use of special carbon blacks to gain unique properties and processing

In daily discussions with rubber chemists, it's clear that only a few of these chemists take advantage of all the unique properties that can be obtained by using the full range of available carbon blacks. Very often the reason for not using a unique black is due to reluctance to inventory another black. And this is understandable. But you should be aware that you limit your compounds' properties by not making use of carbon blacks that may provide better physical properties, processing, or dispersion than that of a run-of-the-mill black. Choosing a black that more precisely fits the product can sometimes mean meeting a specification, minimizing mixing problems, or maximizing production efficiencies.

Carbon Black 101: Although most compounders cut their teeth formulating with carbon black and therefore have a good working knowledge of the subject, in order to discuss how certain blacks differ from ordinary blacks, we have to be sure everyone starts with the same basic understanding of carbon black. By having a working knowledge of how blacks differ, you can discern why certain blacks may be better in particular applications. You will see how to make better use of available standard ASTM carbon blacks and you will have an opportunity to see the specialty blacks available from Cabot Corporation. Akrochem represents Cabot Corporation, the most dependable, yet innovative, carbon black line in the rubber industry. While manufacturing a full line of standard ASTM grade carbon blacks, Cabot has also created blacks that differ from competitive products and can help you produce a unique rubber product:

- The cleanest carbon blacks in the industry. While many rubber products don't require a black this low in impurities, these blacks are actually a low-cost insurance against some of the problems caused by blacks containing more grit, charred carbon, metallic residue, or salts. These problems are usually not recognizable in tensile or abrasion properties. Problems like surface appearance of extrusions or flex fatigue resistance may not show up until much later in product development.

- Novel morphology placement (where a black falls on a structure and surface area grid - see the graph on page 3). Blacks that fall in-between common ASTM grades and allow the use of one black where a blend may have been used before. In most cases the single black is better suited for the desired dispersion and reinforcement that the blend tries to create. Two such blacks are Spheron 1416 and Sterling 1120.

- Unusual morphology or modifications to the black to make it more viable in molded goods. How many carbon blacks do you know of that are specially designed for use in molded goods and not tires? Blacks with unusual combinations of surface area and structure that lend themselves to properties unobtainable with standard blacks. An example is Spheron 5000A black that has the low surface area of an N762 but the high structure of an N550. These two features make for the absolute ultimate dispersion/reinforcement properties. Upside-down mixing of EPDM with Spheron 5000A results in an exceedingly well-dispersed carbon black with good reinforcement. We'll discuss this in more detail later. Unusual morphology is not strange to Cabot. They patented the way to make low structure HAF black (Regal 300 - N326) in the 1950's. They still dominate this particular black's usage.

- Two modified blacks that have been fine-tuned for injection-molded goods are Spheron 4000 for nitriles and other polar elastomers and IRX 1072 for EPDM. Both blacks provide better flow and much better mold cleanliness than comparable blacks.
- Carbon blacks that are predispersed in natural rubber called "CEC" or Cabot Elastomer Composites. Like SBR black masters, the black is dispersed in the natural rubber at the latex stage. This creates a highly unusual product. Black dispersion is no longer an issue. Hard-to-disperse blacks like N231 come totally dispersed. Performance properties like flex fatigue resistance of the finished product are far superior to what can be achieved by internal mixing of black and rubber. Physical properties like abrasion resistance, tensile and tear are moderately, but consistently, better due to the natural rubber's polymer chains not having been scissioned by high shear mixing. These composites with black predispersed promise to revolutionize high-quality products made from natural rubber. Because this is an involved topic, an entire Solutions will be devoted to the CEC products.
- Truly FDA-certified furnace blacks. The only FDA organic black colorant used to be channel black. Cabot's high purity blacks have levels that exceed (that is, are lower than) the FDA standards for polynuclear aromatic hydrocarbons (PAH) and benzo[a]pyrene (see Code of Federal Regulations 21, Section 178.3297, Colorants for Polymers, under "High purity furnace black"). High quality, FDA-certified black (channel blacks have a dubious history of quality control) from a U.S. manufacturer. Due to space limitations, we'll have to discuss these FDA blacks at another time. Call Akrochem tech service if you need to know more.

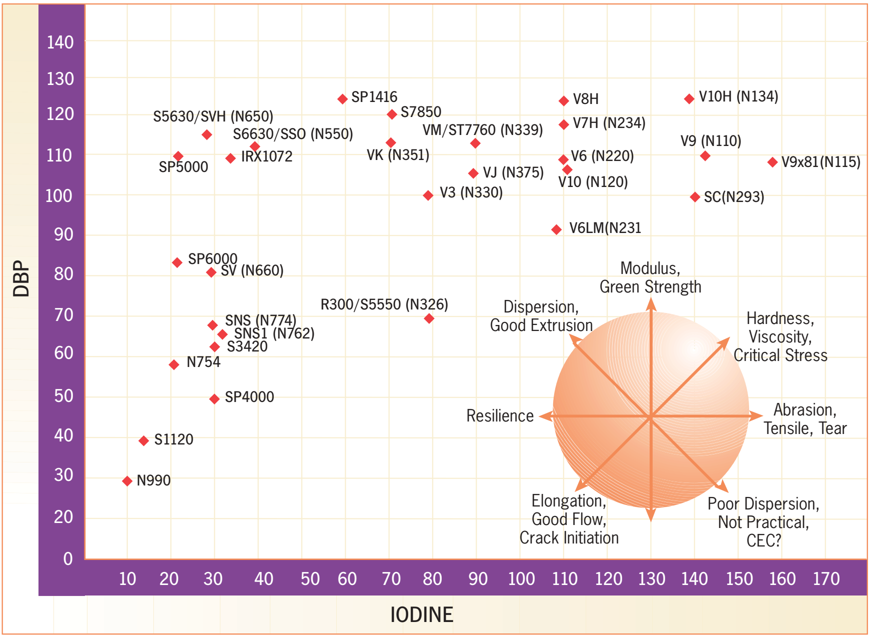
what is carbon black and how is it made?

Carbon black is simply elemental carbon. Carbon is nature's most flexible element – it comes in pure forms that can radically differ like diamonds and graphite. Carbon black is a spherical particle of carbon formed by burning an aromatic feedstock. Most black today is derived from controlled burning of petroleum oil. Thermal black and channel are made from natural gas feedstock. In simple terms, carbon black results from the following formula:

$$CxHy + O_2 \longrightarrow C + CH_2 + CO + H_2 + CO_2 + H_2O$$

The primary particles of carbon collide with other particles and become an aggregate. Groups of aggregates are loosely held together in agglomerates. When rubber mixing takes place, the agglomerates are being broken back down into aggregates. The aggregate is the smallest functional unit of carbon black in rubber. Thus the ability of a carbon black to disperse well relates to first, how easy or difficult it is to break agglomerates of that black into aggregates; and second, how much interaction between the black surface and the rubber can be achieved.

There are two main characteristics of carbon black that determine most of its functionality in rubber: surface area and structure. It is crucial that a compounder understand these properties of carbon black and how they relate to the rubber's final properties. By tweaking either property or using a unique combination of the two properties, you can optimize your rubber compound. Part of the compounders' decision-making process is to choose the best black for a product's needs. Can the requirements be met with in-house blacks or should a special black be considered to optimize the product properties? Too often compounders choose to make compromises by sticking with their in-house blacks. They struggle to meet properties, they struggle to get the proper mix, and they struggle to get the product through processing. Oftentimes by using a special black, many or all of these problems are eliminated. Understanding how blacks differ is the first step in choosing the right carbon black. Refer to the following morphology map to understand the positioning of different blacks .



V = Vulcan S = Sterling SP = Spheron

Surface Area (SA)

Surface area is simply the amount of carbon black surface available to interact with the rubber. It is directly related to the carbon black's individual particle and/or aggregate size. The smaller the particle, the more surface area (SA). The more SA available, the more reinforcing the black will be. Thus, tensile and abrasion are usually directly related to the surface area; tear and hardness are partially related. SA is typically measured by absorbing I_2 in a monolayer on the black's surface. Thus, a highly reinforcing black like N220 will have an I_2 number of 120 while a lower-reinforcing grade like N762 will be around 28. Black terminology refers to a high surface area black as a "hard" black and a low surface area black as being a "soft" one. This refers to the durometer effect a black has on a rubber compound. As most compounders know, in the ASTM method of naming carbon blacks, the smaller the first digit, the higher the surface area and the more reinforcing a black will be. Thus N110 is much, much more reinforcing than N990 and moderately more reinforcing than N330.

Surface area is a double-edged sword, however. You have to take into consideration that the more SA a black has, the harder it will be to disperse (harder to reduce agglomerate size), the harder processing will be, and the dynamic properties (flex, hysteresis resistance) will be worse. Take into account the fact that in certain cases, the poorer dispersion may make high surface area blacks result in worse tensile, not better. Low-to-medium durometer polychloroprenes and EPDMs with a lot of loose oil will have great difficulty making high tensile requirements – and you can't simply bludgeon them with more reinforcing blacks. Sometimes a special black may be called for to achieve the necessary dispersion and tensile.

Structure (DBP)

Structure is a measurement of the shape and size of a black's aggregate. I'll refer to the most common method for measuring a black's structure, adding DBP or dibutyl phthalate to the black,as a convenient abbreviation for this characteristic. The more DBP a black will absorb, the more convoluted the aggregate; the more nooks and crannies there are in the black. Higher DBP number leads to higher viscosity, higher hardness, higher modulus, and higher electrical conductivity. Higher DBP numbers also mean a better dispersing black and a reduction in calendar and extruder swell. High structure blacks are known for their good extrusion properties like low nerve, smooth surfaces, with sharp corners and edges.

Black structure can be taken advantage of with both high structure and low structure. Low structure blacks, while harder to disperse, have the advantages of higher tear (compared to a similar surface area black of higher structure), lower modulus with higher elongation, and finally lower viscosity and better mold flow. If tear is a critical property, a small particle, low structure black will optimize this value. The smoother black particle surface allows the rubber to "slip," relieving energy buildup and preventing rupture. Certain products lend themselves to the use of low structure (LS) blacks. An example of one is oil well blowout preventers (BOP) where very good physicals (tensile and tear) are combined with high elongation needs at high durometer (meaning low modulus rubber). Using the LS blacks also improves mold flow in the large BOP parts.

Getting good dispersion of low structure blacks is often an issue. One way to improve dispersion is to use the LS black in combination with a high structure (HS). ⅔ N326, an LS black, with ⅓ N550, an HS black, is a good compromise to get better overall properties than all-N326. In some circumstances like a high quality, low durometer polychloroprene, good dispersion of reinforcing low structure black is very difficult, and it may be better to avoid LS in these cases.

High structure means there are many rough surfaces on the black aggregate with which rubber can interact. This leads to higher viscosity and green strength and better dispersed black prior to cure. After cure, the high structure results in higher modulus, higher durometer products. The combination of higher durometer with good dispersion usually leads to greater use of oil, which reduces costs.

The ideal dispersion black is one with high structure but low surface area. Among standard furnace blacks, N650 is a good compromise of dispersion and reinforcement. Cabot has several ways to improve upon N650 results: Spheron 1416 will achieve equal dispersion while giving better physicals or Spheron 5000 will achieve better dispersion with equal physical properties.

specialized carbon blacks

While standard grade furnace blacks will fill most rubber product requirements, there are many applications that could use a particular, specialized black that better fits the product needs. Yes, a standard grade may well work in the product but it may be marginal or it may fall out-of-spec occasionally. For just slightly more cost, a black that better fits the product might produce fewer rejects while meeting specifications all the time.The specialized black will be an insurance that the rubber will not only meet spec but be unlikely to fail for unforeseen reasons. Cost should be a variable in your carbon black selection, but not the primary one.

An example I can relate was a customer who called regularly about one particular compound he ran almost daily. And almost daily the compound did not meet some part of the specification. Durometer, modulus, and tensile problems – as well as erratic scorch and cure rates. The variability centered on the fact that a very hard-to-disperse black was being mixed in one pass. A two-pass was out of the question so a better choice would have been to choose an easier-to-mix black that was similar, or even slightly lower, in reinforcement. Better dispersion would have made up for lesser reinforcement and the erratic physical and processing properties would have greatly improved. The small additional cost for a more manageable black would have been minimal compared to reworking/remilling batches every day. But the cost on paper overruled any such changes. As long as the rejects were not accounted for in the true cost of the stock, every pound mixed was probably losing money.

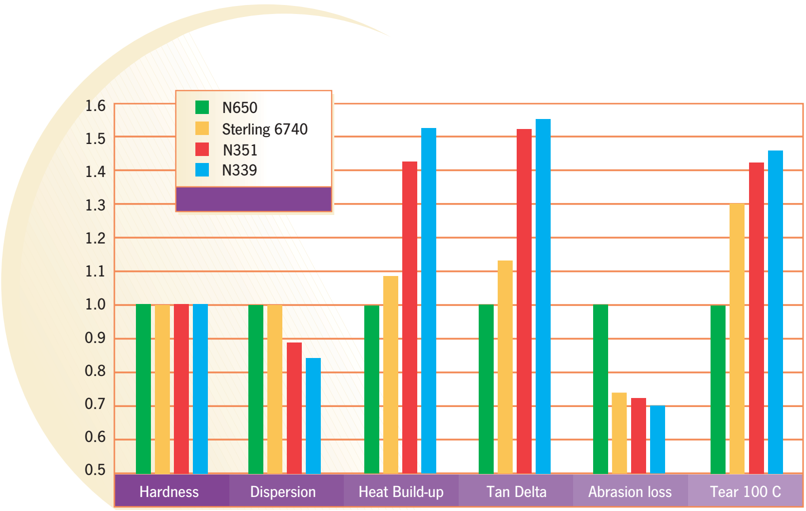
Sterling 4-Digit ASTM Blacks

These blacks are standard blacks that have been cleaned of the normal black contaminants. Until a customer has some kind of problem with standard blacks, they are hesitant to buy the same product, only cleaner. My rule-of-thumb is that the higher the part quality, the more the customer needs to consider the extra "insurance" that the Sterling products offer. Cost difference is small vs. standard grades, so the cost of this insurance is small. Extrusions will be cleaner, smoother, and glossier (less refraction of light due to bumps and pips on the surface). Flexing parts will have fewer high stress points to initiate cracks. We used to buy a cleaner grade N550 (Sterling 6630 type) for front wheel drive grease seals. It was a minor cost to make sure the product had these advantages. It also made compounding other stocks less stressful since you knew this was a clean, quality black and you didn't have to question putting it into other demanding applications. Impurities like hard particle carbon grit, metallic rust, stainless steel, aluminum salts, sulfur, etc., can affect physical and surface properties of elastomeric vulcanizates. Compounders have seen physical improvements primarily in dynamic properties (flex fatigue), surface appearance, and ECD (electrochemical degradation) as well as some benefits in tensile strength, elongation, tan delta, hot tear resistance, etc., utilizing these carbon blacks. Also due to their cleaner nature, these blacks have contributed to smoother injection, extruded and transfer-molded stocks; lower scrap rates; improved dispersion; fewer screen changes and less wear on production equipment. A frequent problem is that it is difficult to put tangible numbers to these improvements (reduction in equipment wear might not be evident for months) to justify the slightly higher cost of cleaner blacks.

Sterling	Iodine	DBP	Replacing	Applications
3420	30	65	N762 – Sterling NS-1	Wiper blades/o-rings, hose, thin-wall, dynamic parts
5550	82	72	N326 – Regal 300	Mounts, bushings, belts, injection molded parts
5630	36	122	N650 – Sterling VH	Weather stripping, channeling, roofing membranes
6630	43	121	N550 – Sterling SO	Seals, stripping, hose, belts, extruded profiles
7760	90	120	N339 – Vulcan M	Shoes soles, belts, seals, calendared goods

Spheron 1416 (fka Sterling 6740)

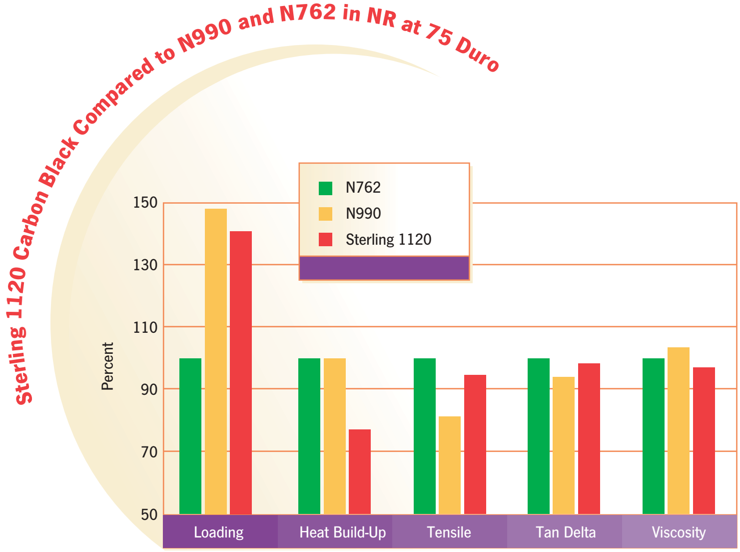
Even on paper, this looks like a black that has some unusual properties. The morphology map shows the 1416 fills the gap between N550 and N351 or the surface area between 45 and 65. Based on the ASTM system, this would be classified as an N400 grade. I know of no other black in this surface area range (55) as well as having a very high DBP (129) value. From this graph below, you see you get the dispersion and heat buildup resistance of the N650 while also getting abrasion resistance and tear that resembles an N300 grade.



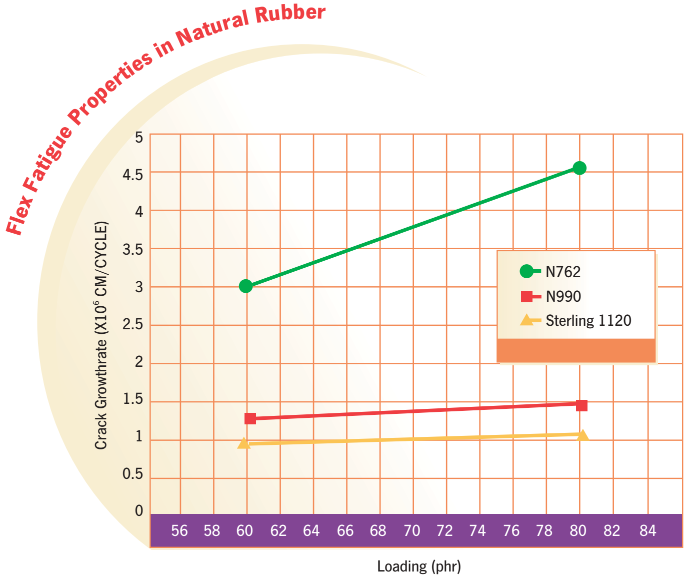
- Disperses like an N550 but has properties close to N351. Can use in upside down mixed EPDM where good physicals of an N300 grade are needed but dispersion must be much better.
- Eliminates blends of N330 or N351 with N550 or N650 to get "in-between" properties. Such blends usually result in the worst properties of both blacks.
- Excellent choice for microwave-cured extrusions. Microwave receptivity is very high (like N351), but dispersion, which is important for controlled microwave heat-up, is more like N650.
- Dynamic parts that need low hysteresis and excellent dispersion but also good reinforcement. Compression set is lower compared to other reinforcing grades.
- Lower costs possible by adding additional oil to batch. The high structure along with slightly smaller particle size allows more oil to be added with no fall-off in properties compared to N550. Dispersion remains good.

Sterling 1120

From the morphology map you can see this is another "in-between" black. Sterling 1120 is the closest Cabot black to N990 thermal black but with more surface area for reinforcement-basically an N800 grade with SA 21 and DBP 34. From the graph below, you can see how the 1120 provides many of the good properties of both N762 as well as N990. You get good loading close to N990, but tensile like N762.



- Nothing else but 1120 between N754 and N990. Again, it is an N800 type.
- Helps overcome one of the weaknesses of N990: its lack of reinforcement. Most compounders would like to use all-N990 formulas but tensile and tear are usually low. Then, blends are made with N550 or N762 to get more tensile, tear and green strength. Total loading is then about the same or lower than what ST 1120 will deliver.
- The 1120 gives better flex-cracking resistance than N990 even at equal loadings. This is very unusual since it usually follows that the larger particle blacks flex better. The graph below shows this – a compound could be run at a higher duro and get equal flex-cracking or run at the same duro and get better flex-cracking resistance.



- Lower HBU (heat build-up) and tan delta than blends of N990 and N762.

- Low electrical conductivity due to low surface area and low structure. Only N900 is better in this regard. Along with this, the cleanliness of the black (low metal content) means metal in contact with rubber part does not corrode as easily.

- High duro parts can be made with manageable viscosities. N990 has so little reinforcement value that 90+ duros are tough to do. The 1120 reinforces better while maintaining a workable viscosity. Spheron 4000 may be an even better choice for high duro NBR parts (for example, oil field parts).

- While FKM loading of 1120 would be slightly less, it is still more than any other black plus you get better hot tear (often a problem in FKM) and higher tensile. The 1120 is FDA-acceptable for rubber use while N990 is not. Other expensive polymers like Vamac, Hypalon, HNBR, and polyacrylates can make use of the high loadings and decent physicals offered by 1120.

Spheron 5000 and 6000

These are dual personality blacks. Spheron 5000 has the surface area of an N700 black but the structure of N650 or N550. The 6000 black has the surface area of an N800 but structure like an N600. No blacks are currently offered with similar properties. The Spheron 5000 and 6000 are designed for optimum dispersion along with moderate reinforcement. (Obviously N990 will give perfect dispersion but with very little reinforcement.) Ideal application is in upside-down mixed EPDMs that require good physicals and/or a near-perfect extrusion finish (Class A finish).

- Low duro dense rubber and soft sponge mixes can make use of the good dispersion.

- Good blacks for butyl dispersion. A maker of low permeation water tubing for gas masks found N550 to disperse poorly. This allowed mustard gas to permeate easier. Use of SP5000 solved this problem.

- Can create higher-loaded stocks with the 6000 that extrude like N550 and N650 but are lower cost.

- The low surface area and high structure makes for faster mixing. Some two-pass mixes can be converted to a single pass. Look over the accompanying data comparing Spheron 6000 to standard blacks. You will see how you can get dispersion like N990 but extrusion and reinforcement near N650.

Spheron 4000

Another black with odd combination of morphology: moderate particle size (more reinforcing than N700 grades but with extremely low structure). The low structure promotes outstanding mold flow permitting the use of fewer process aids.

- Designed for injection molded O-rings, seals and gaskets, and intricate molded parts. Primarily designed for NBR's, HNBR's and other polar polymers. Deflashing of parts is easier due to higher loadings.

- Low viscosity is an advantage in high duro parts that have to be molded or extruded. High durometer oil field packers come to mind.

- Molds remain clean longer. Reduces downtime for mold cleaning.

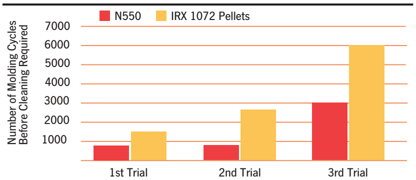
Spheron IRX 1072

Another specialty black designed for high volume, injection-molded EPDM parts. High structure to permit dispersion plus a special additive included at the reactor that promotes better flow in EPDMs. The 1072 also improves mold cleanliness. Between the two improved molding properties, EPDMs can be molded faster with less downtime for cleaning.

- Physicals like N650 or N550.
- Twice the injection molding cycles between cleanings (see chart below).
- Improved flow means more complete cavity fills in less time.

Carbon Blacks	N650	N660	N774	N762	N990	SPHERON 6000
Hose Extrusion Performance						
Loading	80	80	95	95	140	95
Loading Rating	5	5	2	2	1	2
Mooney Viscosity – ML 1+4 @ 100C	92	74	73	70	60	90
Viscosity Rating	1	3	4	5	6	2
Exrusion Shrinkage, %	21	30	34	35	50	27
Shrinkage Rating	1	3	4	5	6	2
Extrusion – Smoothness Garvy Rating	16/16	9/16	11/16	11/16	7/16	16/16
Smoothness Rating	1	5	3	3	6	1
Green Strength, MPa	0.83	0.74	0.79	0.81	0.62	1.02
Green Strength Rating	2	5	4	3	6	1
Dispersion – Philip's Rating	8.3	7.8	8.0	7.8	9.1	9.1
Dispersion Rating	3	5	4	5	1	1
Total Extrusion Rating	13	26	21	23	20	9
Best Carbon Black NBR Hose Extrusion	2nd	6th	4th	5th	3rd	1st
Physical Properties						
Hardness Shore A	76	74	74	73	74	75
Tensile, MPa	18.39	18.25	16.60	16.39	13.5	16.73
Elongation	340	348	363	393	503	360
100% Modulus	5.78	4.60	4.32	4.16	2.93	5.18
Die C Tear – kN/m	48.34	49.91	48.16	50.79	48.98	50.01
Compression Set	72.5	71.3	70.5	71.8	68.3	70.7

Test Results in Sulphur Cure Formulation - Different Articles



Note: Injection Temperature: 75°C, Mold temperature: 214°C, Injection Time: 5 sec., Total Cycle Time: 36 sec.

Compound Properties:	IRX 1072 Pellets	N550
Mooney Viscosity	48	49
Hardness	71	71

Test Results in Sulphur Cure Formulation (EPDM 100, oil 90, CB 140, curative 3.5, processing aid 3.5 phr)

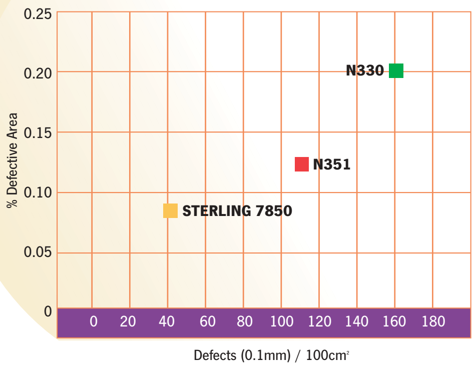
CB Grade	IRX 1072 pellets	ASTM N550
CB Loading, (phr)	140 phr	140phr
MDR @ 180°C, 1° arc		
Min Torque (dNm)	1.2	1.4
Max Torque (dNm)	15.4	16.1
Scorch 1 (m.m.)	1.0	0.9
Scorch 5 (m.m.)	1.5	1.3
T50 (m.m.)	1.7	1.5
T90 (m.m.)	3.9	3.6
Mooney Viscosity		
ML(1+4) @ 100°C (M.U.)	37	41
Shore A (3 sec.)	70	70
Tensile Strength (MPa)	11.2	11.8
Elongation @ Break (%)	450	427
50% Modulus (MPa)	1.7	1.9
100% Modulus (MPa)	3.2	3.7
300% Modulus (MPa)	8.7	9.5

Sterling 7850

One of my favorite carbon blacks for mechanical goods is N351 (Vulcan K). It is a black of which only a few compounders make good use. It provides very good reinforcement but also has very good dynamic properties. I first made use of this black in an exercise part that required flex crack resistance, low heat buildup (HBU) and extreme toughness. The only drawback is dispersion problems in softer materials like Neoprene. The Sterling 7850 is a souped-up version of N351 that provides better dispersion. Structure is significantly higher (128 vs 120) but surface area is the same. If you need a tough, dynamic 70-duro product, you can get there faster with the 7850 since the higher DBP will give you more durometer. The lower loading reduces hysteresis, improves set while the improved dispersion helps reduce flex cracking.

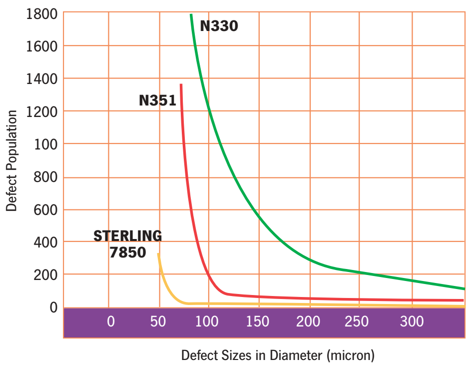
Comparison of Extruded Surface Quality

In extruded NBR compounds at equal hardness, the compound containing STERLING 7850 carbon black exhibits a significantly lower number of surface defects and lower overall defective surface area compared with compounds containing N330 and N351 grades.



Comparison of Surface Defect Size Distribution

Compared with conventional reinforcing grades, STERLING 7850 carbon black shows fewer surface defects at all defect sizes in extruded NBR compounds.This superior surface smoothness is attributable to the high cleanliness and excellent extrudability of STERLING 7850 carbon black.



Because these Solution articles are limited to about 10 pages, there is much information about these unusual carbon blacks that could not be added to this publication. Take some time to consider how these specialized blacks could make some of your products better or different from your competitor's. Then give Akrochem a call to discuss your needs.

AKROCHEM CORPORATION

SEVEN DECADES OF SUPERIOR SERVICE