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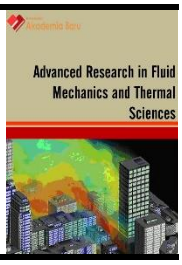

Optimization of Molding Process Parameter for Jute Reinforced Poly Lactic Acid Composite

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ABSTRACT

Molding process parameters decide the quality of the composite. Optimization of Molding Process Parameter will improve the quality of the composite. In this paper, molding process parameter optimization is carried out for molding Jute Reinforced Polylactic Acid polymeric Composite in the compression molding machine. Response surface methodology with the composite design is used. Curing temperature, curing time, pressure and mold temperature are taken as an input factor and tensile strength, hardness and impact strength are taken as a response. The analysis is evident that that smaller changes in the mold temperature will reduce the mechanical properties of the mold. With molding process parameters of 190°C curing temperature, 1300 seconds curing time, 80 bar pressure and 190°C mold temperature gives composite with significantly improved mechanical properties.

1. Introduction

The composite material is a material made from two or more materials with different physical and chemical properties but the individual components remain separate and distinct in the final product [1]. From the literature review, the molding process parameters play a significant role in deciding the mechanical properties of the composite plate. For making a composite plate with the help of a compression molding machine several molding process parameters need to be considered. Research on biodegradable thermoplastic fiber-reinforced composites is becoming popular due to the reuse and recycled properties and biodegradability [2,3]. Polylactic acid (PLA) is known for its renewability and biodegradability when compared to other composite resins [4]. Moreover, poly-lactic acid has a small carbon footprint as it is obtained from natural resources. Along with this, PLA is also eco-friendly and is compatible with a variety of fibers (Bamboo, Banana, Sisal, Basalt, and Jute) [5,6] and additives (Talc, ENR, wood flour, polyethylene waste, and hazelnut shell, ultrafine bamboo-

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char, PEG, SiO_2) [7,8]. Poly-lactic acid is famous for high rigidity and tensile strength. Pure virgin PLA has glass transition temperature 63ºC and melting temperature is 153ºC [9].

Figure 1 shows the compression molding machine and Figure 2 shows the assembled mold which is used for making a composite plate. The addition of bamboo fiber in PLA increases the melting temperature from 151.70ºC to 154.42ºC and recycled bamboo fiber at 155.56ºC [10]. Pure PLA exhibited brittle morphology and smooth surface after fracture [11]. The compatibility between the PLA resins with other resins are higher and shows significant improvement in the properties [12]. Jute fiber reinforced PLA Composite was made by using Poly Lactic Acid provided by Dow Cargill in a pellet form with a density of 1.24 g/cm^3, melting temperature of 165ºC and glass transition temperature of 65ºC, Jute fiber provided by the National Institute of Research on Jute and Allied Fibre Technology, Kolkata, India. The mold must be assembled by attaching the base plate to the middle piece. An even layer of silicon mold release agent should be sprayed inside the mold to facilitate the removal of the completed sample [13]. Complete the mold assembly and check for any gaps and crevices [14]. Composites were prepared with different molding process parameter as per the design of expert runs. The sample consisted of only PLA and Jute fiber in the ratio of 80:20 and the sample Jute Fibre Reinforced Polylactic Acid Composite Plate is shown in Figure 3.

Fig. 1. Compression molding machine

Fig. 2. Assembled mold

Fig. 3. Jute fibre reinforced polylactic acid composite plate

1.1 Tensile Strength

Ultimate tensile strength is measured by the maximum stress that a material can withstand while being stretched or pulled before breaking [15]. Totally 10 samples were made for Tensile testing's as per ASTM Standards D638 and the average of the result was taken for consideration.

1.2 Impact Strength

Izod impact testing is a method of determining the impact resistance of materials [16]. Totally 10 samples were made for both Izod with ASTM D256 standard and Charpy with D638 ASTM standard and the average of the result was taken for consideration.

1.3 Hardness Strength

The Brinell the scale is a hardness scale based on the indentation hardness of a material [17]. Totally 15 readings were taken on the sample due to high variations in the samples as per the ASTM E10-14 standard and the average of the test results were taken for consideration.

2. ANOVA Test Analysis for Mechanical Properties

Optimization of the molding process parameter is carried out with design expert version 12.0.4. We choose the linear model with 30 runs to fit the model. The data are validated using scatterplots and ANOVA is used to validate the design. From the literature review, the most significant molding process parameters are chosen for the analysis. The selected molding process parameters are Curing temperature, curing time, pressure and mold temperature are taken as a factor. In the same way, as per the literature review, the most significant mechanical properties are selected to characterize the jute fibre reinforced polylactic acid composite plate. The mechanical properties are Tensile strength, impact strength and hardness are taken as a response.

Table 1 shows the input factors i.e. curing temperature, curing time, pressure and mold temperature minimum value and maximum value. Table 2 shows the tensile strength, impact strength, and hardness values. The standard deviation of tensile strength and hardness having less than 2 SN ratio and SN ratio of impact strength is above 2. We consider higher the better analysis. The maximum tensile strength is 61Mpa and the minimum tensile strength is 44Mpa. The maximum impact strength is 14 Joule and the minimum impact strength is 5 Joule. The maximum hardness strength is 74 BHN and the minimum hardness strength is 55 BHN. The curing time having the highest standard deviation whereas all other input factors is having the same standard deviation of 4.55. this is due to the interval between the two values like for curing temperature, pressure and molding temperature having an interval of 5 units whereas the curing time is having an interval of 50 units.

Table 1
Factors (Molding process parameters)

Factor	Minimum	Maximum	Low	High	Mean	Std. Dev.
Curing temp	175	195	180	190	185	4.55
Curing time	1150	1350	1200	1300	1250	45.49
Pressure	65	85	70	80	75	4.55
Mold temp	175	195	180	190	185	4.55

Table 2
Responses (Mechanical properties)

Response	Minimum	Maximum	Mean	Std. Dev.	Ratio	Goal
Tensile strength	44Mpa	61 Mpa	54.7	4.07	1.39	maximize
Hardness	55 BHN	74 BHN	64.9	4.69	1.35	maximize
Impact strength	5 Joule	14 Joule	9.43	2.22	2.8	maximize

Table 3 shows the Results of ANOVA Test Analysis for Mechanical Properties. For tensile strength, The Model F-value of 17.80 and p-value of 0.0001 implies the model is significant. The Predicted R^2 of 0.6204 is in reasonable agreement with the Adjusted R^2 of 0.6986; i.e. the difference is less than 0.2. Adequate Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 16.628 indicates an adequate signal. This model can be used to navigate the design space. For impact strength, The Model F-value of 13.01 and p-value of 0.0001 implies the model is significant. The Predicted R^2 of 0.5050 is in reasonable agreement with the Adjusted R^2 of 0.6235. Adequate Precision ratio of 14.363 indicates an adequate signal. This model can be used to navigate the design space. For Hardness, The Model F-value of 32.94 and p-value of 0.0001 implies the model is significant. The Predicted R^2 of 0.8405 is in reasonable agreement with the Adjusted R^2 of 0.0.815. Adequate Precision ratio of 22.8537 indicates an adequate signal. This model can be used to navigate the design space.

Table 3
Results of ANOVA test analysis for mechanical properties

Source	Sum of Squares	df	Mean Square	F-value	p-value	R^2	Adjusted R^2	Predicted R^2	Adeq Precision
Tensile Strength	355.5	4	88.87	17.8	< 0.0001	0.740	0.698	0.6204	16.6276
Impact	96.83	4	24.21	13.01	< 0.0001	0.675	0.623	0.505	14.3633
Hardness	536.83	4	134.21	32.94	< 0.0001	0.840	0.815	0.7792	22.8537

Scatter plots of Actual vs. Predicted are one of the richest forms of data visualization. All points are little away to a regressed diagonal line, it is due to medium R Square value. The lower the R Square, the weaker the Goodness of fit of your model, the foggier or dispersed your points are (away from this diagonal line).

Figure 4 shows the Scatter plot of Predicted vs. Actual for tensile strength. For Tensile strength, and curing temperature is having the highest positive correlation. Pressure, mold temperature and cutting time does not have any significant correlation. Figure 5 shows the Scatter plot of Predicted vs. Actual for impact strength. For Impact strength, all points are not close to a regressed diagonal line, it is due to less R Square value. However, the R Square value is significant to accept the model.

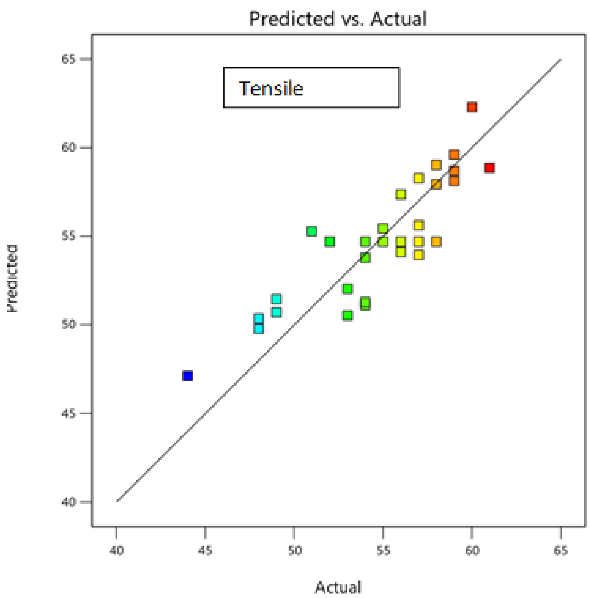

Fig. 4. Scatter plot of Predicted vs. Actual for tensile strength

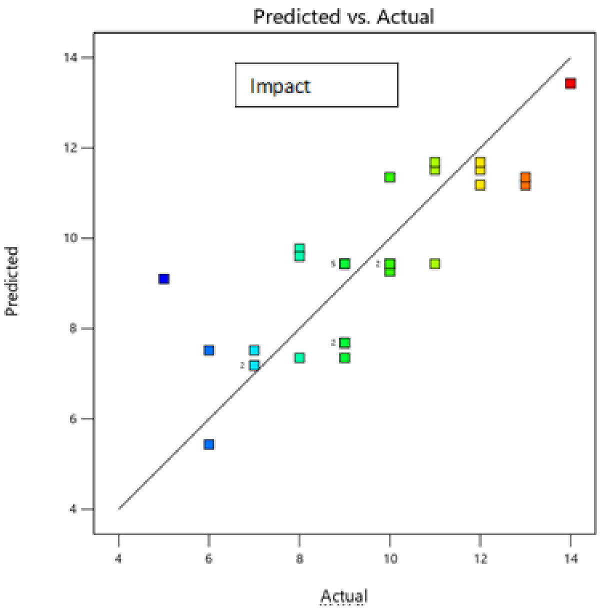

Fig. 5. Scatter plot of Predicted Vs. Actual for Impact strength

Figure 6 shows the Scatter plot of Predicted vs. Actual for hardness. For hardness, all points are close to a regressed diagonal line, it is due to high R Square value. For Hardness, the pressure is having the highest positive correlation. Curing temperature, mold temperature and cutting time does not have any significant correlation. For impact strength, curing time is having the highest positive correlation. Curing temperature, mold temperature and pressure does not have any significant correlation. A scatter plot indicates that tensile strength having a correlation with curing temperature, Hardness having a correlation with pressure and impact strength having a correlation with curing time. So, it is important to optimize the process parameter to get the perfect mold.

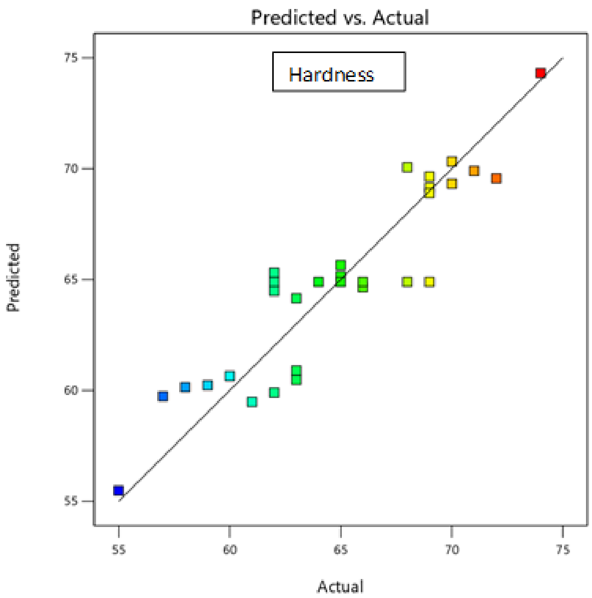

Fig. 6. Scatter plot of Predicted Vs. Actual for hardness strength

3. Optimization Results and Discussion

Optimization of the molding process parameter is carried out with design expert version 12.0.4. Response surface methodology with the composite design is used to optimize the molding process parameters. We choose linear model with 30 runs to fit the model. The data are validated using scatter plots and ANOVA is used to validate the design. Curing temperature, curing time, pressure and mold temperature are taken as a factor (molding process parameters). Tensile strength, impact strength, and hardness are taken as a response (mechanical properties).

Table 4 shows the results of the response surface method desirability function analysis. By response surface method, it is found that with 190°C curing temp, 1300 seconds curing time, 80 bar pressure and 190°C mold temperature given mold with good mechanical properties and having tensile strength desirability value of 0.87451, hardness desirability value of 0.792982, impact strength desirability value of 0.742593 and a combined desirability value of 0.801542 as shown in Figure 7 which shows desirability chart for optimized molding process parameters. Followed by 190°C curing temp, 1300 seconds curing time, 80 bar pressure and 189.888°C mold temperature gives the second-best mechanical properties. The difference between the two optimized values is 0.2°C. Mold temperature which shows that smaller changes in the mold temperature will reduce the mechanical properties of the mold.

Table 4
Results of response surface method desirability function analysis

No.	Curing temp	Curing time	Pressure	Mold temp	Tensile strength	Hardness	Impact strength	Desirability
1	190	1300	80	190	58.867	70.067	11.683	0.802
2	190	1300	80	189.888	58.86	70.069	11.683	0.801
3	190	1300	80	189.733	58.851	70.073	11.683	0.801
4	190	1300	79.98	189.818	58.855	70.058	11.683	0.801
5	190	1299.9	80	189.27	58.824	70.085	11.683	0.801
6	190	1300	79.99	189.227	58.821	70.085	11.683	0.801
7	189.98	1300	80	189.545	58.83	70.077	11.683	0.801
8	190	1300	80	189.034	58.81	70.091	11.683	0.801
9	190	1299.9	80	189.111	58.815	70.088	11.681	0.801
10	190	1300	80	188.742	58.793	70.098	11.683	0.801

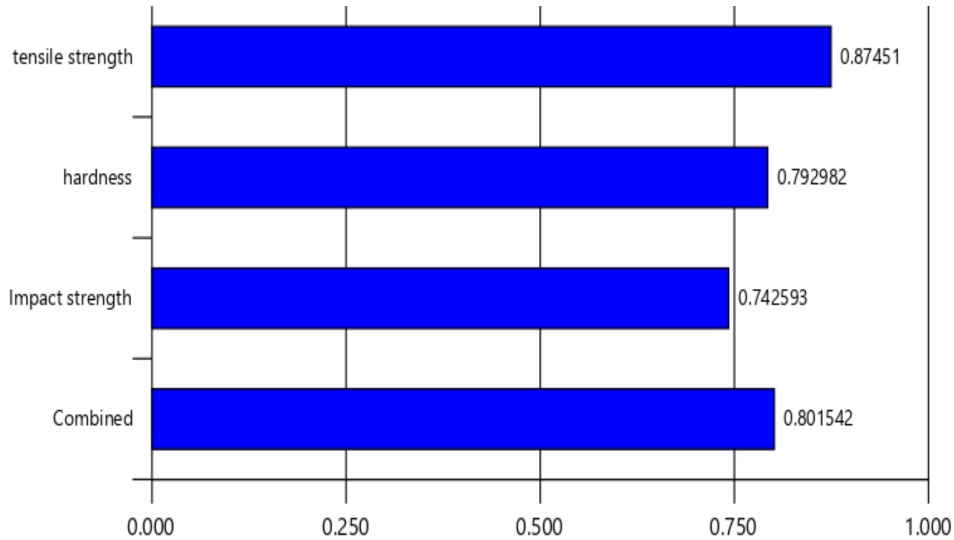

Fig. 7. Desirability chart for optimized molding process parameters result

4. Conclusions

The optimization of the molding process parameter was carried out with a design expert. The data are validated using scatter plots and ANOVA. Curing temperature, curing time, pressure and mold temperature are taken as a factor (molding process parameters). Tensile strength, impact strength and hardness are taken as a response (mechanical properties). By response surface method, it is found that with 190°C curing temp, 1300 seconds curing time, 80 bar pressure and 190°C mold temperature given mold with good mechanical properties with a combined desirability value of 0.801542. It is also revealed that smaller changes in the mold temperature will reduce the mechanical properties of the mold.

References

[1] Kumar, J. Pradeep, and P. Packiaraj. "Effect of drilling parameters on surface roughness, tool wear, material removal rate and hole diameter error in drilling of OHNS." *International Journal of Advanced Engineering Research and Studies* 1, no. 3 (2012): 150-154.

[2] Sultan, A. Z., Safian Sharif, and Denni Kurniawan. "Effect of machining parameters on tool wear and hole quality of AISI 316L stainless steel in conventional drilling." *Procedia Manufacturing* 2 (2015): 202-207. https://doi.org/10.1016/j.promfg.2015.07.035

[3] Sait, A. Naveen, S. Aravindan, and A. Noorul Haq. "Optimisation of machining parameters of glass-fibre-reinforced plastic (GFRP) pipes by desirability function analysis using Taguchi technique." *The International Journal of Advanced Manufacturing Technology* 43, no. 5-6 (2009): 581. https://doi.org/10.1007/s00170-008-1731-y

[4] Kurt, Mustafa, Eyup Bagci, and Yusuf Kaynak. "Application of Taguchi methods in the optimization of cutting parameters for surface finish and hole diameter accuracy in dry drilling processes." *The International Journal of Advanced Manufacturing Technology* 40, no. 5-6 (2009): 458-469. https://doi.org/10.1007/s00170-007-1368-2

[5] Manickam, Ramachandran. "Back propagation neural network for prediction of some shell moulding parameters." *Periodica Polytechnica Mechanical Engineering* 60, no. 4 (2016): 203-208. https://doi.org/10.3311/PPme.8684

[6] Lin, Yan-Cherng, Yuan-Feng Chen, Der-An Wang, and Ho-Shiun Lee. "Optimization of machining parameters in magnetic force assisted EDM based on Taguchi method." *Journal of Materials Processing Technology* 209, no. 7 (2009): 3374-3383. https://doi.org/10.1016/j.jmatprotec.2008.07.052

[7] Manickam, Ramachandran, and Nidhi Agarwal. "Identification of Most Affected Parameter for Design for Remanufacturing of Scrap Piston by Taguchi Desirability Function Analysis." *Advances in Intelligent Systems and Computing* 659 (2017): 320-329. https://doi.org/10.1007/978-3-319-67792-7_32

[8] Krishnaraj, Vijayan, A. Prabukarthi, Arun Ramanathan, N. Elanghovan, M. Senthil Kumar, Redouane Zitoune, and J. P. Davim. "Optimization of machining parameters at high speed drilling of carbon fiber reinforced plastic (CFRP) laminates." *Composites Part B: Engineering* 43, no. 4 (2012): 1791-1799. https://doi.org/10.1016/j.compositesb.2012.01.007

[9] Kilickap, Erol, Mesut Huseyinoglu, and Ahmet Yardimeden. "Optimization of drilling parameters on surface roughness in drilling of AISI 1045 using response surface methodology and genetic algorithm." *The International Journal of Advanced Manufacturing Technology* 52, no. 1-4 (2011): 79-88. https://doi.org/10.1007/s00170-010-2710-7

[10] Tagliaferri, V., G. Caprino, and A. Diterlizzi. "Effect of drilling parameters on the finish and mechanical properties of GFRP composites." *International Journal of Machine Tools and Manufacture* 30, no. 1 (1990): 77-84. https://doi.org/10.1016/0890-6955(90)90043-I

[11] Purohit, Pulkit, and M. Ramachandran. "Selection of Flywheel Material using Multicriteria Decision Making Fuzzy Topsis." *Indian Journal of Science and Technology* 8, no. 33 (2015): 1-5. https://doi.org/10.17485/ijst/2015/v8i33/80028

[12] Rajmohan, T., and K. Palanikumar. "Optimization of machining parameters for surface roughness and burr height in drilling hybrid composites." *Materials and Manufacturing Processes* 27, no. 3 (2012): 320-328. https://doi.org/10.1080/10426914.2011.585491

[13] Das, Partha Protim, Priyank Gupta, Ranjan Kumar Ghadai, Manickam Ramachandran, and Kanak Kalita. "Optimization of turning process parameters by Taguchi-based Six Sigma." *Mechanics and Mechanical Engineering* 21, no. 3 (2017): 649-656.

[14] Jenarthanan, M. P., and R. Jeyapaul. "Optimisation of machining parameters on milling of GFRP composites by desirability function analysis using Taguchi method." *International Journal of Engineering, Science and Technology* 5, no. 4 (2013): 22-36. https://doi.org/10.4314/ijest.v5i4.3

[15] Mukhraiya, Vikas, Raj Kumar Yadav, and Pooja Tiwari. "Optimization of Drilling Parameters Using Grey Based Taguchi Method." *International Journal of Advanced Research in Engineering and Technology* 6, no. 12 (2015): 16-24.

[16] Galgali, Varsha S., M. Ramachandran, and G. A. Vaidya. "Multi-objective optimal sizing of distributed generation by application of Taguchi desirability function analysis." *SN Applied Sciences* 1, no. 7 (2019): 742. https://doi.org/10.1007/s42452-019-0738-3

[17] Dadhaniya, Jaydeep K., and Dr Mohammad Israr. "Optimization of Investment Casting Parameters of A443 Alluminium Alloy with Adding Trace Elements Using Taguchi Method." *International Journal of Advanced Research in Engineering and Technology* 6, no. 8 (2015): 1-11.