

Abrasion Characteristics of Polypropylene Yarns

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Synopsis

The abrasion characteristics of low-twist polypropylene multi-filament yarns free of surface lubricants were determined by rubbing the yarns against each other by using a reciprocating action device at a frequency of 60 cycles/min. It was found that the abrasion behavior of the yarns varies over a wide range and is related to such fundamental properties as the polymer and fiber molecular weight, undrawn fiber orientation and crystalline structure, drawn fiber properties, and elevated temperature post-treatment. It was also found that presence of surface lubricants could increase the number of abrasion cycles to failure by as much as a factor of 20, depending upon the particular lubricant employed. The mechanism of the process of fiber failure resulting from abrasion damage was examined and appears to be one in which the fiber rupture is preceded by a tearing and peeling back of fiber surface fragments probably initiated at flaws in the fiber surface.

INTRODUCTION

The abrasion characteristics of numerous materials in fabric and fiber form have been studied by using various types of testing techniques. In general, the purpose of these tests has been to evaluate various types of textile materials as an indication of their potential wear and serviceability and to determine their characteristics under various types of abrasion. ASTM D 1175-64T lists six procedures involving different abrasion testers for determining the abrasion resistance of textile fabrics, and the literature contains numerous references to other types of testing devices. It has been pointed out, however, that abrasion tests on fabrics reflect the abrasive behavior of the fiber material itself only in part, since the attrition is influenced by fabric weave and other geometric considerations.

Much of the work reported in the literature regarding the abrasion characteristics of fibers and yarns has been with reference to their relative abrasion resistance characteristics. Susich¹ investigated the inherent abrasion resistance of fourteen different textile materials in multifilament yarn form by determining the loss in fiber weight resulting from flex abrasion over a steel bar using the Stoll abrasion tester. Large differences were found in the abrasion behavior of the various fibers. In an attempt to explain the relative abrasion resistances of various fibers in terms of inherent physical properties, Hamburger² studied the behavior of low-twist multifilament yarns using the Taber abrader. He proposed that the inherent abrasion resistance is related to the energy absorption character-

istics of the fibers and suggested that the fiber properties related to high abrasion resistance are: low elastic modulus, large immediate elastic deflection, high ratio of primary to secondary creep, and high magnitude and rate of primary creep. Backer³ discussed several mechanisms of abrasion with reference to the stress patterns which can be imposed on the individual fibers. In addition to the factor of energy absorption characteristics, Susich noted that the extensibility, yarn surface, and frictional properties must also be considered in interpreting the abrasion behavior. In a further effort to add to the fundamental understanding of the abrasion process, Hadley⁴ reported the results of a study in which single polyester and polypropylene filaments were abraded against fine India stone and related the effect of filament diameter and tenacity on the abrasion properties of the fibers.

Polypropylene fibers have been reported to have good abrasion resistance properties, and the data reported here represent an attempt to gain insight into the relationship of the various factors which govern their abrasion behavior and the mechanism of the abrasion process. The factors of polymer and fiber molecular weight, crystallinity, surface characteristics, and yarn properties and their interrelationships have been examined. This has been accomplished by producing fibers which possess widely different properties from a given polymer and from different polymers by variations in the extrusion and subsequent processing techniques. In this study low-twist multifilament yarns free of finish were used, and the yarns were abraded against each other in a manner similar to that performed by the Walker abrader⁵ (as contrasted to the flex and abrasion over a bar described by ASTM D 1379-64).

EXPERIMENTAL PROCEDURE

Yarns were produced for study by extruding polymers at various temperatures ranging from approximately 240–320°C. at a rate of 20 g./min. in a small-scale experimental spinning unit. The extrusion equipment was conventional and consisted of an extruder, metering pump, and spinneret with 34 orifices. The molten polymer was cooled by blowing conditioned air immediately after emergence from the spinneret. The undrawn yarns were wound at a winding speed of 280 m./min. at an undrawn denier of 640. Some of the data reported were obtained with yarns which were quenched under other experimental conditions which will be described later.

The yarns were drawn at various draw ratios over a heater plate at 120°C. and delivered to the yarn package at a speed of 180 m./min. while inserting 0.5 TPI. Some of the drawn yarns were heat treated prior to abrasion testing. Heat treatment was carried out at 120°C. under vacuum for 3 hr. Birefringence was measured by using a calibrated quartz wedge in conjunction with a polarizing microscope. Yarns were tested by using the Model TM Instron tensile testing machine at a testing rate of 100%/min.

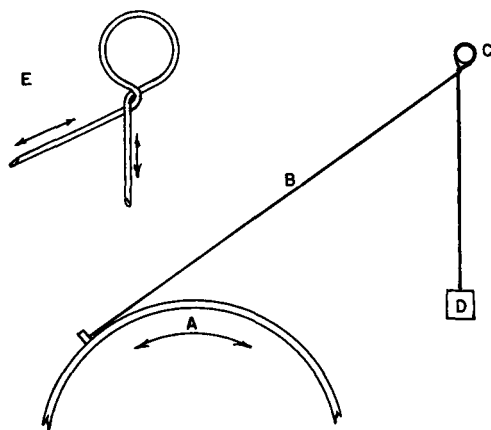


Fig. 1. Schematic diagram of technique of abrasion showing loop detail at left: (A) reciprocating device; (B) yarn; (C) frictionless pulley; (D) weight; (E) loop detail.

The abrasion data were obtained on yarns which were previously washed free of finish with water and isopropyl alcohol. This was found to be extremely important since, as found in a different phase of this study, the abrasion resistance of lubricated yarns could be increased by as much as a factor of 20 depending upon the particular characteristics of the yarn lubricant. It was found necessary to wear gloves in handling the washed yarn since oil on the skin could also appreciably increase the values obtained. It was also necessary to rewash the yarns after carrying out the yarn heat treatments, since apparently a deposit was formed on the yarn surface during the treatment which contributed to a higher abrasion value. Yarns were abraded by using a Wyzenbeek tester which was modified to handle yarns in order to utilize the reciprocating action whose frequency is 60 cycles/min. Yarn was fastened to the drum, then around a frictionless pulley and given a 180° turn around itself. Weight was hung at the free end. A sketch of the method under which the yarns were abraded is shown in Figure 1. Most of the loadings were carried out at 0.10 g./den. and a series of tests was run at various higher loadings to determine the effect. The relationship of load to the number of cycles to break is shown in Figure 2. This relationship is observed to be a straight line function in a log-log plot. Therefore, by using the relatively low load of 0.10 g./den. the differences between the abrasion resistance of the yarns studied were amplified. Statistically the average of six observations on a yarn sample was estimated at a precision of about plus or minus six cycles. Repeated tests on a yarn sample failing at 100 cycles showed that the average difference between means was no more than 2 cycles.

The polymers used were Escon polymers (Enjay Chemical Company). The polymers represent inherent viscosities 2.68, 2.47, 1.84, 1.78, and 1.60 (identified as polymers A through E, respectively) which correspond to melt

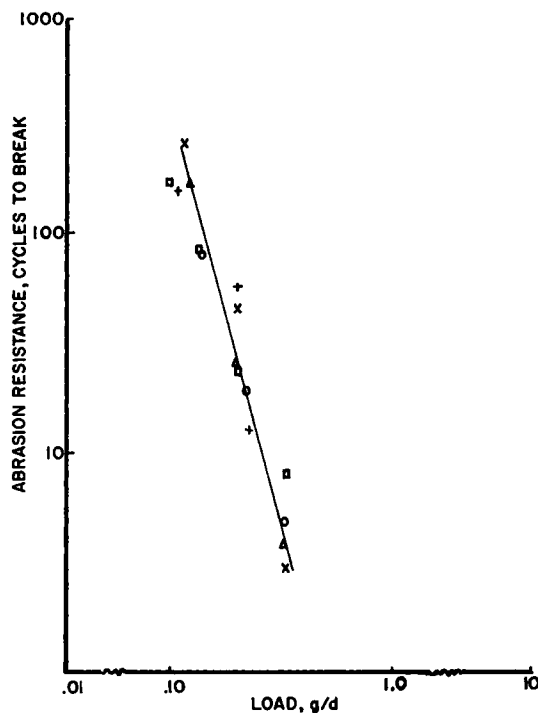


Fig. 2. Abrasion resistance as a function of yarn loading for various denier yarns from polymer B: (+) 184 den.; (X) 176 den.; (Δ) 161 den.; (\square) 150 den.; (O) 144 den.

index values of approximately 2–20 and molecular weights of approximately 340,000–180,000 according to the conversion factor derived by Chiang⁶ ($[\eta] = 1 \times 10^{-4} \bar{M}_w^{0.80}$), assuming the inherent viscosity to be the same as the intrinsic viscosity. All polymers were highly isotactic (over 95%) as determined by heptane extraction. Inherent viscosities on both polymers and yarns were determined in accordance with ASTM D 1601-61 which specifies the flow time measurement of 0.1% polymer concentration in decalin at 135°C.

RESULTS AND DISCUSSION

Before detailing the results of the yarn-to-yarn abrasion investigations it is pertinent at this point to review the behavior of polypropylene polymers and fibers. For a detailed summary the reader is referred to an earlier publication.⁷ Briefly, however, polypropylene polymers are frequently extruded at temperatures considerably higher than the polymer melting point. For a given polymer this results in a reduction in the average molecular weight and a narrowing of the molecular weight distribution of the polymer if the extrusion temperature is high enough.⁸ A plot of average molecular weight as a function of extrusion temperature shows that the molecular weight is relatively unaffected up to temperatures of approxi-

mately 260–270°C. Above this temperature there is a relatively rapid loss of molecular weight up to temperatures of approximately 300–310°C., at which point the molecular weight change is again much more gradual. High molecular weight polymers degrade more rapidly than lower molecular weight polymers and ultimately reach approximately the same level of molecular weight. Accompanying these changes in molecular weight is a reduction in the undrawn yarn orientation (as measured by birefringence and sonic modulus),⁹ an increase in the boiling heptane solubility of the yarns,¹⁰ and a gradual change in the crystalline character of the undrawn yarns characterized by a shift from a highly ordered monoclinic crystalline structure at the lower extrusion temperatures to a less ordered paracrystalline structure at the higher extrusion temperatures.

As these undrawn yarns are oriented by drawing, the drawing tensions of the various molecular weight yarns are measurably different, the higher molecular weight yarns developing higher tensions and higher tensile strengths at common draw ratios. The lower molecular weight yarns, however, are capable of being drawn at higher draw ratios to higher tensile levels presumably because of the lower degree of orientation in the undrawn state. As the yarns are oriented, the heptane solubilities again begin to decrease and the higher molecular weight yarns reach a limiting value of approximately 97% insolubility which is not altered by subsequent heat treatment but which is higher than that reached by the lower molecular weight yarns. Heat treatment of the lower molecular weight yarns, however, further reduces the heptane solubility, and a higher level of insolubility is reached.

The properties of molecular weight, molecular weight degradation, orientation, crystallinity, yarn properties, and yarn surface characteristics are all factors which apparently control the abrasion resistance of polypropylene multifilament yarns. Abrasion resistance has been found to increase with increased crystallinity, energy absorption characteristics, and increased molecular weight when coupled with decreased yarn orientation although the result is one which is a reflection of the various interactions of these factors. No effort was made to determine the effect of filament or yarn denier as such. Hadley⁴ reported that the abrasion resistance at a specific load decreased with the increase in filament diameter and examined filaments covering the range of approximately 3–27 den./filament. The denier range covered in these experiments is considerably narrower, covering a range of approximately 3–6 den./filament and bundle deniers of approximately 100–200. In order to eliminate the variable of denier in comparing the response of the abrasion resistance to the various parameters previously mentioned, all comparisons have been made at equivalent deniers.

Molecular Weight and Orientation

A set of typical abrasion results obtained on yarns originating from a polymer of the group of lower molecular weight polymers (inherent vis-

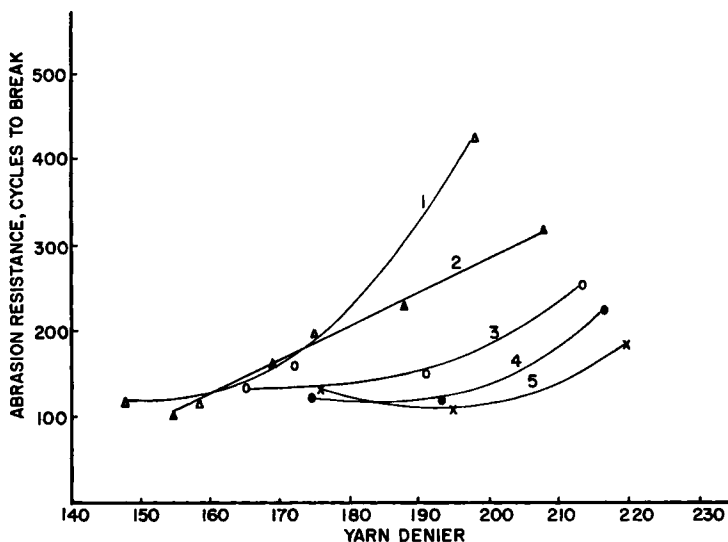


Fig. 3. Relationship of abrasion resistance and denier for various molecular weight yarns produced from polymer C at various spin temperatures $/\eta/\text{undrawn birefringence} \times 10^{-4}$: (1) 304°C./1.59/48; (2) 293°C./1.65/78; (3) 282°C./1.72/107; (4) 271°C./1.79/113; (5) 260°C./1.79/125.

cosity less than 2) is shown in Figure 3, which shows the relationship of the cycles to break as a function of the yarn denier at various molecular weights. During conversion of this polymer into fiber the change in molecular weight is relatively small although the undrawn fiber orientation varies over a considerable range. The abrasion data shown in the figure illustrate that the abrasion resistance of the higher spin temperature yarns is greater than the lower spin temperature yarns over most of the denier range. It is, of course, recognized that the crystallinity characteristics and yarn properties are not necessarily the same, and this will be dealt with later. This relationship further illustrating the effect of undrawn fiber orientation can be seen in Table I, which shows the results obtained for two additional low molecular weight polymers.

TABLE I
Effect of Undrawn Fiber Orientation on Abrasion Resistance of Drawn Yarns

Polymer inherent viscosity	Undrawn yarn birefringence $\times 10^{-4}$	Abrasion resistance, cycles to break*
1.78	30	328
	65	210
	129	174
1.60	21	415
	85	230
	113	195

* Denier of all yarns is 180/34.

The interaction of molecular weight and orientation exhibits a different effect when higher molecular weight polymers are under consideration. In this case, low birefringence yarns are obtained when extrusion temperatures are high and accompanied by a relatively high degree of degradation. This also has the effect of modifying the molecular weight distribution by generating a higher proportion of lower molecular weight fraction. The data shown in Table II were obtained by extruding a relatively high molecular weight polymer at four different temperatures while all other conditions were constant.

These data illustrate that the yarn molecular weight, or rather the degree of molecular weight degradation, appears to be the controlling factor rather than the undrawn yarn orientation, as contrasted to the case of the yarns produced from the lower molecular weight polymers of Table I. It is reasonable to expect, however, that at some low enough undrawn birefringence or that with some intermediate molecular weight polymers the interaction of yarn molecular weight and undrawn orientation will offset each other and direct correlation with either factor will be difficult.

TABLE II
Effect of Yarn Viscosity on Abrasion Resistance of Drawn Yarns

Polymer inherent viscosity	Yarn inherent viscosity	Undrawn yarn birefringence $\times 10^{-4}$	Abrasion resistance, cycles to break ^a
2.47	2.19	163	224
	2.24	163	219
	1.91	94	157
	1.68	34	124

^a Denier of all yarns is 180/34.

In a further effort to determine the relative contributions of the molecular weight and orientation, an experimental device was used to obtain yarns at constant molecular weight and variable birefringence as well as the reverse. In order to obtain a high molecular weight fiber with a birefringence comparable to what would be obtained with a low molecular weight extruded fiber, the fiber was formed at a low temperature but the filaments were rapidly quenched by concentrating the flow of quench air on the filaments immediately on emergence from the spinneret, thereby causing them to draw down in a highly fluid state at a relatively low draw-down tension. The technique of governing the crystallinity in monofilaments by rapid quenching was also used by Sheehan and Cole,¹¹ who used water as the quenching medium. They observed that the lower the extrusion temperature, the lower the quenching temperature had to be to obtain the paracrystalline unoriented state. In our experiments it was found that the filaments could be rapidly air-quenched so as to obtain a series of yarns with relatively low orientation for these comparisons. The results of the abrasion tests are shown in Table III.

TABLE III
Effect of Undrawn Fiber Orientation on Abrasion Resistance of Drawn Yarns (Constant Yarn Inherent Viscosity, Polymer A)

Sample	Undrawn yarn birefringence $\times 10^{-4}$	Abrasion resistance, cycles to break ^a
Control yarn	183	183
Exptl. yarn 1	135	200
“ “ 2	115	314
“ “ 3	85	661

^a All yarns at 200/34 denier and inherent viscosity approximately 2.0.

TABLE IV
Effect of Yarn Inherent Viscosity on Abrasion Resistance of Drawn Yarns Produced From Constant Birefringence Undrawn Yarns (Polymer A, Inherent Viscosity = 2.68)

Yarn no.	Yarn inherent viscosity	Abrasion Resistance, cycles to break ^a
1	2.02	530
2	1.60	194

^a Yarns at 180/34 denier. Yarn 1 produced under experimental conditions to achieve low birefringence. Birefringence of corresponding undrawn yarns approximately 70×10^{-4} .

The same approach was used for yarns selected for comparison which had the same undrawn yarn orientation but which differed in yarn molecular weight. The data are shown in Table IV.

The results given in Tables III and IV show clearly that at a constant molecular weight those yarns having a low undrawn birefringence and drawn to the same denier will have considerably better abrasion resistance than those yarns having a high undrawn yarn birefringence. Also, at a constant birefringence the effect of higher yarn molecular weight from a given polymer is clearly in evidence as being responsible for a higher abrasion resistance. This latter conclusion is consistent with the data shown in Table II which indicated that a high degree of degradation of a high molecular weight polymer results in poorer abrasion characteristics.

In comparing the level of abrasion values of the various yarns produced from the different molecular weight polymers by using standard fiber-forming techniques and without any subsequent heat treatments, it appears that the highest abrasion values are shown by the group of lower molecular weight polymers which have been spun into undrawn yarns with a low level of orientation. High molecular weight without benefit of low undrawn yarn orientation is not in itself sufficient to produce an abrasion value as high as the yarns from the lower molecular weight polymers.

Crystallinity

The effect of crystallinity on the yarn abrasion characteristics has also been shown to be an important factor. Cappuccio¹² has presented data

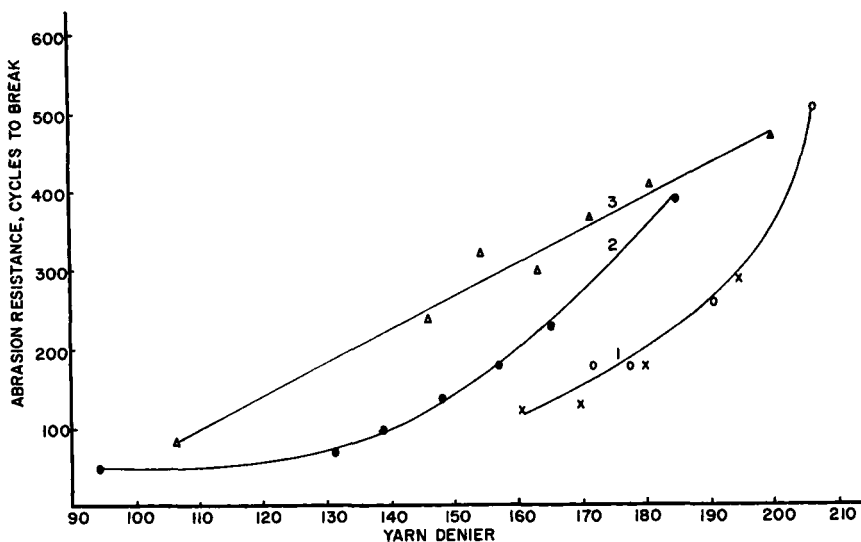


Fig. 4. Relationship of abrasion resistance and denier for drawn and annealed yarns from polymer D: (1) control and annealed yarns at 1.78 inherent viscosity produced at 266°C. spin temperature; (2) control yarns at 1.39 inherent viscosity produced at 316°C.; (3) yarns from curve (2) annealed at 120°C.

which were obtained by abrading single polypropylene fibers against a rotating carborundum cylinder and determined the number of cycles required to rupture the fiber as a function of load. The results indicated that the abrasion resistance increased with increasing crystallinity. The method of achieving the various crystallinity levels was not described. In addition, it was stated that other parameters, such as intrinsic viscosity and orientation, do not influence abrasion resistance under identical crystallinity conditions. Yasuda¹³ investigated the dependence of the abrasion resistance of nylon 6 fiber (as also measured against an abrasive wheel) on the heat-setting conditions of the fiber. A positive correlation was found between fiber density and abrasion resistance at treatment temperatures up to 180°C., also indicating an increase in abrasion with increased crystallinity. In our experiments the effect of crystallinity was examined by means of annealing yarns under nondegrading conditions and by making comparisons against the unannealed fibers. It has been shown that treatment of polypropylene at elevated temperature has the effect of increasing the crystallite size and increasing the overall crystallinity.^{14,15} The results of these experiments (Fig. 4) show that a large improvement was obtained in the abrasion characteristics of low molecular weight yarns produced from undrawn yarns of low orientation. On the other hand, however, the yarns produced from the same polymer but at a lower spin temperature were relatively unaffected. Similar results were obtained for yarns produced from high molecular weight polymers. The reason for these results is not entirely clear, although it is recognized that there are different

mechanisms at work. As indicated earlier, the lower molecular weight yarns produced at high extrusion temperatures are characterized by the paracrystalline structure. The yarns produced at the lower extrusion temperatures are generally characterized by a more highly ordered monoclinic crystalline structure as evidenced by the characteristic peaks of the x-ray diffraction pattern. It has been shown that undrawn fibers with different crystalline structures respond differently in the drawing process. Fibers with the paracrystalline structure have been shown to increase in crystallinity depending upon the stretching temperature.¹² It has been reported by Wyckoff¹⁶ that orientation of film in the crystalline form resulted in a disruption of the crystallites and their conversion to the paracrystalline state. It was also shown that on heating, the paracrystalline phase was converted to the crystalline form.¹⁶

Presumably, the response to heat treatment of these two yarns, which are characterized not only by a different crystallinity history but also by having different molecular weights and distributions, is such that the beneficial effects of the heat treatment are obvious only with the yarns derived from the paracrystalline undrawn yarn.

Fiber Properties

The data indicate that another important property which affects the abrasion characteristics of the yarns which have been studied is the energy absorption characteristics. It has been shown that drawing of undrawn yarns is accompanied by an increase in tenacity and modulus and decrease in elongation and, consequently, toughness and energy to rupture. This study has been carried out by determining the number of abrasion cycles which the yarn can sustain prior to breaking while under a given load. The load in itself will elongate the yarns approximately 1% at conventional rates of loading, and as filament breakage occurs and the number of filaments in the bundle decreases, the load on the remaining filaments is correspondingly increased. Nevertheless, it is likely that a major portion of the contributing force development on the fiber bundle is derived from the fact that the frictional forces and surface characteristics of the abraded yarns are now factors. The degree to which the yarns can absorb energy, as determined by the conventionally determined stress-strain properties, should correlate qualitatively with the degree to which the yarns can be abraded prior to reaching the rupture load under the combined initial and frictional loads. By the nature of the test, the yarns are subjected not only to tensional forces but also to torsional and shear stresses, and if the yarns are characterized by high toughness and high rupture energy, their abrasion resistance should be high. The effect of the surface and frictional properties of the yarns can also be expected to contribute to the net result, in that frictional heat generated by surface characteristics can further lessen the rupture time by increasing the rate of nonrecoverable creep by virtue of the now higher yarn and filament temperature.

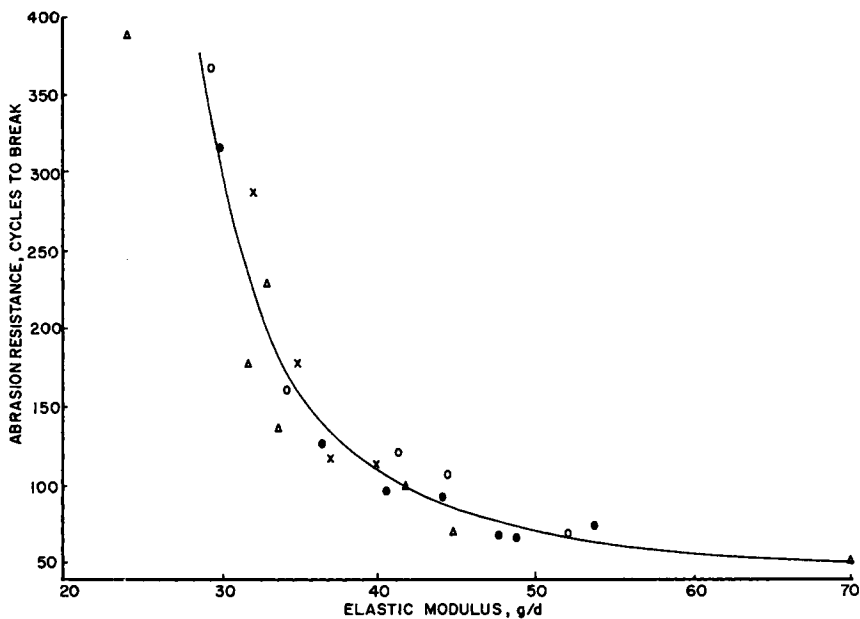


Fig. 5. Relationship of abrasion resistance to modulus of drawn yarns from polymer D for various yarn inherent viscosities: (X) 1.78, (O) 1.73, (●) 1.59, (Δ) 1.39.

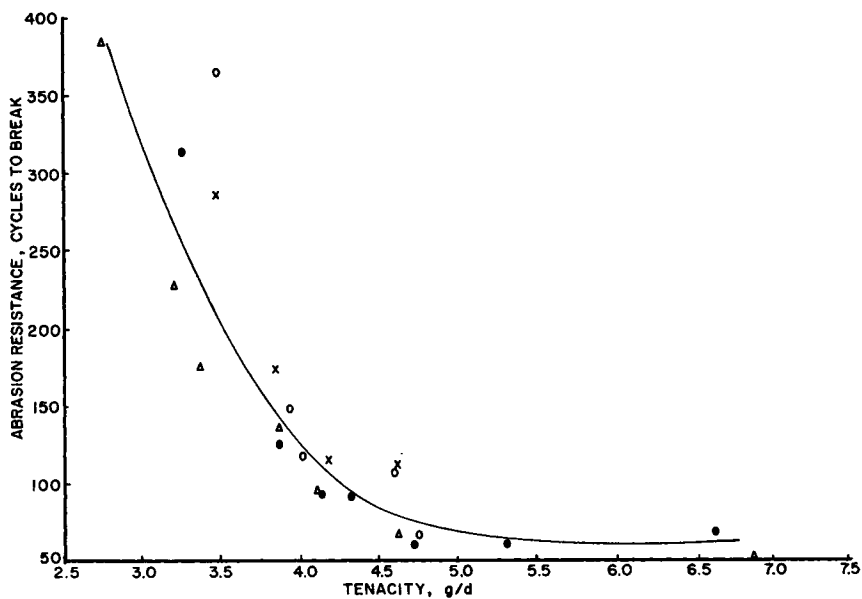


Fig. 6. Relationship of abrasion resistance to tenacity of drawn yarns from polymer D for various yarn inherent viscosities: (X) 1.78, (O) 1.73, (●) 1.59, (Δ) 1.39.

Properties of yarns derived from the various polymers under discussion were determined in order to examine the relationship between energy absorption capability and abrasion resistance. Figures 5 and 6 illustrate typical data for yarns from one of the lower molecular weight polymers and show the relationship of elastic modulus and tensile strength to abrasion resistance. When the points representing the various molecular weight yarns from this polymer are plotted, they fall on a common curve indicating that these relationships are independent of molecular weight as contrasted to the data shown earlier in Figure 3. The figures indicate that the abrasion resistance decreases with increasing modulus and tenacity. It is true that this is also associated with a general denier reduction because of the manner in which the experiments were carried out. However, it can be shown that, within the denier range involved, the abrasion is relatively insensitive to denier at a constant tensile level and that, at constant denier, abrasion decreases with increased tensile level.

The higher molecular weight polymers do not show as clear-cut a relationship and indicate an insensitivity of abrasion to these properties. This might be the net effect of two opposing conditions. Combinations of the properties of high molecular weight with high modulus and low molecular weight due to molecular weight degradation with low modulus might tend to balance each other out and give the resultant effect.

Undrawn Yarns

The relationship of the abrasion behavior to the properties of undrawn yarns is somewhat different from those of drawn yarns. Undrawn yarns, of course, have a higher level of toughness and energy absorption capacity than the drawn yarns, and it might be assumed based on the previous data reported that the abrasion behavior might be superior to the drawn yarns. The results of studies carried out on undrawn yarns are shown in Table V.

TABLE V
Abrasion Resistance of Undrawn Yarns
(Polymer A: Inherent Viscosity = 2.68)

Spin temp., °C.	Yarn inherent viscosity	Birefringence $\times 10^{-4}$	Abrasion resistance, cycles to break ^a	
			As spun	Annealed 120°C.
293	2.13	173	562	640
304	1.90	113	100	490
316	1.60	62	15	334

^a Yarns at 640/34 denier.

The studies showed that the low birefringence yarns from a given polymer tended to creep rapidly and could withstand only several abrasion cycles. Higher molecular weight, higher birefringence yarns, however, did not creep as rapidly and performed better. Annealing of these yarns had the effect of increasing the abrasion resistance. The increase, again, was especially

significant for the low birefringence yarns and probably can be attributed to an increase in crystallinity. These results are interesting, in that abrasion of the as-spun yarns is not in general better than that of the drawn yarns, despite the higher level of energy absorption capacities and higher denier. Presumably the importance of these factors is diminished by the very low level of orientation in some cases which does not furnish a sufficient number of crystalline tie-points to prevent the yarn from extending to break under the testing load. This would tend to indicate that maximum abrasion characteristics might be obtained from yarns drawn just past the yield point to furnish a degree of orientation sufficient to prevent creep failure of the type exhibited by undrawn yarn combined with the high energy absorption characteristics shown by the yarns with high elongations, low moduli, and low tenacities.

MECHANISM OF ABRASION

Chapman and Menter¹⁷ examined nylon filaments abraded by a flat platinum slider by means of electron microscope techniques and related surface deformation and damage to the abrading load. Recently, Hadley⁴ has reported data regarding the mechanism of abrasion of polyester and polypropylene single filaments against fine India stone. His conclusions regarding the polypropylene filaments were that the mechanism appears to be one in which the filament is initially flattened. Fracture was found to occur mainly near the point of maximum pressure and was accompanied by severe fibrillation. It was concluded that attenuation of the flattened fiber by stretching and removal of material appears to be responsible for the break occurring.

The mechanism of abrasion of the yarns against each other as conducted in our experiments appears to be somewhat different although probably related and apparently brings into consideration a number of variable factors. Surface and frictional characteristics are undoubtedly very important since, as noted earlier, the presence of lubricants on the fiber surface can extend the life of the fibers manyfold. However, during the abrasion cycle, once a filament has become damaged it is followed shortly by breakage rather than as a gradual progression of attrition. Final rupture of the bundle occurs soon after the initial breakage of filaments in the bundle. This is to be expected from the relationship shown in Figure 2, which relates the bundle life to the load. An increase in the load from 0.1 to 0.2 g./denier due to loss of half the filaments in the bundle decreases the number of cycles by a factor of approximately 90%. It is interesting to note that the start of severe fuzzing and breakage is signalled by an audible "sawing" sound.

Microscopic examination of abraded filaments does not show evidence of grooves caused by erosion or reduced filament diameters. Typical abraded filaments prior to their rupture are shown in Figure 7. It can be seen that rupture under these abrasion conditions is preceded by the tearing

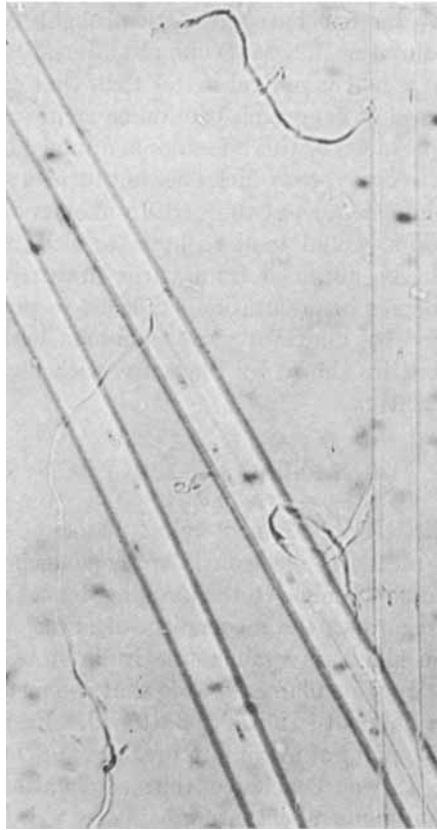


Fig. 7. Photograph of abraded filaments showing peeling back of fiber surface fragments. 250X.

and peeling back of fiber fragments in the form of narrow bands from the fiber surface. It would be expected that flaws in the fiber surface would serve as initiating points for the abrasion damage. A possible explanation for the improved abrasion resistance of annealed yarns is that these yarns have harder surfaces resulting from the higher level of crystallinity, and it is possible that annealing might make for a more uniform surface with fewer flaws. The peeling back of the surface fragments is reminiscent of a skin-core structure, and it might also be expected that annealing of drawn fibers might make for a more uniform filament throughout compared to its unannealed counterpart.

SUMMARY AND CONCLUSIONS

The fiber-to-fiber abrasion characteristics of polypropylene fibers have been investigated for the purpose of determining the relative importance of several parameters which are normally used to characterize fibers. The fibers used for these tests were free of any surface lubricants and were pro-

duced under a number of experimental conditions. The factors of polymer and fiber molecular weight, undrawn fiber orientation, and crystalline structure, drawn fiber properties which are a reflection of energy absorption capabilities, and crystallinity have all been shown to exert an effect on the abrasion characteristics. Maximum abrasion resistance is obtained from polypropylene yarns which have high molecular weights, relatively low tenacities, and high elongations and which were produced from undrawn yarns of low orientation. Heat treatment of lower molecular weight yarns was also found to increase their abrasion resistance to a high level by virtue of increased crystallinity. Heat treatment did not appear to improve the abrasion properties of high molecular weight yarns, however. The mechanism of abrasion to failure has been found to be one in which fiber rupture is preceded by a tearing and peeling back of fiber surface fragments, probably initiated at flaws in the fiber surface.

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Résumé

Les caractéristiques à l'abrasion de fibres multi-filaments de polypropylène tordu, dépourvu de lubrifiant de surface, ont été déterminées en frottant les fils l'un contre l'autre utilisant un procédé de frottement réciproque à une fréquence de 60 cycles/sec. On a trouvé que le comportement à l'abrasion des filaments varie sur une vaste gamme et est reliée à des propriétés fondamentales telles que le poids moléculaire du polymère et de la fibre, l'orientation de la fibre étirée et sa structure cristalline, les propriétés de la fibre étirée et le post-traitement thermique ultérieur. On a également trouvé que la présence de lubrifiant de surface pouvait accroître le nombre de cycles d'abrasion avant la rupture par un facteur aussi important que de 20, suivant la nature du lubrifiant particulier utilisé. Le mécanisme du processus de la rupture de la fibre résultant du dommage par abrasion a été examiné. La rupture de la fibre est précédée d'une déchirure et d'un décortiquement de la surface de la fibre probablement initié par des défauts de la surface de la fibre elle-même.

Zusammenfassung

Das Abreibeverhalten von schwach gezwirnten Polypropylen-Vielfadengarnen ohne Oberflächengleitmittel wurde durch Reiben der Garne aneinander mit einer periodisch wirkenden Vorrichtung von 60 Schwingungen pro Minute bestimmt. Das Abreibeverhalten kann über einen weiten Bereich variieren und steht zu fundamentalen Eigenschaften wie Molekulargewicht des Polymeren, Orientierung und Kristallstruktur un-
verstreckten Faser, Eigenschaften der verstreckten Faser sowie Nachbehandlung bei erhöhter Temperatur in Beziehung. Weiters wurde gefunden, dass die Anwesenheit von Oberflächengleitmitteln die Anzahl der zur Zerstörung notwendigen Reibungszyklen, je nach dem verwendeten Gleitmittel, um bis zu einen Faktor 20 steigern konnte. Der Mechanismus des Vorganges der Faserzerstörung durch Reibungsschädigung wurde untersucht und scheint derartig zu sein, dass der Faserbruch durch ein Abreißen und Abschälen von Faserflächenbruchstücken eingeleitet wird, das wahrscheinlich bei Fehlstellen in der Faseroberfläche beginnt.

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