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HIGH SPEED TOOL STEELS

BY

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An Engineering Experiment Station was established at the University of Illinois by action of the Board of Trustees, December 8, 1903. It is the purpose of the Station to carry on investigations along various lines of engineering and to study problems of importance to professional engineers and to manufacturing, railway, constructional, and industrial interests of the state. The laboratories of the College of Engineering are being equipped with additional apparatus and facilities to further such research work. It is believed that this experimental work will result in contributions of value to engineering science and that the presence of such investigations will give inspiration to students and add efficiency to the College of Engineering.

This Circular No. 1 is designed to furnish the engineers and manufacturers of Illinois some information regarding the recent advance in certain shop processes,—those involving the removal of metal. It will be followed by bulletins giving a complete account of a series of experiments and investigations now in progress in the shops of the Mechanical Department.

Credit is due Mr. Henry B. Dirks, Fellow in Mechanical Engineering, for collecting much of the information contained herein and for preparing the tables of results.

Copies of this circular may be obtained by addressing the Engineering Experiment Station, Urbana, Illinois.

HIGH SPEED TOOL STEELS

By L. P. Breckenridge, Professor of Mechanical Engineering

INTRODUCTION

One of the most striking advances in recent years, from the point of view of the manufacturer, is the increase of the cutting speeds of machine tools and the consequent marked increase of output of machine shops. Less than ten years ago cutting speeds ranged from 5 to 30 feet per minute; now speeds of 150 feet per minute are frequently employed. The first steps in this advance were taken by Messrs. Taylor and White at the Bethlehem Steel Works during the years 1898-1900, and the work of high speed tool steels was first shown to the public at the Paris exhibition in 1900.

It can not be doubted that the introduction of high speed tool steels is destined to work radical changes in shop processes and to exert a marked influence on the cost of manufacturing.

Properties of Tool Steels

At the time of Taylor and White's first experiments Mushet and Jessop tool-steels were in general use. These steels were of the self-hardening type. According to Mr. F. Reiser in an article on high speed steel in "Stahl and Eisen," January 15, 1903, they had the following chemical composition:

Carbon 2.0%	Manganese 2.5%	Silicon 1.3%
Tungsten 5.0%	Chromium 0.5%	

The self-hardening property is called into play by the manganese, an alloy which favors the combining of the carbon with the iron. These steels were tempered simply by heating to a temperature of 1600° F. and then cooling in air. Mushet and Jessop tools, however, did not prove durable at high speeds, although they were far in advance of the ordinary carbon steels, and chromium was substituted for manganese with good results. The chromium-steels required an entirely different treatment, as was found by Messrs. Taylor and White in their experiments at the Bethlehem Steel Works.

The exact chemical compositions of the new tool steels are secrets of the separate makers, and probably vary; however, it is known that the steels contain the following elements in varying quantities: carbon, tungsten, chromium, manganese, molybdenum and titanium. They usually run high in the percent of alloy, the Taylor-White steel having as high as 12% of tungsten and 4% of chromium, while Böhler Bros.' Styrian steel, according to Mr. Reiser, has a maximum of 28% of alloys. With this increase the carbon element has greatly decreased; most of it combines with tungsten, chromium, and the other elements at high temperatures, remains in that state when cooled in an air blast and forms carbides of extreme hardness and durability at high temperatures. For best results of toughness and hardness these high-speed steels require for tempering a temperature of from 2000° to 2250° F., or a white heat bordering on the fusion point, and are then cooled in an air blast, lead bath, or oil bath, according to the different makers. Mr. Reiser in his discussion has for this reason correctly named them "superheated steels."

Advantages of High-Speed Steels.

High-speed steels, due to their hardness and durability at high temperatures, retain their edge when cutting at extremely high speeds, cases having been noted in which the tool worked at dark red heat without losing its edge. As can be seen from the tables, the speeds obtained are from three to four times those obtained with ordinary carbon steels. This of course means an increased output for a given shop and a consequent increase in the returns. This is not the only advantage of high-speed steel. It has been proved that such steel is more economical from the power standpoint, a given power removing a greater quantity of metal per unit of time at high speed than at slow speed. Of course the total power required is increased, but the increase is by no means proportional to the increase in the amount of work done.

There is, however, one condition that must be carefully considered before the introduction of high-speed steels in a shop. Machine tools constructed to use the old carbon steels are limited in capacity and will not stand the heavy stresses to which they would be subjected if using high-speed steels at maximum speeds and feeds. This condition, however, is being met by the machine-tool builders, who are now designing and building especially heavy tools with powerful feed mechanisms with a view towards obtaining the highest possible efficiency of the steel used.

Proposed Investigations.

While numerous investigations of tool steels have been made, there is still much to be done along the following lines: (1.) Determination of the most economical speeds at various feeds and depths of cut for different materials and different sizes of tools. (2.) Determination of the effect of different angles of rake and clearance on the power required to drive the tool. In order to obtain some of this information the Mechanical Engineering Department of the University of Illinois has installed an equipment for testing high-speed steels. This consists of a Pratt and Whitney 15″x7′-6″ high-speed lathe of latest design, driven by a Westinghouse induction motor of 7½ horse-power. The arrangement is such that 56 speeds can be obtained for any given diameter of work. The power required is measured by a Westinghouse portable polyphase wattmeter in circuit with the motor, so that readings can be taken at all times. Arrangements have been made for weighing all metal removed and for obtaining cutting speeds and feeds. An apparatus for tempering tools in an air blast has been set up and the angles of all tools will be accurately measured.

For the present, tests will be made on cast iron of various grades, a chemical analysis of each of which will be made. In the future other materials will be tried.

TABLE No. 1.

RESULTS OF EXPERIMENTS

MADE BY

MANCHESTER MUNICIPAL SCHOOL OF TECHNOLOGY, ENGLAND.

Reported by Dr. J. T. NICOLSON, Oct. 30, 1903.

Name of tool steel maker.	Material operated on.	Size of cut. Inches.	Cutting speed Ft. per min.	Material removed Lb. per min.	Duration of trial. Min.
Samuel Osborn & Co.	Soft C. I.	$\frac{3}{16}$x$\frac{1}{16}$	84.7	3.175	20
T. Firth & Sons .	" "	$\frac{3}{8}$x$\frac{1}{8}$	53.2	7.33	20
Samuel Buckley .	Medium C. I.	$\frac{3}{16}$x$\frac{1}{16}$	49.0	1.73	20
" "	" "	$\frac{3}{8}$x$\frac{1}{8}$	24.35	3.32	20
C. Cammell & Co.	Hard C. I.	$\frac{3}{16}$x$\frac{1}{16}$	31.9	1.18	20
" "	" "	$\frac{3}{8}$x$\frac{1}{8}$	18.1	2.54	20
Armstrong, Whitworth & Co.	Soft steel	$\frac{3}{16}$x$\frac{1}{16}$	111.	4.14	20
" "	" "	$\frac{3}{8}$x$\frac{1}{8}$	54.5	7.35	20
C. Cammell & Co.	Medium steel	$\frac{3}{16}$x$\frac{1}{16}$	80.	3.17	20
Samuel Buckley .	" "	$\frac{3}{8}$x$\frac{1}{8}$	36.	5.30	20
" "	Hard steel	$\frac{3}{16}$x$\frac{1}{16}$	41.2	1.71	20
C. Cammell & Co.	" "	$\frac{3}{8}$x$\frac{1}{8}$	20.	3.00	20

Reported in *London Engineering*, Oct. 30, 1903, and in *American Machinist*, Nov. 19 and 26, 1903. The tools in the above cases were all in good condition at the end of the trial. The experiments were made on cast iron and steel cylinders turned in a lathe furnished by Armstrong, Whitworth & Co.

TABLE No. 2.

RESULTS OF EXPERIMENTS

MADE BY

BÖHLER BROS. & CO., VIENNA AND BERLIN.

Reported by F. HEISSIG, Jan. 1, 1901.

Name of tool steel maker.	Material operated on.	Size of cut. Inches.	Cutting speed. Ft. per Min.	Material removed Lb. per min.	Duration of trial. Min.
Böhler Bros. & Co.	Cast Iron	$\frac{1}{8}$x$\frac{1}{16}$	44.	.735	21
" " "	" "	$\frac{5}{16}$x$\frac{5}{64}$	43.7	2.59	4
" " "	" "	$\frac{11}{64}$x$\frac{5}{64}$	44.	1.69	6.5
" " "	" "	$\frac{11}{64}$x$\frac{3}{32}$	29.4	1.14	30
" " "	" "	$\frac{9}{32}$x$\frac{3}{32}$	45.9	3.86	4
" " "	" "	$\frac{9}{32}$x$\frac{3}{32}$	45.9	4.025	4
" " "	" "	$\frac{7}{32}$x$\frac{1}{16}$	45.9	1.97	28
" " "	" "	$\frac{3}{32}$x$\frac{1}{16}$	34.8	.882	15
" " "	" "	$\frac{1}{16}$x$\frac{1}{16}$	45.2	.601	22
" " "	Cast Steel	$\frac{5}{32}$x$\frac{1}{32}$	9.85	.203	114
" " "	Forged Steel	$\frac{5}{64}$x$\frac{1}{8}$	98.65	.230	7
" " "	" "	$\frac{5}{32}$x$\frac{1}{16}$	97.7	4.18	5
" " "	" "	$\frac{5}{64}$x$\frac{1}{16}$	157.6	10.46	2
" " "	" "	$\frac{9}{64}$x$\frac{1}{8}$	66.75	2.39	14
" " "	" "	$\frac{1}{8}$x$\frac{1}{8}$	152.6	4.51	4.5
" " "	" "	$\frac{1}{8}$x$\frac{1}{8}$	36.1	6.05	3.5
" " "	" "	$\frac{1}{16}$x$\frac{1}{8}$	150.	7.06	3
" " "	" "	$\frac{15}{64}$x$\frac{1}{8}$	53.5	1.29	8.5

Reported in *Stahl & Eisen*, Jan. 1, 1901. Böhler Bros. & Co. are represented in the United States by Houghton & Richards, Boston, Mass., and their steel is known as Styrian steel.

TABLE No. 3.

RESULTS OF DAILY WORK

AT

UNION PACIFIC RAILROAD SHOPS, OMAHA, NEBRASKA.

Reported by HENRY H. SUPLEE, July, 1903.

Name of tool steel	Machine tool used.	Material operated on.	Cutting speed. Ft. per min.	Size of cut. Inches.	Re-marks.
Air Novo .	32-inch Pond lathe	Piston valve bushing Soft cast iron	74	$\frac{1}{2}$x$\frac{3}{32}$	
" "	" "	4″ Piston rod No. 1 Scrap iron . .	18	$\frac{3}{4}$x$\frac{1}{16}$	
" "	27½-inch Pond lathe	Crank pin No. 1 Scrap iron . .	26	$\frac{1}{2}$x$\frac{1}{8}$	
" "	Niles vert. boring mill	Locomotive driver tyre Tyre steel . .	40	$\frac{1}{8}$x$\frac{1}{8}$	Limit of belt on machine
" "	Bullard vert. boring mill	Piston head Cast iron . . .	20	$\frac{13}{32}$x$\frac{1}{8}$	
" "	Bement-Miles hor. cylinder boring mill	19-inch Cylinder. Cast iron (very hard) . .	18	$\frac{3}{8}$x$\frac{1}{8}$	Limit of motor
" "	88-inch Pond driver lathe	Driver tyre hardened by sliding on sand	24	$\frac{3}{8}$x$\frac{3}{32}$	Limit of machine
" "	30-foot Pond planer	Connecting rod. No. 1 Scrap iron . .	15	$\frac{9}{16}$x$\frac{1}{4}$	

Reported in the *Proceedings Institution of Mechanical Engineers*, July, 1903, and in *London Engineering*, July 31, 1903.

TABLE No. 4.

RESULTS OF EXPERIMENTS

MADE BY

BERLIN SECTION, VEREINES DEUTSCHER INGENIEURE,

Reported in their Proceedings, Sept. 28, 1901.

Name of tool steel.	Material operated on.	Size of cut. Inches.	Cutting speed. Ft. per min.	Material remov'd Lb. per min.	Duration of trial. Min.
Poldi-Schnell—dreher. . .	Siemens—Martin Steel .	$\frac{3}{32}$x$\frac{1}{16}$	194	3.33	20
" "	" "	$\frac{11}{64}$x$\frac{1}{16}$	136	4.84	63
Böhler Rapid . .	" "	$\frac{3}{16}$x$\frac{3}{32}$	126	5.92	95
" "	" "	$\frac{13}{64}$x$\frac{1}{8}$	45.2	3.21	113
Poldi-Diamant .	" "	$\frac{15}{64}$x$\frac{7}{64}$	35.5	2.64	140
Böhler Rapid . .	" "	$\frac{1}{2}$x$\frac{3}{32}$	31.6	4.71	120
Böhler Titan-Boreas .	" "	$\frac{15}{32}$x$\frac{3}{64}$	17.4	1.43	120
Böhler Rapid . .	Cast Iron . .	$\frac{9}{64}$x$\frac{3}{16}$	72.9	7.39	59
Poldi-Diamant .	" "	$\frac{3}{16}$x$\frac{11}{64}$	50.3	5.21	61
Böhler Rapid . .	" "	$\frac{33}{64}$x$\frac{5}{32}$	47.3	14.43	120
Bergische-Stahl Industry . .	" "	$\frac{9}{16}$x$\frac{1}{16}$	37.4	4.61	120
Poldi-Diamant .	" "	$\frac{33}{64}$x$\frac{9}{64}$	35.4	7.39	120
" "	" "	$\frac{5}{16}$x$\frac{9}{64}$	35.4	5.65	103
Bergische-Stahl Industry . .	" "	$\frac{33}{64}$x$\frac{5}{32}$	33.5	10.45	30
" "	" "	$\frac{25}{64}$x$\frac{3}{32}$	33.5	4.31	148
Poldi-Diamant .	" "	$\frac{7}{16}$x$\frac{7}{64}$	27.6	5.74	190
Böhler-Rapid . .	Cast Steel . .	$\frac{7}{32}$x$\frac{1}{16}$	47.3	2.45	120
" "	" "	$\frac{7}{32}$x$\frac{1}{16}$	33.5	1.45	120
Poldi-Diamant .	" "	$\frac{19}{32}$x$\frac{1}{32}$	31.55	2.34	100
Bergische-Stahl Industry . .	" "	$\frac{25}{64}$x$\frac{3}{64}$	26.6	2.15	120
" "	" "	$\frac{39}{64}$x$\frac{3}{64}$	19.71	2.15	120
Böhler-Rapid . .	" "	$\frac{5}{8}$x$\frac{3}{64}$	17.73	2.11	120

TABLE No. 5.

RESULTS OF TESTS

MADE BEFORE

REPRESENTATIVES OF TECHNICAL PRESS AT BETHLEHEM, PA., August, 1900.

Name of tool steel.	Material operated on.	Size of cut. Inches.	Cutting speed. Ft. per min.	Duration of trial. Min.
Taylor-White . . .	Unusually hard tool steel	$\frac{3}{16}$x$\frac{1}{16}$	15	15
Mushet	"	"	15	$\frac{3}{4}$
Taylor-White . . .	Cast iron	"	50	20
Mushet	"	"	50	1$\frac{3}{4}$
Taylor-White . . .	Soft machine steel	"	150	15
Mushet	"	"	150	$\frac{1}{2}$

Reported in the *American Machinist*, August 16, 1900.

TABLE No. 6.

TABLE SHOWING INCREASE IN CUTTING-SPEED, ETC., AT BETHLEHEM STEEL CO., SINCE THE INTRODUCTION OF THE TAYLOR-WHITE PROCESS.

Average.	Oct. 25, 1898	May 11, 1899.	Jan. 15, 1900.	Gain in % cut of 3rd over 2nd.	Gain in % cut of 3rd over 1st.
Cutting speed .	8′-11″	21′-9″	25′-3″	16%	183%
Depth of cut . .	.23″	.278″	.30″	8%	30%
Feed	.07″	.0657″	.087″	32%	24%
Lb. metal removed per hour .	31.18	81.52	137.3	68%	340%

Average metal removed per hour per tool (round nose)=310 pounds in April, 1901, and has probably increased some since that time.

Reported in *American Machinist*, August 16, 1900.

TABLE No. 7.

RESULTS OF TRIALS

MADE BY

MESSRS. ARMSTRONG, WHITWORTH & CO., WITH TWIST DRILLS,

Reported by MR. J. GEDHILL, Dec. 4, 1903

Name of tool steel.	Material operated on.	Size of drill. Inches.	R. P. M. of drill.	Travel of drill. In. per min.	Duration.	Remarks.
"A. W."	Cast iron block 4″ thick . . .	$\frac{3}{4}$	525	$13\frac{1}{4}$	Drilled several holes	Drill uninjured
"	"	$\frac{3}{4}$	360	6	Drilled 137 holes	Not reground
"	"	1	240	$4\frac{3}{8}$	Drilled 76 holes	"
"	Steel plate 2″ thick .	1	250	5	Drilled 150 holes	Required grinding
"	Steel gun cradle 5″ thick .	2	80	$\frac{5}{6}$	Drilled 124 holes	

Reported in *Engineering*, (London) December 4, 1903.