

A TECHNICAL ANALYSIS OF RUBBER STRIP

By Carl Bakay

To start with a little background, I was working at Union Carbide Corporation in the 1960's as an organic R&D chemist at their Silicones plant in West Virginia. Although it was not my area, many of my friends were involved in the new field of synthetic silicone rubber, as were their counterparts at General Electric and Dow Chemical. The task was to make uniform batches of gum feedstock, and use it to make silicone elastomers for demanding environments such as aircraft window and door seals, engine o-rings, and the like. You have seen the gum sold in a slightly doctored form as Silly Putty, and it's also spread on paper as a non-stick backing for postage stamps and address labels everywhere.

Well, as you might expect, not only did the silicone gum come out of the extruder in a wide range of viscosities, but when blended with fillers and catalysts, the resulting rubber it produced had properties all over the scale. One batch of rubber would be outstanding, with everyone running around congratulating themselves, and then the next run would be so bad it would have to be burned. We liked to relate a similar tale of woe in the paper making industry. The paper mill made an outstanding roll of card stock for IBM cards, better in quality than any that had been made before, and the foreman wanted to know if he should ship it to the customer. The quality control guy said no, destroy it, because once IBM saw it they would want more of the same, and the paper mill could never make it that good again. Although my friends at Union Carbide worked on the problem for years, to this day, synthetic rubber manufacturing is more an art than a science. This is true even more so for natural rubber products.

FROM SAP TO STRIPS

We rubber fliers find ourselves in an even worse predicament than the stories told above. Tan II is a natural rubber product that relies on tree sap as a raw starting ingredient. And as John Clapp said, like wine made from grapes, some years are better than others. As you will see, adding in the variable of manufacturing just compounds this problem (a little pun, that).

Most of today's natural rubber comes from the sap of the Hevea tree. Its bark contains a white milky fluid called latex, from the Latin lac, meaning milk. From the time the tree is six years old until it is about thirty-six, it can be counted on to produce about four to fifteen pounds of latex a year. As shown in the photos, this is collected from each tree in cups, and taken by truck to a processing plant. There it is mixed with acid causing it to curdle and separate into rubber and water.



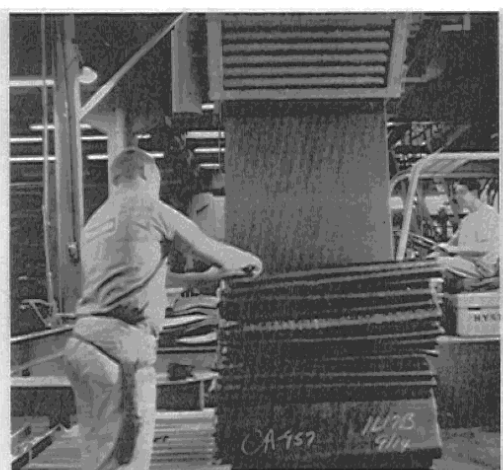
Rubber comes from a white sticky liquid found in the bark of the Hevea tree. (The Firestone Tire & Rubber Company)



Latex is taken from the field trucks to the processing plant by truck. (The Firestone Tire & Rubber Company)



In the mixing operation, rubber, carbon black, sulphur, and other materials are carefully measured into a large machine. (The Firestone Tire & Rubber Company)



After the final mixing, the rubber is rolled into a continuous sheet ready for further processing. (The Firestone Tire & Rubber Company)

This crude product is then squeezed, dried, and formed into bales for shipment all over the world. When a bale of rubber arrives at the manufacturing location, it is first opened and sliced into small pieces.

It is again washed and dried to get rid of impurities, and heads to a compounding room. Here, strips of crude rubber are fed through rollers to soften the rubber. Here, too, vulcanizing agents such as sulfur and charcoal, accelerators, pigments, and antioxidants are added as specified by the laboratory.

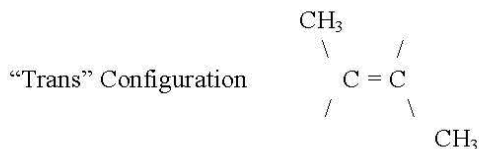
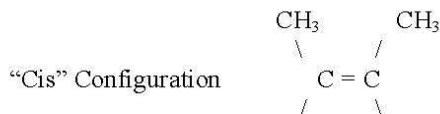
It is now combined with about an equal amount of reclaimed rubber, and fed into a Banbury mixer, which has grooved rollers and can do a better job of mixing than a smooth roller mill. At this point, it is still a crude, workable mixture, and what happens to it next depends on its end use. If it's going to be made into rubber bands, the mix is fed through an extruder which forms a rubber tube ten to twenty feet long. These tubes are then baked to vulcanize them, and sliced into circular rubber bands. If it's going to be made into rubber strip, it is warmed on a warming mill and passed through a calender, which has a series of rollers which can be adjusted to turn out a sheet of any thickness. For Tan II, it is calendered into sheets 0.021" thick, and two of these sheets are then pressed together and vulcanized to get a 0.042" thick finished rubber sheet. A more uniform product can be made in this way than by rolling one, thicker sheet. This is treated with talcum powder and fed through slitters to get Tan II rubber strip.

As far as size goes, this customer can testify that quality control is very good. FAI Supply says the thickness is 0.042 ± 0.005 ", and I've seen a range from 0.0415 to 0.0433 by measuring 6 to 8 strip stacks with a micrometer, which is considerably better than claimed. As for the width, my 1/8" strip samples are always exactly 0.125" with no discernible variation. However, I only have experience with 1998-2000 batches.

THE CHEMICAL SIDE OF RUBBER

Natural rubber is a unique material. It is malleable and can be extruded and molded like a liquid, yet it is elastic and retains its shape like a solid. What modelers are concerned with is its ability to absorb energy in the form of stretching and twisting, and then give back most of that energy in returning to its original shape. It is able to do this because rubber is a matrix of long polymer chains. "Poly" means many and "mer" means units, so these long chains are made up of many, repeating, units.

The monomer is called isoprene, and is made up of four carbon atoms, with what chemists call a "double bond" in the middle. On either side of this bond are two methyl, or CH_3 , groups, large and bulky.



As latex forms in the bark of the hevea tree, the monomer units join up to make a rubber polymer. The size of the molecules are determined during the growing season. Since the double bond holds the two central carbon atoms rigidly in a plane, the methyl groups can either be on the same side of the rubber chain (cis), or on opposite sides of the rubber chain (trans) as it forms. So, aside from the molecule size, or molecular weight, the cis-trans ratio is determined at this time. This is because the molecule is never all of one or the other, but a mixture of the two configurations.

This is not so important to us while the latex is in a watery solution, and the long chains are just floating about in a dissolved state. But as the latex is coagulated, dried, rolled, and generally beat to death, the molecules fold into an ordered, semisolid mass. If there is a high proportion of Cis units in the chains, the bulky methyl groups prevent folding, and the final vulcanized product will have one set of properties. If there is a higher proportion of Trans units, the chains are more flexible and can fold easily into a more ordered solid. This final product will have a different set of properties. What is known at this point is that the “cis-trans ratio” in rubber is very important in determining, and eventually predicting, its properties. What is also known is that a more highly folded solid will crystallize more easily, and then break under high stress.

THE ENGINEERING SIDE OF RUBBER

Engineers have long known of elasticity when measuring the strength of materials—it can be measured in the form of a stress-strain curve. An applied stress, or pulling, yields a resulting strain, or elongation and/or twisting. This is reversible, so all solids are elastic to a certain degree, until the stress exceeds the strength of the material, and it breaks. Vulcanized rubber is a tremendously strong material, but it doesn’t give much warning of its yield point - it just breaks.

As shown in the sketch at right, in its relaxed state, the chains are folded and entwined around each other. They are also crosslinked, or joined to other chains by linkages in the sulfur atoms formed during the vulcanization (or heating) step in manufacturing. But when stretched, the coils unwind and absorb energy. If kept lined up at the right temperature for too long, crystallization and breakage can occur.

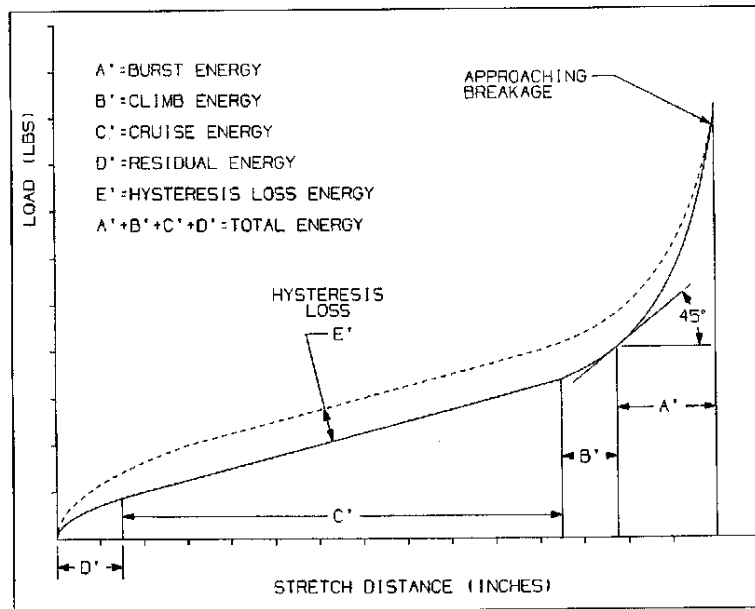


An important feature of a reversible stress-strain chart is that the stretching and relaxation curves don’t lie on top of each other. In other words, you never get out what you put in. This is due to hysteresis, a French word meaning ‘to fall short’. In the case of rubber, it is energy lost. Pull on a rubber band and press it to your skin; it will feel warm. This is stretch energy lost in the form of heat. Pull very hard on it and hold it for a long time, and it may turn brittle and snap. This is energy lost in forming brittle crystals and the failure of weak crosslinks in the rubber matrix.

FINDING THE ENERGY IN A RUBBER LOOP

All this leads us to the heart of this article, which is how and why rubber loops are tested for something called “total energy”, and what this means to the serious flier. The whole point of the introduction *From Sap to Strip* was to highlight all the variables inherent in making the box of rubber we buy and use. But, as a friend of mine asked, “Why all of this testing? Are we going to send it back?” No, I’m not, but I can accumulate many different batches, test them and see how others have tested them, and use the best to compete with and the rest for practice or sport flying. Also, Chilton and Tenny and Rash and Coslick will tell you that you have to wind a lot of samples and break a lot of motors to get good at it. Testing is a way to speed up that process.

The hysteresis stretch-strain energy curve for a rubber loop drawn by John Clapp is shown below. It should be familiar to most readers. It is dimensionless, in that it doesn’t have actual numbers on the axes, but if it did, the best numbers to have would be 0 to 100% on both. That way all sizes and weights and batches can be drawn on the same plot, and only the differences between samples would show up.



Whether we are winding or stretching, the first step is to make up 5 to 10 identical loops from the same batch, weigh them, break them in if desired, and wind or pull a few until they snap. This will establish the 100% point on the x (horizontal) axis. Then we record force in either pounds pull every 3 inches, or inch-ounces of torque every 100 turns, up until 95 to 98% of the breaking point, and then record the same increments while relaxing or unwinding the strip. The difference between the two curves is the hysteresis loss due to friction heat, broken links and crystallization mentioned earlier. The area under the return (lower) curve is the useable energy of the rubber sample.

ENERGY FROM STRETCH TESTS

Let's take stretch testing first. If we divide the return energy curve into slices, or bars to denote the sample size, the calculation method to find the area becomes obvious. Merely add up the pieces to get the whole. We add these bars together into one long strip of forces, three inches wide. The actual amounts of pull recorded during the test are noted on the graph below as F values. We first sum the forces by totaling up the average heights of all the rectangles under the return energy curve. The average value is simply the force on one side plus the force on the other divided by two. So the sum of the forces looks like

$$F = (F_{\max} + F_1)/2 + (F_1 + F_2)/2 + (F_2 + F_3)/2 + \dots,$$

But this can be simplified. If we multiply through by 1/2, we get

$$F = \frac{1}{2}F_{\max} + \frac{1}{2}F_1 + \frac{1}{2}F_1 + \frac{1}{2}F_2 + \frac{1}{2}F_2 + \frac{1}{2}F_3 + \frac{1}{2}F_3 + \dots,$$

and combining like forces, gives

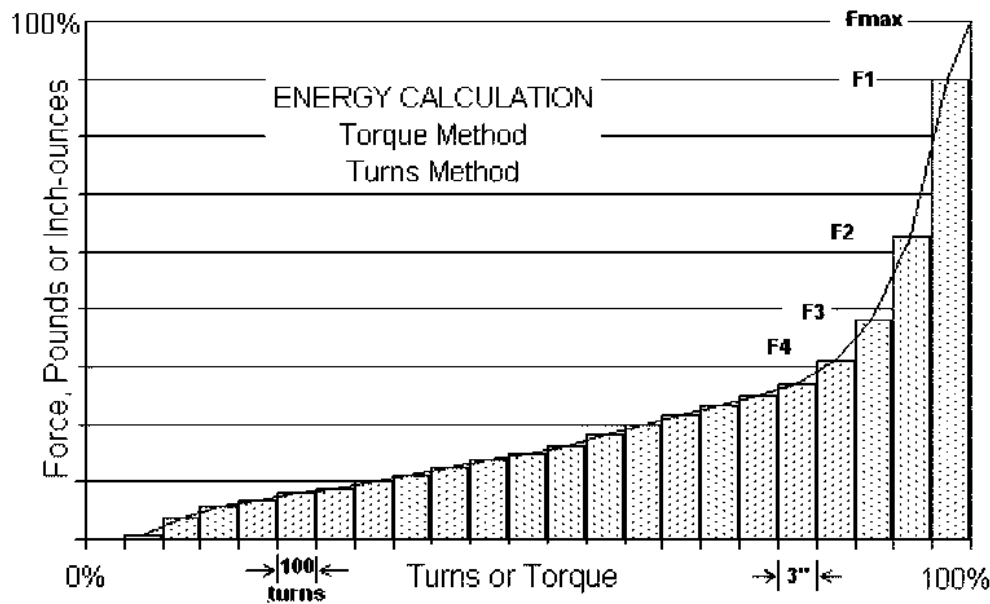
$$F = \frac{1}{2}F_{\max} + F_1 + F_2 + F_3 + \dots$$

$$F = \frac{1}{2}F_{\max} + \text{sum of all the remaining forces,}$$

(or the way Gibbs writes it, $(2\text{sum} + F_{\max})/2$, which is the same thing).

The last step is to convert to foot-pounds/pound, using 1/4 to change the 3-inches to feet, and 16 to change the strip weight in ounces to pounds.

$$\text{Energy} = \frac{1}{4} \times 16 F / \text{Wt of strip in oz.} = 4F/\text{Wt of strip in oz.}$$



ENERGY FROM TORQUE TESTS

The good news is that we don't have to go through the explanation of summing all the forces again, because finding the energy under a torque/turns curve is the same as for stretch. We are adding up strips that are T units high by 100 turns wide. Now we use T instead of F, so

$$T = \frac{1}{2}T_{\max} + T_1 + T_2 + T_3 + \dots$$

$$T = \frac{1}{2}T_{\max} + \text{sum of all the remaining Torques.}$$

We have angular energy being measured, so multiplying by 2π converts this to linear, there are 100 turns and 12 inch-pounds to the foot-pound, so the final equation needed is

$$E = 100 \times 2\pi \times T / (12 \times \text{Loop wt in oz}) = 52.35 \times T / \text{Loop wt. in oz.}$$

The last question to be asked when talking about measuring rubber energy is, "How do these two methods compare, and are the results meaningful?" The answer is, "It depends." Mathematically, the two analyses are the same, in that they accurately find the area under each curve, whether it be stretch or torque. But the following variables enter in to the test findings:

- Are tests adjusted for the same temperature?
- Are the samples from the same batch? The same box?
- Were the loops broken-in before testing?
- Was winding done by turns or by torque?
- Was the winding slow or fast?
- How close to the breaking point limit were the samples stressed?
- Was a lubricant used?
- Were enough samples tested to get a good average?

Without some examples, the usefulness of energy testing will be debated forever, but as background for this article, the table of energies below was assembled. It not only includes stretch and winding results, but also rerun values that show that all samples benefit from a breaking-in of some sort. To get some idea of the range in values, ordinary office rubber bands have an energy of 1800, and a steel spring an energy of about 8100 ft-lbs/lb. Readers are asked to search their files, and help INAV expand even further on this list.

RUBBER TEST ENERGIES – 1976 to 2000

Type	Batch	E @ 75°	Type	Batch	E @ 70°	Type	Batch	E @ 70°
FAI	2/76	3400-3500	Tan I	11/91	3596 ft-lb/lb	Tan II	9/00	4014
FAI	3/77	3200-3500	Tan II	5/94	3475		Rerun	4277
FAI	6/77	2700-3300	Tan II	6/94	4100+	Tan II	4/01	4172
FAI	11/77	3050	Tan II	8/94	4100+		Rerun	4327
FAI	9/78	3020	Tan II	4/95	3497			
FAI	2/79	3350	Tan II	1/96	4042			
FAI	6/79	3360	Tan II	4/96	4272			
FAI	11/79	3290-3500	Tan II	6/96	4137			
	Rerun	3370-3600	Tan II	7/97	3580-4140			
Pirelli	1978	3910	Tan II	10/97	4513			
Pirelli	1978	3680	Tan II	2/98	4485			
Pirelli	4/79	3500	Tan II	5/98	4042-4325			
Pirelli	6/79	3700	Tan II	7/98	3942-4390			
Pirelli	9/79	3430-3615	Tan II	2/99	4582			
	Rerun	3600-3720	Tan II	3/99	4198			
FAI Tan	1991	3770-4100	Tan II	5/99	4110-4675			
FAI Tan	1990	3050-3120	Tan II	7/99	4093-4215			

BRINGING IT ALL TOGETHER

Some technical types I know are in love with data; lots and lots of data. But the real value comes when this is organized into information that the reader can use. Two modelers who have shown the way in turning energy testing into contest performance are Lt Col. Bob Randolph of F1D fame, and Wakefield flier Jim O'Reilly. In his short article in April 1993 INAV, Randolph states:

“Suddenly the idea hit me that what makes F1D so great is that everything is important. You need a good design, a well built model, a well adjusted model, good rubber, and capability to find the optimum motor to obtain really long flights. Any one factor that doesn't measure up will reduce duration. Therefore your goal should be to improve all of the skills required. Some may question what skill has to do with rubber. The skill is in being able to identify which of the rubber you possess is the best and to keep an active lookout for better.”

Since 1983, Randolph has been using quarter motors in practice, and using his best quality, full motors for contest day. This way he stays with the best batch, and conserves what he has at the same time.

Jim O'Reilly has taken this a step further and has outlined a system of integrated testing and flying. This means that his stretch testing is done on actual contest motors, not samples from the box they came in, and this both breaks in and sorts the motors by specific energy. Although developed for outdoor, it is just as applicable to indoor.

1. Make up motors to weight and length and put motors and labels in plastic bags.
2. Lube motors and check their lubed weights.
3. Conduct pull-type energy and break-in tests.
4. Make a table of motors and their energies for the contest. Plan the best motors for early morning and flyoff rounds, with lesser motors for the warmer, thermal part of the day.
5. Wind to torque values on the torque vs. length chart. Finish winding very slowly.
6. Don't be afraid to re-use a motor if it has no broken strands or nicks.

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