DEVELOPMENT AND TESTING OF SILICA FILLED MILITARY TRACK PADS

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Outline

- Project Goals
- Military Track Pad Requirements
- PPG Silica
- Compound Development
- Results
- Conclusions
- Acknowledgements

A3 Bradley Fighting Vehicle

Project Summary

Goal:

- Develop and test Improved Energy Management Elastomers (IEME) rubber-silica compound prototype for military track system components that reduce fatigue, increase tear resistance and toughness, and manage energy more efficiently.

- Deliver a 20% improvement in energy management and a 30% durability improvement over current requirements (1,500 miles)

Payoff:

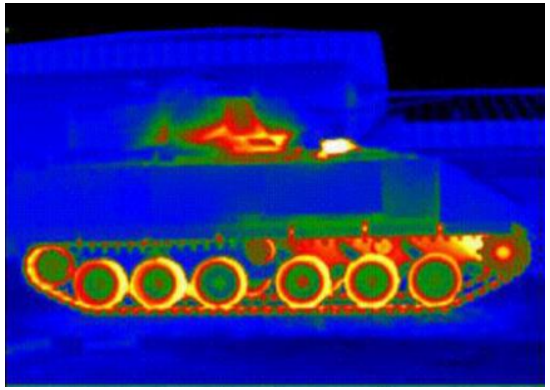
- The increases in durability, reliability, and performance have a compounding advantage by reducing the sustainment demands at expeditionary basing levels while improving safety and lethality.

Strategy:

- Define compound requirements
- Evaluate the performance of PPG AGILON® silica in military track pad (a.k.a ground pad) compounds
- Produce ten ground pad compounds for GVSC (Ground Vehicle Systems Center) evaluation
- Down-select three compounds, scale-up in collaboration with third party (AirBoss®) and test on an A3 Bradley Fighting Vehicle.

Rubber Parts in Track System

Track systems contain several rubber components with different requirements:



Heat Build-up in M2 Bradley track system[1]

Failure start in road wheel[1]

Backer pad after 500 and 1,000 miles[2]

Worn and new track pads on an M1 Abrams battle tank.

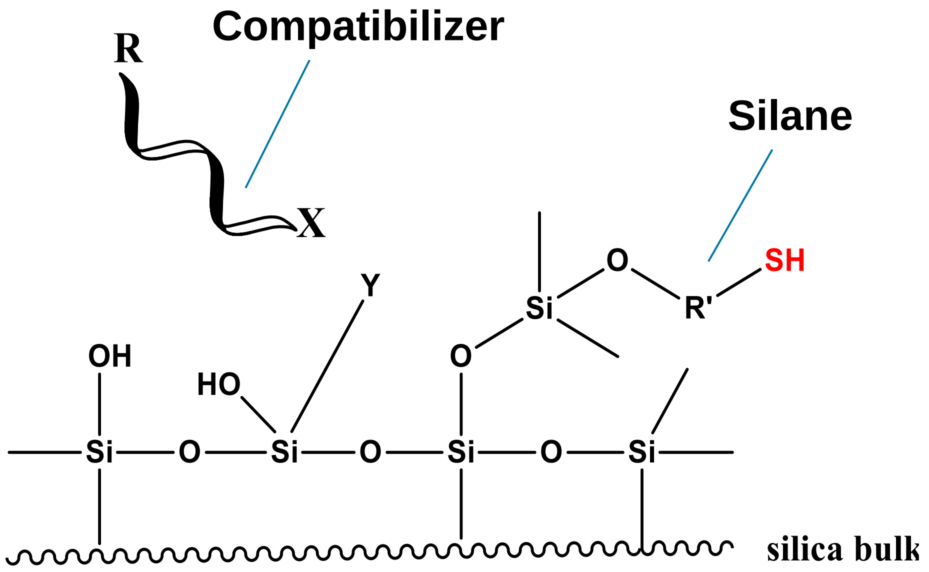
Hypothesis: Improvement on tear strength and hysteresis should improve durability.

- Military track pads addressed in this project
- PPG AGILON® high performance silica has shown to significantly improve hysteresis in natural rubber based compounds

1. Ostberg, D.; Bradford, B. *Proceedings of the 2009 Ground Vehicle Systems Engineering and Technology Symposium (GVSETS)*
2. Mars, W. V.; Ostberg D. *2012 SIMULIA Community Conference*

PPG AGILON® Performance Silica Technology Platform

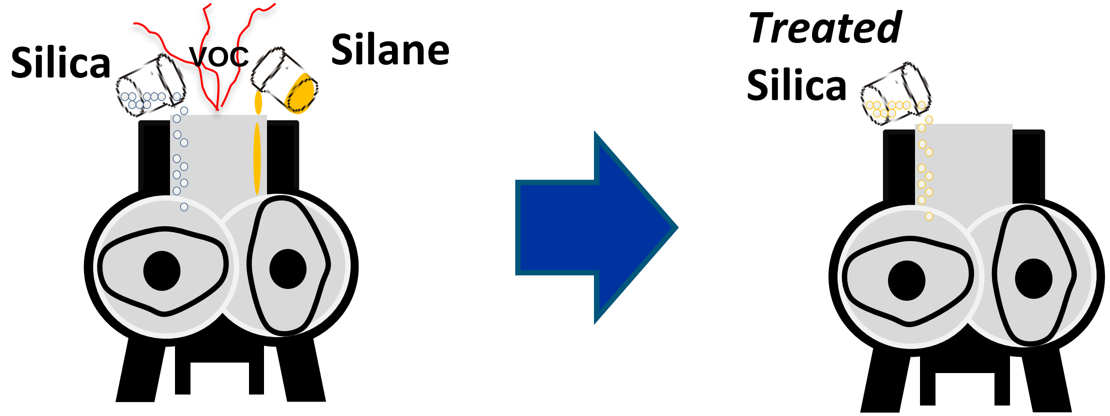
<u>Unique patented process and chemistry</u>



- Builds on the performance benefits of silica-filled tire treads
  - Ease of incorporation. Reduced viscosity.
  - Lower filler-filler interaction resulting in reduced heat build up, improved dispersion

In-Situ Silica + Silane Technology

Agilon Silica Technology



Agilon silica manufacturing benefits:

- ✓ Eliminates nearly all alcohol-related VOCs
- ✓ Eliminates outgassing resulting in smoother sheets
- ✓ Reduces mixing complexity
- ✓ Increases throughput/efficiency
- ✓ Reduced mixing energy
- ✓ Lower temperature mixing
- ✓ Increases effectiveness in NR
- ✓ Can be mixed like CB

- Ease of processing similar to CB mixing

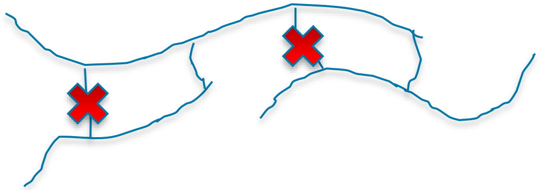
Untreated vs. Treated Silica in Natural Rubber

Untreated Silicas

- Dispersion
  - ➢ Polar silica does not disperse well in NR
- Protein & impurities adsorption during mixing

Poor reinforcement
Reduced mechanicals

- Effect of Mixing Temperature

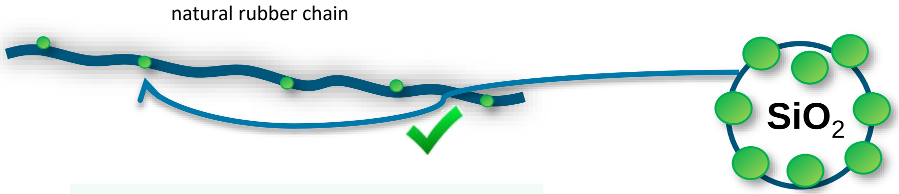


Higher temperatures needed to mix common silanes degrade NR.

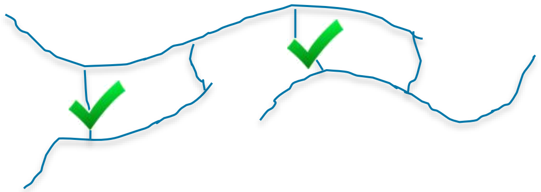
Treated Silica

➢ Surface chemistry and polarity can be tweaked for optimum interaction with NR

Chemistry already on silica



Excellent reinforcement
Improved mechanicals



Can be mixed at more favorable NR temperatures below 140°C

Treated silicas are good candidates for NR compounds

"Innovating the silica surface for Improved NR truck tire vulcanisates" *Tire Technology International* 2/2014.
"Functionalized silicas for improved NR truck tire vulcanizates" *Rubber World* (2014) 249(2), 19-24.
"Bringing Innovation to the Surface: Functionalized Silicas for Improved Natural Rubber Truck Tire Vulcanizates," 184th Technical Meeting of the ACS Rubber Division, October 2013, #33.
"Agilon Performance Silicas in Natural Rubber Truck Tire Tread Compounds" 180th Technical Meeting of the ACS Rubber Division, October 2011, #70.

Track Pad Baseline Determination

	Target	Track Pad data
Tensile, psi **(D412 C)**		2,542
Elongation, %		391
Modulus @ 50 %, psi		402
Modulus @ 100 %, psi		638
Modulus @ 200 %, psi		1467
Tensile, psi **(ISO 37 type 3)**	2600-3200	3022
Elongation, %	310-430	308
Modulus @ 50 %, psi	290-370	446
Modulus @ 100 %, psi	530-610	913
Modulus @ 200 %, psi	1460-1590	2049
Tensile @ 82°C/23°C	>70%	86
Elongation @ 82°C/23°C	>70%	76
Modulus @ 50 % @ 82°C/23°C	>70%	89
Modulus @ 100 % @ 82°C/23°C	>70%	105
Modulus @ 200 % @ 82°C/23°C	>70%	-
Hardness @ 23 °C	67-75	80
Rebound @ 23 °C, %		31
Die C Tear, lb/inch **(D624 C)**	>750	827
Die C tear @ 82°C/23°C	>70%	91
DIN Abrasion loss, mm^3		0.155

- ✓ Lab targets determined by GVSC
- ✓ Commercially available track pad tested

- ✓ Characterization data shows pad values near target

DISTRIBUTION A. See first page.

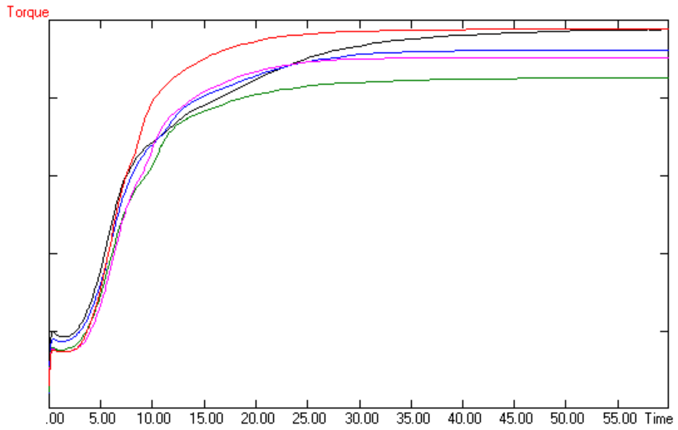
Track Pad – Initial Compound Development

- ✓ Starting formulation provided by GVSC
- ✓ Emphasis on improving tear strength, hysteresis and retention of properties at high temperature
- ✓ High surface area silica (PPG AGILON® 454G silica) used for improved tear strength
- ✓ Low surface area silica (PPG AGILON® 400G silica) used for improved hysteresis
- ✓ Other silica prototypes evaluated (not shown)

Formulations:

	Parts, phr
Natural Rubber SS # 1	100
Carbon Black N-351	10
Agilon 454G and Agilon 400G	**Low Medium High**
Curatives	**Low Medium High**
Other ingredients	10.5
Total phr:	variable

Cure Curves:



Cure curves with stable modulus. Final modulus affected by curatives loading

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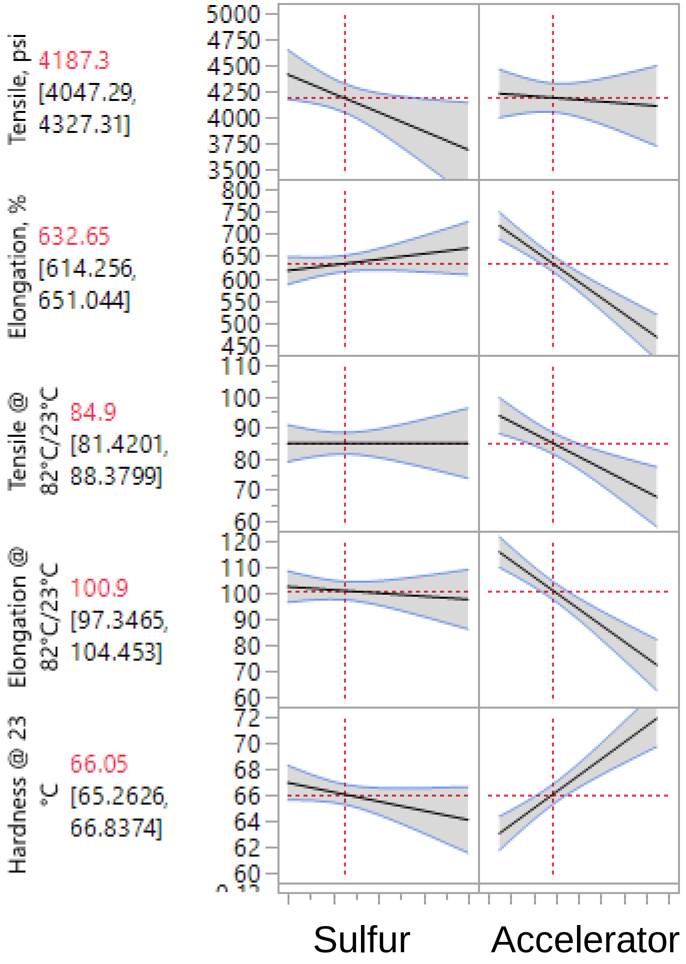
Compounds with PPG AGILON® 400G and 454G

Filler	Target	Agilon 454 GD					Agilon 400 GD				
Silica loading, phr		High	Medium	**Low**	Low	Low	High	High	High	Medium	Medium
Curatives		Low	Low	**Low**	Medium	High	Low	Medium	High	Medium	High
Tensile, psi (D412 C)	2600-3200	3593	4119	**4379**	4237	4127	4307	3985	4000	4201	4199
Elongation, %	310-430	608	614	**616**	624	540	530	473	410	479	457
Modulus @ 50 %, psi	290-370	227	213	**207**	228	232	268	307	342	266	302
Modulus @ 100 %, psi	530-610	376	343	**334**	385	398	519	597	675	511	582
Modulus @ 200 %, psi	1460-1590	1034	945	**875**	1008	1047	1466	1653	1828	1443	1586
Tensile @ 82°C/23°C	>80%	96	87	**78**	94	86	72	71	70	67	62
Elongation @ 82°C/23°C	>80%	107	108	**112**	103	107	100	98	98	102	96
Modulus @ 50 % @ 82°C/23°C	>80%	85	96	**85**	98	101	81	75	82	81	75
Modulus @ 100 % @ 82°C/23°C	>80%	80	98	**82**	96	96	76	70	78	78	72
Modulus @ 200 % @ 82°C/23°C	>80%	65	81	**69**	83	88	66	62	70	66	65
Hardness @ 23 °C	67-75	71	69	**67**	68	70	70	70	72	67	70
Rebound @ 23 °C, %		51	53	**56**	57	58	54	55	56	54	56
G' @ 60 °C, psi		540	502	**439**	451	456	428	443	466	337	375
Tan (δ) @ 60 °C		0.101	0.078	**0.068**	0.063	0.070	0.077	0.070	0.072	0.060	0.062
Permanent Set %		5.2	4.6	**3.4**	4.2	4.1	4.0	3.5	2.4	3.4	13.1
Heat Build Up, C		20	15	**13**	12	12	14	14	13	14	12
Die C Tear, lb/inch (D624 C)	>454pli	833	871	**590**	824	449	506	320	386	531	404
Die C tear @ 82°C/23°C	>70%	58	52	**69**	50	82	72	99	61	60	75
DIN Abrasion loss, normalized		141	130	**131**	132	138	135	138	145	135	138

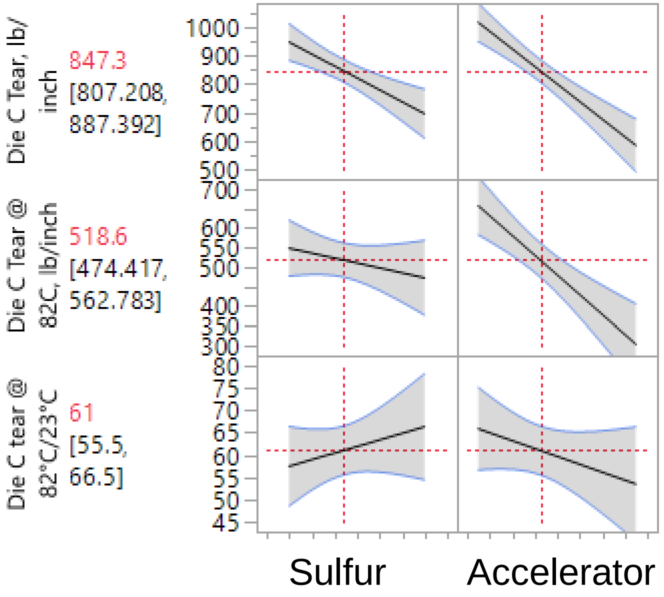
- ✓ *Agilon* 454G silica necessary for optimum tear strength.
- ✓ Compound with low level of *Agilon* 454G silica and curatives has enough hardness, low hysteresis and high tear strength
- ✓ Further optimization of compounds with *Agilon* 454G silica performed

DOE Around Curatives Levels

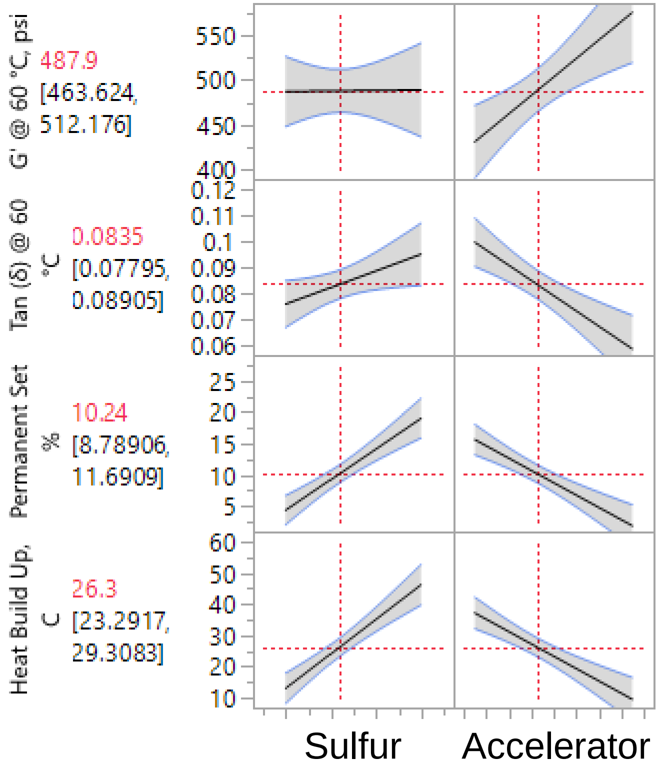
Mechanical Properties



Tear Strength



Hysteresis



Higher sulfur:

- Lower tear strength
- Higher tear retention
- Higher hysteresis
- Higher permanent set

Higher accelerator:

- Higher hardness
- Lower tear strength
- Lower tear retention
- Lower permanent set

Lab Compound Data for Samples Sent to GVSC for Evaluation

	1	2	3	4	5	6	7	8	9	10
Tensile, psi (D412 C)	**3183**	4447	**4282**	**4315**	4265	3872	4683	4274	4334	4621
Elongation, %	**630**	612	**549**	**587**	627	630	644	709	687	678
Modulus @ 50 %, psi	**200**	207	**239**	**239**	233	217	216	186	217	210
Modulus @ 100 %, psi	**289**	315	**404**	**394**	361	342	341	258	311	319
Modulus @ 200 %, psi	**769**	889	**1119**	**1105**	969	899	894	586	728	771
Tensile @ 82°C/23°C	**92**	77	**72**	**78**	83	78	77	67	75	80
Elongation @ 82°C/23°C	**118**	109	**98**	**97**	106	97	105	115	109	103
Modulus @ 50 % @ 82°C/23°C	**82**	97	**103**	**102**	100	98	99	80	91	99
Modulus @ 100 % @ 82°C/23°C	**79**	84	**99**	**95**	92	90	94	76	86	100
Modulus @ 200 % @ 82°C/23°C	**58**	72	**79**	**68**	71	68	69	64	76	89
Hardness @ 23 °C	**70**	66	**67**	**67**	70	67	68	64	64	66
Rebound @ 23 °C, %	**41**	52	**59**	**57**	50	55	51	48	45	49
G' @ 60 °C, psi	**683**	613	**558**	**553**	765	516	353	446	578	396
Tan (δ) @ 60 °C	**0.152**	0.106	**0.069**	**0.080**	0.104	0.083	0.085	0.104	0.111	0.086
Permanent Set, %	**BO**	5.8	**3.4**	**3.1**	6.8	4.5	4.7	12.4	8.7	6.5
Heat Build Up, C	**64**	18	**12**	**15**	21	16	16	31	23	17
Die C Tear, lb/inch (D624 C)	**686**	863	**801**	**530**	863	712	698	689	965	889
Die C Tear @ 82C, lb/inch	**541**	593	**338**	**487**	616	485	463	527	513	441
Die C tear @ 82°C/23°C	**79**	69	**42**	**92**	71	68	66	77	53	50
DIN Abrasion index	**111**	117	**105**	**115**	115	118	114	119	119	124

- Rubber samples of ten track pad compounds sent to GVSC for initial lab evaluation
- All compounds filled with PPG AGILON® 454G silica
- Compounds contained different amounts of filler, curatives, and sulfur/accelerator ratios

Compounds 1, 3 and 4 selected for scale-up due to their optimum balance of tear strength, hysteresis and other properties

Compounds for Vehicle Testing

- Three compounds selected for vehicle testing
- Compound 1 showed best retention of properties at high temperature
- Compound 3 showed largest improvement in hysteresis
- Compound 4 showed largest improvement in tear strength
- Scale-up performed by AirBoss Flexible Products
- AirBoss confirmed lab data was comparable to PPG’s data. Small cure adjustments needed to increase scorch safety

Track pad compounds mixed at AirBoss for Vehicle Testing:

Pad	Control	1	3	4
ML(1+4)	78	125	90	89
S' Max	33.4	35.1	39.7	29.0
S' Min	5.2	11.3	7.7	6.7
MH-ML	28.1	23.8	32.1	22.3
T10	4.9	2.1	2.6	3.1
T50	6.1	3.5	4.0	6.0
T90	14.0	6.1	7.7	21.5
Dispersion, %	94	91	92	91
Hardness @ 23 °C	72	72	68	63
Hardness @ 100 °C	65	67	65	60
Rebound @ 23 °C, %	41	44	53	50
Rebound @ 100 °C, %	62	59	71	66
G' @ 60 °C, MPa	4.12	6.45	4.15	3.22
Tan (δ) @ 60 °C	**0.201**	**0.162**	**0.091**	**0.113**
Tan (δ) @ 0 °C	0.243	0.219	0.161	0.186
G' @ 1.0 %, 30 °C, MPa	3.81	8.87	4.74	3.75
DIN Abrasion index	111	92	108	106
Die C Tear, normalized	68	115	123	123

Track Pad Testing at Aberdeen Proving Grounds[1]

Track Link	Road Side Outboard	Curb Side Inboard	Road Side Inboard	Curb Side Outboard
	Track Pad No.			
1 - 20	1	1	1	1
21 - 40	3	3	3	3
41 - 60	4	4	4	4
61 - 82/83	Production Pads	Production Pads	Production Pads	Production Pads

Production

Pad #1

After 500 miles:

After 1,100 miles:

- Three prototype track pads tested
- Pads inspected every day
- Tracks reversed according to procedure
- Pad temperatures measured
- Individual pads changed when worn to the grousers
- Once 40% of pads failed, it is considered that they reached their end of lifetime

1. *Information, data, and pictures obtained from ATEC Project No. 2020-DT-ATC-BFVSU-F9657, Test Record No. AD-F-01-22*

Final Results[1]

Removed Pads:

Production

Pad #1

Final durability:

	Curbside (miles)	Roadside (miles)
Control	**2,074**	**2,691**
Pad #1	**2,077**	**2,656**
Pad #3	1,424	1,846
Pad #4	1,708	1,881

- **Durability was above minimum requirements**
  - **~38% above on curbside (heavy side)**
  - **~77% above on roadside (light side)**
- **Best performer showed durability COMPARABLE TO BEST-IN-CLASS production pads**
- It seems failure would occur at the pad edges. This indicates that tear at the edges might be predominant failure mechanism
- Compound formulations and lab performance indicators were correlated with observed performance and failure mode
- Lab hysteresis and tear performance, in conjunction with temperature measured during field testing and chip and chunk observed in the pads used to further improve performance

1. *Information, data, and pictures obtained from ATEC Project No. 2020-DT-ATC-BFVSU-F9657, Test Record No. AD-F-01-22*

Conclusions

- Novel military track pad compounds were developed filled with PPG AGILON® 454G silica
- Compounds were optimized in the lab and three compounds were scaled-up at AirBoss® for vehicle testing
- On-vehicle testing was performed at the U.S. Army Aberdeen Proving Ground on an A3 Bradley Fighting Vehicle
- Best performer showed durability comparable to best-in-class track pad and 38-77% above minimum qualification requirements
- Insight into failure mechanism was obtained and will be used for further development.

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