
E. I. du Pont de Nemours and Company	Mohawk Industries, Inc.	PTT Poly Canada, L.P.

May 2, 2008

Office of Secretary
Federal Trade Commission
Room H-135 (Annex K0)
600 Pennsylvania Ave., NW
Washington, DC 20580

**Petitioners' Response To Comments Submitted
Regarding the September 7, 2006 Petition To
Establish A New Generic Sub-Class for Fibers
Made From PTT**

**Reference 16 CFR Part 303 – Textile Rule 8,
Mohawk, DuPont and PTT Comment, Matter No. P074201**

Mohawk Industries, Inc. (Mohawk), E. I. du Pont de Nemours and Company (DuPont), and PTT Poly Canada, L.P. (PTT Canada) (collectively "Petitioners") submit the following comments and additional information ("Petitioners' Response") regarding (a) the 48 supportive comments submitted by carpet retailers and professionals, an independent testing laboratory, and a large Italian manufacturer of yarns and fabrics that support Petitioner's September 7, 2006 Petition (the "Petition") for the designation of a new generic subclass for fibers made from PTT, and (b) the sole opposing comment submitted on November 9, 2007 by Invista S.a.r.l.

Petitioners' Response is submitted pursuant to the Commission's April 7, 2008 Federal Register Notice reopening the comment period with respect to the above Matter.

a) Petitioners' Comments Regarding Letters Submitted By Carpet Retailers and Professionals

Petitioners submit that the 48 comments submitted to the FTC in support of the Petition demonstrate that the scientific evidence submitted by Petitioners correlates well with observations by carpet professionals, an independent testing laboratory, and a fabric manufacturer regarding the performance of carpet and fabric produced from PTT fibers. There follow excerpts from a representative sampling of these 48 letters and e-mails submitted to the FTC:

Comments From Carpet Retailers

Southern Tile and Carpet

"PTT fiber is a better product than what people traditionally think of as polyester since PET historically has not had a good wear characteristics. If called polyester, it is misleading to the consumer and the dealer as to how good the product really is. The product performs so much than PET that it should be allowed a new name."

Burton Floor Covering

"According to Mohawk, Burton Floor Covering, Inc. is one of their largest users of Sorona in this market. I believe that with the styling, feel, look, and durability, as well as being virtually claim-free, the Sorona fiber should be a stand alone fiber. It should not be related or categorized as a polyester."

C&J Carpet Center

"C & J Carpet Center has used both P.E.T. polyester and P.T.T. polyester. We have found that the P.T.T. products have had a superior history. They are much more resilience and have superior stain resistance. We have also found them to have a much softer feel."

"We find that because the product has to be labeled as polyester, that many of our customers confuse these products made with P.T.T. with the products made with P.E.T. products. Because P.E.T. products don't perform at the same level as the P.T.T., some of our consumers that have had the P.E.T. in the past are more likely not to purchase these products based on past results. The average consumer does not understand that these products are very different in their performances. Therefore we feel that a separation is very much needed."

Carol's Carpet, Inc.

"Carol's Carpet, Inc asserts the following: 1) PTT fiber is a better product than what people traditionally think of as polyester since PET historically has not had good wear characteristics. If we have to call it polyester, it is misleading the consumer and the dealer as to how good the product really is. 2) Our experience shows that the product performs so much better than a PET that it should be allowed a new name. 3) Prior experience with PET has jaded dealers and caused them to not want to sell anything called polyester. Forcing a fiber, with much better performance than a PET, to use the same name, will limit the consumer's ability to purchase the product."

Coastal Carpet & Tile

"Having been in the floorcovering business for over 20 years, we have seen many things come and go in our industry. Now we have something, which is truly new, exciting and will be a great consumer product. Mohawk has created the PTT fiber system, which unlike its predecessors is performing well above standard. Unfortunately its composition is similar to the traditional polyester fiber which dealers have had many bad experiences with."

"The mere mention of the word "Polyester" in our industry brings about nothing but negative images in the dealers and consumers minds. So, to group this new breakthrough fiber in the polyester category is unfair to all parties from the makers to the end user."

Colonial Floors

"I have been in the floor covering business for over 28 years and have seen many new fiber introductions and, generally, the last better than the previous. However, this new fiber introduction which has a molecular structure that of polyester, yet is substantially more durable and stain resistant, is a gigantic leap forward in technology. Polyester has a history, in my business, of not having good wear characteristics. The new "Smartstrand" fiber wears extremely well, so well that it is on a par with nylon carpet. I have done my own testing on this product to assure myself and my customers that it will perform as claimed, and it has! So, in my opinion, it should not be put on an equal footing with polyester fibers. To do so would be to mislead our customers."

Commercial Surfaces, Inc.

"It would be a terrible disservice to our industry to label this as a polyester fiber. The characteristics are not consistent with the poor long term performance we witnessed in carpet made from polyester fiber, such as pilling, crushing, and difficulty to dye. This is a fiber that must have its own identity to parallel with its outstanding performance."

Tom Davis Flooring

"PET is generally associated with polyester, which people view as lower end product because of its negative track record. Forcing a fiber that is in a category far above PET to use the same name is misleading the buyer as to how good the product really is."

A&R Flooring, Inc.

"I would like for the Smartstrand Carpet to not say polyester because it tends to lead customers away from the product. We all know that it is a wonderful product and would like to sell more of it. I feel as if the back of the carpet saying "polyester" is a misrepresentation."

Flooring Gallery

"I have been: selling polyester since 1978 and the new PTT for approximately two years. This new fiber performs in such a superior manner we are doing an injustice to our customers by calling it polyester. The product we have installed in all of our showrooms, is out performing nylons that were installed at exactly the same time."

"Our 1978 experiences with polyester caused us to be unable to sell it for many, many years. We now have a new performance tested product that out wears PET so well that it should be allowed a new name. We no longer want to taint the consumer consideration for this product by calling it a PET. Please strongly consider this new sub class and allow this fantastic new fiber to be sold for what it truly is."

Greer Flooring Center

"The product is far different from traditional "polyester" products. People can feel the obvious difference in the product, as Sorona products are much softer than most polyesters of similar construction. When we tell the customer about the built in permanent stain resistance and the lack of any fluorocarbons to protect the fiber they wonder how this can be a polyester product. For that matter, so do our salespeople as they have built up many prejudices about polyester over the years. Forcing a fiber with much better performance than PET to use the same name, will limit the consumer's ability to purchase the product."

Kelly's Carpet

"As a retailer it is important to have PTT in its own class because classification as polyester is misleading to our customers. While having the general chemical composition of polyester, PTT wears much better and should not be in the same class. I have never had a wear complaint on PTT, however I can't say the same about polyester. The performance of PTT is not comparable to polyester and having PTT in the same class as polyester is not only misleading to consumers, but can make it difficult to sell because consumers think it will wear like polyester."

The Floor Store

"I have been selling carpet for many years now, & carpet made from PTT definitely is more durable, more stain resistant & softer than any polyester fiber I have ever seen. The response from customers has been nothing short of amazing!"

Mill Creek Carpet & Tile

"Mill Creek Carpet and Tile, with its 11 store locations, has been selling this fiber for the last two and one-half years and has not filed a single consumer complaint over that time period. Contrary to original polyester (PET) fiber products, this amazing fiber has separated itself from all other classifications in my opinion."

"Our samples carry the fiber description as "polyester" but the former reputation of that classification should not apply to this new "wonder fiber". The stain resistance, texture retention, and overall beauty of the finished product demonstrate a dramatically upgraded finish compared to those products made with PET."

J&J Carpets, LLC

"In deciding whether to give PTT a sub class of polyester fiber, I think it SHOULD be given a separate category because of it's better wear characteristics and it performs better than the PET polyester products that are now on the market. Sales people and consumers alike will be misled if this new product is lumped in with the present polyester fibers currently available and will not know how good this PTT fiber product really is unless it is classified differently."

McCool's Flooring

"As an owner/manager of McCool's Flooring, a four store family flooring business, and McCool's Floor Care, a Mohawk Floor Care Essentials carpet cleaning business, I would like to express my opinion of giving PTT fiber a new classification other than polyester. I personally have had the opportunity to clean PTT after it has been installed for at least one year. I am qualified and able to tell by the look of the carpet after normal wear what kind of fiber it is. I am always able to easily distinguish PET yarn by its notable matting in higher traffic areas. This situation is not noticed when carpet is nylon or PTT."

Capitol Carpet and Tile

"Putting PTT fiber in the same subclass as PET is misleading. The performance is far superior to PET. In addition as a retailer we have never had a claim ever, which I cannot say about any other fiber. In addition, because PET does and has not performed as well as some other fibers, it has a bad connotation for retail salespeople as well as consumers. Considering that PTT performs so much better than PET it is not only unfair not to give it a new name it is definitely misleading to the consumer. Putting PTT in a separate subclass will rightfully distinguish it from the inferior PET products."

Prattville Carpet, Inc.

"We feel PTT fiber, while having the general chemical composition of polyester, is a better product than what people traditionally think of as polyester. PET historically has not had good wear characteristics and many customers will not even consider this product. If we have to call it polyester, we believe it will mislead the consumer as to how good the product really is. The product performs so much better than PET that it should be allowed a new name. Furthermore, forcing a fiber, with much better performance than PET, to use the same name, will limit the consumer's ability to purchase the product."

Premier Carpets

"We at Premiere Carpets have used both P.E.T. polyester and P.T.T. polyester and have found in carpet installations that the P.T.T. products have had a superior history as far as resilience and stain resistance as well as a much softer hand in feel. We have found that since the product has to be labeled as polyester that' " many consumers compare these products made with P.T.T. with the products made with P.E.T. Since P.E.T. products don't perform at the same level as the P.T.T. goods some consumers that have had P.E.T. in the past are more likely not to purchase these products based on past results. This happens even though the products perform differently. We feel that a separation is very much needed."

Professional Carpet Systems

"We have been in business for 20 years selling and installing carpet and have seen many changes in the industry. I have had the chance to test PTT fibers and have been impressed with the way that they perform. We have sold & installed Smartstrand carpet over the past year or so, with very positive results from our customers."

"The problem that we do encounter is the stigma that surrounds the polyester label that has been placed on this product. Customers have a pre-conceived notion about polyester fibers and at times tend to steer clear of this product just because of that label. I feel that this makes a more difficult sales process for us, and is also unfair to the product."

"Based on the tests that we have done, and the response that we have received from the customers that have purchased a PTT fiber product, we feel that it should carry a label different from PET, since it is obviously a different product and performs and wears much better than PET."

Accoustical Floors Inc.

"Based on prior experience with PET fiber we have had a tough time getting customers to separate it from PTT fiber. The PTT fiber is much more resilient than your standard PET products are. However, due to the association with polyester we have a hard time separating the two in the customers mind. Our experience with the PTT fiber has been that it is far superior than that of the PET polyester fiber. As a retail flooring establishment we would like to see PTT product class."

Airbase Carpet Market

"Historically, PET polyester has had a bad reputation compared to other fiber systems made from nylon and olefin. At one point in its history, many carpets made from PET polyester failed so miserably that retailers had to replace many jobs which quickly gave PET polyester a bad name. Today, through technological advancements in heat setting, the twist has improved and the carpets do perform. However, the reputation of PET polyester still remains tainted by its past. I am very supportive of the new fiber technology of PTT as it will allow us, the retailer, to sell with more confidence. While the new PTT fiber does have the same general chemical composition of polyester, it is unfair to the consumer to label it as such because she will believe that the fiber will perform poorly like PET polyester of the past and will be inferior to its counter part fiber systems in nylon today. At the same time, the exact opposite is true; the fiber performs much better than PET and is comparable to premium nylon products. For this fiber to be successful and the consumer to have a clearer understanding of its benefits, it is imperative that it not be labeled as polyester. This product performs so much better than PET that it should be allowed a new name that extols its benefits and will not confuse the consumer by PET polyesters soiled and matted past."

Comments From Independent Carpet Testing Laboratory

Independent Textile Testing Service, Inc.

“Over the past 10 years we have been involved in extensive testing of the PTT fiber pertaining to carpet usage. Testing has included everything from pedestrian traffic, soiling, staining, static, colorfastness to atmospheric contaminants, flammability and many others. Based on our experience with the PTT fiber, it would seem that the test results consistently show a marked difference when compared to PET in regards to performance. Not knowing the chemistry patents and processes for this PTT yarn, we are at the understanding that the polymeric structure is very similar to PET. However, the significant overall performance of the fiber to foot traffic and in use areas is remarkably better. It is of our opinion that the differences shown do indeed indicate that a need for a separate classification is a good idea. It would be very difficult to continue to try and let the marketplace separate these on its own. PTT indeed performs much better in general than PET in traffic ratings and it would benefit the consumer to know that there were distinct differences, thereby eliminating PET from being confused with PTT. We think a separate class of fiber generic name would be in good order and an overall benefit to end users.”

Comments From Italian Manufacturer Of Yarns and Fabrics

Filature Miroglio S.p.A.

“We have proved that PTT yarns give to the final product (textile fabrics and garments) different and specific properties compared to standard polyester like better: softness, drapability, abrasion resistance (especially important for upholstery and rugs application), resilience, recovery. PTT has as well easy care capability and is easy dyable allowing energy consumption diminution. PTT has a natural touch that allows it to be blended with natural fibers as well as with man-made and elastomeric filaments. In the interest of the consumer, we support the idea, based on the previous argumentation, PTT should be differentiated from standard polyester.”

Petitioners submit that there are consistent themes running through these supportive comments which can be summarized as follows:

- *Conventional polyester (PET) has disappointed carpet consumers with its performance and has a bad reputation with both carpet retailers and consumers.*
- *The performance of carpet made from PTT fibers is far superior to polyester and approximates the performance of nylon carpet with respect to resilience, durability and resistance to wear. In addition, carpet made from PTT fibers is perceived to be softer than carpet made from PET fibers.*
- *Requiring carpet made from PTT to be labeled as polyester makes it difficult to sell such carpet because consumers and others in the carpet industry associate the generic “polyester” with poor carpet performance. A fiber regulation that would permit consumers to identify carpet and apparel products made from PTT fibers would provide consumers with additional choice.*

- *PTT fibers when used in the manufacture of fabrics provide different and specific properties compared to standard polyester including superior softness, and stretch and recovery.*
- *Requiring carpet and apparel made from PTT fibers to be labeled as polyester is misleading to the consumer because the properties of PTT are far superior to the properties of PET in carpet and apparel applications.*

While the carpet retailers and professionals referred to a variety of attributes of carpets made from PTT fibers, there is broad agreement that with respect to the three carpet performance attributes identified at pages 3 and 4 of the Petition, carpet made from PTT fibers offers significant performance advantages over carpet made from PET fibers. These attributes were:

1. The carpet will stand up to years of foot traffic without matting down,
2. The pile of the carpet stays tight and will stand up like new after normal vacuuming, and
3. The carpet is soft and comfortable to sit on or lie on.

With respect to the use of PTT fibers in apparel applications, the Italian fabric manufacturer which submitted comments regarding the properties of fabrics made from PTT fibers likewise commented favorably on the two properties imparted to fabrics by the molecular structure of PTT fibers:

1. Softness; and
2. Stretch and recovery.

Petitioners submit that the above comments concerning carpet and fabric attributes confirm the significance of the scientific evidence submitted by Petitioners and that such evidence meets the regulatory requirement for designation of a new sub-generic class for fibers made from PTT. The superiority of PTT over PET was of a magnitude that many of those firms which submitted supportive comments were of the view that consumers would benefit from the designation of a new generic subclass for PTT that would permit consumers to distinguish between carpet and apparel made from PTT and such products made from PET.

As will be discussed below, the sole dissenting submission from Invista can be summarized as an attack from a competitor on the testing methods used by the Petitioners and the significance of the test results. Petitioners submit that there can be no stronger evidence of the importance of the PTT fiber properties described in the Petition than the support from firms who are closest to the consumer and who have no business reason to favor PTT over PET.

b) Petitioners' Comments Regarding November 9, 2007 Opposition From Invista

The only comments submitted in opposition to the Petition were submitted by Invista S.a.r.l., one of the world's largest integrated producers of man-made fibers. Invista's carpet fiber products are based on nylon, which is the highest price man-made fiber used to manufacture carpet. Significantly, Invista does not supply PTT polymer or PTT fibers for use in carpet applications. Accordingly, the availability of carpet made from PTT fibers, and informed consumers who are given a tool (a new generic) to differentiate PTT fibers from lower performance PET fibers, represent a competitive threat to Invista. This may explain why Invista's November 9, 2007 comments seem to be inconsistent with all of the other comments submitted to the Commission.

Likewise, Invista has reason to oppose the designation of a new generic for PTT fibers when such fibers are used to produce fabrics and apparel. This motivation arises from the fact that Invista is the world's largest supplier of spandex, a man-made, stretchable fiber used for apparel and personal care applications. Invista does not sell fibers based solely on PTT, although PTT is used in the production of Invista's T-400 brand elasterepp fibers. Fibers produced from PTT are likely perceived by Invista to be competitive with the products it sells to the apparel industry.

When viewed as a whole, Invista's November 9, 2007 submission does not challenge the fact that the molecular structure of PTT provides fibers with properties that can impart superior durability, resilience, and softness to carpets, and enhanced stretch and recovery and softness to apparel products. Rather it attacks the test methods used to prepare the data set forth in the Petition and the significance of such results. Before turning to a point by point discussion of Invista's arguments, Petitioners refer the Commission to Invista's own web site where Invista rates the performance of five carpet fibers with respect to nine different carpet performance parameters. See Figure 1 below. This table confirms the superior performance of PTT over PET for residential carpet applications.

Figure 1

	STAINMASTER® NYLON TYPE 6,6 FIBER	NYLON TYPE 6 FIBER	POLYESTER PET (ZGT)	POLYESTER PTT (3GT)	OLEFIN POLYPROPYLENE
ASSORTMENT OF COLORS & STYLES	EXCELLENT	EXCELLENT	GOOD TO FAIR	GOOD TO FAIR	FAIR
APPEARANCE RETENTION	EXCELLENT	EXCELLENT TO GOOD	POOR	EXCELLENT TO GOOD	POOR
RESISTANCE TO FOOT TRAFFIC & FURNITURE WEIGHT	EXCELLENT	EXCELLENT TO GOOD	POOR	EXCELLENT TO GOOD	POOR
KEY SOB. RESISTANCE	EXCELLENT	EXCELLENT TO GOOD	GOOD TO FAIR	GOOD TO FAIR	POOR
RESISTANCE TO MELTING (FROM HOT IRON OR LIGHT BULB)	EXCELLENT	GOOD	EXCELLENT	GOOD	POOR
DURABILITY OF STAIN RESISTANCE	EXCELLENT TO GOOD	GOOD TO FAIR	EXCELLENT	EXCELLENT	EXCELLENT
RESISTANCE TO FADING	EXCELLENT TO GOOD	GOOD	EXCELLENT TO GOOD	EXCELLENT TO GOOD	EXCELLENT
RESISTANCE TO DAMAGE FROM CHAIR CASTERS	EXCELLENT TO GOOD	EXCELLENT TO GOOD	FAIR TO POOR	FAIR TO POOR	FAIR TO POOR
BUILT-IN PERMANENT STATIC CONTROL	ALWAYS	SOMETIMES	NO	NO	NO

The five fibers rated by Invista were:

1. Stainmaster Nylon Type 6,6 Fiber (the nylon fiber sold by Invista)
2. Nylon Type 6 fiber
3. Polyester PET (2GT)
4. Polyester PTT (3GT)
5. Olefin Polypropylene.

This table lists two carpet attributes which are substantially the same properties as those identified by Petitioners in the Petition:

“Appearance Retention”, which is comparable to “The pile of the carpet stays tight and will stand up like new after normal vacuuming”, and

“Resistance To Foot Traffic & Furniture Weight”, which is comparable to “The carpet will stand up to years of foot traffic without matting down”

The Invista table (which significantly lists PTT separately from PET presumably to reflect the different molecular structure and superior performance of PTT), rates the performance of PTT as EXCELLENT TO GOOD and conventional PET as POOR with respect to both of the above properties. This table from Invista’s web site, which reports carpet performance aligned with the experience of the 47 other firms which have submitted comments with respect to the superiority of PTT over PET in residential carpet applications, is inexplicably inconsistent with the following quotation from page 17 of Invista’s November 9 Opposition:

“Tests of various 50 oz. carpets (numerous PET carpets, one nylon and one PTT) showed that similarly-constructed PTT and PET carpets behave very similarly.”

The Commission has summarized Invista’s arguments in five paragraphs at pages 5-7 of the Federal Register notice reopening the comment period. In order to respond most directly to the issues identified by the Commission, Petitioners will comment on Invista’s arguments in the order raised by the Commission. The Commission’s summaries of Invista’s arguments are shown indented in bold italics. Petitioners’ response to the Invista arguments follows directly after each indented paragraph.

First, INVISTA asserts that because PTT performed differently than PET on such a small percentage of performance characteristics important to consumers (two out of 10), PTT is not sufficiently distinctive. Thus, INVISTA argues, the Petition is “fatally flawed” and the Commission cannot conclude that PTT fibers are “significantly better suited” than PET fibers in carpet applications.

The consumer survey referenced in the Petition (Table 1) inquired about 14 different carpet characteristics of importance to consumers for residential applications. The top eight ranked carpet performance characteristics of importance to consumers can be grouped into two subjects: carpet durability and resistance to staining and soiling. The failure of residential carpet to perform with respect to either characteristic results in the need for the consumer to replace the carpet.

While PTT is not advantaged over PET with respect to staining, soiling and color retention where both fibers perform well, it is significantly advantaged with respect to durability, the second property where a failure to perform will result in the need to replace a residential carpet. See comments from carpet retailers set forth above and Figure 1 reproduced above from Invista's web site. Appearance Retention and Resistance To Foot Traffic and Furniture Weight are the second and third attributes from the nine important carpet attributes identified by Invista. With respect to both properties, Invista rated carpet made from PET fibers "Poor," while carpet made from PTT fibers was rated "Excellent To Good." Likewise, durability was the second most important characteristic cited by the 1600 consumers surveyed in the study cited by Petitioners. In that study, sixty seven percent of consumers rated as "Very Important" the fact that: "The carpet will stand up to years of foot traffic without matting down."

As a result, Petitioners submit that carpets made from PTT fibers are significantly advantaged with respect to one of the two most important carpet characteristics that produce a need for consumers to replace residential carpet. Referring to page 6 from Invista's November 9, 2007 comments where it recounts the "troubled history" of polyester in the manufacture of carpets, the poor durability of carpets made from PET is cited by Invista as a performance deficiency which caused polyester carpet to receive "poor in-use performance ratings from consumers within a couple of years after installation."

Contrasting this poor consumer experience with PET to the consumer reaction to PTT and referring to the comments submitted by carpet retailers, the superior resilience of PTT fibers and durability of carpet made from PTT has resulted in enthusiastic consumer acceptance and the very favorable claim experience reported by retailers. There can be no more important evidence of the superiority of PTT over PET than consumer acceptance and a low frequency of consumer complaints, compared to the long and troubled history cited by Invista for carpet made from PET fibers.

Second, even if superiority as to only two of the top 10 carpet applications could satisfy the standard, INVISTA argues that the Petition does not substantiate the assertion that PTT is superior to PET. With regard to carpet durability, INVISTA states that Petitioner's test was inadequate because: (1) Petitioners used the Hexapod Wear Test, a relatively light-duty test of the performance of PET and PTT, and did not use the Vettermann Drum test, which INVISTA alleges better simulates how carpet holds up under actual use; (2) INVISTA's own testing using the Vettermann Drum test showed no meaningful difference between PET and PTT; and (3) Petitioners compared finer, lighter weight PET fibers with thicker, heavier weight PTT fibers, thus making a meaningful comparison impossible.

With respect to the three arguments made by Invista as cited above, points 1 and 3 are factually incorrect. In the first point, Invista argues that use of a heavy impact ball in the test would have produced more discriminating results than the use of the light ball. In fact, Mohawk advises that in conducting the tests reported in the Petition, it did use the heavy ball as advocated by Invista. Invista's assumption regarding the testing method used by Mohawk is factually incorrect.

With respect to the third point, the tests summarized at pages 13-15 of the Petition and in Appendix A were performed by Mohawk. Though the Petition correctly reports at page 14 that the carpets tested by Mohawk were of identical constructions, the dpf numbers provided in Appendix A with respect to PET were incorrectly transcribed by Mohawk in preparing Appendix A. In fact, Mohawk advises that the PTT and PET fibers used for the test were of identical dpf ("denier per filament"). The actual dpf used for PET fibers was 18, the same dpf as was used for PTT fibers. Invista's argument is again based on an incorrect assumption.

As to the second point, Petitioners do not have access to Invista's testing methods or test results. However, it should be noted that Invista tested carpet with face weights far heavier than that typically used by consumers in residential carpet¹. See pages 14 and 15 of Invista's Opposition where Invista reports test results for 60 oz/sy and 60-80 oz/sy carpets. For this reason, Petitioners submit that the test results reported by Mohawk are far more relevant to what consumers will experience. Further, the unfavorable test results cited by Invista conflict with (a) results obtained by Mohawk, a manufacturer of residential carpets made from both nylon (the fiber sold by Invista) and PTT, (b) the comments submitted by Independent Textile Testing Service, Inc. which reports 10 years of testing of PTT fiber for carpet applications, and (c) the very favorable real world durability reports submitted by carpet retailers. Through the date of this submission, not a single retailer or consumer has submitted any comment critical of carpets made from PTT fibers.

INVISTA also argues that the Petition does not substantiate the assertion that PTT is superior with respect to softness. INVISTA states that rather than submitting any test results or survey data indicating how soft PTT fibers feel to consumers in actual carpet application, Petitioners presented "irrelevant" laboratory testing regarding deflection properties. INVISTA argues that Petitioners failed to show that such testing reveals differences meaningful to consumers evaluating the softness of carpets. INVISTA relies on a similar analysis to argue that the Petitioners failed to demonstrate that PTT fabrics are softer than PET fabrics.

Petitioners based their comments about carpet softness on the observation that carpet fibers that bend more easily are perceived to be softer. An illustration of the connection between flexibility of fibers and perceived softness is that a brush made from flexible polymer fibers is going to be perceived as softer than a brush made from stiff steel wire of equal cross section. Petitioners submitted stress vs. strain curves in support of its arguments rather than subjective consumer testing of perceived softness because the FTC's published requirements for approval of a new generic subclass required Petitioners to submit evidence regarding distinctive properties of importance to the general public ***"as a result of a new method of manufacture or substantially differentiated physical characteristics, such as fiber structure,"*** not subjective consumer tests. Petitioners submitted results based on the unique chemistry and molecular and fiber structure because this is what is required by the Commission's published advice regarding those factors that are required to establish a new generic fiber subclass. See 67 FR 7104.

¹ Mohawk data indicates that most consumers purchase carpets for their homes in the 35-45 oz per square yard weight range and that only a small percentage (approximately 10%) of consumer carpets are sold in the 60+ oz weight range. The average weight is less than 40 oz. For this reason, Petitioners conducted their tests on carpet samples that are representative of what most consumers purchase for their homes.

Petitioners' test reports regarding fiber properties that result in the perceived softness of carpets and fabrics made from PTT compared to carpets and fabrics made from PET are supported by comments submitted by the carpet retailers and the fabric manufacturer summarized above.

Furthermore, INVISTA contends that the Petition does not substantiate the assertion that PTT is superior with respect to stretch with recovery of apparel products. INVISTA argues that Petitioners failed to present the results of any reliable testing methodology showing that PTT "recover" from stretching better than PET fibers. INVISTA states that Petitioners' testing for stretch and recovery was flawed, in part, because Petitioners failed to demonstrate that the amount of tension used in the test simulates the tension applied in actual consumer use of garments.

Stretch and recovery is important to consumers because greater stretch and recovery improves the shape retention properties of a garment, e.g., reduced bagginess at elbows and knees, the parts of a garment that are subjected to greater stretching.

Because of the enormous variety of yarns, fabrics and garments that are produced, it is difficult to do meaningful comparative testing of the stretch and recovery properties of fabrics. This is because the stretch and recovery properties of a fabric that is constructed from PET or PTT can be influenced by, among other factors, the tension under which it is woven, the number of picks or courses per inch, and the degree of allowance for inherent shrinkage that can occur during subsequent fabric finishing steps. Accordingly, when one wants to compare the properties of different man-made fibers as they affect fabric performance, it is the stretch and recovery properties of the fibers and yarns themselves that are measured. For this reason, and because the stretch and recovery properties of a fabric are (all other factors being equal) proportional to the properties of its constituent fibers, Petitioners submitted test results based on a comparison of the stretch and recovery properties of fully drawn PET and PTT fibers/yarns.

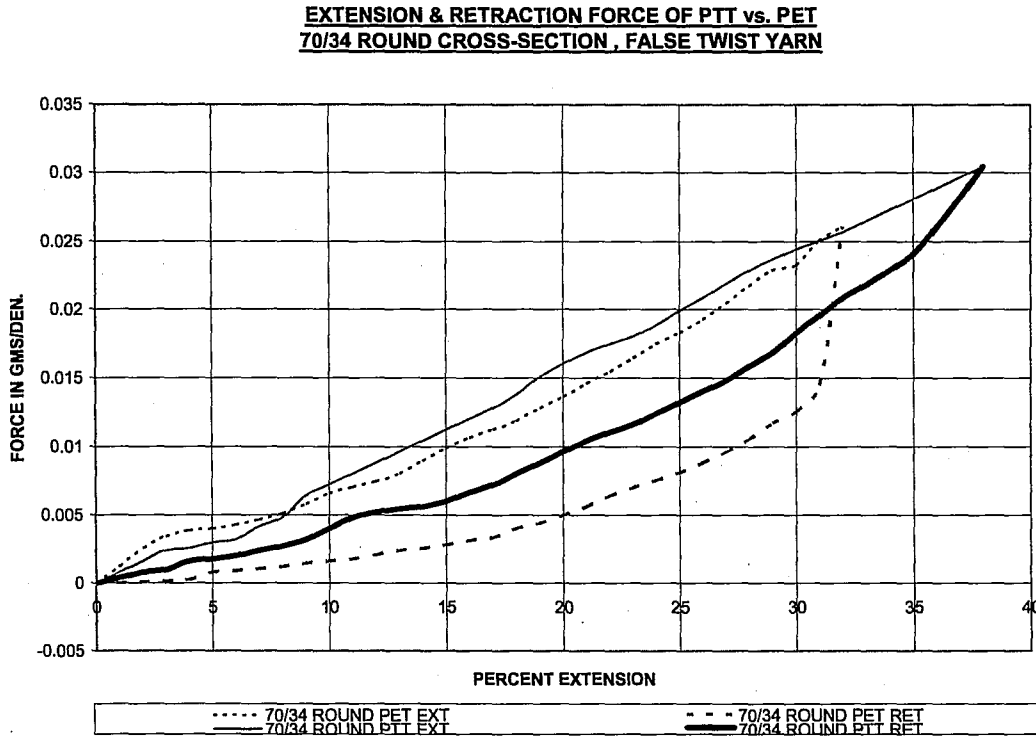
Addressing the second sentence from the Commission's summary of Invista's comment above, Invista is incorrect. The superior stretch and recovery of fully drawn PTT fibers/yarns is demonstrated in Figure 8 from the Petition. This graph was prepared from third party run test results reported in greater detail in the scientific paper listed as Reference 5² to the Petition, a copy of which is attached. In this paper published in the Journal of Polymer Science, fully drawn yarns made from PET and PTT filaments were tested under identical conditions. Because of the different molecular structure of PTT compared to PET, PTT fibers/yarns demonstrated significantly better stretch and recovery properties than PET yarns. **The data demonstrated that PTT yarns can be stretched approximately five times as much as PET fibers before taking the set that results in the failure of a garment to retain its shape.**

In addition to the above reference property difference between fully drawn PTT and PET fibers/yarns, there is also a significant difference between PTT and PET textured yarns with respect to stretch and recovery. The graph below clearly demonstrates that PTT

² I.M. Ward, M.A. Wilding and H. Brody, *The Mechanical Properties and Structure of Poly (m-methylene Terephthalate) Fibers*, *J. Polym. Sci., Polym. Phys. Ed.*, **14**, 263 (1976).

false twist textured yarn has much better recovery properties than PET in terms of retraction force. Greater retraction force translates into better shape retention after a fabric is stretched and relaxed after normal wearing. Since, retraction force is a good indicator of the stretch and recovery properties of a fabric, this is another data point that demonstrates the superior performance of PTT compared to PET.

Measured Force (Grams/denier) of PTT vs. PET False Twist Yarn Skein (70/34 Denier)



Finally, the superior stretch and recovery of PTT fibers and yarns carries over to fabrics made from PTT. See Figures 17(a), 17(b) and 18 set forth in the Petition. Petitioners refer again to the comment to the Petition from the Italian fabric manufacturer Filature Miroglio S.p.A.:

*"We have proved that PTT yarns give to the final product (textile fabrics and garments) different and specific properties compared to standard polyester like better: **softness, drapability, abrasion resistance** (especially important for upholstery and rugs application), **resilience, recovery.**" (emphasis supplied)*

In order to eliminate the influence of other variables, and as required by the FTC's guidelines for submission of data in support of a petition for a new generic fiber subclass (see 67 FR 7104), Petitioners' submission is based on a comparison of the stretch and recovery properties of PTT and PET fully drawn fibers/yarns and false twist textured yarns.

INVISTA's comment discusses another reason why it believes the Commission should deny the Petition. Specifically, INVISTA states that two of Petitioners' three suggested new generic subclass names for PTT "appear to be intentionally designed to create confusion with existing INVISTA trademarks."

This argument by Invista is completely irrelevant to whether a new fiber subclass is appropriate in that the names proposed by Petitioners have nothing to do with the merits of the Petition. It should be noted that Petitioners' preferred name "triexta" has not been challenged by Invista or any third party and would be acceptable to Petitioners.

Questions regarding this Response may be addressed to:

Carl G. Bartholomaus, Corporate Counsel
DuPont Company
Building 328 - Experimental Station
Wilmington, DE 19880
302-695-6831
Carl.G.Bartholomaus@usa.dupont.com

Respectfully submitted:

Mohawk Industries, Inc.

By

PTT Poly Canada, L.P.

By _____

E. I. du Pont de Nemours and Company

By _____

The Mechanical Properties and Structure of Poly(*m*-methylene Terephthalate) Fibers

I. M. WARD and M. A. WILDING, *Department of Physics, University of Leeds, Leeds, England*; and H. BRODY, *I.C.I. Fibers Division, Harrogate, England*

Synopsis

A study has been carried out of the differences in mechanical properties of oriented fibers of poly(ethylene terephthalate) (2GT), poly(trimethylene terephthalate) (3GT), and poly(tetramethylene terephthalate) (4GT). The properties studied include the tensile stress-strain behavior, the recovery from strain, shrinkage at 100°C and the glass-transition temperatures. The stress-strain curves of the three materials differ markedly. 2GT shows a monotonic increase in stress with increasing strain up to failure, which occurs at ~20% strain, and the oriented fibers possess a comparatively high initial modulus. 3GT shows a much lower initial modulus and there is an inflection in the stress-strain curve at about 5% strain. The stress-strain curve of 4GT shows a number of distinct features. Although the initial modulus of 4GT is similar to that of 3GT, the stress-strain curve shows a pronounced plateau in the region between 4% and 12% strain. At higher strains the stresses rise rapidly before failure. These features of the stress-strain curves in the three polymers can be related to previous studies where the x-ray diffraction spectrum and the Raman spectrum have been examined for fibers under stress. The ranking of both the recovery and shrinkage behavior of these materials is in the order 3GT > 4GT > 2GT. These results can also be understood in terms of the results of the previous structural studies, and it is concluded that the molecular conformations in both the crystalline and noncrystalline regions play a key role in determining the mechanical behavior.

INTRODUCTION

Although many aromatic polyesters can form oriented fibers and films with comparatively good mechanical properties in terms of stiffness and strength, only in the case of poly(ethylene terephthalate) have extensive studies been undertaken of the relationship of mechanical properties to structure.¹⁻³ The present paper considers the mechanical behavior of three related polyesters, poly(ethylene terephthalate) (2GT), poly(trimethylene terephthalate) (3GT), and poly(tetramethylene terephthalate) (4GT). It also attempts to gain an understanding of this behavior in terms of our existing knowledge concerning the structural changes which occur on deformation. In this it has been possible to draw on information gained in recent structural studies which have been reported elsewhere.^{4,5}

EXPERIMENTAL

Preparation of Samples

Special samples of each polyester were prepared free from delustrant, each at two levels of molecular weight as determined by the relative viscosity of a

1% solution in *o*-chlorophenol at 25°C. The polymers were spun on a laboratory melt-spinning equipment to produce a spun yarn with five filaments, except for the high molecular weight 3GT sample which was spun on a rod-spinning equipment to give a yarn with three filaments. Each of the spun yarns was drawn on a Meccano draw frame, over a heated roller (the pin) and a heated plate, to three draw ratios. The spinning and drawing conditions, together with some of the physical properties to be discussed, are given in Table I.

Tensile Measurements

Load-extension curves were determined on single filaments mounted on cards using an Instron tensile testing machine. For each material, twenty 5-cm samples were tested at a crosshead extension rate of 5 cm/min and the load-extension curves averaged to give a single curve. The load is quoted as nominal stress, i.e., load divided by initial cross-sectional area which was determined separately for each filament using a vibrascope. The moduli quoted from these data are 2% secant moduli, calculated from the nominal stress at 2% strain.

Recovery Measurements

The recovery test is shown schematically in Figure 1, where the terms used are also defined. The filament is initially extended in an Instron tensile testing machine to the required strain (at a crosshead speed of 2 cm/min), and then held at constant strain for 2 min, after which the crosshead is returned to its original position. After a further 5 min, the filament is then re-extended. Below a certain strain the filament re-extends immediately after this 5 min waiting period, but at higher strains there is some slack in the filament which we term "permanent set." The "immediate recovery" is defined as the strain recovered after the first 2 min stress relaxation, and the "total recovery" as the strain recovered after the full cycle (2 min at constant strain, followed by return of the crosshead, followed by 5 min waiting period). It has also been found useful to compare the recovery behavior of different fibers by comparing the applied strains at which the recovery is 95%. This quantity will be termed the "specific recoverability" and may be applied to either the immediate or total recovery.

Shrinkage Measurements

The shrinkages of the fibers were determined by measuring the change in length of 100 meters of each fiber, after immersion in boiling water for 15 min, care being taken to allow free shrinkage.

Dynamic Mechanical Measurements

Dynamic mechanical measurements were carried out on the drawn fibers using the TFA (Transfer Function Analyser) testing equipment, which has been described in detail in a previous publication.⁶ The measurements were

TABLE I
Spinning and Drawing Conditions and Some Physical Properties of the Fibers

Polymer	Wind-up speed, ft/min	Pin temp., °C	Plate temp., °C	I.V.	Spun Δn	Draw ratio	Decitex (filament mean) ^a	Tenacity, GNm ⁻²	Breaking extension, %	2% secant modulus, GNm ⁻²	Shrinkage (boiling water), %	Birefringence		
2GT	3000	100	170	0.50	0.0042	3.50	3.5	0.43	44	8.1	3.1	0.156		
						3.75	3.4	0.49	34	10.3	3.4	0.164		
						4.00	3.1	0.53	21	10.9	3.5	0.177		
						0.72	0.0075	3.00	4.1	0.45	39	7.7	4.6	0.146
						3.33	3.7	0.51	25	8.9	5.4	0.159		
						3.75	3.3	0.69	22	9.2	5.6	0.172		
3GT	3000	70	90	0.59	0.0048	3.20	4.1	0.24	49	2.6	13.6	0.069		
						3.50	3.6	0.28	47	2.6	14.1	0.073		
						3.75	3.7	0.30	40	2.4	—	0.73		
						0.65	0.0052	3.00	4.4	0.30	69	2.7	14.3	0.070
						3.75	3.6	0.35	38	2.4	—	0.073		
						4.00	3.3	0.37	32	2.7	16.4	0.073		
4GT	4200	90	160	0.54	0.064	1.50	4.6	0.24	107	2.4	8.0	0.146		
						2.00	4.6	0.32	54	2.2	7.2	0.157		
						2.60	3.6	0.49	20	2.6	6.0	0.158		
						0.72	0.065	1.50	5.7	0.24	95	2.6	8.0	0.148
						2.00	4.6	0.32	54	2.0	8.1	0.154		
						2.60	3.6	0.50	23	2.3	6.5	0.161		

^a For a density of 1 g cm⁻³, 1 decitex is equivalent to a cross-sectional area of 10⁻¹⁰ m².

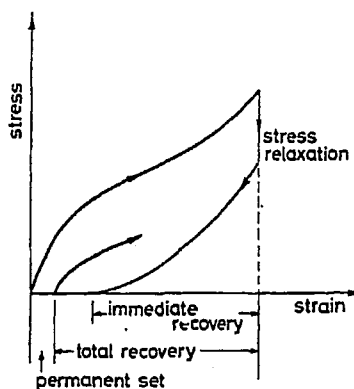


Fig. 1. The recovery cycle and definition of terms.

undertaken on a carefully aligned bundle of 20–30 filaments, of length 10 cm. A fixed frequency of 1 Hz was selected, and the temperature range was from ambient to 170°C. These measurements provided a comparative measure of the glass-transition temperature T_g for the oriented fibers, defined as the temperature corresponding to the maximum in the dynamic loss ($\tan \delta$) at the frequency of 1 Hz.

RESULTS

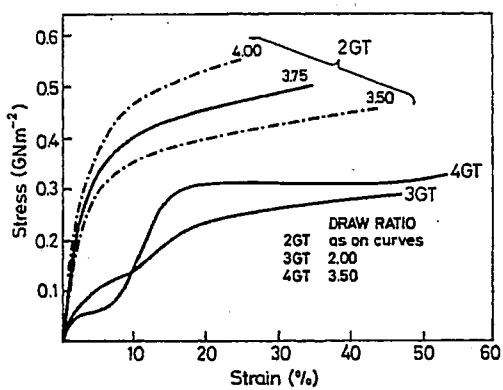
The room temperature load-extension curves are shown in Figure 2. They are grouped according to molecular weight, although this appears to have very little effect on their shape. To avoid confusion and aid comparison these curves are for the middle draw ratio of each species since it is only the relative shape of the load-extension curves that is important. The effect of changes in draw ratio are shown in Figure 2a for 2GT; they affect the absolute level of properties, but do not change the shape of the curve. This is also true for 3GT and 4GT. The property level changes (i.e., tenacity and breaking extension) are shown in Table I.

Figure 2c shows the relaxed stress-strain curves of 3GT and 4GT compared with the constant strain rate curves. The relaxed stress-strain curves were obtained on the Instron by increasing the strain in steps of 1%, and measuring the stress at each strain level after stress relaxation for 2 min.

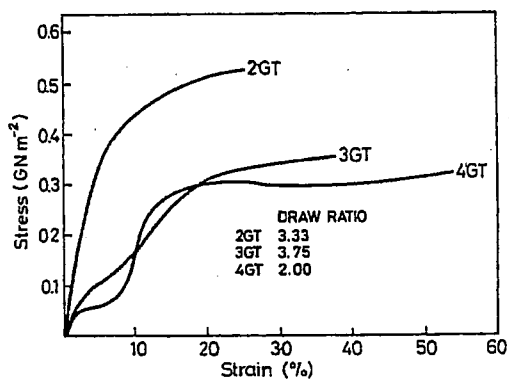
The total recoveries, immediate recoveries, and permanent sets are plotted in Figure 3 for all molecular weights and draw ratios, since the small changes due to these parameters do not produce any appreciable scatter in the results.

The 2% secant moduli for the curves of Figure 2b, the high molecular weight samples, are plotted in Figure 4 versus the number of methylene groups. The glass-transition temperature T_g for the fibers is plotted in a similar manner in Figure 5. (The spread shown for each point represents the range of values obtained in three separate determinations.)

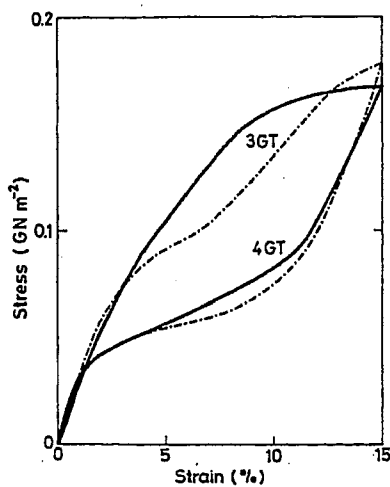
The strain at which the total recovery curve leaves the abscissa in Figure 3a represents the maximum strain before permanent set occurs. It can be seen that this point is somewhat indeterminate, due to the asymptotic nature of the relationship, hence the usefulness of comparing the strain for 95% total



(a)



(b)



(c)

Fig. 2. Stress-strain curves of the fibers, (a) low molecular weight, (b) high molecular weight, (c) stress-relaxed curves of 3GT and 4GT compared with the constant strain-rate curves. Solid curve, relaxed; dashed curve, constant strain rate.

recovery, which we have termed the specific recoverability. This is plotted as a function of draw ratio in Figure 6 together with the boiling water shrinkages. The results for samples of different molecular weight have been separated to show that the differences between them is not significant.

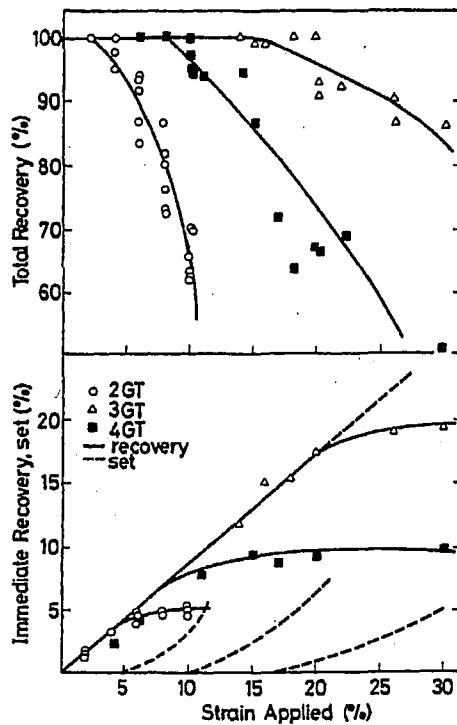


Fig. 3. Total recoveries, immediate recoveries, and permanent sets of the fibers vs. applied strain.

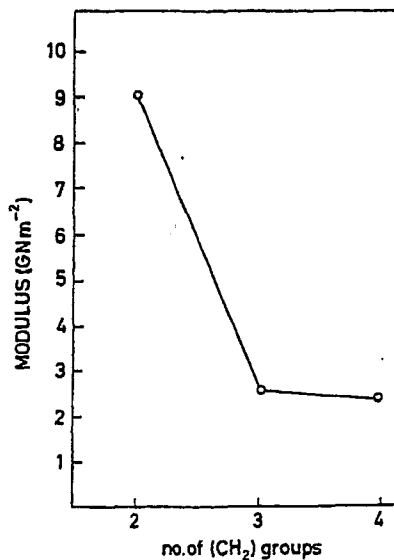


Fig. 4. Mean room temperature 2% secant modulus as a function of the number of methylene groups in the monomer unit.

The effect of heat treatment on the fibers was investigated by placing them in a relaxed condition in a preheated air oven for 10 min. The shrinkage during annealing was about 25%. Figure 7 shows the effect on the stress-strain curves and on the recovery. The effect of heat treatment on recovery is summarized by Table II, which shows the strain for 95% total recovery for each fiber before and after the annealing treatment.

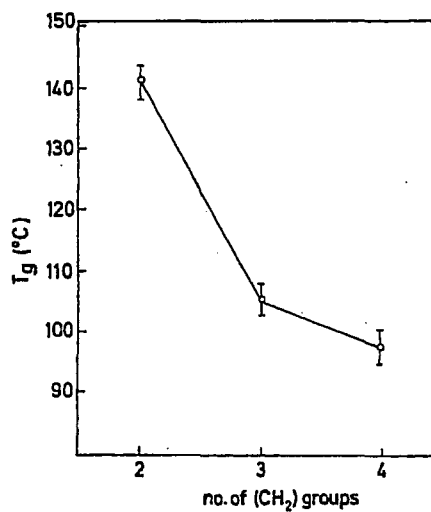


Fig. 5. Mean glass-transition temperatures as a function of the number of methylene groups in the monomer unit.

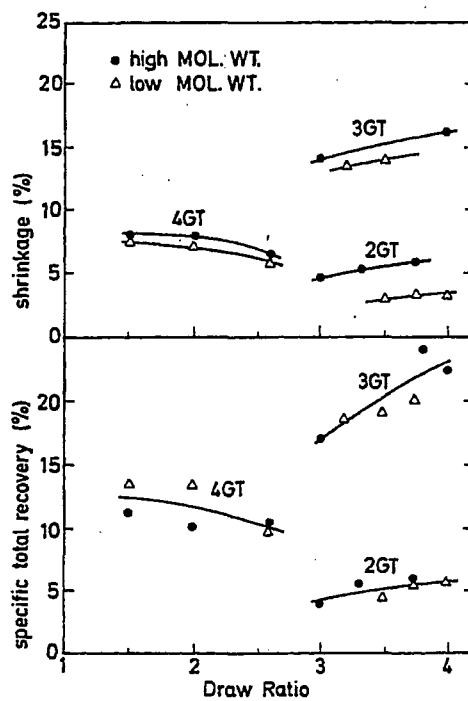


Fig. 6. Shrinkages and specific total recoveries as a function of draw ratio.

TABLE II
Effect of Annealing on 2% Secant Modulus and Specific Total Recoverability

GT	Property	Annealed	Unannealed
2	Modulus, gNm^{-2}	5.23	9.15
	Specific recoverability	2.1%	4%
3	Modulus, gNm^{-2}	3.88	2.58
	Specific recoverability	2.1%	22%
4	Modulus, gNm^{-2}	2.6	2.4
	Specific recoverability	4.9%	10.6%

All the results shown in Figure 7 and Table II are for a single molecular weight and draw ratio of each fiber type. This is because these mechanical properties are insensitive to these parameters, as has already been emphasized.

DISCUSSION

The major problem in comparing fibers by relating fiber properties to structure is that of establishing a reference level. It is difficult to know *a priori* whether the properties in question are due to fundamental differences in molecular structure or whether they are due to the methods used for preparing the fibers. The best that can be done is to prepare the fibers under as comparable conditions as possible.

Draw ratio is clearly a variable which could override molecular structure. With this in mind, a range of draw ratios was obtained for each molecular weight. The range was rather limited, and in the case of 3GT and 4GT the

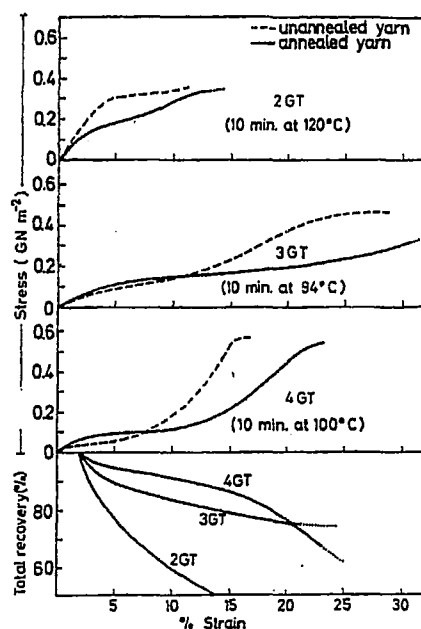


Fig. 7. The effect of annealing on the stress-strain curves and total recoveries of the fibers.

highest draw ratio was the maximum which could be obtained without altering the drawing conditions. The lowest draw ratios were those below which the yarn began to slough on the bobbins. The sensitivity of gross behavior to small changes in draw ratio was found to be very low, over this range, and so, for further work, it was assumed that draw ratio was not a critical parameter. Molecular weight is another important variable, and the molecular weights were matched as closely as possible. As with draw ratio, the use of two levels of molecular weight for each species showed that this was not a critical variable in the molecular weight range used.

The chief point of difference between the three fiber types is the shape of the stress-strain curves, as shown in Figure 2. 3GT and 4GT have a primary yield at about 5% strain. This shows as a pronounced knee or plateau region and is most evident in 4GT. 2GT, on the other hand, does not display this characteristic. The plateau is followed by a strain hardening region, the onset of which, in 3GT, is at about 12-15% strain, and in 4GT is about 8% strain. A second yield point is ultimately reached before failure. The plateau region in 3GT and 4GT appears to be closely related to recovery, as shown by Figure 3. For unannealed fibers, at least, the total recovery does not start to decrease until the strain has reached the strain hardening region at the end of the plateau. The immediate recovery also falls off near this point.

The second major difference between the fibers is that the modulus of 2GT is much greater than either 3GT or 4GT, with 4GT being slightly less than 3GT. The final very clear difference between these three fibers comes from the comparison of shrinkage and recovery behavior shown in Figure 6. It is extremely interesting to note that the ranking is the same for both shrinkage and recovery, with the order 3GT > 4GT > 2GT.

The x-ray diffraction studies reported in the previous publication⁴ show that there is a major difference between the molecular conformations in the crystalline unit cells of these three polymers. In 2GT the *c*-axis dimension corresponds to a molecular conformation which is very nearly planar with the chains almost fully extended. In 3GT, on the other hand, the fiber identity period is only 76% of the repeat distance for a fully extended chain and it appears that the molecular conformation is helical with successive monomer units lying at approximately 60° to one another about the helix axis. Although 4GT shows a unit cell dimension in the *c*-axis direction which is markedly longer than in 3GT, the value corresponds only to 86% of the fully extended chain repeat distance.

The comparatively low modulus of 3GT and 4GT can therefore be associated with the fact that the molecular conformation never corresponds to the fully extended form so that deformation always involves bond angle rotations and bond bending rather than bond stretching. It is interesting that in 3GT the x-ray measurements of the strained fibers show that the deformation of the crystalline regions is approximately identical with the overall deformation, i.e., the lattice deforms like a coiled spring. The low overall modulus in this case corresponds exactly to the low crystal modulus. In 2GT the measured macroscopic modulus is much less than the crystal modulus (as shown by Dulmage and Contois⁷). Nevertheless there is still a proportion of molecules taking the stress which are in the fully extended form. These

would correspond to the tie molecules which Peterlin has proposed for crystalline fibers of polyethylene.⁸

The dynamic mechanical results (Figure 5) show that the glass-transition temperature T_g is also very considerably lower in 3GT and 4GT than in 2GT. This can also be attributed to the increased flexibility of the two former polymers due to the more crumpled conformation of the glycol residue.

The x-ray diffraction studies^{4,5} also included measurements of the deformation of the crystalline regions of 3GT and 4GT when the oriented fibers or tapes were extended. It was found that in both cases there were comparatively large reversible lattice strains. In the case of 3GT, the lattice strains increased monotonically with increasing macroscopic strain and at low strains these were approximately identical. Thus the initially linear part of the stress-strain curve in 3GT corresponds to an elastic uncoiling of the molecules, which the structural studies have shown to take up helical conformations, as discussed above. It is therefore not surprising that the recovery of 3GT from strain is very good, particularly at low strains. It is also not surprising that the onset of nonrecoverable strain corresponds approximately to the end of the plateau region where there is a distinct inflection in the stress-strain curve. In molecular terms it can be inferred that this occurs when the macroscopic strain causes irreversible movements of the molecular chains. At this point the deformation becomes inhomogeneous at a molecular level, so that the deformations in the crystalline and noncrystalline regions now begin to differ appreciably.

In 4GT, the x-ray diffraction studies on strained fibers reveal a somewhat different pattern of behavior at a molecular level. In this case there is no detectable change in the x-ray diffraction pattern at low macroscopic strains. At a macroscopic strain of about 4%, reflections corresponding to a unit cell in which the molecular chain is fully extended start to appear in the diffraction pattern. As the macroscopic strain is increased from 4% to about 12% these new reflections grow in intensity, and those corresponding to the zero strain unit cell diminish, so that there is a complete transformation of the material in the crystalline regions from one crystal form to the other. In 4GT the knee in the stress-strain curve therefore corresponds to the onset of this crystal transformation. It can be considered to correspond to a yield point for this process, and the plateau region of the stress-strain curve corresponds to increasing strain in the crystalline regions as the crystalline material transforms at constant stress, very similar to classical plastic flow. When this process is exhausted, further deformation can only proceed by processes which require greater stress for their activation, and the stress-strain curve rises again. This deformation of the crystalline regions has been shown by x-ray and Raman spectroscopy measurements to be completely reversible.⁵ Recovery in 4GT is therefore also associated to a major degree with the elastic recovery of the crystalline regions. The mechanical recovery in quantitative terms (see Figs. 3 and 6) is not as good as in 3GT, and this can be attributed to the fact that the crystal deformation process is exhausted at about 10% macroscopic strain, whereas the elastic distortion of the crystalline regions in 3GT continues to the highest strains and is reduced in magnitude only as the whole structure is disrupted and the distribution of stress becomes very inhomogeneous at a molecular level, as already discussed.

Finally there is the comparison of shrinkage and recovery behavior shown in Figure 6 which indicates very clearly that these two properties have equivalent ranking and behavior over the range of draw ratios. This is a very important observation, the significance of which is not yet fully understood, but from our discussion above it can be inferred that a common factor such as the geometrical shape of the molecular chain is involved. This common factor is involved in the molecular mechanisms responsible for both recovery from extension and in reduction in length in shrinkage. This is not surprising if both recovery and shrinkage involve the contraction of an extended network. The results imply that 3GT has a greater number of effective random links between network junction points than 4GT, which in turn has a greater number than 2GT. This line of argument points back to the basic molecular flexibility which in terms of the molecular conformations in the crystalline regions ranks these three polymers in the same order. Thus, although shrinkage is a process involving only the amorphous regions and their disorientation, the general link is that the conformational situation is at a molecular level, and therefore affects both the crystalline and the noncrystalline material.

The main effect of annealing in all these fibers is to cause large scale disorientation of the amorphous network.^{9,10} The network may be thought of as an entropic rubber which possesses an equilibrium extension for any given temperature. When the fiber is annealed the increase in temperature causes a shrinkage because the network attains a new equilibrium extension. As the fiber is cooled to room temperature this new configuration is "frozen". The fiber is now extended. Because the network is more crumpled than in the initial fiber, the extension in the plateau region is greater. In addition, when the stress is removed the network will revert back not to its annealed configuration, but to the equilibrium state at room temperature. Thus, the recovery is much reduced. This argument may equally well apply to both 3GT and 4GT, and since the recovery of the crystal lattice now plays little part in the recovery of the annealed fiber it is not surprising that after annealing the recoverabilities of the two species are very similar.

After annealing the fibers, another important observation is that the modulus of 2GT drops very appreciably (from 9.3 to 6.2 GN/m²) and that of 3GT and 4GT actually increases slightly (from 2.7 to 3.8 GN/m² for 3-GT, and from 2.3 to 2.95 GN/m² for 4GT). It is easy to explain the decrease in the 2GT modulus. The relaxed heat treatment causes the amorphous regions to relax and since these regions control the modulus, the modulus will be correspondingly reduced. In 3GT and 4GT, on the other hand, it can be implied that the molecules in the noncrystalline regions are in crumpled conformations with a correspondingly low modulus. In this case the increased crystallinity on annealing leads to a small increase in modulus. The corresponding reduction in recovery of 3GT and 4GT on annealing is also consistent with the removal of the flexible crumpled conformations in the amorphous regions. It appears that this effect is greater than the increase in recovery which might be expected due to a greater proportion of crystalline material with high elastic recovery.

In 2GT, the much earlier studies of Dulmage and Contois⁷ showed that the strain in the crystalline regions was a factor of about ten less than the macroscopic strain for macroscopic strains up to 1.8%. The stress-strain behavior

must therefore be associated mainly with deformation of the amorphous regions. As we have mentioned the high modulus is consistent with the stress being taken by a few extended tie molecules. In this case it is therefore reasonable to find that there is not a knee in the stress-strain curve, as there is no dramatic change in the nature of the deformation with strain.

It should be mentioned that a knee can be produced, followed by a plateau region, if the 2GT fibers are annealed.¹⁰ The plateau region produced by annealing in 2GT is, however, not similar to that present in unannealed 3GT and 4GT in that it does not represent a region in the stress-strain curve where there is good recovery from strain. This suggests that the plateau in this case has a quite different origin at a structural level, and possible explanations have been proposed by Wilson.¹⁰

CONCLUSIONS

(1) There are very distinct differences between the mechanical behavior of oriented fibers of 2GT, 3GT, and 4GT which are irrespective of the smaller differences produced in each species by changes in molecular weight or process draw ratio.

(2) The different nature of the stress-strain curves for these three materials, including their initial moduli, can be fairly well understood in terms of the previous structural studies.^{4,5} In particular, there is a substantial contribution to the overall deformation in 3GT and 4GT which arises from deformation of the crystalline regions. This feature also provides a satisfactory explanation of the different recovery behavior of 2GT, 3GT, and 4GT.

(3) The correlation between the ranking of these three materials with regard to recovery from strain and shrinkage at 100°C suggests that the molecular conformational state in both the crystalline and noncrystalline regions is the underlying factor in determining the physical properties of these polymers.

References

1. I. M. Ward, *Textile Res. J.*, **31**, 650 (1961).
2. I. M. Ward, *J. Macromol. Sci.—Phys.*, **B1**, 667 (1967).
3. D. E. Bosley, *J. Polym. Sci., Pt. C*, **20**, 72 (1967).
4. R. Jakeways, I. M. Ward, M. A. Wilding, I. H. Hall, I. J. Desborough, and M. G. Pass, *J. Polym. Sci., Polym. Phys. Ed.*, **13**, 799 (1975).
5. R. Jakeways, T. Smith, I. M. Ward, and M. A. Wilding (submitted for publication).
6. P. R. Pinnock and I. M. Ward, *Polymer*, **7**, 255 (1966).
7. W. J. Dulmage and L. E. Contois, *J. Polym. Sci.*, **28**, 275 (1958).
8. A. Peterlin, *Polym. Eng. Sci.*, **9**, 172 (1964).
9. D. Patterson and I. M. Ward, *Trans. Faraday Soc.*, **53**, 1516 (1957).
10. M. P. S. Wilson, *Polymer*, **15**, 277 (1974).

Received August 11, 1975