NEW CABOT CARBON BLACKS FOR IMPROVED ELECTRO-CHEMICAL DEGRADATION RESISTANCE

By **Maurizio Lucchi***, European Business Segment Manager, Hose & Belt Products,
Cabot Italiana SpA, Via Baiona, 190, 48100 Ravenna, Italy,
Tel. ++39-0544-519511, Fax: ++39-0544-451946,
E-mail: Maurizio_Lucchi@Cabot-Corp.com

Prepared with the contribution of:

Theo Al, European Application Development Manager, Industrial Products Division,
E-mail: Theo_Al@Cabot-Corp.com

Based on a study made at:

Cabot Leiden Technical Center
Archimedesweg, 15,
NL-2333 CM Leiden, The Netherlands
Tel. ++31-71-5600300,
Fax: ++31-71-5227129

Presented at the IRC 2000
Rubber Conference
Helsinki, Finland
12th–15th June 2000

* Speaker

CABOT

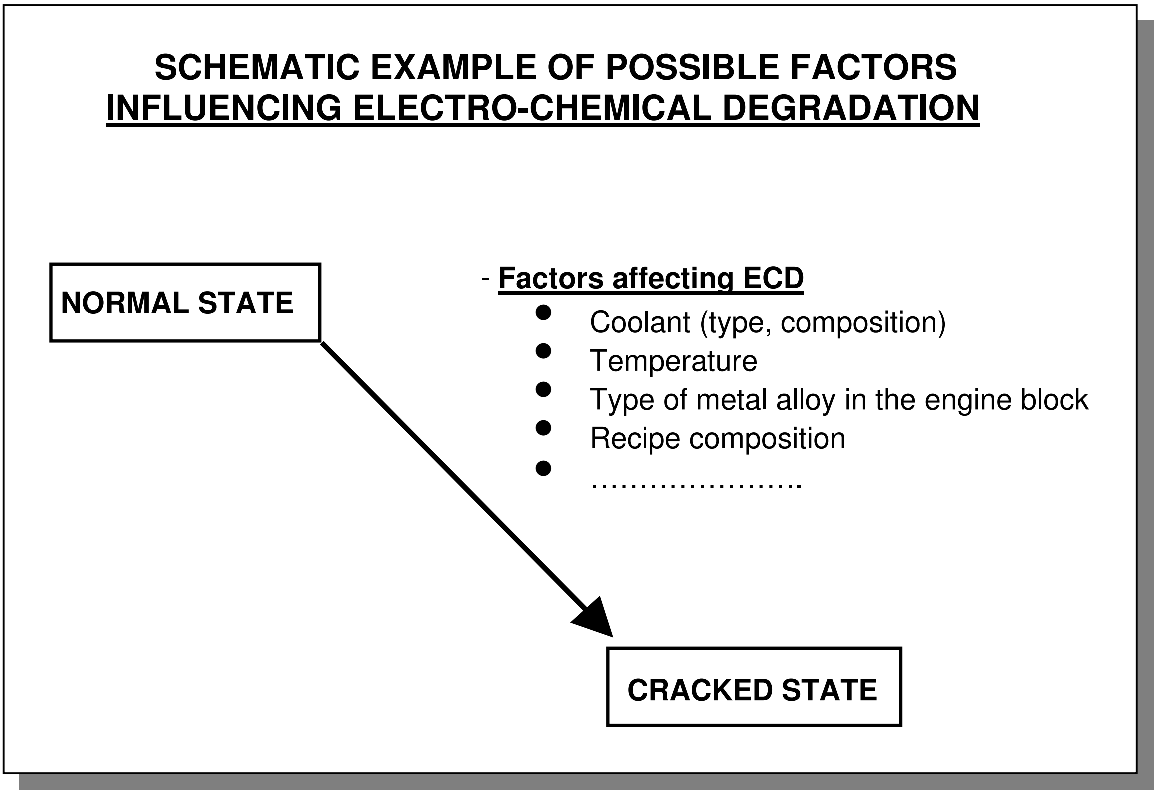
INTRODUCTION

Since the middle 80's, the degradation phenomenon called "Electro-Chemical Degradation" (hereafter referred to as "ECD") has been identified as cause of failure in coolant hoses. (1)

ECD shows up via the development of peculiar longitudinal cracks, initiating from the innerlayer and propagating through the coolant hose section, leading to hose leakage or even to the hose bursting. Typical for an electro-chemical degradation process is also the "striaes" and "trees" type structure, which have been found in hoses before actual cracks develop.

The automotive industries trend toward increased under-the-hood temperature and longer warranty times is driving the introduction of more stringent specifications and technical requirements for all rubber components and specifically for coolant hoses.
Test methods able to measure the hose and/or rubber compound tendency to develop electro-chemical degradation phenomena have been developed for some years. These methods are now part of many coolant hose specifications with a trend toward more severe test conditions (longer testing time and higher testing temperature).

Electro-Chemical Degradation is affected by several factors. Even if the exact mechanism is being debated it has been demonstrated that several components of a typical cooling system can affect the ECD phenomena as schematically represented as follows:



CABOT

Type and composition of cooling fluid, hose service temperature, type of metal alloy in the engine block, recipe composition and relative interaction between these different components are all having an effect on the tendency of the hose to develop ECD.

From a recipe point of view, electrical conductivity has been demonstrated to play an important role in ECD. Carbon black loading and type can significantly influence the compound electrical properties and therefore, as a direct consequence, the compound tendency to develop ECD.

SPHERON®6000 and SPHERON®6400 carbon blacks have a unique morphology able to provide increased resistance to ECD at much higher carbon black loadings compared to a standard carbon black such as N550. These new types of carbon black have been developed by Cabot to help hose manufacturers address the most restrictive specification requirements, without sacrificing other compound characteristics like dispersibility, processability and final physical properties.

This performance feature of SPHERON®6000 and SPHERON®6400 carbon blacks gives the formulation compounder a higher degree of flexibility to develop an optimum hose compound from both performance and economical point of view to meet today's requirements.

EXPERIMENTAL SET-UP

A sensitive and quite basic peroxide cured EPDM formulation has been selected for this study to assess performances of new Cabot SPHERON®6000 and SPHERON®6400 carbon blacks vs. standard ASTM N550:

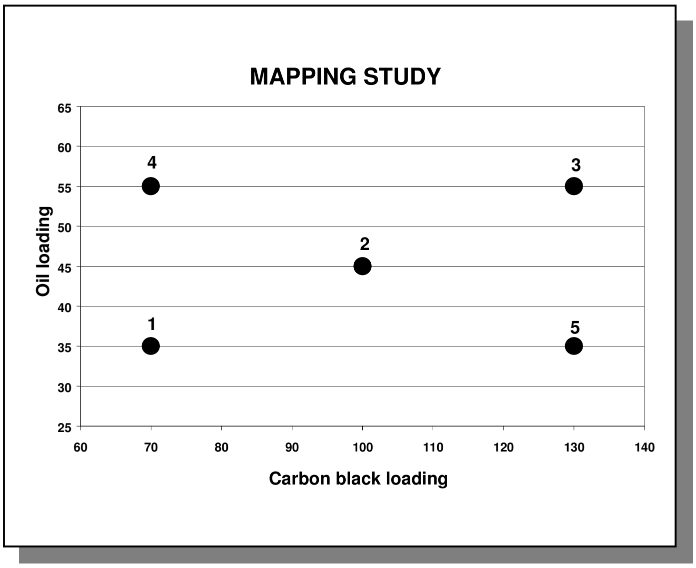
STUDY FORMULATION

EPDM (52% C2, 4.5 % ENB)	100
Stearic Acid	0.5
Paraffinic Oil	Variable
Carbon Black	Variable
Co-agent (TMPT 50%)	1.5
Peroxide (Di-(tert, butyl-peroxy-isopropyl)-benzene 40% on carrier)	6.5

The formulation has been selected to highlight the carbon black effect, antioxidant or anti-degradants have been deliberately excluded. Carbon blacks selected for the study are the following:

- STERLING®SO-N550: Typical ASTM grade used for EPDM extrusion application
- SPHERON®6000: Cabot grade with tailored morphology developed for ECD resistant hoses.
- SPHERON®6400: Newly developed Cabot product for applications requiring very high electrical resistivity.

Carbon black and oil loading have been varied in order to make a mapping study around typical levels used in coolant hose applications.
Five compounds for each carbon black have been prepared as per the following scheme:



Test results have been analysed using experimental design software able to provide contour graphs for all tested properties. This approach facilitates the comparison of the three carbon blacks not only at equal phr loading, but also at e.g. equal hardness or modulus.

Electro-Chemical Degradation has been measured using the V&V testing equipment developed by DSM [(2)].
This equipment permits a measurement of ECD directly on laboratory specimens prepared according to ISO 37.
Besides visual observation, it is possible to obtain a quantitative assessment of the degradation by determining the compound characteristics after ECD testing (for example: variation of Elongation @ Break).

A schematic representation of the V&V equipment is reported in Attachment 1 and 2.

Two dumbbells for each compound have been tested as per following testing conditions:

- Testing time: 168 hours
- Temperature: 80°C
- Tension: 10V
- Dumbbells under 50% strain
- Cooling liquids: Fina Permafluid diluted 1:1 with distilled water

Test results have been analysed using ECHIP software able to provide contours graph for each property.

Mixing cycles and testing conditions were the same for all the compounds (see for details Attachment 3).

RESULTS

All obtained test results for N550, SPHERON®6000 and SPHERON®6400 carbon blacks are listed in Attachments 4, 5, and 6. ECD test results are reported as variation of the Tensile properties (percentage change versus initial compound values).

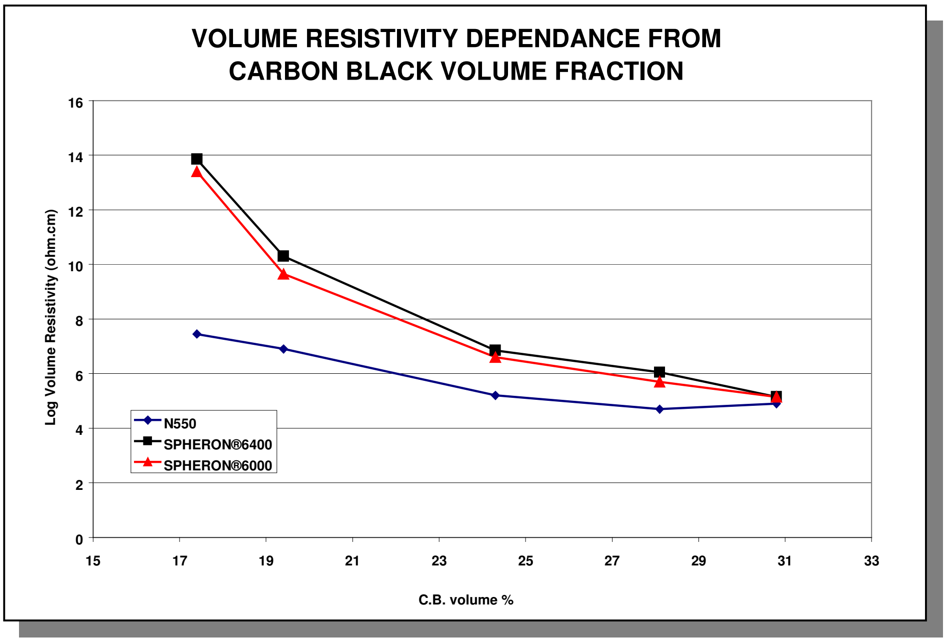
The contour graphs for basic properties like Mooney Viscosity, Shore Hardness, 100% Modulus, Tensile Strength, Elongation @ Break and Volume Resistivity are listed in Attachments 7 and 8.

Before testing of Tensile properties on dumbbells after ECD, pictures have been taken under 10% Elongation at 16X magnification to visually highlight compound degradation (see Figures 1, 2, 3, 4 and 5).

DISCUSSION

1. **Analysis of main compound properties**
   The contour graphs in the Attachments show clearly that Volume Resistivity is strongly dependent on carbon black type and loading. SPHERON®6000 and SPHERON®6400 carbon blacks show a significantly higher level of Volume Resistivity vs. N550 carbon black.

   Another way to look at this, is to plot Volume Resistivity versus carbon black volume fraction:



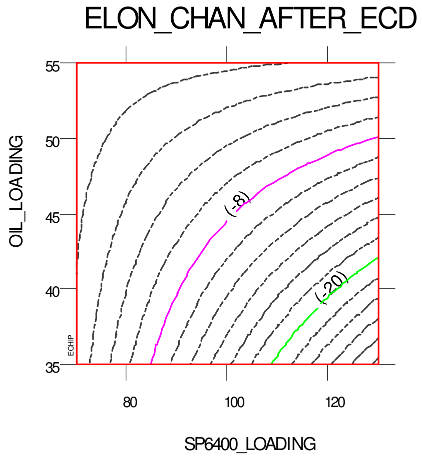
   N550 carbon black has reached the plateau in term of compound conductivity at around 24% volume fraction (~ 40% weight fraction). Both SPHERON®6000 and SPHERON®6400 carbon black achieves the conductivity level of N550 carbon black at a volume fraction of about 31% (~ 48% weight fraction).

2. Electro-Chemical Degradation

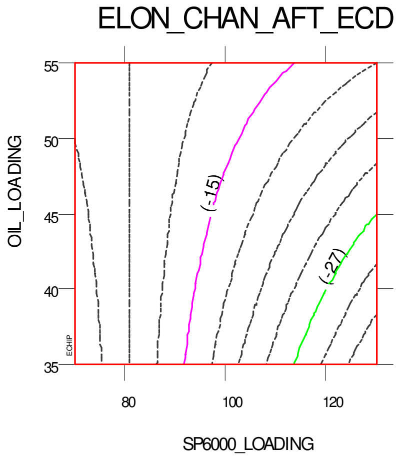
The Electro-Chemical Degradation is quite different between the three evaluated carbon blacks as can be seen on the pictures taken at 16X magnification under 10% elongation of the dumbbells after ECD testing (see fig. 1 to 5 in Attachment)

SPHERON®6400 carbon black is the black showing the highest ECD resistance, SPHERON®6000 carbon black is having an intermediate behaviour, while N550 carbon black shows a strong degradation even at relatively low level of carbon black loading. This can be seen in below contour plots showing the change in El. At Break after ECD testing:

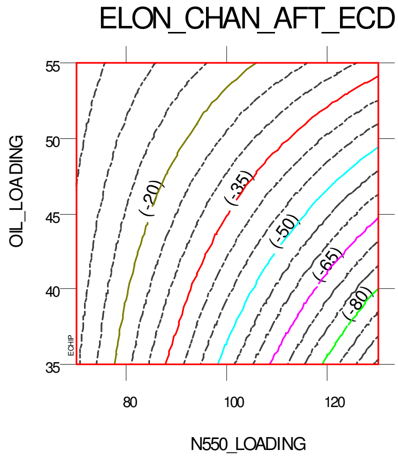
SPHERON®6400



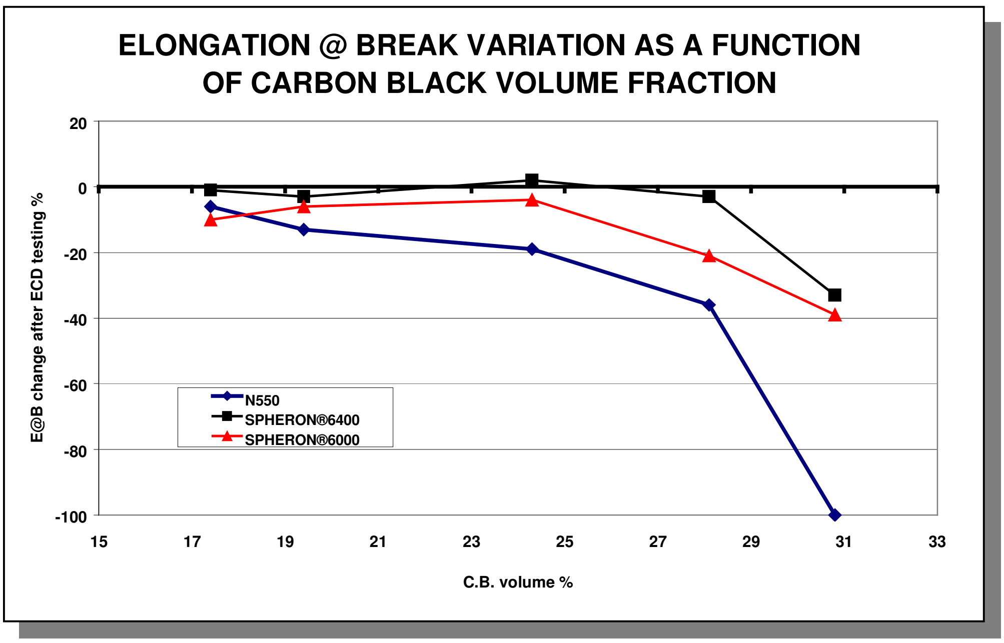
SPHERON®6000

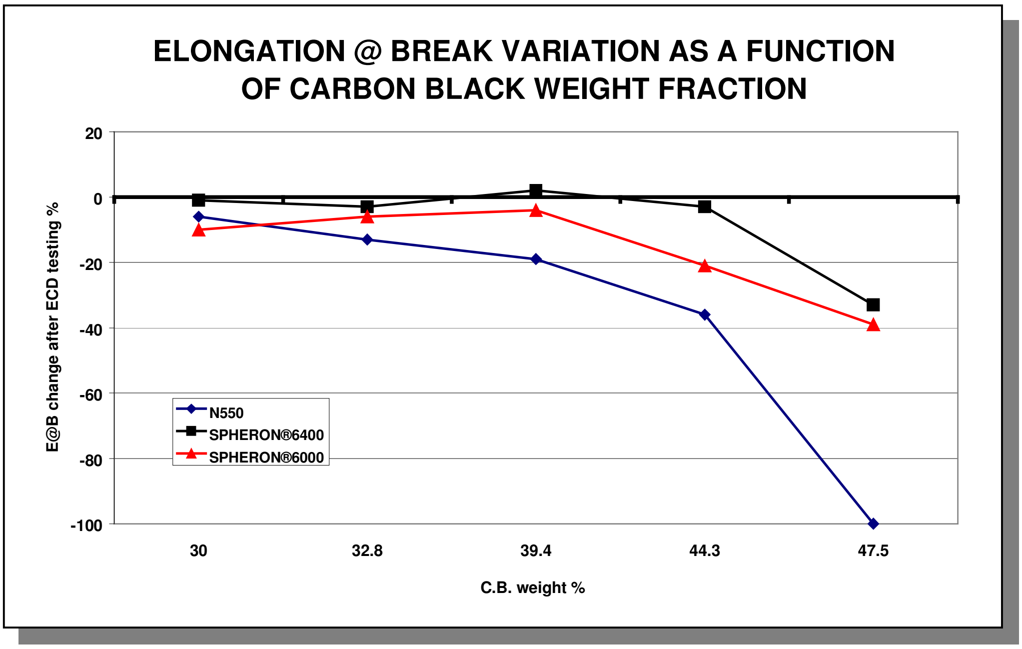


N550



The Elongation @ Break change after ECD vs. carbon black weight and volume fraction, can also be presented via the following 2 graphs:





Above 2 graphs show that, ECD seems to start above 29% carbon black fraction (~ 45% carbon black weight fraction) using SPHERON®6400 carbon black. For SPHERON®6000 carbon black, the limit seems to be around 26% volume fraction (~ 42% volume fraction) while ECD is appearing with N550 carbon black already around 21-22% carbon black volume fraction (~ 36% weight fraction). At higher N550 carbon black loading levels the ECD performance becomes rapidly very poor.

Interestingly, at relative high carbon black loading, usage of SPHERON®6400 and SPHERON®6000 carbon blacks offer advantages in terms of ECD over N550 carbon black even if compounds show same Volume Resistivity. This indicates that Volume Resistivity (as measured in this work) should only be used as an indicative type of measurement and its adoption as a test method to predict ECD performance is not suggested.

Several hypotheses to explain above behaviour are possible.

From a carbon black point of view a possible explanation can be related to the existing carbon black morphology differences between N550 and the SPHERON® carbon blacks.

N550 offers a much higher number of contact points in the compound between carbon black aggregates compared to SPHERON®6400 and SPHERON®6000 carbon blacks.

As previously shown N550 is reaching a plateau in terms of compound conductivity at around 24% Volume Fraction. Increasing the loading of N550 does not lead to an increase of Volume conductivity, but will still provide higher number of contact points between aggregates. Assuming that some contact points are broken down as a consequence of the current flow, the effect in terms of reduction of ECD sensitivity will be minimal.

On the other side Volume conductivity of compounds based on SPHERON®6400 and SPHERON®6000 carbon blacks is expected to be more sensitive and therefore to be significantly reduced by the possible breaking of the fewer contact points existing between aggregates. Further investigations are in progress to assess/prove this type of hypothesis.

3. Comparison of the three carbon blacks at equal 65 Shore hardness

By interpolation of properties using the experimental design software, it is possible to compare compounds at equal hardness i.e. taking the different carbon black reinforcing level into account. Below table shows the regression result at a very typical hardness level for coolant hoses:

<u>Example:</u> 65 Shore Hardness

Carbon Black:	**N550**	**SPHERON®6000**	**SPHERON®6400**
Oil loading	45	45	45
Carbon Black loading	105	125	125
---MDR@170°C---			
Min Torque (dNm)	6.1	5.0	5.1
Max Torque (dNm)	34.9	34.8	36.2
Scorch 1(m.m.)	0.4	0.5	0.5
Scorch 3(m.m.)	0.7	0.8	0.8
Scorch 5(m.m.)	0.9	1.0	1.0
T50(m.m.)	2.4	2.1	2.2
T90(m.m.)	9.5	8.6	9.1
---Mooney Viscosity @100°C---			
ML(1+4)(M.U.)	122	103	104
---ASTM Compression Set (25%)---			
Set after 22 hrs @150°C, (%)	27	24	22
---Volume Resistivity---			
Log (Rho)	5.6	5.6	5.8
---Shore A Hardness---			
3 seconds	65	65	65
---IRHD Hardness---			
IRHD	67	67	66
---Initial tensile properties---			
Tensile Strength, (MPa)	13.0	12.7	12.1
Elongation @ Break, (%)	385	371	376
50% Modulus, (MPa)	1.6	1.5	1.5
100% Modulus, (MPa)	3.0	3.1	3.2
200% Modulus, (MPa)	7.1	7.3	7.2
---Tensile after ECD testing--- 168 hrs @80°C, 10V, 50% strain			
2 dumbbells tested			
---Average result of 2 dumbbells---			
Tensile Strength, (MPa)	8.7	9.5	10.5
Elongation @ Break, (%)	274	287	333
50% Modulus, (MPa)	0.7	1.1	1.2
100% Modulus, (MPa)	1.8	3.1	3.2
---% Change in properties---			
Tensile Strength, (MPa)	-34.2	-24.1	-12.2
Elongation @ Break, (%)	-39.8	-25.2	-14.3
50% Modulus, (MPa)	-35.2	-22.4	-23.2
100% Modulus, (MPa)	-14.9	3.7	-0.4
Carbon Black weight, %	40.0	44.9	44.9
Carbon Black volume, %	24.9	28.7	28.7

Above data shows that SPHERON®6000 and SPHERON®6400 carbon blacks give the following advantages vs N550 carbon black when compounded at equal hardness:

- Controlled (lower) Mooney Viscosity
- Slightly improved compression set
- ECD resistance significantly improving passing from N550 to SPHERON®6000 and to SPHERON®6400 carbon black

All above is reached at much higher carbon black loading which is positive in terms of compound processability and compound cost.

Tensile Strengths (initial values) are slightly decreasing when moving from N550 to SPHERON®6000 and SPHERON®6400 carbon blacks. This is reflecting the lower reinforcing level provided by the SPHERON® blacks. The obtained Tensile values remain anyway quite high and able to meet all the existing specification limits. Important to note is Tensile Strength of SPHERON®6400 and SPHERON®6000 carbon black after ECD testing is higher than Tensile Strength of N550 compound, reflecting the lower compound deterioration and the expected improved performance in service.

CONCLUSIONS

ECD resistance (as measured by V&V equipment) of peroxide cured compounds is strongly dependant from carbon black type.

The Cabot's new SPHERON®6400 and SPHERON®6000 carbon blacks offer the highest resistance to ECD at relatively high carbon black loading.

It has been shown that both SPHERON blacks facilitate improvement of ECD performances vs. N550 at much higher loading level. Even when compounded at equal volume resistivity, SPHERON®6400 and SPHERON®6000 carbon blacks show improved ECD performance vs. N550.

Of the carbon blacks tested in this study:

- SPHERON®6400 carbon black is the best carbon black in terms of ECD resistance.

- SPHERON®6000 carbon black is a good compromise able to grant excellent ECD resistance at slightly higher level of reinforcement.

The optimum choice between the two blacks will, of course, depend from the final coolant hose specification requirements.

CABOT

Aknowledgements

Special thanks to Mr. Mike Smith – Technical Service Manager, Industrial Products, German Region and to CABOT Leiden Technical Center staff, for the helpful contribution given.

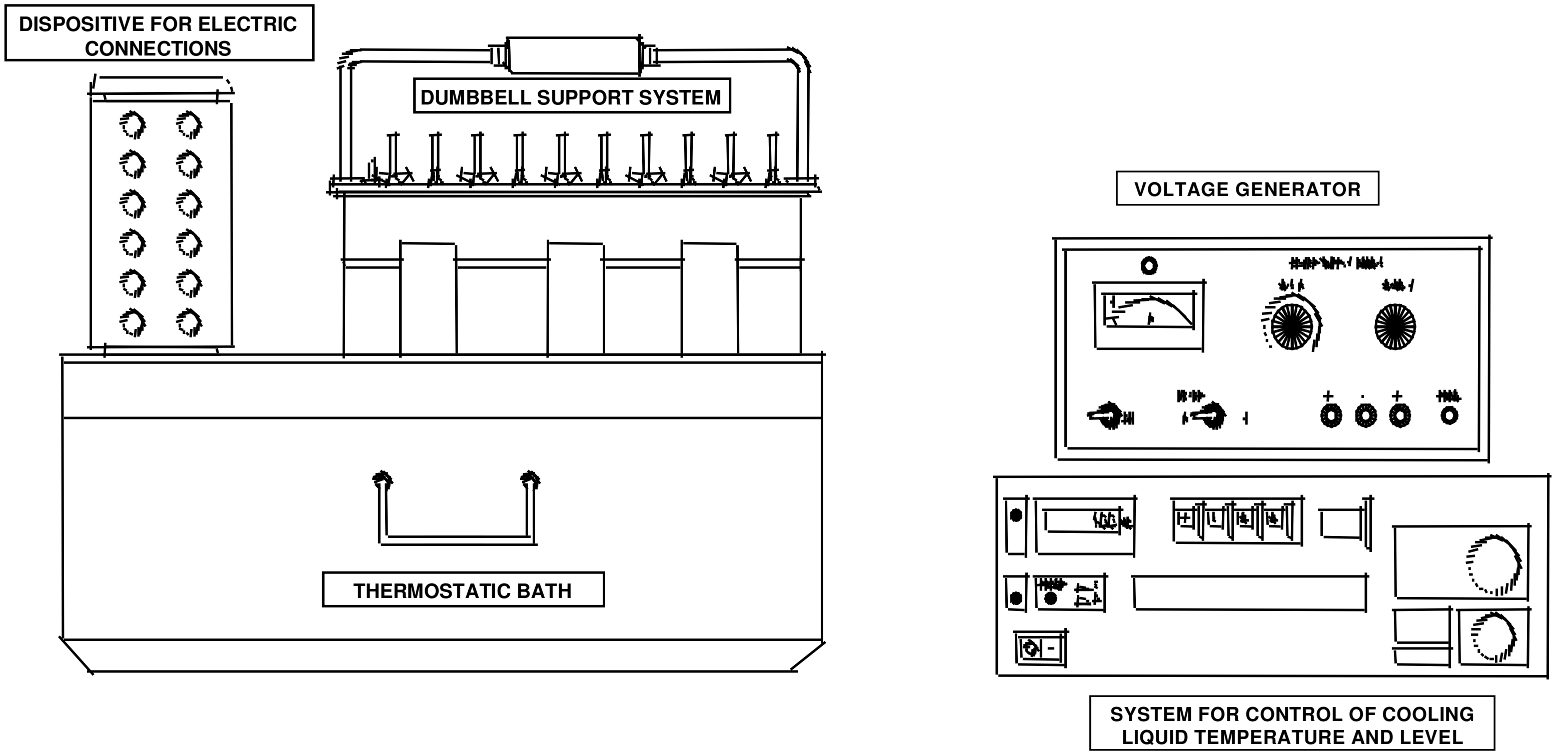
References

(1): *H. Schneider, H. Tucker and T. Seo: "Electrochemical degradation of coolant hoses" Elastomerics-August '92*

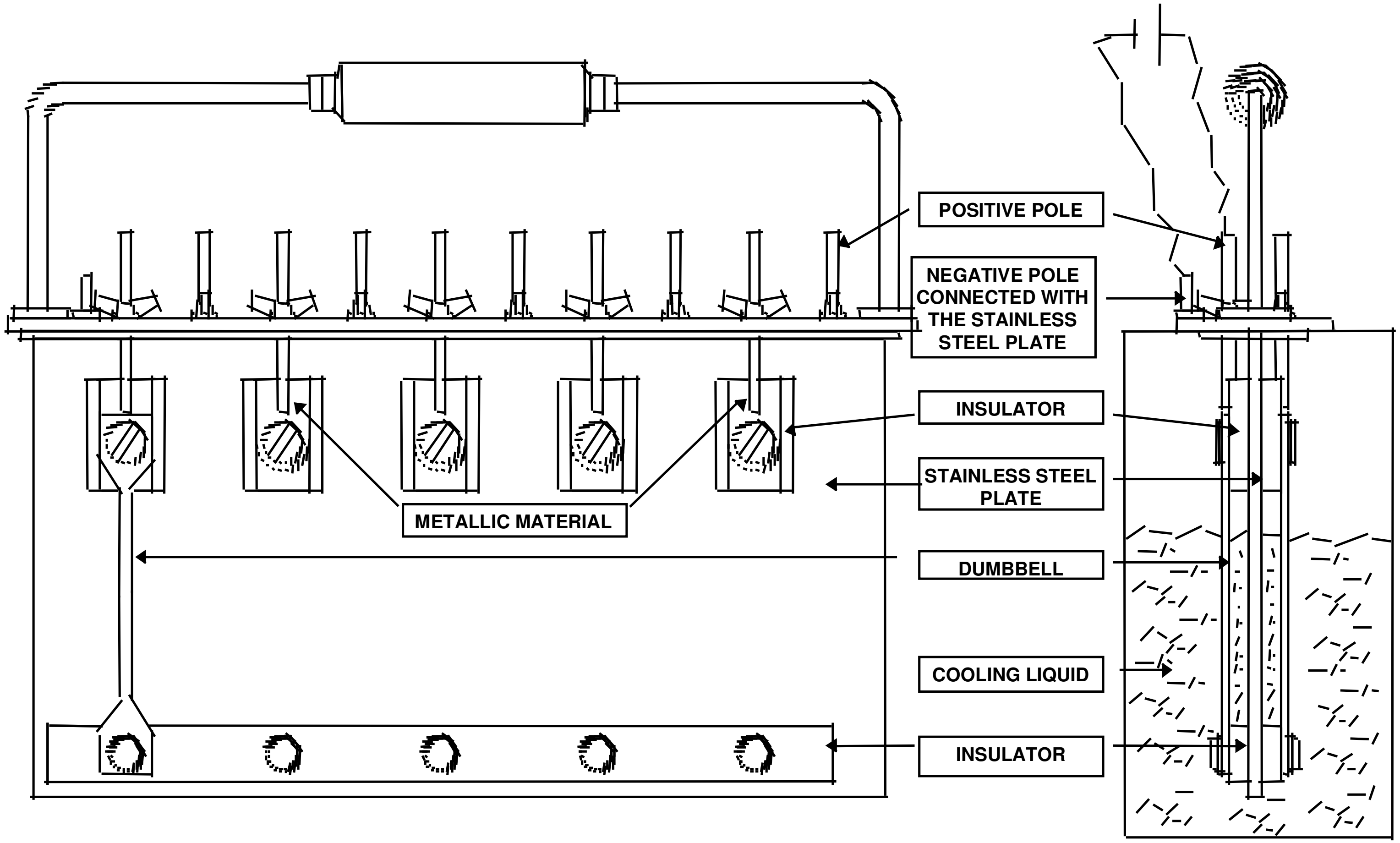
(2): *G. Vroomen, H. Verhoef (DSM Elastomers): "Electrochemical degradation of EPDM cooling water hoses", Kautschuk Gummi Kunststoffe 48, Nr. 10/95*

CABOT

GENERAL VIEW OF V&V EQUIPMENT



SCHEME OF DUMBBELL SUPPORT SYSTEM



CABOT

MIX CYCLE

Brabender, 390cc., 70% fill factor, 40℃, 50RPM, 1 bar.

0' : Add Carbon Black. Smalls, oil & polymer on top.
½': Raise ram pressure to 2 bar.
2' : Sweep
3½': Dump, check weight and transfer to mill.

Mill @40℃

0' : Add stage-1 masterbatch, band on back roll.
½': Add peroxide.
1' : Start x-cut every 20 seconds.
5' : Three end rolls at 0.1 mm nip setting.
6' : Band on, obtain grain.
6½': Sheet off at tensile thickness.

TEST CONDITIONS

Test	Number	Parameters
MDR	CLTC-B1	170℃, 1° ARC
Mooney Viscosity	CLTC-B3	100℃, 1 + 4 MIN., ML,
ASTM Compression Set	CLTC-C7.02	25% set, 22hrs@150℃, cure time test blocks 15' @170℃.
Volume Resistivity	CLTC-C11.0	DIN53482 in duplicate
Tensile	CLTC-C15	Test sheets were cured for 12½' @170℃.
ECD Tensile	CLTC-C14	168hrs@80℃,10V,50%strain
Hardness Shore A	CLTC-C3.01	Cure times test blocks: 15' @170℃.
Hardness IRHD	CLTC-C3.01	Cure times test blocks: 15' @170℃.

CABOT

Attachment 4

Batch number	**1**	**2**	**3**	**4**	**5**
CB Grade	**N550**	**N550**	**N550**	**N550**	**N550**
CB Loading, (phr)	70	100	130	70	130
Oil Loading, (phr)	35	45	55	55	35
--- MDR @170℃ ---					
Min Torque(dNm)	4.1	4.8	5.9	2.6	11.1
Max Torque(dNm)	33.9	33.3	30.1	19.9	51.3
Scorch 1(m.m.)	0.5	0.5	0.4	0.6	0.3
Scorch 3(m.m.)	0.7	0.8	0.7	1.1	0.5
Scorch 5(m.m.)	0.9	1	1	1.4	0.6
T50(m.m.)	2.2	2.3	2.5	2.3	2.4
T90(m.m.)	9.7	9.3	9.6	9.6	9.4
--- Mooney Viscosity @100℃ ---					
ML (1+4)(M.U.)	89	104	120	61	>200
--- ASTM Compression Set (25%) ---					
Set after 22 hrs @150℃, (%)	26	24	28	31	26
--- Volume Resistivity ---					
Log(Rho) test sheet-1	7.2	5.3	4.7	7.7	4.9
Log(Rho) test sheet-2	6.6	5.1	4.7	7.2	4.9
--- Shore A Hardness ---					
Maximum	62	68	72	51	82
3 seconds	58	64	69	47	79
--- IRHD Hardness ---					
IRHD	61	66	69	48	81
--- Initial tensile properties ---					
Tensile Strength, (MPa)	16.0	14.1	10.3	13.0	12.8
Elongation @ Break, (%)	466	372	329	671	214
50% Modulus, (MPa)	1.1	1.3	1.5	0.7	2.7
100% Modulus, (MPa)	1.8	2.4	2.8	1.1	5.8
200% Modulus, (MPa)	5.2	6.8	6.4	2.6	12.3
300% Modulus, (MPa)	9.3	10.8	9.6	4.9	--
--- Tensile after ECD testing --- 168 hrs @80℃, 10V, 50% strain -2 dumbbells tested					
--- Average result of 2 dumbbells ---					
Tensile Strength, (MPa)	15.4	12.4	7.2	13.3	--
Elongation @ Break, (%)	406	303	209	628	--
50% Modulus, (MPa)	1.0	1.1	1.1	0.7	--
100% Modulus, (MPa)	2.1	2.7	3.1	1.2	--
200% Modulus, (MPa)	6.0	7.4	--	2.8	--
300% Modulus, (MPa)	10.2	--	--	5.2	--
--- Variation, (%) ---					
Tensile Strength	-4	-12	-30	+2	-100
Elongation @ Break	-13	-19	-36	-6	-100
50% Modulus	-9	-15	-27	0	-100
100% Modulus	+17	+13	+11	+9	-100
200% Modulus	+15	+9	--	+8	-100
300% Modulus	+10	--	--	+6	--
Carbon Black weight, %	32.8	39.4	44.3	30	47.5
Carbon Black volume, %	19.4	24.3	28.1	17.4	30.8

CABOT

Attachment 5

Batch number	**1**	**2**	**3**	**4**	**5**
CB Grade	**SPHERON 6000**	**SPHERON 6000**	**SPHERON 6000**	**SPHERON 6000**	**SPHERON 6000**
CB Loading, (phr)	70	100	130	70	130
Oil Loading, (phr)	35	45	55	55	35
--- MDR @170℃ ---					
Min Torque(dNm)	3.6	3.7	3.9	2.3	6.7
Max Torque(dNm)	31.2	29.1	26.8	18.4	45.1
Scorch 1(m.m.)	0.5	0.5	0.5	0.6	0.4
Scorch 3(m.m.)	0.7	0.8	0.9	1.0	0.6
Scorch 5(m.m.)	0.9	1.0	1.1	1.4	0.8
T50(m.m.)	2.1	2.1	2.1	2.2	2.0
T90(m.m.)	9.7	8.9	8.3	9.9	8.8
--- Mooney Viscosity @100℃ ---					
ML (1+4)(M.U.)	76	79	85	52	130
--- ASTM Compression Set (25%) ---					
Set after 22hrs @150℃, (%)	28	27	26	33	20
--- Volume Resistivity ---					
Log(Rho) test sheet-1	9.7	6.6	5.6	13.3	5.2
Log(Rho) test sheet-2	9.6	6.6	5.8	13.5	5.3
--- Shore A Hardness ---					
Maximum	58	62	64	48	76
3 seconds	54	58	60	44	73
--- IRHD Hardness ---					
IRHD	57	59	62	45	75
--- Initial tensile properties ---					
Tensile Strength, (MPa)	14.4	12.7	11.4	12.5	14.0
Elongation @ Break, (%)	520	489	427	852	271
50% Modulus, (MPa)	1.0	1.0	1.1	0.6	2.2
100% Modulus, (MPa)	1.7	1.8	2.0	0.9	4.7
200% Modulus, (MPa)	4.3	4.7	5.3	1.9	10.3
300% Modulus, (MPa)	7.5	7.7	8.0	3.5	--
--- Tensile after ECD testing ---168 hrs @80℃, 10V, 50% strain -2 dumbbells tested					
--- Average result of 2 dumbbells ---					
Tensile Strength, (MPa)	14.7	13.6	9.2	13.5	8.0
Elongation @ Break, (%)	491	468	337	768	164
50% Modulus, (MPa)	0.9	0.9	0.9	0.6	1.5
100% Modulus, (MPa)	1.8	2.0	2.2	1.0	4.4
200% Modulus, (MPa)	4.6	5.3	5.7	2.3	--
300% Modulus, (MPa)	7.9	8.5	8.4	4.1	--
--- % Change in properties ---					
Tensile Strength, (%)	+2	+7	-19	+8	-43
Elongation @ Break, (%)	-6	-4	-21	-10	-39
50% Modulus, (%)	-10	-10	-18	0	-32
100% Modulus, (%)	+6	+11	+10	+11	-6
200% Modulus, (%)	+7	+13	+8	+21	--
300% Modulus, (%)	+5	+10	+5	+17	--
Carbon Black weight, %	32.8	39.4	44.3	30	47.5
Carbon Black volume, %	19.4	24.3	28.1	17.4	30.8

CABOT

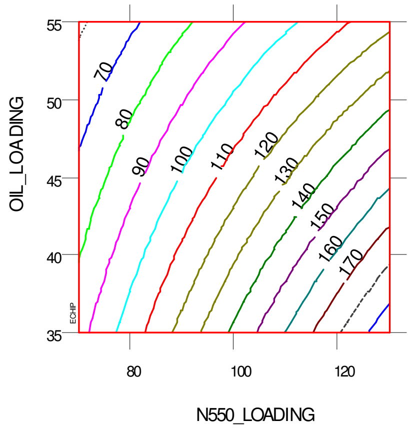
Attachment 6

Batch number	**1**	**2**	**3**	**4**	**5**
CB Grade	**SPHERON 6400**	**SPHERON 6400**	**SPHERON 6400**	**SPHERON 6400**	**SPHERON 6400**
CB Loading, (phr)	70	100	130	70	130
Oil Loading, (phr)	35	45	55	55	35
--- MDR @170°C ---					
Min Torque(dNm)	3.5	3.7	3.9	2.3	6.8
Max Torque(dNm)	32.0	29.9	27.8	18.7	47.1
Scorch 1(m.m.)	0.5	0.5	0.5	0.7	0.4
Scorch 3(m.m.)	0.7	0.8	0.9	1.0	0.6
Scorch 5(m.m.)	0.9	1.0	1.1	1.4	0.8
T50(m.m.)	2.2	2.2	2.3	2.2	2.1
T90(m.m.)	10.2	9.6	9.0	10.1	9.1
--- Mooney Viscosity @100°C ---					
ML (1+4)(M.U.)	76	80	86	53	133
--- ASTM Compression Set (25%) ---					
Set after 22hrs @150°C, (%)	27	25	23	32	21
--- Volume Resistivity ---					
Log(Rho) test sheet-1	10.3	6.7	5.6	13.7	5.2
Log(Rho) test sheet-2	10.3	7.0	6.5	14.0	5.3
--- Shore A Hardness ---					
Maximum	58	62	64	48	76
3 seconds	54	58	60	44	73
--- IRHD Hardness ---					
IRHD	57	59	61	45	75
--- Initial tensile properties ---					
Tensile Strength, (MPa)	13.2	12.6	10.8	11.6	13.1
Elongation @ Break, (%)	533	491	423	803	286
50% Modulus, (MPa)	1.0	1.2	1.2	0.7	2.0
100% Modulus, (MPa)	1.7	2.2	2.3	1.0	4.5
200% Modulus, (MPa)	4.2	5.4	5.6	2.1	9.6
300% Modulus, (MPa)	6.9	8.1	8.0	3.6	--
--- Tensile after ECD testing --- 168 hrs @80°C, 10V, 50% strain -2 dumbbells tested					
--- Average result of 2 dumbbells ---					
Tensile Strength, (MPa)	13.7	12.5	10.8	12.8	9.3
Elongation @ Break, (%)	516	500	409	792	191
50% Modulus, (MPa)	0.9	0.9	0.9	0.6	1.6
100% Modulus, (MPa)	1.7	2.0	2.3	1.0	4.7
200% Modulus, (MPa)	4.5	5.1	5.7	2.2	--
300% Modulus, (MPa)	7.4	7.8	8.1	3.9	--
--- % Change in properties ---					
Tensile Strength, (%)	+4	-1	0	+10	-29
Elongation @ Break, (%)	-3	+2	-3	-1	-33
50% Modulus, (%)	-10	-25	-25	-14	-20
100% Modulus, (%)	0	-10	0	0	4
200% Modulus, (%)	+7	-6	+2	-5	--
300% Modulus, (%)	+7	-4	+1	+8	--
Carbon Black weight, %	32.8	39.4	44.3	30	47.5
Carbon Black volume, %	19.4	24.3	28.1	17.4	30.8

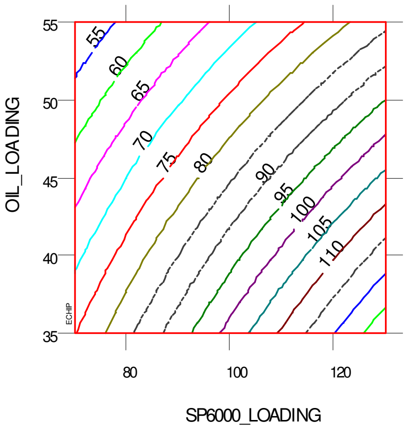
Attachment 7

N550 | **SPHERON®6000** | **SPHERON®6400**

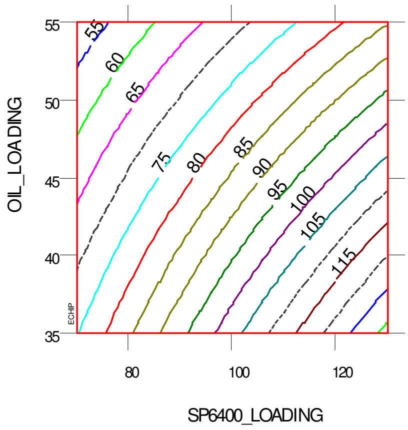
MOONEY_VISCOSITY



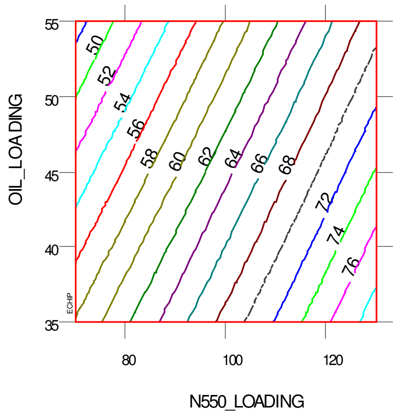
MOONEY_VISCOSITY



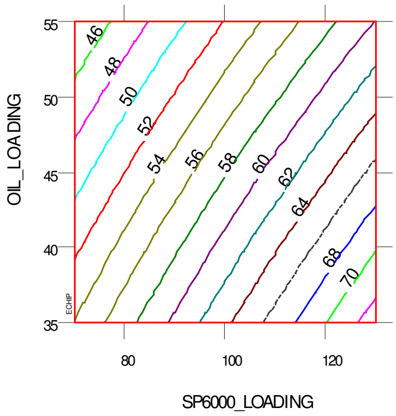
MOONEY_VISCOSITY



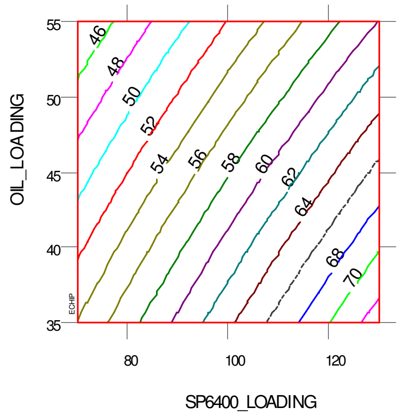
HARDNESS(SHORE-A)



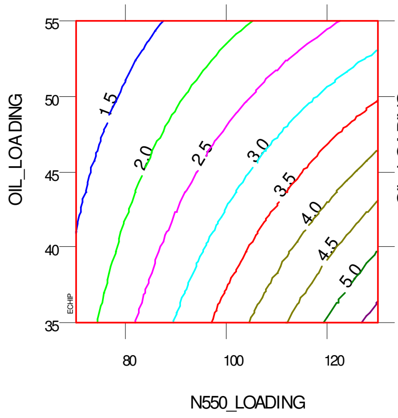
HARDNESS(SHORE-A)



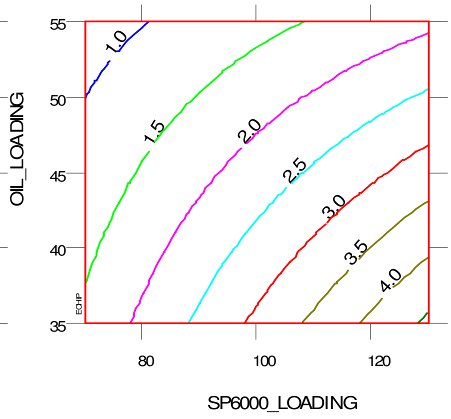
HARDNESS (SHORE-A)



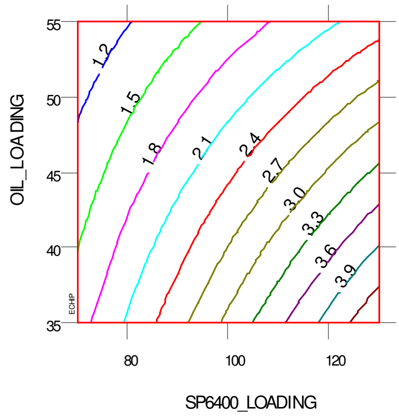
100%MODULUS



100%MODULUS

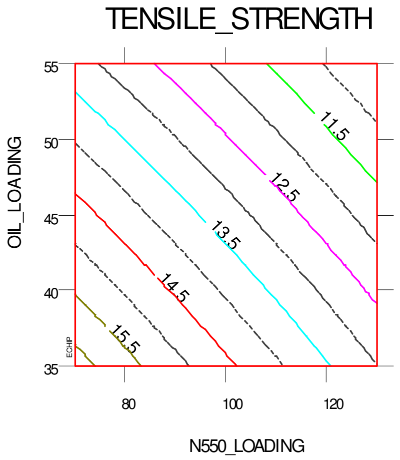


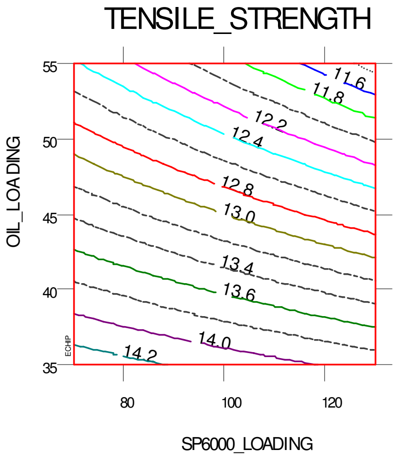
100%MODULUS

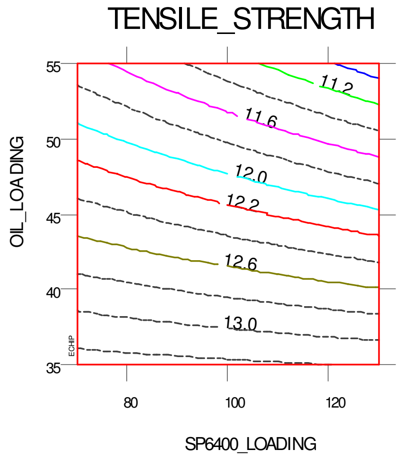


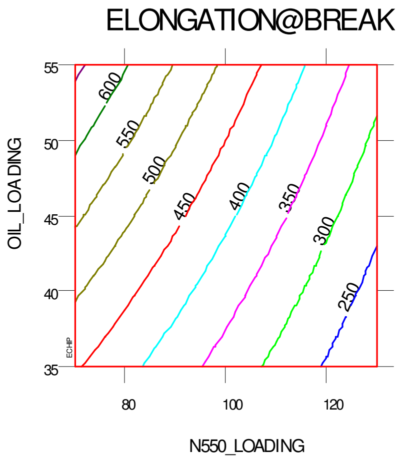
Attachment 8

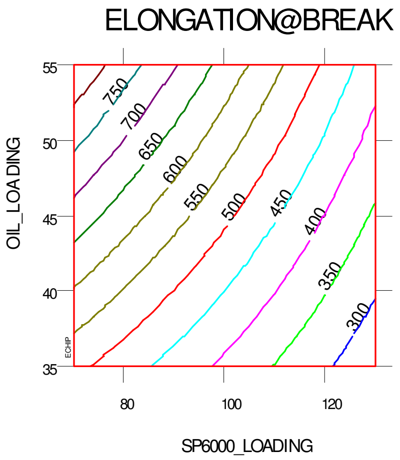
N550	SPHERON®6000	SPHERON®6400

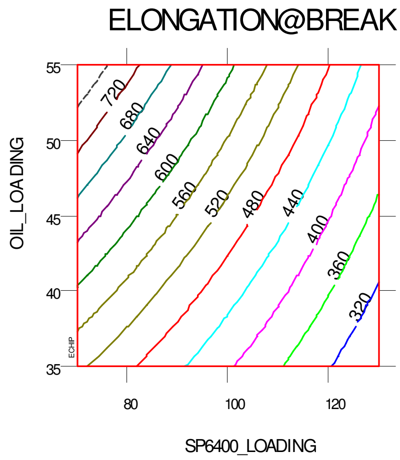


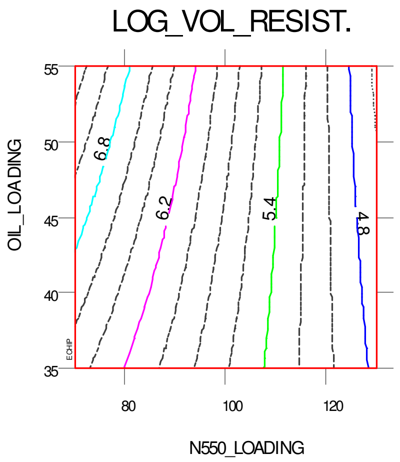


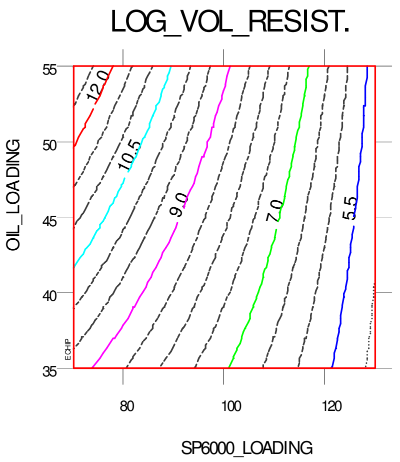












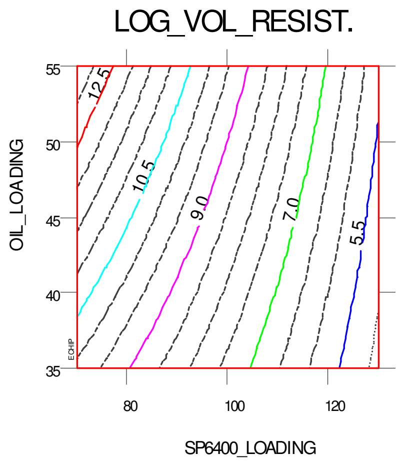
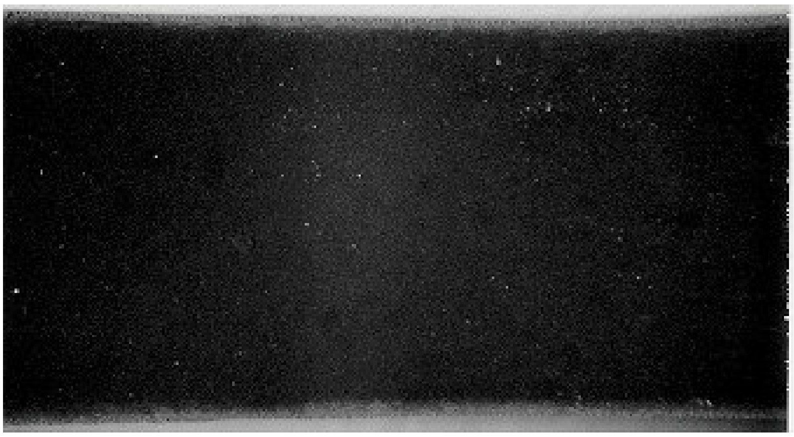
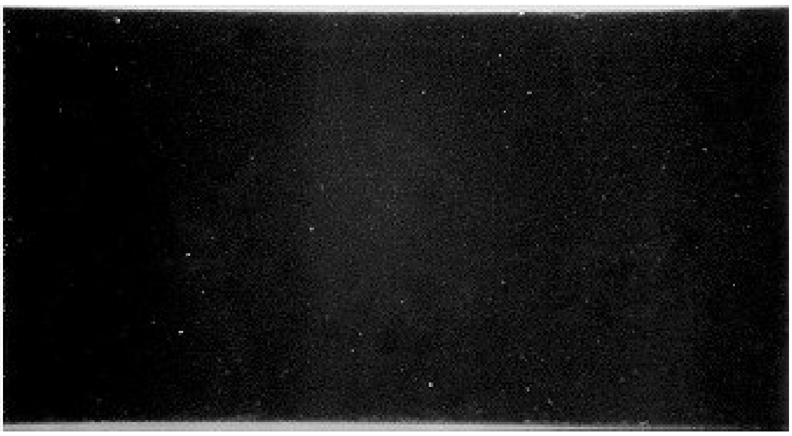


Figure 1: 70 phr Carbon Black / 35 phr oil

SPHERON®6400



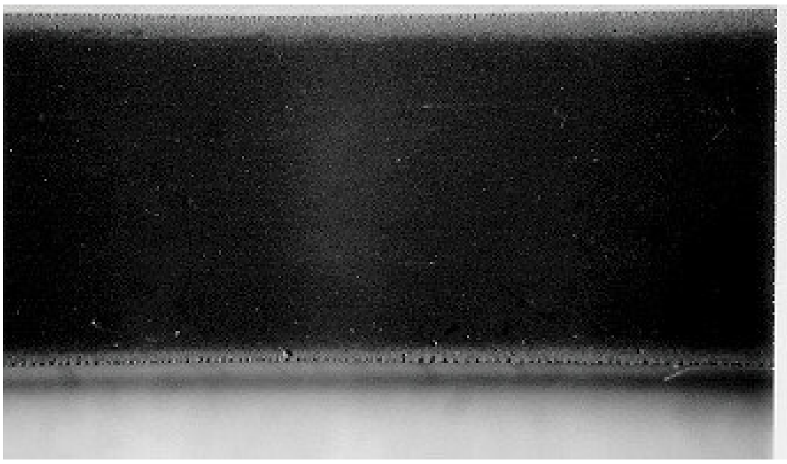
SPHERON®6000



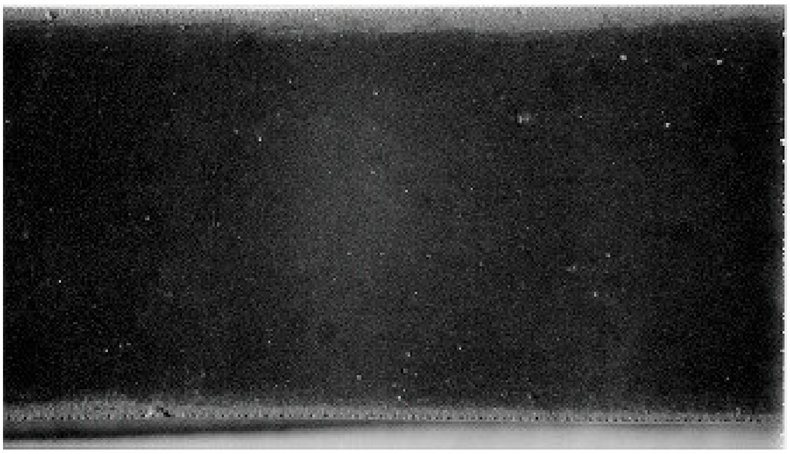
ASTM N550

CABOT

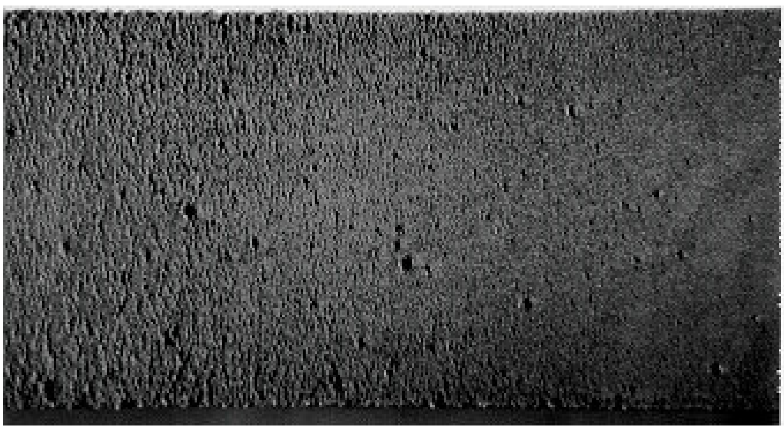
Figure 2: 100 phr Carbon Black / 45 phr oil



SPHERON®6400

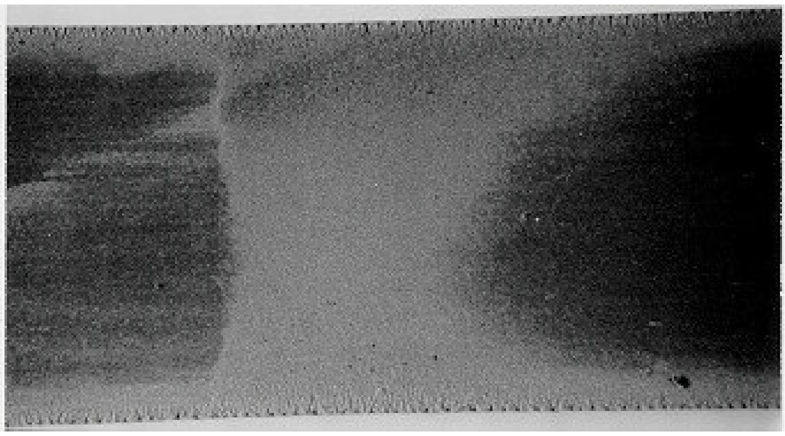


SPHERON®6000

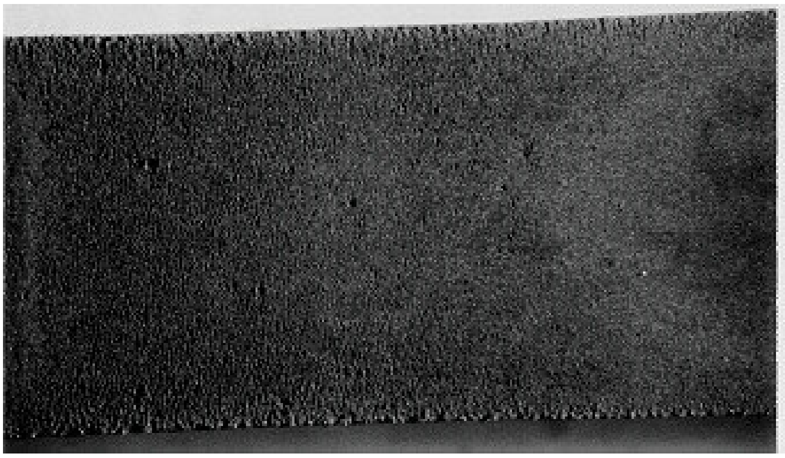


ASTM N550

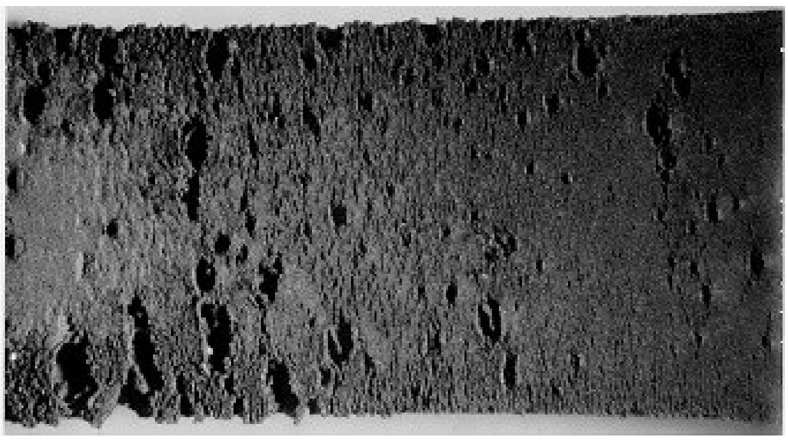
Figure 3: 130 phr Carbon Black / 55 phr oil



SPHERON®6400



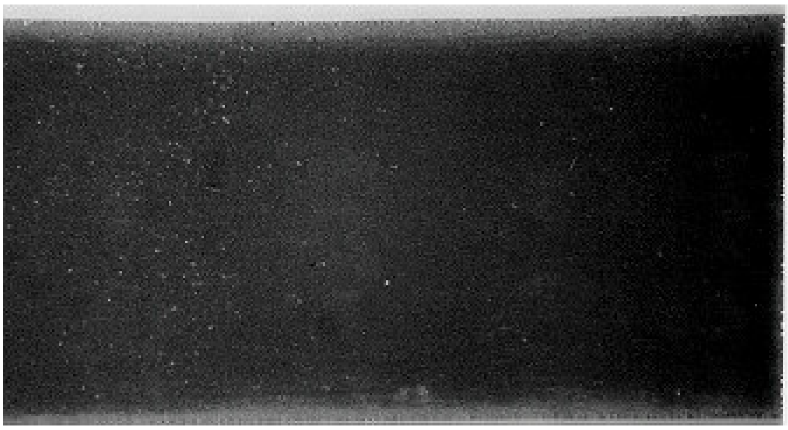
SPHERON®6000



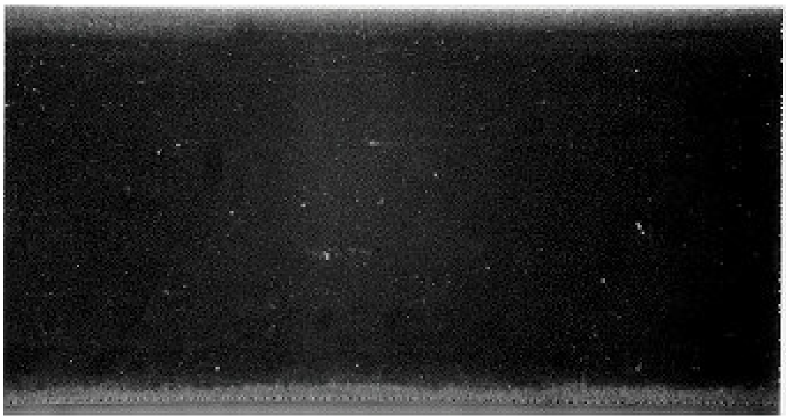
ASTM N550

CABOT

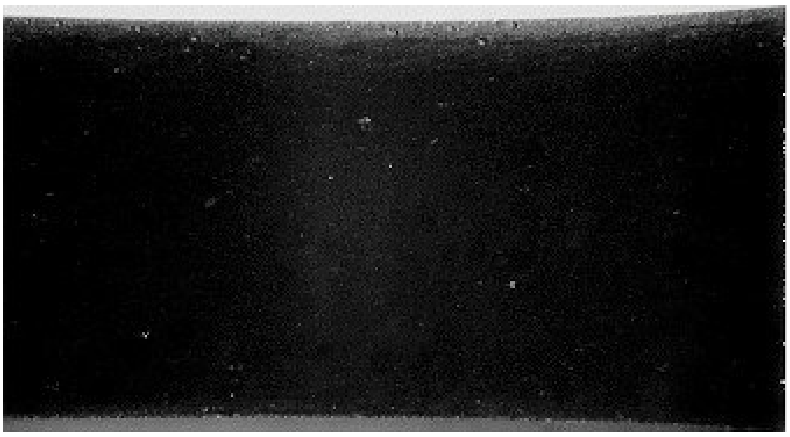
Figure 4: 70 phr Carbon Black / 55 phr oil



SPHERON®6400



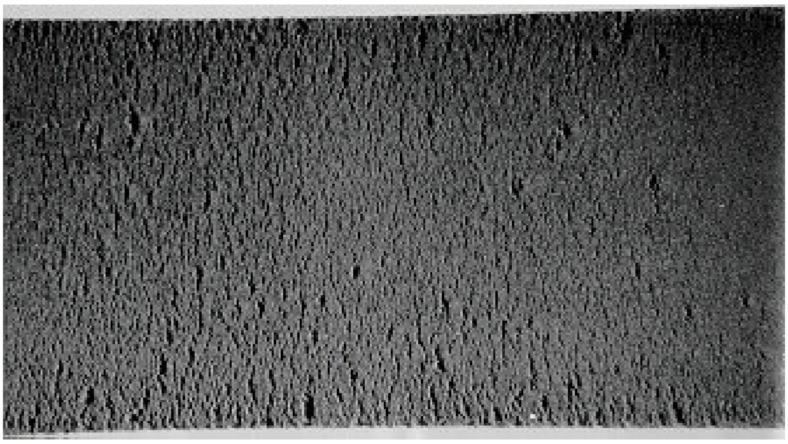
SPHERON®6000



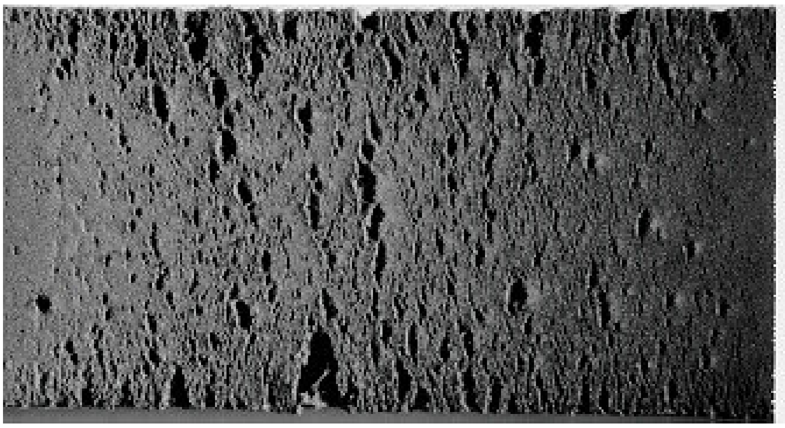
ASTM N550

CABOT

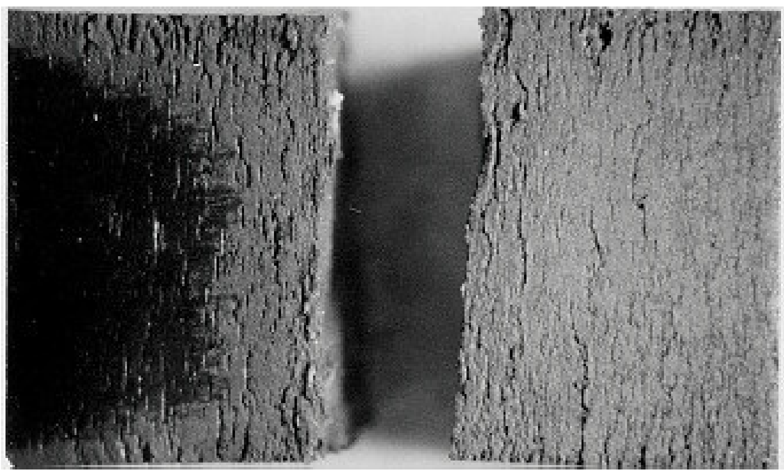
Figure 5: 130 phr Carbon Black / 35 phr oil



SPHERON®6400



SPHERON®6000



ASTM N550