TYPES OF ADVANCED CUTTING TOOL MATERIALS AND THEIR PROPERTIES

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Abstract: For mechanical machining the quality of cutting-tool materials is one of the most significant issues that need to be addressed. In modern industry, a variety of cutting tool materials are used to satisfy Enhancement of cutting tool performance may be achieved through the use of modern composition ceramic cutting tools.

Keywords: Cutting tool, ceramic materials, mechanical properties, machining, hard alloys

Introduction: Cutting tool development is important for enhancing the mechanical properties especially in high-speed machining with a long duration. However the production of its cutting tools faces challenges for many reasons. Firstly the material must meet mechanical property requirements. Secondly conventional sintering methods are restricted with the number of materials and the time needed to achieve the sintering cycle, which are reflected in the product cost. These are significant constraints in the manufacture of these tools [1]. Additionally, cutting tools materials must be able to resist extreme cutting conditions such as high temperature and friction between the workpiece and the cutting tool surface. Therefore cutting tool materials should exhibit a variety of properties to meet these requirements [2]. These are highlighted below.

- Mechanical properties:
- High hardness at elevated temperature.
- High deformation resistance to prevent plastic deformation at cutting edge.
- High stiffness to maintain accuracy.
- High fatigue resistance to resist maximum mechanical load.
- High fracture toughness.
- Thermal properties:
- High thermal conductivity to transfer the temperature away from the cutting edge.
- High thermal shock resistance.
- Chemical composition being stable.
- Tribological properties:
- Wear resistance.
- Adequate lubricity to prevent build-up on the cutting edge.

There are many types of cutting process done in different conditions. In such conditions along with the general requirements of the cutting tool, they need some unique properties. To achieve this properties the cutting tools are made up of different material. The material chosen for a particular application depends on the material to be machined, type of machining, quantity and quality of production. According to the material used the tools are classified into:

1. Carbon tool steel
2. High speed steel tool (HSS)
3. Cast non-ferrous alloys
4. Carbides

5. Ceramics tool
6. Cermet
7. Cubic boron nitride Tool (CBN)
8. Diamond tool

Carbon tool steel. Carbon tool steel is one of the inexpensive metal cutting tools used for the low-speed machining operation. These plain carbon steel cutting tool have the composition of 0.6-1.5% carbon and very small amount of (less than 0.5 %) Mn, Si. Other metal like Cr, V are added to change the hardness and grain size. High carbon steels are abrasion resistant and have the ability to maintain sharp cutting edge. Carbon tool steels possess good machinability. This material loses their hardness rapidly at a temperature about 250°C. Therefore, it can't use high-temperature application. It does not prefer in a modern machining operation.Carbon steel tool is used in twist drills, milling tools, turning and forming tools, used for soft material such as brass, aluminum magnesium, etc.Temperature - 450°C.Hardness – up to HRC 65.

High-speed steel (HSS). This is a high carbon steel with a significant amount of alloying element, such as tungsten, molybdenum, chromium, etc. to improve hardenability, toughness and wear resistance. It gives a higher metal removal rate. It loses its hardness at a moderate temperature about 650°C. Therefore, a coolant should be used to increase tool life. It can use many times by re-sharpening. Some surface treatment is done on the HSS to improve its property. High-speed steel tools are used in drills, milling cutters, single point lathe tools, broaches. Cutting speed range - 30-50 m/min. Temperature - 650°C. Hardness – up to HRC 67.

High speed steel comes in two series:

Tungsten Series : In the tungsten series, the most famous material is 18-4-1 HSS, it means it has 18% tungsten, 4% chromium and 1% vanadium. Apart from these there is 0.5% to 0.75% carbon is also available in this material.

Molybdenum Series. In the molybdenum series, the most used material 6-6-4-2 HSS. In this material, there is 6% tungsten, 6% molybdenum, 4% Chromium and 2% vanadium. It also has 0.6% carbon [3].

Cast non-ferrous alloys. It is named so because it is nor-ferrous alloy and made using casting. A typical alloy of this type is stellite which has 30-35% chromium, 43-48% cobalt, 17-19% tungsten, and nearly 2% Carbon. Cast non-ferrous alloys can maintain their hardness up to 900°C. Cast non-ferrous alloys can cut at double speed than the speed of the high speed steel. These materials are corrosion resistant. But these are brittle which is a disadvantage. These are in the form of inserts and are brazed to tool shank.

Carbides. Carbides are the cutting tool that mainly consists of tungsten carbides particles that are held together by cobalt and nickel. Straight tungsten carbide tools contain about 94% tungsten carbide and 6% cobalt. Straight tungsten carbides are used for machining cast iron. It is not used for machining steel because if we use it for machining steel then the chips tend to stick to the tool. To overcome this problem tantalum, titanium is added to the carbides. These carbides are made by powder metallurgy techniques. The initial cost of carbides is high but it can cut at a speed which is 4 to 5 times the speed of High speed steel (H.S.S). Carbides can retain their cutting edges up to 1200°C. They are very hard and they also have very high compressive strength. The disadvantage with carbides is that they are brittle in nature and cant withstand impact loading.

Ceramics. Most common ceramic materials are aluminum oxide and silicon nitride. Powder of ceramic material Compacted in insert shape, then sintered at high temperature. Ceramic tools are chemically inert and possess resistance to corrosion. They have high compressive strength. They are stable up to temperature 1800°C. They are ten times faster than HSS. The friction between the tool face and chip are very low and possess low heat conductivity, usually no coolant is required. They provide the very excellent surface finish. Cutting speed 300-600m/min.

Temperature - 1200°C.Hardness – up to HRC 93. All ceramic cutting tools have excellent wear resistance at high cutting speeds. There are a range of ceramic grades available for a variety of applications. Oxide ceramics are aluminium oxide based (Al_2O_3), with added zirconia (ZrO_2) for crack inhibition. This generates a material that is chemically very stable, but which lacks thermal shock resistance.

(1) Mixed ceramics are particle reinforced through the addition of cubic carbides or carbonitrides (TiC, Ti(C,N)). This improves toughness and thermal conductivity. (2) Whisker-reinforced ceramics use silicon carbide whiskers (SiCw) to dramatically increase toughness and enable the use of coolant. Whisker-reinforced ceramics are ideal for machining Ni-based alloys. (3) Silicon nitride ceramics (Si_3N_4) represent another group of ceramic materials. Their elongated crystals form a self-reinforced material with high toughness. Silicon nitride grades are successful in grey cast iron, but a lack of chemical stability limits their use in other workpiece materials.

Sialon (SiAlON) grades combine the strength of a self-reinforced silicon nitride network with enhanced chemical stability. Sialon grades are ideal for machining heat resistant super alloys (HRSA).

Cermets. Cermets are the combination of ceramics and metals and they are produced using powder metallurgy technique. In the combination of metal and ceramics, ceramics will give high refractoriness, and metals will give high toughness and thermal shock resistance. For cutting tools made with cermets, the usual combination is Al_2O_3 + W + Mo + born + Ti etc. It contains 90% cermaic, 10% metals. As the quantity of metal is increased in cermets, the brittleness reduces to some extent, and the wear resistance also reduces.

Cubic boron nitride (CBN). It is the second hardest material after diamond. They are generally used in hand machines. They offer high resistance to abrasion and use as an abrasive in grinding wheels. Sharp edges are not recommended. Speed 600-800m/min. Hardness - higher than HRC 95 [4].

Diamond. Diamond is currently the hardest substance with the best thermal conductivity among known mineral materials. The wear amount of friction with various metal and non-metal materials is only 1/50 – 1/800 of cemented carbide, which is the most ideal for cutting tools. However, the tools are mostly made of artificial single crystal diamond. The cutting edge of the diamond tool is very sharp (this is important for cutting chips with very small sections). The roughness of the cutting edges is very small, and the friction coefficient is low. It is not easy to produce chipping during cutting, so the quality of the machining surface can be high. There are three types of diamond cutting tools: natural sing crystal diamond, solid synthetic crystal diamond tools, and diamond compound tools. Natural diamond tools are rarely used in actual production due to high cost.

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