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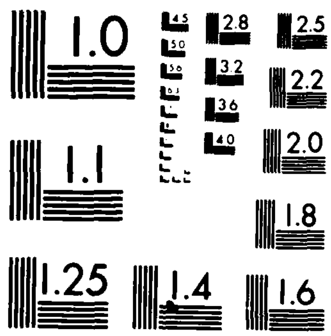

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COMPATIBILITY OF WHEEL-BEARING SEAL ELASTOMERS WITH MIL-G-10924 GREASES

By
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June 1986

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Swelling or shrinkage and changes in physical properties of several commercial seal elastomers were determined subsequent to their exposure in existing and improved MIL-G-10924 multipurpose greases. Preliminary results indicate that seal/grease compatibility cannot be assumed merely on the basis of favorable minimal swelling or shinkage. Sealing capability is also contingent upon minimization of changes in other physical characteristics of the seal achieved through seal elastomer compound optimization.

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ABSTRACT: This report details the scope of work and results obtained in a program to evaluate the compatibility of typical elastomeric seal compounds with existing and improved MIL-G-10924, "Grease, Automotive and Artillery" (GAA), formulations. In accordance with relevant American Society For Testing and Materials (ASTM) and Federal Test Method Standard (FTMS) procedures, the swelling or shrinkage and changes in physical properties of various seal compounds after exposure to the greases at elevated temperature were determined.

Preliminary results indicate that the acceptability of seals for use with GAA compositions cannot be assumed merely on the basis of known elastomer-type grease compatibilities. Within-type differences for certain categories such as nitrile rubbers, combined with a multitude of possible compounding ingredient variations, can lead to acceptable, marginal, or grossly inferior seal performance.

Success in the Army's effort to improve the performance of GAA-based systems and to achieve extended service life is contingent upon evolution of a comprehensive data base encompassing all known aspects of elastomer/grease compatibility.

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COMPATIBILITY OF WHEEL-BEARING SEAL ELASTOMERS WITH MIL-G-10924 GREASES

I. INTRODUCTION

This report details work conducted and results obtained in an evaluation of the compatibility of commercially available elastomeric compounds with MIL-G-10924, "Grease, Automotive and Artillery" (GAA), products. The compounds are typical of those used to fabricate wheel-bearing seals for commercial and military vehicles. This initial effort is part of a broader investigation intended to determine the relationship between adequate lubrication and minimization of corrosion of system components. Optimization of seal performance is requisite to preclude water and particle contamination and the loss of lubricating oil. The research is being conducted in conjunction with the planned promulgation of the "E" revision of the specification and the on-going development of a DOD long-life grease for use in ground equipment, vehicles, and artillery.

II. BACKGROUND

The original MIL-G-10924 GAA was developed in 1951 and was preceded by an assortment of ordnance specifications for wheel-bearing greases. The traditional formulation consisted of a 70 SUS at 210°F viscosity naphthenic mineral oil thickened with a calcium or lithium soap. MIL-G-10924, which is currently interchanged under Annex C to STANAG 1135 under NATO Code Number G-403, is a multi-purpose NLGI Number 2 consistency grease intended for the lubrication and surface corrosion protection of all automotive and artillery equipment operated in the -65°F to 125°F ambient temperature range (-65°F to 225°F operational temperature range). Changes in the types and operational requirements of military vehicles imposed demand for increased capabilities of the lubricating greases. Therefore, a program was initiated in 1976 to develop such an improved lubricating product.

A field performance survey of DOD user activities established GAA as a marginal multi-purpose grease for use in DOD tactical vehicles, artillery, and equipment as well as the commercial vehicle support fleet. The major problems identified by the survey were categorized in specific operational or storage environments. However, the general consensus revolved around three major points: (1) insufficient capability of the grease to properly lubricate at high temperatures, resulting in extreme oil loss due to oil separation and evaporation; (2) corrosion inhibition, especially when the lubricated components contact sea water; and (3) a tendency for grease to be washed from the bearing assemblies when they are immersed in water.

In view of these problems, it was determined that the basic GAA grease required re-formulation in order to meet the following criteria:

- Wide operating temperature range of -65°F to 350°F.
- Resistance to softening when subjected to shear stress or immersion in water.
- Corrosion preventive properties to reduce corrosion caused by humidity, fresh water, and salt water.
- Compatibility with other types of lubricating greases and elastomeric seal material.
- Cost-effectiveness.

The initial developmental effort was directed toward comparing the proposed requirements of improved GAA to the performance potential of those raw materials available. This research indicated that the use of a lithium 12 hydroxystearate thickener and a higher viscosity mineral oil would potentially meet the projected performance and cost-effectiveness requirements.

The second stage examined methods applied in the GAA specification by the American Society for Testing and Materials (ASTM) and the Federal Test Method Standard (FTMS). It was noted that the majority of laboratory test methods had limited correlation with actual field service. These laboratory tests are used as reference standards for comparison rather than as indicators of performance. Several of the test methods used in the GAA specification to evaluate low temperature performance[1] and corrosion[2] were determined not to be capable of identifying the critical elements underlying the actual performance requirements and have necessitated the requirement to develop improved test methods. It was also noted that the MIL-G-10924 specification did not contain requirements for compatibility between other qualified greases and elastomeric seals used in prescribed applications.

Initial laboratory formulation research indicated that a 200 SUS at 210°F viscosity naphthenic oil with a lithium 12 hydroxystearate thickener resulted in an acceptable NGLI Number 2 consistency grease. The pursuit of this base lubricant for further development experienced problems in the formulation of an adequate additive package capable of retarding saltwater corrosion. The required increased amounts of corrosion inhibitors degraded the mechanical and water stability of the lubricant.

In 1980, the scope of the program was broadened to include the polyalfaolefin (PAO) synthetic hydrocarbon (SHC) fluid greases and products containing combinations of PAO/SHC fluids and mineral oils as well as the traditional mineral oil formulations. The PAO/SHC fluid greases provided an enhanced operating temperature range and the opportunity to evaluate additives not previously tested in the original mineral oil formulation. The selection of a suitable SHC fluid for use in military lubricating grease was defined by the need for compatibility with present lubricants and elastomeric materials contacting the grease. Polyalfaolefins were the selected type since other synthetic fluids (copolyalkylated benzene derivatives) have a tendency to degrade the rubber materials which are generally used in military vehicles.

The broadened scope of the program provided a variety of improved GAA formulated products for evaluation. The Belvoir RD&E Center initially evaluated 34 formulated greases, three of which met the performance requirements and successfully transitioned from laboratory pilot batches to full-scale production. The greases were of different types: the first, an original mineral oil, lithium-thickened formulation; the second, a PAO fluid with a polyurea thickener; and the third, a combination of PAO and mineral oil(s) with a lithium 12 hydroxystearate thickener.

Field performance studies were conducted in which the formulated lubricants were evaluated in the wheel-bearings of tactical vehicles. The results indicated that seal failures are directly responsible for bearing failures as substantiated by contamination and corrosion. The lubricating greases in the rear wheels of the 1¼-, 2½-, and 5-ton trucks experienced washout as they were exposed to the MIL-L-2105 Gear Oil, Grade 80W-90, used to lubricate the differential.[3] From this perspective, these bearings could not be considered grease lubricated as the washout occurred within 200-300 miles after lubrication. The question of grease vs. oil lubrication was previously addressed.[4] However, the policy for the lubrication of these vehicles has not been changed. The design of the seals that facilitate the present combination of grease and gear oil lubrication allows for further problems. The failure of the inner oil seal contaminates and destroys the brake shoes. The combination of gear oil washout and failure of inner seals creates a potential for bearing failure due to lubricant starvation which appears to be a frequent occurrence.

Observations from the field performance evaluation of these lubricants indicated that the elastomeric seal failures are directly related to bearing failures previously attributed soley to the lubricating grease. Based on these observations, the direction of the program to improve the performance of the GAA lubricant must be augmented

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[1] See page 11.

[2] See page 11.

[3] See page 11.

[4] See page 11.

by an effort to evaluate and improve the oil seals. Such a seal program must be directed toward the types of elastomeric materials used and the design of the seals. This is requisite to prevent leakage and contamination. Location of the seals within the automotive wheel-bearing application is critical to prevent future gear-oil washout and its subsequent problems.

The goals of the US Army program to develop improved lubricating greases are to reduce maintenance costs, materials, and manpower, and ultimately to extend the re-lubrication interval of the tactical vehicle and equipment fleet. This cannot be cost-effectively achieved without addressing the problems of seal failures and gear-oil washout.

III. OBJECTIVE

The initial step in addressing the field performance problems observed with the oil seals was to identify the types of elastomeric materials that can potentially be used in manufacturing oil seals for use in DOD vehicles, equipment, and artillery. Currrently, no military or federal documents covering wheel-bearing seals are known to exist. Procurement is generally on the basis of commerical specifications and recommendations. The purpose of this work is to determine the relative resistance to deterioration in physical properties of commercially used elastomeric wheel-bearing seal compounds when exposed to the current MIL-G-10924D, Amendment 1 GAA multipurpose greases and several improved GAA grease formulations.

The short-term objective is to provide a baseline of data to be used in the future development of a military specification delineating requirements for wheel-bearing seals. The ulimate objective of this study is to provide additional information that suggests the use of specific elastomeric seal materials. The results of the initial investigation on wheel-bearing elastomers can facilitate a dialogue between the MACOMs to examine, in conjunction with the current long-life DOD multi-purpose grease program, how modifications can be made to improve the performance and longevity of oil seals. A similar objective is the extension of relubrication intervals.

IV. APPROACH

Examples of typical seal compounds, furnished as ASTM test slabs and compression set buttons, were requested from known industrial suppliers. A total of eleven materials encompassing four elastomer types (nitrile, silicone, acrylic, and fluorinated polymers) were received from four sources. The three lubricating greases evaluated were: A.) MIL-G-10924C, "Grease, Automotive and Artillery"; B.) MIL-G-10924D, Amendment 1, high dropping point formulation; and C.) an experimental SHC formulation. These greases were selected to provide data on standard GAA and improved products representing different fluid and thickener types. Grease A is formulated with a low viscosity naphthenic mineral oil and a calcium thickener. Lubricant B is composed of a combination of PAO/SHC fluid and mineral oils with a lithium 12 hydroxystearate thickener. Lubricant C represents the PAO/SHC fluid thickened with polyurea.

The criteria for testing the lubricant /elastomer compatibility were obtained from several standard test methods. Method 3603.4 of FTMS 791B cites the procedure used to compare seal compound performance. Volume change after exposure for seven days at 70°C is the only information derived from this test method. ASTM-D-4289, "Testing Compatibility of Lubricating Grease with Elastomers," covers similar procedures, but exposures are conducted at 100°C or 150°C. It was decided, therefore, to include in the program certain features of ASTM-D-471, namely measurement of changes in compound tensile strength, elongation, and modulus resulting from direct exposure in the greases at 70°C (158°F). In cases where suppliers furnished compression set buttons, these results were also obtained using 70 hours air aging at 70°C as the test conditions, according to ASTM-D-395.

V. RESULTS

The data obtained are summarized in the accompanying Tables (1-5, pp 7-11). Since compounds identified as WB-2, 5, and 7 had initial elongations below 200%, their initial modulus values and corresponding percent retention data are based on 100% rather than 200% elongation. Tensile and modulus retention is shown both as a percentage of the initial values and based on the swollen cross-sectional area of the test specimens described in paragraph 4.8.1 of FTMS 601, Method 6111, which is being proposed for incorporation into ASTM-D-471. In cases where the compression set specimens were not supplied, manufacturer's data are included.

VI. DISCUSSION

Because of the unusual and, in some cases, anomalous nature of the results, analysis of the data and comparison of performance will focus on each factor individually.

a. *Tensile Strength Retention*: Using 80% tensile strength retention as an acceptable performance level, few seal compound/grease combinations could be categorized as being marginal or acceptable. Compound WB-3 is obviously a poor candidiate for use with any of the three greases. Compound WB-6 (81.4% retention based on initial and 80% based on the swollen area) is marginally satisfactory for use in contact with grease B, while compound WB-11 performs poorly in greases B and C. A consistent pattern of good tensile retention was displayed by compounds WB-4, 5, 8, 9, and 10 regardless of grease type. Since volume changes were relatively small, tensile retention based on swollen cross-sectional areas agreed closely with retention based on initial values.

b. *Elongation Retention*: Again applying 80% retention of the initial value as a guideline, it is apparent that elongation losses resulting from exposure to these greases are erratic and more significant. Only compound WB-10 maintained excellent retention regardless of grease type. With the exception of compounds WB-5, 6, and 10, retention was noticeably poorest when the synthetic grease C was the exposure medium. Six of the candidate compounds (WB-1, 2, 7, 8, 9, and 11) evidenced orderly, decreasing retention according to grease type (A-highest to C-lowest). The varying results observed for the other compounds signify that while a pattern or trend exists, compound/grease compatibility data must be screened closely for exceptions.

c. *Modulus Retention*: Eight of the eleven compounds evidenced parallel increases in modulus according to grease type (i.e., least for grease A; intermediate for grease B; and highest for grease C, the synthetic). Only compound WB-3, exposed in grease A, displayed any *significant* decrease. While increases in modulus are considered normal, they are indicative of further polymer crosslinking and deemed excessive when computed retention reaches 130-170%. This appears to be the case with nine of the eleven compounds exposed in grease C. High post-exposure modulus is also indicative of undesireable set and hardening, with a corresponding negative effect on seal effectiveness. The results of this static exposure test underscore as suspect the adequacy of seal performance of many of these compounds when using the synthetic grease C under in-service dynamic conditions.

d. *Volume Change*: Only four elastomer compound/grease systems displayed volume increases exceeding 10%: WB-2, 3, and 5 in grease A and WB-5 in grease B. Conversely, four other compounds: WB-1, 7, 8, and 11, evidenced measurable shrinkage--all occurring upon exposure to synthetic grease C. Compounds WB-2 and WB-5 maintained good tensile and elongation retention in spite of the high swelling observed. Compound WB-3 fared poorly, regardless of type of grease or the magnitude of swelling encountered. Shrinkage is usually considered as evidence of extraction of plasticizer or other compounding ingredients. Effects are possibly mainfested in the low elongation retention of WB-1, 7, 8 and the overall poor showing of WB-11.

e. *Compression Set*: Values for the six compounds tested (70 hours at 158°F) and as furnished by the suppliers are favorable. The 302°F data for WB-5 and 6 are sufficiently low to indicate acceptability for 158°F service. However, it must be considered that these results were obtained under static conditions--i.e., no exposure to the greases. In view of the high moduli obtained in direct exposure, final judgement should be withheld pending appraisal in a dynamic environment.

f. *Elastomer Types*: Limited information furnished by the seal material suppliers confirms that all candidates except WB-5, 6, and 10 are composed of nitrile rubber. WB-8 and WB-9, from the same supplier, are purported to be "highly extractable" and "non-extractable" respectively. Their performance in all greases, however, was acceptable and essentially identical. Two nitriles, WB-3 and WB-11, displayed unfavorable performance characteristics, the former in all three greases and the latter in greases B and C. Compound WB-10, based on Viton-fluorelastomer, displayed the best balance of property retention in all greases. WB-5, a silcone, and WB-6, an acrylic, had low, possibly unfavorable initial tensile strength which could preclude endorsement for use unless high temperature (>250°F) performance is required.

g. *Grease Type*: Compatibility of the three multipurpose greases with the representative elastomeric compounds obtained for this study is most favorable for grease A and least favorable for the synthetic type C. Generally, the synthetic lubricant tends to effect excessive post-cure crosslinking (modulus build-up) and in some cases shrinkage, indicative of compound ingredient extraction. Variations in the chemical nature of additives contained in these greases preclude the assumption that high swelling action correlates with high tensile and elongation losses. Thus, it is apparent that elastomer compound/grease compatibility must be considered on a case by case basis, and volume change should not be the only property used to measure grease/elastomer compatibility.

VII. SUMMARY

The data generated in this effort clearly emphasizes the complexity of elastomer/wheel-bearing grease compatibility. Static immersion testing can be used to screen out obvious poor seal compounds. However, selection of optimum seal candidates involves compromise: What degree of modulus buildup and swelling or shrinkage can be tolerated without sacrificing service life? Limits, based on the performance of the Viton-fluorelastomer compound WB-10,would preclude acceptance of seals fabricated from nitrile, acrylic, or silicone rubber. Ideally, these acceptable criteria should be supplemented by inclusion of dynamic performance procedures and limits. Compatibility determination procedures must be expanded beyond the limiting scope of FTMS 791B and ASTM-D-4289. Inclusion of additional physical data generated as per ASTM-D-471 and D-395 and encompassing tensile, elongation, and modulus properties--initially, and subsequent to direct exposure and compression set characteristics--is suggested. Development of more comprehensive laboratory performance data can effect significant DOD cost savings in terms of reduced need for time-consuming on-vehicle testing and quicker resolution of seal/grease compatibility.

TABLE 1

INITIAL PHYSICAL PROPERTIES WHEEL-BEARING SEAL COMPOUNDS

	TENSILE STRENGTH - psi	ELONGATION %	MODULUS psi	TENSILE SET - %
WB-1	1650	353	900	27.5
WB-2	2087	178	993	10.0
WB-3	2251	543	679	27.5
WB-4	1276	298	1010	27.5
WB-5	579	184	380	7.5
WB-6	913	253	513	27.5
WB-7	2040	183	1115	10.0
WB-8	2560	435	1400	17.5
WB-9	2643	320	800	12.5
WB-10	1520	268	1103	20.0
WB-11	2028	423	710	35.0

TABLE 2

RETENTION OF PHYSICAL PROPERTIES EXPOSURE IN GREASE A, MIL-G-10924C

	TENSILE RETENTION %	TENSILE RETENTION %*	ELONGATION RETENTION %	MODULUS RETENTION %	MODULUS RETENTION %*	VOLUME CHANGE %
WB-1	87.0	83.9	88.9	100.0	96.7	5.6
WB-2	99.5	89.0	93.8	107.8	96.4	18.3
WB-3	55.1	48.0	74.9	79.6	69.3	23.1
WB-4	96.4	92.6	107.3	98.7	92.0	6.2
WB-5	103.7	93.4	81.8	135.7	122.2	17.1
WB-6	94.2	90.6	56.5	133.0	17.1	6.1
WB-7	112.3	108.7	109.3	104.3	101.1	4.9
WB-8	90.6	90.8	78.9	110.5	110.7	-0.3
WB-9	90.1	87.3	84.4	104.2	101.0	4.8
WB-10	93.9	93.5	100.7	98.9	98.5	0.6
WB-11	91.4	89.4	92.2	107.5	105.1	3.4

*Based on swollen cross-sectional area

TABLE 3

RETENTION OF PHYSICAL PROPERTIES
EXPOSURE IN GREASE B, HPD, MIL-G-10924D
(HIGH DROPPING POINT VERSION)
AMENDMENT I

	TENSILE RETENTION %	TENSILE RETENTION %*	ELONGATION RETENTION %	MODULUS RETENTION %	MODULUS RETENTION %*	VOLUME CHANGE %
WB-1	93.9	93.3	84.1	112.0	116.0	0.9
WB-2	93.9	89.8	85.9	120.8	115.4	7.0
WB-3	72.5	70.6	79.3	97.7	95.1	4.2
WB-4	96.1	94.2	106.3	95.4	93.5	3.1
WB-5	104.6	91.3	74.5	136.8	119.5	22.5
WB-6	81.4	80.0	44.7	135.1	132.6	2.8
WB-7	93.3	91.4	76.5	127.4	124.7	3.2
WB-8	90.9	90.9	72.0	122.4	0.0	-0.3
WB- 9	93.3	90.7	81.2	115.0	111.8	4.4
WB-10	92.5	94.8	103.4	101.3	100.9	0.5
WB-11	76.0	74.0	78.0	125.8	122.6	3.9

*Based on swollen cross-sectional area

TABLE 4

RETENTION OF PHYSICAL PROPERTIES EXPOSURE IN GREASE C, PAO WITH POLYUREA THICKENER

	TENSILE RETENTION %	TENSILE RETENTION %*	ELONGATION RETENTION %	MODULUS RETENTION %	MODULUS RETENTION %*	VOLUME CHANGE %
WB-1	86.6	89.2	64.3	142.2	146.6	-4.4
WB-2	103.5	103.6	71.3	169.3	169.3	-0.13
WB-3	59.1	59.0	57.8	128.2	128.0	0.3
WB-4	95.6	95.3	81.5	110.2	109.9	0.45
WB-5	104.6	91.3	74.5	136.8	119.5	4.1
WB-6	113.6	112.6	77.9	159.1	157.7	1.3
WB-7	98.5	100.0	65.6	155.2	157.7	-2.1
WB-8	88.8	90.8	60.5	141.7	141.9	-3.4
WB-9	90.2	89.9	64.7	136.3	135.8	0.5
WB-10	95.0	95.0	103.4	98.2	98.3	-0.1
WB-11	66.6	67.8	66.2	129.6	131.9	-2.7

*Based on swollen cross-sectional area

TABLE 5

COMPRESSION SET
WHEEL-BEARING SEAL COMPOUNDS

	70 HOURS 158°F %	22 HOURS 212°F %	22 HOURS 302°F %
WB-1	10.8	22.9	—
WB-2	9.8	10.0	—
WB-3	—	20.0	—
WB-4	—	18.0	—
WB-5	—	—	60.0
WB-6	—	—	31.0
WB-7	—	7.0	—
WB-8	8.7	—	—
WB-9	13.2	—	—
WB-10	15.2	—	—
WB-11	12.3	—	—

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