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Application of Alcohol Soluble Phenol Formaldehyde Resin for Manufacturing Cut-off Wheel in Vietnam

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Abstract: This study presented the application of alcohol soluble phenol formaldehyde resin – a binder was researched for manufacture cut-off wheel. The abrasion of the cut-off wheel has tested. The results showed that the cut-off wheel has high abrasion resistance as machined with alcohol soluble phenol formaldehyde resin at the time of synthetic resin (60 minutes), the heat press temperature (150^{o}C), the heat press time (50 minutes) and the mass ratio of abrasive particles and resin is 200/25 (g/g). Compared with the cut-off wheel from other resins such as polyimide, unsaturated polyester resin, our product has been the same abrasion resistance, higher heat resistance but cheaper price. Consequently, this resin can be applied to cut shaped iron in mechanical processing.

Keywords: Alcohol soluble phenol formaldehyde resin, the cut-off wheel, abrasion

I. INTRODUCTION

In recent years, the metal cut-off wheel in the field of mechanical processing is commonly used. In Vietnam, many factories have imported and used them from Thailand, China, America... However, the cost of these products are high. Besides, a few cut-off wheelfactories were established in Vietnam.

The cut-off wheels are created by embedding abrasive particles in a bonding matrix. For ensured the flexural strength, reinforcement materials are used. The wheel's characteristics used to cut shaped iron. So, the cut-off wheel must have high mechanical strength, good abrasion resistance, high heat resistance and good fire resistance.

The unsaturated polyester resin has used as a binder. The cut-off wheel from this resin is good mechanical and thermal properties. However, it is easily decomposed under the effect of heat [1]. Besides, the epoxy resin has the requirements of mechanical strength but its heat resistance is low and the price is high [2]. Therefore, the researchs have study to find another type of binder that satisfies the requirements of high mechanical properties, good fire resistance and lower cost.

Phenolic resin (PR) has been known for approximately 100 years, but still widely used as laminate, adhesive, thermal insulation materials and ablative materials from commodity and construction materials to high technology aerospace industry due to its desirable characteristics, such as superior thermal stability, mechanical properties, dimensional stability, high char yield and solvent resistance [3] [4] especially burning PR produces a relatively low amount of smoke at a relatively low level of toxicity and the low price [5]. PR in particular is an important component of ablative thermal protection materials. In addition to PR, other high char yield materials have been tested as matrices of ablatives such as polyimide, bismaleimide resins and cyanate esters [6] [7] [8]. However, when compared to phenolics, they generally tend to exhibit limitations in terms of cost and processability [9]. Consequently, alcohol solublephenol formaldehyde resin is selected for research as binder in cut-off wheel fabrication.

The production cost of any process can be considerably reduced by process optimization. To answer this problem, we analized and optimized two parameters (factors) for obtained the minimum abrasion of cut-off wheel including:

- Z_1 (minutes): the heat press time
- Z_2 (minutes): the heat press temperature
- y: the abrasion of cut-off wheel

By using the statistical model, we carried out and determined the optimal conditions. The experimental data used and analyzed in the preparation of this model were obtained according to the use of a two-level, factorial experimental design. After obtained the parameters of the statistical model, we applied Box-Wilson’s steepest ascent method to determine the optimal conditions [10][11][12].

II. MATERIAL AND METHODS

2.1 Material

In this study, the materials for the manufacture of cut-off wheel include:

- Alcohol soluble phenol formaldehyde resin was used as a matrix binder in cut-off wheel. It was a thermoset resin that synthesized by the condensation reaction of phenol with a molar excess of formaldehyde under an alkaline condition [13].

- Abrasive particle was a commercially particles supplied by Lekar group.Its ingredients included metal oxides such as: Al_2O_3, SiO_2, TiO_2, FeO, Fe_2O_3, Fe_3O_4...

- Fabric used was polyamide fabric that woven in two perpendicular directions. The fiber diameter was about 0.4 mm.

Synthesis of Alcohol soluble phenol formaldehyde resin

Synthesize alcohol soluble phenol formaldehyde resin carried out:

- The ratio of Phenol to Formaldehyde (P/F): 1/1.5;
- Catalyst: NH_4OH 23-25%;
- pH is maintained at 7.5 - 8;
- The reaction temperature is controlled at 80^{o}C for 60 minutes.

Phenol, formaldehyde and catalyst were added into three-necked flask equipped with a stirrer, a cooling condenser, a thermometer [14] [15]. Subjecting the system to a vacuum until the total extraction of water was completed.

Preparation of Cut-off Wheel

The cut-off wheel was created by pouring into the mold and pressing under heated hydraulic press. The abrasive particles were dried at 105^{o}C in 2 hours to remove moisture. Alcohol soluble phenol formaldehyde resin was preheated to 40 - 50^{o}C and dissolved in alcohol in order to increase mixing efficiency. Weigh 25g alcohol soluble phenol formaldehyde resin into a glass beaker. Next weigh 200g of abrasive particles into a glass containing the phenol formaldehyde resin above. The mixture was mixed until homogeneous, molded and shaped before pressing to reduce the density of the pressed material and to obtain a product of the desired size.

After shaping, we put the mold in the hydraulic press and pressed the sample at 120 KG/cm^2, 150^{o}C for 50 minutes. Then, turned off the press and took the mold out of the press table. The mold was let cool at room temperature and then removed the cut-off wheel from the mold.

The cut-off wheel is 120mm in diameter, 2 mm in thickness

Fig 1. The cut-off wheel

2.2. Methods

Abrasion test

The abrasion of the cut-off wheel on the Makita - 9525 NB hand-cut cutter carried out a cutting speed of 10000 rpm. The sample was tested for cutting steel plate CT3 (thickness of 4mm). For each study, triplicate samples were simultaneously carried out, and independently repeated at least three times.

Fig 2. Testing abrasion of the cut-off wheel

Experimental design

Using the Box-Wilson optimization method to design and build the mathematical model about relationships between y and technological factors effect on the abrasion of cut-off wheelfor the blade (Z_1, Z_2). The mathematical model of y was described as follow:

$$y = b_0 + b_1x_1 + b_2x_2 + b_{12}x_1x_2 \qquad (1)$$

In the equation (1), x_i (i=1…n)are the code values of the heat press time and the heat press temperature andb_i (i =0…n) is the model coefficient. Y is the abrasion of cut-off wheel. In two-level, factorial experimental design there are n variables (factors). The factors have two different levels including: minimum and maximum levels. For these designs, we studied in a dimensionless coordinate system using following definitions.

The design matrix has orthogonal properties, the coefficient matrix were calculated by the following equation:

$$b_j = \frac{1}{N}\sum_{i=1}^{N} x_{ji} y_i \qquad (2)$$

For a dimensionless coordinate system, we have: the maximum level is +1, minimum level is -1, and the central experiment is zero. Besides, the number of experiments is 2^n. In this study, 2^2= 4 experiments (3 variables) and five experiments at central points were carried out to identify the regression model.

These variables x_1, x_2, x_3 were coded by variables of Z_1, Z_2 presented as follow:

$$x_j = \frac{Z_j - Z_{jo}}{\lambda_j} \ ; j = 1,2 \ (3)$$

Where,

$$\begin{aligned} &Z_j^o = (Z_j^{max} + Z_j^{min})/2 \\ &\Delta Z_j = (Z_j^{max} - Z_j^{min})/2 \qquad (4) \\ &Z_j^{min} \le Z_j \le Z_j^{max}; \ j = 1 \text{ to } 2 \end{aligned}$$

The experimental number is determined:

$$N = 2^k + n_o = 7 \qquad (5)$$

With: k=4, n_o=3.

III. RESULTS AND DISCUSSION

3.1Effect of the time of resin synthesis on abrasion of the cut-off wheel

Alcohol-soluble phenol formaldehyde resin wastested and synthesized from 40 minutes to 70 minutes. Machining the cut-off wheel from the resin synthesized in different times above. Measured the abrasion of the cut-off wheel. The results obtained are shown inthe figure 3 and table 1.

Table 1. Effect of the time of resin synthesis on abrasion of the cut-off wheel

The time of resin synthesis (minutes)	40	50	60	70
The abrasion of the cut-off wheel (mm/cm)	0.299	0.253	0.120	0.154

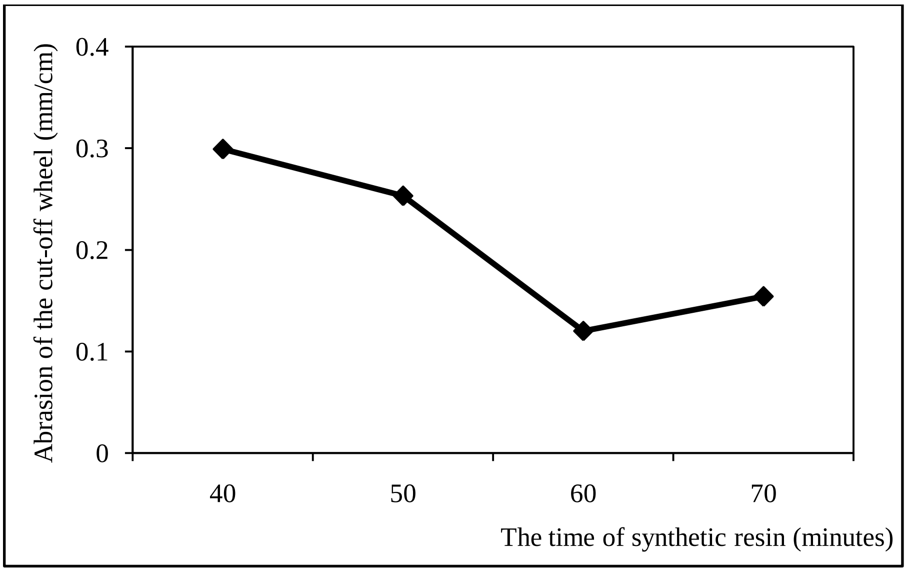

Fig 3. Effect of the time of resin synthesis on abrasion of the cut-off wheel

Result of the figure 3 showed that the abrasion of the cut-off wheel was decreases from 0.299 to 0.120 (mm/cm). The lowest abrasion of the cut-off wheel (0.120 mm/cm) was achieved at the time of resin synthesis 60 minutes.

The time of resinsynthesis is short, the efficiencyof resin synthesis is low. Resin synthesized has low average molecular weight and small viscosity. Therefore, the resin can leak out of the mold in the pressing.The cross-linking density of the cured resin was sparsed and not tighted. So the destruction of resin will be easilier when the cut-off wheel has a great impact in the cutting process, corresponding the abrasion is high. Increasing the time of resin synthesis, the free phenolic content decreases, the average molecular weight of the resin increases. The cross-linking density of the cured resin is denser. Consequently, the abrasion of the cut-off wheel will decrease after be synthetic 60 minutes.

3.2 Develop the mathematical models of the abrasion of cut-off wheel

The design matrix included coded values of the independent and coded dependent variables. The interrelation between the coded independent variables presented in Table 2. The constituent objective function for abrasion of the cut-off wheel (y) depended on the parameters (factors), including: heat press time (Z_1, min) and heat press temperature (Z_2, ^oC). The experimental results presented that abrasion of cut-off wheel (y) has related to Z_1, Z_2. The experiments were performed with the levels of two parameters in Table 1 to determine the abrasion of cut-off wheel. With the statistical model, the design matrix showed in Table 3 and Table 4. The samples were conduted with the fixed pressure (120kg/cm^2).

Table 2.Levels of independent variables

Parameters	Levels			Deviation ΔZ_1
	Low -1	Central 0	High +1	
	-1	0	+1	
T (min)	140	150	160	10
t (^oC)	40	50	60	2

Table 3. Optimal design matrix (k=2, n_o=3)

Experiment	Value of real variables		Value of coded variables			Value of objective function
N_o	Z_1	Z_2	x_1	x_2	x_1x_2	Y
1	160	60	+	+	+	0.292
2	140	40	-	-	+	0.152
3	160	40	+	-	-	0.228
4	140	60	-	+	-	0.199
5	150	50	0	0	0	0,098
6	150	50	0	0	0	0,116
7	150	50	0	0	0	0,125

Table 4.Matrix planning for value of code variables

No	x_0	x_1	x_2	x_1x_2	**Y**
1	+ 1	+ 1	+ 1	+ 1	y_1
2	+ 1	- 1	- 1	+ 1	y_2
3	+ 1	+ 1	- 1	- 1	y_3
4	+ 1	- 1	+ 1	- 1	y_4
5	0	0	0	0	y_5
6	0	0	0	0	y_6
7	0	0	0	0	y_7

By applying the design matrix presented in Table 3 and Table 4, the mathematical model of regression equations (6) were calculated after processing the experimental data, determining the coefficients (Table 5), testing the significance of the coefficients by the Student test (Table 6), and testing the regression equations for the fitness of the experimental results by Fisher test (Table 7) [9]:

$$y= 0.218 + 0.042x1 + 0.028x2 + 0.004x1x2 \quad (6)$$

Table 5.The value of the coefficients b

b_0	0.218
b_1	0.042
b_2	0.028
b_{12}	0.004

Table 6. The regressionequations for the fitness of the experimental results (at the centre) by Fisher test

No	Z_1	Z_2	y_u	$\overline{y_u}$	$\left\|y_u - \overline{y_u}\right\|^2$
5	150	50	0.098	0.113	$2.25.10^{-4}$
6	150	50	0.116	0.113	9.10^{-6}
7	150	50	0.125	0.113	$1.44.10^{-4}$

From the results, the error mean square was determined from Eq. (7) as $1.89.10^{-4}$. The tabulated value of the Student's t distribution $Fp(f_1f_2)$ was 0.386 for a significance level of p =0.05 and f_1 = 1, f_2 =8. Besides, p= 0.05, f=2, the value $t_p(f)$ determined:

$$t_p(f) = t_{0,05}(8) = 2{,}31$$

$$S^2_{du} = \frac{\sum_{i=1}^{8}\left(y_u - \bar{y_u}\right)^2}{N - N'} = 6.87.\ 10^{-3} \qquad (7)$$

$$S^2_{th} = 1.89.10^{-4}$$

Since the t_{12} was less than tabulated t value, constants of b_{12} was omitted from the regression equations. Moreover, the application of Fisher's F test determined the estimated regression equation fits the experimental data (8).

$$y = 0{,}218 + 0{,}042.x_1 + 0{,}028.x_2 \quad (8)$$

From Eq. (8) and the identification of the statistical model, Box-Wilson's steepest ascent optimization method was utilized. After optimisation, the results presented in Table 8.

Table 8. Values predicted statistically according to optimal parameters and values obtained after validation

Parameters	T (min)	t (^{o}C)	Prediction Abrasion of cut-off wheel (mm/cm)	Value obtained after experiment Abrasion of cut-off wheel (mm/cm)
Content	150	60	0.113	0.119

From Table 8, the abrasion of cut-off wheel was minimum value at the optimal conditions. The abrasion of cut-off wheel was 0.119 (mm/cm), corresponding to the heat press temperature (150^{o}C) and the heat press time (50 minutes).

Each parameter had a certain influence on the responses obtained. Analysing the influence of the variables on the abrasion of cut-off wheel that the heat press time and the heat press temperature strongly influenced and had positive effects on this response. The resin curing process has incompleted at low temperature and a short time [16]. The cured resin has a sparse and not tight cross-linking density. Consequently, the ability to destroy resin in cutting has increased. The heat press temperature and heat press time increase, the degree of curing reaction increase. So, the cross-linking density of the resin were denser. The abrasion has decreased and was the minimum value at 150^{o}C (heat press temperature), 50 minutes (heat press time). However, if the heat press temperature/time continue to increase, it will increase the brittleness of the resin. In addition, the heat press temperature is too high, it can cause the product which is swell, crack and discolor. Consequently, the abrasion of the cut-off wheel will increase again.

3.3Effects of the mass ratio of abrasive particles and resin on abrasion of the cut-off wheel

After optimized the abrasion of the cut-off wheel, we continued study the effects of the mass ratio of abrasive particles and resin on the cut-off wheel. The samples were tested with the mass ratios of abrasive particles and resin such as 200/15, 200/20, 200/25, 200/30 (g/g). Then, the abrasion of the samples were determined and presented in table 9 and figure 4.

Table 9. Effects of the mass ratio of abrasive particles and resin on abrasion of the cut-off wheel

The mass ratio of abrasive particles and resin (g/g)	200/15	200/20	200/25	200/30
The abrasion of the cut-off wheel (mm/cm)	0.492	0.212	0.119	0.336

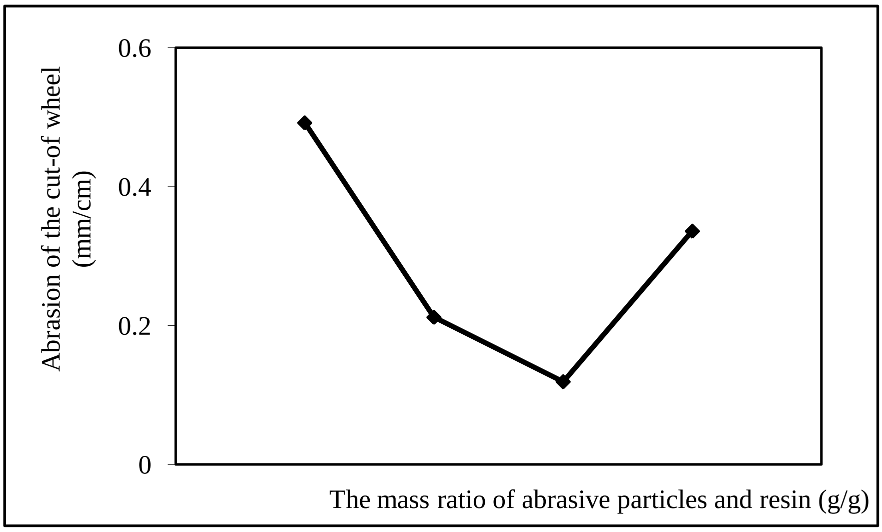

Fig4. Effects of the mass ratio of abrasive particles and resin on abrasion of the cut-off wheel

The results indicated that the mass ratio of abrasive particles and resin had a significant influence on the abrasion of the cut-off wheel. The abrasion of the cut-off wheel ranged from 0.492 to 0.119 (mm/cm). The best result was obtained by using the mass ratio of abrasive particles and resin 200/25(g/g). The low resin content is not enough to surround the abrasive particles. Therefore, it is not possible to create a continuous resin phase in the entire system. The homogeneous structure of the abrasive particles/resin system is broken.

Under the effect of external forces, stress will be distributed unevenly in the cut-off wheel, making their abrasion high at the mass ratio of abrasive particles and resin is 200/15 (g/g). Increasing the resin content, the residual abrasive particles in the system will decrease. Under the effect of external force, the stress will be evenly distributed throughout the cut-off wheel, so the abrasion of the cut-off wheel will decrease and reach the minimum value.

IV. CONCLUSION

In this study, the mathematical models presented và described the relationship between the heat press time and the heat press temperature with abrasion of the cut-off wheel.This study provides a simpleand low-cost method to synthesize alcohol soluble phenol formadehyde resinimproved abrasion resistance, heat resistance and fire resistance.

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References

[1] Anjali A.Athawale, JyotiA.Pandit, Unsaturated Polyester Resins, ScienceDirect, 2019.
[2] Bradley Siddans, ‘‘Epoxy/Clay Nanocomposites: Effect of clay and resin chemistry on cure and properties’’, Queensland University of Technology, 2004.
[3] L. Pilato,‘‘Phenolic resins: 100 years and still going strong’’. Reactive & Functional Polymers, 73,2013,270–277.
[4] K. Hirano, M.Asami, ‘‘Phenolic resins-100 years of progress and their future’’,Reactive & Functional Polymers,73, 2013, 256–269.
[5] https://plenco.com/phenolic-novolac-resol-resins.htm
[6] X. Lei, Y. Chen, H. Zhang, X. Zhang, P. Yao, Q. Zhang, ‘‘Space survivable polyimides with excellent optical transparency and self-healing properties derived from hyperbranchedpolysiloxane’’,Applied Material Interfaces, 5, 2019,10207–10220.
[7] LA. Pilato, JH. Koo, GA. Wissler, S. Lao, ‘‘A reviewphenolic and related resins and their nanomodificationinto phenolic resin FRP systems’’, JournalAdvanced Material, 40, 2008, 5–16.

[8] J. Gu, W. Dong, Y. Tang, Y.Guo, L. Tang, J. Kong, S.Tadakamalla, B. Wang, Z.Guo, ‘‘Ultralow dielectric fluoride-containing cyanate ester resins with improved mechanical properties and high thermal and dimensional stabilities’’. Journal MaterialChemistry, 5, 2017.,6929–6936.

[9] M. Natali, J. Kenny, L. Torre, ‘‘Science and technology of polymeric ablative materials for thermal protection systems and propulsion devices: a review. Program Mater Sciences, 84, 2016, 192–275.

[10] M.A Lo ´pez-Manchado, M. Arroyo, ‘‘Effect of the incorporation of pet fibers on the properties of thermoplastic elastomer based on PP/elastomer blends’’, Polymer 42 (15), 2011, 6557–6563.

[11] G.P.E Box, K.B Wilson. Montgomery, D.C. Design and Analysis of Experiments. Journal of the Royal Statistical Society Series B, 1991, 1-45.

[12] M. Alpbaz, N. Burasli,S. Ertunc. Akay, ‘‘Application of a statistical technique to the production of saccharomyces cerevisiae (baker’s yeast)’’, Biotechnology Applied Biochemistry, 26, 1997, 91–96.

[13] F. Cardona, C.Moscou, ‘‘Synthesis and characterization of modified phenolic resins for composites with enhanced mechanical properties’’, In: 20th Australasian Conference on the Mechanics of Structures and Materials (ACMSM20): Futures in Mechanics of Structures and Materials, Toowoomba, Australia, 2009,2-5.

[14] Y. Jin, C.Lixin,Z.Xiaofei, Z.Hui, W. Ziyou,Z. Defu, ‘‘Synthesis and structure evolution of phenolic resin/ silicone hybrid composites with improved thermal stability’’, Journal Material Science,2009, 14185-14203.

[15] George Odian, Principles of polymerization, JhonWiley and Son, 1981.

[16] https://www.up-resin.com/info/study-on-the-curing-mechanism-of-unsaturated-p-45834067.html.