Comparison of Dynamic Testing Equipment and Test Methods for Tire Tread Compounds

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Abstract

This study is to evaluate various tire tread compounds for dynamic properties and crack growth properties. Properties such as E*, G* and Tan δ are evaluated in compression and shear, using different specimen geometry, over wide ranges of temperature and strain. Four compounds (three tire tread compound and one seal compound) are tested for dynamic properties and crack growth performance. No attempt was made to optimize any of the properties. Correlation of dynamic testing equipment and test methods are shown. Dynamic testing equipment used in this study are the Rubber Process Analyzer 2000 (RPA), Dynamic Mechanical Analyzer (DMA) and MTS 831.20 Elastomer Test System (MTS).

Introduction

Tires are made of different layers of rubber composite - that is - layers of rubber matrix with reinforcements. Modern quality tires depend on the ability to operate under static and dynamic conditions with good performance and longer service life. The dynamic response under sinusoidal force or deformations (dynamic testing) determine overall performance of tire compounds. Major dynamic properties are dynamic modulus (E* or G*), loss modulus (E" or G"), storage modulus (E' or G') and loss tangent (tan δ). The dynamic properties are related to tire performance like rolling resistance, wet traction, dry traction, winter performance and wear resistance.[1,2,3]

Testing tire compounds for dynamic properties, in service conditions, has improved considerably due to the availability of high-tech testing equipment. The expensive traditional method is to build tires with one or two development compounds and then evaluate them on the drum test.[4] A good repeatable dynamic test will reduce the number of iterations of traditional expensive drum test needed for qualification. Traditional tests used by the tire industry can be divided into the following categories:

1. Laboratory test
2. Tire machine test or drum test
3. Field test

Drum tests and field tests are very expensive and time consuming. Therefore, to predict the performance of a new compound, it is necessary to have repeatable and reproducible laboratory test. Good correlation of laboratory test to actual tire field performance test was reported by several sources.[5,6]

Reliable dynamic tests data will be extremely helpful for a straight forward and successful tread compound development. Aim of this study is to verify or establish correlation between following three laboratory dynamic tests:

1. Dynamic processibility test (uncured and cured sample) - Rubber Process Analyzer 2000 (RPA)
2. Laboratory dynamic test (new compound which is already screened by processibility test) - MTS Elastomer Test System (MTS)
3. Laboratory dynamic test (test on failed sample or field "return" sample) - Dynamic Mechanical Analyzer (DMA)

This paper discusses the correlation between above mentioned three dynamic tests using three standard tire compounds. Correlation between test data on different sample geometry are discussed. This paper also discuss a new ARDL crack growth propagation test method.

Experimental

Dynamic Testing Equipment:

- Rubber Process Analyzer 2000 (RPA)
- MTS 831.20 Elastomer Test System (MTS)
- Dynamic Mechanical Analyzer (DMA)

Rubber Process Analyzer 2000

Precise rheological information
Unvulcanized properties
Vulcanization *in situ*
Dynamic properties
Strain Sweeps: 0 - 1255 % uncured, 0 - 42 % cured
Frequency Sweeps: 0.033 - 33.33 Hz
Temperature Sweeps: ambient - 200°C

MTS 831.20 Elastomer Test System

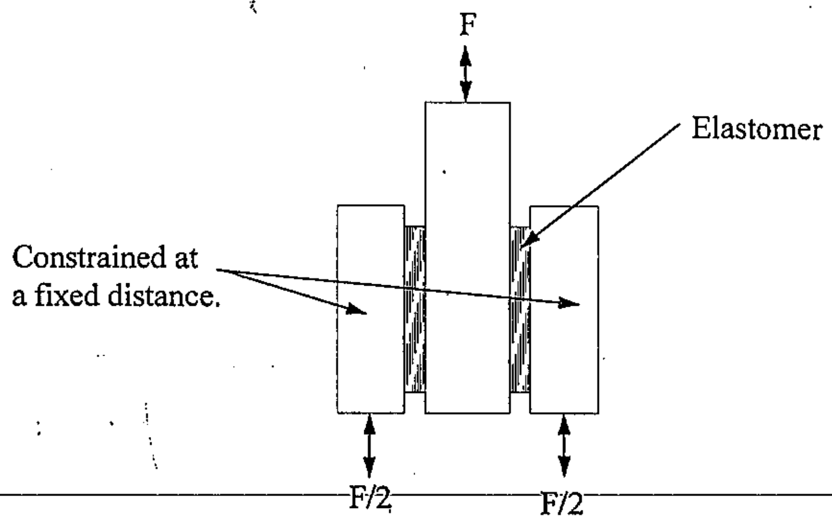
Frequency: 0.01 Hz to 400 Hz
Load: -25 kN to +25 kN (-5 kips to +5 kips)
Displacement: -35 mm to +35mm (±1.35 in)
Temperature: -100°C to 300°C

Dynamic Mechanical Analyzer

Frequency: 0 - 51 Hz
Temperature Sweep: -100°C to +1000°C
Strain Sweep: up to 5%
Load: 75 grams
Sample Size: 1/8 inch dia. x 1/8 inch thick

Specimen Geometry
Dual Lap Shear
Compression Set Button
DMA Button
RPA - Uncured Sample

Dual Lap Shear Test



Specimens:

- RPA
    - Uncured and cured
- MTS
    - Compression Set Button
    - Double Lap Shear
- DMA
    - DMA Button

Test Parameters:

- Measurement Temperatures, °C
    - 0, 40 and 80
- Strain, %
    - 1, 5, 10 and 20
- Property
    - Tan d

Compounds:

- Truck Tire Tread
- Passenger Tire Tread (Black Reinforced)
- Passenger Tire Tread (Silica Reinforced)
- MRG Hydrogenated Nitrile Rubber (Dynamic Seal Compound)

Truck Tire Tread - TT1

TSR 20 Natural Rubber	80
cisPoly BD	20
SAF Black (N-110)	50
ANTOZITE 67P	2
AGERITE RESIN D	2
VANWAX H Special	1.5
Aromatic Oil	4
Stearic Acid	2
Zinc Oxide	4
Sulfur	1.75
DURAX	1.75
VANTARD PVI	0.5

Passenger Tire Tread (Black Reinforced) - PT1

NS-116 (SBR)	100
N-234	80
Silane (Si-69)	6.4
Aromatic Oil	37.5
Zinc Oxide	2.5
Stearic Acid	1.0
Antioxidant	2.0
Parrafin Wax	1.5
Sulfur	1.35
Sulfenamide	1.35

Passenger Tire Tread (Silica Reinforced) - PT2

NS-116 (SBR)	100
Silica	80
Silane (Si-69)	6.4
Aromatic Oil	37.5
Zinc Oxide	2.5
Stearic Acid	1.0
Antioxidant	2.0
Parrafin Wax	1.5
Sulfur	1.35
Sulfenamide	1.35

Hydrogenated Nitrile Rubber - HNBR

Zetpol 2010	100
N990 Black	30
TOTM	5
Maglite D	10
Naugard 445	2
Vanax ZMTI	1
HVA #2	7.5
Vulcup YOKE	5

Results and Discussions

Table 1 and 2 show the tan δ values at three different temperatures (0°C, 40°C and 80°C). Figure 1 through 4 summarizes the correlation between DMA, RPA and MTS. Figure 5 shows the correlation between sample geometries (compression set button and dual lap shear) tested on the MTS. Statistical analysis of the data indicates that the standard deviation for a single measurement was found to be ±5% in higher temperatures, while that of the measurement taken in cold temperatures was found to be ±8%.

Table 1

	Tan δ at 40°C at 5%			
	PT1	PT2	TT1	HNBR
RPA	0.347	0.197	0.168	0.154
DMA	0.375	0.272	0.211	0.201
MTS (CSB)	0.305	0.178	0.131	0.122
MTS (DLS)	0.304	0.198	0.152	0.132

Table 2

Temp		PT1	PT2	TT1	HNBR
0°C	MTS (CSB)	0.505	0.575	0.285	0.475
	MTS (DLS)	0.345	0.425	0.155	0.355
	DMA	0.481	0.561	0.281	0.469
40°C	MTS (CSB)	0.305	0.178	0.131	0.122
	MTS (DLS)	0.304	0.198	0.152	0.132
	DMA	0.375	0.272	0.211	0.201
80°C	MTS (CSB)	0.315	0.151	0.162	0.152
	MTS (DLS)	0.281	0.145	0.141	0.115
	DMA	0.331	0.172	0.185	0.175

MTS (CSB): 5% mean, 5% peak to peak amplitude
MTS (DLS): 0% mean, 5% peak to peak amplitude
DMA: 5% mean, 5% peak to peak amplitude

Figure 1

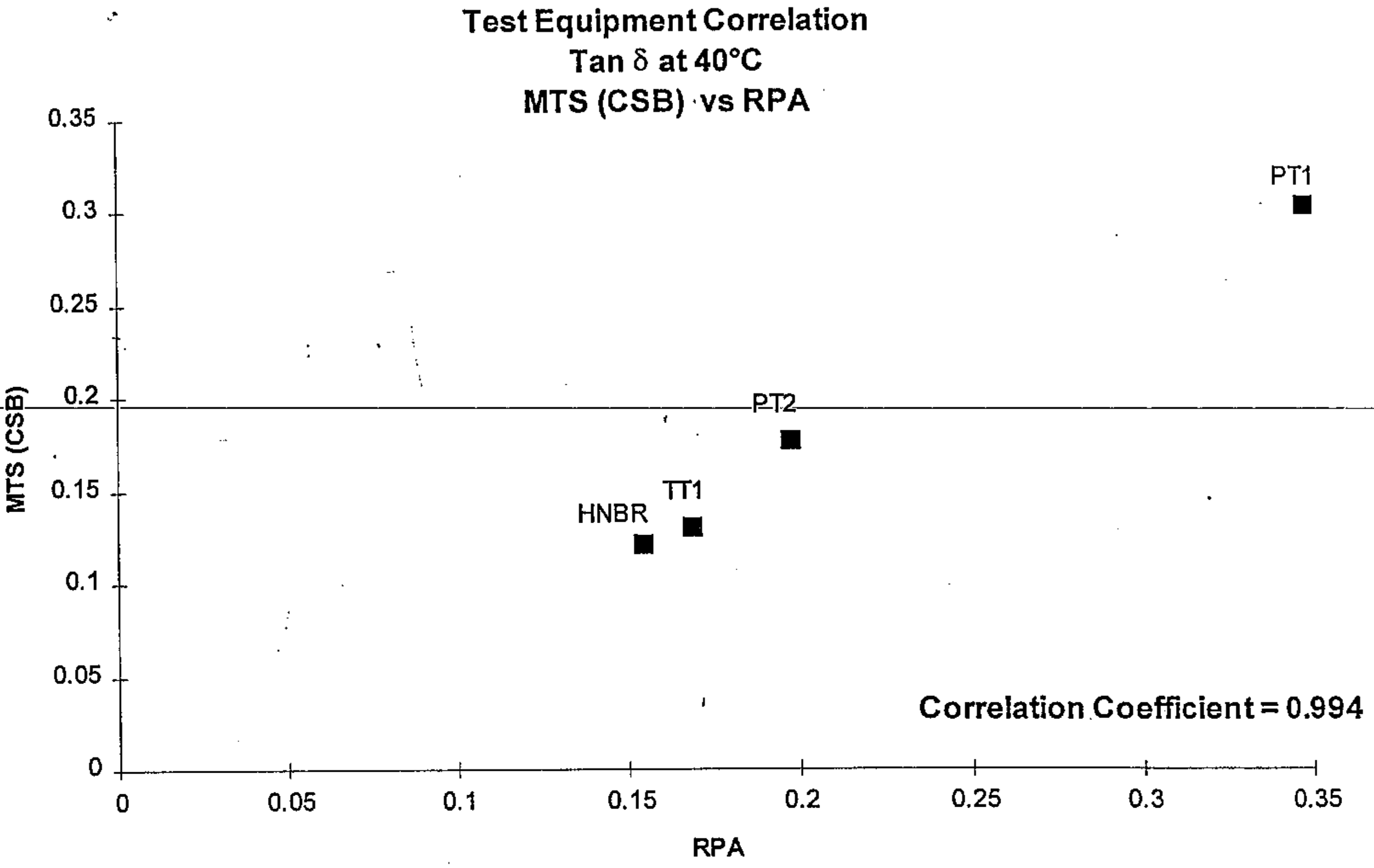

Test Equipment Correlation
Tan δ at 40°C
MTS (CSB) vs RPA
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
MTS (CSB)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
RPA
PT1
PT2
TT1
HNBR
Correlation Coefficient = 0.994

Figure 2

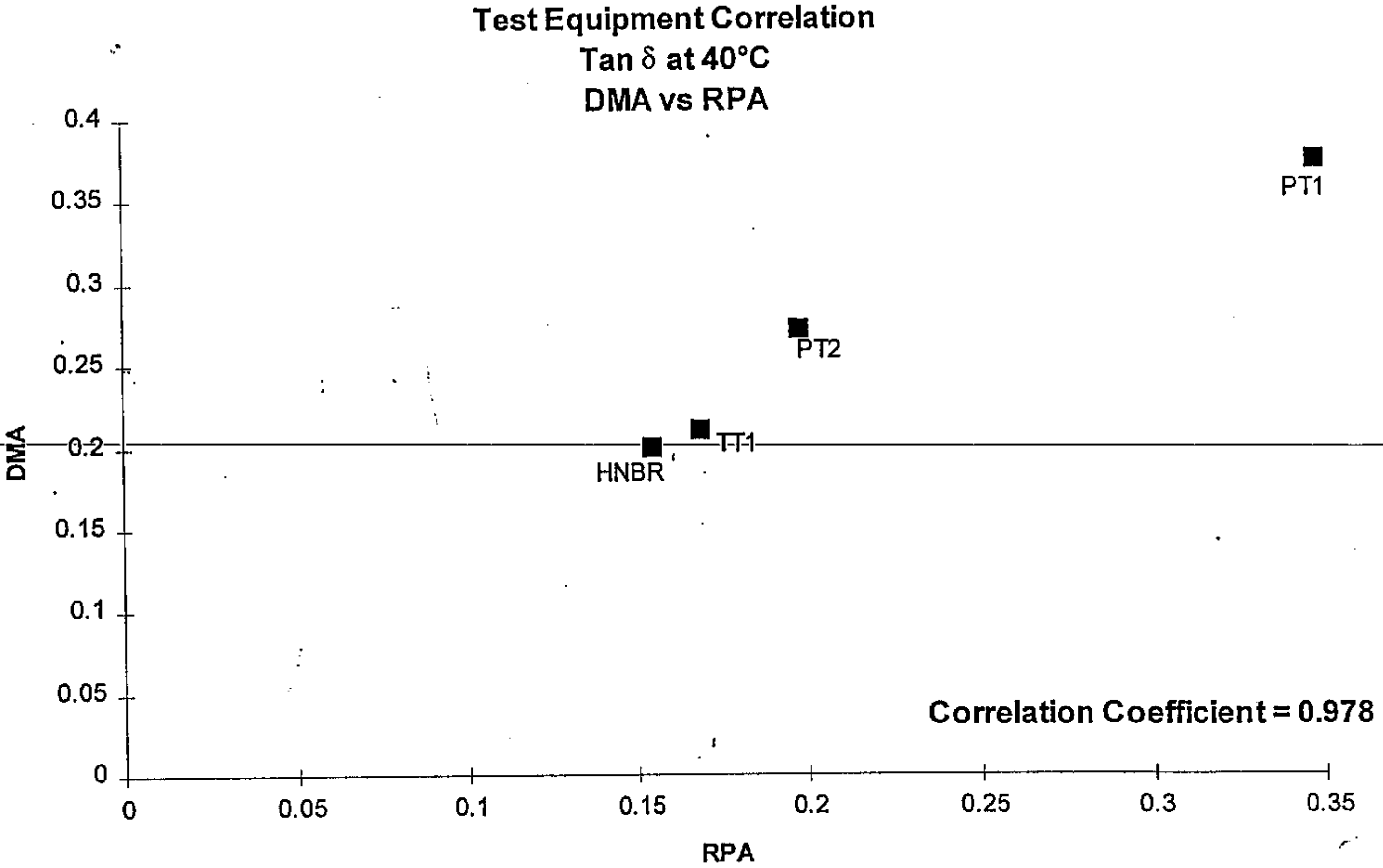

Test Equipment Correlation
Tan δ at 40°C
DMA vs RPA
DMA
RPA
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
PT1
PT2
TT1
HNBR
Correlation Coefficient = 0.978

Figure 3

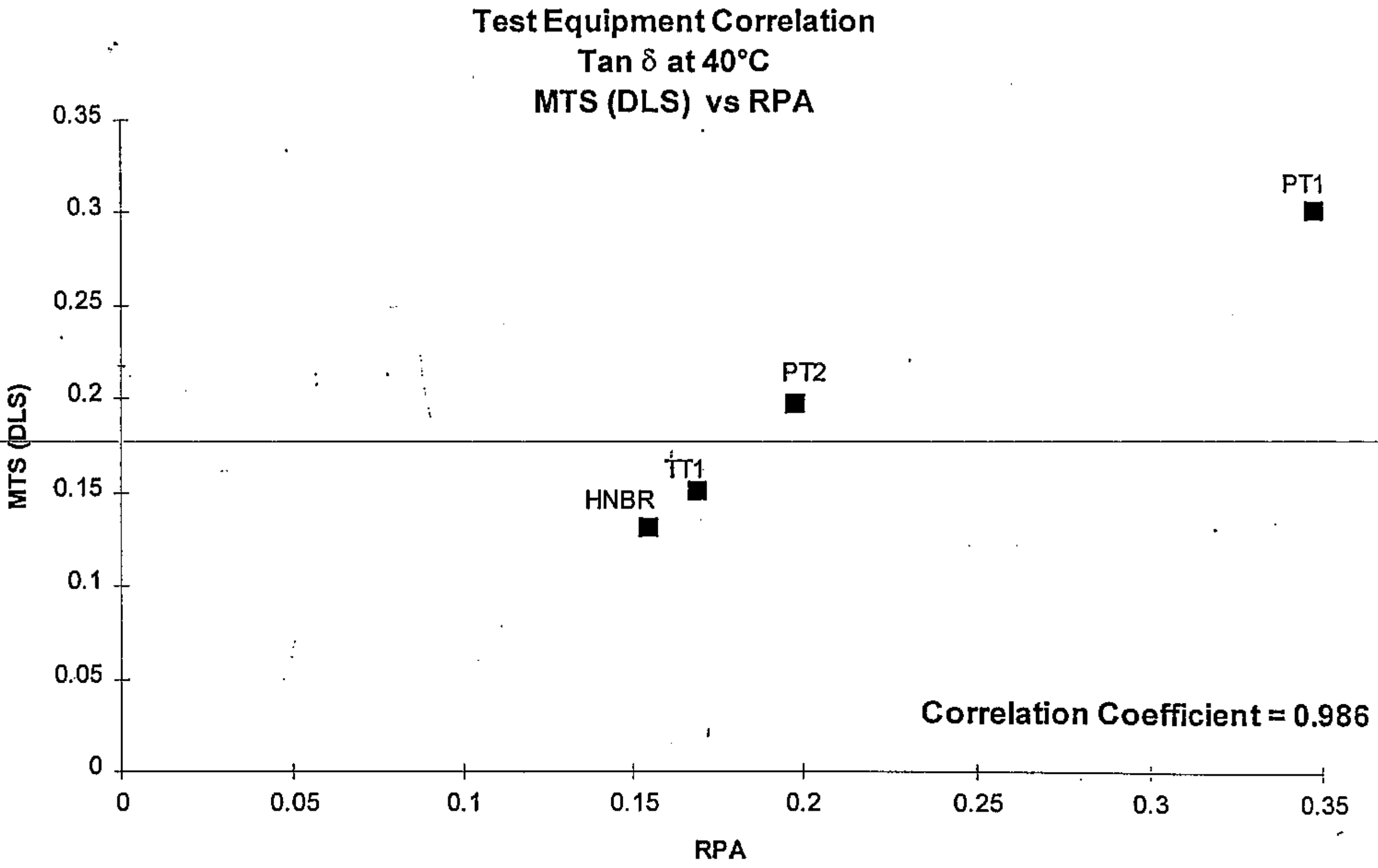

Test Equipment Correlation
Tan δ at 40°C
MTS (DLS) vs RPA
PT1
PT2
TT1
HNBR
Correlation Coefficient = 0.986
MTS (DLS)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
RPA
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35

Figure 4

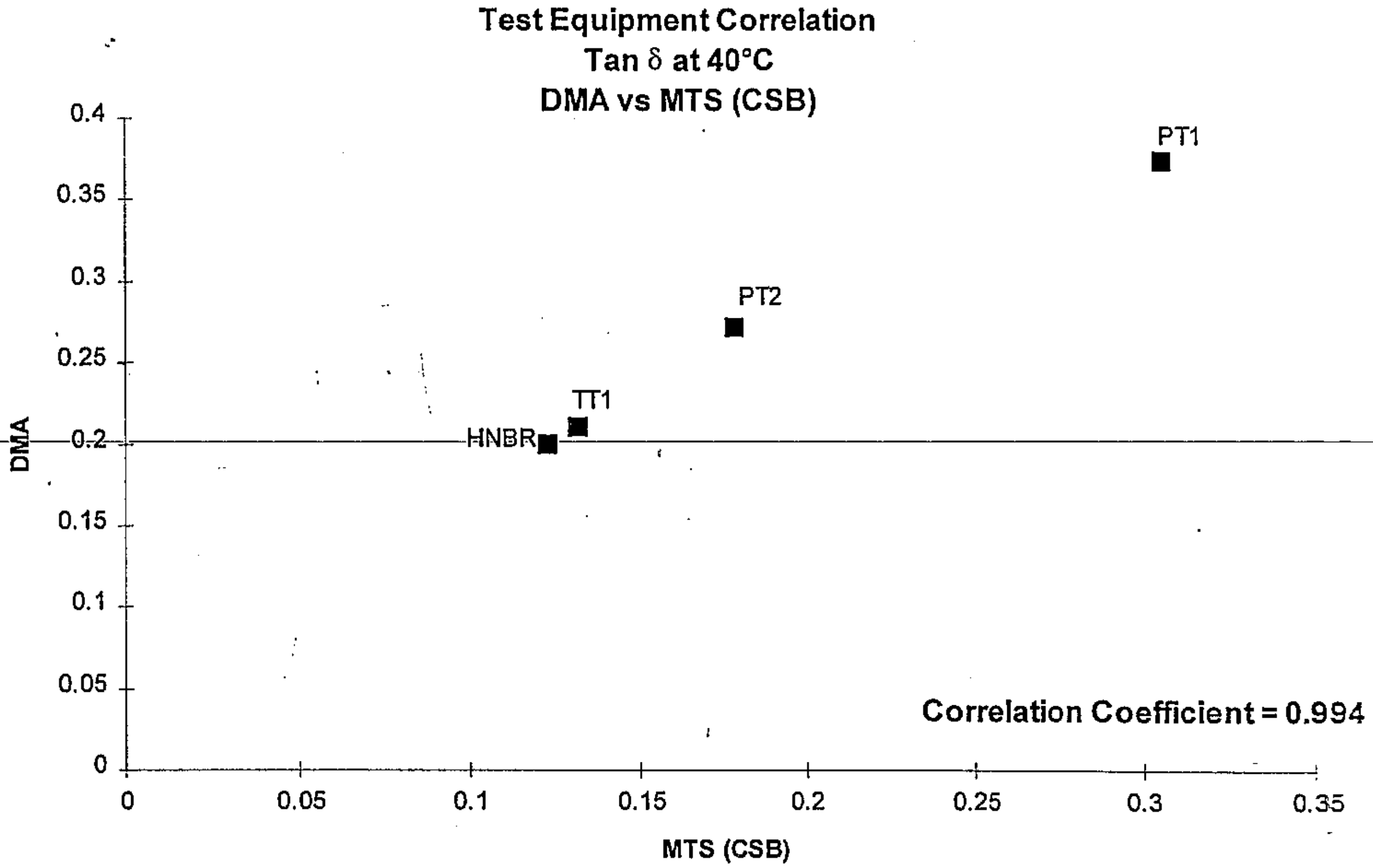
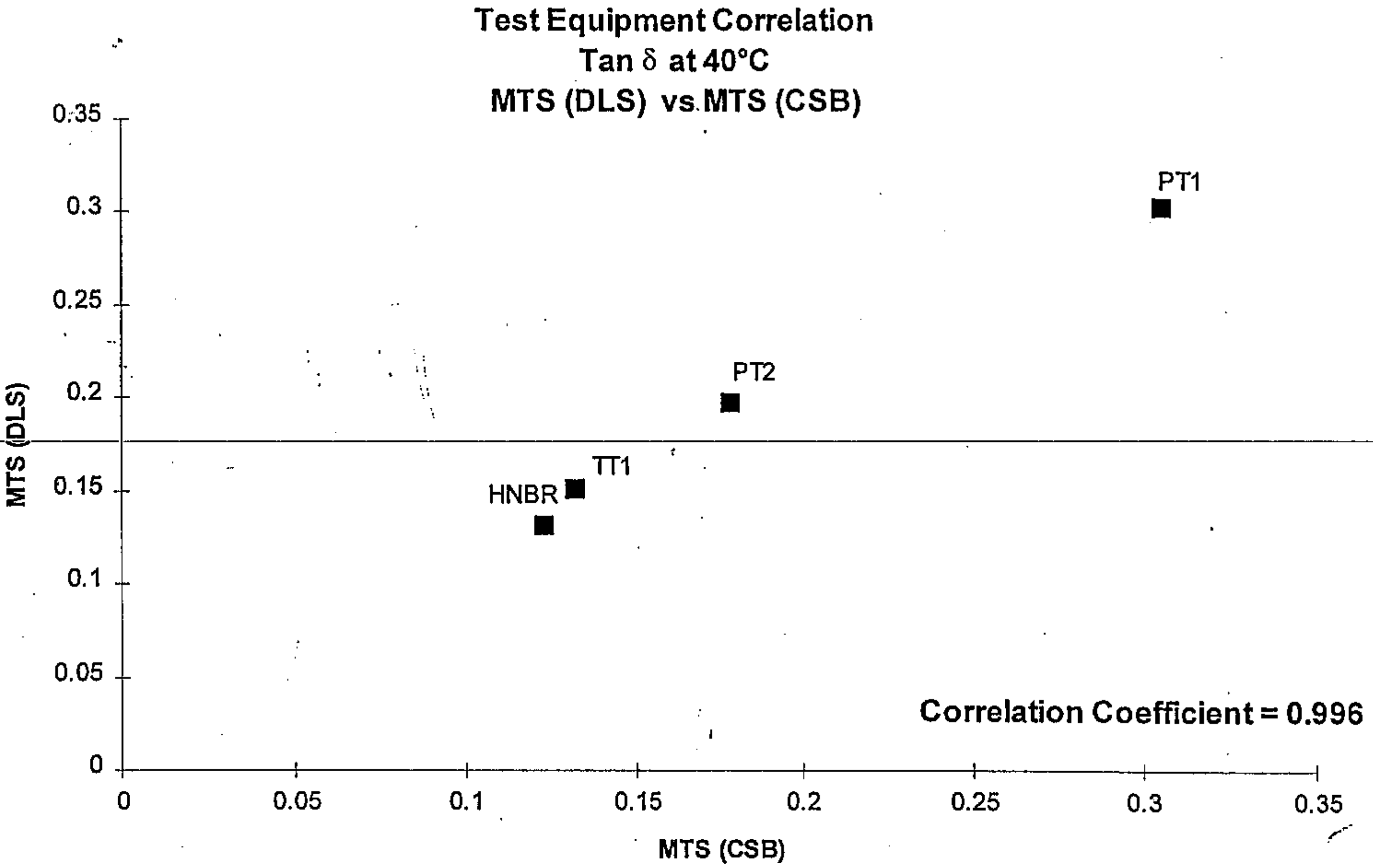

Test Equipment Correlation
Tan δ at 40°C
DMA vs MTS (CSB)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
DMA
PT1
PT2
TT1
HNBR
Correlation Coefficient = 0.994
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
MTS (CSB)

Figure 5


Test Equipment Correlation
Tan δ at 40°C
MTS (DLS) vs MTS (CSB)
MTS (DLS)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
MTS (CSB)
PT1
PT2
TT1
HNBR
Correlation Coefficient = 0.996

Conclusion

Test data generated on standard rubber compounds using three different dynamic test equipment showed good (correlation coefficient of 0.97) to excellent (correlation coefficient of 0.99). A critical review of the results from this study shows that the test repeatability, reproducibility and correlation problem inherent in dynamic tests can be resolved up to some extent by carefully selecting the measurement condition, test procedure, sample preparation and sample geometry.

References

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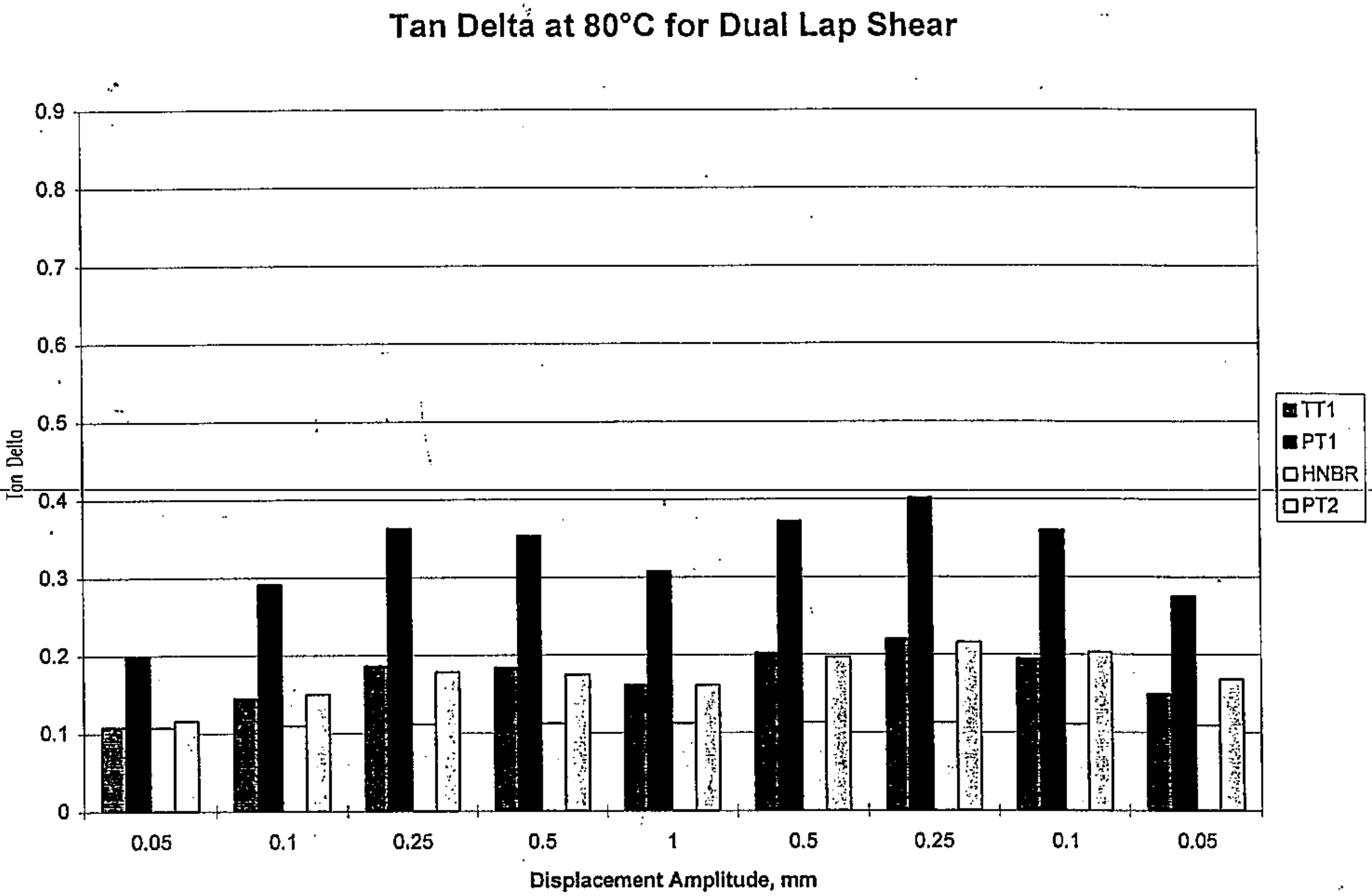
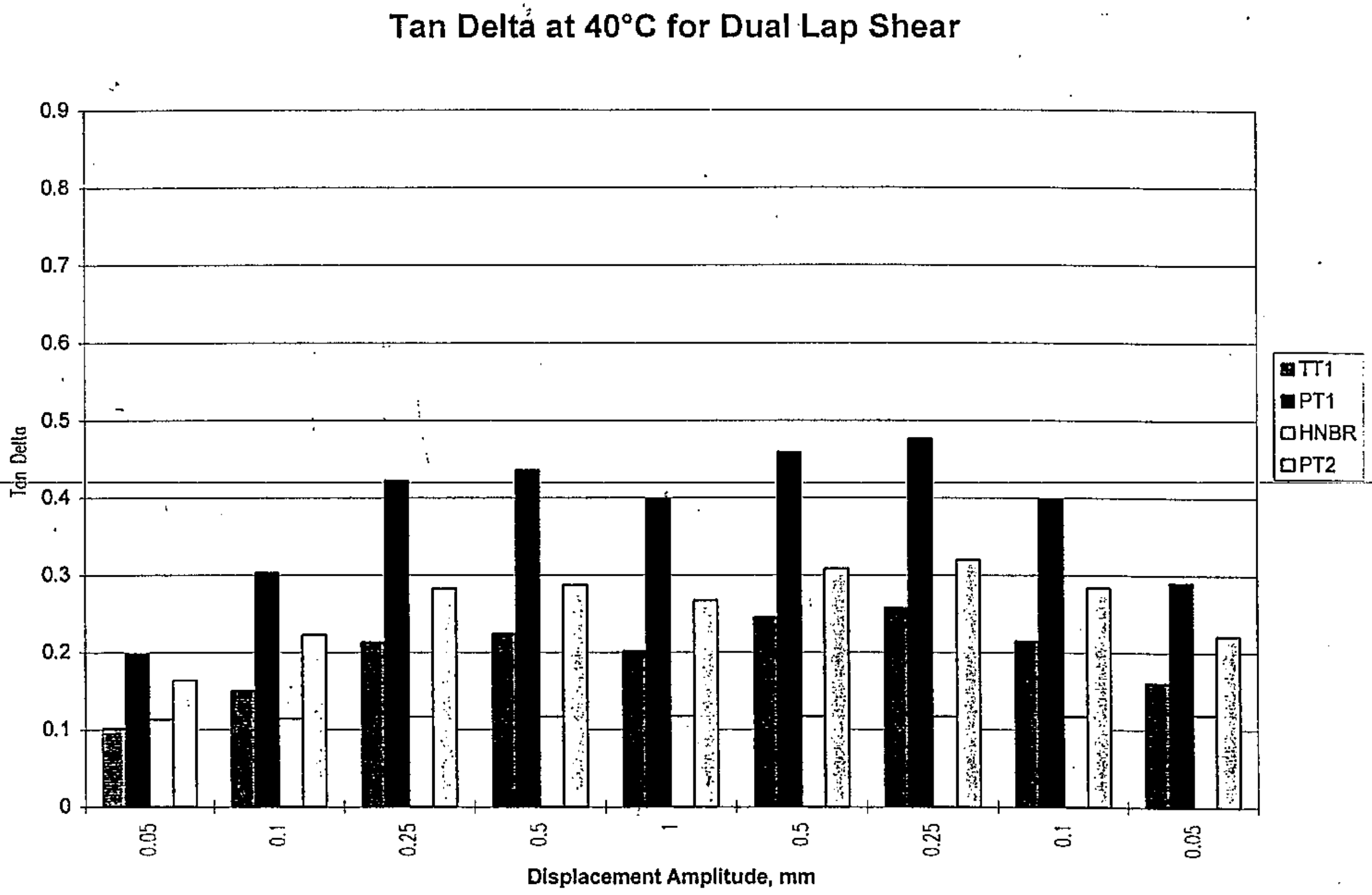
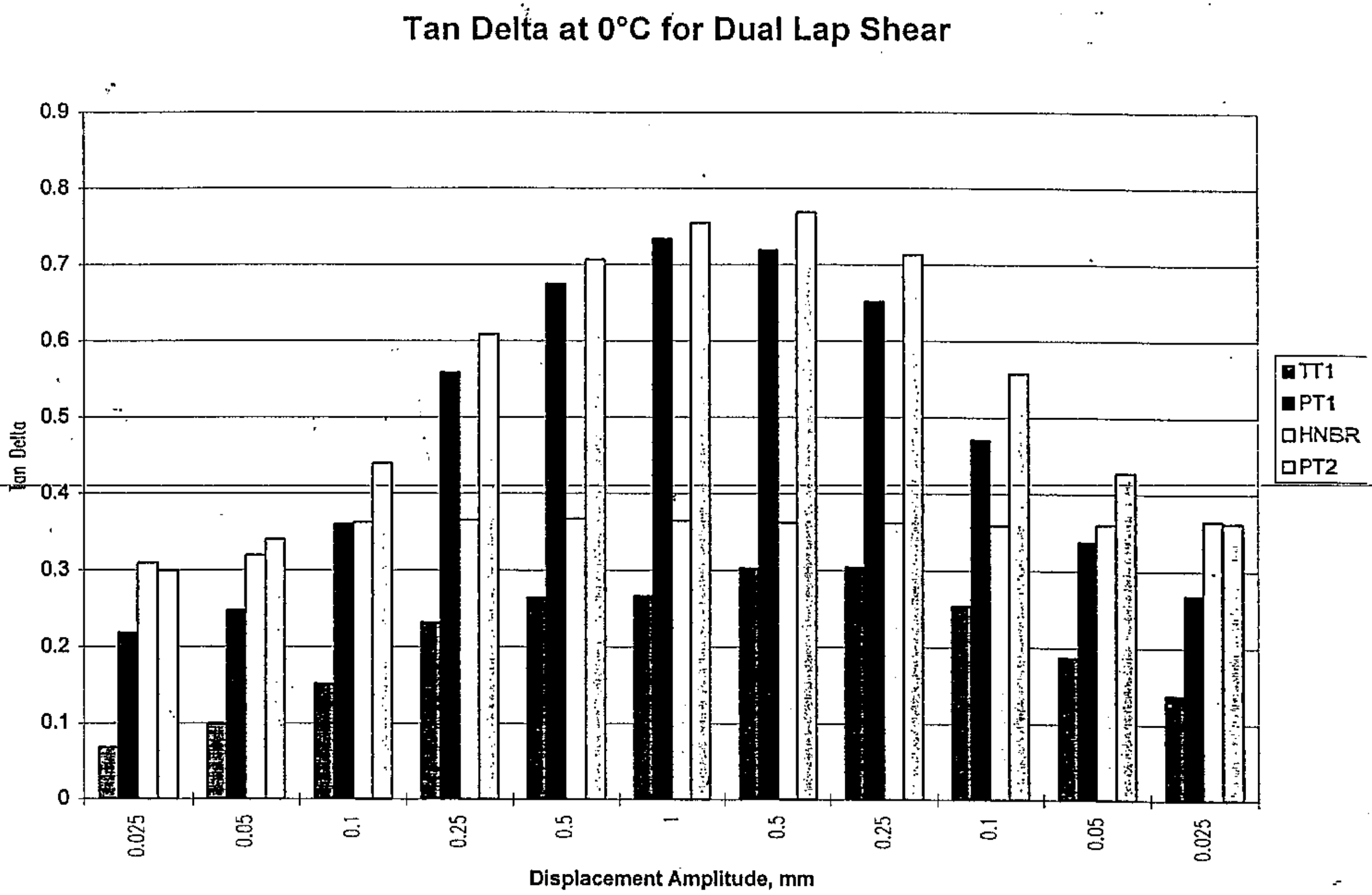
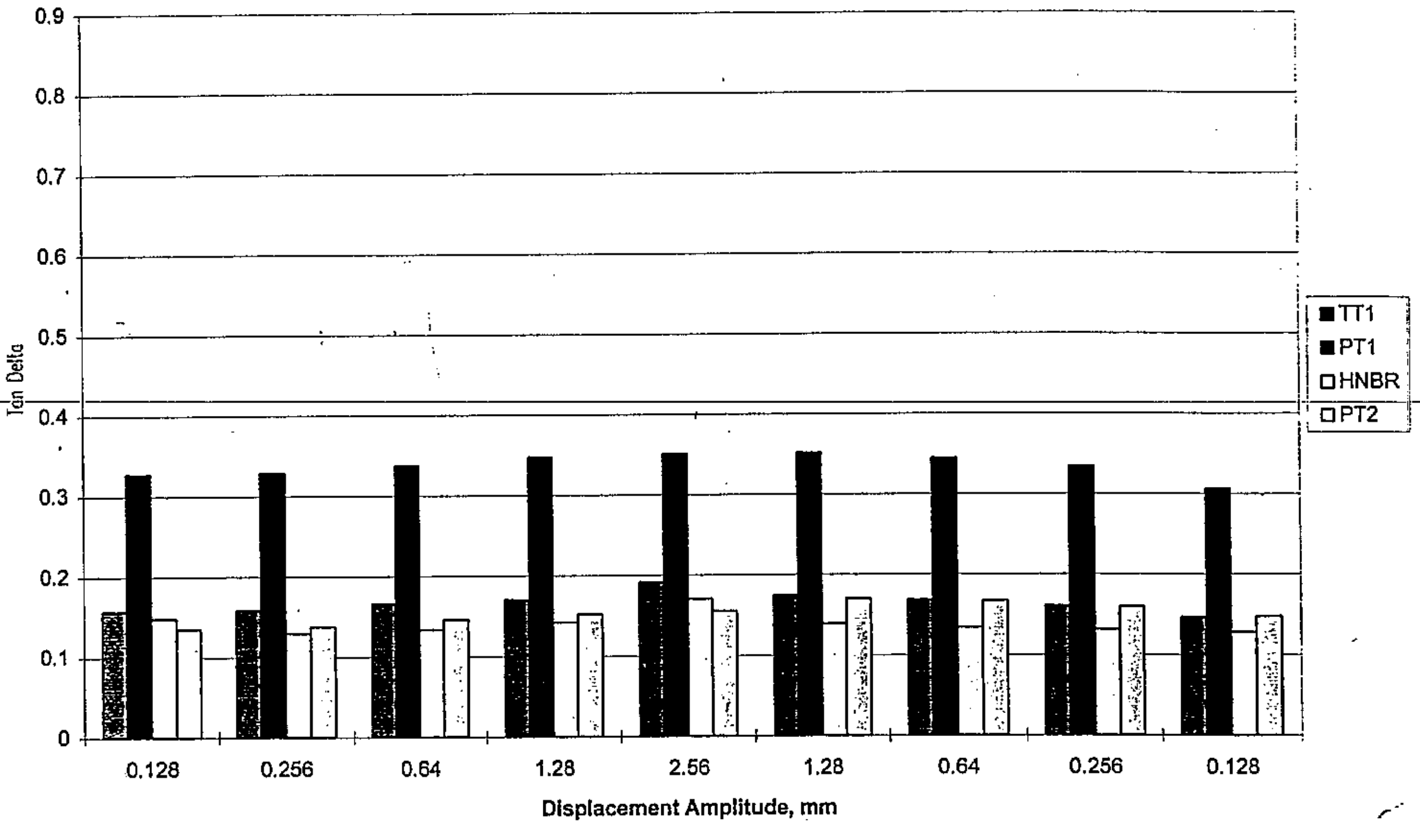
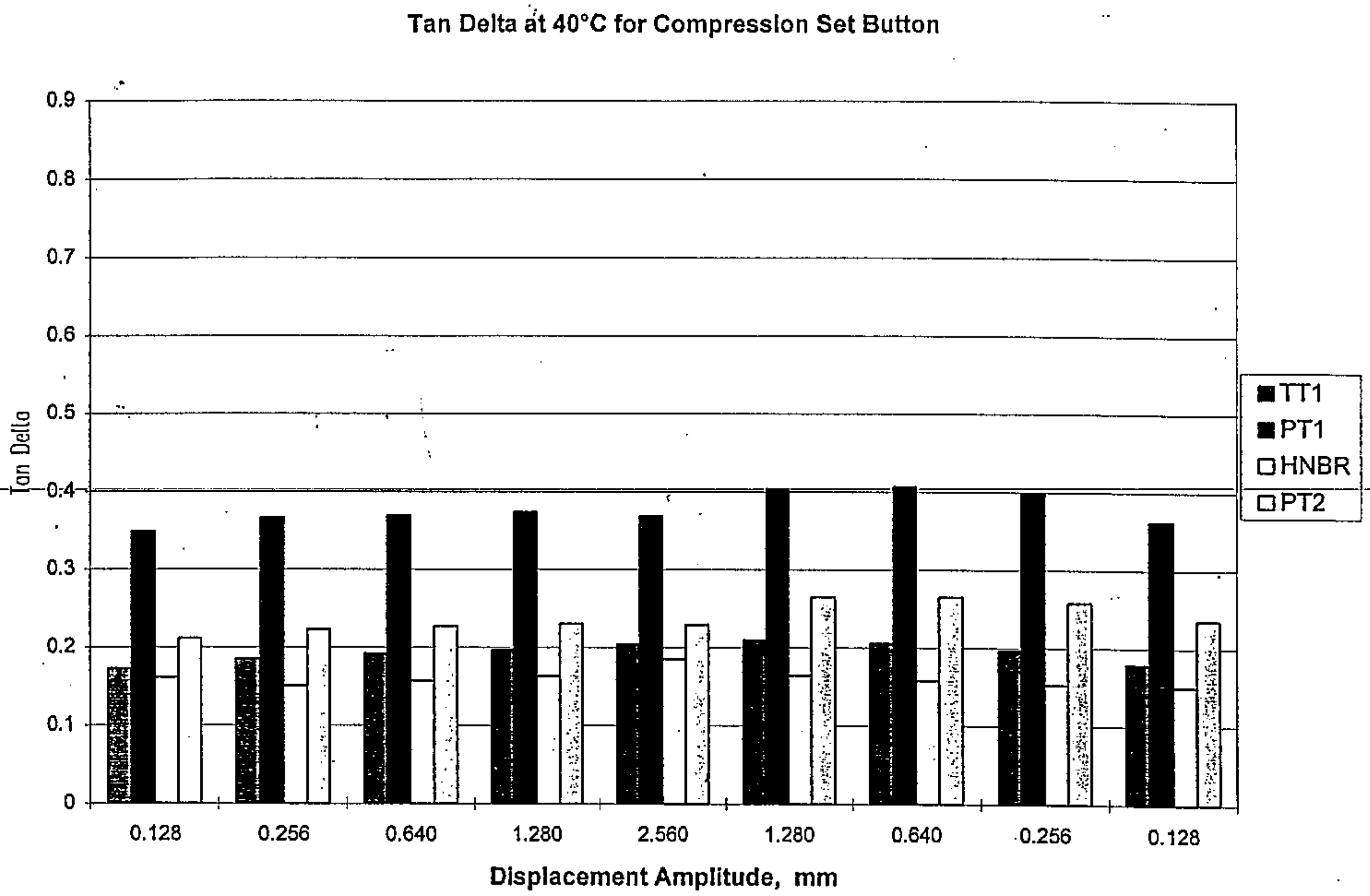

Tan Delta at 80°C for Dual Lap Shear
Tan Delta
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.05
0.1
0.25
0.5
1
0.5
0.25
0.1
0.05
Displacement Amplitude, mm
TT1
PT1
HNBR
PT2

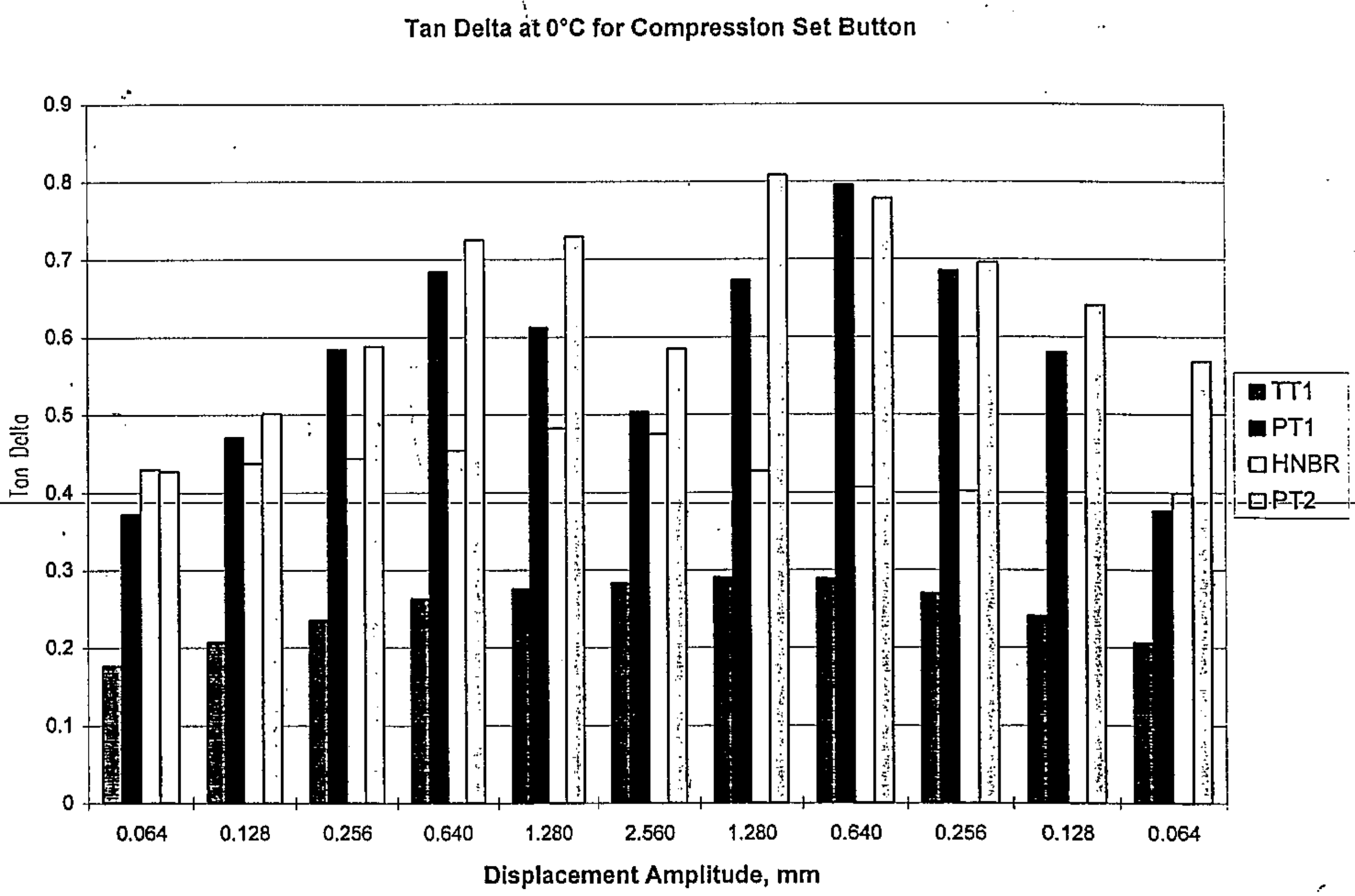

Tan Delta at 40°C for Dual Lap Shear
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Tan Delta
0.05
0.1
0.25
0.5
1
0.5
0.25
0.1
0.05
Displacement Amplitude, mm
▨ TT1
■ PT1
☐ HNBR
☐ PT2


Tan Delta at 0°C for Dual Lap Shear
Tan Delta
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.025
0.05
0.1
0.25
0.5
1
0.5
0.25
0.1
0.05
0.025
Displacement Amplitude, mm
TT1
PT1
HNBR
PT2

Tan Delta at 80°C for Compression Set Button




Tan Delta at 40°C for Compression Set Button
Tan Delta
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.128
0.256
0.640
1.280
2.560
1.280
0.640
0.256
0.128
Displacement Amplitude, mm
■ TT1
■ PT1
□ HNBR
□ PT2


Tan Delta at 0°C for Compression Set Button
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Tan Delta
0.064
0.128
0.256
0.640
1.280
2.560
1.280
0.640
0.256
0.128
0.064
Displacement Amplitude, mm
TT1
PT1
HNBR
PT2