Some information about chips thickness on mill cutting

The thickness of the chips on milling operation changes continuously and they have a complex shape which depends from many different factors.

In order to simplify the matter it's better to talk about the average thickness of the chips: this is a parameter which give an idea about the cutting force and how much the milling cutter and the milling machine are stressed.

For starting we can consider the figure N°1. It shows a milling cutter 100% engaged: bad working condition that it's better to avoid in order to reduce the contact time and the heating of the cutting edges.
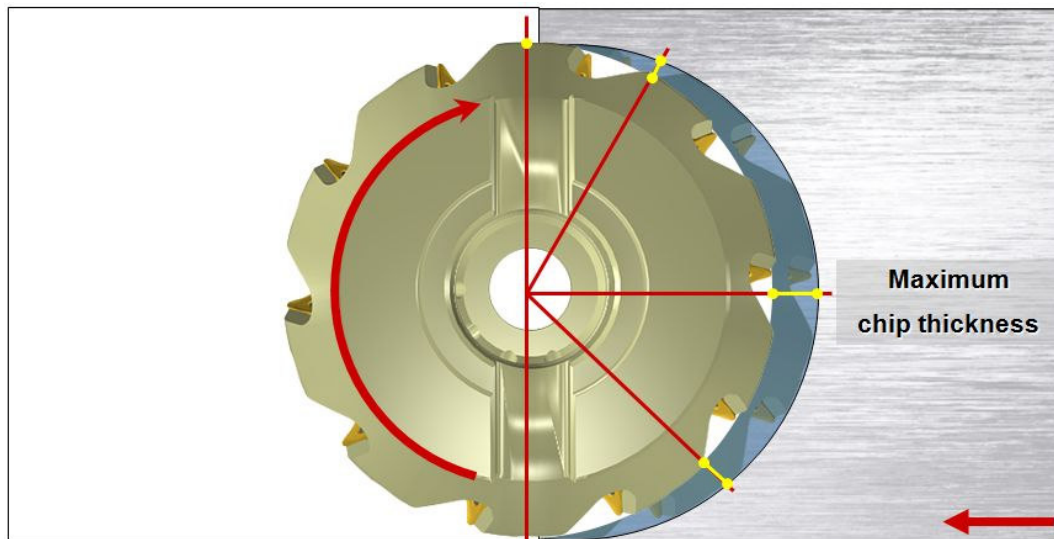

Figure N°1 – *Insert milling cutter with 100% engagement*

The figure shows that the thickness of the chip change from zero on the beginning and end position of the edge to the maximum in the middle of the stroke.

In the situation shown by the figure N°2, we can see that the contact arc is reduced to 50%, but the maximum chips thickness is not changed. It's reduced only the contact time and therefore the milling cutter works in better condition. The average chip thickness is the same of the previous example.
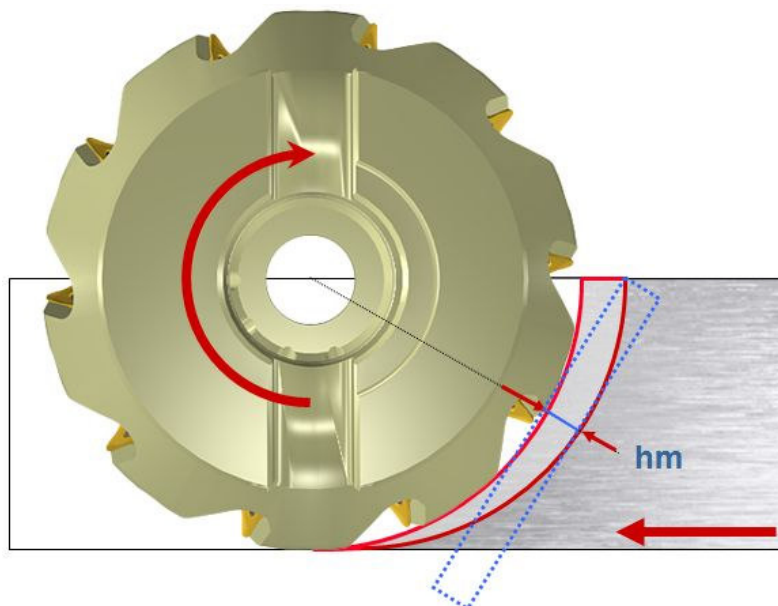

Figure N°2 – *Insert milling cutter with 50% engagement*

If the arc if engagement is reduced also the average chip thickness becomes smaller, how it's illustrated in the figure N°3
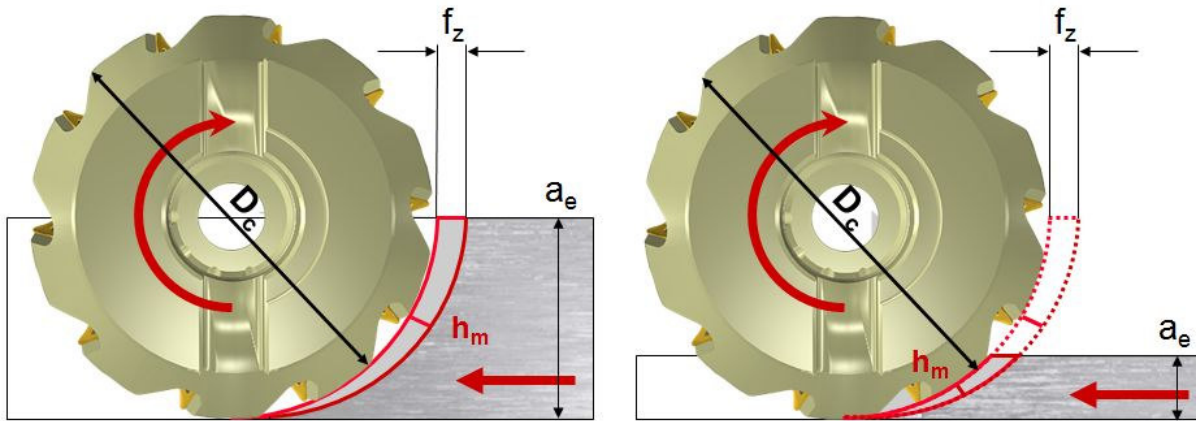

Figure N°3- *If the arc if engagement is reduced also the average chip thickness becomes smaller*

Up to now we examined the chip thickness in the radial section, and we can see that it's depends from the length of engagement arc, that is from depth of cut and of course from the feed per tooth f_z. But the chip thickness is also greatly influenced by the entering angle, how the figure N°3 shows clearly.

This figure shows that with an entering angle of 45° the chip thickness is 30% less, but its width is increased of the same value.
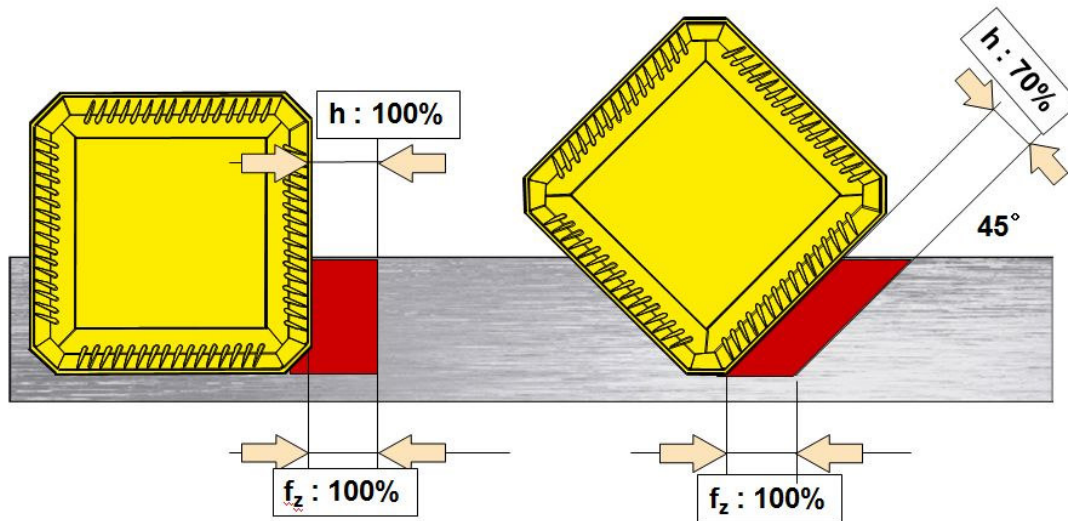

Figure N°4- *The chip thickness depends of the entering angle*

In accordance with the above figures and with the followings symbols we have the formulae:
- D = Outside diameter of milling cutter (mm)
- a_e = Depth of cut in the radial direction (mm)
- a_p = Depth of cut in the axial direction (mm)
- Z = Number of edges of milling cutter
- V_c = Cutting speed (m/min)
- n = Number of revolution per minute
- f_z = Feed per tooth (mm)
- f = Feed per devolution of milling cutter (mm/revolution)
- V_f = Speed of feed (mm/min)
- Ψ = Entering angle

$$f_z = h_m \cdot \frac{D \cdot \pi}{a_e} \cdot \frac{\omega_e}{360} \cdot \frac{1}{\sin \psi} \quad \text{(mm/revolution)}$$

It's possible to use the simplified formula in case the ratio $\frac{a_e}{D}$ is between 0,4 – 0,3.

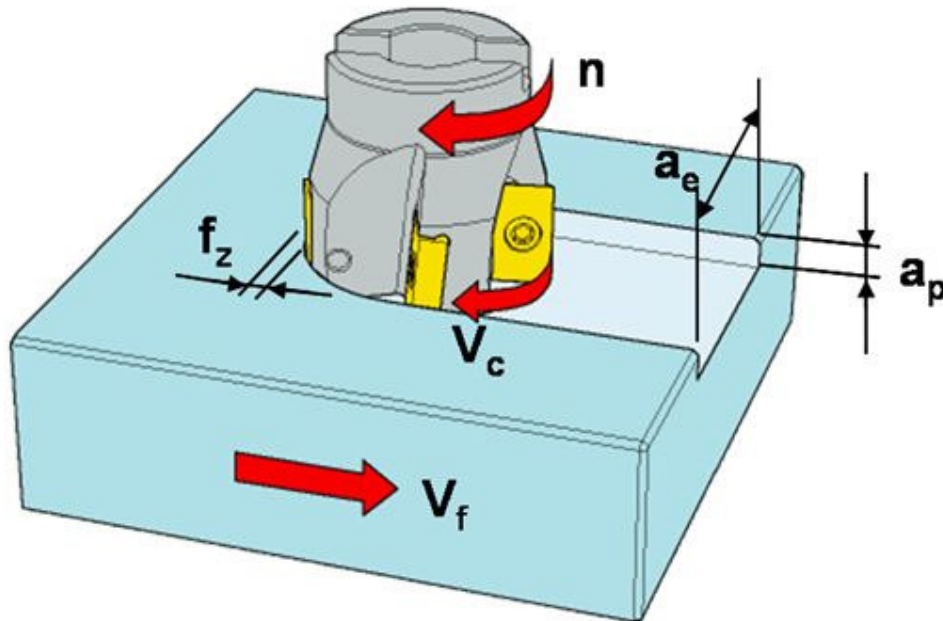$$f_z = h_m \cdot \sqrt{\frac{D}{a_e}} \cdot \frac{1}{\sin \psi}$$

Figure N°5 – *Calculation of the working condition on milling operation.*

With reference of the figure N°5 there are the following most common formulae:
Cutting speed

$$V_c = \frac{\pi \cdot D \cdot n}{1000} \qquad n = \frac{V_c \cdot 1000}{\pi \cdot D}$$

Feed per devolution and feed per minute

$$f = f_z \cdot Z \quad \text{(mm/revolution)} \qquad V_f = f \cdot n \quad \text{(mm/min)}$$

Metal removed rate Q

$$Q = \frac{a_e \cdot a_p \cdot V_f}{1000} \quad \text{(cm}^3\text{/min)}$$

Chip thickness

$$h_m = f_z \cdot \sqrt{\frac{a_e}{D}} \qquad \text{(With the angle } \psi = 90°)$$

$$h_m = f_z \cdot \sqrt{\frac{a_e}{D}} \cdot \sin 45° = f_z \cdot \sqrt{\frac{a_e}{D}} \cdot 0{,}707 \qquad \text{(With the angle } \psi = 45°)$$

The experience gives the following rules:
  ➢ *If the chip is too thick there are a danger of edge breakage*
  ➢ *If the chip thickness is too thin   there are a danger of big wear*

The shape of the cutting edge must be made in according to the machined material.
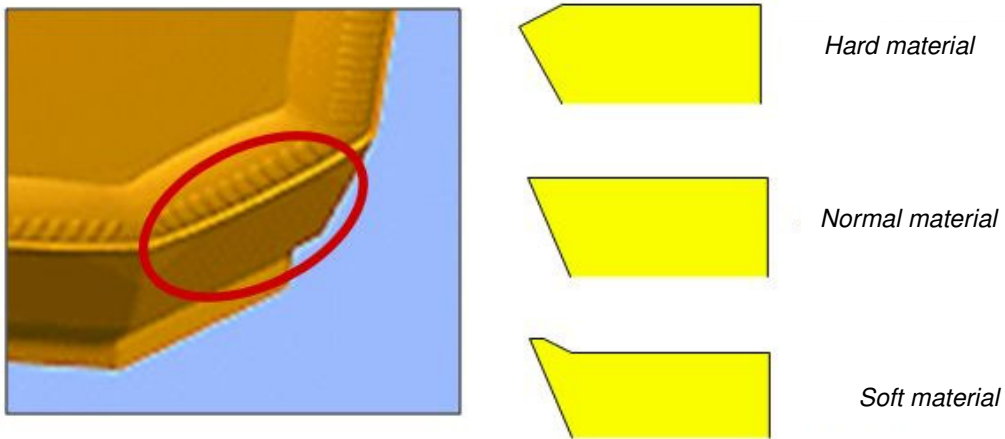If the cutting edge has a protection chamfer, its size must be equal or bigger than the feed per tooth f_z.

Hard material

Normal material

Soft material

Figure N°6 – *Shape of the cutting edge*