



A Review of Cutting Temperature and Cutting-Tool Material Effects on Surface Integrity During CNC Turning of Hardened AISI M2 Tool Steel

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ABSTRACT

Hard turning of hardened tool steels is governed by a coupled thermo-mechanical and tribological system in which cutting speed, feed, depth of cut, tool material, tool geometry and interface conditions jointly determine heat generation, heat partition, tool wear and work piece surface integrity. This review critically examines the role of cutting temperature and cutting-tool material in CNC turning, with particular emphasis on hardened AISI M2 high-speed tool steel. Cemented carbide, ceramic and polycrystalline cubic boron nitride (PCBN/CBN) tools are compared in terms of hot hardness, fracture toughness, thermal transport, chemical stability and dominant wear mechanisms. Published studies show that cutting temperature is strongly affected by cutting speed and by thermal and tribological characteristics of the tool-chip interface. Comparative hard-turning work also demonstrates that a tool with superior hot hardness is not automatically the best choice at every speed because coatings, thermal conductivity, tribo-film formation and friction can change heat partition and tool life. The supplied AISI M2-CBN experimental dataset is used as a quantitative case-study baseline: feed accounts for 95.35% of surface-roughness variation, feed and depth of cut contribute 48.83% and 48.20% of cutting-force variation, and cutting speed contributes 78.05% of flank-wear variation. The review identifies direct temperature measurement, controlled tool-material comparison, uncertainty quantification, cross-validated modeling and multi-objective optimization as key requirements for future AISI M2 research.

Keywords: AISI M2, hard turning; cutting temperature, PCBN, CBN, ceramic, cemented carbide, surface roughness, flank wear, cutting force, surface integrity.

1. Introduction

Hard turning is widely used as an alternative or complementary finishing route to grinding for hardened steels because it can shorten the process chain, support flexible CNC production and reduce coolant dependence. Hard machining is generally associated with work piece hardness above about 45 HRC, with ceramic and PCBN tools being important choices at high hardness [1,2].

Cutting temperature is a critical process variable because plastic deformation and friction convert mechanical energy into heat. The resulting thermal field is highly localized and depends on cutting speed, feed, and depth of cut, friction, tool geometry, tool material, work piece properties and lubrication. Temperature measurement is therefore method-dependent and requires careful calibration and uncertainty assessment [3,4].

Tool material changes this thermal balance through hardness, hot hardness, fracture toughness, thermal conductivity, chemical stability and tool-chip friction. Carbides provide a useful hardness-toughness balance; ceramics provide high hardness and thermal stability but are relatively brittle; and PCBN/CBN offers very high hot hardness and strong compatibility with hardened ferrous alloys [5,6].

The present review focuses on the interaction between tool material and cutting temperature during CNC turning of hardened AISI M2. The uploaded experimentation chapter supplies a complete 27-run AISI M2-CBN baseline for Ra, Fc, VB and MRR, but it does not contain measured cutting-temperature data or comparative ceramic/carbide results. Those missing quantities are therefore treated as research gaps rather than invented results.

2. Review Scope and Method

The review covers heat generation and partition, temperature measurement, carbide/ceramic/PCBN tool behavior, coatings, wear mechanisms, surface integrity, statistical and machine-learning modeling, and multi-objective optimization. The supplied experimentation chapter is used for the AISI M2 quantitative baseline; external literature is used for broader interpretation and comparison.

Priority is given to review papers and experimental studies that directly address cutting temperature, hard turning, tool materials and tool wear. Particular attention is given to comparative PCBN/coated-carbide evidence because it demonstrates why tool-material ranking is process dependent.

3. Cutting temperature in CNC turning

3.1 Heat generation

Heat is generated primarily in the primary shear zone through plastic deformation and in secondary/tertiary regions through friction at the tool–chip and tool–work piece interfaces. The magnitude and location of the thermal field change with cutting speed, chip thickness, contact length and friction [3,7].

3.2 Heat partition

Generated heat is partitioned among the chip, tool and work piece. The chip commonly removes a large fraction of heat, but the partition is process specific. Tool thermal conductivity, coating architecture and contact conditions influence the heat retained near the cutting edge [7].

3.3 Cutting speed

Cutting speed is commonly a major thermal driver because it increases deformation and frictional sliding rates. In one hard-turning study of D2 steel, measured cutting temperature at 60 m/min was about 779 °C for PCBN and 824 °C for coated carbide; the coated-carbide temperature approached 930 °C around 100 m/min in that particular setup [8]. These values are material- and setup-specific and should not be transferred directly to AISI M2.

3.4 Feed and depth of cut

Feed increases chip thickness and generally increases cutting load, while depth of cut increases the cross-sectional area of removed material. Both can increase heat generation, but their temperature effects should be measured because chip evacuation and heat partition can change with geometry.

4. Cutting tool materials

4.1 Cemented carbide

WC–Co cemented carbide is versatile because of its combination of hardness, fracture toughness and thermal conductivity. Its major thermal limitation is loss of hot hardness associated with binder softening. Coatings such as TiAlN, AlCrN and Al₂O₃-containing systems can improve oxidation resistance, wear resistance and thermal behavior [5, 7].

4.2 Ceramic

Alumina-based and mixed ceramic tools retain high hardness at elevated temperature and can provide good chemical stability. Their lower fracture toughness makes them sensitive to vibration, impact and thermal shock, so stable continuous cutting is particularly important [5].

4.3 PCBN/CBN

PCBN/CBN is a leading tool material for hardened steels because of its high hardness, hot hardness and wear resistance. Performance depends strongly on CBN content, binder phase, edge preparation and cutting regime. High cost and susceptibility to chipping or chemical wear under unsuitable conditions remain limitations [6, 8].

4.4 Tool coatings

Coatings modify friction, thermal resistance, oxidation resistance and heat flow at the tool–chip interface. A comprehensive review identifies coating geometry, thermal properties, contact characteristics and coating–substrate diffusion as important temperature determinants [7]. Therefore, tool-material studies should specify grade, coating, edge preparation and nose radius.

5. Comparative Thermo-Mechanical Behavior

Tool material	Hot hardness	Fracture toughness	Thermal transport	Strength	Limitation
WC–Co carbide	Moderate–high	High	Good	Versatile and economical	Hot-hardness loss at high T
Ceramic	High	Low–moderate	Grade dependent	High-temperature stability	Brittle; shock sensitive

Tool material	Hot hardness	Fracture toughness	Thermal transport	Strength	Limitation
PCBN/CBN	Very high	Moderate	Grade dependent	Hard-turning performance	High cost; chipping/chemical wear

Table 1. Qualitative comparison based on reviewed literature [5,6,8]. Exact properties depend on grade and temperature

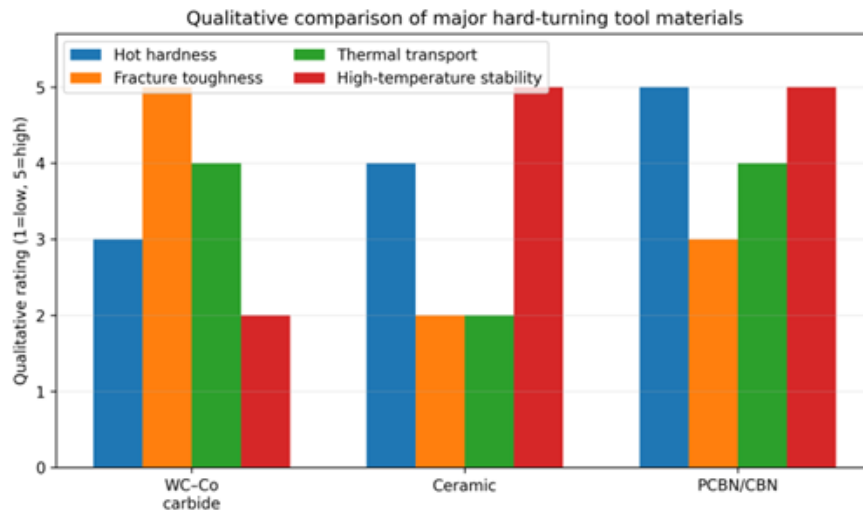


Figure 3. Qualitative comparison of major tool-material characteristics; synthesis of literature trends, not a measured property dataset.

6. Tool Wear And Thermal–Tribological Coupling

Flank wear, crater wear, notch wear, chipping and catastrophic fracture are common degradation modes in hard machining. Abrasion is important for hardened steels, while diffusion, oxidation and adhesion become increasingly relevant as temperature increases [8].

Temperature and wear form a feedback system: increasing temperature can accelerate diffusion and chemical reactions, while progressive flank wear can increase frictional contact and modify heat generation. Wear also changes edge geometry, which affects surface generation and dimensional accuracy.

The practical implication is that a tool should not be selected using temperature alone. A tool may tolerate a high temperature because of superior hot hardness, while another tool may operate at a higher measured temperature but benefit from a protective tribo-film and therefore achieve good tool life [8].

7. Surface Integrity Of Hardened Work pieces

Surface roughness is affected by feed, nose radius, edge condition, tool wear, cutting force and vibration. Tool material influences surface integrity through wear resistance and thermal behaviour. CBN has shown strong performance in several hardened-steel conditions, but coated carbide can also perform competitively within favourable temperature windows [8].

A complete surface-integrity study should consider R_a together with dimensional deviation, flank wear and cutting force. Where resources permit, residual stress, micro hardness and near-surface metallurgical changes should also be measured because excessive thermal and mechanical loading can alter functional performance.

8. AISI M2 Quantitative Case-Study Baseline

The supplied experimentation chapter uses hardened AISI M2 high-speed tool steel at 62–64 HRC with an L27 design: $V_c = 80, 120$ and 160 m/min; $f = 0.05, 0.10$ and 0.15 mm/rev; and $a_p = 0.10, 0.20$ and 0.30 mm. Responses are R_a , F_c , VB and MRR . The study found feed to be the dominant R_a factor, feed and depth of cut to dominate cutting force, and cutting speed to dominate flank wear Cutting-Temperature Measurement Methods

Response	Dominant factor	Contribution	Interpretation
R_a	Feed	95.35%	Surface finish strongly feed dependent
F_c	Feed	48.83%	Chip-load effect

Response	Dominant factor	Contribution	Interpretation
Fc	Depth of cut	48.20%	Chip cross-section effect
VB	Cutting speed	78.05%	Strong speed-related wear effect

Table 2. Dominant ANOVA contributions from the supplied AISI M2–CBN study.

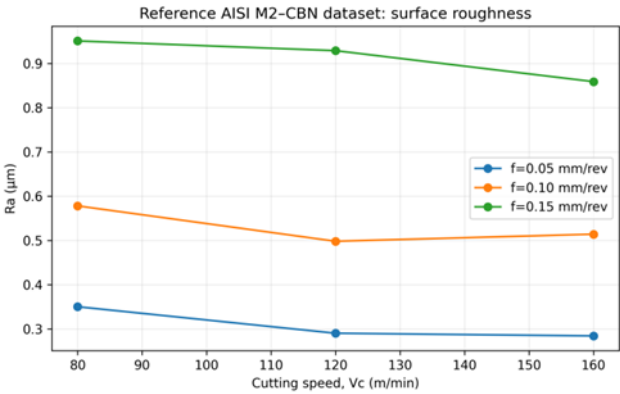


Figure 1. Surface-roughness trends extracted from the supplied 27-run AISI M2–CBN dataset at $a_p = 0.10\text{ mm}$.

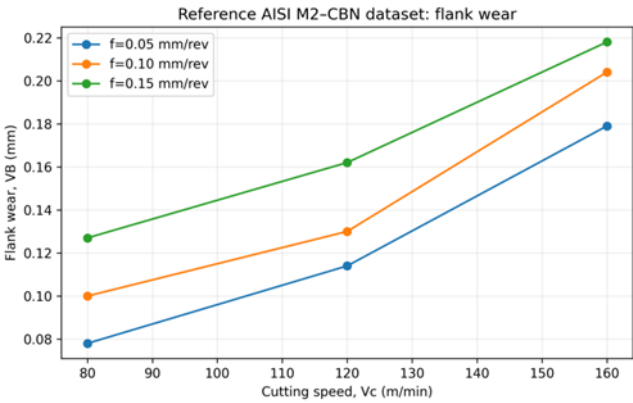


Figure 2. Flank-wear trends extracted from the supplied 27-run AISI M2–CBN dataset at $a_p = 0.10\text{ mm}$.

The reference dataset provides an important justification for temperature measurement: flank wear changes strongly with cutting speed, but the original study did not directly measure temperature. Direct thermal measurement can therefore test whether temperature is a mediator of the observed speed–wear relationship.

9. Cutting Temperature Measurement Method

Method	Basis	Advantages	Limitations	Research use
Tool–work piece thermocouple	Thermoelectric voltage	Simple; comparative	Average/contact temperature	Comparative experiments
Embedded thermocouple	Sensor response	Robust	Not direct edge peak	Trend monitoring
Infrared/pyrometry	Radiated energy	Non-contact	Emissivity and optical alignment	High-resolution research
Two-colour pyrometry	Spectral ratio	Reduced emissivity sensitivity	Complex calibration	Advanced thermal studies
FE simulation	Numerical heat solution	Spatial field	Needs validated models	Complement to experiment

Table 3. Comparison of cutting-temperature measurement and modelling approaches [3,4,7].

For AISI M2, a calibrated infrared or two-colour approach is particularly attractive for observing the tool–chip region without physically disturbing the cutting zone. The experimental paper should report calibration, emissivity treatment, field of view, sampling rate, optical alignment, chip obstruction and uncertainty.

10. Statistical, Machine-Learning and Optimization Approaches

Taguchi and ANOVA are effective for factor screening and contribution analysis, but they describe discrete experimental levels. Response-surface models provide continuous approximations, while machine-learning models can represent nonlinear relationships. The supplied AISI M2 study compared ANN, SVR, RF, GPR and RSM; ANN achieved test R^2 values of 0.984 for Ra, 0.995 for Fc and 0.988 for VB, with GPR and RSM as close competitors [9].

For a temperature-inclusive study, Vc, f, ap and tool material should be treated as process inputs, with Tmean/Tmax, Ra, Fc, VB and MRR evaluated as responses. Five-fold cross-validation is preferable to relying on a single train/test split for small datasets. Permutation sensitivity can determine whether temperature adds predictive information beyond cutting parameters.

The optimisation problem is inherently multi-objective: Ra, Fc, VB and temperature should generally be minimised while MRR is maximised. NSGA-II or SPEA2 can generate a Pareto front, while TOPSIS or VIKOR can select a compromise solution. Tmax can also be treated as a hard safety constraint.

11. Major Research Gaps

1. Direct temperature measurements for hardened AISI M2 under controlled PCBN, ceramic and carbide comparisons are still needed.
2. Tool grade, coating, edge preparation and nose radius must be controlled when comparing materials.
3. Temperature studies should report measurement uncertainty and the exact measurement location.
4. The coupled chain temperature $\rightarrow$ wear $\rightarrow$ surface integrity should be experimentally verified rather than inferred.
5. Small datasets require cross-validation and uncertainty analysis before strong ML claims are made.
6. Future studies should combine temperature with Ra, Fc, VB, dimensional deviation and, where feasible, residual stress and micro hardness.
7. Optimisation should include thermal constraints and tool cost as well as productivity and surface quality.

12. Proposed Experimental Framework for AISI M2

Review-derived framework for linking tool material, temperature and surface integrity

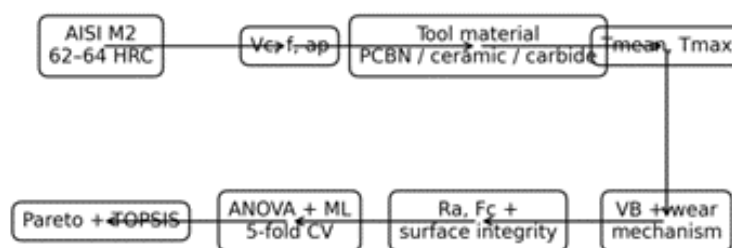


Figure 4. Review-derived experimental framework for linking tool material, cutting temperature, wear and workpiece surface integrity.

A rigorous future experiment should keep work piece hardness, diameter, tool geometry, nose radius, edge preparation, machine and machining environment constant. Tool material should be introduced as a categorical factor while Vc, f and ap are selected from the established AISI M2 window. For every run, Tmean and Tmax should be recorded together with Ra, Fc, VB and MRR. Tool microscopy before and after machining should be used to identify wear mechanisms.

The analysis should include ANOVA, Pearson/Spearman correlation, regression or ML with 5-fold cross-validation, sensitivity analysis, Pareto optimisation and a confirmation experiment. This structure allows the thermal contribution to be separated from the direct effects of cutting speed, feed and depth of cut.

13. Critical Discussion

The literature indicates that cutting temperature is a mechanism-level variable linking cutting conditions, tool material, wear and surface integrity. Cutting speed is a strong thermal driver, but the tool material changes heat generation and heat partition. Consequently, tool rankings by temperature are not universal.

The D2 comparison is particularly instructive: coated carbide exhibited higher temperature than PCBN over part of the tested range but benefited from tribo-film formation and achieved competitive performance [8]. This shows why a review or experimental paper should interpret temperature together with friction, wear mechanism and tool life.

The AISI M2 baseline strengthens this research direction because cutting speed contributed 78.05% of flank-wear variation. The logical next step is to measure temperature directly and test whether the strong speed effect on wear can be explained quantitatively by the thermal state. At the same time, the very large feed contribution to Ra (95.35%) indicates that temperature alone is unlikely to explain surface roughness.

Literature temperature values from other steels should not be inserted as AISI M2 measurements. Thermal conductivity, hardness, composition, tool grade, coating, geometry and measurement method all influence temperature. Therefore, the final AISI M2 publication should clearly separate reference data, literature evidence and newly measured results.

14. Conclusions

- Cutting temperature is a central thermo-mechanical variable linking process conditions, tool material, wear and surface integrity.
- PCBN/CBN, ceramics and cemented carbides offer different combinations of hot hardness, toughness, thermal transport and chemical stability; no single material is universally optimal.
- Coatings can substantially modify friction, heat flow and high-temperature behaviour and must be specified in tool-material comparisons.
- Published evidence shows that coated carbide can outperform PCBN in selected temperature windows, whereas PCBN offers strong hard-turning capability because of its hot hardness and ferrous-material compatibility.
- The supplied AISI M2–CBN case-study data show feed as the dominant factor for Ra (95.35%), feed and depth of cut as major factors for Fc (48.83% and 48.20%), and cutting speed as the dominant factor for VB (78.05%).
- Direct temperature measurement under controlled PCBN/ceramic/carbide conditions is the most important next experimental step for AISI M2.
- Cross-validated ML and multi-objective optimization can connect thermal behaviour with surface quality, tool life and productivity.
- The strongest scientific contribution would be an experimentally validated tool material → temperature → wear → surface integrity relationship.

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