Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol. 14, Issue 26s (2025)
https://www.jneonatalsurg.com

Utilizing Multi-Criteria Decision-Making for Selecting the Optimal Cutting Fluid in the Turning Process under Various Operating Conditions

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Cite this paper as: Prof. Devendra Patel, Prof. Abhishek Shrotriya, Prof. Pradeep K Mehta, Prof. Gourav Patel, Prof. Lekhraj Patidar, (2025) Utilizing Multi-Criteria Decision-Making for Selecting the Optimal Cutting Fluid in the Turning Process under Various Operating Conditions, *Journal of Neonatal Surgery*, 14 (26s), 105-114

ABSTRACT

With the rapid advancement of computer-aided engineering tools, design methodologies have undergone significant transformation, particularly in the areas of computational design and optimization. This study focuses on selecting the most suitable cutting fluid for turning operations based on key machining parameters such as feed force, cutting force, radial force, and surface roughness. Multi-criteria decision-making techniques, specifically TOPSIS and VIKOR, are used to analyze and rank different cutting fluids. Parametric modeling is carried out using MS Excel, allowing for efficient evaluation by adjusting input variables without manual calculations. The experimental work involves machining mild steel using a single-point High-Speed Steel (HSS) cutting tool under varying cutting speeds, feed rates, and eco-friendly cutting fluids. The results are presented through graphical analysis to identify the most effective cutting fluid under specific conditions. Additionally, the study investigates the influence of coolant flow, spindle speed, feed, depth of cut, and cutting force on surface finish. Recognizing the critical role of cutting fluid in machining performance, this research proposes an optimization model to manufacturers in selecting the most appropriate cutting fluid for improved turning process outcomes.

Keywords: *Turning, Cutting Fluid, Cutting Force Measurement, Surface Roughness, Instrumentation and Experimentation, Cutting Parameter*

1. INTRODUCTION

Optimizing machining process parameters is crucial to reducing cutting forces, as excessive cutting force can lead to several undesirable effects, including increased energy consumption, higher surface roughness, reduced tool life, and poor surface quality. Cutting force directly influences important variables such as depth of cut, rake angle, cutting speed, feed rate, and tool durability. To accurately monitor these forces, a variety of measurement techniques have been developed. Dynamometers equipped with transducers like load-cell, piezoelectric, thermoelectric, and photoelectric sensors are commonly used in turning operations to measure cutting forces. Numerous experimental investigations have been conducted to measure cutting forces directly, as well as to estimate them based on process conditions. Additionally, simple analytical models have been applied to demonstrate the effects of parameters like cutting speed and feed rate on cutting forces.

1.1 Fundamentals of Turning

Turning is one of the primary operations performed on a lathe and accounts for a significant portion of lathe machining tasks. During turning, the cutting tool is typically fed from right to left, and the resulting cutting forces should be directed toward the headstock. This orientation helps to press the workpiece firmly against the work-holding device, enhancing stability and support during machining.

For achieving precise dimensions and a smooth surface finish, roughing cuts are generally followed by finishing cuts. Roughing involves removing a substantial amount of material and should be performed within the limits of acceptable chip thickness, tool durability, machine power, and the material properties of the workpiece. In cases where efficiency is prioritized, a greater depth of cut combined with a lower feed rate is often used, as this approach minimizes the number of passes and reduces the time spent repositioning the carriage.

1.2 Types of Cutting Fluids

1.2.1 Gaseous Fluids: Used mainly when liquid coolants are not suitable due to material or process constraints. Common types include:

- Compressed air

- Carbon dioxide (CO_2), which cools through sublimation
- Argon
- Oil mist

1.2.2. Liquid Fluids:

- **Water:** Used for cooling and chip removal, though it may cause rusting. It has high thermal conductivity but low lubricating properties.
- **Oil-Based Fluids:**
  - *Straight Mineral Oils:* Ideal for light-duty tasks on non-ferrous metals.
  - *Fatty Oils:* Effective for heavy-duty operations but prone to spoilage and skin irritation.
- **Water-Miscible:**
  These are emulsions formed by mixing oil with water using an emulsifier (e.g., soap). They offer excellent cooling and are preferred for high-speed operations with high metal removal rates.
- **Vegetable-Based Oils:**
  - *Sunflower Oil:* Derived from sunflower seeds, commonly used in food and cosmetics, and known for its mild lubricating properties.

Coconut Oil: Extracted from mature coconuts, resistant to oxidation, and remains stable at room temperature. It offers environmental and health benefits, making it a potential eco-friendly cutting fluid.

Table Error! No text of specified style in document. **Viscosity of Fluids**

S.no.	**Temp (°C)**	**Viscosity (Centipoise)**		
		Vegetable-based Cutting Fluid (Sunflower Oil)	**Vegetable-based Cutting Fluid (Sunflower Oil)**	**Vegetable-based Cutting Fluid (Sunflower Oil)**
1	32	38	36.5	38.5
2	42	21	21.5	27.5
3	52	13	18.5	21.4
4	62	14	12.5	16.3

2. METHOD & MATERIALS

The objective of this research is to evaluate and compare various turning process parameters for different cutting fluids, with the aim of selecting the most suitable fluid using (MCDM) methods. The study also seeks to compare the effectiveness of different MCDM methods in identifying the best cutting fluid and to perform a sensitivity analysis to assess the reliability and robustness of the cutting fluid selection process under varying conditions.

2.1 Method for Ranking Alternatives by Closeness to Ideal Solution (TOPSIS)

TOPSIS is a widely used method in (MCDM) that ranks alternatives by their distance from the Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS). The steps include:

1. **Decision Matrix Construction**: A decision matrix is created, listing alternatives and criteria.
2. **Normalization**: Each value in the matrix is normalized to show the relative performance of each alternative.
3. **Weighted Decision Matrix**: The normalized values are multiplied by the weights of the criteria derived from AHP.
4. **Ideal Solutions**: The PIS and NIS are defined by selecting the maximum and minimum values for each criterion.
5. **Separation Distances**: The Euclidean distance from each alternative to both the PIS and NIS is calculated.
6. **Determining Closeness to Ideal:** Alternatives are evaluated based on how close they are to the ideal solution, forming the basis for their ranking.
7.

2.2 VIKOR Method

The VIKOR method is used for MCDM) to evaluate alternatives based on how close they are to the ideal solution. It involves:

1. **Best and Worst Function Values**: The best and worst values for each criterion are determined, depending on whether the criterion is a benefit or cost.
2. **Calculation of Sj and Rj**: The values for Sj and Rj are calculated using weighted averages for group utility and individual regret, respectively.
3. **Compromise Ranking**: A compromise ranking (Qj) is computed by combining the group utility and individual regret values, with a weight factor (v) applied to balance the two.
4. **Final Ranking**: The alternatives are ranked in descending order based on the values of S, R, and Q, where higher values correspond to better alternatives.

2.3 Working Condition and Input Parameters

The below observation is based on the working condition and for variable input parameters. In this calculation the based on the different cutting fluids is been considered.

Work material = Mild Steel

Cutting speed in RPM = 222

Cutting feed in mm/min = 104

Rake angle = 61

Depth of cut = 0.101mm

Table 2 Observed Results at 222 RPM

Sr.No.	SS (rpm)	FR (mm/min)	DOC (mm)	Used Coolants	F_X(N)	F_Y(N)	F_Z(N)	SR (µm)
1	222	104	0.101	**Vegetable-based Cutting Fluid (Sunflower Oil)**	29.5	219.2	39.4	11.39
2				**Natural Oil-based Coolant (Coconut Oil)**	19.3	199.32	29.34	17.65
3				**Commercially Available Coolant**	32.45	149.21	29.32	12.98
4				**No Lubrication/Cooling (Dry Condition)**	40.34	199.32	49.32	21.34

3. EXPERIMENTAL RESULTS

The selection of cutting fluids for Case 1 was evaluated using both TOPSIS and VIKOR methods, applying the criteria weights specified in Table 3.

Table 3 Weighted Decision Matrix

Weights	0.139	0.19	0.047	0.59
Coolant Selection/Cutting Performance Influencers	FX(N)	FY(N)	FZ(N)	SR (µm)
Sun flower oil(D1*)	0.059	0.10	0.021	0.20
Coconut oil(D2*)	0.041	0.11	0.02	0.31

Normal Coolant (D3*)	0.069	0.07	0.01	0.24
Dry Condition(D4*)	0.08	0.11	0.029	0.4

Using this data various graphs are plotted.

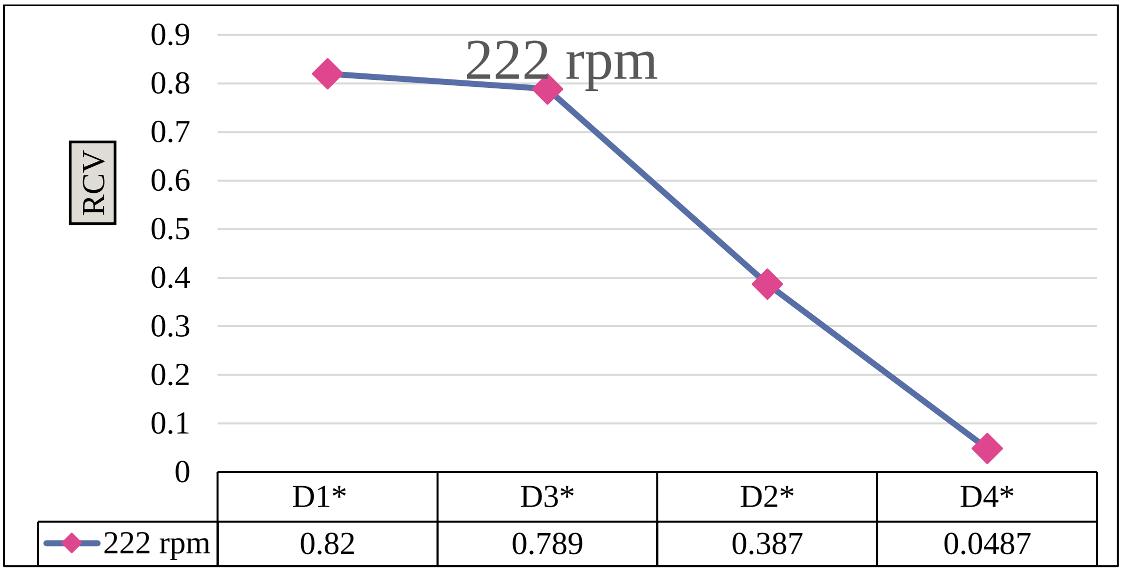

Figure 1 TOPSIS-Derived RCV for Cutting Fluids Using Weights from Table 3

Conclusion from Graph 1: The graph indicates that cutting fluid D1 has the highest RCV (0.82), identifying it as the most preferred option, while D4 has the lowest value (0.048), making it the least preferred cutting fluid at 222 rpm, based on the criterion weights provided in Table 3.

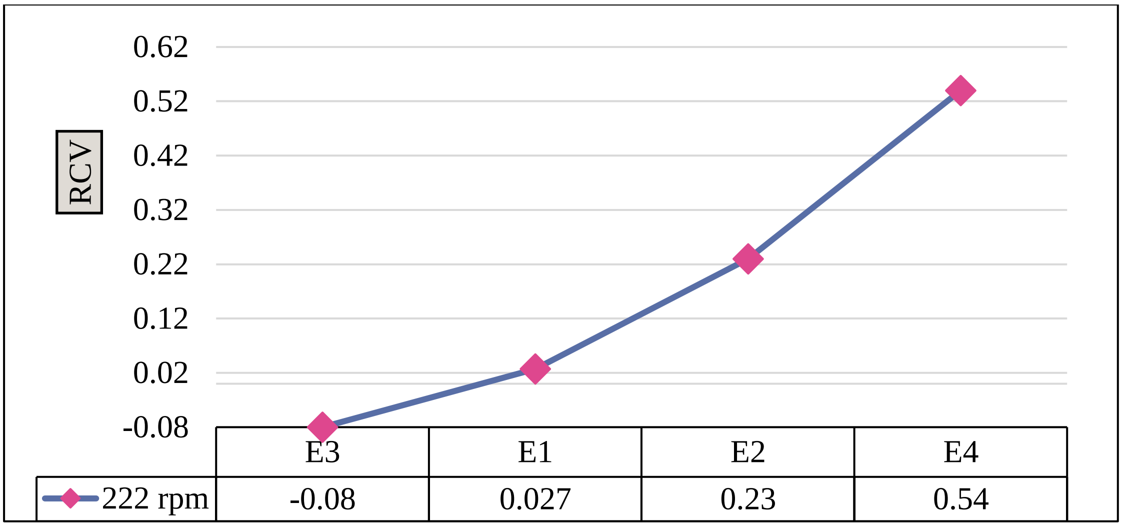

Figure 1 Evaluation of Cutting Fluids Using VIKOR: RCV Based on Table 3 Weights

Conclusion from Graph 2: The graph reveals that cutting fluid E3, with the lowest relative closeness value of -0.08, is identified as the most preferred option, while E4, having the highest value of 0.54, is considered the least effective at 222 rpm, based on the criterion weights presented in Table 3.

Table 4 Weight for Factors influence cutting

Cutting Factors	**F_X (N)**	**F_Y(N)**	**F_Z(N)**	**SR (μm)**
WEi	**WE1**	**WE2**	**WE3**	**WE4**
Weight	0.249	0.249	0.249	0.249

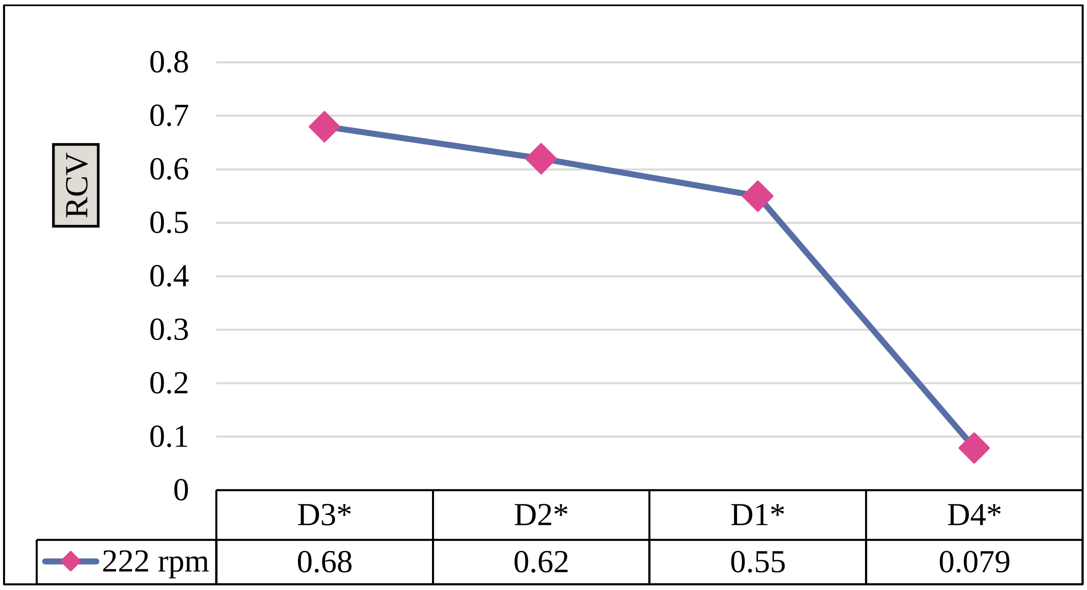

Figure 3 Evaluation of Cutting Fluids Using TOPSIS: RCV Based on Table 4 Weights

Conclusion from Graph 3: The graph indicates that cutting fluid D3 achieves the highest relative closeness value of 0.68, marking it as the most effective option, while D4, with the lowest value of 0.079, is identified as the least effective at 222 rpm, based on the criterion weights outlined in Table 4.

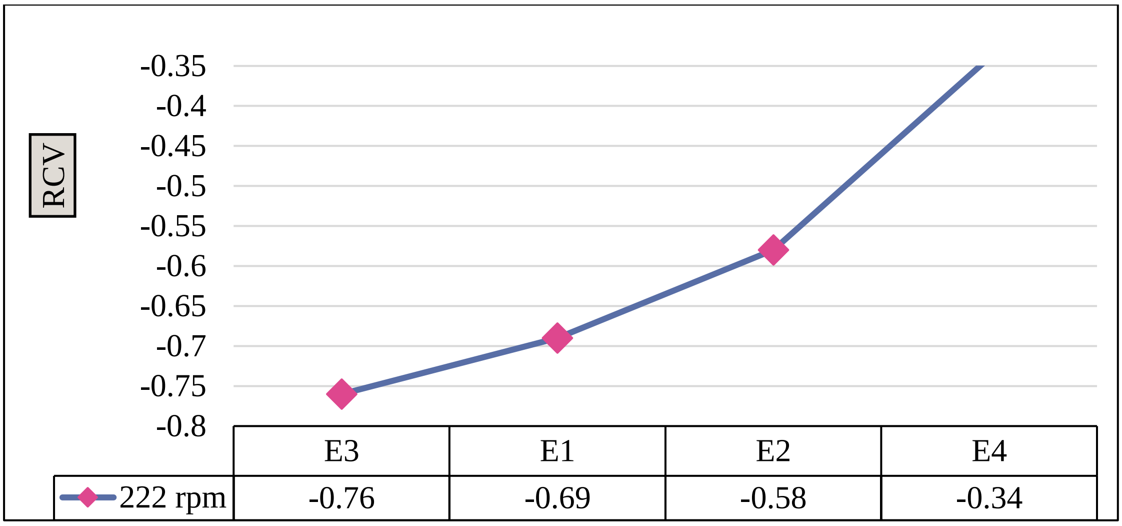

Figure 4 Evaluation of Cutting Fluids Using VIKOR: RCV Based on Table 4 Weights

Conclusion from Graph 4: The graph reveals that cutting fluid E3, with the lowest relative closeness value of -0.76, is the most preferred option, while E4, with the highest value of -0.34, is identified as the least effective at 222 rpm, based on the criterion weights provided in Table 4.

Table Error! No text of specified style in document. **Weight for Factors influence cutting**

Cutting Factors	**Fx (N)**	**Fy(N)**	**Fz(N)**	**SR (µm)**
WEi	**WE1**	**WE2**	**WE3**	**WE4**
Weight	0.39	0.21	0.19	0.21

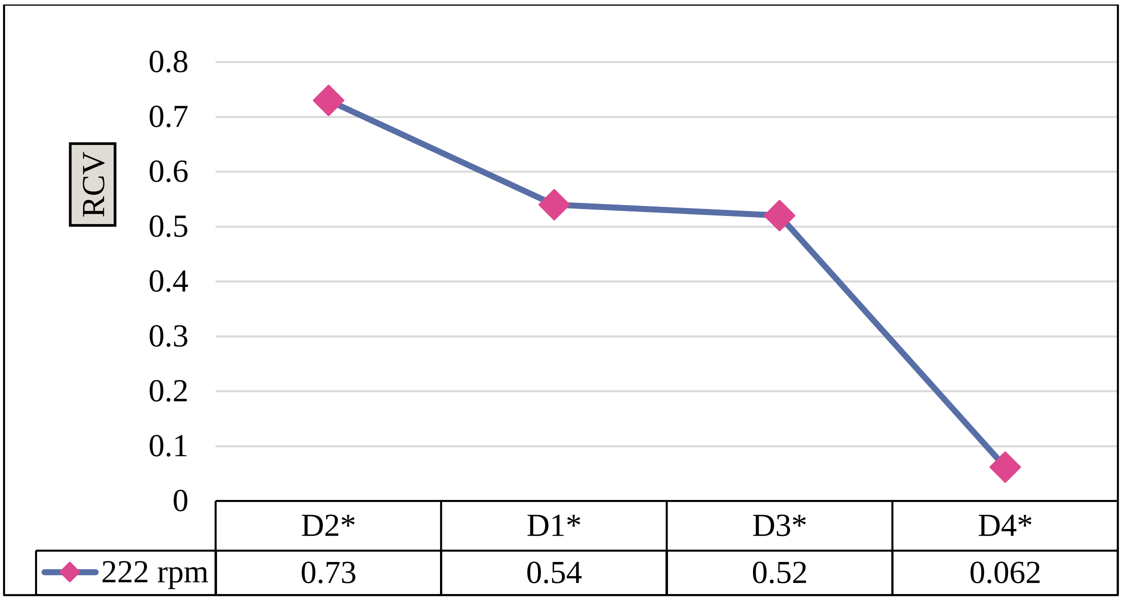

Figure 5 TOPSIS-Based Evaluation of Cutting Fluids: RCV Using Table 5 Weights

Conclusion from Graph 5: The graph shows that cutting fluid D2 has the highest relative closeness value of 0.73, identifying it as the most effective option, while D4, with the lowest value of 0.062, is considered the least effective at 220 rpm, based on the criterion weights outlined in Table 5.

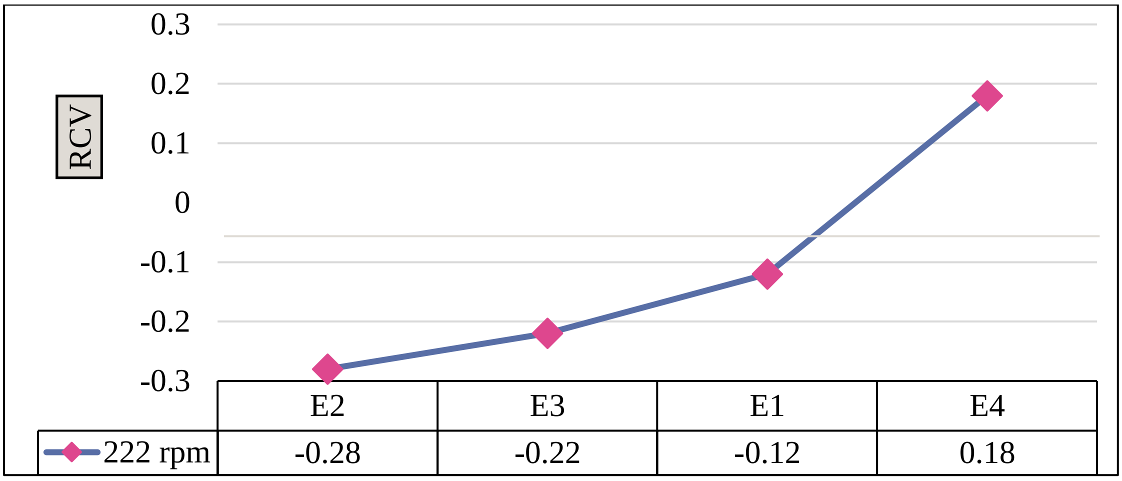

Figure Error! No text of specified style in document. **VIKOR-Based Evaluation of Cutting Fluids: RCV Using Table 5 Weights**

Conclusion from Graph 6: The graph reveals that cutting fluid E2, with the lowest relative closeness value of -0.28, is the most preferred option, while E4, with the highest value of 0.18, is identified as the least effective at 222 rpm, based on the criterion weights presented in Table 5.

Table 61 Weight for Factors influence cutting

Cutting Factors	**F_X (N)**	**F_Y(N)**	**F_Z(N)**	**SR (µm)**
WEi	WE1	WE2	WE3	WE4
Weight	0.21	0.39	0.21	0.19

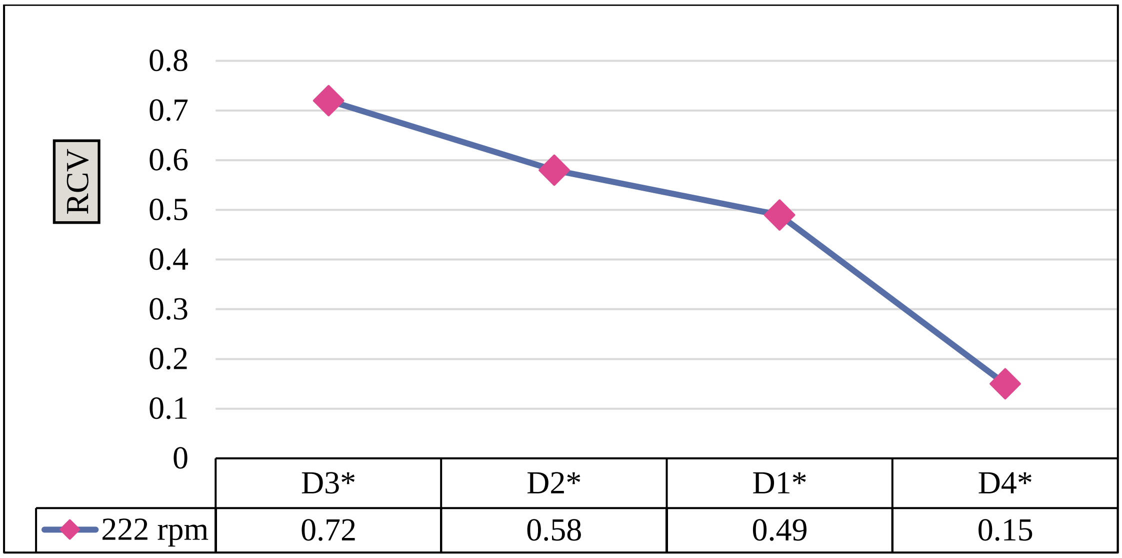

Figure 7 TOPSIS-Based Evaluation of Cutting Fluids: RCV Using Table 6 Weights.

Conclusion from Graph 7: The graph indicates that cutting fluid D3, with the highest relative closeness value of 0.72, is the most effective, while D4, with the lowest value of 0.15, is the least effective at 222 rpm, based on the criterion weights outlined in Table 6.

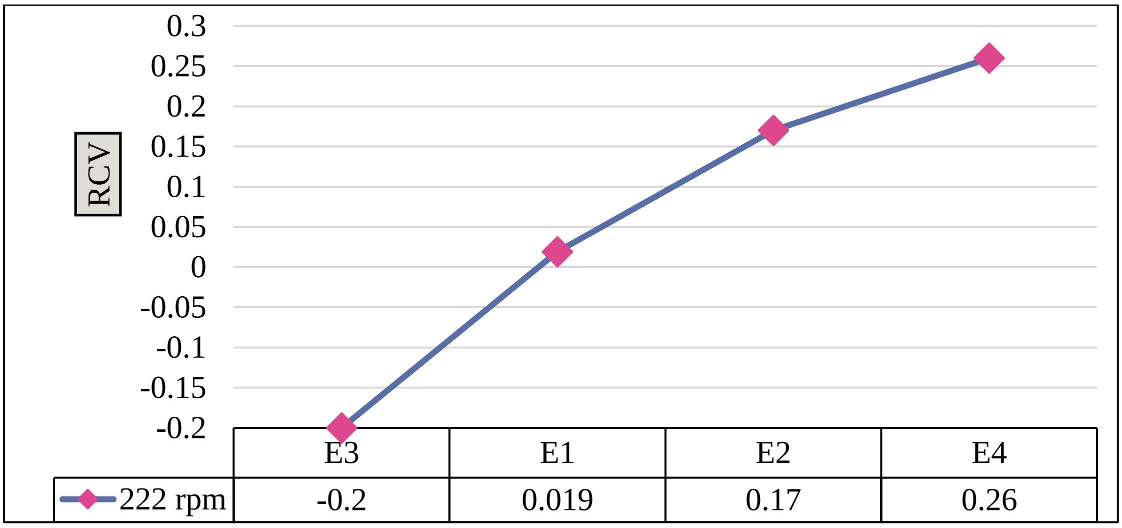

Figure 8 "VIKOR-Based Evaluation of Cutting Fluids: RCV Using Table 6 Weights.

Conclusion from Graph 8: The graph shows that cutting fluid E3, with the lowest relative closeness value of -0.20, is the most preferred, while E4, with the highest value of 0.26, is identified as the least effective at 222 rpm, based on the criterion weights provided in Table 6.

Table 7 Weight for Factors influence cutting

Cutting Factors	FX (N)	FY(N)	FZ(N)	SR (µm)
WEi	WE1	WE2	WE3	WE4
Weight	0.19	0.21	0.39	0.21

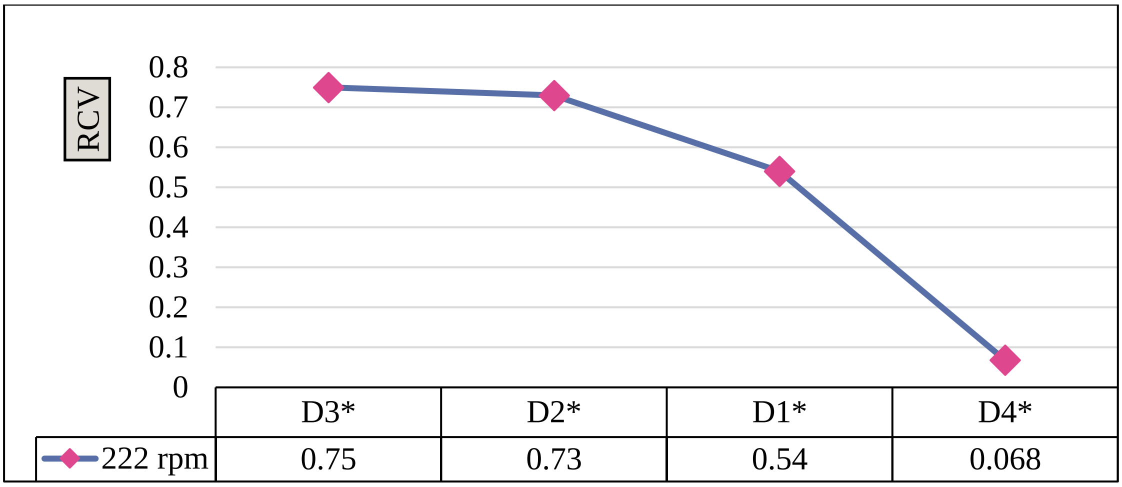

Figure 9 TOPSIS-Based Evaluation of Cutting Fluids: RCV Using Table 7 Weights.

Conclusion from Graph 9: The graph demonstrates that cutting fluid D3 has the highest relative closeness value of 0.75, indicating it as the most effective option, while D4 has the lowest value of 0.068, marking it as the least effective at 222 rpm, based on the criterion weights shown in Table 7.

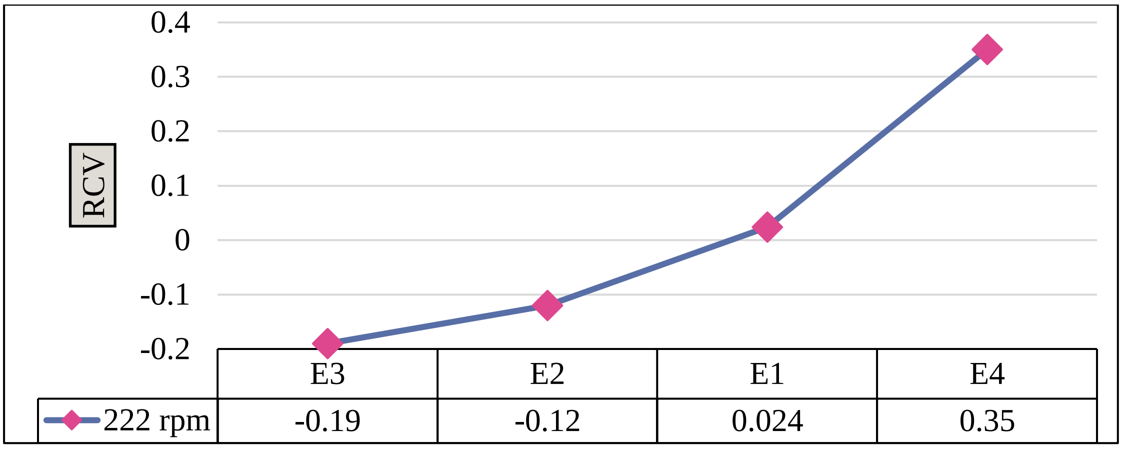

Figure 10 VIKOR-Based Evaluation of Cutting Fluids: RCV Using the Weights from Table 7.

Conclusion from Graph 10: The graph illustrates that cutting fluid E3, with the lowest relative closeness value of -0.19, is the most effective, while E4, having the highest value of 0.35, is the least effective at 222 rpm, based on the criterion weights outlined in Table 7.

Table 8 Weight for Factors influence cutting

Cutting Factors	FX (N)	FY(N)	FZ(N)	SR(μm)
WEi	WE1	WE2	WE3	WE4
Weight	0.19	0.21	0.21	0.39

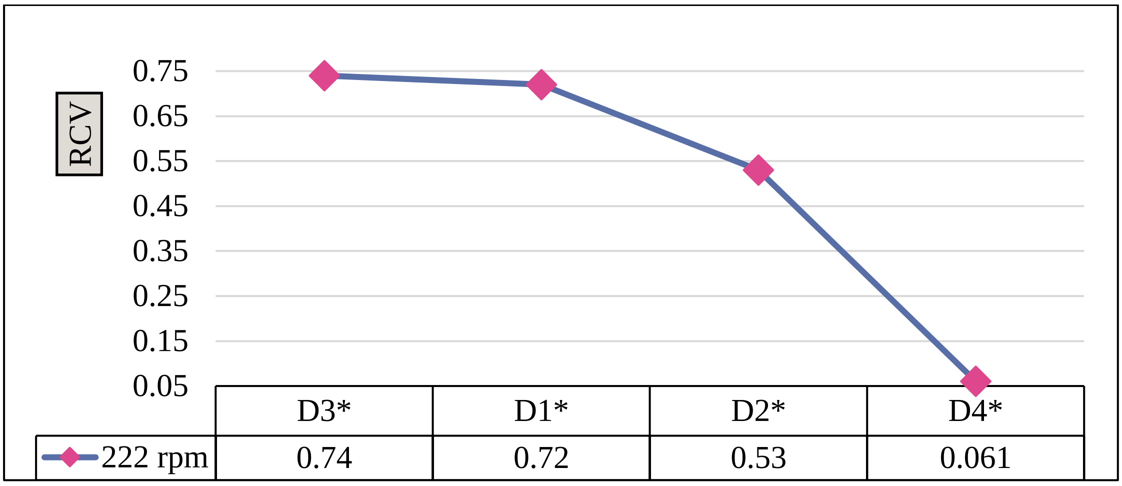

Figure 11 TOPSIS Evaluation of Cutting Fluids: RCV Based on Table 8 Weights.

Conclusion from Graph 11: The graph reveals that cutting fluid D3 has the highest relative closeness value of 0.74, indicating it as the most effective option, while D4 has the lowest value of 0.061, marking it as the least effective at 220 rpm, based on the criterion weights detailed in Table 8.

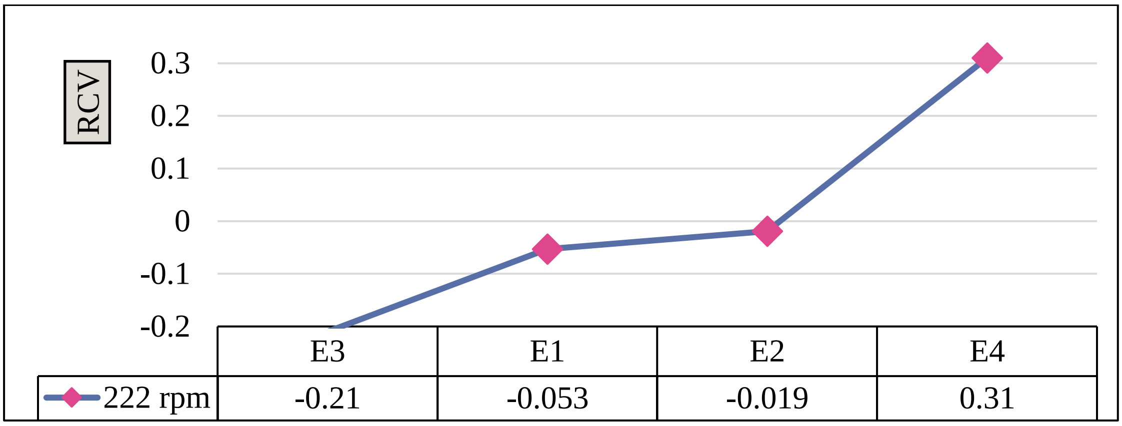

Figure 12 VIKOR Analysis of Cutting Fluids: RCV Based on Table 8 Weights"

Conclusion of graph 12: This graph shows lowest value of relative closeness -0.019 which indicates the E2 as the best as well as maximum value of relative closeness 0.31 which indicates E4 as the worst cutting fluid at 220 rpm at the criterion weights depicted in Table 8.

4. CONCLUSION

Based on the investigations and experimental analysis conducted in this study, key machining parameters such as thrust force, SR, radial force, and feed force were evaluated. An optimization model was developed to support designers and manufacturers in selecting the most suitable cutting fluid for the turning process. This model contributes to improving surface finish and enhancing overall process performance.

The results show that cutting forces are significantly lower at cutting speeds of 222 rpm. Among the cutting forces, the radial force (Fz) was found to be nearly equal to the thrust force (Fx) and consistently lower than the feed force (Fy) across speed.

The use of eco-friendly cutting fluids was found to be advantageous not only in performance but also in operator safety and environmental impact. Operators did not face any handling issues during machining or disposal. Due to their higher viscosity, eco-friendly fluids demonstrated greater reusability, leading to a reduction in operational costs associated with cutting fluids.

Across all combinations of CS, FR, and DOC, sunflower oil consistently outperformed conventional coolants in terms of surface quality.

Comparative evaluation of different cutting fluids was carried out with respect to thrust force, radial force, and surface roughness. Using the (MCDM) approach, optimal cutting fluid selection was performed, based on predefined weightage criteria

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