Optimization of tensile strength of Reinforced Rubber Using Taguchi Method

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Abstract— Reinforced rubber has many mechanical applications such as belt conveyers hose and power transmission. The reinforced rubber of mechanical belt conveyor is contained rubber covers and fabric-rubber core (carcass). Tension test is performed on reinforced rubber belt conveyor to study the effect of number of reinforcement plies, loading direction and speed of loading on the tensile strength of the tested belt. Specimens of 2, 3 and 4 reinforcement plies are used. The direction of loading is alternative by 00, 450, and 900. Moreover, the loading velocity is 50, 100, and 150 mm/min. Taguchi optimizations method is achieved to obtain maximum and minimum tensile strength at corresponding test conditions. The results concluded that loading direction has a great effect than a number of reinforcement plies variation or even loading velocity. The maximum tensile strength could be achieved at factors; 4 plies, loading direction 0 degrees and loading speed 100 mm/min., whoever the minimum tensile strength could be achieved at factors; 3 plies, loading direction 90 degrees and loading speed 50 mm/min.

Index Terms— Rubber – Belt conveyer- Tension test, Woven fabric, Taguchi optimizations.

1 Introduction

Reinforced rubber is widespread in many industrial fields [1-3]. Therefore, the belt conveyer before being in service should meet characteristic standers [3-10].

Barburski [11] investigated the mechanical properties of belt conveyor at three different stage condition of belt manufacturing. They studied the effect of fabric structure on these properties. They reported that for different conditions, there was an observable change in the mechanical properties with the intersections of fabric yearn and bundles, moreover on the number or layer or weaves.

Fedorko *et al.*[12] Experimentally investigated the physical and mechanical properties of belt conveyor rubber using non-destructive test. They concluded that the ability to form pipes was lost and there was no change in elastic elongation for dynamically damaged conveyer belt. Moreover, there was a change in the adhesive strength between belt conveyer layers.

Nair *et al*.[13] Studied the effect of change of rubber particle and glass-fiber contents and rubber particle sizes on the fracture toughness of a hybrid amorphous thermoplastic composite. The investigation reported that the addition of rubber particles to glass-fiber reinforced composite increases the overall toughness of the hybrid composite.

Ismail *et al*.[14] Investigated the effect of fiber surface treatment using various bonding materials on the mechanical properties of natural reinforced rubber composite with oil palm fiber reinforcement. There was an enhancement in the mechanical properties of the fibers that were cured which led to higher torque values with the addition of bonding material when compared with the uncured fibers.

Ishak et al. [15] Studied the effect of varying glass fiber and rubber contents, testing temperature, and loading rate on the fracture toughness of various short glass fibers reinforced rubber composites. The investigation results in an improvement in the fracture toughness of the investigated materials.

Laura et al.[16] Investigated the effect of glass fibers treated with three reactive silane agents on the mechanical properties of glass fiber reinforced nylon 6. The study showed that the type of glass fibers treatment has no effect on the tensile properties, while there was a significant effect on the yield and impact strengths of the investigated materials. The three reactive silane used has a significantly different effect on the mechanical properties when 20% by weigh of malleated ethylene propylene rubber added to the polymer matrix, while the effects were about to be the same with 0% weight of it.

Moraleda et al.[17] Studied the effect of strength and toughness of fiber-matrix interface on the tensile strength of fiber reinforced elastomers. A finite element simulation was used in this study including fracture of the fiber matrix interface through bi-dimensional and quadratic interface elements. The investigation reported that the fiber

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matrix interface has a significant effect on the crack initiation and tensile properties in a direction perpendicular to the fibers, while the crack propagation was corresponding to the interface toughness.

Mohammed et al.[18-24] studied the mechanical and fracture characteristic of reinforced plastic. They illustrated the importance of studying the loading direction and stacking sequences.

Experimental evidence reported that conveyor belt's physical properties were gradually changed under loading. This change was reflected by the deterioration of belt structure and changing the dimensional parameters, resulting in increasing operating costs. Several experimental tests on the mechanical properties of belts can be found in the literature including, investigating the breaking and splice strength of steel cord belts using a magnetic flux leakage device [25] and the tensile strength as well as strength parameters of the adhesive-bond joint in splices [26].

2 The Objective of the Present Work

The two main goals of the present study are:

To obtain characteristic tensile properties of reinforced rubber used in belt conveyor in different conditions

To obtain the optimum values corresponding to maximum and minimum strength values using Taguchi Method.

The paper is organized as follows: first paragraph, the material of belt conveyor rubber is described, secondary the tensile test procedures are outlined, in the third term the optimization method using Taguchi method is extracted, finally, results and discussion are summarized.

3 Material and Sample Preparation

The present study used a textile-reinforced conveyor belt intended for general use. The carcass of the conveyor belt consists of 2 to 4 reinforcement layers of woven fabric made of polyester, and special rubber skim coat to provide a good adhesion with reinforcement layers as shown in Figure 1. Styrene-butadiene layers used as top and bottom covers to provide abrasion resistance, and protection for the belt carcass. The test specimens were prepared according to ISO 283 standard [4] instructions. A dog bone type A specimen was selected as shown in Figure 2 and prepared by means of a die cutter as shown in Figure 3. The test specimens were cut in three directions, 0o, 45o, and 90o related to the conveyor belt axis, which is the direction of warp fabric reinforcements.

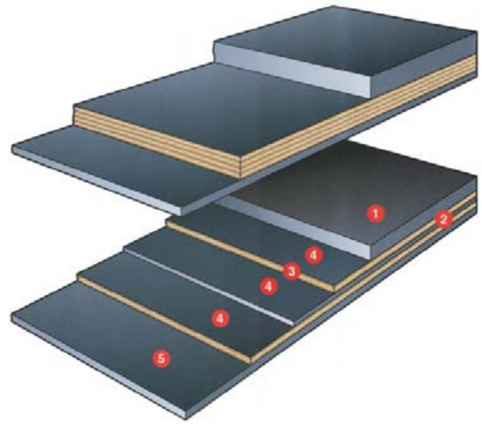


Figure1. Structure of Conveyor belt with the textile carcass. 1- Top cover, 2- Carcass, 3- Textile, reinforcement, 4- Rubber skim coat, 5- Bottom cover

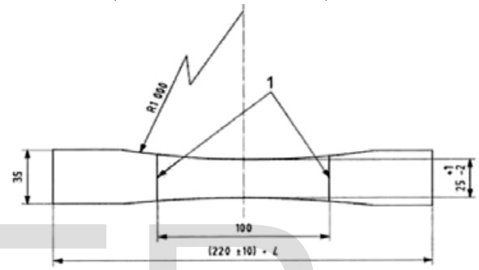


Figure 2 Type A specimen, L – length of both grips, 1- reference line

Figure 3 Type A specimen die cutter

3.1 Tension test

A simple tension test was performed on a specimen cut out prepared as mentioned. The test was performed according to ISO 283 standard [4] using Zwick Rowell Z50 KN type testing machine, at 50,100,150 mm/min loading rates until rupture. The testing machine was equipped with a contactless deformation measurement extensometer, that couldn't be affected by specimen rupture at the end of the test. The testing grips were selected to be with transverse serrations to prevent any slippage of the test specimen during the test. Test specimen axis was positioned aligned with the grips centerline by means of a guiding piece on the grips holder, so as to align the tensile force of the testing machine.

4 Taguchi Method

In the Taguchi method, the investigation parameters are called design variables or control factors which affect the output variable. Three factors are used in this study with three level for each factor. Table 1 shows the process control factors and their levels. The array chosen was L9 (34) orthogonal array, to investigate the impact of three factors: number of reinforcement plies (factor A), loading direction (factor B) related to the axis of the belt, and loading speed (factor C) defined by the speed of the machine crosshead during the test. The signal to noise (S/N) ratio characteristics was classified into three groups, smaller is the better, nominal is the better, and larger is the better. In this study, the S/N ratio large is the better was chosen as a larger tensile strength represents a better-quality characteristic. The Taguchi method was used to determine the significant control parameters that affect the response factor, which in this case is the tensile strength of the conveyor belt. The analysis of variance (ANOVA) was performed to measure each control factor effect on the tensile strength, by determining the percentage contribution (p%) for each factor.

Table 1 Control factors and levels

Control factor	**Level 1**	**Level 2**	**Level 3**
A Number of reinforcement plies (ply)	2	3	**4**
B Loading direction (deg.)	0o	45o	**90o**
C Loading speed (mm/min	50	100	**150**

The experimental results for the conveyor belt tensile strength based on Taguchi orthogonal array L9, shown in Table 2, was analyzed using MINITAB 17 software. Table 3 shows the response table of S/N ratio based on the larger is the better for the tensile strength and illustrate the effect significance rank of the control factors on the tensile strength. This means that the loading direction has the most significant effect, followed by the reinforcement number of plies and loading speed, that was illustrated from their delta values which were 9.21, 3.8, and 1.69 respectively. The best combination of the control factors is A3, B1, and C2, this result was observed from the mean S/N ratio graph for the tensile strength based on larger is the better shown in Figure 4. This combination of control factors gives the maximum tensile strength, in the same way, the combination of control factors that give the minimum tensile strength is A2, B3, and C1, as shown in Figure 4. The Analysis of variance (ANOVA) was used to estimate the effect percentage contribution of each control factor on the response factor, the results of ANOVA in Table 4 shows that the loading direction is the most significant factor affecting the tensile strength with percentage contribution 85.3% followed by the number of reinforcement plies with percentage contribution of 11.89%. The loading speed has a very small percentage contribution as well as delta value, so this parameter may be neglected from the prediction and added to the pooled error value.

Table 2 Experimental results for conveyor belt tensile strength

	Control factor (level)	**Tensile strength (MPa)**			**S/N ratio (dB)**
	C	Trial 1	Trial 2	Trial 3	
1	1	38.31	34.99	40.80	31.551
2	2	16.40	14.12	17.61	23.995
3	3	14.62	12.22	11.84	22.097
4	2	37.37	37.57	35.57	31.318
5	3	12.51	12.93	12.41	22.014
6	1	11.44	10.22	10.76	20.645
7	3	45.19	53.97	55.05	34.116
8	1	16.09	17.98	17.36	24.656
9	2	23.36	23.51	18.53	26.605

Table 3 Response Table for Signal to Noise Ratios Larger is better

Level	**Number of Plies**	**Load Direction**	**Loading speed**
1	25.88	32.33	25.62
2	24.66	23.55	27.31
3	28.46	23.12	26.08
Delta	3.80	9.21	1.69
Rank	2	1	3

Table 4 Analysis of Variance (ANOVA) for the tensile strength

Source	**DF**	**Seq. SS**	**Adj. MS**	**p (%)**
# plies	2	22.578	11.289	11.89
direction	2	162.040	81.020	85.30
speed	2	4.576	2.288	2.41
Error	2	0.765	0.3825	0.40
Total	8	189.958		100

4.1 Confirmation Experiment:

The confirmation experiments were performed to check the validity or reproducibility of the results using the optimal levels of the design parameters and with three replications for each experiment. The confirmation experiments were performed with the combination at levels A3, B1, and C2 for maximum tensile strength and A2, B3, and C1 for minimum tensile strength. The factorial effects that were used to estimate the S/N ratio of the optimal level parameters are A3 and B1 for maximum tensile strength, A2, and B3 for minimum tensile strength. The weak factorial effects were recommended to be excluded from the prediction to avoid overestimates, according to [27], i.e. the effect of loading speed (factor C). Tables 5 and 6 show the results of the confirmation experiments for S/N ratio values for maximum and minimum tensile strengths respectively compared to their predicted values. The absolute percentage of prediction error shows the amount of variation between the predicted and actual experimental values, which indicates the effectiveness of the proposed method in identifying the optimal parameters of maximum and minimum tensile strength.

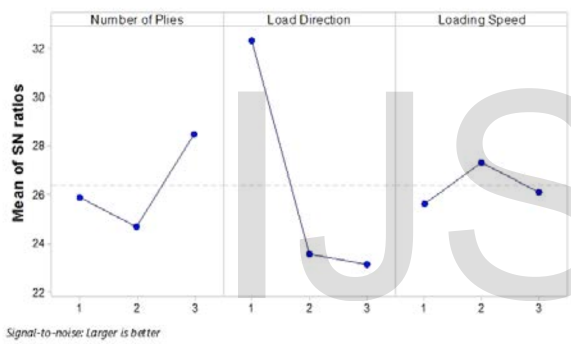


Figure 4 Signal-to-noise (S/N) ratio graph for control factors effect on tensile strength

Table 5 Results of the confirmation experiment for S/N ratio values for maximum tensile strength

Maximum Tensile Strength			
	Experiment	Prediction	Error %
Optimal Level	A3, B1	A3, B1	
S/N ratio (dB)	34.526	34.454	0.21

Table 6 Results of the confirmation experiment for S/N ratio values for minimum tensile strength

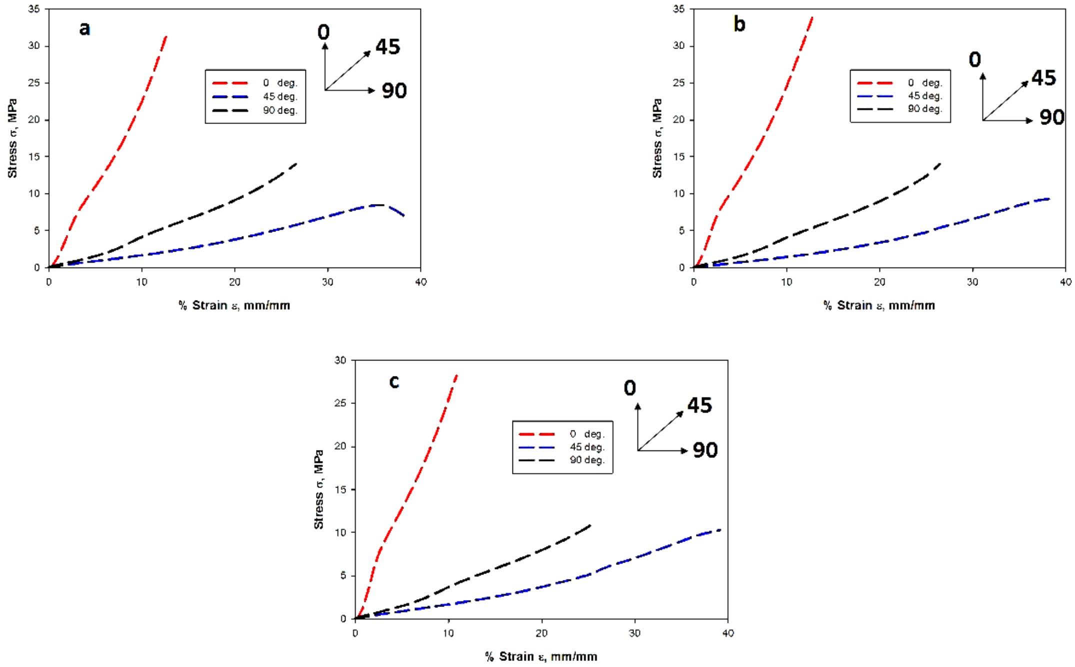
Minimum Tensile Strength			
	Experiment	Prediction	Error %
Optimal Level	A2, B3	A2, B3	
S/N ratio (dB)	20.51	21.44	4.55

5 Results and Discussion

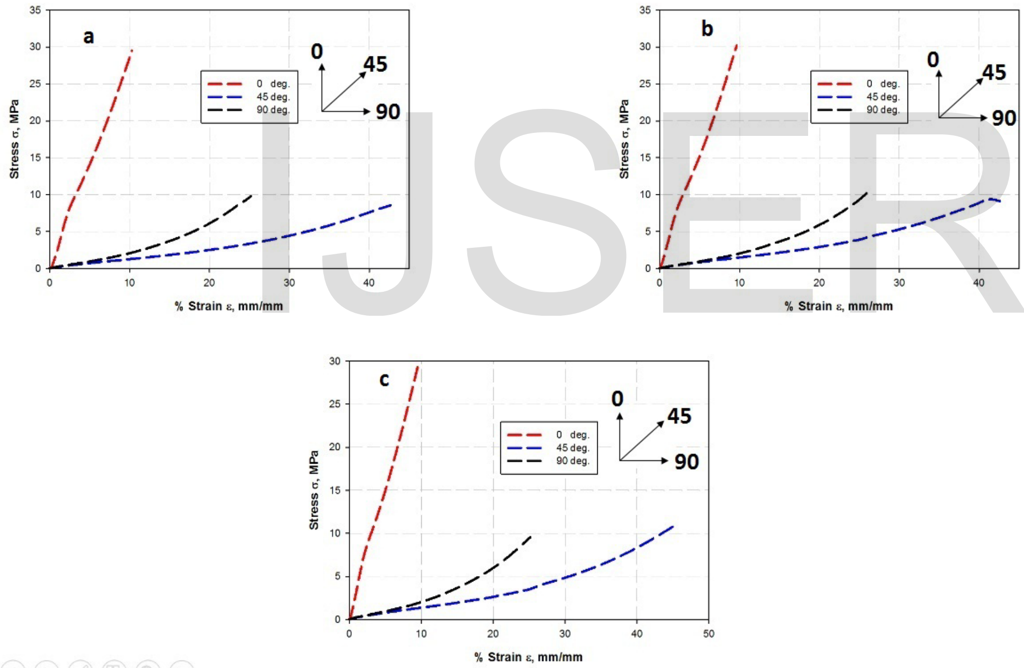
Figures 5, 6 and 7 show stress-strain diagram variation with loading direction for a specimen of 2, 3, and 4 plies of reinforcements respectively at various crosshead velocity 50, 100 and 150 mm/min. it is clearly illustrated that loading direction gives a large decrease in the tensile strength of a reinforced rubber specimen. This can be due to shear stress induced with the reinforcement inclination in direction of 45 deg.. it is clearly observed that with increasing of testing velocity range of strength little decrease, this can be attributed to increasing plastic deformation through the specimen thickness. This trend in the behavior pattern of reinforced rubber can be attributed to shaping the surface of the fabric to obtain optimal properties in the final product. The structure of the fabric also influences several of the features such as appearance, smoothness, permeability, arrangement, thermal protection, flexibility and durability [28-34]. During draping, there are four different types of deformations that can be observed: in-plane and bi-axial tension, in-plane shear, out-of-plane bending and transverse compression. The way in which each fabric complies or resists these modes is different. According to the literature [28, 29, 35-39], the mechanical properties of fabrics depend on the material used, the type of yarns, the weaving parameters as well as; the weave types. Each of these factors is important individually but the interactions between them make it difficult to isolate the effect of each on the mechanical properties of the fabric.

6 Conclusion

The tensile properties of reinforced rubber used as belt conveyor are characteristic and evaluated at the variation of loading direction and n, it is concluded that changing loading direction over reinforced fabric woven has a serve effect on tensile properties of belt conveyor which give a recommendation for engineering designer too but fabric optimum direction for the user. The loading speed has little effect. The optimization method of Taguchi gives a reasonable result to the maximum and minimum value of strength corresponding to specimen and test condition. According to the proposed levels of the control factors it was concluded that the maximum tensile strength could be achieved at factors levels A3B1C2, i.e., number of reinforcement plies 4 plies, loading direction 0 degrees and loading speed 100 mm/min., the minimum tensile strength could be achieved at factors levels A2B3C1, i.e., number of reinforcement plies 3 ply, loading direction 90 degree and loading speed 50 mm/min.



Figures 5 stress strain diagram variation with loading direction for specimen of 2 plies a) 50 mm/min, b)100 mm/min, c) 150 mm/min



Figures. 6 stress strain diagram variation with loading direction for specimen of 3 plies a) 50 mm/min, b)100 mm/min, c) 150 mm/min

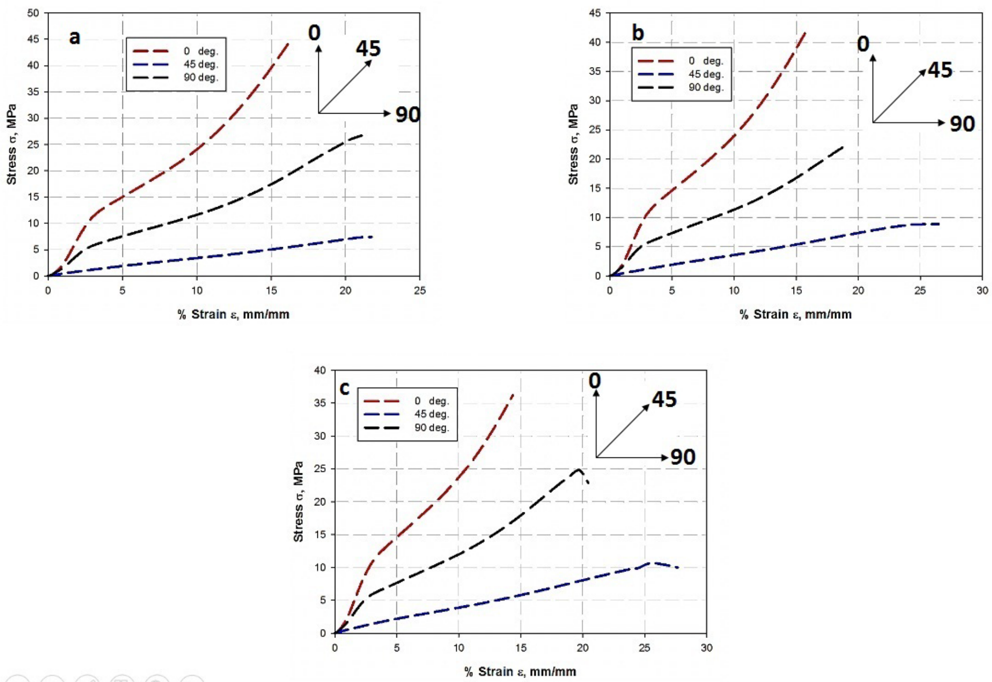


Figure 7 stress strain diagram variation with loading direction for specimen of 4 plies a) 50 mm/min, b)100 mm/min, c) 150 mm/min

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