A New Approach to Determination of the Instability of Air-jet Textured Yarns

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ABSTRACT
Determination of the instability of air-jet textured yarns is a very important aspect of their quality characterization. To overcome this problem many researchers have suggested different techniques, however none has been accepted as a standard method. Among all the methods, that suggested by Demir *et al.* takes attention, since it was improved after investigating the advantages and disadvantages of most of the techniques in use. Recovery from strain measurements are commonly used to get information about fiber molecular structure. In this study, instability of air-jet textured yarns was investigated by using both Demir's instability test method and recovery from strain measurements. It was observed that Demir's method is a practical and reliable way to compare the instability of air-jet textured yarns produced from the same raw material. For comparing different materials it was more beneficial to use recovery from strain measurements.

Keywords: Air-jet texturing, polyester yarn, instability tests, recovery from strain measurements.

INTRODUCTION
Air-jet texturing is a versatile method to produce spun like yarns from synthetic filaments. Air-jet textured yarns have a characteristic voluminous (bulked) construction with loops on the surface locked in the core of the yarn. The looped structure can be distorted under forces during production and usage of the products. Therefore the stability of the loops is of crucial importance in characterizing the quality of the air-jet textured yarns. Stability of air-jet textured yarns is affected by both feed yarn properties, such as material, fineness, cross sectional shape, rigidity, and frictional characteristics of the filaments, as well as process parameters, such as overfeed, type of nozzle, and air pressure. Determination of the stability of air-jet textured yarns is a challenge. In the literature there are many methods to determinate the stability or instability of the yarns, however they all depend on different principles [1-4].

The DuPont method [5] is commonly used for determination of instability of air-jet textured yarns [3, 6-8]. The equipment needed for this method is a vertical board with a clamp at the top from which the air-jet textured yarn is suspended. It defines the percentage permanent increase in length of the yarn after removal of an applied load (0.33 gf/den) for 30 s as instability.

Heberlein methods [9] are also based on weight hanging; however, the suggested load and loading duration are different from the DuPont method. Moreover instead of a single yarn they recommended the use of a hank of textured yarn. Heberlein Instability I measures the percentage elongation of the yarn under a certain applied load, while Heberlein Instability II measures the permanent elongation after the load is removed.

Before the modern air-jets were developed pre-twisted yarns were fed to the air-jet texturing machines. Therefore losing yarn twist due to straining may be a disadvantage for weight hanging methods. In order to overcome this limitation Wray suggested using the Instron constant-rate-of-loading tensile tester or a strainometer for more rapid measurements [10]. He used load-elongation curves to estimate the percentage elongations of the feed and the textured yarns. Then he calculated instability by subtracting these two values from each other.

Acar also used a tensile testing machine to determinate the instability of the air-jet textured yarns. He recommended the elongation of textured yarn under applied loads as instability [11].

In 1989 Sengupta et al. mentioned that textured yarns are subjected to cycling loading during further processing and usage. Therefore they introduced the use of cycling loading instead of single loading methods. In their work they compared the decay values with the values obtained from the DuPont and

Acar methods. They concluded that all the methods showed similar trends of instability with texturing process variables; however cycling loading gave more realistic values about the structure of the textured yarns [12].

In one of their works Demir, Acar, and Wray critically reviewed the stability test methods used in industry and research (DuPont, Heberlein I, Heberlein II, Wray, and Acar). Since there was no consensus between the methods, they investigated the effects of specimen length, test duration, and form of the specimen. Finally they recommended an improved test method as a standard instability test. For the tests they suggested the use a tensile testing machine, and they calculated instability from the obtained load-elongation graph. They measured instability of the yarns using their method and compared the results of the other methods. They observed the same trend for all the instability tests [4].

Instead of static loading, textile fibers and yarns are mainly subjected to cycling loading. For this reason using methods based on cycling loading give more beneficial information about their real mechanical behavior. Recovery from strain measurements are based on the cycling loading principle. Therefore they are generally preferred to investigate the real mechanical behavior of the fibers. Many researchers have used this measurement for their investigations [13, 14].

In this study recovery from strain measurements were used to determinate the instability of air-jet textured yarns as they are also subjected cycling loading during usage. Two of the most important process parameters, namely polymer type and overfeed, were changed and six different air-jet textured yarns were produced. Instability of these yarns was investigated by means of recovery from strain measurements and the method suggested by Demir et al. The results were compared to show advantages and disadvantages of the two methods.

EXPERIMENTAL

Materials

Three different polyester filament yarns namely, poly(ethylene terephthalate) (PET), poly(butylene terephthalate) (PBT), and Vectran were used. These three yarns were chosen due to their pronounced different mechanical behavior. Properties of the yarns are presented in *Table I*.

Air-Jet Texturing of the Yarns

Air-jet texturing of the filaments was carried out on a SSM Stähle RM3-T machine, with the following parameters: 250 m/min texturing speed, Hemajet A347 type of nozzle, 0.8 MPa air pressure. The filaments were fed to the machine as single end method with two different overfeeds (15%, 30%). PET and PBT were partly oriented yarns (POY), therefore they were subjected to drawing between the feed rollers when being fed into the machine. The draw ratio was selected according to the manufacturers' specifications. Vectan is a liquid crystalline fiber, and was in fully-drawn state; therefore it was not subjected to drawing. Details of the process and the given yarn codes are given in *Table II*.

TABLE I. Properties of the feed yarns.

Type of the feed yarn	Yarn count (tex)	Number of filaments	Modulus (N/tex)	Breaking strain (%)	Tenacity (N/tex)
PET (POY)	27.6	36	2.34	131.87	0.187
PBT (POY)	23.5	36	2.07	82.22	0.194
Vectran	110	200	47.40	6.188	2.239

TABLE II. Details of the air-jet texturing process and the given yarn codes.

Feed yarn	Yarn code	Draw ratio (%)	Overfeed (%)	Heat-setting temperature (°C)
PET	PET15 PET30	1.65	15 30	210
PBT	PBT15 PBT30	1.56	15 30	150
Vectran	Vectran15 Vectran30	-	15 30	210

Characterization of the Air-Jet Textured Yarns

After air-jet texturing, the yarns were characterized by means of tensile tests and optical microscopy analysis.

Tensile measurements were carried out on a 4301 Instron tensile tester with a gauge length of 250 mm and a crosshead speed of 300 mm/min. Tensile tests were carried out for the yarns before and after air-jet texturing.

Geometry of the yarns was observed by using an automatic trinoculer stereo zoom microscope (Olympus SZ6045 Model).

Instability Tests

Recovery from strain measurements can be performed on any tensile tester equipped with suitable software. In this study the tests were carried out on a Universal Fiber Tester (UFT) [15]. On the other hand, the instability tests performed according to Demir's method were carried out on a 4301 Instron tensile tester.

As an improved instability test method Demir et al. recommended using a tensile testing machine with a gauge length of 300 mm and a crosshead speed of 20 mm/min. They operated the machine until the load was slightly higher than the load corresponding to 0.5 cN/dtex, based on the feed yarn linear density. From the recorded load-elongation graph, they calculated the percentage elongation between the loads 0.01 cN/dtex and 0.5cN/dtex, which was taken as the instability of the yarn [4].

The procedure for the recovery from strain measurements was as follows; the specimen was first extended to a predetermined applied strain (the region labelled 1 in *Figure 1*) to represent a specified proportion (30%) of the fiber's normal breaking strain as determined in the tensile test. The specimen was then held at this strain for two minutes (region 2). During this time, some stress-relaxation took place, result of internal flow. The cross head was then returned to its original position (region 3). After a further pause of five minutes (region 4), the filament was re-extended (region 5). These measurements were all carried out at a constant crosshead speed of 20 mm/min with a gauge length of 300 mm [14].

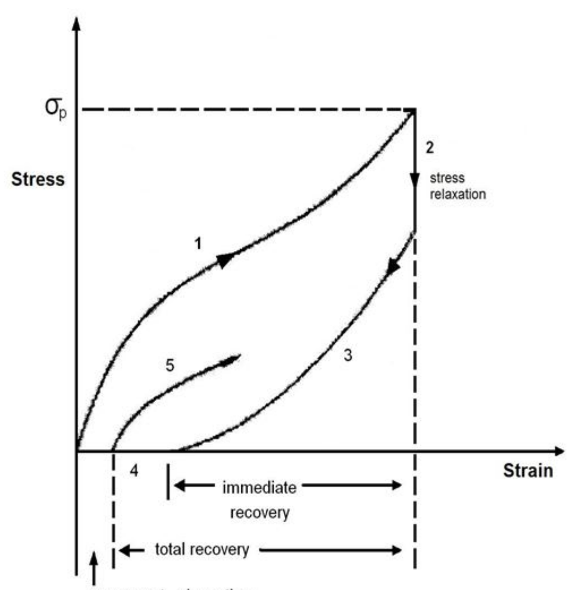

FIGURE 1. Recovery cycle and definition of terms [14].

In analyzing the recovery data, we used the following terms: *immediate recovery,* the strain recovered during stage 3, expressed as a percentage of the total imposed strain; *total recovery,* the total strain recovered after the full cycle, again expressed as a percentage of the total imposed strain; *secondary recovery,* the difference between the total recovery and the immediate recovery; and *permanent elongation,* the *actual strain* remaining in the filament (as slack) after the five-minute waiting period [14]. In recovery from strain measurements permanent elongation was considered as instability.

Instability tests and recovery from strain measurements were carried out according to the given procedures.

All the experiments were performed in the laboratories of Uludag University, Textile Engineering Department.

RESULTS AND DISCUSSION

In air-jet texturing, yarn is overfed into the jet to achieve extra length needed to generate the looped structure. When overfeed is increased, it becomes possible for a longer length of filament to be blown out in a given time interval resulting in an increase in loop size and loop frequency [16] (*Figure 2*). Properties of the feed yarn affect the shape of the loops. The filaments that can easily bent form closed, stable loops, while stiffer filaments form arcs and open loops [17]. The materials used in this study were all polyester fibers. However their chemical structures are quite different. Among these three fibers Vectran is the most different. It is an aromatic polyester with stiff, highly oriented molecular domains. On the other hand PET and PBT have more similar chemical structures compared to Vectan. The difference between PET and PBT is the number of methylene groups present in the repeating units of the polymer molecule. In Vectran an aromatic ring is added to the structure (*Figure 3*). Therefore they have different mechanical properties resulting in different bending behavior. In case of PET and PBT the shapes of the loops are quite similar. However Vectran forms loops with very different structures compared to PET and PBT.

For an air-jet textured yarn, analyzing the shape and number of the loops is very important since they determine most of the yarn properties. The disorientation of the filaments forms the loops and results in an increase in yarn count and breaking strain and a decrease in tenacity (*Table III*).

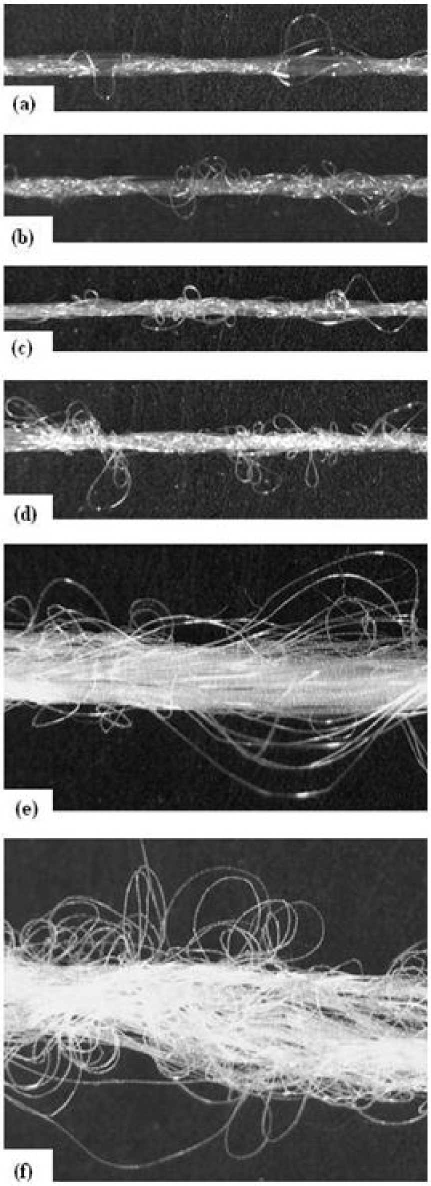

FIGURE 2. Optical microscopy images of the yarns: (a)PET15, (b)PET30, (c)PBT15, (d)PBT30, (e)Vectran15, (f)Vectran30.

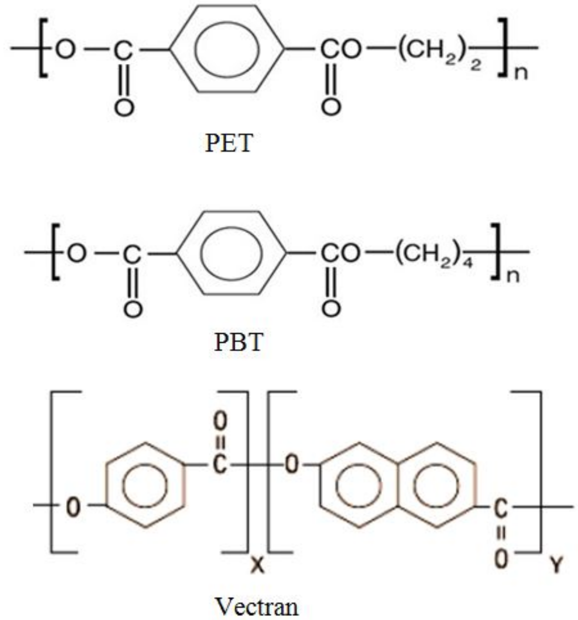

FIGURE 3. Molecular structures of the samples.

TABLE III. Tensile test results.

	Yarn count (tex)	Breaking strain (%)	Tenacity (N/tex)
PET15	20.08	20.93	0.2060
PET30	22.04	24.48	0.1541
PBT15	18.86	28.44	0.2401
PBT30	20.45	24.99	0.1552
Vectran15	131.84	11.17	0.8832
Vectran30	139.93	17.50	0.7906

Instability of the yarns is also related to the behavior of the loops under stress. When PET, PBT and Vectran are considered, it is known that PBT gives the highest elastic recovery while Vectran gives the lowest. It is a result of their chemical structure.

It is also known that increasing overfeed increases the instability of the air-jet textured yarns by increasing the number of loops to be removed under low loads [3, 10, 12]. This work was carried out to see if the performed test methods reflect these facts. According to recovery from strain measurements PBT has the highest immediate recovery and the lowest permanent elongation, while Vectran has the lowest immediate recovery and the highest permanent elongation (*Table IV*). Analyzing the hysteresis loops obtained from the recovery tests also gives useful results about the elastic behavior of the yarns (*Figure 4*). All the yarns give a prominent hysteresis loop with different sizes. However for both overfeeds Vectran gives the largest loop, and PBT gives the smallest indicating their elastic recovery behavior.

TABLE IV. Results of recovery from strain measurements and instability tests.

	Immediate recovery (%)	Secondary recovery (%)	Permanent elongation (%)	Instability (%)
PET15	55.55	24.42	20.03	2.11
PET30	47.81	24.73	27.46	5.44
PBT15	86.00	13.15	0.85	6.08
PBT30	65.24	21.26	13.50	10.22
Vectran15	9.88	9.42	80.70	2.96
Vectran30	7.46	13.94	78.60	7.78

According to Demir's test method, PET gives the lowest instability, while PBT gives the highest. This result seems to conflict with results of the recovery measurements. However these two methods express the behavior of air-jet textured yarns under tension in different ways. When a tension is applied some of the loops are easily pulled out while some remain intact. The behavior of the loops is closely related to whether they are open or closed loops. Rigidity of the filaments is another important factor since the elongation of a textured yarn under stress is the combination of elongation of the individual filaments and the pulled up loops. It is very difficult to estimate which one is more dominant. Demir's test method measures the elongation of an air-jet textured yarn under tension. Demir et al. specify that air-jet textured yarns are not stretch yarns and they are under maintained tensions during most of the processes. Therefore they recommended considering the elongation of the yarn under maintained tension as a measure of yarn instability. For this reason their method doesn't take account the elastic recovery of the yarn when the applied tension is removed.

Both the test methods confirm that increase in overfeed results in an increase in the instability of the air-jet textured yarns.

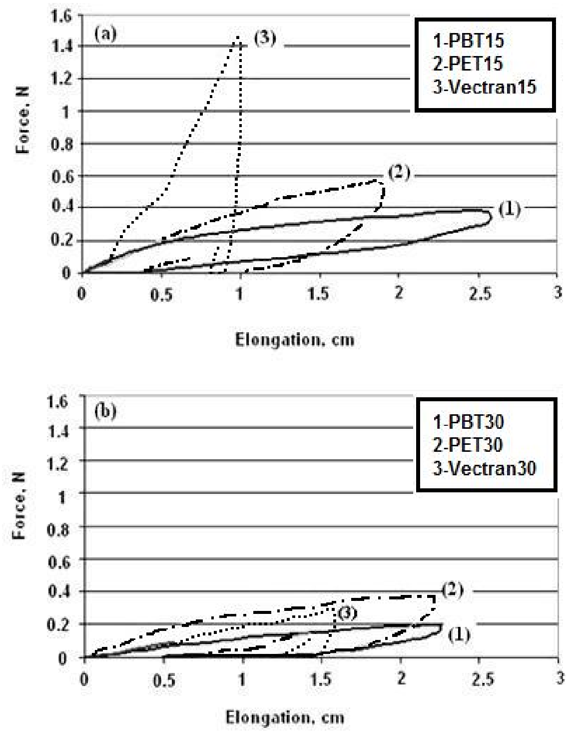

FIGURE 4. Recovery cycles: (a)PET15, PBT15, Vectran15, (b)PET30, PBT30, Vectran30.

CONCLUSION

Demir's instability test method is practical, fast, and gives satisfactory results in comparing air-jet textured yarns produced from the same type of polymer. On the other hand, recovery from strain measurements consider the behavior of the polymer itself. Therefore in comparing yarns produced from different polymers it is more beneficial to use recovery from strain measurements.

In this study, it is clearly seen that the loop type plays an important role on the stability. Arcs and open type loops, as seen in Vectran (*Figure 2 e,f*) give lower stability, on the other hand closed loops, as seen in PET and PBT (*Figure 2 a,b,c,d*), introduced more stable yarn structures. The recovery from strain measurements reflect this fact clearer compared to Demir's method.

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