Recent Advances in Flexible Foam

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Agenda

TOPIC 1: Improved Green Strength in Slab and Molded Applications (Mark McBride)

- Overview
- Experimental Design
- Results
- Conclusion & Takeaways

TOPIC 2: Next Generation Gel Formulations for Flexible Slab Foams (Willie Wesley III)

- Overview
- Experimental Design
- Results
- Conclusions & Takeaways

Q&A

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Overview: Improved Green Strength in Slab and Molded Applications

Current Challenges

- HyperSoft™ foam formulations exhibit slow cure times and poor green strength on production slab lines
- Foam buns adhere to conveyer lines and rollers
- Softer formulations in molded applications exhibit similar processing drawbacks

Solution

- Develop new high ethylene oxide polyether polyol (Pluracol® 2029/1) to use in place of Pluracol® 593
- Compare foam formulations made with Pluracol® 2029/1 to those made with Pluracol® 593 polyol

Table 1 – Pluracol® 2029/1 Polyol Properties

Pluracol® 2029/1 Properties	
Hydroxyl number, mg KOH/g	44.0 - 47.0
Molecular Weight	4,360
Viscosity @77F, cps	985

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Experimental Design: Improved Green Strength in Slab and Molded Applications

Experiments

- Experiment #1 – Gel Viscosity Testing
- Experiment #2 – Cannon Viking Slab Foam Machine Testing
- Experiment #3 – Molded Pillows Testing

Experiment #1 – Gel Viscosity Testing

- Measure viscosity throughout TDI-based urethane reaction
- Brookfield DV-III Ultra Programmable Rheometer (LV-3 spindle) - collect data every 10 sec during reaction

Figure 1 – Benchtop Rheometer Set-Up

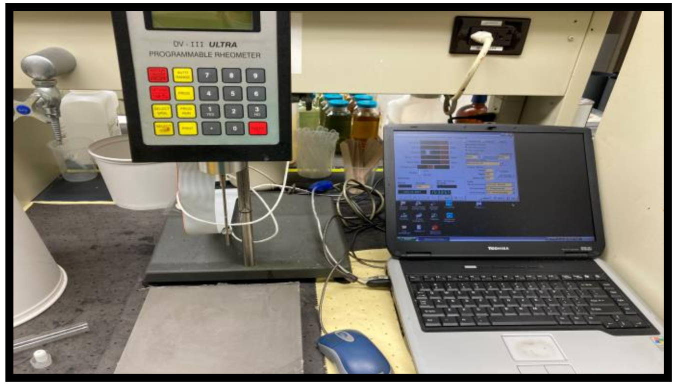

Table 2 – Formulations for Gel Viscosity Testing

Formulation (pbw)	1	2
Pluracol® 593 polyol	100	
Pluracol® 2029/1 polyol		100
Stannous Octoate	0.2	0.2
Lupranate® T-80 TDI	7.1	7.1
TDI Index	100	100

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Experimental Design: Improved Green Strength in Slab and Molded Applications

Experiment #2 – Cannon Viking Slab Foam Machine Testing

- Compare HyperSoft™ foam formulations: Pluracol® 2029/1 vs. Pluracol® 593 polyol on pilot slab machine
- 42” height by 50” width foam buns made in accordance with ASTM D3574

Table 3 – Low Density HyperSoft™ Foam Formulations

Formulation (pbw)	1	2	3	4	5	6
Pluracol® 593 polyol				78	78	78
Pluracol® 2100 polyol	22	22	22	22	22	22
Pluracol® 2029/1 polyol	78	78	78			
Water	4.5	4.5	4.5	4.5	4.5	4.5
Momentive NIAX™ Silicone L635	1.4	1.4	1.4	1.4	1.4	1.4
Evonik DABCO® NE500	0.09	0.09	0.09	0.09	0.09	0.09
Evonik DABCO® NE300	0.03	0.03	0.03	0.03	0.03	0.03
Evonik DABCO® T-9	0.16	0.12	0.08	0.16	0.12	0.08
Methyl Formate	3	3	3	3	3	3
Lupranate® T-80 TDI	50.8	50.8	50.8	50.9	50.9	50.9
TDI Index	102	102	102	102	102	102

Table 4 – Higher Density HyperSoft™ Foam Formulations

Formulation (pbw)	1	2	3	4	5	6
Pluracol® 593 polyol				78	78	78
Pluracol® 2100 polyol	22	22	22	22	22	22
Pluracol® 2029/1 polyol	78	78	78			
Water	3.2	3.2	3.2	3.2	3.2	3.2
Momentive NIAX™ Silicone L635	1.4	1.4	1.4	1.4	1.4	1.4
Evonik DABCO® NE500	0.12	0.12	0.12	0.12	0.12	0.12
Evonik DABCO® NE300	0.04	0.04	0.04	0.04	0.04	0.04
Evonik DABCO® T-9	0.16	0.12	0.08	0.16	0.12	0.08
Lupranate® T-80 TDI	37.7	37.7	37.7	37.8	37.8	37.8
TDI Index	101	101	101	101	101	101

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Experimental Design: Improved Green Strength in Slab and Molded Applications

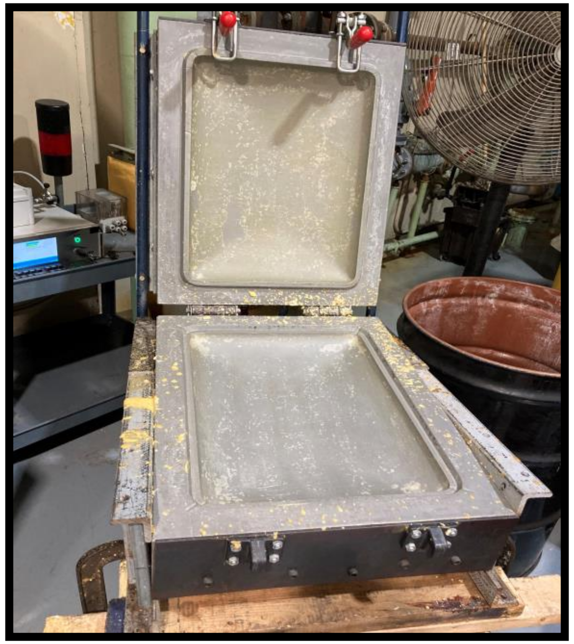
Experiment #3 – Molded Pillows Testing

- Compare hybrid-viscoelastic formulations: Pluracol® 2029/1 vs. Pluracol® 593 polyol in molded pillows
- Pillow mold heated to 125°F and all formulations demolded after 10 minutes

Table 5 – Hybrid Foam Molded Pillows

Formulation (pbw)	Formulation 1		Formulation 2	
Pluracol® 593 polyol	82.0		82.0	
Pluracol® 2029/1 polyol		82.0		82.0
Pluracol® 4156 polyol	18.0	18.0		
Pluracol® 1538 polyol			18.0	18.0
Evonik DABCO® DC198	1.5	1.5	1.5	1.5
Evonik DABCO® NE300	0.25	0.25	0.25	0.25
Evonik DABCO® NE500	0.25	0.25	0.25	0.25
Water	3.0	3.0	3.0	3.0
Lupranate® L5100 MDI	43.9	43.9	43.9	43.9
MDI Index	80	80	80	80

Figure 2 – Pillow Mold Set-Up



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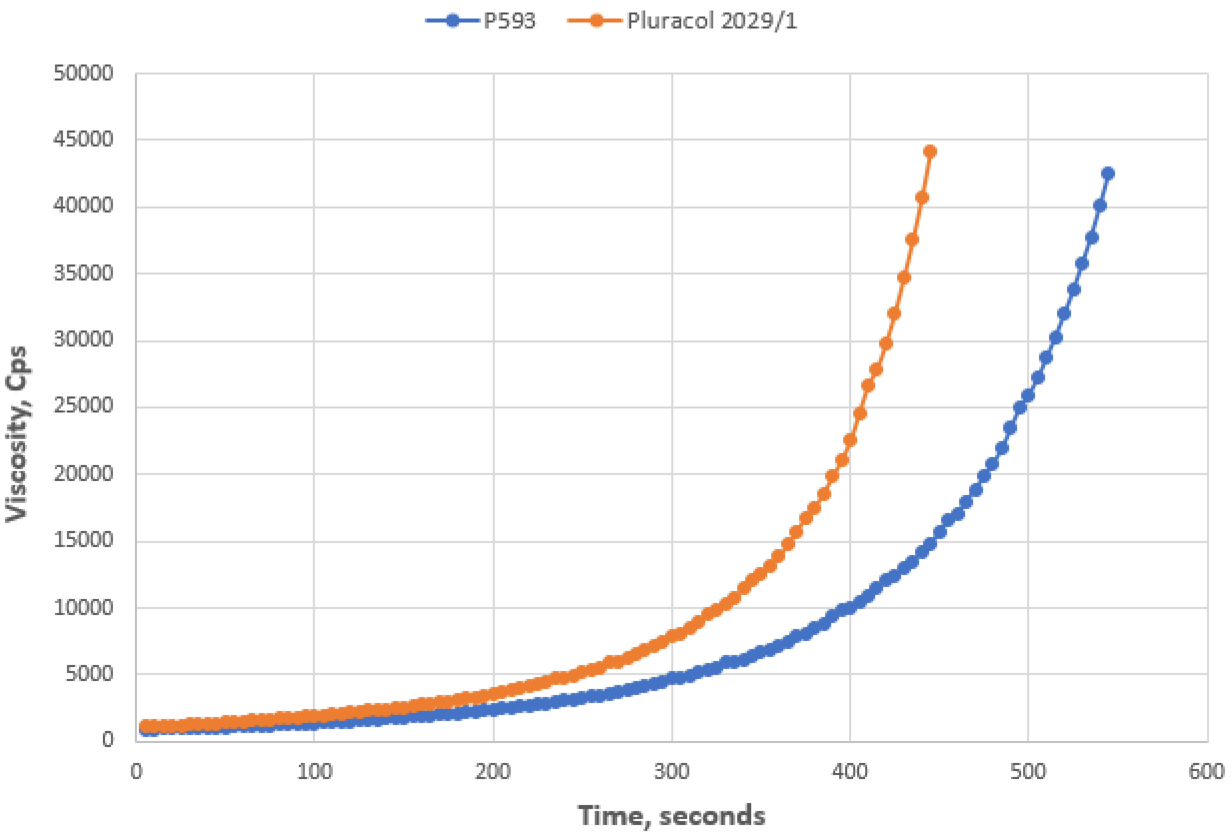
Results: Improved Green Strength in Slab and Molded Applications

Experiment #1 – Gel Viscosity Testing

- Pluracol® 2029/1 polyol demonstrated a *20% faster cure time* compared to Pluracol® 593 polyol in identical TDI formulations

Figure 3 – Gel Viscosity Test: Pluracol® 593 vs. Pluracol® 2029/1 polyol



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Results: Improved Green Strength in Slab and Molded Applications

Experiment #2 – Cannon Viking Slab Foam Machine

- HyperSoft™ foam formulations with Pluracol® 593 polyol are not fully cured coming off pilot scale slab line, causing foam buns to stick to rollers leading to difficulty handling
- HyperSoft™ foam formulations with Pluracol® 2029/1 polyol displayed reduced tackiness and faster cure times, allowing for easier handling of foam buns
- No negative impact on physical properties were observed

Figure 4 – Handling of Foam Buns on Pilot Scale Slab Machine

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Results: Improved Green Strength in Slab and Molded Applications

Experiment #3 – Molded Pillows

- Slightly higher density and IFD when Pluracol® 2029/1 polyol was used in formulations
- De-mold times held constant; however, pillows made with P2029/1 were less tacky coming out of mold

Table 6 – Molded Pillow Formulation Physical Properties

	Formulation 1		Formulation 2	
Physical Properties	P593	P2029/1	P593	P2029/1
Air Flow (cfm)	>8	>8	>8	>8
CFD Humid Aged (50 % Retained)	64	64	64	66
Compression Set (Ct) 50 %	4	5	4	4
Compression Set (Ct) 90 %	3	5	4	6
Compression Set Humid Aged (Ct) 50 %	7	7	5	5
Compression Set Humid Aged (Ct) 90 %	7	7	4	5
Core Density (pcf)	2.63	2.73	2.71	2.79
Original IFD at 25 %	5.8	7.5	7.0	9.2
Original IFD at 65 %	15.6	20.0	17.3	22.5
Original IFD at 25 % Return	5.3	6.8	6.6	8.3
% Recovery	92	91	94	90
Support Factor	2.69	2.67	2.48	2.46
Recovery Time (sec)	1	1	1	1
D3574 Resilience (%)	27	30	25	25
Tensile Strength (psi)	8	9	7	7
Ultimate Elongation (%)	173	149	153	130
Tg (°C)	0	-5	-1	-1

Results: Improved Green Strength in Slab and Molded Applications

Additional Experiments – TDI Viscoelastic Foams

- Formulations using 59 pbw of Pluracol® 2029/1 in comparison to Pluracol® 593 polyol
  - No change in hardness and density
  - Higher airflow
    - Formulation 1: 66% increase
    - Formulation 2: 39% increase
  - Better damping
    - Higher hysteresis (+4%)
    - Lower ball rebound (6% vs. 9%)

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Conclusions: Improved Green Strength in Slab and Molded Applications

- Pluracol® 2029/1 polyol demonstrates *faster cure times* and *improved green strength* compared to Pluracol® 593 polyol as a drop-in for flexible foam formulations
- These improvements can aid in slab and molded production processes by:
  - Ease of bun handling
  - Faster processing times
- No negative impacts on mechanical properties of the finished polyurethane foams were observed

→ Contact Mark McBride (mark.mcbride@basf.com) for Pluracol® 2029/1 polyol inquires

Table 1 – Pluracol® 2029/1 Polyol Properties

Pluracol® 2029/1 Properties	
Hydroxyl number, mg KOH/g	44.0 - 47.0
Molecular Weight	4,360
Viscosity @77F, cps	985

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Overview: Next Generation Gel Formulations for Flexible Slab Foams

Current Challenges

- Solid formation with original Elastopan® polyurethane gels caused clogging in CO_2 process filters
- Next gen offerings must provide same benefits:
  - Cooling effects
  - Ease of use
  - Neutralization of tin (HR gel)
- Improve sustainability / environmental position of get components

Solution

- Improve processing ease of Elastopan® polyurethane gels while maintaining performance
  - Gel catalyst was hypothesized to be the driver of solids formation
    - → Test Elastopan® 5291TW gel using CO_2 process to verify gel is no longer clogging filters
    - → Pour HR foams via trough pour process to demonstrate HR-2 gel performance

Experimental Design: Next Generation Gel Formulations for Flexible Slab Foams

Experiments

- Experiment #1 – Catalyst Selection Testing
- Experiment #2 – Gel Viscosity Testing
- Experiment #3 – Cannon Viking CO_2 Process Slab Foam Machine Testing
- Experiment #4 – Cannon Viking HR Slab Foam Machine Testing

Experiment #1 – Catalyst Selection Testing

- Synthesize gel prototypes varying only the catalyst between formulations
- Confirm gel reactions profiles via smooth flow and no solids generation

Table 7 – Basic Polyurethane Gel components

Polyol
Plasticizer
Isocyanate
Catalyst
Colorant (optional)

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Results: Next Generation Gel Formulations for Flexible Slab Foams

Experiment #1 – Catalyst Selection Testing

- Catalysts were evaluated by the following criteria:
  - Potency
  - Environmental impact
  - Supply availability
- Catalyst type was varied, but remaining parameters were held constant:
  - Catalyst concentration
  - Addition process
  - Resonance time

Figure 5 – NOVAFLEX® dispensing process

Experiment #2 – Gel Viscosity Testing

- Gel viscosities curves were generated to confirm desired processing range (<5000 cPs)

Experiment #3 – Cannon Viking HR Slab Foam Machine Testing

- HR slab foams were produced via trough pour process on Cannon Viking Slab Pilot Machine

Experiment #4 – Cannon Viking CO_2 Process Slab Foam Machine Testing

- Experimental gel was foamed in a conventional formula via NOVAFLEX® dispensing process
- Formulations with and without gel were run side-by-side to measure potential pressure increase
  - Loading levels were varied to ensure safe pressures at multiple outputs

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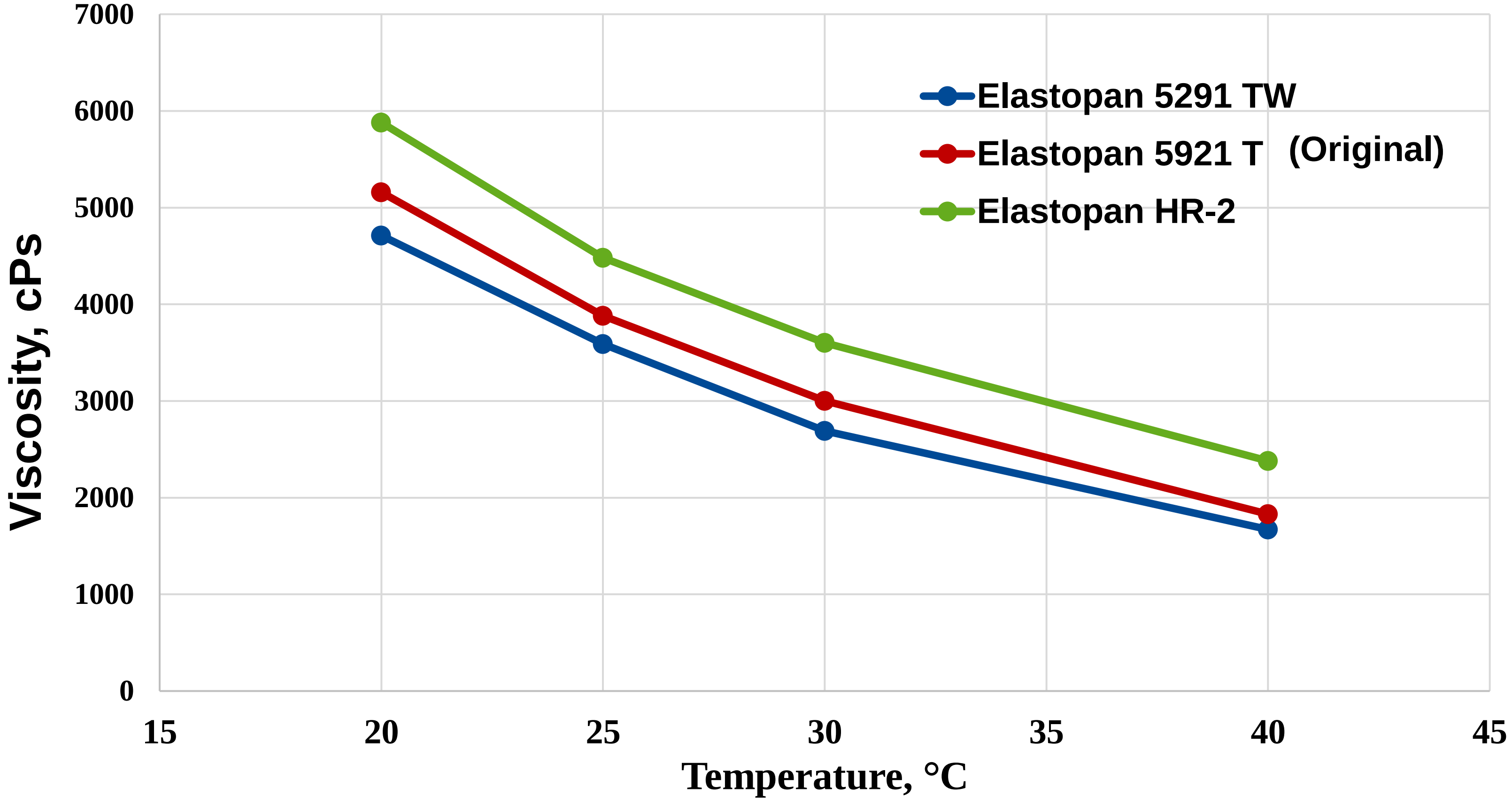
Results: Next Generation Gel Formulations for Flexible Slab Foams

Experiment #2 – Gel Viscosity Testing

- Elastopan® 5291 TW gel showed a slight decrease in viscosity compared to original formulation
- Elastopan® HR-2 gel met acceptable viscosity range for urethane gel used in slab processes

Figure 6 – Gel Viscosity Curves for Elastopan® Polyurethane Gel Prototypes



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Results: Next Generation Gel Formulations for Flexible Slab Foams

Experiment #3 – Cannon Viking HR Slab Foam Machine Testing

- Elastopan® HR gel performs two primary functions: neutralizes T-12 (dibutyltin dilaurate) and provides cooling effect
- HR foam was poured via trough method using the new HR-2 formula to verify tin neutralization continued
  - Proper tin neutralization was confirmed by a significant reduction in compression set loss

Table 8: HR-2 Gel Trough Pour Trial Compression Set Properties

Physical Properties	1	2	3	4	5	6
Compression Sets (% set)						
50%	10.0	7.8	5.3	6.1	4.6	6.5
90%	39.5	8.8	8.1	6.7	5.9	5.5
50%**	14.9	8.4	7.5	8.1	7.0	7.0
90%**	69.1	18.3	15.8	36.4	14.2	11.2
CFD (% Of Original 50%)	0.4	0.4	0.5	0.5	0.6	0.6
Air Flow (cfm)	0.9	0.9	1.1	0.8	0.8	0.7

NOTE: Samples 1 and 4 have 0 pts, Samples 2 and 5 have 4 pts and Samples 3 and 6 have 8 pts of HR gel.
**Humid Aged – 220°F for 3hrs

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Results: Next Generation Gel Formulations for Flexible Slab Foams

Experiment #4 – Cannon Viking CO_2 Process Slab Foam Machine Testing

- Original Elastopan® 5291T gel led to consistent shutdowns due to pressure increases from clogged filters
- Elastopan® 5291TW gel ran successfully with same foam formulations generating +21 – 29 psig pressure

Table 9 - NOVAFLEX® Manifold Pressures

Process Data	1	2	3	4	5	6
Manifold Pressure (psig)	153	154	154	182	180	175
Throughput (kg/min)	30.0	30.0	30.0	30.0	30.0	30.0
Conveyor Speed (ft/min)	11.0	11.0	11.0	11.0	11.0	11.0

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Conclusions: Next Generation Gel Formulations for Flexible Slab Foams

- BASF has developed the next generation of Elastopan® polyurethane gels via a catalyst change:
  - No CO_2 filter clogging while still maintaining desired physical properties as a drop-in
  - Tin neutralization in HR foam formulations to prevent urethane “unzipping”
  - Improved sustainability profile of gels

→ Contact Willie Wesley III (willie.wesley@basf.com) for Elastopan® gel product inquires

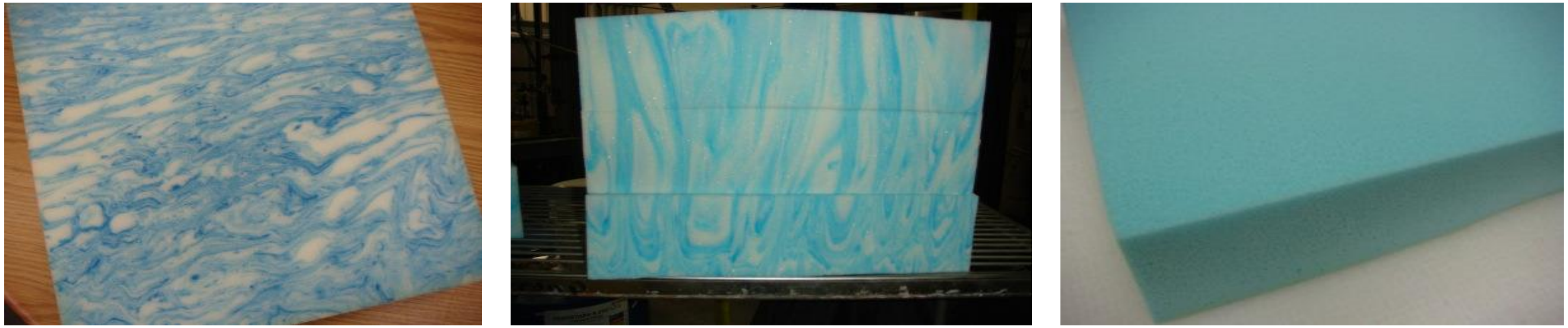

Figure 7 – Elastopan® gel incorporated via swirl pattern (left). Elastopan® gel incorporated in ribbon pattern (middle). Elastopan® gel fully mixed into the foam (right).

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Back-Up Slides

Table 10 – Low Density HyperSoft™ Foam Formulations Physical Properties

	Pluracol® 2029/1			Pluracol® 593		
Physical Properties	1	2	3	4	5	6
Density (pcf)	0.99	1.01	1.02	1.06	1.09	1.08
Tensile (psi)	10	13	14	8	10	11.
Elongation (%)	289	332	347	338	310	419
Heat Aged Tensile (psi)	10	11	12	7	9	10
Heat Aged Elongation (%)	296	311	340	304	297	384
Tear (pi)	2.7	3.1	3.2	2.7	2.5	2.7
Resilience (%)	43	43	44	40	44	47
IFD, lb. /50 sq. in. (4 in.)						
25%	9.3	10.0	10.0	9.9	9.9	9.2
65%	19.9	21.7	22.0	21.2	21.3	20.4
25% Return	6.0	6.7	6.8	6.7	6.8	6.6
Support Factor	2.15	2.17	2.20	2.13	2.16	2.20
Recovery (%)	65	67	68	68	69	71
Compression Sets, % set						
50%	10	8	13	8	8	7
90%	16	22	39	8	10	12
50%**	26	26	25	25	24	25
90%**	43	40	41	41	57	44
CFD (% of Original 50%)	54	48	47	44	45	41
Air Flow (cfm)	>8	>8	>8	>8	>8	>8
Fatigue Properties						
Static Fatigue						
Height (% Loss)	3.8	4.0	4.7	2.7	3.4	4.4
IFD: 25% Loss	39	37	35	35	36	37
IFD: 65% Loss	34	32	30	31	31	32
Pounding, 80k cycles						
Height (% Loss)	4.0	4.0	4.5	2.7	3.5	3.8
40% IFD (% Loss)	44	42	39	41	40	38

Table 11 – Higher Density HyperSoft™ Foam Formulations Physical Properties

	Pluracol® 2029/1			Pluracol® 593		
Physical Properties	1	2	3	4	5	6
Density (pcf)	1.62	1.67	1.70	1.77	1.77	1.82
Tensile (psi)	20	21	20	21	23	23
Elongation (%)	383	382	382	483	439	419
HTAG Tensile (psi)	18	20	19	18	21	21
HTAG Elongation (%)	364	391	385	470	442	407
Tear (pi)	3.8	4.2	4.1	4.3	4.2	4.2
Resilience (%)	31	38	41	33	30	40
IFD, lb. /50 sq. in. (4 in.)						
25%	14.9	14.6	14.6	14.0	14.9	14.6
65%	33.9	33.0	32.0	32.1	34.3	33.1
25% Return	10.8	10.8	11.1	10.4	11.4	11.5
Support Factor	2.28	2.27	2.20	2.30	2.30	2.27
Recovery (%)	73	74	76	74	77	79
Compression Sets (%set)						
50%	11	6	4	9	5	4
90%	69	55	24	62	58	43
50%**	23	27	28	26	28	34
90%**	66	66	70	63	57	73
CFD (% Of Original 50%)	37	37	33	33	33	31
Air Flow (cfm)	1.8	2.2	2.6	1.3	1.0	1.8
Fatigue Properties						
Static Fatigue						
Height (% Loss)	5.2	2.9	3.0	3.5	2.9	4.3
IFD (25% Loss)	32	26	28	32	28	28
IFD (65% Loss)	28	23	26	29	26	25
Pounding (80k cycles)						
Height (% Loss)	3.4	3.2	1.9	2.8	2.8	3.1
40% IFD (% Loss)	34	36	30	35	30	31

****NOTE:** Heat Aged 22 hrs. @ 284°F

Table 12 - Elastopan® 5291TW Polyurethane Gel NOVAFLEX® CO_2 Trial Physical Properties

Physical Properties	1	2	3	4	5	6
Density (pcf)	1.17	1.19	1.25	1.27	1.24	1.25
Tensile (psi)	14.5	12.3	14.8	15.5	13.8	12.6
Elongation (%)	142	129	154	174	138	143
Heat Aged Tensile (psi)	14.4	14.6	14.6	16.1	15.6	13.8
Heat Aged Elongation (%)	178	194	182	212	194	176
Tear (pi)	2.3	2.1	2.0	2.2	2.2	2.2
Resilience (%)	41	45	47	46	45	46
IFD, lb. /50 sq. in. (4 in.)						
25%	30.2	28.6	26.6	29.8	29.1	25.5
65%	61.3	57.8	55.1	60.4	58.5	51.2
25% Return	20.6	20.0	19.3	21.2	20.6	18.2
Support Factor	2.03	2.02	2.07	2.02	2.01	2.01
Recovery (%)	68	70	73	71	71	72
Compression Sets (% set)						
50%	0.6	1.3	0.7	1.9	1.1	0.9
90%	5.3	3.3	2.7	11.8	3.7	3.2
50%**	3.7	2.6	1.4	3.5	2.4	1.7
90%**	26.4	27.5	16.5	35.8	16.7	13.4
CFD, % Of Original 50%	0.44	0.41	0.37	0.38	0.42	0.38
Air Flow (cfm)	1.7	4.2	5.2	2.6	3.7	5.4
Fatigue Properties						
Static Fatigue						
Height (% Loss)	3	1	1	2	2	1
IFD (25% Loss)	29	20	19	19	20	23
IFD (65% Loss)	24	17	17	16	18	22

**NOTE: Heat Aged 22 hrs. @ 284°F

Table 13 – HR-2 Gel Trough Pour Trial Physical Properties

Physical Properties	1	2	3	4	5	6
Density (pcf)	1.67	1.80	1.92	2.23	2.51	2.83
Tensile (psi)	19.5	21.5	20.4	22.5	22.7	23.7
Elongation (%)	183	177	171	170	146	138
Heat Aged Tensile (psi)	16.2	19.9	19.1	8.0	22.7	23.5
Heat Aged Elongation (%)	196	178	177	119	179	163
Tear (pi)	2.3	2.3	2.1	1.9	1.8	1.7
Resilience (%)	52	59	60	59	64	63
IFD, lb. /50 sq. in. (4 in.)						
25%	19	21	23	24	27	30
65%	45	51	56	59	71	84
25% Return	15	17	18	20	24	26
Support Factor	2.37	2.44	2.46	2.48	2.58	2.82
Recovery (%)	77	80	80	84	86	87
Compression Sets (% set)						
50%	10.0	7.8	5.3	6.1	4.6	6.5
90%	39.5	8.8	8.1	6.7	5.9	5.5
50%**	14.9	8.4	7.5	8.1	7.0	7.0
90%**	69.1	18.3	15.8	36.4	14.2	11.2
CFD (% Of Original 50%)	0.4	0.4	0.5	0.5	0.6	0.6
Air Flow (cfm)	0.9	0.9	1.1	0.8	0.8	0.7
Fatigue Properties						
Static Fatigue						
Height (% Loss)	6	7	4	4	4	4
IFD (25% Loss)	31	33	23	22	20	19
IFD (65% Loss)	26	28	18	19	20	22
Pounding, 80k cycles						
Height (% Loss)	3.9	3.6	3.4	2.8	2.2	1.6
40% IFD (% Loss)	30	31	17	18	18	19