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OPTIMIZATION OF COLD SPLICING PARAMETERS IN CONVEYOR BELT JOINTS ON SHEAR STRENGTH USING TAGUCHI METHOD

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Abstract *Cold splicing method is one of solution to repair conveyor belt damage. The purpose of this study is to investigate the effect of cold splicing parameters on the shear strength of conveyor belt joints. This research uses orthogonal array Taguchi matrix L9 with 3 factors and 3 levels, then replicated 3 times of each experiment. The material of conveyor belt is rubber belt with polyester reinforcement. The process parameters selected are number of layers of belt reinforcement (ply), slope angle and adhesive thickness. The ultimate shear strength based on ASTM D 3165 is observed. Based on the results, number of belt ply is the most influential factor with percentage contribution was 86.22%. The optimal combination factor result from Taguchi method is obtained on number of belt 4 ply, slope angle 0.6xB and adhesive thickness 2 mm.*

Keywords*: conveyor belt, cold splicing, shear strength,, Taguchi method, ANOVA*

1. Introduction

Based on data released by Badan Pusat Statistik (BPS) in 2019, the production growth of large and medium manufacturing industries in the third quarter increased by 5.13% compared to the second quarter. The industry that experienced the highest increase in production was the non-metallic mineral industry, which increased by 14.15% [1]. Non-metallic minerals are mining materials, one of which is limestone. Limestone is one of the raw materials or basic ingredients for making cement. The increase in cement production requires the industry to be more productive while maintaining the company's facilities and infrastructure, such as production machines. Production machines whose existence is widely found because they have high benefits in helping human work are material transfer devices or often referred to as conveyors [2]. There are various types of conveyors, including screw conveyors, roller conveyors and belt conveyors [3]. Belt conveyor is a material handling equipment that uses an endless belt as its main component. The belt consists of several layers, one of which is a reinforcement layer located in the middle. The basic materials of the reinforcing layer are varied, some are made from fabric belt such as nylon, polyester and steel fibers or more often the term steel cord. Belt that is used continuously will not be always in good condition, as it will experience light to severe damage [4]. Based on research on the classification of belt damage, the damage is divided into 3 types, namely mechanical, physical and chemical damage. Mechanical damage is the occurrence of abrasions and cracks on the cover belt while physical and chemical damage are changes in hardness, changes in modulus of elasticity and thermal oxidizing. However, the damage that generally occurs is mechanical such as wear abrasions fine cracks (crack), torn to break [5]. These damages are caused mainly by the impact of fallen materials onto the belt which in turn rub against the belt.

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The conveyor belt damage can be overcome with corrective actions to prevent delays in the production process. The corrective action is splicing. Belt splicing is done to reduce maintenance costs compared to replacing the belt as a whole [6]. There are several kinds of joints to the belt, namely mechanical and vulcanizing. Mechanical splicing is using a material in the form of hinges while vulcanizing splicing is done chemically using an adhesive material in the form of glue. Vulcanizing splicing is divided into two methods, namely cold splicing and hot splicing. The splicing method that is most often used is cold splicing, because the process is faster and requires fewer tools than hot splicing, it does not stop the conveyor belt operation for too long. In the cold splicing process, there is a step of coating the adhesive material or often referred to as adhesive layering. Research on adhesive coatings continues to be developed. The thickness of the adhesive is the most influential thing on the strength of the joints [7]. This allows *conveyor belt* which tend to experience tensile loads when operating and affect the shear stress in the belt joints. This study was conducted on the effect of the splicing parameters on the shear strength of the conveyor belt joints using the Taguchi optimization method and *Analysis of Variance* (ANOVA) to determine the most influential parameters and able to produce strength values slide the highest joints.

2. Materials and Method

2.1 Material

The work material selected for the study of conveyor belt is rubber belt with polyester reinforcement. Table 1 shows the specification of conveyor belt. The dimension of the work piece used in the experiment was 200 mm x 25 mm x 10 mm.

Tabel 1. Conveyor Belt Specification

Equipment Name	Equipment Description	
Belt Conveyor Reclaimer Limestone Raw Material	Belt capacity	300 mtph
	Belt width	900 mm
	Belt strength	500 kg/cm
	Belt speed	1,27 m/sec
	Horizontal length	40 meter
	Including	Shaft mounted reducer (link-belt model 207 d24), v-belt, driver sheave, driven sheave and v-belt guards
	Motor power	5,5 kw
	Motor speed	1500 rpm

2.2 Experimental Setup

This experiment uses cold splicing belt joints method and the machine for shear strength test used computer type universal testing machine with the loading speed is 1.27 mm/minute until the belt breaks or adhesive failure occurs. In **Fig 1** shows the electro-hydraulic servo Universal Testing Machine (UTM HT9502) with maximum load of 500 kN. The shear test was carried out according to ASTM (American Society for Testing Materials) D3165 standard test method for strength properties of adhesives in shear by tension loading of single-lap-joints laminated assemblies.

Fig 1. Computer Type Universal Testing Machine

2.2.1 Selection of Parameters Cold Splicing

Typical fabric-rubber belt used in the belt conveyors are joined using one of the three following methods: high temperature vulcanization, room temperature vulcanization (cold bonding) or

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mechanical fastening [8]. Mechanical belt joints, which may or may not be permanent, must have a relative strength of at least 60% of the nominal belt tensile strength. Vulcanized and bonded joints of fabric-rubber belt are formed using the same joints constructions but with the use of progressive overlap joints. In addition to the several factors above that affect cold splicing. There is another factor that needs to be investigated, it is the effect of the adhesive layer [9]. In this study, 3 ply belt, BANDO SUNPAT ECO 310 and SC 2000 adhesive types were used with uniform drying time. Based on the research, it was found that the use of BANDO SUNPAT ECO 310 adhesive was better with a maximum tensile strength of 27.5 MPa with cost efficiency and good gluing quality to support conveyor belt performance. Another study with the same type of adhesive by using the BANDO SUNPAT ECO 310 and SC 2000 adhesives showed similar results where the shear strength of BANDO SUNPAT ECO 310 joints was better than SC 2000 [10]. In the next study, the efficiency of belt splicing time using the cold splicing method was observed [11]. This study uses a 3ply belt with variations in drying time of 2 hours, 4 hours, 6 hours and 8 hours. The adhesive used is BANDO SUNPAT ECO 310. From this research, it is known that the use of the cold splicing method is most efficient at a drying time of 2 hours, with the shortest drying time, the belt strength has reached 7.46 MPa. Based on the research above, the authors set the same characteristics for each spliced specimen. The splicing method used is cold splicing, curing time is 2 hours and the type of adhesive used is BANDO SUNPAT ECO 310.

2.2.2 Selection of Parameters Level Range of Ply Belt, Slope angle and Adhesive Thickness

Taguchi method was used to determine the effect of the belt reinforcement layer and optimal tensile test parameters on the tensile strength of the rubber-textile belt [12]. The variations used in this study are the number of layers of reinforcement 2 ply, 3 ply and 4 ply, loading direction 0°, 45°, 90° and loading speed 50 mm/minute, 100 mm /min, and 150 mm/min. The results showed that the maximum tensile strength value was the number of layers of 4 ply belt reinforcement, with a loading direction of 0° and a loading speed of 100 mm/minute. reinforcement on the belt with a loading direction of 0° and with a moderate loading speed. Slope angle is an important factor affecting the strength of conveyor belt joints other than the adhesive material [13]. Incorrect slope angle size will result in weak joints strength. The area of the short joints area will make the joints easier to open. In his study, the size of the slope angle used was 0.2 x belt width (BW), 0.3 x belt width (BW), 0.4 x belt width (BW), and 0.5 x belt width (BW), then a shear test was performed. Based on the research that has been done, the highest shear strength value is in the belt joints with a slope angle of 0.5 x BW which produces a shear strength value of 39.71 MPa, while the slope angle of 0.2 x BW has a shear strength value of 20.67 MPa, 0.3 x BW of 24.52 MPa. and 0.4 x BW of 27.85 MPa. The selection of slope angle is an important step for cutting belt joints in cold splicing procedures [14]. In this study, an investigation was carried out to determine the effect of slope angle on a belt with a 3ply reinforcement layer using a combination of slope angle parameters. The variations used are 0.1 x BW, 0.3 x BW, and 0.7 x BW. The results of this study indicate that the tensile strength of the belt joints increases with increasing slope angle from 0.2 x BW to 0.5 x BW with a change in tensile strength from 20.9 MPa to 25.92 MPa. For a slope angle of 0.7 x BW the tensile strength decreases to 18.68 MPa. The adhesive thickness is important in the conveyor belt joints process. Increasing the adhesive thickness can increase lifetime of the belt [15]. In this study, using variations in adhesive thickness of 0.13 mm, 0.38 mm, and 0.79 mm. Investigation about increasing belt lifetime with increasing adhesive thickness was carried out using variations of adhesive thickness 0.1 mm, 0.2 mm, 0.5 mm, 1.0 mm, 2.0 mm. The optimal value occurs at the highest adhesive thickness is 2.0 mm [16]. A study about the analysis of the effect of joints strength on composite materials was carried out to investigate the type of adhesive cohesive damage cohesive zone model (CZM) and the most influential parameters based on the mechanical properties of the joints, the type of adhesive material AV138/HV998 brittle type and Hysol EA 9361 ductile type and the adhesive thickness (tad) variations are 0.1mm, 0.5mm and 1.0mm. Based on the study, it was found that the joints shear strength increased in the brittle adhesive type and the adhesive layer was 0.1 mm [17].

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Based on the previous study, the process parameters selected are number of layers of belt reinforcement (ply), slope angle and adhesive thickness. The number of ply belts used are 2 ply, 3 ply and 4 ply. Variations in the slope angle used are 0.3xB, 0.6xB and 0.9xB and the adhesive thickness variations used are 1 mm, 2 mm and 3 mm. In addition, the shear strength of belt joints data are analyzed using Taguchi optimization method and analysis of variance (ANOVA).

2.2.3 Cold Splicing Procedures

The research process begins with making joints using cold splicing consisting of eight stages, namely:

1. Calculate and draw the joints using a roll meter, elbow ruler and mark with a marker according to the splicing formula on the two parts of the belt to be joined.
   Calculation and Cutting of Specimens as shown in equation 1.
   $L = (0.3 \times B) + (S \times (n-1) + 25 + 5$ (1)
   Information :
   L = Joints length (mm)
   B = Belt width (mm)
   S = Step or step(mm)
   n = Number of Ply (reinforcement layer)
2. Cutting and peeling belt using cutters, ply lifters and pincers
3. Roughen the peeled surface using a grinder until a little part of the reinforcement layer is visible
4. Clean the surface to be joined using a palm fiber brush then wipe with a cleaning solvent
5. Apply a layer of adhesive, mix glue and hardener liquid in a container with a ratio of 100:8, then coated on the part to be joined evenly using a brush according to the research parameters 1 layer, 2 layers and 3 layers where double 1 mm coating and dosing volume using a digital scale. The following is the calculation of the volume of adhesive used.
6. Dry the joints area using a dryer. Pay attention to the drying time of each layer is 10-20 minutes using a stopwatch and make sure the temperature and humidity of the joints are maintained, measure using a Hygrometer
7. Connect the two parts of the belt, straighten and stick it slowly then press it with a hand roll and a rubber hammer
8. Check the neatness of the joints, measure the thickness of the joints using a caliper

2.2.4 Shear Strength Measurements

The next process is to test the joints shear using the Universal Testing Machine to get the highest shear strength value or ultimate shear strength based on ASTM D 3165 which is a test standard for adhesive shear joints (lap shear joints) [18]. Shear stress is a stress that acts in a direction parallel to the surface of an object and is often called tangential stress [19]. Shear stress measurement as shown in equation 2.

$$\tau = \frac{P}{A} \quad (2)$$

Information;
τ = Shear stress *(shear stress)* [MPa]
P = Style parallel to the surface of the object (N)
A = Area cross section subjected to shear force (mm2)

2.3 Method

The next stage is the experimental planning stage with the Taguchi Method as follows:

1. Identification of problems
   Problem identification is carried out based on a literature study of the object of research in the form of a conveyor belt joints
2. Determination of Dependent or Bound Variable Response
   This determination is carried out in determining the characteristics that can be measured based on the quality of the dependent variable and selecting factors that affect the independent variables. The quality characteristic used is Larger the better, which means that the greater the target value of the shear strength, the better the quality is declared.
3. Identification of Important Factors or Independent Variables
   Identification of important factors is done to determine the factors that can have a major influence on the output of the object under study. An important factor is obtained from the identification of possible causes. Based on the brainstorming results from observations in the field and interviews with operators, members of the belt splicing team, team leaders, planners and head of the conveyor belt construction section, the cause of the weak belt joints strength can be

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described in the following cause-and-effect diagram [20]. **Fig 2** shows cause effect diagram by fishbone diagram type

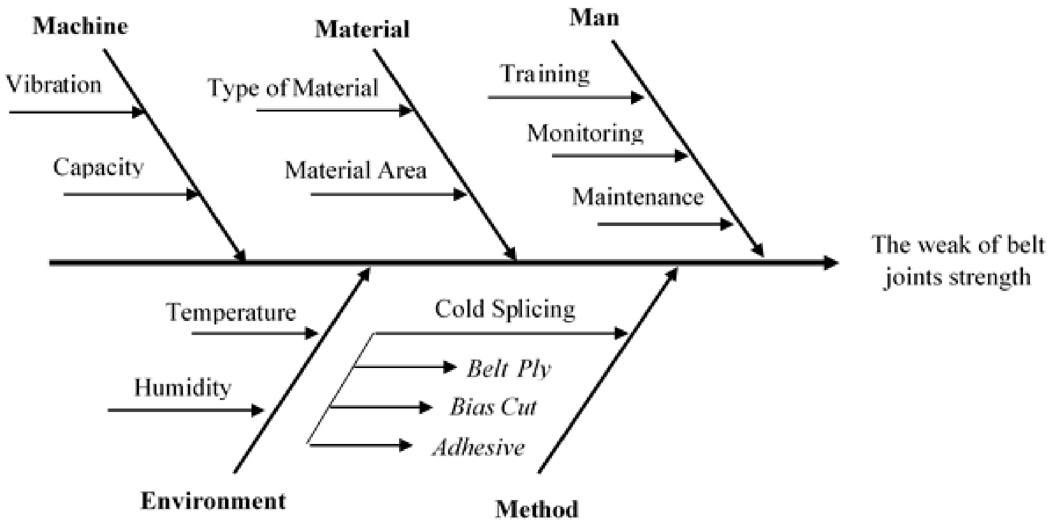

Fig 2 Cause and Effect Diagram (Fishbone Diagram)

4. Separation of Control Factors and Interference Factors
The observed factors were divided into control factors and disturbance factors. The control factor is a factor whose value can be controlled, while the noise factor is a factor whose value cannot be controlled.
5. Setting the Amount and Level of Each Factor
Determining the number of factors and the level of each factor is the most important thing in the experimental design of the Taguchi method to be implemented in simplifying the process of data quantification and data analysis. Table 2 shows selection of factors and the level of each parameters based on a literature study.

Table 2. Factor and Level Used

No	Factor	Level 1	Level 2	Level 3
1	Number of Ply Belts	2 ply	3 ply	4 ply
2	Slope Angle	0.3xB	0.6xB	1.0xB
3	Adhesive Thickness	1 mm	2 mm	3 mm

6. Factor Interaction
Factor interaction is a very important and useful step to investigate which factors can have a significant influence on the shear strength of conveyor belt joints.
7. Counting the Degrees of Freedom
The degree of freedom serves as a benchmark for the minimum amount required to carry out the Taguchi experiment in this study. The calculation value of the degrees of freedom = (number of factors) x (number of levels - 1) = 3 x (3 - 1) = 6
8. Choosing a Taguchi Orthogonal Array
After calculating the degrees of freedom, then determine the orthogonal array selection which depends on the number of factors and the level of each factor. Determination of the orthogonal array matrix that has been selected is arranged for further quantification. In Taguchi method, analysis of the measured response shows the importance of the process parameters to be use [21]. The selected orthogonal array is a matrix that has a degree of freedom value equal to or greater than the experimental degree of freedom value. In this study, the matrix o*rthogonal array* is L9 (3^3) is selected due to its value is above the experimental degrees of freedom. The data input process of the test results is carried out into the worksheet column. The test results data is entered into the next column on the title of tensile strength.

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Table 3. Data Retrieval Worksheet

⬇	C1 Number of Ply Belts	C2 Slope Angle	C3 Adhesive Thickness	C4 Shear Strength
1	2	0.3XB	1	
2	2	0.6XB	2	
3	2	1.0XB	3	
4	3	0.3XB	2	
5	3	0.6XB	3	
6	3	1.0XB	1	
7	4	0.3XB	3	
8	4	0.6XB	1	
9	4	1.0XB	2	

Table 4. Experimental Design of The Taguchi L9 (3^3) Method

Experiment	Factors		
	Factor 1	Factor 2	Factor 3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

9. Carrying out Experiments
   In carrying out the experiment, the number of experiments corresponds to the selected orthogonal array matrix. Experimental preparation includes determining the number of replications. Replication to reduce the error rate of the experiment, resulting in a more accurate, better estimate of the mean effect of a factor.
10. Data retrieval
    Data collection was carried out after carrying out the experimental design, in this study the data taken was the value of the shear strength of the conveyor belt joints.
11. Data processing
    Data processing was carried out with the Taguchi experimental design as the main instrument, continued until the confirmation experiment was carried out to determine the factors that had a significant effect and to determine the optimal level setting to produce a conveyor belt joints that produced the highest shear strength value.
12. Calculating Analysis of Variance (ANOVA)
    Calculating ANOVA was carried out to analyze the results of the Taguchi experiment, namely the calculation of the total number of squares, the number of squares to the average, the sum of the squares of each factor and the number of squares of errors.

3. Result and Discussion

Based on the research that has been done, the results and discussion are as follows. Table 5 shows the results results of experimental of belt joints on shear strength.

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Table 5. Experimental Results of Belt Joints Shear Strength

Experiment	Number of Ply Belts	Slope Angle	Adhesive Thickness	Shear Strength (MPa)			Mean of Shear strength (MPa)
				Trial 1	Trial 2	Trial 3	
1	2	0.3xB	1	12.4	12.3	12.6	12.4
2	2	0.6xB	2	14.6	14.8	14.7	14.7
3	2	1.0xB	3	12.0	11.2	11.7	11.6
4	3	0.3xB	2	18.2	18.4	18.2	18.3
5	3	0.6XB	3	16.1	16.3	16.0	16.1
6	3	1.0xB	1	17.3	17.5	17.4	17.4
7	4	0.3xB	3	18.1	18.3	18.3	18.2
8	4	0.6xB	1	19.1	19.1	19.0	19.1
9	4	1.0xB	2	20.4	20.5	20.3	20.4

Table 6. Response Signal to Noise Ratios (S/N Ratio) Larger is better

Level	Number Ply Belts	Slope Angle	Adhesive Thickness
1	21.82	23.95	23.94
2	24.61	24.21	24.71
3	25.58	23.85	23.36
Delta	3.76	0.36	1.35
Rank	1	3	2

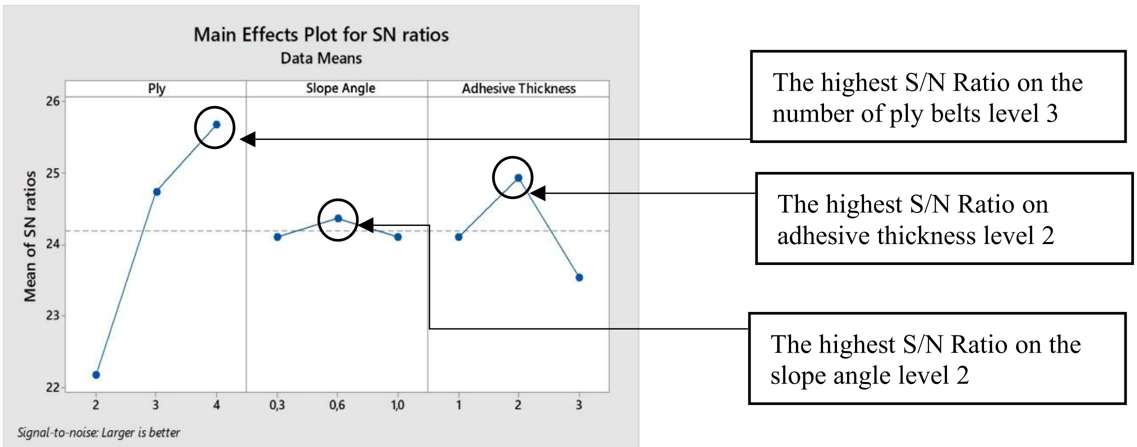

Fig 3 Main Effect Plots SN Ratios

Table 6 shows that the number of plies is in the first order, then the second is the adhesive thickness, then the third is the slope angle. It is shown in the table that increasing the number of plies can increase the shear strength of the conveyor belt joints. The greater the number of plies the shear strength will be greater. Adhesive thickness is also a factor that has a major influence on the shear strength where it is shown in the table that increasing the adhesive thickness to a certain size can increase the shear strength of the conveyor belt joints. **Fig 3** shows that the optimal process parameters setting on number of belts is 4 ply, slope angle is 0.6xB and adhesive thickness is 2 mm.

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Table 7. Results of Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Number of Ply Belts	2	63,0467	31,5233	155,03	0,006
Slope Angle	2	0,1667	0,0833	0,41	0,709
Adhesive Thickness	2	9,5000	4,75	23,36	0,041
Error	2	0,4067	0,2033		
Total	8	73,1200			

In Table 7, it can be seen that the analysis of sequence variance shows that statistically influential variables are ply belt, adhesive thickness and slope angle. The magnitude of the influence of each variable can be seen from the P-Value and F-Value Hypothesis Testing in the Variant Analysis result table.

To test the output of the analysis of variance, a hypothesis structure is used. In this analysis, the hypothetical structure used for testing the variables that affect the strength of the conveyor belt joints are as follows:

- Ho = Factor does not affect the average value significantly
- Ha = Factors affect the average value significantlyn
- The initial hypothesis will be rejected if F > Fa a, df-num, df-den
- *a* is the level of significance, taken 0.05
- df-num is the degrees of freedom used as the numerator
  df-num = k-1, k= Number of variables
  In this study df-num = 3-1 = 2
- df-den is the degree of freedom used as the denominator
  df-den = Tk, T = the total number of samples in this study df-den = 9-2 = 7
- Based on the F distribution table for F 0.05, 3, 14 is 4.74

P-Value or probability value can be interpreted as the magnitude of the observed error opportunity from a statistical test. When the P-Value analysis process is always compared with a, which is the significance value or also referred to as the maximum acceptable error value. In this study, a significance level of 0.05 was used, namely if the P-Value 0.05 then the Ho hypothesis was accepted, which means that the independent variable tested has no effect on the dependent variable and if the P-value 0.05 then the Ho hypothesis is rejected which means the variable independent has an influence on the dependent variable. The greater the P-Value value, the smaller the effect of the tested variable on the fixed variable [22].

In addition to looking at the P-Value, it is used to make decisions about parameters that affect the shear strength of the conveyor belt joints. This F-Value test is done by comparing the calculated F-value with F in the Statistics table. Table 8 shows the results of the calculation of decision making based on the F-value.

Table 8. Decision Acceptance of The Hypothesis

Variable	Camparison between F-Value and F-Table	Hypothesis Decision
Number of Ply Belts	155,3 ≥ 4,47	Rejected Ho
Slope Angle	0,41 ≤ 4,47	Accepted Ho
Adeshive Thickness	23,36 ≥ 4,47	Rejected Ho

Based on the results, it can be shown that the amount of Ply has a large influence on the shear strength of the conveyor belt joints followed by adhesive thickness while the slope angle has no effect on shear strength. Table 6 above shows the F-value tested, it is known that not all variables affect the shear strength of the conveyor belt joints, so the size of the influence of each variable being tested is seen from the percentage contribution of each variable. The percentage value of the variable contribution can be calculated using the equation as shown in equation 3.

Calculating the % contribution of each variable:

$$\%P = \frac{Sum\ of\ Squares\ (Variable)}{Sum\ of\ Total\ Squares}\ x\ 100\% \quad (3)$$

Examples:

$$\%P = \frac{63,0467}{73,1200}\ \text{x}\ 100\%$$

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Table 9. Contribution Percentage

Variable	Contribution Percentage (%P)
Number of Ply Belts	86,22 %
Slope angle	0,23%
Adeshive Thickness	12,99%
Error	0,56%
Total	100,00%

Based on Table 9, it can be seen that the number of plies has the largest contribution, namely 86.22%, then adhesive thickness is 12.99% and slope angle has a contribution of 0.23%. From the calculation of the percentage contribution, it is known that the error in this analysis is 0.56%, it can be said that the experiments that have been carried out have accurate results because they have a small percentage of error.

4. Conclusion

This investigation studied the optimum condition of cold splicing parameter in conveyor belt joints using ANOVA and Taguchi method. Furthermore, using ANOVA and Taguchi method, the percentage of contribution of each controllable factor within the current investigation range was also determined. Interestingly, the optimum conditions of the shear strength conveyor belt based of cold splicing parameters was number of belt ply, its percentage contribution was 86.22%. The optimal combination factor result from Taguchi method is obtained on number of belt 4 ply, slope angle 0.6xB and adhesive thickness 2 mm. This study supports the application of a simple and traditional vulcanizing method to effectively splice a fabric conveyor belt on-site.

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