



SURFACE VEHICLE INFORMATION REPORT

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Selection and Heat Treatment of Tool and Die Steels

RATIONALE

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1. **Scope**—The information in this report covers data relating to SAE J438, Tool and Die Steels, and is intended as a guide to the selection of the steel best suited for the intended purpose and to provide recommended heat treatments and other data pertinent to their use.

Specific requirements as to physical properties are not included because the majority of tool and die steels are either worked or given special heat treatments by the purchaser. The purchaser may or may not elect to use the accompanying data for specification purposes.

2. **References**

- 2.1 **Applicable Publication**—The following publication forms a part of the specification to the extent specified herein. Unless otherwise indicated the latest revision of SAE publications shall apply.

2.1.1 SAE PUBLICATION—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J438—Tool and Die Steels

2.1.2 ASM PUBLICATION—ATTN: MSC/Book Order, ASM International, PO Box 473, Novelty, OH 44072-9901.

ASM Handbook—1948 Edition, pp. 658-659

3. **The Selection of Tool and Die Steels¹**

Simplification of the problems connected with the selection of tool steels has long been an aim of both producers and consumers. This article is restricted to a discussion of the general principles involved in selection and will include a tabulation of the metallurgical characteristics of the principal tool steel types as an aid in selection. A correlation of these metallurgical characteristics with the requirements of the tool in operation should form the basis of a sound approach to the selection of a steel for any application. Table 1.

1. Condensed from the ASM Handbook, 1948 edition, pp. 658–659, with the permission of the American Society for Metals.

TABLE 1—COMPARISON OF TOOL STEELS ON BASIS OF PROPERTIES AFFECTING SELECTION

SAE Steel Designation	Nondeforming Properties	Safety in Hardening	Depth of Hardening ⁽¹⁾	Toughness	Resistance to Softening Effect of Heat	Wear Resistance	Machinability
Water Hardening Tool Steels							
W108	Poor	Fair	Shallow	Good ⁽²⁾	Poor	Fair	Best
W109	Poor	Fair	Shallow	Good ⁽²⁾	Poor	Fair	Best
W110	Poor	Fair	Shallow	Good ⁽²⁾	Poor	Good	Best
W112	Poor	Fair	Shallow	Good ⁽²⁾	Poor	Good	Best
W209	Poor	Fair	Shallow	Good	Poor	Fair	Best
W210	Poor	Fair	Shallow	Good	Poor	Good	Best
W310	Poor	Fair	Shallow	Good	Poor	Good	Best
Shock Resisting Tool Steels							
S1—Chromium-Tungsten	Fair	Good	Medium	Good	Fair	Fair	Fair
S2—Silicon-Molybdenum	W Poor ⁽³⁾	W Poor ⁽³⁾	Medium	Best	Fair	Fair	Good
	O Fair ⁽³⁾	O Good ⁽³⁾					
S5—Silicon-Manganese	W Poor ⁽³⁾	W Poor ⁽³⁾	Medium	Best	Fair	Fair	Fair
	O Fair ⁽³⁾	O Good ⁽³⁾					
Cold Work Tool Steels							
Oil Hardening Types							
O1—Low Manganese	Good	Good	Medium	Fair	Poor	Good	Good
O2—High Manganese	Good	Good	Medium	Fair	Poor	Good	Good
O6—Molybdenum Graphitic	Fair	Good	Medium	Fair	Poor	Good	Best
Medium Alloy Air Hardening Types							
A2—5% Chromium Air Hard	Best	Best	Deep	Fair	Fair	Good	Fair
High Carbon-High Chromium Types							
D2—High Carbon-High Chromium (Air)	Best	Best	Deep	Fair	Fair	Best	Poor
D3—High Carbon-High Chromium (Oil)	Good	Good	Deep	Poor	Fair	Best	Poor
D5—High Carbon-High Chromium-Cobalt	Best	Best	Deep	Fair	Fair	Best	Poor
D7—High Carbon-High Chromium-High Vanadium	Best	Best	Deep	Poor	Fair	Best	Poor
Hot Work Tool Steels							
Chromium Base Types							
H11—Chromium-Molybdenum-V	Good	Good	Deep	Good	Good	Fair	Fair
H12—Chromium-Molybdenum-Tungsten	Good	Good	Deep	Good	Good	Fair	Fair
H13—Chromium-Molybdenum-VV	Good	Good	Deep	Good	Good	Fair	Fair
Tungsten Base Types							
H21—Tungsten	Good	Good	Deep	Good	Good	Fair	Fair
High Speed Tool Steels							
Tungsten Base Types							
T1—Tungsten 18-4-1	Good	Good	Deep	Poor	Good	Good	Fair
T2—Tungsten 18-4-2	Good	Good	Deep	Poor	Good	Good	Fair
T4—Cobalt-Tungsten 18-4-1-5	Good	Fair	Deep	Poor	Best	Good	Fair
T5—Cobalt-Tungsten 18-4-2-8	Good	Fair	Deep	Poor	Best	Good	Fair
T8—Cobalt-Tungsten 14-4-2-5	Good	Fair	Deep	Poor	Best	Good	Fair
Molybdenum Base Types							
M1—Molybdenum 8-2-1	Good	Fair	Deep	Poor	Good	Good	Fair
M2—Molybdenum-Tungsten 6-6-2	Good	Fair	Deep	Poor	Good	Good	Fair
M3—Molybdenum-Tungsten 6-6-3	Good	Fair	Deep	Poor	Good	Best	Fair
M4—Molybdenum-Tungsten 6-6-4	Good	Fair	Deep	Poor	Good	Best	Fair
Special Purpose Tool Steels							
Low Alloy Types							
L6—Nickel-Chromium	Fair	Good	Medium	Fair	Poor	Fair	Fair
L7—Chromium	Fair	Good	Medium	Fair	Poor	Good	Fair

- These are intended to emphasize major differences between the groups of steels and do not account for the minor differences in depths of hardening that exist between steels of the same group. This is particularly true of the Water Hardening W Steels which are frequently furnished with varying degrees of hardenability as listed in Table 1.
- Toughness decreases somewhat with increasing depth of hardening.
- W as shown here indicates water quench. O as shown here indicates oil quench.

Practical experience indicates that in the majority of instances the choice is not limited to a single type of tool steel or even to a particular family of tool steels for a workable solution to an individual tooling problem. Because it is desirable to select the steel that will give the most economical overall performance, the tool life obtained with each steel under consideration should be judged by weighing such factors as expected productivity, ease of fabrication, and cost.

The majority of tool steel applications can be divided into a small number of groups or types of operations: cutting, shearing, forming, drawing, extrusion, rolling, and battering. Cutting tools include drills, taps, broaches, hobs, lathe tools, and the like. Shearing tools include shears, blanking and trimming dies, punches, and such. Forming tools include draw, forging, cold heading, and die casting dies. Battering tools include chisels and all forms of tools involving heavy shock. Many of these classifications can be further divided into cold and hot working tools.

For each of these groups, certain metallurgical characteristics are of utmost importance. Most cutting tools require high hardness, high resistance to the softening effect of heat, and high wear resistance. Shearing tools require high wear resistance combined with fair toughness, and these characteristics must be properly balanced depending on the tool design, thickness of stock being sheared, and temperature of the shearing operation. Forming tools must possess high wear resistance or high toughness and high strength, and many require maximum resistance to heat softening. In battering tools high toughness is most important.

Hardness, strength, toughness, wear resistance, and resistance to heat softening are, therefore, prime selective factors for tool steel applications. Many other properties must be seriously considered in individual applications; these include permissible distortion in hardening, permissible surface decarburization, hardenability or depth of hardness desired, resistance to heat checking, machinability and grindability, as well as heat treating requirements, including temperatures, atmospheres, and equipment.

Table 1 lists those properties which merit special consideration when selecting steels for any application, from the list shown. For compositions of these steels, Table 1 of SAE J438.

Table 2 is presented as an aid in the relative evaluation of those properties which must be considered for the proper heat treatment of the steels.

- 4. *Relation of Design to Heat Treatment***—The design bears, in many ways, upon the serviceability of the tool or machine part, and unsatisfactory performance may frequently be traced directly to faulty design. This discussion is concerned only with design as it affects the heat treating operation and, through the heat treatment, the serviceability of the finished part. It is the purpose of this discussion to bring about a better mutual understanding between the designer and the steel treater so that faulty design which may cause cracking or distorting during heat treating can be avoided.

The fundamental principles of good design from a heat treatment standpoint are quite simple. Heat treated steel has a certain strength depending upon the analysis of the steel, the quality of the metal, and the heat treatment which it has received. When subjected to a combination of forces its ultimate strength, the steel cracks or fails. There are 2 types of force combining to break steel, which are:

- a. The internal stress set up during fabrication and heat treatment of the tool.
- b. The external force of service.

Sometimes the internal stresses alone exceed the strength of the metal, and the parts crack in hardening. Again, the internal stresses may equal 90% or more of the total strength, in which case failure will develop in service under relatively light loads. It therefore appears that the useful strength of a part decreases in proportion as the internal stresses increase.