ME-661A TERM PROJECT

TOPIC: SINGLE GRIT GRINDING

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Contents

What is Grinding?

- Many engineering components require **high form and dimensional accuracy**, as well as a very good surface finish.
- Traditional machining methods cannot achieve these results at a desirable material removal rate (MRR).
- Grinding is a machining process that uses **abrasive grits** to remove material from a workpiece in the form of **microchips**.
- Millions of abrasive grits are held together strongly typically in a shape of a circular wheel by a suitable **bonding material**.
- Grinding can achieve high form and dimensional accuracy, as well as a **very good surface finish**, at a high MRR.

Purposes of Grinding

- Dimensional accuracy.
- Good form and positioning accuracy.
- Good surface finish.
- Sharpening tools and finishing objects of harder materials.
- Removing burrs and imperfections
- Creation of specific geometric features

Single Grit Grinding

- It is a grinding process where only a single grit of abrasive is used for material removal.
- The process is mainly used for research purposes to study different characteristics and parameters of grinding.
- Using single grit helps in closely monitoring the interactions between abrasive and workpiece.
- Single grit grinding can achieve very high levels of accuracy and precision.
- It can produce extremely smooth surfaces which is important in precision components like bearings

Single Grit Grinding

- Single grit grinding offers better control over the process than multi grit grinding.
  - In multi grit grinding, non-uniformity in the thickness of the grits can lead to non-uniformity in the resulting chip thickness.
  - This can result in unstable forces on the grinding machine.
  - This problem can be ruled out in single grit grinding.
- Single grit grinding process can be easily customized for grinding multiple materials.
- Single grit grinding wheels can be reused multiple times whereas multi-grit grinding wheels are usually discarded after significant usage.

Abrasive Materials Used in Grinding

Table 1: Properties of Various Abrasive Materials Used in Grinding

	Aluminium Oxide	Silicon Carbide	Cubic Boron Nitride	Diamond
Crystal Structure	Hexagonal	Hexagonal	Cubic	Cubic
Density (g/cm^3)	3.98	3.22	3.48	3.52
Melting Point (°C)	2040	2830	3200	3700
Knoop Hardness (GPa)	20.6	23.5	46.1	78.5

Bond Materials Used in Multi-grit Grinding

- Property Requirements
  - Withstand high magnitude of forces during grinding operations.
  - Withstand high temperatures.
  - Resistance to chemical attack by cutting fluid.
- Popular bond materials
  - Vitrified – Hard, Cheap, Affected by alkaline solution, Most common
  - Resinoid – Used for roughing and fettling off, Affected by alkaline solution
  - Shellac – Easy to manufacture, Used for fine finish and ceramic materials
  - Oxychloride – Less brittle, Affected by shocks and alkaline solution
  - Rubber – High strength and elasticity, Used for parting, tool grinding
  - Metallic – Suitable for ECG

Single Grit Wheel Manufacturing Methods

Using cyanoacrylate (super glue)

- Clean the area on the steel wheel at the desired location with the help of solvent such as acetone or isopropyl alcohol. This will remove any dirt or grease that could prevent the adhesive from forming a strong bond.
- Apply a small amount of adhesive to the grit using the toothpick or other small object. Be careful not to apply too much adhesive, as this can make the grit difficult to position and may also weaken the bond.
- Place the grit on the steel wheel and press down firmly to ensure a good bond.

Single Grit Wheel Manufacturing Methods

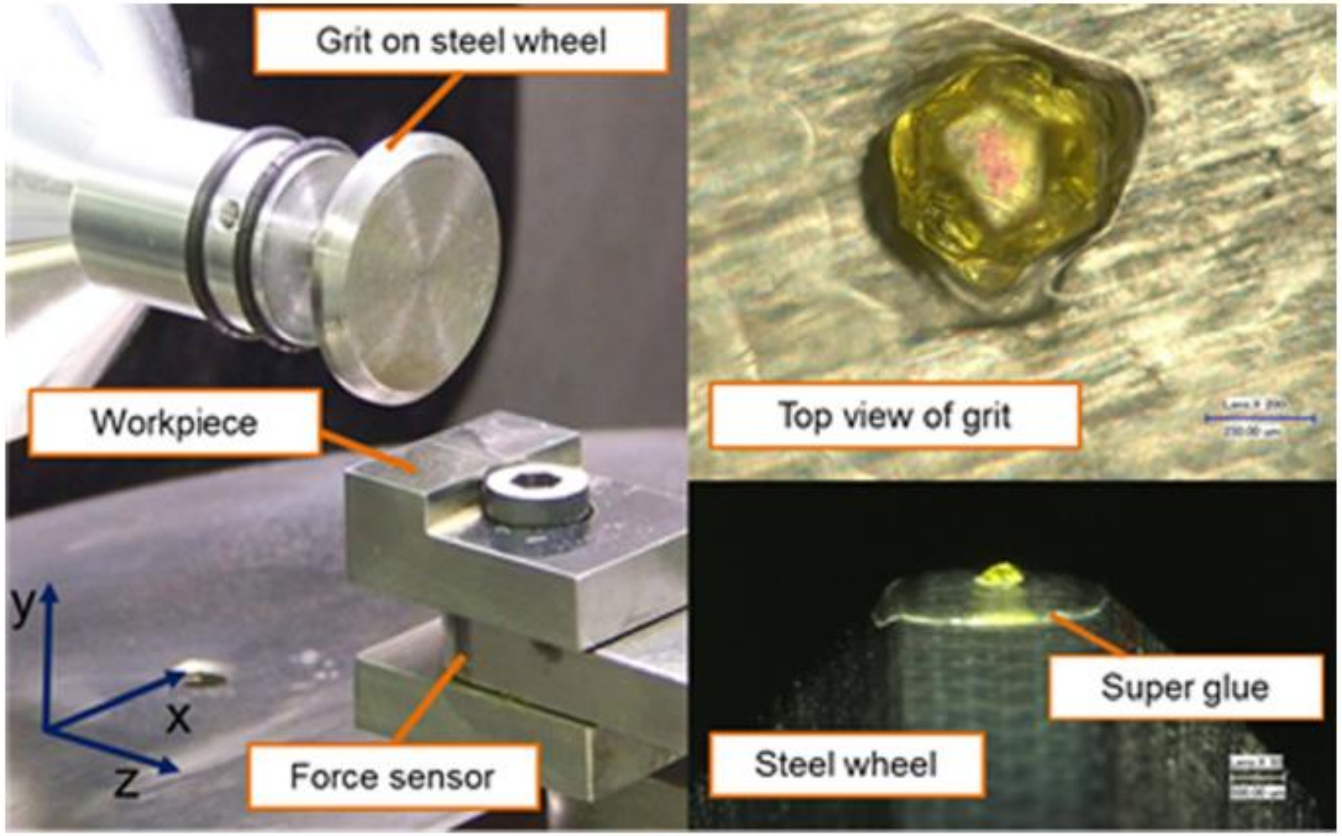


Fig: CBN grit glued to a steel wheel

Single Grit Wheel Manufacturing Methods

Brazing is a strong and durable method for attaching a single grit to a steel wheel. It is particularly well-suited for applications where the grit needs to be able to withstand high forces and temperatures.

- Make sure that the grit and the steel wheel are clean and dry before brazing.
- Apply a thin layer of flux to the grit and the steel wheel.
- Use a heat source that is appropriate for the brazing alloy you are using.
- Heat the grit and the steel wheel until the brazing alloy melts and flows between them.
- Allow the brazing alloy to cool and solidify completely before using the grinding wheel.

Single Grit Wheel Manufacturing Methods

Fig: Multifaceted diamond grain brazed at the tip of a steel shank

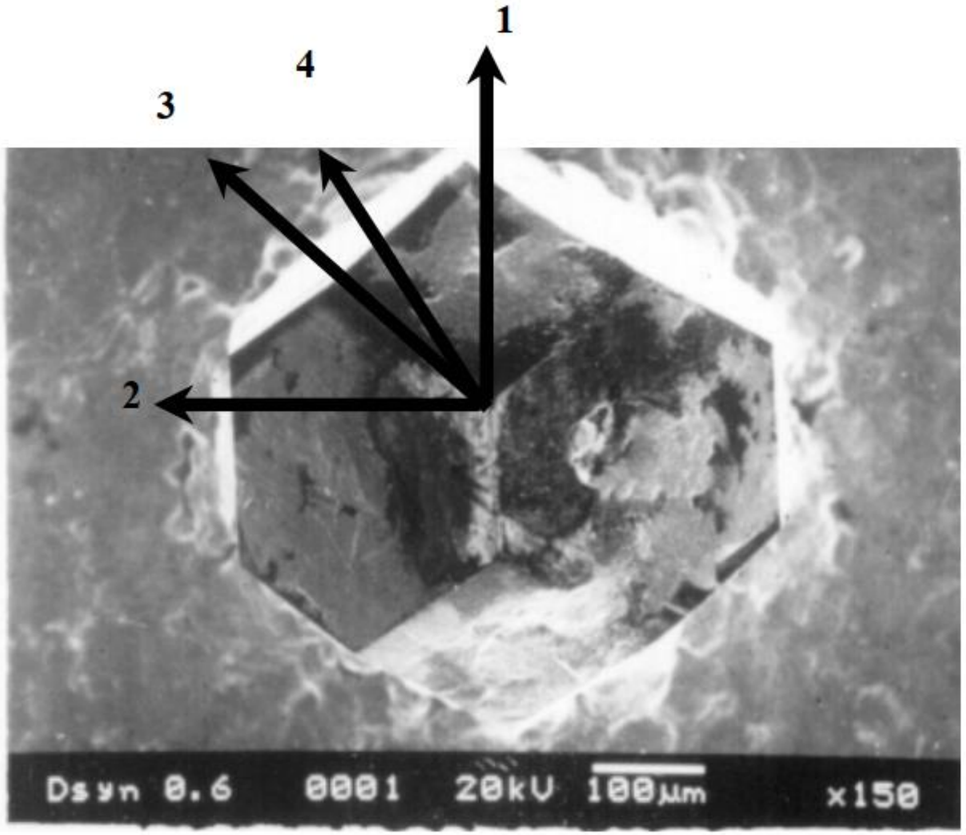


Fig: SEM image of Multifaceted diamond grain brazed at the tip of a steel shank

Single Grit Wheel Manufacturing Methods

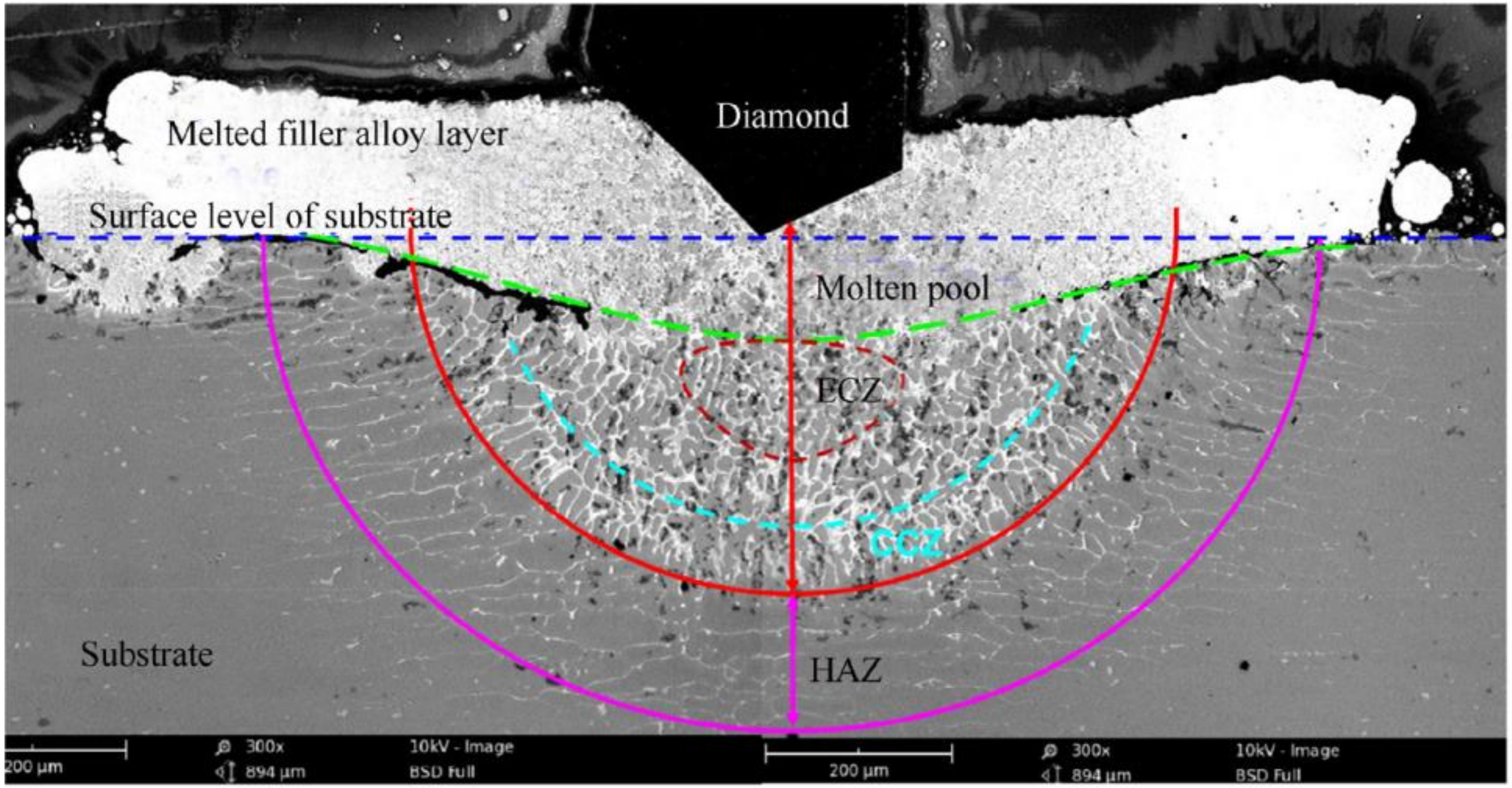


Figure: SEM image of the cross-section of a brazed diamond joint

Single Grit Wheel Manufacturing Methods

Sintering:

Sintering is a process in which the grit is heated to a high temperature, causing it to bond to the steel wheel. This method is very strong and durable, but it can be difficult to control the temperature and ensure that the grit is evenly bonded to the wheel.

Electroplating:

Electroplating is a process in which the grit is coated with a metal, such as nickel or copper, and then bonded to the steel wheel using an electrical current. This method is also very strong and durable, but it can be more expensive than other methods.

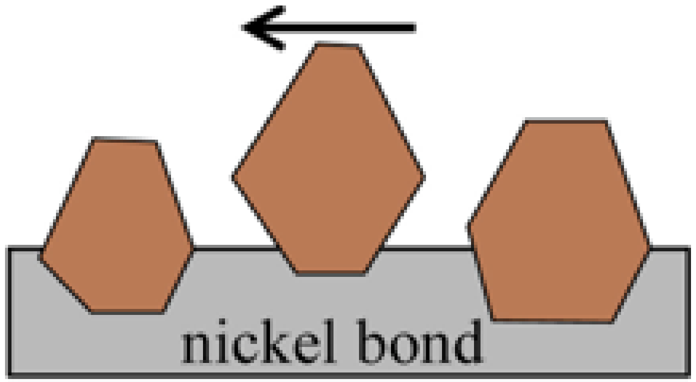


Fig: Schematic of grits bonded by electroplating

Single Grit Wheel Manufacturing Methods

Mechanical bonding:

Mechanical bonding is a process in which the grit is physically attached to the steel wheel using a mechanical fastener, such as a rivet or screw. This method is not as strong as sintering or electroplating, but it is easier to apply and can be used for applications where the grit does not need to be as securely attached.

Adhesive tape:

Adhesive tape can be used to temporarily attach a single grit to a steel wheel. This method is not as strong as the other methods, but it is very easy to apply and can be used for applications where the grit does not need to be permanently attached.

Single Grit Wheel Manufacturing Methods

Soldering:

Soldering is a process of joining two metals together using a metal alloy with a lower melting point than the metals being joined. In this case, you would solder the abrasive grain to the steel wheel. (The grit must be metal, which is usually not)

Pre-bonded wheel:

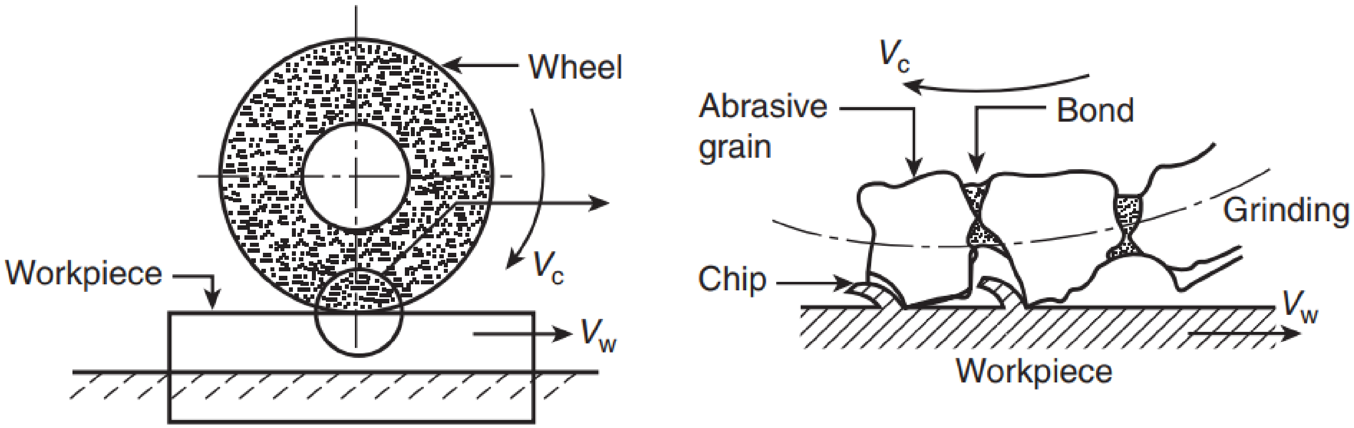
Another alternative is to use a pre-bonded grinding wheel. Pre-bonded grinding wheels are manufactured with the abrasive grain already bonded to the wheel. This eliminates the need to glue the grit on yourself. (Readily casted with the single grit already positioned)

Single Grit Wheel Manufacturing Methods

Table: Pros and Cons of different single grit wheel manufacturing methods

Method	Advantages	Disadvantages
Gluing	Simple, inexpensive, easy to apply	Not as strong as other methods, adhesive can fail under high forces or temperatures
Sintering	Very strong and durable	Can be difficult to control the temperature and ensure that the grit is evenly bonded to the wheel
Electroplating	Very strong and durable	Can be more expensive than other methods
Brazing	Very strong and durable, well-suited for applications where the grit needs to be able to withstand high forces and temperatures	Relatively complex process, requires specialized equipment and skills

Mechanism of Material Removal



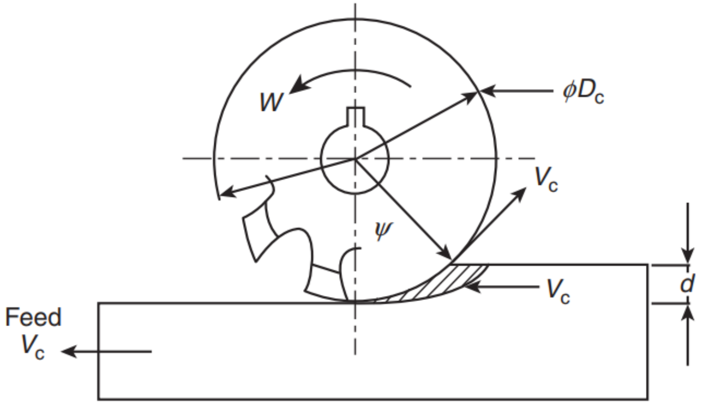


Fig 1: Material removal by abrasives in grinding process [2]

Fig 2: Material removal in plain milling [2]

Mechanism of Material Removal

- Abrasive grits in grinding wheels do not have a definite shape, unlike cutters used in machining operations.
- The statistical average rake angle of abrasive grits is highly negative (-60°).
- To minimize the unfavorable effect of high negative rake, the cutting speed is kept very high compared to machining.
- For conventional grinding wheels, the grinding velocity can be as high as 50 m/s for steel components.

Mechanism of Material Removal

- Grinding wheels rotate at high speed to achieve high grinding velocity.
- The workpiece moves in contact with the wheel, either by reciprocating or rotating.
- The workpiece speed is much slower than the grinding velocity, typically around 10-20 m/min for conventional grinding wheels and steel workpieces.
- The depth of engagement between the workpiece and the wheel is known as infeed.
- Infeed in grinding is typically very small, in the range of 2-50 μm for surface grinding of steel with conventional wheels.

Mechanism of Material Removal

Three stages in material removal by an abrasive grit:

1. Rubbing
2. Ploughing
3. Shearing (Chip formation)

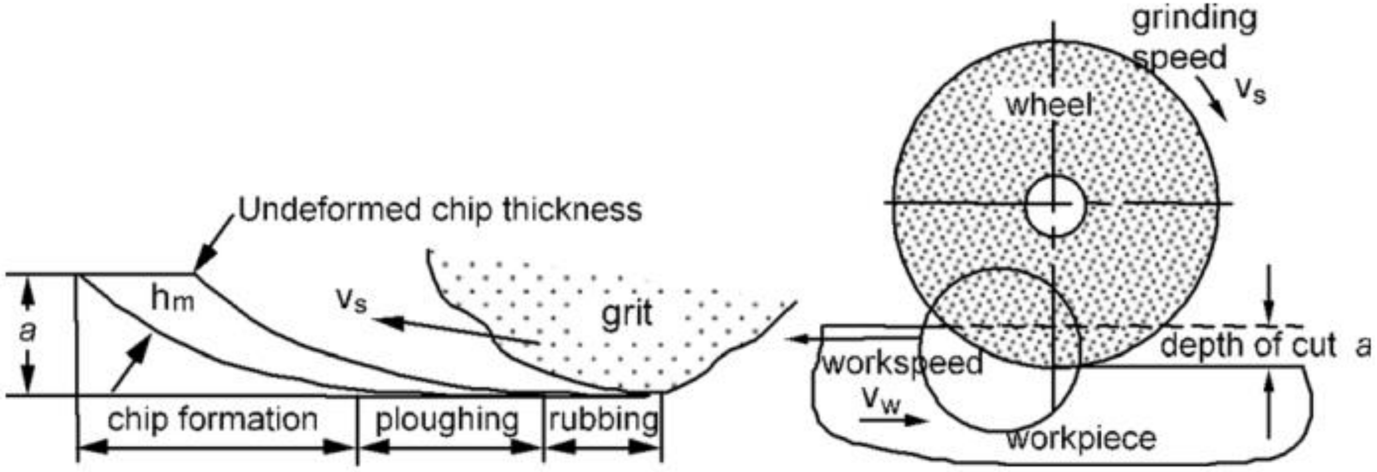
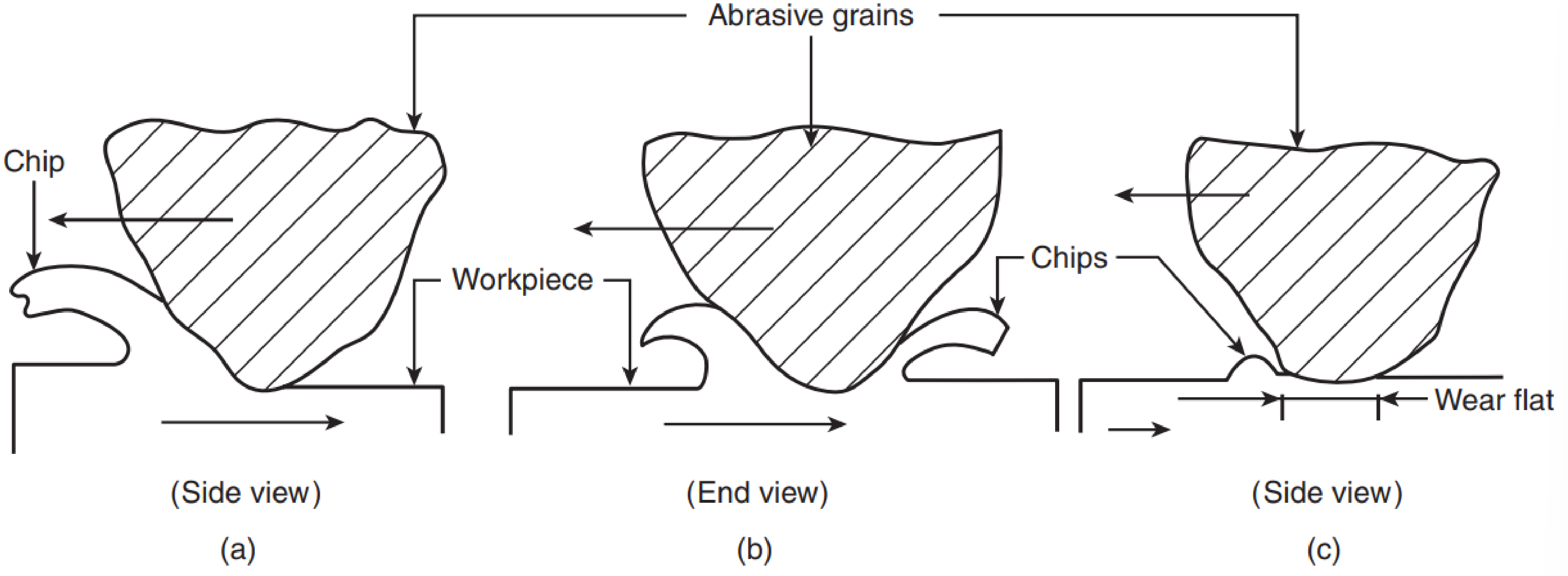


Figure 3: Material Removal by an Abrasive Grit [1]

Mechanism of Material Removal



Shearing **Ploughing** **Rubbing**

Figure 4: Schematic illustration of (a) Shearing, (b) Ploughing & (c) Rubbing [2]

Mechanism of Material Removal

- **Fracturing and Crushing**:

  This mode of chip formation occurs in grinding brittle materials such as ceramic, carbides, etc. where the chips are produced as fine powders of fractured debris for brittle fracture of the work material ahead the grit.

- **Spherical Chip Formation**:

  Chip particles at high temperature leaving the grinding zone and entering the atmosphere would tend to oxidize and melt. During such oxidation or melting they take near-spherical shape.

Effect of grinding velocity

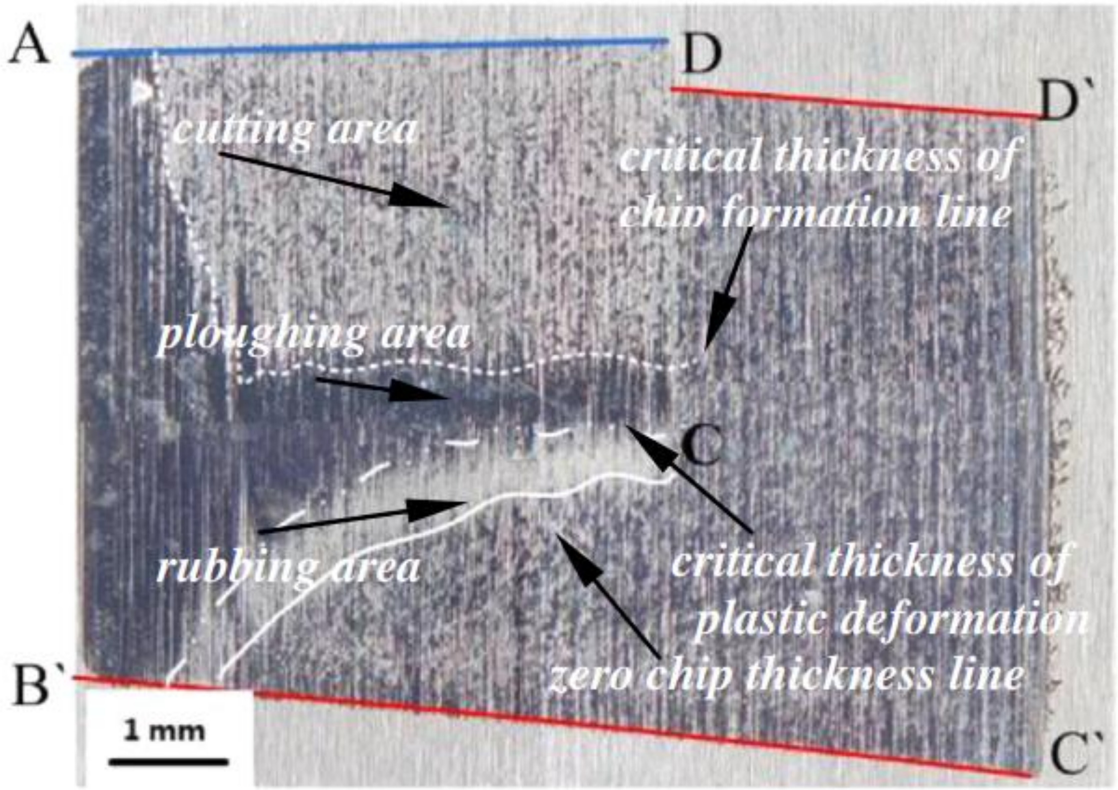


Figure 4: Three zones of grinding on a ground workpiece

Critical thickness for plastic deformation:
Threshold after which plastic deformation takes place

Critical thickness of chip formation line:
Threshold after which chip formation takes place

Effect of grinding velocity

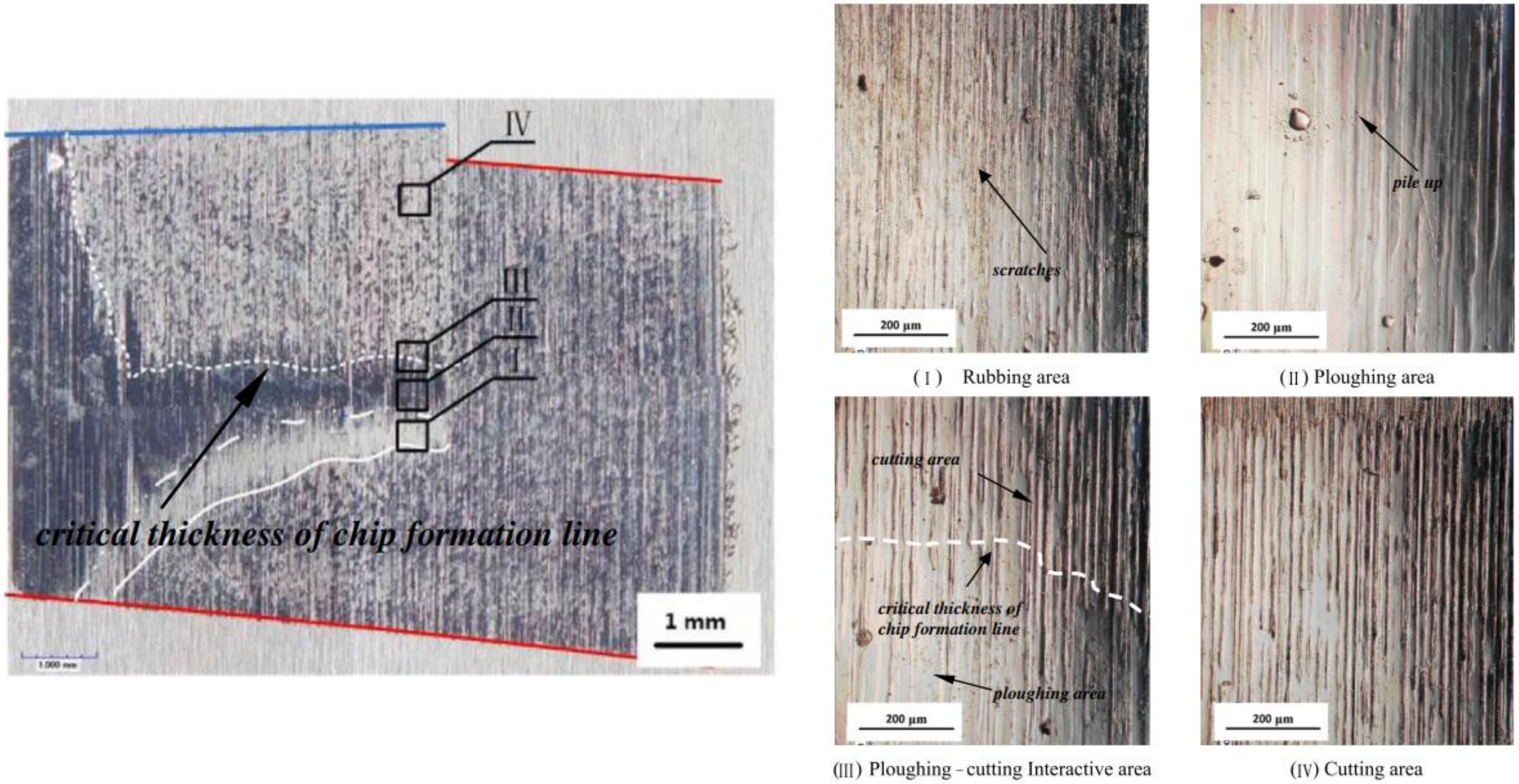


Figure: Morphology of the surface and its detailed views at a grinding speed of 20 m/s

Effect of grinding velocity

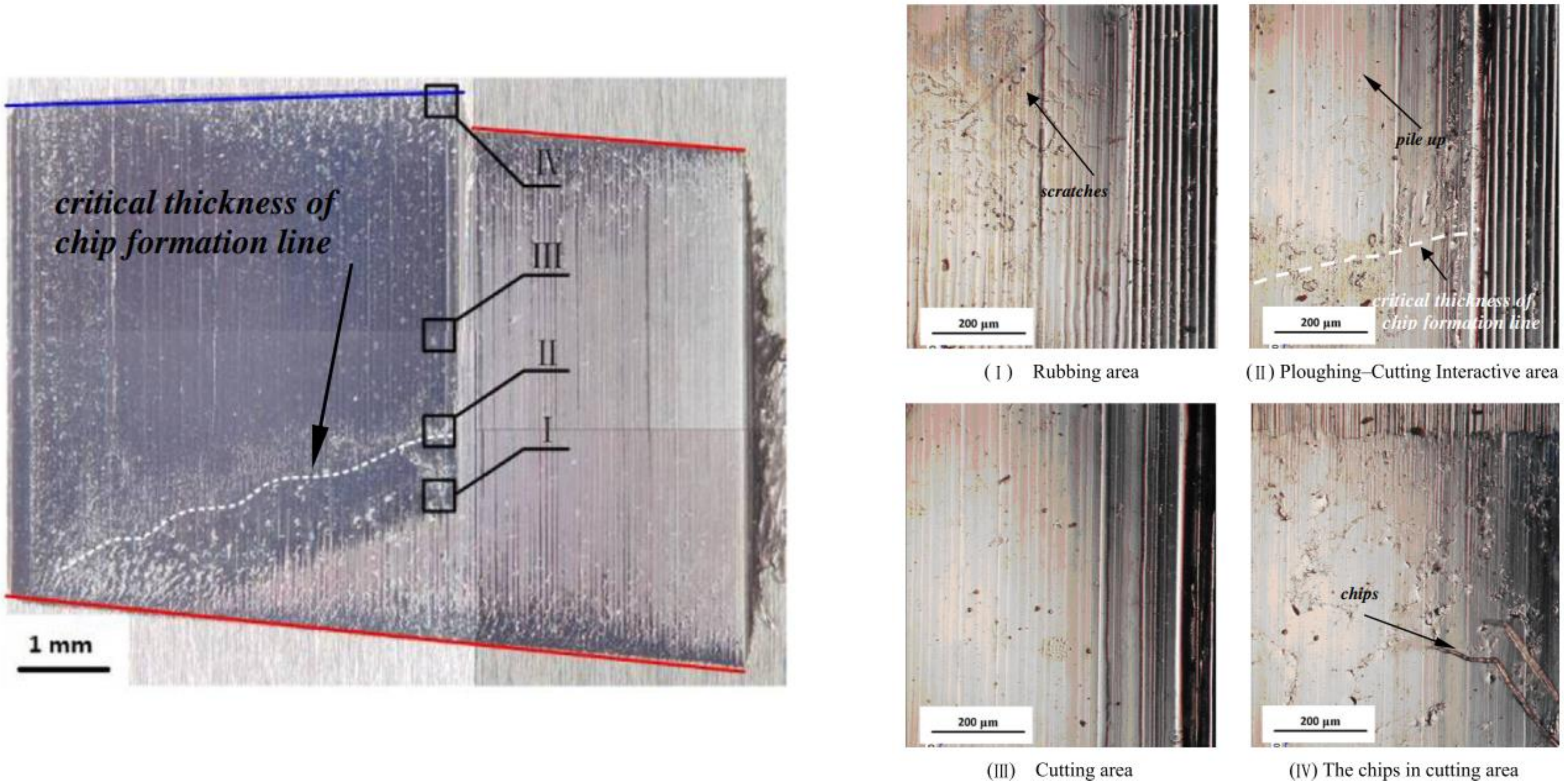


Figure: Morphology of the surface and its detailed views at a grinding speed of 100 m/s

Effect of grinding velocity

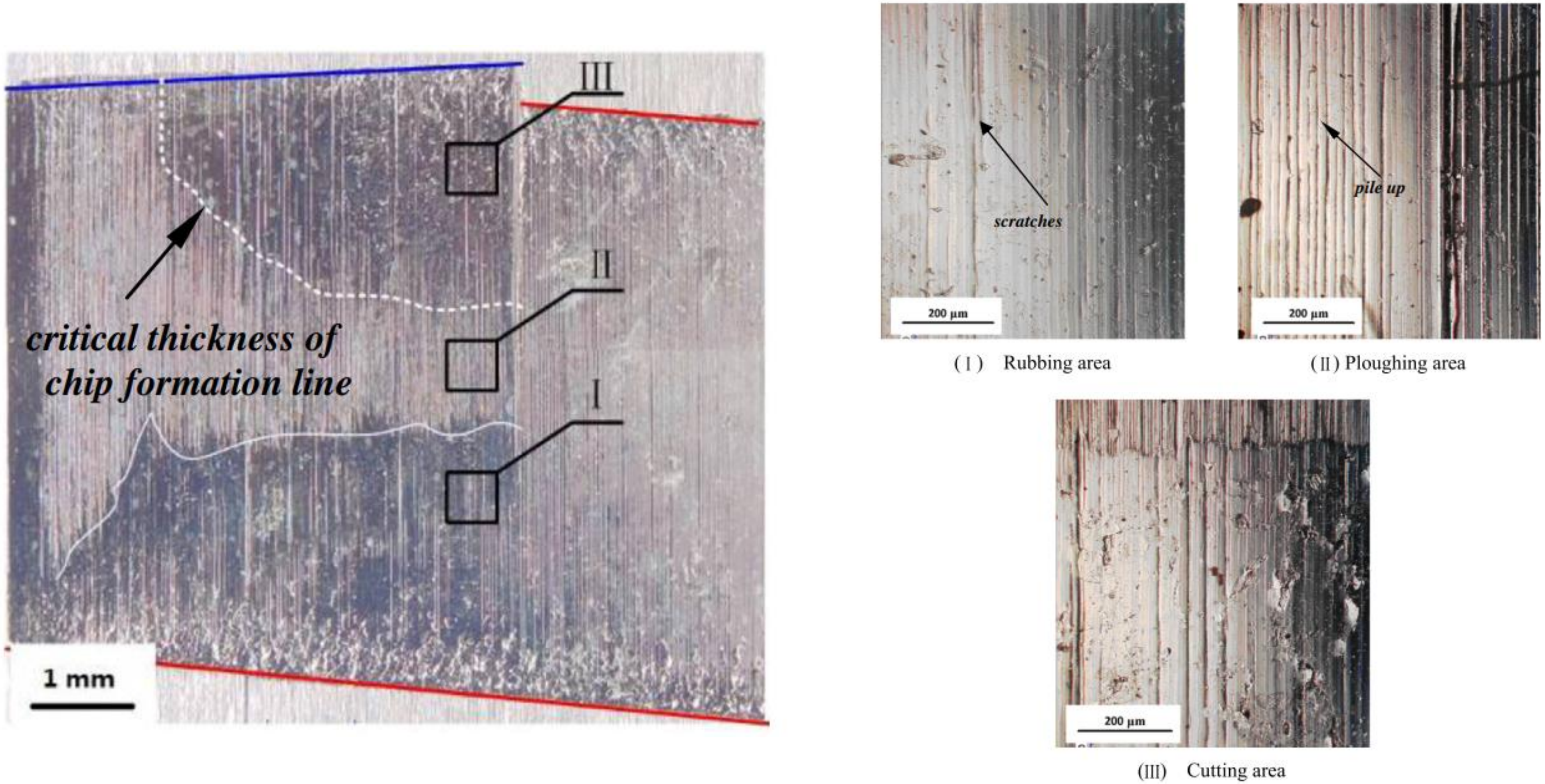


Figure: Morphology of the surface and its detailed views at a grinding speed of 165 m/s

Effect of grinding velocity

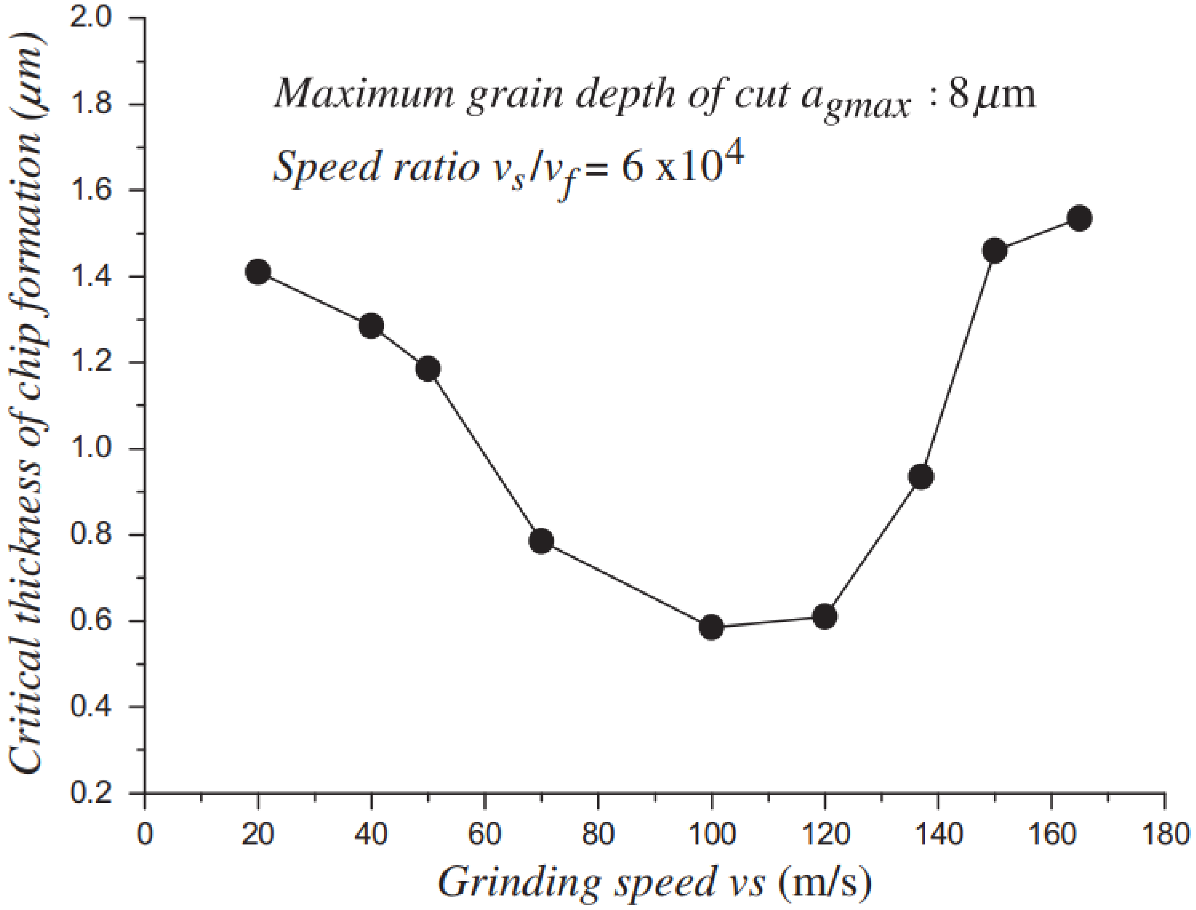
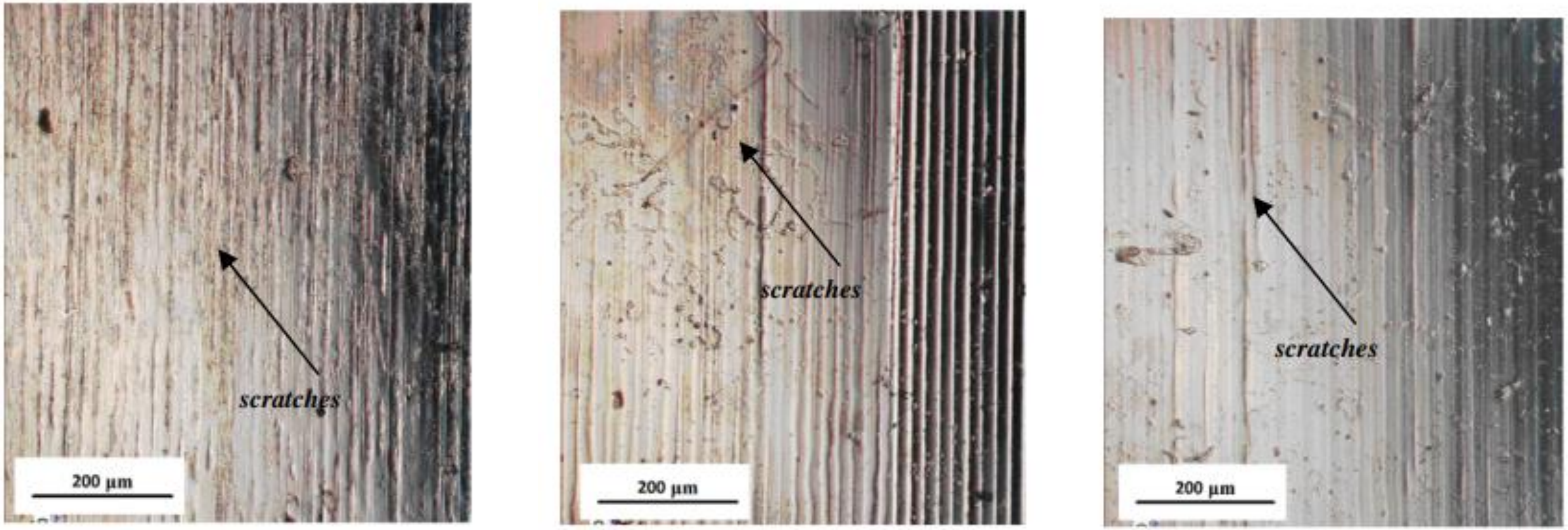


Figure: Effect of speed on critical thickness of chip formation

Effect of grinding velocity



(a) 20 m/s (b) 100 m/s (c) 165 m/s

Figure: Comparison of surface morphologies in rubbing zones at different grinding speeds

Effect of grinding velocity

Figure: Comparison of surface morphologies in ploughing zones at different grinding speeds

Effect of grinding velocity

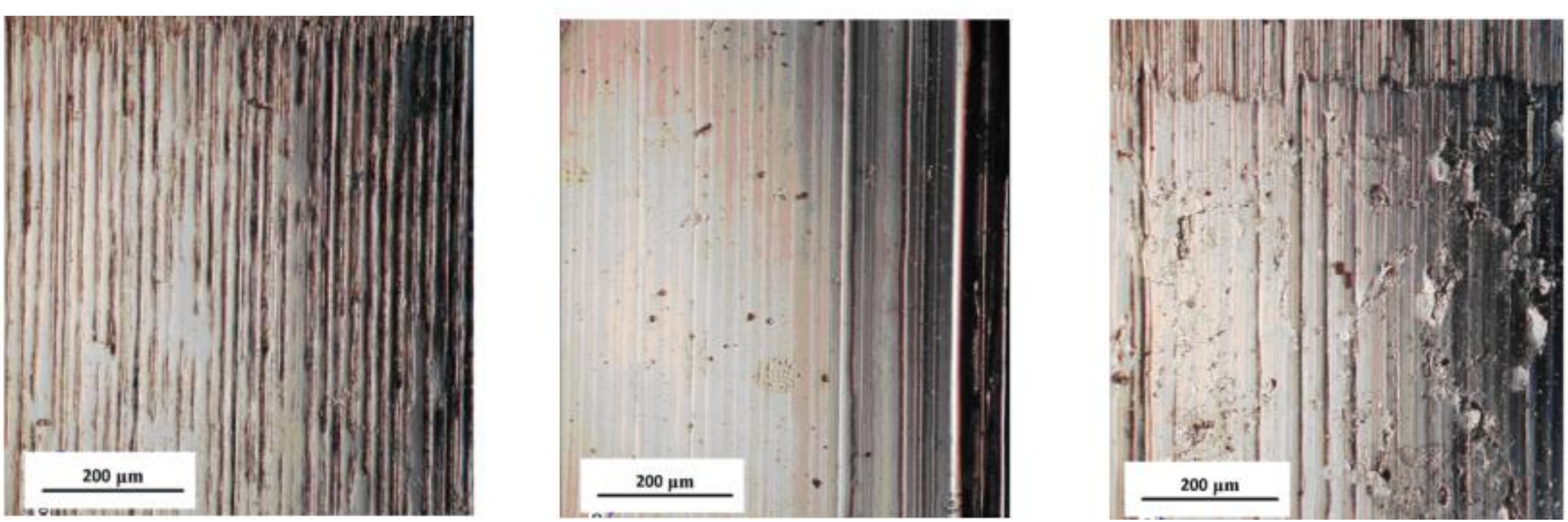


Figure: Comparison of surface morphologies in cutting zones at different grinding speeds

Effect of depth of cut

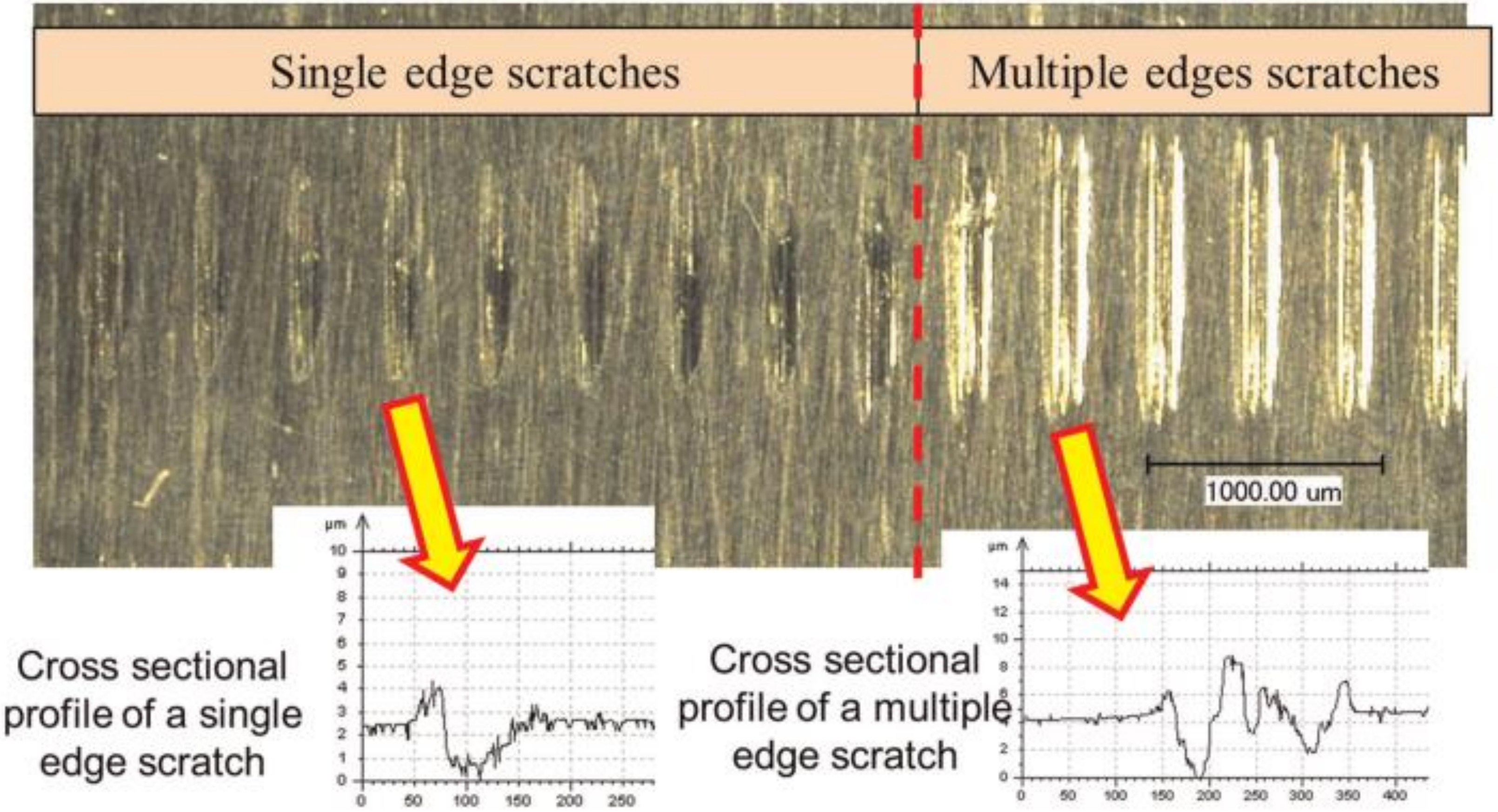
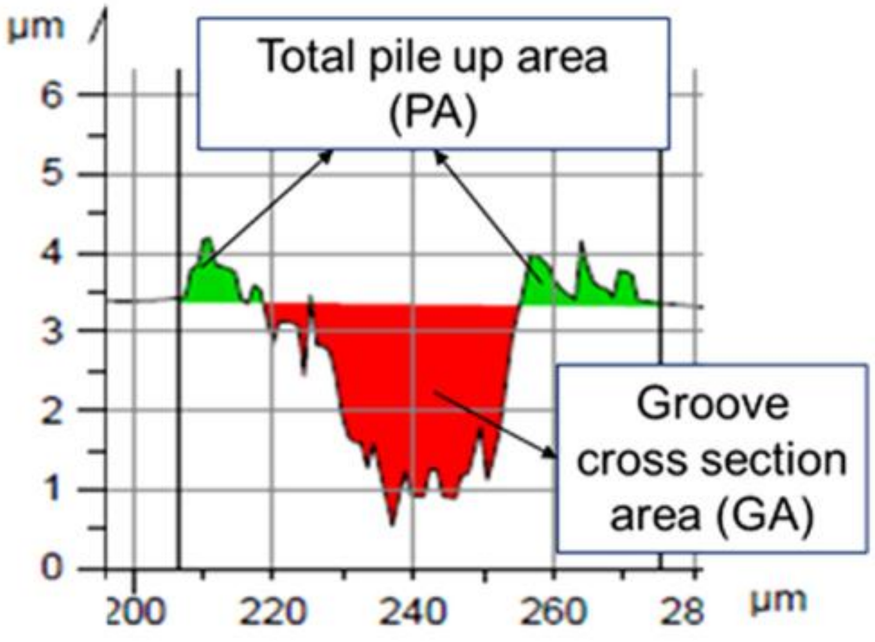


Figure: Increase in number of cutting edges with an increase in depth of cut

Effect of depth of cut



$$\textit{Pile up ratio} = PA / GA$$

$$\textit{Actual material removal area}\,(\mu m^2) = GA - PA$$

Figure: Illustration on calculation of pile-up ratio

Effect of depth of cut

- Pile up ratio increases with a decrease in depth of cut.
- Pile-up ratio can have a value larger than unity when the depth of cut is very small (less than 1 micron).
- At smaller depth of cut, the grit pushes material forward leading to residual accumulation at different positions along the scratch path.
- Cutting might exist with a very small proportion compared to that exists at a higher depth of cut.

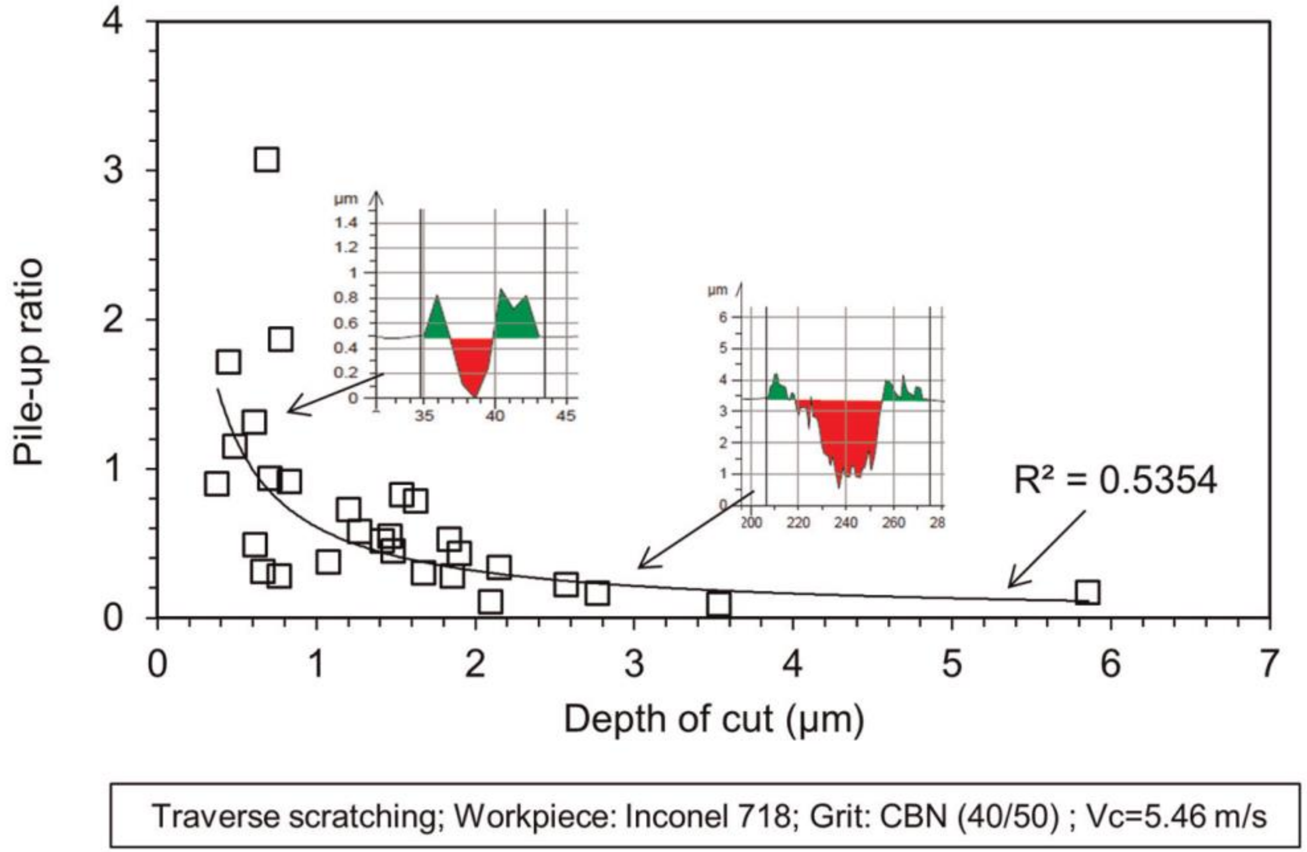


Figure: Variation of pile-up ratio with depth of cut.

Effect of grit shape

- Increased number of cutting edges on a single grit reduces the specific cutting force for brittle materials.
- Reducing the contact area between the grit and the workpiece is important to get a reduced specific cutting force for ductile materials.
- The grit cutting edge shape changes continuously during the grinding process. Starting with single cutting edge, the attritions and fracture wear lead to formation of multiple cutting edges.
- The formation of these new sharp cutting edges is known as the process of self-sharpening.

Grit wear

- The two most important reasons for grit wear are grit fracture and failure of bonding material.
- Some grits will be loosely bonded with the bonding material. During the initial grinding cycles, these grits get easily pulled out from the bonding materials. This contributes to the initial radial wear.
- Grit fracture take place when the forces on any property bonded grit exceed the fracture strength.

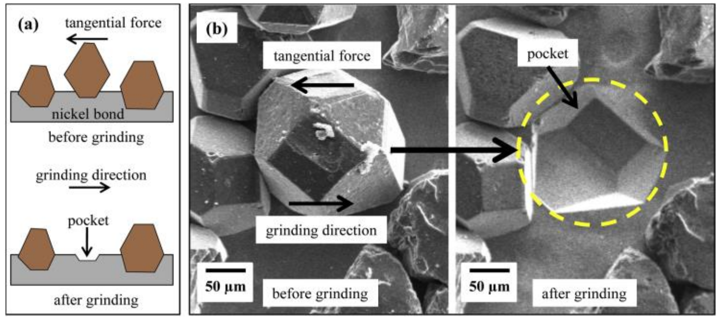


Figure: Dislodgement of a diamond grit from the bond

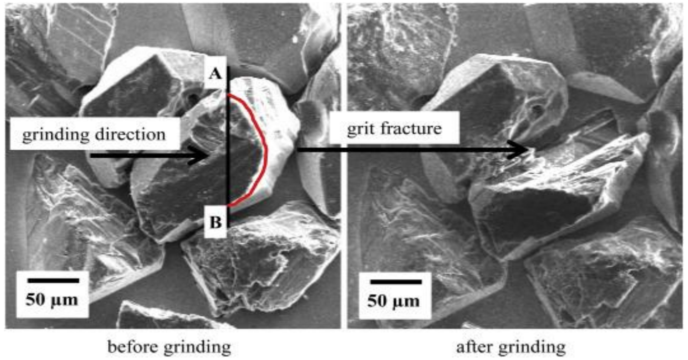


Figure: Fracture of a diamond grit

Grit wear monitoring

- Cutting parameters of grit depends on geometric parameters, however geometry changes with the progression of attrition and fracture wear, hence decrease grinding efficiency.
- Acoustic Emission (AE) signals used in monitoring conditions to detect wear.
- AE arises from elastic waves generated by the release of strain energy, relate to fracture and wear.
- AE sensor is very sensitive to minor molecular and geometric changes, considering that grit wear leads to wear flats, result in geometric changes which is detected by AE sensor.

Grit wear monitoring

- Differences of AE signals (both in frequency and energy domain)between sharp and blunt grits were investigated and results were used to influence of grit wear.
- Frequency spectrum obtained by Fourier transform and energy proportion by discredit wavelet transform(DWT).
- AE signals emitted during single grit grinding primarily generated from displacement of material particles caused by elastic or plastic deformation.
- AE signals in time domain primarily include signal amplitude, amplitude, mean value, RMS and AE counts.
- AE counts were calculated as $Nc = C \times \log_e k\ (1/V)$
- C AND k are factors and V is the volume of material removed.

Grit wear monitoring

- It has been observed that AE counts of the signals generated by sharp grit was bigger than the blunt grit due to more material deformation.

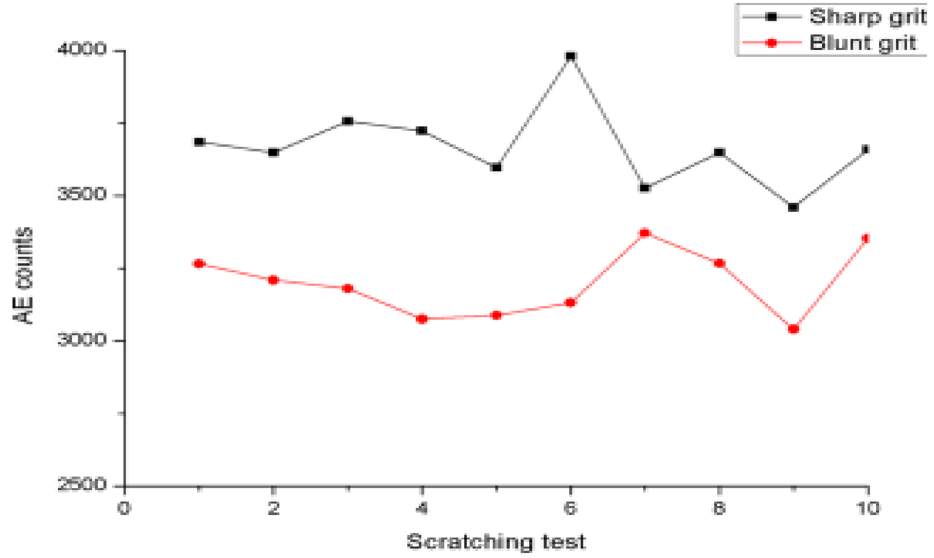


Figure: AE counts vs Scratch length

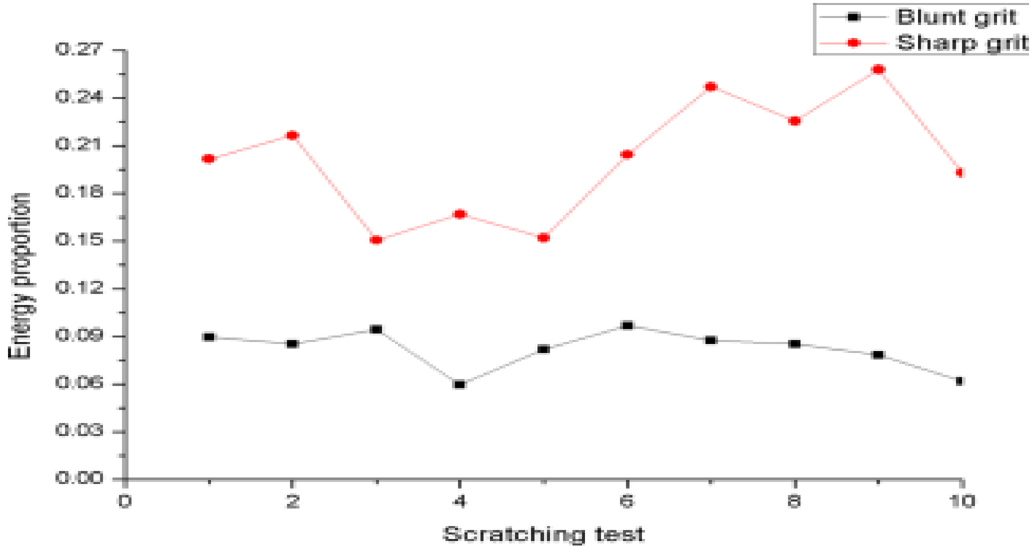


Figure: Energy proportion vs Scratch length

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