

Hob wear

The problem of hob wear is very complex but several considerations must be made on this matter since it has a direct impact on the final cost of the gear.

Over the last three decades and still very much today, research has been carried out continuously with the basic aim of trying to reduce the speed with which wear develops near the cutting edge.

This research has certainly given us a better understanding of the mechanisms that cause this phenomenon. New types of cutting materials have been studied such as, for example, modern superalloy high speed steels or new types of carbide and coating technology has been optimised.

Over the last few years, the life of hobs has been remarkably prolonged and, at the same time, the cutting speeds and feeds at which modern hobs can work have dramatically increased.

When non-coated hobs in steels such as M2 were still in use, it was possible to hob a gear with $R = 600 \text{ N/mm}^2$ and a cutting speed of about 50 – 60 m/min, hour. With some superalloy steels and appropriate coatings, it is now possible to reach cutting speeds of even 170 – 200 m/min and a higher number of pieces can be hobbed with less than half the amount of wear.

There are two types of wear that occur on hob teeth.

The first is known as crater-type wear and it forms on the cutting face, that is on the surface that is resharpened. The second type is abrasive-type wear and this forms immediately behind the cutting edge.

Apart from the extension and the position, the crater is characterised by its depth K_D . See figure No.1.

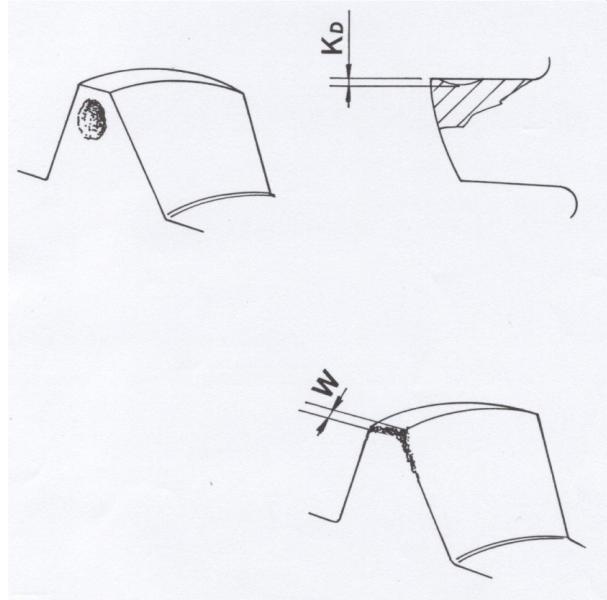


Figure No.1

When the chip breaks off from the gash, the contact point between the material of the workpiece and the tool is not the cutting edge but it is an area which is nearer the inside part. See figure No.2.

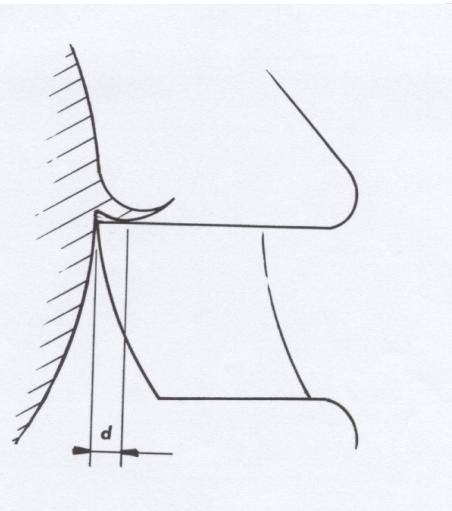


Figure No.2

This means that the centre of the crater will be at a certain distance **d** from the cutting edge. This distance depends on many elements. Apart from the rake angle, which for the purpose of this calculation is considered as zero degrees, it depends on the type of material that is being cut, that is whether it is more or less resistant and above all it depends on the chip thickness, that is on the feed and the hob characteristics such as the number of starts and the number of teeth.

It is not easy to calculate the chip thickness, also because the form and the thickness vary continuously but it can generally be said that the greater the feed per workpiece revolution, the larger the chip and the larger the number of gashes of the hob (equal to the number of starts), the smaller the chip thickness. The interdependence of the various factors that influence the chip thickness is illustrated well by the Hoffmeister formula which will be examined in more detail in another article.

The greater the thickness, the greater the pressure that the chip exerts on the tool surface and therefore the higher the speed at which craters form.

The mechanism by which craters are formed, that is the way in which material is removed from the tool, is equally complex.

In simple terms it is possible to say that it occurs in two phases. A first phase in which a part of the chip welds itself onto the tool surface which is possible thanks to a chemical affinity between the cut material and the tool steel. This welding effect occurs more easily, the greater the pressure exerted on the tool by the chip and the higher the temperature at the point of contact.

In the second phase this welded material separates from the tool surface, taking with it particles of material of the tool itself. This phenomenon lasts about a hundredth of a second.

After a certain amount of time the crater therefore forms and it tends to expand, spreading gradually towards the cutting edge until the latter is so weak that it may break and cause chipping. Such chipping may vary in entity but in a short space of time it will, in any case, render the cutting edge unsuitable for removing material.

It is clear that this process progresses at a much slower rate if the material of the cutting edge is hard.

Considering that the temperatures at the point of contact reach very high levels - even above 600 °C - it is important that the tool steel retains its hardness properties when heated.

This is in fact the advantage of steels with a high alloy content. To slow this process down, however, it is also important that there is a weak chemical affinity between the two surfaces that are in contact, the chip and the tool.

This is where TiN and TiAlN coatings come onto the scene or so-called multi-layer coatings which are formed by multiple layers of different chemical composition.

This film, which is deposited onto the tool surface and which is normally about 3 microns thick, is extremely hard and is able to retain its hardness properties at high temperatures without chemically reacting with the tool steel. The formation of material build up behind the cutting edge does therefore not occur.

It is also important to remember that the maximum temperatures at which the most common recoatings may be utilised are the following. The approximate temperatures at which the coating completely loses its properties and flakes off are indicated in brackets.

- $TiN = 500 \text{ } ^\circ\text{C} (600 \text{ } ^\circ\text{C})$
- $TiCN = 400 \text{ } ^\circ\text{C} (450 \text{ } ^\circ\text{C})$
- $TiAlN = 700 \text{ } ^\circ\text{C} (800 \text{ } ^\circ\text{C})$.

This greatly limits the formation of craters and it also becomes clear why the recoating of tools after each resharpening is so important.

Apart from the feed per workpiece revolution, the cutting speed also plays an important part. The higher the cutting speed, in fact, the greater the amount of heat that is produced within a said time and therefore the greater the temperature of the chip at the point of contact.

This, however, is not as simple as it may seem.

It is in fact necessary to consider two phenomena which, in a certain sense, reduce the danger of increased cutting speeds.

The first is that if the chip is machined at high temperatures, it becomes more plastic and it is therefore easier to remove. It exerts less pressure on the tool surface. The second is that if the chip runs at high speeds, it has less time to transmit heat to the tool. A great amount of the heat produced remains within the chip itself.

This can perhaps explain the strange and, at a first glance, surprising influence that the cutting speed has on hob performance. If we draw a graph with the cutting speed indicated on the abscises and the metres of material cut per tooth shown on the ordinates, the curve obtained is the type illustrated in figure No.3.

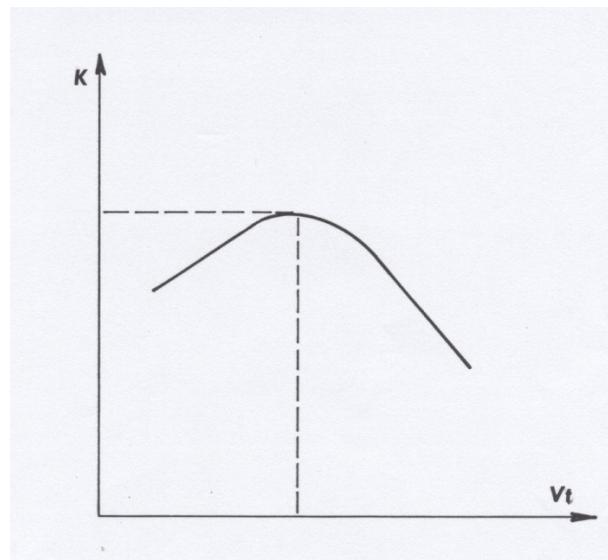


Figure No.3

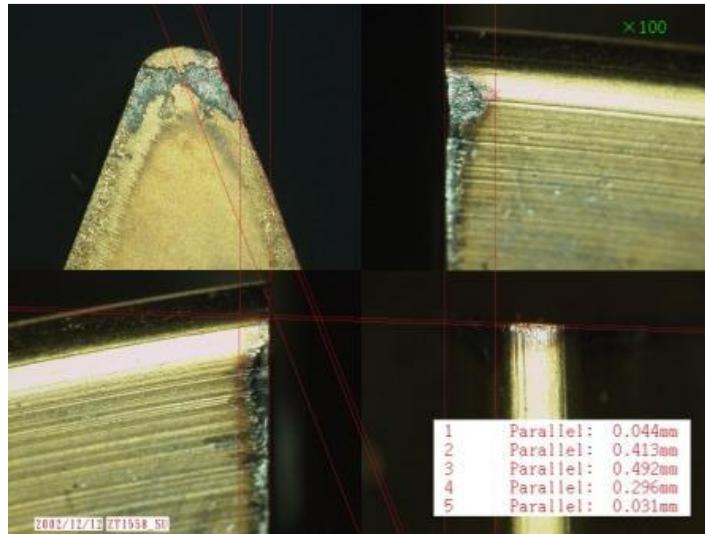


Figure No.4 – Abrasion type wear



Figure N°5 – Crater type wear

In other words there is only one optimum speed and this depends on many factors such as, for example, the type of material that is being cut, the material from which the hob is made, the feed per workpiece revolution and so on.

As each of these elements vary, the optimum speed, that is the highest point on the curve, moves left or right or up and down accordingly.

This generally goes against the common opinion that the reduction of the cutting speed must correspond to a decrease in wear formation and therefore an increase in hob performance.

As can be seen, however, in certain conditions the reduction of the cutting speed may correspond to a lower hob performance.

Abrasive-type wear is formed through a similar process to that of crater-type wear, the only difference being that the situation worsens as cutting speeds increase.

Increasing temperatures caused by friction as well as the resistance limits of the coating causes a rapid decrease in the wear resistance properties of the tool and it provokes gradual deterioration of the gash.

The side relief angle, as has been previously examined, is generally between 2 and 3° but when the cutting edge starts weakening and rounding, the area behind it rubs against the section of the gear which has just been cut and wear therefore amplifies.

It is extremely important to remove the hob from the machine before the level of wear becomes too advanced. After a certain limit, the development of wear itself rapidly increases. Currently this limit is about 0,2 – 0,3 mm.

The formation of abrasive-type wear in relation to the metres of gear teeth hobbed per tooth (K), is governed by an unusual law which is roughly illustrated in figure No.6.

The curve may be divided into three parts. In the first part the wear increases rapidly, in the second the wear increases more slowly and proportionally to K and in the last part the curve increases at an exponential rate.

Clearly the hob must be removed from the machine before getting to this last part of the curve.

Depending on the job at hand, the length of the different parts of the curve varies. To accurately estimate the length of each phase, it would be necessary to carry out a series of practical trials.

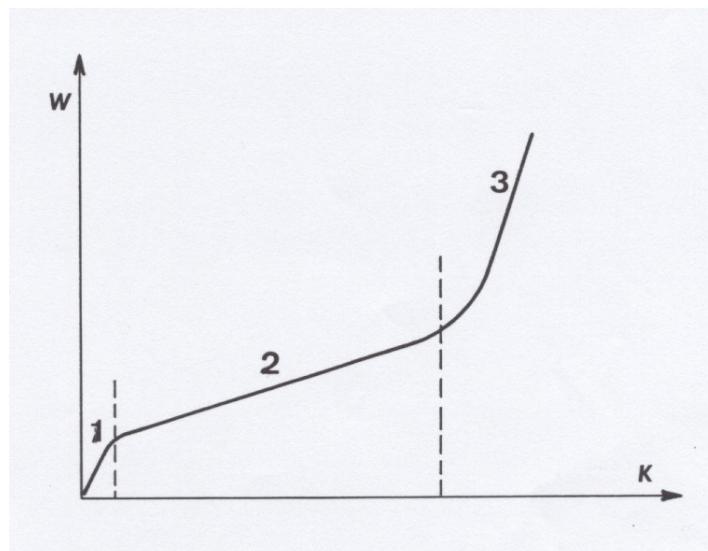


Figure No.6

Since abrasive-type wear is caused by the area behind the tooth rubbing on the section of the gear tooth that has just been cut, it is possible to say that the more times a hob tooth passes on the workpiece, the more it will be subject to wear.

It is therefore damaging, as far as wear is concerned, to reduce the feed per workpiece revolution and in a more general sense to decrease the chip thickness.

We might imagine that by reducing the volume of the material that each tooth removes per each revolution, the cutting pressure would be reduced, less heat would be generated and the pressure on the tooth and relative wear would also be reduced. This is, however, true to a certain extent. If the feed per revolution is reduced, the length of tooth travel in making contact with the workpiece increases since the number of revolutions that the hob must perform to finish the gear increases and therefore the effect of the friction between the hob and the workpiece becomes more damaging.

Abrasive-type wear therefore develops more quickly.

Other considerations may be made with regard to the formation of abrasive-type wear on coated hobs.

First of all, if we examine figure No.7, it is possible to see that right on top of the coated cutting edge where the two TiN layers meet, there is an area which is subject to micro-chipping and it is exactly in this area that the coating layer starts flaking. This flaking then progresses more or less quickly. The substrate, that is the body of the high speed steel or carbide tool, must then resist the tooth completely giving way.

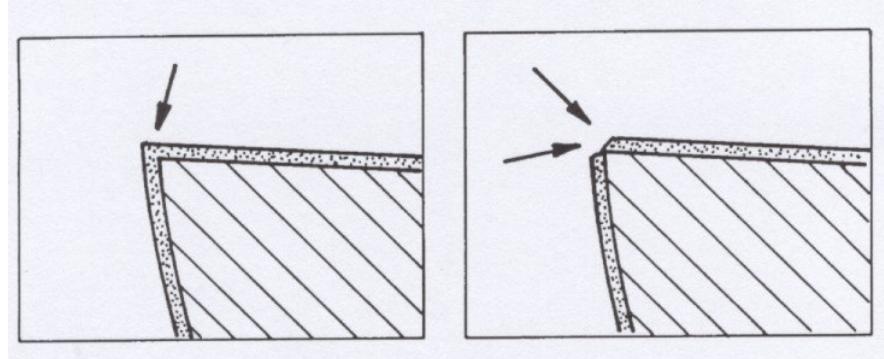


Figure No.7

This is why the cutting edge is usually slightly rounded off on carbide hobs since this material is more fragile (only 0,01 – 0,02 mm). The TiN layer better adheres to the surface and it is more resistant around the cutting edge.

The tolerable wear entity is different if we compare coated and non-coated hobs. If a hob is not coated, it is possible to utilise it until the maximum wear area reaches 0,50 mm whilst with coated hobs it is opportune to substitute the hob when the level of wear reaches 0,20 mm.

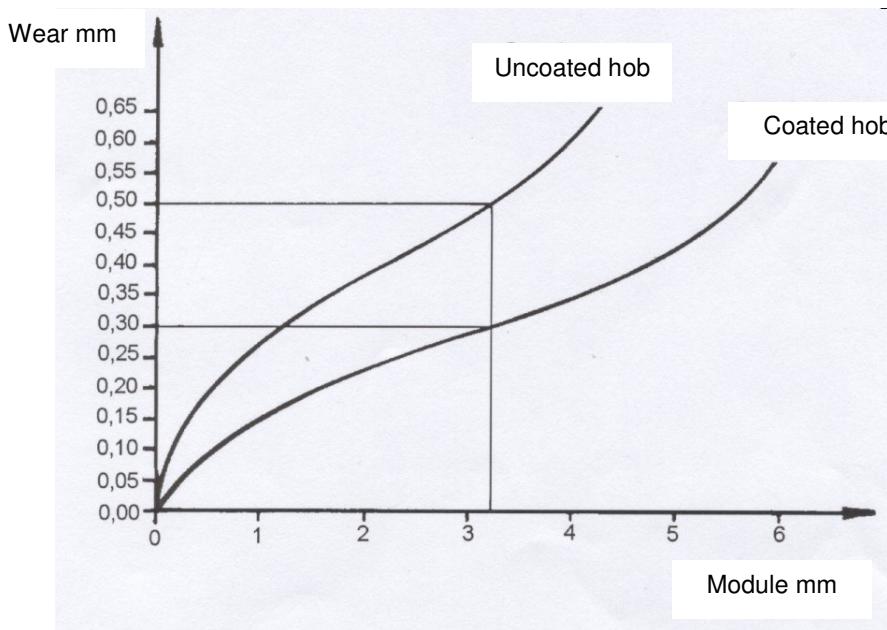


Figure No.8

This is because the wear forms differently in the two cases. In figure No.8 it is possible to see that the wear on uncoated hobs develops quickly for the first 0,15 – 0,20 mm and it then progresses slowly and steadily until around 0,50 – 0,60 mm where it reaches a critical point in which wear increases in an exponential manner.

With coated hobs, however, wear progresses much more slowly but the critical point is around 0,25 – 0,30 mm.

The above applies to gear manufacturing with gears that are made of steel and with a module of below 3 mm as are utilised in the automotive industry.

One final observation regards the influence that the outside diameter of the hob has on abrasive-type wear.

The greater the hob diameter, the longer the contact arc between the workpiece and the hob, that is the chip becomes longer.

This means that the cutting edge remains in contact with the workpiece for longer. Furthermore there is more space between the workpiece and the hob with a small diameter hob and the coolant can therefore access the critical zone or contact area more easily.

In conclusion it is therefore better to use a small diameter hob to combat abrasive-type wear.