

A Practical Look at Compression Set: Effect of Temperature and % Deflection

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ABSTRACT

ASTM D395 Method B (1) is the standard test method for evaluating compression set for a polyurethane. Originating in 1934, this test method would have been developed for rubber and thus its procedures optimized for applications involving rubber. The industry standard is to run a sample at 70°C under 25% deflection for 22 hours. The standard allows the user to choose a "suitable temperature and time for the compression set, depending upon the conditions of the expected service" and suggests times of 22 hours or 70 hours. In this paper, the effect of temperature and % deflection changes will be investigated on a number of different polyurethane elastomers of varying composition and stoichiometry, since in many applications the temperature is lower than 70°C and the deflection less than 25%.

INTRODUCTION

The standard testing method for compression set is ASTM D395 (1). This test which was first approved in 1934 was originally designed for rubber, but over time has been used for other "rubber like" or elastic materials such as polyurethane elastomers. The standard conditions for compression set of rubber are 25% deflection at 70°C for 22 hours. Over the years these same test conditions have become the standard for polyurethane elastomers and are presented in polyurethane reference books such as the Polyurethane Handbook, 2nd Edition (2) and Polyurethanes: Chemistry and Technology, Part 1 (3). The test conditions for ASTM D395 may work well for rubber, however, most polyurethane elastomer applications have % deflections much less than 25% and are used at temperatures significantly below 70°C except for dynamic applications like high-load wheels where there is heat buildup due to hysteresis.

The ASTM method for compression set is actually quite flexible. The temperature and duration of the test can be easily modified as stated in Section 13.3 of ASTM D395; "choose a suitable temperature and time for the compression set, depending of the conditions of the expected service" (1). Although the ASTM method only allows for 25% deflection, Method B can be easily modified to different % deflections by machining different size spacers. The goal of this paper is to study the effect of temperature and % deflection on the compression set of polyurethane elastomers. Although numerous PMA papers have presented compression set data, only one previous PMA paper has focused on compression set which was entitled "Designing Polyurethane Elastomers with Low Compression Sets" and authored by A. Sarpeshkar, P. Markusch and R. Cline in 2002 (4).

It is important to think about what compression set means in terms of the elastomer hard-segment and soft-segment phases also known as the elastomer morphology. Polyurethane elastomers form a two phase morphology where the hard-segment phase is dispersed in a continuous soft-segment phase. The hard segment consists of the diisocyanate and curative which is relatively short and rigid and the soft segment consists of the much more flexible and higher molecular weight (long) polyol. In a "perfect world", when a polyurethane elastomer is compressed or deflected, the flexible soft-segment phase (polyol) would deform and the rigid hard-segment phase would remain intact. When compression is released, the flexible soft-segment phase or polyol segments return to their original position resulting in a 0% compression set. However, in the "real" world, the compression sets of polyurethane elastomers are significantly higher than 0%. The reason for this is because there are permanent changes that take place in the hard-segment phase and even the soft-segment phase which cause the elastomer to not return to its original position.

EXPERIMENTAL

To study the effects of temperature and % deflection on the % compression set the following elastomers were cast (5):

LFTDI/PTMEG: 85A (Andur[®] 85 APLF); 95A (Andur[®] 95 APLF); and 60D (Andur[®] 60 DPLF)
LFTDI/Ester: 85A (Andur[®] 8-5 APLF); 95A (Andur[®] 9-5 APLF); and 60D (Andur[®] 6 DPLF)
Curatives: MBOCA (Curene[®] 442); and DMTDA (Curene[®] 107, Ethacure[®] 300)

LFTDI is a toluene diisocyanate (TDI) prepolymer containing less than 0.1 weight % of TDI monomer.

PTMEG is polytetramethylene glycol

Ester is polyethylene adipate

MBOCA is methylene bis(ortho chloro aniline)

DMTDA is dimethylthio toluene diamine

In general, the following conditions were used to cast the elastomers:

Prepolymer Temperature: 185°F (85°C)

Curative Temperature:

MBOCA: 230-240°F (110-115.5°C)

DMTDA: ambient temperature

To study the effect of stoichiometry (amine equivalents/isocyanate equivalents), the following levels were used:

Stoichiometry: 0.90, 0.95, 0.98, 1.00 and 1.05

Open molds were used to cast ½ inch thick buttons for compression testing. The mold temperature was 212°F (100°C). All samples were then post cured for 16 hours at 212°F (100°C). They were then conditioned at 23°C and 50% humidity for at least one month prior to compression set testing because it takes approximately one month for the final compression set to develop.

The compression set was determined according to ASTM D395 Method B. The following temperatures were used to study the effect of temperature on the compression set:

Compression Set Temperatures: 25°C, 50°C, 70°C and 85°C

To determine the effect of % deflection, the following levels were used:

% Deflection: 3%, 5%, 10% and 25%

To achieve these % deflection levels, the following steel spacers were fabricated:

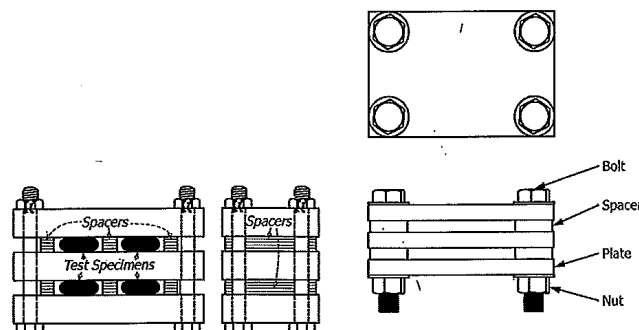
Steel Spacers: 3% (0.485 inches); 5% (0.475 inches); 10% (0.450 inches); and 25% (0.375 inches)

The ½" thick elastomer buttons were placed in the compression set jigs and then placed in an oven at the appropriate temperature for 22 hours. They were then taken out of the jig and conditioned at ambient temperature for 2 hours prior to measuring the thickness. All the raw compression set data is located in the Appendix.

The following equation was used to calculate the % Compression Set using ASTM D395 Method B:

% Compression Set = (initial thickness – final thickness)/(initial thickness – spacer thickness) x 100

An illustration of the devices used for the compression set test under constant deflection, ASTM D395, Test Method B is shown below (1):

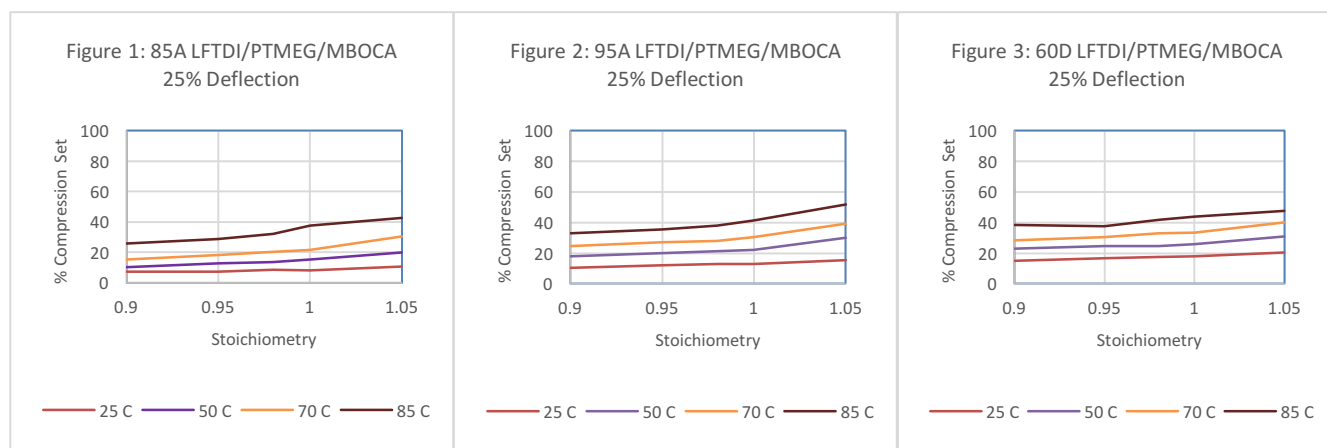


RESULTS AND DISCUSSION

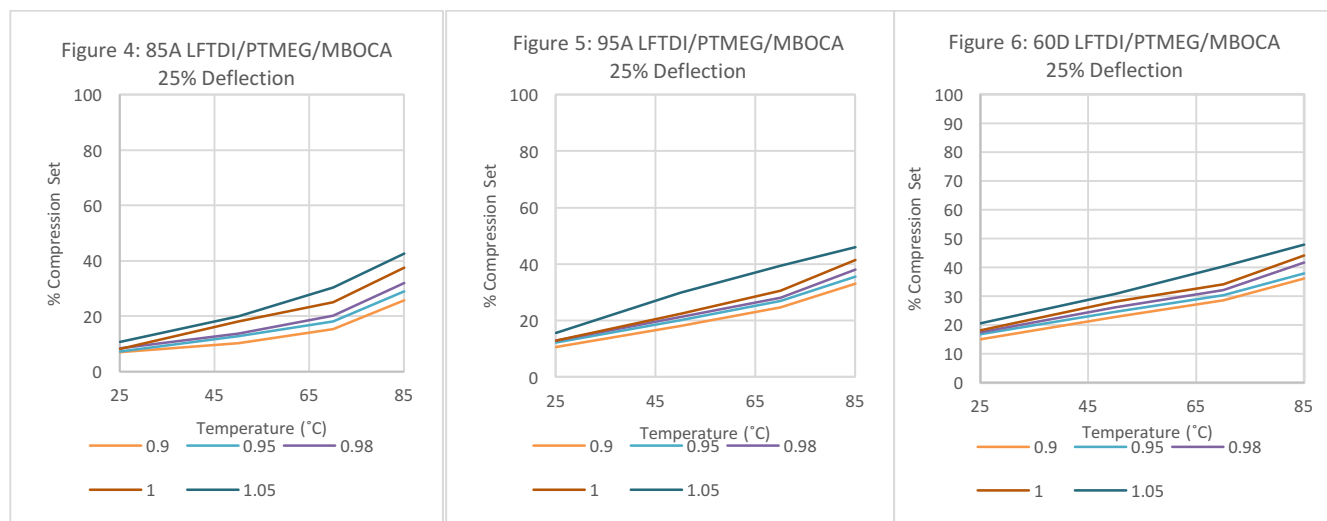
Effect of Temperature on % Compression Set: LFTDI/PTMEG/MBOCA

As mentioned in the Introduction, the typical conditions for determining the % compression set are 70°C for 22 hours at 25% deflection. The discussion of the effect of temperature on % compression set begins by plotting the % compression set versus the stoichiometry using a 25% deflection. The % compression set lines for each temperature (25°C, 50°C, 70°C and 85°C) were then plotted on each graph. Figures 1 through 3 show the graphs for an 85A, 95A and 60D LFTDI/PTMEG elastomers cured with MBOCA.

All the graphs clearly show the increase in % compression set with increasing temperature from 25°C up to 85°C. Interestingly, at 25°C there is very little change in compression set with increasing stoichiometry. However, as the temperature increases, the effect of stoichiometry increases such that the compression set gets higher with increasing stoichiometry. These results would suggest that if the application is at ambient temperature, that there is an opportunity to increase the stoichiometry significantly above the typical 0.95 to improve the tear strength and abrasion resistance of the elastomer. As expected, when one compares these Figures going from 85A up to 60D, the compression set increases. This trend is likely due to the increased compressive forces that occur at higher hardness which causes permanent change in the hard-segment phase.

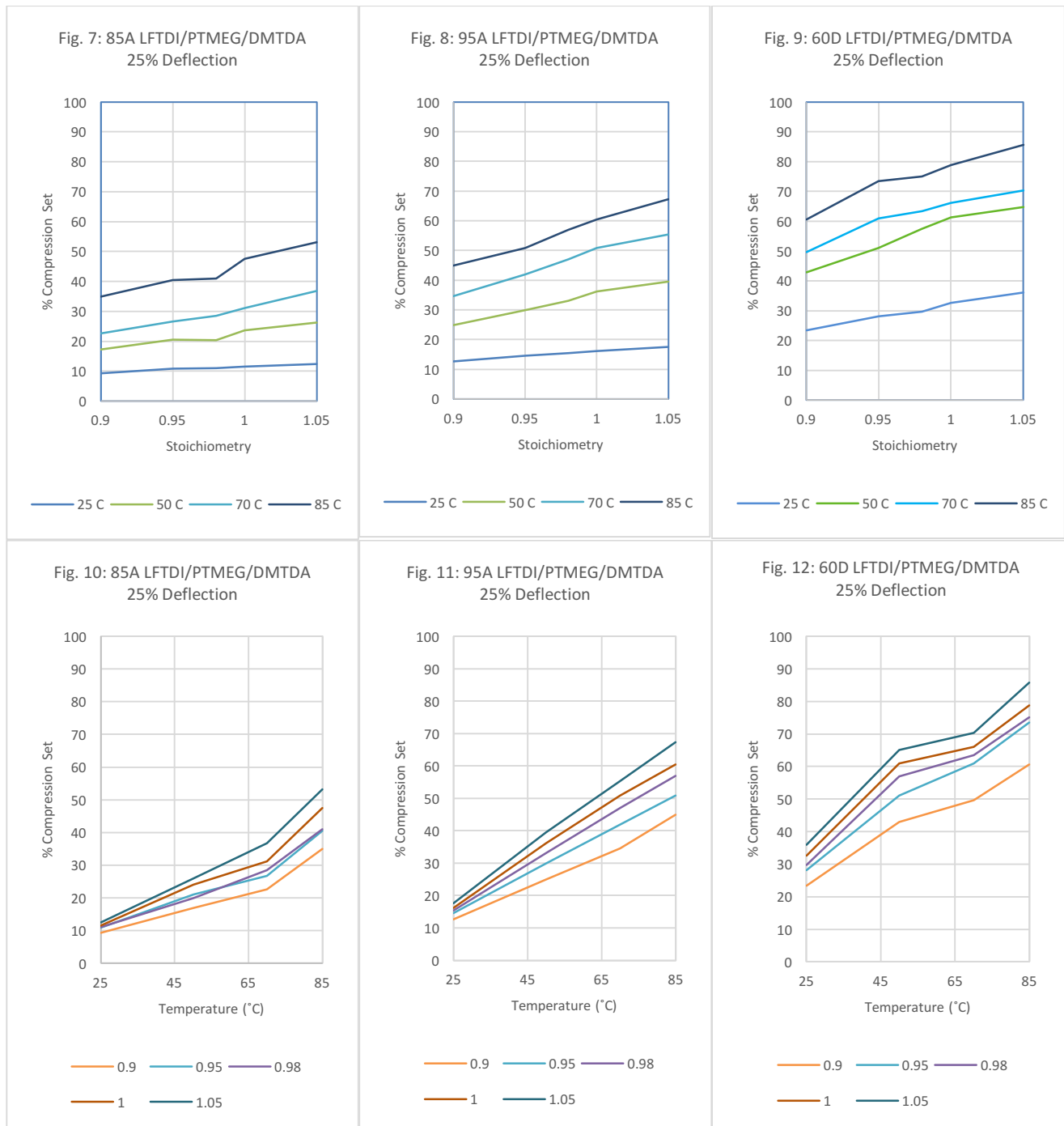


In Figures 4 through 6, the compression set is plotted versus the temperature instead of the stoichiometry. The compression set lines for each stoichiometry are then plotted on the graph. Figures 4, 5 and 6 show graphs for an 85A, 95A and 60D LFTDI/PTMEG/MBOCA elastomers. These figures clearly show that there is little to no effect of the stoichiometry at 25°C, but as the temperature increases up to 50°C, 70°C and 85°C, the effect on % compression set increases.



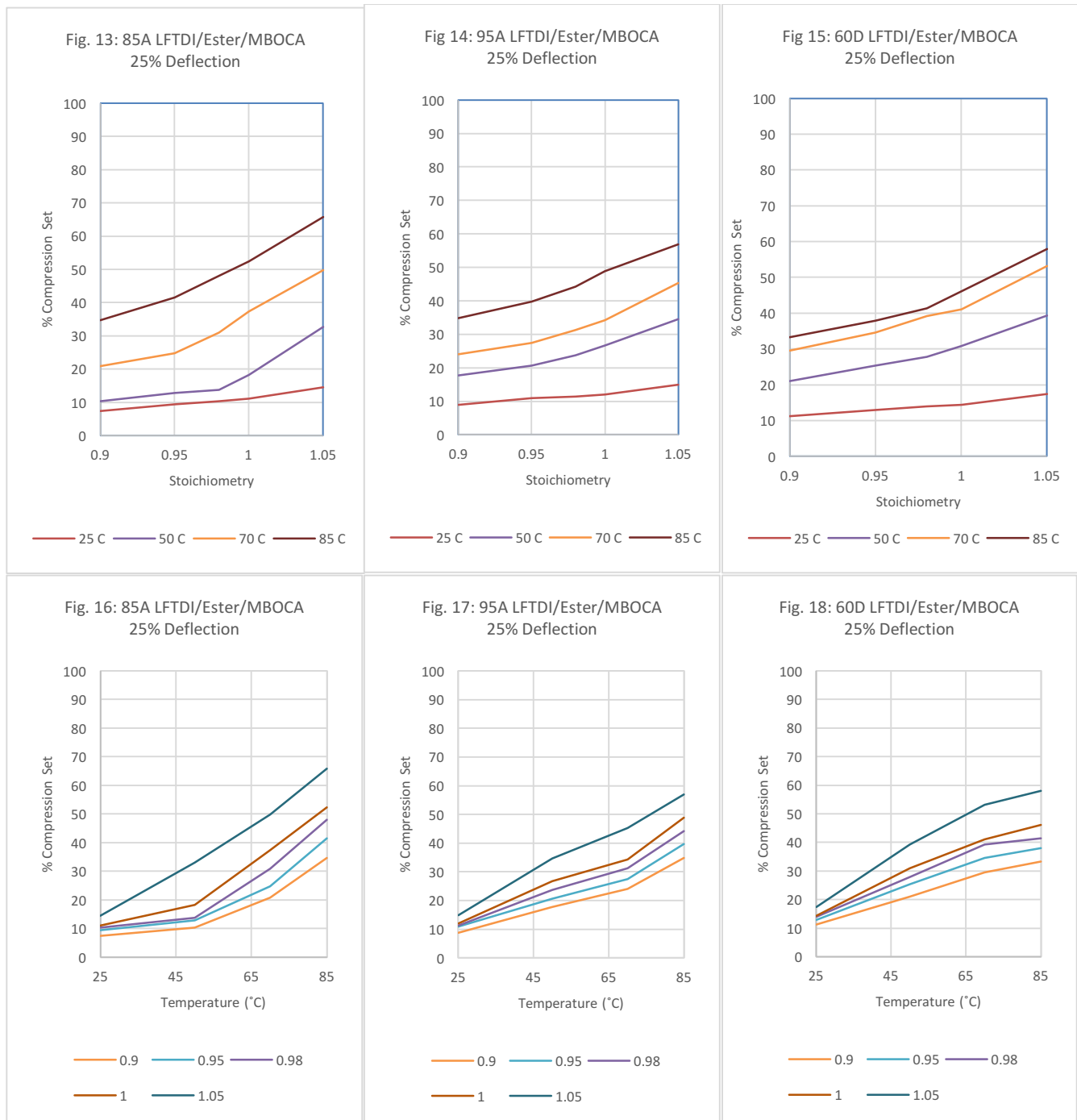
Effect of Temperature on % Compression Set: LFTDI/PTMEG/DMTDA

Figures 7 through 12 show the same graphs as before, except that DMTDA was used as the curative instead of MBOCA. At 25°C there is very little effect of the stoichiometry on compression set with the 85A elastomers, some effect at 95A and a very significant effect at 60D. The compression set of DMTDA cured LFTDI/PTMEG prepolymers increases more with increasing temperature than when using MBOCA as a curative. Additionally, the increase in compression set with increasing stoichiometry is higher with DMTDA than with MBOCA as a curative. These trends indicate that the TDI-DMTDA hard segment changes more readily upon compression than a TDI-MBOCA hard segment resulting in a higher compression set. These results are consistent with known history of TDI/PTMEG/MBOCA elastomers performing superior to TDI/PTMEG/DMTDA elastomers in dynamic applications.



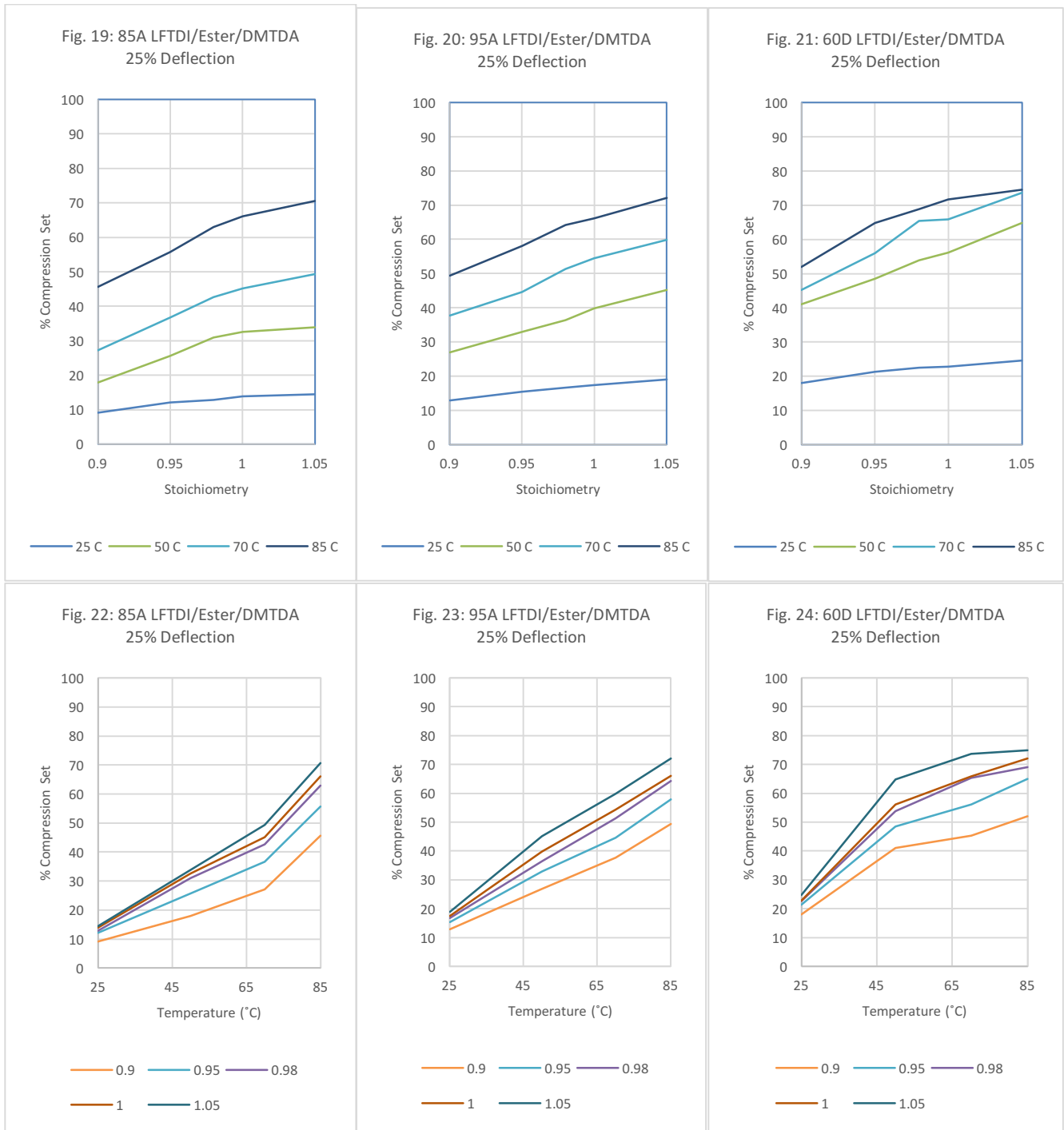
Effect of Temperature on % Compression Set: LFTDI/Ester/MBOCA

Figures 13 through 18 show the effect of temperature on the % compression set of LFTDI/Ester/MBOCA elastomers. The general trends are the same as with the LFTDI/PTMEG/MBOCA elastomers in Figures 1 through 6. The % compression sets at 25°C were not affected much by stoichiometry. However, at higher temperatures (70°C and 85°C), the effect of stoichiometry on compression set increases significantly. This trend can be clearly seen in Figures 16 through 18. One difference between the LFTDI/Ester/MBOCA and LFTDI/PTMEG/MBOCA elastomer is that the ester based elastomers had a higher compression set at stoichiometry of 1.00 and 1.05 at 70°C and 85°C. This behavior in a high-load wheel application would likely reveal itself as a higher tendency to flat spot at higher stoichiometry than a PTMEG-based elastomer.



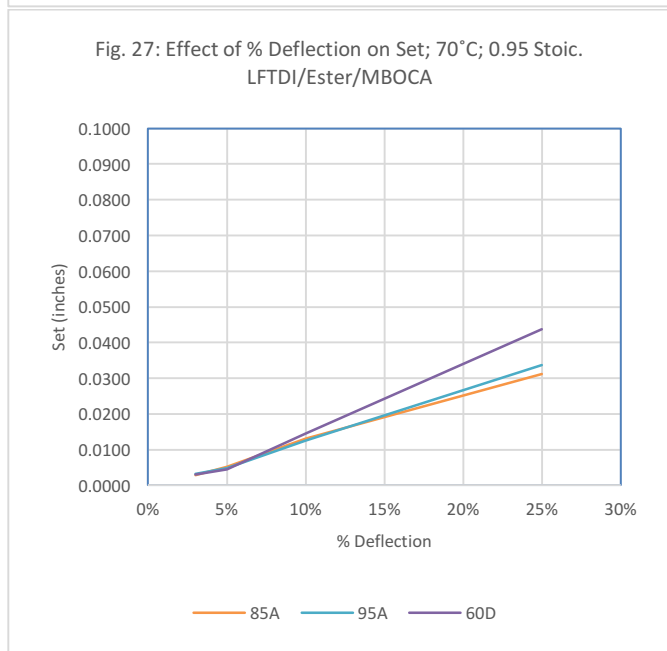
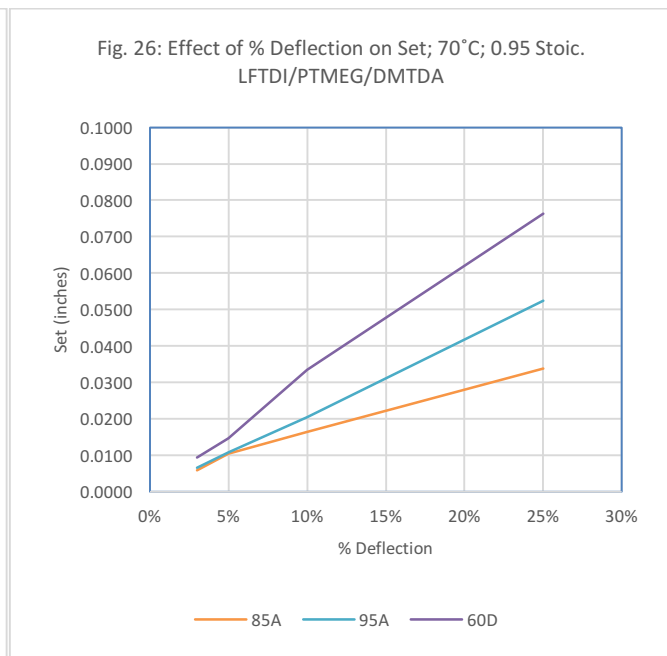
Effect of Temperature on % Compression Set: LFTDI/Ester/DMTDA

Figures 19 through 24 show the same type of graphs for LFTDI/Ester but using DMTDA as a curative. Using DMTDA as the curative there is slightly more of an effect of stoichiometry on % compression set at 25°C than with MBOCA. As with MBOCA, at higher temperatures (50°C, 70°C and 85°C) the effect of stoichiometry on % compression set is significantly higher. As with the PTMEG results, DMTDA has overall higher % compression sets than using MBOCA as a curative. Again this supports the historical findings that MBOCA cured elastomers are superior to DMTDA cured elastomer in dynamic applications.



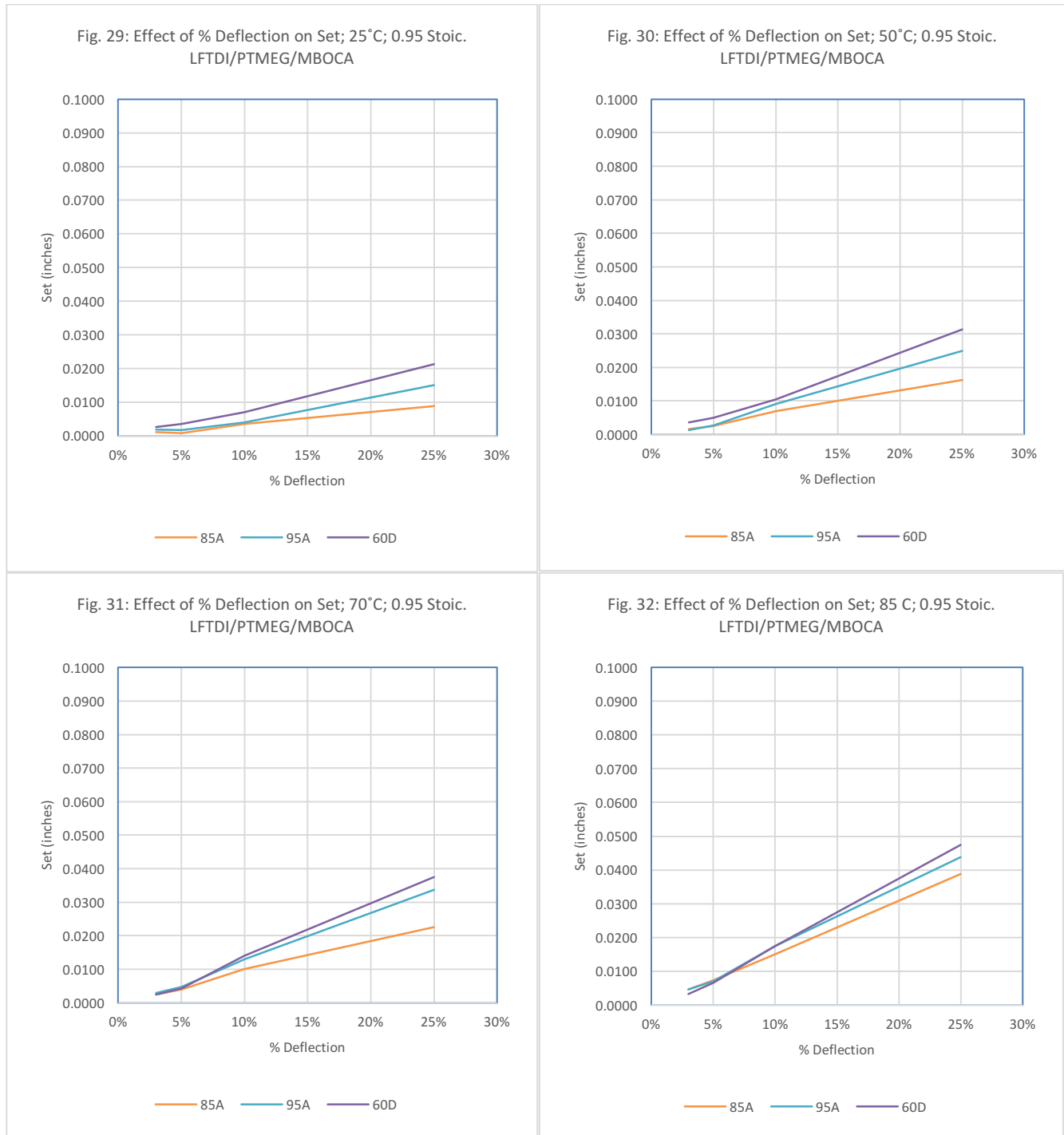
Effect of % Deflection on the Actual Set in Inches

To illustrate the effect of % deflection on the compression set of polyurethane elastomers, the % compression set was converted to actual set in inches. This was done by dividing the % compression set by 100 to convert to a fraction and then multiplying by the actual deflection in inches. Figures 25 through 28 show the effect of % deflection on the actual sets for 85A, 95A and 60D MBOCA and DMTDA cured elastomers, respectively at 70°C and 0.95 stoichiometry. As expected, the amount of set in inches increases with increasing % deflection. The amount of set at a 3% and 5% deflection is similar for 85A, 95A and 60D hardness, however, at higher % deflections the sets increase with increasing elastomer hardness. For the MBOCA cured elastomers the hardness effect does not become significant until a 25% deflection, but the effect on the DMTDA cured elastomer shows up at a 10% deflection. Also, these graphs clearly show that DMTDA has overall higher sets than MBOCA cured LFTDI prepolymers. These results are indications that the TDI-MBOCA hard segment forms a more permanent hard-segment phase than TDI-DMTDA.



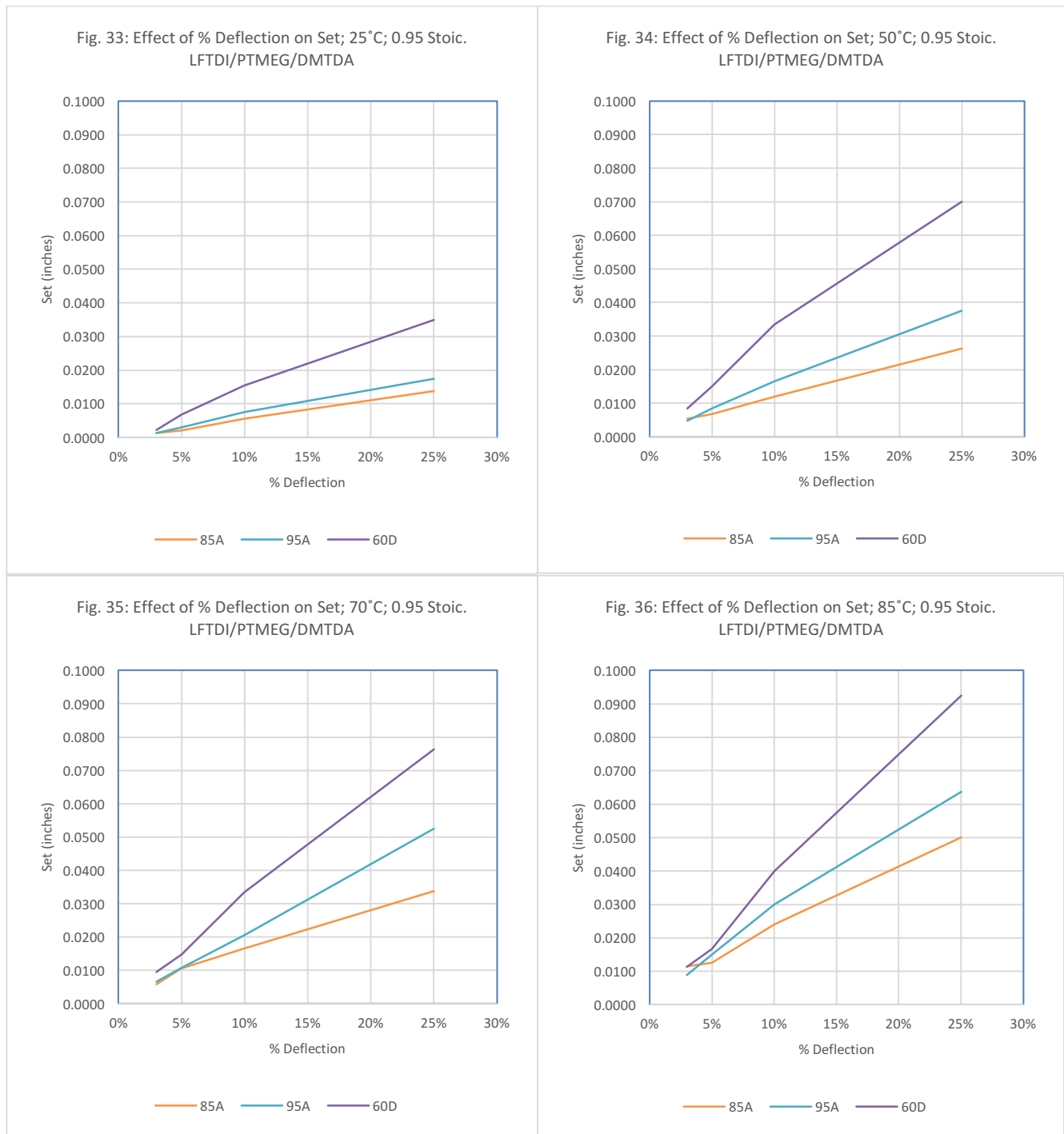
Effect of Temperature on the Actual Set in Inches: LFTDI/PTMEG/MBOCA

Figures 29 through 32 show the effect of % deflection on the actual sets for 85A, 95A and 60D LFTDI/PTMEG/MBOCA at a 0.95 stoichiometry at temperatures of 25°C, 50°C, 70°C and 85°C, respectively. At 25°C (Figure 29), the actual sets in inches are very low and does not increase significantly until % deflections greater than 10. At higher test temperatures of 50°C, 70°C and 85°C, the actual sets increase in a linear fashion with increasing % deflection. As expected, the actual sets increase with increasing elastomer hardness and with higher % deflections. Overall the effect of hardness on the actual sets are significantly lower when using MBOCA as a curative versus DMTDA even for the ester based elastomers as shown later in Figures 29 through 44.



Effect of Temperature on the Actual Set in Inches: LFTDI/PTMEG/DMTDA

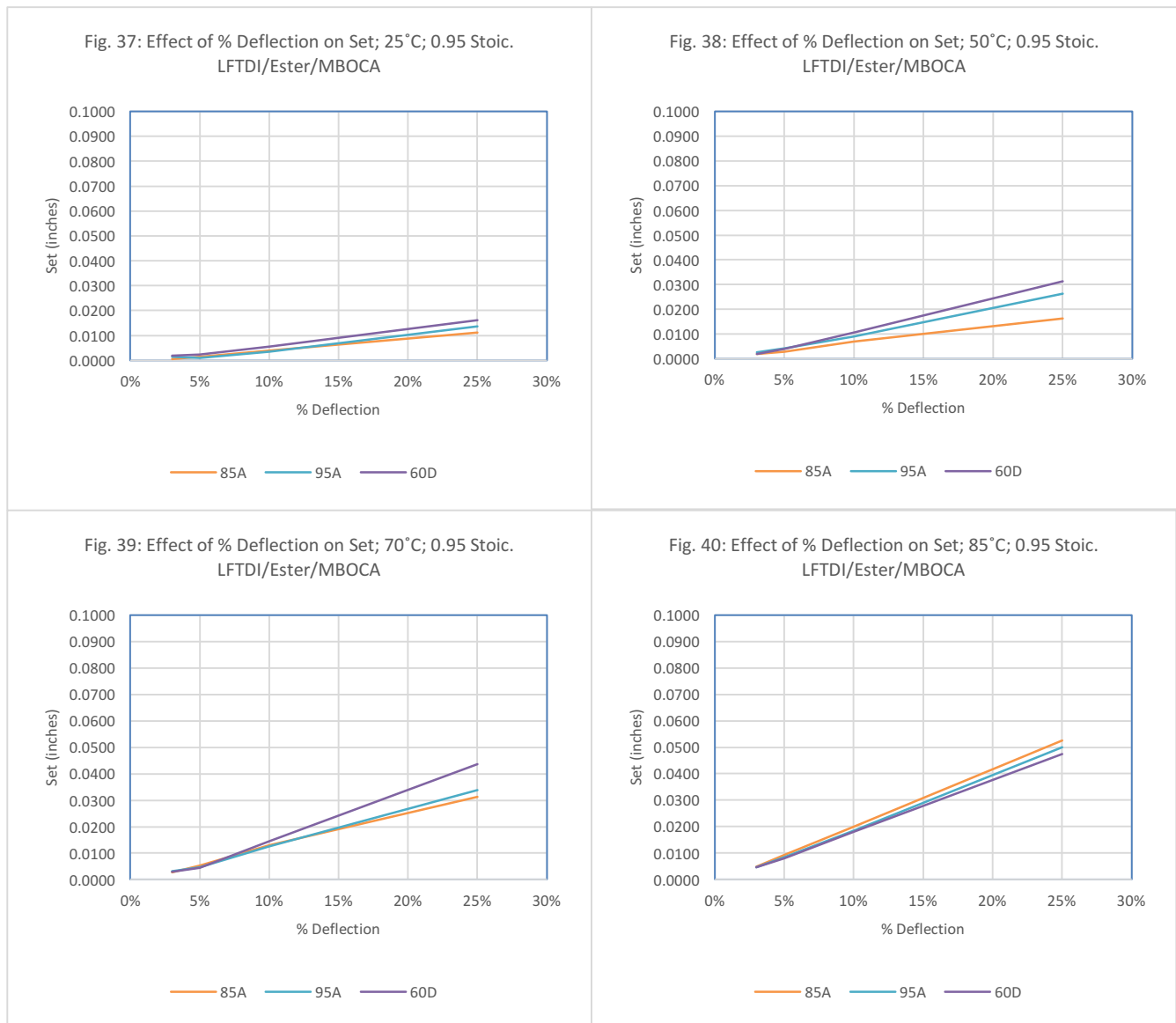
The effect of % deflection on the actual sets for 85A, 95A and 60D LFTDI/PTMEG/DMTDA at a 0.95 stoichiometry at temperatures of 25°C, 50°C, 70°C and 85°C are shown in Figures 33 through 36, respectively. At 25°C (Figure 33), the actual sets in inches are relatively low at an 85A and 95A hardness. At a 60D hardness, the sets increase more with increasing % deflection. This may be the result of the higher compressive forces at a higher elastomer hardness. At higher test temperatures of 50°C, 70°C and 85°C, the actual sets increase with increasing elastomer hardness and with higher % deflections. As discussed earlier, this effect is greater with DMTDA than with MBOCA due to the TDI-DMTDA hard-segment phase being more easily changed than the TDI-MBOCA hard-segment phase.



Effect of Temperature on the Actual Set in Inches: LFTDI/Ester/MBOCA

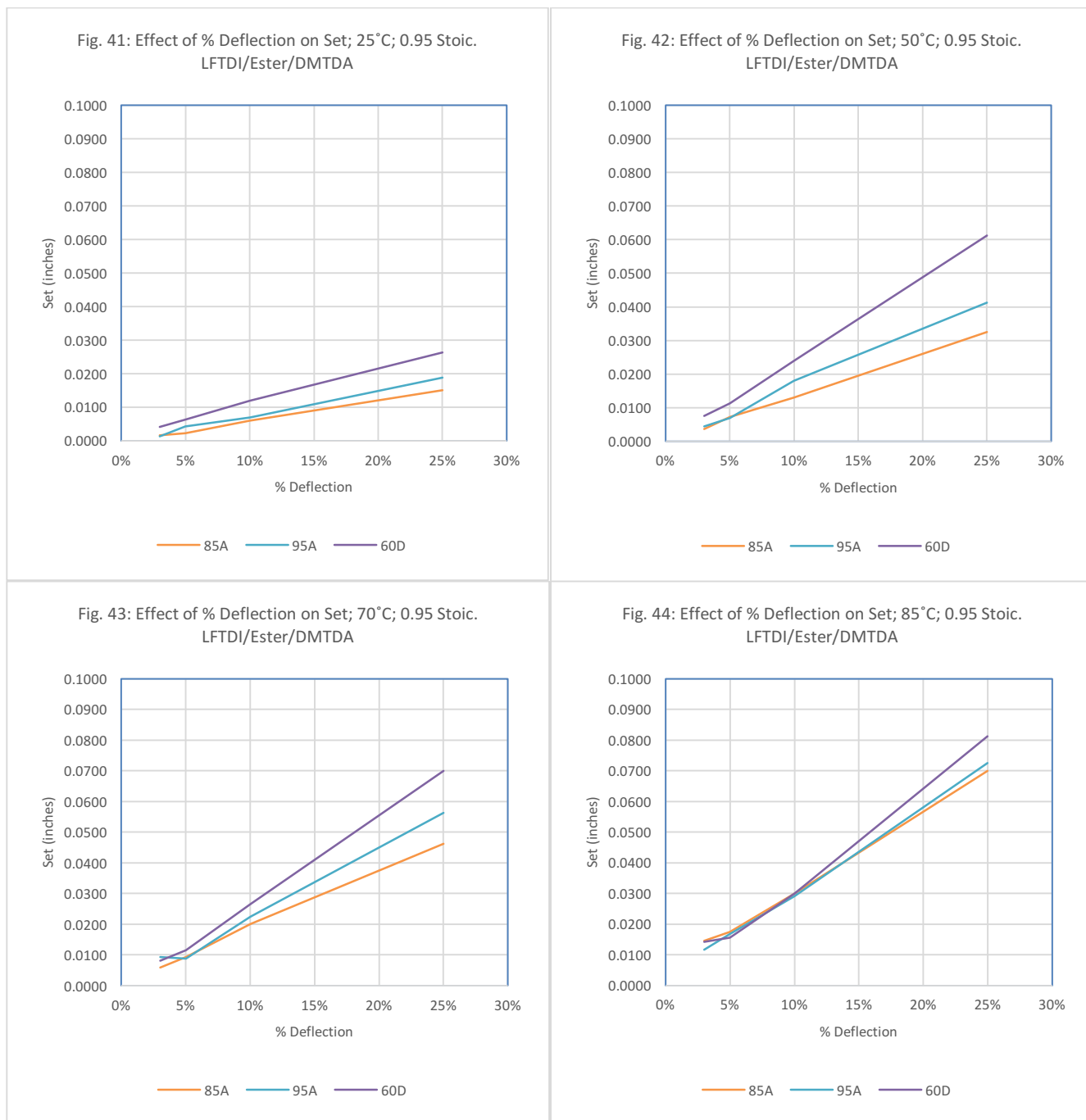
Figures 37 through 40 show the effect of % deflection on the actual sets for 85A, 95A and 60D LFTDI/Ester/MBOCA at a 0.95 stoichiometry at temperatures of 25°C, 50°C, 70°C and 85°C, respectively. The trends and overall shapes of the lines on these graphs are the same as those with the LFTDI/PTMEG/MBOCA elastomers. At 25°C (Figure 25), the actual sets in inches are very low and does not increase significantly until % deflections greater than 10. At higher temperatures of 50°C, 70°C and 85°C, the actual sets increase in a linear fashion with increasing % deflection. This implies that the TDI-MBOCA hard-segment phase is the major controlling factor in determining the actual set, not the soft-segment phase.

However, there are also indications that the soft-segment may also affect the actual set. At temperatures of 50°C, 70°C and 85°C, the actual sets of the 85A and 95A increasing more rapidly to become more similar to the actual sets at a 60D hardness. In fact at 85°C, the actual set of the 85A elastomer is higher than the 60D. This phenomena may be occurring because of the fact that at a lower hardness there is less of the hard-segment phase. The ester soft-segment phase being more polar than the PTMEG soft-segment phase may cause the hard-segment phase to be less permanent in its two-phase structure or morphology. In other words, the TDI-MBOCA hard-segment phase may be more compatible or soluble in the more polar ester soft-segment phase. Thus as the temperature increases, it causes the elastomers with less hard-segment phase (85A) to change more easily than elastomers with more hard-segment phase (60D). This is illustrated at 85°C in Figure 41 where the set of the 85A and 95A elastomer is actual slightly higher than the 60D elastomer.



Effect of Temperature on the Actual Set in Inches: LFTDI/Ester/DMTDA

The effect of % deflection on the actual sets for 85A, 95A and 60D LFTDI/Ester/DMTDA at a 0.95 stoichiometry at temperatures of 25°C, 50°C, 70°C and 85°C are shown in Figures 41 through 44, respectively. At 25°C (Figure 41), the actual sets in inches are relatively low at an 85A and 95A hardness which is the same trend as the LFTDI/PTMEG/DMTDA elastomers in Figure 33. However, at temperatures of 50°C, 70°C and 85°C, the actual set of the 85A and 95A are increasing more rapidly to become more similar to those at a 60D hardness. This is the same phenomena that was observed with the LFTDI/Ester/MBOCA elastomers. As the temperature increases, it is proposed that the more highly polar ester soft-segment phase causes the elastomers with less hard-segment phase (85A and even 95A) to change more easily than elastomers with more hard-segment phase (60D).



CONCLUSIONS

In a “perfect world”, when a polyurethane elastomer is compressed or deflected, the flexible soft-segment phase (polyol) would deform and the rigid hard-segment phase would remain intact. When compression is released, the flexible soft-segment phase or polyol segments return to their original position resulting in a 0% compression set. However, in the “real” world as shown by the results, the compression sets of polyurethane elastomers are significantly higher than 0%. The reason for this is because there are permanent changes that take place in the hard-segment phase and even the soft-segment phase which cause the elastomer to not return to its original position.

Historically, a vast majority of compression set data for polyurethane elastomers has been run at a temperature of 70°C and at 25% deflection. However, most polyurethane elastomer applications experience temperature below 70°C and deflections less than 25%. This study showed that at 25°C there is very little change in compression set with increasing stoichiometry at deflections of 10% or less. This would suggest that if the application is static and at ambient temperature that one could consider increasing the stoichiometry to improve the tear strength and abrasion resistance without compromising the % compression set.

At higher temperatures there is an increasing effect of stoichiometry on the compression set. If an application is at higher temperature or is a dynamic application such as high-load wheels then it is very important to target a lower stoichiometry to achieve low compression set values. This is particularly important at higher hardness levels.

Overall the data showed that MBOCA is a better curative than DMTDA in regards to compression set, particularly at higher temperatures and % deflections. This result is consistent with historical field results which indicate that MBOCA cured elastomers outperform DMTDA cured elastomers in dynamic applications. These results suggest that the TDI-MBOCA hard-segment forms a more permanent hard-segment phase than TDI-DMTDA. Thus the hard-segment phase composition in terms of its symmetry, order and crystallinity plays a major factor in determining the effects of temperature and % deflection on compression set. The compression set method could be considered a very useful tool to indicate the dynamic performance of a polyurethane elastomer composition. For example, a polyurethane elastomer composition that has low compression set at higher temperatures would potentially be a good candidate as an ultra high-performance elastomer for high speed roller coaster wheels.

The hard-segment plays a major role in determining the compression set, however, the data supports that the soft-segment phase may also affect the compression set. For example, even at low deflections of 3% and 5%, where likely only the soft-segment phase was affected there is a significantly high amount of compression set on a percentage basis. Also, it was observed that the actual sets of 85A and 95A ester-based elastomers increased more rapidly than 60D ester-based elastomers with increasing temperature. This phenomena may be occurring because of the fact that at a lower hardness there is less of the hard-segment phase. The fact that the ester soft segment is more polar than the PTMEG soft-segment may cause the hard-segment phase to be less permanent in its two-phase structure or morphology. Thus, as the temperature increases, it causes the elastomers with less hard-segment phase (85A) to change more readily than elastomers with more hard-segment phase (60D). This would suggest that softer TDI/ester/amine cured elastomers could be more sensitive in regards to compression set for higher temperature or dynamic applications.

In summary, compression set is a very important measurement which can not only be used to determine the permanent set of polyurethane elastomers under various conditions but may also be a “leading indicator” of the dynamic performance of the elastomer. This information can be used to make informed decisions in regards to which polyurethane composition to use and the stoichiometry to target for various applications.

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- 2) Guenther Oertel, Polyurethane Handbook, 2nd Edition, (1994), Hanser Gardner Publications
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- 4) A. Sarpeshkar, P. Markusch and R. Cline, Designing Polyurethane Elastomers with Low Compression Sets, May 7, 2002, PMA conference.
- 5) Andur[®] and Curene[®] are registered trademarks of Anderson Development Company; Ethacure[®] is a registered trademark of Albemarle Corporation.

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 University. 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 Covestro). In 1993, he joined ARCO Chemical/Lyondell Chemical. He has been working at Anderson Development Company since 2000.

Caleigh Elliott

Caleigh Elliott recently graduated with a bachelor's degree in Chemistry from Siena Heights University in Adrian, Michigan. She is currently an R&D intern in the Polyurethane Elastomers Group at Anderson Development Company. Her future plans are to either pursue graduate school or an entry level chemist position in industry.

Jordan Duckett

Jordan Duckett is currently a Urethane Technical Support Chemist 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 as a Urethane Technical Support Chemist in the Polyurethane Elastomers Group at Anderson Development Company.

APPENDIX: Raw Data for % Compression Sets of LFTDI/PTMEG Based Elastomers

% Dfl.	85A LFTDI/PTMEG/MBOCA					95A LFTDI/PTMEG/MBOCA				60D LFTDI/PTMEG/MBOCA			
	Stoic.	25°C	50°C	70°C	85°C	25°C	50°C	70°C	85°C	25°C	50°C	70°C	85°C
3%	0.9	2	10	12	29	4	8	16	30	11	11	11	20
	0.95	2	11	16	31	6	9	19	31	12	15	16	21
	0.98	3	11	14	33	4	11	15	28	16	18	21	24
	1	3	11	17	39	6	12	17	30	20	22	25	26
	1.05	4	10	25	41	11	14	20	36	21	33	37	30
5%	0.9	4	10	13	28	8	9	15	31	13	18	16	23
	0.95	3	10	16	29	7	11	19	28	14	20	17	26
	0.98	3	9	11	30	8	12	17	19	14	26	19	28
	1	7	15	21	43	10	11	21	38	16	28	21	28
	1.05	5	17	25	46	11	16	22	44	13	32	24	35
10%	0.9	7	12	14	30	8	17	26	33	12	19	25	36
	0.95	7	14	20	30	8	18	26	35	14	21	28	35
	0.98	7	14	22	30	10	18	28	35	14	25	30	38
	1	8	14	24	40	9	22	30	36	15	27	34	40
	1.05	9	17	30	46	13	22	33	48	15	26	33	41
25%	0.9	7	12	15	30	11	18	25	33	15	23	29	36
	0.95	7	13	18	31	12	20	27	35	17	25	30	38
	0.98	8	14	20	32	13	21	28	38	18	26	32	42
	1	8	18	25	38	13	22	30	41	18	28	34	44
	1.05	11	20	30	43	16	30	39	46	20	31	40	48
	85A LFTDI/PTMEG/DMTDA					95A LFTDI/PTMEG/DMTDA				60D LFTDI/PTMEG/DMTDA			
	Stoic.	25°C	50°C	70°C	85°C	25°C	50°C	70°C	85°C	25°C	50°C	70°C	85°C
3%	0.9	12	34	31	77	7	23	36	57	13	47	49	53
	0.95	9	36	39	77	9	32	44	59	15	56	63	75
	0.98	8	36	48	90	9	35	49	71	21	59	62	71
	1	13	34	47	98	10	40	54	87	27	69	78	81
	1.05	10	42	50	100	13	42	52	81	26	68	74	86
5%	0.9	6	25	36	49	13	27	36	51	22	49	50	57
	0.95	8	27	42	50	12	34	43	60	27	50	59	67
	0.98	6	26	38	57	10	34	44	64	25	55	62	69
	1	13	23	40	60	14	38	45	69	27	60	62	70
	1.05	16	30	47	68	12	39	51	72	30	63	66	80
10%	0.9	10	25	30	44	14	29	36	52	26	46	57	59
	0.95	11	24	33	48	15	33	41	60	31	51	67	70
	0.98	10	26	35	49	15	37	45	64	32	55	69	77
	1	13	26	37	53	16	41	51	70	35	60	73	80
	1.05	13	31	40	63	16	41	52	62	36	63	75	86
25%	0.9	9	17	23	35	13	25	35	45	23	43	50	61
	0.95	11	21	27	40	14	30	42	51	28	51	61	74
	0.98	11	20	29	41	15	33	47	57	30	57	63	75
	1	12	24	31	48	16	36	51	60	33	61	66	79
	1.05	12	26	37	53	18	40	55	67	36	65	70	86

APPENDIX: Raw Data for % Compression Sets of LFTDI/Ester Based Elastomers

% Dfl.	85A LFTDI/Ester/MBOCA					95A LFTDI/Ester/MBOCA				60D LFTDI/Ester/MBOCA			
	Stoic.	25°C	50°C	70°C	85°C	25°C	50°C	70°C	85°C	25°C	50°C	70°C	85°C
3%	0.9	3	10	23	31	10	17	20	22	8	14	18	30
	0.95	3	13	19	32	9	18	21	31	12	13	20	31
	0.98	4	11	22	37	10	15	22	34	10	18	21	32
	1	4	11	30	47	15	19	25	32	11	19	27	32
	1.05	5	10	37	56	16	35	40	50	11	22	27	41
5%	0.9	2	10	17	25	5	18	15	32	8	14	15	26
	0.95	6	11	21	37	4	17	19	34	9	16	18	32
	0.98	6	9	19	41	5	20	21	36	8	18	17	34
	1	6	15	35	53	4	23	27	43	10	21	28	39
	1.05	7	17	40	58	7	27	32	44	10	25	35	43
10%	0.9	7	12	23	40	5	15	21	31	9	18	25	31
	0.95	8	14	26	40	7	18	25	37	11	21	29	36
	0.98	8	14	30	47	8	20	29	38	11	21	30	38
	1	8	14	37	51	9	22	30	43	11	24	32	43
	1.05	10	17	44	60	10	25	36	48	12	27	37	49
25%	0.9	7	10	21	35	9	18	24	35	11	21	29	33
	0.95	9	13	25	42	11	21	27	40	13	25	35	38
	0.98	10	14	31	48	11	24	31	44	14	28	39	41
	1	11	18	37	52	12	27	34	49	14	31	41	46
	1.05	14	33	50	66	15	35	45	57	17	39	53	58
% Dfl.	85A LFTDI/Ester/DMTDA					95A LFTDI/Ester/DMTDA				60D LFTDI/Ester/DMTDA			
	Stoic.	25°C	50°C	70°C	85°C	25°C	50°C	70°C	85°C	25°C	50°C	70°C	85°C
3%	0.9	10	22	40	98	12	24	54	62	28	52	53	86
	0.95	11	24	39	97	9	30	62	77	27	51	54	95
	0.98	9	30	43	100	13	42	62	78	29	48	55	100
	1	10	33	48	100	19	35	64	75	27	54	61	100
	1.05	14	34	48	100	16	35	77	76	25	53	60	100
5%	0.9	10	18	32	54	17	31	36	55	20	41	40	57
	0.95	9	29	37	70	17	28	35	67	23	45	46	62
	0.98	9	31	35	59	16	39	48	66	20	40	43	65
	1	13	31	51	76	19	43	53	67	29	56	62	70
	1.05	13	32	50	73	17	43	54	74	30	56	66	72
10%	0.9	9	20	32	50	10	30	38	50	20	41	45	52
	0.95	12	26	40	60	14	36	45	58	24	48	53	60
	0.98	13	30	45	66	14	39	48	62	24	51	57	63
	1	14	31	48	64	15	41	49	69	26	52	59	66
	1.05	12	30	52	68	14	45	55	71	26	53	63	76
25%	0.9	9	18	27	46	13	27	38	49	18	41	45	52
	0.95	12	26	37	56	15	33	45	58	21	49	56	65
	0.98	13	31	43	63	17	36	51	64	23	54	65	69
	1	14	33	45	66	17	40	54	66	23	56	66	72
	1.05	14	34	49	71	19	45	60	72	25	65	74	75