Dial-a-Durometer (DAD): A Versatile Approach for Polyurethane Elastomer Production

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ABSTRACT

Dial-a-Durometer (DAD) is an elastomer production approach where one uses a low-hardness and high-hardness TDI prepolymer and blends the two to get any hardness in between. One can achieve a hardness from 70A to 75D using this approach. Physical/mechanical properties of these systems will be presented and compared to the traditional single prepolymer approach. The positives and negative of DAD will be presented. The versatility of this approach will be highlighted.

INTRODUCTION

The two major classes of cast elastomers are those based on MDI (methylene diphenyl diisocyanate) and TDI (toluene diisocyanate). MDI-based cast elastomers can be processed using three approaches.[1] The first is the prepolymer approach where all the MDI and polyol are prereacted to form the prepolymer and then the prepolymer is reacted with a linear symmetrical short-chain diol curative like 1,4-butanediol. The second is the quasi-prepolymer approach where all the MDI and part of the polyol are prereacted to form a quasi-prepolymer and then the quasi-prepolymer is reacted with polyol and curative to form the elastomer. The third is the one-shot approach where the MDI monomer, polyol and curative are reacted in a single step or one shot to form the elastomer. Now for the quasi-prepolymer and one-shot approaches, one can achieve a variety of formulations or hardness' by varying the amount of MDI quasi-prepolymer or MDI monomer, polyol and curative. Typically, a hardness range of 60A to 60D can be achieved with an MDI ester-based system and a 90A to 65D for an MDI ether-based system. The quasi-prepolymer and one-shot approaches are viable for MDI based systems because MDI monomer is safer to work with since it has a low vapor pressure or low volatility.

TDI has a significantly higher vapor pressure or volatility than MDI. For this reason, TDI-based cast elastomers are made by only the prepolymer approach. TDI prepolymers are prepared in such a way as to minimize the TDI monomer content. In conventional TDI prepolymers, this is done by reacting the TDI and polyol at a maximum ratio of 2 to 1. Typically, TDI to polyol ratios are in the 1.6:1.0 to 2.0:1.0 range which results in unreacted TDI monomer contents in the 0.5 to 2.0 weight percent range. In low-free TDI prepolymers, the unreacted TDI monomer contents are less than 0.1 weight percent because the excess TDI monomer is stripped or distilled off by passing the prepolymer through a wiped-film evaporator under high vacuum and high temperature. Low-free and conventional TDI prepolymers are typically reacted with aromatic diamine curatives such as MBOCA (methylene bis-(orthochloroaniline)) or 2,4-/2,6-isomer mixture of 3,5-dimethylthio toluene diamine (Ethacure® 300 or Curene® 107) resulting in a single given hardness. In summary, TDI prepolymers are designed to give a specific hardness. One can lower the hardness of a given TDI-based elastomer by adding polyol or plasticizer to the formulation, however, it is generally accepted that the properties of the resulting elastomers are inferior to a "straight" prepolymer/curative approach. This technical paper is going to show that if one uses a low-hardness TDI prepolymer and a high-hardness TDI prepolymer, blends of the two prepolymers result in hardness' in between the two without losing significant physical/mechanical properties. We call this approach "Dial-a-Durometer (DAD)" since one can simply "dial" in the desired hardness using only two prepolymers and a curative.

Polyurethane cast elastomer processors will usually inventory individual prepolymers for each hardness that they need to make. Typical Shore hardness points for conventional TDI/ester prepolymers are 70A, 80A, 83A, 85A, 90A, 93A, 95A, 60D and 70D and for conventional TDI/PTMEG prepolymers are 83A, 90A, 92A, 95A, 60D, 65D, 70D and 75D. So, if a processor was producing every "typical" hardness of TDI/ester based elastomers then they would have to inventory nine (9) prepolymers and for TDI/PTMEG based elastomers, they would need to inventory eight (8) prepolymers. Using the Dial-a-Durometer (DAD) approach one can achieve every typical hardness plus anywhere in between with only two prepolymers.

Another advantage of the DAD approach is that since one is only inventorying two prepolymers there is less of a chance to have those prepolymers go "bad" due to age or exposure to humidity from the air, or an excessive heat history.

There are some disadvantages as well. If one is hand casting, then you have to weigh out two prepolymers instead of one which is an extra step and a potential extra weighing error. However, if one is using a three-component meter, mix and dispense machine, then it is just as simple to mix two prepolymers as it is one. Another potential disadvantage is in the area of dynamic applications such as treads for high-load caster wheels. Even though we will show that the physical/mechanical properties of a blended DAD system are comparable to the "straight" prepolymer approach, one needs to be cautious putting this type of system into a dynamic application. A blended DAD system will likely have a broader polyol backbone molecular weight distribution which may affect the dynamic performance. Also, many high-hardness TDI prepolymers use short-chain diols like diethylene glycol (DEG), dipropylene glycol (DPG) or 1,4-butanediol (BDO) in their formulations. This "TDI:short-chain diol" adduct will phase out into the hard-segment phase which will likely lower the melting or softening temperature of the elastomer which could negatively affect the load and speed capabilities in a high-load caster wheel. The blended DAD systems which were evaluated in this study are shown below.

EXPERIMENTAL

General Experimental Procedure

The following prepolymer systems below were blended at ratios from 100 weight percent to 0 weight percent at 10 percent increments, heated to processing temperature (150 to 212 F) and then cured with MBOCA and/or Curene 107 (80:20 2,4-:2,6- isomer mixture of 3,5-dimethylthiotoluene diamine, Ethacure 300) at a 0.95 stoichiometry. A Vortex mixture was used to mix the components and then the elastomer solution was cast into molds preheated to 212 F. They were demolded and then post cured for about 16 hours at 212 F. The resulting plaques and buttons were conditioned at ambient conditions for at least one month before measuring the physical/mechanical properties.

TDI/Ester-Based Elastomer Systems

Andur® 7 APLM/Andur® 7 DPLM	70A and 70D Conventional TDI Prepolymers
Andur 7-3 APLF/Andur 7 DPLM	73A Low-Free TDI Prepolymer and 70D Conventional TDI Prepolymer
Andur 7 APLF/Andur 6 DPLF	70A and 60D Low-Free TDI Prepolymers

TDI/PTMEG-Based Elastomer Systems

Andur 80-5 AP/Andur 1-75 DP	82A and 75D Conventional TDI Prepolymers

TDI/PPG-Based Elastomer Systems

Andur 8000 AP/Andur 7500 DP	80A and 75D Conventional TDI Prepolymers
Andur 8000 APLF/Andur 6500 DPLF	80A and 65D Low-Free TDI Prepolymers

Physical/Mechanical Properties Evaluated

Property	ASTM Method
Hardness, Shore	D2240
Elongation, %	D412
Tensile Strength, psi	D412
100% Modulus, psi	D412
300% Modulus, psi	D412
Die C Tear, pli	D624
Split Tear, pli	D1938
Compression Set, %	D395, Method B, 22 hours @ 70 C
Compression Deflection, psi	D575

@ 5%, 10%, 15%, 20% and 25%
Bashore Rebound, % D2632

RESULTS AND DISCUSSION

TDI/Ester Prepolymer Blends

Table 1 illustrates the physical/mechanical properties of a conventional, low-hardness, 70A TDI/ester (Andur 7 APLM) and a conventional, high-hardness, 70D TDI/ester (Andur 7 DPLM) blended at 10% increments using MBOCA as a curative. This approach would work well for a meter, mix and dispense machine operation. It would only be recommended for a hand cast operation if there was adequate ventilation controls due to the high-free TDI content of the Andur 7 DPLM. The plaques and buttons were conditioned at ambient temperature for at least one month prior to testing. The physical/mechanical data was tabulated and the data "massaged" to give the "typical" properties of the elastomers. This data analysis process was used for all the DAD systems evaluated in this paper.

As expected, the hardness varies from 70A to a 70D. The elongation is highest for the softest elastomer and then steadily declines with increasing hardness. The tensile strength increases with hardness until about a 52D and then declines slightly to a 64D and then declines more sharply to a 70D. We believe the tensile strength declines due the increasing hard-segment content which could make it more difficult for the reactive end groups to find each other and therefore lower the overall polymer molecular weight. The Die C and split tear strength increases with increasing hardness. The compression set was below 30 percent up to a hardness of 56D and then increased significantly at higher hardness. We did not measure the compression set of the 70D elastomer. As expected, the compression deflection increased with increasing hardness. The Bashore rebound decreased from 70A down to 88A and then increased with increasing hardness.

The physical/mechanical properties of the DAD blends compared to the "straight" prepolymer approach are shown below. The first value is the DAD approach and the value in the parenthesis is the straight prepolymer approach.

Property	80A	90A	95A (50D)	60D
Elongation, %	600 (640)	540 (420)	510 (525)	420 (415)
Tensile Strength, psi	6600 (6000)	7500 (7850)	8500 (8570)	8300 (8000)
Die C Tear, pli	370 (360)	450 (545)	510 (600)	680 (775)
Split Tear, pli	140 (140)	160 (210)	200 (310)	300 (385)
Compression Set, %	22 (26)	22 (24)	25 (29)	31 (35)
Bashore Rebound, %	42 (39)	39 (30)	44 (33)	47 (44)

As you can see above, the % elongation and tensile strength are very comparable between the DAD and the straight prepolymer (in parenthesis) approach. The Die C and split tear strength is comparable at low hardness but is lower than the straight prepolymer at higher hardness. The compression set is slightly better via the blend approach and the Bashore rebound is significantly higher for the blend approach.

Table 2 shows the same blends of Andur 7 APLM and Andur 7 DPLM using Curene 107 as a curative. Most of the trends were generally the same as the results using MBOCA as a curative. The hardness range was slightly narrower with the Curene 107 (72A-68D versus 70A-70D). The compression sets were slightly higher at low hardness and then increased significantly higher at a hardness above 85A. For example, the compression set for the 60D MBOCA cured elastomer was only 31%, whereas, the Curene 107 cured elastomer was about 80%. It is generally known that elastomers based on Curene 107 have higher compression sets than MBOCA cured elastomers. The compression deflection and Bashore rebounds were comparable.

One of the disadvantages of using conventional TDI prepolymer Andur 7 APLM as the low-hardness prepolymer is that the viscosity is very high at 1900 cps at 212 F (100 C). This high viscosity would be a limitation for hand casting in terms of its difficulty to degas and its difficulty to mix. It would also be a limitation for meter, mix and dispense machines in terms of the maximum achievable flow rates at an acceptable pressure.

Tables 3 and 4 show the physical/mechanical properties of blends using the low-free TDI prepolymer, Andur 7-3 APLF, which has a viscosity of only 1000 cps at 212 F (100 C), with the Andur 7 DPLM, which has a viscosity of 800 cps at 212 F (100 C), cured with MBOCA and Curene 107, respectively. This approach would work well with a meter, mix and dispense machine operation. It would only be recommended for a hand cast operation if there was adequate ventilation controls due to the high-free TDI content of the Andur 7 DPLM. The results show that using this approach resulted in higher tensile strengths at low hardness. However, there was a significant increase in the compression set, particularly at higher hardness. All the other general trends were the same.

Tables 5 and 6 illustrate the all low-free TDI approach using Andur 7 APLF and Andur 6 DPLF using MBOCA and Curene 107, respectively. These systems would be recommended for both hand cast and meter, mix and dispense machine operations. Using this approach one can achieve a hardness range of 70A to 60D using MBOCA and 72A to 58D using Curene 107. In general, the trends are the same as the previous systems. However, using the Andur 7 APLF did result in a significantly lower split tear strength at low hardness with MBOCA as a curative. With Curene 107, the split tear strengths were significantly lower throughout the hardness range compared to the other systems. Surprisingly, the compression sets were comparable to the all conventional TDI prepolymer approach for the MBOCA cured elastomers. Even more surprising, the Curene 107 cured elastomers had significantly lower compression sets than the other two approaches at high hardness. Overall, the Bashore rebound was lower for both the MBOCA and Curene 107 cured elastomers using this all low-free TDI DAD system.

TDI/PTMEG Prepolymer Blends

Table 7 shows the physical/mechanical properties of a DAD system using conventional TDI/PTMEG prepolymers cured with MBOCA. The low hardness prepolymer was Andur 80-5 AP and the high hardness prepolymer was Andur 1-75 DP. Using this system resulted in a hardness range of 82A to 75D. The percent elongation was highest for the softest elastomer and then decreased as the hardness increased. The tensile, Die C and split tear strengths all increased with higher hardness. The compression set was below 30% at 58D hardness and below. We did not measure the compression set of the elastomers with a hardness 65D or higher. As expected, the compression deflection increased with increasing hardness. The Bashore rebound was highest with the softest 82A elastomer at 64% , decreased to 48% at a 90A and then increased with increasing hardness until it reached 58% at a 75D hardness.

The physical/mechanical properties of the DAD blends compared to the "straight" prepolymer approach are shown below. The first value is the DAD approach and the value in the parenthesis is the straight prepolymer approach.

Property	90A	92A	95A (45D)	60D
Elongation, %	360 (425)	370 (410)	370 (375)	290 (265)
Tensile Strength, psi	6000 (6000)	6300 (7140)	6500 (7000)	6900 (7300)
Die C Tear, pli	330 (360)	370 (440)	410 (475)	590 (665)
Split Tear, pli	80 (80)	90 (110)	95 (145)	140 (165)
Compression Set, %	19 (30)	20 (27)	22 (30)	35 (32)
Bashore Rebound, %	51 (48)	48 (46)	49 (46)	53 (55)

The percent elongation and tensile strength of the elastomers based on the blends are comparable or lower than those based on the straight prepolymer approach. The Die C and split tear strengths are in general lower for the elastomers prepared by the DAD approach. The compression sets of the DAD elastomers are lower except at 60D hardness and the Bashore rebound is slightly higher except at 60D hardness.

Table 8 shows the blends of Andur 80-5 AP and Andur 1-75 DP using Curene 107 as a curative. The hardness range for this system was 80A to 69D. The percent elongation is higher at a given hardness for the Curene 107 versus MBOCA. At 95A hardness and below, the tensile, Die C and split-tear strengths are comparable for Curene 107 and MBOCA, however, at higher hardness the strengths were slightly higher for the Curene 107. The compression deflection and Bashore rebound are comparable for both curatives.

TDI/PPG Prepolymer Blends

Table 9 shows conventional TDI/PPG prepolymer blends using the low-hardness Andur 8000 AP and the high-hardness Andur 7500 DP cured with MBOCA. Using these prepolymer blends one can achieve a broad hardness range of 80A to

75D. As expected, the percent elongation decreases as the hardness increases. The tensile strength, Die C tear and split tear strengths all increase with increasing hardness although the overall strengths are lower than the ester or PTMEG DAD systems. The compression sets are 30 or less for a hardness of 95A or lower. The compression deflection increases with hardness. The Bashore rebound does show a different behavior than the ester or PTMEG blends. The PPG-based elastomers have the lowest rebound at the lowest hardness and then the rebound steadily increases with hardness.

The physical/mechanical properties of the DAD blends compared to the "straight" prepolymer approach are shown below. The first value is the DAD approach and the value in the parenthesis is the straight prepolymer approach.

Property	82A	85A	90A	95A (44D)
Elongation, %	380 (400)	340 (400)	310 (350)	280 (335)
Tensile Strength, psi	2800 (3400)	3100 (3800)	3400 (4000)	4200 (4500)
Die C Tear, pli	230 (205)	250 (230)	270 (270)	340 (350)
Split Tear, pli	55 (45)	50 (55)	65 (65)	90 (95)
Compression Set, %	24 (29)	27 (30)	27 (32)	30 (29)
Bashore Rebound, %	21 (22)	25 (26)	30 (28)	35 (37)

As you can see from the data above, the percent elongation and tensile strength are slightly higher using the straight prepolymer approach. The Die C and split tear strengths, compression sets and Bashore rebounds are comparable for both the straight prepolymer and DAD approaches.

Table 10 shows an example using low-free TDI/PPG prepolymers using Curene 107 as a curative. The low-hardness prepolymer was Andur 8000 APLF and the high-hardness prepolymer was Andur 6500 DPLF. This system was choosen due to its optimal processability in that the prepolymers are both pourable at room temperature and the curative is a liquid. We processed the prepolymers at 150 F, however, they could be processed at temperatures as low as 120 F. The pot lives of these systems were 22 minutes for the 80A hardness and 3 minutes for the 64D hardness. The demold times were 75 minutes and 15 minutes, respectively. The tensile strengths increased with hardness from 2300 psi to 5100 psi. The Die C tear ranged from 220 pli to 700 pli and the split tear ranged from 55 to 190 pli. As expected for Curene 107, the compression sets were poor. The Bashore rebound was comparatively high for a PPG-based elastomer system. It started at a 58% at 80A, decreased to a 46% at 86 to 93A and then increased from there up to 57%.

CONCLUSIONS

We have shown that a broad hardness range can be achieved using the "Dial-a-Durometer" (DAD) approach for polyurethane elastomer production. This approach can be used for both hand casting and meter, mix and dispense machine operations. Depending on the requirements for the application, one can use an ester, PTMEG or PPG based TDI prepolymers. One can optimize the processability and properties by their choice of conventional or low-free TDI prepolymers. Various aromatic diamines can be utilized such as MBOCA and Curene 107; Lonzacure® MCDEA or Versalink® 740M could be used as well. The physical/mechanical properties of DAD systems are comparable to those based on the "straight" prepolymer approach. The DAD approach allows the elastomer processor to inventory just a few prepolymers but gives them the versatility to "dial in" any hardness that they desire. Inventorying fewer TDI prepolymers will result fewer problems with them going "bad" due to age, exposure to humidity, or an excessive heat history. We recommend going through a systematic qualification if utilizing these blended systems in dynamic applications such as high-load caster wheels. Dial-a-Durometer is a versatile approach for polyurethane elastomer production.

REFERENCES

1. I.R. Clemitson, Castable Polyurethane Elastomers, p. 24-28.

BIOGRAPHIES

Steve Seneker

Steve Seneker is a Senior Scientist in the Polyurethane Elastomers Group at Anderson Development Company. He received his B.A. Degree in Chemistry from Point Loma Nazarene College. He received his Ph.D. in Chemistry with an emphasis on Polymers and Coatings from North Dakota State University. After graduation in 1986, he joined Mobay Corporation (currently Bayer Material Science). In 1993, he joined ARCO Chemical/Lyondell Chemical. He has been working at Anderson Development Company since 2000.

Jordan Duckett

Jordan Duckett is currently a Urethane Technical Support Representative in the Polyurethane Elastomers Group at Anderson Development Company. He has a Bachelor's degree in Chemistry from Siena Heights University. He has been working at Anderson Development Company since 2007. He began as an intern while attending Siena Heights University. Upon his graduation, he worked as a Quality Control Technician. In 2011, he accepted his current position at Anderson Development Company.

Robert Czeiszperger

Robert Czeiszperger is currently a Senior Chemist in the Polyurethane Elastomers Group at Anderson Development Company. He has Bachelor's degrees in Chemistry and Mathematics from Siena Heights University and earned a Master's degree in Polymer and Coatings Technology from Eastern Michigan University in 2003. He has been working at Anderson Development Company since 1998.

Jessica Lampkowski

Jessica Lampkowski is currently an R&D Intern in the Polyurethane Elastomers Groups at Anderson Development Company. She is a senior Chemistry major from Siena Height University and will be graduating with a Bachelor's degree this May 2013. Jessica will be leaving Anderson Development Company this summer to attend William and Mary's University in Williamsburg, VA. She will be pursuing her Master's degree in Chemistry and working as a teaching assistant.

Table 1

Dial-a Durometer (DAD) using Andur 7 APLM and Andur 7 DPLM cured with MBOCA

Andur 7 APLM(wt%)	100	90	80	70	60	50	40	30	20	10	0
Andur 7 DPLM (wt%)	0	10	20	30	40	50	60	70	80	90	100
% NCO (calc.)	2.40	2.91	3.42	3.93	4.44	4.95	5.46	5.97	6.48	6.99	7.50
Stoichiometry (actual)	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Hardness, Shore	70A (20D)	79A (26D)	88A (32D)	92A (37D)	94A (42D)	96A (47D)	52D	56D	60D	64D	70D
Elongation, %	670	600	560	540	530	510	480	450	420	380	350
Tensile Strength, psi	5500	6600	7000	7500	8500	8500	8500	8400	8300	8100	7400
100% Modulus, psi	420	630	790	970	1200	1500	1800	2200	2600	3000	3600
300% Modulus, psi	620	1100	1400	1700	2100	2500	3300	3800	4500	5600	5400
Die C Tear, pli	290	370	410	450	480	510	540	590	680	770	960
Split Tear, pli	120	140	150	160	180	200	230	260	300	340	400
Compression Set											
22 hrs @ 70 C	22	22	22	22	22	25	26	26	31	39	***
Compress. Deflect.											
@5%	70	100	140	190	250	310	370	440	510	580	670
@10%	150	230	300	400	510	720	900	1100	1400	1900	2700
@15%	240	380	500	630	800	1000	1400	1700	2100	2900	4200
@20%	300	480	620	780	1000	1300	1700	2100	2600	3500	5000
@25%	380	580	740	920	1200	1500	1900	2400	3100	4000	5700
Bashore Rebound, %	47	42	38	39	41	44	46	47	47	47	47

Table 2

Dial-a Durometer (DAD) using Andur 7 APLM and Andur 7 DPLM cured with Curene 107

Andur 7 APLM(wt%)	100	90	80	70	60	50	40	30	20	10	0
Andur 7 DPLM (wt%)	0	10	20	30	40	50	60	70	80	90	100
% NCO (calc.)	2.40	2.91	3.42	3.93	4.44	4.95	5.46	5.97	6.48	6.99	7.50
Stoichiometry (actual)	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Hardness, Shore	72A (23D)	78A (25D)	83A (27D)	88A (31D)	92A (36D)	95A (42D)	97A (48D)	53D	58D	63D	68D
Elongation, %	670	660	650	620	590	570	540	510	460	420	360
Tensile Strength, psi	5200	6300	7000	8000	8400	8400	8500	8500	7200	6900	6700
100% Modulus, psi	500	610	720	850	1000	1200	1400	1700	2000	2300	2700
300% Modulus, psi	790	940	1100	1400	1700	2000	2300	2800	3400	4100	5000
Die C Tear, pli	350	410	440	470	500	540	580	650	730	820	920
Split Tear, pli	160	180	210	240	280	320	370	420	480	550	530
Compression Set											
22 hrs @ 70 C	26	26	28	34	38	54	65	69	77	88	***
Compress. Deflect.											
@5%	70	90	110	150	200	250	310	370	430	510	640
@10%	160	190	250	360	510	680	870	1100	1400	1800	2200
@15%	250	310	390	560	780	1000	1300	1700	2100	2700	3300
@20%	340	420	520	710	960	1300	1600	2000	2500	3100	3800
@25%	440	530	640	850	1100	1400	1800	2300	2800	3400	4100
Bashore Rebound, %	50	43	38	40	42	45	46	47	49	50	50

Table 3

Dial-a Durometer (DAD) using Andur 7-3 APLF and Andur 7 DPLM cured with MBOCA

Andur 7-3 APLF (wt%)	100	90	80	70	60	50	40	30	20	10	0
Andur 7 DPLM (wt%)	0	10	20	30	40	50	60	70	80	90	100
% NCO (calc.)	2.30	2.82	3.34	3.86	4.38	4.90	5.42	5.94	6.46	6.98	7.50
Stoichiometry (actual)	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Hardness, Shore	22D (72A)	25D (78A)	28D (84A)	32D (88A)	37D (92A)	42D (94A)	47D (96A)	52D	58D	64D	70D
Elongation, %	700	690	620	560	550	490	470	440	420	370	350
Tensile Strength, psi	7500	7500	7500	7600	7700	7800	8000	8200	8200	7600	7400
100% Modulus, psi	500	600	700	800	1000	1200	1600	2000	2400	2900	3600
300% Modulus, psi	900	1000	1200	1500	1800	2200	2700	3800	4500	5400	5400
Die C Tear, pli	330	350	400	430	460	480	510	580	610	750	960
Split Tear, pli	200	180	180	180	180	200	240	260	270	280	400
Compression Set											
22 hrs @ 70 C	25	25	25	25	25	25	30	36	61	70	n.d.
Compress. Deflect.											
@5%	60	80	110	120	190	220	240	320	370	460	670
@10%	150	170	250	310	420	550	700	930	1300	1700	2700
@15%	240	280	400	500	660	860	1100	1400	2000	2600	4200
@20%	320	360	510	620	810	1100	1400	1800	2500	3200	5000
@25%	390	430	610	740	950	1300	1600	2100	2800	3600	5700
Bashore Rebound, %	40	40	37	37	38	40	42	44	45	46	47

Table 4

Dial-a Durometer (DAD) using Andur 7-3 APLF and Andur 7 DPLM cured with Curene 107

Andur 7-3 APLF(wt%)	100	90	80	70	60	50	40	30	20	10	0
Andur 7 DPLM (wt%)	0	10	20	30	40	50	60	70	80	90	100
% NCO (calc.)	2.30	2.82	3.34	3.86	4.38	4.90	5.42	5.94	6.46	6.98	7.50
Stoichiometry (actual)	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Hardness, Shore	21D (71A)	24D (77A)	27D (83A)	31D (88A)	36D (92A)	41D (95A)	46D (96A)	51D	56D	62D	68D
Elongation, %	700	700	690	680	670	640	600	550	500	440	360
Tensile Strength, psi	6600	6800	7000	7000	7000	6700	6700	6700	6700	6700	6700
100% Modulus, psi	440	510	590	690	820	980	1200	1500	1800	2100	2700
300% Modulus, psi	740	850	950	1100	1300	1600	2000	2500	3100	4000	5000
Die C Tear, pli	350	380	410	440	470	510	560	650	750	850	920
Split Tear, pli	180	180	240	300	360	410	460	490	520	550	530
Compression Set											
22 hrs @ 70 C	32	38	43	47	52	68	83	85	90	98	***
Compress. Deflect.											
@5%	50	60	80	120	160	200	250	290	340	430	640
@10%	120	140	180	300	390	490	680	940	1200	1600	2200
@15%	200	220	280	470	600	740	1000	1400	1800	2300	3300
@20%	280	300	380	600	760	930	1200	1700	2200	2900	3800
@25%	360	390	480	730	900	1100	1400	1900	2400	3200	4100
Bashore Rebound, %	50	40	36	36	37	40	43	45	46	48	50

Table 5

Dial-a Durometer (DAD) using Andur 7 APLF and Andur 6 DPLF cured with MBOCA

Andur 7 APLF(wt%)	100	90	80	70	60	50	40	30	20	10	0
Andur 6 DPLF (wt%)	0	10	20	30	40	50	60	70	80	90	100
% NCO (calc.)	2.65	3.00	3.35	3.70	4.05	4.40	4.75	5.10	5.45	5.80	6.15
Stoichiometry (actual)	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Hardness, Shore	70A (20D)	75A (24D)	80A (26D)	84A (28D)	87A (30D)	90A (34D)	92A (38D)	94A (43D)	96A (48D)	54D	60D
Elongation, %	580	580	550	520	500	480	460	440	410	390	380
Tensile Strength, psi	6600	6900	7100	7200	7300	7400	7500	7600	7800	7500	7200
100% Modulus, psi	360	420	540	740	800	900	1100	1300	1600	1900	2700
300% Modulus, psi	720	800	1000	1300	1600	2000	2500	3100	3700	4400	5500
Die C Tear, pli	280	300	320	340	360	380	400	430	480	550	730
Split Tear, pli	90	92	95	100	110	130	170	220	250	270	290
Compression Set											
22 hrs @ 70 C	25	25	25	30	30	30	30	30	30	40	40
Compress. Deflect.											
@5%	40	70	90	110	140	170	210	250	290	330	380
@10%	90	150	200	250	320	380	480	580	690	870	1100
@15%	150	250	320	410	500	610	750	890	1100	1400	1900
@20%	200	330	420	530	650	780	960	1200	1400	1900	2600
@25%	270	410	520	650	780	940	1200	1400	1700	2300	3000
Bashore Rebound, %	36	31	27	26	26	27	28	30	31	35	40

Table 6

Dial-a Durometer (DAD) using Andur 7 APLF and Andur 6 DPLF cured with Curene 107

Andur 7 APLF(wt%)	100	90	80	70	60	50	40	30	20	10	0
Andur 6 DPLF (wt%)	0	10	20	30	40	50	60	70	80	90	100
% NCO (calc.)	2.65	3.00	3.35	3.70	4.05	4.40	4.75	5.10	5.45	5.80	6.15
Stoichiometry (actual)	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Hardness, Shore	72A (22D)	77A (25D)	81A (27D)	85A (29D)	88A (31D)	90A (34D)	92A (38D)	94A (43D)	96A (48D)	53D	58D
Elongation, %	640	600	560	530	510	490	470	450	440	430	420
Tensile Strength, psi	7200	7200	7300	7400	7500	7500	7500	7500	7400	7300	7300
100% Modulus, psi	570	630	700	840	970	1100	1300	1600	1900	2200	2500
300% Modulus, psi	1000	1100	1200	1400	1600	1800	2100	2500	3100	3800	4500
Die C Tear, pli	350	360	370	380	400	420	440	460	490	560	810
Split Tear, pli	120	120	130	130	140	150	160	180	210	270	360
Compression Set 22 hrs @ 70 C	34	34	34	37	39	45	46	48	50	52	53
Compress. Deflect.											
@5%	60	70	90	110	140	180	210	240	270	320	370
@10%	130	160	200	270	340	430	450	630	720	920	1200
@15%	210	270	310	420	540	660	710	990	1200	1400	1700
@20%	300	370	420	570	710	860	940	1200	1500	1800	2200
@25%	380	480	540	710	880	1100	1200	1500	1800	2200	2600
Bashore Rebound, %	40	35	32	30	29	30	31	32	34	35	37

Table 7

Dial-a-Durometer (DAD) using Andur 80-5AP and Andur 1-75 DP cured with MBOCA

Andur 80-5 AP (wt %)	100	90	80	70	60	50	40	30	20	10	0
Andur 1-75 DP (wt %)	0	10	20	30	40	50	60	70	80	90	100
% NCO (calc)	3.20	3.73	4.26	4.79	5.32	5.85	6.38	6.91	7.44	7.97	8.50
Stoichiometry (actual)	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Potlife (minutes)	6.5	6.0	5.5	5.0	4.5	4.25	4.0	3.75	3.5	3.25	2.75
Demold Time (minutes)	35	35	30	30	30	20	20	15	15	10	10
Hardness, Shore	82A	86A	90A	93A (37D)	95A (44D)	97A (51D)	56D	61D	65D	70D	75D
Elongation, %	480	390	360	370	370	320	300	290	280	260	240
Tensile Strength, psi	5300	5500	6000	6300	6500	6600	6700	6900	7500	8000	8300
100% Modulus, psi	800	1000	1200	1400	1800	2200	2800	3300	3800	4500	5600
300% Modulus, psi	1400	1900	2500	3000	3800	5000	****	****	****	****	****
Die C Tear, pli	270	290	330	370	410	440	510	590	700	820	1100
Split Tear, pli	60	70	80	90	95	100	120	140	170	190	240
Compression Set											
22 hrs @ 70 C	14	17	19	20	22	25	27	35	****	****	****
Compress. Deflect.											
@5%	130	150	210	250	300	340	440	530	620	690	1000
@10%	290	370	460	570	720	920	1100	1500	1900	2400	3500
@15%	480	590	730	900	1100	1400	1900	2400	2900	3700	5500
@20%	600	740	920	1100	1400	1800	2400	3000	3600	4600	6800
Bashore Rebound, %	64	57	51	48	49	50	52	53	54	55	58

Table 8

Dial-a-Durometer (DAD) using Andur 80-5AP and Andur 1-75 DP cured with Curene 107

Andur 80-5 AP (wt%)	100	90	80	70	60	50	40	30	20	10	0
Andur 1-75 DP (wt%)	0	10	20	30	40	50	60	70	80	90	100
% NCO (calc.)	3.20	3.73	4.26	4.79	5.32	5.85	6.38	6.91	7.44	7.97	8.50
Stoichiometry (actual)	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Hardness, Shore	80A (25D)	83A (28D)	87A (32D)	92A (37D)	95A (43D)	96A (48D)	53D	57D	61D	65D	69D
Elongation, %	570	530	500	470	440	420	400	380	360	340	290
Tensile Strength, psi	6100	6300	6500	6700	6900	7100	7300	7600	7900	8300	7700
100% Modulus, psi	690	830	980	1200	1500	1800	2200	2700	3200	4000	4700
300% Modulus, psi	1300	1500	1900	2400	2900	3600	4400	5400	6200	7200	----
Die C Tear, pli	250	320	350	380	410	440	490	560	670	790	910
Split Tear, pli	60	70	80	100	110	120	140	160	180	200	220
Compression Set											
22 hrs @ 70 C	30	30	33	35	45	55	60	65	70	75	***
Compress. Deflect.											
@5%	100	120	140	170	210	260	320	400	510	650	850
@10%	220	280	350	490	630	860	1100	1400	1800	2300	3000
@15%	340	440	550	750	980	1300	1600	2100	2600	3400	4300
@20%	460	580	730	960	1200	1600	2000	2500	3100	4000	5000
@25%	580	730	900	1200	1500	1900	2300	2900	3500	4500	5800
Bashore Rebound, %	62	56	52	49	50	51	53	53	54	54	55

Table 9

Dial-a-Durometer using Andur 8000 AP and Andur 7500 DP cured with MBOCA

Andur 8000 AP (wt %)	100	90	80	70	60	50	40	30	20	10	0
Andur 7500 DP (wt %)	0	10	20	30	40	50	60	70	80	90	100
% NCO	3.50	3.87	4.23	4.60	4.96	5.33	5.69	6.06	6.42	6.79	7.15
Hardness, Shore	80A (25D)	83A (28D)	86A (31D)	90A (36D)	94A (42D)	96A (49D)	55D	60D	65D	70D	75D
Elongation, %	420	380	340	310	290	270	260	240	220	210	200
Tensile Strength, psi	2100	2800	3100	3400	3900	4400	4900	5300	5700	6000	6200
100% Modulus, psi	540	740	960	1300	1600	1900	2500	3100	3600	4200	5200
300% Modulus, psi	1200	1900	2500	3100	****	****	****	****	****	****	****
Die C Tear, pli	220	230	250	270	320	360	440	540	660	800	1000
Split Tear, pli	55	40	50	65	80	100	120	140	160	180	210
Compression Set											
22 hrs @ 70 C	24	27	27	27	29	32	36	43	****	****	****
Compress. Deflect.											
@5%	90	120	150	190	240	280	340	410	500	650	850
@10%	200	250	340	440	590	770	1000	1300	1800	2400	3000
@15%	320	400	520	700	910	1200	1600	2100	2700	3500	4400
@20%	410	510	700	880	1200	1500	2100	2700	3500	4400	5400
@25%	500	640	810	1100	1400	1800	2400	3200	4100	5100	6200
Bashore Rebound, %	20	21	25	30	33	36	42	48	51	52	52

Table 10

Dial-a-Durometer (DAD) using Andur 8000 APLF and Andur 6500 DPLF cured with Curene 107

Andur 8000 APLF (wt%)	100	90	80	70	60	50	40	30	20	10	0
Andur 6500 DPLF (wt%)	0	10	20	30	40	50	60	70	80	90	100
% NCO (calc.)	3.60	3.99	4.38	4.77	5.16	5.55	5.94	6.33	6.72	7.11	7.50
Potlife (min., sec)	22	18	14	10	8	7	6	5	4	3.5	3
Demold Time (min.)	75	65	55	45	35	30	25	20	20	15	15
Hardness, Shore	80A (25D)	83A (28D)	86A (31D)	90A (34D)	93A (38D)	95A (43D)	96A (48D)	97A (52D)	56D	60D	64D
Elongation, %	610	570	560	550	500	480	460	440	420	390	350
Tensile Strength, psi	2300	2600	3000	3400	3700	4200	4700	4800	4900	5000	5100
100% Modulus, psi	760	840	920	1100	1200	1400	1600	1800	2000	2200	2600
300% Modulus, psi	1100	1200	1300	1600	1900	2200	2500	2900	3300	3800	4300
Die C Tear, pli	220	250	270	300	330	360	400	450	520	600	700
Split Tear, pli	55	65	75	90	110	120	130	140	160	180	190
Compression Set											
22 hrs @ 70 C	64	68	73	76	79	87	91	94	100	100	100
Compress. Deflect.											
@5%	110	120	140	190	220	270	330	430	530	630	730
@10%	220	250	300	400	490	640	830	1100	1400	1700	2200
@15%	330	380	450	590	730	940	1200	1500	1900	2400	3300
@20%	440	500	590	750	910	1100	1400	1800	2200	2700	3600
@25%	560	630	730	900	1100	1300	1600	2000	2400	3000	4200
Bashore Rebound, %	58	51	46	46	46	49	52	55	56	57	57