DUPONT™ VAMAC® FOR HALOGEN FREE FLAME RETARDANT (HFFR) APPLICATIONS

Introduction

Vamac® ethylene acrylic elastomer (AEM), introduced in 1975, has been successfully used for many years in the transportation sector, where excellent resistance to heat, engine and transmission fluids and low temperature flexibility is required. DuPont's latest manufacturing technology allows production of enhanced AEM grades that have significantly improved compared to the existing standard Vamac® elastomers. These grades, designated and sold as Vamac® Ultra, provide a step-change improvement in processability, performance and customer value for targeted applications, including for peroxide cure E/MA dipolymer grade, Vamac® Ultra DX (formerly VMX2122).

Vamac® Ultra DX for Halogen Free Flame Retardant (HFFR) Applications

Vamac® ethylene acrylic elastomers are halogen-free polymers and can be compounded for applications where high safety requirements regarding flammability, toxicity, and smoke density are critical. Vamac® Dipolymers (DP and Ultra DX) are the first choice for flame retardant applications. Higher viscosity is the major difference between Vamac® DP and Vamac® Ultra DX. The optimized polymer structure ensures gains in physical properties, resulting in improved performance of rubber parts such as cables, seals, gaskets or extruded hoses.

Both Dipolymers can be mixed with high loadings of metal hydroxides without negatively impacting compound viscosity like often seen with Vamac® Terpolymers where the acidic cure site interacts with the filler system. Such HFFR compounds find often usage in wire & cable applications for the automotive, building or railway industries where not only excellent temperature and fluid resistance are needed, but also high safety requirements are critical. Additionally, Vamac® HFFR compounds find use in rubber parts where low flammability of materials is an important criterion and can be interesting for various components in railways and/or buildings.

Best physical properties of Vamac® Ultra DX are obtained in rubber parts having a hardness range between 50 and 90 Shore A.

Handling Precautions

Because Vamac® Ultra DX contains small amounts of residual methyl acrylate monomer, adequate ventilation should be provided during storage and processing to prevent workers' exposure to methyl acrylate vapor. Additional information may be found in the Vamac® Ultra DX Safety Data Sheet (SDS), Safe Handling and Processing of Vamac® (VME-A10628), available on the DuPont website.

Like every other grade of Vamac®, Ultra DX is halogen-free.

Table 1: DuPont™ Vamac® Ultra DX - Typical Product Properties

Property	Target Values	Test Method
Mooney Viscosity, ML 1+4 at 100°C	26	ASTM D1646
Volatiles, wt%	≤0.4	Internal DuPont Test
Form, mm (in)	Bale size is nominally: 560 x 370 x 165 (22 x 15 x 7)	Visual Inspection
Color	Clear to light yellow translucent	Visual Inspection

Mixing

Vamac® Ultra DX has higher viscosity than Vamac® DP which allows better and faster dispersion of fillers and other compounding ingredients. Due to the general good scorch safety of peroxide cured compounds, changes in mixing cycle due to higher viscosity are not considered necessary.

Mixing of HFFR compounds: physical properties of the compounds will vary depending on the mixing procedure and the mixing time. Compounds mixed using only an open roll mill with long mixing cycles will have improved physical properties compared to compounds mixed in an internal mixer and a short time on the open mill.

HFFR Compounding and Physical Properties

a) General Starting Point Formulations

Typical non-halogenated flame retardant fillers like aluminum or magnesium hydroxide (ATH, $Mg(OH)_2$) can be used with Vamac® Dipolymers to achieve flame resistance, low smoke density and low toxicity performance as required by the railway industry. A typical HFFR compound formulation, which can be used as a starting point for halogen-free, flame retardant compounds, based on Vamac® Dipolymer, is shown in **Table 2**.

Table 2: HFFR Starting Point Formulation with Vamac® Dipolymers

Formulation	phr	Description
Vamac® DP/Ultra DX	100	Polymer
Armeen® 18D	0,5	Process aid
Stearic Acid	1	Process aid
Naugard® 445	1	Antioxidant
Martinal® OL 111 LE	150	ATH
Silanogran® HVS	2	Silane coupling agent
Ofalub® SEO	1	Process aid
Luperox® 101 XL 45	5	Peroxide
Vulcofac® 13 PDM	2	Co-agent

Table 3 shows a comparison of Vamac® Ultra DX to Vamac® DP in an identical formulation. Higher Mooney viscosity is the major difference between Vamac® Ultra DX and Vamac® DP. The tighter crosslink network and faster cure leads to slightly higher Hardness, with higher Tensile Strength, and still slightly higher Elongation at Break. Tear strength is improved with Vamac® Ultra DX while the Tg is comparable.

Table 3: Comparison of Physical Properties of Vamac® DP and Ultra DX

Compound No.	1*	2*
Vamac® DP	100	
Vamac® Ultra DX (formerly VMX2122)		100
Naugard® 445	1	1
Armeen®18 D	0.5	0.5
Stearic Acid	1.5	1.5
Martinal® OL-111 LE	160	160
Dynasylan® 6490	1	1
Perkadox® 14-40B-GR	4.5	4.5
Rubber chem HVA-2	1	1

Mooney Viscosity ML 1+4, 100°C [MU] - Polymer	22	28
Mooney Viscosity ML 1+4, 100°C [MU] - Compound	41	51
MDR, 0.5°arc, 12 minutes at 180°C		
ML [dNm]	0.44	0.48
MH [dNm]	16.3	17.6
T50 [min]	1.36	1.34
T90 [min]	4.41	4.26
Press-Cure 15 minutes at 180°C		
Hardness Shore A	76	79
Tensile Strength [MPa]	9.8	11.5
Elongation at break [%]	261	267
Modulus at 100% [MPa]	6.6	7.0
Tear Die C at 23°C [N/mm]	39	38
Trouser Tear Die A at 23°C [N/mm]	5.5	6.5
Tg by DSC [°C]	-29	-28

*mixed by open roll mill

After heat ageing, Vamac® Ultra DX maintains its properties better than Vamac® DP while the performance after fluid aging (IRM 903) is comparable. **Table 4** summarizes the results.

Table 4: Heat and Fluid Aging of Vamac® DP and Ultra DX

Compound No.	1	2
Heat ageing 168hrs at 160°C		
Hardness Shore A	82	82
Delta Hardness [pts.]	7	4
Tensile Strength [MPa]	11.4	12.3
Delta TS [%]	16	7
Elongation at break [%]	209	241
Delta Elong. [%]	-20	-10
Modulus at 100 % [MPa]	8.3	8.6
Delta 100% [%]	26	23
Heat ageing 168hrs at 175°C		
Hardness Shore A	82	83
Delta Hardness [pts.]	6	5
Tensile Strength [MPa]	10.8	11.7
Delta TS [%]	10	2
Elongation at break [%]	170	184
Delta Elongation [%]	-35	-31
Modulus at 100 % [MPa]	9.2	9.4
Delta 100% [%]	39	34
Fluid ageing 168hrs at 150°C in IRM 903		

Hardness Shore A	62	65
Delta Hardness [pts.]	-14	-13
Tensile Strength [MPa]	10.3	11.8
Delta TS [%]	5	3
Elongation at break [%]	163	181
Delta Elong. [%]	-38	-32
Modulus at 100 % [MPa]	7.1	7.2
Delta 100% [%]	8	3
Volume change [%]	29	27
Weight change [%]	17	16

b) Effect of Filler Amount, Particle Size, and Surface Treatment

Vamac® Dipolymer can be filled with high amounts of flame retardant filler, such as ATH. **Table 5** shows the physical properties of Ultra DX compounds using different amounts of ATH filler. Higher ATH loadings lead to increased Tensile Strengths and Modulus, while Elongation at Break is decreasing. Compression set remains comparable. The same recipes were used with Vamac® DP. All compounds passed the UL 94 V-0 test (2mm thick samples), similar results are expected by using Ultra DX.

Table 5: Effect of ATH Filler Loading on Compound Properties

Compound No.	3	4	5
Vamac® Ultra DX (formerly VMX2122)	100	100	100
Silane treated ATH 7.5m^2/g BET surface area	125	150	175
Hindered Amine AO	1	1	1
Dicumyl Peroxide, 40% active	5	5	5
TAIC	2	2	2
Mooney Viscosity ML 1+4, 100°C [MU]	49	56	60
Press-Cure 20 minutes at 170°C			
Hardness Shore A	68	73	76
Tensile Strength [MPa]	8.4	9.4	9.6
Elongation at break [%]	222	177	164
Modulus at 100% [MPa]	6.8	8.6	9.0
Compression set 70hrs at 150°C [%]	13	14	16

Surface area of the used ATH grade will also affect compound properties. Higher surface area ATH will increase the tensile strength while the LOI remains fairly constant. Special attention has to be paid to the use and type of plasticizer which can interfere with the peroxide cure and can lead to decrease cure state and mechanical properties, see **table 6**, compound 10. Best retention of properties after heat aging is achieved with higher surface area ATH, while the modulus change after fluid aging is highest with high surface ATH.

Table 6: Effect of ATH Surface Area on Compound Properties

Compound No.	6*	7*	8*	9*	10*
Vamac® DP	100	100	100	100	100
Naugard® 445	1	1	1	1	1
Armeen® 18D	0.5	0.5	0.5	0.5	0.5
Stearic Acid	1.5	1.5	1.5	1.5	1.5
Martinal® OL-107 LEO (BET 7m^2/g)	150				
Martinal® OL-111 LE (BET 11m^2/g)		150			
Apyral® 120E (BET 12 m^2/g)			150		
Apyral® 200SM (BET 20 m^2/g)				150	150
ADK Cizer® RS 735					7
Vinyl silane	1.5	1.5	1.5	1.5	1.5
Perkadox® 14-40B-GR	5	5	5	5	5
Rubber Chem HVA-2	1	1	1	1	2
Mooney Viscosity ML 1+4 @100°C	26.5	30.7	36.1	39.5	16.5
MDR 180°C/0.5deg/20min					
ML (dNm)	0.1	0.2	0.4	0.4	0.2
MH (dNm)	15.4	16.3	19.5	17.5	7.8
t50 (min)	1.8	1.6	1.4	1.5	0.7
t90 (min)	5.4	4.9	4.5	4.6	2.4
Press-Cure 15 minutes at 180°C					
Hardness Shore A	74	80	84	84	68
Tensile Strength [MPa]	8.1	12.3	12.7	14.0	7.3
Elongation at break [%]	238	196	193	196	275
Modulus at 50% [MPa]	2.9	4.0	4.9	4.7	1.7
Modulus at 100% [MPa]	6.0	8.1	9.5	10.1	3.2
LOI [%]	37	34	35	35	32

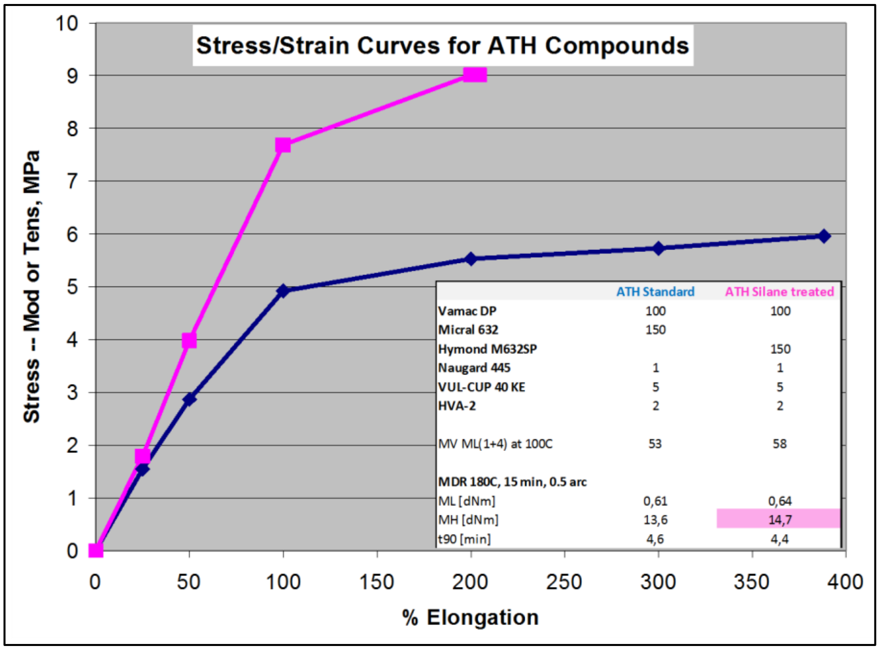
* mixed by open roll mill

Compound No.	6	7	8	9
Heat aging 168hrs at 160°C				
Hardness Shore A	79	84	88	86
Delta Hardness [pts]	5	4	4	2
Tensile [MPa]	9.0	11.6	12.5	13.9
Delta TS [%]	11	-6	-2	-1
Elongation [%]	170	178	156	175
Delta Elongation [%]	-29	-9	-19	-11
Modulus at 100 % [MPa]	7.4	9.3	10.6	10.5
Delta 100 % [%]	23	15	12	4
Fluid aging IRM 903 168hrs at 100°C				
Hardness Shore A	56	58	63	61
Delta Hardness [pts]	-19	-22	-21	-22

Tensile [MPa]	7.1	9.4	10.4	12.1
Delta TS [%]	-13	-23	-18	-13
Elongation [%]	186	179	179	170
Delta Elongation [%]	-22	-9	-7	-13
Modulus at 100 % [MPa]	4.9	5.6	6.3	6.6
Delta 100 % [%]	-20	-31	-34	-34

Surface treatment of ATH has a significant effect on the physical properties of the compound. Graph 1 shows the difference of using untreated ATH versus surface treated ATH that can crosslink with the cure system. Instead of using surface treated ATH, a silane coupling agent can be used as well.

Graph 1: Effect of ATH Surface Treatment



Vamac® Dipolymer Blends with Thermoplastic Polymers

For Wire & Cable (W&C) applications Vamac® Dipolymer HFFR compounds are often blended with thermoplastic polymers, partly to reduce cost but also to improve processing and physical properties. Suitable thermoplastic resins include e.g. Elvax® or Hytrel®.

Vamac® Dipolymer Blends with EVA Resins

Vamac® Dipolymers can be blended with Elvax® 40L-03, an ethylene-vinyl acetate copolymer, to obtain a HFFR compound that shows improved processing and handling parameters important for W&C compounds. Elvax® 40L-03 is a high molecular weight polymer containing 40wt% VA being fairly resistant to mechanical damage and elevated temperatures. The melting point is at 58°C and the maximum processing temperature is at 230°C. It can be processed using conventional rubber processing techniques such as internal mixers, two-roll milling and compression molding.

Addition of Elvax® 40L-03 to Vamac® Dipolymer in a typical HFFR starting point formulation increases hardness, tensile strengths, and modulus, while elongation at break is reduced. Smoke toxicity is comparable and very low, while the smoke density is increased in the Elvax® blend from D_{smax} of 39 to 109 compared to a pure Vamac® HFFR compound.

Table 7: Vamac® Ultra DX in Blends with Elvax® 40L-03

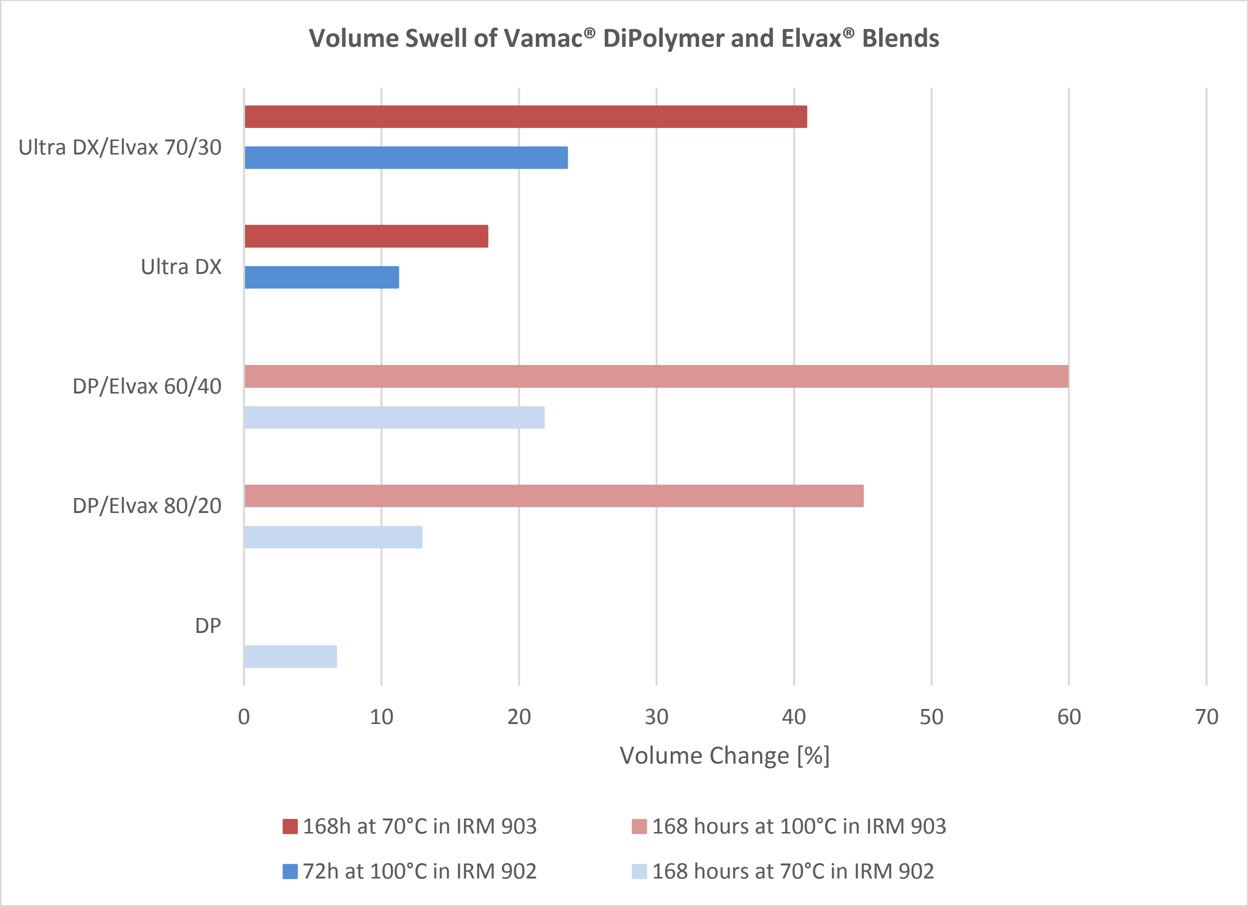
Compound No.	11	12	13	14	15
Vamac® Ultra DX	100	70			
Vamac® DP			100	80	60
Elvax® 40L-03		30		20	40
Struktol® WS 280			0.5	0.5	0.5
Armeen® 18D	0.5	0.5	0.5	0.5	0.5
Stearic Acid Reagent (95%)	1	1			
Struktol® WS 280			0.5	0.5	0.5
Ofalub® SEO	1	1	1	1	1
Naugard® 445	1	1			
Martinal® OL 111 LE	150	150			
Martinal® OL 107 ZO			150	150	150
Luperox® 101 XL 45	5	5	5	5	5
Silanogran® HVS	2	2	2	2	2
Rubber chem HVA 2			2	2	2
Vulcofac® 13 PDM	2	2			
Mooney Viscosity ML 1+4 at 100°C	50	42	38	37	35
MDR 15 minutes at 180°C, arc 0.5°					
ML [dNm]	0.6	0.7	0.4	0.6	0.6
MH [dNm]	13.5	15.9	14.0	16.5	17.9
T50 [min]	1.0	1.1	1.1	1.1	1.2
T90 [min]	3.5	3.7	4.0	4.3	4.8
Press-Cure 10 minutes at 180°C					
Hardness Shore A	74	82	72	78	81
Tensile Strength [MPa]	8.7	9.7	9.2	9.5	10.6
Elongation at break [%]	211	192	139	109	115

Modulus at 50 % [MPa]	2.9	5.1	3.3	4.5	5.1
Modulus at 100 % [MPa]	6.0	8.6	7.4	9.1	9.7
Flammability Behavior					
LOI [%]*	37	39	-	-	-
Ds max (ISO 5659-2)	20	64	39	-	109
CIT EN 45545-2	0.11	0.08	0.05	-	0.05

*according to ISO 4589 on 3mm thick test specimen

Volume Swell in IRM 902 and IRM 903 increases with increasing amounts of Elvax® blended into Vamac® and reaches for IRM 902 between 10-20% and for IRM 903 between 20-60% depending on aging conditions and blends ratio, see Graph 2.

Graph 2: IRM 902 and IRM 903 Swell if Vamac® Ultra DX/Elvax® 40L-03



Vamac® Dipolymer Blends with Thermoplastic Elastomers (TPE)

Hytrel® Thermoplastic Polyester Elastomer has excellent low temperature flexibility and toughness, a broad temperature range and good fluid resistance. In blends with Vamac® Dipolymer it leads to compounds for the W&C industry where excellent heat and oil resistance, low temperature flexibility and low fire hazard properties are key requirements.

Hytrel® 4056 has a Shore D hardness of 40, with a melting point of 150°C and a Tg of -50°C and can be blended in various ratios with Vamac® Dipolymer. **Table 8** shows how Tg, viscosity and physical properties change with increasing amounts of Hytrel®. A commonly used blend ratio in W&C applications is 70/30 Vamac®/Hytrel®.

Table 8: Vamac® Ultra DX in Blends with Hytrel® 4056

Compound No.	16	17	18	19
Vamac® Ultra DX	100	70	60	50
Hytrel® 4056		30	40	50
Armeen® 18D	0.5	0.5	0.5	0.5
Stearic Acid Reagent (95%)	1	1	1	1
Ofalub® SEO	1	1	1	1
Naugard® 445	1	1	1	1
Martinal® OL 111 LE	150	150	150	150
Luperox® 101 XL 45	5	5	5	5
Silanogran® HVS	2	2	2	2
Vulcofac® 13 PDM	2	2	2	2
Blend Ratio Vamac® Ultra DX / Hytrel® 4056	**100**	**70/30**	**60/40**	**50/50**
Mooney Viscosity ML 1+4 at 80°C [MU]	75	147	187	194
Mooney Viscosity ML 1+4 at 100°C [MU]	45	99	123	*
MDR 15 minutes at 180°C, arc 0.5°				
ML [dNm]	0.5	0.8	0.8	1.0
MH [dNm]	14.2	10.2	9.8	9.4
T50 [min]	1.1	0.5	0.5	0.5
T90 [min]	3.6	1.1	0.9	0.8
Press-Cure 10 minutes at 180°C				
Hardness Shore A	77	91	93	94
Tensile Strength [MPa]	9.0	9.3	9.9	10.6
Elongation at break [%]	199	170	158	138
Modulus at 50 % [MPa]	3.3	6.6	7.6	9.1
Modulus at 100 % [MPa]	6.6	9.0	9.7	10.5
Low Temperature properties				
Tg by DSC [°C]	-28	-29	-30	-30
Tensile Properties at -30°C				
Tensile Strength [MPa]	32.8	31.9	33.5	33,9
Elongation at break [%]	18	36	34	34
Modulus at 10 % [MPa]	27.2	22.4	25.6	23.6
Modulus at 25 % [MPa]	32.5	30.8	32.3	32.8

Table 9 shows the typical properties of a 100% based Vamac® Ultra DX compound versus a Vamac®/Hytrel® blend (70/30). Compounds were mixed using the starting point formulation shown in Table 2, for compound **20,** 30 phr of Vamac® Ultra DX were replaced with Hytrel® 4056.

Table 9: Vamac® Ultra DX and in 70/30 Blend with Hytrel® 4056 – Heat Aging

Compound No.	11	20
Vamac® Ultra DX	100	70
Hytrel® 4056		30
Armeen® 18D	0.5	0.5
Stearic Acid Reagent (95%)	1	1
Ofalub® SEO	1	1
Naugard® 445	1	1
Martinal® OL 111 LE	150	150
Luperox® 101 XL 45	5	5
Silanogran® HVS	2	2
Vulcofac® 13 PDM	2	2
Blend Ratio Vamac® Ultra DX / Hytrel® 4056	**100**	**70/30**
Press-Cure 10 minutes at 180°C		
Hardness Shore A	74	92
Tensile Strength [MPa]	8.7	8.5
Elongation at break [%]	211	175
Modulus at 50 % [MPa]	2.9	6.6
Modulus at 100 % [MPa]	6.0	8.3
Heat ageing 168hrs at 135°C		
Hardness Shore A	82	91
Delta Hardness [pts.]	8	-1
Tensile Strength [MPa]	11.3	9.3
Delta TS [%]	30	9
Elongation at break [%]	189	162
Delta Elongation [%]	-10	-7
Modulus at 50 % [MPa]	5.0	7.5
Delta 50% [%]	72	14
Modulus at 100 % [MPa]	8.9	9.2
Delta 100% [%]	48	11
Heat ageing 168hrs at 160°C		
Hardness Shore A	84	92
Delta Hardness [pts.]	10	0
Tensile Strength [MPa]	12.1	10.6
Delta TS [%]	39	24
Elongation at break [%]	175	152

Delta Elongation [%]	-17	-13
Modulus at 50 % [MPa]	5.7	8.2
Delta 50% [%]	96	24
Modulus at 100 % [MPa]	9.9	10.2
Delta 100% [%]	65	23
Heat ageing 240hrs at 175°C	**cmpd no.16**	**cmpd no.17**
Hardness Shore A	87	93
Delta Hardness [pts.]	10	2
Tensile Strength [MPa]	12.3	9.1
Elongation at break [%]	116	33
Modulus at 50 % [MPa]	6.9	-
Modulus at 100 % [MPa]	11.0	-

Heat aging performance of both compounds is very good at temperatures of 135°C and 160°C (168hrs each). At temperatures of 175°C (240hrs) the 100% Vamac Ultra DX compounds show significant better retention of properties while after aging at 200°C (240hrs) both compounds have lost their elastomeric behavior. Fluid aging results in IRM 902 and IRM 903 are shown in **Table 9**.

Graph 3: Heat Aging Performance Ultra DX and Hytrel® Blend at Different Temperatures

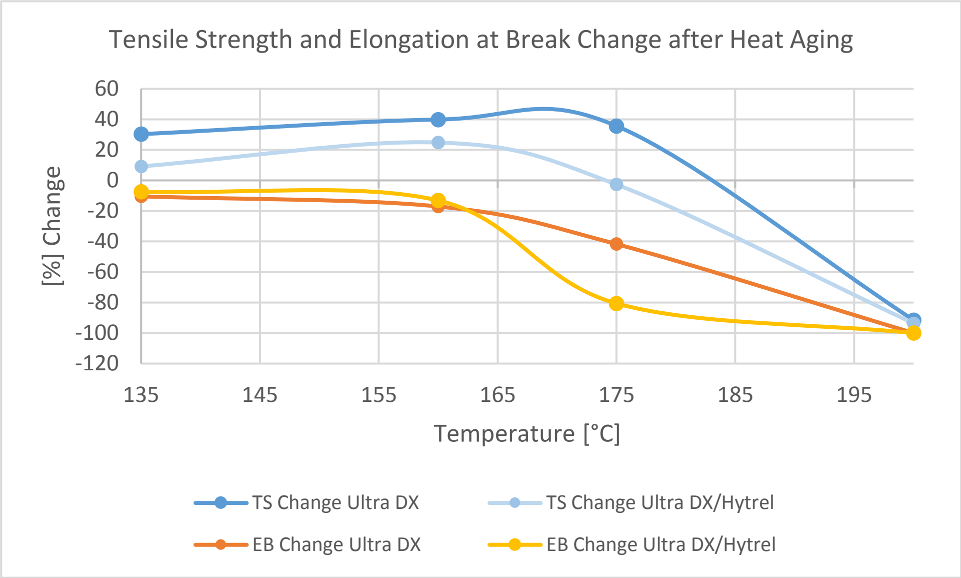


Table 9: Vamac® Ultra DX and in 70/30 Blend with Hytrel® 4056 – Fluid Aging

Compound No.	11	20
Blend Ratio Vamac® Ultra DX / Hytrel® 4056	100	70/30
Fluid ageing 72hrs at 100°C in IRM 902		
Hardness Shore A	70	88
Delta Hardness [pts.]	-5	-4
Tensile Strength [MPa]	11.0	10.1
Delta TS [%]	28	19
Elongation at break [%]	197	155
Delta Elongation [%]	-7	-11
Modulus at 50 % [MPa]	3.0	6.1
Delta 50% [%]	3	-8
Modulus at 100 % [MPa]	6.9	9.2
Delta 100% [%]	14	11
Weight Change [%]	6	5
Volume change [%]	11	8
Fluid ageing 168hrs at 70°C in IRM 903		
Hardness Shore A	63	84
Delta Hardness [pts.]	-11	-8
Tensile Strength [MPa]	9.5	9.5
Delta TS [%]	10	12
Elongation at break [%]	170	144
Delta Elongation [%]	-19	-18
Modulus at 50 % [MPa]	2.4	5.2
Delta 50% [%]	-18	-21
Modulus at 100 % [MPa]	6.0	8.2
Delta 100% [%]	-1	-1
Weight Change [%]	10	8
Volume change [%]	18	14

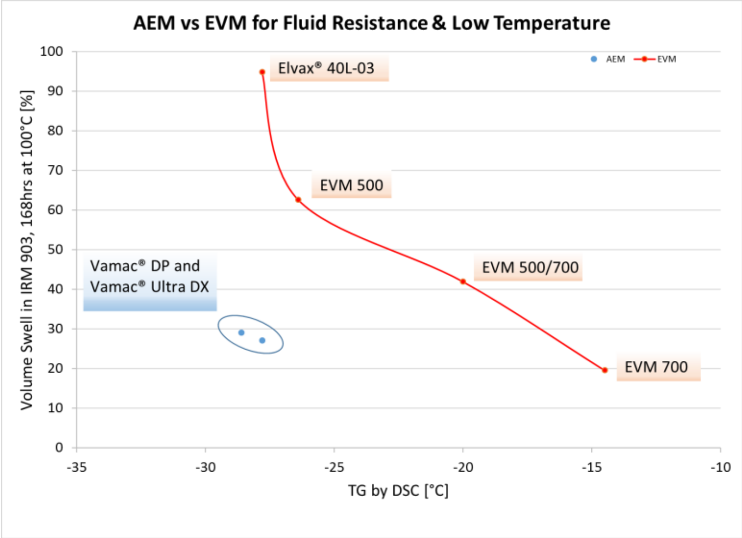
Table 10 summarizes some low temperature properties of the two compounds in comparison to a 100% EVM compound (same formulation as AEM compounds). Tg for the AEM compounds is more than 10°C lower than for the EVM compound and the Vamac®/Hytrel® blend passes also the low temperature bend test.

Table 10: Vamac® Ultra DX. 70/30 Hytrel® Blend and EVM 700 – Low Temperature Properties

Compound No.	**11**	**20**	**21**
Vamac® Ultra DX	100	70	
Hytrel® 4056		30	
EVM 700			100
Armeen® 18D	0.5	0.5	0.5
Stearic Acid Reagent (95%)	1	1	1
Ofalub® SEO	1	1	1
Naugard® 445	1	1	1
Martinal® OL 111 LE	150	150	150
Luperox® 101 XL 45	5	5	5
Silanogran® HVS	2	2	2
Vulcofac® 13 PDM	2	2	2
Press-Cure 10 minutes at 180°C			
Low Temperature bend test -30°C	crack	no crack	crack
Tensile properties rt			
Hardness Shore A	74	92	84
Tensile Strength [MPa]	8.7	8.5	10.6
Elongation at break [%]	211	175	172
Modulus at 50 % [MPa]	2.9	6.6	5.6
Modulus at 100 % [MPa]	6.0	8.3	9.2
Tg by DSC [°C]	-28	-29	-16
Tensile Properties at -30°C			
Tensile Strength [MPa]	32.8	31.9	47.6
Elongation at break [%]	18	36	11
Modulus at 10 % [MPa]	27.2	22.4	45.4
Modulus at 25 % [MPa]	32.5	30.8	

Graph 4 shows a general low temperature comparison of AEM vs EVM. Vamac® compounds will have a ca. 10°C lower Tg at a comparable oil swell to EVM and a ca. 20-30% better oil resistance at the same Tg as EVM.

Graph 4: Comparison of the oils swell and Tg of AEM vs EVM



Flammability, Smoke Density, and Toxicity Data

Vamac® base polymers are all halogen free. The Limiting Oxygen Index (LOI) for the different Vamac® grades is between 19-21%. Vamac® Ultra DX base resin has a LOI of 21%. Through use of flame retardant fillers like ATH or $Mg(OH)_2$ LOI values >30% can be reached depending on the exact compound composition.

Table 11 summarizes some relevant flame properties of compound No. 11 and 20 (Vamac® Ultra DX and Vamac® Ultra DX/Hytrel® Blend) as well as an EVM (70% VA content) compound (No. 21) with identical formulation.

LOI measurements were conducted on 3mm thick test pieces. UL 94 measurements were done on 2mm thick test pieces.

Smoke density and cone colorimeter testing was done with a 25 kW/m^2 flame. Toxicity testing was done according to NF X 70-100-1/2, calculation according to EN 45545-2. Sample thickness was 2mm.

Table 11: Flammability, Smoke Density, and Toxicity Data

	Norm	11	20	21
		Ultra DX	Ultra DX/Hytrel 70/30	EVM 700
Optical Density (25kW/m^2 with flame)	ISO 5659-2			
Dsmax		20	21	218
VOF4		7	7	9
Gas Toxicity Analysis - CIT	NF X 70-100-1/2	0.11	0.06	0.07
Limited Oxygen Index (LOI) [%]	ISO 4589-2	37	37	34

Cone Calorimeter (25kW/m²)	ISO 5660-1			
Time To Ignition TTI [s]		159	120	409
Peak Heat Release Rate HRR [kW/m²]		111	121	282
Total Heat Release THR [MJ/m²]		37	38	35
Total Smoke Release TSR [m²/s]		311	295	791
MARHE [kW/m²]		61	67	51
UL 94 (2mm thick)		V-0	V-0	V-0

Vamac® Dipolymer Blends with Vamac® Diamine Curable Grades

Vamac® DP and Vamac® Ultra DX are the only two Dipolymers in the Vamac® portfolio without an acidic cure site monomer that can be used for diamine cure reactions. In HFFR formulation the Dipolymers are typically the first choice of polymer grades because flame retardant metal oxides are not interacting with the polymer chains, increasing viscosity of the compound and making processing difficult. **Graph 5** shows a comparison of Mooney Viscosity of different Vamac® base polymers and compounds. All compounds use standard HFFR formulation (150 phr ATH, peroxide cured) and blends use 70/30 Vamac®/Elvax® ratio. The viscosity increase from base resin to a mixed HFFR compound is significantly lower with the Dipolymer Ultra DX compared to the Terpolymers. Overall polymer viscosity has an additional effect, as can be seen with VMX4017 (low temperature polymer) and Vamac® G which are lower viscosity base polymers.

Graph 5: Comparison Mooney Viscosity Increase Dipolymer versus Terpolymer

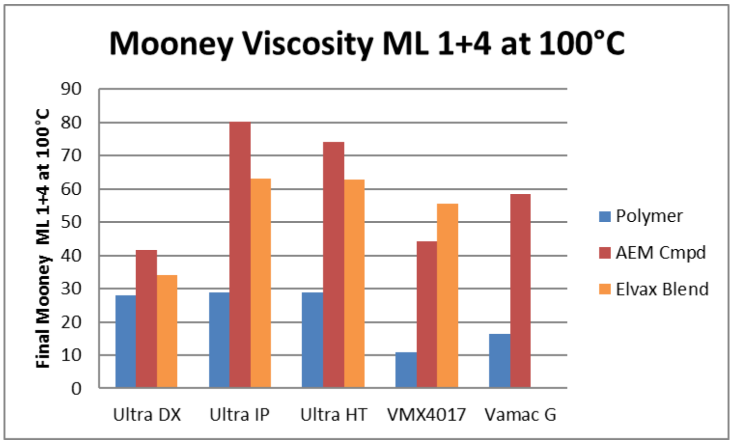


Table 12 shows some blends of Vamac® DP with Vamac® G (60/40) and Vamac® VMX4017 (70/30) that still provide compounds with reasonable viscosity ranges while showing some additional property benefits that can be achieved in HFFR formulations by blending different polymer types.

Table 12: Vamac® Ultra DX blends with VMX4017 and Vamac® G

Compound No.	22	23		24	25
Vamac® Ultra DX	100	70		100	60
Vamac® VMX 4017		30			
Vamac® G					40
Martinal® OL 111 LE	150	150		150	150
Armeen® 18D PRILLS	0.5	0.5		0.5	0.5
Stearic Acid Reagent (95%)	1	1		1	1
Ofalub® SEO	1	1		1	1
Naugard® 445	1	1		1	1
Silanogran® HVS	2	2		2	2
Spheron™ SOA (N 550)	0.5	0.5			
Rubber chem HVA 2	2	2		2	2
Luperox® 101 XL 45	5	5		5	5
MDR cure rate 15 minutes at 180°C, arc 0.5°					
ML [dNm]	0.58	1.17		0.51	1.01
MH [dNm]	14.0	13.82		14.20	13.47
T50 [min]	1.02	1.06		1.08	1.08
T90 [min]	3.59	4.16		3.60	4.84
Mooney Viscosity ML 1+4 at 100°C	50	55		45	50
Press-Cure 10 minutes at 180°C					
Hardness Shore A	77	74		77	75
Tensile Strength [MPa]	10.2	8.9		9.03	10.67
Elongation at break [%]	273	225		199	188
Modulus at 50 % [MPa]	3.1	4.2		3.3	4.9
Modulus at 100 % [MPa]	6.2	7.5		6.6	9.5
Tg by DSC [°C]	-30	-30		-28	-28
LOI [%]	39	39		-	-

List of Test Methods

Test Method	Norm
Rheology	
Mooney Viscosity	ISO 289-1
MDR	ISO 6502
Mooney Scorch	ISO 289-2
Physical Properties	
Hardness	ISO 7619-1
Tensile	ISO 37
Heat ageing	ISO 188
Fluid ageing	ISO 1817
Compression set	ISO 815-1
Tear	ISO 34-1
Tg by DSC	ISO 22768
Low-temperature bend test	ISO 4675
Flammability	
LOI	ISO 4589-2
Optical Density	ISO 5659-2
Cone Calorimeter	ISO 5660-1
Acidity of Combustions Gases	IEC 60754-1

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