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Research Article

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Implementation of Control Chart for Statistical Process Control Considering Temperature and Humidity Effect in Synthetic Staple Fiber Industry

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Abstract

The purpose of this paper is to identify various fluctuations of temperature and humidity effecting synthetic staple fibers quality such as strength and tenacity as a final finished product and address these fluctuations effect through implementation of control chart for establishing statistical process control over synthetic fiber production process. Critical observations and test results are analyzed to show that temperature and humidity effect over synthetic staple fiber quality such as strength and tenacity. Establishing statistical process control in the synthetic staple fiber processing sector is one key to improving the quality of synthetic staple fiber sector considering temperature and humidity effect. The resultant variations and fluctuations are addressed through categorizing various kinds of fiber by implementing control chart. The paper addresses the fluctuations and variations of synthetic fiber quality such as strength and tenacity due to temperature and humidity effect in the production processing of synthetic fiber industry, using control chart as an approach to solve these variations which was hardly attempted before. Strength and tenacity individually prioritized to reduce fluctuations into the entire production process system.

Keywords: Synthetic staple fiber; Control chart; Temperature; Humidity; Statistical process; Quality

Introduction

The manufacture of synthetic fibers represents a huge industry, both in the Bangladesh and worldwide. In the twenty first century, the dollar value of synthetic fibers was roughly $100 billion in the worldwide. We sometimes forget how much of these fibers we consume, especially since the appeal of "natural" fibers of cotton and wool has grown in recent years. Despite questions of aesthetics and taste, there should continue to be a significant demand for synthetic fibers, in large part because these fibers can be tailor-made to provide specific properties that natural fibers cannot provide.

Statistical methods play a vital role in the quality improvement process in manufacturing and service industries. Control charts are used to check for process stability. In this context, a process is said to be "in statistical control" if the probability distribution representing the quality characteristic is constant over time. If there is some change over time in this distribution, the process is said to be "out of control."

As students of production engineering, we are interested in implementing control chart to improve synthetic fibers quality because the process involves several fundamental aspects of production and quality control engineering. The goal here to address the fluctuations and variations of synthetic fiber quality such as strength and tenacity due to temperature and humidity effect in the production processing of synthetic fiber industry, using control chart as an approach to solve these variations which was hardly attempted before.

Synthetic Fiber Manufacturing

True synthetics are products of the polymerization of smaller chemical units into long-chain molecular polymers. Fibers are formed by forcing a viscous fluid or solution of the polymer through the small orifices of a spinneret and immediately solidifying or precipitating the resulting filaments. Synthetic fibers are produced typically by two easily distinguishable methods, melt spinning and solvent spinning [1].

For the common spinning of filaments in the finished range of about 0.1-2 tex spinnerets of a diameter 0.1-0.7 mm for melt spinning. Melt spinning is done for most polymers (PET, PP) between 240°C and 320°C [2].

Polyester fiber spinning is done almost exclusively with extruders, which feed the molten polymer under pressure through the spinnerets. Filament solidification is induced by blowing the filaments with cold air at the top of the spin cell. The filaments are then led down the spin cell through a fiber finishing application, from which they are gathered into tow, hauled off, and coiled into spinning cans. Depending on the desired product, post-spinning operations vary but may include lubrication, drawing, crimping, heat setting, and stapling [1,3].

Synthetic fiber measurement

Various units are used to refer to the measurement of a fiber, such as: the denier and tex (linear mass density of fibers), super S (fineness of wool fiber), worsted count, woollen count, cotton count (or Number English Ne), Number metric (Nm) and yield (the reciprocal of denier and tex) [4].

Denier /'or den (abbreviated D), a unit of measure for the linear mass density of fibers, is defined as the mass in grams per 9000 meters. The denier is based on a natural reference: a single strand of silk is approximately one denier; a 9000-meter strand of silk weighs about one gram.

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Denier=(weight of fiber × 9000) ÷ (number of fiber × length of fiber) (1)

Tex is a unit of measure for the linear mass density of fibers, yarns and thread and is defined as the mass in grams per 1000 meters. The unit code is "tex". When measuring objects that consist of multiple fibers, the term "filament tex" is sometimes used, referring to the mass in grams per 1000 meters of a single filament. Tex is used for measuring fiber size in many products, including cigarette filters, optical cable, yarn and fabric [5].

Tex=Denier ÷ 9 (2)

Temperature and humidity effect during polypropylene spinning

The rate of crystallization depends on the molecular weight, the history of the PP melt, and the temperature and humidity. In the Spinneret capillary there is a minor pre orientation. The major portion of the orientation is created from the outside filament portion that solidifies first in the border phase between the liquid inside portion and the solidified filament portion [2]. The temperature effect can described below:

- A hot shroud below the spinneret lengthens the freezing zone, delays the filament thinning and cooling, and increases the yarn tension;
- Cooler quench air and/or higher quench air velocity result in faster filament thinning and higher yarn tension;
- Higher spinneret temperatures result in higher yarn temperatures along the first part of the filament axis, reduce the yarn tension;
- Higher throughputs per spinneret with constant take-up speed increase the cooling time and cooling zone with little influence on the yarn tension.

Case study: The temperature and humidity effect during polypropylene (pp) spinning is studied at a synthetic fiber manufacturing company named Dird Polytex Limited. Here, the tenacity of the PP fiber increases due to lower temperature and humidity during winter from October to March and the tenacity of the PP fiber decreases due to higher temperature and humidity during summer from April to September. The data was taken from July, 2014 to May, 2015 of average monthly temperature, humidity and tenacity (Figure 1).

Control Chart

Control chart is graphical representation of the collected information. A control chart indicates whether a process is in control or out of control. It determines processes variability and detects unusual variations taking place in a process. It provides information about the selection of process and setting of tolerance limits. There are two types of control charts. They are variable and attribute chart. Variable charts involve the measurement of the job dimensions whereas an attribute chart only differentiates between a defective item and a non-defective item.

X-bar and R chart

X-bar and R chart is one kind of variable chart. X-bar chart shows changes in process and is affected by changes in process variability. R chart secures information in establishing or modifying processes, inspection procedures. X-bar and R-bar chart when used together form a powerful instrument for diagnosing quality problems [6].

$\bar{X} = \left(\sum(X1, X2 \ldots Xn)\right)/n, n$ is the number of observations (3)

$\bar{\bar{X}} = \left(\sum(\bar{X}1, \bar{X}2 \ldots \bar{X}k)\right)/k, k$ is the number of subgroups (4)

$UCL_X = \bar{\bar{X}} + A_2 \times \bar{R}$ (5)

$UCL_X = \bar{\bar{X}} - A_2 \times \bar{R}$ (6)

Range=$X_{max} - X_{min}$ (7)

$\bar{R} = \left(\sum(R1, R2 \ldots Rk)\right)/k, k$ is the number of subgroups (8)

$UCL_R = D_4 \times R$ (9)

$UCL_R = D_3 \times R$ (10)

Case study of control chart implementation

Synthetic fiber company: Table 1 shows monthly tenacity value of PP white fiber which has been recorded and among them randomly eight days value have been taken for implementation of x-bar and r chart (Table 2).

Result Analysis

Here Figures 2 and 3 depict x bar and r chart in which Figure 2 shows 4 points below lower limit and 1 point above upper limit and Figure 3 shows 4 points below lower limit and 2 points above upper limit. That means both x bar and r chart shows the process is out of control.

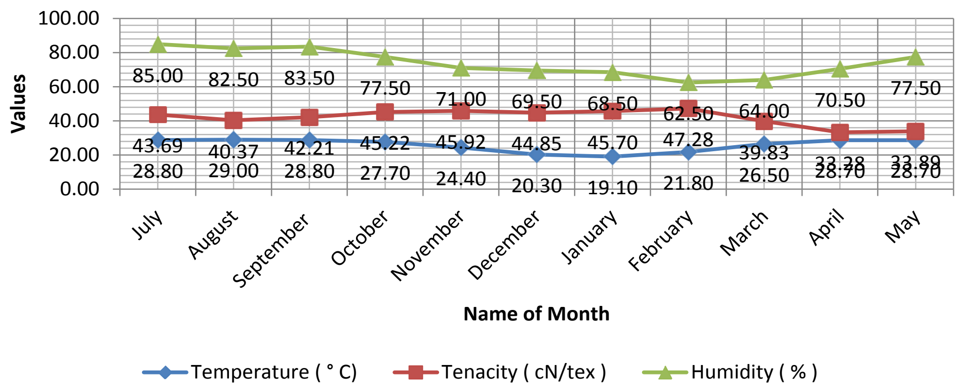

Figure 1: Temperature and humidity effect over PP fiber tenacity.

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Month	Tenacity (cN/tex)									
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	X bar	Range
July,14	39.49	47.66	46.91	38.33	45.22	42.71	43.75	45.44	43.69	7.11
August,14	37.73	42.89	35.17	36.62	38.72	42.81	45.41	43.62	40.37	8.79
September ,14	36.1	39.05	43.37	43.93	44.94	37.38	43.27	43.54	41.45	8.84
October,14	42.64	45.29	42.88	46.28	47.61	43.73	48.95	41.79	44.90	5.82
November,14	41.25	48.77	42.86	45.00	43.18	45.98	50.22	45.41	45.33	8.97
December,14	45.77	40.03	43.24	44.96	49.56	44.34	43.49	48.31	44.96	9.53
January,15	45.69	41.41	49.25	45.93	46.51	49.97	45.44	41.41	45.70	8.56
February,15	49.47	46.45	55.17	49.93	48.92	43.46	45.22	41.79	47.55	13.38
March,15	44.38	39.45	37.39	38.62	43.33	38.48	38.02	38.93	39.83	6.99
April,15	35.94	26.69	31.06	29.14	30.4	32.6	39.62	40.78	33.28	14.09
May,15	31.78	34.3	34.3	36.43	34.1	34.23	29.64	36.3	33.89	6.79
									X double bar	R bar
									44.29	8.79

Table 1: PP fiber tenacity result for eight days and calculation of x double bar and r bar through equations 3,4,7,8.

Bar chart type	Description	Formula
X bar	Upper control limit	46.80
	Upper warning limit	45.96
	Lower warning limit	42.62
	Lower control limit	41.79
Range	Upper control limit	10.53
	Lower control limit	8.53
Warning limit is the two third portion of the corresponding control limit.		

Table 2: Resultant value of x bar and r chart using previous formula of equations 5,6,9,10.

Fiber quality limit	Tenacity(cn/tex)	Fiber grade	Fiber Quality
Above upper limit	>46.8	A	Very good
Between upper warning limit to upper limit	45.96-46.8	B	Good
Between upper warning limit and mean	44.29-45.96	C	Average
Between mean to lower warning limit	42.62-44.29	D	Below Average
Between lower warning limit to lower limit	41.79-42.62	E	Bad
Below lower limit	<41.79	F	Very Bad

Table 3: A grading system of fiber quality.

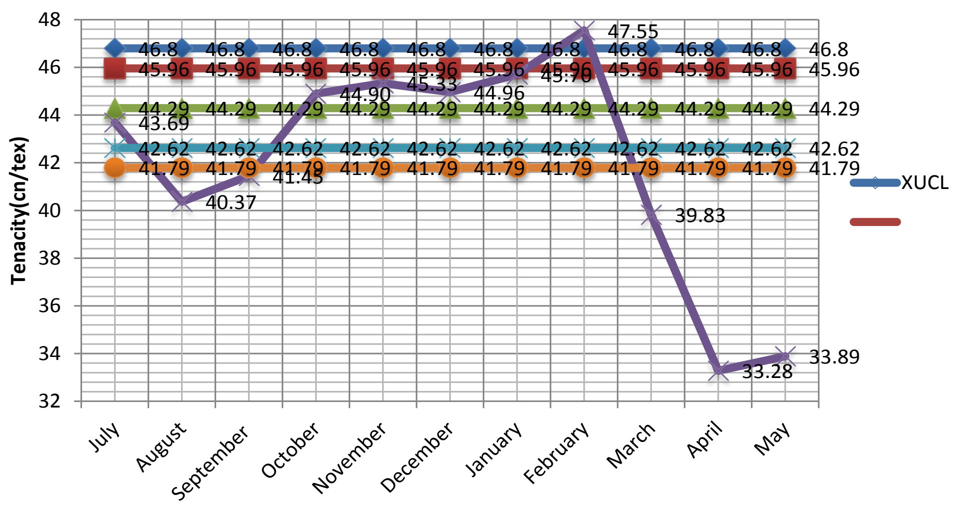

Figure 2: X-bar chart for monthly average PP fiber tenacity.

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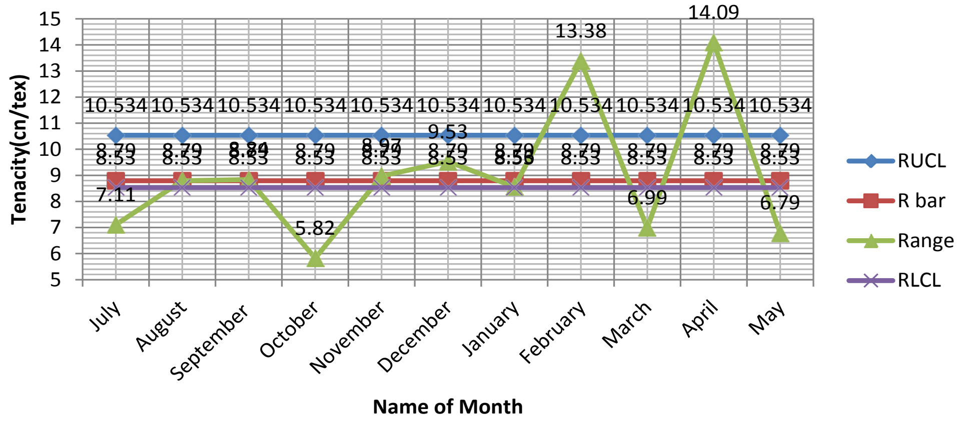

Figure 3: R chart of PP fiber tenacity.

As the corresponding figure shows the process is out of control, this happens due to variation of temperature and humidity across the year 2014-15. The weather phenomena cannot be controlled so to solve this problem. A proper grading system is developed for different quality fibers in Table 3 according to the x bar chart (Appendix A).

Conclusion

There is significant effect of temperature and humidity over synthetic staple fiber production process. Control chart is applied to categorize various kinds of synthetic staple fiber considering temperature and humidity effect for establishing statistical quality control over synthetic fiber production process. The paper addresses the fluctuations and variations of synthetic fiber quality such as strength and tenacity due to temperature and humidity effect in the production processing of synthetic fiber industry.

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