(REFEREED RESEARCH)

A STATISTICAL AND EXPERIMENTAL INVESTIGATION ON PRODUCT DESIGN FOR COPOLYMER BASED MULTICHANNEL POLYESTER DRAW TEXTURED YARNS

KOPOLİMER ESASLI MULTİKANAL POLYESTER TEKSTÜRE İPLİK ÜRÜN TASARIMINDA İSTATİSTİKSEL VE DENEYSEL ARAŞTIRMA

Işık İ. İLBAY
Dow Chemical Iberica SL
Research and Development
Tarragona, Spain
e-mail: iilbay@yahoo.com

Nihat ÇELİK
Çukurova University
Textile Engineering Department

ABSTRACT

Polyester yarns, the most important synthetic fibers produced via melt spinning process, increase its volume every year in textile world. The copolyesters such as ionic dyeability together with modified cross sections for speciality market, create additional benefits like better hand feel and high fastness dyeability with cationic dyes as well as moisture management capability via increased surface of multi channel cross section. On the other hand, spinnability increases with an increase in cohesive energy density. Conversely, any additive present in the polymer such as sulfoisophthalic acid for cationic dyeability (cat dye) causing a decrease in cohesive energy density of the melt would decrease the spinnability of the polymer. In addition to lowered cohesive energy density, modified cross section to a multi channel concept decreases the tensile properties as well. Therefore the goal of this work is to design and develop cationic dyeable multi channel textured yarn as speciality product via implementing statistical and experimental studies on texturing process to design a commercially acceptable product which will further give high margin. To achieve this goal, the DOE; Design of Experiments and Response Surface Methodolgy have been used. Design of Experiments and Response Surface Methodology are difficult for researchers to implement in practice on Industrial Engineering and Statistics science, therefore the studies had remained theoretical and applied research of these methods are very rare or nearly zero in Textile Engineering area. The main goal of this work is to reach to the scientific and optimal solution in a shortest time on value added product design in textile industry and enlight to future developments with this approach via implementing Response Surface Methodology. The studies were carried out in Advansa SASA Polyester Industries Inc. R&D Center.

Key Words: Design of experiment, Response surface methodology, Polyester, Texturing, Yarn.

ÖZET

Eriyikten lif çekimi ile üretilen polyester iplikler, her yıl tekstil dünyasındaki hacmini artırmaktadır. Özel ürün piyasası için modifiye kesitli ve iyonik boyanabilirliğe sahip kopolyesterler daha iyi tuşe, katyonik boyanabilirliğin getirdiği daha iyi renk haslıkları ve multi kanallı kesitin sağladığı daha yüksek yüzey sayesinde nem transferi avantajlarını sağlamaktadırlar. Öte yandan, eriyikten lif çekimi koheziv enerji yoğunluğu ile doğru orantılı olarak artmaktadır. Tam tersine, polimerde bulunan, örneğin katyonik boyanabilirlik (cat dye) için kullanılan sülfoizoftalik asit gibi herhangi bir katkı maddesi koheziv enerji yoğunluğunu düşürmekte ve bu da lif çekimini; tabiatıyla filamentin üretilebilirliğini düşürmektedir. Kohesiv enerji yoğunluğuna ek olarak, multikanallı modifiye kesit, filamentin mukavemet özelliklerini negatif yönde etkilemektedir. Dolayısıyla bu çalışmanın amacı; tekstüre prosesinde istatistiksel ve deneysel çalışmalar yapılarak, özel ürün piyasası için yüksek marjine sahip ticari olarak kabul edilebilir katyonik boyanabilir multikanallı tekstüre iplik tasarımını yapmaktır. Bu hedefe ulaşmak için DOE (Design of Experiments, Deney Tasarımı) ve Tepki Yüzeyi Metodolojisi (Response Surface Method) kullanılmıştır. Deney Tasarımı ve Tepki Yüzeyi Metodolojisi; araştırmacılar için uygulama zorluğu nedeniyle Endüstri Mühendisliği ve İstatistik biliminde genelde teoride kalmış olup, Tekstil Mühendisliği'nde ise uygulamalı araştırması yok denecek kadar azdır. Bu araştırmanın ana hedefi, tekstilde katma değeri yüksek ürün tasarımlarında Tepki Yüzeyi Metodolojisinin uygulanarak bilimsel ve optimal çözüme daha kısa sürede ulaşılmasını sağlamak ve gelecek çalışmalara ışık tutmaktır. Çalışmalar Advansa SASA Polyester Sanayi A.Ş. Adana, ARGE Merkezi'nde gerçekleştirilmiştir.

Anahtar Kelimeler: Deney tasarımı, Tepki yüzeyi metodolojisi, Polyester, Tekstüre, İplik.

Received: 05.01.2009 Accepted: 14.09.2009

1. INTRODUCTION

An engineer is someone who solves problems of interest to society by the efficient application of scientific principles. Engineers accomplish this by either refining an existing product or process or by designing a new product or process that meet customers' needs. The steps in the engineering method are shown in Figure 1. Notice that the engineering method features a strong interplay between the problem, the factors that may influence its solution, a model of phenomenon, and experimentation to verify the adequacy

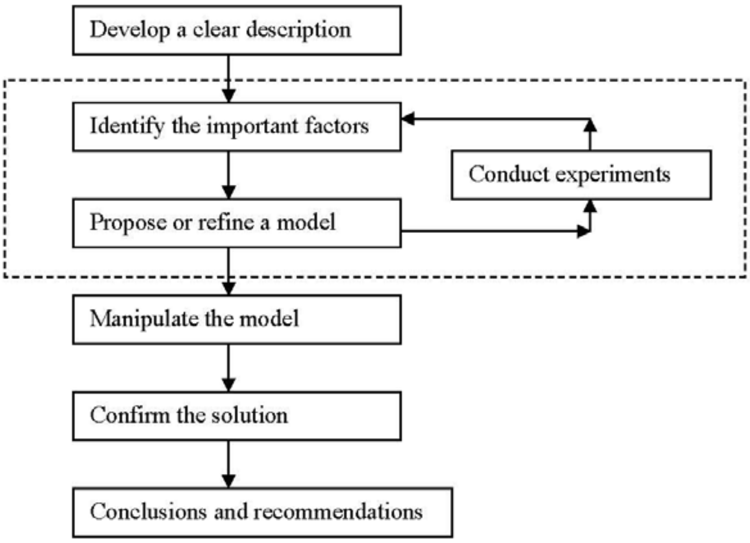

Figure 1. The problem solving method (1)

of the model and the proposed solution to the problem. The field of statistics deals with the collection, presentation and use of data to make decisions, solve problems, and design and products and processes. Because many aspects of engineering practice involve working with data, obviously some knowledge of statistics is important to any engineer (1).

An experiment is just a test or series of tests. Experiments are performed in all engineering and scientific disciplines, and are an important part of the way we learn about how systems and processes work. Some applications of experimental design techniques are; development of new processes, in new product design and optimization (1).

The traditional approach, which most of us learned is to hold all factors constant except one. When this approach is used we can be sure that the variation is due to a cause and effect relationship. However this approach suffers from a number of problems (i.e. it usually is not possible to hold all other variables constant. There is no way to account for the effect of joint variation of independent variables, such as interaction. There is no way to account for experimental error, including measurement variation and etc.)

The statistically designed experiment usually involves varying two or more variables simultaneously and obtaining multiple measurements under the same experimental conditions. The advantage of the statistical approach is as below;

1. Interactions can be detected and measured. Failure to detect interactions is a major flaw in the “one factor at a time” approach.
2. Each value does the work of several values. A properly designed experiment allows you to use the same observation to estimate several different effects. This translates directly to cost savings when using the statistical approach (2).

Also similar to Response Surface Methodology, expert systems have been adopted to provide substantial support in the textile industry. These systems are computer models of human expertise in a specific domain of work. They are capable of offering advice and decision-support related to specific problem-solving in a well-defined knowledge domain. An expert system acts like an expert consultant, asking for information, applying this information to the rules it has learned and drawing conclusions (3).

In this study, we focused on new product design for commercialization and in order to cover all factors’ effects on the product properties; response surface methodology is used. Response Surface Methodology, or RSM, is a collection of mathematical and statistical techniques that are useful for modeling and analysis in applications where a response of interest is influenced by several variables and the objective is to optimize this response.

Response dependent variable; y in RSM, is a function of independent variables of $\xi_1,\xi_2,\ldots,\xi_k$.

$$y = f(\xi_1,\xi_2,\ldots,\xi_k) + \varepsilon \qquad [1]$$

ε, is the observed error, y is response variable. It is assumed that this term has normal distribution with zero average and σ^2variance. Expected response is:

$$E(y) = \eta = E[f(\xi_1,\xi_2,\ldots,\xi_k)] + E(\varepsilon) \qquad [2]$$

$E(\varepsilon) = 0$ hence the response surface will be;

$$\eta = f(\xi_1,\xi_2,\ldots,\xi_k) \qquad [3]$$

$\xi_1,\xi_2,\ldots,\xi_k$ are real variables. If these terms explained in coded terms, the response surface will be;

$$\eta = f(x_1,x_2,\ldots,x_k) \qquad [4]$$

Response surface methodolgy is applied in below orders:

a. Method of steepest ascent

Frequently, the initial estimate of the optimum operating conditions for the system will be far from the actual optimum. In such circumstances, the objective of the experimenter is to move rapidly to the general vicinity of the optimum. The method of steepest ascent is a procedure for moving sequentially along the path of steepest ascent, that is, in the direction of the maximum increase in the response. The fitted first order model is;

$$y = \beta'_0 + \sum_{i=1}^{K} \beta'_i x_i \qquad [5]$$

and the first order response surface (1). Once optimal region is reached, then a new experiment should be conducted, this is a second order response surface in our development.

b. Analysis of a second order response surface

When the experimenter is relatively close to the optimum, a second order model is ususally required to approximate the response because of curvature in the true response surface. The fitted second order model is;

$$y = \beta'_0 + \sum_{i=1}^{k} \beta'_i x_i + \sum_{i=1}^{k} \beta'_{ii} x_i^2 + \sum_{i} \sum_{j(i<j)} \beta'_{ij} x_i x_j + \varepsilon \quad [6]$$

where *β'* is the least squares estimate of *β*; the regression coefficient (1).

c. Response optimisation

Response optimisation is used for adjusting the factors that will optimise the single response or response group. Response optimisation is used in general to set and fine tune the process settings for the products that have desired properties. First of all, the parameters, so called factors are defined with desired descriptions such as target, minimum or maximum, then required datas are set with importance priorities. Based on the local and global desirabilities, required parameters can be reached via changing the factor settings according to software's proposals, suggestions. Local and/or global desirability can be justified by the experimenters. The value 1 represents the maximum desirability, the higher value of desirability indicates the success on the requirements on the experienced products.

2. MATERIAL AND METHOD

The studies were carried out in Advansa SASA Polyester Industries Inc., Research and Development Center. In this experiment, 133 decitex (mass of 10000 meters of yarn in grams) single ply, 47 filaments, semi-dull cationic dyeable POY (Partially Oriented Yarn) was used. Polyester has no dye attachment sites for chemically active dyes. It is possible to add ionic dyeability by forming copolymers of polyester with monomer species those posess active sites, for example, on a pendant side chain. The most common of these has been the incorporation of a sodium salt of a cicarboxylic acid, e.g. of 5-sulfoisophtalic acid (Figure 2).

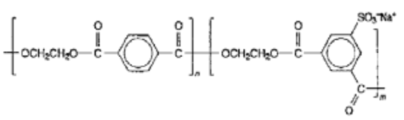

Figure 2. Structure of a PET copolymer with sulfoisophtalic acid, used for cationic dyeable fibers

The acidic sulfo group allows the attachment of cationic dye molecules (4). Filament intrinsic viscosity is 0.644 dl/dg and TiO_2 content is 0.3 %. Filament cross section is six channels as it is shown in Figure 3. The logic behind the multichannel cross section approach is moisture management capability via increasing the surface area of yarn. The property of POY is given in Table 1.

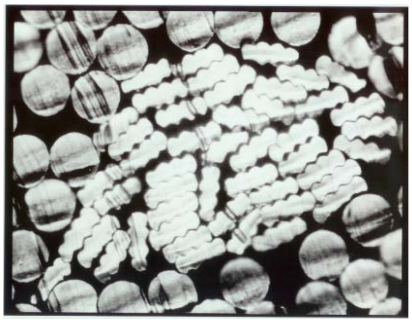

Figure 3. Six channels, 47 filaments, 133 decitex POY cross section

Targeted final textured yarn linear density is 90 decitex. Nominal texturing process settings were shown in Table 2 and comparative properties of commercial homopolymer six-channels and cationic dyeable round cross section POYs are given in Table 3.

Experiments were performed in a short heater high speed Barmag FK-6 1000 V type false twist draw texturing machine as it can be seen in Figure 4. Textured yarn is a generic term for filament yarns that have been given notably greater apparent volume than conventional yarn of similar filament number and linear density. The apparent increased volume is achieved through physical, chemical or heat treatments, or a combination of these. The process we used for this experiment is, one of the thermo mechanical texturing techniques which is false twist texturing. The basic requirements of thermo mechanical texturing technique are;

i. Heat the thermoplastic filament above glass transition temperature by primary heaters.

ii. Deform the filaments to the desired shape by twisting with friction discs.

iii. Cool the filaments below glass transition temperature while they are held in the desired shape.

iv. Rearrange the cooled filaments so that they occupy a greater volume.

Table 1. Comparison of the properties of six channel cationic dyeable (cat-dye) and homopolymer Partially Oriented Yarns (POY)

	Test Method	133f47 six channel cat-dye	133f47 six channel homopolymer
Linear density dtex	ASTM D1577-96	133,9	133
Tenacity Cn/dtex	BS EN ISO 2062, 1995	1,42	2,1
Elongation %	BS EN ISO 2062, 1995	120,7	130
Draw tension cN	ASTM D 5344-99, 2005	66,50	66

Table 2. Homopolymer DTY (Draw Textured Yarn) nominal texturing process conditions

Production speed	500 m/min
Draw ratio	1,63
D/Y	1,80
Disc configuration	1-4-1
Disc type	Polyuretane (PU)
Primary heaters Secondary heater	315 / 295 ºC 150ºC
CI IMG CI IMG Pressure	off off
IMG Pressure	1,4 bar
Taper angle	80º
Twist direction	S

Table 3. Comparison of textured yarn properties according to homopolymer texturing process conditions and properties of cationic dyeable (cat-dye) textured yarn according to method of steepest ascent

Properties	Test Method	Homopolymer textured yarn	Cat-dye textured yarn*
Linear density, dtex	ASTM D1577-96	88,00	100,80
Tenacity cN/dtex	BS EN ISO 2062	3,92	1,20
Elongation %	BS EN ISO 2062	30,44	14,00
CC %	DIN 53840, 1983	14,62	7,98
CM %	DIN 53840, 1983	8,40	4,31
CS %	DIN 53840, 1983	76,54	37,32
S %	ASTM D4031	3,00	3,42

*500 m/min production speed, 1,40 draw ratio, 250ºC temperature.

Figure 4. Barmag FK6 1000 pilot texturing machine

This process also requires a draw while the yarn is heated for deformation. Continuous intermingling (CI IMG) is applied before feeding the feed yarn to heaters in order to ordering the filament bundle in more circular shape to increase its heat strength. This operation reduces yarn bundle weakness and prevents breaks especially speciality products.

The factors in texturing process was selected as yarn speed in meter per minute, draw ratio, disc order configuration, first heater temperature, D/Y ratio (disc speed / yarn speed) and CI (Continuous Intermingling) pressure in bar.

Experimental design is conducted according to Response Surface Methodology; RSM. Software used for the design and analysis is Microsoft Minitab and the design order together with test results (responses) is shown in Table 4. Response surface method was executed according to three levels with six factors. If this evaluation would be set up with a full factorial experiment; 3^6=729 runs should have been performed. This design, especially considering a plant's availability in practice, we would say that it is not possible to handle regarding both timing and economics. During this product development study, a statistical experimental design is used according to response surface method which is central composite design and 54 runs were set up. Each run is an output of texturing of two POY feed stocks and their textured yarns.

Decitex which is the yarn mass in grams per 10.000 meters is used as linear density via using a reel and scale according to ASTM D1577-96.

Tensile tests determine the overall strength of the yarn by measuring its resistance to stretching when pulled in one direction (5). Tensile properties of a draw textured yarn are directly related with supply yarn used. Therefore there is little that texturizer can do (6). This study aims to show how a textured yarn can be industrially commercial via application of design of experiments by concerning the joint effects of all factors to the responses. In practice, polyester textured yarns for apparel end use need to have minimum 1,5 cN/dtex tenacity and 20 % elongation at break values based on industrial feedbacks and commercial products. Uster Tensorapid 3 is used for tensile property measurements.

The quality of textured yarn is measured by its crimp properties as these have a profound influence on fabric quality. The German Standard DIN 53840 for the measurement of crimp properties is usually the method followed by major textured yarn manufacturers. This standard specifies a method of determining crimp contraction (CC %), crimp module (CM %) and mechanical crimp retention (CS %). The crimp contraction is then the reduction in length of a textured filament yarn as a result of its crimped structure when the crimp is developed. The crimp module characterizes the elongation behavior of a textured yarn in the range of crimp elasticity. The mechanical crimp retention indicates the crimp contraction of a textured filament yarn following a defined tensile strain (5). The textured yarn shrinkage (S %) is measured according to ASTM D4031 (6).

Table 4. Factors and response measured values according to response optimization

Run Order	Speed mpm	Draw Ratio	D/Y	First Heater Temperature ºC	Disc Config	CI IMG pressure bar	Dtex	CC%	CM%	CS%	Shrinkage %	Tenacity cN/dtex	Elongation %
1	600	1,6	1,7	210	6	0	91,0	6,12	2,90	39,35	4,49	1,60	14,74
2	600	1,4	1,7	210	6	1,6	96,9	4,45	1,24	33,89	5,28	1,75	31,27
3	500	1,5	1,8	200	5	0,8	93,8	4,45	3,44	77,91	4,40	1,68	18,08
4	600	1,4	1,9	190	6	1,6	96,8	4,88	0,60	32,50	5,71	1,79	29,54
5	400	1,6	1,9	190	6	1,6	91,7	9,26	4,75	67,52	3,84	1,45	16,20
6	400	1,4	1,7	210	6	0	97,5	7,34	4,38	44,35	3,30	1,43	16,30
7	600	1,4	1,7	190	4	1,6	96,7	6,03	3,87	44,70	4,51	1,83	33,69
8	500	1,5	1,8	200	5	0,8	93,8	8,61	4,99	55,80	4,74	1,63	17,02
9	600	1,6	1,9	190	6	0	90,5	6,14	1,74	17,21	5,46	1,59	15,70
10	400	1,6	1,7	190	4	1,6	91,3	6,84	4,20	38,32	4,03	1,61	14,24
11	400	1,4	1,9	210	4	0	97,6	7,99	3,53	2,75	3,89	1,46	15,69
12	400	1,6	1,7	210	6	1,6	91,2	6,05	2,25	21,37	5,51	1,46	12,99
13	600	1,4	1,9	210	4	1,6	97,2	6,00	3,29	47,81	4,03	1,87	30,84
14	600	1,6	1,7	190	4	0	90,6	5,71	1,18	18,02	5,15	1,82	17,88
15	400	1,6	1,9	210	4	1,6	92,1	7,61	4,34	54,04	4,21	1,36	11,77
16	400	1,4	1,7	190	4	0	97,4	5,92	2,90	27,05	4,47	1,69	21,61
17	600	1,6	1,9	210	4	0	91,3	4,25	2,97	41,49	4,48	1,70	16,07
18	500	1,5	1,8	200	5	0,8	94,2	9,98	6,81	65,16	3,56	1,58	17,21
19	500	1,5	1,8	200	5	0,8	94,2	5,09	1,57	20,39	5,13	1,57	16,88
20	400	1,4	1,9	190	6	0	97,2	6,03	2,32	28,52	4,63	1,58	21,44
21	500	1,5	1,8	200	4	0,8	94,0	5,10	1,82	35,87	5,00	1,67	17,15
22	500	1,6	1,8	200	5	0,8	91,2	5,60	3,05	47,58	4,36	1,56	14,55
23	500	1,5	1,7	200	5	0,8	93,9	5,33	2,13	34,05	4,45	1,62	16,88
24	500	1,5	1,8	200	5	0,8	94,2	6,59	2,01	33,16	4,41	1,63	17,48
25	500	1,5	1,9	200	5	0,8	94,7	6,21	3,46	49,28	4,16	1,62	17,51
26	500	1,4	1,8	200	5	0,8	97,1	5,12	1,78	27,09	3,88	1,72	23,17
27	500	1,5	1,8	210	5	0,8	94,1	6,31	3,34	39,05	4,59	1,54	15,91
28	600	1,5	1,8	200	5	0,8	93,7	7,35	3,48	35,28	3,79	1,83	22,98
29	500	1,5	1,8	190	5	0,8	93,6	5,03	1,71	28,96	3,09	1,67	18,42
30	400	1,5	1,8	200	5	0,8	94,6	6,65	3,47	43,62	6,45	1,54	16,00
31	500	1,5	1,8	200	6	0,8	94,4	6,71	3,72	37,39	3,93	1,56	17,08
32	500	1,5	1,8	200	5	0	94,3	6,07	2,83	38,80	4,37	1,68	17,62
33	500	1,5	1,8	200	5	0,8	94,3	5,83	2,90	37,46	4,43	1,68	18,08
34	500	1,5	1,8	200	5	1,6	94,6	5,92	2,75	38,02	4,43	1,72	17,55
35	400	1,6	1,9	190	4	0	91,2	5,09	1,90	37,59	5,15	1,58	13,97
36	500	1,5	1,8	200	5	0,8	93,6	6,03	2,67	38,58	4,49	1,65	17,22
37	500	1,5	1,8	200	5	0,8	94,4	6,13	2,92	37,99	4,46	1,56	16,06
38	600	1,4	1,9	210	6	0	96,9	5,13	1,88	35,67	5,10	1,79	25,86
39	600	1,4	1,7	210	4	0	97,4	4,70	1,08	27,34	5,62	1,70	25,51
40	400	1,6	1,7	190	6	0	91,2	6,17	3,09	41,66	4,22	1,50	14,10
41	600	1,6	1,7	210	4	1,6	91,2	5,79	2,33	42,07	5,69	1,65	15,29
42	400	1,4	1,9	210	6	1,6	97,6	8,82	5,57	50,71	3,48	1,65	21,66
43	400	1,6	1,9	210	6	0	91,5	8,32	5,03	54,18	3,60	1,41	15,58
44	500	1,5	1,8	200	5	0,8	94,3	5,96	2,56	36,90	4,47	1,60	16,89
45	400	1,4	1,7	210	4	1,6	97,4	7,37	3,65	50,35	4,54	1,49	16,37
46	500	1,5	1,8	200	5	0,8	94,2	6,08	2,88	37,92	4,45	1,64	17,19
47	600	1,4	1,9	190	4	0	96,5	3,04	-0,12	-13,09	6,91	1,83	30,47
48	400	1,4	1,9	190	4	1,6	97,9	4,56	1,24	27,69	4,77	1,68	22,27
49	600	1,6	1,9	210	6	1,6	91,5	7,52	4,39	43,21	4,61	1,59	17,02
50	600	1,4	1,7	190	6	0	96,6	3,30	0,13	4,42	5,92	1,78	29,52
51	400	1,4	1,7	190	6	1,6	97,8	5,61	2,40	34,59	3,71	1,66	20,51
52	600	1,6	1,9	190	4	1,6	90,6	3,84	0,74	8,66	6,13	1,91	20,46
53	600	1,6	1,7	190	6	1,6	90,4	4,70	1,26	21,31	5,11	1,74	17,10
54	400	1,6	1,7	210	4	0	91,6	7,55	4,19	55,26	4,88	1,38	10,55

3. RESULTS AND DISCUSSION

In this study, the effects of the 6 factors on 7 responses are investigated. Table 1 shows the comparative POY properties of both six channel cationic dyeable and hompolymer 133 decitex 47 filament yarns. As it can be easily realized that the tensile properties of cationic dyeable multichannel POY is significantly lower and this prevents conversion to commercial textured yarn due to the low tensile properties and potential processing problems such as breaks.

Table 3 shows the textured yarn comparative properties of six channel homopolymer and cationic dyeable POY. As it is previously explained, according to the method of steepest ascent, an assumption is made to understand the initial responses at 250°C first heater temperature and 1.4 draw ratio. The application of steepest ascent method indicates that the tensile properties are significantly lower than a target of 1.5 cN/dtex tenacity and 20% elongation (actual values are 1.2 cN/dtex tenacity and 14% elongation).

According to 54 runs, a response optimization was evaluated and finally a set of textured yarn properties were reached based on the targeted values with their importance levels (priorities) shown in Table 5 for second optimization. During this design, first priority responses are accepted as linear density, tenacity and elongation because these values are primary factors for yarn validation. Second degree priorities were set on crimp and shrinkage properties (CC %, CS %, CM % and S %) which are mainly related with yarn volume and visual structure. These secondary importance responses can be fine tuned once the product is available for commercial scale according to its tensile properties.

Figure 5 indicates the effects of the factors on responses and suggested process settings. These graphs show the interactions between factors and responses and optimal desirability. If Figure 5 is analyzed in detail, it can be concluded that the optimal solution is acceptable commercially. But, if further detailed investigation is made on this solution, the texturing speed has effect as primary importance on decitex, tenacity and elongation values. Therefore, suggested 597 mpm speed was increased to 600 mpm in order to improve individual desirability values. Because, decitex is at the lowest value as it can be, tenacity and elongation values are on the maximum levels under the solution perspective. This situation is the same at D/Y ratio and disc configuration settings. But, any intention on decreasing draw ratio to increase tenacity and elongation will effect negatively of yarn linear density; that means the yarn will become coarser. If the temperature is decreased to 198°C, tenacity and elongation values will increase. It can be concluded that increase on Continuous Intermingling (CI IMG) pressure will have positive impact on increase of tensile properties based on the outcomes of the response

Table 5. Target values and optimal solution of second optimization according to response optimization

	Goal	Minimum	Target	Maximum	Priority
DTEX	Target	90,0	95	100,0	1
CC%	Target	6,0	7	8,0	2
CM%	Target	2,0	3	4,0	2
CS%	Target	40,0	45	50,0	2
SHRINKAGE %	Target	5,0	6	7,0	2
TENACITY cN/dtex	Target	1,6	2	2,4	1
ELONGATION %	Target	18,0	23	28,0	1

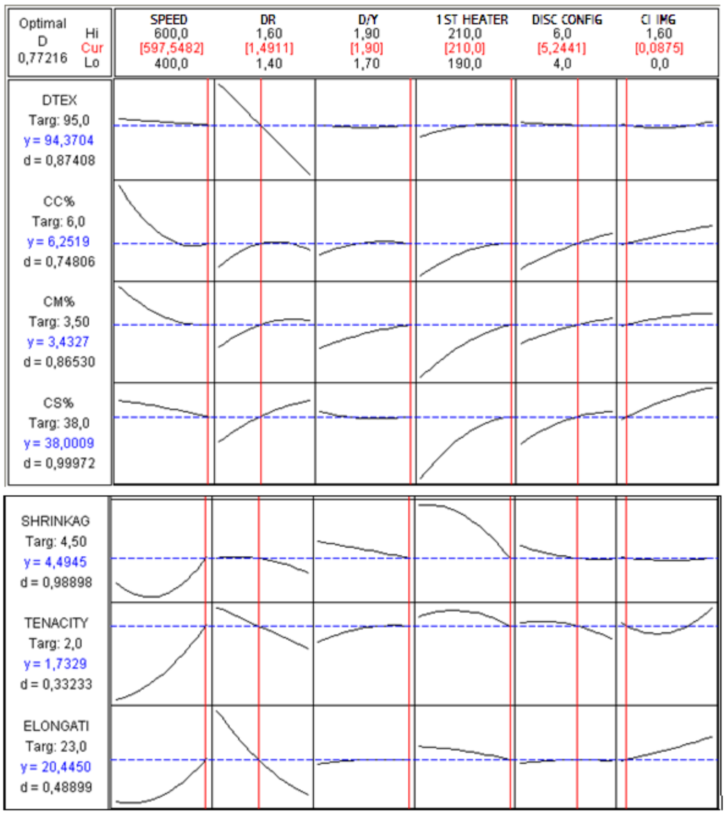

Figure 5. Relations between factors and responses including suggested process conditions (factors) and expected product properties (responses) according to response optimization (first optimization).

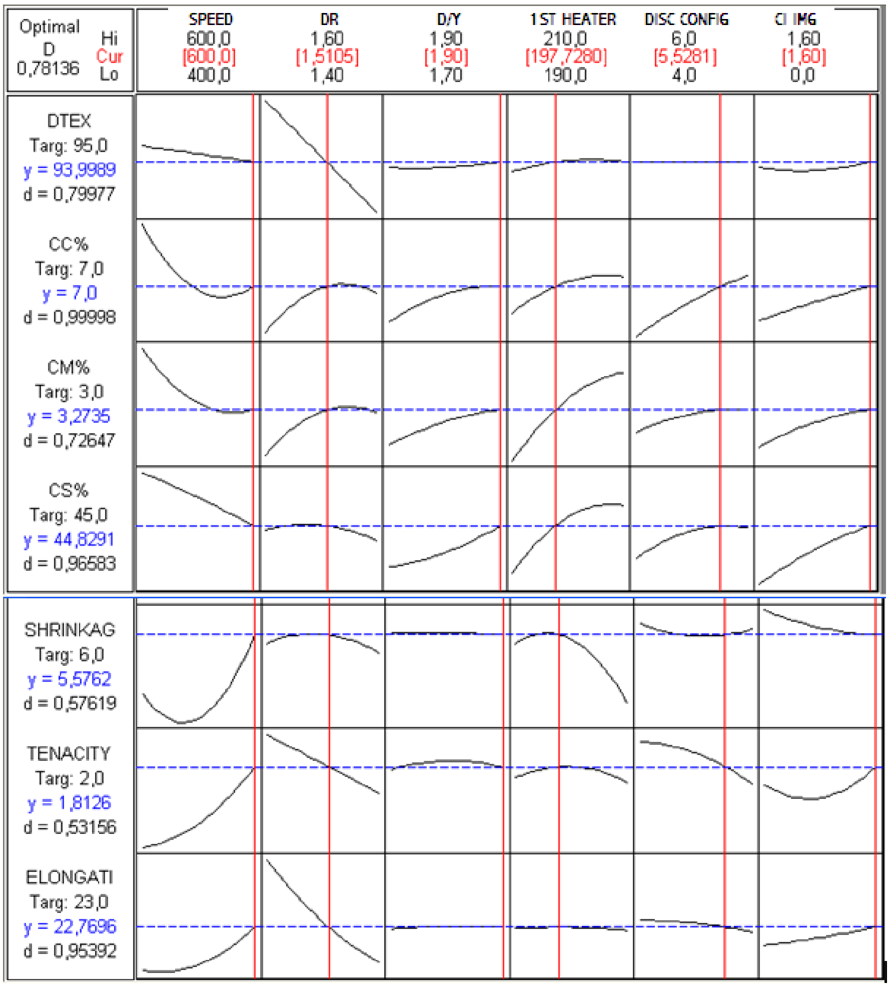

Figure 6. Relations between factors and responses including suggested process conditions (factors) and expected product properties (responses) according to response optimization (second optimization).

Table 6. Comparison of optimised conditions of 133f47 six channel cationic dyeable and nominal conditions

Process conditions	Nominal conditions	Optimized conditions (first optimization)	Optimized conditions (second optimization)
Production speed	500 m/min	597 m/min	600 m/min
Draw Ratio (DR)	1,63	1,49	1,51
D/Y	1,80	1,90	1,90
Disc configuration	1-4-1	1-5-1	1-5-1
Disc type	Polyuretane (PU)	Polyuretane (PU)	Polyuretane (PU)
Primary heaters **Secondary heater**	315 / 295 ºC 150ºC	210 / 205 ºC 150ºC	197 / 192 ºC 150ºC
CI IMG **CI IMG Pressure (bar)**	off off	on 0,08	on 1,60
IMG Pressure	1,4 bar	0,6 bar	0,6 bar
Taper angle	80º	80º	80º
Twist	S	S	S

optimizations. As a result, composite desirability was increased to 0.78 from 0.77 by second optimization as it can be seen in Figure 6.

Table 6 shows the optimized texturing process settings for 133f47 six channel cationic dyeable and nominal settings for homopolymer POY. This comparative dataset indicate that the process settings are quite different from each other concerning temperatures, draw ratios, D/Y ratios,

Table 7. Textured yarn properties from method of steepest ascent, first and second optimizations and design of experiment predictions of first and second optimizations.

Properties	Method of steepest ascent values	Prediction of design of experiment (First optimization)	Actual values according to first optimization	Prediction of design of experiment (Second optimization)	Actual values according to second optimization
Linear density dtex	100,80	94,37	94,80	93,99	94,95
Tenacity cN/dtex	1,20	1,73	1,57	1,81	1,76
Elongation %	14,00	20,45	19,12	22,76	21,38
CC %	7,98	6,25	5,28	7,0	5,10
CM %	4,31	3,43	2,20	3,27	1,72
CS %	37,32	38	16,45	44,83	26,99
S %	3,42	4,49	4,27	5,58	4,37

disc configurations, IMG and CI IMG pressures. Table 7 shows the response values from the steepest ascent method, first and second optimization predicted values from the response surface design and response optimizer and the actual measured values from the suggested (predicted) process settings.

Finally, we can conclude that the response estimations according to the factor settings that were provided from response surface method and actual responses from the application of suggested factor settings are identical with minor differences. Therefore, the product properties are acceptable in commercial point of view.

As a result, with this statistical experimental investigation by using response surface methodology approach, a scientific method suggestion was made on product development and new product design areas. This study and methodology aim to enlight that experimental designs should be planned and evaluated according to a consideration of joint effect of all factors concerning all critical responses in order to benefit from optimum economical experimental development costs.

REFERENCES / KAYNAKLAR

1. Montgomery, D.C. and Runger, G.C., 1999, *Applied Statistics and Probability for Engineers*, John Wiley and Sons Inc. New York, USA, pp:1-3, 619-621, 705-719.
2. Pyzdek, T., 2003, *The Six Sigma Handbook*, McGraw Hill Co. Inc., USA, pp:607-608.
3. Dlodlo, N., Hunter, L., Cele C., Botha, A.F., Metelerkamp, R., 2008, “An Expert Yarn Engineering System”, *Tekstil ve Konfeksiyon*, Yıl: 18(1), pp: 48-55.
4. Scheirs, J. and Long, T.E., 2003, *Modern Polyesters: Chemistry and Technology of Polyesters and Copolyesters*, John Wiley and Sons Ltd., Sussex, England, pp: 425-426.
5. Hearle, J.W.S., Hollick, L. and Wilson, D.K., 2001, *Yarn Texturing Technology*, The Textile Institute, Woodhead Publishing Ltd., Cambridge, England, pp: 256-257.
6. Demir, A. and Behery, H. M., 1997, *Synthetic Filament Yarn Texturing Technology*, Prentice Hall Inc., USA, pp: 143-147.
7. Ahmed, M., 1982, *Polypropylene Fibers- Science and Technology*, Elsevier Publishing, Netherlands, pp: 222-224.

Bu araştırma, Bilim Kurulumuz tarafından incelendikten sonra, oylama ile saptanan iki hakemin görüşüne sunulmuştur. Her iki hakem yaptıkları incelemeler sonucunda araştırmanın bilimselliği ve sunumu olarak ***“Hakem Onaylı Araştırma”*** *vasfıyla yayımlanabileceğine karar vermişlerdir.*