# Materials used to manufacture hobs

There are many materials that may be used for the manufacture of gear cutting tools and it is necessary to briefly examine this topic in order to understand how this sector has evolved, affecting both the performance of the tools themselves, their cost and their manufacturing capabilities.

It is possible to make a distinction between two large categories of material with which gear cutting tools can be manufactured:

a)- High speed steel
b)- Carbide (sintered carbides)

## High speed steel

High speed steels may be divided into normal high speed steels, also referred to as HSS and into high speed steels that are made of powder which are generally known as PM (**P**owder **M**etals).

The technical characteristics of the various types of steel depends very much on the so-called alloy components.

In fact high speed steel is made up from a base of iron (Fe) which is mixed with carbon (C) and other precious metals such as vanadium (V), tungsten (W), chromium (Cr), molybdenum (Mo), cobalt (Co), etc.

Combined with carbon, these compounds produce the so-called carbides that give the high speed steel properties of hardness, wear resistance and tenacity.

The various percentages of alloy components give origin to the various types of high speed steel.

In recent years there has been a great evolution in terms of cutting steels with a gradual improvement in technical characteristics so that today we have modern superalloy steels that can give performances that were unthinkable until just a few years ago.

It is a well-known fact that one of most fundamental laws of mechanics states that the harder a metal is, the more it is fragile. Diamond, for example, is the hardest material but it is also the most fragile.

A good steel for cutting tools, however, must be as hard as possible while at the same time conserving a high level of tenacity.

Modern metallurgy is in fact concentrating its efforts on improving these two characteristics.

In table No.1 the compositions of the main types of high speed steel used today for the manufacture of gear cutting tools are indicated.

We can immediately observe that the sum of all the alloy components passes from around 17% in the case of M2 to over 30% for some types of superalloy steel.

Powder metals are produced with a technology that is different from traditional casting.

In fact the components are first reduced to a very fine powder and they are then compacted together at a high temperature and under great pressure until a compact mass which is made up of the various carbides is obtained.

The advantage of this type of steel is that the various carbides remain small in size and they are very well distributed within the steel mass.

In traditional steel, on the other hand, one of the most serious inconveniences is that it is possible to obtain carbides which are notable in size and irregular in distribution (e.g. in strips). See figure No. 1.

Table No.1 – Composition of the main types of high speed steel

| **Sigla AISI e HRC obtainable** | **Commercial abbreviation** | **Chemical composition** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **C** | **Si** | **Mn** | **Cr** | **W** | **Mo** | **V** | **Co** |
| M2 (63,5 - 65) | S600 | 0,90 | | | 4,10 | 4,60 | 5,00 | 1,80 | |
| idem | EM25 | 0,90 | | | 4,20 | 6,40 | 5,00 | 1,80 | |
| idem | ISORAPID 2000 | 0,89 | | | 4,30 | 6,40 | 5,00 | 1,90 | |
| idem | THYRAPID 3343 | 0,90 | | | 4,10 | 6,40 | 5,00 | 1,90 | |
| idem | DMO5 | 0,90 | | | 4,00 | 6,50 | 5,00 | 2,00 | |
| M2-PM (63,5 - 65) | CPMREX M2 | 0,85 | 0,30 | 0,30 | 4,15 | 6,40 | 5,00 | 1,95 | |
| M35 (64 - 65,5) | S705 | 0,92 | | | 4,10 | 6,40 | 5,00 | 1,90 | 4,80 |
| idem | EM35 | 0,93 | | | 4,20 | 6,40 | 5,00 | 1,80 | 4,80 |
| idem | THYRAPID 3243 | 0,92 | | | 4,10 | 6,40 | 5,00 | 1,90 | 4,80 |
| idem | VASCO Commentry M35 | 0,84 | 0,30 | 0,30 | 4,20 | 6,35 | 5,00 | 1,90 | 4,75 |
| idem | EMO5CO5 | 0,92 | | | 4,10 | 6,40 | 5,00 | 1,90 | 4,80 |
| M35 PM (64 - 65,5) | CPMREX M35 | 0,85 | 0,30 | 0,30 | 4,15 | 6,00 | 5,00 | 2,00 | 5,00 |
| M3-2PM (64 - 65,5) | ASP 2023 | 1,28 | 0,30 | 0,30 | 4,10 | 6,40 | 5,00 | 3,10 | |
| idem | APM 23 | 1,28 | | | 4,20 | 6,30 | 5,00 | 3,10 | |
| idem | S790 | 1,28 | | | 4,20 | 6,30 | 5,00 | 3,00 | |
| Group F-PM(65-66,5) | ASP 2030 | 1,28 | | | 4,20 | 6,40 | 5,00 | 3,10 | 8,50 |
| idem | HS 30 | 1,27 | 0,60 | 0,30 | 4,20 | 8,25 | 5,00 | 3,10 | 8,50 |
| idem | CPMREX 45 | 1,30 | 0,50 | 0,40 | 4,05 | 6,25 | 5,00 | 3,05 | 8,25 |
| idem | APM 30 | 1,29 | | | 4,20 | 6,30 | 5,00 | 3,10 | 8,40 |
| idem | S590 | 1,30 | | | 4,20 | 6,30 | 5,00 | 3,00 | 8,40 |
| Group G-PM(64,5-66,5) | ASP 2052 | 1,60 | | | 4,80 | 10,50 | 2,00 | 5,00 | 8,00 |
| idem | S390 | 1,60 | | | 4,80 | 10,50 | 2,00 | 5,00 | 8,00 |
| Group H-PM(64,5-66,5) | CPMREX 76 | 1,50 | 0,30 | 0,30 | 3,75 | 10,00 | 5,23 | 3,10 | 9,00 |
| Group I PM (65 - 67) | ASP 2060 | 2,30 | | | 4,20 | 6,50 | 7,00 | 6,50 | 10,50 |
| Group L PM (65 - 67) | CPM REX T15 | 1,55 | 0,30 | 0,30 | 4,00 | 12,25 | | 5,00 | 5,00 |
| M4 PM | CPMREX M4 | 1,35 | 0,30 | 0,30 | 4,00 | 5,75 | 4,50 | 4,00 | |
| idem | S690 | 1,33 | | | 4,30 | 5,90 | 4,90 | 4,10 | |
| Group N (65,5-69,5) | CPMREX 121 | 3,40 | | | 4,00 | 10,00 | 5,00 | 9,50 | 9,00 |
| M42 (66,5 - 69) | MO 88 | 1,08 | | | 3,90 | 1,50 | 9,40 | 1,20 | 8,00 |
| idem | EM 42 | 1,08 | | | 3,80 | 1,50 | 9,40 | 1,20 | 8,00 |
| idem | S 500 | 1,10 | | | 3,90 | 1,40 | 9,20 | 1,20 | 8,40 |
| M34 (64,5 - 66,5) | EMO 9 CO | 0,92 | | | 4,00 | 2,00 | 8,00 | 2,00 | 8,00 |

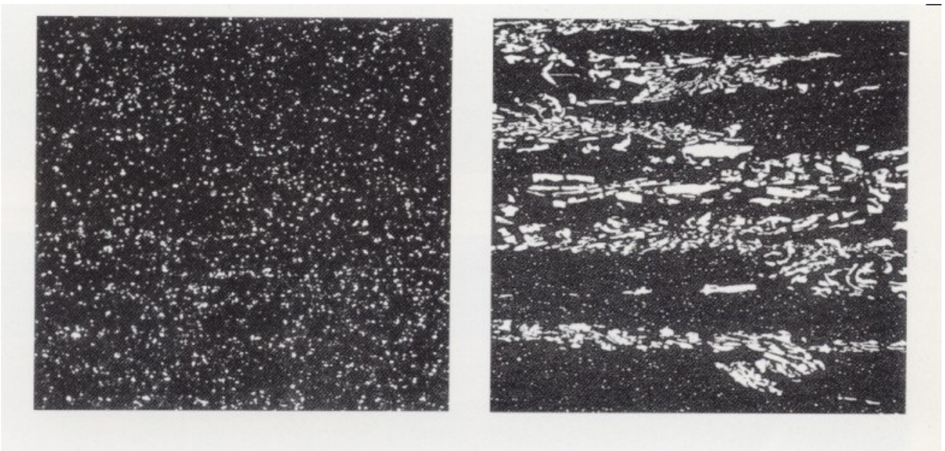

**Figure N°1-** *Comparison of distribution of carbides (Left: Powder steel – Right: Forged steel)*

In fact it is very difficult to manage the dimensions and the distribution of carbides. Steel may therefore have a series of defects such as the non-uniformity of metallurgic characteristics, excessive hardness and fragility in some zones, poor machinability, high level of heat treatment deformation and so on.
With powder metals it is possible to have more control over the size and distribution of the carbides and therefore the percentage of alloy components may be increased, bettering the cutting abilities of the tool.
One of the most important characteristics of high speed steels is the hardness which in general is measured in Rockwell degrees on the scale C (HRC= **H**ardness **R**ockwell **C**).

The desired hardness is obtained by performing a correct Heat Treatment process. This is a very delicate operation and just a slight error in temperature or in the actual time that the steel is in the furnace may compromise the results.
Heat treatment (hardening and tempering) is carried our either in a salt bath furnace or in a vacuum oven.
In the first type of furnace, the workpieces are immersed in a crucible which is filled with dissolved salt (Barium chloride). The desired temperature is controlled by electrodes and it is regulated automatically and driven by thermocouples immersed in the salt bath; these thermocouples are more commonly known as immersed pyrometers. Alternatively the bath temperature may be monitored by optic pyrometers which can measure the temperature according to the luminous radiation emitted by the bath.
This type of heat treatment guarantees a good level of accuracy in terms of temperature and the workpieces immersed in the bath are heated in a uniform manner.
The problems which salt baths generate are essentially of an ecological nature. Disposal of the waste tempering salts is very difficult and expensive. It is no longer legal to manufacture new units of this type.
Another inconvenience of this system is that the workpiece must be carefully cleaned after heat treatment in order to avoid rapid oxidation and corrosion.
Naturally the working environment where salt bath furnaces are installed is somewhat warm and especially in hot seasons, it is not very pleasant to be near such equipment.
Vacuum ovens are, on the other hand, essentially closed chambers which are placed under vacuum and in which the temperature is maintained at the desired level by a series of electrodes that are monitored by an electronic control system. This receives input from a series of thermocouples which are placed inside the oven.

It would actually be incorrect to speak of vacuum treatment since it is true that air is aspired from inside the chamber until there is a pressure level of around $5 \cdot 10^{-3}$ Bar but Nitrogen (N) is then released into the chamber up to a pressure level of around 1,5 Bar.

In the cooling phase Nitrogen is again released until the pressure level reaches up to even 8 Bar.

The advantage of this type of oven is the cleanliness of the process, the surrounding working environment and the absence of products that may have a negative impact on the environment. More precisely there are no ecological difficulties with this system.

A disadvantage, however, of this system is that it is difficult to maintain a constant and uniform temperature within the chamber since it more sensitive to the characteristics of the load, that it the group of tools that are placed inside the oven for treatment. It is possible to obtain good results only after extensive experience and by paying a great deal of attention to the type of load and how it is arranged within the chamber.

In any case good results are attainable on the workpiece only if the cycle indications that are given by the steel supplier are strictly adhered to.

A typical treatment cycle could be the following for example:

- First pre-heating phase at 600 °C for 10 – 20 minutes
- Second pre-heating phase at 800 °C for 10 – 20 minutes
- Heating up to austenitic temperature at 1150–1250 °C according to the type of steel at hand
- Drastic cooling down to 500°C
- Slow cooling until room temperature
- First tempering phase with heating up to around 550 °C for at least 2 hours
- Cooling to room temperature
- Second tempering phase with heating up to around 560 °C according to the desired hardness
- Cooling and final stress relieving phase to around 540 °C.

This cycle is presented graphically in figure No.2.

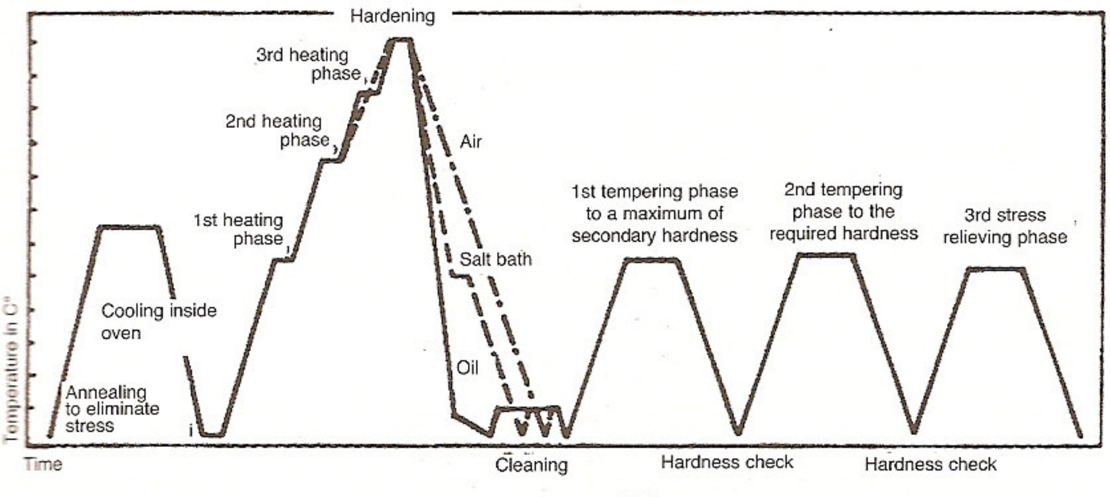

**Figure No.2**-

In this cycle there are some very delicate phases upon which depends the end quality of the tool and its hardness. Apart from the austenisation temperature which is typical to each steel and which increases with the increase in the percentage of tungsten (see the following table), it is of extreme importance to know the tempering temperature since it is on the basis of this that the final hardness of the treated steel is fixed.

Table No.2– Austenitic temperature in relation to the percentage of W

| **Type of steel** | **W percentage** | **Austenitic temperature** |
|---|---|---|
| ASP 2023 | 6,4 | 1150 ℃ |
| M2 | 6,3 | 1180 ℃ |
| M35 | 6,4 | 1195 ℃ |
| S390 | 10,5 | 1210 ℃ |
| T15 | 12,25 | 1225 ℃ |

All steel suppliers provide diagrams which indicate the tempering temperature in relation to the hardness (see figure No.3 )

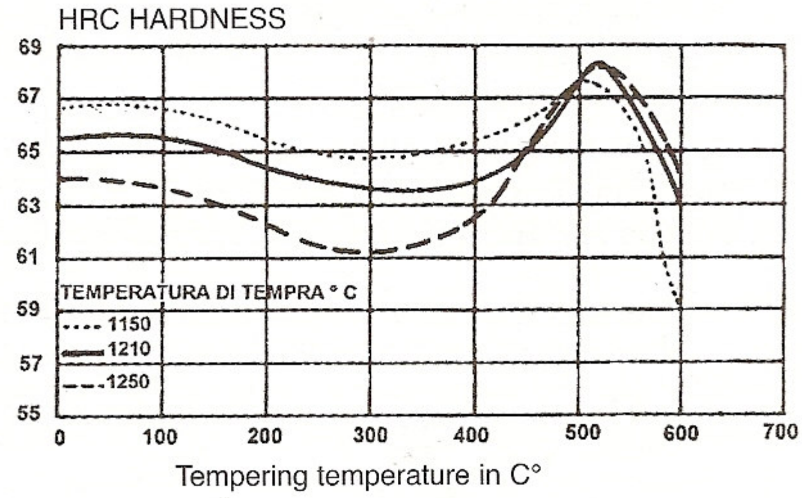

Figure No.3

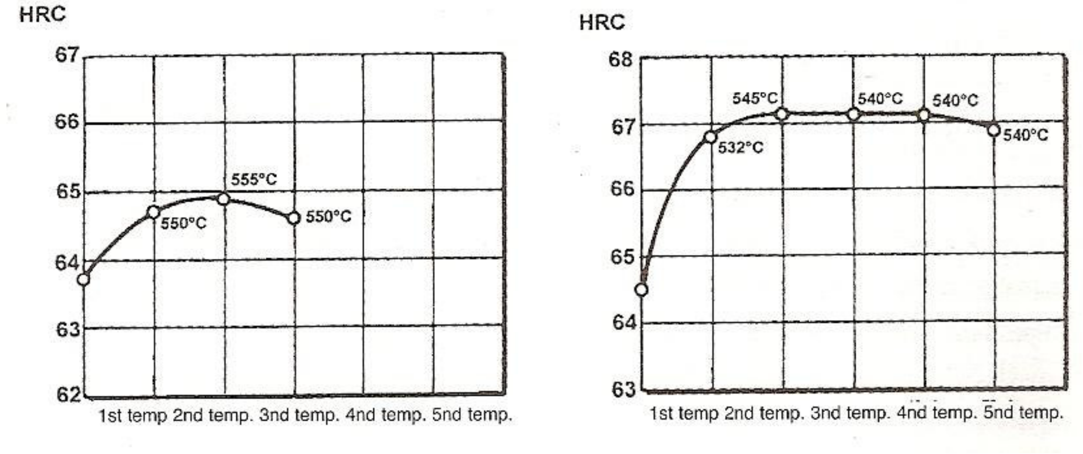

Figure No. 4

In figure No.3 a complete tempering diagram is shown. The part that is used, however, is that which is near the highest point. In figures No.4 the hardness levels obtained during the subsequent tempering operations of M2 and T 15 steels at the temperatures indicated are illustrated.

It is possible to note from these diagrams that M2 steel for example achieves its maximum hardness level (HRC 65) with a tempering temperature of 555 °C, whilst T15 steel can achieve HRC 67 with a tempering temperature of 540 °C.

All types of gear cutting tools must have certain properties and so the hob, for example, must be able to work at high cutting speeds and to bear excessive pressure caused by the repeated collisions that each tooth endures. Furthermore it needs the highest possible wear resistance properties against both crater-type and abrasive-type wear. It is therefore necessary to use steel which is extremely hard, as tenacious as possible and which maintains its hardness at high temperatures. Clearly not all hobs need to have these qualities at their highest levels. In fact sometimes a hob which is manufactured with superalloy steel and a very high hardness level may produce poor results if the hobbing machine is not rigid enough or if it cannot cut at adequate speeds.

Shaper cutters do not work at high cutting speeds but they endure much more frequent and more violent collisions. The steel used for these tools must therefore give more importance to tenacity while the hardness level must be as high as possible in order to minimise wear. It is not usually necessary, however, that the steel used be particularly resistant to high temperatures.

The case of shaving cutters, on the other hand, is completely different. The stress under which the tools work is relatively modest. In fact the chips generated are very small and the effective cutting speed is very low. It would therefore be superfluous to use a superalloy steel but it is in any case necessary to use a steel which is relatively hard. Given the particular geometry of the shaving cutter, it has a number of very delicate areas of very small thickness (for example the teeth) and it is therefore necessary that the steel is resistant to breakage.

The most commonly used steels for hobs are:

- **M2** - This is the traditional type of steel which has been used for decades in the manufacture of hobs. Nowadays it is not used very often and only on tools that do not endure much strain, that are used on old machinery or on standard tools where manufacturing speeds are not particularly important. This is the most economic steel.
- **M35** - This steel is used a lot since it has a high percentage of cobalt and therefore good wear resistance properties. It is a very tenacious steel and it is therefore suitable for hobs that endure a lot of strain. Modern coating technology with TiN or TiAlN help reduce crater-type and abrasive-type wear and therefore this steel makes hobs of excellent quality.
- **F-PM Group** - The universally known ASP 2030 (Erasteel) belongs to this category. Thanks to the very high percentage of cobalt and in general to the presence of alloy components (more than 27%), this steel is suitable for very arduous working conditions especially as regards cutting speeds.
- **G-PM Group -** Steels such as ASP2052 (Erasteel) and S390 (Boehler) belong to this category and they are characterised by a high alloy component content (about 30%) especially tungsten which allows the steel to reach very high levels of hardness and good heat resistance properties. With suitable coatings, these are the steels which enable the user to reach excellent cutting speeds.
- **Superalloy steels** – All other steels may be grouped under this category including the most well known T15, M4, M42 and M34. All these steels must be used with a certain level of care. Whilst they may allow for excellent performance, this is not necessarily true for all applications and they do not give good results on all hobbing machines. Below is an example of hobbing with a Samputensili hob manufactured in CPMREX76 steel. The working conditions are extreme and the results are exceptional. If this same hob were to be used on an old hobbing machine which was not sufficiently rigid or that cut at lower

speeds, the results would probably not be so good. It is also necessary to make another important observation: when using these steels, it is not possible to design the hob tooth with traditional geometry. It is necessary to study new tip and side relief values.

Modern superalloy steels guarantee exceptional performances which, until recent years, were unthinkable.

A recent dry cutting trial with a Samputensili hob is shown below as an example.

The results, as can be seen, are very exceptional and are certainly not inferior to those that could be achieved with a carbide hob. Since carbide hobs can, at present, only be manufactured with a maximum of two starts. To obtain the same results as the hob in the example, a carbide hob would have to machine at a cutting speed of 340 m/1’.

Table No. 3 – Example of manufacturing with a superalloy steel hob

| **HOB DATA** | |
|---|---|
| Module | 1,5821 |
| Pressure angle | 14°30’ |
| Number of starts | 4 |
| Number of gashes | 21 |
| Outside diameter | 80 mm |
| Total length | 150 mm |
| Characteristics of profile | Protuberance and semitopping |
| Material | CPMREX 76 steel |
| Coating | TiAlN |
| **GEAR DATA** | |
| Number of teeth | 47 |
| Face width | 14,30 mm |
| Helix angle | 33° |
| Material | 16 Mn Cr 5 steel |
| **WORKING DATA AND RESULTS** | |
| Cutting speed | 170 M/1’ |
| Feed | 3 mm/piece revolution |
| Total shifting length | 90 |
| Cooling | Dry |
| Hobbing machine | Liebherr LC82 |
| Floor to floor time | 23 seconds |
| Cutting time | 13 seconds |
| Number of pieces cut | 2.000 |
| K factor | 6,9 m per hob tooth |
| Wear | 0,15 mm |

## Sintered carbides

This particular type of material is more commonly known as Carbide.

Over the last few years, carbide has been increasingly utilised in the manufacture of hobs first for those used in the finishing process with skiving and subsequently for actual hobbing of workpieces before heat treatment.

Carbide is made up of 70 – 90% of precious metal carbides such as Tungsten (W), Tantalum (Ta), Titanium (Ti), Niobium (Nb) etc., which are held together by an alloy which is normally Cobalt (Co).

Carbide may vary significantly according to numerous characteristics such as chemical composition, size of the carbides, compactness, purity, etc. Carbides may therefore differ in nature in terms of the following:

- *Resistance to abrasive-type wear;*
- *Resistance to crater-type wear;*
- *Resistance to collision;*
- *Resistance to variations in temperature*

Clearly it is important to know the value of the above-mentioned characteristics if the operator is to make the correct choices for the job at hand.
Considering that if some of the above characteristics are given more importance, others will be necessarily given less which means that a single, ideal carbide type which would be suitable for all manufacturing cannot exist.

Resistance to abrasive-type wear

Wear caused by abrasion can be found in the area immediately behind the cutting edge on the tooth flank, that is on the relieving area of the tooth . It occurs when cutting any material, whether metallic or not, clearly in varying entities and it is generated by friction between the workpiece surface and the tool flank.
When cutting material with short chips (normal, non-alloyed cast iron), non-ferrous material with plastic chips (aluminium, copper, bronze) and non-metallic materials (synthetic resin, wood, carbon, rubber etc.), the type of wear that arises is more often this type rather than the other type of wear, that is the formation of craters.

Resistance to crater-type wear

The phenomenon of crater formation is caused by the chip rubbing against the upper face of the cutting edge (resharpening face) and a pronounced crater is consequently generated in the area immediately behind the cutting edge.
Crater-type wear tends to form when cutting materials with long chips as significant plastic deformation is required to remove the chip (steel, alloyed cast iron, etc.)
The phenomenon of crater-type wear is in any case very complicated and it not only involves actual mechanical pressure but also chemical and thermal phenomena.
The crater causes a direct increase in the back relief angle and consequently the cutting edge is gradually weakened and it may eventually break if the situation becomes critical.

Resistance to collision

This requirement does not need particular explanation since it is clear that material which is not resistant to collision would chip and break in a discontinuous cutting operation like that performed with the hob
Carbides are less resistant to collision than high speed steels and this is a notable limitation for hobbing which has slowed down their widespread use.

Resistance to variation in temperature

This type of resistance to thermal strain is not to be confused with resistance to constant high temperatures during use. In fact the former is connected to the coefficient of thermal conductivity and to the coefficient of thermal dilation whilst the latter is linked to the ability of the carbide to maintain its own mechanical properties at high temperatures.
It is important to remember that each single hob tooth is subject to continuous and violent variations in temperature.

According to the main international normatives (DIN, ISO etc.) hard alloys are divided into three groups which are distinguished by different colours and which are in general suitable for machining different types of material.

- *Group P (distinguished by the colour blue): suited to machining steel*
- *Group M (distinguished by the colour yellow): universal quality.*
- *Group K (distinguished by the colour red): suited to machining cast iron*

In turn these categories are subdivided into numerous sub-groups according to their chemical composition and other physical characteristics.
All manufacturers vary the composition and the other characteristics in order to constantly improve the material and therefore table No.4 below, which shows the chemical composition of each type of carbide, is purely indicative, also because nowadays other components such as Niobium (Nb), for example, are also used to obtain the required physical and mechanical characteristics.
In the abbreviations that are used to distinguish between the different types of carbide, the smallest numbers represent the carbides with the highest hardness levels and the lowest resistance to collision.
Hard alloys which are referred to using abbreviations that have high numbers are those that are more tenacious and softer.

Table No. 4 - Chemical composition of hard alloys

| Group | Type of alloy | Approximate Composition | | |
|---|---|---|---|---|
| | | WC % | TiC + TaC % | Co % |
| P<br>(blue) | P01 | 30 | 64 | 6 |
| | P05 | 62 | 33 | 5 |
| | P10 | 65 | 26 | 9 |
| | P20 | 76 | 14 | 10 |
| | P25 | 70 | 20 | 10 |
| | P30 | 82 | 8 | 10 |
| | P40 | 74 | 12 | 14 |
| | P50 | 67 | 15 | 18 |
| M<br>(yellow) | M10 | 84 | 10 | 6 |
| | M20 | 82 | 10 | 8 |
| | M30 | 80 | 8 | 12 |
| | M40 | 79 | 6 | 15 |
| K<br>(red) | K01 | 92 | 4 | 4 |
| | K05 | 91 | 3 | 6 |
| | K10 | 92 | 2 | 6 |
| | K20 | 92 | 2 | 6 |
| | K30 | 91 | -- | 9 |
| | K40 | 88 | -- | 12 |

Influences of the various parameters on the characteristics of carbide
All physical characteristics depends on the make up of the carbide. Below several fundamental concepts are briefly summarised.

<u>The effect of the cobalt content</u>. In carbide the level of hardness is inversely proportionate to the cobalt content. On the other hand, the maximum tensile stress of the cutting force increases as the percentage of cobalt increases. Resistance to abrasive-type wear decreases with an increase in cobalt content. This could seem logical if by increasing the

cobalt content, the hardness level were to decrease but it is important to note that the resistance to abrasive-type wear also depends on the size of the grain as will be examined later.

The effect of the size of the grain. The hardness level is inversely proportionate to the average size of the grain. The bigger the grain diameter, the lower the level of hardness. Vice versa the maximum tensile stress of the cutting force, and therefore the tenacity, is directly proportional to the average grain diameter. It is necessary to note that in the field of metal carbides, the maximum tensile stress of the cutting force is used as an indication of product tenacity.

The effect of the titanium carbide content. Adding titanium carbides increases crater-type wear resistance. Unfortunately, however, it has the opposite effect as regards abrasive-type wear and the tenacity of the carbide also decreases as the titanium content increases.

The effect of the tantalum carbide content. By adding tantalum carbides, the resistance to abrasive-type wear increases without compromising the resistance to crater-type wear. Furthermore resistance to the plastic deformation of the cutting edge, which has to endure high temperatures, also improves.

Nowadays sintered metal carbides have become highly sophisticated. As mentioned above there is a tendency to add carbides of rare elements, such as niobium, to these metals in order to improve their physical properties. The elements added have varying effects also in relation to the percentage of the other components present. There has also been further very important progress made in terms of micro grains of carbide. These are utilised to make the structure of the material extremely fine.
This last type of carbide in fact gives the best results today.

For some time now carbides which contain ceramic grains, known as Cermet are also available on the market. Apart from being notably hard, these materials also boast a very low coefficient of thermal conductivity which means that the gashes can be kept at a temperature which is lower than in normal circumstances. Although this type of material is still undergoing trials, it is regularly utilised by some gear manufacturers.
It does in fact have several notable advantages compared to standard carbide. First of all it has a lower specific weight and therefore the hob weighs less. This is not in itself a particular advantage but at very high cutting speeds, the perfect dynamic balance of the hob is also an important factor. If the hob is lighter, it is easier to balance.
Furthermore cermet also has a great advantage in that it is not necessary to apply any coating.
In terms of disadvantages the material is still quite difficult to machine and this is the main reason why it does not yet enjoy widespread use.

Physical and mechanical properties of carbides.
Let us briefly examine the main characteristics of sintered metal carbides.

Specific weight. This depends on the chemical composition of the alloy and to a certain extent on its compactness. Hard alloys with tungsten carbides and cobalt have higher specific weights. Depending on the cobalt content which may vary from 4 to 25%, the specific weight oscillates between 15,5 and 13,4 g/cm$^3$.

Hard alloys which contain other elements such as titanium carbides in particular, have a lower specific weight. The higher the titanium content, the lower the weight.

Hardness. The Vickers hardness level of common sintered alloys is between 1100 and 1900 (85 – 93 Rockwell A). At the top end we have alloy types such as P01, P10, K01, K10 whilst at the lower end types such as P50 and K40, which have a high cobalt content, can be found.
At 700°C high speed steel loses most of its hardness properties while hard alloys, especially those which belong to the P group, loses about 25 – 30%. This means that at these temperatures, the hardness level of hard alloys is practically the same as that of high speed steel when it is cool.

Resistance to transverse breakage. The resistance to bending stress is one of the fundamental characteristics of hard alloys and it can be indicative, albeit approximately, of the tenacity of the material.
Breakage by flexion is in fact a critical combination of cutting strain, compression and traction.
As a rule the maximum tensile stress caused by bending increases as the cobalt content increases and it decreases as the titanium content increases.
In tungsten-cobalt alloys the maximum tensile stress oscillates between 120 and 240 Kg/mm$^3$ whilst with compound alloys (WC+Co+TiC+TaC) the values of resistance vary between 90 and 220 Kg/mm$^3$.

Elasticity modulus. It is very important to know the value of the elasticity modulus. Whilst high speed steels have an elasticity modulus of 22.000 Kg/mm$^2$, that of hard alloys may reach levels as high as 50.000 – 65.000 Kg/mm$^2$. When working with hard alloys, plastic deformation does not usually follow elastic deformation. The materials usually just breaks.

Resistance to traction. Calculating the maximum tensile stress under traction of very fragile material is difficult and results are often not very reliable. The values that are obtained with hard alloys are in any case relatively low: 80 – 100 Kg/mm$^2$.

Resistance to compression. The level of resistance of hard alloys is more or less the same at that of high speed steel, that is 410 – 565 Kg/mm$^2$. The highest levels of resistance are obtained with K group alloys.

Thermal conductivity. This characteristic is very important since it determines the speed at which the heat diffuses within the material. High thermal conductivity means that a substantial part of the heat generated during machining passes to the tool which consequently heats up more. On the other hand, if the heat is diffused rapidly, there is less danger that the different points of the cutting edge will be under tension. The highest conductivity values are found in tungsten carbide based alloys which are low in cobalt content. The more titanium carbides present, the more the thermal conductivity level decreases.

Coefficient of thermal dilation. The linear elongation rate of hard alloys is about half that of high speed steels. This is particularly relevant if the hard alloys have to be soldered onto steel supports. With large module hobs which are used in operations such as skiving, for example, this is usually the case. This factor also needs to be taken into careful consideration when the hob is coated as if there is a large difference in thermal dilation coefficients between the coating and the hob body, localised heating may occur which can cause the coating film to flake.

Table No. 10 - Physical and mechanical properties of sintered carbides

| | |
|---|---|
| Elasticity modulus | 45.000 – 67.000 |
| Resistance to compression Kg/mm$^2$ | 400 – 590 |
| Maximum tensile stress caused by flexion Kg/mm$^2$ | 90 - 260 |
| Rockwell Hardness at 60 Kg | 85 – 93 |
| Rockwell Hardness at 150 Kg | 75 – 82 |
| Vickers Hardness at 20 Kg | 1.100 – 1.900 |
| Specific weight g/cm$^3$ | 9 – 15 |
| Thermal conductivity cal/℃/sec/cm | 0,05 – 0,20 |
| Coefficient of thermal dilation $10^{-6}$/℃ | 5 – 7 |
| Specific heat cal/g/℃ | 0,05 – 012 |
| Electric resistance $\Omega / mm^2 / m$ | 0,23 – 0,80 |