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Overview of Manufacturing Parameter Selection for Grinding Inconel 718 Superalloy Using CBN Grinding Wheels

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ABSTRACT: *This paper presents an overview of the selection of manufacturing parameters in grinding Inconel 718 superalloy using CBN grinding wheels. The results indicate that CBN grinding wheels with vitrified bond, medium hardness, and grit size 100–120 are highly suitable for grinding Inconel 718 superalloy. The cutting speed can be selected either in the low-speed range of 25–30 m/s or the high-speed range of 100–120 m/s; feed rate ranges from 0.05–0.5 m/s; and depth of cut ranges from 0.01–0.05 mm. Minimum Quantity Lubrication (MQL) assisted with nanoparticles improves grinding performance significantly.*

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I. INTRODUCTION

Grinding is a final finishing machining process. The grinding process is a continuous scratching action of abrasive grains randomly distributed on the wheel surface against the workpiece surface. [1]

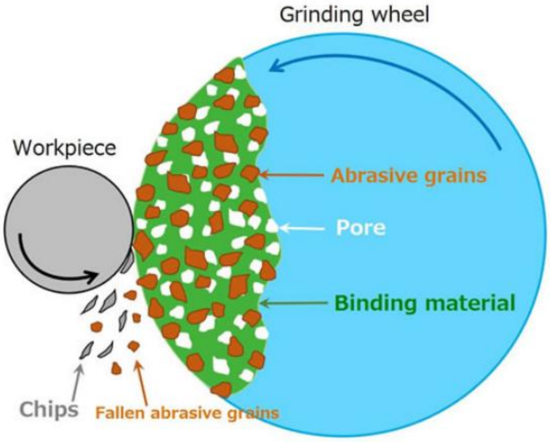


Fig 1. Diagram of grinding process

Grinding wheels using diamond and CBN abrasives are called superabrasive wheels to distinguish them from conventional grinding wheels using aluminum oxide (Al_2O_3) and silicon carbide (SiC) abrasives.

CBN grinding wheels possess high thermal conductivity, which helps reduce the amount of heat transferred into the workpiece, thereby facilitating the generation of compressive residual stresses on the product surface and minimizing surface damage. In addition, CBN abrasive grains have high hardness, which increases wheel life and reduces the influence of wheel wear on machining accuracy [2].

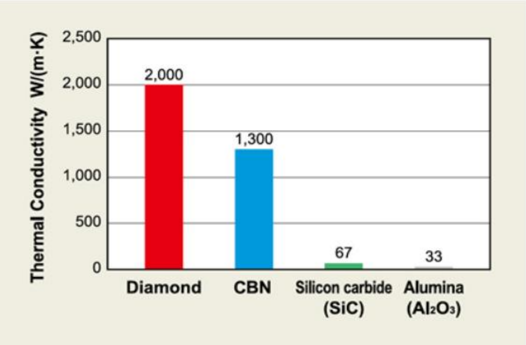


Fig 2. Thermal Conductivity of Abrasives

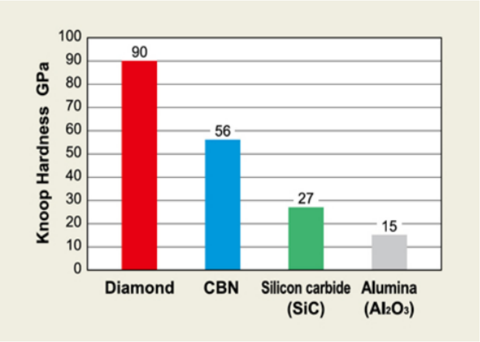


Fig 3. Hardness of Abrasives

CBN grinding wheels are classified according to bonding materials as follows: Resin bond wheel (B-CBN), Metal bond wheel (M-CBN), Vitrified bond wheel (V-CBN), and Electroplated wheel (EP-CBN) [2].

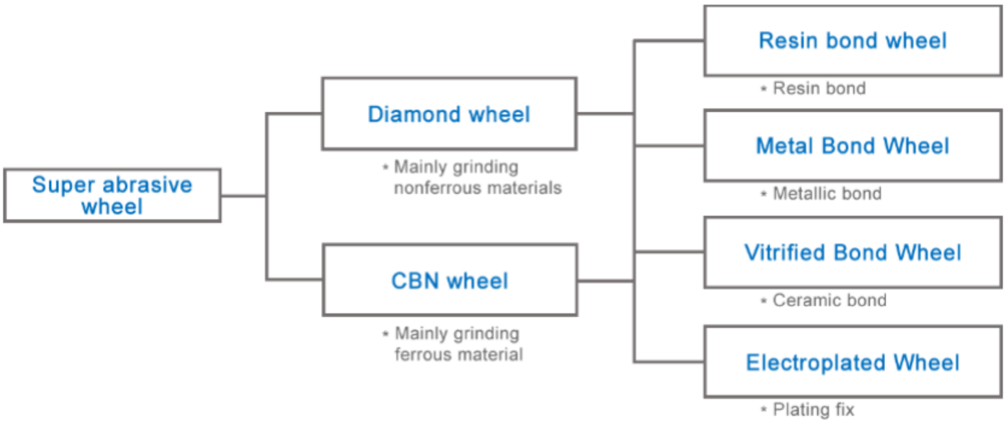


Fig 4. CBN grinding wheel classification

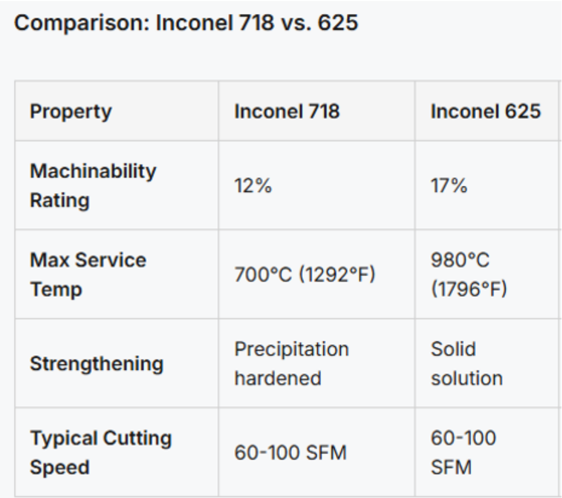
Inconel is a nickel-based superalloy used for manufacturing machine components operating under severe conditions such as high temperature, high stress, and corrosive environments. Inconel exhibits work hardening, low thermal conductivity, and high ductility, making it difficult to machine. According to the American Iron and Steel Institute (AISI), the machinability of Inconel 718 is only 12% [3].

Therefore, selecting appropriate manufacturing parameters is essential for improving the techno-economic efficiency when machining Inconel 718.

Inconel 718 Chemical Composition

Element	Content (%)
Nickel (Ni)	50.0 - 55.0
Chromium (Cr)	17.0 - 21.0
Iron (Fe)	Balance
Niobium (Nb) + Tantalum (Ta)	4.75 - 5.50
Molybdenum (Mo)	2.80 - 3.30
Titanium (Ti)	0.65 - 1.15
Aluminum (Al)	0.20 - 0.80
Cobalt (Co)	1.0 max
Carbon (C)	0.08 max
Manganese (Mn)	0.35 max
Silicon (Si)	0.35 max

Fig 5. Inconel 718 Chemical Composition [3]



Comparison: Inconel 718 vs. 625

Property	Inconel 718	Inconel 625
Machinability Rating	12%	17%
Max Service Temp	700°C (1292°F)	980°C (1796°F)
Strengthening	Precipitation hardened	Solid solution
Typical Cutting Speed	60-100 SFM	60-100 SFM

Fig 6. Machinability of Inconel 718 [3]

II. SELECTION OF GRINDING WHEEL

Grinding wheel selection greatly affects grinding performance. Proper abrasive material selection determines cutting ability and wheel durability. Grit size influences material removal rate and surface roughness. Coarse grit increases productivity but results in poorer surface finish, and vice versa. Wheel hardness affects cutting performance and self-sharpening capability. Bonding material affects durability and operating speed. Wheel porosity influences chip evacuation and heat dissipation.

Pei-Lum Tso et al. [4] compared surface roughness, dimensional accuracy, grinding force, and wheel wear in grinding Inconel 718 using GC, WA, and CBN wheels. The results indicated that CBN wheels exhibited superior grinding characteristics and were most suitable for grinding Inconel 718.

Dhanavathu Naresh Naik et al. [5] investigated the wear of electroplated CBN wheels with grit size 120 in grinding Inconel 718 superalloy. The study showed that EP-CBN wheels are commonly used for grinding superalloys. Their advantage lies in low cost due to having only one abrasive layer. However, their disadvantage is that they cannot be dressed or reground, causing gradual changes in wheel surface condition as wear progresses, which affects grinding performance.

Curtis, D., Krain, H., Winder et al. [6] studied the influence of grinding wheels on surface integrity and residual stress when grinding Inconel 718. The results showed that using EP-CBN wheels produced better compressive residual stress and surface quality compared with Al_2O_3 wheels. This was explained by the higher thermal conductivity of EP-CBN wheels, which reduced cutting temperature and friction in the grinding zone.

Sridhar Kompella and Kai Zhang et al. [7] evaluated the effectiveness of CBN wheels in grinding Inconel 718 superalloy. The two commonly used wheel types are V-CBN and EP-CBN. EP-CBN wheels cannot be dressed or reground and are discarded once the CBN layer wears out. V-CBN wheels can be reground, increasing wheel life. Moreover, V-CBN wheels require less frequent dressing, resulting in higher material removal rates. Regarding abrasive grain types, when the material removal rate (MRR) was 4.8 $mm^3/mm/s$, wheels using CBN B grains had four times longer life than CBN A, while CBN C had 1.7 times longer life than CBN B.

Zhongde Shi, Amr Elfizy et al. [8] used medium-hardness V-CBN wheels with grit size 100–120 to grind nickel-based superalloys. The study concluded that CBN wheels are widely used for grinding Inconel. EP-CBN wheels are more flexible for low-volume production and profile grinding applications. However, they have lower wheel life and material removal rates. V-CBN wheels exhibit higher grinding performance, are suitable for mass production and tight tolerances, and can be reground to increase wheel life.

Thus, vitrified-bond CBN grinding wheels with medium hardness (N) and grit size 100–120 are suitable for grinding Inconel 718 superalloy.

III. SELECTION OF CUTTING PARAMETERS

Cutting parameters (cutting speed, feed rate, and depth of cut) directly affect productivity, surface quality, machining accuracy, and wheel life. Increasing cutting speed improves cutting ability, reduces grinding force, and decreases surface roughness. However, excessive cutting speed generates high heat, causing surface burn and microcracks. Increasing feed rate enhances material removal productivity but also increases surface roughness, grinding force, grinding temperature, and reduces machining accuracy. Increasing depth of cut improves productivity but generates larger grinding forces and heat, reducing surface quality and dimensional accuracy.

C.F. Yao et al. [9] investigated surface integrity in grinding Inconel 718 using Al_2O_3 and V-CBN wheels. The results showed that good surface quality could be achieved with depth of cut $p = 0.005$ mm, feed rate $w = 16$ m/min, and cutting speed $v = 25$ m/s. In this case, the surface roughness was $Ra = 0.012$ µm, surface residual stress was +700 MPa, surface hardness was 440 HV, and the hardened layer depth was 40–60 µm.

Chen-Wei Dai et al. [10] studied the effect of cutting speed on grinding temperature and power consumption when grinding Inconel 718 using V-CBN wheels. The results showed that grinding force reached a minimum at a grinding speed of 120 m/s, while grinding temperature remained below 1000°C. The authors recommended a cutting speed range of 100–120 m/s to achieve surface roughness $Ra \leq 0.4$ µm and prevent crystal lattice deformation.

Hao Liu et al. [11] evaluated the effect of cutting speed on surface quality and surface damage in grinding Inconel 718 using CBN wheels. As cutting speed increased, surface roughness decreased, surface quality improved, and surface microhardness decreased. The depth of the damaged layer remained unchanged when grinding speed was below 15 m/s. This phenomenon was explained by the thermo-mechanical interaction during grinding.

Therefore, grinding at cutting speeds of 100–120 m/s achieves minimum grinding force and the best surface roughness ($Ra \leq 0.4$ µm). Grinding at low speeds of 25–30 m/s is referred to as creep feed grinding (CFG), which is suitable for difficult-to-machine materials such as Inconel 718. At low cutting speeds, grinding heat generation is lower, reducing surface damage, improving cutting capability, and increasing wheel life. The feed rate may range from 0.05–0.5 m/s. Higher feed rates reduce undeformed chip thickness and minimize surface scratching. The depth of cut may be selected within the range of 0.01–0.05 mm.

IV. SELECTION OF LUBRICATION–COOLING CONDITIONS

Lubrication and cooling conditions play a crucial role in grinding because the contact zone between the grinding wheel and the workpiece experiences extremely high temperatures. Proper cooling and lubrication reduce grinding temperature and force, remove chips effectively, minimize surface burn, thermal deformation, and microcracks, and improve surface finish…

Manoj Kumar Sinha et al. [12] studied the effect of Minimum Quantity Lubrication (MQL) on grinding force and surface roughness when grinding Inconel 718. The selected MQL parameters were flow rate 150 ml/h, pressure 8 bar, and nozzle distance 72 mm. The results showed that minimum grinding force and best surface finish were achieved using MQL.

Roshan Lal Virdi et al. [13] compared surface roughness, grinding power, and grinding temperature under flood cooling, MQL, and nano-fluid MQL (NF-MQL) using Al_2O_3 nanoparticles. Flood cooling flow rate was 80 L/h. MQL parameters included flow rate 100 ml/h, pressure 4.6 bar, nozzle distance 20 mm, and Al_2O_3 nanoparticle concentrations of 0.5% and 1%. The results indicated that vegetable-oil-based NF Al_2O_3 MQL improved grinding performance in terms of surface roughness, grinding energy, and G-ratio due to the formation of a stable lubricating film at the wheel–workpiece interface.

Manoj Kumar Sinha et al. [14] compared grinding performance under dry, MQL, NF Ag MQL, and NF ZnO MQL conditions. MQL parameters were flow rate 150 ml/h and pressure 8 bar. The results showed that tangential grinding force under NF-MQL was lower than under dry and conventional MQL conditions. Compared with dry grinding, tangential force decreased by 15%, 25%, and 30% under MQL, NF Ag MQL, and NF ZnO MQL, respectively.

Michal Wojtewicz et al. [15] studied the effect of grinding fluids mixed with graphite and MoS_2 powders delivered using Minimum Quantity Cooling (MQC) in internal grinding of Inconel 718. MQC parameters were flow rate 1080 ml/h, pressure 0.8 MPa, and graphite/MoS_2 concentration 30 g/dm^3. The results showed that optimal grinding conditions were achieved using MQC with an aerosol mixture made from demineralized water combined with MoS_2 and graphite under minimum flow conditions.

Sirsendu Mahata et al. [16] compared grinding force, grinding power, surface roughness, and chip morphology in grinding Inconel 718 under dry, flood cooling, drop-by-drop, and micro-jet lubrication conditions. The study demonstrated the effectiveness of soap-water solution as an environmentally friendly and cost-effective grinding fluid. Among the soap-water methods, the micro-jet technique provided the best results regarding grinding force, specific energy consumption, surface finish, grinding ratio, and chip shape.

R. Bhanu Pavan et al. [17] experimentally investigated graphene nanoplatelet-based MQL in grinding Inconel 718. The results indicated that graphene nanoplatelets reduced grinding force, grinding temperature, grinding power consumption, and surface roughness.

Prashant Patil et al. [18] used water mixed with Al_2O_3 nanoparticles as a cooling lubricant. Experimental results showed that Al_2O_3 nanoparticles reduced grinding force and grinding temperature while achieving the best surface roughness.

Thus, lubrication and cooling are essential in grinding Inconel 718 to avoid surface burning and tensile residual stresses. MQL assisted with nanoparticles provides the best lubrication and cooling performance. Common nanoparticles include Al_2O_3, MoS_2, ZnO, Ag, and graphene. Typical MQL conditions involve flow rates of 80–120 ml/h and pressure of 5–8 bar.

V. RESULTS AND DISCUSSION

This paper reviewed the selection of technological parameters for grinding Inconel 718 superalloy using CBN grinding wheels. The study identified suitable CBN grinding wheels, cutting conditions, and lubrication–cooling methods to improve grinding performance for Inconel 718.

However, current MQL and NF-MQL approaches mainly focus on using single nanoparticles. Research on hybrid nanofluids and interactions among different nanoparticles remains limited. Furthermore, in-depth studies on grinding Inconel superalloys under hybrid nano-MQL conditions, particularly in the direction of multi-objective optimization among grinding force, temperature, and surface quality, have not yet been fully explored.

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