Material Compatibility of Motor Materials with Low GWP Refrigerants and Lubricant

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ABSTRACT

Phase insulation, tie cord, and varnish used in hermetic motors are critical materials used in the construction of heating ventilation, air conditioning and refrigeration (HVAC&R) equipment. Understanding of the compatibility of these materials with new low global warming potential (GWP) refrigerants and lubricants is necessary to ensure reliable equipment operation over 10-20 years. AHRTI (Air-Conditioning Research Technology Institute), with funding from the US Department of Energy Building Technology Office, and NYSERDA (New York State Energy Research & Development Authority) sponsored the second phase of the AHRTI Project 9016 to continue the study of Low GWP (global warming potential) refrigerants. Phase II of this project expanded upon the chemical stability testing with more system materials of construction and included material compatibility of common non-metallic materials used in refrigerant containing systems.

This paper will focus on the material compatibility results of motor materials, specifically phase insulation, tie cord, and varnish, with R-1233zd(E) and R-1224yd(Z) with and without mineral oil, R-1336mzz(E), R-514A, R-515B, R-516A, and R-454B with and without PAG (polyalkylene glycol), POE (polyol ester), and PVE (polyvinyl ether) lubricants.

1. INTRODUCTION

A comprehensive understanding of chemical stability and material compatibility of a refrigerant and lubricant with the materials used in HVAC&R equipment is critical to ensure reliable operation over the lifetime of the equipment. Phase I of the AHRTI 9016 research program was completed in 2021 to investigate chemical and thermal stability of a wide range of new low GWP refrigerants (Sorenson et al., 2021). Based on the findings in this study, Phase II of the AHRTI 9016 research program was started in 2022 focusing on expanding the chemical stability and materials compatibility understanding of low GWP refrigerants with additional materials. Material compatibility evaluations were conducted with various elastomer, gasket, polymer & motor materials to further characterize these refrigerant systems as part of this project.

A similar program screening material compatibility was completed under AHRI MCLR Project #08007 which assessed the compatibility of R-1234yf and R-1234ze(E) with comparable materials tested under the AHRTI 9016 test program (Majurin et al., 2014a). This study revealed that many elastomers, gaskets, and polymers that were used in HFC (hydrofluorocarbon) systems are suitable for use with low GWP HFO (hydrofluoroolefin) refrigerants, however, the project recommended additional motor material studies for R-1234ze(E) to better understand system level implications. The same recommendations were not made with R-1234yf since it showed satisfactory compatibility with all evaluated materials. AHRTI Project 9016 Phase II included assessments of 8 elastomers, 3 flat sheet gaskets, 9 polymers and 7 motor materials with HCFO (hydrochlorofluoroolefins), HFO, and HFO blended refrigerants (R-1233zd(E), R-1224yd(Z), R-514A, R-1336mzz(E), R-515B, R-516A, and R-454B and limited materials were evaluated with R-466A). Materials selected were the same or similar to materials evaluated in AHRI MCLR Project #08007. Most refrigerants were evaluated with PAG, POE, and PVE lubricants, with the exception of R-1233zd(E) and R-1224yd(Z), which were evaluated with a white naphthenic mineral oil (MO), and R-466A, which was evaluated with an additized POE. The POE was unadditized except for low levels of an antioxidant, common in synthetic lubricants, while the PVE and PAG lubricants were evaluated with additive packages designed to stabilize the lubricant with the refrigerant.

This paper will focus on the material compatibility results of motor materials, specifically phase insulation, tie cord, and varnish, with R-1233zd(E) and R-1224yd(Z) with and without mineral oil, R-1336mzz(E), R-514A, R-515B, R-516A, and R-454B with and without PAG, POE, and PVE lubricants. These results will be summarized and further discussed in the AHRTI 9016 Phase II final report.

2. EXPERIMENTAL

Table 1 summarizes the times and temperatures for the exposures of these motor materials. Test conditions were selected to align with previous work in AHRI MCLR Project #08007 and Report DOE/CE/23810-13 (Majurin et al., 2014a; Doerr and Kujak, 1993).

Table 1: Refrigerant – Lubricant Test Conditions

HCFO Conditions		HFO Conditions		HFO-Containing Blend Conditions		
Description	Exposure Conditions	Description	Exposure Conditions	Description	Exposure Conditions	Nominal Composition (% wt.)
100% R-1233zd(E)	90°C 21 Days	100% R-1336mzz(E)	90°C 21 Days	100% R-514A	90°C 21 Days	R-1336mzz(Z) (74.7%) R-1130(E) (25.3%)
50% R-1233zd(E) 50% Mineral Oil	127°C 21 Days	50% R-1336mzz(E) 50% PAG Oil	127°C 21 Days	50% R-514A 50% PAG Oil	127°C 21 Days	
100% R-1224yd(Z)	90°C 21 Days	50% R-1336mzz(E) 50% POE Oil		50% R-514A 50% POE Oil		
50% R-1233zd(E) 50% Mineral Oil	127°C 21 Days	50% R-1336mzz(E) 50% PVE Oil		50% R-514A 50% PVE Oil		
		100% R-1234yf[1]	90°C 21 Days	100% R-515B	90°C 21 Days	R-1234ze(E) (91.1%) R-227ea (8.9%)
		50% R-1234yf[1] 50% POE Oil	127°C 21 Days	50% R-515B 50% PAG Oil	127°C 21 Days	
		50% R-1234yf[1] 50% PVE Oil	127°C 21 Days	50% R-515B 50% POE Oil		
		100% R-1234ze(E)[1]	90°C 21 Days	50% R-515B 50% PVE Oil		
		50% R-1234ze(E)[1] 50% POE Oil	127°C 21 Days	100% R-516A	90°C 21 Days	R-1234yf (77.5%) R-134a (8.5%) R-152a (14.0%)
		50% R-1234ze(E)[1] 50% PVE Oil	127°C 21 Days	50% R-516A 50% PAG Oil	127°C 21 Days	
				50% R-516A 50% POE Oil		
				50% R-516A 50% PVE Oil		
				100% R-454B	60°C 21 Days	R-32 (68.9%) R-1234yf (31.1%)
				50% R-454B 50% PAG Oil	127°C 21 Days	
				50% R-454B 50% POE Oil		
				50% R-454B 50% PVE Oil		

[1]Data collected in AHRI MCLR Project #08007 (Majurin et al, 2014a).

The samples selected for study are either materials that are currently in use or have been previously assessed for use in HVAC&R systems. Table 2 summarizes the motor materials selected for this work. All materials, except for the motor varnish, were exposed in their condition as received, after being cut to an appropriate size for testing. Mica glass cloth material was received pre-cut in the appropriate dimensions. For the motor varnish, cured pucks were prepared in thin disks to appropriately assess the effects of the test fluids on pure varnish. Samples of magnet wire were coated in varnish to provide a more accurate simulation of varnish as used in an application with a hermetic motor, because the thickness of a cured varnish puck is thicker than the film build typically seen on a motor. The magnet wire samples allowed for observations of varnish adherence, flexibility, and bond strength. Varnish pucks were cured following the procedure outlined in AHRI MCLR Project #08007 (Majurin et al., 2014a), and magnet wire samples (single strands for mandrel bend and helical coils for bond strength) were coated and cured by the varnish supplier following a similar curing procedure. After exposure, motor materials were evaluated for physical changes such as appearance, weight, tensile property changes, and evaluation of the electrical insulation properties, as identified in Table 2.

The Mylar® MO21 material was tested independently of the other phase insulations due to results previously observed with this material, while the remaining phase insulation materials and polyester tie cord were exposed in the same test vessel for each test condition per the procedure used in AHRI MCLR Project #08007 (Majurin et al., 2014a). Varnishes tested in this study were tested in three forms: a cured varnish puck, a varnished magnet wire in a single strand, and a varnished helical coil. All three forms were exposed in the same test vessel in each test condition.

Table 2: Materials and Testing Summary of Motor Materials

Motor Material	Appearance Change	Weight Change	Volume Change	Dielectric Strength	Tensile Property Changes	Post-Bakeout Appearance Change	Post-Bakeout Weight Change	1X Mandrel Bending (Single Strand)	Bond Strength (Helical Coils)
Mylar® MO21 Polyester phase insulation	X	X	-	X	X	-	-	-	-
Melinex® 238 Polyester phase insulation	X	X	-	X	X	-	-	-	-
Nomex® 410 Phase insulation	X	X	-	X	X	-	-	-	-
Mica Glass Cloth NEMA #311 phase insulation	X	X	-	X	X	-	-	-	-
Polyester Tie Cord	X	X	-	-	X	-	-	-	-
Pedigree® 923-35 Solvent-based varnish pucks	X	X	X	-	-	X	X	-	-
Elan-Guard® EM59-60MR Water-borne varnish pucks	X	X	X	-	-	X	X	-	-
Magnet Wire Samples A, B, C, D[1]	-	-	-	-	-	-	-	X	X

[1]Four different magnet wire/varnish combinations were tested, see details below. Single strands and helical coil samples were prepared and tested for each magnet wire/varnish combination.
A – Film insulated round magnet wire with Pedigree® 923-35 solvent-based varnish
B – Film insulated round magnet wire with Elan-Guard® EM59-60MR water-borne varnish
C – Fibrous covered round magnet wire with Pedigree® 923-35 solvent-based varnish
D – Fibrous covered round magnet wire with Elan-Guard® EM59-60MR water-borne varnish

3. NON-VARNISHED MOTOR MATERIALS RESULTS AND DISCUSSION

Materials tested in this study were assessed and given risk levels as defined in Table 3, which are directly related to the tables in previous work (Majurin et al., 2014b). The authors of that study created the risk levels based on results from critical tests and experience from system applications. It is noted that, in addition to the general requirements listed in Table 3, other factors should be considered during material selection, such as application intent and other material specifications. Lastly, other original equipment manufacturers (OEMs) and test labs may have different ranking criteria and selection processes than those reported here. A full presentation of results will be found in the AHRTI Project 9016 Phase II final report, which will provide more detail and discussion of the test results to provide insights to the industry when selecting materials for an application. All risk levels for the materials and conditions tested in this study are summarized in Table 4, while noteworthy trends and results are discussed in the following subsections. As a note, materials noted as high risk for a given attribute may also have additional attributes that would fall under medium or low risk categories.

For the discussion of tensile test results in this study of unvarnished materials (tensile strength change from control, break load strength change from control, percent elongation change from control), it is assumed that changes in these properties of ±15% are considered within the error of the method. This is because variations in sample preparation and the tensile test procedure itself can result in batch-to-batch variation of the physical properties of the tensile samples. That said, it was determined to define risk levels for changes in only tensile strength and break load strength, as the behavior of these properties was much more consistent for each material tested. Discussion on percent elongation change is limited to if a material exhibited elongation change outside of the range of ±15% from control and was not a determining factor in the risk level for a test condition. This is because the risks vary from application to application and are dependent on if the elongation increased or decreased. Therefore, it is recommended to fully understand and review the application of these materials in tandem with the elongation data seen and the risk levels of the other properties defined here before selecting a material for use in a low-GWP refrigerant environment; due to these reasons, elongation values were included for review in Table 5.

For comparison purposes, HFO-containing blend results are compared against results for R-1234ze(E) and R-1234yf (where applicable) published in the AHRI MCLR Project #08007 report (Majurin et al., 2014a).

Table 3: Classification of motor phase insulation and tie cord materials.

Material Risk Category	Weight Change	Appearance Change	Dielectric Strength	Tensile Property Change
High	>20% increase or >2% decrease	Significant material changes such as cracking, crazing, or blistering	>50% decrease	>50% decrease
Medium	10% - 20% increase	Marginal material changes such as color change or minor extractables (>5% by weight)	25% - 50% decrease	15% - 50% decrease
Low	0% - 10% increase	No notable material changes	0% - 25% decrease	0% - 15% decrease

3.1 Mylar® MO21

Mylar® MO21 exhibited no notable appearance changes and minimal weight, dielectric strength, and tensile strength changes resulting in classification of low risk for all test conditions. The only elongation change of note is an increase observed in all R-454B conditions.

For weight, dielectric, and tensile strength, less change was seen in the R-1234yf and R-1234ze(E) containing blends than in the single component R-1234yf and R-1234ze(E) testing performed previously. The elongation results of the R-515B, R-516A, and R-454B conditions with lubricant show slight increases, while the single components R-1234yf and R-1234ze(E) with lubricant tested previously showed significant decreases.

3.2 Melinex® 238

A faint residue was seen on the surface of the Melinex® 238 after exposure in most conditions but not in quantities significant enough to change the risk classification or merit further investigation. This residue is likely an extract from the polyester based material, but future study is necessary to understand the root cause of the extraction and its implications. All conditions showed minimal weight and dielectric change after exposure. Only four conditions resulted in a medium risk decrease in tensile strength (R-1233zd(E)/MO, R-1224yd(Z)/MO, R-1336mzz(E)/POE, R-516A/POE), while all others remained low risk. All lubricant containing R-515B conditions showed a notable decrease in elongation compared to control samples. With the exception of less elongation observed with R-1234yf and R-1234ze(E) containing blends, all other properties were similar between blends and the single components tested.

Table 4: Risk classification of motor phase insulation and tie cord materials.

Test Condition		Mylar® MO21	Melinex® 238	Nomex® 410	Mica Glass Cloth	Polyester Tie Cord
Refrigerant	**Oil**					
HCFO Refrigerants						
R-1233zd(E)	No Oil	Low	Low	Low	High[2]	Low
	MO	Low	Medium[2]	Medium[1,3]	Medium[2]	High[1]
R-1224yd(Z)	No Oil	Low	Low	Low	Medium[2]	Low
	MO	Low	Medium[2]	Low	Low	High[1]
HFO Refrigerants						
R-1336mzz(E)	No Oil	Low	Low	Low	Low	Medium[1]
	PAG	Low	Low	Low	Low	High[1]
	POE	Low	Medium[2]	Low	Low	High[1]
	PVE	Low	Low	Low	Low	High[1]
HFO Blended Refrigerants						
R-514A	No Oil	Low	Low	Low	High[2]	Low
	PAG	Low	Low	Medium[1]	Medium[2]	High[1]
	POE	Low	Low	Medium[1]	Medium[2]	High[1]
	PVE	Low	Low	Medium[1]	Medium[2]	High[1]
R-515B	No Oil	Low	Low	Low	Medium[2]	Medium[1]
	PAG	Low	Low	Low	Medium[2]	High[1]
	POE	Low	Low	Low	Low	High[1]
	PVE	Low	Low	Low	Medium[2]	High[1]
R-516A	No Oil	Low	Low	Low	Low	Low
	PAG	Low	Low	Low	Medium[3]	High[1]
	POE	Low	Medium[2]	Low	Medium[2,3]	High[1]
	PVE	Low	Low	Low	Medium[2,3]	High[1]
R-454B	No Oil	Low	Low	Low	Medium[2]	Medium[1]
	PAG	Low	Low	Low	Medium[2]	High[1]
	POE	Low	Low	Low	High[2]	High[1]
	PVE	Low	Low	Low	Medium[2]	High[1]

[1]Placed in this risk category due to weight change.
[2]Placed in this risk category due to tensile strength change.
[3]Placed in this risk category due to appearance change.

3.3 Nomex® 410

The Nomex® 410 phase insulation material exhibited significant discoloration in the mineral oil containing conditions (transitioned from white to dark grey) as seen in Figure 1. Most POE and PVE test conditions also experienced discoloration to a lesser extent, which is consistent with discoloration seen in AHRI MCLR Project #08007, also shown in Figure 1. Similar darkening of Nomex® 410 was seen in an extended exposure with mineral oil and synthetic based insulation fluids, where after examination with infrared microscopy it was theorized that the darkening could be due to hydrolysis of the aramid material or adherence of oil degradation product (Arroyo-Fernández et al., 2020). Further investigation would be needed to fully understand the cause; the authors believe a similar occurrence is being observed in this study, however, the presence of refrigerant accelerates the discoloration of the material. Ultimately, the color change is not expected to negatively affect the material in application. All conditions containing chlorinated refrigerants and lubricant (any type) resulted in a medium risk for weight change, increasing between 10-20%. All test conditions showed a low risk change in tensile strength. Only four conditions (100% R-1336mzz(E), 100% R-514A, and 100% R-454B, R-454B/PVE) showed elongation change within 15% of the controls, while remaining conditions showed larger deviations from control. Most other conditions decreased in elongation (R-1224yd(Z)/MO showed an increase). Similar property changes were observed between R-1234yf and R-1234ze(E) containing blends and their single components tested previously.

Figure 1. Grey coloration of Nomex® 410 seen after exposure to R-1233zd(E) and MO (left), after exposure to R-454B and POE (center), and after exposure to R-1234yf and POE in AHRI MCLR Project #08007 (right). An unexposed sample of Nomex is on the left in each photo for reference.

Table 5: Elongation changes (% from control) seen in each material tested.

Test Condition		Mylar® MO21	Melinex® 238	Nomex® 410	Mica Glass Cloth	Polyester Tie Cord
Refrigerant	**Oil**					
HCFO Refrigerants						
R-1233zd(E)	No Oil	NC	NC	-27%	-37%	+43%
	MO	-80%	NC	-47%	NC	+59%
R-1224yd(Z)	No Oil	NC	NC	+16%	NC	+30%
	MO	NC	-17%	-53%	+29%	+79%
HFO Refrigerants						
R-1336mzz(E)	No Oil	+24%	-19%	NC	-21%	+29%
	PAG	NC	NC	-42%	NC	+73%
	POE	NC	NC	-32%	+89%	+75%
	PVE	NC	-29%	-48%	NC	+69%
HFO Blended Refrigerants						
R-514A	No Oil	NC	-35%	NC	-61%	+103%
	PAG	NC	NC	-45%	+21%	+108%
	POE	NC	-16%	-28%	-18%	+105%
	PVE	+21%	-25%	-26%	+17%	+112%
R-515B	No Oil	+15%	NC	-39%	-30%	+49%
	PAG	NC	-22%	-52%	-23%	+92%
	POE	NC	-29%	-57%	-36%	+91%
	PVE	NC	-19%	-52%	-35%	+85%
R-516A	No Oil	NC	NC	-17%	+17%	+48%
	PAG	NC	NC	-46%	+73%	+82%
	POE	+43%	NC	-39%	-32%	+85%
	PVE	+21%	-27%	-38%	-31%	+82%
R-454B	No Oil	+31%	NC	NC	+32%	+51%
	PAG	+25%	NC	-23%	-40%	+108%
	POE	+37%	-25%	-30%	-53%	+102%
	PVE	+36%	NC	NC	NC	+113%

3.4 Mica Glass Cloth

Delamination between the glass layer and fibrous layer of the mica glass cloth material was observed in most samples in varying severity after exposure to all test conditions. Most significant delamination was observed in all lubricant containing conditions with R-516A. This delamination behavior likely impacted the tensile properties due to existing separation of the fibrous layers from glass layer prior to tensile testing. A majority of conditions resulted in a medium risk change for tensile change with the exception of R-454B/POE (high risk decrease) and 8 low risk conditions (all R-1336mzz(E) conditions, R-515B/PAG, R-515B/POE, 100% R-516A, R-516A/PAG). R-514A showed some of the more significant decreases in tensile strength, which contrasts with the low-risk behavior of R-1336mzz(E) samples. No clear trends in elongation change were observed; many conditions experienced large increases or decreases while only the five conditions identified in Table 5 showed no change.

All test conditions for both weight and dielectric strength change were low risk. Notably, all R-454B test conditions had dielectric strength values higher than could be measured after exposure, and R-516A conditions also showed increases, which align with increases seen in the R-1234yf conditions tested previously.

3.5 Polyester Tie Cord

No notable appearance changes were observed of the polyester tie cord material in any condition. The polyester tie cord material showed significant changes in weight in all oil containing conditions after exposure resulting in a classification of high risk, however, this weight change is likely due to oil saturation of the cord material. Upon removal from the vessel, material was gently wiped to remove excess oil from the surface, but the material was not aggressively wiped or rinsed with solvent to remove all remaining oil. The corresponding oil free conditions exhibited less weight change than their corresponding oil conditions, however, select conditions (100% R-1336mzz(E), 100% R-515B, and 100% R-454B) were classified as a medium risk due to changes in weight. The break load strength of the material decreased in most conditions but did not change significantly from the control. Elongation significantly increased (around 50% or greater) in all test conditions except the lubricant free R-1233zd(E), R-1224yd(Z), and R-1336mzz(E) conditions, which increased between 25-50% from control. Some slippage of the material in the tensile test fixture was noted, which could affect these results.

5. VARNISHED MOTOR MATERIALS RESULTS AND DISCUSSION

Like the non-varnished motor materials, the varnished motor materials tested in this study were assessed and given risk levels as defined in Table 6. All risk levels for the materials and conditions tested in this study are summarized in Table 7, while noteworthy trends and results are discussed in the following subsections. For comparison purposes, HFO-containing blend results are compared against results for R-1234ze(E) and R-1234yf (where applicable) published in the AHRI MCLR #08007 report (Majurin et al., 2014a).

It was found that the varnished helical coils presented consistent tensile test results with minimal scatter in the unexposed pieces. Because of this, it was determined to include bond strength changes as a part of the risk assessment matrix.

Table 6: Classification of motor varnish.

Material Risk Category	Weight/Volume Change	Appearance Change	1X Mandrel Bend	Bond Strength Changes
High	>20% increase or >5% decrease	Significant material changes such as cracking, crazing, or blistering	Severe cracking	>50% decrease
Medium	5% - 20% increase	Marginal material changes such as color change or minor extractables	Moderate cracking	25% - 50% decrease
Low	<5% increase or decrease	No notable material changes	No cracking to minor cracking	0% - 25% decrease

Table 7: Risk classification of motor varnish materials.

Test Condition		Pedigree® 923-35	Elan-Guard® EM59-60MR
Refrigerant	Oil		
HCFO Refrigerants			
R-1233zd(E)	No Oil	Low	Medium[1]
	MO	High[4]	Medium[1,4]
R-1224yd(Z)	No Oil	Medium[3]	Medium[3]
	MO	High[2,4]	Medium[3,4]
HFO Refrigerants			
R-1336mzz(E)	No Oil	Medium[3,4]	Medium[3]
	PAG	High[2,4]	Medium[3,4]
	POE	High[1,2,4]	Medium[3,4]
	PVE	High[1,2]	Medium[3,4]
HFO Blended Refrigerants			
R-514A	No Oil	Medium[1,2]	High[4]
	PAG	Medium[3,4]	Medium[1,2,3,4]
	POE	Medium[3]	Medium[1,2,3]
	PVE	Medium[3,4]	Medium[1,2,3,4]
R-515B	No Oil	Medium[3]	Low
	PAG	High[2]	Medium[3,5]
	POE	High[1,2]	Medium[3,5]
	PVE	Medium[3]	Medium[3,5]
R-516A	No Oil	Medium[3]	Medium[3]
	PAG	High[2]	Medium[3]
	POE	High[2]	Medium[3]
	PVE	Medium[3]	Medium[1,2,3]
R-454B	No Oil	Medium[3]	Medium[1,3]
	PAG	Medium[3]	Medium[1,2,3]
	POE	High[1,2]	Medium[3]
	PVE	Medium[3]	Medium[1,3]

[1]Placed in this risk category due to weight change.
[2]Placed in this risk category due to volume change.
[3]Placed in this risk category due to mandrel bend change.
[4]Placed in this risk category due to bond strength change.
[5]Placed in this risk category due to appearance change.

3.1 Solvent Based Motor Varnish (Pedigree® 923-35)

The solvent-based varnish pucks exhibited no notable appearance change in any condition tested. In general, most pucks experienced a decrease in weight and volume after exposure with several conditions decreasing more than 5% resulting in a high risk classification. However, many of these values were only slightly beyond acceptability with up to 8% decrease in the worst performing condition. The 100% R-514A condition was unique in that it experienced an increase in weight and volume after exposure up to 15% resulting in a medium risk classification. When comparing R-1336mzz(E) and R-514A conditions, all R-1336mzz(E) lubricant containing conditions exhibited weight and/or volume decreases that resulted in a high risk classification while comparable R-514A conditions did not experience similar behavior. These results could suggest the R-1130(E) component is mitigating the weight and volume decrease experienced with R-1336mzz(E) conditions.

Most film insulated single strands of wire showed significant cracking after exposure, with the exception of select conditions. For example, PVE containing R-515B, R-516A, and R-454B conditions showed either minor or no cracking in some test conditions, which contrasts with the severe cracking seen in R-1234yf and R-1234ze(E) with PVE seen in previous work. The presence of the HFC component in these blends could be positively impacting this property. The fibrous insulated single strands of wire also showed significant cracking across most conditions with the exception of all test conditions with R-514A. Those conditions showed no cracking while all conditions of R-

1336mzz(E), except for R-1336mzz(E)/PVE, showed significant cracking, again suggesting that the R-1130(E) component in R-514A and potentially the presence of PVE may be positively impacting the varnish.

Lastly, helical coils of both magnet wire types were coated with Pedigree® 923-35 for bond strength tensile testing after exposure to the test fluids. Both mineral oil containing conditions showed high risk decreases in bond strength for both types of wire. In oil containing conditions with fibrous insulated wires, R-1234yf and R-1234ze(E) containing blends showed similar or less bond strength decrease than the single component refrigerants tested previously. This was not the case however with film insulated wire, where R-515B showed less decrease in bond strength than the decreases previously observed with R-1234ze(E); no clear trends were observed with R-1234yf and its blends with film insulated wire. Further confirming the trends seen with the other varnished sample types, R-1336mzz(E) containing conditions performed worse than R-514A containing conditions with both wire types, except for in the PAG and PVE conditions with fibrous insulated wire, where both decreased in strength equivalently.

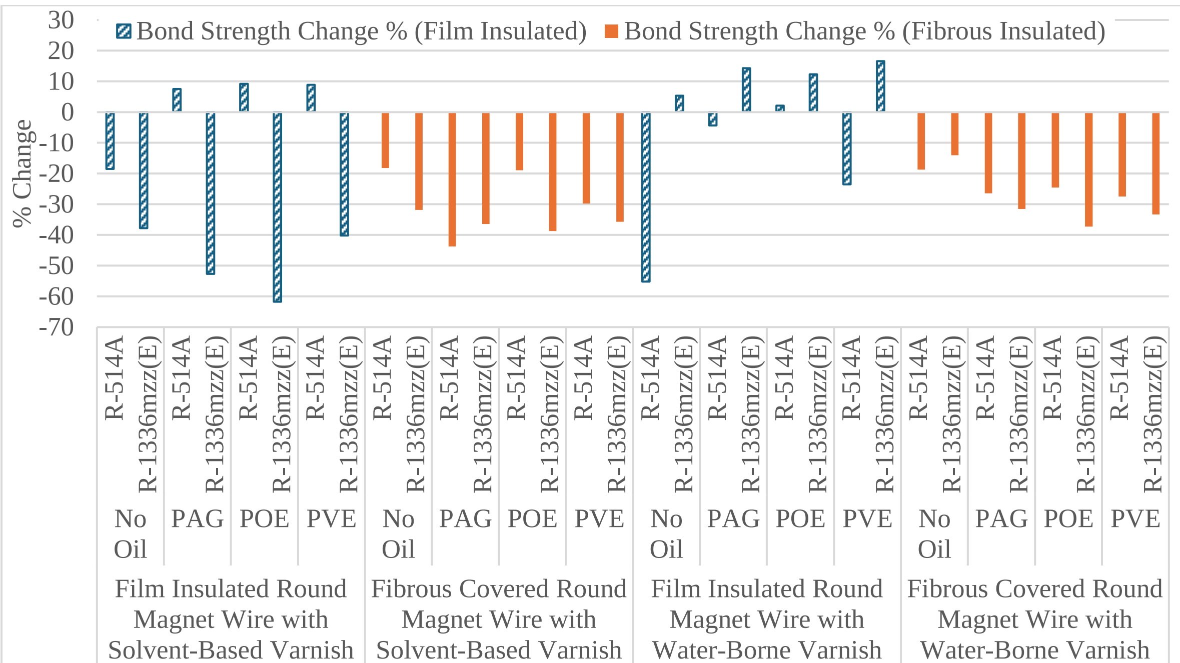

Figure 3. Graphical comparison of varnished wire bond strength in R-514A and R-1336mzz(E) conditions.

3.2 Aqueous Based Motor Varnish (Elan-Guard® EM59-60MR)

The aqueous based varnish pucks exhibited slight yellowing after exposure in most conditions with the exception of all R-515B conditions with lubricant where the pucks transitioned to an orange color. Unlike the solvent based varnish, several aqueous based varnish conditions experienced an increase in weight and volume after exposure, resulting in medium risk classifications. Consistent with the solvent based results, the R-514A exposures experienced a higher increase in weight and volume change after exposure compared to the R-1336mzz(E) indicating the R-1130(E) component may have similar impacts on the aqueous based varnish.

Mandrel bend testing of the coated single strand film insulated wires exhibited no cracking in nearly all conditions, and only minor cracking in the three conditions (R-1233zd(E)/MO, R-514A/POE, and 100% R-454B). R-1234yf and R-1234ze(E) containing blends performed similarly to testing previously in AHRI MCLR Project #08007. On the contrary, the fibrous insulated wire showed significant cracking in most test conditions, with the exception of 100% R-1233zd(E) and 100% R-515B where only minor cracking was observed. Based on previous results, R-515B appeared to perform similarly to R-1234ze(E), however, there was not a clear trend between R-1234yf and its blends.

Bond strength testing of coated film insulated helical coils exhibited low risk behavior in most test conditions with the exception of the 100% R-514A condition (high risk) due to a decrease in bond strength. R-1336mzz(E) containing conditions showed an increase in bond strength with film insulated wire, while the R-514A conditions showed decreases in the lubricant free and PVE conditions and marginal changes in the PAG and POE conditions. In POE conditions with R-1234yf and R-1234ze(E) blends, increases in bond strength with film insulated wire were observed while previous testing reported decreases in bond strength with the single component refrigerants and POE. Unlike the coated film insulated helical coils, both the R-514A and R-1336mzz(E) lubricant containing conditions showed nearly equivalent medium risk decreases in bond strength of the fibrous insulated helical coils. The mineral oil containing conditions were the only additional fibrous insulated wire samples to experience medium risk decreases in bond strength.

5. CONCLUSIONS

Phase insulation, tie cord, and varnish materials were tested for identifying material compatibility concerns of materials typically used in hermetic motors. They were tested with refrigerants R-1224yd(Z), R-1233zd(E), R-514A, R-1336mzz(E), R-515B, R-516A, and R-454B with and without lubricant. Risk criteria were determined and applied to each test condition. All materials tested (Mylar® MO21, Melinex® 238, Nomex® 410, mica glass cloth, polyester tie cord, Pedigree® 923-35, and Elan-Guard® EM59-60MR) were identified to be a medium risk in at least one test condition. Additional comparisons were made between R-1234yf and R-1234ze(E) containing blends and the data collected in AHRTI MCLR Project #08007 with the single components to understand the effects of the blend components on the materials. Similar comparisons were made from this study's test matrix including R-1336mzz(E) and R-514A. The results suggest that many of these motor materials that are currently used should be properly assessed in their application before use with these low GWP refrigerants.

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NOMENCLATURE

NC No Change

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