



DEPARTMENT OF MECHANICAL
ENGINEERING
INDIAN INSTITUTE OF INFORMATION
TECHNOLOGY, DESIGN AND
MANUFACTURING KANCHEEPURAM
CHENNAI - 600127

Synopsis Of

**Machinability and Sustainability Assessment
of WAAM-Fabricated Difficult-to-Cut
Materials under Hybrid Nanofluids**

A Thesis

To be submitted by

PRAMEET VATS

For the award of the degree

Of

DOCTOR OF PHILOSOPHY

Abstract

Wire Arc Additive Manufacturing (WAAM) enables the near-net-shape fabrication of large metallic components; however, machining is required to achieve dimensional accuracy and surface integrity. This study investigates sustainable machining strategies for WAAM and wrought Inconel 625 (IN625) and Ti-6Al-4V alloys using mono- and hybrid-nanofluid-assisted lubrication. A biodegradable hybrid nanofluid based on jojoba oil with hexagonal boron nitride (hBN) and graphene nanoplatelets (1:2 ratio) was synthesised and characterised, exhibiting enhanced thermal conductivity, wettability, heat capacity, and viscosity compared to the base fluid. Drilling experiments demonstrated that hybrid nanofluids significantly improved machinability for both alloys. For IN625, reductions in cutting temperature (31–34%), surface roughness (21–32%), and tool wear were achieved, along with improved chip morphology and preservation of the tool coating. For Ti-6Al-4V, hybrid nanofluids reduced cutting forces by up to 45.67%, power consumption by up to 28.8%, and flank wear by up to 50.59% for both WAAM and wrought materials. A sustainability assessment using a Pugh decision matrix consistently ranked hybrid-nanofluid-assisted machining as the optimal solution. A cradle-to-gate Life Cycle Assessment (ReCiPe 2016 midpoint) revealed that WAAM machining generated 34–39% higher CO₂ emissions and up to 75% higher terrestrial ecotoxicity compared to wrought machining due to additional energy requirements. However, hybrid nanofluids mitigated these impacts, reducing human toxicity by up to 55.18%, marine eutrophication by 43.47%, and mineral resource depletion by 21.51%.

1 Introduction

Sustainability in manufacturing focuses on minimising environmental impact through optimised energy use, resource efficiency, and eco-friendly processes while ensuring operator safety and economic viability. The rapidly growing machining sector, a core of global manufacturing, contributes significantly to resource depletion and greenhouse gas emissions, with global environmental costs estimated at USD 4.7 trillion annually Solarin (2020). Sustainable machining practices are therefore essential to balance productivity with resource conservation. Core goals include reducing energy use, emissions, waste, and costs, while improving operator health and safety. A comprehensive sustainability framework operates across three levels: product, process, and system. The 6R principles (reduce, reuse, recycle, redesign, remanufacture, recover) enhance product-level resource efficiency, while process-level improvements such as optimised parameters and advanced technologies minimise environmental burdens. At the system level, integrating sustainability throughout the product life cycle ensures long-term environmental and social benefits, with Life Cycle Assessment (LCA) serving as a key tool for quantifying these impacts Maheshwari *et al.* (2023). According to ISO 14040 and 14044, LCA consists of four phases: goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation ISO (2006). In the goal and scope phase, the study purpose, assumptions, limitations, system boundaries (cradle-to-gate, cradle-to-grave, or gate-to-gate), and impact categories are defined. In machining, boundaries typically include material extraction, transportation, machining, and waste management. The LCI phase compiles inputs such as energy, tools, lubri-

cants, and material removal rates, alongside outputs like worn tools, emissions, water and lubricant waste, and chips. The LCIA stage classifies these variables by ecological impact, and interpretation translates the results into actionable insights, supporting informed decision-making Hauschild *et al.* (2018). Integrating LCA into machining processes is crucial, particularly when working with intricate materials like Inconel and titanium alloys.

Titanium and Inconel alloys are widely used in aerospace, automotive, and biomedical sectors due to their high strength-to-weight ratio, corrosion resistance, and biocompatibility. Yet, machining these alloys is difficult. Low thermal conductivity causes heat accumulation in cutting zones, accelerating tool wear and fracture risks. Their chemical reactivity promotes galling, degrading surface quality. Work hardening further increases cutting forces, energy demand, and tool wear while heightening risks of surface defects Khanna *et al.* (2021). These challenges intensify when machining additively manufactured (AM) components.

WAAM has recently garnered significant attention in the field of additive manufacturing for its ability to produce large, complex components while simultaneously reducing material waste and shortening lead times compared to traditional methods. WAAM also makes production more flexible and efficient. However, the anisotropic property of the material makes machining harder and challenging Wieczorek *et al.* (2025). Additionally, the high reactivity of Titanium, Chromium, and Nickel with oxygen can result in oxide formation, which necessitates fabrication in an enclosed and inert gas environment to avoid oxidation in Inconel and Ti-6Al-4V Bermingham *et al.* (2018); Bolukbasi *et al.* (2023). Variations in material characteristics may exacerbate machining issues by increasing cutting forces and causing erratic heat distribution Wu *et al.* (2018). The challenges are particularly pronounced in demanding operations, such as drilling, where the semi-enclosed design restricts chip removal and leads to heat accumulation in the cutting zone. The buildup of heat increases tool wear and negatively affects the quality of the drilled holes Şirin *et al.* (2024).

Addressing such issues requires strategies such as optimal cutting tool selection, parameter optimisation, and effective chip control. Metalworking fluids (MWFs) play a crucial role in reducing friction, dissipating heat, and extending the life of tools Naik and Sharma (2022). Recently, nanofluids, colloidal suspensions of nanoparticles in base fluids, have emerged as sustainable MWF alternatives, offering biodegradability, renewability, and superior machinability. Nanofluids provide enhanced lubrication, higher load-bearing capacity, improved thermal conductivity, and reduced friction. Nanoparticles induce micro-scale turbulence, enhancing heat transfer, while Brownian motion further improves thermal conductivity, making nanofluids attractive for sustainable machining Gajrani *et al.* (2019). To further improve performance, hybrid nanofluids comprising two or more distinct nanoparticles have been engineered. This combination utilises the synergistic enhancement of thermal, physical, and tribological properties. The integration of diverse nanoparticles featuring distinct shapes and structures effectively diminishes van der Waals forces, thereby enhancing the stability of particle dispersion. The improved stability results in enhanced heat transfer and lubrication efficiency Cui *et al.* (2025).

2 Objectives

After conducting an extensive literature survey, the following objectives were formulated to address the identified research gaps. The schematic to achieve the objective is shown in Figure 1.

- To fabricate and characterise difficult-to-cut metallic alloys (Inconel 625 and Ti-6Al-4V) fabricated using wire arc additive manufacturing (WAAM).
- To synthesise eco-friendly hybrid nanofluids as an alternative to conventional MWFs.
- To evaluate the machining performance of hybrid nanofluids during drilling of WAAM-fabricated alloys and to compare the results with their wrought counterparts.
- To assess the sustainability of the drilling process employing hybrid nanofluids for the WAAM-fabricated alloy.

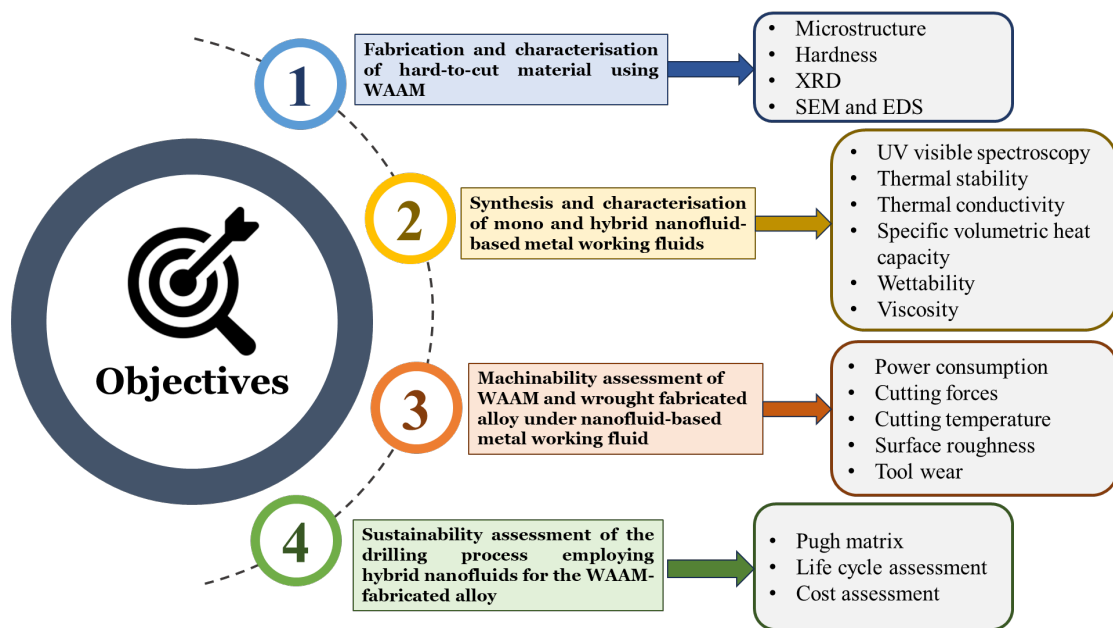


Figure 1: Plan to achieve objective

3 Gaps in Literature

Based on an extensive survey of the relevant literature, the following research gaps were identified, which form the basis and motivation for the present work:

- A systematic evaluation of thermal, rheological, and wettability properties of hybrid nanofluids, and their direct influence on drilling performance of additive manufactured material, is largely limited.

- Numerical and analytical studies addressing machinability behaviour of additively manufactured parts, particularly under sustainable lubrication strategies, are limited.
- A combination of hybrid nanofluids and other lubricant additives has not been explored much till date.
- Comparative machinability studies between different additive manufacturing processes, such as WAAM and LPBF, have not been explored much.
- Integrated sustainability assessments, including life cycle analysis, carbon emissions, energy consumption, and eco-efficiency of hybrid nanofluid in the drilling of additively manufactured parts, are rarely reported.

4 Most Important Contributions

4.1 Thermophysical properties of synthesised nanofluids

4.1.1 Thermal conductivity

Machining superalloys generates excessive heat due to their high strength and low thermal conductivity, leading to tool wear and poor surface quality. Since jojoba oil has low thermal conductivity (0.1351 ± 0.0046 W/m.K), adding nanoparticles significantly improves heat dissipation. Thermal conductivity increased with nanoparticle concentration and reached an optimum at a concentration of 0.4%. At this concentration, hBN and graphene nanofluids exhibited enhancements of 23.7% and 28.14%, respectively, with graphene outperforming hBN due to its exceptionally high thermal conductivity (>3000 W/m.K). The hybrid nanofluid with a 1:2 hBN–graphene ratio achieved the highest value (0.1953 ± 0.0009 W/m.K), corresponding to a 44.55% improvement over the base fluid, owing to synergistic effects between the two nanoparticles. The thermal conductivity characteristics of nanofluids across various particle concentrations and mixing ratios are illustrated in Figure 2.

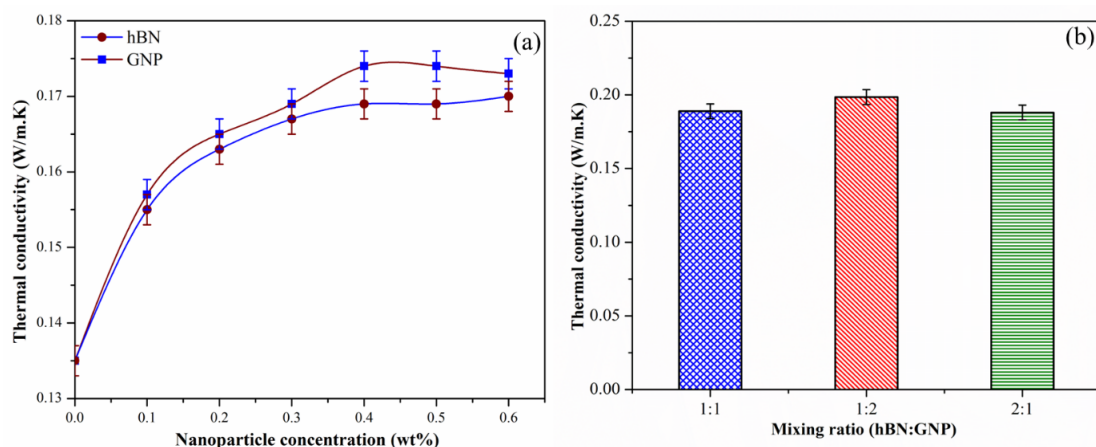


Figure 2: Thermal conductivity of nanofluids for: (a) mono nanofluids with varying nanoparticle concentration and (b) hybrid nanofluids with varying mixing ratio

4.1.2 Wettability

Wettability is evaluated through the contact angle, where a lower angle indicates better fluid spreading and lubrication performance. As shown in Figure 3, the base fluid exhibited the highest contact angle of 42.3° on the Inconel 625 surface, indicating poor wettability. The addition of nanoparticles reduced the contact angle by lowering surface tension and enhancing fluid spreadability. Contact angles decreased with increasing nanoparticle concentration up to an optimum of 0.4%, beyond which agglomeration led to a slight increase due to reduced effective interaction area. Among all fluids, hybrid nanofluids showed the best wettability. The hybrid nanofluid with a 2:1 hBN-to-graphene ratio achieved the lowest contact angle of $14.7^\circ \pm 0.8^\circ$, compared to $17.6^\circ \pm 1.6^\circ$ for hBN and $19.8^\circ \pm 0.9^\circ$ for graphene mono-nanofluids. Overall, hybrid nanofluids reduced the contact angle by 59–65.24% relative to the base fluid, owing to the synergistic effects of oleophilic hBN and high-surface-energy graphene, resulting in a stable and effective lubricating layer.

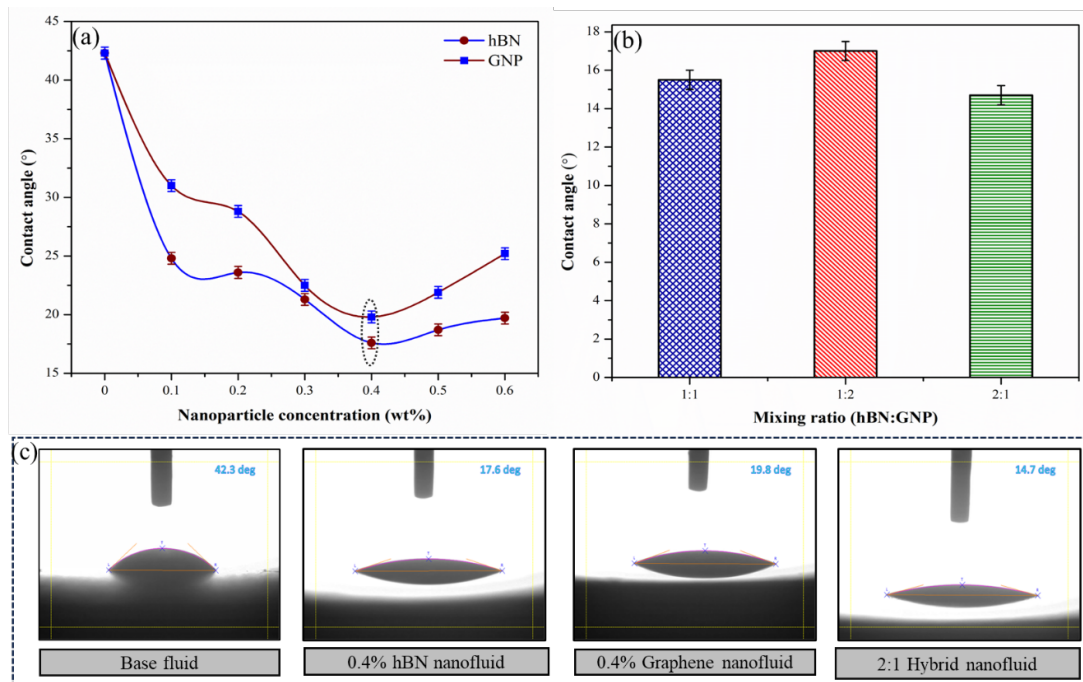


Figure 3: Wettability assessment of nanofluids on workpiece surface at varying: (a) concentration of mono nanofluids and (b) mixing ratios of hybrid nanofluids and (c) optimum concentration of mono nanofluids and hybrid nanofluid on the Inconel surface

4.1.3 Viscosity

Viscosity is crucial for lubrication, as higher viscosity promotes the formation of a stable tribofilm that separates the contacting surfaces and reduces wear. As shown in Figure 4 (a–b), the dynamic viscosity of all nanofluids decreases with increasing temperature (20–100 °C) due to enhanced molecular mobility and reduced intermolecular forces. Conversely, viscosity increases with nanoparticle concentration, reaching a

maximum at 0.4% for both hBN and graphene nanofluids because of increased resistance to flow.

Beyond 0.4%, viscosity decreases, likely due to poor dispersion and sedimentation of excess nanoparticles. At 20 °C, nanofluids with 0.4% hBN and graphene showed viscosity increases of 48.27% and 39.24%, respectively, compared to the base fluid, with graphene-based nanofluids exhibiting higher viscosity due to larger platelet size. Among hybrid nanofluids, the 1:2 hBN–graphene ratio showed the highest viscosity (see Fig.3c), being 20% higher than mono-nanofluids, attributed to synergistic effects of mixed particle geometry and improved dispersion, which increase flow resistance.

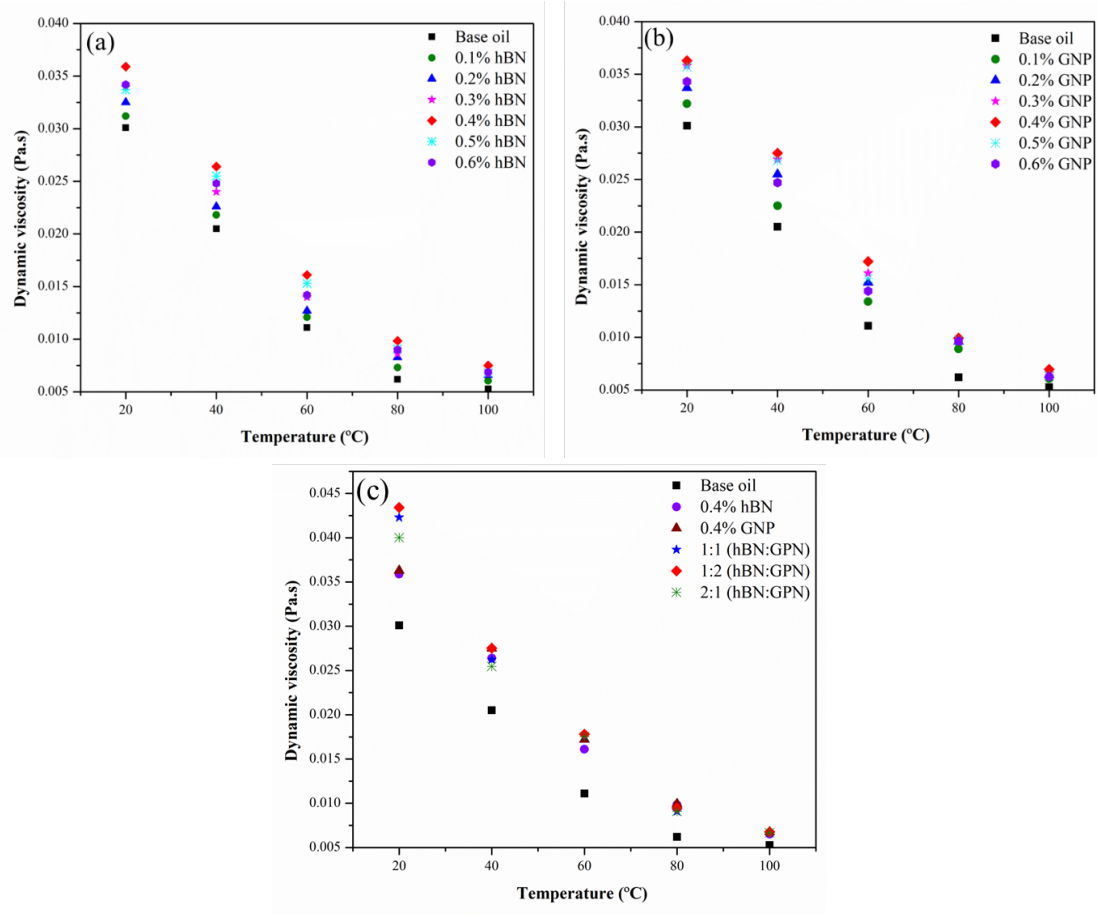


Figure 4: Calculation of viscosity for (a) hBN, (b) graphene and (c) hybrid nanofluids with change in temperature

4.2 Machining of Inconel 625 under hybrid nanofluid environment

Cutting temperature has a strong influence on tool life, wear mechanisms, and surface integrity, particularly in drilling, where chip compaction intensifies heat generation. Machining IN625 is inherently challenging due to its high strength and low thermal conductivity, and these difficulties are further amplified in WAAM-fabricated IN625 because of its anisotropic heat flow. As shown in Figure 5 (a), dry drilling produced the highest cutting temperatures, reaching 526.8 K for wrought IN625 and 518.8 K for WAAM IN625, which severely limits tool life. The application of mono-nanofluids sig-

nificantly reduced cutting temperatures. hBN nanofluids achieved reductions of 22.74% (wrought) and 25.25% (WAAM), while graphene nanofluids performed better, reducing temperatures by 26.91% and 28.77%, respectively, due to enhanced heat dissipation and stable lubricating film formation. The lowest cutting temperatures were achieved using hybrid nanofluids, with measurements of 341.6 K for WAAM IN625 and 359.3 K for wrought IN625 after the 15th hole. This corresponds to reductions of 34.15% and 31.79% compared to dry cutting and an additional 6–12% reduction over mono-nanofluids. The superior performance of hybrid nanofluids is attributed to their higher thermal conductivity and synergistic lubrication mechanisms, resulting in reduced friction, improved heat dissipation, and enhanced tool life during IN625 machining.

Surface roughness is a key indicator of drilled hole quality and is influenced by machining parameters, tool condition, material properties, and cooling environment. As shown in Figure 5 (b), dry drilling produced the highest surface roughness, reaching $2.09 \pm 0.095 \mu\text{m}$ for wrought IN625 and $1.852 \pm 0.0825 \mu\text{m}$ for WAAM IN625 after 15 holes, mainly due to severe tool wear. Overall, WAAM IN625 exhibited 16–18% lower roughness than wrought IN625, as the latter is harder and more difficult to machine. The use of mono-nanofluids significantly improved surface quality, reducing roughness by 20–38% compared to dry drilling. Graphene nanofluids performed better than hBN, achieving surface roughness values as low as $1.141 \pm 0.057 \mu\text{m}$ for WAAM IN625. The best surface finish was obtained with hybrid nanofluids, yielding minimum surface roughness values of $1.05 \pm 0.05 \mu\text{m}$ (WAAM) and $1.091 \pm 0.054 \mu\text{m}$ (wrought IN625). This superior performance is attributed to synergistic lubrication, enhanced heat dissipation, and the formation of a protective tribofilm, which together reduce friction, tool wear, and surface irregularities.

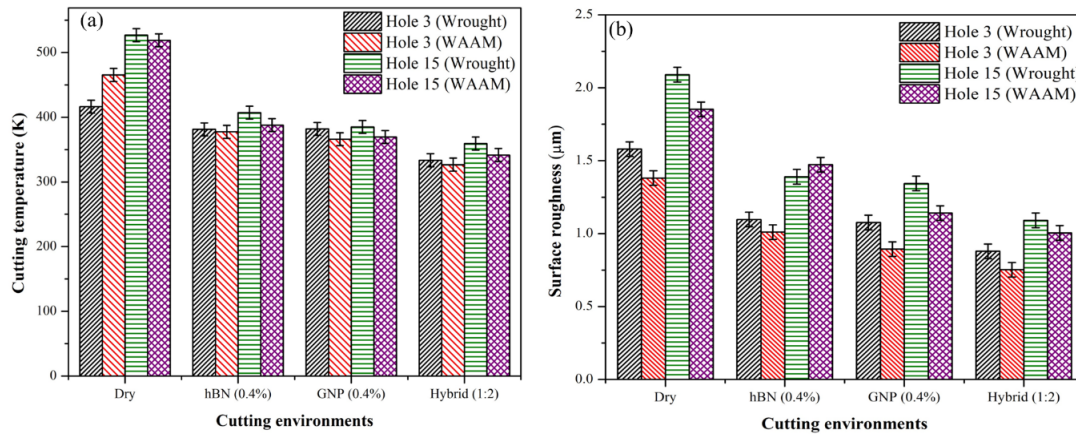


Figure 5: Variation in (a) cutting temperature and (b) surface roughness with respect to cutting environments during drilling of wrought and WAAM Inconel 625 plates

4.3 Machining of Ti-6Al-4V under hybrid nanofluid environment

Cutting forces increased progressively with the number of drilled holes due to tool wear and thermal effects (Figure 6 a). Dry drilling produced the highest forces, with wrought Ti-6Al-4V reaching $339.73 \pm 14.50 \text{ N}$, while WAAM Ti6Al4V showed lower

values (198.03 ± 12.7 N) because of its comparatively lower hardness. The application of nanofluids significantly reduced cutting forces. hBN-based mono nanofluid lowered forces by 37.58% (wrought) and 5.25% (WAAM), whereas graphene-based mono nanofluid achieved greater reductions of 42.03% and 10.65%, respectively, due to improved heat dissipation and tribofilm formation. The hybrid nanofluid provided the lowest forces throughout drilling, reducing them by 45.67% for wrought and 20.6% for WAAM Ti6Al4V, and by an additional 6–16% compared to MNFs. This improvement is attributed to synergistic lubrication, higher wettability, and thermal stability of the hybrid system.

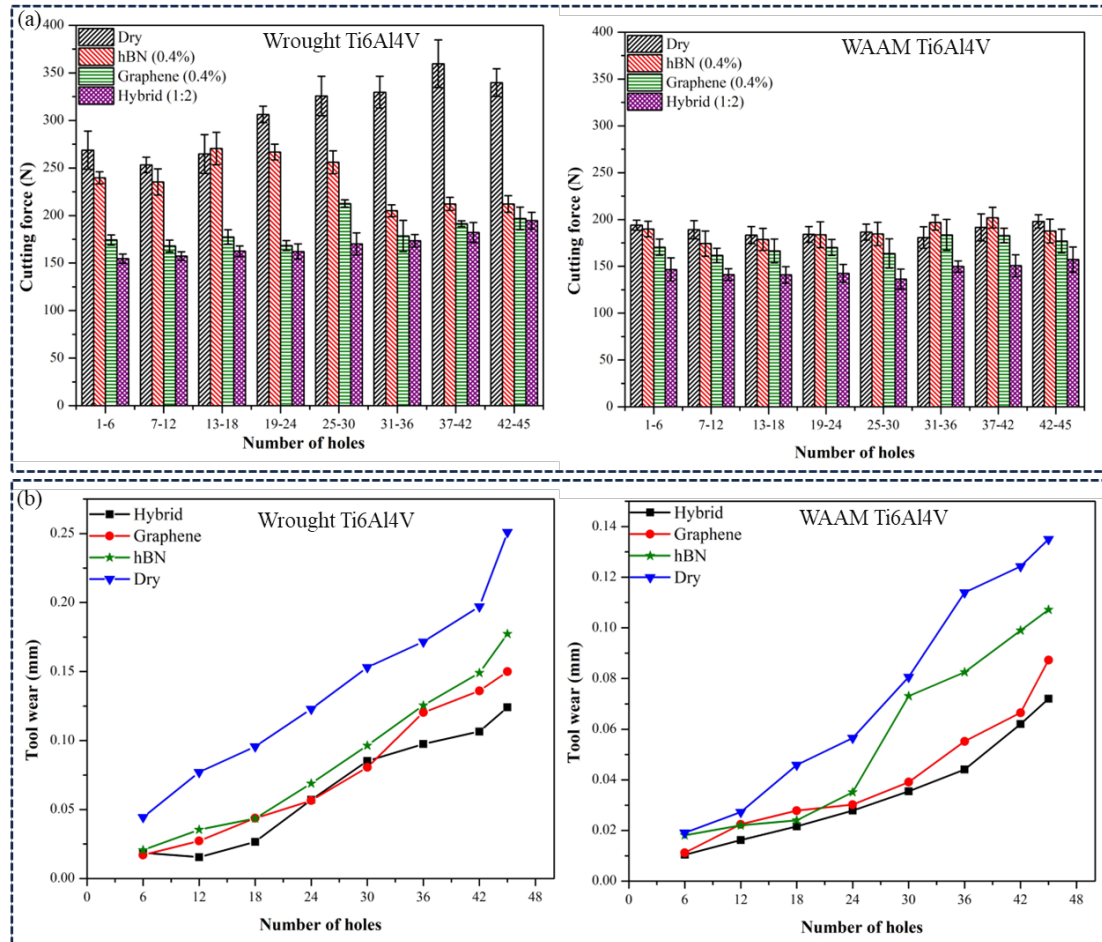


Figure 6: Variation in (a) cutting force and (b) tool wear with respect to the number of holes during drilling of wrought and WAAM Ti-6Al-4V plates

Flank wear increased rapidly under dry conditions due to severe heat and friction. Drilling of Wrought Ti-6Al-4V under dry environment reached the wear limit of 0.25 mm after 45 holes, whereas WAAM Ti6Al4V exhibited lower wear (0.14 mm). Further, the use of nanofluids markedly improved tool life. hBN mono nanofluids reduced wear to 0.177 mm (wrought) and 0.107 mm (WAAM), while graphene mono nanofluid further lowered it to 0.15 mm and 0.087 mm, respectively. The best performance was achieved with a hybrid nanofluid, limiting flank wear to 0.124 mm for wrought and 0.073 mm for WAAM Ti6Al4V. Overall, wrought material showed nearly twice the

wear of WAAM due to its higher hardness, confirming the effectiveness of hybrid nanofluids in reducing cutting forces and tool wear. The variation in flank wear for both wrought and WAAM Ti-6Al-4V is shown in Figure 6 (b).

4.4 Sustainability assessment

4.4.1 Life cycle assessment

A cradle-to-gate life cycle assessment (LCA) was conducted in accordance with ISO 14040/14044 to evaluate the environmental impacts of drilling WAAM and wrought Ti-6Al-4V under dry, mono-nanofluid (hBN and graphene), and hybrid nanofluid (HNF) conditions, using the ReCiPe 2016 midpoint (H) methodology. The functional unit was defined as a single drilled hole with a diameter of 5 mm and a depth of 3.5 mm.

Energy consumption during drilling was highest under dry conditions, measuring 0.5996 Wh (wrought) and 0.6021 Wh (WAAM) per hole. The use of hBN nanofluids reduced energy consumption to 0.4535 Wh (wrought) and 0.4286 Wh (WAAM), while graphene nanofluids resulted in 0.5213 Wh (wrought) and 0.5306 Wh (WAAM). The lowest energy demand was achieved with hybrid nanofluids, at 0.4561 Wh (wrought) and 0.4508 Wh (WAAM) per hole.

Figure 7 shows 18 midpoint environmental effect categories for drilling of WAAM and wrought Ti-6Al-4V under mono and hybrid nanofluid environments. WAAM-based drilling showed higher overall environmental impacts than wrought machining due to additional energy demands from wire production (108.5 MJ/kg) and deposition (2.39 MJ/kg). In contrast, wrought processing involved only raw material production (556.2 MJ/kg) and forging (14.7 MJ/kg). Among all 18 midpoint impact categories, dry drilling resulted in the highest impacts, particularly for climate change, human toxicity, particulate matter formation, and fossil resource depletion.

Compared to dry drilling, hBN-based nanofluids reduced multiple impacts for WAAM Ti-6Al-4V, including terrestrial acidification (2.29%), freshwater and marine ecotoxicity (2.5%), marine eutrophication (4.16%), and non-carcinogenic human toxicity (5.06%). Greater reductions were observed for wrought Ti-6Al-4V, reaching up to 21.73% in marine eutrophication and 16.77% in non-carcinogenic human toxicity. Graphene nanofluids outperformed hBN, achieving reductions for WAAM Ti-6Al-4V of 4.02% (terrestrial acidification), 4.5% (ecotoxicity), 12.5% (marine eutrophication), and 8.72% (non-carcinogenic human toxicity). For wrought Ti-6Al-4V, corresponding reductions reached 34.78%, 29.63%, and 19.5% across key impact categories. Hybrid nanofluids delivered the best environmental performance. They reduced CO₂ emissions by approximately 35%, lowered terrestrial acidification by 5.3% (WAAM) and 16.29% (wrought), and decreased freshwater and marine ecotoxicity by 6% (WAAM) and 28% (wrought). Based on the impact analysis, hybrid nanofluids consistently demonstrated the lowest environmental burdens across all categories, including human health, ecosystem quality, and resource depletion.

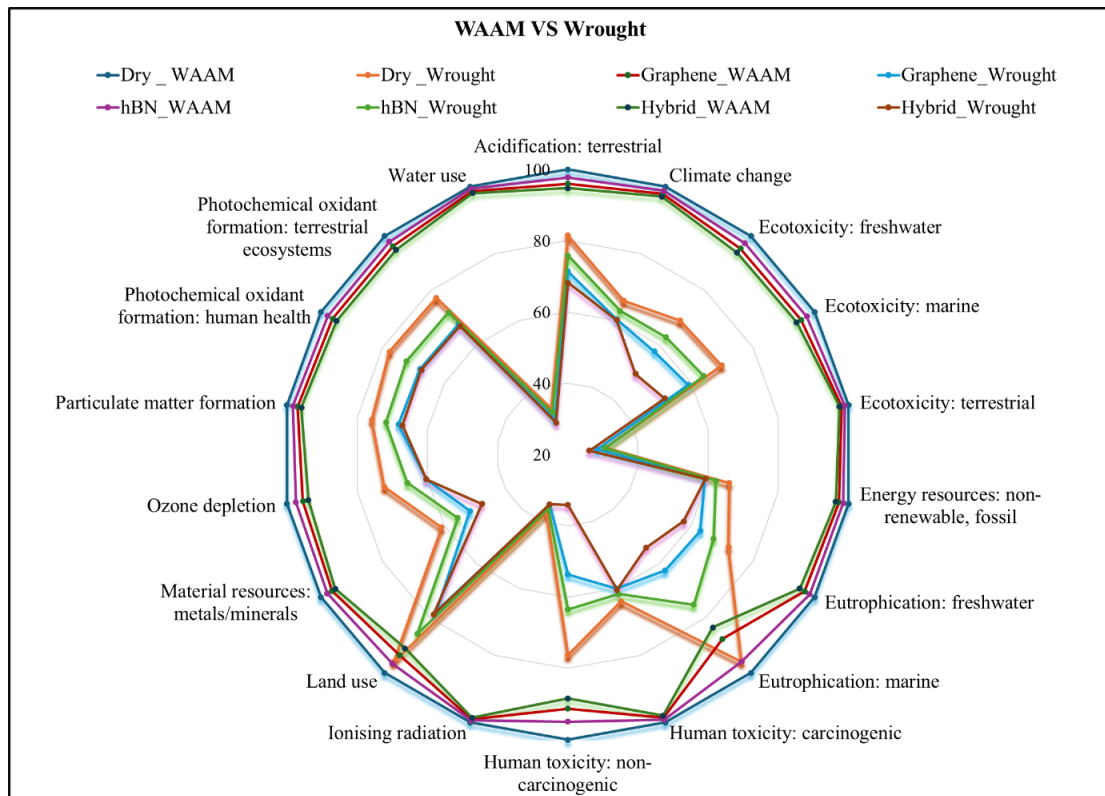


Figure 7: Normalised radar map depicting the 18 midpoint environmental effect categories for drilling of WAAM and wrought Ti6Al4V under dry, mono, and hybrid nanofluid lubrication environments

5 Conclusions

This thesis demonstrates that hybrid nanofluid–assisted lubrication is a viable and effective solution for addressing the machinability and sustainability challenges associated with drilling of WAAM-fabricated and wrought superalloys. By integrating advanced nanofluid engineering with systematic machinability evaluation and sustainability assessment, the work establishes clear links between improved thermal–tribological performance, reduced tool degradation, lower energy demand, and minimised environmental, social and economic impact. The findings provide a strong foundation for adopting hybrid nanofluids as a sustainable metalworking fluid alternative in industrial machining of additively manufactured IN625 and Ti-6Al-4V components, paving the way for greener and more resource-efficient manufacturing practices. Based on the findings of this work, the following conclusions were drawn:

- Hybrid nanofluid improves thermal conductivity by 44.55%, 16.94%, and 12.24% compared to dry, hBN, and graphene nanofluids, respectively. This may be owing to the higher dispersion of particles, which results in a higher rate of micro-convection between the particles.
- Adding nanoparticles to the jojoba oil lowered the contact angle by 58.39% and 53.19% for hBN and graphene particles, respectively, while hybrid nanofluids showed a maximum reduction of 65.24%.

- The viscosity with variable temperature of hybrid nanofluids is 20.94% higher than that of hBN, 19.61% higher than graphene, and 44.12% higher than the base fluid.
- The cutting surface temperature in hybrid nanofluid-assisted drilling is 6-12% lower than mono nanofluids for WAAM and wrought Inconel 625 plates. Whereas, compared to dry, a reduction in cutting temperature of up to 34.15% was observed for WAAM IN625 and 31.79% for wrought Inconel 625.
- Use of hybrid nanofluid during drilling minimises the surface roughness by 47.79% for wrought Inconel 625 and 45.73% for WAAM Inconel 625.
- In comparison to dry drilling, the use of hybrid nanofluids resulted in a significant decrease in cutting forces, specifically, a reduction of 45.67% for wrought materials and 20.6% for WAAM.
- Drilling using a hybrid nanofluid reduced flank wear significantly, by 50.59% for wrought Ti6Al4V and 46.67% for WAAM, compared to dry machining.
- The application of hybrid nanofluid has demonstrated a reduction in energy consumption, resource utilisation, ecotoxicity, and adverse human health indicators, as well as freshwater and carbon emissions, thereby promoting sustainable manufacturing and highlighting their potential for greener machining operations.

6 Organization of the Thesis

This thesis is organised into eight chapters. The first two chapters provide the necessary background and literature review for the study. A brief description of the scope and focus of each remaining chapter is presented below.

Chapter 1 highlights the importance of metal-based additive manufacturing, especially during the fabrication of difficult-to-cut materials. Also, discuss the challenges in AM parts and the importance of the analysis of the machinability of AM-fabricated parts. Furthermore, this chapter highlights the significance of MWFs in machining AM-based difficult-to-cut materials. Furthermore, this chapter explores how to achieve sustainability by minimising or eliminating the use of conventional MWFs in machining processes. It provides a brief review of the literature on the fabrication of AM parts, environmentally friendly MWFs, near-dry machining, and nanofluids.

Chapter 2 provides a comprehensive overview of the fabrication method, as well as the minimisation or alternative replacement of conventional MWFs in machining operations. Furthermore, an in-depth literature review was conducted on the critical aspects of nanofluid-based MWFs, including their thermo-physical, rheological, and stability properties, as well as their applications in machining additive-manufactured parts. The chapter concludes by identifying the potential gaps in the existing research and presenting the detailed objectives of the thesis.

Chapter 3 presents the complete materials and methodology employed in the present research work. The chapter includes a selection of workpiece materials, the fabrication of workpiece materials, tool materials, base oils, and nanoparticles, followed by

the synthesis of environmentally friendly hybrid nanofluids and their characterisation. Furthermore, the selection of workpiece and tool materials, machining parameters and different techniques used to measure the machining responses.

Chapter 4 presents the detailed WAAM fabrication process of Inconel 625 and Ti-6Al-4V alloy plate, followed by a comparative study with wrought material via various characterisations, including microstructure, hardness, morphology, elemental analysis, and X-ray diffraction.

Chapter 5 presents an in-depth analysis of the thermo-physical and rheological properties of synthesised hybrid nanofluids. Different properties, such as dispersion and thermal stability, thermal conductivity, specific volumetric heat capacity, wettability, viscosity, and Raman spectroscopy of synthesised hybrid nanofluids, were analysed to check their potential compatibility with base oil.

Chapter 6 discussed a comparative analysis of the machining performance of WAAM and wrought fabricated materials in various synthesised hybrid nanofluid environments. The machining performance was evaluated based on their machining responses.

Chapter 7 discusses the sustainability aspects of machining WAAM and wrought fabricated alloys using synthesised nanofluid-based MWFs, aligning with the United Nations Sustainable Development Goals 2030 (SDGs). This chapter provides a comprehensive overview of the sustainability assessment of the overall process, utilising the Pugh matrix, life cycle assessment, and cost assessment in terms of social, environmental, and economic aspects.

Chapter 8 summarises current research results, draws critical inferences, and explores future opportunities in sustainable machining.

7 List of Publications

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1. **Prameet Vats**, Navneet Khanna, Avinash Kumar, Kishor Kumar Gajrani Lubrication-driven surface and tool performance in sustainable machining of additively manufactured nickel superalloy, *Surface and Coatings Technology*, 515, 132637, (2025).
2. **Prameet Vats**, Navneet Khanna, Avinash Kumar, Kishor Kumar Gajrani Tribological performance of hBN and graphene-enriched hybrid nanofluids on tool wear and hole surface quality in drilling: A comparative study on WAAM and wrought Inconel 625, *Wear*, 574–575, 206090, (2025).
3. **Prameet Vats**, Tarang Lotwala, Navneet Khanna, Avinash Kumar, Kishor Kumar Gajrani, Machinability Data to Sustainability Metrics: Cradle-to-Gate Life Cycle Assessment of Lubrication-Assisted Drilling of CMT-WAAM Ti-6Al-4V, *Journal of Tribology–Transactions of the ASME*, 1–35, (2025).
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5. **Prameet Vats**, Arun Kumar Bambam, Navneet Khanna, Avinash Kumar, Kishor Kumar Gajrani, Green Machining of CMT-WAAM Ti-6Al-4V Alloy with TiN-Coated WC Drill: Insights into Energy, Surfaces, and Carbon Emissions, *International Journal of Refractory Metals and Hard Materials*, (**Manuscript Number: IJRMHM-D-25-01329**), (2025). (Under Review)
6. **Prameet Vats**, Navneet Khanna, Avinash Kumar, Kishor Kumar Gajrani, Novel drilling characteristics of wrought, WAAM, and LPBF IN718 Alloys under dry and hybrid nanofluid lubrication environment. (**Under Preparation**)

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3. **Prameet Vats**, Piyush Kumar Sinha, Kishor Kumar Gajrani, Numerical Assessment of Thermomechanical Behaviour of a Multi-Layer Additive Manufacturing, *Advances in Additive Manufacturing Volume—I: Proceedings of the AIMTDR 2023* (Springer Nature), (p. 303), (2025).

BOOK CHAPTERS

1. **Prameet Vats**, Kishor Kumar Gajrani, Avinash Kumar, Laser-based additive manufacturing, *Laser-based Technologies for Sustainable Manufacturing*. CRC Press (Taylor and Francis Group), (pp. 67–83) , (2023).
2. **Prameet Vats**, Arun Kumar Bambam Kishor Kumar Gajrani, Avinash Kumar Characterisation of titanium feedstock powder prepared by recycling of machining chips using ball milling, *Hybrid Metal Additive Manufacturing*. CRC Press (Taylor and Francis Group), (pp. 157–172) , (2023).

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