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Designing High Performance Safety Belts

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Abstract

Safety belts are the life saving product for the persons working on high rise buildings, factories etc. The objective of this research work is to investigate the effect of various constructional variables on the properties and performance of safety belts. The samples were prepared using different denier of polyester filament yarn. Box-Behnken design of experiments with 3 factors and 3 levels has been used for the sample plan, the statistical analysis and the optimization. The results showed that the number of warp yarn is the most influencing parameter for strength and elongation of safety belts followed by the weft density and warp denier respectively.

Keywords: Safety belts; Narrow fabric; Strength; Elongation; Box-behnken design

Introduction

Safety belt is a type of protective device designed to protect a person, animal, or object from injury or damage. Fall from height is a primitive hazard for a worker who is working at height. The local safety regulations and laws are forced to provide suitable working platform, safe access and proper fencing to dangerous places [1-4]. The use of safety belts is the only and best option when it is impracticable to provide above mentioned safety measures at work place. It is usually attached between a stationary and non-stationary object and is fabricated from rope, cable or webbing and locking hardware. Some safety belts are used in combination with a shock absorber, which is used to regulate deceleration when the end of the rope is reached. Safety belt and upper-body restraints that relax to permit comfort but tighten automatically during an impact are now common.

Safety belt is a collective name for the different types of harnesses and belts like (i) Safety harness or full body harness; (ii) Semi-harness or chest harness; (iii) Rescue harness; (iv) Work positioning belt pole safety belt or lineman safety belt; (v) General purpose safety belt. Seat belt is the most well-known and important safety device. It is an energy-absorbing device that is designed to keep the load imposed on a victim's body during a crash down to survivable limits [5-7]. Fundamentally, it is designed to provide non-recoverable extension to reduce the deceleration forces which the body encounters in a crash. Non-recoverable extension is particularly important to prevent occupants from being pulled back into their seats and sustaining whiplash injuries immediately after an impact. To stop any more webbing from paying out after an accident, the automatic belt has a locking mechanism known as the inertia reel.

Technical textiles in automotive sector, where woven, knitted and nonwoven fabrics are used, makes up approximately 15% of the total manufactured technical textiles in the world. More than 50% of it is woven fabric because of their appropriate properties for this application [8,9]. These fabrics are manufactured using synthetic material such as polyester, polyamide and polypropylene fibres due to special requirements and properties. The most important properties are: tenacity, elasticity, stability, inflammability, abrasion resistance, porosity, comfort and aesthetic appearance, colour fastness in order to meet ecological requirements etc. Moreover, some necessary properties are obtained by subsequent fabric treatments such as by coating a thin synthetic layer to achieve fabric inflammability and air impermeability [10,11]. Safety belts are manufactured by narrow weaving and high tenacity, stability, the raw material composition is mostly polyester multifilament, a relatively high density of warp yarns and a relatively low density of weft yarns, twill weave is used in the weaving. Tensile strength and elongation are the crucial characteristics for the safety belts.

Breaking strength, elongation, resistance to abrasion, resistance to light, resistance to micro-organisms, resistance to temperature etc are some of the important properties of the safety belts [12,13]. This research work is focused on improving the performance of safety belt by improving breaking strength and elongation.

Methodology

Materials

In this research work, various important constructional parameters of the safety belts have been investigated for their effect of the tensile strength and elongation behavior of the safety belts. Polyester multifilament of different denier has been used to produce safety belt. Samples were prepared on the needle loom (Narrow Woven Fabric Manufacturing) of MODEL –KYANG – JYE (80/2). The details of the prepared samples were shown in the Table 1. Machine parameters are as under:

- Number of Ribbon: 2
- Width of Reed: 80

Variable	-1	Levels 0	+1
Independent Variables			
A=No of warp yarns per inch	80	90	100
B=No of weft yarns per inch	15	20	25
C=Count of warp yarn (Denier)	210	255	300
Dependent Variables			
Y1=Breaking strength (Kgf)			
Y2=Elongation (%)			

Table 1: Variables and their Levels in Box-Behnken Design.

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- Direction of Weft Insertion: Clockwise
- Roller: Double Roller
- Number of Frame: 14
- Weft Density: 3.5~36.7/cm
- Motor Power: 1.5 KW
- Cycle Pattern Chain: 1:48

Methods

Strength and elongation testing: The samples were tested for the breaking strength and elongation at break following the standard test method [14] (BS2576). The samples were conditioned under standard laboratory conditions for 24 hours. ASTM D5035-06 (standard test method) is used for the measurement of breaking force and elongation of textile fabrics. The Breaking Strength of the fabric was determined using the breaking strength tester manufactured by Texcare Industries. Digital Tensile Testing Machine Parameters are as follows:

- Measuring Unit : Kgf (Kilogram), N (Newton) Lbs (Pound)
- Operating: Fully Automatic and Manual Both
- Maximum Grip Separation : 1000mm
- Motor :½ hp 1440RPM with Worm Reduction Gear Box Noise Less
- Display Units : Load, Speed , Elongation
- Traverse Speed: 300 mm/min
- Calibration : Self Calibrated

B. No.	A	B	C	Y_1	Y_2
1	1	1	0	283	29.0
2	-1	- 1	0	176	38.6
3	1	- 1	0	269	31.6
4	1	0	1	306	28.8
5	0	1	1	282	30.8
6	0	- 1	- 1	235	36.0
7	-1	0	- 1	172	39.8
8	-1	0	1	196	36.8
9	1	0	- 1	256	35.5
10	-1	1	0	180	38.2
11	0	1	- 1	265	35.1
12	0	-1	1	266	34.1
13	0	0	0	256	35.5

Table 2: Box-Behnken experimental design with measured responses.

- Protection: Over Load, Over traverse up & Down.
- Auto Stop: At Test Finish. At Over Load, At Over Traverse
- Report: Tensile Strength, Elongation.

Design of experiment: Box-Behnken statistical design with 3 factors, 3 levels and 13 runs (one centre point) was used for the optimization study. The independent and dependent variables are listed in Table 1. The polynomial equation generated by this experimental design (using Design- Expert 8.0.7.1) is as follows:

$$Y_i = b_0 + b_1A + b_2B + b_3C + b_{12}AB + b_{13}AC + b_{23}BC + b_{11}A^2 + b_{22}B^2 + b_{33}C^2. \quad (2)$$

Where Y_i is the dependent variable; b_0 is the intercept; b_1 to b_{33} are the regression coefficients; and A, B and C are the independent variable that was selected from the preliminary experiments. Box and Behnken design with measured responses are shown in Table 2.

Results and Discussion

Results obtained from testing of the samples were analysed and optimised using design expert software are presented in this section.

Effect of different variables on breaking strength of safety belts

Effect of different variables like number of warp ends, number of picks per inches and warp yarn count on the breaking strength of safety belts were studied, analysed and discussed in this section. The parameters in the ANOVA Table 3 clearly show the analysis and effect of different variables on the breaking strength of the safety belts. The model p-value depicts that the model is significant.

Effect of number of warp yarn on breaking strength of safety belts

Table 3 clearly shows that the number of warp yarns has a significant effect on the breaking strength of the safety belt. Breaking strength of safety belts increases with increase in the number of warp yarns. The relation is non-linear as depicted by the analysis of variance and the Figure 1. The increase in number of warp yarns increases the breaking strength in a non-linear manner i.e. the increase is not in straight line. The reason behind this is that the more number of warp yarn will have more load bearing capacity. The nonlinear relationship is unexpected in this case. It is mainly due to the interaction effect of other parameters of constructions.

Effect of warp denier on breaking strength of safety belts

Table 3 clearly shows that the warp denier also has a significant

Source	Sum of Squares	Degree of freedom	Mean Square	F-value	p-value 'Prob > F'
Model	24683.77	9	2742.64	44.96	0.005
A-No of Yarns	19012.50	1	19012.50	311.68	0.000
B-PPI	512.00	1	512.00	8.39	0.063
C-Count	1860.50	1	1860.50	30.50	0.012
AB	25.00	1	25.00	0.41	0.568
AC	169.00	1	169.00	2.77	0.195
BC	49.00	1	49.00	0.80	0.436
A^2	1955.57	1	1955.57	32.06	0.011
B^2	0.14	1	0.14	0.00	0.964
C^2	75.57	1	75.57	1.24	0.347
Residual	183.00	3	61.00		
Cor Total	24866.77	12			

Table 3: Analysis of variance for response surface quadratic model for breaking strength of safety belts.

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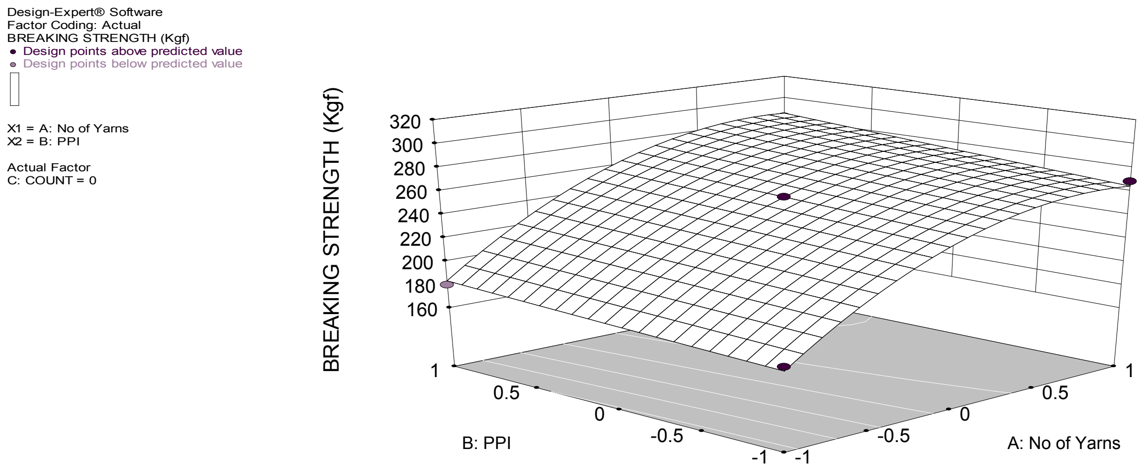

Figure 1: Effect of number of yarns and the picks per inches.

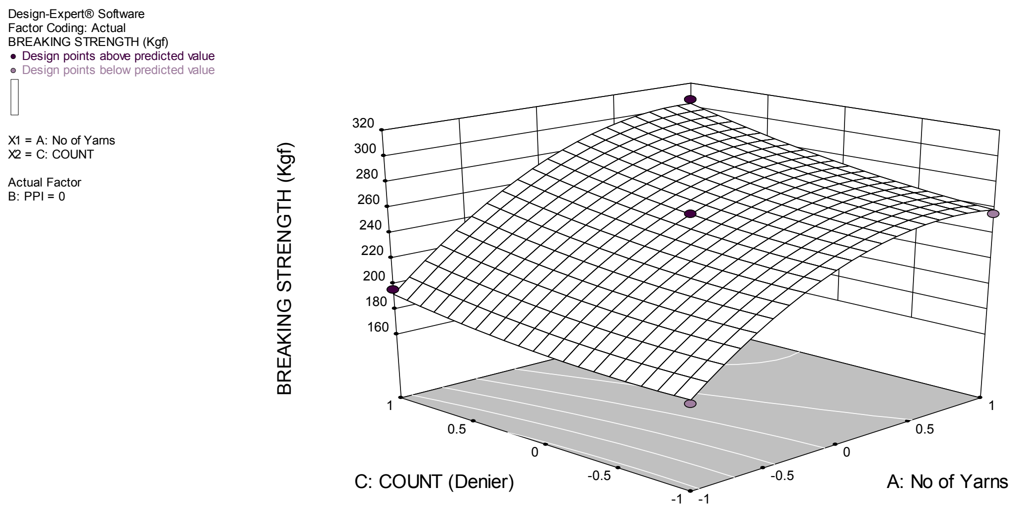

Figure 2: Effect of warp denier and weft density.

effect on the breaking strength of the safety belt. But the effect is relatively low as compared to the effect of number of yarns. Breaking strength of safety belts increases with increase in the denier of warp yarns. The relation is linear in this case as depicted by the analysis of variance and the Figure 2. The reason behind this is that the higher denier will have the more number of filaments in the warp direction and consequently will have more load bearing capacity.

Effect of weft density on breaking strength of safety belts

Table 3 depicts that the weft density also has insignificant effect on the breaking strength of the safety belt. However, the effect is relatively quite low as compared to the effect of warp denier. Breaking strength of safety belts increases with increase in the weft density. The relation is linear in this case as depicted by the analysis of variance and the Figure 3. It is mainly due to the higher weft density, which will have the better binding on the warps and consequently will have more load bearing capacity. The linear relationship is unexpected in this case. The reason behind this may be due to the interaction effect of other parameters of constructions.

Optimizing the dependent variable for maximum breaking strength of safety belts: Optimizing the independent variables for maximum breaking strength by using Box-Behnken design of experiments shows that the maximum breaking strength of safety belts can be achieved at maximum number of warp, weft density and warp denier. This behaviour is clearly shown in the perturbation plot in Figure 4. The contribution of the evaluated factor can also be seen in the Figure 4 which exhibits that the number of warp yarn is most important followed by the denier and the weft density respectively.

Effect of different variables on elongation at break of safety belts

Effect of different variables like number of warp ends, number of picks per inches and warp yarn count on the elongation at break of safety belts were studied, analysed and discussed in this section. The parameters in the ANOVA Table 4 clearly show the analysis and effect of different variables on the elongation at break of the safety belts. The model p-value depicts that the model is significant.

Effect of number of warp yarn on elongation at break of safety belts

Table 4 clearly shows that the number of yarn has a significant

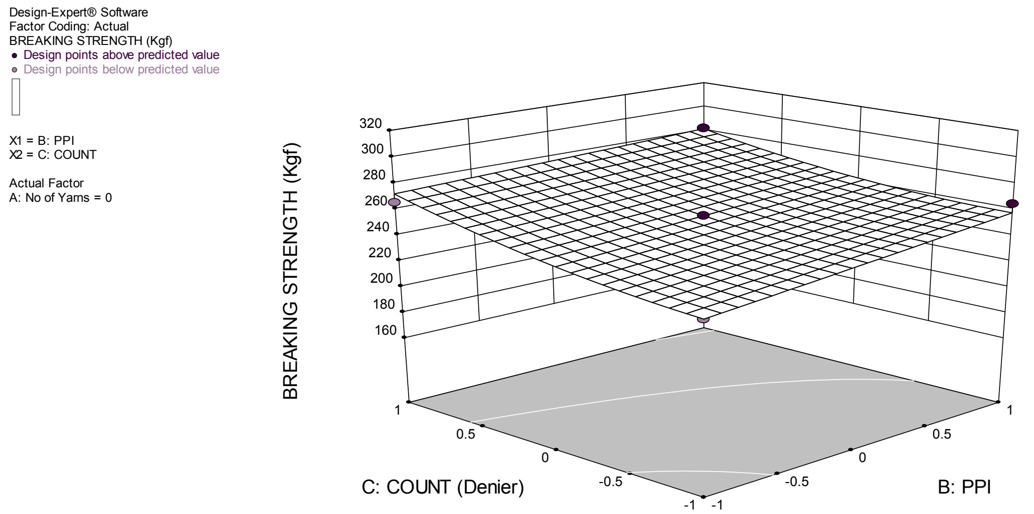

Figure 3: Effect of warp denier and weft density.

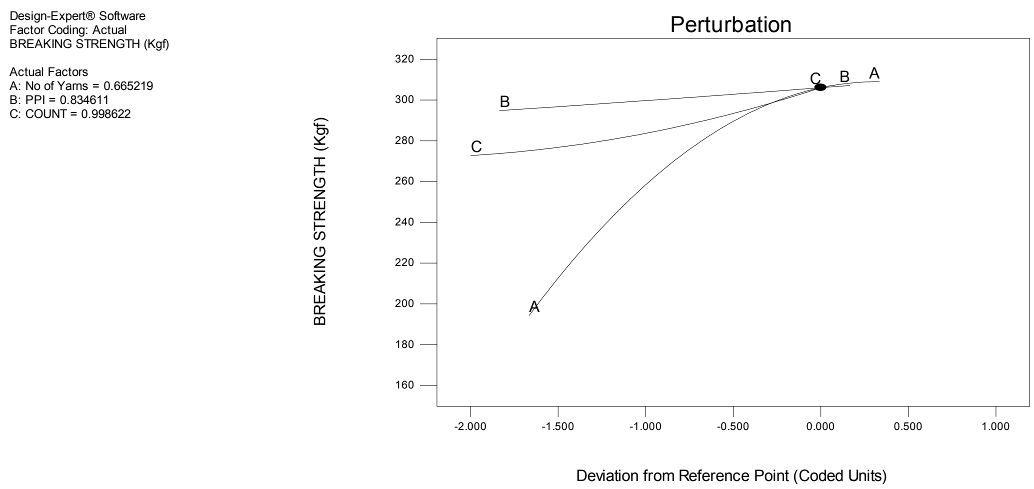

Figure 4: Optimization of predictor variables for maximum breaking strength of safety belts.

Source	Sum of Squares	Degree of freedom	Mean Square	F-value	p-value 'Prob > F'
Model	149.73	9	16.64	13.77	0.026827
A-No of Yarns	101.53	1	101.53	84.04	0.002744
B-PPI	6.49	1	6.49	5.38	0.103158
C-Count	31.56	1	31.56	26.13	0.01449
AB	1.21	1	1.21	1.00	0.390676
AC	3.42	1	3.42	2.83	0.190936
BC	1.43	1	1.43	1.18	0.356485
A^2	0.003	1	0.004	0.003	0.960843
B^2	3.23	1	3.23	2.67	0.200537
C^2	0.23	1	0.23	0.19	0.695193
Residual	3.63	3	1.21		
Cor Total	153.35	12			

Table 4: Analysis of variance for response surface quadratic model for elongation at break of safety belts.

effect on the elongation at break of the safety belt. The elongation at break of safety belts reduces with increase in the number of warp yarns. The relation is linear as depicted by the analysis of variance and the Figure 5. The reason behind this is that the more number of warp yarn will have more load bearing capacity hence low elongation. In this case, the interaction effect of other parameters of constructions is not significant to the second order.

Effect of warp denier on elongation at break of safety belts

Table 4 clearly shows that the number of yarn has a significant

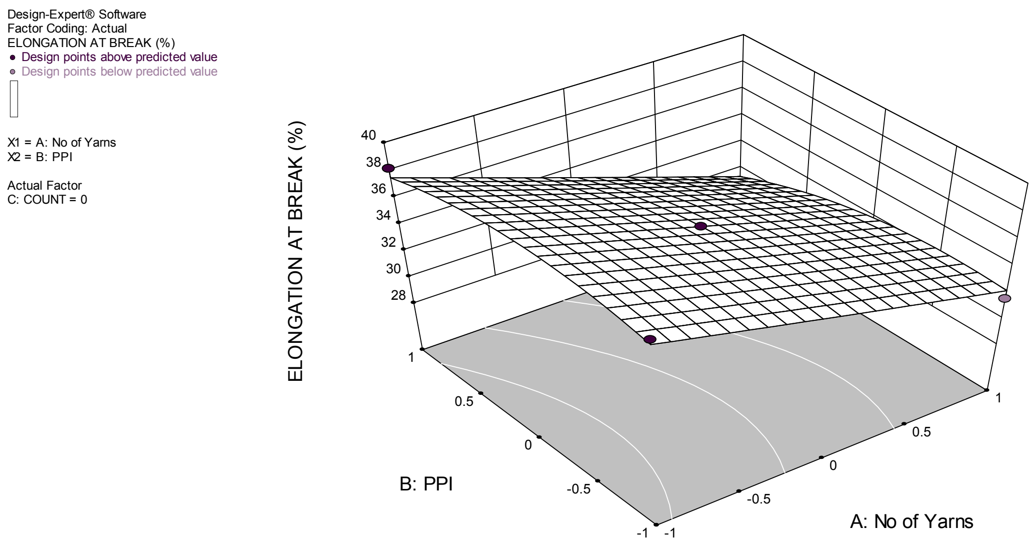

Figure 5: Effect of number of yarns and the picks per inches.

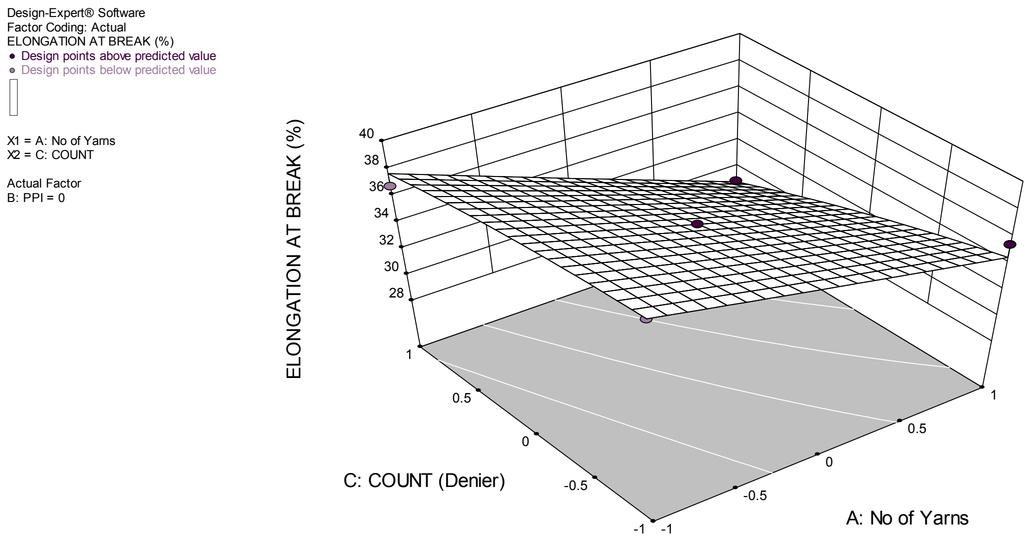

Figure 6: Effect of warp denier and number of yarn.

effect on the elongation at break of the safety belt. The elongation at break of safety belts reduces with increase in the number of warp yarns. The relation is linear as depicted by the analysis of variance and the Figure 6. The reason behind this is that the higher denier will have the more number of filaments in the warp direction and consequently will have more load bearing capacity and hence low elongation at break. Effect of warp denier is more pronounced at higher number of yarns.

Effect of weft density on elongation at break of safety belts

Table 4 clearly shows that the number of yarn has insignificant effect on the elongation at break of the safety belt.

The elongation at break of safety belts reduces with increase in the number of warp yarns. The relation is non-linear as depicted by the analysis of variance and the Figure 7. However the non-linearity is not significant. The reason behind this is that the higher weft density will have the better binding on the warps and consequently will have low elongation at break.

Optimizing the dependent variable for minimum elongation at break of safety belts: Optimizing the independent variables for minimum elongation at break by using Box-Behnken design of experiments shows that the minimum elongation at break of safety belts can be achieved at maximum number of warp, weft density and warp denier. This behaviour is clearly shown in the perturbation plot in Figure 8. The contribution of the evaluated factor can also be seen in the Figure 8 which exhibits that the number of warp yarn is most important followed by the denier and the weft density respectively.

Conclusions

Safety belts produced with different fabric variable such as number of warp, warp denier and weft density. Statistical analysis of

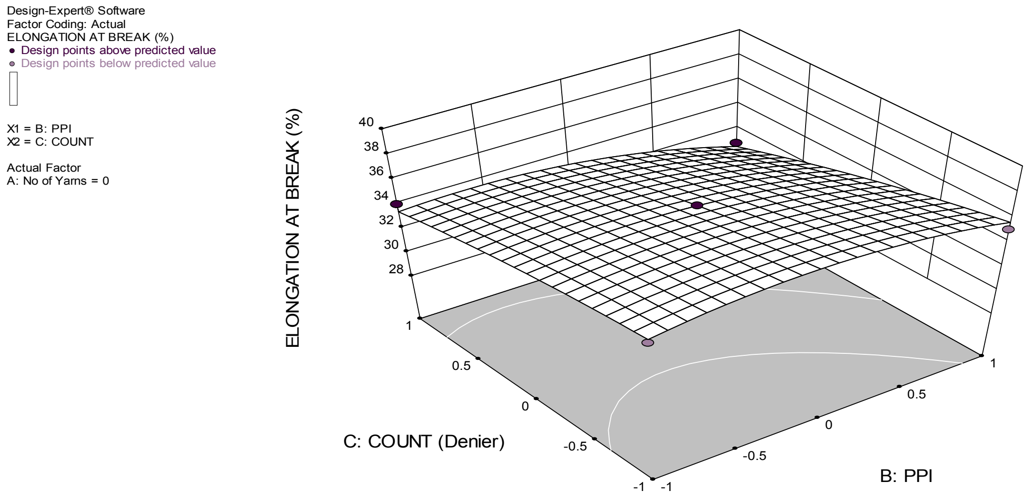

Figure 7: Effect of weft density and warp denier.

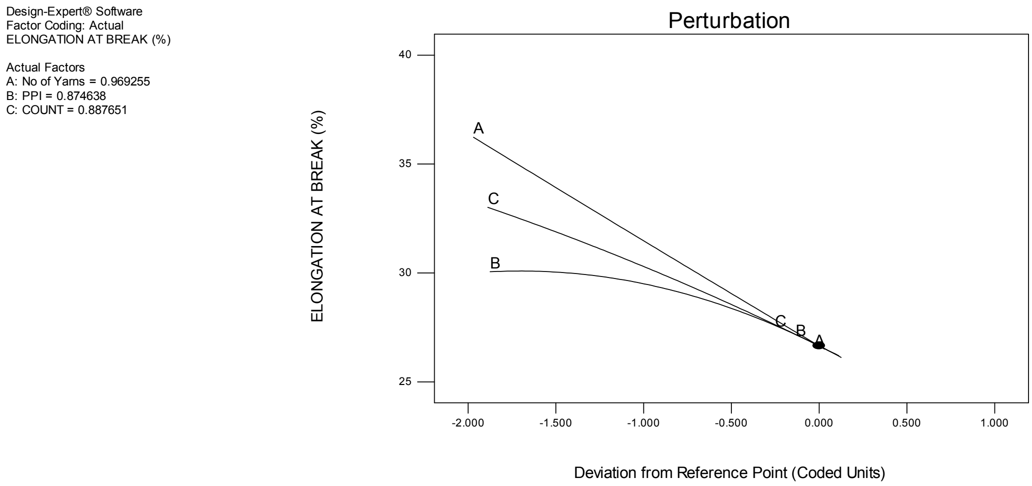

Figure 8: Optimization of predictor variables for minimum elongation at break of safety belts.

the test results shows that the number of warp is the most influencing parameters followed by the weft density and warp denier respectively. Optimizing the dependent variables for maximum breaking strength and minimum elongation at break by the Box-Behnken design of experiments shows that maximum breaking strength can be achieved at number of yarn = 99, weft density = 24.7, warp denier = 298. Minimum elongation at break can be achieved at number of yarn =100, weft density = 24.2, warp denier = 291.

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