The Selection and Hardening of TOOL STEELS

Vol. II. Metallography of Tool Steels

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Dedicated to

HAROLD B. CHAMBERS

Retired Vice President of Metallurgy Atlas Steels Company, Canada — and a Past Chairman of the Ontario Chapter of the American Society for Metals. He is currently a life member of the society.

He developed the first really practical system for classifying tool steels and kept it updated for 35 years.

He started as the first graduate metallurgist with Atlas Steels in 1931 and arranged for their first melt shop. Through the years his philosophy was you cannot always furnish the customer a better tool steel, but you can always give better service.

Harold Chambers was born in Lancaster, Pennsylvania. He is a graduate of LeHigh University in metallurgical engineering. He was associated with the Crucible Steel Company, and the steel division of Timken Roller Bearing Co., before joining Atlas in 1931.

After serving in a number of executive positions in the metallurgical department, he was appointed Director of Metallurgy in 1958.

He is also a member of the American Society of Automotive Engineers, and Canadian Standards Association. He has authored many papers and articles on metallurgy during his career. He is a member of the Niagara Falls Club and an ardent worker for the Canadian Heart Foundation.

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PREFACE

It has been seven years since our last edition of "Selection and Hardening of Tool Steels" was published.

During that time, we have had numerous inquiries for more information on the tool steels listed before. Typical of these, was the question, "How do treatments such as electrodischarge machining (EDM) and vacuum melting effect the properties of hardened tool steels?" The study of these subjects, along with other case histories is intended to furnish not only basic heat treating information, but also an in depth record of what may be expected from the steels under a variety of service conditions.

Since we have frequently stressed the importance of the optimum ratio of wear and toughness, we have had inquiries on how these may be controlled and evaluated. For this reason, we are including impact test curves with an explanation of their evaluation for most of the steels listed. Toughness and related problems are discussed in the chapter "Toughness and Tool Steel". Numerous case histories are given with the steels listed. These are analyzed and classified with other information on the steel concerned.

References have been used from recent literature. These are usually shown at the end of the appropriate chapters. We are especially indebted to the following companies for case histories and illustrations, which have been most helpful in the preparation of this book: Bethlehem Steel Co., Latrobe Steel Co., Atlas Steels Co., (Canada), Vasco, Allegheny Ludlum Steel Corp., Timken Roller Bearing Co., Cleveland Twist Drill Co.

It has been my pleasure and privelege to have had the fine cooperation of my wife Frances in the preparation of this manuscript. "Many thanks Fran, you made all this possible."

It was with considerable regret, that I learned Harold Chambers had retired from Atlas Steels Co. My friendship with Mr. Chambers has been one of those priceless associations through the years. For that reason, I take pleasure in dedicating this book to him.

L.H. Seabright

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Chapter 1

INTRODUCTION

Tool Steels are vital materials in our industrial economy. They are so numerous, have so many treatments and applications and pose such varied questions that it would be impossible to treat the entire topic in the space allotted. For this reason, we covered heat treating instructions* in a previous book and plan to cover metallography and related subjects in this book.

In order to better understand the comparative merits of various tool steels, H.B. Chambers developed the "Wear-Toughness Ratio" method for classification. This system is based on the fact that for increases in carbon content there is an increase in wear-resistance and a corresponding decrease in toughness. Accordingly, Chambers has divided tool steels into four distinct fields of application and further classified them according to their hardening requirements and resistance to elevated temperatures as shown in Table 1.

Table 1. Primary Steel Requirement

Primary field of application	Movement in hardening unimportant (water-hardening steels)	Movement in hardening important (oil- and air-hardening steels)	Resistance to high temperature important (high-speed and hot-work steels)
Maximum wear resistance	Group 1	Group 5	Group 9
General cutting tools	Group 2	Group 6	Group 10
General die work	Group 3	Group 7	Group 11
Maximum toughness	Group 4	Group 8	Group 12

Unless the tool steel consumer could identify his steels according to the theoretical classification in Table 1, its practical application would be very limited. To simplify this method of identification, a composite chemical analysis of the steels falling into each group has been made, as shown in Table 2. Thus in the selection of a steel for a particular tool, a degree of compromise between toughness and wear resistance is required. Table 4 shows these main groups of steels broken down into 45 types according to their analysis. In the limiting of compositions it was necessary to consider how much of one element was equivalent to a given quantity of another. Footnotes are given for Table 4; which indicate the variation in properties with additions of carbon or alloys. A.I.S.I. designations are also listed where they are equivalent. Table 3 lists the A.I.S.I. reference numbers.

REFERENCES

1. H. B. Chambers, "Tool Steels Classified by Wear-Toughness Ratio", Metal Progress, Vol. 37 No. 6 665-67 (1940).

2. Seabright*, L. H., "The Selection and Hardening of Tool Steels", Seabright Texts Ltd., 1968

Table 2. Composite Chemical Analysis of Steels in Each Group

Group	C, %	Mn, %	Si, %	Cr, %	W, %	V, %	Mo, %	Co, %	Ni, %	Cu, %
1	1.25-1.50	0.15-0.50	0.15-0.75	0.0 - 1.80	0.0- 6.0	0.0 -0.35	0.0- 0.50			
2	1.10-1.50	0.15-0.50	0.15-1.00	0.0 - 1.20	0.0- 2.50	0.0 -0.30	0.0- 0.30	(Al 0.00-0.25)		
3	0.90-1.10	0.15-0.50	0.15-0.50	0.0 - 1.50	0.0- 2.50	0.0 -0.50				
4	0.45-0.90	0.15-1.50	0.15-2.50	0.0 - 1.50	....	0.0 -0.35	0.0- 0.75	....	0.0-0.50	
5	0.80-2.50	0.15-1.20	0.15-2.00	4.00-14.00	0.0- 2.00	0.0 -5.00	0.0- 2.50	0.0- 4.00	0.0-1.00	
6	1.10-1.30	0.15-0.95	0.15-0.35	0.25- 1.75	0.0- 2.50	0.0 -0.40	0.0- 0.75			
7	0.80-1.55	0.30-3.25	0.15-1.40	0.0 -12.00	0.0- 1.10	0.0 -1.00	0.0- 1.75		0.0-2.00	
8	0.40-0.90	0.15-1.25	0.15-2.25	0.0 - 2.00	0.0- 3.00	0.0 -0.60	0.0- 2.20	....	0.0-2.50	
9	0.65-1.30	0.15-0.35	0.15-0.50	3.5 - 4.75	0.0-23.00	0.75-3.25	0.0-10.00	1.00-15.0		
10	0.55-1.60	0.15-0.35	0.15-0.75	3.5 - 4.75	0.0-21.00	0.50-5.25	0.0- 9.50	0.0- 5.75		
11	0.23-0.65	0.15-0.75	0.15-1.75	1.25-13.00	0.0-19.0	0.0 -2.50	0.0- 9.00	0.0- 4.50	0.0-3.00	
12	0.25-1.00	0.15-1.25	0.15-1.35	0.50- 7.50	0.0- 4.25	0.0 -1.20	0.0- 3.00	0.0- 0.60	0.0-5.00	0.0-5.00

Table 3. AISI Tool Steel Designations

Designation	Symbol	Type
High Speed Tool Steels	M	Molybdenum
	T	Tungsten
Hot Work Tool Steels	H	
	H1-H19	Chromium
	H20-H39	Tungsten
	H40-H59	Molybdenum
Cold Work Tool Steels	D	High Carbon High Chromium
	A	Medium Alloy Air Hardening
	O	Oil Hardening
Shock Resisting Tool Steels	S	
Special Purpose Tool Steels	L	Low Alloy
	F	Carbon Tungsten
Mold Steels	P	
Water Hardening Tool Steels	W	

By correlating the two classifications, it becomes possible to equate a steel's properties on the basis of the wear-toughness ratio (W.T.R.) and its chemical composition. This results in a better understanding of the relative characteristics of the tool steel sub-groups which fall into the same general AISI group.

Evaluation of the comparative qualities for each of the sub-groups can be made through use of the footnotes that follow Table 4. These footnotes indicate general variations in hardenability, and movement in hardening as a function of alloy content. Thus, it can be seen that in the selection of a steel for a particular tool, a degree of compromise between toughness and wear resistance is required. The relation of these two properties to each other, while not expressed quantitatively is termed the "wear-toughness ratio".

Table 4 shows all the 45 sub-groups for the Wear-Toughness Ratio Classification, together with analyses for comparable AISI equivalents. In general, AISI steels should give equivalent service to that of the corresponding W.T.R. class.

There are times when the question of economics enters into the selection of a tool steel. For example, many dies which are made from a steel selected from Group 7 could also be made from a steel in Group 5, but the additional cost of purchasing and machining a steel from Group 5 instead of Group 7 is not justified unless a particularly long operating run is anticipated or a very abrasive material is to be processed.

ALLOYING ELEMENTS

As we observe the footnote information in Table 4 for comparing the tool steels, the notes refer to varying additions of the alloying elements and carbon. Some detail on the effect of these alloys may be of interest. In general, alloy tool steels are specified, when higher strength, toughness or hardenability are required, than could be available with carbon tool steels. Engineering reasons are commonly given for the need to use an alloy tool steel. However economic considerations need also to be weighed. That is, some alloy steels cost many times the price of a corresponding carbon steel and are much more difficult to machine. These costs must be weighted against the savings involved in having the tool made from a better grade of steel.

Table 4 - Tool Steels Classified By Wear - Toughness Ratio And AISI Designation

AISI WTR	C	Mn	Si	W	Cr	V	Mo	Co	Ni	Notes
					Water-Hardening Steels					
					Tungsten finishing or graphitic-tungsten					
1A	1.25-1.50	0.15-0.50	0.15-0.75	2.50-6.00	1.80 max.	0.35 max.	0.50 max.	–	–	*abc*
F-2	1.25	–	–	3.50		–	–	–	–	
F-3	1.25	–	–	3.50	0.75	–	–	–	–	
					Carbon or carbon-vanadium					
1B	1.30-1.45	–	–	–	0.35 max.	0.30 max.	–	–	–	*ac*
W-1	1.40	–	–	–	–	–	–	–	–	
W-2	1.40	–	–	–	–	0.25	–	–	–	
W-3	1.40	–	–	–	–	0.50	–	–	–	
					High carbon, low tungsten					
2A	1.10-1.30	0.15-0.35	0.15-0.35	1.00-2.50	0.35 max.	0.30 max.	0.30 max.	–	–	*ab*
					Low-chromium or chromium-vanadium					
2B	1.10-1.30	0.15-0.35	0.15-0.35	–	0.10-1.20	0.30 max.	–	–	–	*ac*
W-5	1.10	–	–	–	0.50	–	–	–	–	
					Carbon or carbon-vanadium					
2C	1.10-1.30	0.15-0.35	0.15-0.35	–	–	0.30 max.	–	–	–	*a*
W-1	1.20	–	–	–	–	–	–	–	–	
W-2	1.20	–	–	–	–	0.25	–	–	–	
W-3	1.20	–	–	–	–	0.50	–	–	–	
					Aluminum-graphitic or graphitic-silicon					
2D	1.10-1.50	0.15-0.50	0.15-1.00	–	–	–	–	(Al 0.25 max.)		*ac*

				High-carbon, Low-tungsten						
3A	0.90-1.10	0.15-0.35	0.15-0.35	1.00-2.50	0.80 max.	0.30 max.	–	–	–	*abc*
F-1	1.00	–	–	1.25	–	–	–	–	–	
				Low-chromium or chromium-vanadium						
3B	0.90-1.10	0.15-0.50	0.15-0.35	0.30 max.	0.10-1.50	0.30 max.	–	–	–	*ac*
W-4	1.00	–	–	–	0.25	–	–	–	–	
W-5	1.00	–	–	–	0.50	–	–	–	–	
				Carbon or carbon-vanadium						
3C	0.90-1.10	0.15-0.35	0.15-0.50	–	–	0.50 max.	–	–	–	*ad*
W-1	1.00	–	–	–	–	–	–	–	–	
W-2	1.00	–	–	–	–	0.25	–	–	–	
				Chromium-molybdenum or chromium-vanadium						
4A	0.55-0.90	0.15-0.35	0.15-0.35	–	0.40-1.20	0.35 max.	0.35 max.	–	0.50 max.	*ac*
				Carbon or carbon-vanadium						
4B	0.70-0.90	0.15-0.35	0.15-0.35	–	–	0.30 max.	–	–	–	*a*
W-1	0.80	–	–	–	–	–	–	–	–	
W-2	0.80	–	–	–	–	0.25	–	–	–	
				Silicon-manganese or silicon-molybdenum						
4C	0.45-0.75	0.30-1.50	0.75-2.50	–	1.50 max.	0.35 max.	0.75 max.	–	–	*ac*
S-2	0.50	–	1.00	–	–	–	0.50	–	–	
S-4	0.55	0.80	2.00	–	–	–	–	–	–	
S-5	0.55	0.80	2.00	–	–	–	0.40	–	–	
S-6	0.45	1.40	2.25	–	1.50 max.	–	0.40	–	–	
				Oil-Hardening and Air-Hardening Steels (tools of intricate design)						
				High-carbon, high-chromium						
5A	1.80-2.50	0.15-1.20	0.15-1.00	2.00 max.	10.50-14.00	1.25 max.	0.30 max.	1.00 max.	1.00 max.	*afg*