Application News

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Electron Probe Micro Analyzer

# Analysis of High Speed Tool Steel

A variety of tools are used to cut parts and finishing products. These tools and blades are made of so-called tool steels, which are categorized into carbon tool steels (SK), alloy tool steels (SKS, SKD and SKT), and high speed tool steels (SKH). They are widely used for files, press punches and dies, gauges, and tool bits. Tool steels are required to have resistance to heat and wear, as well as toughness and hardenability according to the intended use. High speed tool steels in particular are suited to high speed cutting and used for high speed drills whose cutting edges need to be resistant to heat and wear.

This article introduces an example analysis of high speed tool steel (SKH) using an EPMA-8050G electron probe micro analyzer (FE-EPMA).

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## High Speed Tool Steel (SKH)

High speed tool steels are manufactured by adding high amounts of vanadium, chromium, molybdenum and tungsten. When quenched and then tempered at above 500 °C, carbides are precipitated (secondary hardening), and steels obtain heat resistance, wear resistance and toughness. These steels do not lose their hardness even if raised to the temperature near the tempering temperature. Such steels are used as sharp cutting tool steels (high speed tool steels).

There are several kinds of high speed tool steels: tungsten-based, molybdenum-based, and vanadium-based steels. Tungsten-based high speed tool steels contain approx. 0.8 to 1.5 % carbon, 18 % tungsten, 4 % chromium, and 1 % vanadium, and the standard SKH2 is called 18-4-1. Molybdenum-based high speed tool steels contain approx. 0.8 to 1.5 % carbon, 6 % tungsten, 5 % molybdenum, 4 % chromium, and 2 % vanadium, and typical SKH51 (former SKH9) is called 6-5-4-2. Molybdenum-based high speed tool steels have a higher toughness than tungsten-based or vanadium-based high speed tool steels, and feature easy heat-treatment since the quenching temperature is low and heat conductance is good.

Fig. 1 shows the mapping analysis result of a molybdenum-based high speed tool steel, indicating the distribution of vanadium, chromium, molybdenum and tungsten carbides resulting from the secondary hardening.

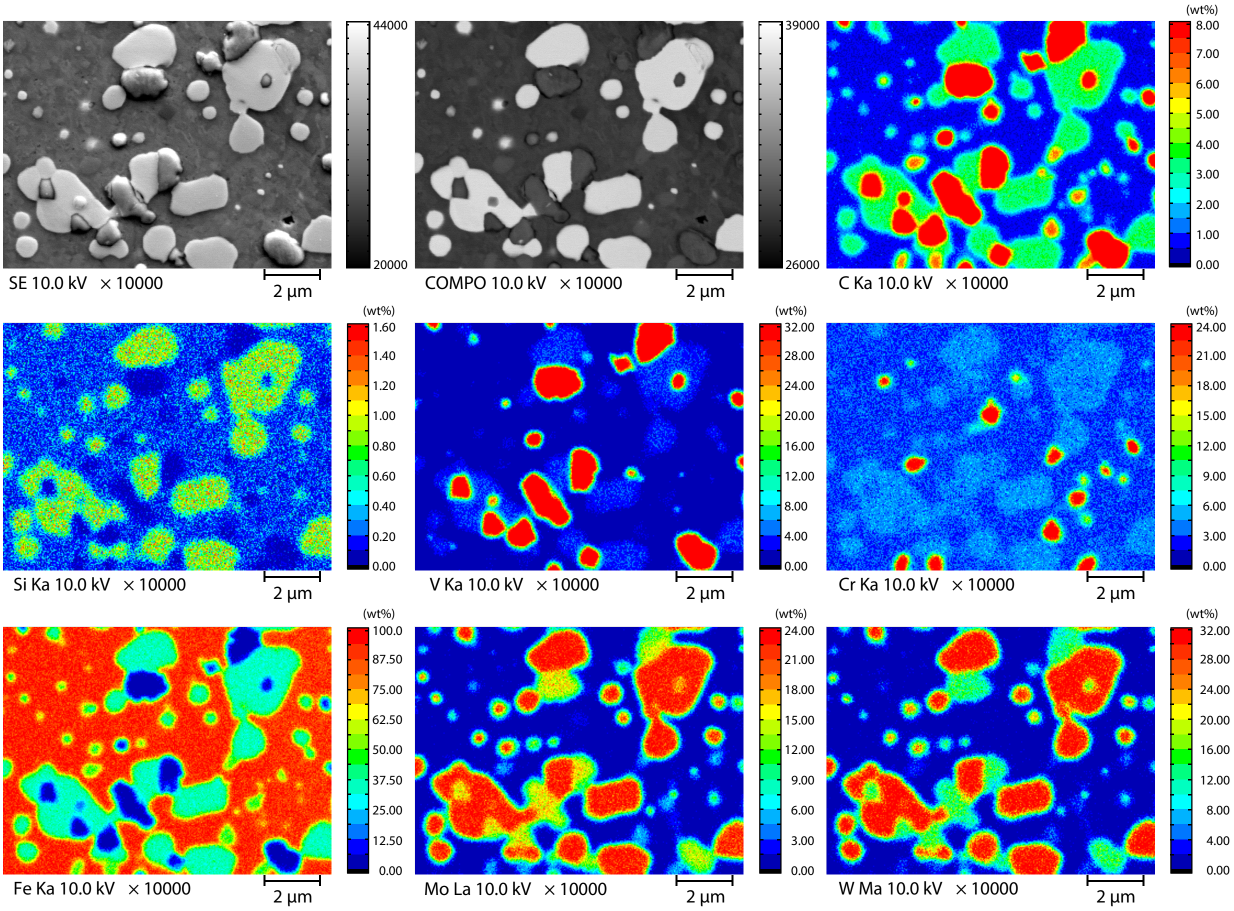


**Fig. 1 Mapping Analysis of High Speed Tool Steel**

## Carbides of Alloy Elements

When multiple kinds of special elements are added to steel at one time, carbides of the element whose amount is the highest tend to be generated. If multiple elements are added in the same amount, the element having a greater affinity for carbon will be more precipitated in the carbide phase. Among the elements added to molybdenum-based high speed tool steels, vanadium (V) has the greatest affinity, followed by tungsten (W), molybdenum (Mo), chromium (Cr) and then manganese (Mn). Nickel (Ni), cobalt (Co), copper (Cu) and silicon (Si) have a smaller affinity than iron (Fe).

Alloy steels containing multiple carbide forming elements with a great affinity to carbon (C) follow a complicated composition trajectory from the first carbide precipitate to the final stable carbide phase in terms of the carbide type, transition sequence, and change in its toughness and hardness, depending on the content and ratio of each alloying element. In the softening process at a low tempering temperature up to 773 K (500 °C), the carbide precipitate is M3C. When the tempering temperature rises and exceeds 773 K (500 °C), the carbide phase concentrates in $Fe_3C$, and after the solid solubility limit, alloy carbides other than $Fe_3C$ are formed. Among Cr, V, W and Mo, Cr is precipitated in $Fe_3C$ in the form of $Cr_7C_3$, and the other elements are coherently precipitated in the matrix in the form of $V_4C_3$, $W_2C$ and $Mo_2C$, which indicates the secondary hardening.

## Phase Analysis of Carbides

Phase analysis extracts the strength (concentration) plotted on a scatter diagram as a point set (cluster) to accurately represent each compound phase. From the mapping data of high speed tool steels shown in Fig. 1, V, Cr, Mo, W and C clusters are extracted and formed into a ternary scatter diagram as shown in Fig. 3. We can identify, from the phase diagram shown in Fig. 2, that there is a blue compound phase mainly consisting of Mo carbides and W carbides, a red compound phase mainly consisting of V carbides, and a green compound phase mainly consisting of Cr carbides.

Being that the ternary scatter diagram in Fig. 3 is planar, plotted point sets are overlapped; however, the 3D scatter diagram (triangle) shown in Fig. 4 gives a spatial view of these point sets, facilitating in grasping the existence of different phases. From this figure, we can confirm the existence of overlapped phases (the solid solution phase in yellow shown in Fig. 2 and the Cr carbide phase in green above it).

Fig. 5 shows a multi-component diagram (binary scatter diagram matrix) where multiple binary scatter diagrams can be displayed at the same time. We can see that, from the horizontal lines indicating the correlation of carbon to other elements in this figure, the compound phase in red contains Mo and W carbides in addition to the V carbide.

The 3D scatter diagram (XYZ) shown in Fig. 6 is created by assigning a maximum of six elements in the positive and negative directions of X-, Y- and Z-axes. The maximum value in each of Cr, C and V axes are taken as vertices of a triangle, graphically representing a ternary scatter diagram (blue). In addition, by combining the X-, Y- and Z-axes, a maximum of eight patterns of ternary scatter diagrams can be visualized.

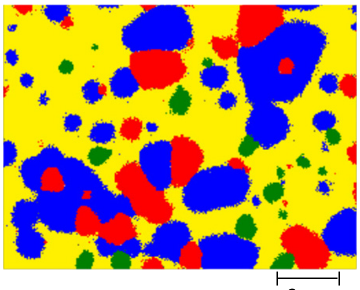


**Fig. 2 Phase Diagram**

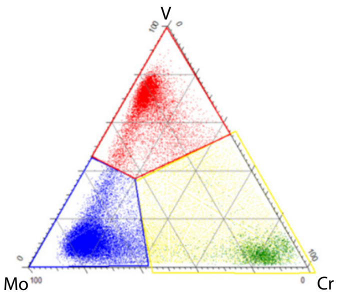


**Fig. 3 Ternary Scatter Diagram**

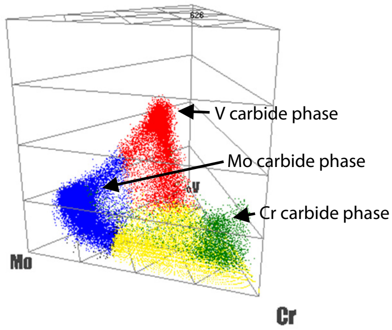


**Fig. 4 3D Scatter Diagram (Triangle)**

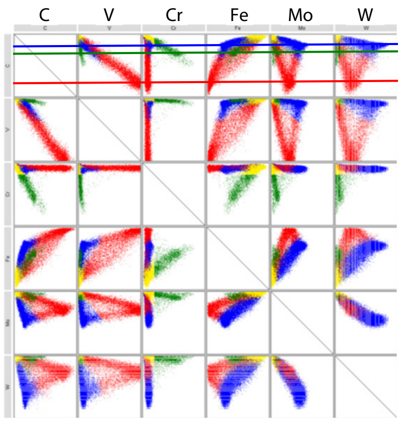


**Fig. 5 Multi-component (Binary Scatter Diagram Matrix)**

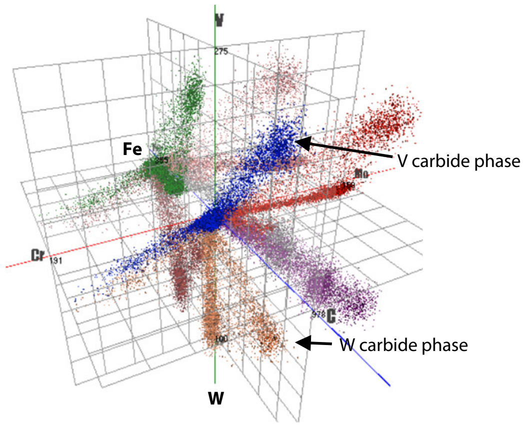


**Fig. 6 3D Scatter Diagram (XYZ)**

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