Terbit *online* pada laman web jurnal : http://metal.ft.unand.ac.id

METAL: Jurnal Sistem Mekanik dan Termal

| ISSN (Print) 2598-1137 | ISSN (Online) 2597-4483 |

Research article

Effect of Spindle Speed, Feedrate, Tool Geometry, and Polyester & Vinylester Blends on Surface Roughness and Surface Hardness Alteration of the Hole

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ARTICLE INFORMATION

Article History:
Received : 10 January 2023
Revised : 30 April 2023
Accepted : 27 May 2023

KEYWORDS

Polymers
Mixed
Polyester
Vinylester
Blend

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ABSTRACT

In this study, 2 types of polymers were mixed, namely polyester and vinylester called polyester-vinylester blend (PVB) as the test workpiece. The experiments carried out were testing the surface quality of the hole, namely surface roughness (R_a), and surface hardness alteration (SHA) after drilling. In this study, the effects of spindle speed (n) & feedrate (f), cutting-edge angle (K_r), and PVB composition ($P\%V\%$) were tested. The results showed that the factor that most influenced the surface roughness value was the feedrate with a contribution value of 39% and the PVB composition (32%) for PVB dominantly polyester. Whereas in vinylester dominant PVB, the most influential factor is the spindle speed (50%). For the measurement of surface hardness alteration that occurs, the factor that affects surface hardness alteration is the cutting-edge angle (44%) in PVB dominantly of polyester. While in vinylester dominant PVB, the influencing factor is spindle speed (44%).

1. INTRODUCTION

Polymers are widely developed and researched nowadays, because of their corrosion resistance, relatively light material compared to metal, relatively high strength compared to their weight, high aesthetics, making them an alternative material in the manufacturing industry [1]. The increase in the potential of the polymer can be done by mixing several polymers, which is called a polymer blend [2]. The polymer blend aims to obtain the mechanical and thermal properties of each polymer that is mixed, so as to produce an alloy material that has better properties [3].

Polymer blend machining aims to obtain the desired component geometry [4]. Among them is the drilling process to produce a cylindrical surface (hole). In its application, this cylindrical surface must have certain requirements, especially roughness and surface integrity after machining, for example, the cylindrical surface of pins and holes in the application of joining polymer materials.

Surface integrity is a description of the surface condition of components produced by manufacturing operations, which consists of 2 aspects, namely the topography/surface geometry and the mechanical, crystallographic, chemical, thermal, and electrical properties of the surface. Aspects of surface geometry involve; roughness, flatness, texture, and dimensional accuracy of the surface. While the aspects of mechanical, crystallographic, chemical, thermal, and electrical

https://doi.org/ 10.25077/metal.7.1.27-33.2023

properties involve; surface hardness alteration, micro-cracks, tear cracks, plastic deformation, etc. [5]

Generally, during machining operations and or after both metal and non-metal workpiece materials, there is a significant change in physical and mechanical characteristics that will affect the surface integrity of the resulting product. The selection of independent variables (factors) and the determination of the right factors will result in optimal surface integrity of the machining. The effect of several factors such as PVB composition (percentage of polyester with vinylester, *P%V%*) and machining parameters on surface roughness and surface hardness alteration was studied. The surface integrity of the product is good if the R_a that occurs is very small, and the SHA is not significant.

This study aims to examine the effect of *P%V%* of PVB, variable cutting speed, feedrate, and cutting-edge angle (K_r) of the drilling cutting tool on R_a and SHA of the hole surface after drilling. Then find out the contribution of each of these factors. This research is useful to obtain information or data on polymer blend machining on the quality of components made with drills.

Surface Hardness Alteration (SHA) & Surface Roughness (Ra)

Hardness indicates a material's resistance to plastic deformation. There are three types of hardness measurements, depending on how the experiment is carried out, namely: (1) scratch hardness, (2) indentation hardness, (3) rebound hardness. In this research, indentation hardness is used, namely the Vickers Hardness Test. This hardness value can change if the machining process is carried out on the surface. These changes can occur during the process or after [5].

What is meant by "surface" is the boundary that separates a solid object from its surroundings [6]. When viewed on a small scale with respect to the virtual plane perpendicular to the surface, the surface is depicted in the form of a profile consisting of peaks and valleys. The position of the points on the crest and valley lines is the roughness of the surface that forms the surface. The wider the position of the point, the rougher the surface, and vice versa, the smoother the surface.

2. MATERIALS AND METHOD

Polymers are very useful materials in engineering, which are used as alloying materials with other materials to form composite materials. With the use of polymers as alloys for strength and toughness, it is necessary to improve the mechanical properties of polymers in order to form better mechanical properties [7].

Polymer blend (PB) is a mixture of several polymers into one material [7]. Basically, different types of polymers will have different characteristics as well. The purpose of the mixing is to obtain the properties of each polymer, which is expected to form better mechanical properties than before.

Polyester (P) is a basic material in the manufacture of polymer materials. Its mechanical properties are classified as good and cheap [8]. Polyester is a substance that is clear in color, has a slight odor, and has a high viscosity and hardness. To reduce the hardness, it is mixed with other polymers that are more ductile. The type of polyester used is unsaturated polyester with the brand Yukalac1560 BL-EX. Unsaturated polyester has a double bond between carbon and carbon in the main chain. For the application, a 4% catalyst is used as a hardener and accelerates the reaction between the bonds [9].

Vinylester (V) is a thermosetting polymer that has high performance against an alloying element, good processability, and better thermal properties when compared to other polymers. Vinylester has good potential to improve the material properties of an alloying element. Basically, vinylester is an alloy of polyester and epoxy resin which has a combination of chemical properties, mechanical properties, and thermal properties that are better than epoxy resins with better purity than polyester resins [10].

Polyester and vinylester are mixed to form a mixed polymer material called polyester-vinylester blend (PVB). The mixture consisted of 6 compositions, then drilled to see the smoothness of the surface and surface hardness alteration after drilling.

In this study, the Taguchi method [11] was used to achieve the goal. This method is very effective to see the influencing factors and their contribution to the R_a and SHA of the observed holes, in this case, are K_r from the drilling cutting tool, *P%V%* composition of PVB, and drilling parameters (*n* & *f*). This method is implemented in 4 phases, namely;

planning, designing, conducting, and analyzing the experiment.

In the experimental planning phase, the research objectives are determined (read in the introduction). Next, the characteristics of the surface integrity being tested and their values are R_a with a value of smaller is better, and SHA with a nominal value of is best. The next method is the measurement of the quality, for R_a is measured using a surface roughness tester, while SHA is measured using a Vickers hardness measuring instrument. Next again the factors that affect the quality and level, namely *n* with a level of 330 rpm, 510 rpm, and 770 rpm. *f* with levels of 0.01 mm/r, 0.05 mm/r, and 0.10 mm/r. K_r with levels 68°, 60° and 56°. *P%V%* has 6 compositions so that it becomes 3 levels divided by 2 into Composition I and Composition II. Composition I a mixture of Polyester & Vinylester with a dominant polyester with a level of 100% Polyester (P100V), 80% Polyester (P80V), 60% Polyester (P60V) and Composition II a mixture of Polyester & Vinylester with a dominant vinylester with a level of 60% Vinylester (PV60), 80% Vinylester (PV80), 100% Vinylester (PV100). The following factors and their levels are tabled in Table 1 and Table 2. Experiments are planned using drilling which produces a hole surface using a lathe.

The phase of designing the experiment chose a test set that had been designed by Taguchi, namely the arrangement of Orthogonal Arrays, (OAs) based on how many factors and their levels were reviewed in the test. Among them are OAs-$L_4(2^3)$, $L_8(2^7)$, $L_9(3^4)$, $L_{16}(4^5)$, and so on. In the research that will be conducted, there are 4 main factors to be studied, namely *n, f,* K_r, and *P%V%*, each factor has 3 levels. For the 4-factor test design with 3 levels according to Taguchi, the appropriate test set is OAs-$L_9(3^4)$ as shown in Table 3 and table 4, which consists of 9 experiments per set. The numbers 1, 2 and 3 in the table above represent level 1, level 2 and level 3 of each factor. The next step of this phase is to put the factors and their levels into the appropriate rows and columns of the OAs-$L_9(3^4)$.

Table 1. Factors and their levels for composition I of PVB dominant of P

Factors	**Level**		
	L_1	**L_2**	**L_3**
n (rpm)	330	510	770
f (mm/r)	0.01	0.05	0.10
K_r (-°)	68	60	56
P%V%	**P100V**	**P80V**	**P60V**

Table 2. Factors and their levels for composition II of PVB dominant of V

Factors	**Level**		
	L_1	**L_2**	**L_3**
n (rpm)	330	510	770
f (mm/r)	0.01	0.05	0.10
K_r (-°)	68	60	56
P%V%	**PV60**	**PV80**	**PV100**

The phase of conducting the experiment preparing test materials and testing equipment; workpiece materials, cutting tools, lathes, and measuring tools to check the quality of the hole surface, as well as testing procedures. After that carry out the cutting test. The cutting tool that was prepared consisted of an HSS drilling cutting tool (Fig.1). The test workpiece material is PVB which is molded in the form of a cylindrical rod test specimen size ∅38 x 200 mm.

The phase of analyzing the experiment is the last phase in the research using the Taguchi Method, which includes; (1) Calculation of the main influence of each factor, (2) Calculation of analysis of variance (ANOVA), (3) Pooling of factors that have a very small effect, (4) Calculation of confidence interval (CI) of influential factors, and (5) Estimated yield under optimum conditions. Analysis of test results using the OAs-$L_9(3^4)$ test set has 9 test data, namely y_1, y_2, y_3, y_4, y_5, y_6, y_7, y_8, y_9. Four factors were analyzed: Factors A(*n*), B(*f*), C(K_r), and D(*%PV*). Three levels of each factor are L1, L2, and L3.

(a) (b) (c)

Figure 1. (a) Workpiece & Drilling Cutting Tool, (b) Surface Roughness Tester, (c) Vickers Hardness Tester

For the calculation of the main effect, the average of each factor level is calculated. The results of this calculation are plotted into a response graph of the main influence of each factor as shown in Fig.2 and Fig.3. The graph shows how much influence each factor has on the R_a and SHA.

ANOVA establishes the relative significance of the individual factor effects. The steps are as follows [11]:

Step 1. Total of all results:

$$T = y_1 + y_2 + y_3 + y_4 + y_5 + y_6 + y_7 + y_8 + y_9 \quad (1)$$

Step 2. Correction Factor:

$$CF = T^2/n \quad (2)$$

Step 3. Total sum of squares:

$$S_T = \sum_{i=1}^{n} y_i^2 - CF \quad (3)$$

Step 4. Factor sum of squares:

$$S_A = {A_1^2}/{N_{A1}} + {A_2^2}/{N_{A2}} + {A_3^2}/{N_{A3}} - CF \quad (4)$$

for Factor A and so on

$$Se = S_T - (S_A + S_B + \cdots + S_{\dots}) \quad (5)$$

Step 5. Total and factor degrees of freedom (DOF):
DOF total = number of test runs minus 1

$$f_T = n - 1 \quad (6)$$

DOF of each factor is 1 less than the number of levels
DOF of the error, $fe = f_T - (f_A + (f_B + \cdots + f_{\dots})$.. (7)

Step 6. Mean square (variance):

$$V_A = {S_A}/{f_A} \text{ ; for Factor A and so on} \quad (7)$$

Varian *error*:

$$V_e = {S_e}/{f_e} \text{ ;} \quad (8)$$

Step 7. Percentage contribution:

$$P_A = {S_A}/{S_T} \text{ ; for Factor A and so on} \quad (9)$$

$$F_A = {V_A}/{V_e} \text{ and } F_C = {V_C}/{V_e} \text{; for Factor A \& C} \quad (10)$$

Calculation of confidence interval (CI), the factors that influence. The CI of the factors that are estimated to have an effect can be calculated by the following equation:

$$CI = \pm\sqrt{\left(\frac{F(1,n)xV_e}{N_e}\right)} \quad (11)$$

Estimated yield under optimum conditions. Estimated Result at Optimum Condition (ROC) can be calculated from the factors that have a significant effect, the factors that have been set aside are not included. For example, significant factors B2 and C1, then the value at optimum conditions can be estimated at:

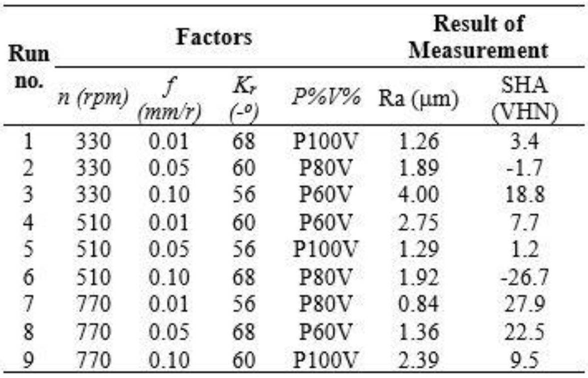
$$ROC = \bar{T} + (\overline{B_2} - \bar{T}) + (\overline{C_1} - \bar{T}) \quad (12)$$

3. RESULTS AND DISCUSSION

3.1. Results

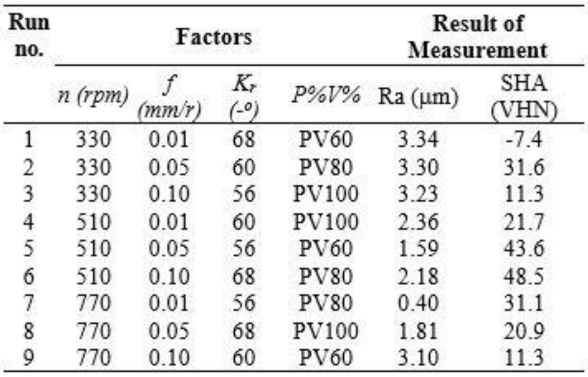
The results of the measurement of R_a and the SHA of the hole are shown in Table 3 and Table 4. To see the effect of each factor, the average value is calculated and the results can be seen in Fig.2 and Fig.3.

Table 3. The results of surface hardness & surface roughness alteration measurements for PVB dominant of P



Run no.	Factors				Result of Measurement	
	n (rpm)	*f (mm/r)*	*K_r (-°)*	*P%V%*	Ra (µm)	SHA (VHN)
1	330	0.01	68	P100V	1.26	3.4
2	330	0.05	60	P80V	1.89	-1.7
3	330	0.10	56	P60V	4.00	18.8
4	510	0.01	60	P60V	2.75	7.7
5	510	0.05	56	P100V	1.29	1.2
6	510	0.10	68	P80V	1.92	-26.7
7	770	0.01	56	P80V	0.84	27.9
8	770	0.05	68	P60V	1.36	22.5
9	770	0.10	60	P100V	2.39	9.5

Table 4. The results of surface hardness & surface roughness alteration measurements for PVB dominant of V



Run no.	Factors				Result of Measurement	
	n (rpm)	*f (mm/r)*	*K_r (-°)*	*P%V%*	Ra (µm)	SHA (VHN)
1	330	0.01	68	PV60	3.34	-7.4
2	330	0.05	60	PV80	3.30	31.6
3	330	0.10	56	PV100	3.23	11.3
4	510	0.01	60	PV100	2.36	21.7
5	510	0.05	56	PV60	1.59	43.6
6	510	0.10	68	PV80	2.18	48.5
7	770	0.01	56	PV80	0.40	31.1
8	770	0.05	68	PV100	1.81	20.9
9	770	0.10	60	PV60	3.10	11.3

To see the large contribution of each factor to the surface quality of the holes studied, ANOVA was performed using Equations 1 to 9, and graphs of their effects can be seen in Fig.2 and Fig.3.

The contribution of the factors that influence the surface roughness value and surface hardness alteration after drilling can be seen from the slope of the line between one level and another. The steeper the slope of the line, the greater the effect. The contribution of each of these factors is plotted into a graph.

3.2. Discussion

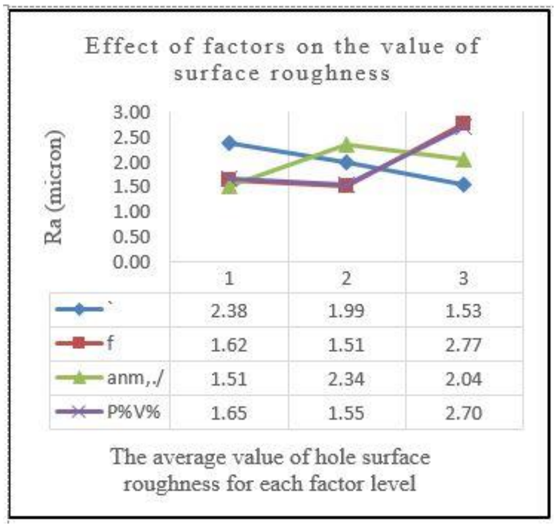
From the graphs in Fig.2 and Fig.3, it can be seen the influence of all the factors studied and their effect on the R_a and SHA of the hole after being drilled, and its contribution to this effect can be seen. Almost all the factors studied have an effect on R_a and SHA, except for the K_r factor in the vinylester dominant PVB workpiece drilling where its effect on the SHA is very small and its contribution is only 5% (Table 5).

Table 5. Contribution of factors

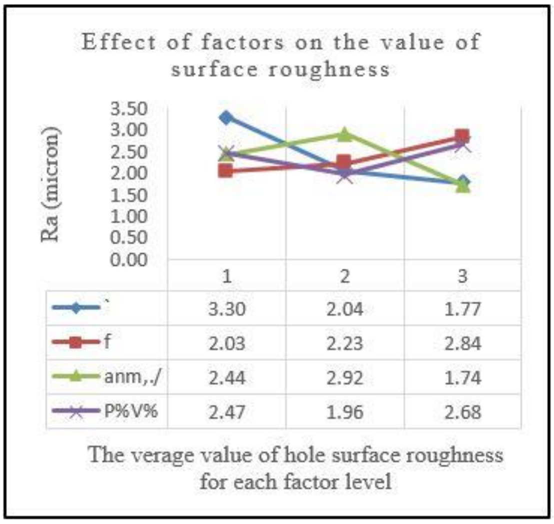
Factors	PVB dominant of P		PVB dominant of V	
	R_a	SHA	R_a	SHA
n	15%	30%	**50%**	**44**%
f	**39**%	7%	13%	13%
K_r	14%	**44%**	27%	5%
P%V%	32%	19%	10%	38%

From the graphs in Fig. 2 and Table 5, changes in each factor level have varying effects on the surface roughness of the hole. The roughness decreased when the spindle speed increased (*n*=770 rpm), feedrate at *f*=0.05 mm/r, K_r=56°, and *P%V%*=P80V, in polyester dominant PVB drilling. While the vinylester dominant PVB, Ra decreased at *n*=770 rpm, feedrate at *f*=0.01 mm/r, K_r=68°, and *P%V%*=PV80. The biggest contribution of *f*-factor (39%), and *P%V%*-factor (32%) for polyester dominant PVB, seen from the value of Ra batten is quite large 2.77-1.51=1.26 micron in the *f*-factor, and 1.15 micron in the *P%V%*-factor. While in vinylester dominant PVB, the largest contribution is *n*-factor (50%) with a roughness range of 1.53 micron.

The optimum surface roughness can be achieved at high spindle speed, medium feedrate, low cutting-edge angle, and PVB composition of 80% polyester and 20% vinylester, it is estimated that R_a is +/- 0.20 micron for PVB dominantly Polyester. At high spindle speed, low feedrate, high cutting-edge angle, and PVB composition of 20% polyester and 80% vinylester, it is estimated that Ra is achieved at +/- 0.40 microns for vinylester dominant PVB.



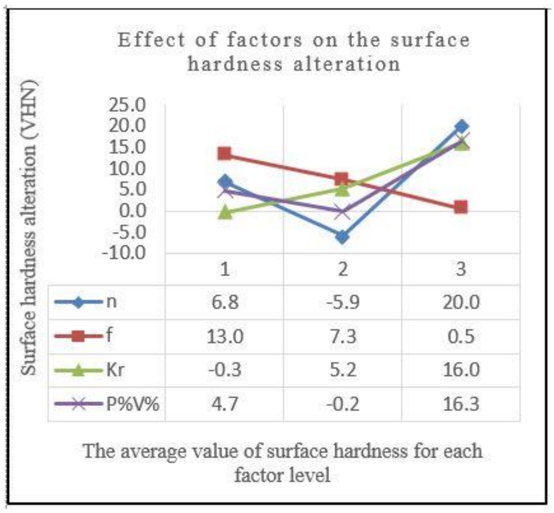
(a) PVB dominant of polyester



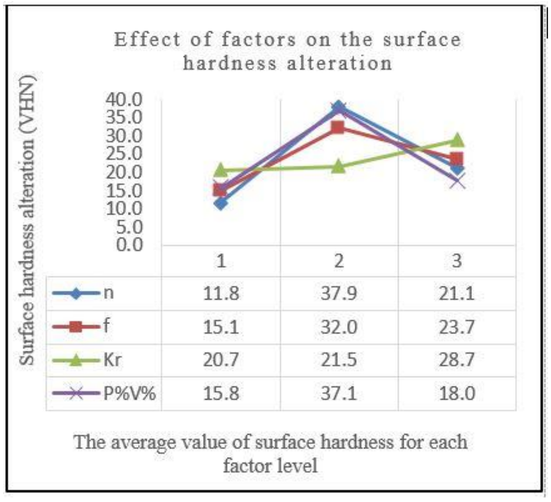
(b) PVB dominant of vinylester

Figure 2. The effect of each factor on the value of the surface roughness of each factor level.

From the graphs in Fig.3 and Fig,5, the surface hardness alteration after being drilled is expected to be insignificant compared to the previous surface. This is achieved when *n*=550 rpm, *f*=0.1 mm/r, K_r=56°, and *P%V%*=PV80 are used, in which PVB drilling is dominated by polyester. Whereas in vinylester dominant PVB, the surface hardness alteration was quite large, the best at *n*=330 rpm, *f*=0.01 mm/r, K_r=56°, and *P%V%*=PV60. The biggest contribution of factor K_r (44%) to the polyester dominant PVB, and factor *n* (44%) for vinylester dominant PVB.



(a) PVB dominant of polyester



(b) PVB dominant of vinylester

Figure 3. The effect of each factor on the value of the surface hardness alteration of each factor level

4. CONCLUSION

From the research conducted, it can be concluded that:

1. All of the factors studied have varying effects on the surface roughness and changes in the surface hardness of the hole after being drilled with an HSS chisel.
2. The best surface roughness is achieved at a high level of *n*-factor for both polyester and vinylester dominant workpieces. The *f*-factor is medium-level on the polyester dominant workpiece and low-level on the vinylester dominant workpiece. The K_r-factor is low in the polyester dominant workpiece and the high level in the vinylester dominant workpiece. The composition factor of medium-level PVB is *P80%V20%* and *P20%V80%*, both polyester and vinylester dominant workpieces.
3. Changes in surface hardness that did not change much at medium level *n*-factor for polyester dominant workpieces and low levels on vinylester dominant workpieces. The *f*-factor level is high in polyester dominant workpieces and low in vinylester dominant workpieces. Low K_r-factor, both polyester dominant workpiece, and vinylester dominant workpiece. The PVB composition factor is medium-level *P80%V20%* on the polyester dominant workpiece and low-level *P20%V80%* on the vinylester dominant workpiece.
4. The biggest contribution of factors to the surface roughness of the hole for polyester-dominant PVB workpieces is an *f*-factor of 39%, for vinylester-dominant PVB workpieces the *n*-factor is 50%. The biggest contribution of factors to changes in surface hardness for polyester-dominant PVB workpieces is the Kr-factor of 44%, for vinylester-dominant PVB workpieces is the *n*-factor of 44%.

ACKNOWLEDGMENTS

Thank you to the Mechanical Engineering Department and Engineering Faculty Andalas University who have supported the implementation of this research.

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NOMENCLATURE

I	electrical current, A
N	number of coil, n
Hz	frequency, hertz