DuPont™ Vamac® Ultra LS

(formerly VMX-3110)

High Viscosity, Low Fluid Swell, Fast Curing Terpolymer

Technical Information – Rev. 2, December 2013

Vamac® Ultra LS

Introduction

Vamac® ethylene acrylic elastomer, introduced in 1975, has been successfully used for many years in demanding automotive applications, where excellent resistance to heat, engine and transmission fluids or Blow-By is required. DuPont's latest manufacturing technology allows production of enhanced AEM grades that are significantly improved compared to the existing standard Vamac® elastomers. These grades, designated and sold as Vamac® Ultra, provide a true step-change improvement in processability, performance and customer value for targeted applications.

Major Performance Properties and Applications

Higher viscosity is the major difference between the standard AEM grades and the Vamac® Ultra family of polymers, of which four grades have been either already commercialized or are under customer evaluation. Table 1 gives an overview of these grades and comparable lower viscosity standard countertypes.

Table 1 – Overview on Vamac® Ultra and Standard Vamac® Grades

Standard Grade ML (1+4) 100°C, Tg	**Vamac® G** 16.5 MU, -30 °C	**Vamac® GXF** 17.5 MU, -31 °C	**Vamac® GLS** 18.5 MU, -24 °C
High Viscosity Grade ML (1+4) 100°C, Tg	**Vamac® Ultra IP** 29 MU, -31 °C	**Vamac® Ultra HT** (formerly VMX-3038) 29 MU, -32 °C **Vamac® Ultra HT-OR** (formerly VMX-3121) 31 MU, -25 °C	**Vamac® Ultra LS** 33 MU, -25 °C (formerly MVX-3110)
Major Features	Best Compression Set, Fast Cure	Best Dynamic Fatigue Resistance	Best Compression Set, Fast Cure, Low Oil swell
Major Applications	General Purpose, Seals & Gaskets, Hoses	Turbo Charger Hoses, Air Ducts	Oil Seals, Oil Cooler Hoses, PCV Hoses

Vamac® Ultra LS is a high viscosity version of Vamac® GLS. A primary goal for the development of this grade was to provide a product having improved performance in injection molding processes compared to Vamac® GLS to reduce the frequency of mold cleaning.

The miracles of science™

The high viscosity of Vamac® Ultra LS compared to standard AEM grades results in better mixing, provided mixing conditions are adapted to requirements of polymers with higher viscosity. Increased green strength of compounds helps to avoid collapse during extrusion processes. The optimized polymer structure ensures gains in physical properties, resulting in improved performance of rubber parts such as seals, dampers and extruded hoses.

The best physical properties of Vamac® Ultra LS are obtained in rubber parts having a hardness range between 50 and 90 Shore A. Extensions to the lower hardness range may be more easily achieved with Vamac® Ultra grades than standard AEM using appropriate compounding.

Handling Precautions

Because Vamac® Ultra LS contains small amounts of residual methyl acrylate monomer, adequate ventilation should be provided during storage and processing to prevent worker exposure to methyl acrylate vapor. Additional information may be found in DuPont Material Safety Data Sheet (MSDS), and bulletin, *Safe Handling and Processing of Vamac®* (VME-A10628), available from DuPont Performance Polymers.

Like every other grade of Vamac®, Vamac® Ultra LS is halogen-free. Typical properties of this product are shown in Table 2.

Table 2 - Vamac® Ultra LS - Typical Product Properties

Property	Target Values	Method
Mooney Viscosity, ML 1+4 at 100 °C (212 °F)	33	ASTM D1646
Volatiles, wt%	≤0.6	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 LS has higher viscosity than Vamac® GLS which permits better and faster dispersion of fillers and other compounding ingredients. Low hardness compounds or formulations with high plasticizer levels profit most from this property. The higher viscosity of Ultra LS however results in an onset of incorporation of powdery ingredients at higher temperature than for lower viscosity Vamac® grades. It is therefore recommended to ensure that the total time at mixing temperatures between 80 and 100°C is identical as for standard grades that processing conditions are adjusted, for example by reducing rotor speed. If the compound is discharged in relation to mass temperature at identical mixing conditions, the higher viscosity of the Ultra grades would lead to higher shear forces and faster temperature increase, followed by earlier discharge of the compound, and shorter time for dispersion of fillers and other ingredients. Bad dispersion would necessarily lead to poorer compound properties and mold fouling.

Compounding and Physical Properties

Physical properties of the Ultra grades are known to be significantly superior to their lower viscosity reference grades at same methyl acrylate level. Both families are fully compatible to each other and can be blended at every ratio required. Ultra LS requires lower levels of diamine curative than Vamac® GLS for same compression set levels, whilst at the same time achieving highest Elongation at Break. Property losses, known from a replacement of formerly used coagent DOTG with alternative accelerators, can be compensated by use of Vamac® Ultra grades, as can be seen in Table 3.

Table 3 - Compound Properties, DOTG replacement

Compound No.	**1**	**2**	**3**	**4**	**5**
Vamac® GLS	100	100	50	50	
Vamac® Ultra LS			50	50	100
Naugard® 445	2	2	2	2	2
Armeen® 18D	0.5	0.5	0.5	0.5	0.5
Vanfre® VAM	1	1	1	1	1
Stearic acid	1.5	1.5	1.5	1.5	1.5
Spheron® SO A N 550	60	60	60	60	60
Rhenosin® W 759	10	10	10	10	10
Diak™ No 1	1.75	1.75	1.5	1.25	1.25
Vulcofac® ACT 55		2	2	4	2
Ekaland® DOTG C	4				
Mooney Viscosity ML 1+4, 100ºC (MU)	37	40	54	51	64
Mooney Scorch MS 121ºC, Ts5 (min)	9.1	7.7	8.2	7.1	9.5
MDR, 0.5ºarc, 12 minutes at 180ºC					
ML (dNm)	0.37	0.45	0.61	0.62	0.77
MH (dNm)	14.46	14.33	14.62	13.73	14.68
Ts2 (min)	0.85	0.81	0.79	0.66	0.79
T10 (min)	0.72	0.69	0.67	0.56	0.67
T50 (min)	2.03	2.01	1.93	1.37	1.94
T90 (min)	6.34	6.62	6.22	4.54	6.01
Cure Time, 5 minutes at 180ºC					
Post-Curing, 4 hours at 175ºC					
Hardness Shore A, 1 second at 23ºC	73	76	76	75	74
Tensile Strength (Mpa)	14.9	17.1	17.5	15.9	17.9
Elongation at break (%)	259	211	234	251	290
Modulus at 50% (Mpa)	2.4	3.3	3.2	2.9	2.8
Modulus at 100% (Mpa)	5.7	7.8	7.4	6.4	6.1
Tear Die C at 23ºC (N/mm)	26.7	23.0	24.8	26.5	27.0
C. set, 70 h at 150ºC (%), ISO815	21	28	26	27	24
C. set, 94 h at 150ºC (%), PV 3307	49	57	71	77	49
C. set, 22 h at 150ºC, 2 h cooled in clamps (%)	22	28	28	32	29

Further optimization of Compression Set can be achieved by using less volatile plasticizers, as shown in Table 4, compounds No. 6 and 7.

Compounding Variations for Faster Cure

Vamac® Ultra grades are cleaner in injection molding and do not tend to stick to metallic surfaces of mixing or molding equipment as much as lower viscosity AEM polymers. This can allow further optimization and variations in compounding, such as reduction of process aids. Possible advantages would be a reduced tendency to get flow lines on injection molded parts, or further acceleration of cure speed and reduction of cure cycle time, or optimization of Compression Set. Some compounding variations with 60 Shore A general purpose sealing compounds are shown in Table 4.

Table 4 – Compounding Variations for Faster Cure and improved CSet

Compound No.	**6**	**7**	**8**	**9**	**10**	**11**
Vamac® Ultra LS	100	100	100	100	100	100
Naugard® 445	2	2	2	2	2	2
Vanfre® VAM	1	1				
Armeen® 18D	0.5	0.5	0.5			
Stearic acid	2	2	2	2		
MT Thermax® Floform N 990	20	20	20	20	20	20
Regal® SRF N 772	45	45	45	45	45	45
Rhenosin® W 759	15					
Edenol® TOT stabilized		15	15	15	15	15
Diak™ No 1	1.3	1.3	1.3	1.3	1.3	1.3
Vulcofac® ACT 55	3	3	3	3	3	
Alcanpoudre® DBU-70						3
Mooney, ML1+4, 100°C [MU]	30.8	33.4	35.7	36.6	44.1	46.3
MDR, 15 min at 180°C, arc 0.5°						
ML [dNm]	0.28	0.29	0.31	0.34	0.4	0.37
MH [dNm]	9.56	10.41	10.51	11.14	11.65	11.1
Ts2 [min]	0.97	0.93	0.87	0.75	0.72	0.63
T50 [min]	1.85	1.88	1.74	1.48	1.45	1.19
T90 [min]	6.42	6.62	6.28	5.41	5.45	3.58
Compression moulding 5 min at 190°C, no post-cure						
Comp. set, 24 h /150°C, plied (%)	55.7	54.1	49.5	46.2	49.6	45.2
PV3307, 94 h /150°C (%)	86.1	82.8	79.6	79.3	78.4	76.1
Compression moulding 1 min at 210°C Post-cure 30 min at 175°C						
Comp. set, 24 h /150°C, plied (%)	30	27	25	25	24	25
PV3307, 94 h /150°C (%)	71	64	65	65	64	62
Hardness, Shore A	58	58	58	59	59	59
Tensile Strength [MPa]	14.1	15.3	15	14.9	15.4	14.1
Elongation at break [%]	368	386	370	338	330	330
Modulus at 100 % [MPa]	2.5	2.4	2.6	2.9	3	3.1

By optimizing compound formulations, cure times can be reduced by about 40 to 50%, as can be seen when comparing compound No. 6 and 11. At the same time, scorch times are reduced as well, but compound flow of 60 Shore A compound with 15 phr of plasticizer is typically sufficient to fill even molds with complex shape. Compression Set values before post-cure are reduced significantly as well. For some parts like molded air ducts, the values obtained without process aids and a more heat resistant plasticizer may be adequate even without post-cure. Outstanding Compression set values may be obtained in some cases after a very short post-cure cycle, which can be of help when post-cure oven capacities are limited.

Heat Resistance

Vamac® Ultra LS combines excellent dry heat resistance at about 170 °C over a period of 1000 h (six weeks) with very good resistance to automotive lubricants. Peak temperatures of 200°C are possible without major property changes up to four days. Sealing applications typically require resistance to upper temperature of 150°C maximum, as automotive lubricants would not withstand higher temperatures.

At the same time, Tg of -25°C of Ultra LS provides very good low temperature flexibility. The low temperature properties may be further enhanced by addition of plasticizers. In comparison to standard Vamac® grades, the high viscosity of Ultra LS allows addition of more plasticizer, while still maintaining a compound viscosity that allows good filler dispersion and good processing.

Good compression set properties make Vamac® Ultra LS an excellent choice for sealing applications. Good resistance to Blow-By (hot air, acids, oil and petrol fumes), present in automotive crankcase venting systems and air ducts combined with increased dynamic resistance are additional attributes of Vamac®

Ultra LS. The resistance to water based acids and blow-by can be further improved by blending Ultra LS with Vamac® grades with lower methyl acrylate content, such as Vamac® Ultra IP.

Some tests at harsher temperatures are shown in Table 5. Compression Set is partially influenced by loss of plasticizer, as can be seen from weight loss data.

Table 5 – Compression Set and Heat Ageing at 180 °C and 165 °C

Compound No.	**12**	**13**
Vamac® Ultra LS	100	100
Naugard® 445	2	2
Armeen® 18D PRILLS	0.5	0.5
Vanfre® VAM	0.5	0.5
Stearic acid	2	2
Spheron® SO A N 550	35	35
Nycoflex® ADB 30	10	
Edenol® T810T stabilized		10
Diak™ no 1	1.5	1.5
Vulcofac® ACT 55	2	2
Compression molding 10 minutes at 180°C		
Post-cure 4 hours at 175°C		
Hardness IRHD - Method M (microtest), ISO 48:2007	55	56
Tensile Strength [MPa]	17.6	17.8
Elongation at break [%]	350	343
Modulus at 100 % [MPa]	2.78	2.80
C. set 72 h at 180°C, Type A (13 mm molded buttons), ISO 815-1 [%]	26	20
C. set 1028 h at 165°C, Type A [%]	43	29
C. set 1028 h at 165°C in Total MA4 G06190, 5W30, Type A [%]	32	23
Heat ageing 168 hours at 180°C		
Hardness IRHD - Method M (microtest, points), ISO 48:2007	57	54
Delta Hardness ISO 188:2007	2	-2
Tensile Strength [MPa]	16.7	16.5
Delta TS [%]	-5	-7
Elongation at break [%]	369	368
Delta Elong. [%]	5	7
Modulus at 100 % [MPa]	3.0	2.8
Weight change [%]	-5.1	-3.0
Heat ageing 1008 hours at 165°C		
Hardness IRHD - Method M (microtest) ISO 48:2007	68	62
Delta Hardness ISO 188:2007	13	7
Tensile Strength [MPa]	9.6	12.0
Delta TS [%]	-45	-32
Elongation at break [%]	177	257
Delta Elongation [%]	-49	-25
Modulus at 100 % [MPa]	4.7	3.4
Weight change [%]	-9.6	-6.5

Long term sealing performance

In Compression Set and Compressive Stress Relaxation (CSR) tests, Vamac® Ultra grades have outperformed their respective standard Vamac® grades. Table 6 shows various Compression Set results of five different 60 Shore A compounds which differ from each other in polymer type, curative level and plasticizer content. Charts 1, 2 and 3 show CSR results of these compounds in Engine Oil, in Automatic Transmission Fluid and in Air at 150°C. Tests were conducted according to ISO3384, Type %, with 6 mm high buttons on Shawbury-Wallace testing equipment for 504 hours.

Table 6 – Different Compression Set Test Conditions

Compound No.	**14**	**15**	**16**	**17**	**18**
Vamac® Ultra IP	100				
Vamac® Ultra LS		100	100	100	100
Regal® SRF N 772	50	50	50	40	30
MT Thermax® Floform N 990	20	20	20	20	20
Nycoflex® ADB 30	20	20	20	10	
Naugard® 445	2	2	2	2	2
Stearic acid	1	1	1	1	1
Armeen® 18D PRILLS	0.5	0.5	0.5	0.5	0.5
Vanfre® VAM	1	1	1	1	1
Rubber chem Diak™ no 1	1.3	1.75	1.3	1.3	1.3
Vulcofac® ACT 55	3	3	3	3	3
Compression moulding 10 minutes at 180°C					
Post-cure 4 hours at 175°C					
Hardness Shore A (1 second)	60	63	61	61	63
Tensile Strength [MPa]	16.0	15.8	16.0	16.8	18.5
Elongation at break [%]	363	313	346	352	356
Modulus at 100 % [MPa]	2.7	3.4	2.9	2.8	3.2
Tear Strength type C- Crescent, [kN/m]	24.1	21.2	22.6	23.5	16.7
TG by DSC, ISO 22768 [°C]	-44	-40	-40	-33	-23
Cset VW 22 h at 150°C, VW PV 3307 [%]	52	39	43	41	38
Cset VW 94 h at 23°C, VW PV 3307 [%]	29	20	27	25	26
Cset 70 h at 150°C, 6mm plied disks, ISO 815-1 [%]	26	24	26	22	18
Cset 70 h at 150°C, 6mm molded buttons, ISO 815-1 [%]	24	20	22	20	17
Compression Set, ISO-815-1, Type A, 13 mm buttons, at 150°C					
70 h [%]	16	14	15	13	12
168 h [%]	20	19	20	18	14
504 h [%]	28	29	28	25	23
1008 h [%]	34	37	34	33	30
168 h in Castrol® SLX Longlife IV 0W30 [%]	28	25	27	22	16

Chart 1: CSR – ISO 3384 Type B, Shawbury-Wallace, Castrol SLX Longlife 4 0W30, 150°C

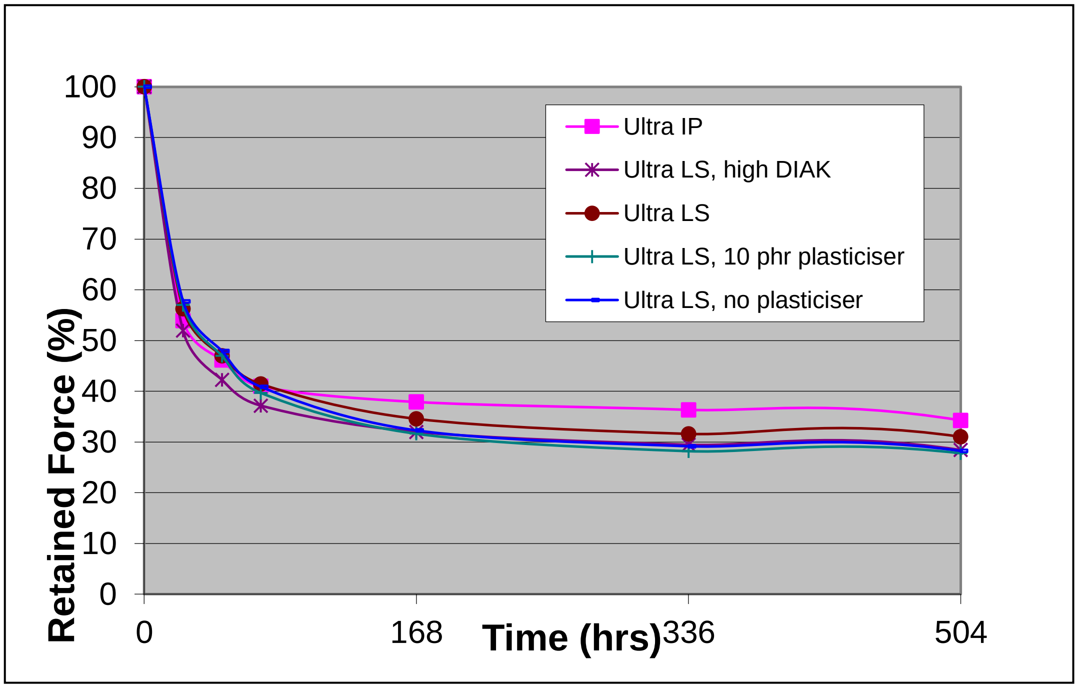
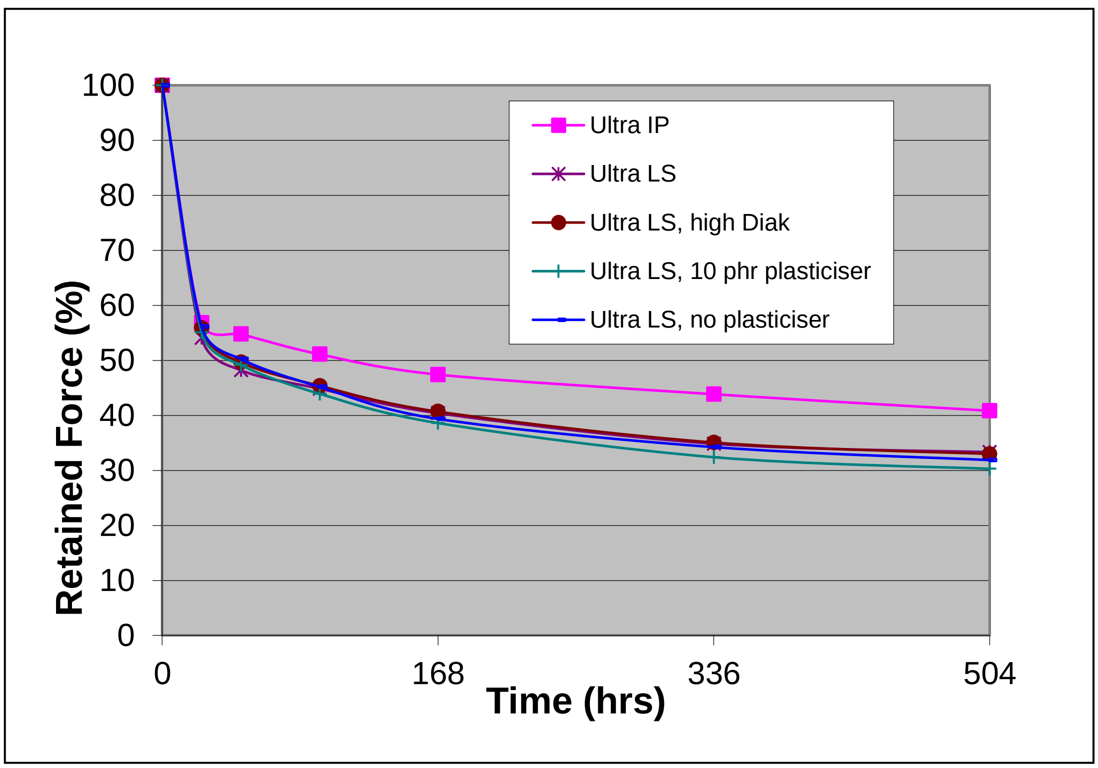
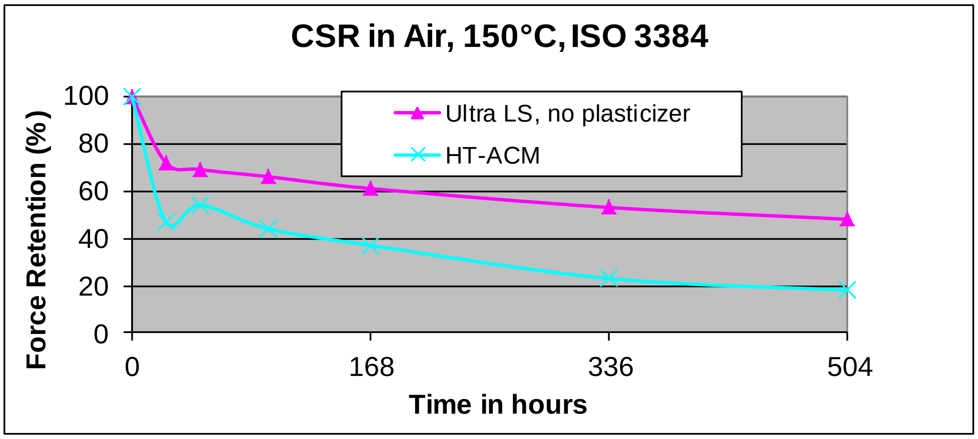


Chart 2: CSR – ISO 3384 Type B, Shawbury-Wallace, Dexron VI, 150°C



In Compressive Stress Relaxation (CSR) tests, Vamac® Ultra grades have not only outperformed their respective standard Vamac® grades, they also have increased the gap in long time sealing performance to polyacrylates. Chart 3 shows CSR test results of two 60 Shore A compounds without any plasticizer, based on both types of polymers.

Chart 3: Compressive Relaxation, Vamac® Ultra LS vs. HT-ACM



Ageing in different Automotive Fluids – Oils, Oil/Fuel Blends

Vamac® Ultra LS and Vamac® Ultra IP are both members of the higher viscosity Vamac® Ultra range. The difference between both polymers is the methyl acrylate (MA) content, which is significantly higher for Ultra LS. Whereas low MA content favours resistance to water-based fluids, high MA content provides better resistance to hydrocarbon based fluids present in automotive engines. Compounds No. 14-18 shown in Table 6 have been aged in different fluids. Results after ageing in engine and transmission oils at 150°C and oil/fuel blends at room temperature are shown in Table 7. B-30 is a mixture of Diesel with 30% Biodiesel (RME), and E-85 is a blend of gasoline with 85% of Ethanol.

Table 7 – Fluid Ageing Results, Oils, Oil/Fuel Blends

Compound No.	**14**	**15**	**16**	**17**	**18**
Fluid ageing 168 h at 150°C in IRM 903					
Hardness Shore A (1 s)	47	59	57	54	53
Delta Hardness (pts.)	-13	-4	-4	-7	-9
Tensile Strength [MPa]	11.1	14.9	14.4	14.6	14.8
Delta TS [%]	-31	-6	-10	-13	-20
Elongation at break [%]	240	269	300	293	243
Delta Elong. [%]	-34	-14	-13	-17	-32
Modulus at 100 % [MPa]	3.4	4.0	3.4	3.5	3.5
Delta 100% [%]	25	16	15	24	7
Volume change [%]	47	19	20	26	34
Weight change [%]	34	13	13	19	26
Fluid ageing 168 h at 150°C in Castrol® SLX Longlife IV, 0W 30					
Hardness Shore A (1 s)	63	73	71	67	61

Delta Hardness (pts.)	4	10	10	6	-2
Tensile Strength [MPa]	15.2	15.2	15.1	16.4	16.2
Delta TS [%]	-5	-4	-5	-2	-13
Elongation at break [%]	328	276	309	313	301
Delta Elong. [%]	-10	-12	-11	-11	-15
Modulus at 100 % [MPa]	3.0	4.2	3.7	3.5	3.3
Delta 100% [%]	12	24	26	27	3
Volume change [%]	-1	-6	-7	-2	5
Weight change [%]	-3	-6	-7	-3	3
Fluid ageing 168 h at 150°C in Petro Canada Dexron® VI RDL 3434					
Hardness Shore A (1 s)	61	70	69	63	60
Delta Hardness (pts.)	1	7	8	2	-3
Tensile Strength [MPa]	61	70	69	63	60
Delta TS [%]	-4	-2	-6	-2	-12
Elongation at break [%]	304	229	247	283	242
Delta Elong. [%]	-16	-27	-29	-20	-32
Modulus at 100 % [MPa]	3.4	5.1	4.7	4.2	3.9
Delta 100% [%]	25	49	60	50	21
Volume change [%]	8	-1	-1	5	11
Weight change [%]	4	-2	-2	2	8
Fluid ageing 168 h at 23°C in Mixture Castrol® SLX Longlife IV, 0W30 / B-30 (90/10)					
Hardness Shore A (1 s)	59	62	60	59	59
Delta Hardness (pts.)	-1	-1	-1	-2	-4
Tensile Strength [MPa]	15.6	15.8	15.7	16.7	18.7
Delta TS [%]	-3	1	-1	0	1
Elongation at break [%]	372	318	360	362	352
Delta Elong. [%]	2	2	4	3	-1
Modulus at 100 % [MPa]	2.7	3.3	2.7	2.7	3.0
Delta 100% [%]	1	-4	-9	-3	-7
Volume Change (%)	1	0	0	0	0
Weight Change (%)	1	0	0	0	0
Fluid ageing 168 h at 23°C in Mixture Castrol® SLX Longlife IV, 0W30 / E-85 (90/10)					
Hardness Shore A (1 s)	50	55	53	50	52
Delta Hardness (pts.)	-10	-8	-8	-11	-11
Tensile Strength [MPa]	9.4	8.1	8.5	9.2	8.1
Delta TS [%]	-41	-48	-47	-45	-56
Elongation at break [%]	232	178	214	216	189
Delta Elong. [%]	-36	-43	-38	-39	-47
Modulus at 100 % [MPa]	2.8	3.5	2.9	3.0	3.1
Delta 100% [%]	3	3	0	7	-3
Volume Change (%)	24	22	22	25	29
Weight Change (%)	15	13	13	16	19

Ageing in Fuels

It is generally not recommended to use AEM in contact to liquid gasoline, as volume swell and permeation are very high. Contact to gasoline fumes however can be handled by Vamac® polymers depending on concentration. AEM compounds are not destroyed in gasoline, as physical properties after an appropriate re-drying step are nearly identical to original properties for compounds without plasticiser.

Compounds including plasticizer show weight loss after the re-drying step, which shows that the plasticizer is principally extracted by the fuel during immersion. Contact to Diesel fuel results in moderate swell of high

MA Vamac® polymers like Ultra LS. Table 8 shows results after immersion in fuel; compounds are identical to those shown in Table 6.

Table 8 – Ageing in Fuels

Compound No.	14	15	16	17	18
Fluid ageing 168 hours at 23°C in ASTM Fuel C or ISO Liquid C					
Hardness Shore A (1 second)	38	45	42	42	44
Delta Hardness (pts.)	-22	-18	-19	-19	-19
Tensile Strength [MPa]	4.4	5.3	5.0	4.9	5.1
Delta TS [%]	-72	-66	-69	-71	-73
Elongation at break [%]	113	113	117	113	112
Delta Elong. [%]	-69	-64	-66	-68	-69
Modulus at 100 % [MPa]	3.8	4.5	3.7	4.1	4.3
Delta 100% [%]	40	31	25	48	35
Volume change [%]	107	83	84	97	112
Weight change [%]	68	51	51	61	73
Fluid ageing 168 hours at 23°C in ASTM Fuel C or ISO Liquid C					
After redrying 22h @ 80°C					
Hardness Shore A (1 second)	71	73	72	67	63
Delta Hardness (%)	11	10	11	6	1
Tensile Strength [MPa]	17.3	17.7	17.2	18.8	18.4
Delta TS [%]	8	12	7	12	-1
Elongation at break [%]	396	331	372	360	338
Delta Elong. [%]	9	6	7	2	-5
Modulus at 100 % [MPa]	3.1	3.9	3.4	3.2	3.0
Delta 100% [%]	14	13	15	14	-6
Volume change [%]	-15	-14	-15	-10	-3
Weight change [%]	-13	-12	-12	-8	-3
Fluid ageing 48 hours at 23°C in DIN FAM B or ISO Liquid 2					
Hardness Shore A (1 second)	48	53	50	50	50
Delta Hardness (pts.)	-12	-10	-11	-11	-13
Tensile Strength [MPa]	4.0	4.0	4.5	4.1	3.9
Delta TS [%]	-75	-75	-72	-76	-79
Elongation at break [%]	93	80	94	87	76
Delta Elong. [%]	-74	-74	-73	-75	-79
Modulus at 100 % [MPa]	-	-	-	-	-
Delta 100% [%]	-	-	-	-	-
Volume change [%]	159	134	150	154	176
Weight change [%]	101	84	94	99	114
Fluid ageing 48 hours at 23°C in DIN FAM B or ISO Liquid 2					
After redrying 22h @ 80°C					
Hardness Shore A (1 second)	71	72	73	68	63
Delta Hardness (pts.)	12	9	12	7	1
Tensile Strength [MPa]	18.0	18.5	18.1	17.8	17.4
Delta TS [%]	13	18	13	6	-6
Elongation at break [%]	387	334	362	332	311
Delta Elong. [%]	7	7	5	-6	-13
Modulus at 100 % [MPa]	3.2	4.0	3.5	3.2	3.2
Delta 100% [%]	16	16	19	16	0
Volume change [%]	-16	-15	-16	-11	-4
Weight change [%]	-14	-12	-13	-9	-4
Fluid ageing 168 hours at 23°C in Conventional Diesel (from a Gas Station)					

Hardness Shore A (1 second)	ISO 7619-1:2004	50	56	54	52	53
Delta Hardness	ISO 188:2007	-10	-7	-7	-9	-10
Tensile Strength [MPa]		10.3	12.1	12.5	12.6	12.0
Delta TS [%]		-36	-23	-22	-25	-35
Elongation at break [%]		246	247	290	274	252
Delta Elong. [%]		-32	-21	-16	-22	-29
Modulus at 100 % [MPa]		2.7	3.2	3.0	3.3	2.8
Delta 100% [%]		1	-5	3	17	-14
Volume change [%]		27	13	13	17	20
Weight change [%]		17	8	7	11	14

Ageing in Blow-By and EGR Condensates

AEM has been successfully used in applications which are in contact to blow-by such as positive crankcase ventilation hoses. Blow-by varies a lot depending on engine type and driving conditions, and includes fuel, engine oil and acid condensates. Exhaust gas recirculation increases the amount of acids present in engines. Vamac® with its high Ethylene monomer content, combined with highly polar MA ester monomer, offers a good combination of resistance to hydrocarbon fluids as well as to water-based acids. As an example, compounds No. 14 to 18 of Table 6 have been tested in two different Blow-By condensates as defined in specification BMW GS 97018, 2010-11. The tests were made with lab autoclaves that have been filled to 50% of their volume. The slabs have been hung into the liquid phase prior to ageing.

Table 9 – Condensates According to BMW GS 97018, 2010-11

Condensate 1 (fuel/oil)	Weight-%	Condensate 2 (water/acid)	Weight-%
Naphthalene	1	Formaldehyde-10%	1
FAM-A (DIN51604-1)	88	Deionized water	89.7
Oil Lubrizol® OS206304	10	HNO3 (65%)	0.18
Formaldehyde-10%	1	Formic Acid (98-100%)	0.06
		Acetic Acid (96%)	0.06
		Ethanol	9

Table 10 – Results after ageing in BMW Condensates

Fluid ageing 70 h at 120°C in BMW Condensate 1 (fuel/oil condensate)

Liquid Phase- Before redrying					
Hardness Shore A (1 second)	43	47	44	45	47
Delta Hardness (pts.)	-17	-16	-17	-16	-16
Tensile Strength [MPa]	4.3	4.9	4.1	4.3	4.3
Delta TS [%]	-73	-69	-74	-74	-77
Elongation at break [%]	107	119	110	116	114
Delta Elong. [%]	-71	-62	-68	-67	-68
Modulus at 100 % [MPa]	3.7	4.1	3.6	3.5	3.7
Delta 100% [%]	37	20	23	25	17
Volume Change (%)	136	72	113	88	102
Weight Change (%)	84	45	68	56	67

Fluid ageing 70 h at 120°C in BMW Condensate 1 (fuel/oil condensate)

Liquid Phase - After redrying 22 h @ 80°C

Hardness Shore A (1 second)	63	68	65	63	60
Delta Hardness (pts.)	3	5	4	2	-3
Tensile Strength [MPa]	15.2	15.7	15.3	16.9	17.1
Delta TS [%]	-5	-1	-4	1	-8
Elongation at break [%]	393	349	372	376	337
Delta Elong. [%]	8	12	7	7	-5
Modulus at 100 % [MPa]	2.9	3.5	3.0	3.0	3.0
Delta 100% [%]	6	4	3	8	-6
Volume Change (%)	-9	-9	-11	-6	0
Weight Change (%)	-9	-8	-10	-6	-1

Fluid ageing 70 h at 120°C in BMW Condensate 2 (acid condensate)

Liquid Phase- Before redrying

Hardness Shore A (1 second)	61	63	62	59	57
Delta Hardness (pts.)	2	0	1	-2	-5
Tensile Strength [MPa]	15.3	15.0	14.8	15.1	15.6
Delta TS [%]	-4	-5	-7	-10	-16
Elongation at break [%]	393	347	387	358	361
Delta Elong. [%]	8	11	12	2	1
Modulus at 100 % [MPa]	2.6	3.2	2.9	2.8	2.7
Delta 100% [%]	-4	-8	-2	0	-15
Volume Change (%)	2	1	1	6	12
Weight Change (%)	1	0	0	4	10

Fluid ageing 70 h at 120°C in BMW Condensate 2 (acid condensate)

Liquid Phase - After redrying 22 h @ 80°C

Hardness Shore A (1 second)	67	72	71	66	62
Delta Hardness (pts.)	7	9	10	5	-1
Tensile Strength [MPa]	16.2	16.2	16.1	17.5	18.2
Delta TS [%]	1	3	1	4	-2
Elongation at break [%]	395	369	397	392	366
Delta Elong. [%]	9	18	15	11	3
Modulus at 100 % [MPa]	3.1	3.6	3.2	3.1	3.0
Delta 100% [%]	13	6	9	11	-8
Volume Change (%)	-12	-12	-12	-7	-1
Weight Change (%)	-10	-10	-10	-6	-1

List of Compound Ingredients

Material	Chemical Composition	Supplier
Polymers		
Vamac® GLS	Ethylene Acrylic Elastomer	DuPont Performance Polymers
Vamac® Ultra LS	Ethylene Acrylic Elastomer	DuPont Performance Polymers
Vamac® Ultra IP	Ethylene Acrylic Elastomer	DuPont Performance Polymers
Release Aids		
Armeen® 18D	Octadecyl Amine	Akzo Nobel
Vanfre ® VAM	Complex Organic Phosphate Ester	R.T. Vanderbilt
Stearic Acid		
Anti-Oxidant		
Naugard® 445	Diphenyl Amine	Chemtura
Plasticizers		
Rhenosin® W 759	Mixed Ether/Ester Plasticizer	Rhein Chemie
Edenol® T810T	Trimellitate Plasticizer	Emery Oleochemicals
Nycoflex® ADB 30	Mixed Ether/Ester Plasticizer	Safic-Alcan
Fillers		
Spheron® SO N550	Carbon Black	Cabot
Regal® SRF N 772	Carbon Black	Cabot
MT Thermax® Floform N 990	Carbon Black	Cancarb
Curatives		
Diak™ No. 1	Hexamethylene Diamine Carbamate	DuPont Performance Polymers
Accelerators		
Vulcofac® ACT 55	DBU accelerator	Safic-Alcan
Ekaland® DOTG	Di-ortho-tolyl Guanidine	MLPC International
Alcanpoudre® DBU-70	DBU accelerator	Safic-Alcan
Test Fluids		
Dexron® VI	Transmission Fluid	Petro Canada
Castrol® SLX Longlife IV	Engine Oil	Castrol
Lubrizol® OS206304 5W40	5W40 Reference Engine Oil	Lubrizol

Test Methods

Test	Method
Rheology	
Mooney Viscosity	ISO 289-1:2005
Mooney Scorch	ISO 289-2:1994
MDR	ISO 6502:1999
Physical Properties	
Hardness	ISO 868:2003
Tensile Strength, Elongation, Modulus	ISO 37:1994
Compression Set	ISO 815:1991
Compression Set	Volkswagen PV3307
Compressive Stress Relaxation (CSR)	ISO 3384
Aging in Air Oven	ISO 188:2007
Fluid Aging	ISO 1817:2005
Tg by DSC	ISO 22768:2006
Tear Strength Die C	ISO 34-1:2004

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