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ELASTOMER COMPOUND DEVELOPED FOR HIGH WEAR APPLICATIONS

D. Crawford, H. Feuer, D. Flanagan, G. Rodriguez, A.Teets, & P. Touchet
Engineering Materials & Coatings Division
Materials Directorate
Army Research Laboratory
Ft. Belvoir, VA 22060

ABSTRACT

The U. S. Army is currently spending 300 million dollars per year replacing rubber track pads. An experimental rubber compound has been developed which exhibits 2 to 3 times greater service life than standard production pad compounds. To improve the service life of the tank track pads various aspects of rubber chemistry were explored including polymer, curing and reinforcing systems. Compounds that exhibited superior physical properties based on laboratory data were then fabricated into tank pads and field tested. This paper will discuss the compounding studies, laboratory data and field testing that led to the high wear elastomer compound.

BACKGROUND

Track laying vehicles, wherein a continuous track is constantly laid down in the direction of movement of the associated vehicle, are well known. Examples of such track laying devices are the military tanks and personnel carriers. Such devices have an endless track with a plurality of linked metal track shoes. These military tracked vehicles are equipped with rubber track pads, rubber blocks or endless-band rubber track to reduce shock, noise, wear and damage to road surfaces. The endless tracks render the vehicles operational in rough, uneven terrain when necessary under military conditions. The vehicle, however, also travels over roads and hard surfaces, therefore, the elastomeric components of the endless track should be of the type that wears well under abrasion and rough terrain.

Historically, field performance of these elastomeric components have been poor, especially for the medium to heavy tonnage tracked vehicles. The problem is further complicated with off-the-road service conditions where pads fail at a much faster rate. The severity of the wear is more pronounced on the M-1 main battle tank than on the older M-60 due to an increase in weight and acceleration, while using a pad with a smaller footprint. This produces higher stresses resulting in higher heat build-up. Therefore, costly and frequent replacement is necessary to keep the tanks operational. The cost of maintaining and replacing track pads is consuming about 25% of the total U.S. Army Operational Maintenance Budget or about 300 million dollars per year.

The service life of these tank pads is affected not only by the terrain conditions but also by the speed, weight of the vehicle and track design. While the operational life of the metal components is approximately 5000 miles for heavy vehicles, the average life of the rubber pads is seldom more than 1500 miles under the best circumstances and is usually less than 550 miles under the severest conditions. During service, the elastomeric pad components are adversely affected in several ways. Most common effects of wear include cuts, tears, heat build-up, flex fatigue, and abrasion.

Conventional track pads, based on styrene-butadiene rubber (SBR), usually fail prematurely in service because of excessive wear, blow-out, which then leads to chunks of material leaving the track pad, and rubber-to-metal bond failure. The widespread use of SBR rubber in tank pad applications is primarily due to the relative low cost of the base SBR polymer along with a U.S. Government policy that requires materials used for military applications to have a domestic source. This policy resulted from the non-availability of natural rubber during World War II. Performance specification MIL-T-11891D was approved in 1984 allowing the use of polymers other than SBR for tank track applications. This option provided infinite alternatives to the compounder to approach the optimization of specific material properties. Until this point, previous efforts since the mid 1960's had only provided incremental improvements in service life of tank pads of about 5%.

APPROACH

To improve field performance of tank pads, one must first identify those properties that are critical and then optimize them. This is by no means a trivial task. Any rubber compounder would agree that to improve performance of tank pads, properties such as cutting and chipping resistance, tear and tensile strength, crack initiation and growth resistance, abrasion resistance, hysteresis and retention of properties at elevated temperatures would have to be improved. To achieve this tremendous task the U.S. Army sponsored a series of investigations involving industry, government and academia. In 1983 the Rubber and Coated Fabrics Research Group, Belvoir RD&E Center (currently the Engineering Materials and Coatings Division of the Army Research Laboratory) was tasked to conduct a series of studies to improve the service life of tank pads.

Compounding Studies

Comprehensive compounding and processing studies were performed to determine what combinations of formulation ingredients and/or mixing variables affect physical properties. Various polymer systems were evaluated including chloroprene, nitrile (NBR), highly saturated nitrile (HNBR), urethane, natural and synthetic polyisoprene, carboxylated nitrile, polybutadiene, SBR and blends of the above polymers.

Selection of the base polymer is critical to obtain specific characteristics of the final product. For example, natural rubber compounds will most likely exhibit superior resistance to tear and lower hysteresis when compared with polybutadiene compounds which in turn provide excellent flexibility, superior resistance to abrasion, crack growth and heat build-up. Nitriles and neoprenes have high resistance to oils and chemicals.

Various fillers and curing systems were explored to enhance physical properties and minimize reversion. Carbon black and novel non-black fillers were used to improve dispersion, increase toughness and abrasion resistance.

Laboratory Physical Testing

The experimental materials underwent extensive physical testing in the laboratory. Physical tests included tensile strength and tear strength at ambient and elevated temperatures, abrasion, cutting and chipping and dynamic tests such as blow-out and flex crack growth. Compounds that exhibited superior physical properties based on laboratory data were then fabricated into tank pads by Caterpillar Tractor Company. These tank pads were subjected to field testing on the Counter Obstacle Vehicle (COV) and the M-60 tank. Simultaneous to the field testing, samples were taken from the fabricated tank pads for additional laboratory testing. In addition to the experimental formulations, standard production SBR pads were also included in the laboratory and field tests. The laboratory data generated from the fabricated pads is shown in Tables I and II. Table III lists the test methods that were used.

Vehicle Field Testing

Two types of vehicles were employed to carry out the field testing. The COV is an engineering type tracked vehicle that weighs about 72 tons. The other vehicle used was the M-60 battle tank weighing about 45 tons. The testing of the T-107 (COV) pads was performed over a severe course designed to combine all possible operational and terrain factors. The COV testing was conducted at the Engineering Proving Grounds at Ft. Belvoir, Virginia. The testing was performed from November 1986 through April 1987. A total of 1600 miles was accumulated on the T-107 pads.

The test plan for the M-60 (T-142 pads) field test was designed to include three phases consisting of a 2000 mile paved surface course, a 900 mile hilly cross-country course and a 1000 mile combination course. The M-60 test was conducted at the U.S. Proving Grounds in Yuma, Arizona. The testing began in October 1986 and was completed in May 1988.

RESULTS AND DISCUSSION

NBR-12, an experimental compound based on a highly saturated nitrile elastomer and a novel filler and curing system exhibited superior physical properties based on laboratory data as shown in Tables I and II. The tensile strength of NBR-12 is about 30% higher than that of the commercial pads. The NBR-12 material retained 100% of its original tensile strength after heat aging, compared to about 50% tensile retention for the standard materials. This material also exhibited higher hardness and load bearing capability (see 40% compressibility). SBR rubber with an equivalent hardness is too difficult to mix and process into tank pad configurations. Another significant improvement was achieved on tear resistance. Improvements in tear strength of about 50% were observed at ambient temperature and in some cases tear strength of NBR-12 doubled that of the standard material at elevated temperatures.

Abrasion resistance, a critical tank pad property, was measured by the Tabor and Pico methods. A 24 fold increase in the Tabor abrasion resistance was exhibited by the NBR-12 material. The increase in resistance to abrasion as measured by the Pico method ranged from 300% on COV pads to as much as 600% on the M-60 pads.

A common mode of failure for pads during cross-country operations is cutting and chipping. This property was measured with the Goodrich Cutting and Chipping Machine and both specimen diameter and weight loss were recorded. Test results for both measurements were in excellent agreement and the NBR-12 material provided a 75% improvement for COV pads and over 30% for M-60 pads.

The NBR-12 elastomeric tank pad materials exhibited higher heat build- up but the unique combination of the highly saturated nitrile polymer (HNBR) with the novel curing and reinforcement system produced an unparalleled retention of physical and dynamic properties at high operating temperatures, thus reducing premature failures.

Crack growth resistance relates to the ability of the rubber to deter crack propagation once the rubber has been cut, typical of operation over cross-country terrain. Crack propagation further deteriorates into tear and eventually chunks of rubber can be removed from the pad. Crack growth was measured using a Demattia Flex Tester. The crack growth resistance of NBR-12 showed greater than 400% improvement over the standard COV pad material at ambient temperature while providing at least a 60 fold improvement in crack growth resistance over the standard COV pad material at elevated temperature (250 °F). NBR-12 exhibited a 300% improvement in crack growth resistance at room temperature compared to the standard M-60 pad material and greater than a 30 fold improvement at elevated temperature.

NBR-12 showed exceptional resistance to wear during field testing, extending the service life 2 to 3 times that of standard production pads during the M-60 field test. During the paved course portion of the M-60 field test, standard production pads failed on the average at 1200 miles. The pads with the NBR-12 material were tested to 2000 miles (the maximum duration allowed under the test plan) with out failures. The limited wear of these pads indicated a projected life of 3400 miles, a service level never before achieved by any commercial or other experimental material. Subsequent field tests on M-60 vehicles confirmed the original projections of the service life of the NBR-12 material by exhibiting serviceability beyond 3700 miles on the combination course at Yuma, AZ. Table IV and Figure I, show the improved service life of NBR-12 over the standard production pads.

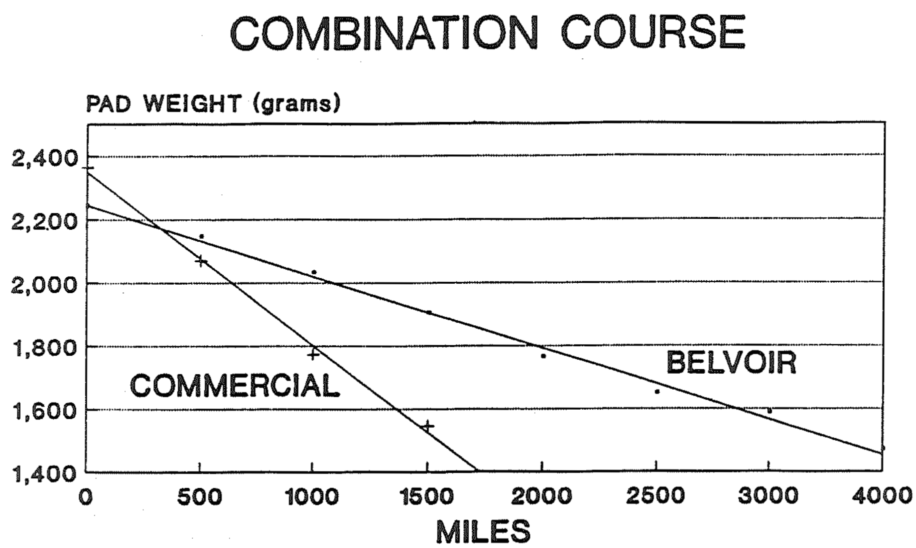
CONCLUSIONS

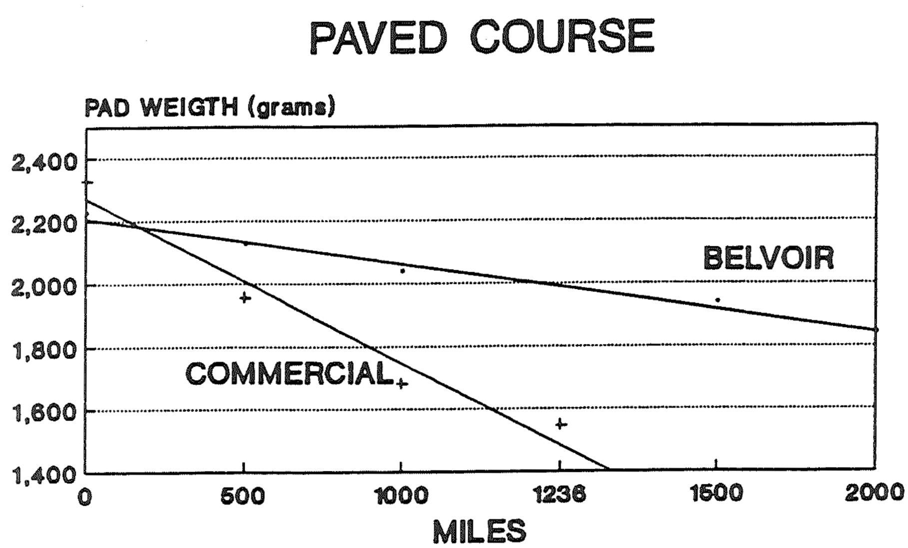
The superior physical properties of NBR-12 have been demonstrated in the laboratory as well as in the field. A U.S. patent has been awarded for this material and patents have been filed in 7 foreign countries. Although initial fabrication cost using NBR-12 is approximately 2.5 times as expensive as standard production pads, a preliminary economic analysis indicates a possible savings on future "higher life" tracks (with 6000 mile life expectancy) currently being designed. Further changes in track design using this improved pad material could contribute significantly to a more reliable and dependable fleet of battle tanks for the U.S. Army while reducing track operating and support costs.

Future research on this high wear elastomer compound is aimed at improving processibility and reducing cost by blending it with other polymers. There is an on-going program to coat NBR-12 and blends of this material onto nylon fabric to be field tested on the Army's Lighter Air Cushion Vehicle (LACV-30). This is a challenging application from the processing standpoint as well as field performance where abrasion resistance and high frequency dynamic flexing or flagellation are critical.

As discussed earlier, NBR-12 is the result of research and development aimed to improve the life of rubber pads used on military vehicles. Applications which require a high resistance to abrasion, resistance to chemicals and fuels, or retention of physical properties at elevated temperatures could benefit from NBR-12's outstanding wear properties. Potential commercial applications for this material include conveyor and "V" belts, treads for off the road tires, gaskets, o-rings and seals for the oil industry, fenders and bumpers on loading docks, shock and vibration pads, and rubber covered rolls for paving equipment.

FIGURE I: Field Performance of T-142 Track Pads





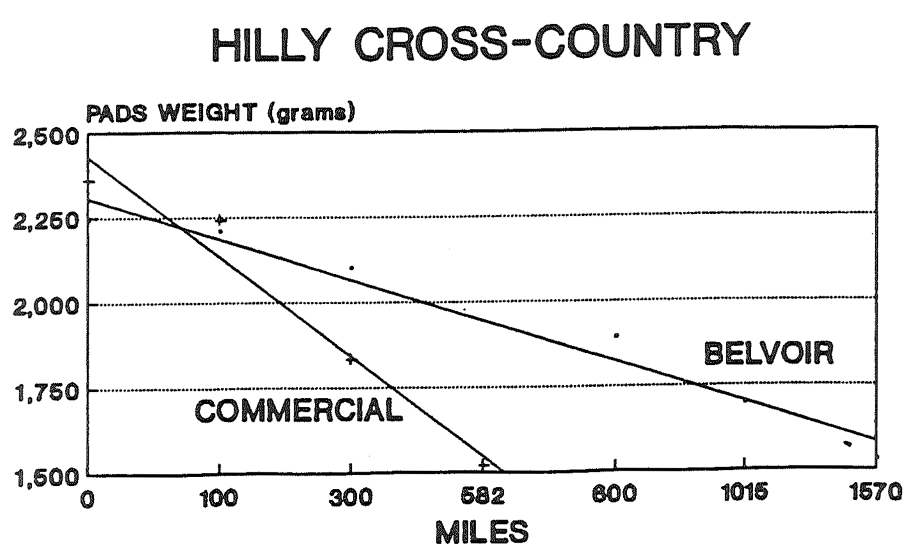


TABLE I: Physical Properties of Materials From T-107 (COV) Pads

MATERIAL I. D. CODE	NBR-12	STD. PAD TP-AF	NAT-150	NN-9
PROPERTIES				
ORIGINAL				
TENSILE STRENGTH, psi	3960	3075	4424	4293
200% MODULUS, psi	841	1102	1944	1566
ELONGATION, %	570	460	380	430
SHORE A HARDNESS, POINTS	78	70	87	84
BASHORE REBOUND, %	30	30	52	51
SPECIFIC GRAVITY	1.1373	1.1626	1.1426	1.1396
40% COMPRESSIBILITY, psi	972	511	1291	1073
TEAR STRENGTH, DIE C				
ROOM TEMP, lb/in	449	268	384	347
AT 250 °F, lb/in	234	141	254	204
OVEN AGED 70 HRS AT 250°F				
ELONGATION RETENTION, %	81	33	71	84
TENSILE RETENTION, %	100	82	59	72
ABRASION				
TABOR, GRAMS/1000 CYCLES	0.0015	0.0434	0.5222	0.4344
PICO RATING	691	179	348	221
GOODRICH CUTTING AND CHIPPING				
DIAMETER LOSS, cm	0.137	0.582	0.516	0.361
WEIGHT LOSS, GRAMS	0.75	3.276	2.965	2.066
DYNAMIC PROPERTIES				
GOODRICH FLEX				
BLOW OUT TIME, MINUTES	5	21	58	120
TEMPERATURE RISE				
INTERNAL, °C	84	72	46	101
EXTERNAL SURFACE, °C	58	28	15	43
DEMATTIA FLEX				
CRACK GROWTH				
UNAGED, in/MINUTE	0.060	0.350	0.300	0.169
20 HR @ 250 °F, in/MIN.	0.118	8.110	0.142	0.382
CRACK INITIATION, 1000 CYCLES	110	10	39	112

NOTES:

NBR-12 - Experimental pad material based on HNBR polymer.
STD PAD - Commercial pad material based on SBR rubber.
TP-150 - Experimental pad material based on natural rubber.
NN-9 - Experimental pad material based on a nat./HNBR blend.

TABLE II: Physical properties of Materials From T-142 (M-60)Pads

MATERIAL I. D. CODE	NBR-12	STD. PAD TP-A	TP-I	TP-K
PROPERTIES				
ORIGINAL				
TENSILE STRENGTH, psi	3960	2814	3437	4119
200% MODULUS, psi	841	580	1015	1059
ELONGATION, %	570	510	520	500
SHORE A HARDNESS, POINTS	78	69	73	66
BASHORE REBOUND, %	30	36	23	49
SPECIFIC GRAVITY	1.1373	1.1559	1.2314	1.1210
40% COMPRESSIBILITY, psi	972	508	508	450
TEAR STRENGTH, DIE C				
ROOM TEMP, lb/in	449	310	535	554
AT 250 °F, lb/in	234	115	345	320
OVEN AGED 70 HRS AT 250°F				
ELONGATION RETENTION, %	81	38	33	27
TENSILE RETENTION, %	100	57	41	27
ABRASION				
TABOR, GRAMS/1000 CYCLES	0.0015	0.0364	0.0257	0.0338
PICO RATING	691	101	120	131
GOODRICH CUTTING AND CHIPPING				
DIAMETER LOSS, cm	0.137	0.208	0.495	0.610
WEIGHT LOSS, GRAMS	0.75	1.145	2.916	3.228
DYNAMIC PROPERTIES				
GOODRICH FLEX				
BLOW OUT TIME, MINUTES	5	37	37	120
TEMPERATURE RISE				
INTERNAL, °C	84	50	74	37
EXTERNAL SURFACE, °C	58	30	32	15
DEMATTIA FLEX				
CRACK GROWTH				
UNAGED, in/MINUTE	0.060	0.240	0.060	0.118
20 HR @ 250 °F, in/MIN.	0.118	4.331	0.300	0.272
CRACK INITIATION, 1000 CYCLES	110	18	48	161

NOTES:

NBR-12 - Experimental pad material based on HNBR polymer.
STD PAD, TP-A - Commercial pad material based on SBR rubber.
TP-I - Experimental pad material based on chloroprene rub.
TP-K - Experimental blend pad material from industry.

TABLE III: Test Methods

PROPERTY TESTED	TEST METHOD ASTM
ORIGINAL PROPERTIES	
SPECIFIC GRAVITY	D 792, PARA 15
TENSILE, ELONGATION & MODULUS	D 412
HARDNESS, SHORE A	D 1415
RESILIENCE, BASHORE REBOUND	D 2632
TEAR STRENGTH, DIE C	D 624, DIE C
ABRASION, TABOR	D 3389
ABRASION, PICO	D 2228
PROPERTIES RUN AT 250 °F	
TEAR STRENGTH, DIE C	D 573 & D 624
TENSILE AND ELONGATION RETENTION	D 573 & D 412
FLEX FATIGUE TESTS	
DEMATTIA	
CRACK INITIATION	D 430, METH B
CRACK GROWTH, UNAGED	D 813
CRACK GROWTH, AGED 20 HR @ 250 °F	"
GOODRICH FLEX, BLOW OUT & TEMP. RISE	D 623

TABLE IV: Field Performance of Tank Pads

MATERIAL I D	M-60 PADS TESTED IN YUMA			COV PADS
	PAVED ROAD (Miles)	HILLY X-COUNTRY (Miles)	COMBINATION (Miles)	BELVOIR COURSE (Miles)
NBR-12	3402	1251	3302	2802
STD PADS	1237	530	1351	1305
TP-I	2002	470	1451	----
TP-K	1590	380	1321	----
NAT-150	920	710	1526	2101
NN-9	1237	681	1701	2052