

Predicting surface roughness: more than just a formula

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From classical formula to more reliable forecasting

The classical roughness formula has been the basis for predicting surface roughness for decades. In practice, though, the measured values are often considerably higher than theory predicts. As part of the Vlaio-COOCK+ 4.0 Maturity Acceleration project, Sirris and VIVES University of Applied Sciences are working on a model that helps to explain this gap.

The classical formula remains a good starting point

Surface roughness is one of the most important quality parameters in machining. At the same time, it is hard to predict. A workpiece may have a measured Ra of 1.2?µm when 0.8?µm was required. Yet the machine settings, the tool and the NC programme have remained unchanged.
The result? Additional measurements, reworking or even rejection.

The classical formula gives a theoretical lower limit:

$Ra = f^2 / (32 \cdot r)$

Here, f is the feed rate and r is the tool's corner radius. The formula yields two well-known rules of thumb: halving the feed rate improves surface roughness by a factor of four, while doubling the corner radius approximately halves the surface roughness.

In practice, however, the measured values are almost always higher. This is because the formula assumes ideal conditions: a perfectly sharp tool, a rigid machine, homogeneous material and no vibrations.



Why theory and practice differ

Three mechanisms account for most of the difference between the theoretical and measured surface roughness.

1. Material behaviour

Materials such as titanium, austenitic stainless steel and some aluminium alloys form a 'built-up edge' during machining. As a result, the effective cutting geometry changes and the surface roughness increases. For this reason, a material factor is often used, which varies depending on

the type of material.

2. Tool wear

A worn tool gradually changes shape. Flank wear generates additional heat and friction, which increases surface roughness. This is why many models also include a tool condition factor.

3. Dynamic behaviour of the machine

The machine itself also plays an important role. Vibrations, chatter and deflection of the tool or workpiece leave direct marks on the machined surface. These effects are completely ignored in the classical formula.

Including these factors results in a more realistic model:

Ra ? k??? · C???? · f^2 / (32 · r)

The material factor (kmat) and tool condition factor (Ctool) make the prediction much more useful in practice.

Research combines physics and machine data

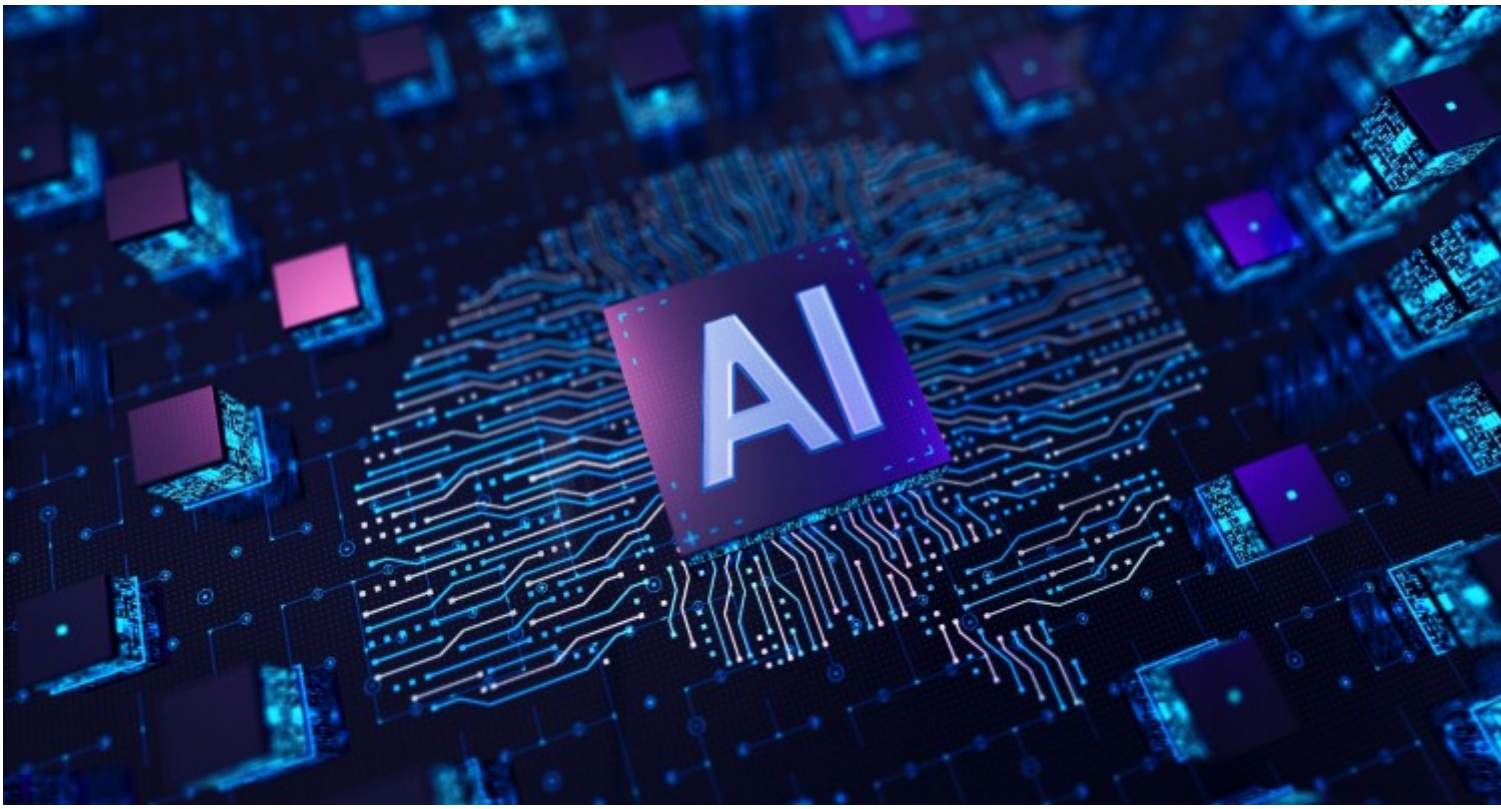
This approach is not new. It forms part of a clear line of research in which the classical geometric formula is being expanded step by step to include additional process information.

Muñoz-Escalona and Maropoulos (2015) demonstrated that a purely geometric model for face milling can achieve an accuracy of almost 98?per cent, provided that run-out and the insert geometry are also taken into account correctly.

Martínez-Arellano et al. (2017), a reference closely aligned with the COOCK approach, took this a step further. They demonstrated that the main drive power of modern CNC machines, which is available in real time, can be used directly to predict surface roughness (Ra) as a function of tool wear (VB). Their model uses AI to learn the relationship between strength, wear and surface roughness.

Even more recent publications on physics-informed machine learning (2022–2024) combine classical equations with trained neural networks. The physical formulas serve as a starting point, called ‘prior’, while the AI model learns from measurement data. On experimental datasets, these models report prediction errors of just 7 to 15?per cent. At the same time, the predictions remain consistent with the known laws of physics.

The common thread running through all these studies is the same. The classical formula is not being replaced, but forms the foundation on which corrective factors and data-driven models are being built.



From theory to practice in the COOCK+ project

As part of the Vlaio-COOCK+ 4.0 Maturity Acceleration project, Sirris and VIVES University of Applied Sciences are using the same approach. The mobile measurement platform builds on the classical formula and combines it with material properties and machine data.

For example, for face milling titanium (Ti6Al4V), the geometric formula predicts an Ra of around 0.21?µm. After correcting for the material, that prediction rises to approximately 0.38?µm. If tool condition is also taken into account, the prediction works out at around 0.6?µm. The actual measured value lies between 1.0 and 1.2?µm.

This residual deviation can be explained by increased vibrations and further wear on the tool. This is precisely what makes the model valuable: it not only predicts surface roughness, but helps to identify the cause of the loss of quality.

What can you do today?

You don’t need to start with complex AI models immediately. Even with limited effort, you can improve the predictability of your process.

- Use the classical formula as an initial way of checking achievable roughness requirements
- Record systematically measured Ra values for various materials and tools
- Monitor machine data such as spindle power and vibrations to detect anomalies at an early stage

In this way, you build up a valuable dataset step by step that can also be used later on for more advanced predictive models.

From research to practice

Within the VLAIO COOCK+ 4.0 Maturity Acceleration project, Sirris and VIVES University of Applied Sciences are working together on methods for more accurate prediction and optimisation of machining processes. A comprehensive white paper on surface roughness is available, which covers the theory, the current state of research and possible implementation pathways in detail. Feasibility testing on our own machines is possible until early 2027.

Discover the project

Want to learn more about surface roughness in machining?

Download the ‘Surface Roughness in Machining’ casebook and discover how sensor and machine data can complement traditional models. Learn how to achieve more reliable predictions that reflect your actual production environment.

Download the casebook (in Dutch only)

Get started with surface roughness prediction

Would you like to know how accurately surface roughness can be predicted on your own machines? Or are you interested in a feasibility test using the mobile platform? Feel free to contact Sirris or your contact person within the VLAIO COOCK+ 4.0 Maturity Acceleration project

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