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RESEARCH ARTICLE

Analysis of Adhesive Wood Bond Strength Using Taguchi Methods Technique

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ABSTRACT

Gluing is one of the methods that can improve the productivity of producing glued construction products from wood. The researchers aim to compare the durability of different types of glue when bonded with wood, conduct analytical statistic of glue strength on wood for different selection parameters towards levels of variation as well as to determine the optimal parameters of glue strength on wood. In this experiment, the materials used are wooden sticks, UHU adhesive, Epoxy glue, hot glue gun, and timer. Taguchi's experimental design approach is applied to optimize setup parameters with three levels that may have affected adhesion duration. The investigation of the influence of controllable factors affecting response, the Mood-Median Test with a 95% confidence interval, was discovered. Thus, the optimal result of the study parameter within area consumption (cm2), open exposure time (ms), and type of glue have the optimal condition when set as 4cm2, 5ms, and using the hot glue gun.

1 INTRODUCTION

Wood adhesives have played an important role in the development and efficient use of wood. In wood products, the most commonly used material is glue. Adhesives increase the resistant strength and stiffness of the composite sheet. The adhesion of the glue depends on the wood- adhesive bonding chain [1]. Adhesive bonding performance between wood elements is presumed to be significantly influenced by the degree of penetration of the adhesive into the porous network of interconnected cells. Gluing is one of the methods that can improve the productivity of producing glued construction products from wood. In order to produce goods with more adhesives, numerous scientists examined the challenges of understanding the mechanical processing of wood and ways of gluing wood [2]. Adhesives have played a significant role in the effective use of wood resources and will continue in the future. Adhesives were employed in ancient Egypt to bond expensive veneers to furniture. Nowadays, adhesives are essential for turning practically all shapes and sizes of wood into useful goods. Which is it offers more adhesive strength [3]. The researchers aim to compare the durability of different types of glue when bonded with wood, conduct analytical statistic of glue strength on wood for different selection parameters towards levels of variation as well as to determine the optimal parameters of glue strength on wood.

Wood adhesives need to evolve continuously so as to meet new product requirements and to deal with changes in regulatory and consumer preferences which is produce wood products that meet the needs of consumer and provide good long-term performance Manufacturers are focusing on the development of wood adhesives which have better resistance to moisture content of wood and humidity also to decrease in overall product costs and labour costs. The Taguchi method is used to the conditions that maximize the tensile strength of a bonded piece of wood [4]. Taguchi Methods have become an extremely popular approach to improving the quality of products. These techniques provide a systematic approach for the application of experiments to improve the product design and production process. Hot melt adhesives have a simple bonding mechanism at a fairly high bonding rate once applied [5]. Hot melt adhesives are solvent-free, a selling point which increases their desirability in potential markets due to the lower health risks associated with using these products. Adhesives play a vital role in allowing almost all types and sizes of wood to be converted to functional products [6]. Adhesives have played and will continue to play an important role in the efficient utilization of wood resources. Early Egyptians used adhesives to attach rare veneers to wood furniture.

2 METHODOLOGY

In this experiment, the materials used are the wooden sticks, UHU adhesive, Epoxy glue, hot glue gun, and timer. Firstly, all the wooden sticks were affixed with labels containing the parameters that were designed. After that, an adhesive glue called UHU glue was applied in accordance with an area consumption, and a stick made of wood was affixed to a surface made of wood that was flat. After that, the wooden stick was exposed to open air for the designated amount of time so that it may dry. Thereafter, a bottle that is secured with raffia rope is used as a weight, and it is held before it is let to hang from a wooden stick. As soon as the open exposure period comes to a conclusion, the dangling bottle is taken down, and then the clock starts counting down the amount of time it takes for the wooden stick to fall. The amount of time spent falling was measured and noted, and the same procedures were carried out using various types of adhesive glue, such as epoxy glue and hot glue gun. Figure 1 below depicts the steps to carry the experiment and Table 1 indicates the process parameters and its levels for this experiment.

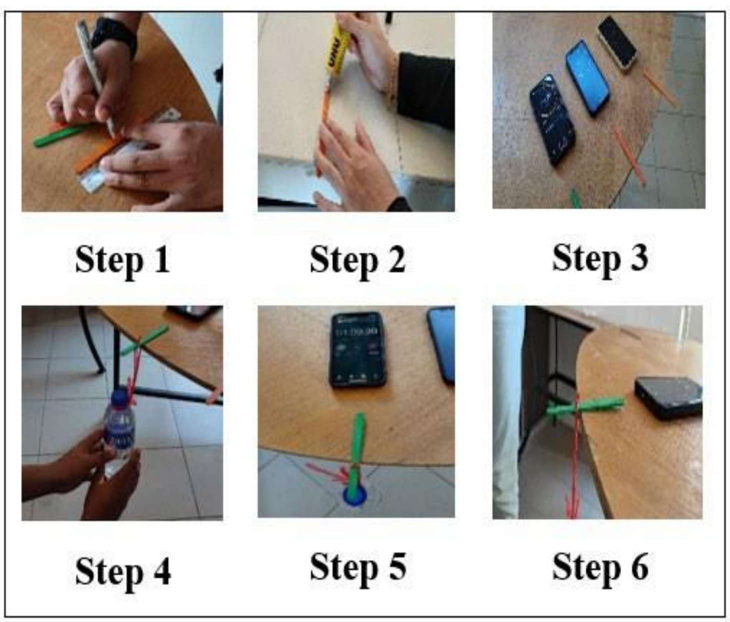

Figure 1: Steps of the experiment

Table 1: Process parameters and levels

Factor level	Area of consumption (cm^2)	Open exposure time (min)	Type of glue
1	2	5	Hot glue gun
2	4	10	All-purpose glue (UHU)
3	6	15	Epoxy glue

The parameters selected include consumption area, open exposure time, and glue type. The trials were completed in accordance with the L-9 orthogonal array test parameters (Table 2). To avoid the influence of noise factors, the experiments were repeated and replicated thrice. Therefore, the total number of experiments includes 27 runs.

Table 2: Orthogonal Array L-9

Run	Columns			
	1	2	3	4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

3 RESULTS AND DISCUSSIONS

3.1 Probability Plot

Probability plots compute the dispersion of experimental results to duration of adhesion measured in milliseconds unit. As a results, normal probability plots prove on hypothesis of the experiments by using Anderson Darling (AD) tests. Based on the normality plot shown in Figure 2, it shows that p-value is below than 0.05, implying that the data follows is not normally distribution. As a result, the data need to compute non-parametric test by using median. The normal probability plots show that all points are not close to a straight line and not evenly distributed, with outliers. Nevertheless, the experiment rejects null hypothesis of the experiment which stated that type of glue, area of consumption and open exposure time will give a significant impact on the wood bond strength ($\mu A = \mu B = \mu C$).

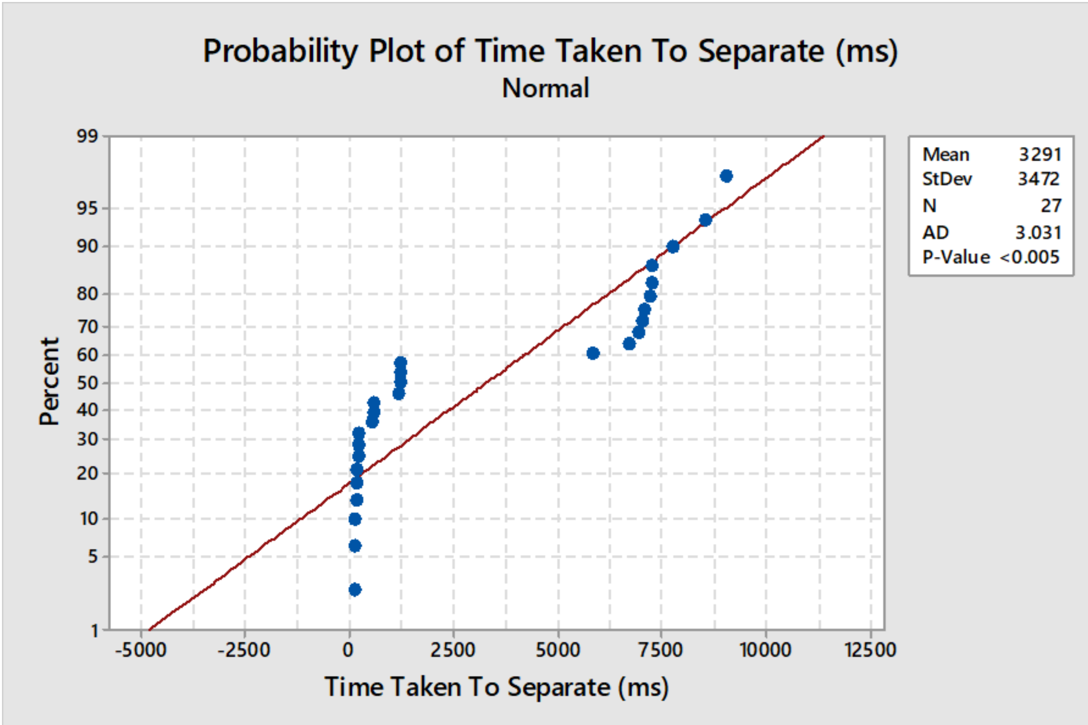

Figure 2: Probability plot

3.2 Analysis of Variance (ANOVA)

To investigate the influence of controllable factors affecting on response, an ANOVA with 95% of confidence interval was discovered. Mood-Median Test was used since the data is not normally distributed. For ANOVA test, if the p-value is less than 0.05, the controllable factors is significant in terms of responses. The most significant factor is Type of Glue as shown in Figure 5, since the p-value is 0.002. Next factor is Area Consumption with p-value 0.025 as shown in Figure 3. The remaining controllable factor which is Open Exposure Time with p- value of 0.354, was not significant according to p-values is larger than 0.05 shown in Figure 4. The results support the discussion made in 3.1 Probability Plot to reject null hypothesis that stated type of glue, area of consumption and open exposure time will give a significant impact on the wood bond strength (μA = μB = μC).

Mood Median Test: Time Taken To Se versus Area Consumption

```
Mood median test for Time Taken To Separate (ms)
Chi-Square = 7.42    DF = 2    P = 0.025

Area
consumption                                  Individual 95.0% CIs
(cm2)        N≤  N>  Median  Q3-Q1  ---------+---------+---------+-------
1             3   6    6710   6978  (-------------------------*-)
2             3   6    7052   7921  (--------------------------*----)
3             8   1     585   1008  (*--)
                                    ---------+---------+---------+-------
                                          2500      5000      7500

Overall median = 1208
```

Figure 3: Non-Parametric Test on Area Consumption and Response

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Mood Median Test: Time Taken To Se versus Open Exposure Time

Mood median test for Time Taken To Separate (ms)
Chi-Square = 2.08    DF = 2    P = 0.354

Open
exposure                              Individual 95.0% CIs
time (ms)  N≤  N>  Median  Q3-Q1  ---------+---------+---------+-------
1           3   6    6930   7711  (--------------------------*----)
2           5   4    1208   6055  (---*--------------------)
3           6   3     585   6991  (*---------------------------)
                                  ---------+---------+---------+-------
                                        2500      5000      7500

Overall median = 1208
```

Figure 4: Non-Parametric Test on Open Exposure Time and Response

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Mood Median Test: Time Taken To Separate (ms) versus Type of Glue

Mood median test for Time Taken To Separate (ms)
Chi-Square = 12.76    DF = 2    P = 0.002

Type
of                               Individual 95.0% CIs
glue  N≤  N>  Median  Q3-Q1  ---------+---------+---------+-------
1      2   7    7047   6023      (----------------------*)
2      3   6    5849   7290   (--------------------*---------)
3      9   0     179     55  *
                             ---------+---------+---------+-------
                                   2500      5000      7500

Overall median = 1208
```

Figure 5: Non-Parametric Test on Type of Glue and Response

3.3 Effect of Different Factors on Variable Response

An experiment has identified three controllable factors for adhesion duration to bond with wood. Each factor can be applied at three level. The experiment wants to optimal parameters of glue strength on wood and to know the contribution of each parameter. Table 3 computed a similar manner the average effects of each factor.

Table 3: Average Effects of Other Factors

Factor levels	Equation	Average
$\overline{A1}$	$Y_1 + Y_2 + Y_3 + Y_4 + Y_5 + Y_6 + Y_7 + Y_8 + Y_9 /9$	4603.56
$\overline{A2}$	$Y_{10} + Y_{11} + Y_{12} + Y_{13} + Y_{14} + Y_{15} + Y_{16} + Y_{17} + Y_{18} /9$	4614.44
$\overline{A3}$	$Y_{19} + Y_{20} + Y_{21} + Y_{22} + Y_{23} + Y_{24} + Y_{25} + Y_{26} + Y_{27} /9$	654.56
$\overline{B1}$	$Y_1 + Y_2 + Y_3 + Y_{10} + Y_{11} + Y_{12} + Y_{19} + Y_{20} + Y_{21} /9$	4512.33
$\overline{B2}$	$Y_4 + Y_5 + Y_6 + Y_{13} + Y_{14} + Y_{15} + Y_{22} + Y_{23} + Y_{24} /9$	2672.22
$\overline{B3}$	$Y_7 + Y_8 + Y_9 + Y_{16} + Y_{17} + Y_{18} + Y_{25} + Y_{26} + Y_{27} /9$	2686.67
$\overline{C1}$	$Y_1 + Y_2 + Y_3 + Y_{16} + Y_{17} + Y_{18} + Y_{22} + Y_{23} + Y_{24} /9$	5210.33
$\overline{C2}$	$Y_4 + Y_5 + Y_6 + Y_{10} + Y_{11} + Y_{12} + Y_{25} + Y_{26} + Y_{27} /9$	4481.67
$\overline{C3}$	$Y_7 + Y_8 + Y_9 + Y_{13} + Y_{14} + Y_{15} + Y_{19} + Y_{20} + Y_{21} /9$	181.22
	Grand average $\overline{T}$	**3290.78**

3.4 Main Effect Plot for Means

Main effect plot is a graph that used for comparing strength contribution of uncontrollable factors in an experiment. Main effects are generally expressed by the differences in the average effects at the two levels. Table 3 shows the main effect of this factor. It shows that the factor on type of glue shows the highest contribution with the response. Factor contribution is the amount of improvement obtained by setting the factor to the desired level. The improvement is measured relative to the grand average of performance. Grand average performance is the average of all trial results as shown in Table 3, Grand average, $\bar{T}$.

Table 4: Factor Contribution for Main Effect

Contribution factor	Equation	Contribution value
A: Area consumption (cm^2)	$\overline{A2} - \bar{T}$	1323.67
B: Open exposure time (ms)	$\overline{B1} - \bar{T}$	1221.56
C: Type of glue	$\overline{C1} - \bar{T}$	1919.56

The experiment has set quality characteristics to the bigger the better. Therefore, Figure 6 shows the main effect plot of means for area consumption, open exposure time and type of glue, respectively. The result illustrates that area consumption at A2 (4 cm2), open exposure time at B1 (5 ms) and type of glue at C1 (hot glue gun) will contribute to highest time taken to separate of adhesive from wood. Overall, this type of glue contributes a greater value of adhesion duration in milliseconds. Therefore, an estimate performance at the optimum condition is as follows:

$$
\begin{aligned}
Y_{opt} &= \bar{T} + (\overline{A2} - \bar{T}) + (\overline{B1} - \bar{T}) + (\overline{C1} - \bar{T}) \\
&= 3290.78 + (4614.44 - 3290.78) + (4512.33 - 3290.78) + (5210.33 - 3290.78) \\
&= 3290.78 + (1323.67) + (1221.56) + (1919.56) \\
&= 7755.57
\end{aligned}
$$

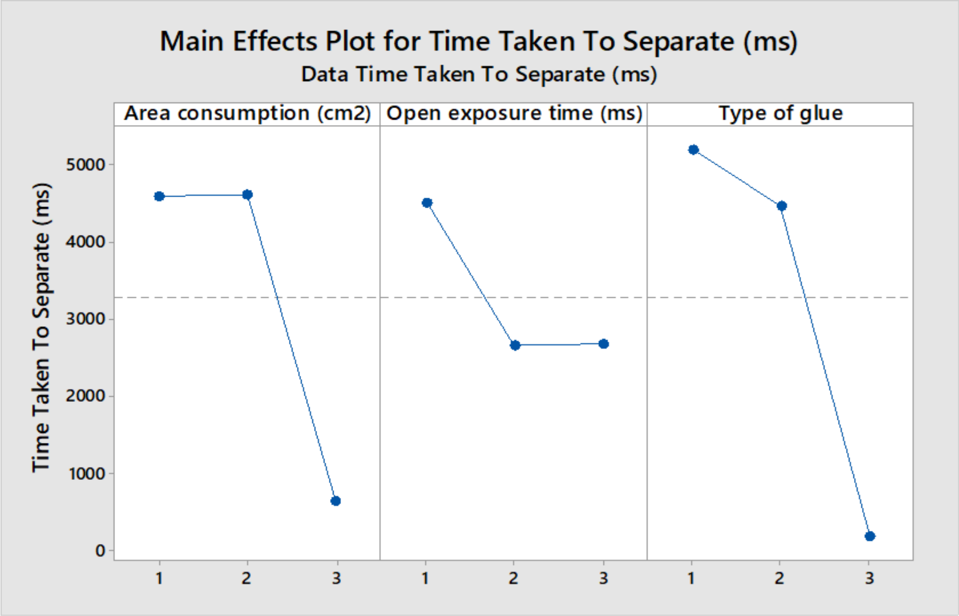

Figure 6: Main plot effect of different level factors

3.5 Signal to Noise (S/N) Ratio

Rule of thumb for S/N Ratio is to determine the highest possible S/N ratio for the results. Figure 7 shows the highest value of S/N is area consumption which implies that the signal is much higher than the random effects of noise factors. Then followed by type of glue and lastly is open exposure time. Figure 8 shows the main effects plot for the S/N ratios of time taken to separate with adhesive parameters such as area consumption, open exposure time, type of glue and surrounding temperature. Since the aim of the study is to optimize the value of responses, the S/N ratio was selected to be 'larger the better'. The optimal levels are obtained by the average values of the S/N ratios for each response at each level, and the higher values of S/N ratios show good quality characteristic. Table 5 shows the best data set on the basis of minimum variation. Run 12 is selected for the bigger is better characteristics for this experiment. Overall, the optimal result of the study parameter within area consumption (cm2), open exposure time (ms) and type of glue have the optimal condition when set as 4cm2, 5ms and using hot glue gun, respectively.

Response Table for Signal to Noise Ratios
Dynamic Response

Level	Area consumption (cm2)	Open exposure time (ms)	Type of glue
1	-0.6432	0.4331	-0.5577
2	0.9063	-0.7156	0.8087
3	-1.3134	-0.7679	-1.3013
Delta	2.2197	1.2010	2.1100
Rank	1	3	2

Figure 7: Delta rank for S/N ratio

Table 5: S/N Ratios for Bigger is Better Quality Characteristics

Run	A	B	C	R1	R2	R3	S/N Ratio
1 (Y1)	1	1	1	7049	7045	7048	76.9605
2 (Y2)	1	1	1	7255	7259	7256	77.2148
3 (Y3)	1	1	1	6928	6931	6930	76.8141
4 (Y4)	1	2	2	6710	6707	6713	76.5345
5 (Y5)	1	2	2	5850	5847	5849	75.3411
6 (Y6)	1	2	2	7210	7211	7214	77.1607
7 (Y7)	1	3	3	150	153	155	43.6725
8 (Y8)	1	3	3	130	135	132	42.4302
9 (Y9)	1	3	3	150	147	152	43.5000
10 (Y10)	2	1	2	1250	1247	1245	61.9196
11 (Y11)	2	1	2	8541	8539	8542	78.6299
12 (Y12)	2	1	2	9053	9052	9050	79.1346

13 (Y13)	2	2	3	210	213	208	46.4570
14 (Y14)	2	2	3	240	238	242	47.6035
15 (Y15)	2	2	3	200	203	202	46.0922
16 (Y16)	2	3	1	7233	7230	7232	77.1847
17 (Y17)	2	3	1	7051	7052	7054	76.9667
18 (Y18)	2	3	1	7752	7750	7748	77.7861
19 (Y19)	3	1	3	180	178	179	45.0568
20 (Y20)	3	1	3	200	198	196	45.9324
21 (Y21)	3	1	3	160	162	165	44.2061
22 (Y22)	3	2	1	1206	1210	1208	61.6413
23 (Y23)	3	2	1	1237	1235	1234	61.8357
24 (Y24)	3	2	1	1185	1186	1183	61.4719
25 (Y25)	3	3	2	586	583	585	55.3381
26 (Y26)	3	3	2	591	587	589	55.4022
27 (Y27)	3	3	2	546	543	548	54.7384

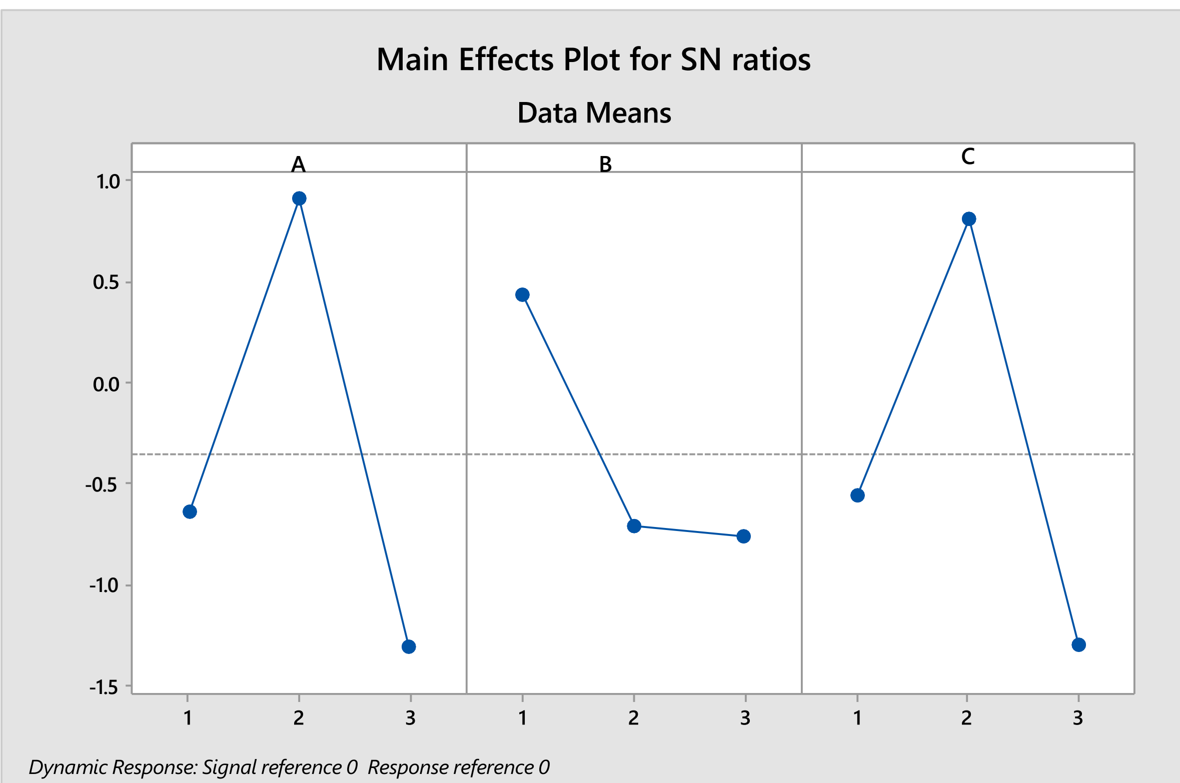

Figure 8: Main Effect Plot for S/N Ratios

4.0 CONCLUSION AND RECOMMENDATION

In conclusion, due to the not normal distribution of the data, the investigation of the influence of controllable factors affecting response, the Mood-Median Test with a 95% confidence interval, was discovered. Thus, the optimal result of the study parameter within area consumption (cm2), open exposure time (ms), and type of glue have the optimal condition when set as 4cm2, 5ms, and using the hot glue gun. Not only that, as shown in the result, the most contributing factor to the response of this experiment is the Type of Glue, which means if any changes in the type of glue happen, these will have an impact on the whole experiment in finding the optimum results. Selection of the run 12 experiment for the "bigger is better" of the S/N ratio rule of thumb is due to the highest possible selection in time to separate the adhesive from wood with parameters such as area consumption, open exposure time, type of glue, and surrounding temperature.

For future research, may explore further the type of glue used at hot glue guns which the details ingredients or materials. Is there any significant difference in the type of hot glue gun? On the other hand, since 5ms was the optimal exposure time, future work may look on this parameter which has to reduce less than 5ms to evaluate the condition. Perhaps it has optimal cut off time that reflects the strength of the bond.

REFERENCES

[1] O. Ülker, "Wood adhesives and bonding theory," IntechOpen, 23-Nov-2016. [Online]. Available: https://www.intechopen.com/chapters/52676. Accessed on 21-Jan-2023.

[2] Rusakov, D, "IOP conference series: Earth and environmental science paper open." [Online]. Available: https://google.iopscience.iop.org/article/10.1088/1755-1315/574/1/012070/pdf. Accessed on 20-Jan-2023.

[3] C. R. Frihart, "Introduction to special issue: Wood Adhesives: Past, present, and future," Allen Press, 01-Mar-2015. [Online]. Available: https://meridian.allenpress.com/fpj/article/65/1-2/4/136384/Introduction-to-Special-Issue- Wood-Adhesives-Past. Accessed on 21-Jan-2023.

[4] Myszka, D. (2017). A single session, laboratory primer on taguchi methods. ASEE Annual Conference Proceedings, 1059–1066. https://doi.org/10.18260/1-2--9780

[5] Kadam, P., Vaidya, P., & Mhaske, S. (2014). Synthesis and characterization of polyesteramide based hot melt adhesive obtained with dimer acid, castor oil and ethylenediamine. International Journal of Adhesion and Adhesives, 50, 151–156. https://doi.org/10.1016/j.ijadhadh.2014.01.028

[6] Frihart, C. R. (2015). Wood adhesives: Past, present, and future. Forest Products Journal, 65(1–2), 4–8. https://doi.org/10.13073/65.1-2.4