Sustainability:
An Engineering Perspective

Presentation by Dr Jim Clarke
at the PROFESS 12
Launch Day Event
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Environmental Context:

Manufacturing: accounts for 40% & 25% of global energy and resource consumption respectively.

Machining: very power-intense manufacturing operation, significant environmental footprint.

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Case Study: Environmental performance analysis of CNC Lathe Turning

Reference:

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Strategy & Objectives

Identify key parameters contributing to environmental impacts of conventional turning. Turning machine time: 1 hour

Parameter Analysis: Wet and Dry machining of AISI P20 Steel

- Electrical energy consumption
- Metalworking fluid (MWF),
- Surface roughness,
- Material removal rate (MMR)

Life Cycle Assessment (LCA):

Conduct LCA to assess environmental performance of turning. Identify optimum operating conditions.

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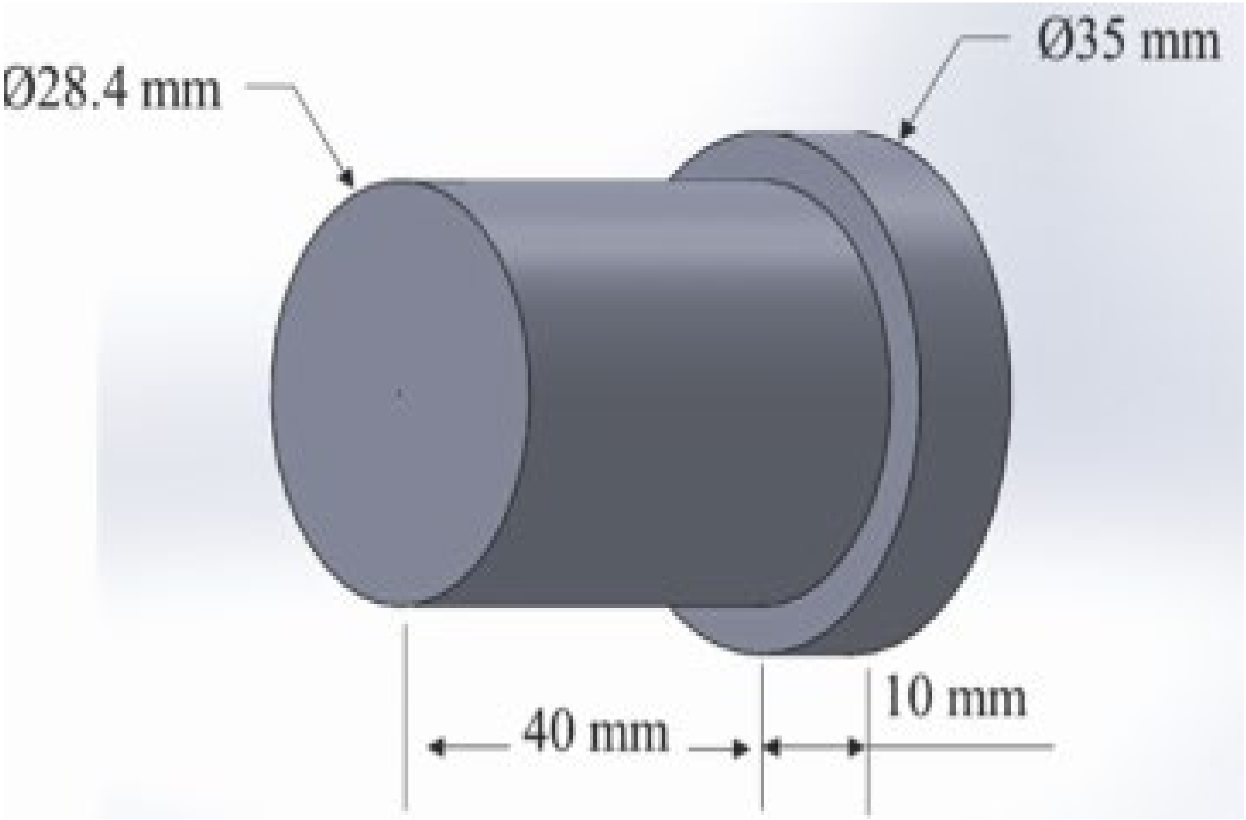
Workpiece Dimensions



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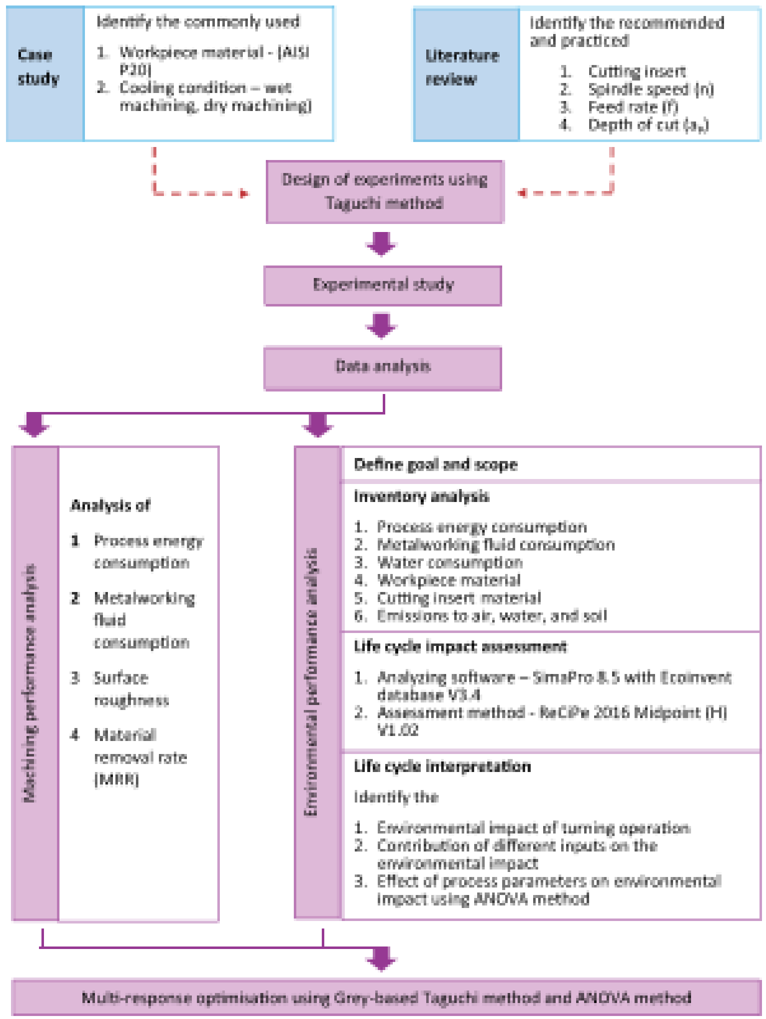
Methodology



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Design of Experiments: Cutting Parameters

Table 2. Summary of selected cutting parameters.

Cutting parameters	Selected range	Selected values		
		Level 1	Level 2	Level 3
Cutting speed, V_c (m/min)	160–270	189	215	241
Spindle speed, n (rev/min)	728–1228	860	980	1100
Feed rate, f (mm/rev)	0.08–0.23	0.10	0.15	0.20
Depth of cut, a_p (mm)	0.30–2.00	0.55	1.10	1.65

Table 3. Design of experiments using Taguchi L_9 orthogonal array.

Array No. (Operating condition)	Parameters' values			Parameters' levels			Experiment Number	
	n	f	a_p	n	f	a_p	Wet machining	Dry machining
1	860	0.10	0.55	1	1	1	E1	E10
2	860	0.15	1.10	1	2	2	E2	E11
3	860	0.20	1.65	1	3	3	E3	E12
4	980	0.10	1.10	2	1	2	E4	E13
5	980	0.15	1.65	2	2	3	E5	E14
6	980	0.20	0.55	2	3	1	E6	E15
7	1100	0.10	1.65	3	1	3	E7	E16
8	1100	0.15	0.55	3	2	1	E8	E17
9	1100	0.20	1.10	3	3	2	E9	E18

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Machining Performance Analysis

Measuring energy consumption

Energy consumption & air conditioning system measured using power logger.

All lights in machining centre switched on during working time, thus simulating maximum energy use conditions for lighting.

Lighting consumes between **9.5% and 29.1% of total overhead** for electricity consumption in manufacturing.

Significant component contributing to environmental impacts.

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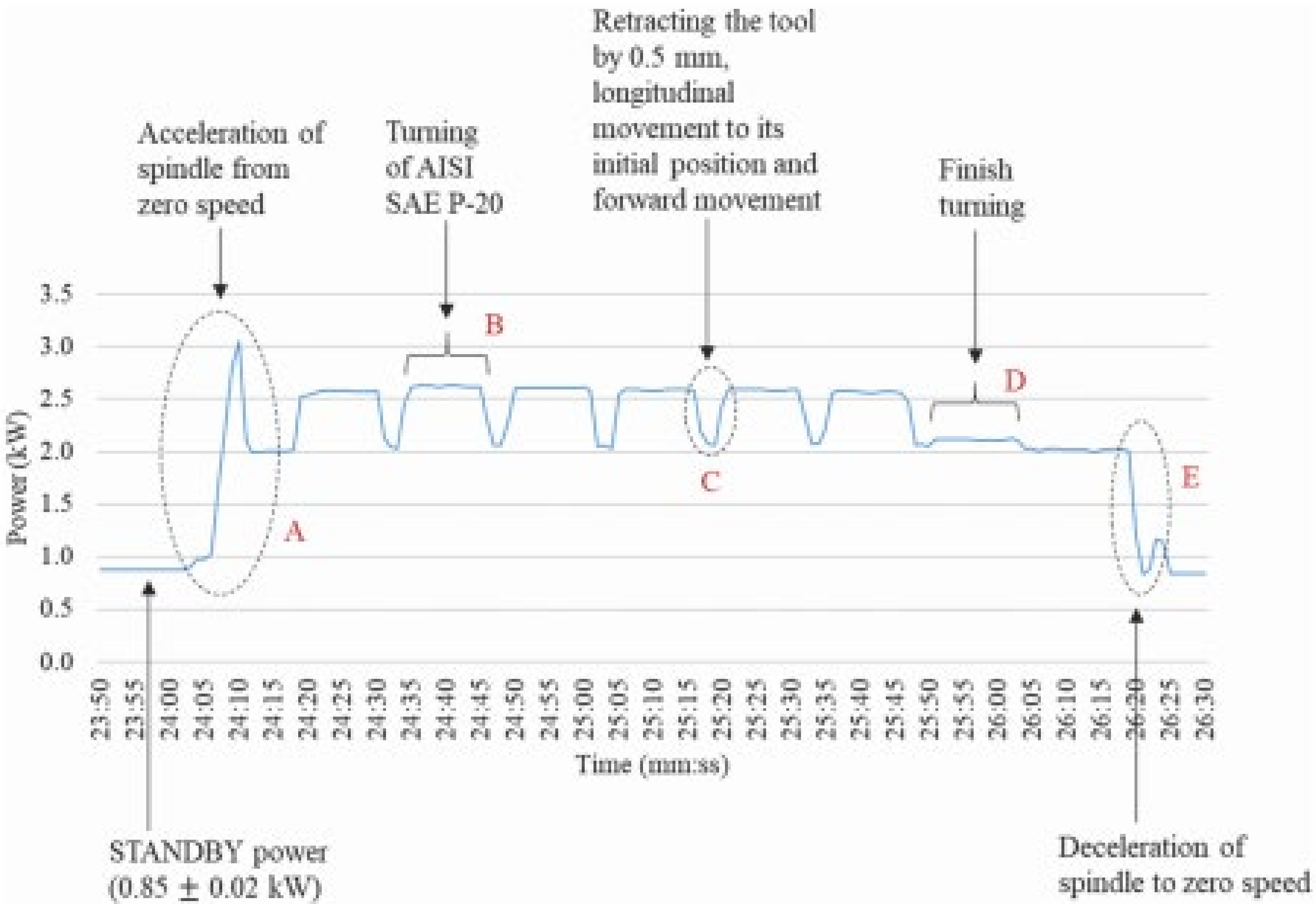
Energy consumption pattern (Experiment 6)



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Measuring metalworking fluid (MWF) consumption

Mixture, 95%/5% water/additive. Approx. 75 Litres disposed to environment over a 6 months period

Measuring surface roughness (R_a)

Arithmetic mean surface roughness is commonly used indicator to evaluate machined surface quality.

Calculating material removal rates (MRR)

Three cutting parameters changed in each experiment:

spindle speed, feed rate and depth of cut.

Volume of material removed kept constant. Workpiece diameter (Ø) reduced from 35 mm to 28.4 mm.

Cut length 40 mm. MRR calculated.

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Results: Machining Performance

Energy Consumption

Energy consumption for dry machining greater than for wet machining. Absence of MWF results in larger frictional forces between cutting insert and workpiece, and also between chip and cutting insert. Larger frictional forces lead to larger cutting forces. Higher values of cutting forces lead to an increase in energy consumption during cutting

Energy consumption during turning consists of three major components:

- machining
- non-machining
- energy for overheads

Energy for overheads highest percentage of energy, **40–44%,** compared to other components. Reduce by minimising operator waiting periods.

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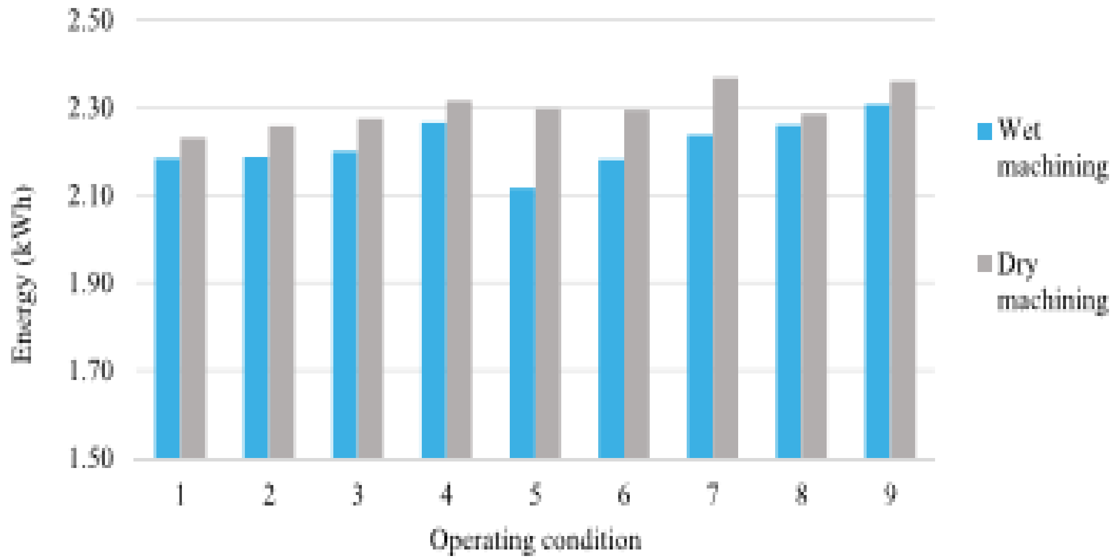

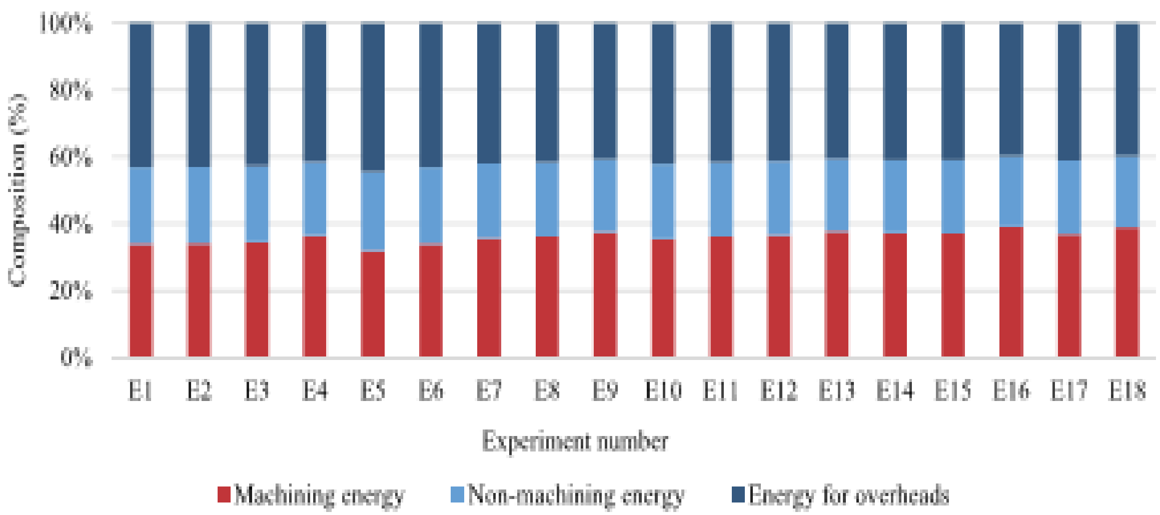

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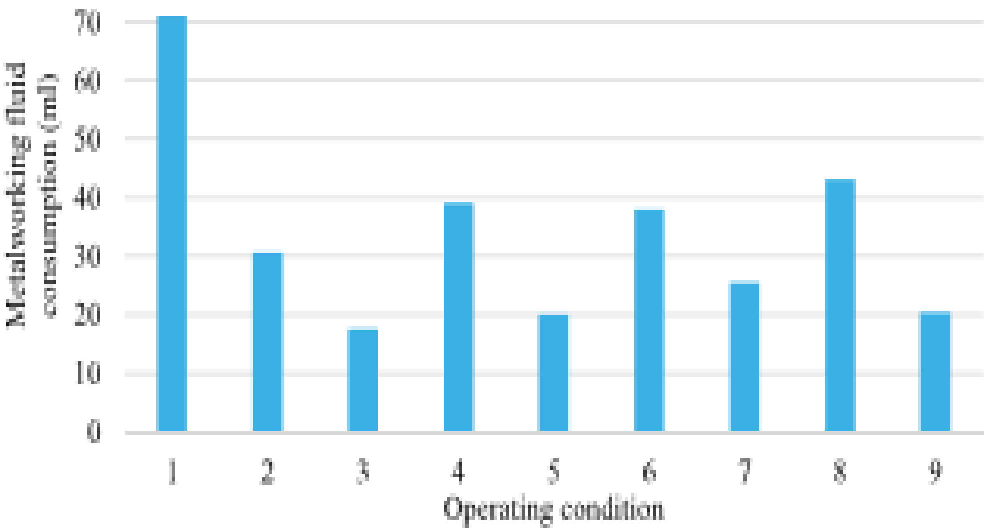
Metalworking Fluid Consumption

Varies with different operating conditions. Conditions, 3, 5, 7 and 9 in wet machining result in smaller values of MWF usage. Common cutting parameter for operating conditions 3, 5 and 7 is largest cut depth, 1.65 mm. Under condition 9, spindle speed and feed rate values at maximum values. Hence, larger cut depth and combination of higher spindle speed and feed rate leads to lower machining time, resulting in reduced MWF consumption. Top-up volume is now smaller.



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Surface Roughness, R_a

R_a under both machining conditions shows increasing roughness with increasing feed rate. The cutting insert easily moves over the workpiece at low feed rates resulting in a better surface finish. At higher feed rates, R_a becomes higher due to appearance of feed marks on machined surface.

R_a in dry machining: higher than in wet machining. Wet machining efficiently controls cutting zone temperature. Lower cutting temperature results in lower thermal distortion of machined region, resulting in less R_a.

Wet machining fails to absorb heat in cutting region effectively **at high spindle speeds and feed rates**, resulting in poor surface quality, as for dry machining.

Range of surface roughness of machined workpieces varies between 0.9 µm and 4.3 µm. To use a shaft with minimum vibration and noise during bearing fitting, R_a should be between 0.8 µm and 1.6 µm.

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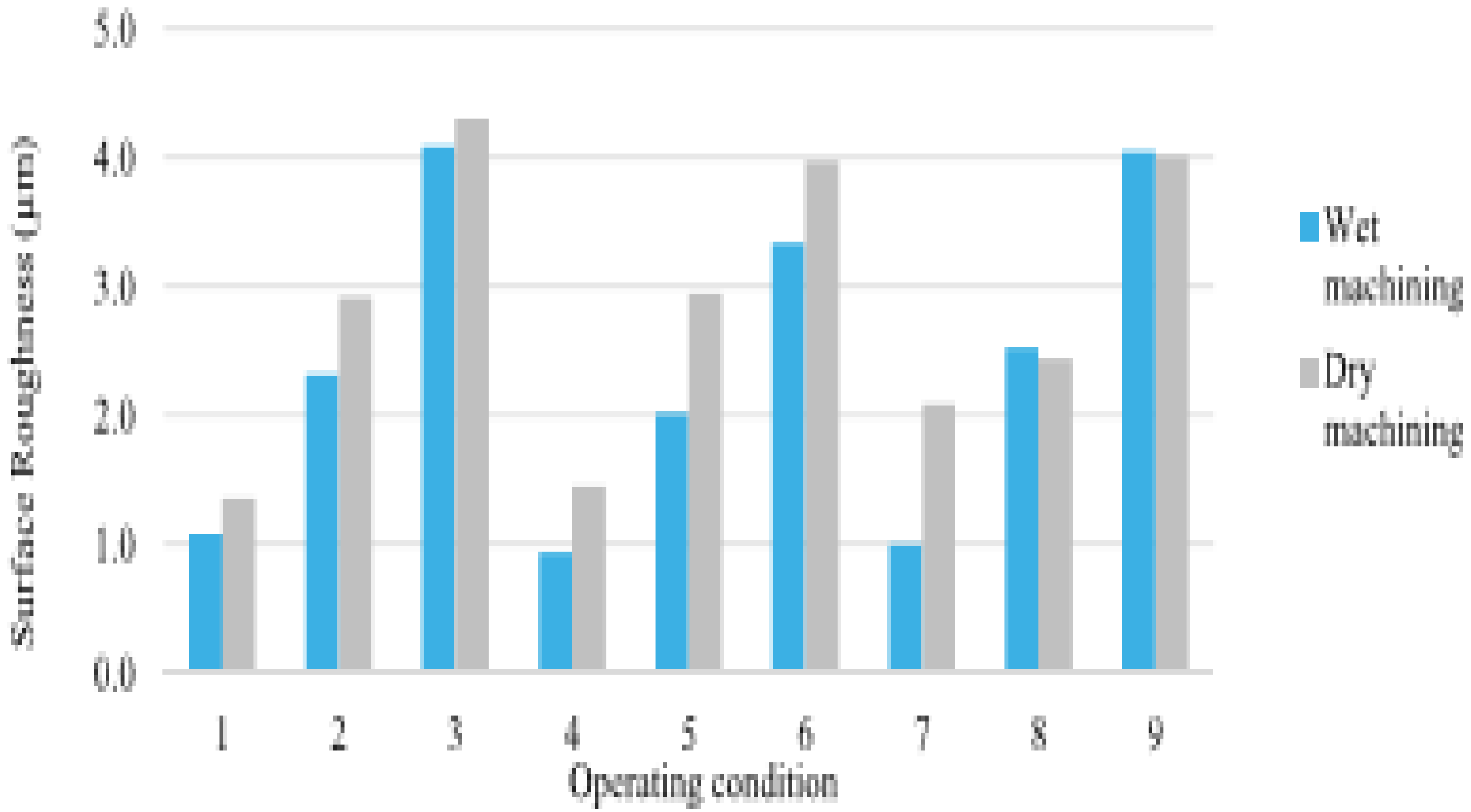
Variation in Surface Roughness with Machining Conditions



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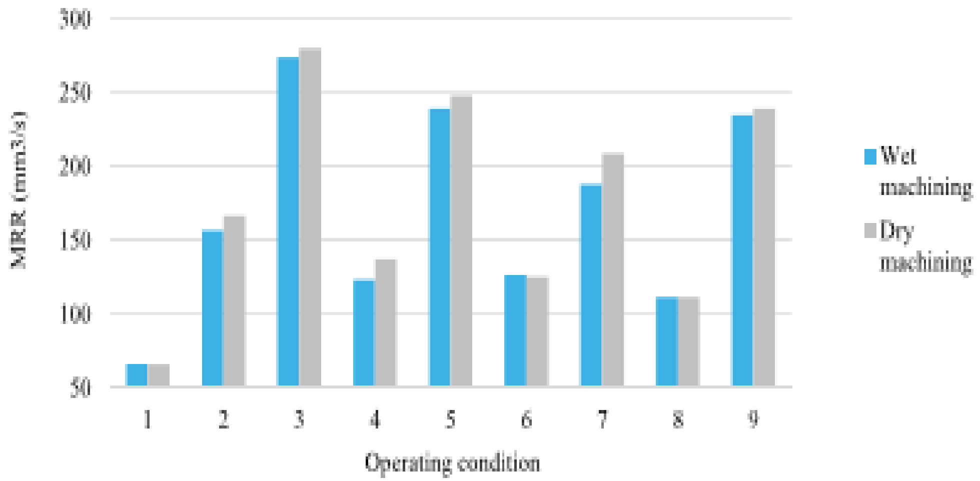
Material Removal Rate

MRR depends on machining time. Higher cut depth, feed rate and spindle speed, lower the machining time. With higher cutting speed, more material is removed in less cutting time. When feed rate increases, cycle time reduces. Similarly, at a higher cut depth, more material removed in one cut. Highest value of cut depth (1.65 mm) & combination of largest feed rate (0.2 mm/rev) and spindle speed (1100 rpm) give smaller machining times. Smaller machining time gives higher MRR. MRR in a given operating condition in wet machining approx similar to that in dry machining.



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Results: Environmental Impact

Environmental performance analysis

Nine bars under an impact category represent operating conditions 1 to 9. For convenience, only bars with odd numbers (1, 3, 5, 7 and 9) or even numbers (2, 4, 6 and 8) named in x-axis.

Energy consumption highest impact in most categories, responsible for over 77%, 66% and 75%, respectively in climate change (CC), terrestrial ecotoxicity (TET) and fossil resource scarcity (FD).

Workpiece material AISI P20 Steel contributes more than 70% of impact in categories eutrophication and toxicity. Contribution of cutting insert material with increasing spindle speed to categories ionising radiation (IR), land use (LO) and mineral resource scarcity (MRD): 35%, 54% and 60% respectively.

Due to the larger composition of Ti and Cr in workpiece & cutting insert materials, effects on aquatic ecosystems are higher.

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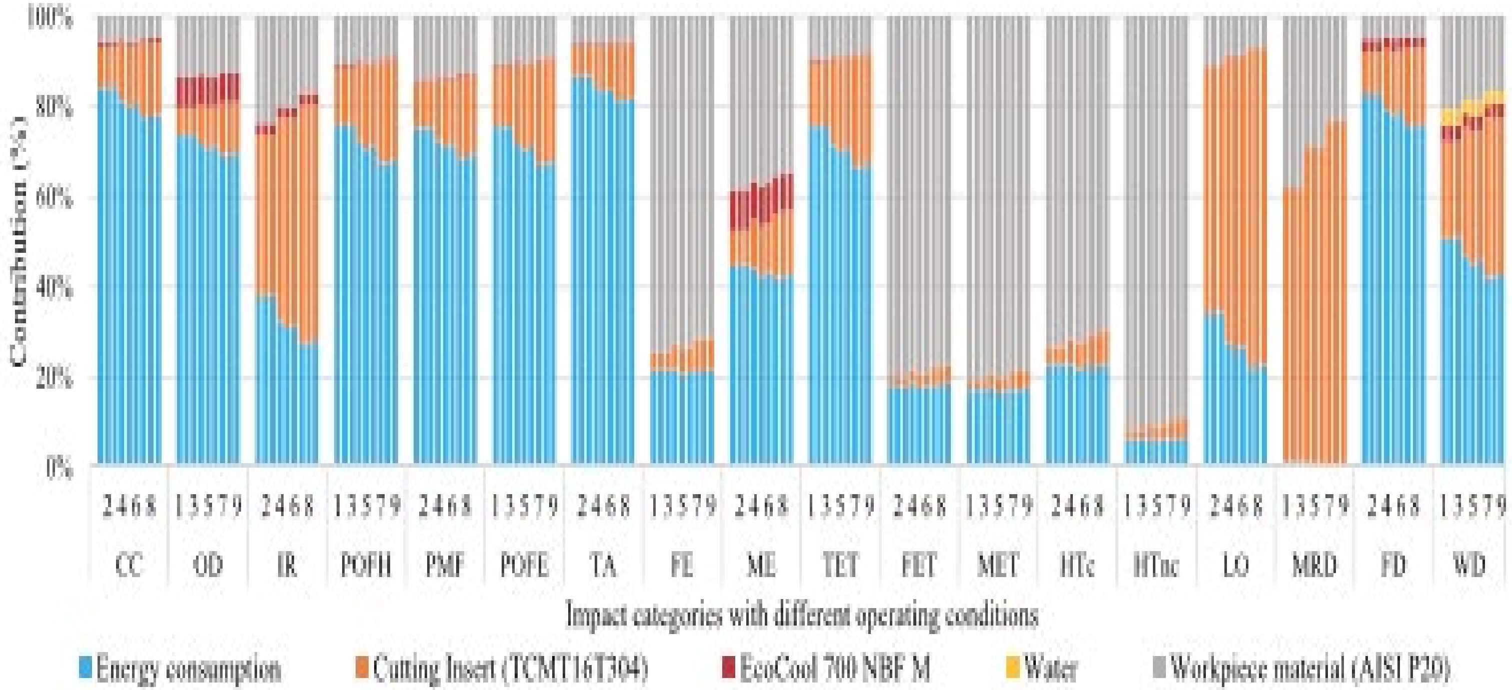
Wet machining.
Impact on categories, different operating conditions



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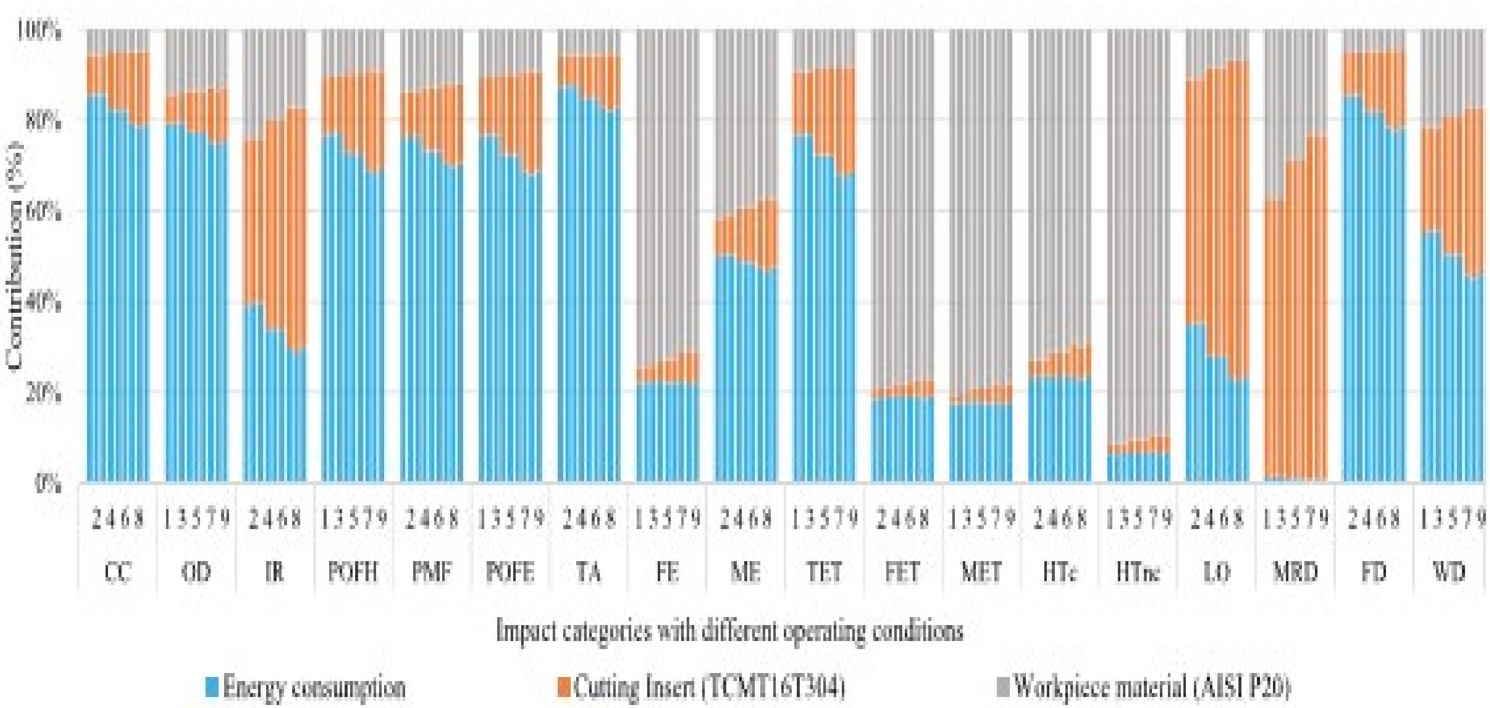
Dry machining.
Impact on categories, different operating conditions.



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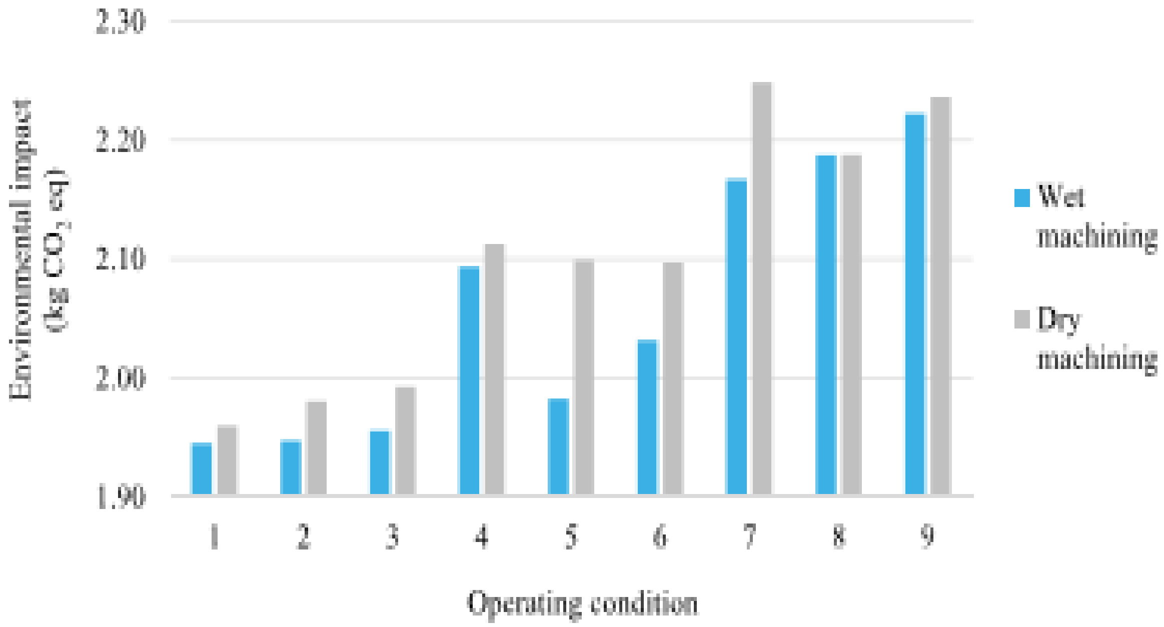
Effect on Climate Change

Wet machining shows lower impact on Climate Change, (kg CO_2 equivalent) in each operating condition compared with dry machining.

Energy is the largest contributor to Climate Change therefore energy consumption is directly proportional to Climate Change impact.



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Implications for Sustainable Machining

Electrical energy consumption is **largest contributor** to environmental impact under each damage category.

Approx. 22% and 42% of total energy are consumed for non-machining operations and overheads, respectively. Are essential to perform a machining job.

Reduce unnecessary energy consumption during turning by reducing non-machining operations time. Set standard times via time studies.

Reduce overhead energy.

Smart use of Air Conditioning (AC) systems and lights during non-working period would be effective.

Keep other non-operating machines switched off to reduce overall energy consumption and heat load on shop floor, thus reducing cooling energy requirement.

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Second-highest impact: cutting insert material, TCMT16T304 CVD coated carbide UE6110 and workpiece material AISI P20. Environmental impact is considerable, around 50% of the human health damage category and 30% of the other two categories, ecosystems and resources.

Select appropriate cutting parameters for turning. Essential in improving the sustainability of machining. From results, environmental impact highly dependent on spindle speed variation. Very important to keep both machining and environmental performance at their optimum levels.

Use machining parameters identified through multi-response optimisation to develop more sustainable turning operations. Follow same approach to obtain better machining parameters for the sustainable turning of other materials.

Overall, machining sustainability can be improved if tool manufacturers recommend acceptable ranges of cutting parameters by considering not only machining performance but also environmental impact.

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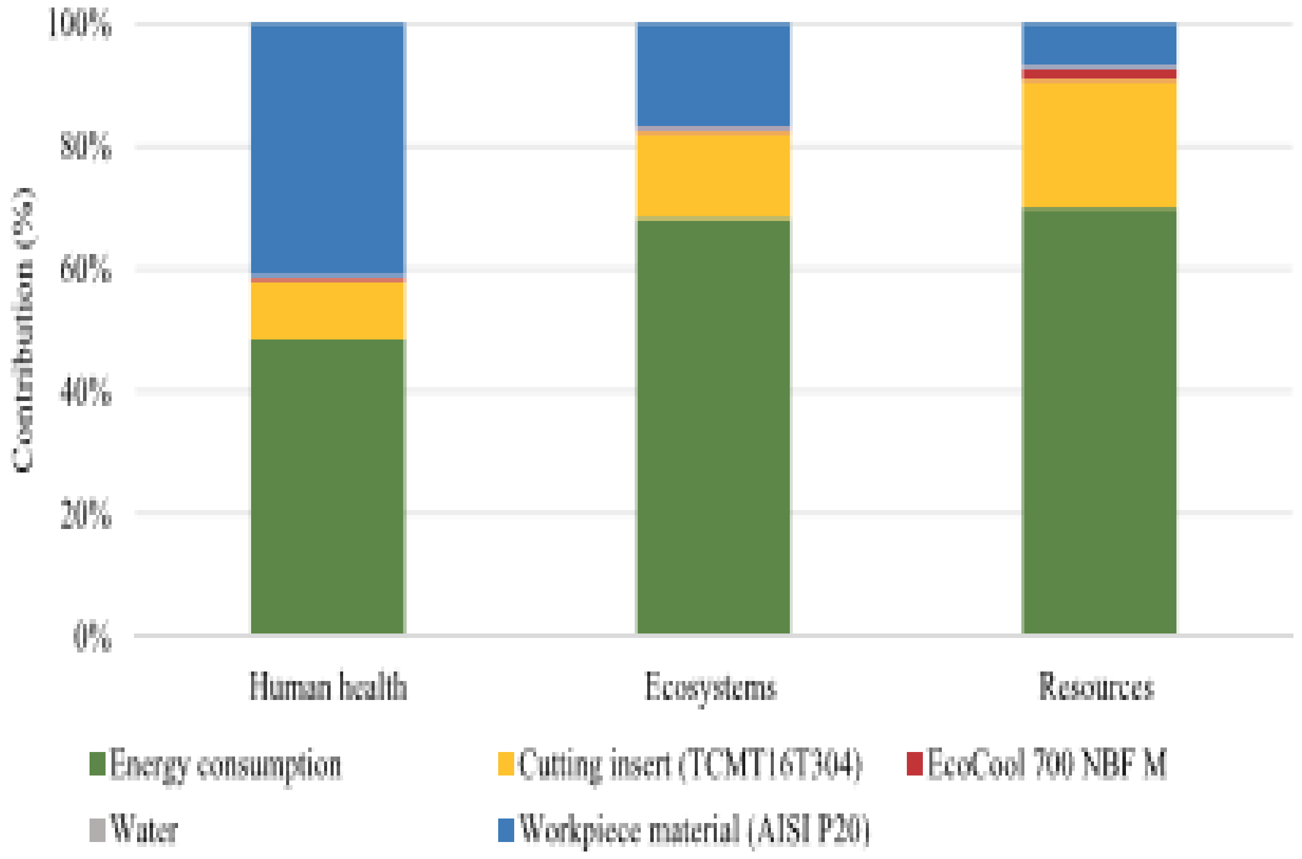

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Conclusions

Machine Performance

Wet machining yields better machining & environmental performance compared to dry machining.

Lifetime Cycle Analysis results

Electrical energy is highest contributor for environmental impact. Effect of MWF is negligible. Workpiece & cutting insert material contribute significantly to environmental impacts for aquatic ecosystem and resource depletion damage categories.

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Thank You

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