

Heat-treatment and properties of high-speed steel cutting tools

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Abstract. The high speed steels (HSS) have been widely adopted as the most basic material for cutting tools in mechanical processing since it was born. At present, HSS cutting tools still occupy the dominant position of the tool market. Although the development of tipped carbide cutting tools and grinding of cemented carbide cutting tools is very rapid, other varieties of the cutting tools still mainly adopt HSS material. In spite of the differences in the smelting mode of the HSS, the durability of tools is more directly with the chemical composition and reasonable heat processing. Therefore, the choice of the HSS cutting tool material and heat treatment process are very important to ensure the performance of HSS cutting tool.

1. Introduction

With the comprehensive progress of manufacturing technology, cutting technology has been promoted to a new stage of high-speed cutting. As a new cutting process, high speed cutting has strong vitality and superiority comparing traditional cutting technology. The requirements of the new cutting technology for cutting tools are high cutting speed, high intake, high reliability, long life, high precision and good cutting controllability. Because of its high hardness and thermal stability, high speed steel is widely used to make cutting tools such as knives, hobs, broaches, drills and taps. In the service process, the blade of the tool not only subjects to the stress effect of bending, torsion, shear and vibration and shock effect, but also bears a strong friction from the workpiece and chip, resulting in wearing, bending, cracking or even broken that shortens the service life, increase production costs and reduce the economic efficiency of enterprises. Therefore, it is of great economic and profound historical significance to understand the tool material, study the heat treatment process and develop the surface toughening process. High-speed steel (HSS) is a high carbon alloy ledeburite steel that contains lots of alloy carbides. Carbide plays a key role on the quality and performance of HSS. Carbide is a double-edged sword for HSS that ensuring high hardness, wear resistance and red hardness for HSS, but also may be an important source of various quality problems. In order to improve the life of HSS cutting tools, it is necessary to study the carbides in the steel and understand the law of the formation and change of carbides. There are many kinds and forms of carbides in HSS, and the number, type, distribution, shape and size of carbide may affect the performance and quality of steel, which should be concerned in the cutting tool heat treatment process.



2. Characteristics of heat treatment of HSS cutting tools

In the existing steel, HSS is undoubtedly one of the most complex steel species because of the complex relationship between composition, organization and performance, and the difficulty of the whole manufacturing process including smelting, pouring, forging, rolling, plastic forming and heat treatment. For a long time, a lot of basic research and application practice have been performed on heat treatment process of HSS, which enriched the knowledge base of heat treatment process, and made an indelible contribution to rapid development of manufacturing industry in our country and occupation of the foreign tool market.

Heat treatment of cutting tools has been paid more and more attention. The heat treatment of HSS cutting tools have many characteristics.

(1) The morphology of the Laplace carbide in HSS will not change during heat treatment, and thus it is necessary to pretreat the laibei carbide into granular particles and improve the heterogeneity of carbide. Therefore, the forging quality of the cutting tools is very important.

(2) in order to improve the machinability of HSS, it is necessary to emphasis on the annealing and tempering process and the impact on the tool life [1,2].

(3) HSS is high alloy steel that the treatment needs to preheating more than two times.

(4) There is a large number of carbides in HSS, which strongly prevent the growth of austenite grain when heated, even until the melting temperature, HSS still maintains fine austenite grains. Only when heated at a very high temperature and the carbide is dissolved enough, it can obtain high wear and red hardness, while toughness decreases with the increase of quenching temperature. The quenching temperature is very sensitive to the performance of HSS cutting tools, which is mainly depends on the quenching temperature. The best quenching temperature is selected according to the type of tool, the condition of use and the failure condition. The production of various cutting tools using steel with same grade and furnace number should have a larger difference between the quenching temperature that the heat treatment process should be individualized [3]. Under the full utilization of toughness, the quenching temperature can be improved as far as possible to improve the wear resistance and hardness.

(5) HSS has very high hardenability. According to the specific conditions, air cooling, oil cooling, and salt bath quenching can be implemented.

(6) HSS cutting tools need to be tempered 3 times near the temperature of the two hardening peaks and 4 times of tempering is needed for isothermal quenching.

3. Problems in heat treatment process of HSS

Heat treatment of HSS cutters has made substantial progress than before. Lots of tools have entered the international high-end market, and have been recognized by international instruments. But the gap is still very large that and shown in the following four aspects.

3.1 Backward materials

Powder HSS typified the level of HSS in twenty-first Century and has been widely used on complex cutting tools abroad, but it is still missing in China. At present, powder HSS used at home is imported materials. And the component of M42 and M35 HSS is not stable. Mixed furnace number and mixed steel grade cause lots of trouble.

3.2 Poor machinery

The domestic processing of HSS cutting tools still use the old type of salt bath furnace, whose environmental pollution is big, energy consumption is high, and the treatment of the three wastes is poor.

3.3 Poor quality of personnel

A considerable number of enterprises without qualifications of heat treatment engineer or technician. The technical staff between 40-60 year old is lack and many companies have invited engineers

above 60 years old to come back. The tempers in most private enterprises without training and quality accidents happen frequently.

3.4 Poor technology and equipment

The manufacturing technology of advanced heat treatment equipment is lagging behind the situation. Technology level and auxiliary material quality are not high and varieties are not enough. All of these factors restrict the development of heat treatment industry of cutting tools. The situation in which some tool plants always value cold processing and despise hot processing and this situation has not been fundamentally improved. It has been proved by practice that a unit that does not pay attention to heat treatment will pay the price and many of the gaps are caused by human beings. We are responsible for the task of reducing the gap between the advanced level of the world that talk less and do more practical things.

4. Measures for improving cutter life

As a consumable product, the life of the cutting tool directly determines the production cost of the application enterprises. Thus, improving tool life is a topic of common concern in the industry. The factors that affecting tool life are complex that involving three elements of cutting, cooling conditions, quality of tool itself (material, coating, angle), parts material and so on. The life of the domestic cutting tool still has a large gap compared with the foreign cutting tools. Some people doubt the tool materials are not as good as foreign ones, and import M42 and M35 HSS and HSS powder from abroad. But the quality is still inferior to foreign tools. Expert analysis, the reason should be that the heat treatment skill is inferior to foreigners. The following is some way about how to improve the tool life [4].

4.1 Value the core role of carbides

The heat treatment of HSS is the transformation of carbides. Carbide is a double-edged sword for HSS cutting tools, which can guarantee high hardness, wear resistance and heat hardness with the reasonable treatment, while poor treatment leads to overheating and over burning that affecting tool life. In order to prolong the life of HSS tools, we must know the carbides in steel deeply and understand the law of generation and variation of carbide profoundly to develop towards the direction of improving tool life. The most direct inspections are to check the degree of heterogeneity of carbides, to improve the morphology and distribution of carbides by pressure processing, to quench the heating and pay attention to the solubility of carbides, and to examine the change of tempered carbides.

4.2 The test of grain size must concern the solubility of carbides

The test of grain size has always been used as an important means to test the quenching quality of HSS, and some even used as the only way to detect the hardness of HSS. The domestic and foreign counterparts have very different views on the effect of grain size on the life of HSS cutting tools. When the grain size is 9.5 grade, the cutting tool has the best service life that can drill 460 holes. Too small or too coarse grain will reduce the life of drill bit. Moreover, the dissolution of carbides must be sufficient and the hardness after heat treatment should larger than 65HRC. Different cutting tools have different requirements for austenite grain size and carbides solubility. For example, the required grain size of the gear hob is 9 grade, the lathe tool is 8 grade, and the carbide should dissolve fully; the machine taps require 10.5 fine grain, but has no more requirement on the carbide dissolution. The grain size reflects the quenching temperature. For high thermosetting cutting tools, the solubility of carbide is more important than grain size. Therefore, in reading metallographic phase, we must give consideration to both of carbide solubility and grain size.

4.3 Hardness problem

Many papers have repeatedly stressed that hardness is a superficial phenomenon and the metallographic organization is the essence. For HSS cutting tool, to obtain high hardness above

64HRC is easy. But it is not easy to get an ideal metallographic organization. The hardness of the super hard HSS, such as M42, is not as high as better, but has a suitable range. Too high hardness will not increase but decrease the service life. HSS cutting tools never hero by high hardness. Practice finds that cutting tools with high life usually have high hardness, but those with high hardness will not always have long lifespan. Therefore, we must strive for high hardness under the premise of full use of toughness.

4.4 surface strengthening

The potential of increasing life by heat treatment is small that we should be achieve the goal from the surface. This view has some truth but is not comprehensive. The surface strengthening technology of HSS cutting tool has been developing very fast. At present, steam treatment, oxygen nitriding, TiN coating, TiAlN coating and multi-layer compound coating are all very helpful for improving tool life [5,6]. Two problems should pay attention in surface hardening. First, the preprocessing must be perfect that low hardness or overheating will not increase the life of cutting tools. Then, the surface hardening must be targeted to ultimately improve the tool life.

5. Classification and material selection of HSS

5.1 Basic characteristics and classification of chemical composition of HSS

HSS is a tool steel with high carbon and high alloy. The content of carbon elements is generally from 0.7% to 1.6%, and the sum of the weight percentage of the major alloy elements, such as W, MO, Cr, V and CO, is between 10% and 40%. According to the different ratio of alloying elements, HSS can be divided into W-HSS, MO-HSS, W-MO HSS and high-performance HSS containing CO, AI and high V elements, respectively. Another characteristic that different from other types of steel is that the content of Cr element is fixed at about 4%.

5.2 Main grade of HSS and selection of cutting tools

Among the HSS cutting tools, the proportion of the tools made by the general HSS is the largest. At present, the output of the general HSS accounts for more than 80% of the total HSS. W18Cr4V (W18), which has a history of 100 years, is the earliest general HSS tool steel that the components were established and widely used in the world. Since the 40s of last century, after the composition establishment of general HSS W6MO5Cr4V2 (M2), the development and evolution of various kinds of HSS are based on the above two brands. Materials workers by testing W equivalent, replacing W with MO and adding CO, AI, V and other elements to increase the number of high speed steel to more than 100 kinds.

W18 steel has low super-heat sensitivity, wide thermal plastic temperature range, strong anti-oxidation and decarburization ability, good machinability and grindability. The disadvantages of W18 steel is that the ledeburite organization is too coarse, distribution of carbides is uneven, thermal conductivity and thermal plasticity are poor, the toughness is low, and the the productivity is not high. At present, the supply and demand of W18 steel are light, which is in the list of eliminated steel. M2 steel is the most international HS brand in the recent years, and its application is also the most widely used. The carbide particles of M2 steel are finer and well distributed. The strength and toughness of M2 steel are much better than those of W18 steel, but their overheating sensitivity is high, oxidative decarburization tendency is large and machinability is slightly worse. W9WO3Cr4V (W9) steel is our self-developed W-MO general HSS that metallurgical quality and process performance has the both advantages of W18 and M2, which has been incorporated into the national standard in 1988, and has wide applied in China.

5.3 The heat treatment of HSS cutting tools

The choice of quenching heating temperature depends on the content of main alloy elements in HSS such as C and W, MO, Cr, V, which determines the temperature range of quenching during final heat

treatment of HSS. The final quenching temperature is the most important parameter in the heat treatment process of cutting tool. The proper quenching and heating temperature can ensure that the tool has the necessary high hardness (including secondary hardening), high hardness and good toughness to meet the needs of lathe and machined parts. Generally, HSS with small balance carbon and high carbon saturation should be quenched at a lower heating temperature.

Through the study of M2 steel, it is found that each 1% increase in carbon content, the temperature that grain boundary melting drops 11°C [7]. On the other hand, if the carbon saturation is low, the temperature can chose the temperature above the middle limit to heat and quench that the carbide can be dissolved more fully, and obtain high thermal hardness and wear resistance. The morphology and distribution, dissolution and precipitation of abundant alloy carbides in HSS also affect the selection of quenching temperature. Under the conditions of more large grained carbide, serious carbide segregation, high level of macrostructure and large segregation of components, it should be quenched below the medium limit.

5.4 Quenching temperature selection and quenching and tempering control of different cutting tools

The requirements of tool performance are different for different service conditions, different machining environment. In general, the cutting tools with simple shape, continuous cutting and single-edged semi-finished tools can choose higher quenching temperature. Other HSS cutters with complex shape, large thickness difference, super large size, slender structure can be quenched with medium and low temperature. In addition, for the products such as rod and tooth round saw blade, it is necessary to heat the surface locally in a high temperature salt bath furnace, and use the upper limit temperature to quench. While for the tools need whole heating in the high temperature salt bath furnace, the middle and upper limit quenching temperature can be selected for the small and medium size, and the lower limit quenching temperature should be selected for the larger size.

5.5 Selection of heating time for quenching and heat treatment of large size cutting tools

The selection of quenching heating time is closely related to the temperature of quenching and heating. For HSS products, the selection of quenching heating temperature is the first choice. Within the range of temperature requirements for quenching process, the heating time can be relatively reduced for the higher heating temperature, while the heating time can be increased for the lower heating temperature. Usually, the quenching time can be calculated according to the effective thickness of the product, and the heating coefficient can be 8~10 S/mm. For cutting tools with small effective thickness, the heating time can take upper limit (the minimum heating time should not be less than 2 min), while if the effective thickness is large, it can take the lower limit. The choice of heating time for large size broach and hob can be determined according to the actual conditions of the field equipment and temperature. Generally, the temperature can be recovered to the set value at the high temperature heating furnace and heated for 8~10 min after heating. During the heating and cooling in the salt bath furnace, it must keep the single piece heating state.

The heat treatment of large specification, except reasonable quenching temperature, holding time and choosing suitable fixture tools, another important key technology is how to take measures to ensure the hardness requirements of heat treatment and avoid cracking or severe heat treatment deformation. Through the accumulation of work experience in many years, the following measures are often taken to achieve better results in the process of actual heat treatment production. First, the poor design and improper processing of the potential heat treatment defects must be improved, such as reducing the sharp change of the cross section, increasing the corner of the keyway and avoiding the sharp angle of the gap to prevent the excessive local stress concentration in the tool heat treatment. Second, before final heat treatment, it can choose 2~4h high temperature tempering in the 720~760°C range according to the actual situation of the workpiece to eliminate the processing stress and prepare for quenching organization [8]. Third, quenching heating and quenching cooling can use multistage temperature preheating, and multistage temperature isothermal technology. To prevent the cracking of tempering, the preheating can be increased when tempering [9]. Forth, to carry out low temperature

aging treatment after the heat treatment and finish of the products. With the extensive application of advanced machining equipment such as CNC machine tools and machining centers and the striving for high speed and high precision cutting, higher requirements for metal cutting tools are put forward, and HSS cutting tools are faced with great challenges. Therefore, the research and development of HSS tool material with high performance and heat treatment technology is the heavy responsibility of workers work on metal materials and heat treatment.

6. Conclusion

The market feedback from domestic and foreign shows that a high quality tool product not only has a high average life span, but also has a stable quality and a good tool repeatability. A large number of cutting tools in our country have a low life. The fact is that not all products are of low life span, but have quite different life. The dispersion is too large, resulting in greatly decrease of the average life. For a cutting tool, domestic cutting tools are not worse than foreign ones. Many tool factories have done the experiments that compared with single parts, but when take 10 tools, there will always be 1~2 pieces of domestic tools unsatisfactory. The quality and stability of product of the tool life is a comprehensive reflection of the technical and management level of a factory. It is not easy to make a high tool life, which is a system engineering. It must have a set of strict rules and regulations, correct technical documents from the raw material control, machining, heat treatment to the final product packaging factory. The successful application of computer on precision temperature control of heat treatment furnace and other advanced heating equipment has made a positive contribution to stabilizing and improving the quality of cutting tools. Furthermore, the German Zeiss metallographic microscope also increases weight to the stability of product quality. Overall, steel mills and mechanical process should be powerful, and the most important is that our colleagues engaged in Heat treating should to prove ourselves. As long as we do well in every link, we will be able to create cutting tools with high life and do our best to make China become a great power in the world.

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