



Filament Performance in Brushes

The global choice for premium brush filaments.





For more than 70 years, DuPont has been pioneering innovative synthetic filaments to enable brush manufacturers to address emerging trends and meet evolving consumer expectations.

Whether you manufacture cosmetic brushes, toothbrushes, industrial brushes or paintbrushes, DuPont Filaments has a reliable, high-performance solution to meet your product design requirements. In addition to offering a broad range of innovative synthetic filaments, we understand the importance of providing you with the technical data you need to make design decisions. In this document, you will find a wealth of technical data concerning brushes made with synthetic filaments.

Tynex®, Tynex® A, Chinex®, Herox® and Orel® are DuPont registered trademarks for its filaments that are used in premium quality brushes.

Applications are:

- Tynex® 612 Nylon level filaments for toothbrushes
- Tynex® 612 Nylon fine filaments for cosmetic brushes
- Tynex® 612 Nylon tapered filaments for paintbrushes
- Tynex® A 612 Nylon abrasive filaments for floor care and industrial brushes
- Chinex® 612 Nylon synthetic bristle for paintbrushes
- Herox® 610 Nylon level filaments for toothbrushes
- Orel® polyester tapered filaments for paintbrushes

Much of the data presented in this bulletin is pertinent to a variety of brushes and brush filaments. But particular emphasis is placed on DuPont filaments that are now manufactured in ISO 9002-qualified plants worldwide.

The information to follow is intended to help designers and engineers become familiar with the unique characteristics of the DuPont Filaments' business family of filaments and how these characteristics are affected by environment and stress. With this knowledge, and the information provided by the Filament Performance in Brushes, it is hoped that proper filament selection coupled with good design practice will result in the development of a successful brush product.

The data contained in this module falls within the normal range of product properties, but should not be used to establish specification limits or used alone as the basis for design; they are not intended to substitute for any testing you may need to conduct to determine for yourself the suitability of a specific material for your particular purposes. Because DuPont Filaments can make no guarantee of results and therefore assumes no liability in connection with the use of this information, confirmation of its validity and suitability should be obtained independently.

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Stiffness of Nylon Filaments

Whether a brush does the job for which it was designed usually depends on a number of factors, such as brush configuration, abrasion resistance, bend recovery, or, perhaps most important, stiffness of the brush. Brush stiffness in turn depends almost entirely on filament stiffness, which is affected by the following factors.

Modulus versus Stiffness

Three factors (modulus, diameter, and trim length) affect the filament property that we call stiffness. The confusion about the property of stiffness results from using the word “stiffness” interchangeably with “modulus.”

Modulus is a physical property of a material that can be defined as resistance to deformation or, more simply, as resistance to bending. Modulus is based on a unit area (1 in²) and is, therefore, independent of the diameter of the sample used to make the determination. Modulus (stiffness for equal caliper and length) is one of the inherent properties of the material, i.e., just as polyethylene has a unique modulus, Tynex® has a unique modulus. In other words, every material has a specific modulus and it is usually different from any other material.

If we attempt to bend two different sized (diameter) rods of the same material, we would say that one is stiffer than the other. What we feel is a combination of modulus and size. The modulus is the same for both, but the larger size of one makes it feel stiffer than the other.

A third factor that affects stiffness is length. A short filament feels stiffer than a long filament of the same size and composition.

Factors Affecting Modulus

Moisture

All filaments are affected to some extent by moisture. *Figure 1* shows the effect of moisture on modulus for Tynex®. As can be seen from the graph, 66 nylon is stiffer than Tynex® when dry, but Tynex® is stiffer when wet. This is caused by the lower

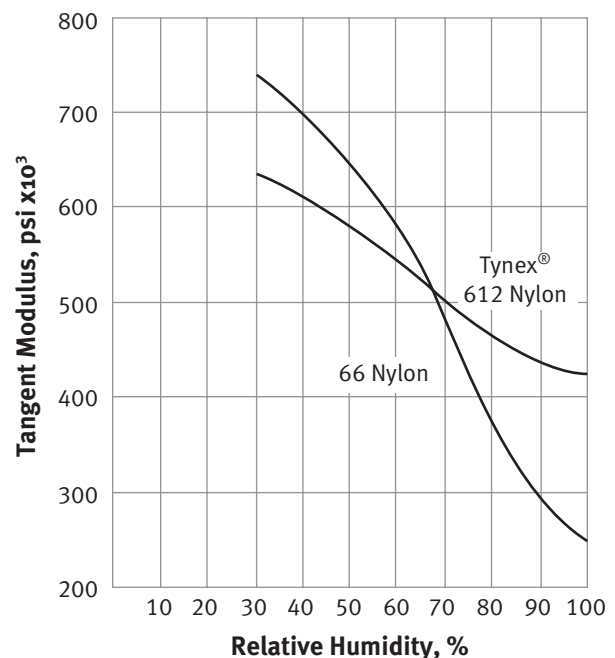


Figure 1. Stiffness versus Relative Humidity of Nylon Filament at 23°C (73°F)

Stiffness of Nylon Filaments

moisture absorption of Tynex®, which absorbs only 3% moisture when saturated. At about 68% relative humidity, the modulus of Tynex® and 66 nylon are equal. Type 6 nylon becomes very limp when wet and does not make a good brush-filling material. In fact, it is used for fishing line.

Although nylons absorb some water, they do not absorb as much moisture as natural hair bristle (horse hair and hog bristle). The natural fibers not only absorb more water than Tynex®, but they absorb it much faster, as shown in *Figure 2*. This figure shows percent stiffness retained versus time in water. After only 10 minutes in water, natural hair bristle loses 40% of its stiffness, whereas it takes 10 hours for Tynex® to lose 28% of its stiffness.

Table 1 lists wet and dry moduli for several brush-filling materials. Also listed are the wet-to-dry modulus ratios.

Table 1. Brush Moduli

Modulus Comparison	Modulus, Mpsi		Ratio Wet/Dry
	50% RH, Dry	100% RH, Wet	
Nylon 6	280	140	0.50
Nylon 66	650	230	0.35
Herex® 610 Nylon	530	333	0.63
Tynex® 612 Nylon	580	420	0.72
Natural Hair Bristle	680	410	0.60

Table 2 lists absorption rates for widely used nylons in two relative humidity levels.

Table 2. Absorption Rates

	Moisture Absorbed, %	
	50% RH	100% RH
Nylon 6	2.7	9.5
Nylon 66	2.5	8.5
Herex® 610 Nylon	1.5	3.5
Tynex® 612 Nylon	1.3	3.0

Changing the caliper of the filament will compensate for a high or low modulus. Thus, the wet-to-dry modulus ratio is a more important factor than actual modulus levels in selecting a filler for brushes that will be used under various moisture conditions. A filler with a low wet-to-dry ratio would be too stiff under dry conditions if designed for wet conditions.

Temperature

All filaments are less stiff at elevated temperatures than they are at room temperature. *Figure 3* shows the typical effect of temperature. Nylon filaments are about twice as stiff at 0°C (32°F) as they are at room temperature. The change in stiffness is much less above room temperature than it is below room temperature.

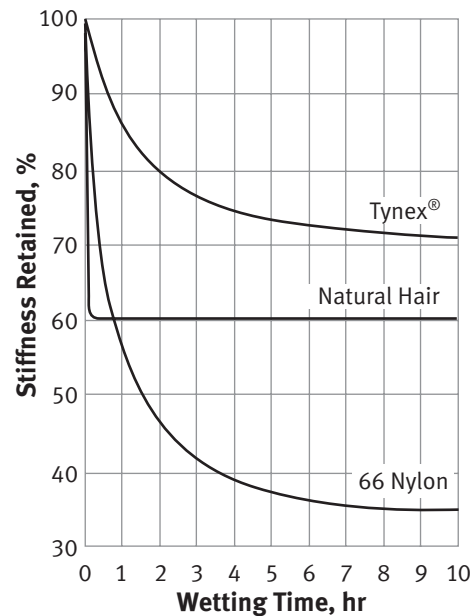


Figure 2. Stiffness Retained versus Wetting Time for 10-mil Filaments and Fibers Submerged in Water at 23°C (73°F)

It should be pointed out that even though nylon filaments become stiff at low temperatures, they do not become brittle.

Brush Stiffness

Effect of Caliper and Trim Length

There are many combinations of filament diameter and trim length that will result in a brush with similar stiffness.

Figure 4 presents this information graphically. For example, let us suppose a given brush has a trim of 2 in and is filled with 10-mil (0.010-in) filament. Draw a line on the chart from 2 in on the trim length scale to 10 mil on the diameter scale. Note where this line crosses the reference line. Assume that a new brush with a 2 ½-in trim length and the same stiffness is required. Draw a line from this point on the trim length scale through the crossover point on the reference line to a new diameter. In the example shown on the chart, the line is drawn to the diameter scale at 14 mil. Therefore, assuming the filling material used is the same, a brush with a 2 ½-in trim filled with a 14-mil filament will have the same stiffness as the original brush with a 2-in trim filled with 10-mil filament.

The answer is only an approximation because tuft stiffness is also affected by the way in which the brush is made (i.e., staple set, wire drawn). Also, because tuft stiffness is a function of the 2nd power of the filament diameter, even a small deviation will have a large effect on stiffness. This chart can be used for any type of level filament as long as both brushes are filled with the same type of filament.

Stiffness of Nylon Filaments

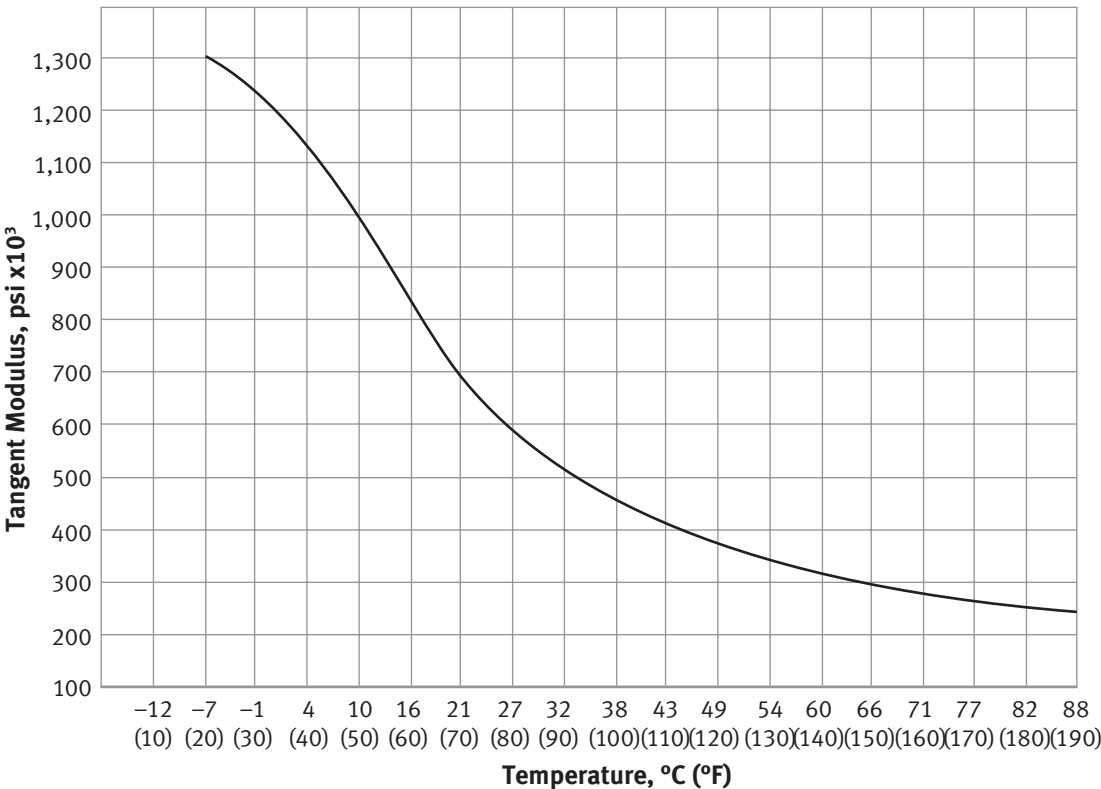


Figure 3. Stiffness versus Temperature for Nylon Filament (Humidity Controlled)

Brush Construction Variables

Brush construction plays a big part in determining brush stiffness. *Figure 4* is for brushes of like construction. It would be impractical to develop a chart that includes all of the various brush constructions. In most brushes, one filament touches another and, therefore, does not function as an individual filament but as a family of filaments. Their interaction varies with each type of construction (strip brush, tuft-staple set, tuft-wire drawn, tuft-adhesive set, etc.). This interaction will also vary with tuft size, trim length, and the rigidity of the tuft in the brush.

Crimping is one way to increase the apparent mass (bushiness) of the filaments. Natural bristles, as a result of their rough surfaces, have more interaction between fibers than noncrimped nylon filament. A brush filled with crimped nylon filament more nearly duplicates the “feel” of a natural fiber brush and gives the bushiness usually associated with a natural fiber.

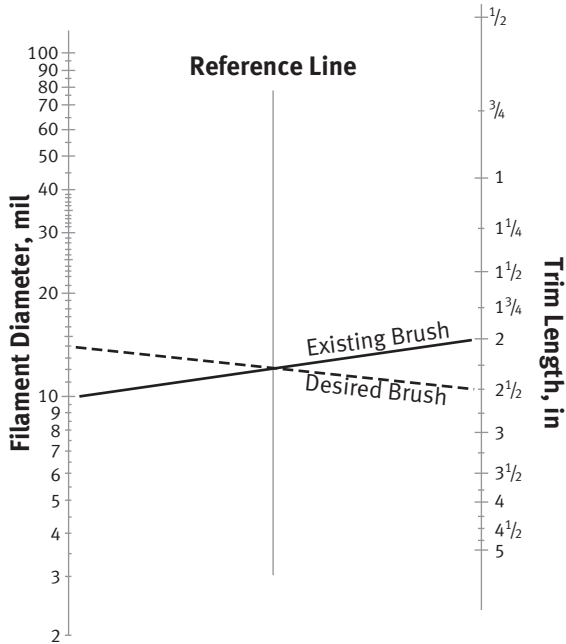


Figure 4. Nomograph for Relating Trim Length and Filament Caliper for Equal Brush Stiffness

Stiffness of Nylon Filaments

Calculation of Brush Stiffness

The following equation is a basic engineering formula that relates the factors controlling stiffness for a filament held at one end, such as in a brush.

Brush Stiffness

Equation 1:
$$D = \frac{WL^3}{3EI} \quad (1)$$

Where: D = Deflection of filament, in
 W = Weight (or force causing deflection), lb
 L = Length of filament, in
 E = Modulus of filament, psi
 I = Moment of inertia of the cross section of the filament, in⁴
 $I = 0.0491d^4$ for round filament
 d = Diameter of filament, in

Round Filament

For a round filament, Equation 1 becomes:

$$D = \frac{WL^3}{0.1473Ed^4} \quad (2)$$

The following conclusions can be drawn from Equation 2:

- The stiffness (resistance to bending) of a single round filament fixed at one end is proportional to the 4th power of the diameter.
- The stiffness of a single round filament fixed at one end is inversely proportional to the 3rd power of the length of that filament.

Tufts of Filament

In most cases, brushes are made up of tufts of filaments rather than single filaments. In the case of a tuft, Equation 2 becomes:

$$D = \frac{WL^3}{0.1473Ed4N} \quad (3)$$

where N is the number of filaments per tuft.

The area of a round filament is $\pi d^2/4$, and, therefore, the number of filaments, N , for a given size tuft is inversely proportional to the 2nd power of the diameter of the filament.

The following conclusions can be drawn for tuft stiffness:

- The stiffness (resistance to bending) of a tuft of round filament is proportional to the 2nd power of the filament diameter.
- The stiffness of a tuft of round filament is inversely proportional to the 3rd power of the length of that tuft.

From these conclusions we can write the following formula, which relates filament diameter and trim length of one brush to filament diameter and trim length of another brush for equal brush stiffness, given that the filaments are of the same polymer type:

$$\frac{l^3}{d^2} = \frac{L^3}{D^2} \quad (4)$$

Where: l = Trim length of existing brush
 d = Filament diameter of existing brush
 L = Trim length of desired brush
 D = Filament diameter of desired brush

By substituting the known values in the above equation and assuming either a new trim length or diameter, the one remaining unknown can be computed. This equation can be solved graphically by using the nomograph in *Figure 4*.

Abrasion Resistance and Factors that Affect Brush Wear Rate

The abrasion resistance of a brush filament is often the controlling factor in brush life. This is particularly important if the brush is used for polishing or cleaning and is rotated or operated mechanically against an abrasive surface. The abrasion resistance of different materials used as brush fillers varies widely. Resistance to abrasion is an outstanding property of nylon filaments.

Inherent Abrasion Resistance of Brush-Filling Materials

The abrasion rate of a brush-filling material is primarily an inherent property of that material. In the case of synthetic filaments, it is essentially a property of the material from which the filament is made and is only slightly influenced by the process of filament manufacture. The best way to compare the relative abrasion resistance of one material to another is to measure the rate of wear (abrasion rate) of the materials in question under identical standard test conditions. *Table 3* shows comparative data obtained during testing.

The method used to obtain the data involves the use of 2-in long twisted-in-wire brushes, 1 ¾ in in diameter, filled with 0.012-in diameter filament. The brushes are rotated against sandpaper for a given period of time. The change in brush weight or weight loss is the abrasion rate (expressed in mg/hr).

Tynex® and nylon filaments, in general, have a much lower abrasion rate than any of the natural materials and are about 50% better than the next best economical man-made filament commercially available.

Table 3. Test Data

Material	Abrasion Rate, mg/hr	Abrasion Ratio*
Tynex® 612 Nylon	40	1.00
66 Nylon	46	1.15
Polyester	60	1.50
Hog Bristle	160	4.00
Tampico	220	5.50

*Based on Tynex® = 1

Filament Size

The larger the filament, the faster it will wear, all other factors being constant. *Figure 5* shows where abrasion rate is plotted versus filament size. Abrasion rate is directly proportional to the cross-sectional area of the filament or the square of the filament diameter. Brush stiffness is also directly proportional to the square of the filament diameter. Thus, abrasion rate is proportional to brush stiffness.

Therefore, for the longest life, a brush should be no stiffer than necessary to do the job for which it was designed. Because stiffness is proportional to the square of the filament diameter, a small increase in caliper will result in a much larger abrasion rate. For example, the abrasion rate is almost doubled in going from 10-mil (0.010-in) filament to 14-mil (0.014-in) filament, all other factors being constant (*Figure 5*).

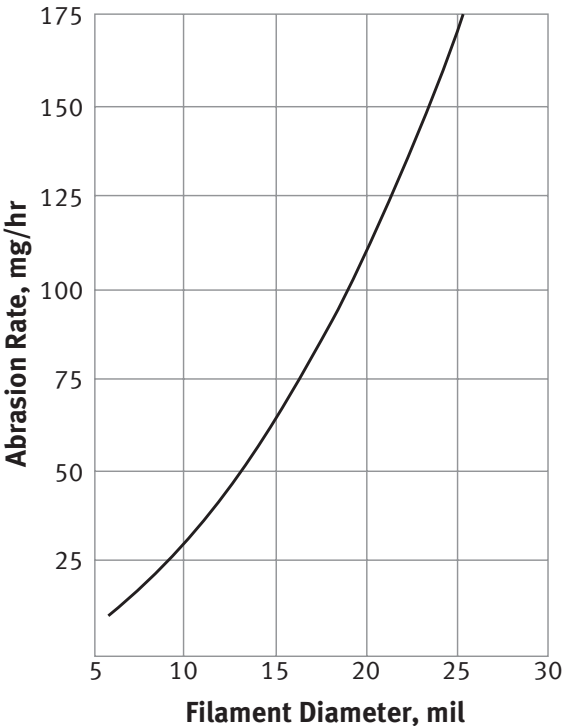


Figure 5. Effect of Filament Diameter on Abrasion Rate of Tynex®

Brush Speed

As would be expected, the abrasion rate increases as the brush speed increases (Figure 6).

The rate of abrasion increases in a straight line with increasing speed up to a point (for example, 2,400 rpm in Figure 6). Above this level, the rate of abrasion increases rapidly. A certain amount of material is removed each time a filament comes in contact with the abrasive surface. Therefore, increasing the number of contacts (increasing the speed) increases the abrasion rate. The departure from a linear relationship above a certain speed is probably a combined effect of heating by friction and impact abrasion. At the higher speeds (greater impact force), it is reasonable to assume that more material is torn away per contact with the abrasive surface.

Applied Load

Again, as would be expected, abrasion rate increases as the applied load on the brush is increased (Figure 7). The effect of filament diameter can also be seen in this graph.

In Figure 7, the abrasion rate varies directly and linearly with the applied load. At much higher applied loads, the abrasion rate increases much faster than the applied load. This departure from linear behavior is a result of excessive deflection of the filament,

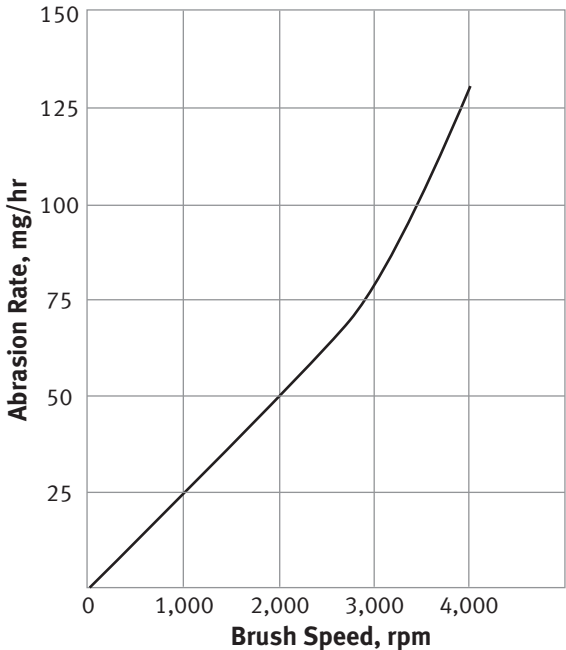


Figure 6. Effect of Brush Speed on Abrasion Rate of Tynex®

which greatly increases the contact area between the filament and the abrasive surface.

Fill Weight

Figure 8 shows that the rate of abrasion is constant when fill weight is changed over a three-fold range. This is at first surprising, but can be explained by remembering that with diameter constant, the rate of abrasion varies with the load

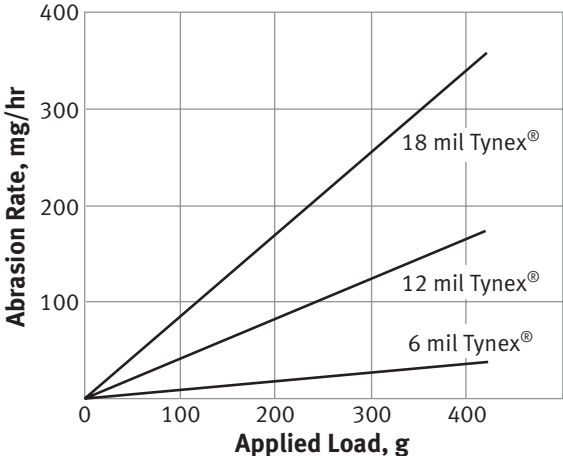


Figure 7. Effect of Applied Load on Abrasion Rate of Tynex®

Abrasion Resistance and Factors that Affect Brush Wear Rate

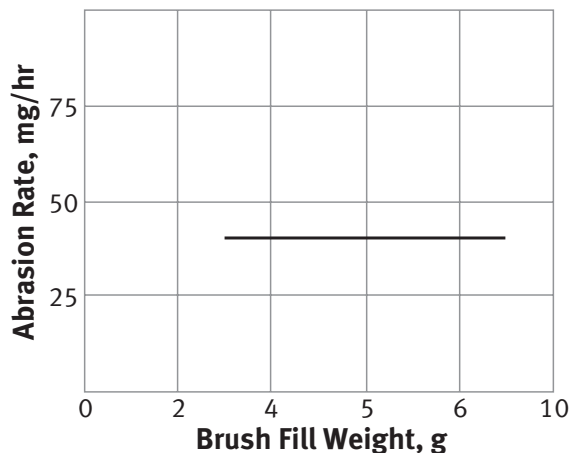


Figure 8. Effect of Brush Fill Weight on Abrasion Rate of Tynex®

per filament. Doubling the number of filaments will halve the load per filament and, hence, halve the abrasion rate. However, there are twice as many filament ends subject to abrasion, so the overall rate is constant.

Although the weight loss is independent of fill weight, the trim loss is proportional to fill weight. This means that within the range explored, the weight of material worn away will be the same regardless of the fill weight. The lighter the fill, the faster the brush will lose trim length.

Temperature

Surprisingly, there is little effect on abrasion rate of normal atmospheric temperature variation. Abrasion rate increases as temperature increases. The effect of temperature over the range -40 to 66°C (-40 to 150°F) is shown in *Figure 9*.

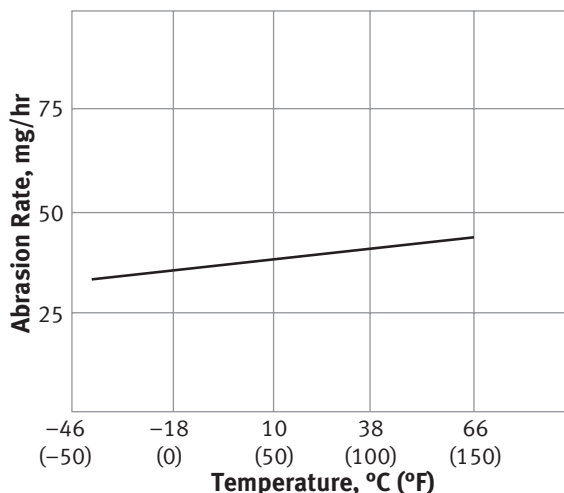


Figure 9. Effect of Temperature on Abrasion Rate of Tynex®

The effect shown in *Figure 9* is actually a combined effect of temperature and stiffness as caused by temperature. As discussed previously (“Stiffness of Nylon Filaments”), temperature has a marked effect on the stiffness of nylon monofilament. Stiffness decreases as temperature increases, and abrasion rate decreases with decreased stiffness. Therefore, abrasion rate should decrease with rising temperature, except for the fact that there are other effects of temperature (such as softening) that tend to increase abrasion rate. The grand total effect of all these factors results in a modest increase in abrasion rate as temperature rises.

Another point to remember is that the filament tips are heated by friction against the abrasive surface, and, therefore, the filament tip temperature in some applications may be somewhat independent of ambient temperature.

Humidity

The effect of relative humidity on abrasion rate is shown in *Figure 10*. The effect of humidity on abrasion rate is similar to that of temperature. It is a combined effect of humidity and stiffness change caused by humidity.

In many cases, the ambient temperature and relative humidity rise and fall together. Therefore, because a rise in humidity reduces the abrasion rate and a rise in temperature increases the abrasion rate, the two effects tend to cancel each other. This being the case, the effect of temperature and relative humidity can be neglected under most conditions.

Trim Length

In the abrasion test used to obtain this data, the trim length was held constant. Trim length as such has no effect on the abrasion

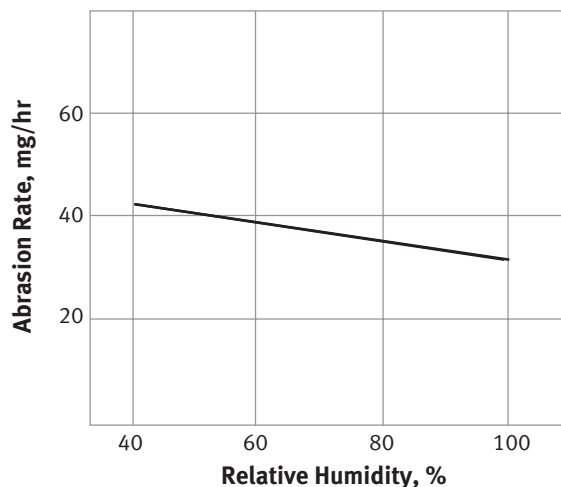


Figure 10. Effect of Relative Humidity on Abrasion Rate of Tynex®

Abrasion Resistance and Factors that Affect Brush Wear Rate

rate of a brush. It does, however, affect the abrasion rate of a brush in practice because it affects the stiffness of the brush, which does affect the abrasion rate.

All other factors being constant, abrasion rate varies inversely with trim length, which is to say that as trim length increases, abrasion rate decreases. Therefore, trim length is certainly a factor to consider with respect to brush life.

Abrasive Surface

The type of surface being brushed is probably the most important factor in the abrasion rate of a given material. In order to study different types of surfaces, a series of tests were run on various grades of sandpaper. The results are interesting in that abrasion rate is maximum on a sandpaper surface with a grit size of about No. 180. Coarser or finer sandpaper gives a lower abrasion rate, as shown in *Figure 11*.

The sandpaper that gives the maximum abrasion rate has abrasive particles of about 5-mil (0.005-in) diameter. As the particle diameter approaches zero, the rate of abrasion approaches zero. Here again the effect of filament diameter can be seen.

The phenomenon of abrasion is rather complicated and not fully understood. One explanation for the dome-shaped curves of *Figure 11* might be that each grain of abrasive functions independently as a tiny cutting tool. The amount of material removed is the volume removed by a single contact between tool and work, multiplied by the number of tools. The volume removed per contact is proportional to the square of the grit diameter. The number of tools is inversely proportional to the first power of the grit diameter. Therefore, the abrasion rate

would be proportional to the first power of the grit diameter. This is the case for grit diameters below 5 mil in *Figure 11*. The fact that the abrasion rate drops off rather than increases above 5 mil is because the particle size is approaching the diameter of the filament. As this happens, the filament tends to move to one side rather than be abraded by the particle. Therefore, the abrasive particle size that gives maximum abrasion rate will depend on the size of the filament being abraded. This is shown in *Figure 11*, where the maximum abrasion rate ("hump" in curve) moves to the right as filament diameter increases.

Summary

The data presented in this bulletin were derived from tests designed to simulate high brush wear rate conditions, using a twisted-in-wire brush rotated mechanically against an abrasive surface.

The various factors affecting brush wear rate are:

- Filament or brush-filling material
- Filament stiffness
- Brush speed
- Load on the brush
- Brush fill weight
- Temperature
- Humidity
- Brush size
- Abrasiveness of surface being brushed

The effect of each factor on brush wear rate was measured by keeping all the others constant. Several general conclusions may be drawn from the data in this bulletin. The more important conclusions are listed below.

- With all factors held constant, abrasion resistance of a filament is an inherent property of the material itself.
- With all factors held constant except filament stiffness:
 - ♦ the stiffer the brush filling of the same material, the faster it will wear.
 - ♦ because stiffness is proportional to filament size, the larger the filaments used, the faster the brush will wear.
- With all factors held constant except brush speed, the faster a brush rotates, the faster it will wear.
- With all factors held constant except load:
 - ♦ the higher the applied load, the faster the brush will wear.
 - ♦ when the applied load is increased to a point that causes excessive deflection of the brush filaments, wear rate increases more rapidly than the proportional increase in load.

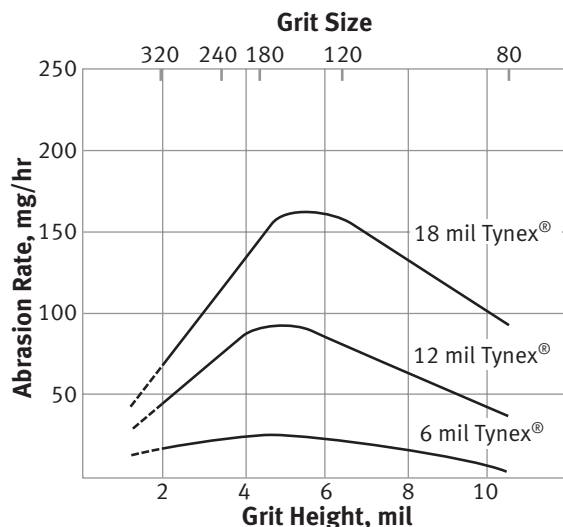


Figure 11. Effect of Abrasive Grit Size on Abrasion Rate of Tynex®

Abrasion Resistance and Factors that Affect Brush Wear Rate

- With all factors held constant except fill weight, within limits the wear rate of a brush based on weight loss is independent of brush fill weight. However, trim loss is proportional to fill weight.
- With all factors held constant except temperature and humidity, abrasion rate increases with rising temperature and decreases with rising relative humidity. In the case where temperature and humidity rise together (most atmospheric conditions), the effects of these two variables cancel each other.
- With all factors held constant except brush diameter, the shorter the trim length, the faster a brush will wear.
- With all factors held constant except abrasive surface, the wear rate of a brush is greatly influenced by the relationship of the filament size used to the abrasive surface being brushed.

Bend Recovery

A desirable property in a brush-filling material is good bend recovery. This depends not only on the materials used as brush fillers, but also on the filament size and the environmental conditions. The bend recovery of the many materials now being used as brush fillers varies widely. High bend recovery is an outstanding property of DuPont™ Tynex® nylon filaments.

What Is Bend Recovery?

Recovery can be described as the ability of a material to return to its original shape after deformation. Recovery of brush-filling materials is usually determined by measuring the ability of the filaments to straighten out after bending. Bend recovery is sometimes confused with fatigue resistance, which is a measure of a material's resistance to breaking, splitting, or complete fracture after many cycles of flexing.

Bend Recovery of Polymers

There are many recovery tests used to characterize man-made fibers and filaments. Tensile, torsional, creep, work, elastic, and dynamic recovery are all tests that are used in the textile trade. All of these tests are similar, but vary in their discriminating power for specific applications. The bend recovery test seems most applicable for characterizing brush-filling materials.

Metal recovers completely from bending provided the yield stress is not exceeded. Stressing above the yield point causes permanent deformation, which is easily predicted from a stress-strain relationship for the material. Recovery for polymers, such as nylon, is not as simple.

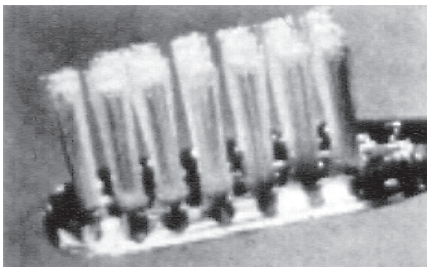


Figure 12a. Shows a brush filler that has good bend recovery.

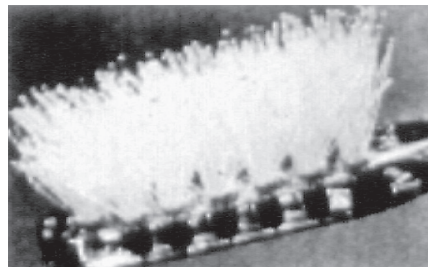


Figure 12b. Shows matting caused by low bend recovery.

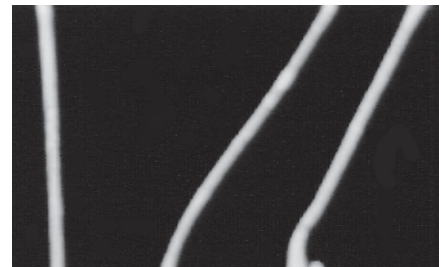


Figure 12c. The filament on the right has failed in fatigue, and the one in the center has failed because of low bend recovery.

Bend Recovery

Polymer Molecules

All man-made filaments are composed of polymer molecules. This means that the molecules are extremely large compared with ordinary molecules such as a molecule of water (H_2O). Polymer molecules consist of a combination of atoms, usually carbon, hydrogen, and oxygen, but sometimes nitrogen, chlorine, or fluorine. Polymer molecules exist because carbon atoms have a chemical affinity for one another and form long chains of hundreds or thousands of atoms. These carbon chains are the backbone of most polymer molecules; however, some have links of oxygen or nitrogen connecting many short chains of carbon atoms. These chains may also have side groups attached at regularly spaced intervals. These side groups on the polymer chains and the different atoms in the backbone are what account for most of the difference among man-made filaments.

These polymer chains could be thought of as a mass of cooked spaghetti. They act like coils and entangled springs. If the molecules are entirely random and without order, the polymer is said to be amorphous. If, however, there are regions in the mass where the molecules are regularly packed, then it is a crystalline polymer. Nylon is such a polymer.

Orientation

Orientation involves cold drawing the polymer, which lines up the molecules more or less parallel to the filament axis. Orientation not only tends to create order in the amorphous region, but also orders the crystalline regions with respect to the filament axis. The high strength of nylon filaments comes from this orientation process.

It is this semi-ordered mass of cold springs with which we are dealing when we talk about recovery of nylon. Small and rapid deformation of nylon is perfectly elastic or springlike and results in complete recovery. This is because the polymer molecules can be compressed, elongated, uncoiled, and bent a certain amount without causing relative motion of the molecules with one another.

With greater deformation (the amount depends on temperature and the time under deformation), movement of chains or chain segments over one another occurs. Opposing this is a chemical attraction of neighboring chains or chain segments.

When stress is applied, there is always a separation of neighbors; however, as the separation becomes large, true flow may set in, and neighbors may slip past one another irreversibly.

Because of points of attraction between chains, tension will extend the chain segments to the point where some of the bonds between neighbors will break and reform with another neighbor in a position of zero stress. When the material is allowed to recover (load removed), the extended chain

segments resume their initial randomly coiled position. This in turn puts tension on the new bonds, causing them to break and reform with their original neighbors. The extent to which the chain segments can resume their initial random position and the extent to which the original neighbors can rebond determines the recovery of a material.

Creep

As mentioned, when a polymer such as nylon is deformed and held at constant stress (load), the chain segments are extended and bonds are stretched. The polymer is uncomfortable in this position, and the various chain segments will rearrange themselves in a direction of lower stress if enough time is allowed. If the load continues to be applied, chain movement continues—in the direction of the applied load. This phenomenon, called creep, is largely irreversible, causing permanent deformation.

Stress Relaxation

If the polymer is deformed and held at constant strain (deformation) instead of constant stress, the same chain segment rearrangement occurs. If allowed enough time, they will finally find positions of zero stress or nearly so. Having done so, they will continue in their new positions even after the material is released. This phenomenon is called stress relaxation, or stress decay, and is really another form of creep. To reach zero stress requires a very long period of time, perhaps years. For shorter periods of time, rearrangement is less than complete, and many chain segments can return to, or in the direction of, their original position. This affords partial recovery.

These processes are both time- and temperature-dependent. Therefore, a polymer will have more complete recovery from deformation at room temperature than if the material is deformed and held at an elevated temperature for the same length of time. A polymer will also deform easier and recover faster at elevated temperatures than at room temperature.

Factors Affecting Bend Recovery

The following is a detailed discussion of the factors affecting bend recovery of brush filaments.

Inherent Bend Recovery of Brush Filaments

Bend recovery of a material is partly an inherent property of that material and partly influenced by the manufacturing process. In the case of man-made filaments, the raw materials from which they are manufactured prescribe a range for bend recovery. Bend recovery can be changed within this range by filament manufacturing techniques.

Bend Recovery

A relative measure of the bend recovery of one material to another may best be obtained by taking measurements of the materials in question under identical standard test conditions.

Comparative data for several materials are shown in *Table 4*.

Table 4. Inherent Bend Recovery (Standard Test)

Material	Bend Recovery, %
Tynex® 612 Nylon	92
Herex® 610 Nylon	92
Type 66 Nylon	90
Hog Bristle	92
Tampico	40
Polystyrene	35
Polypropylene	75
Polyvinylidene Chloride	82

Temperature

Bend recovery of Tynex® is maximum at room temperature and slightly above. Bend recovery of 66 nylon is more temperature-sensitive than that of Tynex®.

Table 5. Bend Recovery versus Temperature

Temperature, °C (°F)	Bend Recovery, %	
	Tynex® 612 Nylon	66 Nylon
-18 (0)	86	76
0 (32)	87	87
23 (73)*	92	90
38 (100)	92	90
66 (150)	92	86
79 (175)	91	85

*Denotes standard test conditions

Humidity

The bend recovery of Tynex® is unaffected by changes in relative humidity.

Table 6. Bend Recovery versus Relative Humidity

Relative Humidity at 23°C (73°F)*, %	Bend Recovery, %	
	Tynex® 612 Nylon	66 Nylon
100	91	82
50*	92	90
10	92	91

*Denotes standard test conditions

Strain

Small and rapid deflection of nylon is perfectly elastic or springlike and results in complete recovery. The larger the strain, the lower the bend recovery. When larger filaments are deflected, they are strained more, which results in higher stress.

Table 7. Bend Recovery versus Filament Caliper

Filament Caliper, in	Bend Recovery, %	
	Tynex® 612 Nylon	66 Nylon
0.008	97	94
0.012 *	92	90
0.020	90	89

*Denotes standard test conditions

Time Under Load

The longer a filament is held in a deflected position, the less complete the recovery.

Table 8. Bend Recovery versus Time Under Load

Time Under Load, min	Bend Recovery, %	
	Tynex® 612 Nylon	66 Nylon
1	95	93
4 *	92	90
10	92	92
30	92	91
120	91	90

*Denotes standard test conditions

Relaxation Time

The longer a filament is allowed to relax, the more complete the recovery.

Table 9. Bend Recovery versus Relaxation Time

Relaxation Time, min	Bend Recovery, %	
	Tynex® 612 Nylon	66 Nylon
1	78	76
3	83	82
10	87	86
30	90	90
60*	92	90
120	92	91

*Denotes standard test conditions

Bend Recovery

Summary

The more important factors affecting bend recovery are:

- Temperature
- Humidity
- Total strain (deflection)
- Strain rate
- Time under load
- Relaxation time

The effect of each factor on bend recovery was measured by keeping the others constant. Several general conclusions may be drawn from the data in this bulletin. The more important conclusions are listed below:

- With all factors held constant, a fundamental bend recovery value may be obtained for each material. This is an inherent property of that material.
- With all factors held constant, except one:
 - ♦ Bend recovery is maximum for Tynex® at room temperature or slightly above and lower at either higher or lower temperatures.
 - ♦ Bend recovery of Tynex® is less temperature-sensitive than that of 6 nylon or 66 nylon.
 - ♦ Humidity has no measurable effect on the bend recovery of Tynex®.
 - ♦ The greater the deflection, the lower the bend recovery for a given material.
 - ♦ Small and rapid deformations of nylon are perfectly elastic and result in complete recovery.
 - ♦ The shorter the time under load, the higher the bend recovery.
 - ♦ The longer the relaxation time, the higher the bend recovery.

Fatigue Resistance and Factors that Affect Flex Life

The fatigue resistance of a brush-filling material is often the controlling factor in brush life. This is particularly true if the brush is heavily loaded and operated mechanically, as is the case for many industrial brushes. Personal and household brushes generally are not heavily loaded or subjected to continuous flexing, and, therefore, their mode of failure is usually not fatigue, but rather bend recovery. Fatigue resistance (or flex life) depends not only on the materials used as brush fillers, but also on the filament size, brush construction, and the environmental conditions. The fatigue resistance of the many materials now being used as brush fillers varies widely. High fatigue resistance is an outstanding property of DuPont™ Tynex® nylon filaments.

What Is Fatigue Resistance?

Fatigue is the most misunderstood and confusing physical property of a material, whether metal or plastic. Fatigue resistance is a measure of a material's resistance to breaking, splitting, or complete fracture after many cycles of flexing. Fatigue failure starts as a small crack and grows with each additional flexing until catastrophic failure occurs.

Fatigue resistance is often confused with bend recovery or matting resistance. Bend recovery is a measure of how completely a material returns to its original shape after bending (flexing). Fatigue resistance is a measure of whether or not the material breaks after repeated flexing. *Figure 13* shows two different types of brushes that have failed in fatigue.

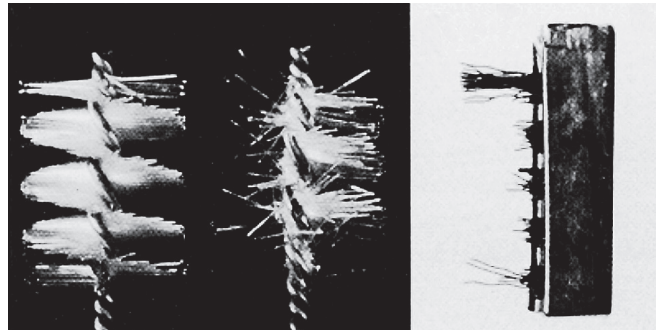


Figure 13a. Bottle brush before and after use; used brush shows fatigue failure.

Figure 13b. Vacuum cleaner brush showing fatigue failure.

Factors Affecting Fatigue Resistance

The following is a more detailed discussion of the factors affecting fatigue resistance of brush-filling materials. A general discussion of fatigue follows this section.

Inherent Fatigue Resistance of Brush Filaments

Fatigue resistance of a material is partly an inherent property of that material, but is also greatly influenced by the manufacturing process. In the case of man-made filaments, the raw materials from which they are manufactured prescribe a range for fatigue resistance values. Fatigue resistance can be markedly changed within this range by filament manufacturing techniques.

A relative measure of the fatigue resistance of one material to another may best be obtained by making measurements of the materials in question under an identical set of test conditions.

Fatigue Resistance and Factors that Affect Flex Life

Comparative data for several materials are shown in *Table 10*.

Table 10. Inherent Fatigue Resistance

Material	Fatigue Resistance, %
Tynex® 612 Nylon	98
66 Nylon	90
Hog Bristle	40
Horse Hair	10
Tampico	10
Polypropylene	98
Polystyrene	30
Polyvinylidene Chloride	20
Polyvinyl Chloride	<5

Temperature

Fatigue resistance of Tynex® decreases with decreasing temperature, as shown in *Table 11*.

Table 11. Fatigue Resistance versus Temperature

Temperature, °C (°F)	Fatigue Resistance, %	
	Tynex® 612 Nylon	66 Nylon
49 (120)	99	92
23 (73)*	98	90
0 (32)	97	85
-18 (0)	90	80

*Denotes standard test conditions

Humidity

High humidity increases the fatigue resistance of Tynex®. However, 66 nylon is more humidity-sensitive than Tynex®, as shown in *Table 12*.

Table 12. Fatigue Resistance versus Relative Humidity

Relative Humidity at 23°C (73°F), %	Fatigue Resistance, %	
	Tynex® 612 Nylon	66 Nylon
100	100	100
50*	98	90
0	97	85

*Denotes standard test conditions

Deflection

The larger the filament deflection, the poorer the fatigue resistance. For a given filament size, the larger the deflection of the filament, the higher the strain in the filament and, correspondingly, the higher the stress. Naturally, the higher the stress, the poorer the resistance to breakage.

Filament Size

At constant strain, the larger the filament size, the lower the fatigue resistance. This can be seen in the *Table 13* data, which lists total number of impacts required to produce 2% failure.

Table 13. Tynex® Caliper versus Number of Impacts to Failure

Filament Caliper, in	Total Number of Impacts
0.012	107,000
0.016	60,000
0.022	32,000
0.032	15,000

Therefore, in order to obtain equivalent results for any diameter filament of the same material, the standard test is run for shorter periods of time for larger filaments.

Flexing Rate

Strain rate, within the range tested, does not affect the fatigue resistance of Tynex® 612 nylon or 66 nylon, as shown in *Table 14*.

Table 14. Fatigue Resistance versus Strain Rate

Strain Rate (Impacts per min)	Fatigue Resistance, %	
	Tynex® 612 Nylon	66 Nylon
500	99	90
750	97	90
1,000 *	98	90
1,250	98	91

*Denotes standard test conditions

The Mechanism of Fatigue Failures

Man noticed early in his use of metals that after a period of satisfactory use a part would sometimes fail, even though the loads were relatively low. Such a failure would usually occur suddenly, such as a ductile steel axle snapping off as if it were brittle. This type of fracture always showed a dull area surrounded by an area of bright crystals.

Such a fracture was naturally considered evidence that repeated twisting or bending had caused a part of the metal to crystallize. This explanation was so simple that it became firmly entrenched and is still used to this day by some to explain a fatigue failure, although the theory has long been disproved.

Fatigue failure occurs in almost every type of material: metals, plastics, and rubbers. Fatigue is an unfortunate word to describe this type of failure, because materials do not get tired, and they do not recover when rested. Regardless, the term “fatigue” has become firmly entrenched in materials terminology.

Fatigue Resistance and Factors that Affect Flex Life

The mechanism of fatigue failure is now more thoroughly understood. Under repeated stress, a material yields at one or more micro sites. This yielding occurs because of weakness or high residual stresses in the molecular structure. When yielding of plastic occurs, segments of molecules slip past others and break atomic bonds, which results in submicroscopic cracks. These cracks frequently cause areas of stress concentration. As the working stress is repeated, the cracks spread, usually inward from the surface. Over time, there is so little sound material left that the normal applied stress exceeds the strength of the remaining material. This is when catastrophic failure occurs.

Summary

The data presented in this bulletin were derived from tests designed to predict the performance of a filling material in a brush with respect to fatigue failure. The test method used does not exactly simulate brush use, but rather measures the fundamental property (fatigue) of the material.

The more important factors affecting fatigue resistance are:

- Type of filling material
- Filament diameter
- Temperature
- Humidity
- Deflection

The effect of each factor on fatigue resistance was measured by keeping the other constant. Several general conclusions may be drawn from the data. The more important conclusions are:

- With all factors held constant, a fundamental fatigue resistance value may be obtained for each filling material.
- With all factors held constant, except one:
 - ♦ High humidity increases the fatigue resistance of Tynex®.
 - ♦ Low temperatures reduce the fatigue resistance of Tynex®.
 - ♦ Fatigue resistance of Tynex® is less temperature- and humidity-sensitive than that of 66 nylon.
 - ♦ The smaller the filament, the higher the fatigue resistance.
 - ♦ The larger the deflection, the lower the fatigue resistance.
 - ♦ Flexing rate, within the range tested, has no effect on fatigue resistance.

Filament Identification

There are many types of man-made filaments in use today throughout the brush industry. Many of these filaments used in the manufacture of brushes are similar in appearance and “feel,” but have widely varying properties, depending on the material from which the filaments are made. Even within family groups, there are wide differences. This is especially true of the several types of nylon being used by the brush industry.

For example, Tynex® nylon filament has a low level of moisture absorption and, thus, retains most of its stiffness in water, in water-based paints, and in aqueous solutions. On the other hand, type 6 and 66 nylon filaments absorb greater amounts of moisture and lose much of their stiffness in aqueous media.

Identification Problems

The brushmaker or brush buyer may at any time be presented with a brush filled with an unknown filament that he or she wants to identify. Identification is more difficult today because of the widespread use of man-made filaments and the fact that most of these filaments are similar in appearance.

This bulletin presents a simplified identification procedure that a brushmaker can use to identify the filament in question. It also defines a method for identifying the type of nylon. These tests do not require elaborate or expensive equipment nor do they require special training by the person doing the analyses.

Identification Procedures

The selection of an identification procedure for a particular brush filament depends on the nature of the sample, the

experience of the person doing the identification, and the equipment available. Quite often, the person analyzing the filament has a good idea as to what the material is, and all that may be necessary is a spot test to confirm this opinion.

Burning Test

One of the most useful spot tests is the burning test. Most filaments display a characteristic burning behavior, and, if controls of known samples are used, the burning test can be very useful. The use of controls is very important because some of the descriptions listed on the following page tend to be subjective.

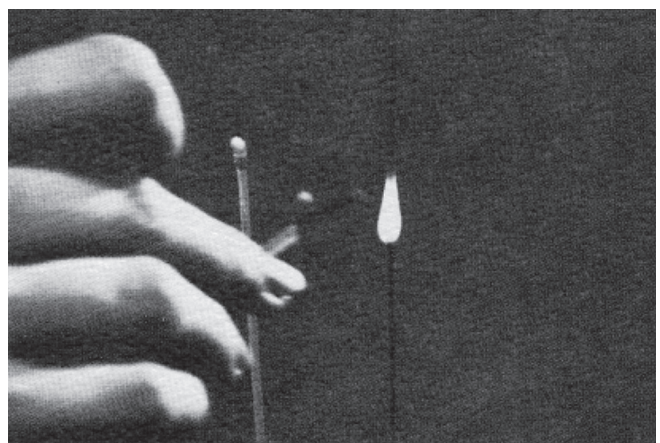


Figure 14. Burning Filament
Filament on left is nylon; filament on right is polystyrene. Note that nylon is barely burning and is starting to melt and drip. Polystyrene burns vigorously and gives off black smoke.

Filament Identification

A gas Bunsen burner is probably the most effective source of heat to use for a burning test, but even a match can be used. The best technique is to hold the filament by one end with forceps or pliers, and bring it slowly into the side of the flame until it ignites (or not more than 10 sec if it does not burn). *Table 15* lists typical burning behavior of several filaments.

Note: Molten plastics are very hot and can give painful burns if they contact the skin.

Table 15. Filament Burning Behavior

Filament	Observation
Nylon (All Types)	Blue flame, yellow top, melts and drips, burned wool odor
Polyesters	Yellow flame, smokes, drips
Polypropylene	Blue flame, yellow top, drippings may burn, paraffin odor
Polystyrene (and Styrene Copolymers)	Yellow flame, smoke, black specks in the air
Polyurethane	Smokes, chars, sharp odor
Polyvinylidene Chloride	Yellow flame, ignites with difficulty, green spurts
Animal Hair	Does not burn, odor of singed hair

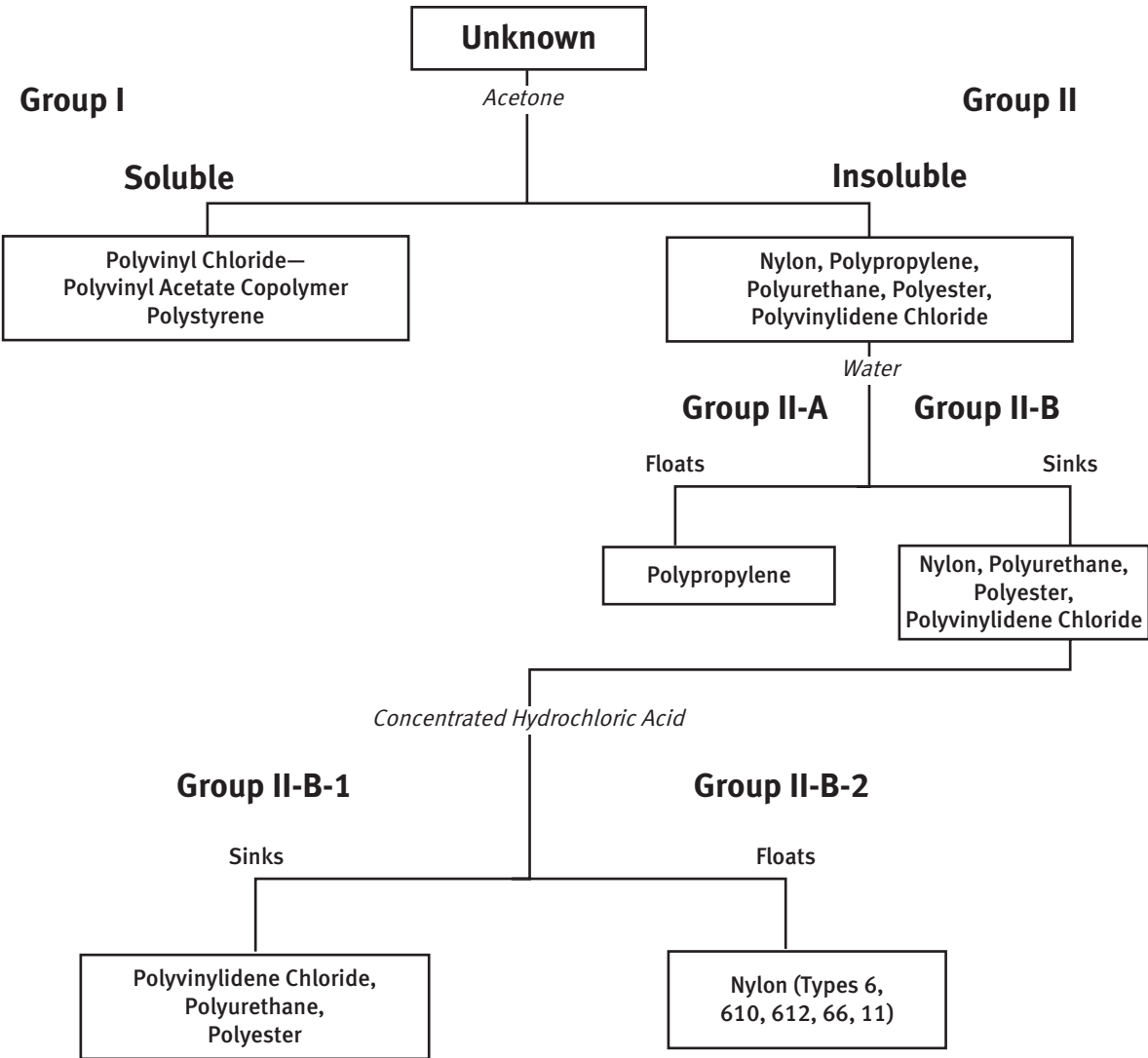


Figure 15. Identification Scheme for Filament Family Type

Filament Identification

Solubility and Float Tests

If one does not have an idea as to the identity of a filament, or if it seems desirable to confirm the results of the burning tests described in *Table 15*, solubility and float tests are commonly used and are extremely helpful. These tests are best carried out with about 4 oz of solvent and one or more of the filaments. Some materials take several hours to dissolve, and occasional stirring or shaking helps. Most solvents are flammable, and some (like hydrochloric acid) are corrosive. Tests should be carried out in a well-ventilated room.

The identification plan shown in *Figure 15* separates most of the materials used for man-made filaments. However, there are some less frequently used materials that may react to the solubility and float tests in the same way as the commonly used materials listed. If there is any doubt about any material, its melting point and/or specific gravity should be checked for a positive identification. It might even be necessary to send the unknown material to a well-equipped laboratory for identification, if it should happen to be particularly rare.

The general identification scheme for the solubility and float tests is shown in *Figure 15*. This scheme requires the following materials, which are available from drug stores or chemical supply houses:

- water
- acetone (flammable)
- concentrated hydrochloric acid (same as muriatic acid). This is commonly sold as 37–38% acid, with a specific gravity of 1.19. (Acids are corrosive.)
- 90% concentrated formic acid

Group I - Soluble in Acetone

Acetone dissolves filaments made from polystyrene (and most styrene copolymers) and polyvinyl chloride-polyvinyl acetate copolymer. Solubility tests should be run on a few filaments in about 4 oz of acetone. Occasional stirring or shaking helps solution, and at least 1 hour should be allowed for solution to take place.

Group II - Insoluble in Acetone

Acetone will not dissolve filaments made from nylons, polypropylene, polyurethane, polyesters, or polyvinylidene chloride.

Group II-A - Floats in Water

The polypropylenes can be quickly identified, because they are the only commonly used man-made brush filaments that float in water. Thus, if the filament is insoluble in acetone and floats in water, it is polypropylene. In making float tests, the filaments should be poked below the surface of the liquid to completely wet them. Polyethylene filaments would also be in Group II-A and can be distinguished from polypropylene filaments by melting point.

Group II-B - Sinks in Water

The nylon, polyurethane, polyester, and polyvinylidene chloride filaments are insoluble in acetone and sink in water. The nylons can be distinguished from the other three types, because they float in concentrated hydrochloric acid; the polyurethanes, polyesters, and polyvinylidene chlorides sink.

Group II-B-1 - Sinks in Concentrated Hydrochloric Acid

Polyester, polyurethane, and polyvinylidene chloride filaments sink in concentrated hydrochloric acid after they have been poked below the surface of the liquid with a glass stirring rod.

Group II-B-2 - Floats in Concentrated Hydrochloric Acid

All the principal types of nylon used as brush filaments (types 610, 612, 66, 6, and 11 nylons) will float in concentrated hydrochloric acid. These five types of nylons can be separated by the identification scheme given in *Figure 16*.

Float tests of filaments in acid should be run by dropping small lengths of filament in the acid rather than by pouring acid into the glass container on top of the filaments. This is because concentrated hydrochloric acid causes some filaments to soften and stick to the walls or to the bottom of the container, which could obscure the results of the float test.

The success of the float test in acid depends on the acid maintaining its specific gravity of 1.18 to 1.19, which it has when purchased. When not in use, the acid should be kept in a closed glass container, and it must not be contaminated with water or other materials that dissolve in it.

Soluble in Concentrated Hydrochloric Acid

Type 66 and type 6 nylons are soluble in concentrated hydrochloric (or muriatic) acid, usually within 1 hour. These tests are run by putting a few lengths of filament in about 4 oz of the acid. (Acids are corrosive and should not be allowed to come in contact with the skin. If this happens accidentally, the exposed areas should be washed immediately with water.) If the filament is either 66 or 6 nylon, it should be completely soluble by this test and not merely deformed or partially dissolved.

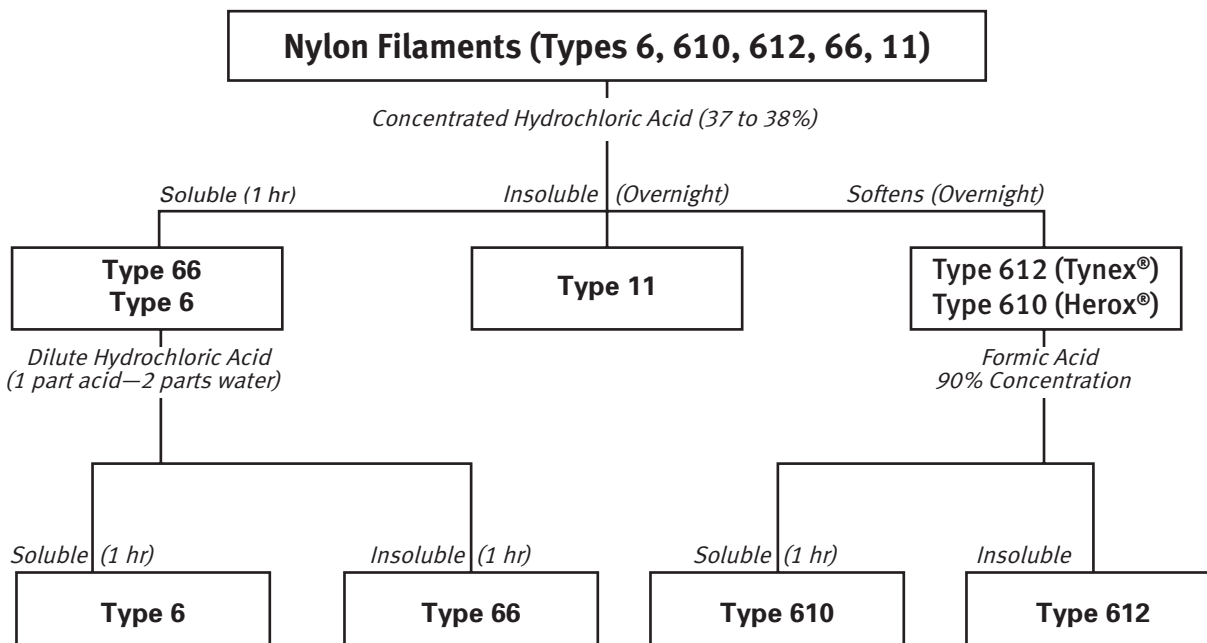


Figure 16. Identification Scheme for Nylon Filaments

Softens in Concentrated Hydrochloric Acid

The 610 nylon will not dissolve in this concentrated acid within 1 hour, but it may start to soften and stick to the sides of the container. After being in the acid overnight, the 610 nylon will have lost its shape and will have a jellylike appearance.

Behavior in Dilute Hydrochloric Acid

The type 66 and 6 nylons that were soluble in concentrated hydrochloric acid can be distinguished from each other by their behavior in dilute hydrochloric acid. This acid is made by pouring one part of acid (by volume) into two parts of water. (Always pour acid slowly into water; never pour water into acid.) Type 6 nylon will dissolve in this dilute acid within 1 hour at room temperature; type 66 nylon will not dissolve.

Insoluble in Concentrated Hydrochloric Acid

Type 11 nylon is virtually unaffected by concentrated hydrochloric acid, even after standing overnight. It is clearly distinguished from the other types of nylon by this behavior.

Insoluble in Concentrated Formic Acid

The 610 nylon will dissolve in this concentrated acid within 1 hour. The 612 nylon will start to soften, but will not dissolve even after 24 hours of exposure.

Specific Gravity

Specific gravity (also known as relative density) can be used for either primary or supplemental identification of many materials. The identification schemes outlined in this bulletin make frequent use of specific gravity.

The specific gravity of the sample is compared with the specific gravity (known) of a liquid by determining whether the sample sinks or floats in the liquid. A wide variety of liquids may be employed.

For example, water (specific gravity 1.0) is used to identify polypropylene; concentrated hydrochloric acid (specific gravity 1.18) is used to identify nylons.

Another useful specific gravity solution is a saturated solution of ordinary table salt in water. (Add salt to water until no more will dissolve and undissolved salt is on the bottom of the container.) This solution has a specific gravity of 1.19 at room temperature. Nylons will float in this solution; polyesters and polyurethanes will sink.

Melting Point

Each type of man-made filament has its characteristic melting point. Some of these are listed in *Table 16*. A melting point apparatus is a useful tool for supplemental identification of filaments that are not clearly identified by other tests described in this bulletin. A good model can be selected from a laboratory supply store.

Filament Identification

Table 16. Specific Gravity and Melting Point

Filament	Specific Gravity	Melt Point*	
		°C	°F
66 Nylon	1.14	257	495
612 Nylon (DuPont™ Tynex®)	1.06	210	410
610 Nylon (DuPont™ Herox®)	1.08	216	420
6 Nylon	1.14	218	425
Polyurethane	1.21	170	338
Polyvinylidene Chloride	1.75	165	330
Polystyrene	1.06	163	325
Polyethylene	0.91–0.96	110–138**	230–280
Polypropylene	0.89	165	330
Polyester Filament (Polyethylene Terephthalate)	1.38	250	482
Polyester Filament (Polybutylene Terephthalate) (DuPont™ Orel®)	1.32	216	420
Hog Bristle	1.32	None	None
Tampico	1.22	None	None

*Approximate melting points are reported. It is a characteristic of most plastic materials that they do not melt sharply, but soften over a range of temperatures.

**Depends on type

Even without a melting point apparatus, some identification of materials by melting point can be made on an electric iron. For example, consider the problem of identifying two brushes, one made of Tynex® (melting point 210°C [410°F]) and one of 66 nylon (melting point 257°C [495°F]). The ends of a filament

from each brush could be jabbed against the face of an electric iron while the iron was being heated stepwise from the lowest to the highest temperature setting. The filament that first left a sticky residue on the iron would be Tynex®, which is the lower melting of the two.

Chemical Resistance of Nylon Filaments

Nylon filaments are outstanding in their resistance to a wide range of solvents and chemical solutions. Hydrocarbons and oils have no effect, and the common organic solvents (alcohols, chlorinated hydrocarbons, ketones, esters) have either no effect or a temporary and small effect on stiffness, which is recovered when the solvent evaporates.

Aqueous solutions of most chemicals, including alkalis such as lye, have no effect other than the temporary effect of the water itself on the stiffness of nylon filaments. Horse hair and hog bristle, on the other hand, dissolve in alkalis.

Materials that do affect nylon filaments usually do so by some degree of solvent action. Phenol (carbolic acid) and formic acid will slowly dissolve nylon. Other acids, such as acetic (organic) and hydrochloric (mineral) acid, degrade and embrittle nylon. Weak solutions of these acids at room temperatures attack nylon very slowly, giving filaments an appreciable life in such solutions. Food acids, including vinegar, have no appreciable effect on nylon.

Horse hair and hog bristle are degraded by most organic and mineral acids.

The resistance of nylon filaments to various chemicals are given in *Tables 17* and *18*.

Effects

The effects of the chemicals tested on nylon were divided into three groups: no effect, temporary effect, and permanent effect. The principal temporary effects were loss of modulus and tensile strength. The permanent effects were a drop in tensile strength or, if serious degradation occurred, brittleness and low elongation.

Chemical Solutions—No Effect

Some chemical solutions have only a temporary effect due to the water present. The original properties are regained upon drying out.

Common Solvents—No Effect

The following common solvents have little or no effect on nylon:

- amyl acetate (lacquer solvent)
- butyl acetate (lacquer solvent)
- cottonseed oil (food oil)
- gasoline
- kerosene
- lard
- linseed oil (paint drying oil)
- naphtha (VMP) (paint thinner)
- naphtha (xylol) (paint remover)
- toluene (paint remover)
- turpentine (paint thinner)

Chemical Resistance of Nylon Filaments

Table 17. Chemical Solutions Having Only a Temporary Effect

Chemical	Comments
Water, Distilled	Slight decrease in stiffness and tensile strength
Ammonium Hydroxide (Ammonia Water)	No effect other than that of water
Paintbrush Cleaner (Alkaline Detergent)	No effect other than that of water
Potassium Carbonate, 20% (Potash)	No effect other than that of water
Salt Water (Sodium Chloride 4%)	No effect other than that of water
Soap (Fels Naphtha)	No effect other than that of water
Sodium Carbonate, 20% (Cleaning Agent)	No effect other than that of water
Sodium Chloride (Saturated) (Salt)	No effect at 24°C (75°F); not tested higher
Sodium Cyanide, 10% (Metal Cleaning Agent)	No effect other than that of water
Sodium Hydroxide, 20% (Strong Alkali)	No effect other than that of water
Sodium Hypochlorite, 1% Chlorine (Bleaching Agent)	No effect other than that of water at this concentration; probably degraded at very high concentration
Sodium Perborate, Saturated (Bleach, Deodorant)	No effect other than that of water
Trisodium Phosphate, 20% (Strong Cleaner)	No effect other than that of water
Surfactant, 2%	No effect other than that of water
Typical Detergents	No effect other than that of water

Table 18. Chemicals or Solvents Having a Permanent Effect

Chemical	Principal Effects	Comments
Acetic Acid	Loss of stiffness Becomes weak	Effect at a minimum in concentrations under 10% at 24°C (75°F). Fails completely upon prolonged exposure at 99°C (210°F).
Diglycolic Acid	Loss of stiffness Becomes weak	Little effect at 1-5% concentrations. Fails completely upon prolonged exposure at 99°C (210°F).
Formic Acid	Loss of stiffness Becomes weak	66 nylon—significant effect even at 5% level at 24°C (75°F). Fails completely upon prolonged exposure at 99°C (210°F). Tynex®—little effect at 90% level at 24°C (75°F). Fails completely at 90% level upon prolonged exposure at 99°C (210°F).
Hydrochloric Acid (Muriatic Acid)	Loss of stiffness Becomes weak	Below 5% level and at 24°C (75°F) effect is about same as water alone. Degrades rapidly at elevated temperatures of higher concentrations.
Hydroxyacetic Acid	Loss of stiffness Becomes weak	Moderate effect up to 63°C (145°F). Fails completely upon prolonged exposure at 99°C (210°F).
Lactic Acid	Loss of stiffness Becomes weak	Only slight effect up to 63°C (145°F) at 15% concentration. Fails upon prolonged exposure at 99°C (210°F).
Dilute Phenol (Carbolic or Cresylic Acid)	Loss of stiffness Becomes weak	Little or no effect at 1% level at 24°C (75°F). Effect more pronounced at elevated temperatures or higher concentrations.
Oxalic Acid, 10% (Strong Cleaning Agent)	Loss of stiffness Becomes weak	Little effect at 24°C (75°F). Seriously degraded upon prolonged exposure at 63°C (145°F).
Phosphoric Acid	Loss of stiffness Becomes weak	Insignificant effect at 24°C (75°F) up to 20% concentration. Fails upon prolonged exposure at 99°C (210°F).
Sulfuric Acid	Loss of stiffness Becomes weak	Little effect at 24°C (75°F) up to 20% concentration. Fails completely at 63°C (145°F).
Zinc Chloride, 50%	Loss of stiffness Becomes weak	Little effect up to 63°C (145°F). Dissolves at 99°C (210°F) upon prolonged exposure.

Chemical Resistance of Nylon Filaments

Common Solvents—Temporary Effect

The following common solvents cause a temporary loss of stiffness, which is rapidly regained upon evaporation of the solvent from the filament:

- acetone (paint remover)
- ethyl alcohol, 95%
- ethylene dichloride (degreasing agent)
- isopropyl acetate (lacquer solvent)
- methyl alcohol (shellac solvent)
- methyl acetate (lacquer solvent)
- methyl ethyl ketone (paint remover)
- trichloroethylene (degreasing agent)

Paints containing any of these solvents would probably cause brushes of Tynex® to become floppy temporarily. However, the use of any of these solvents to clean such brushes would be perfectly satisfactory. Brushes with greater inherent stiffness can be made of Tynex® to compensate for this condition.

Chemicals or Solvents—Permanent Effect

Some chemicals or solvents have a permanent effect on Tynex® filaments. However, some are frequently used with success at normal room temperatures and low concentrations.

Filament Shapes

Typically, monofilament is extruded into a round shape with a consistent diameter along its length. This form is commonly referred to as a “level” filament. However, the shape of an extruded monofilament can be altered to provide performance and cost attributes that are custom fit for specific applications.

Shapes for Density Reduction

The cost of a brush is affected by many variables. Not the least is the amount of fill material used to occupy the volume of the brush ferrule or strip channel. This weight of fill is a function of the bulk density of the filament. Bulk density is simply the weight of the filament divided by the volume of the filament. While the fill weight in a brush can be affected by the density or specific gravity of the polymer used to make the filament, filament shape can also be changed to affect the bulk density, brush weight and cost to make a brush.

One way to change the bulk density is to make hollow filaments with a void running the length of the filament. These are available in a variety of number of holes in the filament. Hollow filaments vary in density depending on the wall thickness of the filament. A thicker wall will make the filament stronger and stiffer, but result in a smaller void in the center of the filament, reducing the amount of density reduction achieved.

Careful design of the hollow filament shape can deliver both density reduction and strength as shown in *Figure 17*, a cross section of a trilocular filament. Density reduction of up to 45% can be achieved with some filaments using this trilocular shape, while the central support structure prevents fracture when the filament is bent.

Another way to achieve density reduction is to alter shape to create space between neighboring filaments. This can be achieved by adding “lobes” to a filament so that filament packing is reduced. An example is the quadrilobal filament shape shown in *Figure 18*. This filament shape typically delivers a 15% density reduction when compared to round filaments.

Filaments can also be crimped, putting a sine wave pattern along the length of the filament, creating small gaps between filaments that allow for easier cooling of the filament as well as reducing the bulk density. Typical brush density reduction of 35% can be achieved by using crimped filaments, *Figure 19*, in place of straight filaments.

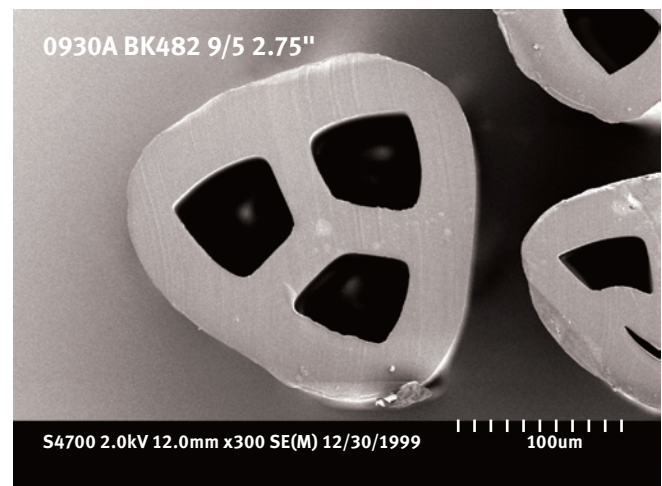


Figure 17. Triocular Filament

Filament Shapes

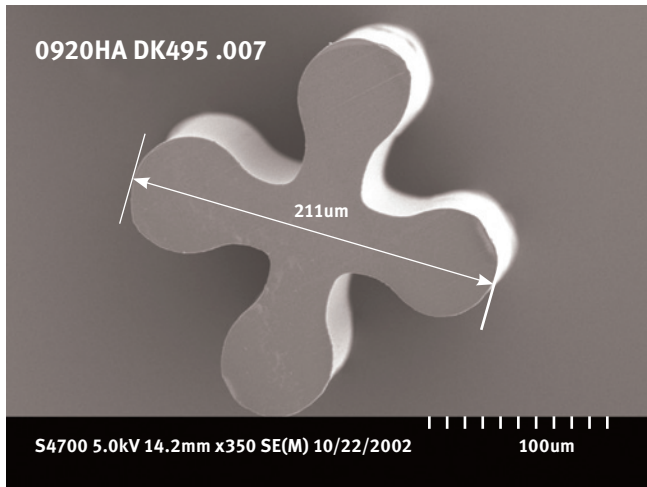


Figure 18. Quadrilobal

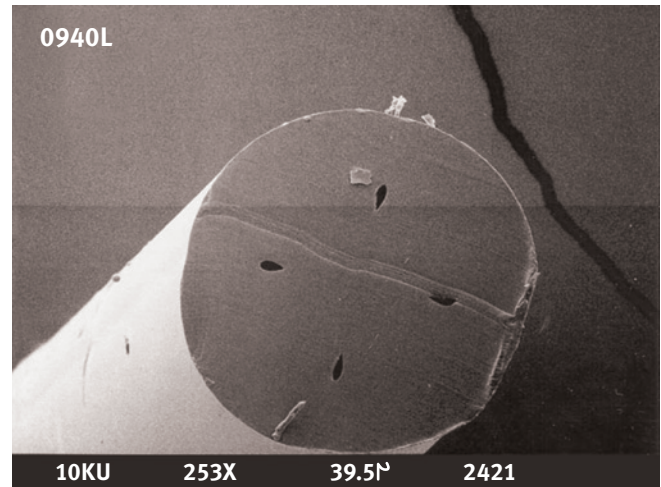


Figure 20. Tetralocular Filament

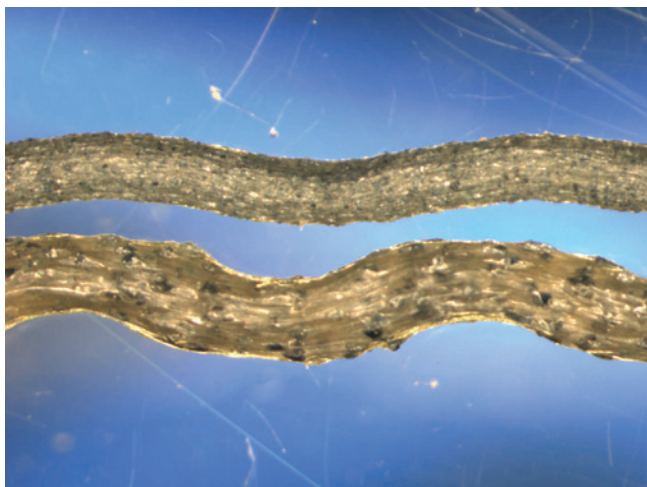


Figure 19. Crimped Filaments

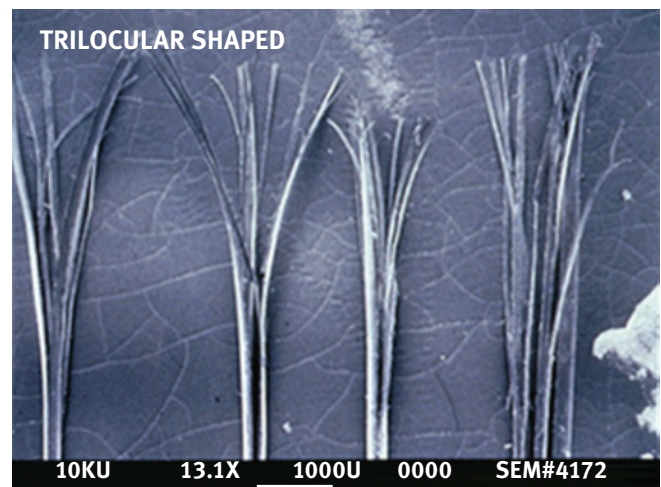


Figure 21. Flagged Filament

Shapes for Material Delivery

One function of a brush is as a tool for delivering a liquid or powder to a surface and depositing it uniformly. Whether this is paint or mascara powder, the brush must have good pickup and laydown performance. Filament shape can affect these brush parameters.

Quadrilobal-shaped filaments are very good at trapping liquids and powders in the open space between the filaments. Other filaments, like the trilocular and tetralocular (*Figure 20*) can be processed to create split ends on one end that serve a dual purpose.

The increased surface area created by the splitting helps capture more coating, while the small diameter of the resulting “flags” leaves fewer brush marks when smoothing the coating

(*Figure 21*). *Figure 22* shows how paint coverage is affected by the amount of flagging in a paintbrush. More paint pickup and delivery results due to the increased surface area created by the flagged filaments.

Shapes for Changing Bending Performance

The discussions above involved modifying the cross-sectional shape of filaments. Filaments can also be made to have a modified diameter along the length of the filament. When filaments are made to have a uniformly decreasing diameter along the longitudinal length of the filament, they are considered “tapered” filaments (*Figure 23*). If the diameter is modified only on one end or along part of the length, these are considered to be “tipped” filaments. Both of these are commonly found in paintbrushes.

Filament Shapes

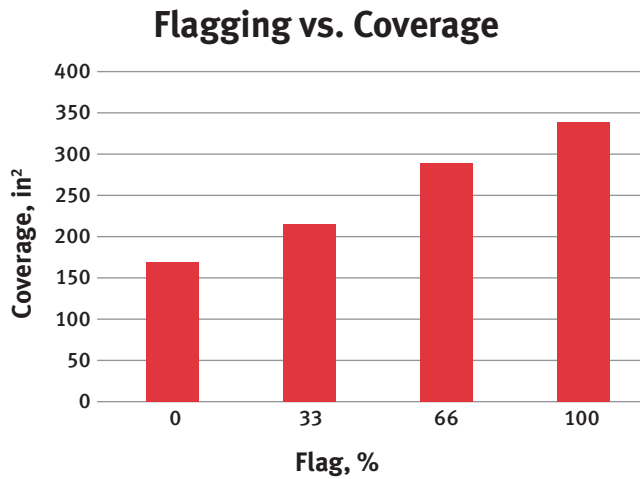


Figure 22. Effect of Flagging on Coverage

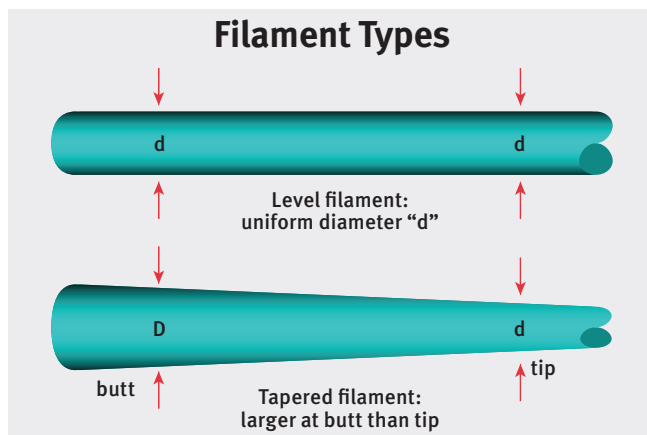


Figure 23. Level and Tapered Filament

The performance of a tapered filament differs from that of a level filament in how it bends in response to a load or deflection. A filament bends like a beam, with little deflection until the load surpasses the cross-sectional strength of the filament. Since tapered filaments have a cross-section that varies along its length, the bending performance also will change depending on the load being applied by the brush user. This allows a painter to apply a

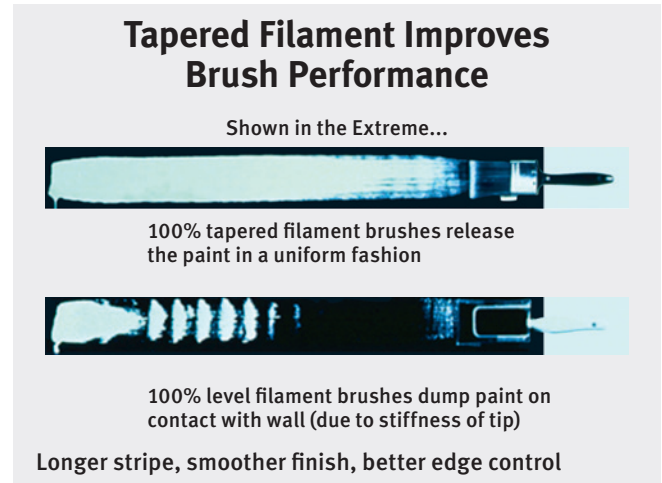


Figure 24. Tapered Filament Brush Performance

heavy force to first distribute paint, and then finish with a lighter force using the smaller tip at the end of the brush.

Another function of a tapered filament when used in a brush is as a pump, pushing paint towards the tip of a brush when it is bent. The result is a uniform supply of paint to the tip of the brush, creating a uniform paint stripe without skipping or interruption.

Changing a filament cross section from round to rectangular is often used as a way to change the stiffness of the filament. The stiffness will be increased if trying to bend across the major dimension, and decreased if bent across the minor dimension.

Shapes for Brush Appearance

The appearance of filament in a brush can be changed through the use of colors or additives like glitter. Filament shape can also affect appearance, changing how light reflects from the brush surface. Diamond- or triangle-shaped filaments are used often to add sparkle to a brush. In some cases, these shapes can also get into tight spaces, enhancing the cleaning efficacy of a brush.

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