Methodological Investigation of Wiper Geometry Inserts' Influence on Surface Quality and Integrity of Al 7136 Aluminum Alloy in Milling

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Abstract: *This paper addresses the optimization of the milling process for the high-performance aluminum alloy Al 7136 using Wiper geometry cutting tools (inserts). Although milling Al 7136 is a productive method, a constant trade-off exists between productivity and achieving superior surface quality. The work's aim is to investigate the detailed influence of Wiper inserts and cutting parameters on a wide range of surface quality indicators. The research questions focus on how the Wiper geometry affects roughness and subsurface integrity (microstructure, defects, residual stresses, hardness), and on identifying the optimal correlations between cutting parameters and these indicators. The proposed experimental research design involves varying the cutting speed, feed per tooth, and depth of cut as independent variables, with measurements of roughness, surface morphology, and microhardness profile as dependent variables. The paper presents the context of the Al 7136 material and the milling operation, defining surface quality beyond roughness to include subsurface integrity. Wiper inserts are introduced as a solution to increase productivity without compromising the surface finish or even improving the finish at standard feeds. The research is motivated by a lack of systematic studies regarding the Wiper effect on the surface integrity of Al 7136. Expected results include identifying optimal milling conditions and understanding the physical mechanisms governing surface formation, contributing to more precise machining guidelines*.

Keywords: *Al 7136, Milling, Productivity, Roughness, Surface Quality, Wiper Inserts*

1 INTRODUCTION

The 7xxx series aluminum alloy (Al-Zn-Mg-Cu), specifically Al 7136, is essential in industries requiring lightweight structural components, particularly the automotive and aerospace sectors. It stands out for its excellent strength-to-weight ratio and high mechanical strength after heat treatment. Milling is a widely used machining method for this material, offering high productivity and the capability to generate complex and precise geometries. Surface quality, which is critical for part performance, is not limited to roughness. It also includes surface integrity, which encompasses:

- The microstructure of the surface layer (the thickness of the plastically deformed layer, grain size).
- Surface defects (cracks, burs, material pull-out).
- Residual stress states (beneficial compressive or detrimental tensile).
- The hardness of the surface layer.

Optimal surface quality directly influences the part's fatigue, wear, friction, and corrosion resistance, making it vital in aerospace applications. Achieving this quality from the outset reduces subsequent finishing costs. Modern research has established milling as a viable method for 7xxx series alloys. A major area of interest is Wiper inserts. A Wiper insert is designed with a wiper edge located where the straight edge meets the corner radius. Their main advantage is the ability to double the feed rate while maintaining or even improving the surface finish compared to conventional inserts, thereby enhancing efficiency and productivity. They can be used in finishing operations in face milling and are effective in external turning, boring, and face milling. Studies have shown that using Wiper inserts at high feed rates shortens machining times, allowing the combination of roughing, and finishing operations (single pass), which reduces production cycles and costs. Furthermore, the high feed rate contributes to improved chip control (thicker and easier-to-break chips) and, by reducing the cutting time per component, to increased tool life, preventing friction. However, recent research, such as that by Wang et al. (2024) and Weber et al. (2024), while confirming the Wiper effect on roughness, indicates that the special geometry can influence residual stresses and the microstructure of the surface layer differently than a conventional edge, particularly in materials sensitive to high strain rates, such as aluminum. Muthuswamy's (2022) research focused on Wiper milling of steel, and Singh et al.'s (2024) targeted Aluminum 7075, but not Al 7136, highlighting a gap. Other works, such as that by Titu et al. (2024), have contributed to the understanding of the Al 7136 milling process, but focus on conventional tools. Publications on High Feed Milling often focus on productivity, overlooking the integrated analysis of surface quality, according to Sushil et al. (2024). Studies by Płodzień et al. (2021) and Gupta el al. (2023) on face milling with different approach angles show how tool geometry modulates cutting forces, an aspect that also requires investigation for the Wiper geometry on Al 7136 (Muthuswamy and Nagarajan, 2021).Although milling the Al 7136 alloy is common, and the benefits of Wiper inserts on roughness are known, there is a lack of systematic studies dedicated to optimizing surface quality with Wiper inserts for this specific alloy (Pimenov et al., 2023 and Phiri et al., 2024). The main gaps identified that motivate this research are:

- *Incomplete understanding of surface integrity*: There is a gap in the knowledge of how the Wiper edge influences the full range of surface quality indicators, such as the microstructure of the surface

layer, the presence of defects, the thickness of the plastically deformed layer, and the hardness profile.
- *Detailed Layer Formation Mechanisms*: In-depth investigations are needed into the detailed mechanisms by which the specific "wiping" action of the Wiper inserts' rectilinear edge modulates residual stress states and other microstructural changes for Al 7136.
- *Specific Parameter-Quality Correlations*: Lack of optimal correlations and precise machining guidelines between cutting parameters (speed, feed, depth) and complex quality indicators when using Wiper inserts on Al 7136.

The primary originality and novelty of the proposed research lie in the systemic and detailed approach to the influence of Wiper inserts on all relevant aspects of surface quality (roughness and microstructural integrity) in the milling of a new alloy with great development potential, Aluminum 7136. This research will contribute to extending fundamental knowledge and enable the development of predictive models.

The fundamental objective of this investigation is to investigate the influence of cutting parameters on the surface quality of Aluminum 7136 workpieces milled with Wiper inserts, with a view to improving the process and obtaining superior finishes.

Specific objectives include:
- Evaluating surface roughness as a function of variations in cutting parameters.
- Analyzing surface integrity (microstructure, defects, deformed layer thickness, surface layer hardness).
- Identifying optimal correlations between cutting parameters and surface quality indicators.
- Developing practical recommendations for selecting milling parameters with Wiper inserts for Al 7136.

2 PROPOSED RESEARCH METHODOLOGY

2.1 Experimental Design and Variables

The methodology is based on a systematic experimental design (Design of Experiments - DOE), tracking the cause-and-effect relationship between cutting parameters and surface quality.

Table 1. Experimental Design and Variables

Independent Variables (Input)	Dependent Variables (Output)
Cutting speed (v) 3-5 levels	Surface Roughness (Ra, Rz)
Feed per tooth 3-5 levels	Surface Morphology (defects, burrs, pull-outs)
Depth of Cut (2-3 levels)	Depth Hardness Profile (Micro/Nanohardness)
Specific Wiper Insert Type/Geometry	Subsurface Microstructure (metallographic analysis)

2.2 Materials and Equipment

Material Studied: Al 7136 aluminum alloy.

Processing Equipment: High-precision CNC milling machine, utilizing tools equipped with Wiper geometry milling inserts.

Processing Conditions: Lubrication/Cooling conditions (e.g., MQL, dry) and part clamping will be specified.

Characterization Equipment:
- Profilometer: For roughness measurement.
- Scanning Electron Microscope (SEM): For surface morphology and microstructural analysis.
- Optical Metallographic Microscope.
- Micro / Nanohardness Tester (Vickers / Knoop / Berkovich) for the subsurface layer.
- Analysis Software: DOE software (such as Minitab) for experimental design and Analysis of Variance (ANOVA).

The proposed experimental methodology is schematically presented in Figure 1.

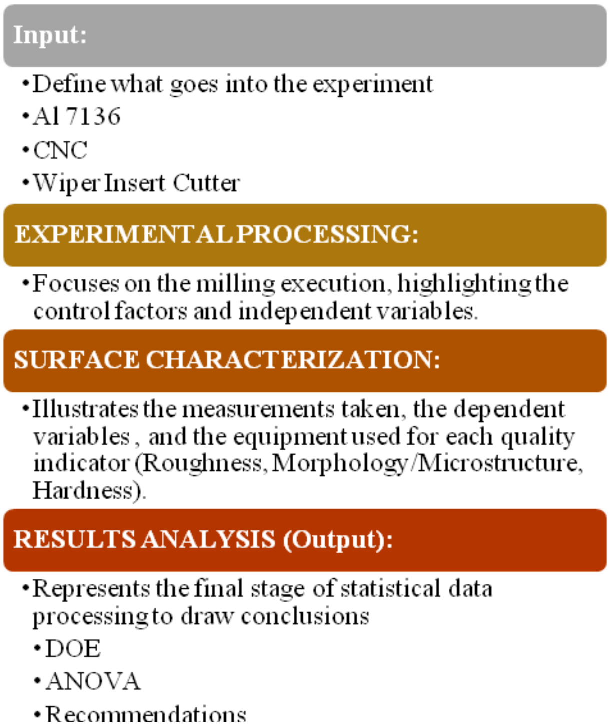

Fig. 1. Outline of the Proposed Experimental Methodology for Milling Al 7136 with Wiper cutting inserts

3.3 Technical Considerations for Wiper Inserts

Wiper inserts can be used to achieve excellent roughness (Mirror finish) at high feed rates, which can be increased by 2-3 times without sacrificing surface quality. This capability is due to the wider parallel land that smooths the grooves left by the main cutting edges. To maintain a step-free surface, it is recommended that the feed per revolution not exceed 60% of the Wiper edge length.

Although Wiper geometry offers finishing benefits, it is important to note that because the Wiper edge protrudes by approximately 0.05 mm beyond the conventional edges, it is subjected to higher loads. Therefore, Wiper inserts should be used for light machining and at moderate depths of cut in finishing to limit axial forces and reduce the risk of vibration.

The major benefits of Wiper inserts are presented in Figure 2.

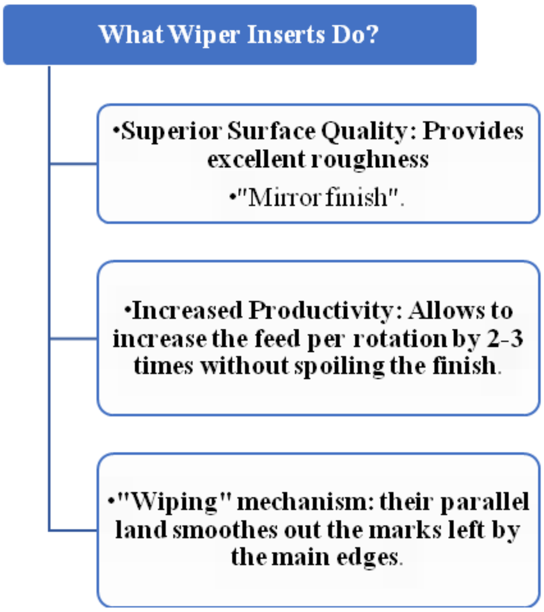

Fig. 2. Major benefits of Wiper Inserts

The critical conditions for Wiper inserts are presented in Figure 3.

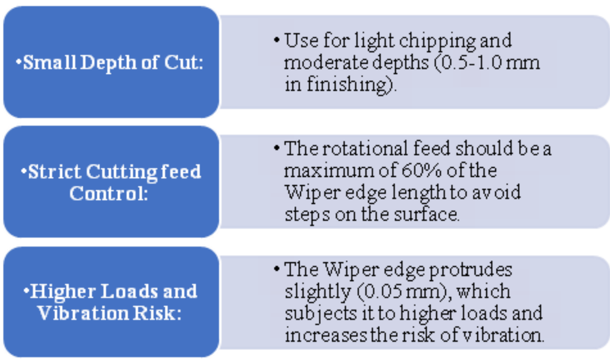

Fig. 3. Critical conditions of Wiper Inserts

3. EXPECTED RESULTS AND CONTRIBUTIONS

Expected results include:

- Identifying precise quantitative relationships between cutting parameters and surface quality.
- Determining the optimal Wiper milling conditions for achieving minimum roughness and maximum surface integrity for Al 7136.
- Understanding the physical and microstructural mechanisms governing surface formation under the action of the Wiper edge.
- Creating a valuable experimental database for the machining of this alloy.

The major scientific contribution is the expansion of fundamental knowledge regarding the high-precision machining of Al 7136 Aluminum and the development of predictive models or empirical correlations between cutting parameters and surface quality.

The potential impact of the research includes:

- Reducing post-processing costs.
- Improving the performance and durability of critical parts in the aerospace and automotive industries.
- Increasing the efficiency of manufacturing processes by optimizing milling parameters.

5. CONCLUSIONS

The proposed research is essential for optimizing the milling processes of the Al 7136 aluminum alloy with Wiper inserts, a critical material for high-technology industries. The main benefit is ensuring superior surface quality of the parts, which is directly correlated with their performance and durability.

The project will bring an in-depth understanding of the complex relationship between cutting parameters, Wiper tool geometry, and surface quality indicators (roughness, microstructural integrity, hardness). This systematic approach for Al 7136 represents an original and necessary contribution to specialized literature. The results obtained will guide the optimal selection of milling parameters, having a significant practical impact by reducing post-processing costs and improving industrial production efficiency.

In the future, the results can serve as a basis for further studies regarding tool wear in the context of Wiper inserts, the influence of different cooling methods (e.g., MQL, cryogenic), and the development of advanced predictive models.

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