

Technical Report

Optimum conditions for vulcanizing a fabric conveyor belt with better adhesive strength and less abrasion

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ABSTRACT

This study focuses on investigating the increase in adhesive strength and reduction of abrasion in the joint of a vulcanized fabric conveyor belt. Using analysis of mean (ANOM) of the Taguchi method, the optimum conditions for field vulcanizing a fabric conveyor belt with better adhesive strength were obtained, and they included: (1) a curing time of 25 min, (2) a curing pressure of 9 kg/cm², (3) a dismantling temperature of 30 °C; and (4) a cooling method of air. Following the same method, the optimum conditions for field vulcanizing a fabric conveyor belt with less abrasion were obtained, and they included: (1) a curing time of 15 min; (2) a curing pressure of 9 kg/cm²; (3) a dismantling temperature of 60 °C; and (4) a cooling method of water. Accordingly, with a fixed curing pressure, it takes a longer period to vulcanize a fabric conveyor belt with better adhesive strength than to vulcanize a fabric conveyor belt with less abrasion. The percentage contribution of each controllable factor within the current investigation range was also determined via analysis of variance (ANOVA) of the Taguchi method. Interestingly, among the four controllable factors, the curing time is the most influential factor on both the adhesive strength of the spliced area (38.61%) and the abrasion of the patched and spliced areas (61.22%).

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1. Introduction

The transportation of bulk solids is in demand in the industries. Due to the fact that conveyor belts are simple in construction, flexible in transport system configuration, and versatile in use [1], they are usually used to transport raw materials (such as ores and grains) over a short or medium conveying distance. Compared with a steel cord conveyor belt, a fabric conveyor belt is more widely used because of its advantages (such as low cost and easy maintenance) [2].

Because the belt is an important component of the conveyor belt system [3], its reliability can substantially influence the safety and performance of a conveyor belt system. For example, the sudden rupture of a conveyor belt will cause the rapid fall of its counterweight and the transported materials, and these fallen objects may not only endanger the workers, but also cause an accidental disaster that will result in a great loss to the company. Therefore, research on conveyor belt systems has attracted considerable attention.

Several innovative methods were recently presented to predict the material behavior of a conveyor belt (such as dynamic elastic modulus, viscous damping, and rheological constants of the belt

[3], the fatigue behavior of fabric conveyor belt subjected to shear loading [4], and the tensile force–length characteristic curve of the steel-cord belt splice [5]), to enhance the lifetime of a conveyor belt using a grooved rubber matrix [6], and to monitor (or inspect) a conveyor belt using the methods (such as the digital X-ray imaging [7], the fuzzy logic to objectify the inspection results [8], and a computer system for monitoring conveyor belt joints [9]). Aside from these, Chou et al. presented optimum conditions for field vulcanizing a fabric conveyor belt with a better capability of elongation using the Taguchi method [2]. However, a conveyor belt is usually used to transport raw materials with sharp edges and corners over a long period of time, and it always causes abrasive wear of the board and rubber cover, breakage of fabric, or separation of joints in a fabric conveyor belt. The splice of a fabric conveyor belt is the weakest part in a conveyor belt system [6]; therefore, improving the adhesive strength and the abrasion resistance of the splice in a vulcanized fabric conveyor belt is worthy of continued study.

Extending the method proposed by Chou et al. [2], the time of curing, the pressure acting on the fabric conveyor belt, the temperature of dismantling platen from the fabric conveyor belt, and the cooling method were used as the controllable factors. The optimum conditions for vulcanizing a fabric conveyor belt with better adhesive strength in the spliced area and the optimum conditions for vulcanizing a fabric conveyor belt with better abrasion resistance in the spliced and patched areas were determined using

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the Taguchi method [10]. Moreover, the percentage contribution of each aforementioned experimental parameter to the process of vulcanizing a fabric conveyor belt with better adhesive strength and abrasion resistance was also investigated.

2. Taguchi method

2.1. Optimum conditions

Following the results described in Chou et al. [2], Table 1 lists four controllable factors and their three levels, and Table 2 lists the experimental conditions for vulcanizing a fabric conveyor belt, which were obtained by combining Table 1 and the $L_9(3^4)$ orthogonal array. This study aimed: (1) to maximize the adhesive strength of the spliced area in a vulcanized fabric conveyor belt, whose signal-to-noise (S/N) ratio with HB (higher is better) characteristics was required; its mean square deviation (MSD) was given by $\frac{1}{n} \sum_{i=1}^n \frac{1}{(Y_i^{Ad})^2}$ [2,10–14], in which n was the number of repetitions under the same test condition and Y_i^{Ad} represented the measured adhesive strength of the spliced area (Table 3A); and (2) to minimize the abrasion of the patched and spliced areas in a vulcanized fabric conveyor belt, whose S/N ratio with LB (lower is better) was required; its MSD was given by $\frac{1}{n} \sum_{i=1}^n (Y_i^{Ab})^2$ [15], in which Y_i^{Ab}

represented the measured abrasion of the patched (or spliced) area (Table 3B).

Substituting the above MSD into Eq. (1), the S/N ratio with HB (or LB) characteristics was given by

$$\frac{S}{N} = -10 \log(\text{MSD}) \tag{1}$$

The mean of the S/N ratio of factor I in level i , $(M)_{\text{Factor}=I}^{\text{Level}=i}$, was given by

$$(M)_{\text{Factor}=I}^{\text{Level}=i} = \frac{1}{n_{ji}} \sum_{j=1}^{n_{ji}} \left[\left(\frac{S}{N} \right)_{\text{Factor}=I}^{\text{Level}=i} \right]_j \tag{2}$$

In Eq. (2), n_{ji} represents the number of appearances of factor I in level i , and $\left[\left(\frac{S}{N} \right)_{\text{Factor}=I}^{\text{Level}=i} \right]_j$ is the S/N ratio of factor I in level i , and its appearance sequence in Table 3A (or Table 3B) is the j th.

By the same measure, the mean of the S/N ratios of the other factors in a certain level could be determined. Therefore, through the above ANOM statistical approach, the S/N response table was obtained, and the optimum conditions to vulcanize a fabric conveyor belt with maximum adhesive strength and minimum abrasion were determined. Confirmation experiments on the vulcanizing process under these optimum conditions were carried out.

2.2. Percentage contribution of each factor-adhesive strength

In addition to ANOM, the ANOVA statistical method was also used to analyze the influence of each controllable factor on the process of vulcanizing a fabric conveyor belt. The percentage contribution of each factor for the adhesive strength, ρ_F^{Ad} , was given by

$$\rho_F^{Ad} = \frac{SS_F^{Ad} - (DOF_F V_{ar}^{Ad})}{SS_T^{Ad}} \times 100 \tag{3}$$

In Eq. (3), DOF_F represents the degree of freedom for each factor, which is obtained by subtracting one from the number of the level of each factor (L). The total sum of squares for adhesive strength, SS_T^{Ad} , was given by

$$SS_T^{Ad} = \sum_{j=1}^m \left(\sum_{i=1}^n (Y_i^{Ad})^2 \right)_j - mn(\bar{Y}_T^{Ad})^2 \tag{4}$$

In Eq. (4), \bar{Y}_T^{Ad} is equal to $\sum_{j=1}^m \left(\sum_{i=1}^n Y_i^{Ad} \right)_j / (mn)$, in which m represents the number of experiments carried out in this study and n represents the number of repetitions under the same experimental conditions. The factorial sum of squares for adhesive strength, SS_F^{Ad} , was given by

Table 1
Controllable factors and their levels.

Factor	Description	Level 1	Level 2	Level 3
A	Time of curing (min)	25	15	40
B	Pressure on belt (kg/cm ²)	7	5	9
C	Temperature of dismantling platen (°C)	60	30	90
D	Cooling method	Natural	Water	Air

Table 2
Test conditions.

	Time of curing (min)	Pressure on belt (kg/cm ²)	Temperature of dismantling platen (°C)	Cooling method
Test 1	25	7	60	Natural
Test 2	25	5	30	Water
Test 3	25	9	90	Air
Test 4	15	7	30	Air
Test 5	15	5	90	Natural
Test 6	15	9	60	Water
Test 7	40	7	90	Water
Test 8	40	5	60	Air
Test 9	40	9	30	Natural

Table 3A
The S/N ratio for the adhesive strength of the vulcanized belt.

Test	A	B	C	D	σ_{TF} (kgf/25 mm)			σ_{BF} (kgf/25 mm)			$\frac{1}{6} \sum_{i=1}^6 Y_i^{Ad}$	MSD	S/N
					Y_1^{Ad}	Y_2^{Ad}	Y_3^{Ad}	Y_4^{Ad}	Y_5^{Ad}	Y_6^{Ad}			
1	1	1	1	1	24	20	16	20	16	16	18.67	0.0031	25.12
2	1	2	2	2	20	20	20	18	16	16	18.33	0.0031	25.13
3	1	3	3	3	24	20	20	18	16	16	19.00	0.0029	25.32
4	2	1	2	3	20	18	18	18	16	15	17.50	0.0034	24.75
5	2	2	3	1	21	18	22	15	16	13	17.50	0.0036	24.42
6	2	3	1	2	20	20	18	16	18	16	18.00	0.0032	25.00
7	3	1	3	2	20	18	18	16	14	14	16.67	0.0038	24.21
8	3	2	1	3	20	18	18	16	20	15	17.83	0.0033	24.88
9	3	3	2	1	22	18	18	18	18	16	18.33	0.0031	25.15

Note: Y_1^{Ad} , Y_2^{Ad} and Y_3^{Ad} represent the adhesive strength between top NR/SBR compound and fabric core of the vulcanized belt at first, second and third test pieces, respectively. Y_4^{Ad} , Y_5^{Ad} and Y_6^{Ad} represent the adhesive strength between bottom NR/SBR compound and fabric core of the vulcanized belt at first, second and third test pieces, respectively. The bold font corresponds to the maximum value of S/N ratio among the nine tests.

Table 3B
The S/N ratio for the abrasion of the vulcanized belt.

Test	A	B	C	D	A_{pa} (mm ³)			A_{sa} (mm ³)			$\frac{1}{6} \sum_{i=1}^6 Y_i^{Ab}$	MSD	S/N
					Y_1^{Ab}	Y_2^{Ab}	Y_3^{Ab}	Y_4^{Ab}	Y_5^{Ab}	Y_6^{Ab}			
1	1	1	1	1	124	120	128	117	119	115	120.50	14539.16	-41.63
2	1	2	2	2	128	133	123	95	97	92	111.33	12683.33	-41.03
3	1	3	3	3	125	130	127	107	110	106	117.50	13906.50	-41.43
4	2	1	2	3	121	118	123	87	88	94	105.17	11307.16	-40.53
5	2	2	3	1	126	124	128	82	85	86	105.17	11496.83	-40.61
6	2	3	1	2	119	118	121	84	88	86	102.67	10820.33	-40.34
7	3	1	3	2	119	121	123	90	92	94	106.50	11555.16	-40.63
8	3	2	1	3	122	121	124	115	117	118	119.50	14289.83	-41.55
9	3	3	2	1	119	123	120	94	96	98	108.33	11891.00	-40.75

Note: Y_1^{Ab} , Y_2^{Ab} and Y_3^{Ab} represent the abrasion of the patched area at first, second and third test pieces, respectively. Y_4^{Ab} , Y_5^{Ab} and Y_6^{Ab} represent the abrasion of the spliced area at first, second and third test pieces, respectively. The bold font corresponds to the maximum value of S/N ratio among the nine tests.

$$SS_F^{Ad} = \frac{mn}{L} \sum_{k=1}^L [(\bar{Y}^{Ad})_k^F - \bar{Y}_T^{Ad}]^2 \quad (5)$$

where $(\bar{Y}^{Ad})_k^F$ is the average value of Y_k^{Ad} for a certain factor in the k th level. Additionally, the variance of error for adhesive strength, V_{ar}^{Ad} , was given by

$$V_{ar}^{Ad} = \frac{SS_T^{Ad} - \sum_{F=A}^D SS_F^{Ad}}{m(n-1)} \quad (6)$$

2.3. Percentage contribution of each factor-abrasion

The percentage contribution of each factor for the abrasion, ρ_F^{Ab} , was given by

$$\rho_F^{Ab} = \frac{SS_F^{Ab} - (DOF_F V_{ar}^{Ab})}{SS_T^{Ab}} \times 100 \quad (7)$$

In Eq. (7), the total sum of squares for abrasion, SS_T^{Ab} , was given by

$$SS_T^{Ab} = \sum_{j=1}^m \left(\sum_{i=1}^n (Y_i^{Ab})^2 \right)_j - mn(\bar{Y}_T^{Ab})^2 \quad (8)$$

In Eq. (8), \bar{Y}_T^{Ab} is equal to $\sum_{j=1}^m \left(\sum_{i=1}^n Y_i^{Ab} \right)_j / (mn)$. The factorial sum of squares for abrasion, SS_F^{Ab} , was given by

$$SS_F^{Ab} = \frac{mn}{L} \sum_{k=1}^L [(\bar{Y}^{Ab})_k^F - \bar{Y}_T^{Ab}]^2 \quad (9)$$

where $(\bar{Y}^{Ab})_k^F$ is the average value of Y_k^{Ab} for a certain factor in the k th level. Additionally, the variance of error for abrasion, V_{ar}^{Ab} , was given by

$$V_{ar}^{Ab} = \frac{SS_T^{Ab} - \sum_{F=A}^D SS_F^{Ab}}{m(n-1)} \quad (10)$$

3. Materials and methods

3.1. Vulcanizing a fabric conveyor belt

The fabric conveyor belt (75.0 cm(L) × 60.0 cm(W) × 1.3 cm(H)) made by San Wu Rubber Mfg. Co., Ltd., Taiwan was used in the experiments of vulcanization, and it consisted of a top natural-rubber and styrene-butadiene-rubber (NR/SBR) compound with a thickness of 6 mm, a bottom NR/SBR compound with a thickness of 2 mm, and a core of polyester fabric with the strength of EP150 × 4. The NR/SBR compound consisted of 50 phr (per

hundred rubber) natural rubber (NR), 50 phr synthetic rubber of SBR 1502, 50–60 phr carbon black (CB), 2–6 phr inorganic fillers, aromatic oil for softening NR and SBR (<8 phr), 5 phr powder of zinc oxide, 1–3 phr stearic acid (C₁₈H₃₆O₂), 4–10 phr tackifier resin, processing agent (<4 phr), 2–4 phr antioxidant, wax (<3 phr), 1.5–2.5 phr sulfur, and vulcanization activator (<1 phr). Recently, Helaly et al. indicated that instead of the conventional zinc oxide and stearic acid; partial and complete replacement of synthesized zinc stearate might enhance the physico-mechanical properties of NR [16], and Wang et al. observed that adding CB enhanced the tensile and the tear strength of acrylonitrile-butadiene rubber (NBR) [17].

Detailed procedures of vulcanizing the ends of two pieces of the fabric conveyor belt had been described in our previous work [2]. Aside from this, the temperature of vulcanizing the ends of two pieces of the fabric conveyor belt was 140 °C [18]. The test conditions were listed in Table 2, which was obtained by combining Table 1 and an L₉(3⁴) orthogonal array of Taguchi method. After the experiment of vulcanization, this vulcanized fabric conveyor belt was removed from the vulcanizing equipment by releasing the pressure acting on the belt and dismantling the platen on the belt.

3.2. Measuring the adhesive strength of a vulcanized fabric conveyor belt

According to CNS K6348 [19], CNS K6343 [20], and JIS K6301 [21], the procedure for measuring the adhesive strength of a vulcanized fabric conveyor belt is as follows: (1) A test piece with a width of 25 mm and a length of 400 mm was cut from the spliced area of the vulcanized fabric conveyor belt (Fig. 1a); (2) at one end of this test piece, the top NR/SBR compound was peeled and then clamped to one jig of a tensile testing machine, and the remaining part of this test piece (including a fabric core and a bottom NR/SBR compound) was clamped to the other jig of the tensile testing machine (Fig. 1b); (3) the tensile testing machine was turned on, this test piece was pulled with a speed of 150 mm/min, and the adhesive strength (kgf/25 mm) between the top NR/SBR compound and the fabric core (σ_{TF}) was registered (Table 3A); (4) at one end of this test piece, the bottom NR/SBR compound was peeled and then clamped to one jig of a tensile testing machine, and the remaining part of this test piece (i.e., a fabric core) was clamped to the other jig of the tensile testing machine; (5) the tensile testing machine was turned on; this test piece was pulled with a speed of 150 mm/min, and the adhesive strength (kgf/25 mm) between the bottom NR/SBR compound and the fabric core (σ_{BF}) was then registered (Table 3A). In this study, three test pieces, which were cut from the same spliced area of the fabric conveyor belt, were used for measuring the adhesive strength of a vulcanized fabric conveyor belt (Table 3A).

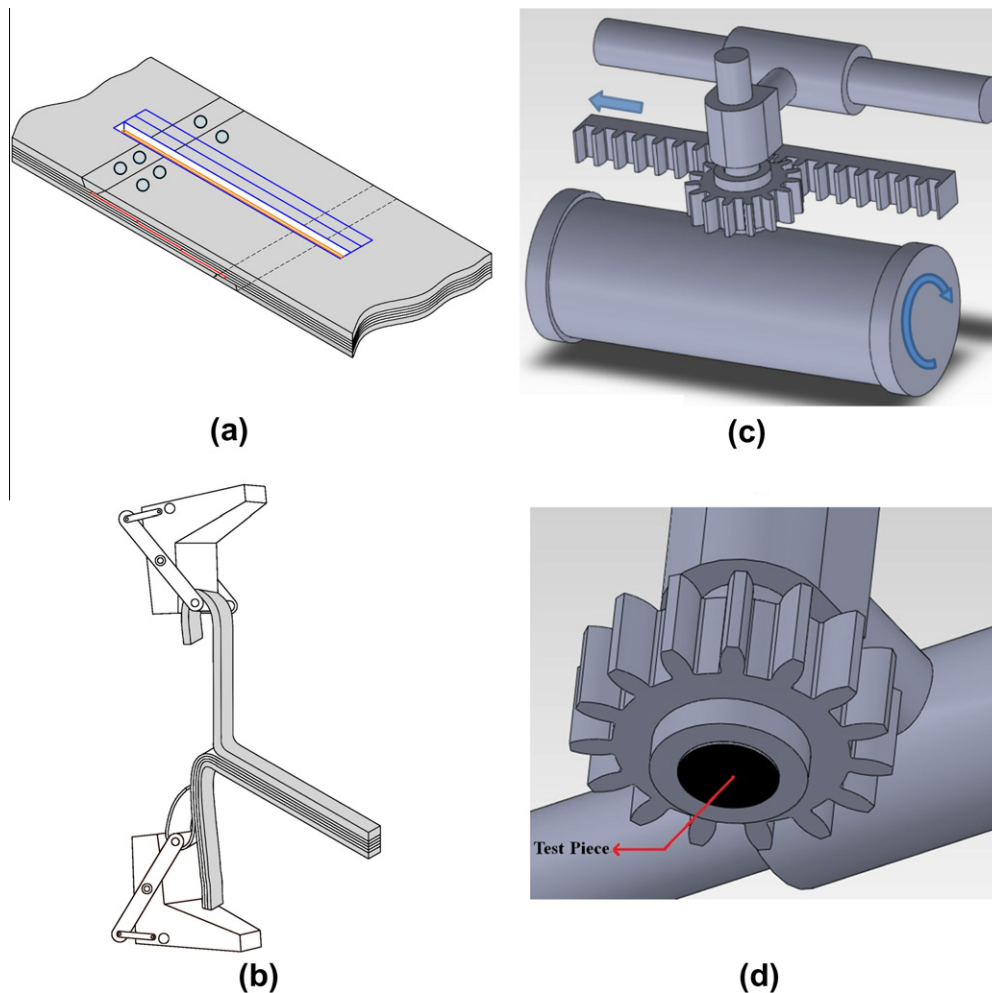


Fig. 1. Schematics of a vulcanized fabric conveyor belt (a), a tensile testing machine (b), a DIN type abrasion tester (c), and a test piece and the chuck of a DIN type abrasion tester (d).

3.3. Measuring the abrasion of a vulcanized fabric conveyor belt

According to JIS K6301 [21] and DIN 53516 [22], the procedure for measuring the abrasion of a vulcanized fabric conveyor belt is as follows: (1) a test piece with a diameter of 16 mm and a thickness of 6 mm was cut from the spliced area (or patched area) of the vulcanized fabric conveyor belt (Fig. 1a), and its mass was measured using a high-precision balance (DENER INSTRUMENT TP-214); (2) two thirds of this test piece (about 4 mm height) was inserted into the inside-aperture of the chuck of a DIN type abrasion tester (JIA-919D) (Fig. 1c and d); (3) a 60# sandpaper was used to wrap around the exterior surface of a roller in the DIN type abrasion tester; (4) the chuck was lowered until the test piece touched the sandpaper; (5) the chuck was moved from left to right while the roller was rotating with a rotation rate of 40 rpm, and a force of 10 N was being applied to the test piece; and (6) after the abrasion test, the test piece was removed from the chuck, and its mass was measured again.

The abrasion of the test piece cut from patched area (A_{pa}) or the abrasion of the test piece cut from spliced area (A_{sa}) was measured using the following equation:

$$A_{pa}(\text{or } A_{sa}) = \frac{\text{Mass before Test} - \text{Mass after Test}}{\text{Density of NR/SBR Compound}} \quad (11)$$

where the density of NR/SBR compound is 0.94 g/cm³. In this study, three test pieces cut from patched area and three test pieces cut

from the spliced area of a vulcanized fabric conveyor belt were used for measuring the abrasion of the vulcanized fabric conveyor belt (Table 3B).

4. Results and discussion

4.1. Optimum conditions to vulcanize a fabric conveyor belt with better adhesive strength

The adhesive strength of the spliced area in a vulcanized fabric conveyor belt prepared in Tests 1–9 was measured according to the method, as shown in Section 3.2, and its value was presented in Table 3A. Substituting the number of experimental repetitions and the MSD of the measurement results (i.e., the adhesive strength of the spliced area) into Eq. (1), the S/N ratio of each test condition was determined (Table 3A). The bold font in Table 3A refers to the maximum value of S/N ratio among the nine tests. Subsequently, the values of the S/N ratio were substituted into Eq. (2), and the mean of the S/N ratios of a certain factor in the i th level, $(M)_{\text{Factor}}^{\text{Level}}$, was obtained (Table 4A). In Table 4A, the bold font refers to the maximum value of the mean of the S/N ratios of a certain factor among three levels, and thus it indicates one of the optimum conditions for vulcanizing a fabric conveyor belt with better adhesive strength.

From Table 4A, the optimum conditions for vulcanizing a fabric conveyor belt with better adhesive strength are as follows: (1) the

Table 4A
S/N ratio response table for the adhesive strength.

Factor/level	$\left[\left(\frac{S}{N} \right)_{\text{Factor}}^{\text{Level}} \right]_j$			$(M)_{\text{Factor}}^{\text{Level}}$
	$j = 1$	$j = 2$	$j = 3$	
A/1	25.12	25.13	25.32	25.19
A/2	24.75	24.42	25.00	24.72
A/3	24.21	24.88	25.15	24.74
B/1	25.12	24.75	24.21	24.69
B/2	25.13	24.42	24.88	24.81
B/3	25.32	25.00	25.15	25.16
C/1	25.12	25.00	24.88	25.00
C/2	25.13	24.75	25.15	25.01
C/3	25.32	24.42	24.21	24.65
D/1	25.12	24.42	25.15	24.90
D/2	25.13	25.00	24.21	24.78
D/3	25.32	24.75	24.88	24.98

Note: The bold font corresponds to the maximum value of the mean of the S/N ratios of a certain factor among the three levels.

Table 4B
S/N ratio response table for the abrasion.

Factor/level	$\left[\left(\frac{S}{N} \right)_{\text{Factor}}^{\text{Level}} \right]_j$			$(M)_{\text{Factor}}^{\text{Level}}$
	$j = 1$	$j = 2$	$j = 3$	
A/1	-41.63	-41.03	-41.43	-41.36
A/2	-40.53	-40.61	-40.34	-40.49
A/3	-40.63	-41.55	-40.75	-40.98
B/1	-41.63	-40.53	-40.63	-40.93
B/2	-41.03	-40.61	-41.55	-41.06
B/3	-41.43	-40.34	-40.75	-40.84
C/1	-41.63	-40.34	-41.55	-41.17
C/2	-41.03	-40.53	-40.75	-40.77
C/3	-41.43	-40.61	-40.63	-40.89
D/1	-41.63	-40.61	-40.75	-40.99
D/2	-41.03	-40.34	-40.63	-40.67
D/3	-41.43	-40.53	-41.55	-41.17

Note: The bold font corresponds to the maximum value of the mean of the S/N ratios of a certain factor among the three levels.

time of curing is 25 min; (2) the pressure acting on the fabric conveyor belt is 9 kg/cm²; (3) the temperature of dismantling platen from the fabric conveyor belt is 30 °C; and (4) the cooling method is air cooling. A confirmation experiment was carried out according to the aforementioned optimum conditions; the adhesive strength of the spliced area was registered, and the S/N ratio was calculated (Table 5A).

The value of the S/N ratio under optimum conditions (26.55) exceeds that in Test 3 (25.32), and the average adhesive strength of the spliced area under optimum conditions (8.398 kgf/cm) substantially exceeds that in Test 3 (7.480 kgf/cm), as shown in Table 5A. This result is pretty exciting due to the fact that under a normal operation the higher average adhesive strength of the spliced area corresponds to a fabric conveyor belt with a longer lifetime. Because the temperature of dismantling the platen from the fabric conveyor belt decreases from 90 °C (in Test 3) to 30 °C (under the optimum conditions), the duration of vulcanization under the optimum conditions is longer compared with that in Test 3, and

Table 5A
S/N ratios for the adhesive strength in Test 3 and optimum.

	A	B	C	D	σ_{TF} (kgf/25 mm)			σ_{BF} (kgf/25 mm)			$\frac{1}{6} \sum_{i=1}^6 Y_i^{Ad}$	MSD	S/N
					Y_1^{Ad}	Y_2^{Ad}	Y_3^{Ad}	Y_4^{Ad}	Y_5^{Ad}	Y_6^{Ad}			
Test 3	1	3	3	3	24	20	20	18	16	16	19.00	0.0029	25.32
Optimum	1	3	2	3	22	22	22	22	20	20	21.33	0.0022	26.55

at this temperature of dismantling the platen (30 °C) accidents such as scalding of the worker's skin can be completely avoided.

4.2. Optimum conditions to vulcanize a fabric conveyor belt with less abrasion

The abrasion of the patched (or spliced) area in a vulcanized fabric conveyor belt prepared in Tests 1–9 was measured according to the method shown in Section 3.3, and its value was presented in Table 3B. According to the method described in Section 4.1, the S/N ratio of each test condition was determined (Table 3B), and the mean of the S/N ratios of a certain factor in the *i*th level, $(M)_{\text{Factor}}^{\text{Level}}$, was then obtained (Table 4B). In Table 4B, the bold font refers to the maximum value of the mean of the S/N ratios of a certain factor among three levels, and thus it indicates one of the optimum conditions for vulcanizing a fabric conveyor belt with less abrasion. A confirmation experiment was carried out according to the optimum conditions (Test 10 in Table 5B); the abrasion of the patched (or spliced) area was registered, and the S/N ratio was then calculated.

However, the value of the S/N ratio under optimum conditions (-41.17) was smaller than that in Test 6 (-40.36), and the average abrasion under optimum conditions (113.83 mm³) exceeds that in Test 6 (102.25 mm³), as shown in Table 5B. Therefore, two extra confirmation experiments (Tests 11 and 12 in Table 5B) were carried out. Comparing their S/N ratio values with the S/N ratio value in Test 6, it indicated that a fabric conveyor belt vulcanized in Test 6 had the best capability to prevent the fabric conveyor belt from abrasion. Consequently, the optimum conditions for vulcanizing a fabric conveyor belt with less abrasion are as follows: (1) the time of curing is 15 min; (2) the pressure acting on the fabric conveyor belt is 9 kg/cm²; (3) the temperature of dismantling platen from the fabric conveyor belt is 60 °C; and (4) the cooling method is water cooling. Mazurkiewicz indicated that the conveyor belt must be sufficiently durable and resistant to punctures, mechanical damages and abrasion, and it is also required to be highly resistant at the joint [1]. Therefore, the optimum conditions for vulcanizing a fabric conveyor belt with less abrasion at the joint (i.e., patched and spliced areas) are valuable and practical.

4.3. Discussion of optimum conditions

At a fixed pressure acting on the fabric conveyor belt of 9 kg/cm², a longer curing time (such as 25 min), a lower temperature of dismantling platen from the fabric conveyor belt (such as 30 °C), and a cooling medium (such as air) with a smaller thermal conductivity (0.024 W/m °C) compared with that of water (0.58 W/m °C) [2] are favorable for vulcanizing a fabric conveyor belt with better adhesive strength. In contrast, a shorter curing time (such as 15 min), a higher temperature of dismantling platen from the fabric conveyor belt (such as 60 °C), and a cooling medium (such as water) with a larger thermal conductivity (0.58 W/m °C) compared with that of air (0.024 W/m °C) are favorable for vulcanizing a fabric conveyor belt with less abrasion. Therefore, with a fixed pressure, it takes a longer time to vulcanize a fabric conveyor belt with better adhesive strength than to vulcanize a fabric conveyor belt with less abrasion.

Table 5B

S/N ratios for the abrasion in Tests 6, 10, 11 and 12.

	A	B	C	D	A_{pa} (mm ³)			A_{sa} (mm ³)			$\frac{1}{6} \sum_{i=1}^6 Y_i^{Ab}$	MSD	S/N
					Y_1^{Ab}	Y_2^{Ab}	Y_3^{Ab}	Y_4^{Ab}	Y_5^{Ab}	Y_6^{Ab}			
Test 6	2	3	1	2	126	121	121	80	87	79	102.25	10875.28	-40.36
Test 10	2	3	2	2	126	126	119	105	114	94	113.83	13086.63	-41.17
Test 11	2	3	2	3	134	127	132	83	108	105	114.81	13513.39	-41.31
Test 12	2	3	1	3	120	123	126	94	86	85	105.54	11445.43	-40.59

This difference can be attributed to the following facts: (1) at a fixed vulcanization temperature of 140 °C and a fixed pressure acting on the fabric conveyor belt of 9 kg/cm², the adhesion strength between the topping (or bottom) NR/SBR compound and the core of polyester fabric could be enhanced through a longer period of vulcanization; (2) during the vulcanization, some of the C–H bonds of one polymer chain of the NR/SBR compound were replaced by chains of sulfur atoms that link with another polymer chain [23], and the number of sulfur atoms in the crosslink strongly influenced the physical properties of the joint in the fabric conveyor belt; and (3) in the third period of curing, over-cure, the reversion might occur in the NR/SBR compound [24], and a longer period of curing might be unfavorable for vulcanizing a fabric conveyor belt with a better capability of resistance (i.e., less abrasion).

Morton indicated that following the curing stage, further heating may result in a stock softening due to reversion [25], and Karaagac indicated that the over cure of many tire compounds results in reversion [24]. Aside from this, comparing with the average abrasion in Tests 6 and 10 (Table 5B), as the temperature of dismantling platen decreased from 60 °C (Test 6) to 30 °C (Test 10), the average abrasion increased from 102.25 to 113.83 mm³. Besides the temperature of dismantling platen, the other test conditions in Tests 6 and 10 were identical. This legitimately supports the explanation that over cure of the NR/SBR compound may result in reversion.

Some reports related to the adhesion between the rubber and the fabric as well as to the curing process of a solid rubber were presented. For example, Sarkar et al. indicated that the rubber to fabric adhesion decreased with ageing time and temperature [26]. Further, Nozu et al. experimentally and numerically studied the cure process of a solid rubber (such as SBR), and they indicated that the cure reaction was clearly enhanced after the heat addition to the rubber had been removed [27]. Aside from this, because the ends of a conveyor belt must be joined together on-site to create a continuous belt [2,28], the optimum conditions of vulcanizing a fabric conveyor belt presented herein become significant and helpful to the manufacturers of the fabric conveyor belt.

4.4. Percentage of contribution

Initially, $(\bar{Y}^{Ad})_k^F$ (the average value of the adhesive strength of a certain factor in the *k*th level) was obtained from Y_i^{Ad} in Table 3A, and they are listed in Table 6A. By substituting $(\bar{Y}^{Ad})_k^F$ and $\bar{Y}_T^{Ad} = 17.98$ into Eq. (5), the factorial sum of squares, SS_F^{Ad} , for each factor was calculated individually, and they are listed in Table 7A. Using Eq. (4), the total sum of squares, SS_T^{Ad} , was determined. By substituting SS_F^{Ad} and $SS_T^{Ad} = 1.09$ in Eq. (6), the variance of error,

Table 6A

$(\bar{Y}^{Ad})_k^A, (\bar{Y}^{Ad})_k^B, (\bar{Y}^{Ad})_k^C$ and $(\bar{Y}^{Ad})_k^D$.

	$(\bar{Y}^{Ad})_k^A$	$(\bar{Y}^{Ad})_k^B$	$(\bar{Y}^{Ad})_k^C$	$(\bar{Y}^{Ad})_k^D$
Level 1	18.67	17.61	18.17	18.17
Level 2	17.67	17.89	18.06	17.67
Level 3	17.61	18.44	17.72	18.11

Table 6B

$(\bar{Y}^{Ab})_k^A, (\bar{Y}^{Ab})_k^B, (\bar{Y}^{Ab})_k^C$ and $(\bar{Y}^{Ab})_k^D$.

	$(\bar{Y}^{Ab})_k^A$	$(\bar{Y}^{Ab})_k^B$	$(\bar{Y}^{Ab})_k^C$	$(\bar{Y}^{Ab})_k^D$
Level 1	116.44	110.72	114.22	111.33
Level 2	104.34	112.00	108.28	106.83
Level 3	111.44	109.50	109.72	114.05

V_{ar}^{Ad} , was obtained. Finally, by the substitution of $SS_F^{Ad}, SS_T^{Ad} = 1.09, V_{ar}^{Ad} = 0.03$, and $DOF_F = 2$ in Eq. (3), the percentage contribution of each factor, ρ_F^{Ad} , was determined sequentially; and these values are presented in Table 7A. At a fixed vulcanizing temperature of 140 °C the rank order of the percentage contributions of each factor for the adhesive strength is as follows: (1) the time of curing (38.61%), (2) the pressure acting on the fabric conveyor belt (32.22%), (3) the temperature of dismantling platen from the fabric conveyor belt (23.49%), and (4) the cooling method (5.67%).

Following the procedures described in the preceding paragraph and the equations shown in Section 2.3, $(\bar{Y}^{Ab})_k^F$, the average value of the abrasion of a certain factor in the *k*th level, obtained from Y_i^{Ab} (Table 3B) is listed in Table 6B, and the factorial sum of squares (SS_F^{Ab}) for each factor and the percentage contribution of each factor (ρ_F^{Ab}) are presented in Table 7B. Aside from this, $\bar{Y}_T^{Ab} = 110.74$ was used to obtain SS_F^{Ab} , and $SS_T^{Ab} = 1.92$ as well as $V_{ar}^{Ab} = 0.004$ were used to determine ρ_F^{Ab} . At a fixed vulcanizing temperature of 140 °C the rank order of the percentage contributions of each factor for the abrasion is as follows: (1) the time of curing (61.22%), (2) the cooling method (21.13%), (3) the temperature of dismantling platen from the fabric conveyor belt (13.67%), and (4) the pressure acting on the fabric conveyor belt (3.98%).

4.5. Discussion of contribution percentage

Among the four controllable factors, the time of curing is the most influential factor on both the adhesive strength of the spliced area and the abrasion of the patched and spliced areas. Aside from this, a longer period of curing (25 min) might facilitate the bonding between the NR/SBR compound and the fabric core, and it might be favorable for vulcanizing a fabric conveyor belt with better adhesive strength. On the other hand, a shorter period of curing (15 min) might prevent the cured NR/SBR compound from reversion, which might occur in the third period of curing and usually have an undesirable effect on the product quality [2,24–25], and it might be favorable for vulcanizing a fabric conveyor belt with a better capability of resistance (i.e., less abrasion). Moreover,

Table 7A

SS_F^{Ad} and ρ_F^{Ad} .

Factor	SS_F^{Ad}	ρ_F^{Ad} (%)
A	0.42	38.61
B	0.35	32.22
C	0.26	23.49
D	0.06	5.67

Table 7B
 SS_F^{Ab} and ρ_F^{Ab} .

Factor	SS_F^{Ab}	ρ_F^{Ab} (%)
A	1.22	61.22
B	0.07	3.98
C	0.25	13.67
D	0.38	21.13

Bando Chemical industries, Ltd. indicated that the minimum vulcanization period for a fabric conveyor belt is 15 min, and it is linearly proportional to the thickness of a fabric conveyor belt [18].

The pressure acting on the fabric conveyor belt is the second influential factor on the adhesive strength of the spliced area among the four controllable factors because insufficient pressure is one of the main reasons that cause the separation of the spliced area. Therefore, Bando Chemical industries, Ltd. suggested that the hydraulic pressure acting on the fabric conveyor belt during vulcanization should range from 7 to 10 kg/cm² [18]. Aside from this, the cooling method is the second influential factor on the abrasion of the patched and spliced areas among the four controllable factors because the cooling process plays an important role in the cure process and the cure reaction is clearly enhanced after the heat addition to the rubber is removed [27].

5. Conclusions

This study investigated the optimum conditions for vulcanizing a fabric conveyor belt with better adhesive strength and less abrasion in the joint using the vulcanizing method and the ANOM of the Taguchi method. Furthermore, using the ANOVA of the Taguchi method, the percentage contribution of each controllable factor to vulcanize a fabric conveyor belt was determined. With a fixed curing pressure, a longer curing period (25 min) might be favorable for vulcanizing a fabric conveyor belt with better adhesive strength because the bonding between the NR/SBR compound and the fabric core could be facilitated under a longer time. In contrast, a shorter period of curing (15 min) might be favorable for vulcanizing a fabric conveyor belt with less abrasion because a shorter period might prevent the cured NR/SBR compound from reversion. Interestingly, the optimum conditions for vulcanizing a fabric conveyor belt presented herein are helpful to the manufacturers of the fabric conveyor belt to reduce their manufacturing costs.

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