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Review

Sintered High-Speed Steels—Manufacturing Methods and Their Influence on the Properties of the Sintered Material

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Abstract

Cutting tools made from sintered high-speed steels have better cutting properties than tools made from conventional high-speed steels of a similar chemical composition when machining difficult-to-cut steels and at higher cutting speeds, especially in the presence of a cooling fluid. Due to their enhanced properties, which guarantee greater durability and reliability than conventional steels, sintered high-speed steels are primarily used for tools used in automated machining processes (in machining lines, on numerically controlled machine tools, or in machining centers). Many grades of sintered high-speed steels are produced, with varying chemical compositions selected depending on the machining conditions. As has been observed in industrial practice, the properties of sintered high-speed steels depend not only on their chemical composition but also on the manufacturing method. This paper describes the most well-known and most commonly used methods for producing sintered high-speed steels, assessing their cost of tool production, the cost-effectiveness of producing large- and small-sized tools, the cost-effectiveness of producing complex-shaped tools, the cost-effectiveness of use in mass and individual production, the suitability for producing tools operating under high static loads and in terms of high resistance to impact loads, and assessing the impact of the method on the properties of the sintered material.

Keywords: sintered high-speed steels; production methods; scope of application

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1. Introduction

As a result of the production of sintered high-speed steels, it was possible to eliminate the basic disadvantages of conventional high-speed steels, such as the uneven distribution of components and carbide bands [1]. This allowed us to improve the performance properties (increase in durability and reliability) of the cutting blades. In other words, tools made of sintered high-speed steels have better cutting properties than tools made of conventional steels with a similar chemical composition. This is particularly evident when machining steels that are difficult to machine and when machining at higher cutting speeds in the presence of coolant. The improvement in performance varies and depends mainly on the cutting conditions, including primarily the properties of the workpiece and the type of tool.

Sintered high-speed steels, in addition to better performance properties compared to conventional ones, have many beneficial technological properties, such as [1,2]: good

machinability, good plasticity, very good grindability when shaping them into tools, and significant dimensional stability after quenching and tempering. Such beneficial technological properties of sintered high-speed steels allow for the relatively easy shaping of many types of tools. Sintered high-speed steels are mainly used for the following: tools for machining materials that are difficult to machine, and tools designed for automated machining processes (in machining lines, numerically controlled machine tools, and machining centers). This range of use of sintered high-speed steels is due to their greater durability and reliability than conventional high-speed steels. It is particularly advantageous to compare the performance properties of tools made of sintered steel with tools made of conventional steels, when they have large sizes and a significant weight and complex shape, such as worm milling cutters, which cannot be made as folding [1]. Although the cost of a tool made of sintered high-speed steels is on average 2.5 times higher than that of conventional steel tools, it is often compensated with the excess results obtained. The grades of sintered high-speed steels for cutting tools are selected depending on the conditions of the cutting process (processed material, method of machining, type of tool load, etc.). Individual grades of sintered high-speed steels differ from each other in their chemical composition. Table 1 shows the most commonly used grades of sintered high-speed steels for cutting tools.

Table 1. Average chemical composition of selected grades of sintered high-speed steels developed on the basis of [2–12].

Steel Designation	Steel Grade (W-Mo-V-Co)	Mass Concentration of an Alloying Element [%] (Rest Fe)					
		C	W	Mo	V	Cr	Co
ASP23	PM 6-5-3	1.27	6.4	5.0	3.1	4.2	–
ASP30	PM 6-5-3-8	1.28	6.4	5.0	3.1	4.2	8.5
ASP60	PM 6-7-6-10	2.30	6.5	7.0	6.5	4.2	10.5
ASP 2030	PMHS6-5-3-8	1.28	6.4	5.0	3.1	4.2	8.5
ASP 2060	PMHS 7-7-7-11	2.3	6.5	7.0	6.5	4.2	10.5
CPM Rex76	PMHS10-4-3-10	1.5–1.55	9.7–10.0	5.25	3.1	3.75–4.0	8.5–9.0
CPM Rex121	PMHS 10-4-3-9	3.4	10.0	5.0	9.5	–	9.0
FYP62	PM 6-5-2	1.00	6.0	5.0	2.0	4.5	–
FYP64	PM 6-5-4	1.30	5.5	4.5	4.0	4.5	–
FYP125	PM 12-1-5-5	1.60	12.0	0.6	5.0	4.5	5.0
M2	PM 6-5-2	0.87	6.4	5.0	1.9	4.2	–
M2N	PM 7-5-2	0.90	6.6	5.0	2.0	4.1	–
M4	PM 6-5-4	1.30	5.7	5.0	4.2	4.5	–
M35	PM6-5-2-5	0.90	6.4	5.0	1.9	4.1	4.8
M35VV	PM 6-6-3-5	1.10	6.3	6.3	2.5	4.2	4.5
UHBASP23	PM 6-5-3	1.27	6.4	5.0	3.1	4.2	–
UHBASP30	PM 6-5-3-9	1.27	6.4	5.0	3.1	4.2	8.5
UHBASP60	PM 7-7-7-11	2.30	6.5	7.0	5.0	4.0	10.5

2. Methods for Manufacturing Sintered High-Speed Steels

The raw material for the production of sintered high-speed steels is a powder with a chemical composition corresponding to finished steel. The basic method of powder production involves spraying liquid steel with water or inert gases, mainly argon and helium, as well as nitrogen. Steel with an appropriate chemical composition is most often smelted in a medium-frequency induction furnace. The liquid metal is poured from the furnace into a vat and, from there, poured into a crucible located on top of a chamber several meters high. Liquid metal flows into the chamber through a centric hole. At the same time, inert gas or water is supplied to the chamber. They spray the flowing stream of metal into very fine droplets, which, after falling to the bottom of the chamber, cool down in the form of grains. The powder obtained in this form is sieved to remove grains that are too large.

Grain sizes can be adjusted by selecting the temperature and amount of liquid metal, as well as changes in pressure and the gas flow rate [12–17].

The grains of the powder obtained by spraying with water have a jagged surface; this powder is characterized by good compressibility. It is most often subjected to further mechanical grinding by grinding in vibratory or ball mills, as a result of which particles with a diameter of 1–2 µm are obtained, or it is smashed against an armored plate after being given a speed of one mach with compressed air [18–25]. The powder particles obtained as a result of gas spraying have a spherical shape and a diameter of 0.01–1 mm and are characterized by good flowability, but poor compressibility [12–16].

There are many methods for obtaining sintered high-speed steels: the Swedish ASP (ASEA-STORA Process) method [12,16,18] and its variations, the STAMP (process by Avesta/Nyby Uddeholm) method [12,16,26], the CAP (Consolidation by Atmospheric Pressure) method [14–16], the French C–L (Cold Isostatic Pressing & Vacuum Sintering) method [7,15,16,22], the American CPM–HSS (Crucible Particle Metallurgy–High-Speed Steel) method [4,7,15,16,27], the British D–L (Davy-Loewy) method [15,16,28,29], the English Powdrex method [14,16], the American CMI (Consolidated Metallurgical Industries, Inc.) Fuldens method [7,14,16] and others [7,12,16,19–23,30–32].

The methods most commonly used for the production of sintered high-speed steels are described below.

The ASP method is one of the most commonly used for the production of sintered high-speed steels. It was developed by ASEA-STORA. This method consists of obtaining a powder of high-speed steel by spraying molten steel in a high-purity nitrogen stream in a vacuum column. In this process, a powder is obtained (its spherical particles have a diameter of 0.06 to 0.6 mm), which is then sieved. Carbon steel containers are filled with the powder obtained in this way with the appropriate granulation, which are subjected to vibrations in order to increase the concentration of the powder. The welded powder container is then cold-pressed isostatically in pressure chambers at room temperature (approximately 293 K (20 °C)) at a pressure of approximately 400 MPa. For cold isostatic pressing, a pressure chamber in the form of a steel cylinder is used, on which a wire with a rectangular cross-section and high tensile strength, amounting to about 2500 MPa, is wound. This wire is so tensioned that, during operation, the compressive stress exerted on the walls of the chamber is greater than the pressure of the liquid or gas filling the chamber. Isostatic pressing is most often carried out with the use of a water–oil emulsion or oil, which are supplied to the chamber by means of pumps. Then, a steel container with cold isostatically pressed powder is annealed in an electric furnace at a temperature of 500 °C. After the degassing process is completed, the port is closed and the container with the powder is placed in a furnace with a protective atmosphere at a temperature of 1100 °C. After closing, the baler chamber is filled with argon. At a temperature of 1370–1420 K (approx. 1100–1150 °C) and under a pressure of about 100 MPa, the powder is sintered. In this way, blocks of sintered high-speed steel weighing about 1.5 tons are made, which are then cut and machined or formed to obtain tools of specific dimensions and shapes [14–16,18–25]. Figure 1 shows a diagram of the ASP (Swedish company ASEA-STORA) method for manufacturing semi-finished products from sintered high-speed steel from powder sprayed with very pure nitrogen.

Figure 2 illustrates a schematic diagram of the pressure chamber used for the isostatic pressing of sintered steel via the ASP method.

The STAMP method differs from the ASP method primarily in that the steel is sprayed with an inert gas in a horizontal column rather than a vertical one. This is advantageous because steel spraying can be carried out in low-rise installations located in typical halls (there is no need to build tall halls for vertical columns). The second difference from the ASP method is that the thickening of the heated powder placed in the container takes place

in the STAMP method in a hydraulic press in a closed die, and is not performed during isostatic pressing, as is the case with the ASP method, and the total cost of the investment is relatively small [14–17,26,27]. Figure 3 shows a diagram of the production of sintered high-speed steels using the STAMP method from inert-gas-sprayed powder.

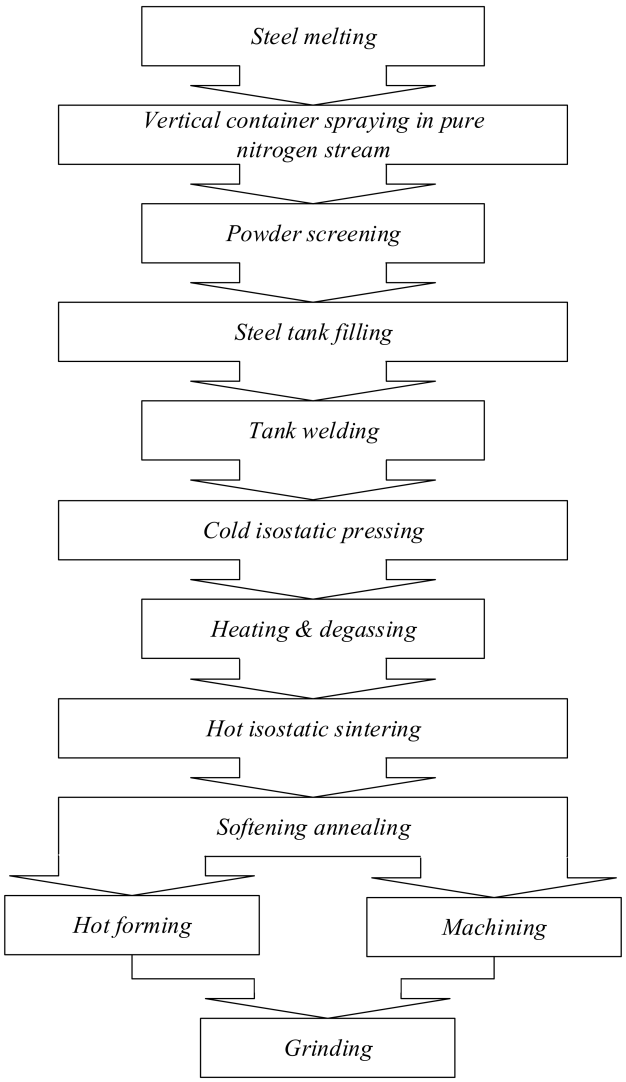


Figure 1. Diagram of the ASP method (Swedish company ASEA-STORA) for the production of semi-finished products from sintered high-speed steel from powder sprayed with very pure nitrogen (developed on the basis of [4,14–16,18–23,26]).

The CAP (Consolidation by Atmospheric Pressure) method of solidification under atmospheric pressure is used to make semi-finished products and finished tools from high-speed steels. In this process, steel is melted in an induction furnace in air or in a vacuum and then sprayed with nitrogen or argon. Droplets of sprayed steel of a small size solidify even before they reach the bottom of the spray chamber. After sieving, chemical cleaning and drying in a vacuum, the powder is poured into glass molds of the required shape. The powder-filled molds are filled with sand in a refractory tank and heated to a temperature exceeding 1370 K (approx. 1100 °C) in a gas or electric furnace. The solidification of semi-finished products occurs as a result of the diffusion of powder particles in a solid state. The next stage in the production of high-speed steel semi-finished products is their cooling, during which the glass mold is automatically broken. In order to obtain the required shape and dimensions, the semi-finished product is hot-melted by rolling or forging. The main

advantage of the CAP method is the low cost of tool manufacturing, comparable to the cost of manufacturing a tool from conventional high-speed steel. It is the cheapest method of producing sintered high-speed steels. Due to the significant reduction in forming compared to conventional high-speed steels, energy savings are estimated at 50% [14–16]. Figure 4 shows a diagram of the production of sintered high-speed steels using the British CAP method from argon- or nitrogen-sprayed powder.

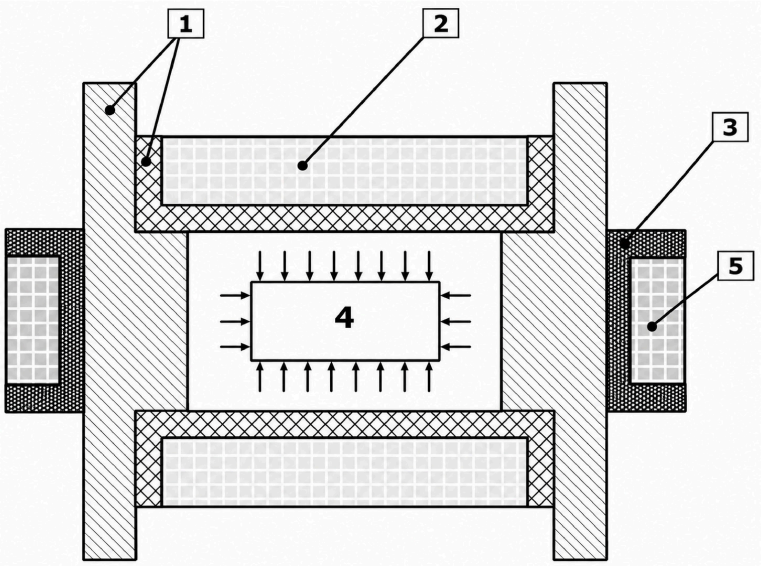


Figure 2. Pressure chamber of a press for isostatic pressing of sintered steel in the ASP method: 1—pressure chamber, 2—high-strength wire, 3—limiting frame consisting of two hemispherical yokes, 4—powder container, 5—high-pressure liquid or gas supply. The inward-pointing arrows indicate the uniform isostatic pressure exerted on the powder container (developed on the basis of [14–17]).

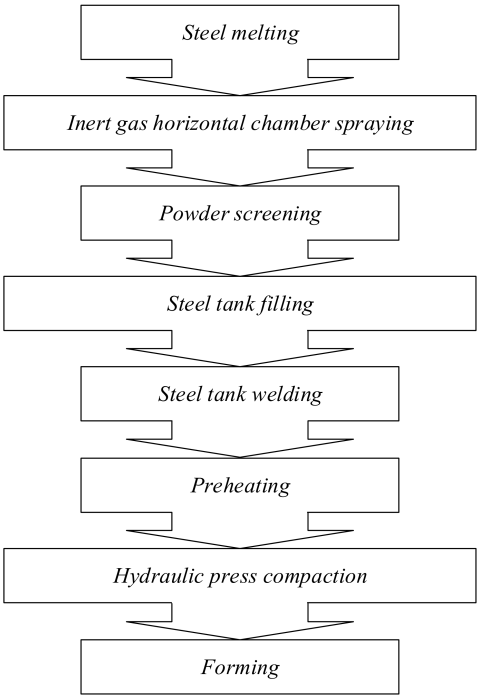


Figure 3. Diagram of the production of sintered high-speed steels using the STAMP method from inert-gas-sprayed powder (developed on the basis of [14–17,24–26]).

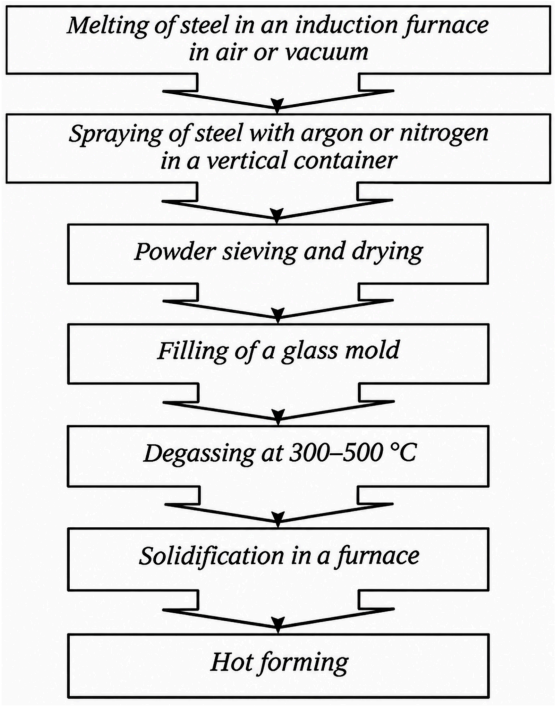


Figure 4. Scheme for the production of sintered high-speed steels using the British CAP method from argon- or nitrogen-sprayed powder (developed on the basis of [14,16]).

The semi-finished products obtained by extrusion are then hot-formed by rolling [7, 14,16,26]. Figure 5 shows a diagram of the process of manufacturing sintered high-speed steel using the C-L method.

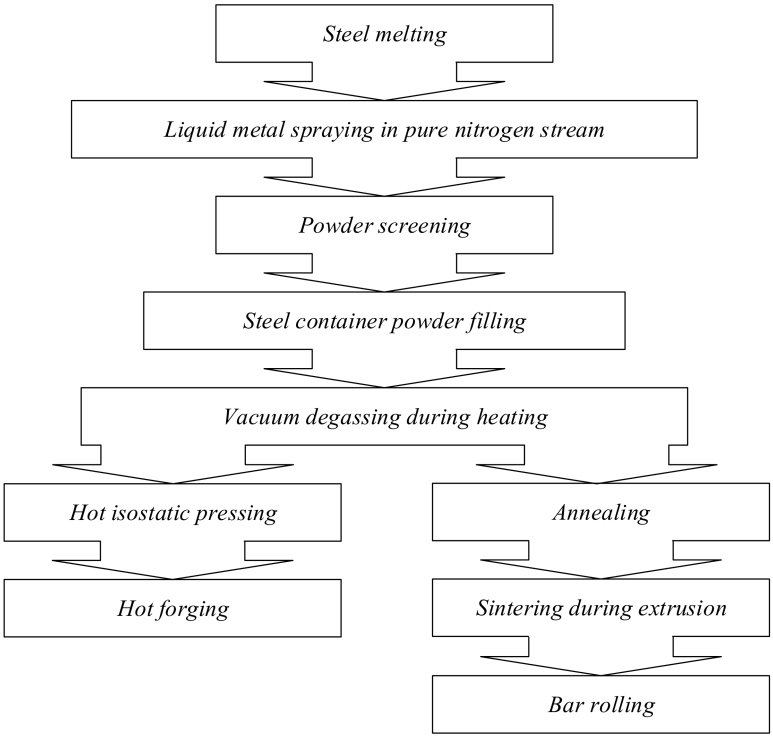


Figure 5. Diagram of the process of production of sintered high-speed steel using the C–L method (developed on the basis of [7,14,16,26]).

The CPM–HSS method is an American method for producing sintered high-speed steels. It consists in the fact that the powder is obtained from liquid metal as a result of nitrogen spraying. Then, the powder with the appropriate granularity, obtained as a result of sieving, is poured into steel containers. After the air has been removed, the powder containers are sealed tightly and subjected to hot isostatic pressing at a pressure of about 200 MPa. The blocks of sintered high-speed steel obtained in this way have a weight of about 360 kg. In order to give the semi-finished product the appropriate dimensions and shape, the blocks are subjected to plastic treatment [7,14,16,23]. Figure 6 shows a diagram of the process of manufacturing sintered high-speed steels using the CPM-HSS method.

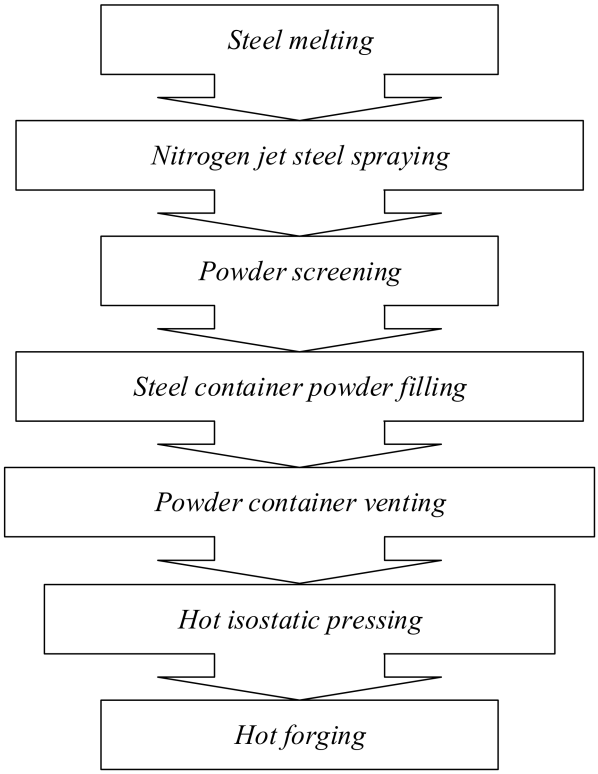


Figure 6. Diagram of the process of production of sintered high-speed steels using the CPM–HSS method (developed on the basis of [7,14,16,23]).

The CMI Fuldens method is an American method for producing high-density high-speed sintered steels [14,16]. The powder is produced by spraying a stream of liquid metal with water and additionally crushed mechanically. Tools with simple shapes and small sizes are made by cold-pressing powders in dies. Tools with a complex shape and a large size are subjected to cold isostatic pressing, and then sintered in a vacuum. This method is mainly used to produce ready-made tools with a small size. Tools with complex shapes are first made in the form of semi-finished products, which are later shaped in the process of mechanical processing. Figure 7 shows a diagram of the fabrication of sintered steel tools using the CMI Fuldens method.

The PIM (Powder Injection Molding) method is one of the most modern methods of manufacturing tools from sintered high-speed steel. Tool manufacturing by this method involves the injection molding of powder mixed with polymer. After the injection and polymerization stage, the resulting fitting is subjected to a depolymerization process to remove the polymer. This process involves long-term annealing at the depolymerization temperature. After the depolymerization process, the fittings are sintered in vacuum furnaces or furnaces with a protective atmosphere. The main advantage of this method is

the possibility of producing elements with complex shapes, impossible to obtain by other methods of production of sintered high-speed steels, and the reduction in the temperature of the sintering process as a result of the fact that there is carbon between the grains of the metallic powder, which is a residue from the degradation of the polymer [14,16].

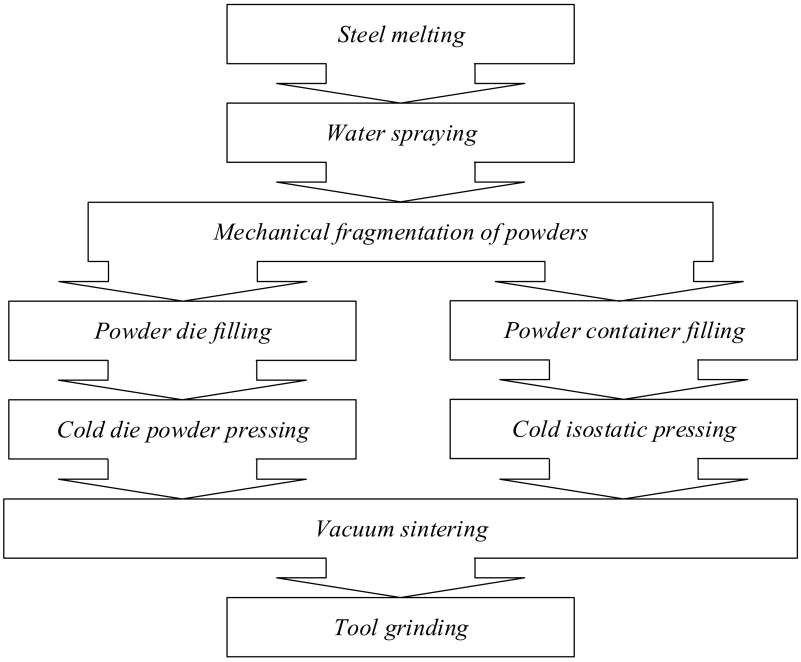


Figure 7. Fabrication diagram for sintered steel tools using the CMI Fuldens method (developed on the basis of [7,14,16]).

Figure 8 shows a diagram of the process for manufacturing tools from high-speed steel using the PIM method.

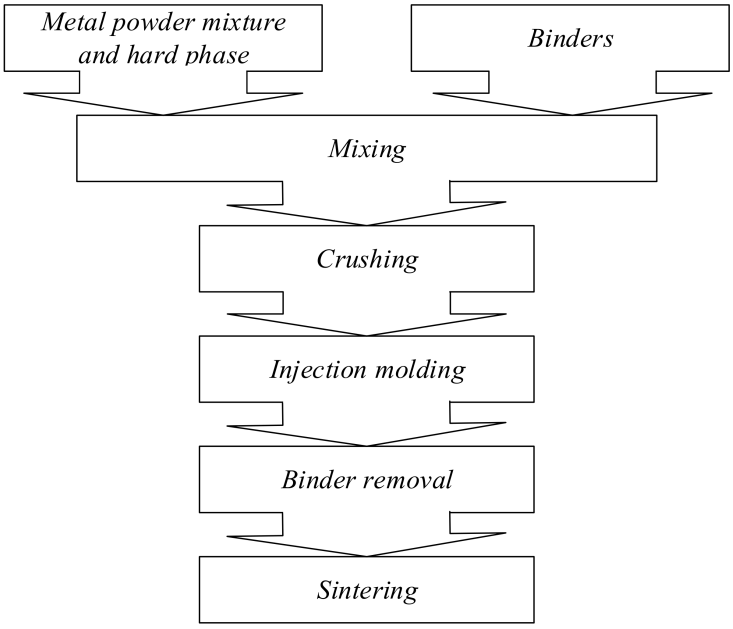


Figure 8. Scheme for the manufacture of high-speed steel tools by powder injection molding (PIM) (developed on the basis of [14,16]).

There is no single method of manufacturing sintered high-speed steels (PM-HSS) that is absolutely the best in every category. The choice of the "best" technology for the production of sintered high-speed steel depends on whether the priority is maximum mechanical properties, low cost, production volume, finished product size or complexity of the shape of the finished tool. Therefore, below, in Section 3, the individual methods are evaluated under a number of criteria.

3. Comparative Analysis of Sintered High-Speed Steel Production Methods

3.1. Comparative Analysis of Methods in Terms of Cost of Production of Cutting Tools

Metals and powder alloys as well as technologies such as ASP, CPM-HSS, PIM (Powder Injection Moulding) and Powdrex are some of the most modern methods for producing ultra-fine-grained steels, ideal for cutting tools. They allow you to achieve exceptional hardness, abrasion resistance and impact strength. The following table compares these methods (among others technologies such as CAP, C-L, CMI Fuldens, D-L, and Stamps) in terms of production costs [14,16,33–38].

With regard to the data presented in Table 2, it should be noted that, in the group of powder metallurgy technologies, alloys such as ASP and CPM are initially more expensive in material and machining, but, in terms of tool life (number of products made), they are often the most cost-effective.

Table 2. Comparison of methods for manufacturing sintered high-speed steels in terms of cost of production.

Method/ Technology	Raw Material Cost	Machinery and Tooling Cost	Machining and Finishing Cost	Overall Cost of Tool Manufacturing
ASP/CPM–HSS	Medium to High (metallurgical powders)	High (requires HIP—Hot Isostatic Pressing)	Medium (tools traditionally machined from bars/blocks)	High (very high quality and service life)
PIM/MIM	Medium (metal powder)	High (injection mold cost)	Low (finished shape close to final)	Medium to High (cost for mass production)
Powdrex	Medium	High	Medium (machining)	Medium to High
CAP	Medium	Extra High (advanced sintering equipment)	Medium	Low
CMI Fuldens	Low to Medium	Medium	Medium	Medium
STAMP	Low to Medium (tool steel)	Low to Medium	High	Low to Medium
C-L	Low to Medium	Medium (casting molds)	Medium to High (need for finishing)	Medium

3.2. Comparative Analysis of Methods in Terms of Cost-Effectiveness in the Production of Large-Sized Tools

Powder metals/technologies like ASP, Stamp, CAP, C-L, CPM-HSS, D-L, Powdrex, CMI Fuldens, and PIM) differ in structure and manufacturing technology. Table 3 compares the cost-effectiveness of producing large-size tools, comparing powder costs, HIP dimensional limitations, machinability and final service life [14,16,33–38].

Table 3. Comparison of methods in terms of cost-effectiveness of large-size tool production.

Method/Material	Availability for Large Dimensions	Cost of Charge and Processing (Cost-Effectiveness)	Main Advantages and Disadvantages for Large Dimensions
ASP	Good. Large blocks and die forgings (e.g., up to 500–600 mm)	Medium/High. Very high cost of raw material, but lower cost of rework, and long service life.	Excellent impact strength and abrasion resistance. Ideal for long-life stamping elements.
STAMP	Medium/Good. Optimized for pressed parts and stamping dies.	Low/Medium. Very cost-effective in mass production of sheet metal parts (high material utilization).	Limited application for complex forms.
CAP	Limited. Relatively small maximum dimensions due to compaction chambers.	High. Complex technology focused mainly on precise details (e.g., punch).	Very high density and homogeneity. Unprofitable for large-size dies and sizes exceeding the capabilities of presses.
C-L	Good. It allows for relatively large tools.	Medium. Lower output costs than with pure HIP, moderate machining efforts.	It allows you to obtain large-sized molds, but the mechanical properties are lower than full HIP.
CPM–HSS	Good. Available as bars and tool blocks with large cross-sections.	High. Very expensive material load. Cost-effective only for cutting/forming tools with critical loads.	High purity of carbide. Difficult machining for large dimensions, high life of the blades.
Powdrex	Medium. For standard commercial forms, fewer restrictions in blocks.	Medium. A competitive pricing alternative to ASP, with similar performance.	Good machinability in the annealed condition. Balanced properties for large dies and tools.
CMI Fuldens	Limited. Most often advanced, relatively small precision elements.	High. Specialized technological process, expensive casting and powder machines.	Exceptional dimensional accuracy and small machining allowances, but no cost-effectiveness for large tools.
PIM/MIM	Very small. Limitations of massive dimensions.	High (pre-launched), low (standard). Very high cost of molding tooling and binders.	Production of ready-made tools. Completely unprofitable for large tools over a dozen kilograms.

3.3. Comparative Analysis of Methods in Terms of Cost-Effectiveness of Small-Sized Tool Production

The methods listed below are advanced powder metallurgy (PM) and materials engineering processes, which are diversified in the production of small tools (e.g., miniature punches, dies, and injection molds). Table 4 shows a comparison of their cost-effectiveness due to the small size of the tools [14,16,33–38].

Summarizing the data contained in the above table on the profitability of using the powder metallurgy method for the production of small-sized tools, it should be emphasized that, if miniature tools are produced in hundreds of thousands of pieces (mass production), PIM powder injection methods and classic Stamp pressing are unbeatable. They achieve the lowest unit cost of production of parts [14,16,20–23,26].

Table 4. Comparison in terms of cost-effectiveness of the production method of small tools [14–16,39–45].

Method/Technology	Unit Cost and Production Preparation (for Small Tools)	Durability of Small Tools	Cost-Effectiveness (for Small Tools)
ASP	High cost of starting material, low machining cost from finished bars (good machinability)	Extremely high due to homogeneous microstructure and no segregation of carbides	High for small batches and prototype production.
STAMP	High die manufacturing cost (only profitable for large scale), low powder unit cost.	Medium to high (depends on alloy), high repeatability	Very high only in mass production of small components
CAP	Low/Medium cost of powder alone, high cost of hot forming	Pressing tooling high with isostatic pressing	Medium, good for simple and small-size blanks
C-L	Medium/High cost of powders	Good, high density after annealing	Medium, specialized in precision & fine components
CPM–HSS	Very expensive input material, but excellent machinability and machinability	Extremely high, high abrasion resistance and impact resistance	High (for cutting tools and fine molds)—excellent value for money
Powdrex	High powder and raw material cost, but saving on finishing treatment	Very High	Medium/High, similar to ASP, an alternative to conventional steels
CMI Fuldens	High cost of advanced technology and specialty ultra-high-density powder	Extremely high density and strength	High (for specific, highly demanding components)
PIM/MIM	Low unit cost for mass production, high initial cost of injection molds	High (close to solid metal), good wear resistance	Very high in mass production of complex miniature tools/parts

In the case of the production of special cutting tools (single pieces/short series), ASP and CPM-HSS steels/technologies are the most cost-effective. The cost of the material is high, but it avoids expensive ironing dies, and the resulting miniature tool has an unbeatable service life [14,16,33–38].

For products with unique geometries with complex shapes or in prototype production due to the lack of special tooling, D-L direct printing and laser processing technologies win in the individual production of these highly complex, small tools.

3.4. Comparative Analysis of Methods in Terms of Cost-Effectiveness in the Production of Tools with Complex Shapes

In the context of tools with complex shapes (e.g., injection molds, dies, and punches), cost-effectiveness depends mainly on the production volume and the extent of subsequent finishing.

Table 5 presents a comparison of the cost-effectiveness of individual technologies in terms of the production of products with a complex shape [14,16,33–38].

Summarizing the data contained in the table above, it should be emphasized that, in the case of the low-volume and unit production of products with complex shapes (e.g., prototypes of injection molds, and single die with internal cooling channels), the D-L method (3D printing from metal) is by far the most cost-effective.

Table 5. Comparison of methods in terms of cost-effectiveness of production of tools with complex shapes.

Method/Process	Main Advantages in Complex Shapes	Profitability Range (Volume)	Cost of Tools
ASP	High isotropy, high wear resistance, precision in defective machining.	Medium and large series, tools with extreme requirements.	Moderate to very high (heat treatment dependent).
CAP	Allows to obtain almost 100% density and homogeneous alloys that are difficult to machine.	Medium series, specialized tools for heavy-duty applications.	High cost of encapsulation and ironing.
C-L	Base tool can be cheap.	Very small series, prototypes, regeneration.	Low (uncomplicated matrices).
CPM–HSS	Excellent machinability before heat treatment, no carbide segregation.	Medium and high series, precision cutting and forming tools.	High cost of starting material (PM blocks/bars).
Powdrex	Metallurgical purity, high abrasion resistance and impact resistance of very complex profiles.	Medium and large series of tools.	High (investment in tool material).
PIM/MIM	Perfect reproduction of details with very complex 3D geometry, elimination of defective machining.	From a few hundred to large mass series (depending on the detail).	Very high (the cost of injection molds is similar to plastic processing).
STAMP	A relatively simple repetitive process with high dimensional accuracy in high-volume production.	Large and mass series.	Extremely high (cost of advanced multi-operation sensors).
CMI Fuldens	Enables precise forming of semi-finished products from metals with complex geometries.	Medium and large series, details requiring high accuracy.	High at the beginning, reduced by the cost of finishing.

In the case of the high-volume production of products with complex geometries (e.g., small machine elements and precision tools), it is most profitable to produce them using the PIM method, where the die is made only once, and each subsequent product is precisely shaped in the injection molding process.

On the other hand, standard tools with complex shapes produced in large series (e.g., punches and dies for deep stamping, and cutting tools) require the shaping of powder materials in the highest-quality processes such as CPM-HSS or ASP, due to the need to ensure maximum tool life, which compensates for production costs [14,16,33–38].

3.5. Comparative Analysis in Terms of Cost-Effectiveness of Methods in Mass Production of Tools

In mass production, where the low cost of production of one part and maximum tool life are crucial, powder metallurgy (PM) technologies achieve the highest cost-effectiveness. Table 6 is a summary of the methods of production of tool steels and sinters, organized in terms of the mass profitability of tool production.

Table 6. Comparison of methods in terms of cost-effectiveness of use in mass production of tools.

Tool Manufacturing Method	Main Advantages in Mass Production	Optimal Tooling Applications
ASP	Eliminates carbide segregation. Excellent machinability, high impact strength and abrasion resistance.	Punches, stamping machines, cutting tools for cold and hot work. Extremely long service life.
CPM	Exceptional dimensional stability, ease of machining while maintaining hardness up to 65 HRC.	Machining tools (drills, milling cutters), cold forging dies.
Powdrex	Ensures high repeatability of metallurgical purity and long service life.	Difficult cutting and shaping applications (e.g., taps, broaching machines).
CAP	Very high density close to theoretical (almost 100%), low installation cost compared to isostatic hot pressing (HIP).	Very hard tools and precision workpieces with complex shapes.
STAMP	Allows you to obtain near-net-shape elements with high resistance.	Heavy-duty dies and structural components.
C–L	Good surface finish, relatively low unit cost of material.	Injection molds and stamping tools with simpler requirements.
CMI Fuldens	Very high purity and stability due to vacuum atmosphere.	Cheaper produced base powder. Machine cutting tools, blades, ironing dies.
PIM/MIM	Ideal for intricate 3D details in large batches. Finished products do not require mechanical processing (cost reduction by about 50%).	Small, precision tools, shaped inserts.

On the basis of the data contained in the table above, it should be stated that in mass production that powder methods allowing for the production of products with a fine-grained structure and uniform distribution of carbide, especially the ASP, CPM and Powdrex methods, outclass other solutions in this respect. The cost of purchasing input material and initial processing is high, but the unit costs of the tool (expressed in the price per piece of product made) in mass production are the lowest. The PIM (MIM) method eliminates machining. If the tool consists of small, complex inserts, PIM beats the classic methods in mass production in terms of cost-effectiveness.

3.6. Comparative Analysis of Methods in Terms of Cost-Effectiveness of Use in Unit Production of Tools

In unit production (i.e., making unique tools in individual copies), the key factor of profitability is minimizing the labor intensity of mechanical processing and the costs of production preparation (e.g., construction of tooling). The following list (Table 7) compared

the methods of tool production (powder materials and forming technologies) in terms of their cost-effectiveness under unit production conditions [14,16,33–38].

Table 7. Comparison of methods in terms of cost-effectiveness of use in unit production of tools.

Method/ Technology	Cost of Material and Semi-Finished Product	Tool Production Time/Labor Intensity	Profitability in Unit Production	Main Limitations in Unit Production
ASP	High	Medium/Low (for finished bars)	Medium	Difficult machining before heat treatment.
CPM	Very High	Medium (Good dimensional stability after machining)	Medium/Low	Very high cost of the blank. Cost-effective only for tools with extreme requirements.
CPM-HSS	High	Medium	Medium	Difficult turning/milling without special carbide cutting tools.
STAMP	Medium	Short	Low	Profitable
CAP	Medium	Medium/Long	Low	Mainly used for molded parts production, not profitable for 1 piece.
Powdrex	High	Medium	Medium	Limited availability for unusual dimensions.
CMI Fuldens	Extra High	Low	Medium	Need to order special powder charges for unique geometries.
PIM/MIM	Low (for powder), high (for mold)	Long (requires mold design and decoupling/ sintering cycle)	Definitely unprofitable	Making an injection mold for 1 piece of tool generates very high costs.
C-L	Low	Medium (Modeling + Casting)	High (for large size)	Large and difficult to predict shrinkage, low final density.

3.7. Comparative Analysis of the Methods in Terms of Suitability for Use in the Production of Tools Operating Under Heavy Loads

Powder methods achieve a fine-grained microstructure, eliminating the carbide segregation typical of conventional casting. Table 8 compares the individual methods in terms of suitability for tools operating under heavy loads (e.g., hot/cold dies, punches, and cutting tools) [14,16,33–38].

Table 8. Comparison of methods in terms of suitability for the production of tools working under heavy loads.

Method/ Material	Suitability for Heavy Duty (Impact, Pressure, Abrasion)	Tooling Use
ASP	Excellent. Very high purity of the feed material, high impact strength and compressive resistance.	Heavy conditions: scrap metal cutting tools, forging dies, precision punches.
STAMP	Good to very good. Depending on the alloy, a good combination of ductility and hardness.	Classic forging dies, presses, injection molds, punches.

Table 8. *Cont.*

Method/ Material	Suitability for Heavy Duty (Impact, Pressure, Abrasion)	Tooling Use
CAP	Good. It allows you to obtain complex shapes of high-density tools.	Elements exposed to dynamic loads, profiles with complex geometry.
C-L	Good. It ensures high surface hardness while maintaining a ductile core.	High impact strength hand tools, some machine parts.
CPM–HSS	Excellent. It provides maximum resistance to abrasion and high temperature, with a higher impact strength than cast HSS.	Cutting tools that process at high speeds (milling, HSS drilling), taps.
Powdrex	Very fine, evenly distributed carbides guarantee very high hardness and wear resistance.	Machining tools, drills, milling cutters, forming tools.
CMI Fuldens	Good/Very good. They are characterized by high density and dimensional stability.	Specialized machine parts and tools with special magnetic or structural requirements.
PIM/MIM	Very high freedom of geometry design, but porosity lowers resistance to very strong impacts (unless full-density HIP is used).	Small, complex tools and precision components (e.g., small cutting elements).

To sum up, it should be stated that, for tools operating in extreme conditions of multi-axis loads, the best choice (the highest impact strength at a high hardness) are technologies based on gas atomization and pressing HIP, i.e., ASP and CPM-HSS. In the case of stamping dies and dies, Powdrex technologies and D-L steels work well, while, in the case of the need to make very complex geometries while maintaining good parameters, CAP works well [14,16,33–38].

3.8. Comparative Analysis of Methods in Terms of Suitability for the Production of Tools with High Durability and Reliability

As mentioned earlier, all powder metallurgy (PM) and surface modification methods eliminate the drawbacks of traditional casting. They guarantee a homogeneous structure and high alloy purity, which translates into the exceptional durability and reliability of cutting and forming tools, as shown in Table 9 [14,16,33–38].

Table 9. Comparison of methods in terms of suitability for the production of tools with high durability and reliability.

Method/ Technology	Main Advantages in Tool Manufacturing	Suitability for Tools with High Durability
ASP	Very fine, uniform grain, no carbide segregation, easy machinability.	Very high. The standard in the production of high-speed steels (e.g., ASP30, ASP60) and dies with high abrasion resistance.
CAP	Total material thickening (near 100% density), high chemical purity.	Very high. It provides excellent impact strength and fatigue strength for tools loaded with dynamics.

Table 9. *Cont.*

Method/ Technology	Main Advantages in Tool Manufacturing	Suitability for Tools with High Durability
STAMP	Fine-grained microstructure, self-stress reduction.	High. It ensures high repeatability and resistance of the cutting edges.
C-L	High. It ensures high repeatability and resistance of the cutting edges.	Good. Useful mainly for less complex geometries while maintaining good impact strength.
CPM–HSS	Fine carbide, tools are more resistant to chipping and cracking than conventional HSS.	Very high. Valued in the production of tools for work in difficult conditions (drills, cutters, cutting tools)
Powdrex	No anisotropy mechanical properties, high purity of alloy.	High. Powdrex powder tools show uniform wear and a long service life.
CMI Fuldens	High degree of compaction, elimination of microporosity.	High. Very good resistance to thermal abrasion, used in the production of forging dies.
PIM/MIM	Freedom and high complexity of the shape (does not require subsequent machining).	Medium/High. Excellent for miniature tools with complex shapes; for large tools, it is inferior to isostatic pressing (HIP) methods.

3.9. Comparative Analysis of Methods in Terms of High Resistance to Shock Loads

Table 10 characterizes the methods for manufacturing sintered high-speed steels in terms of shock load transfer [14,16,33–38].

Table 10. Comparison of methods in terms of high resistance to shock loads.

Method/ Technology	Main Advantages for High Impact Strength Products Typical Applications	Typical Applications
ASP	Fine-grained structure without carbide segregation, isotropic, very high fatigue resistance and impact resistance.	Cutting tools, drills, hot work dies.
STAMP	Allows for almost 100% theoretical density and excellent impact properties in the axial direction.	Engine components, connecting rods, transmission parts.
CAP	Extreme alloy purity, high impact strength and ductility due to the elimination of casting defects.	Tools with simple shapes (e.g., inserts, abrasion-resistant components).
C-L	Provides uniform compaction and high impact strength in complex shapes.	Machine parts, self-lubricating bearings.

Table 10. *Cont.*

Method/ Technology	Main Advantages for High Impact Strength Products Typical Applications	Typical Applications
CPM	Fine, evenly distributed carbide. It provides exceptional impact strength and fracture resistance in tool steels.	Cutting tools (e.g., continuous high-speed tools), punches.
PIM/MIM	Freedom of shape eliminating costly machining; good density but after thickening.	Tools with very complex geometric shapes and small dimensions.
Powdrex	High purity and isotropy of the material, no anisotropy of impact properties.	Tooling elements, special applications.
CMI Fuldens	High sinter density, very good strength properties, good impact results with relatively low final forming costs.	Highly mechanically stressed parts, precision automotive components

According to the analysis, methods that allow for a very large density of the sintered material and isotropic structure allow for the production of sintered material that carries significant shock loads.

To provide a quantitative representation of the key property parameters for sintered high-speed steels, the preceding discussion has been supplemented with tables and descriptions containing specific values—including density, porosity, and mechanical properties (such as strength, impact toughness, and hardness)—for materials produced via the powder metallurgy processes under analysis [39–81].

Table 11 below presents a comparative overview of the properties of high-speed steels (HSSs) produced via powder metallurgy (PM HSS), accounting for the specific characteristics of various manufacturing processes (ASP, CPM-HSS, STAMP, CAP, C–L/Crucible-Logitech, Fuldens (CMI), and Powdrex), with a particular focus on density, porosity, abrasive wear resistance, and service life [39–81].

Table 11. Comparison of density, porosity, service life, and abrasive wear resistance as a function of chemical composition and the manufacturing process employed.

Method/Trademark	Steel Grades	Density and Porosity	Resistance to Abrasive Wear and Operational Durability
ASP (Erasteel)	ASP 2023, ASP 2030, ASP 2060. High content of V (up to 7%) and Co (up to 10.5%).	Density ~100% (99.9%+) No porosity.	Very high abrasion resistance due to the presence of MC (vanadium) carbides. Maximum durability under demanding cutting conditions involving both impact and continuous loads.
CPM-HSS (Crucible)	CPM M4, CPM Rex 76, CPM Rex 121. Extremely high content of V (up to 10%) and Co (up to 12%).	Density ~100% No porosity.	The highest resistance to abrasive wear on the market. Exceptional durability during machining operations, provided there are no extreme lateral impacts.

Table 11. *Cont.*

Method/Trademark	Steel Grades	Density and Porosity	Resistance to Abrasive Wear and Operational Durability
STAMP (ASEA/Surahammars)	Classic tool configurations based on layouts W-Mo-Cr-V.	Density ~100% No porosity.	Good resistance to abrasive wear. Stable durability.
CAP (Conical Anvil Press)	Medium- and high-carbon alloy systems, gas- or water-atomized powders.	Density 98–99.5% Trace porosity.	Good blade durability.
C–L (Cold-Isostatic/Liquid Sintering)	Continuously modified to promote liquid-phase sintering.	Density 99–100% Minimal microporosity.	Local clusters of carbides may occur, which locally reduces wear resistance. Suitable for applications with lower dynamic loading.
CMI Fuldens	Similar to C-L, technologies for pressureless sintering of water-atomized powders.	Density in the range of 96–98.5%. Residual microporosity may be present.	Moderate abrasion resistance. Carbides tend to coalesce (grow) during the liquid phase. Offers an optimal price-to-durability ratio for simple tools.
Powdrex	High-speed steels made from water-atomized powders, consolidated by extrusion or forging.	Full density is achieved only after extensive plastic deformation. Low porosity (unless a final HIP process is applied).	High durability in cold-work dies, though strongly dependent on the degree of carbide refinement.

Based on the data presented in the table above—which provides a comparative analysis of the density, porosity, abrasion wear resistance, and durability of sintered high-speed steels in relation to their manufacturing method—the following can be concluded, within the following ranges [39–81]:

(A) Density and porosity:

- High-pressure processes based on gas atomization and hot isostatic pressing (HIP)—such as ASP and CPM—achieve full theoretical density. This completely eliminates porosity, which, in conventional steels, acts as an initiation site for cracks.
- Methods based on water atomization and pressureless sintering (e.g., Fuldens, and Powdrex) allow for a trace amount of residual porosity, which reduces their density by 1–3%.

(B) Abrasion resistance:

- All these processes allow for the incorporation of significant amounts of vanadium into the steel (up to 8–10% in grades such as ASP 2053). This leads to the precipitation of very hard VC-type carbides (approx. 2800 HV).
- ASP and CPM outperform methods like Fuldens or Powdrex because rapid gas cooling prevents the excessive growth of these carbides. They remain smaller (1–2 μm) and more densely distributed, which maximizes abrasion resistance.
- Wear resistance is determined not only by the manufacturing process itself but also by the chemical composition (the quantity of carbide-forming elements, such as vanadium in the CPM process) and the dispersion of the carbides.

(C) Durability:

- Tools produced using ASP and CPM-HSS technologies exhibit the highest operational durability. The elimination of large carbide clusters prevents the micro-chipping of the cutting edge, ensuring stable and predictable tool performance.
- Economical technologies, such as Fuldens and Powdrex, offer lower durability under extreme operating conditions (e.g., interrupted cutting with high impact loads), but are highly cost-effective for the serial production of complex-shaped components (e.g., machine parts).
- Processes based on the liquid-phase sintering or pressureless sintering of water-atomized powders (part of the CMI Fuldens and C-L product range) may exhibit microporosity, which reduces resistance to high-cycle fatigue and, consequently, to abrasive wear.

Tables 12 and 13 below present data regarding the mechanical properties of sintered high-speed steels. In particular, they cover the strength properties, as well as the hardness and impact toughness of sintered high-speed steels produced via various methods.

Table 12. Comparative summary of the strength properties of sintered high-speed steels [39–81].

Technological Process/Trademark	Range of Functional (Working) Hardness	Tensile Strength (After Heat Treatment to Working Hardness)	Conventional Yield Strength in Compression ($R_{pc0.2}$) After Heat Treatment	Flexural Strength
ASP (ASEA-STORA Process, currently Erasteel)	64–69 HRC	$R_m \approx$ 2000–2800 MPa	3000–4000 MPa (e.g., ASP 2023, ASP 2030, ASP 2060)	3500–5500 MPa
CPM-HSS (Crucible Particle Metallurgy)	62–70 HRC	$R_m \approx$ 1900–3000 MPa	3200–4200 MPa (e.g., CPM M4, CPM T15, Rex 76/121)	3500–5000 MPa
STAMP (process by Avesta/Nyby Uddeholm)	62–66 HRC	$R_m \approx$ 1800–2400 MPa	2800–3500 MPa	2500–4500 MPa
CAP (Consolidation by Atmospheric Pressure)	61–65 HRC	$R_m \approx$ 1700–2200 MPa	2400–3200 MPa	2500–3800 MPa
C–L (Cold Isostatic Pressing & Vacuum Sintering)	63–67 HRC	$R_m \approx$ 1800–2300 MPa	2400–3000 MPa	2500–3500 MPa
CMI Fuldens	64–66 HRC	$R_m \approx$ 1600–2100 MPa	2200–3000 MPa	2500–3200 MPa
Powdrex	63–67 HRC	$R_m \approx$ 1800–2500 MPa	2000–3400 MPa	2200–3300 MPa

A comparison of the strength properties of powder-metallurgy high-speed steels (PM HSS) produced via different powder metallurgy methods reveals distinct differences stemming from the specific nature of each technological process. Key factors influencing mechanical parameters—such as tensile, flexural, and compressive strength, as well as yield strength—include the purity of the microstructure, the degree of densification (the elimination of porosity), and the size and uniformity of the distribution of primary carbides.

Table 13. Comparative summary of impact strength and fracture resistance of sintered high-speed steels [39–81].

Technological Process/Trademark	Impact Strength (Charpy Test Without a Notch)	Specific Impact Strength	Resistance to Cracking K_{Ic} at a Hardness of 62–66 HRC
ASP (ASEA-STORA Process, currently Erasteel)	20–60 J (e.g., ASP 2023 at 64 HRC reaches approx. 40–50 J; the high-cobalt ASP 2060 at 67 HRC drops to approx. 20–25 J).	40–70 (J/cm^2) (for unnotched specimens at approx. 64–66 HRC; for high-vanadium versions such as ASP 60, approx. 30–40) (J/cm^2).	20–35 MPa·m$^{1/2}$ (for steels of extreme hardness, such as ASP 2060/ASP 2030, it drops to approx. 18–25 MPa·m$^{1/2}$
CPM-HSS (Crucible Particle Metallurgy)	25–70 J (e.g., CPM M4 reaches approx. 40–50 J, while the ultra-tough CPM 3V steel—though similar to cold-work tool steels—reaches over 80 J).	35–65 (J/cm^2) (depending on the grade; for example, CPM M4 achieves higher values than its traditional AISI M4 counterpart).	18–32 MPa·m$^{1/2}$ (the values drop sharply as the vanadium and carbon content increases; for example, CPM 10V/15V shows approx. 15–18 MPa·m$^{1/2}$
STAMP (process by Avesta/Nyby Uddeholm)	20–45 J (Properties similar to the ASP process, due to a comparable degree of carbide refinement).	30–50 (J/cm^2) (slightly lower than or comparable to HIP, due to the shorter consolidation time).	18–28 MPa·m$^{1/2}$ (exhibits slight anisotropy due to the directionality of deformation during the extrusion process)
CAP (Consolidation by Atmospheric Pressure)	15–35 J (Impact toughness may be slightly lower than in HIP-processed parts due to minimal residual porosity).	25–45 (J/cm^2) (intermediate values, dependent on the elimination of residual porosity).	15–24 MPa·m$^{1/2}$ (due to a slightly higher risk of residual micro-porosity compared to the HIP process)
C–L (Cold Isostatic Pressing & Vacuum Sintering)	15–30 J (There is a risk of carbide growth during liquid-phase sintering, which slightly reduces impact toughness compared to ASP/CPM materials).	20–35 (J/cm^2) (there is a risk of carbide growth at grain boundaries, which reduces impact toughness compared to HIP processes).	16–26 MPa·m$^{1/2}$ (the carbide structure tends to be somewhat coarser than in gas-based HIP technology, due to the presence of a liquid phase during sintering).
CMI Fuldens	20–40 J (Optimal impact strength for reduced cobalt content).	15–30 (J/cm^2) (the lowest among sintered materials, but still higher than cast materials by 50–100%).	17–25 MPa·m$^{1/2}$
Powdrex	18–35 J (Higher surface oxygen content in water-atomized powders may slightly reduce impact toughness compared to the gas-atomized ASP process).	15–30 (J/cm^2) (the lowest among sintered materials, but still higher than cast materials by 50–100%).	16–24 MPa·m$^{1/2}$

A summary of the strength characteristics and the specific features of the individual technological processes is presented below.

(A) Flexural Strength

- Sintered high-speed steels (HSSs) produced via powder metallurgy (PM) methods exhibit significantly higher flexural strength than conventional steels. Depending on the manufacturing process employed, their flexural strength can range from 2000

to as much as 5500 MPa, whereas traditional high-speed steels typically reach only 2000–3000 MPa. The highest performance levels are achieved through processes that combine gas atomization with hot isostatic pressing (HIP) and subsequent forging or rolling (e.g., ASP, CPM).

- The key factors affecting flexural strength are as follows:
- Plastic deformation (forging/rolling): Processes such as ASP or CPM, which involve forging after sintering, eliminate micro-defects and porosity, drastically increasing strength.
- Atomization method: Gas atomization (using argon or nitrogen) ensures a spherical shape and high purity of the powders, resulting in superior properties compared to water atomization (Powdrex).
- Carbide size: Uniform and extremely fine primary carbides (<3 μm) prevent the initiation of fatigue and bending-induced cracks.

(B) Yield Point

- Powder-metallurgy high-speed steels (PM HSSs)—regardless of the powder consolidation process used—exhibit, following full heat treatment (quenching and multiple tempering, resulting in a maximum secondary hardness of 64–70 HRC), extremely high values for the conventional yield strength $R_{p0.2}$ under compression or bending, ranging from 2500 MPa to over 4000 MPa.
- Due to the high brittleness of these materials, which complicates standard tensile testing, this parameter is typically determined in engineering literature through compression or bending tests. In the annealed (softened) state, the yield strength is generally between 800 MPa and 1200 MPa.

(C) Yield Point VS. Bending Strength

- The yield strength values for powder-metallurgy high-speed steels (PM HSSs) differ from those of conventional alloy steels; in a uniaxial tensile test, these materials—due to their very high hardness (in the range of 60–68 HRC)—exhibit brittle behavior and fracture with almost no plastic deformation. For this reason, engineering literature and technical data sheets rarely specify the conventional tensile yield strength (R_e or $R_{p0.2}$). Instead, the critical parameters are the compressive yield strength $R_{pc0.2}$, which typically ranges from 2500 to as much as 4500 MPa, and the transverse rupture strength (TRS), which can reach 2500–5000 MPa.

(D) Tensile Strength

- The production of powder-metallurgy high-speed steels (PM HSSs) using advanced powder metallurgy processes (such as ASP, STAMP, CAP, C-L, CPM, CMI Fuldens, or Powdrex) eliminates carbide segregation and results in a highly homogeneous, fine-grained structure.
- For PM HSSs in the hardened and tempered condition, the tensile strength (Rm) typically ranges from 1800 to over 3000 MPa, depending on the working hardness (60–68 HRC) and the specific manufacturing process. It should be noted, however, that, due to the high brittleness of these steels following heat treatment, materials engineering practice often favors the assessment and reporting of flexural strength (R_g), which can reach values between 3500 and 5500 MPa. In the annealed (as-supplied) condition, the tensile strength is approximately 800–1000 MPa. In light of this, the table provides both tensile and flexural strength values.

(E) Impact Strength

- Sintered high-speed steels (HSSs) produced via powder metallurgy (PM) exhibit a significantly higher impact toughness (fracture resistance) compared to their conventional counterparts with the same chemical composition. This is due to the elimination

of carbide banding and the achievement of an extremely fine-grained, homogeneous microstructure (carbide sizes of 1–3 µm, as opposed to 10–40 µm).

- Impact toughness values vary depending on the specific technological process, the purity of the powder, the consolidation method, and the target hardness (typically in the 62–68 HRC range).
- Impact toughness values are used as a function of the technological process.
- Due to the high hardness of high-speed steels, the standard Charpy V-notch test (as defined for structural steels) often yields very low values—on the order of a few joules. Consequently, in technical literature and metallurgical laboratories, it is more common to use impact tests on unnotched specimens or to measure the total energy absorbed during dynamic bending (expressed in Nm or J). For this reason, the table provides impact toughness values obtained using unnotched specimens.

(F) Resistance To Cracking

- The fracture resistance of powder-metallurgy high-speed steels (PM HSSs) is most commonly characterized by the plane-strain fracture toughness (K_{Ic}) or the impact toughness measured on unnotched specimens (K_C).
- These values depend primarily on the level of impurities (porosity and inclusions), the size and distribution of carbides, and the final hardness achieved after heat treatment (quenching and tempering). For conventional cast and forged high-speed steels (e.g., M2, and M35), the average K_{Ic} value is only 12–22 MPa·m$^{1/2}$ at a standard working hardness of 62–66 HRC. Powder-metallurgy technologies significantly improve these parameters by eliminating carbide segregation.
- The key metallurgical relationships are as follows:

1. Size of primary carbides: In processes such as ASP and CPM, the size of carbides rarely exceeds 1–3 µm, whereas, in conventional steels, it can reach several tens of micrometers. Fine carbides inhibit the propagation of microcracks, which increases the K_{Ic} value.
2. Effect of alloying: High-vanadium, high-carbon steels (e.g., CPM 15V, and ASP 2060), designed for extreme abrasion resistance, exhibit lower fracture toughness (K_{Ic}) values approaching the lower limit of approx. 15–18 MPa·m$^{1/2}$ compared to less highly alloyed steels (e.g., ASP 2023, equivalent to M3:2, which reaches over 30 MPa·m$^{1/2}$).
3. Powder atomization method: Gas atomization (ASP and CPM) yields cleaner, spherical powders (with fewer oxide inclusions) than water atomization (Powdrex, C-L, and CMI), which directly results in higher and more consistent K_{Ic} values.

(G) Hardness

- Sintered high-speed steels (produced via powder metallurgy—PM HSSs) are characterized by significantly higher hardness and wear resistance compared to traditional cast or forged steels. By eliminating carbide segregation, they achieve working hardness values ranging from 60 to as high as 70 HRC, while maintaining relatively high ductility.
- As shown by the data in the table, hardness values vary depending on the manufacturing process employed and the specific producer.

4. Conclusions

The article presents a comparative analysis of many of the most commonly used methods of manufacturing products from sintered high-speed steels. The analysis shows that the proper selection of the sintering method for the case under consideration is not a simple task, as it requires taking into account many different factors. It was also pointed out that there is no one-size-fits-all method that would be the best in every case.

The criteria considered included production volume, with particular emphasis on the profitability of using the method of manufacturing products from sintered high-speed steel in unit and mass production. The difficulty with the appropriate selection of the method arises, among other things, from taking into account both the powder production process, the working process, and the processing that gives the final shape (finishing treatment).

Another criterion was the size (dimensions) of the manufactured product, considering the possibility of achieving, among other things, a high and uniform material density throughout the product's cross-section, which is a prerequisite for achieving the required mechanical strength under static and dynamic loads.

An important challenge, as the analysis shows, is also the proper selection of the method of manufacturing products from sintered high-speed steels with complex shapes as a function of their dimensions and production volume.

A key requirement for cutting tools is to ensure high durability and reliability, especially in automated machining processes. The loss of cutting properties, especially as a result of strength wear (chipping or breaking of the blade), can result in high costs associated with damage to an expensive workpiece (e.g., a large body made of expensive material). In order to increase the durability and reliability of cutting tools, hard or super-hard anti-wear coatings are often used, which are characterized by a high hardness, which determines the resistance to abrasive wear, and very favorable tribological properties (low coefficient of friction) [82–86]. Another way is to use effective lubrication and the cooling of the cutting zone [87].

In order to enable easy orientation in the course of the processes of the production of sintered high-speed steels using various methods, they have been presented in the article in a graphic manner by the author.

In the next article, a detailed description of the most commonly used grades of sintered high-speed steel in terms of their technological and functional properties is planned.

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