

EFFECT OF TOW BREAK CONDITIONS ON THE PROPERTIES OF HIGH-BULK ACRYLIC YARN

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Synthesized in the 1890s and defined as a fiber containing a minimum of 85% acrylonitrile molecules by weight, acrylic fiber is primarily used in the clothing industry, in apparel products such as sweaters, dresses, suits and children's clothing. Acrylic fibers are similar to wool in terms of high elongation and elastic recovery. These elastic properties ensure that fabrics made from acrylic and wool have a soft handle. High-bulk acrylic yarn is used for hand knitting yarn due to the soft touch. It is produced by blending relax and un-relax acrylic fiber in specific proportions and spinning them into yarn. The relaxation properties of acrylic fiber are affected by tow breaking process parameters. There are 3 main effective process parameters in the tow breaking process, including oven temperature, draw ratio and breaking tension. In this study, the effect of draw ratio on the properties of acrylic yarn in the tow breaking process was investigated. According to the results, draw ratio affected hairiness and unevenness in relaxed acrylic yarns, whereas tensile strength and softness were unaffected.

Keywords: tow breaking process, high-bulk acrylic yarn, relax and un-relax acrylic fiber, temperature, draw ratio.

INTRODUCTION

The first reported synthesis of acrylonitrile and polyacrylonitrile (PAN) dates back to the 1890s [1, 2]. Acrylic fiber is defined by the Federal Trade Commission as a fiber containing at least 85% acrylonitrile by weight [3-6]. Modacrylic fiber was defined by the

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same composition as a fiber containing 35-85% acrylonitrile group by weight [2, 3, 6]. With the development of staple fiber processes, acrylic fibers became a major competitor in markets where wool fibers were widely used. By 1963, the carpet and sweater markets accounted for almost 50% of the total acrylic production. The growth rate in the United States and Western Europe declined rapidly in the 1970s. This was due to the maturation of the wool substitute market and the loss of market share to nylon in carpets and to polyester in apparel industry. In the 1970s, acrylic fiber production capacity increased rapidly in Japan, Eastern Europe and developing countries [2]. This rapid growth had been driven by the advantages of acrylics, including their special properties such as wool-like appearance and handle, as well as the economic benefits provided by acrylonitrile's relatively low cost and ease of dyeability [3, 5]. In 2003, Turkey's annual acrylic fiber production capacity was approximately 277,000 tons. Aksa ranked second globally with a 9% market share. Additionally, Aksa operated the largest single – site production facility among all acrylic fiber manufacturers worldwide [2, 7, 8]. Currently, Aksa stands as Turkey's only acrylic fiber manufacturer and the world's largest in terms of production capacity. In 2023, Aksa announced that it had reached an annual acrylic fiber production capacity of 355,000 tons per year. Acrylic fibers are produced in various lengths depending on their end - use applications, including staple (discontinuous), filament (continuous), and tow forms [2, 4, 5, 9-12]. Due to their hydrophobic surface yet water – absorbing cross – section, they are predominantly used in staple form [9-12]. Depending on the intended application, staple fiber length may range from 25 mm to 150 mm. Fiber fineness ranges from 1 to 22 dtex, with 1.3 dtex, 2.2 dtex, and 3.3 dtex being the most commonly used values. The tow form is typically sold in packages of up to 2.2 million kilotex, depending on customer specifications [2, 5, 13, 14]. The cross – sectional appearance of acrylic fibers varies depending on the drawing conditions [3]. The surface of acrylic fibers is fibrillar, and the size of the fibrils varies according to the spinning process and the type of solvent used during this process [2]. The longitudinal cross -sectional appearance of acrylic fibers is smooth, crimped, and striated [4].

Acrylic fibers are similar to wool in terms of their high elongation and elastic recovery. These elastic properties contribute to a soft handle in fabrics made from both acrylic and wool. Although the tensile strength of acrylic is significantly lower than that of other synthetic fibers, it is higher than that of wool [2, 4, 5].

Polyacrylonitrile fibers are hydrophobic [3]. The moisture content of the fiber, a key factor affecting wear comfort, is approximately 2%, which is lower than that of cotton fibers (7%) and wool fibers (14%), resulting in lower comfort performance [2,5]. Due to their low moisture absorption, acrylic fibers also exhibit low electrical conductivity [2, 5, 9-12]. Among the prominent chemical properties of acrylic fibers are their strong resistance to sunlight and microorganisms [2-5]. One study found that acrylic fibers resist degradation eight times longer than olefin fibers, five times more than cotton and wool, and nearly four times more than nylon [2, 15]. Additionally, acrylic fibers show resistance to the majority of biological and chemical agents [2-4].

The main markets for acrylic fibers are apparel, home textiles, and outdoor fabrics. In the apparel sector, they are used in various knitted outerwear products such as sweaters, dresses, suits and children's clothing. Another important market for acrylic includes hand - knitting yarn, deep - pile fabrics and short socks [2, 5, 9-12].



Polyacrylonitrile fibers are also used in the production of blankets, rugs and carpets due to their good heat retention capacity (similar to wool), high resilience, low specific gravity and wrinkle resistance. In addition, due to these properties, they are utilized in places where wool fibers are especially used, in the production of knitwear and curtains, as well as in outdoor applications such as sunshades, tents and tarps, and in automotive upholstery (such as car covers), owing to their excellent resistance to sunlight [2, 3, 5].

MATERIALS AND METHODS

Within the scope of the study, 4 different machine drawing ratios were applied to 5-denier relax – un-relax acrylic tow in the tow breaking machine. The two drawing zones and the oven temperature were kept constant. The oven temperature was set to 130 °C, while the 4th drawing zone (E₄) and the 5th drawing zone (E₅) were adjusted to 1.32 and 1.47, respectively, as shown in Figure 1.

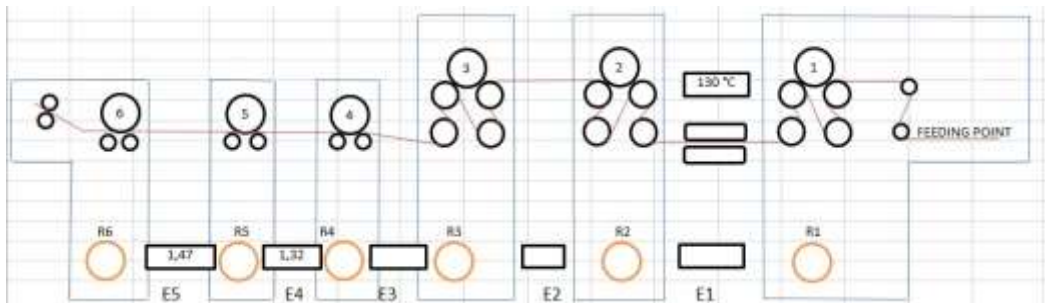


Figure 1. The oven temperature and the drawing zones in the tow breaking machine.

The fibers, in bump form, were dyed using the H. Krantz Marchinenbalt - 51 Aachen (2003) brand machine. The dyeing conditions are presented in Figure 2.

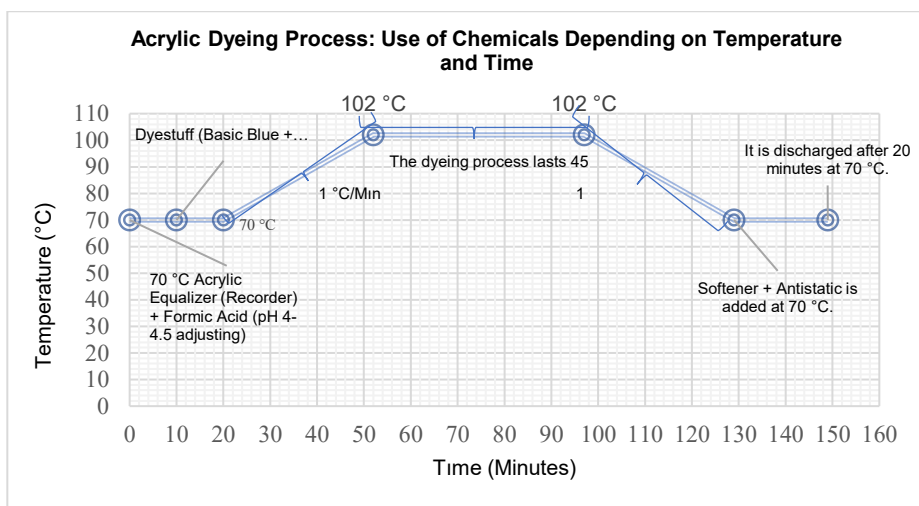


Figure 2. The conditions for dyeing acrylic fiber [16]

Following the dyeing process, the fibers were subjected to a dewatering treatment through vibration – assisted squeezing in a centrifuge machine (Oğuz Machine, 2000 model) operating at a rotational speed of 1200-1500 rpm (turns/min) for 45 minutes. Subsequently, drying was carried out in an RF – type drying machine (Sonar, 2004 model) at a temperature of 50 °C and a line speed of 18 meters per minute.

After these pre – treatment steps, the fibers were converted into drawing sliver form through a four-passage drawing process using GC 30 (NSC N. Scumberger, 2015 model) drawing machines.

The drawing slivers, which were thinned and homogeneously blended through the drafting process, were processed into single – ply yarn with a linear density of 12 Nm using a semi-worsted ring spinning system on an HDB (Houget Duesberg Bosson, 1992) model machine. During the spinning process, a twist of 184 Z-twist per meter was imparted to yarn.

Single-ply yarns were made into bobbins form using a 2005 model Japanese Muratec yarn cleaning machine, which simultaneously transferred the yarn and repaired ring - spinning breaks through air splicing.

There-ply hand knitting yarn was produced by plying on a HMX 132 (HemaksCo, 2021) model automatic plying machine at a speed of 450 rpm. The plied yarns were then twisted using a Volkmann (2002) model multi-ply twisting machine with the two-for-one technique, imparting 120 S-direction twist per meter, at a speed of 45 m/min and the spindle speed to 5400 rpm.

The yarns were heat-set in a Superba fixation machine using steam at 96-104 °C, providing twist stabilization and volume enhancement. They were then converted into cake form suitable for balling. Finally, the cakes were transformed into balls using a Gökhan Machine (2023) model balling machine.

To evaluate the physical and performance characteristics of the yarn samples, the following tests were conducted:



- Tensile strength and elongation were measured using the I.V. Calderara tensile tester in accordance with TS EN ISO 2062,
- Hairiness and unevenness were assessed using the Premier IQ5 device based on ASTM D1425 and ASTM D5647 standards,
- Boiling water shrinkage was determined according to ASTM D2259,
- Pilling behavior was evaluated in accordance with EN ISO 12945-1,
- Handle assessment was carried out based on expert tactile evaluation.

RESULTS AND DISCUSSION

The effects of draw ratio variation, resulting from the modification of the drawing rollers in the tow breaking machine, on the properties of acrylic yarns are presented in Table 1. An increase in the draw ratio from 1.3 to 1.47 led to a noticeable rise in the boiling water shrinkage values. This increase was attributed to the denser packing of the fibers and the enhancement of the yarn's bulk properties. This phenomenon can be explained by the water absorption properties of the staple structure used in acrylic fiber production, where moisture is absorbed through the fiber cross-section. The resistance of the fiber's outer surface to water affects the inward progression of moisture, promoting fiber swelling and consequently contributing to an increase in yarn bulk [9-12].

However, when the draw ratio was increased from 1.47 to 1.59 and subsequently to 1.64, a decrease in the boiling water shrinkage values was observed. This reduction was associated with the increased tension imposed on the fibers at higher draw ratios, which led to a loss in bulk properties. According to the available literature, the cross-sectional morphology of acrylic fibers changes depending on the drawing conditions, and this structural transformation significantly affects the bulk characteristics of the fiber [3]. In this context, as the draw ratio increases, the differential tension between the drawing rollers intensifies, resulting in a more stretched and flattened fiber structure. Consequently, the fiber's ability to create bulk is diminished, leading to a decline in the overall bulkiness of the yarn.

Variations in the draw ratio did not result in a significant change in yarn hairiness. This finding is consistent with the literature, which indicates that the surface characteristics of fibers are influenced more by the spinning method and the solvents used during processing than by the drawing conditions [2].

With the increase in the draw ratio, an enhancement in yarn tensile strength was observed, accompanied by a reduction in elongation. This can be attributed to the improved fiber alignment during drawing, which enhances tensile strength but simultaneously reduces elasticity due to increased structural rigidity. According to the literature, acrylic fibers exhibit higher tensile strength than wool, making them more durable; however, they are generally weaker compared to other synthetic fibers [2, 4, 5].



Table 1. Evaluation of all yarn and fabric properties at different machine draw ratios across tow, single yarn, plied yarn, ball, and fabric forms

Machine draw ratio	1,30 (R1:39 – R2:30)	1,47 (R1:44 – R2:30)	1,59 (R1:46 – R2:29)	1,64 (R1:46 – R2:28)
Boiling water shrinkage (tow)	21	25	23	23
	22	25	24	25
	23	26	24	23
	21	26	25	24
	22	26	25	24
Yarn hairiness (HI)	14,76	14,6	14,84	13,96
	14,54	13,8	14,5	14,84
	14,44	13,76	14,62	14,87
Yarn unevenness CVm (%)	12,85	12,7	14,46	12,68
	12,66	13,02	13,81	13,8
	13,02	14,32	14,22	13,76
Thin (-%50)	0	0	20	0
	10	10	0	0
	10	20	0	10
Thick (+%50)	20	0	0	0
	20	0	0	0
	0	0	20	0
Neps (+%200)	30	60	0	20
	20	20	20	40
	50	30	20	10
Tensile strength	540	700	540	620
	380	700	780	540
	600	540	620	700
	700	540	540	860
	540	620	700	680
	540	620	540	700
	620	540	700	720
	620	680	700	780
	780	700	620	620
	700	620	620	700
Tensile elongation	11	12	11	8
	8	12	11	11
	11	9	10	9
	10	10	9	12
	13	13	12	11
	11	11	10	10
	13	9	11	8
	12	10	12	12
	13	13	10	10
	14	13	12	10
Pilling – nope count (fabric) 7200 turns	0	0	1	2
	0	1	1	2
	0	0	1	2
Pilling - numerical test result (fabric) 7200 turns	0	0	1	2
	0	1	1	2
	0	0	1	2



Pilling - picture test result (fabric) 7200 turns	5 5 5	5 5 5	5 5 5	5 5 5
Handling (based on evaluations by 3 experts using 4 skeins from each test sample)	5/5/4/3 4/4/4/3 4/4/5/3	5/5/5/5 4/4/5/4 5/5/5/5	5/5/4/3 5/4/4/4 4/5/4/4	3/3/3/3 4/4/5/4 4/4/5/4

CONCLUSION

In this study, the effects of variations in the draw ratio – resulting from modifications to the drawing rollers of the tow breaking machine – on the properties of acrylic yarns were investigated. An increased draw ratio led to a rise in yarn tensile strength, while a reduction was observed in elongation at break. However, yarn hairiness was not significantly influenced by changes in the draw ratio.

The most prominent change was observed in the boiling water shrinkage, which was directly associated with its bulkiness characteristics. Increasing the draw ratio up to 1.47 resulted in a higher boiling water shrinkage, indicating the development of a bulkier fiber structure. However, when the draw ratio exceeded 1.47 and reached 1.59 and 1.64, a decrease in boiling water shrinkage was recorded, suggesting a loss in the fiber's bulk properties. These findings revealed that the volumetric response of acrylic fibers to the draw ratio had a threshold: while moderate increases enhanced bulkiness, exceeding this critical value led to a deterioration in bulk-related properties.

The obtained results revealed that the variation in draw ratio had significant effects not only on the strength of the yarn but also on the volumetric structure of the fiber. In particular, the adjustment of the draw ratio through the modification of the drawing rollers used in the tow breaking machine should be considered a critical process parameter in the production of acrylic yarns targeted for high bulk properties.

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Izvod

UTICAJ PROCESNIH PARAMETARA PROIZVODNJE NA SVOJSTVA AKRILNE PREDE VELIKE GUSTINE

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Sintetisano 1890-ih i definisano kao vlakno koje sadrži najmanje 85% molekula akrilonitrila po težini, akrilno vlakno se prvenstveno koristi u industriji odeće, u odevnim



proizvodima kao što su džemperi, haljine, odela i dečija garderoba. Akrilno vlakno je slično vuni po svojoj elastičnosti. Zbog ovih elastičnih svojstava, tkanine napravljene od akrila i vune su meke na dodir. Zbog svoje mekoće, akrilna pređa velike gustine koristi se za ručno pletenje. Ona se proizvodi kombinovanjem relaksiranih i nerelaksiranih akrilnih vlakana u određenim razmerama i njihovim upredanjem. Proces istezanja utiče na relaksaciona svojstva akrilne pređe. Postoje 3 glavna parametra ovog procesa, uključujući temperaturu, stepen istezanja i prekidnu silu pređe. U ovoj studiji istraživan je uticaj stepena istezanja na svojstva akrilne pređe. Prema rezultatima ove studije, stepen istezanja uticao je na svojstva relaksiranih akrilnih vlakana, uključujući maljavost i neravnomernost, dok su zatezna čvrstoća i mekoća ostali nepromenjeni.

Ključne reči: Istezanje, akrilna pređa velike gustine, relaksirana i nerelaksirana akrilna vlakna, temperatura, stepen istezanja

