

The Effect of Hydrolytic and Thermal Degradation on Mechanical Properties of Industrial Polyester Yarns

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Received 18 October 2008; accepted 26 February 2009

DOI 10.1002/app.31683

Published online 7 January 2010 in Wiley InterScience (www.interscience.wiley.com).

ABSTRACT: For industrial polyester yarns, the study of hydrolytic/thermal degradation is important, because of the negative influence of these degradations on mechanical properties of polyester yarns. In this research, tensile force at breaking point and elongation at break were used to assess the hydrolytic and thermal degradation of industrial polyester yarns with two draw ratios of 3.5 and 4, which were exposed in water and in oven for 28 days and at different temperatures of T_g , below and above T_g . Totally, the amount of these degradations at temperatures

of 70 to 90°C is not high. The investigation shows that tensile strength at breaking point of industrial polyester yarn will decrease in water and in oven at higher temperature; this degradation is lower for yarn with high draw ratio. © 2010 Wiley Periodicals, Inc. *J Appl Polym Sci* 116: 1929–1932, 2010

Key words: polyethylene terephthalate; hydrolytic and thermal degradation; tensile force at breaking point; elongation at break; crystallinity

INTRODUCTION

Polyethylene terephthalate is a thermoplastic resin of the polyester family that is used to make beverage, food and other liquid containers, synthetic fibers, as well as for some other thermoforming applications. It is also one of the most important raw materials used in man made fibers. Depending on its processing and thermal history, it may exist both as an amorphous (transparent) and as a semicrystalline (opaque and white) material. It can be synthesized by a transesterification reaction between ethylene glycol and dimethyl terephthalate.

The hydrolytic and thermal degradation of poly(ethylene terephthalate) (PET) is an important problem associated with many of its industrial and commercial applications. For example, in the form of fibers, sheet and film under conditions of high humidity the ester functionality is most vulnerable to degradation.¹

PET is a polymer sensitive to hydrolysis, inducing chain scission and embrittlement. The study of PET ageing in water or in humid or dry atmosphere is of great technical interest, which justifies the relatively abundant literature on this topic.^{2–10}

Significant hydrolysis of PET is known^{2–5} to occur in moist, wet, or humid conditions at temperatures above glass transition temperature (T_g). It is proved

that hydrolytic degradation causes a reduction in molecular weight of PET. The influence of molecular weight on the physical and chemical properties of polymers is well known and well documented. Tensile strength, fatigue life, and impact strength are positively influenced and stiffness, tear strength, and elongation at break are negatively influenced by increasing molecular weight.¹¹ Fiber strength, initial modulus, and flexibility of polyester (PET) are shown to increase with increasing molecular weight.¹²

A number of studies have been made on the thermal degradation of PET.^{2,6–8} Thermal degradation was found to follow a chain scission mechanism that progressive reduction in molecular weight. During thermal degradation process, the annealing process (heating and holding at an appropriate temperature below the crystalline melting point, followed by slow cooling) prepared a significant increase in crystallinity.²

Some investigations¹³ show that in moderate temperature, polyester is stable against the hydrolytic degradation, e.g., polyester hydrolysis in room temperature (20°C) is a slow reaction which will cause 50% decreasing in its tensile property and 25% increasing in crystalline zones during 30–40 years.

In our previous work,² it was shown that molecular weight of PET fibers decreases by hydrolytic degradation at above glass transition temperature (T_g).

To analyze the degradation of PET, technical methods such as determination of the moisture content, viscometric analysis, carboxylic end group titration, and X-ray diffraction were used.

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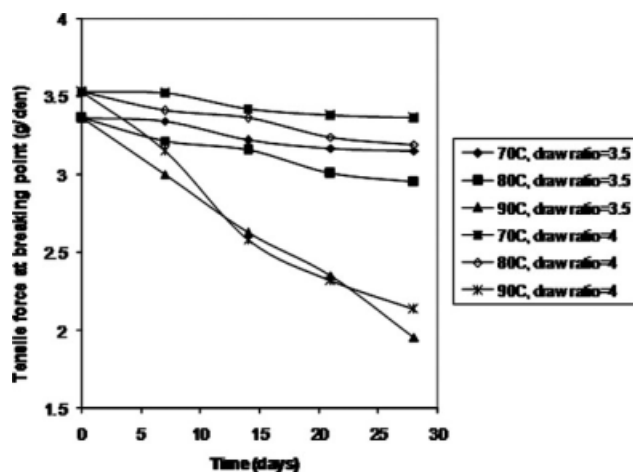


Figure 1 Tensile force at breaking point (g/den) versus ageing time (days) for FDY samples treated in water.

In this study, we have extended our previous work² to a detailed investigation of the hydrolytic degradation effect on mechanical properties of industrial polyester yarns under various temperatures.

EXPERIMENTAL

Sample preparation

Fully drawn polyester (PET) yarns ($T_g = 80^\circ\text{C}$, draw ratio of 3.5 with tenacity of 3.367 gr/den* and draw ratio of 4 with tenacity of 3.532 gr/den) were supplied by Kave Fiber Company, Iran.

The yarns were exposed in demineralize water (hydrolytic degradation) and in an electrical oven (thermal degradation), at three different temperatures: 70, 80 (glass transition temperature), and 90°C for 0–28 days with 7-day intervals. Also, samples are treated in water at room temperature (30°C) for the same period of time. Samples exposed in water were dried with a soft cloth.

Tensile test

Tensile force at breaking point of samples was measured by Zwick (model 1446, Germany). Tensile test was carried out according to the ASTM D 5035-95, 1995.¹⁴

RESULTS AND DISCUSSION

Figure 1 shows the effect of temperature and draw ratio on tensile force at breaking point (gr/den) of treated FDY (fully drawn yarn) samples in water.

The results show that tensile force reduction at breaking point of FDY polyester with draw ratio of

4 is less than the one with draw ratio of 3.5. More compressive and high orientation structure of FDY samples due to the drawing process prevents more hydrolytic degradation. In contrary, FDY samples with lower draw ratio have open structure and lower orientation, so hydrolytic degradation will be higher. Hydrolytic degradation will cause chain scission resulted in molecular weight reduction,^{2–6} hence, resistance of FDY samples against tensile force decreases. Also, the figure illustrates that hydrolytic degradation will increase by enhancing temperature from 70 to 90°C . In terms of temperature effects, degradation rates were significant above the T_g of PET samples.

Figure 2 shows the effect of temperature and draw ratio on elongation at break (%) of treated FDY samples in water.

It can be realized that elongation at break of FDY samples with draw ratio of 3.5 is more than the one with draw ratio of 4, due to more hydrolytic degradation and shrinkage of samples in water. With the chain scissions, the mobility of chains will be easier, and they can slide on each other. As it can be seen, temperature increment causes enhancement of elongation at break, with the exception of 90°C after 20 days due to more chain scission leading to more reduction in chain length which creates weak points in the yarn.

Totally, two processes are assumed during the hydrolytic degradation, the first one is the random tearing of ester bonds and the second one is significant and measurable decrease in molecular weight and more breaking of the chains. The noticeable decrease in mechanical properties will occur in second step.³

Figures 3 and 4 show the effect of draw ratio on tensile force (gr/den) at breaking point and elongation at break (%) of treated FDY samples at room temperature (30°C).

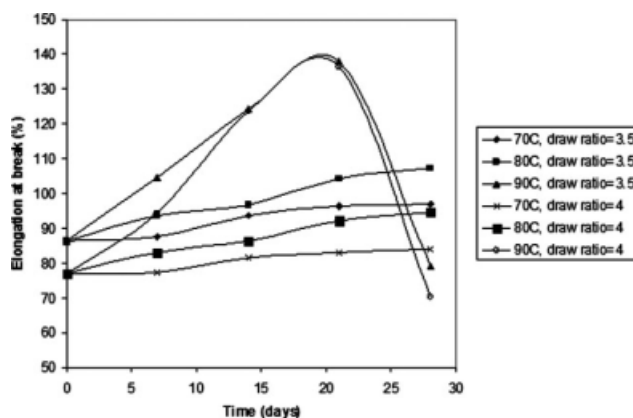


Figure 2 Elongation at break (%) versus ageing time (days) for FDY samples treated in water.

*Denier: [weight (gr) of 9000 meter of yarn].

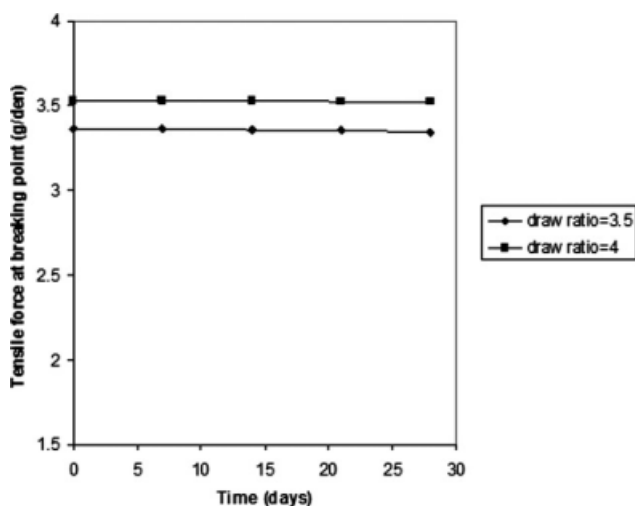


Figure 3 Tensile force at breaking point (g/den) versus ageing time (days) for FDY samples treated in water at room temperature.

The results show that there is no significant change in tensile force at breaking point and elongation at break of samples treated in water at 30°C, even for 28 days.

Figure 5 shows the effect of temperature and draw ratio on tensile force at breaking point (gr/den) of treated FDY samples in oven.

The results show that thermal degradation for temperature higher than T_g (90°C), declining of tensile force at breaking point will be higher, due to more thermal degradation at this temperature. But, tensile force at breaking point for FDY with draw ratio of 4 for 28 days and 90°C increases due to the annealing process and resulted in increment of crystallinity.²

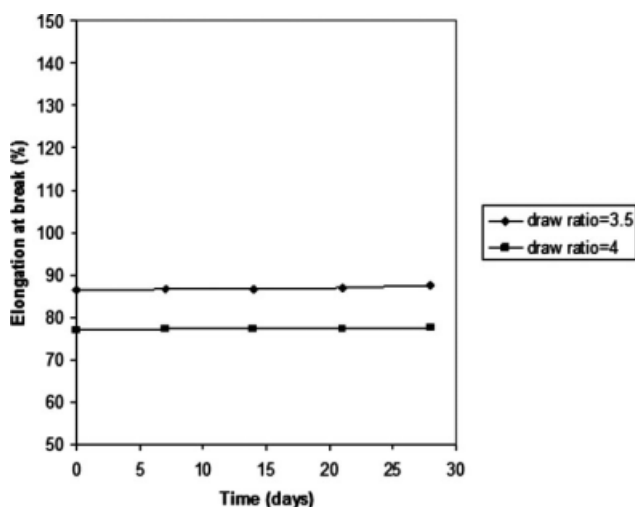


Figure 4 Elongation at break (%) versus ageing time (days) for FDY samples treated in water at room temperature.

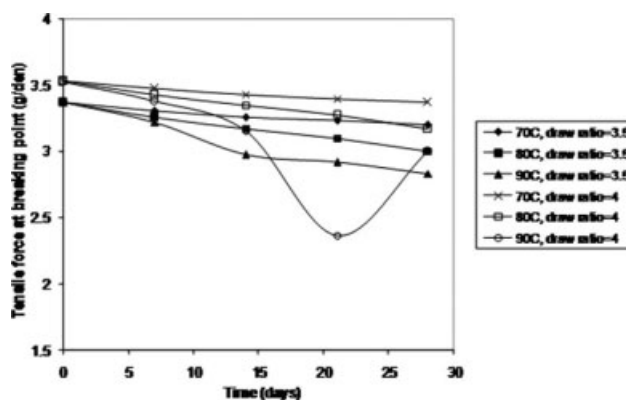


Figure 5 Tensile force at breaking point (g/den) versus ageing time (days) for FDY samples treated in oven.

Figure 6 shows the effect of temperature and draw ratio on elongation at break (%) of treated FDY samples in oven.

It can be seen that elongation at break decreases with temperature enhancement, due the annealing process which leads to more crystallinity.

CONCLUSIONS

The hydrolytic and thermal degradation of poly (ethylene terephthalate) (PET) is an important problem associated with many of its industrial and commercial applications. Our Previous work shows that hydrolytic and thermal degradation will decrease the molecular weight.

In this research work, tensile force at breaking point and elongation at break after thermal and hydrolytic degradation were measured and showed that tensile force at breaking point is decreased by increasing temperature with the exception of thermal degradation of samples with higher draw ratio at higher temperature for more than 20 days. In this condition, samples will be subjected to the

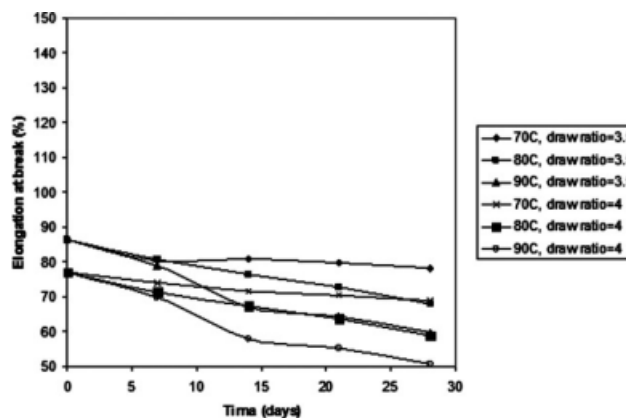


Figure 6 Elongation at break (%) versus ageing time (days) for FDY samples treated in oven.

annealing process in which tensile strength will increase.

It is concluded that hydrolytic degradation of samples will increase elongation at break due to more chain sessions excepting samples degraded at higher temperature for more than 20 days in which elongation at break will decrease due to more weak points. Also, thermal degradation of samples will decrease elongation at break, because of the annealing process.

For samples at room temperature there are no significant changes in these parameters.

In FDY yarns with higher degree of drawing, hydrolytic degradation is lower, due to the compressive structure and higher orientation.

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