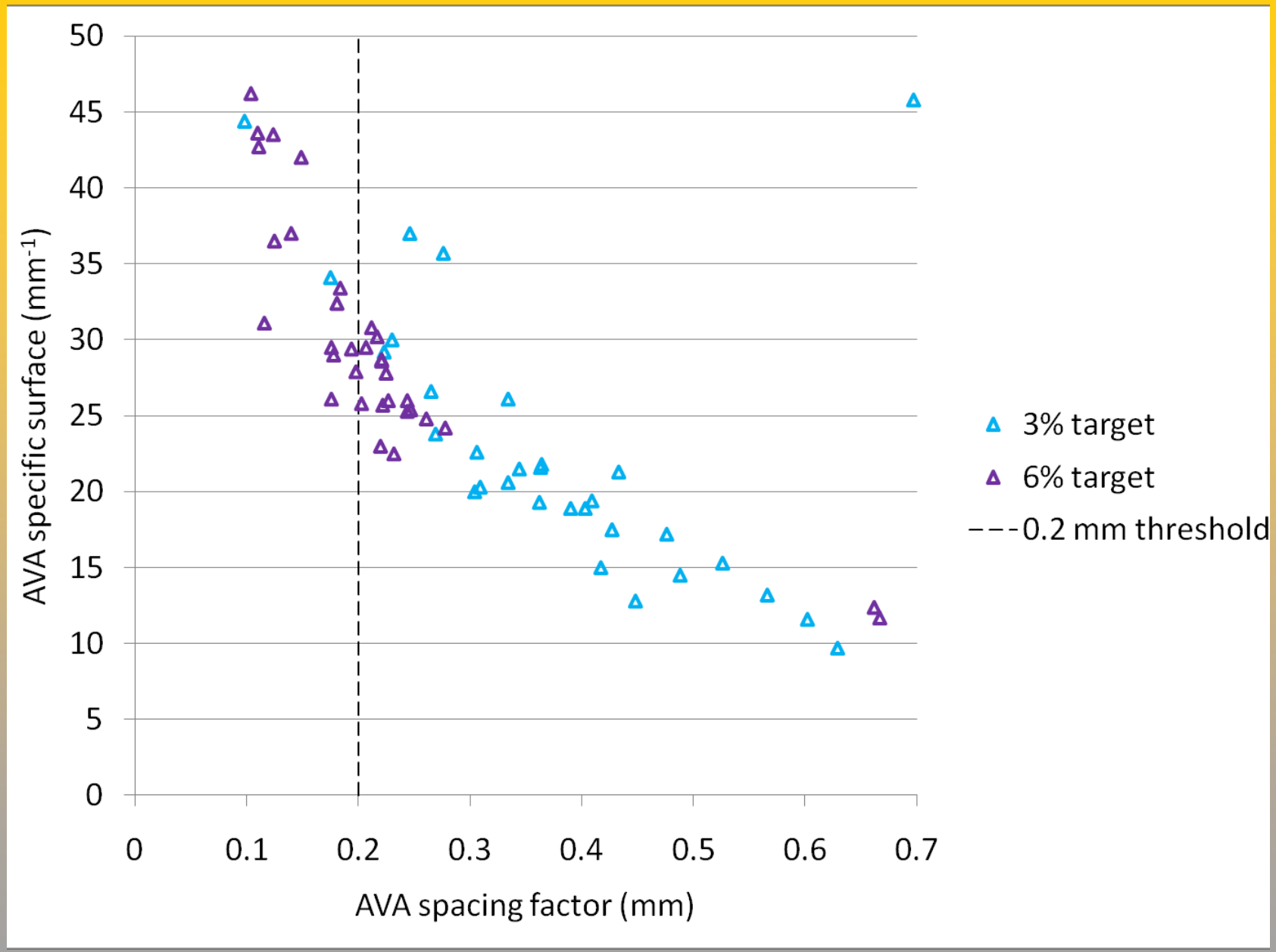

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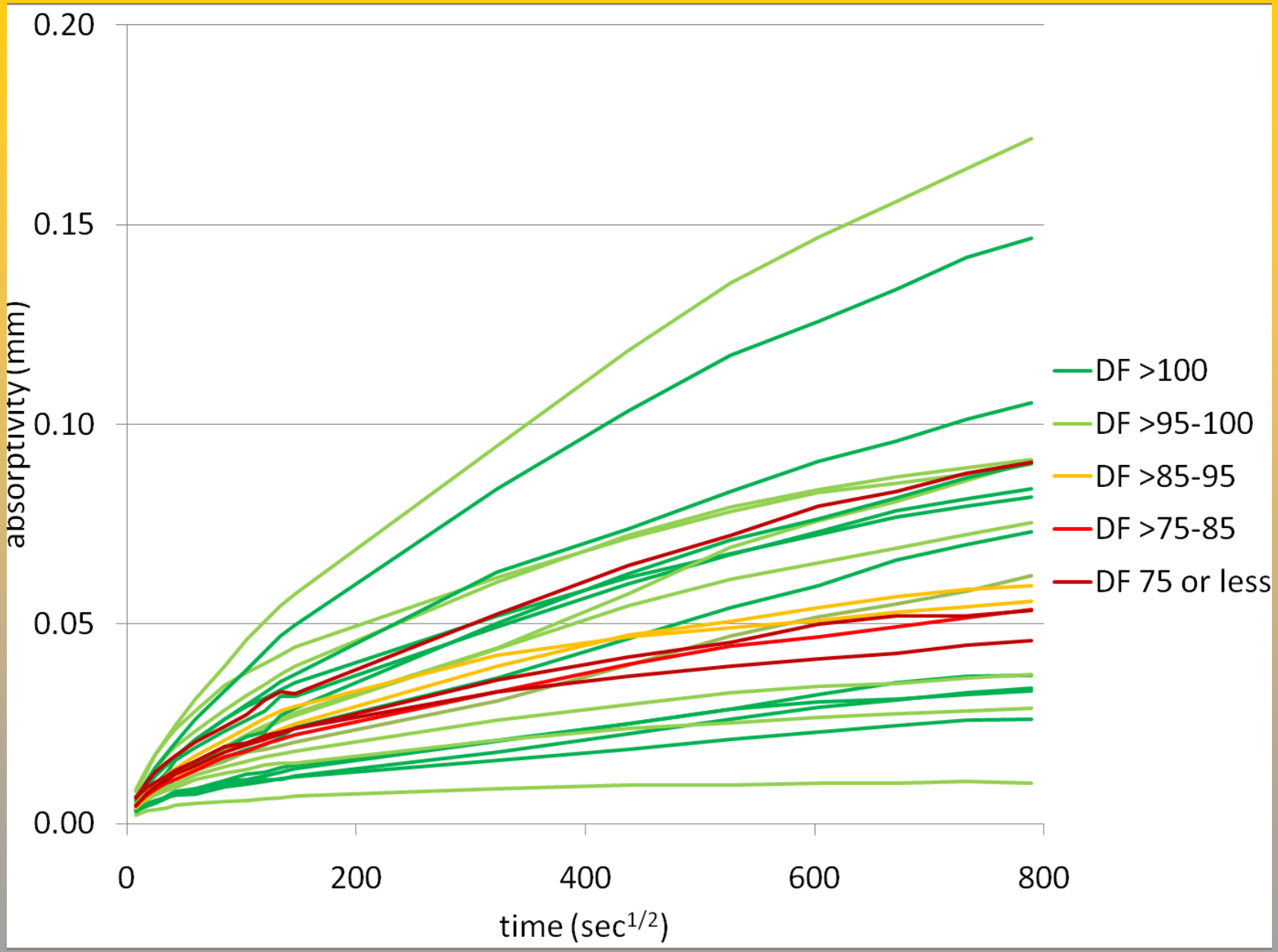

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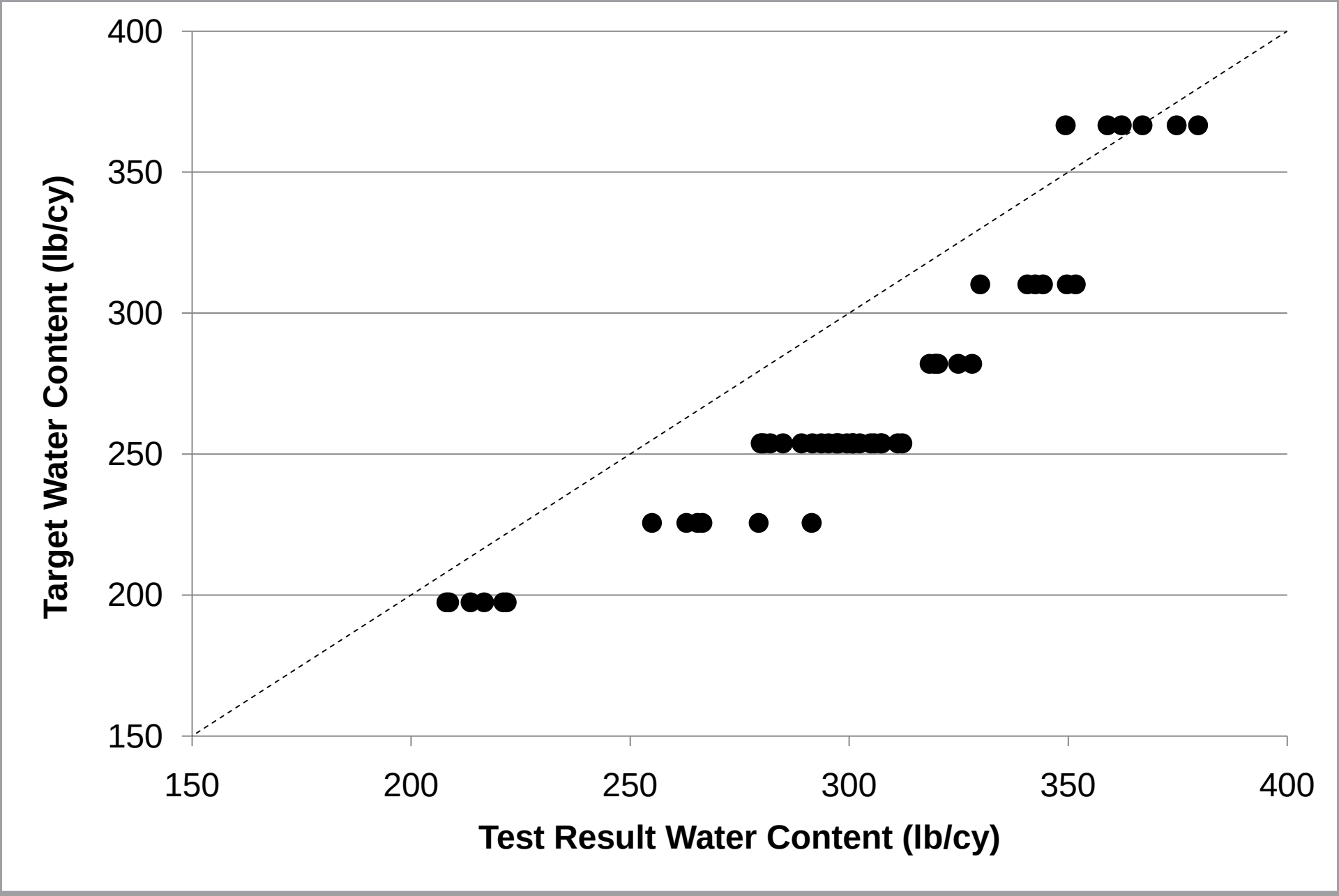
Microwave-Oven Drying Method

- AASHTO T 318-02 *Standard Method of Test for Water Content of Freshly Mixed Concrete Using Microwave Oven Drying*
- Water Content Percentage (WC):

$$WC = (Wt\ Fresh - Wt\ Dry) / Wt\ Fresh$$

- Total Water Content (WT):

$$WT = 27^* (WC)^*(Unit\ Wt) / 100$$


400
350
300
250
200
150
Target Water Content (lb/cy)
150
200
250
300
350
400
Test Result Water Content (lb/cy)

Aggregate Absorption Correction

- Corrected water content percentage:

$$WC=\left[100\times\left(\frac{WF-WD}{WF-WS}\right)\right]-\frac{\left(ABS_C\times WT_C\right)+\left(ABS_F\times WT_F\right)}{UW\times V}$$

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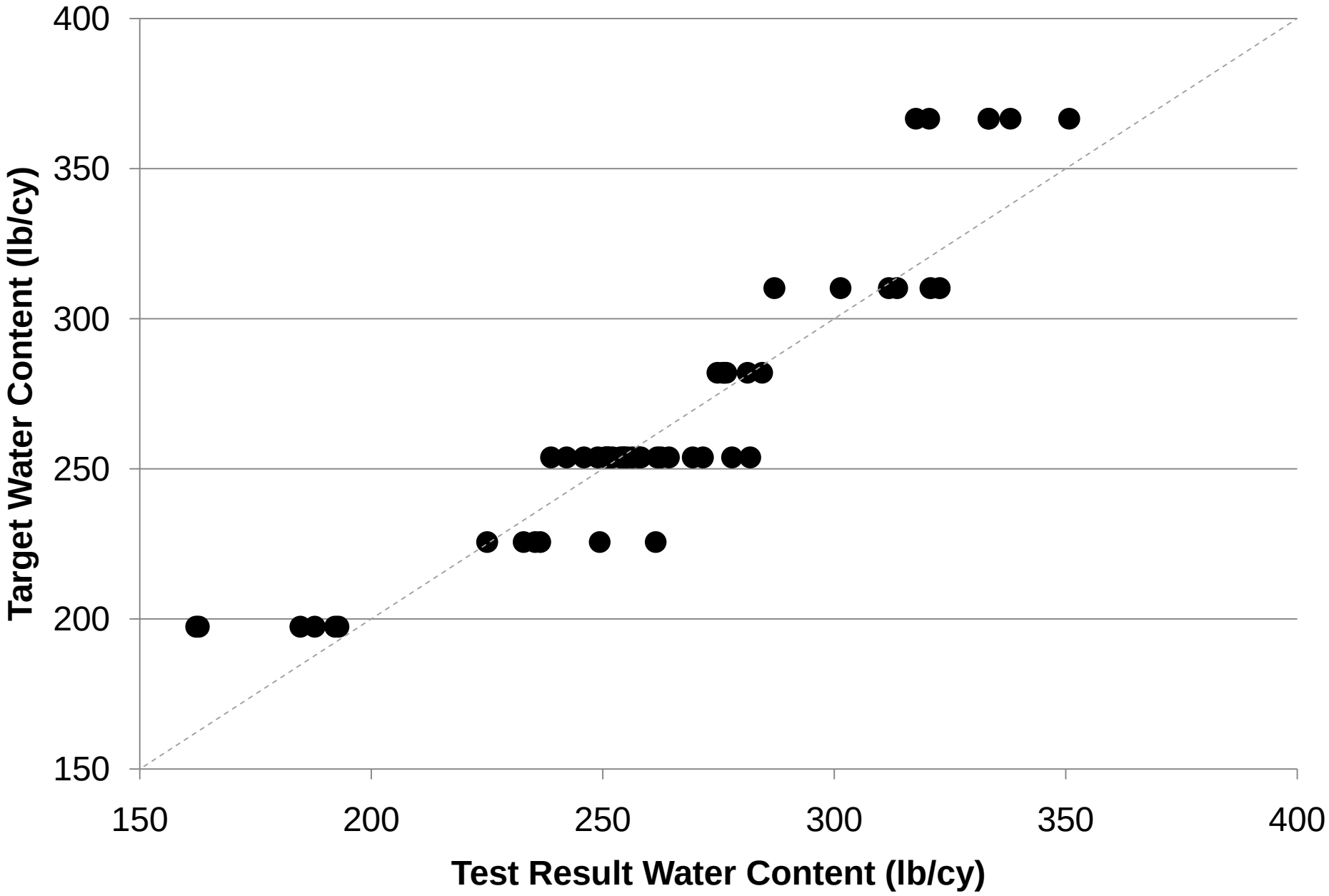
400
350
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Target Water Content (lb/cy)
150
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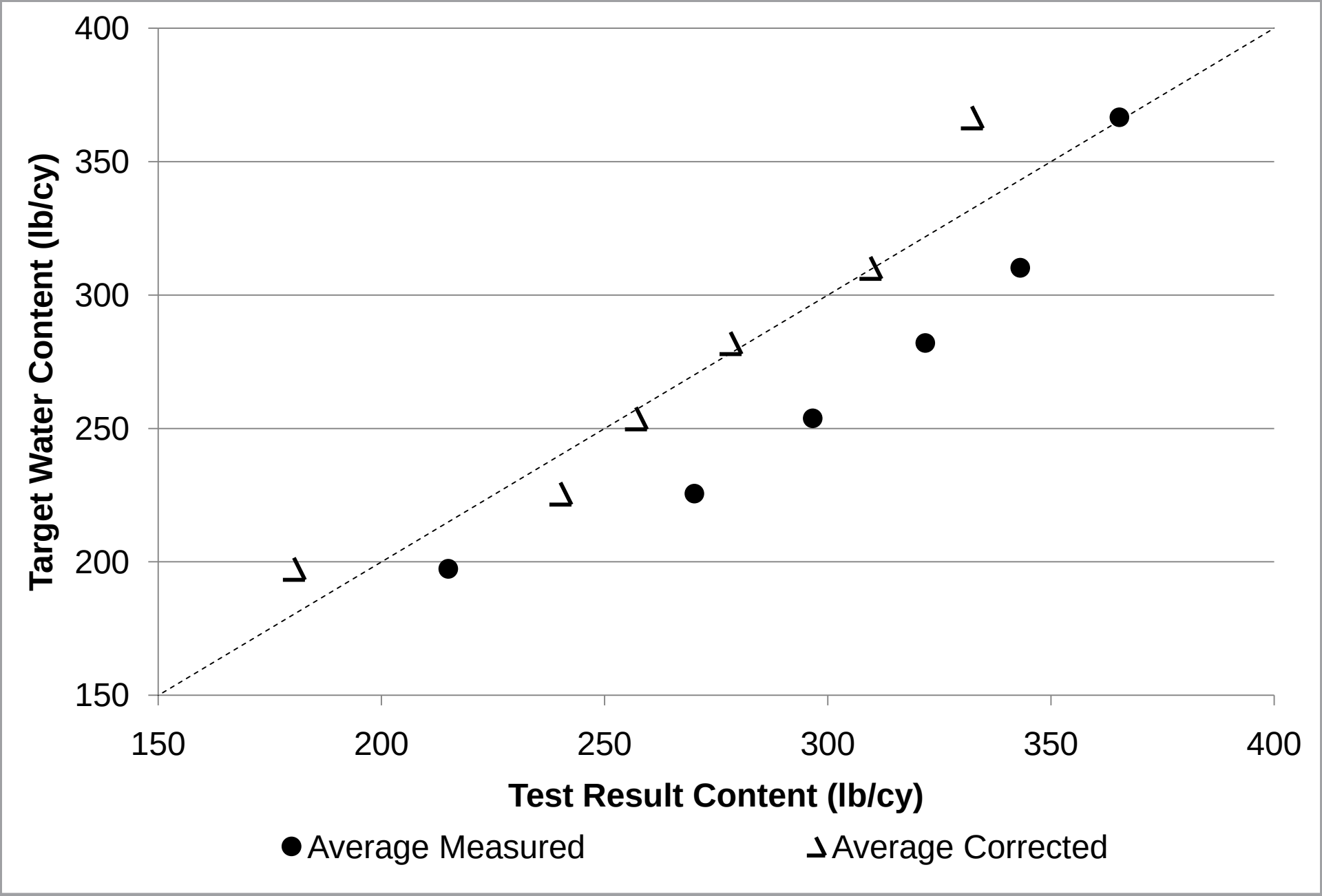
400
Test Result Water Content (lb/cy)


400
350
300
250
200
150
Target Water Content (lb/cy)
150
200
250
300
350
400
Test Result Content (lb/cy)
Average Measured
Average Corrected

Precision Statements

- 1s and d2s limits define the expected variability between individual test results

  1s - an indication of the variability of a large group of individual test results obtained under similar conditions

  d2s - the difference between two individual test results that would be equaled or exceeded in the long run in only 1 case in 20 in the normal and correct operation of the method

- AASHTO T 318 reports a 1s value of 2.7 lb/cy and a d2s value of 7.6 lb/cy

Overall Precision

Limits for data grouped by water content

Water Content (lb/cy)	1s Limit	d2s Limit
197.40	14.22	40.23
225.60	12.81	36.23
253.80	7.71	21.80
282.00	2.49	7.06
310.20	7.70	21.79
366.60	12.08	34.18

Overall Precision

Limits for entire data set

	1s Limit (lb/cy)	d2s Limit (lb/cy)
Measured Water Content	15.14	42.82
Corrected Water Content	12.51	35.37

Overall Precision

Limits for data grouped by water content

Water Content (lb/cy)	1s Limit	d2s Limit
~~197.40~~	~~14.22~~	~~40.23~~
225.60	12.81	36.23
253.80	7.71	21.80
282.00	2.49	7.06
310.20	7.70	21.79
~~366.60~~	~~12.08~~	~~34.18~~

Overall Precision

Limits for limited data set

	1s Limit (lb/cy)	d2s Limit (lb/cy)
Measured Water Content	9.95	28.14
Corrected Water Content	8.37	23.66

Summary

- Although there is reasonable agreement between standard air tests, the AVA tends to underestimate the air content and over estimate the spacing factor

- No mixture failed ASTM C666 with a spacing factor less than 0.20 mm, but many with a greater spacing factor passed

Summary

- Air-void system parameters (i.e. spacing factor and specific surface) track with air content, but F-T performance often does not

- By AVA, spacing factor and specific surface relate to F-T performance, but the the limit of 0.20 mm does not appear to apply

Summary

- The microwave water content measurement is best used with an aggregate absorption correction
- The technique seems most accurate in ranges of water content from ~220 -320 lb/cy
- AASHTO published precision is dubious over the range of the test