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# **Engineered Elastomer for Tire Reinforcement**

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# Engineered Elastomer for Tire Reinforcement

## ABSTRACT

A concentrate of para-aramid pulp in matrix elastomers was developed to facilitate its incorporation into rubber compounds. This concentrate, called KEVLAR<sup>®</sup> engineered elastomer, reinforces more efficiently than simple mixtures or masterbatches of pulp in elastomer. Engineered elastomer added at low loadings to a rubber compound can greatly increase low strain modulus, improve tear resistance, and slow tear propagation without significant increase in hysteresis. Summaries of effects of engineered elastomer on compound properties are presented, as well as an overview of its applications in tire components.

## INTRODUCTION

Para-aramids were introduced in 1972 when DuPont commercialized KEVLAR<sup>®</sup> brand fiber. Para-aramid fibers are known for their high strength to weight ratio, high modulus, and excellent chemical and thermal stability. Initially, they were offered in continuous filament form, and soon found applications in tires, mechanical rubber goods, bullet resistant vests, and composites. In the 1980's, short forms of the fiber - staple, floc, and pulp - were introduced and quickly found acceptance in cut-resistant protective apparel, gaskets, and friction materials. Photographs of these three product forms are shown in **Figure 1**.

Once short para-aramid product forms were introduced, they were evaluated for rubber reinforcement. Using short fibers (such as cellulose, cotton linters, cut scrap denim, polyester, and nylon) to reinforce rubber is common in the rubber industry. They improve green strength, provide dimensional stability prior to cure, and improve mechanical properties of the vulcanizate. Compounders found that they could incorporate para-aramid floc (we define floc as short, uncrimped fiber less than 6 mm in length) into rubber using an internal mixer or a roll mill, often with difficulty. Incorporating the high-surface-area pulp product (**Figure 2**) proved to be exceedingly difficult. Para-aramid pulp is a low bulk density, static-prone material that is difficult to handle in a rubber mixing facility. Some compounders were able to adequately disperse it into a rubber compound, and their work demonstrated the superior reinforcement potential of para-aramid pulp if the dispersion limitation was overcome. Compounds reinforced with pulp had 3-5x higher modulus at a given loading than those reinforced with floc. In dynamic applications, pulp reinforced compounds also had lower heat build up than floc reinforced compounds at a given modulus, and they had had better processing characteristics.

The rubber industry frequently utilizes dispersion or masterbatch technology to incorporate materials that are difficult to mix into a rubber compound. This was quickly identified as the preferred method for incorporating para-aramid pulp into a rubber compound.

Conventional technologies used to prepare masterbatches were not effective in dispersing para-aramid pulp. DuPont initiated studies to define a method to disperse pulp into rubber, and this effort led to development of a proprietary new technology for dispersing pulp into an elastomer matrix. Products produced via this technology (KEVLAR<sup>®</sup> engineered elastomer) showed superior dispersion of aramid pulp in rubber compounds, and are more efficient in reinforcement than mixtures of para-aramid pulp in an elastomer matrix. These products were described in a previous presentation to the Rubber Division of the American Chemical Society.<sup>(1,2)</sup>

## EXPERIMENTAL

Dispersion analysis of para-aramid pulp in rubber compounds was conducted using an optical fluorescence microscope using an ultraviolet source and optical filters.

Compound formulations used in this work were based on those published in the Vanderbilt handbook<sup>(3)</sup> or from the library of testing laboratories. Formulation details and mixing procedures are given in previous papers. In all cases, the para-aramid pulp was introduced to the compound using KEVLAR<sup>®</sup> engineered elastomer.

<u>Compound</u>	<u>Reference</u>
Neoprene Belt Compound	Compression Component – page 649 <sup>(3)</sup>
NR/SBR Tire Tread Compound	Page 603 <sup>(3)</sup>
NBR Roll Cover Compound	Textile Mill Roll – page 684 <sup>(3)</sup>
NR Tire Compound	From testing laboratory (MRPRA)
EPDM Roofing Compound	From testing laboratory (ARDL)

Testing was done using standard ASTM or ISO test methods.

## REINFORCMENT EFFICIENCY AND DISPERSION TECHNOLOGY

The importance of good dispersion of fillers in a rubber compound is well known in the rubber industry. Dispersing fibers into a rubber compound can be more challenging than using traditional fillers. Fibers can form tangles (called neps in the fiber industry) that are not likely to be removed in rubber mixing. These neps can form defect sites in a compound that could lead to failure of the final article. The technology used to

disperse pulp in a rubber compound is important to achieving good dispersion without neps. A comparison of concentrate prepared using two different dispersion technologies is shown in **Figure 3**. Concentrates from two different technologies were pressed into thin nearly transparent films on a heated press. The films were placed on a lightbox and photographed. The technology used to prepare the concentrate pictured on the left side of **Figure 3** resulted in tangled neps that are visible in the photograph. These neps are likely not completely coated with elastomer, and achieving a good coating in rubber mixing is not likely. The photograph of the film prepared using DuPont technology shown on the right side of **Figure 3** is essentially free of defects.

It is also important that the concentrate be well dispersed (mixed) into the final rubber compound. Both fiber neps and undispersed concentrate can form defect sites that may lead to failure of the end product. An example of both tangles and undispersed concentrate in a compound is shown in **Figure 4**. Eliminating defects like those shown in the figure requires not only that the technology used to prepare the concentrate treat the pulp in a manner to avoid forming tangles, but also that the rubber mixing technology subject the concentrate to sufficient shear to blend the concentrate into the compound. The physical form (shape) of the concentrate is also important.

Openness is also essential to maximize the reinforcement potential of para-aramid pulp. Note the number of fine fibrils present in the electron micrograph of the pulp shown in **Figure 2**. Having these fibrils 'open' and extended is essential to maximize their effectiveness in reinforcement. Photographs of two compound samples illustrating openness of pulp are shown in **Figure 5**. The photo on the right of **Figure 5** is of a compound reinforced using a concentrate prepared using DuPont technology. Note the number of extended fibrils present in the photograph. An identical compound formulation, mixed by the same procedure, is shown on the left side. The pulp was incorporated using a concentrate prepared by a different technology. Note that the pulp is not as extended and, in some cases, even appears somewhat compacted.

Openness is essential to achieve interaction between the fiber and rubber. The polymer base for para-aramids is poly(p-phenylene terephthalamide), a rigid rod molecule. When spun into fiber, the polymer becomes highly oriented and highly crystalline. The high orientation allows extensive hydrogen bonding between the components of the amide ( $>C=O$  and  $-N-H$ ) groups of adjacent polymer chains (**Figure 6**.) Para-aramids are spun from highly concentrated sulphuric acid. Free  $SO_3^-$  in the solvent sulphonates some of the aromatic rings, and studies within DuPont suggest that the resulting sulphonic acid groups tend to be accessible at the fibril surface. Thus, the pulp fibril surface contains polar groups (amide and sulphonic acid on the polymer backbone as well as amine and carboxylic acid end groups) that can associate with a group on an elastomer.

We believe that a well-dispersed, well-opened pulp fiber can associate with the elastomer matrix in a manner similar to association between carbon black and elastomer. Bound rubber theories for carbon black assume that segments of elastomer molecules adhere to 'active sites' or 'reactive sites' on the filler particles as described in a recent publication<sup>(4)</sup>. We believe a similar mechanism is possible with p-aramid pulp.

The key requirement for our hypothesis is high accessibility of the surface of the pulp to the elastomer. The process used to prepare the concentrate must present the pulp to the elastomer in a way that the fiber is fully open to allow the elastomer to completely wet the fibrils. The DuPont processes maximize the wetting of the pulp allowing it to reinforce with maximum efficiency, efficiency greater than that of a simple mixture of pulp in elastomer. If pulp is mixed directly in an internal mixer or roll mill, or if a 'masterbatch' of pulp in rubber is made by other technologies, the pulp can become compacted to some degree, and its reinforcing potential cannot be fully realized. The process by which the concentrate is manufactured must create an intimacy between the rubber and the pulp.

## EFFECT ON COMPOUND PROPERTIES

The most striking effect of engineered elastomer on compound properties is its effect on compound modulus, especially modulus at low strain, as shown in **Figure 7**. Fiber and carbon black loadings were varied over a broad range in a SBR/BR heavy-duty tread compound. Modulus increased dramatically at low fiber loading.

Para-aramid pulp has a high L/D aspect ratio. This geometry makes possible an orientation of the particle when sheared in processing. Calendering or extruding compounds reinforced with engineered elastomer leads to modular anisotropy – a difference in modulus between the machine direction (MD) and cross machine direction (XMD.) This is illustrated in the data shown in **Figure 7**. MD modulus is about five times that of XMD modulus in 2-mm test pieces of this NR/SBR compound. Compound calendered or extruded thinner will display even higher anisotropy. MD/XMD modulus ratios greater than 10 can be achieved in these cases.

Increasing compound modulus using traditional stiffening agents typically results in an increase in compound hardness. For a rubber roll cover, an increase in hardness may result in reduced roll grip since a harder roll may have less desirable frictional properties. Adjusting the relative content of engineered elastomer and other reinforcing agents in the compound can result in increased modulus without a significant increase in hardness. This is illustrated in a NBR roll compound formulation in **Figure 8**. Compounds were prepared at different loadings of silica and fiber. The control (no fiber compound) has a Shore 'A' durometer hardness of 81. A compound of 80 durometer was prepared with >6x higher modulus (13.1 vs. 2.1 MPa) by addition of 9 phr engineered elastomer (on a fiber basis), while decreasing silica from 45 to 15 phr.

Additional data from this compound study are shown in **Figure 9**. Incorporating engineered elastomer into this rubber roll cover compound enabled an improvement in both tear and abrasion – two key properties for improved performance not only in a rubber-covered roll, but also in many other applications. Engineered elastomer enabled desirable improvements in modulus, tear and abrasion resistance without affecting hardness.

As mentioned earlier, compounds reinforced with engineered elastomer display modular anisotropy, a large increase in modulus in the machine direction, and a smaller increase in modulus in the cross-machine direction. In contrast, tear resistance increases in both the machine (MD) and cross-machine (XMD) direction. Data from the SBR/BR heavy-duty treadstock study are shown in **Figure 10** (trouser tear) and **Figure 11** (Die C Tear.) We attribute the isotropic increase in tear resistance in compounds reinforced with engineered elastomer to the three dimensional nature of para-aramid pulp, and to the openness of the pulp which results from the engineered elastomer prepared using the DuPont process.

Compounds reinforced with engineered elastomer behave quite differently than their no-fiber controls in tear testing. Control compounds will stretch in the tensile test machine, and then suddenly fail. A compound reinforced with engineered elastomer will stretch as it is pulled in the tensile tester; one or more 'notches' will form on one side as stretching continues. Ultimately, the compound reinforced with engineered elastomer will fail – at higher tear strength than the no-fiber control. Photographs of a tear test are shown in **Figure 12**. The photo on the left is of the control compound; this EPDM based roofing compound failed at 183 lbs/inch. The photo on the right is of the same compound reinforced with engineered elastomer. Note the notch that has developed. This compound had a tear strength of 230 lbs/inch, a 26% improvement over the no-fiber control.

Engineered elastomer is also very effective in increasing compound green (uncured) strength. Its ability to increase compound green strength enables calendering compounds into thin sheets. It has been used as a 'processing aid' because of its ability to increase green strength. The effect of engineered elastomer on compound green strength is shown in **Figure 13**.

The ability of engineered elastomer to efficiently build compound modulus was mentioned previously. We found that engineered elastomer is an order of magnitude more efficient in building compound modulus than traditional reinforcement materials. **Figure 14** illustrates the effect of adding both carbon black and engineered elastomer to a NR tire compound. The lowest curve is a gum rubber compound. The next three stress-strain curves show the increase in modulus by adding 30, 45 and 60 phr N330 carbon black. The upper two curves show the dramatic increase in modulus achieved by adding only 1 and 3 phr engineered elastomer (fiber basis) to the compound. Addition of only 1 phr (fiber basis) gives a greater increase in modulus than 15 parts of N330.

An important characteristic of reinforcement with engineered elastomer is its ability to build compound modulus without significant increase in compound viscosity. In **Figure 15** we compare engineered elastomer with several short fibers (flocs) commonly used to reinforce power transmission belt compounds. Engineered elastomer builds modulus about 3 to 5 times more efficiently than the other short fibers. Compound viscosity is also shown for these compounds. Engineered elastomer builds compound modulus with less increase in compound viscosity than

the other short fibers. In general, compounds reinforced with engineered elastomer have better flow properties at a given modulus than compounds reinforced with carbon black or silica alone.

Most rubber is used in dynamic applications, and rubber compounds see cyclic stress-strain behavior in their end-use. We conducted extensive studies to determine the behavior of a compounds reinforced with engineered elastomer in cyclic, dynamic conditions. This work was reported in detail in previous presentations to the rubber industry<sup>(5,6)</sup>, a few key conclusions from these studies are reported in this paper.

The most significant finding from our dynamic studies is the ability of engineered elastomer to build compound modulus with little effect on the hysteretic properties of the compound. In general, it enables developing high modulus compounds with reduced potential for heat generation. In our study of a high modulus power transmission belt compound in neoprene, we found the compounds reinforced with engineered elastomer developed modulus with lower tan delta than compounds reinforced with floc (**Figure 16**). Similar results were obtained in a natural rubber tire formulation.

The difference between reinforcement with engineered elastomer and traditional materials (carbon black and silica) on dynamic properties is shown in **Figure 17**. As seen in the plot of the left in the figure, the loss angle, a measure of hysteresis (heat generation potential) increases as the concentration of carbon black in a compound increases. The plot on the right illustrates how loss angle is nearly independent of the concentration of engineered elastomer in the compound.

The stress-strain curves of compounds reinforced with engineered elastomer are nearly linear with 'high modulus' at low strain, and at again with 'lower modulus' at high strain. Tensile modulus in the direction of fiber orientation (machine direction - MD) is higher than that perpendicular to the direction of orientation (cross-machine direction - XMD.) The MD/XMD modulus difference (anisotropy) of the compounds peaks near 50% strain. **Figure 18**, shows the relationship between modular anisotropy, strain and fiber content where anisotropy is calculated from the absolute stress values at a given strain. Anisotropy peaks at about 60% strain for the compound reinforced with 1 phr of engineered elastomer (fiber basis), and at about 50% strain for the compound with 3 phr reinforcement. **Figure 19** shows an identical plot where modular anisotropy is calculated by the tangential stiffness at a given strain. Anisotropy peaks at about 40% for the compound with 1 phr of engineered elastomer, and at about 30% for the compound containing 3 phr. The transition or inflection in the stress-strain curve always occurs around 50% strain. Acoustic emission tests were conducted on a number of compounds, both with and without engineered elastomer reinforcement. Specimens were pulled at a constant rate of 2 inches per minute, and the acoustic output monitored throughout. Key observations made during the testing included:

- Each material (non-pulp-reinforced and pulp-reinforced) showed detectable acoustic activity.
- The amount of acoustic activity, as measured by the total number of events, was roughly proportional to the amount of pulp present (**Figure 20**).
- The amplitude (intensity) of the acoustic events was similar; that is, the fiber compounds reinforced with pulp did not produce louder events, just more of them.

The peak acoustic activity was determined by plotting the data as ‘hits’ per strain interval (**Figure 21**). We found that peak acoustic activity occurs in the range 40-60% strain; this corresponds to the region where the stress-strain curve changes slope. The onset and peak of acoustic activity for three compounds is summarized below:

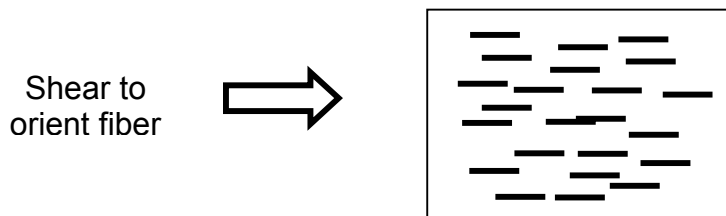
<u>Pulp concentration (phr)</u>	<u>0</u>	<u>1</u>	<u>3</u>
Onset of acoustic activity			
% Strain	14-38	26-36	24-37
Stress (lbs)	<10	16-18	26-30
Peak of acoustic activity			
% Strain	51-85	60	47-54
Stress (lbs)	8-15	22-23	38-40

Earlier in this paper, we hypothesized that reinforcement of elastomers by engineered elastomer involves association between charged groups on the fibril surfaces and those in the elastomer, a mechanism similar to bound rubber theories for carbon black. It is our belief that acoustic emission testing is recording the disruption of the association between the charged groups on fibrils and elastomers. Although engineered elastomer is used successful in applications where the applied strain exceeds 50%, we recommend caution and appropriate end-use testing when it is used in applications where strain exceeds 40 to 50%.

## APPLICATIONS IN TIRES

### Bead Area

Engineered elastomer is finding uses as a fabric or yarn replacement in several applications. In general, fabric replacement utilizes the ability of the fiber in compounds reinforced with pulp to be oriented in the direction of shear. The orientation may be accomplished by extrusion or calendaring; the orientation increases the compound modulus in the direction of fiber orientation.



A compound reinforced with engineered elastomer may be used to replace fabric in tires. A fabric 'toeguard' is sometimes used to retain the shape of the bead heel surface, and to reduce tearing when tires are mounted (**Figure 22**).<sup>(7)</sup> A chafer compound was developed that is extremely cut resistant and durable, and thus it eliminates the fabric toeguard (**Figure 23**).<sup>(7)</sup> This toeguard/chafer compound, reinforced with engineered elastomer, can be extruded and thus eliminates the need for a fabric calendar. Not only does extrusion simplify the manufacturing process, but it also reduces scrap. The compound also has good flow characteristics, improved cut and puncture resistance and improved green strength.

Engineered elastomer may also be used in the bead filler compound. Recent work showed that tires with improved high speed cornering stability, control on wet pavement and rider comfort resulted when engineered elastomer was used in a bead filler along with a polymer containing epoxide groups (**Figure 24**).<sup>(7)</sup>

## Crown

The ability of para-aramid pulp to build modulus efficiently and its low sensitivity to hysteresis makes it suitable for reinforcement in many parts of a tire).<sup>(8)</sup>

Applications in the tire crown include the tread base of high performance tires (**Figure 25**). Often a tire has several components below the tread (**Figure 26**):

- A rubber coated nylon fabric oriented at 0° (cap ply) stabilizes the tire when operated at high speed (NL in **Figure 26**),
- A thin rubber sheet of a high tack compound is used to assure adhesion between the cap ply and tread (RS in **Figure 26**),
- A tread underlayer, formulated to improve handling and reduce rolling resistance (UL in **Figure 26**).

A single compound reinforced with engineered elastomer was developed to replace these three components (**Figure 27**).<sup>(9)</sup> By proper compound formulation and by proper design of the profile of this extruded component, the three layers were eliminated with no sacrifice in tire performance and improved handling. The tire was also easier to manufacture.

Engineered elastomer reinforcement of the lower sidewall (apex) of a tire was used to design a tire with improved maneuvering stability, riding quality and durability while maintaining low rolling resistance (**Figure 28**).<sup>(10)</sup> As with other tire applications, design of the component is critical. Orientation of the fiber and the component profile are critical parameters to achieving performance improvements.

Another application for engineered elastomer reinforced compound is a ply support strip (**Figure 29**). The benefit in this application is reducing pull through of carcass cords during tire manufacture.<sup>(11)</sup> The value of using pulp is reduced scrap, and

most significantly reducing potential for undetected damage to the tire that could result in premature failure in service.

## **Tread**

Reinforcement of tread rubber with para-aramid pulp has been shown to improve the handling characteristics of a tire, enable more uniform tread wear, and improve chipping and chunking characteristics of the tread stock (**Figure 30**)<sup>(12)</sup>.

Reinforcement of tread stock with engineered elastomer is a current area of focus in our work. Field trials have confirmed the improved chipping, chunking and tearing resistance of heavy duty off-road equipment tire tread reinforced with engineered elastomer; we attribute this improvement to the improved tear resistance and reduced tear propagation rate that engineered elastomer brings to rubber compounds (**Figures 10 and 11**).

Effort is also directed toward use of engineered elastomer in tread rubber for truck tire retreads; this work should also be applicable to OE and replacement tires. Some initial results are very promising; tread wear was improved by >40%. This improvement is attributed to the lower heat build-up, lower rolling resistance due to smooth tread wear and improved abrasion resistance of tread stock reinforced with pulp.

Extrusion is a common theme in the tire applications mentioned above. Compounds reinforced with engineered elastomer ease manufacture, and they are quite compatible with new modular tire manufacturing technologies.

## **Motorcycle Tires**

Engineered elastomer has found value in manufacture of motorcycle tires. A thin calendered sheet of compound reinforced with engineered elastomer facilitates the manufacturing process. The sheet, which has high green strength and tack, provides support for the cord layer during manufacture (**Figure 31**)<sup>(12)</sup>.

## **Bicycle Tires**

Reinforcement using engineered elastomer in rubber compounds used in bicycle tires brings many of the same benefits seen in automobile and truck tires. Rolling resistance, cornering performance and abrasion resistance were all improved by its use in the tread or sputread of bicycle tires (**Figure 32**)<sup>(13)</sup>.

Engineered elastomer has also enabled improved puncture resistance in bicycle tires. This has been achieved by two methods:

- Use of a fabric of aramid fiber coated with a compound reinforced with engineered elastomer <sup>(14)</sup>,
- Use of a subtread compound that is very highly loaded with engineered elastomer.

## SUMMARY

- Engineered elastomer is used to reinforce rubber compounds in a number of demanding applications.
- The reinforcement efficiency of engineered elastomer is significantly greater than that of other commonly used reinforcing materials such as carbon black and silica.
- A high level of modular anisotropy can be introduced to a compound by conventional processing techniques.
- Hysteretic properties are nearly unaffected by the concentration of engineered elastomer used in the compound.
- Stress-strain and acoustic emission data suggest that association between elastomer and fiber exists up to 40-50% strain.
- Tear resistance and tear growth resistance can be improved by incorporation of engineered elastomer into a compound.
- Compound formulation development and component design are frequently necessary to achieve optimum performance.

Concentrates of engineered elastomer are available in a number of elastomer matrixes. A list is included in **Figure 33**.

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H-96437 10/04

Figure 1

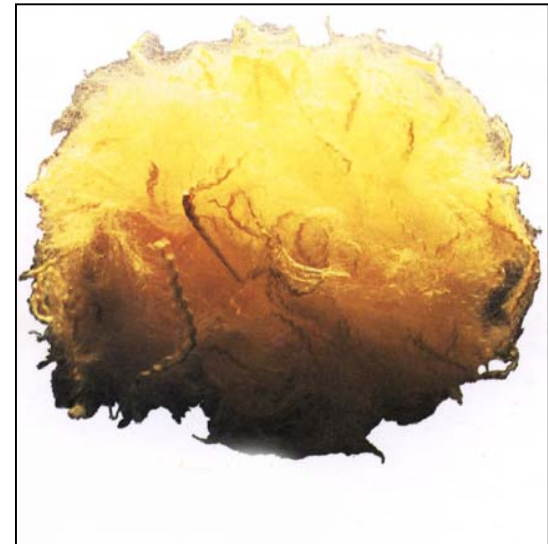
**Commercial Forms of KEVLAR<sup>®</sup>**



**Pulp**



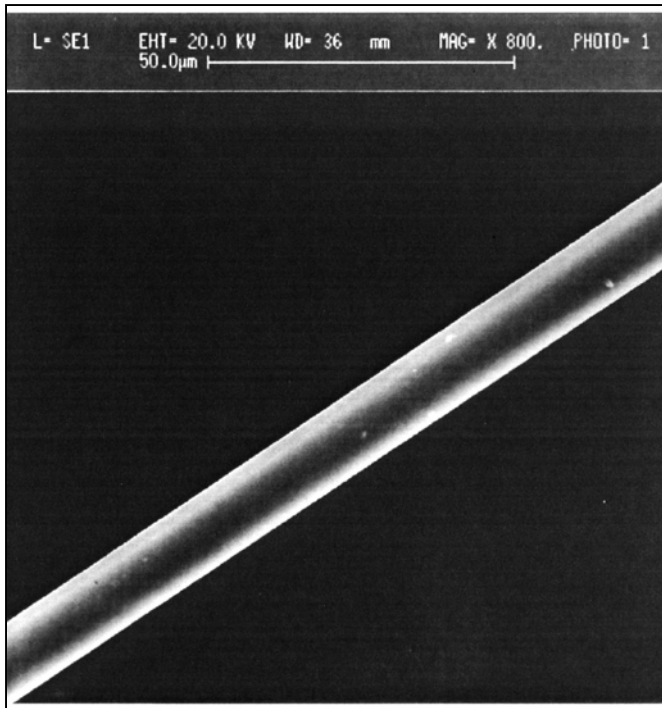
**Filament**



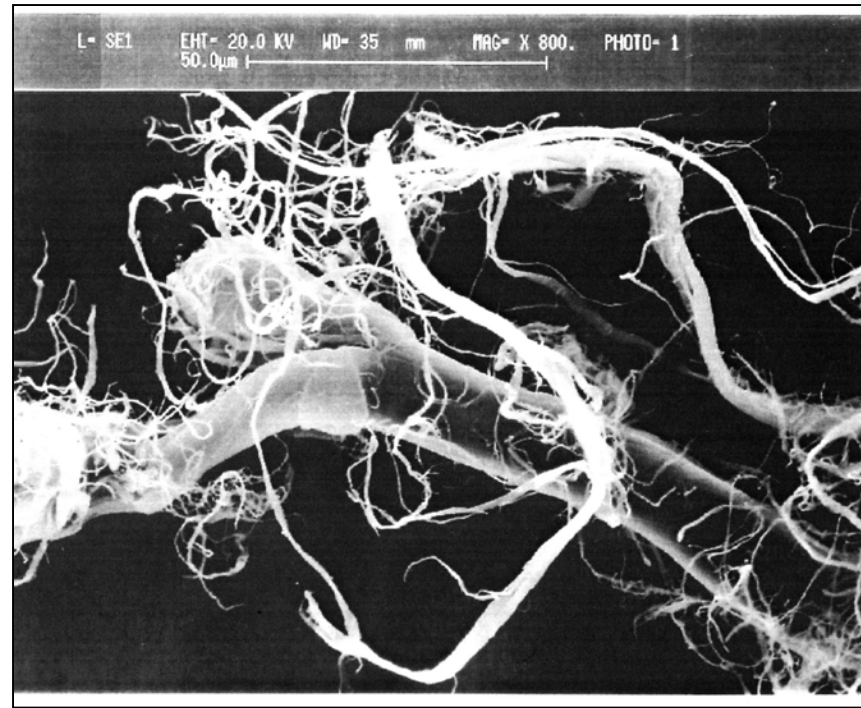
**Staple**

## Figure 2

# Pulp Versus Floc Fiber Form



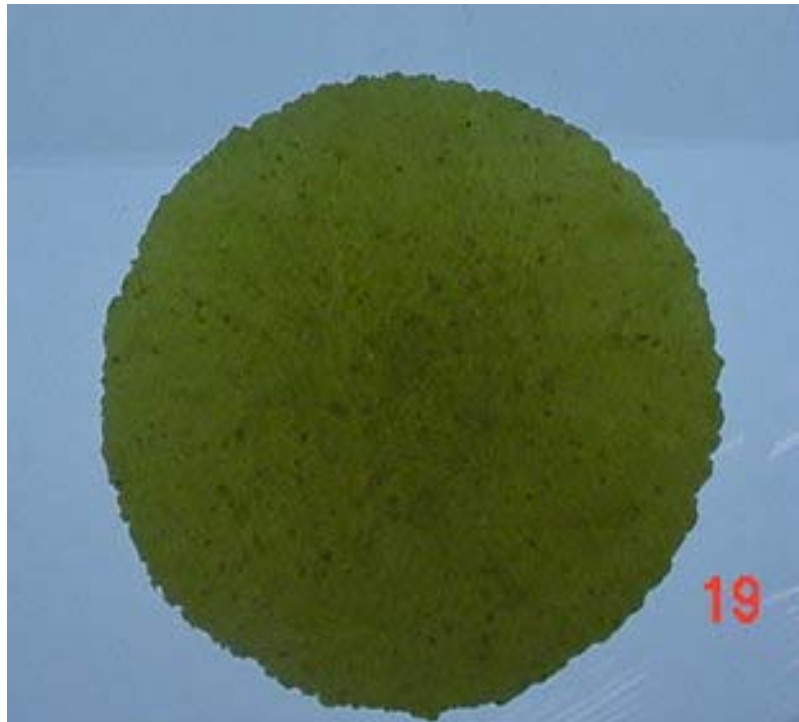
**0.1-0.3 m<sup>2</sup>/g**



**7-9 m<sup>2</sup>/g**

## Figure 3

### Fiber Poorly Dispersed in Concentrate (Photographs of thin pressed films)



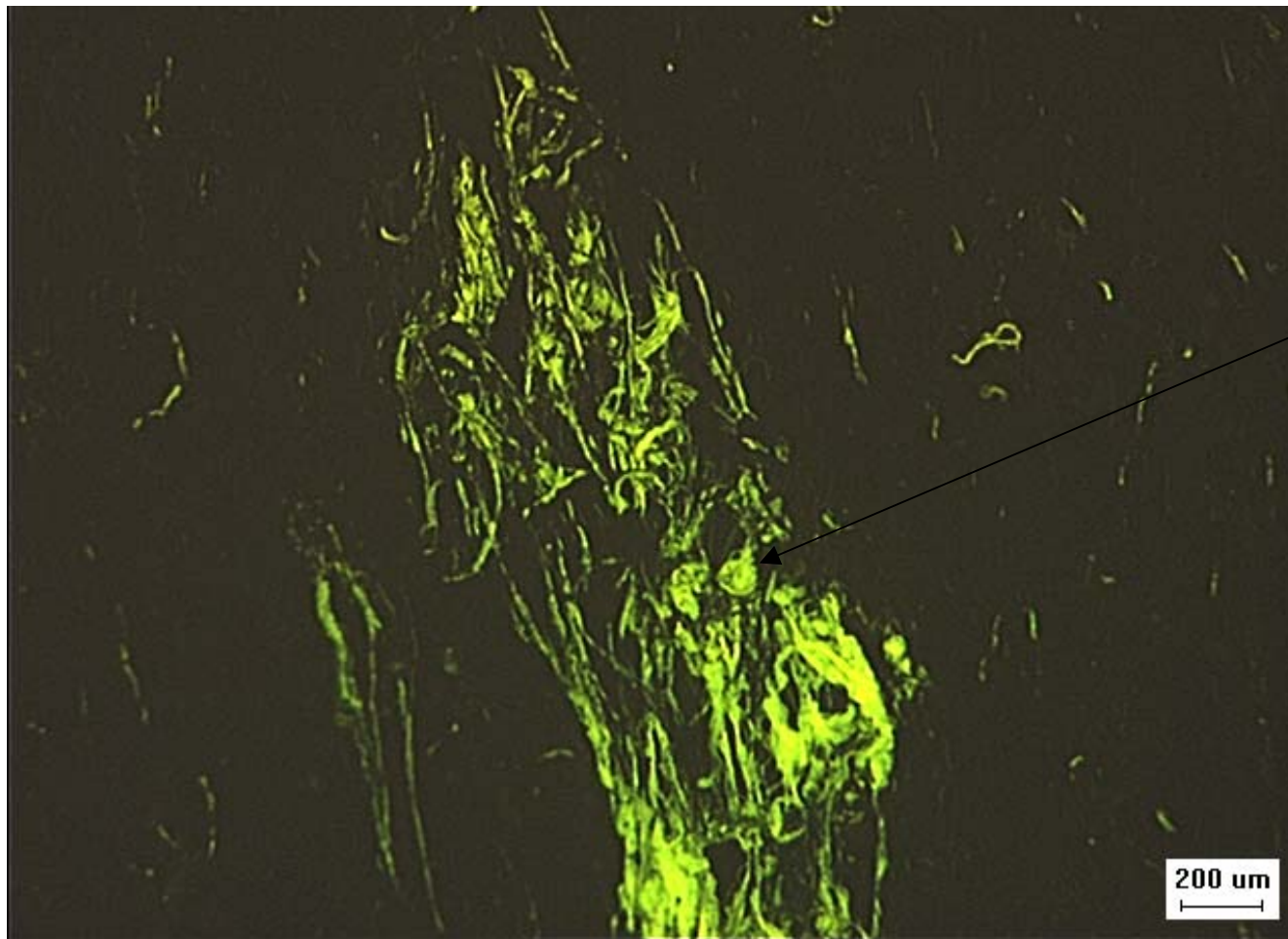
Other dispersion technology



DuPont Technology

## Figure 4

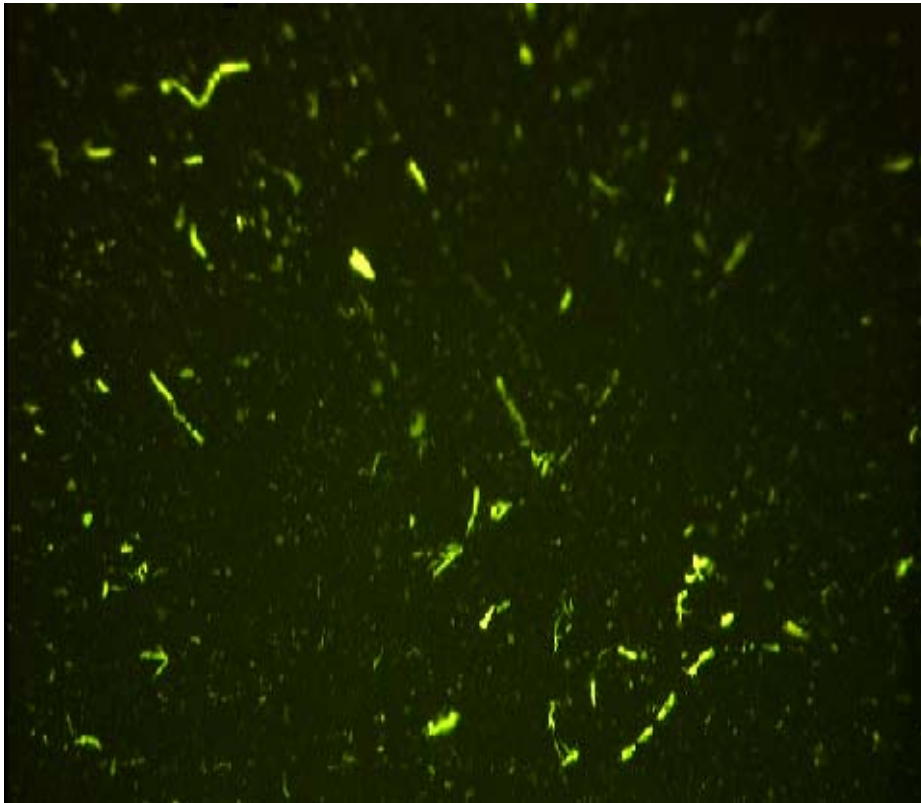
### Compound with Undispersed Concentrate



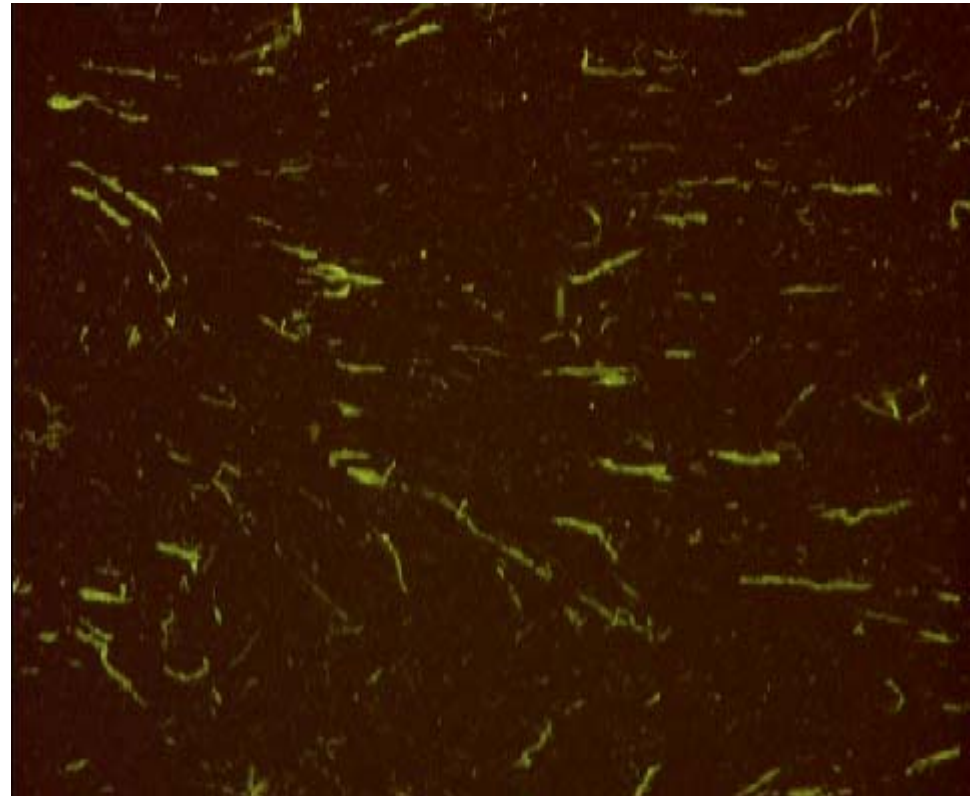
Tangled  
Fiber

## Figure 5

### Compound Samples Illustrating Degree of Openness



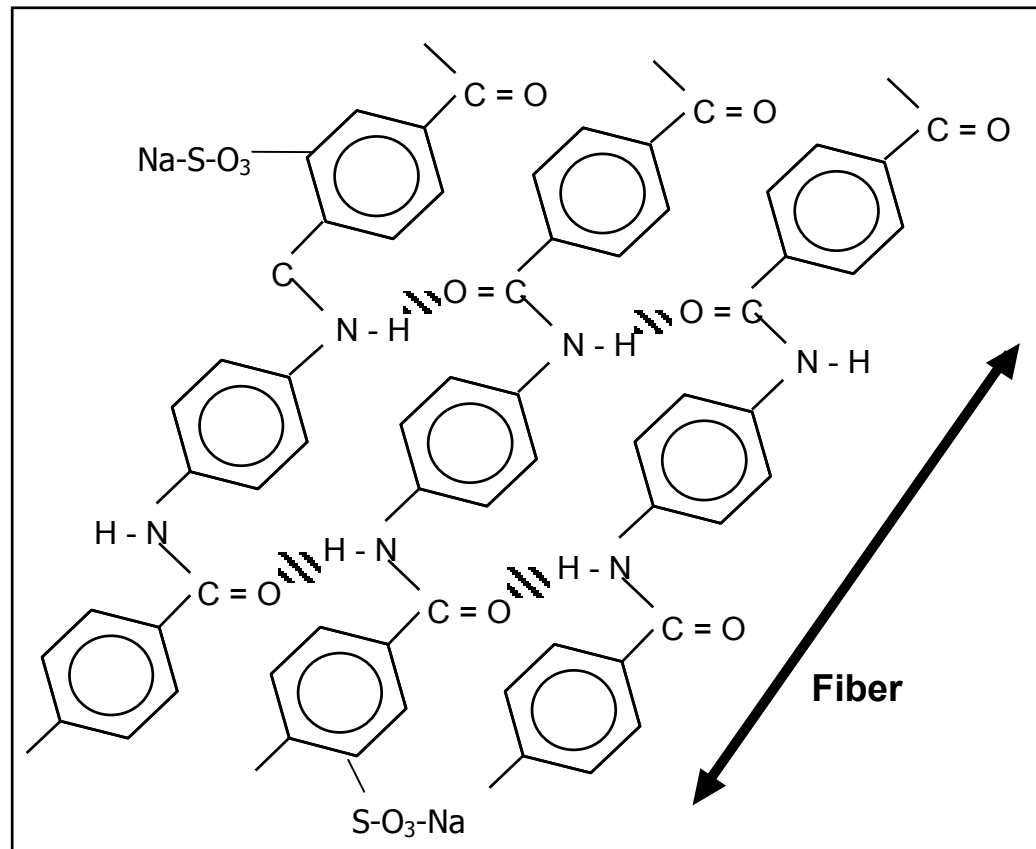
Other dispersion technology



DuPont Technology

## Figure 6

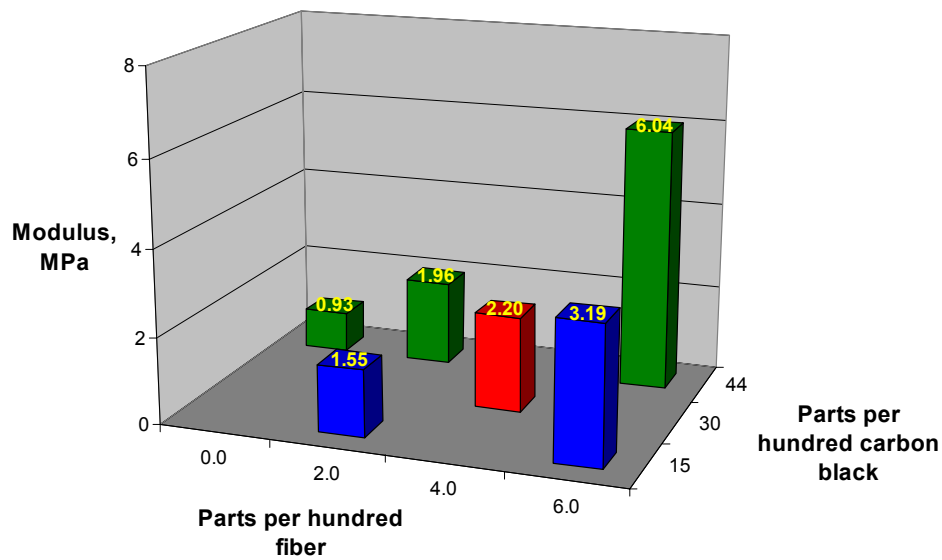
# Chemical Structure of p-aramid



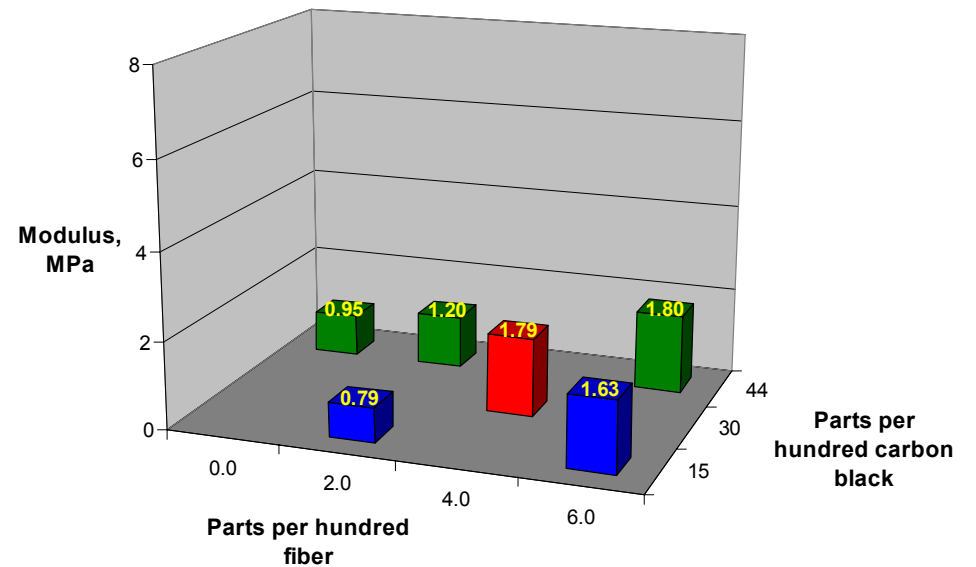
# Figure 7

## Effect of Engineered Elastomer on Compound Modulus

MODULUS AT 20% ELONGATION  
MACHINE DIRECTION



MODULUS AT 20% ELONGATION  
CROSS MACHINE DIRECTION

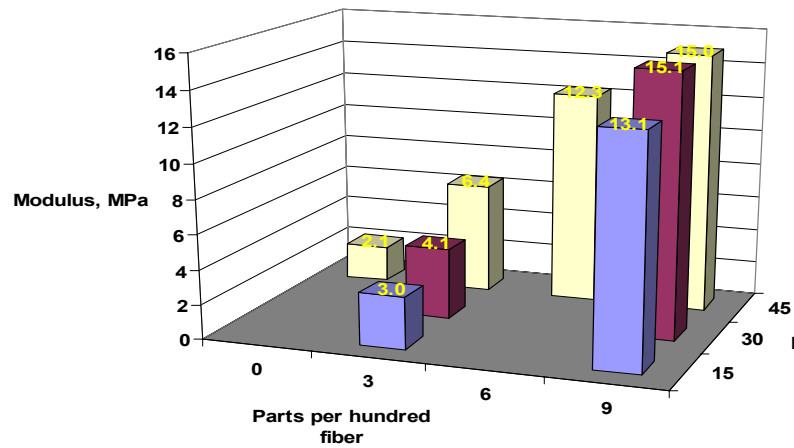


SBR/BR heavy duty tire tread compound

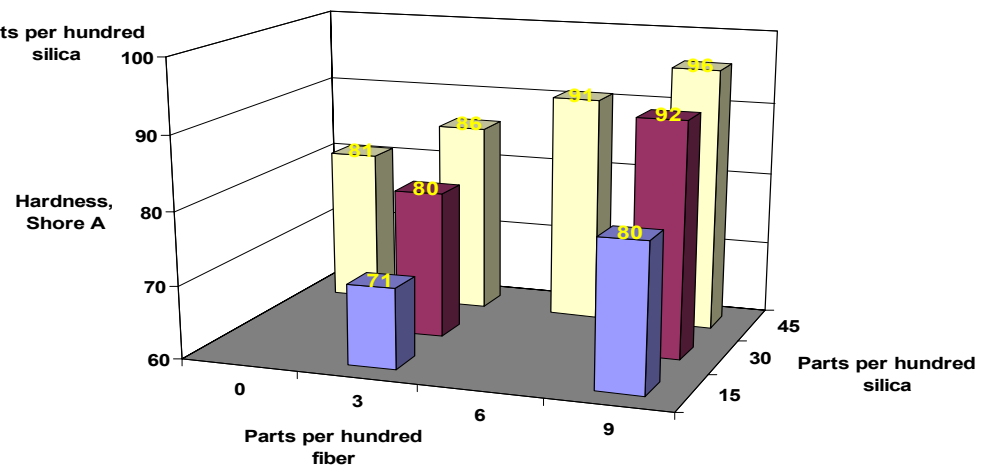
# Figure 8

## Effect of Engineered Elastomer on Modulus and Hardness of a Roll Cover Compound

MODULUS AT 25% ELONGATION



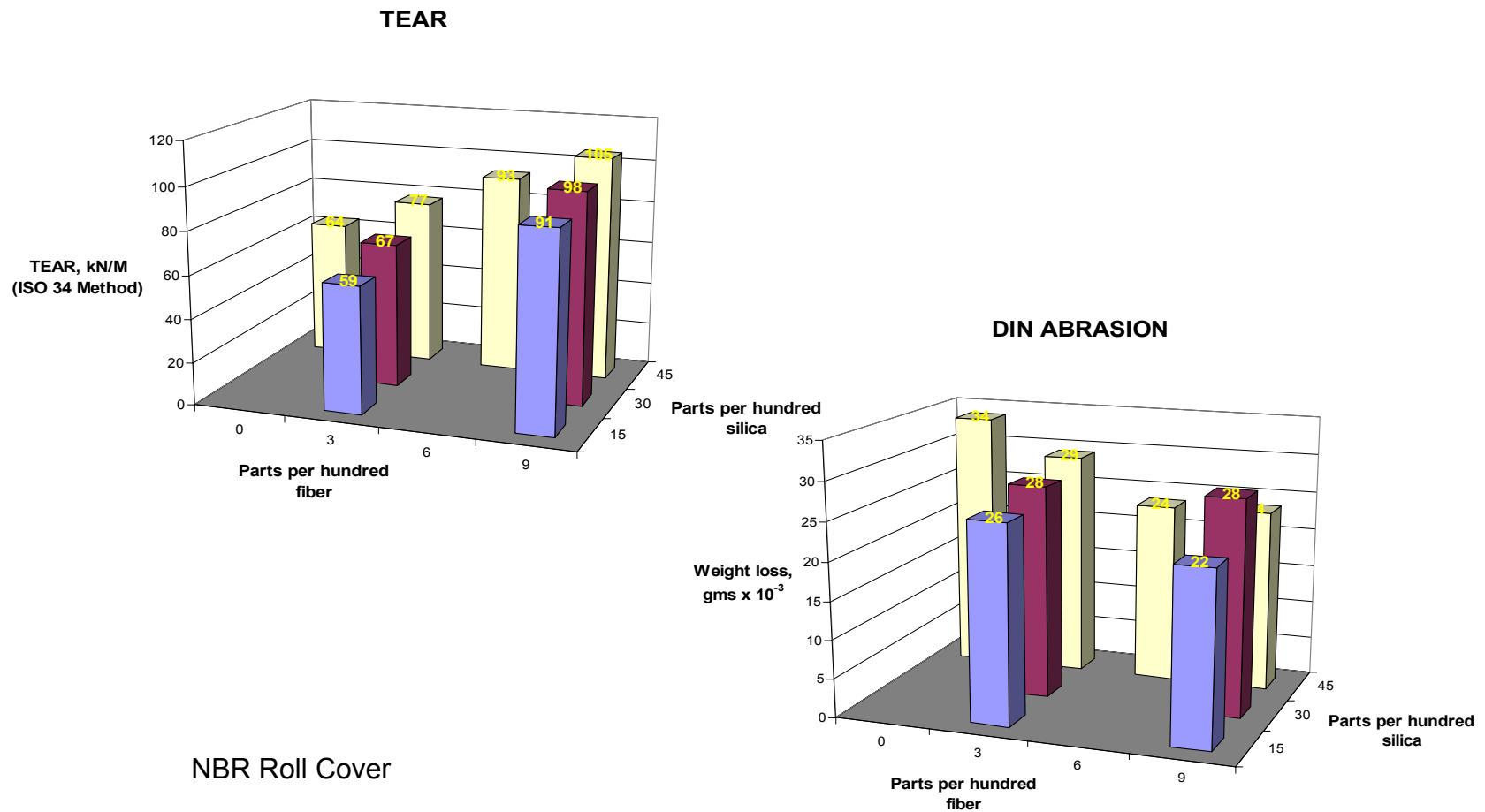
HARDNESS



NBR Roll Cover

# Figure 9

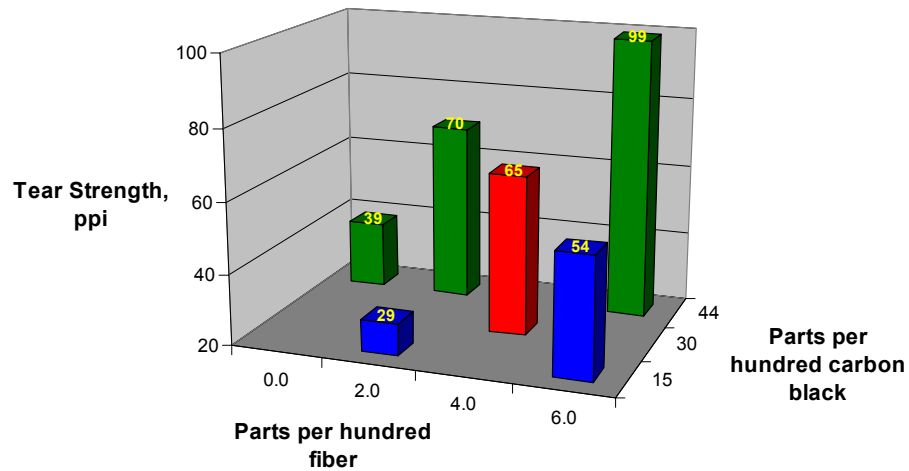
## Effect of Engineered Elastomer on Tear and Abrasion Resistance of a Roll Cover Compound



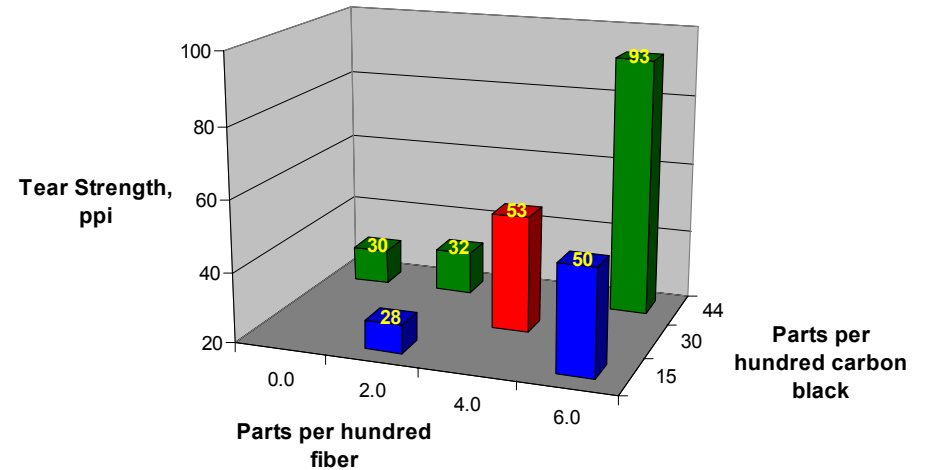
# Figure 10

## Effect of Engineered Elastomer and Carbon Black Loadings on Trouser Tear

TROUSER TEAR  
MACHINE DIRECTION



TROUSER TEAR  
CROSS MACHINE DIRECTION

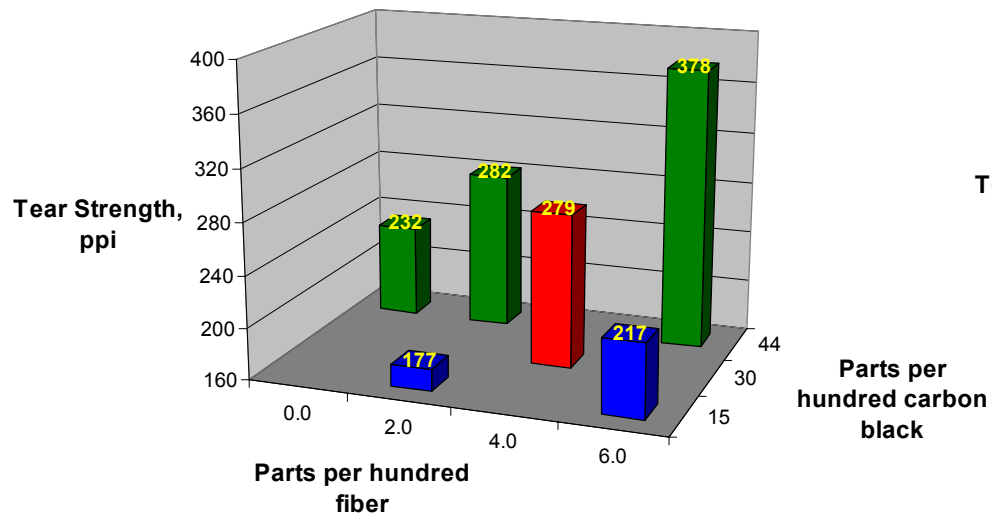


SBR/BR heavy duty tire tread compound

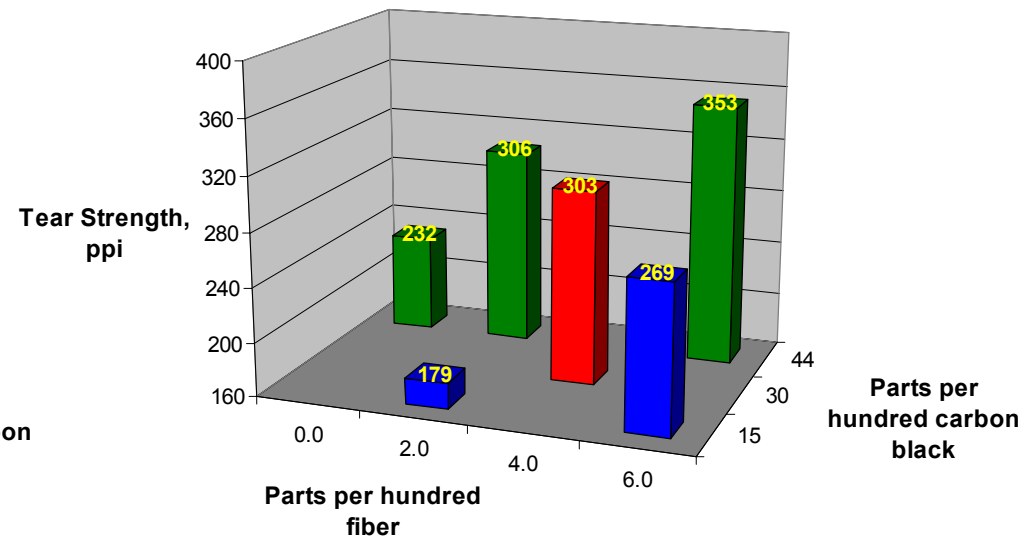
# Figure 11

## Effect of Engineered Elastomer and Carbon Black Loadings on Die C Tear

'DIE C' TEAR  
MACHINE DIRECTION



'DIE C' TEAR  
CROSS MACHINE DIRECTION



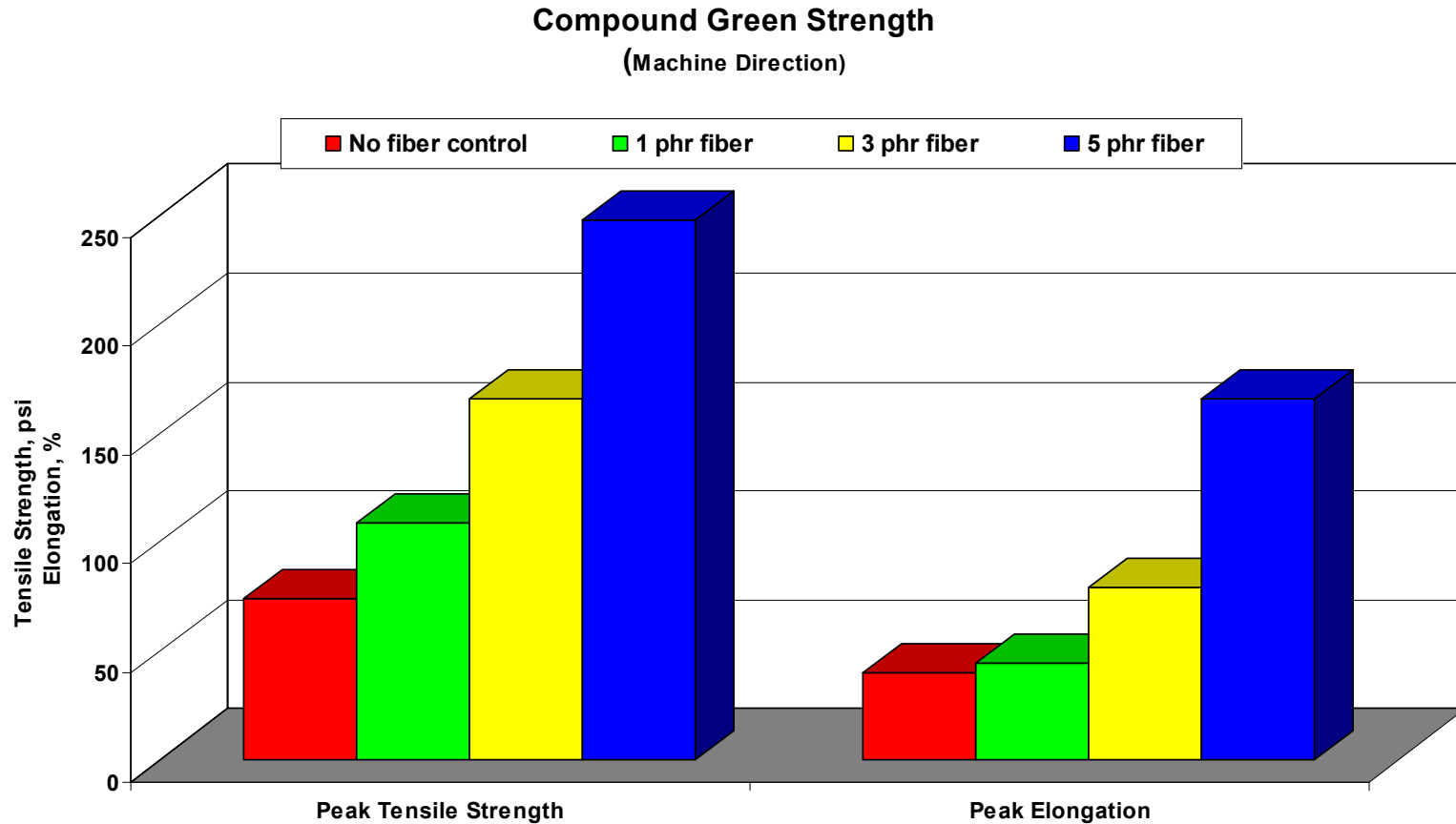
## Figure 12

### Photographs of Die C Tear Test



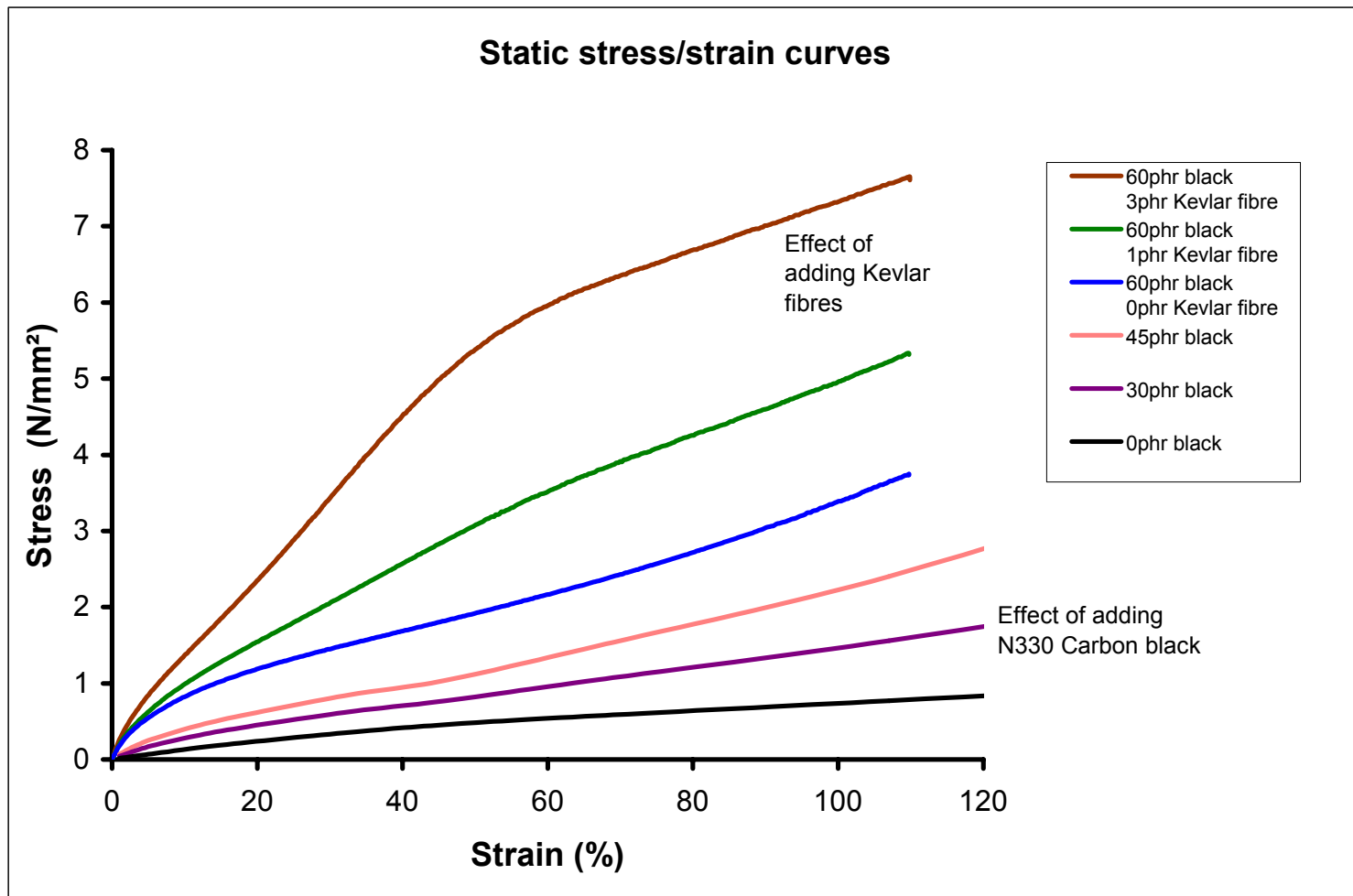
# Figure 13

## Effect of Engineered Elastomer on Compound Green Strength



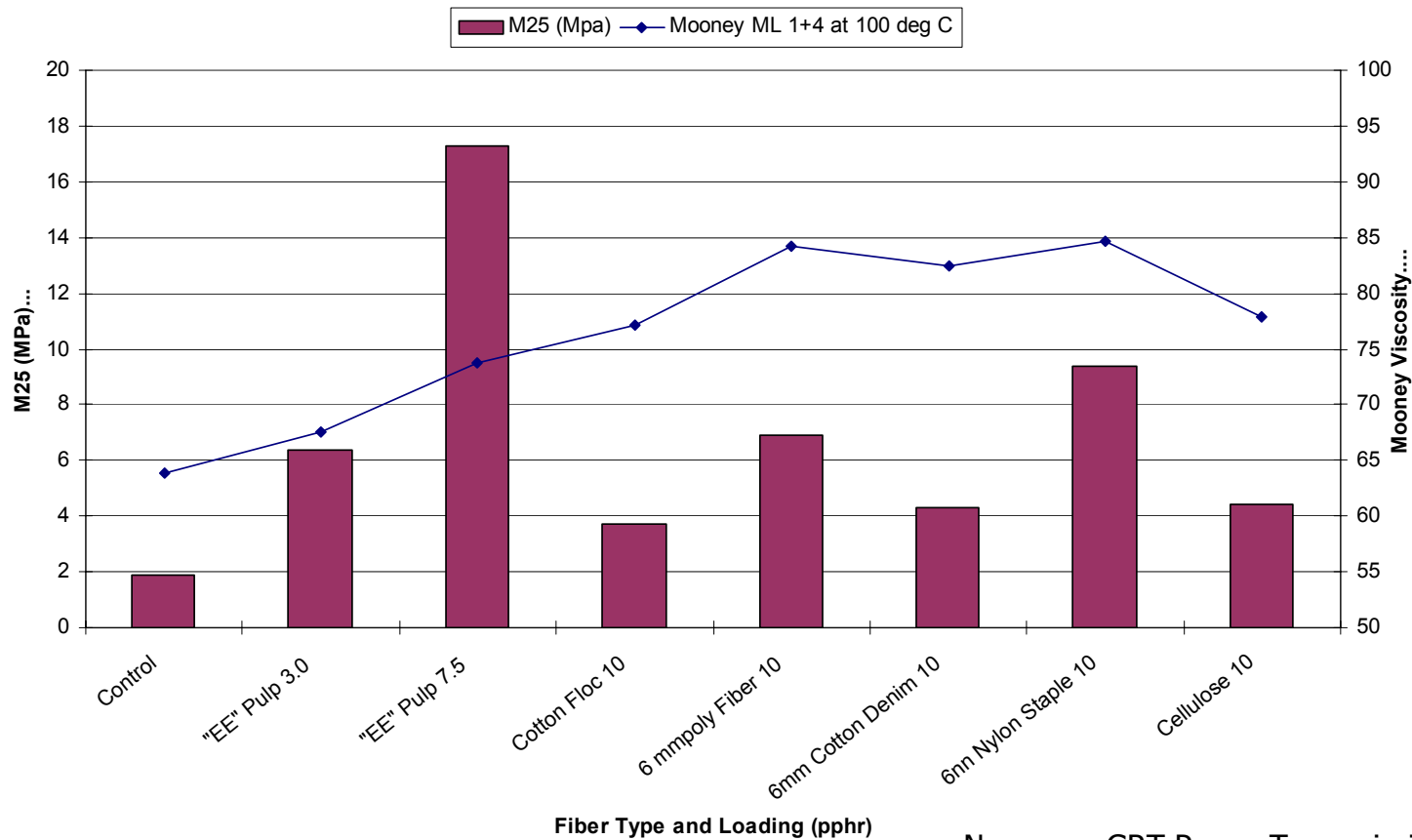
# Figure 14

## Comparison Between Carbon Black and Engineered Elastomer Reinforcement of NR



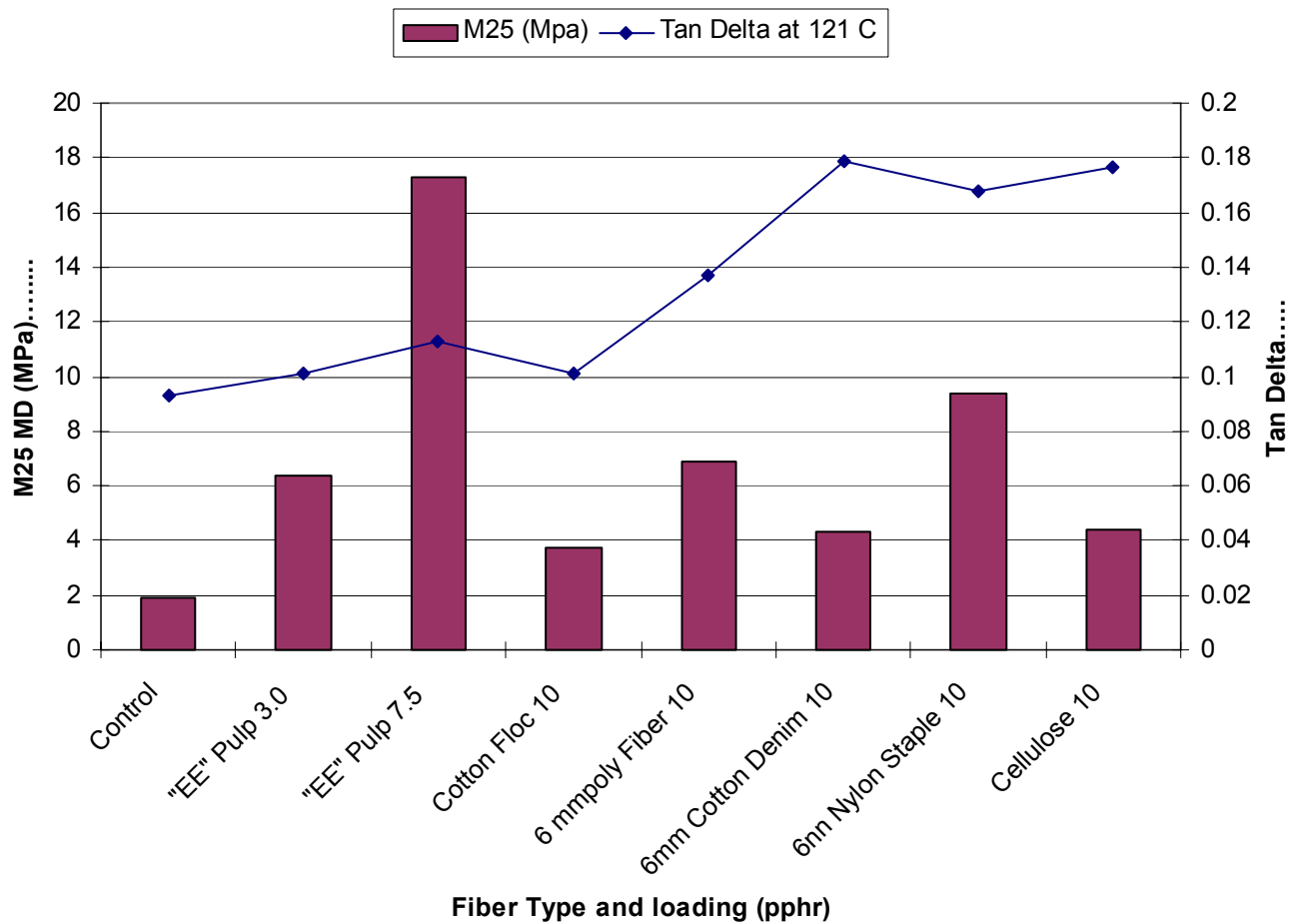
# Figure 15

## Reinforcement and Mooney Comparison Between Engineered Elastomer and Various Flocs



# Figure 16

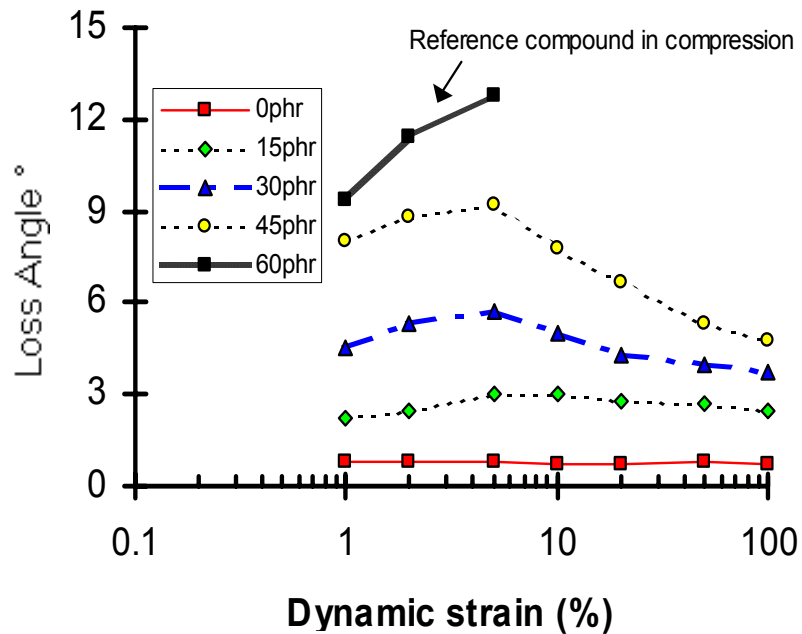
## Reinforcement and Tan Delta Comparison Between Engineered Elastomer and Various Flocs



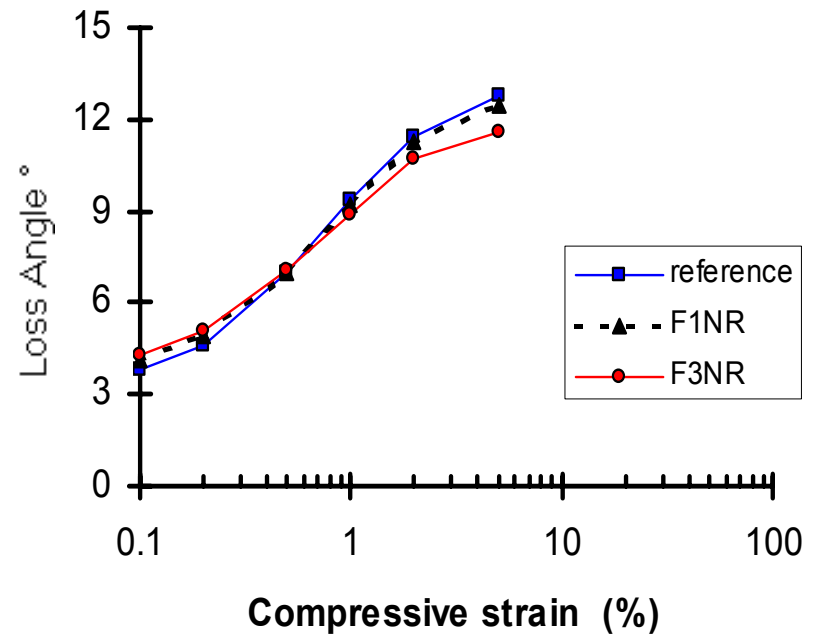
# Figure 17

## Comparison Between Effects of Carbon Black and Engineered Elastomer Upon Loss Angle

Effect of N330 carbon black upon Loss Angle  
Dynamic Shear, Frequency 1Hz, 23°C



Effect of fibre loading on Loss Angle  
Dynamic compression, Frequency 1Hz, 20°C

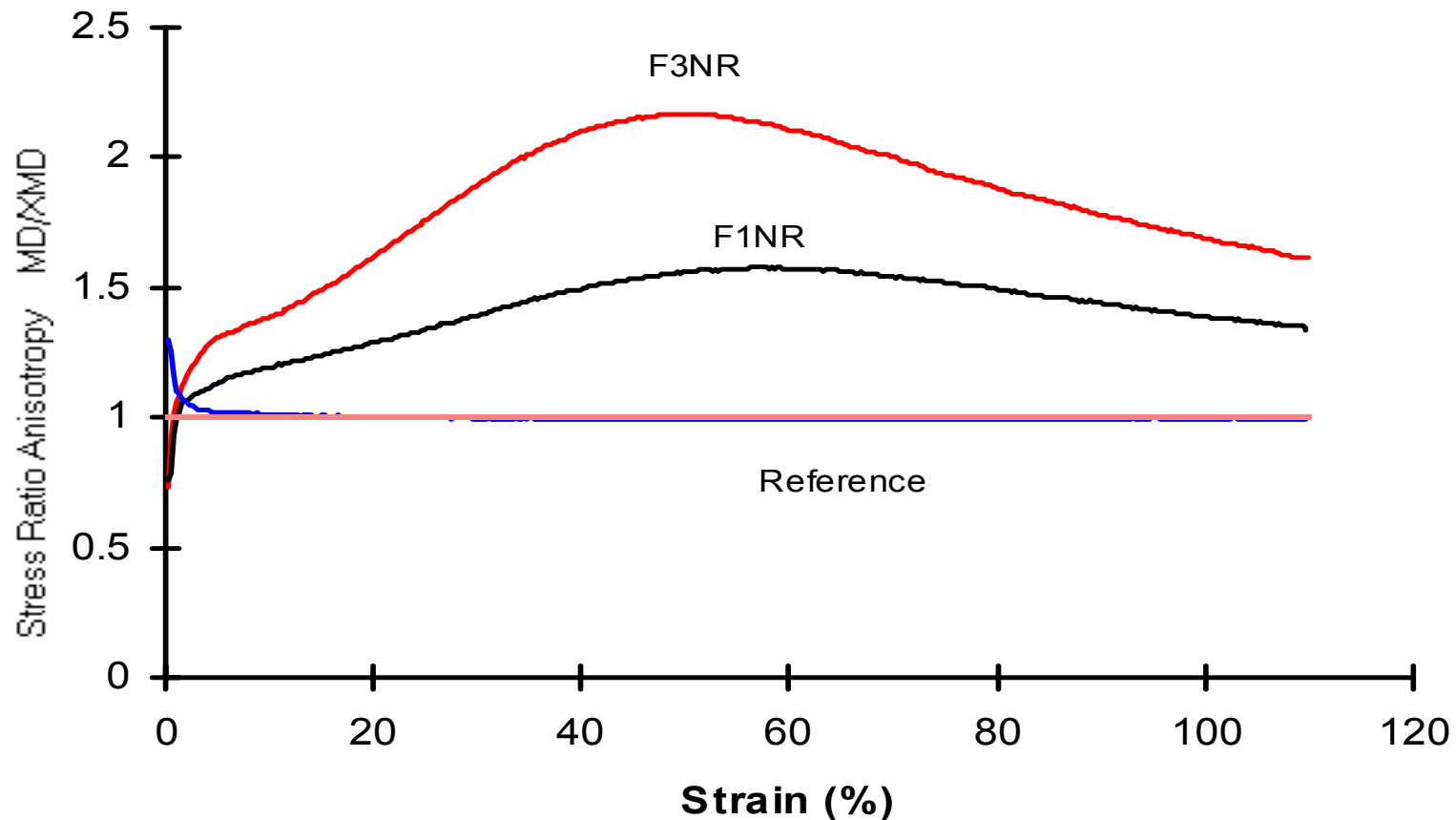


Data from MRPRA, Engineering Data Sheets©

## Figure 18

### Stress Ratio Anisotropy vs. Strain

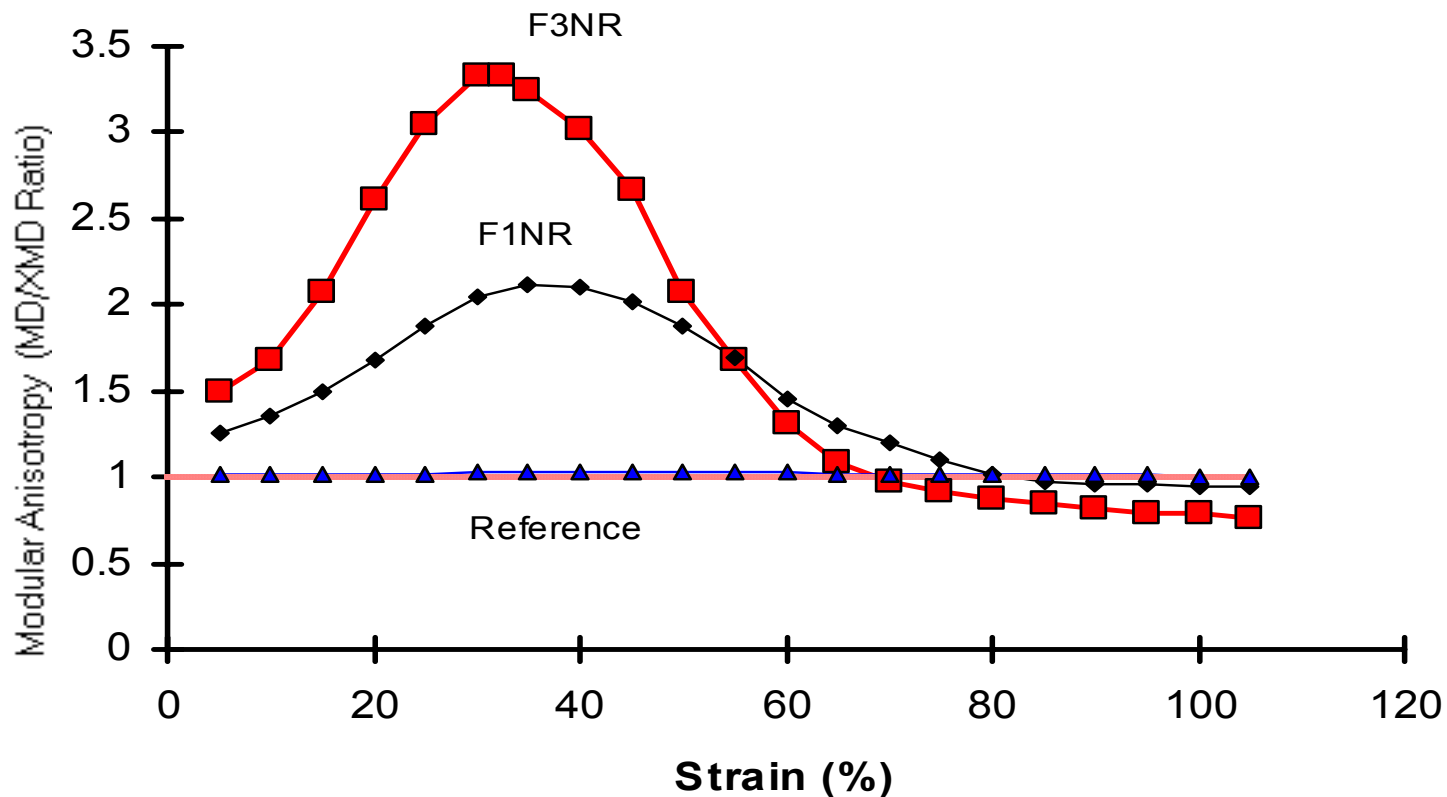
***Stress ratio anisotropy is the ratio of MD/XMD absolute stress values at a given strain***



## Figure 19

### Modular Anisotropy vs. strain

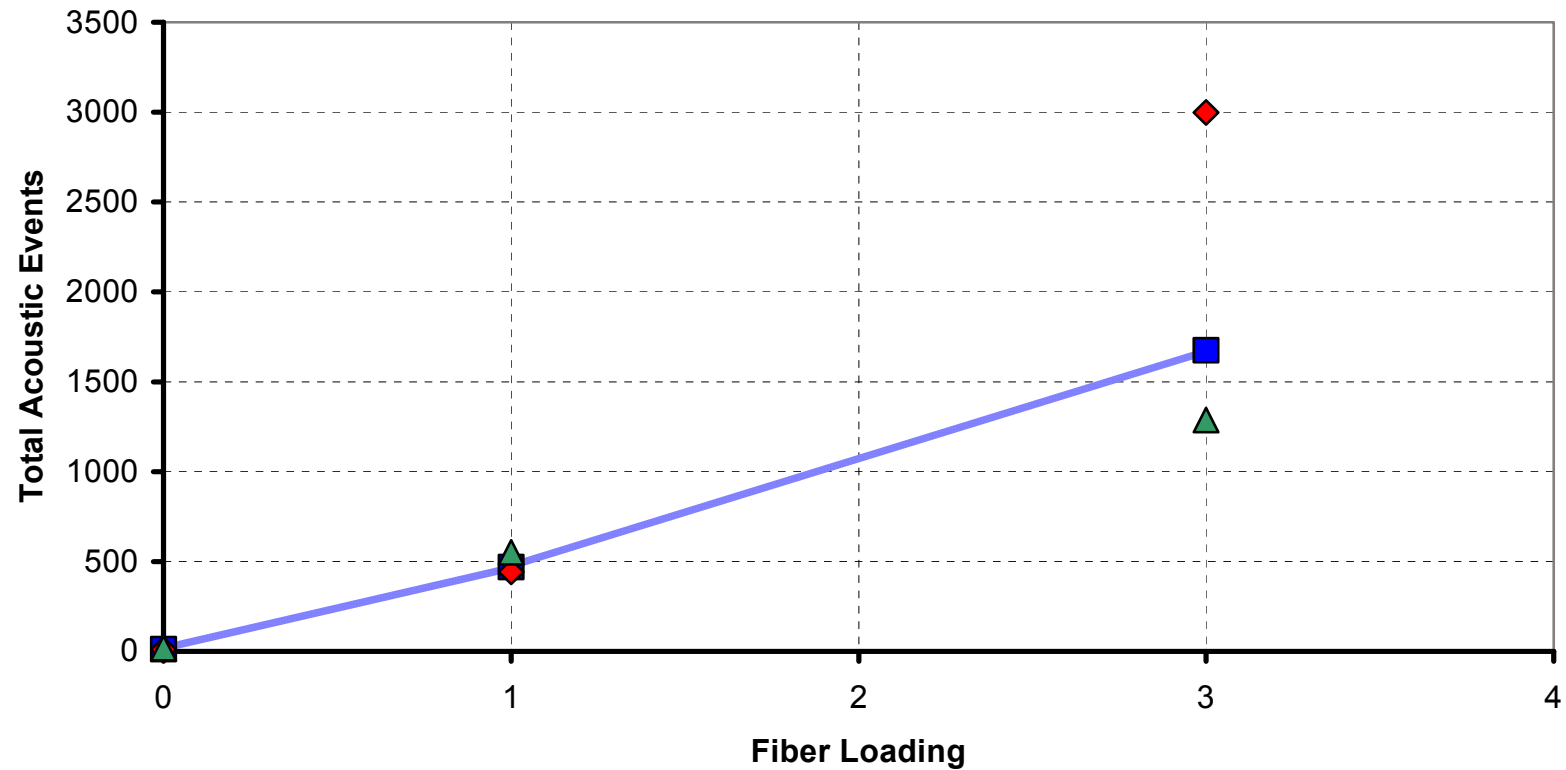
*Modular anisotropy is ratio of MD/XMD tangential stiffness at a given strain*



# Figure 20

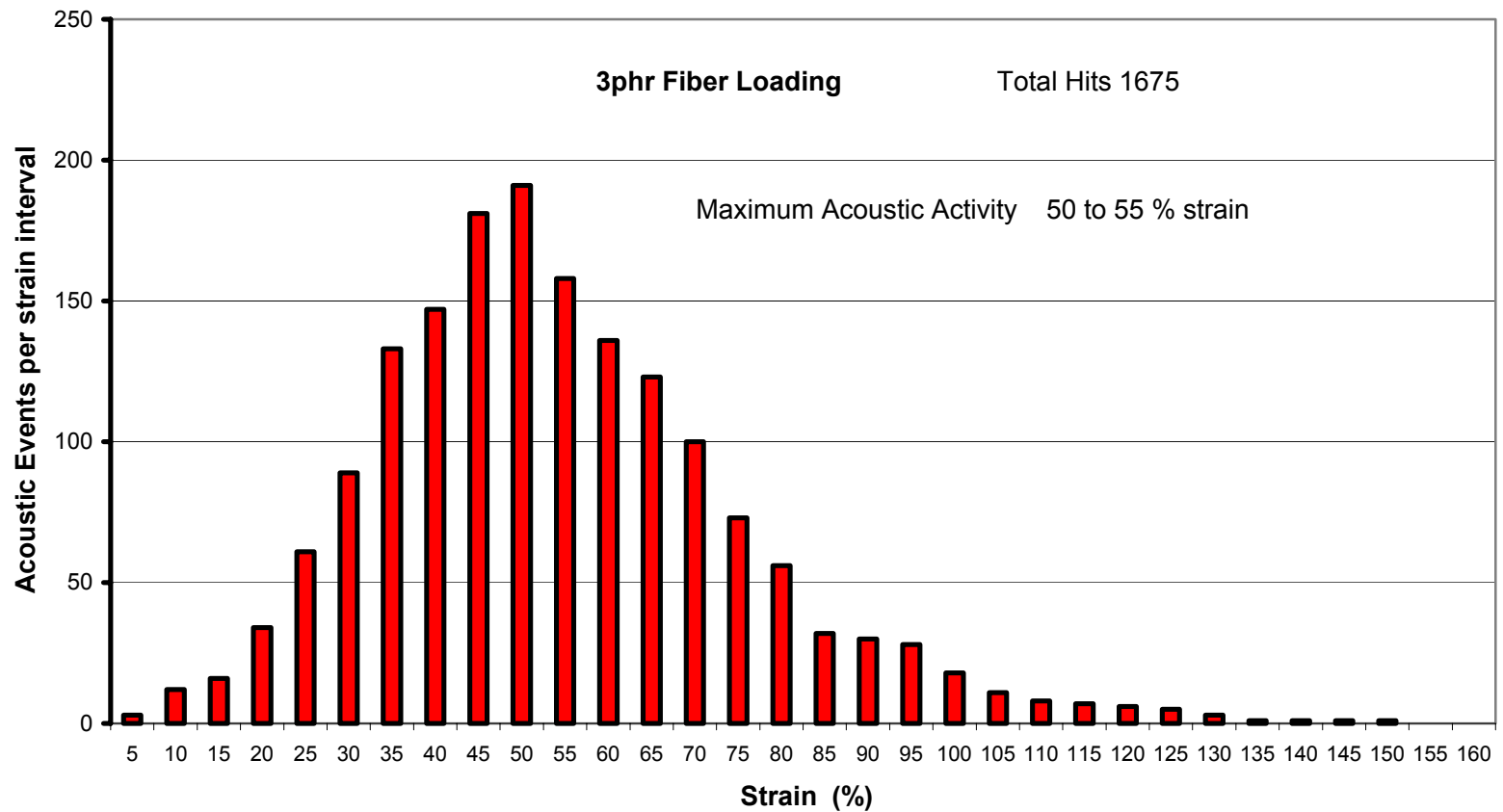
## Acoustic Emission Tests

*Acoustic Events are proportional to Fiber Loading*



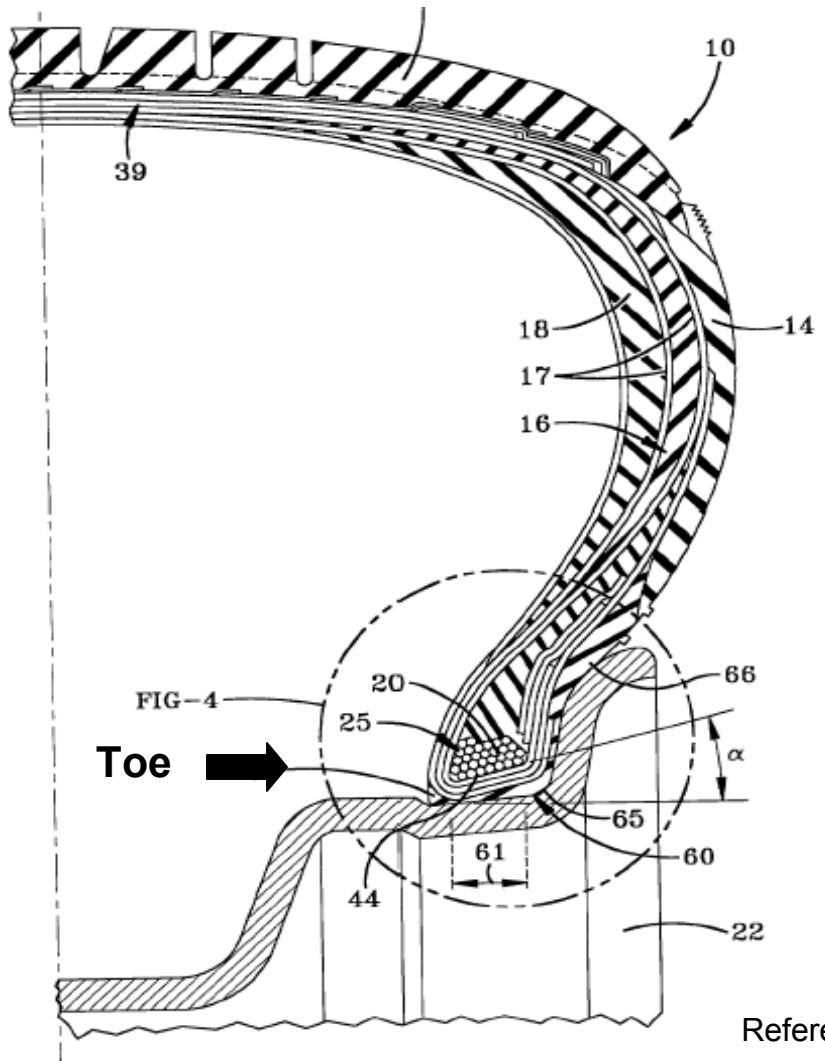
# Figure 21

## Acoustic Emission Tests Acoustic Activity for F3NR



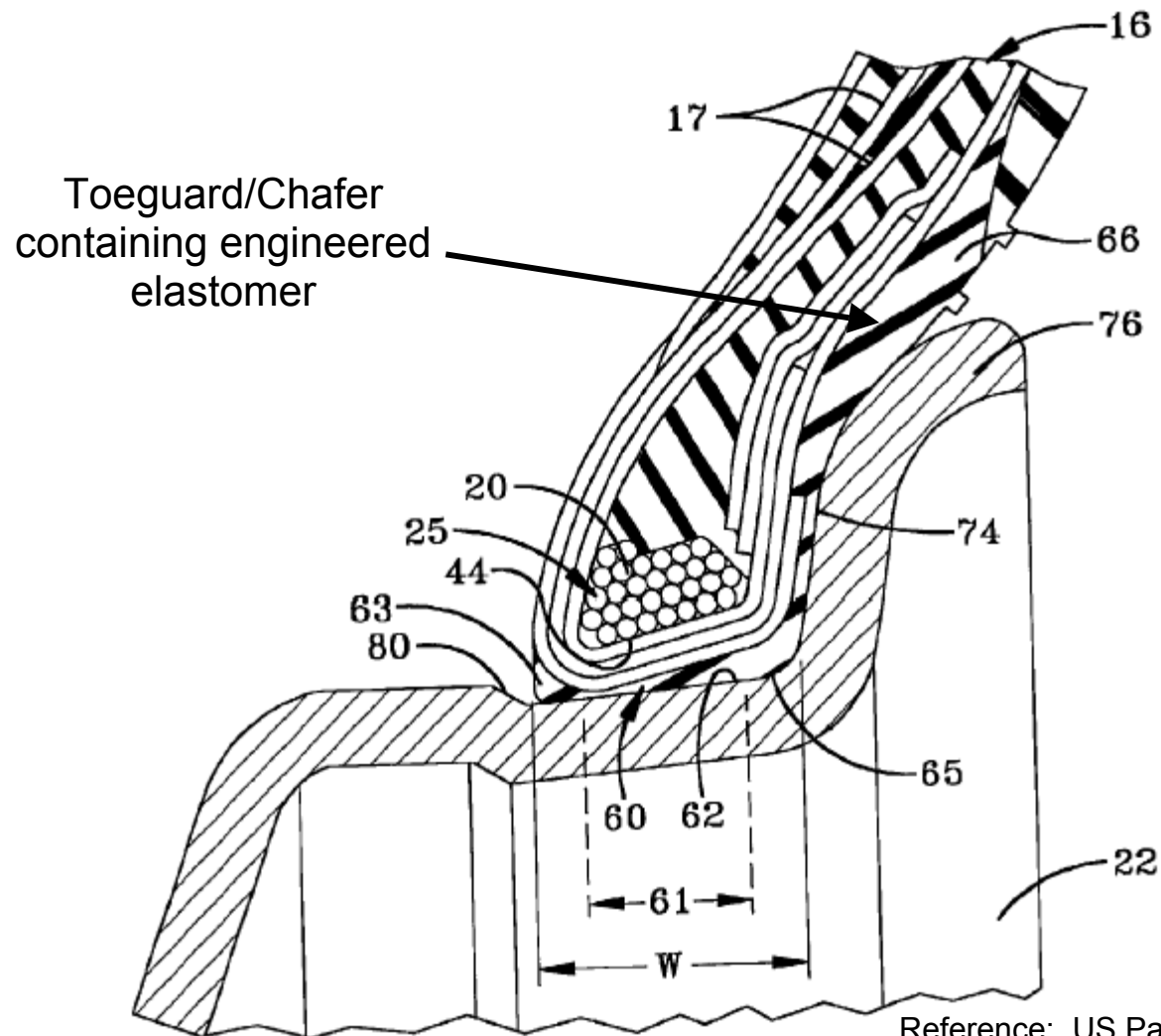
# Figure 22

## Tire Bead Area



# Figure 23

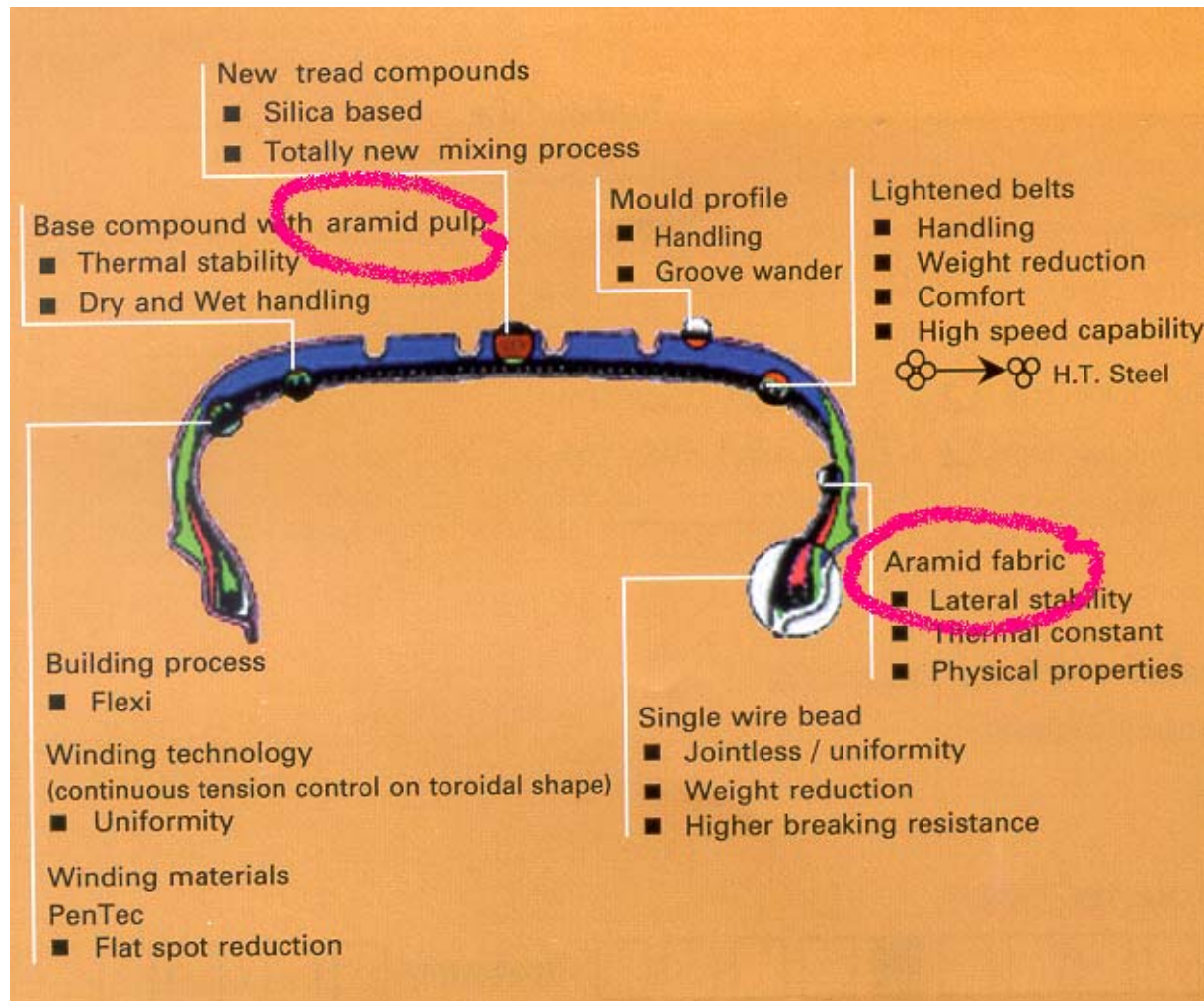
## Toeguard Reinforced with Engineered Elastomer





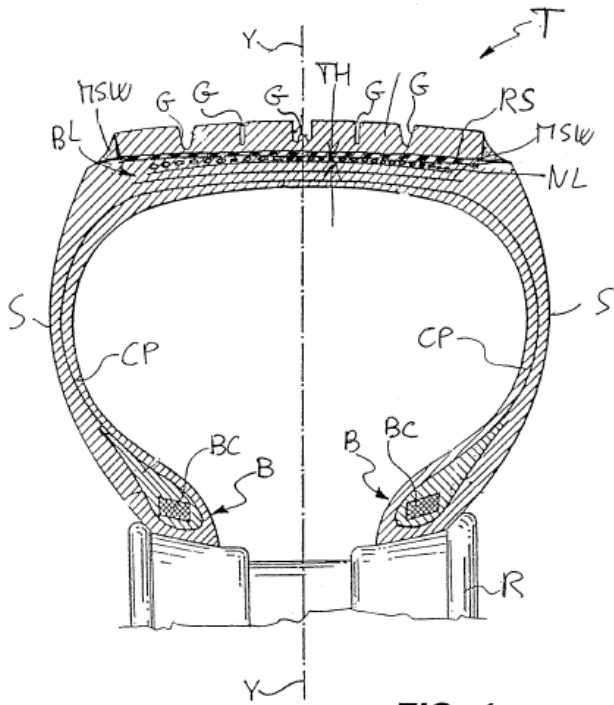
# Figure 25

## Tread Base Application

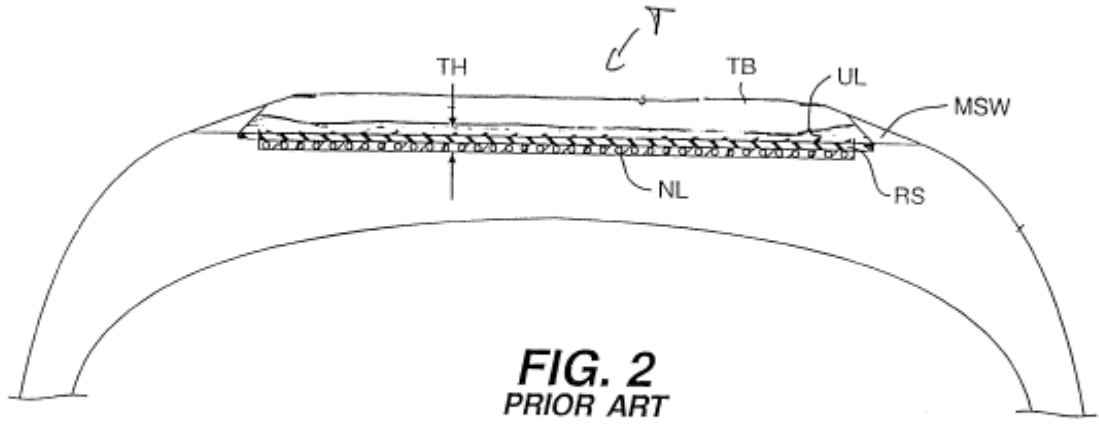


# Figure 26

# Tire Crown



**FIG. 1**  
PRIOR ART

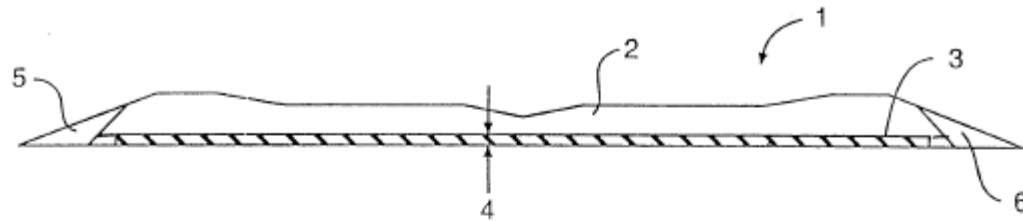


**FIG. 2**  
PRIOR ART

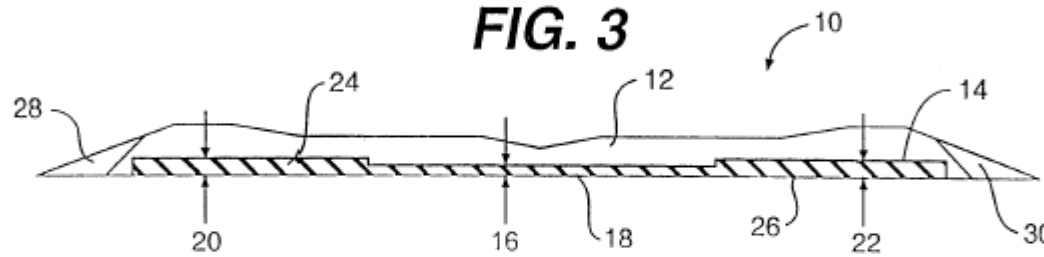
Reference: World Patent 00/24596

# Figure 27

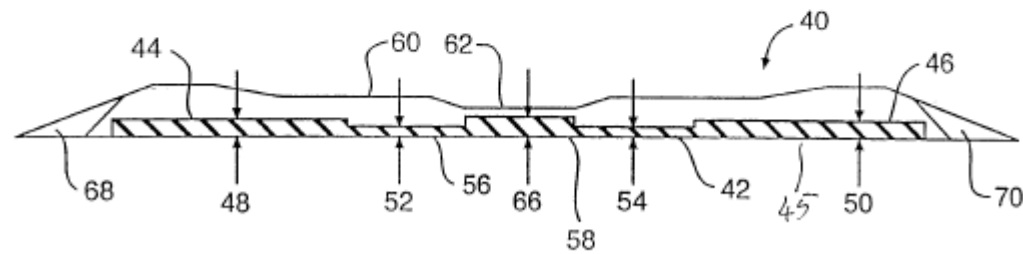
## Tread Base Reinforced with Engineered Elastomer



**FIG. 3**



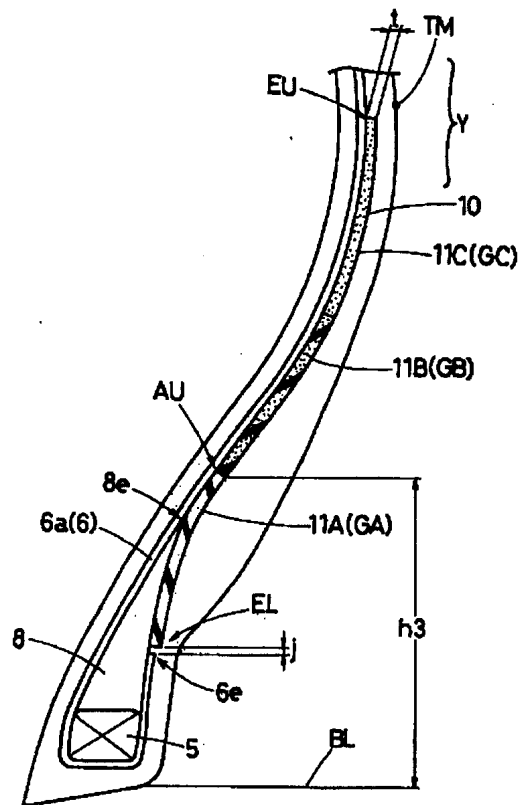
**FIG. 4**



**FIG. 5**

## Figure 28

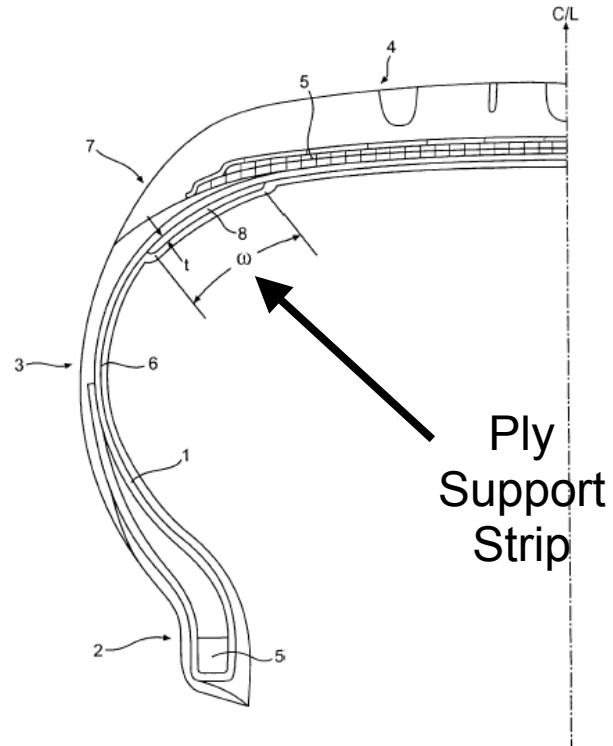
### Lower Sidewall Reinforced with Engineered Elastomer



References: Japanese Patent Application 2003-11623  
[http://www.dunlop.co.jp/newsrelease/user/2002/2002\\_059.htm](http://www.dunlop.co.jp/newsrelease/user/2002/2002_059.htm)

## Figure 29

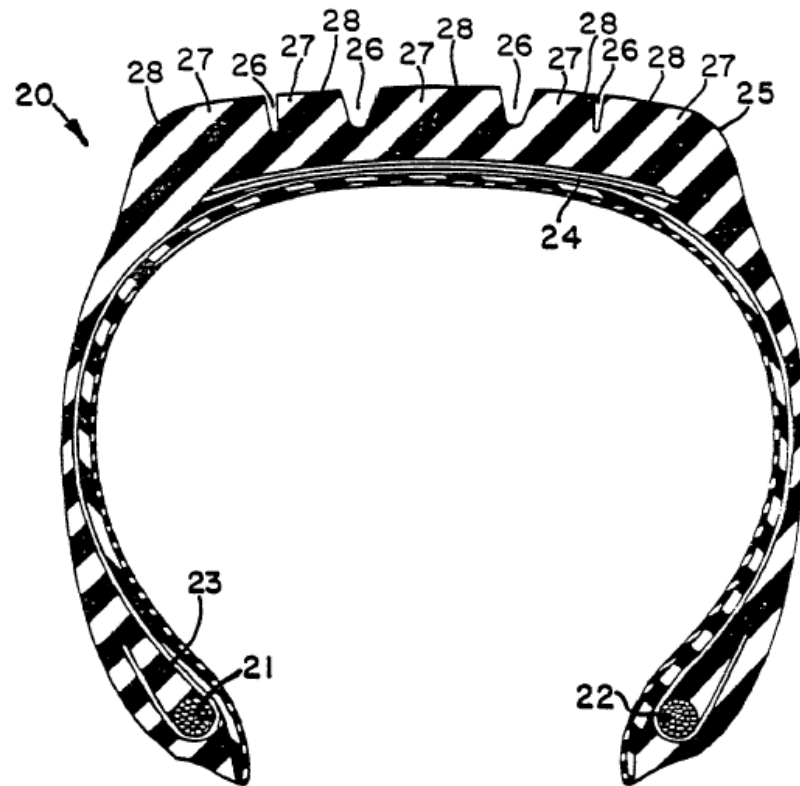
### **Ply Support Strip Reinforced with Engineered Elastomer**



Reference: US Patent 6,123,132

# Figure 30

## Tire Tread



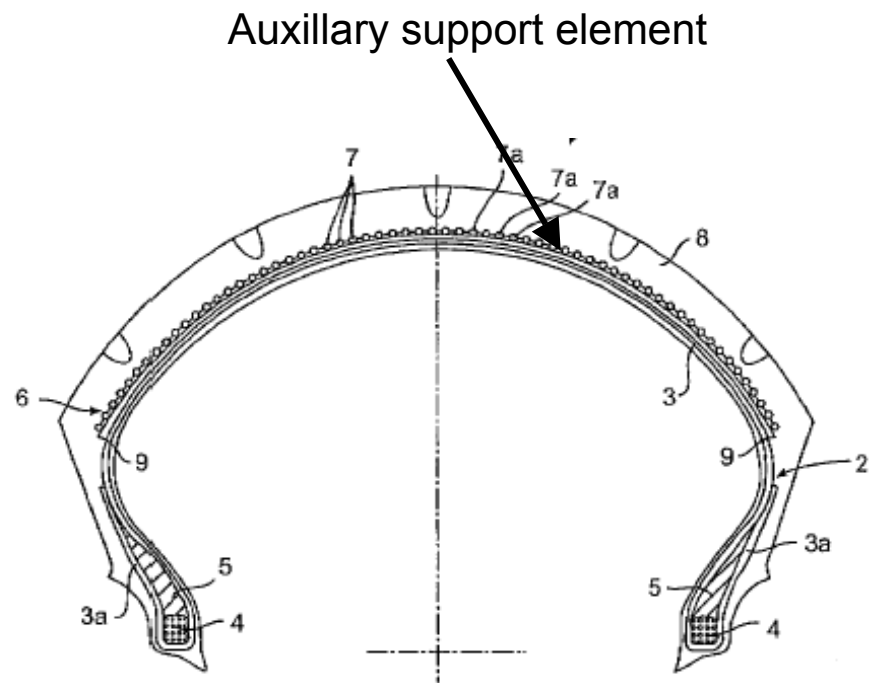
Reference: European Patent Application 0 373 094

## Figure 31

### Motorcycle Tires

Auxillary support element reinforced with engineered elastomer facilitates manufacture of motorcycle tires.

Improved compound green strength allows thin calendered sheet

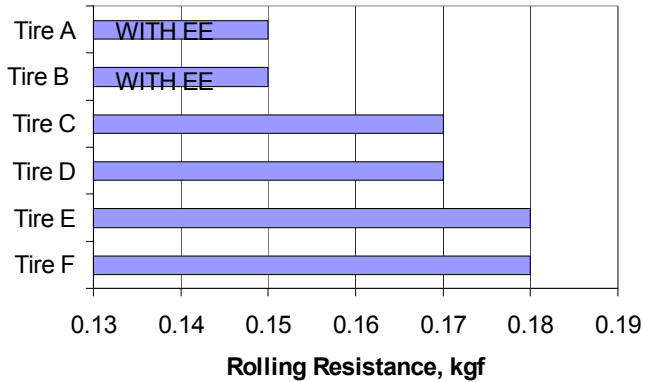


Reference: US Patent 6,283,187

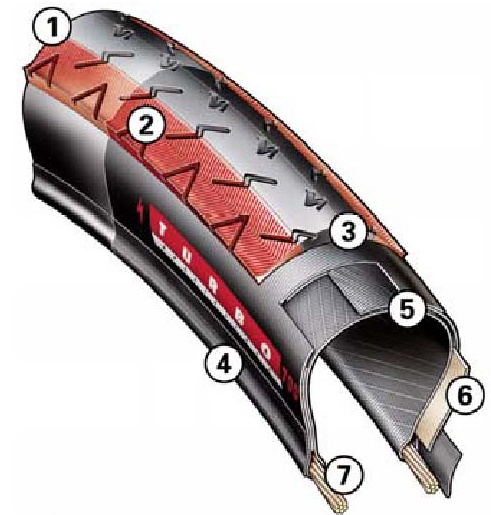
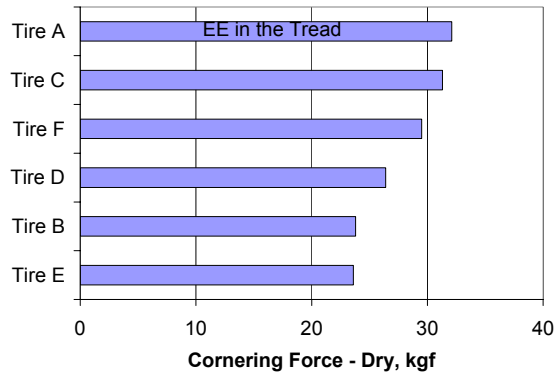
# Figure 32

## Bicycle Tire Performance

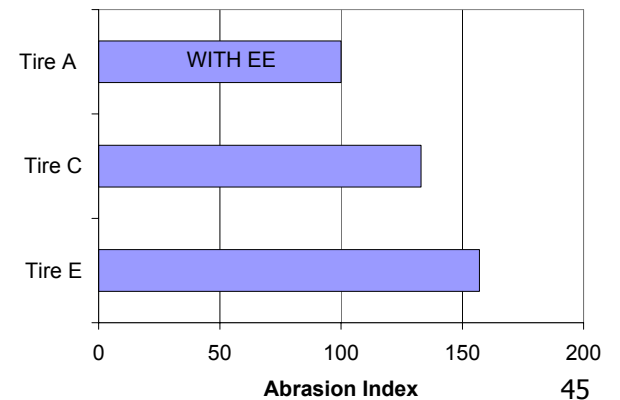
### ROLLING RESISTANCE



### CORNERING FORCE



### ABRASION TEST



Data from Specialized Bicycle

## Figure 33

### KEVLAR<sup>®</sup> brand engineered elastomer

An elastomeric composite of KEVLAR<sup>®</sup> brand pulp and elastomer

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Product Number	1F722	1F724	1F770	1K1239
<i>Properties</i>				
Matrix elastomer	Natural Rubber	SBR 1502	NBR Med ACN	ENGAGE <sup>®</sup> 8400
Pulp concentration	23%	23%	23%	61.5%
Specific gravity	1.05	1.05	1.10	1.22
Physical form	nugget	nugget	nugget	granule

---

Product Number	1F723	1F1234	1F735	1F1168	1F819
<i>Properties</i>					
Matrix elastomer	Neoprene GW	Neoprene GW	Neoprene GRT	Neoprene GRT	Neoprene WRT
Pulp concentration	23%	28.6%	23%	28.6%	23%
Specific gravity	1.28	1.29	1.28	1.29	1.28
Physical form	nugget	nugget	nugget	nugget	nugget

#### *General Recommendations*

KEVLAR<sup>®</sup> engineered elastomer enables the compounder and designer to achieve performance, properties and designs not possible in the past. Compounds have been engineered to improve wear and abrasion, achieve better frictional properties, improve tear, improve shear resistance, replace reinforcing fabric, reduce part thickness, or lower rolling resistance.

KEVLAR<sup>®</sup> is a registered trademark of E. I. du Pont de Nemours and Company  
 ENGAGE<sup>®</sup> is a registered trademark of DuPont Dow Elastomers L.L.C.