Smart Green Machining Technology and Stability Analysis for Carbon Fiber Reinforced Polymer

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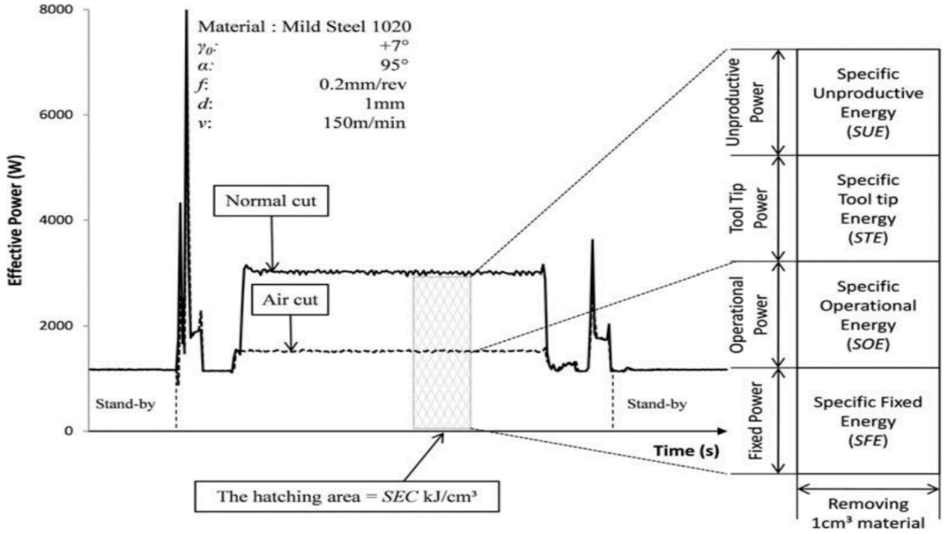
GENERAL OPTIMUM ANALYSIS TECH LAB

Outline

1. **Introduction**
2. **Theory of Machining Process / Experiments**
3. **Results and Discussion**
4. **Conclusion**

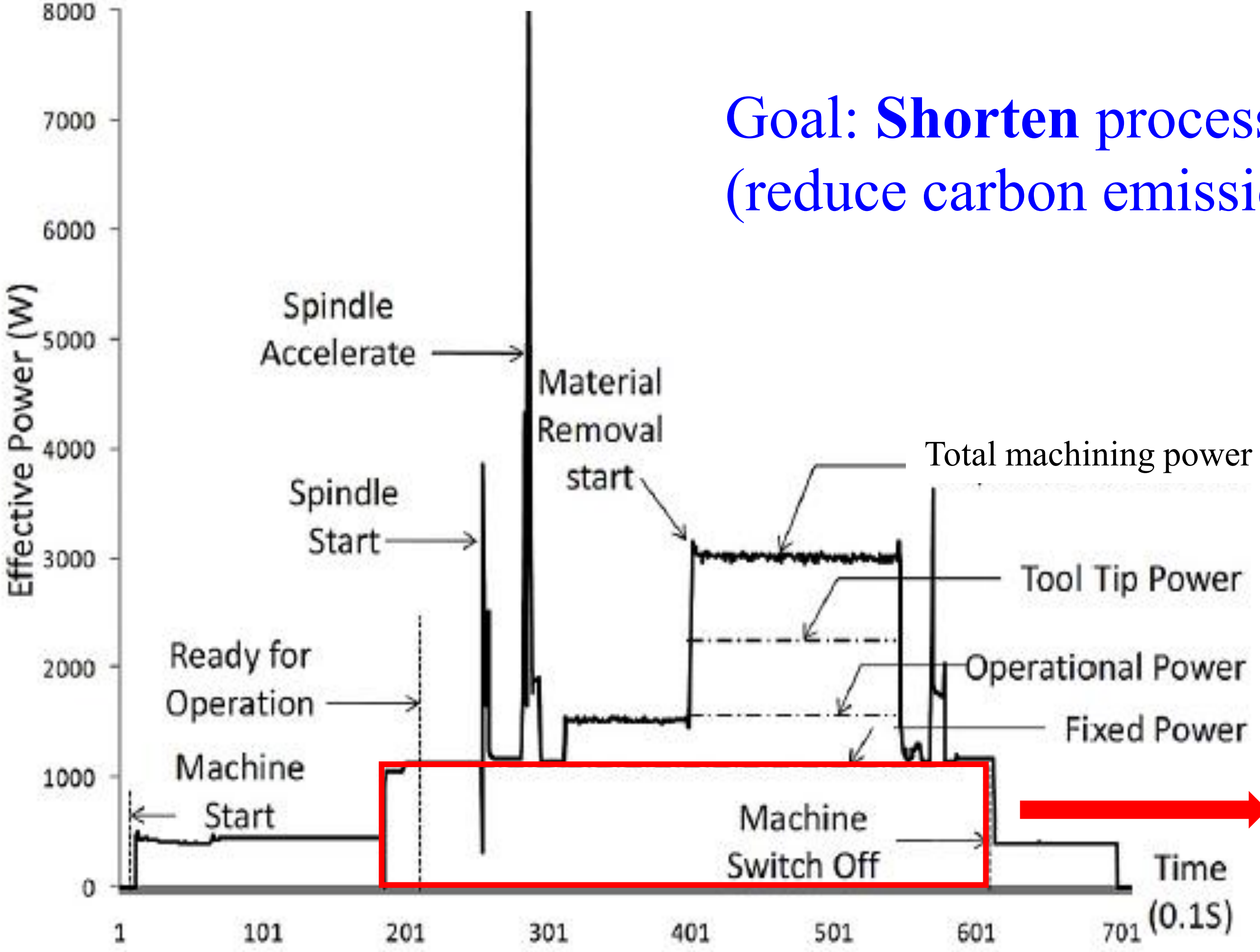
1.Introduction

- According to the International Energy Agency (IEA), the global electric energy demand for machine tools accounts for 1~3% (200~700TWh) of the total demand, and has an increasing trend year by year.
- The manufacturing processing efficiency of machine tools is less than 14%.
- ISO 14955 standard provides the measurement of energy consumption of different machine tools.
- In terms of efficiency, the idea of green machine tools is induced and provided a quantitative standard for the energy consumption of the machine.



Machine tool power profile for a complete machine process

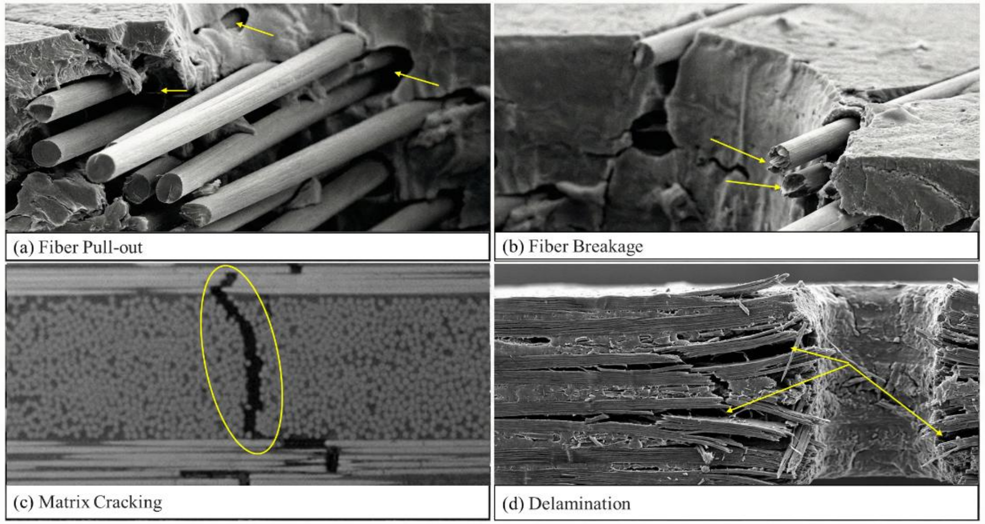
Goal: **Shorten** processing time
(reduce carbon emissions)

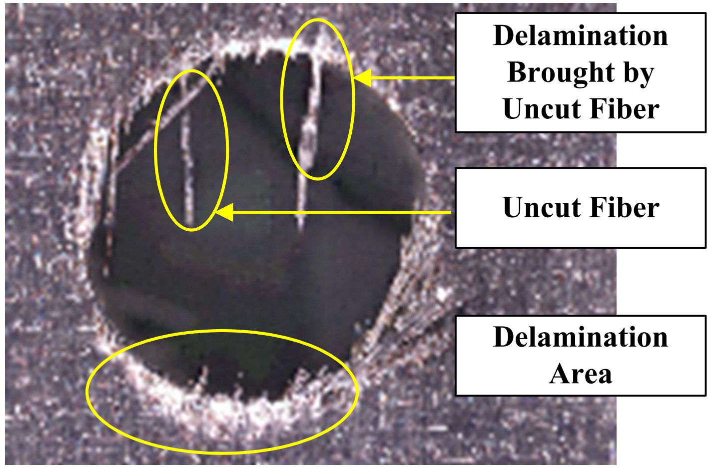


Reduced processing time then background energy consumption will be **saved**

Motivation

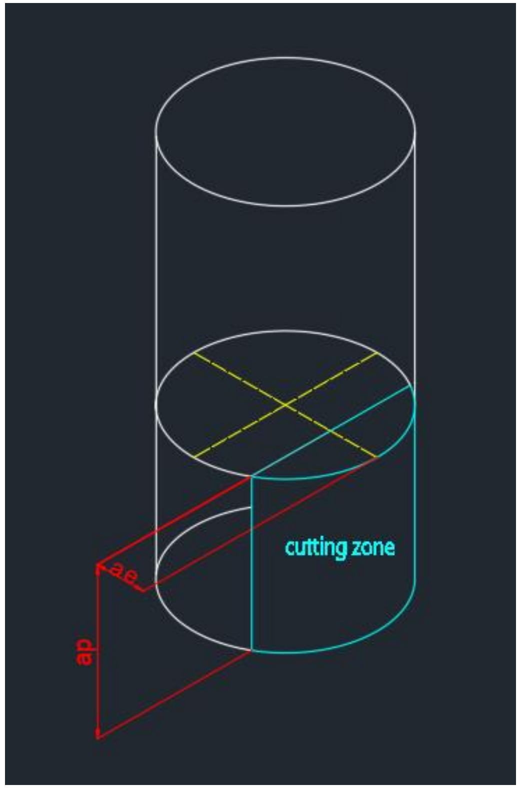
Research Gap	Approach in This Study
Cutting mechanisms at different fiber angles	Fit and validate a piecewise model for shear- and bending-dominated regions
Stacking effects in MD-CFRP	Sum layerwise UD-CFRP cutting forces to predict MD-CFRP
Tool-wear evolution	Conduct 50-slot tests for three stacks at different speeds and feeds
Comparison of wear-prediction methods	Compare an empirical equation, XGBoost, Bi-LSTM, and GRU
Relationship between force and wear	Analyze maximum cutting force as slot count increases





2. Theory of Machining Process

Governing Equations of Cutting Forces



Feed of tool
(tool rotational speed, feed rates, number of flutes)

$$F_{x,j}(\phi_j(z)) = \left\{ \frac{c}{4k_\beta}\left[-K_{tc}\cos 2\phi_j(z) + K_{rc}[2\phi_j(z) - \sin 2\phi_j(z)]\right] + \frac{1}{k_\beta}[K_{te}\sin\phi_j(z) - K_{re}\cos\phi_j(z)] \right\}_{z_{j,1}(\phi_j(z))}^{z_{j,2}(\phi_j(z))},$$

$$F_{y,j}(\phi_j(z)) = \left\{ \frac{-c}{4k_\beta}[K_{tc}(2\phi_j(z) - \sin 2\phi_j(z)) + K_{rc}\cos 2\phi_j(z)] + \frac{1}{k_\beta}[K_{te}\cos\phi_j(z) + K_{re}\sin\phi_j(z)] \right\}_{z_{j,1}(\phi_j(z))}^{z_{j,2}(\phi_j(z))},$$

$$F_{z,j}(\phi_j(z)) = \frac{1}{k_\beta}[K_{ac}c\cos\phi_j(z) - K_{ae}\phi_j(z)]_{z_{j,1}(\phi_j(z))}^{z_{j,2}(\phi_j(z))}.$$

K_{ij} Cutting force coefficients

helix angle of endmill tool

Immersion angle
(Ae and tool diameter)

Ap
(Axial depth of cut)

Experimental Plans

Machine tool

- Tongtai CT350 machining center

End mill

- Yuan Jun 772L-A
- Diameter: 6 mm
- Number of flutes: 2
- Effective cutting length: 16 mm

Cutting-signal measurement

- SPIKE® mobile 1.2 intelligent tool holder

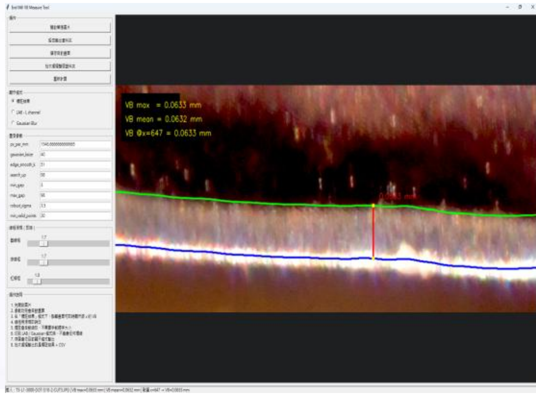
Wear-imaging equipment

- Nikon D7500 DSLR camera
- Nikon PB-6 bellows focusing attachment

▲ Tongtai CT350


▲ SPIKE® mobile 1.2 intelligent tool holder


▲ Nikon PB-6


▲ Tool Wear Monitoring

Experimental Platforms

Tongtai CT350

Machining time

Tool Path control

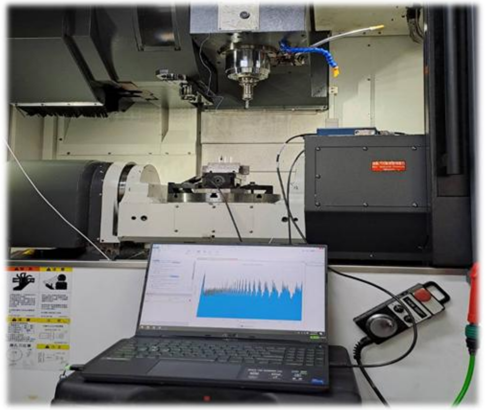
Surface Roughness

Quality Control

KOSAKA DSF-K800

Chatter monitoring

Stability of cutting monitoring

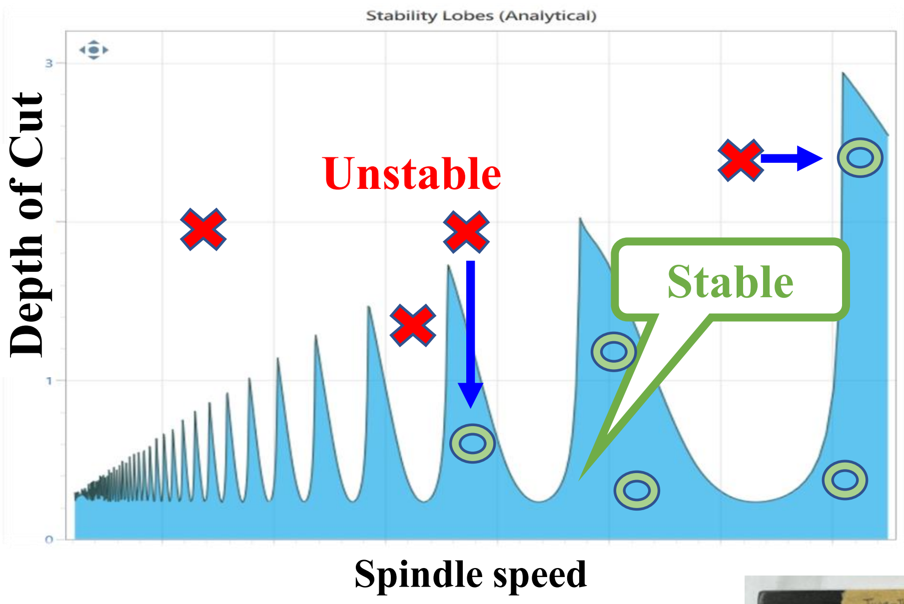


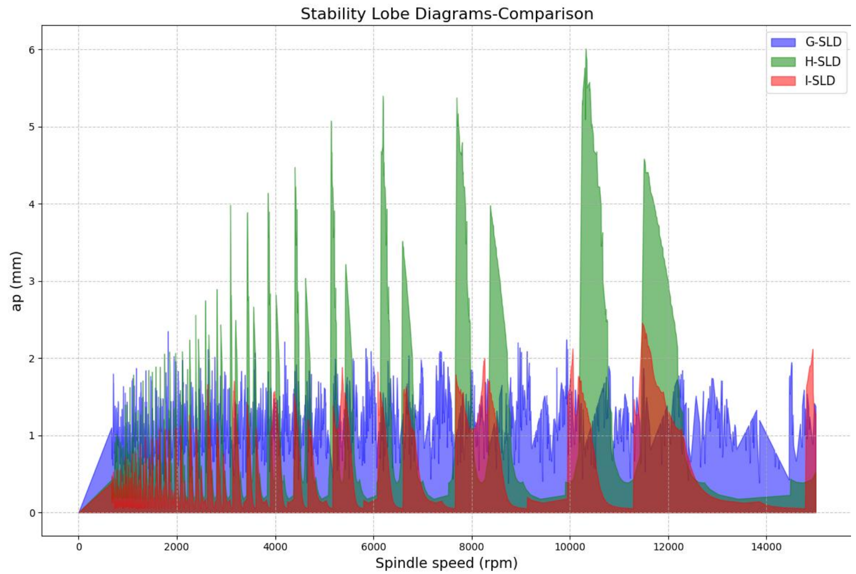
Impact-Acceleration Responses

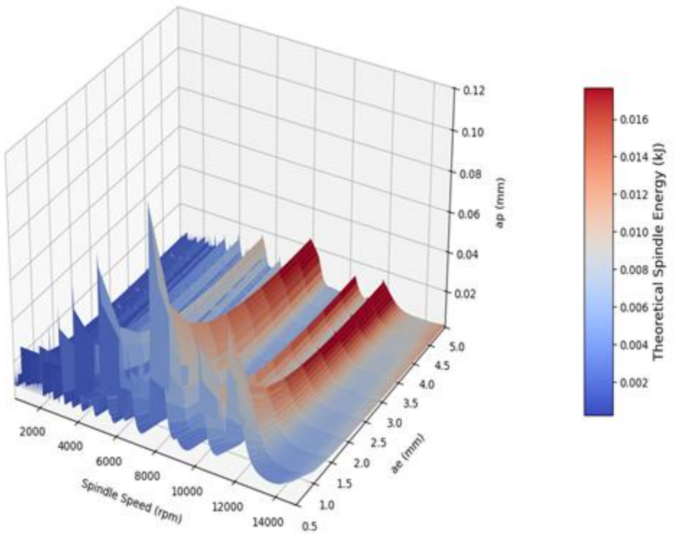
High Frequency Vibration Signal

Microphone sensor

Stability Lobe Diagram (SLD)



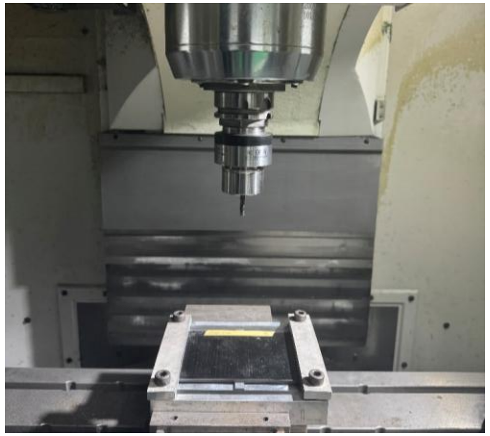




4D-SLD With Energy

When **chatter** occurs, SLD can be applied to **change the speed or depth of cut** to enter the stable processing area.

◄ Finished specimen



◄ UD-CFRP cutting-force test setup

Taguchi Method-Optimization of Parameters

Table 1 Input Parameters

Input parameter	Level 1	Level 2	Level 3
Spindle Speed (RPM)	1000	1500	2000
Feed rate (mm/min)	85	150	200
Depth of cut (mm)	0.3	0.5	0.7
Flowmeter rate (L/min)	12	14	16

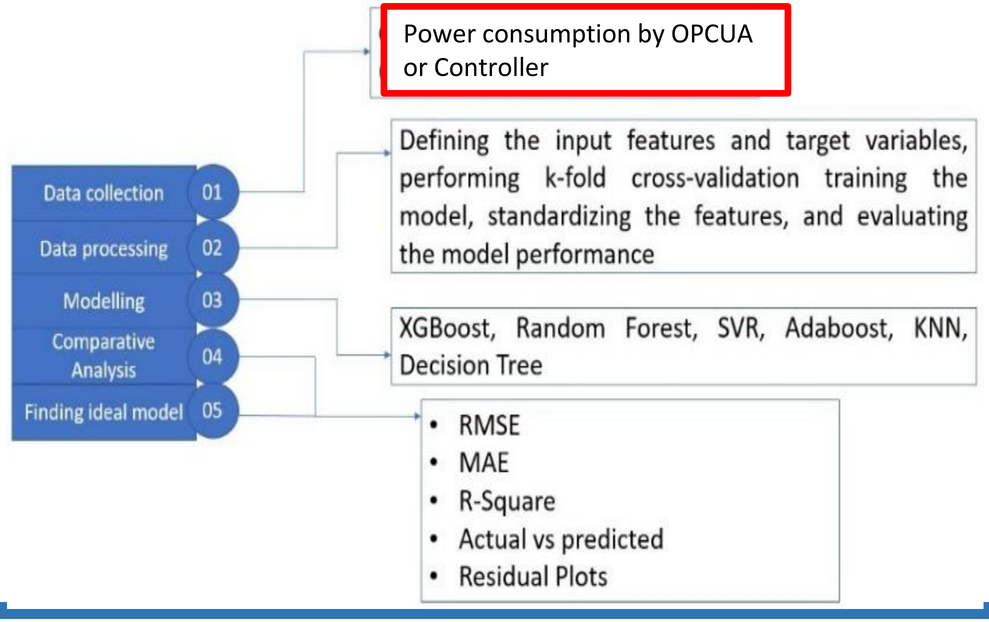


Table 2 Taguchi L9 orthogonal array

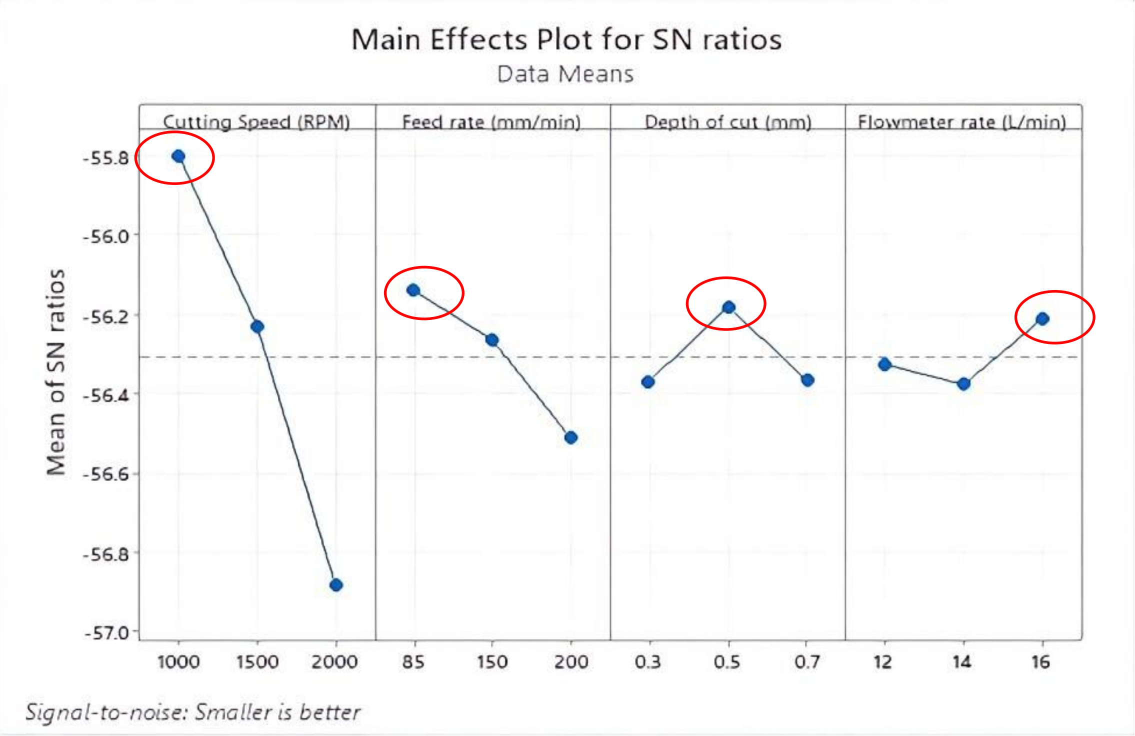
Exp No	Spindle Speed (RPM)	Feed rate (mm/min)	Depth of cut (mm)	Flowmeter rate (L/min)
1.	1000	85	0.3	12
2.	1000	150	0.5	14
3.	1000	200	0.7	16
4.	1500	85	0.5	16
5.	1500	150	0.7	12
6.	1500	200	0.3	14
7.	2000	85	0.7	14
8.	2000	150	0.3	16
9.	2000	200	0.5	12

Results and Discussion(1)

Taguchi Method-Optimization of Parameters

Table 3. Experimental Results

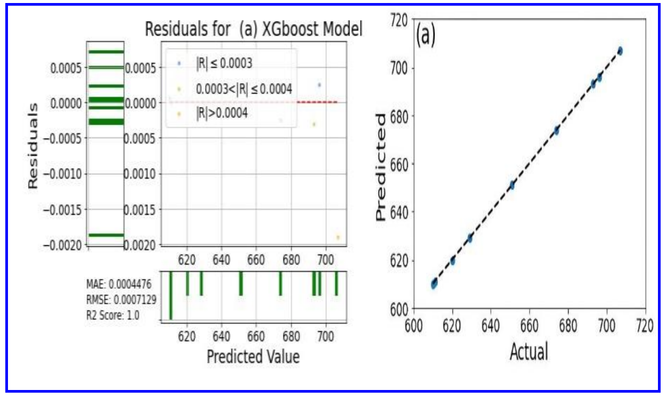
Exp No	Spindle Speed (RPM)	Feed rate (mm/min)	Depth of cut (mm)	Flowmeter rate (L/min)	Energy Consumption (KJ)
1.	1000	85	0.3	12	611
2.	1000	150	0.5	14	610
3.	1000	200	0.7	16	629
4.	1500	85	0.5	16	620
5.	1500	150	0.7	12	651
6.	1500	200	0.3	14	674
7.	2000	85	0.7	14	696
8.	2000	150	0.3	16	693
9.	2000	200	0.5	12	707



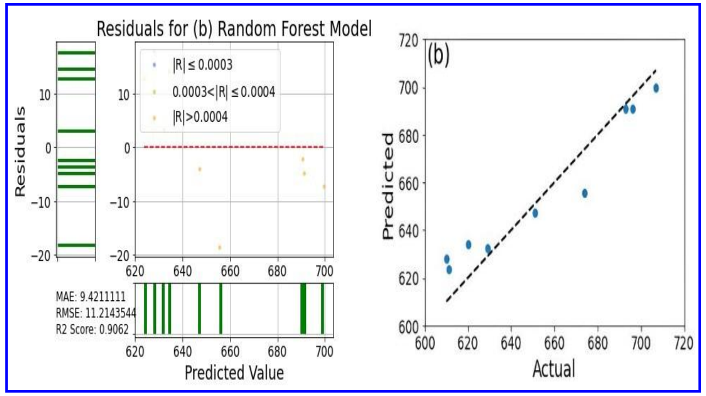
Optimized parameters: spindle speed of 1000 RPM, feed rate of 85 mm/min, depth of cut of 0.5 mm, and flowmeter rate of 16 L/min **(achieved the lowest energy consumption/carbon emissions)**

Results and Discussion(2)

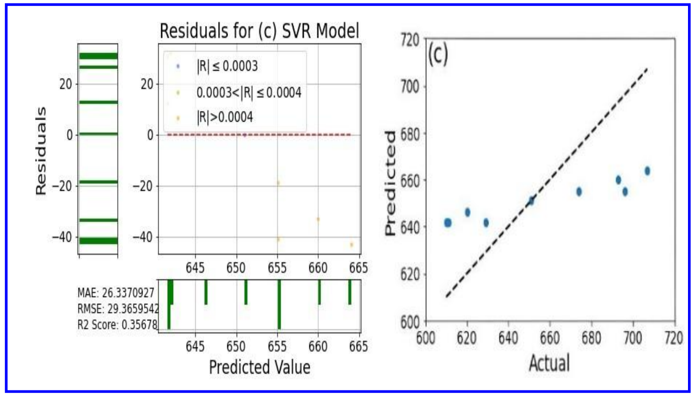
Performance of Machine Learning Algorithms



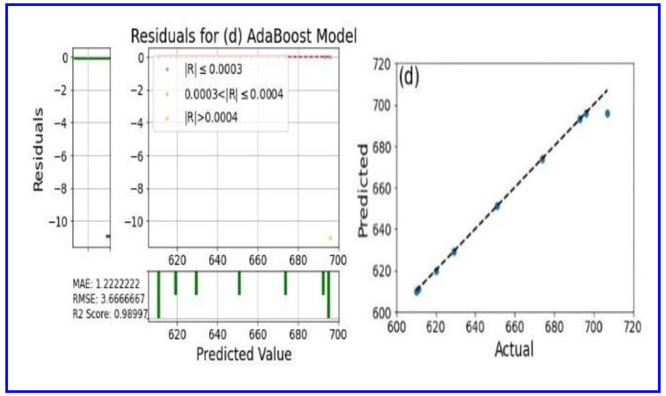
XGBoost



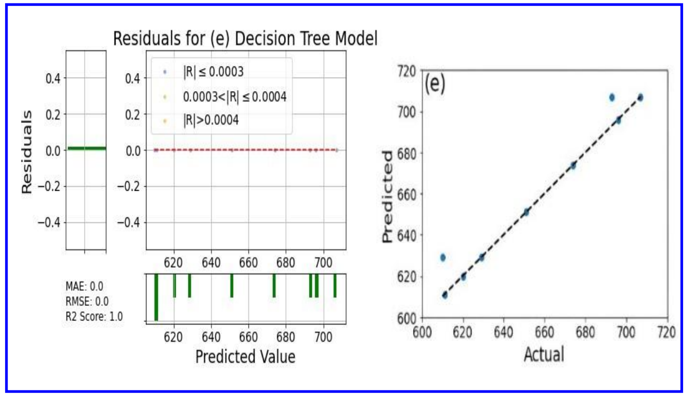
Random Forest



SVR



Adaboost



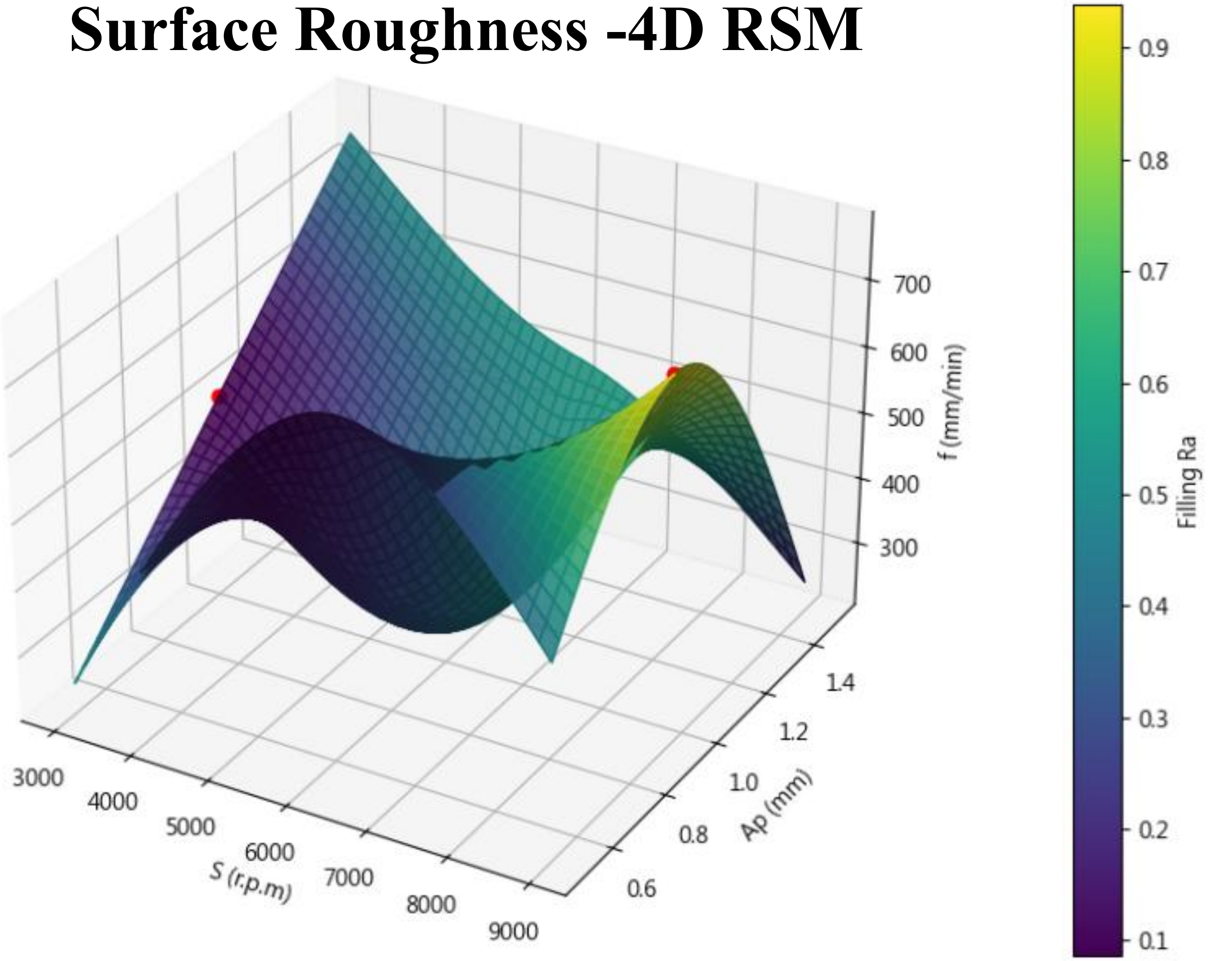
Decision Tree

Table 3. Performance of Machine Learning Algorithms

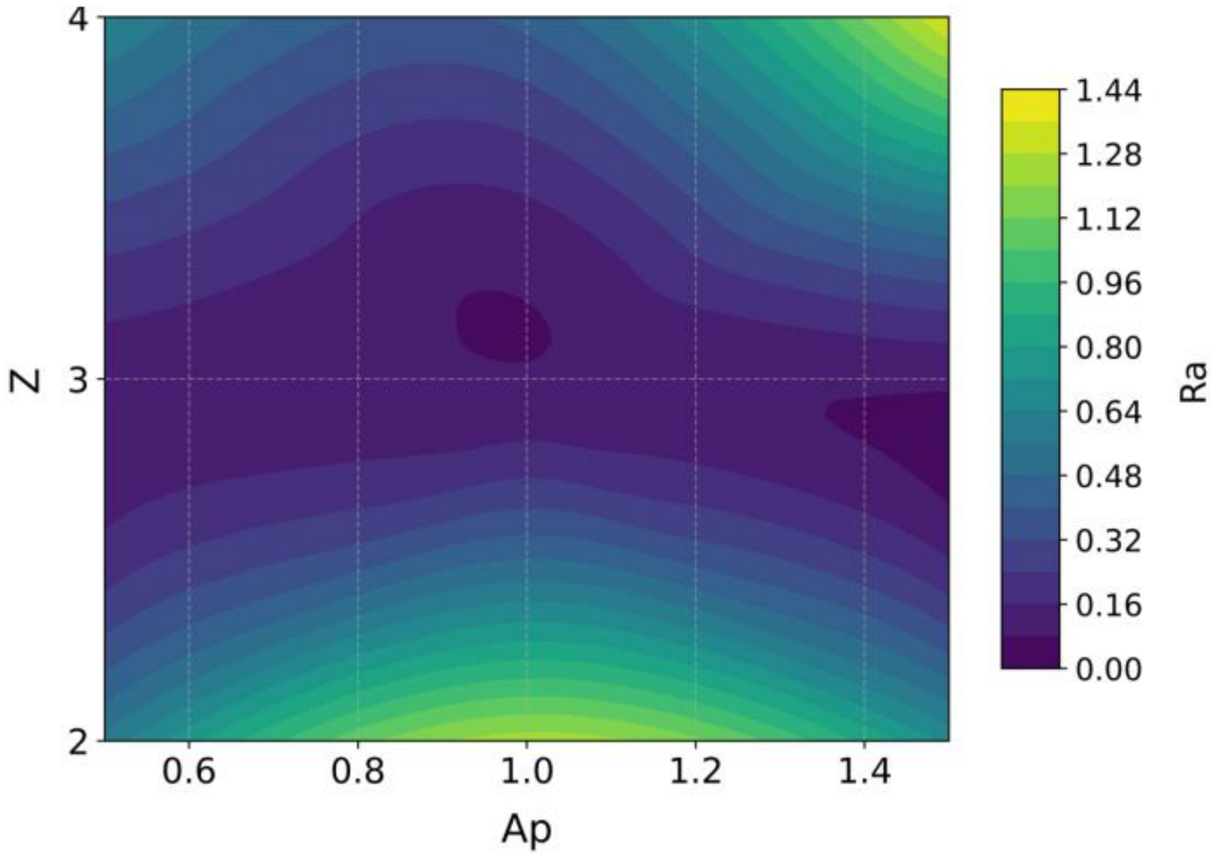
	XGBoost	Random Forest	Decision Tree	SVR	Adaboost
RMSE	0.0012	11.214	5.426	35.818	3.666
R^2	0.999	0.906	0.978	0.043	0.989
MAE	0.0019	9.421	2.666	32.367	1.222

Results and Discussion(3)-XGBoost-4D RSM

Surface Roughness -4D RSM



Z(number of flute) VS Ap



Max: S=9000 r.p.m, Ap=0.936 mm, f=755 mm/min, Ra=0.939
Min: S=3000 r.p.m, Ap=1.013 mm, f=505 mm/min, Ra=0.086

Results and Discussion(4)- UD-CFRP Laminates

Taguchi L9

No. 2

Energy Consumption : 610(KJ)

No. 9

Energy Consumption : 707(KJ)

Multi Optimal:

Energy Consumption : 560 (KJ)

Conclusion

1.Chatter can be analyzed, monitored and suppressed by optimized parameters.

2. *Ae* and *Ap* are highly relative to energy consumption of manufacturing.

3. Surface roughness can be controlled by rotational speed of spindle, *Ae*, and *Ap* selection.

4.Carbon emission are relative to machining time and can be reduced more than 20.7% for production.

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Thank you for your listening!
Q & A

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