Development and Evaluation of Military Track Pads

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ABSTRACT

Rubber parts in U.S. Army Fighting Vehicles Track Systems are subjected to wear and require regular replacement. Replacement of the parts can be time consuming and can put the warfighter at danger if parts fail during combat situations. The goal of this project is to develop track pads with improved durability over the current approved pads. It was hypothesized that the mechanism of failure involves heat build-up and tear of the pads at elevated temperatures. PPG AGILON® silica has shown to provide reduced heat build-up over other available fillers in natural rubber-based compounds. Track pads were developed at PPG, scaled-up at AirBoss of America LLC and tested at the U.S. Army Aberdeen Proving Ground on an A3 Bradley Fighting Vehicle. Track pads showed durability significantly above the qualification requirements.

INTRODUCTION

The U.S. Army utilizes the A3 Bradley Fighting Vehicle (BFV) as a tactical asset in combat and peace operations. Track failure on Army systems, such as those in Bradley Fighting Vehicles, is a significant cost driver for the Army. In-field track failures result in the entire platoon being mobilized to protect the vehicle and crew, putting warfighters at risk in hostile areas. A track's main failure mode is typically related to specialized rubber components, such as elastomeric bushings, backer pads, track pads, and road wheels. Rubber track pads are installed on the tracks for traction, sound dampening and road protection. The track pad consists of a homogeneous rubber pad made generally with a carbon black reinforced rubber compound. Wear life and fatigue failure are common issues with these pads. The service life of these rubber backer pads is approximately 1,500 miles when running over a distribution of paved roads, gravel, and off-road terrain. The costs associated with the repairs and replacements of backer track pads are very high. Increasing the durability of these pads could significantly reduce maintenance costs, increase vehicle availability, and increase warfighter's safety.

Elastomers have the desired compliance required to provide traction and sound dampening since they exhibit high strains at low stress levels. However, elastomers demonstrate hysteretic loss due to their viscoelastic nature. During sustained operation, the cyclic compressive loading of the track pad causes hysteretic loss. There is a subsequent loss of strength of the rubber material due to this hysteretic heat build-up. The heat generated from hysteretic loss and other friction can exceed 150ºC during high-speed operation, as shown in Figure 1 (ref. 1). Therefore, a new rubber compound that achieves high compliance while reducing hysteretic heat loss should improve the rubber compound durability. This work explores a methodology to design an alternate rubber compound that can still provide the desired properties of the current track pads while improving their durability under extreme use conditions.

The objective of this collaboration effort between PPG and the U.S. Army DEVCOM Ground Vehicle Systems Center (GVSC) is to design, develop, and optimize a rubber-silica compound prototype for track pads that delivers a 20% improvement in energy management and a 30% durability improvement over current requirements (1,500 miles).

Natural rubber (NR) is the polymer of choice for compounds that require high tear strength and chip and chunk resistance. When rubber components predominantly consist of NR, compounders depend on carbon black as a filler, because silicas are not very compatible with NR. NR contains proteins, organic matter, and metal ion contaminants. These contaminants are believed to interfere with the *in-situ* coupling reaction required to effectively disperse the silica in non-polar rubber, yielding poor filler dispersion, compound performance, and processing properties.

PPG AGILON® performance silica is pretreated with silane coupling agents, as well as other compatibilizers, which are pre-reacted onto the silica surface so that tire and industrial rubber manufacturers don't need to control this reaction during compounding. Since the silica surface is pretreated, and *in-situ* silanization is not necessary, this technology is able to overcome the contaminant problem when the silica is compounded with the NR. PPG *Agilon* family of products and PPG's work in this area has been published and presented in industry magazines and conferences and has been well-received by customers and industry. (refs. 2-7).

For synthetic rubber-based passenger tires, *Agilon* products have shown to reduce rubber mixing time by 36% and eliminate VOCs from the manufacturing process, while improving the "magic triangle" of tire performance: treadwear, traction, and rolling resistance. Since *Agilon* technology provides an effective means to incorporate silica into both synthetic rubbers and natural rubber, while minimizing energy loss, the development of track pads compounds filled with *Agilon* silica has been chosen for compound development in this work.

EXPERIMENTAL

The chemically treated amorphous precipitated silicas *Agilon* 400G-D and Agilon 454G-D silica characteristics have been described in previous publications (refs. 5-6). Initial cure package adjustments were performed based on non-reported screening work to get optimum crosslink density for the final compounds. Final curatives levels were selected based on results from this pre-screening work. The compounds were mixed in a KSBI 1.5L mixer fitted with 4-wing tangential rotors.

For the first stage, the mixer temperature was set at 65°C, the rotor speed was set at 65 rpm and the ram pressure was 50 bar. A 70% fill factor was used. The natural rubber was added in the mixer and timing was started. At 60 seconds into the mix the fillers were added. At 120 seconds into the mix the other ingredients were added. At 180 seconds a sweep was performed. Compounds were mixed for a total of 300 seconds. The dropped compounds were milled for 60 seconds on a two-roll mill with the rolls at room temperature.

For the second stage, the start temperature was 50°C and the starting rotor speed was 60 rpm. The mix was initiated by adding the master batch from the first stage mix. At 30 seconds into the mix the sulfur, the accelerators were added. At 60 seconds a sweep was performed. The compound was dropped at 150 seconds of mix time, at which time the compound temperature was about 105°C. The dropped compound was milled for 60 seconds on a two-roll mill with the rolls at room temperature.

The compounds were cured for T90 + 5 minutes at 150°C. Test specimens were produced as indicated in the respective test procedures. The cure profiles were determined using a Moving Die Rheometer (MDR) according to ASTM D2084. The Mooney Viscosities were measured according to ASTM D1646.

Shore A hardness was determined following ASTM D2240-02 using a Zwick Digital Durometer at room temperature and 100°C. Stress / strain properties were measured according to ASTM D412 using ASTM type die C dumbbell specimens and also according to ISO 37 using type 3 specimens at 23°C and 82°C.

Dynamic properties (i.e. tan δ and loss modulus) were determined following ASTM D5992-96, parallel plate geometry using an ARES-G2 Rheometer. Rebound was measured according to ISO 4662 at 23°C and 100°C. Heat build-up and permanent set were measured according to ASTM D623. Tear strength was measured according to ASTM D624 Die C at 23°C and 82°C.

RESULTS AND DISCUSSION

Baseline Determination

The first step of the development consisted in establishing a performance baseline to clearly define the compound performance targets. Based on previous data, GVSC defined a compound performance baseline, shown in Table I. Also, GVSC provided a commercial track pad which was skived to measure the properties shown in Table I. Track pad testing was limited to the type of rubber specimens that could be cut from the track pad.

Due to the lack of previous knowledge on how these compound properties affect performance, the values from the Table I are not considered absolute targets, but guidance values. The compound to be developed should have a high Shore A hardness around 75 to support the large vehicle weight (approximately 40 tons), and at the same time, good tear strength and low heat build-up. Historical GVSC data indicated that retention of mechanical properties at high temperature is critical for good performance. Due to size of the tensile specimens that can be cut from a track pad, and maximum elongation possible in tensile testing equipment, GVSC had set the baseline based on ISO 37 type 3 specimen sizes. During this work, both ISO 37 type 3 and ASTM D412C specimen were used, since early on the development we observed higher reproducibility on design of experiment studies with the larger D412C specimens.

Compound Development

Different compounds were prepared using *Agilon* 400G-D and *Agilon* 454G-D as fillers. The main difference between these two silicas is their surface area of 160m^2/g and 200m^2/g, respectively. Studies, not shown here, were performed to optimize the antioxidants package, sulfur/accelerators ratio, mixing conditions and other compound parameters. Results from a study where the silica and curatives loadings were varied are shown in Table II. Silica loadings were varied in a range that provided hardness close to the target, while still obtaining reasonable processability. Curatives were varied within ranges typically used in rubber compounding. Sulfur accelerators loadings were also modified to obtain compounds with different types of crosslinks and explore the effects of cure efficiency on reversion, fatigue and aging properties of the compounds.

It can be seen in the Table that, when the silica loading is reduced, hysteresis is reduced but also hardness and tensile strength are reduced. These properties need to be properly balanced. At constant silica loading, when curatives are increased, hardness increases and hysteresis is slightly decreased, but the effects are not large. It is observed that tear strength reaches the highest value at the intermediate level of curatives. Tear strength is known to go through a maximum as curatives are increased, and further studies were performed to produce a compound around this maximum, since tear strength is a very important property for track pads durability. Similar studies were performed using *Agilon* 400G-D as filler and results for one of the compounds is shown in Table II for comparison. Due to the lower surface area, *Agilon* 400G-D produces compounds with lower hysteresis, but tear strength is significantly reduced. Due to the lower tear strength, *Agilon* 400G-D was not used for further development.

Once the studies were completed, three formulations were selected for scale-up and vehicle testing. The three compounds varied in their silica loading, sulfur loading and sulfur/accelerators ratio. The three compounds showed good performance in the lab, but properties were optimized in different ways. The first compound had the best tear strengths, but the worst hysteresis of the three compounds, even though its hysteresis was still significantly better than the control carbon black-based compound. The second compound had the highest hysteresis reduction. The third compound was intermediate in performance, with a balance of tear strength and hysteresis improvement.

Manufacturing Scale-up

The three experimental rubber formulations selected for scale-up and testing at GVSC were mixed and molded by AirBoss of America LLC. Initially, the rubber compounds were prepared for each of the three rubber formulations and specimens for lab testing were prepared. The specimens were tested in the lab and characterization data is shown in Table III.

Characterization data was comparable to that obtained in the small-scale mixer at PPG, thus the compounds were released for molding. Roughly 100 track pads with each of the rubber compound prototype formulations were molded and sent to the U.S. Army Aberdeen Proving Ground for testing.

Track Pad Testing

Prototype track pads with the three experimental rubber formulations were tested alongside the best-in-class control track pad used by the U.S. Army in a M3A3 Bradley Fighting Vehicle. Track pads were installed in a “rainbow” configuration, as shown schematically in Table IV. Each type of prototype pad and the control pads were installed in each track strand assembly, in the curb and roadsides of the vehicle. Since the curbside of the vehicle is heavier, the curbside track strand wears the pads faster than the roadside track strand. The track end connectors were colored blue, red, yellow and white for identification of the different prototype pads, as shown in Figure II. In total, 80 pads of each prototype, and 90 control pads, were installed in the vehicle.

The vehicle was run on a specific test track according to test specifications for the BFV. The test track has a combination of paved surfaces and gravel, straights and turns, and the vehicle is run at different speeds to represent the characteristic mission profile of the BFV. After each testing cycle is completed, the pads are inspected and replaced once they are worn to the grousers. Once 40% of track pads of an individual compound are replaced, those pads are considered to have reached their durability (mileage) limit. Figure III shows how the pads look at different stages of the testing.

Table V summarizes the final mileage at which the different track pads failed. The table shows that Track Pad #1 achieved a durability comparable to the best-in-class track pad available for the U.S. Army. At the same time, this is about 57% higher durability than the minimum requirement set by the U.S. Army, of 1,500 miles.

CONCLUSIONS

Prototype track pads for the A3 Bradley Fighting Vehicle were prepared using natural rubber-based rubber compounds filled with *PPG Agilon* silica. The most appropriate *Agilon* silica, *Agilon* 454G-D silica, was used in the final stages of development due to its capability to provide good tear strength, while producing low hysteresis and heat build-up. Compounds were optimized in the lab and scaled-up by AirBoss of America LLC. Track pads were tested at the U.S. Aberdeen Proving Ground using a proprietary test procedure to the U.S. Army. The best performing track pad showed an operating life of more than 2,000 miles, comparable to the current best-in-class track pad used by the U.S. Army. The durability is about 57% higher than the minimum requirement set by the U.S. Army for track pads qualification. These results demonstrate that *PPG Agilon* silicas are able to produce natural rubber-based compounds which have best-in-class durability in applications where heat-build up and tear strength are critical requirements.

ACKNOWLEDGEMENTS

The work presented herein was sponsored by the U.S. Government under Other Transaction Agreement (OTA) number W56HZV-16-9-0001, between the Defense Automotive Technologies Consortium (DATC) and the U.S. Army Contracting Command - Warren.

The authors would like to thank AirBoss of America LLC for their collaboration in mixing and molding of the track pads used in the project.

TRADEMARKS

AGILON is a registered trademark of PPG Industries Ohio, Inc.

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Table I
Track Pad Compound Baseline

	Target recommended by GVSC	Commercial Track Pad data
Tensile, psi (D412 C)		2,542
Elongation, %		391
Modulus @ 50 %, psi		402
Modulus @ 100 %, psi		638
Tensile, psi (ISO 37 type 3)	2,600-3,200	3,022
Elongation, %	310-430	308
Modulus @ 50 %, psi	290-370	446
Modulus @ 100 %, psi	530-610	913
Tensile @ 82°C/23°C, % (D412 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
Hardness @ 23 °C	67-75	80
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

Table II
Compound Development Study

Filler	Agilon 454 GD					Agilon 400 GD
Silica loading	High	Medium	Low	Low	Low	High
Curatives loading	Low	Low	Low	Medium	High	Low
Tensile, psi (D412 C)	3593	4119	4379	4237	4127	4307
Elongation, %	608	614	616	624	540	530
Modulus @ 50 %, psi	227	213	207	228	232	268
Modulus @ 100 %, psi	376	343	334	385	398	519
Tensile @ 82°C/23°C, %	96	87	78	94	86	72
Elongation @ 82°C/23°C, %	107	108	112	103	107	100
Modulus @ 50 % @ 82°C/23°C, %	85	96	85	98	101	81
Modulus @ 100 % @ 82°C/23°C, %	80	98	82	96	96	76
Hardness @ 23 °C	71	69	67	68	70	70
Rebound @ 23 °C, %	51	53	56	57	58	54
Tan (δ) @ 60 °C	0.101	0.078	0.068	0.063	0.070	0.077
Heat Build Up, °C	20	15	13	12	12	14
Die C Tear, lb/inch (D624 C)	833	871	590	824	449	506
Die C tear @ 82°C/23°C, %	58	52	69	50	82	72
DIN Abrasion loss, normalized	141	130	131	132	138	135

Table III
Characterization Data of Compounds scaled-up at AirBoss

Pad	Control	1	2	3
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
DIN Abrasion index	111	92	108	106
Die C Tear, normalized	68	115	123	123

Table IV
Track Pad Configuration

Track Link	Roadside Outboard	Roadside Inboard	Curbside Outboard	Curbside Inboard
	Track Pad No.			
1 - 20	1	1	1	1
21 – 40	2	2	2	2
41 – 60	3	3	3	3
61 – 82/83	Production Pads	Production Pads	Production Pads	Production Pads

Table V
Track Pads Durability Results

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

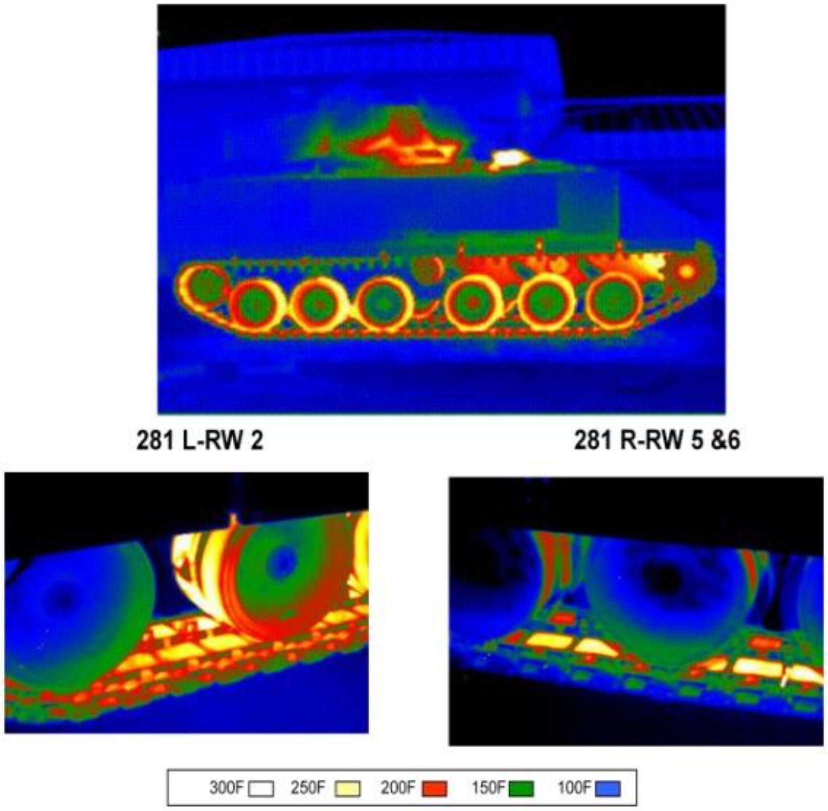

Figure 1. IR measurements, A3 Bradley and M1 Abrams.[1]

Figure 2. Prototype Track Pads in Bradley vehicle.

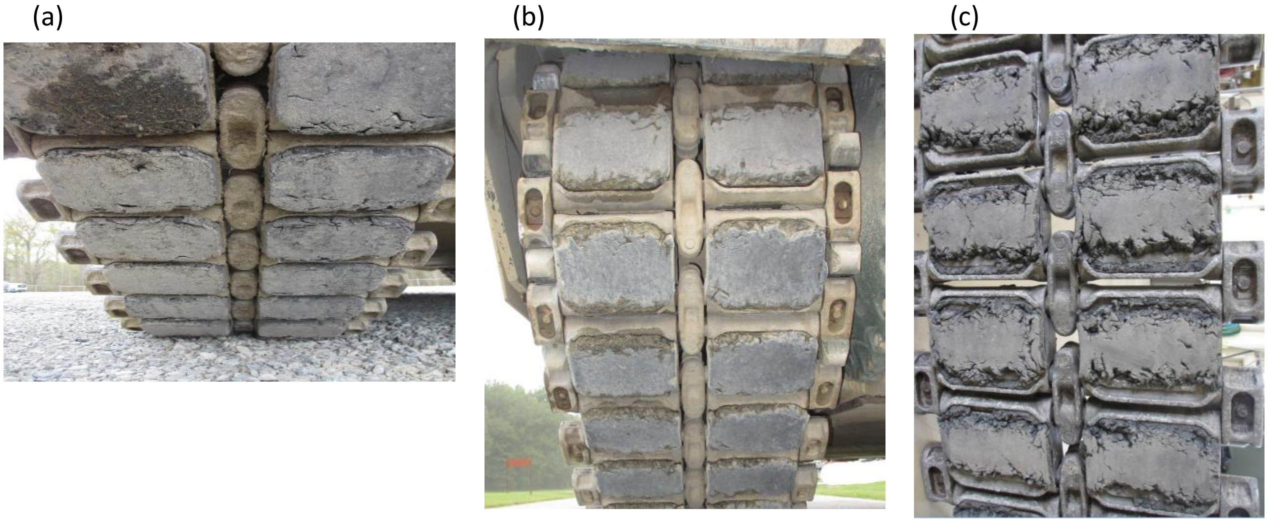

Figure 3. Track pads after (a) 500 miles, (b) 1,100 miles and (c) final mileage of testing.