T H E S I S

COMPARATIVE TESTS OF TOOL STEELS USED IN MACHINE WORK

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In those branches of the engineering world which require tool steels in the manufacture of their products, there is probably no question of greater importance than that of procuring steels that will produce the results sought in the quickest, cheapest possible way. In any manufacturing plant the labor constitutes one of the great items of expense, and anything that can be produced which will enable one workman to very materially increase the amount of work that he can turn out with no additional effort on his part will be gladly welcomed.

Such has been the tendency in late years, especially in this country. To bring about this result, automatic and high speed machines have been largely brought into use. The increase in the size of individual pieces and the corresponding increase in the amount of work to be done have necessitated the use of larger and stronger machines. The cost of power to drive such machines is a small item when the other expenses of the plant are considered.

Steel is known to have been made by the Chinese long before the Christian Era, and certain steels known as "Wootz" and "Damascus" which were made in India centuries ago were crucible steels. A curious fact is that one of these Damascus steels contained certain percentages of tungsten, nickel, manganese, etc., some of the very elements which are incorporated in the high speed steels of today. Hence, we see that the steels commonly known as High Speed Steels are not new but have existed for centuries, and apparently all that would have been necessary to bring out the inherent, latent qualities stored in them, would have been the process of subjecting them to such a degree of hardening heat as was thought would utterly destroy the nature of the steel.

For many years prior to the introduction of Self-hardening Steel by Mushet at about 1860, practically but little advance was made in the cutting powers of tool steels; the feeds and speeds remaining nearly constant. It is not surprising that the even alert American manufacturers should begin to realize that surface speeds of 10' to 40' per minute were unnecessarily low.

As a result of this dissatisfaction and to withstand the abuse of high speeds and heavy cuts of metal, various high speed steels have been produced.. The definite composition and method of their manufacture are secrets known only by the separate companies. While the tool steels which are used for cutting have been improved in quality and durability, the material which has to be machined has been made of tough, denser, material so that its strength is increased and its weight if possible decreased. Thus the duty imposed upon the cutting steels has very nearly kept pace with the inprovements made in them. The credit for introducing high speed steel probably belongs to Messers Taylor and White of the Bethleham Steel Works. The steel they produced, when exhibited in Paris, showed such remarkable power of endurances that they eyes of the manufacturing world were widely opened at the results of the test.

As a rule the self-hardening steels, among the earlier brands of which Mushet and Jessop were among the best, were not adapted to such high speeds as the regular high speed steels, although capable of much higher speed then common tool steel. The self-hardening steel made by Mushet is said to have had the following composition:

Carbon	2.0	per cent
Fungsten	5.0	" "
Manganese	2.5	" "
Chromium	.5	" "
Silicon	1.3	" "

The manganese of this composition facilitates the combining of the iron and carbon and thus brings about the self-hardening property.

As before stated, the compositions of high speed steels are secrets known only by the makers, but it is known that they contain the following in varying proportions:

Chromium,
Carbon,
Tungsten,
Manganese,
Molybdenum,
Titanium.

There must be special care exercised in the melting and subsequent treatment of the metal in order to insure homogeneity of the steel when finished. The carbon in most of the high speed steels is present in small quantities, and combining with the other above named elements forms, at the high hardening temperatures, carbides that are very hard and will withstand the high temperature of heavy cuts and high speeds. Owing to the high cost of the component elements in high speed steels and to the care necessary in manufacture, the price is relatively high.

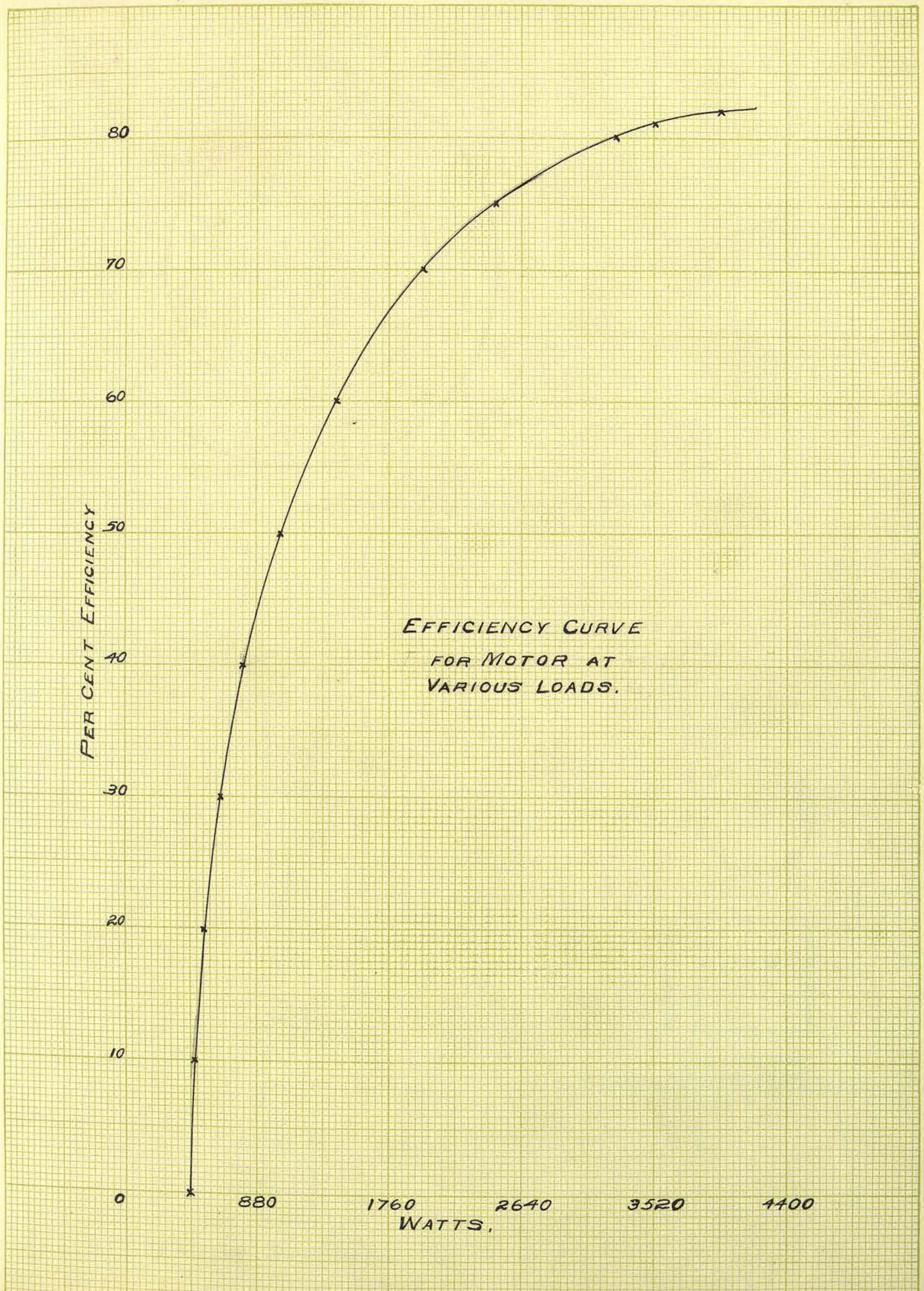
It has been our object in conducting these experiments to test the different tools under such conditions and upon such materials as are met with in machine work. There are many things which influence the shape and condition of a tool when used in machine tools. What a tool will do and what shape the tool requires depends upon;

1. Material of which it is made.
2. Nature of material to be cut.
3. Surface speed at which it is supposed to run.
4. Depth of cut.
5. Feed of tool.

It is reasonable to suppose that for every possible condition there is one and only one combination of the above that will give the best results, and while it is not our intentions to work out a proper combination for each condition, we have sought to gain a few ideas that will apply to all cases.

In foundry work there is quite a difference in the cost of making castings out of the different grades of cast iron and the best and cheapest in the end can be ascertained only from the cost of the finished article, and this depends to a great extent upon the time and expense in machining the castings, so that the cheapest in the foundry may be the most expensive in the finished state.

We have sought to work out in connection with the tool test a comparison between the relative values of the different grades of cast iron as to their relative tensile and compressive strengths, and the cost of removing a pound of metal. Since ultimately everything reduces to a money basis, such tools will be required as will do the work in the least possible amount of time, and the time depends upon the material. With this end in view we have conducted the following tests:


EFFICIENCY CURVE
FOR MOTOR AT
VARIOUS LOADS.
PER CENT EFFICIENCY
80
70
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50
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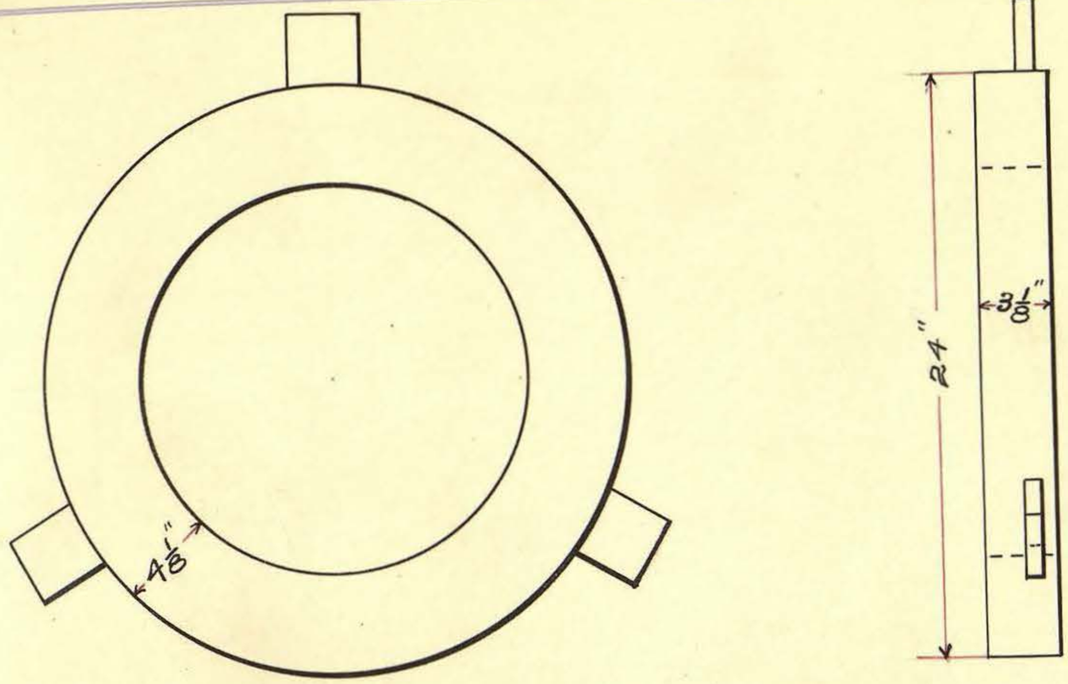
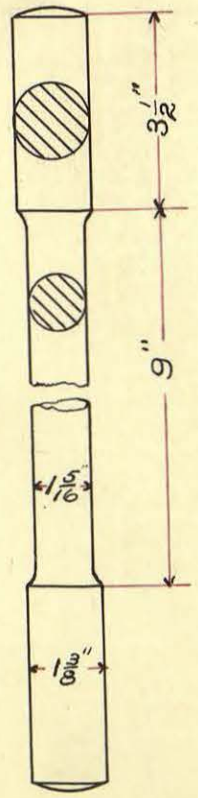
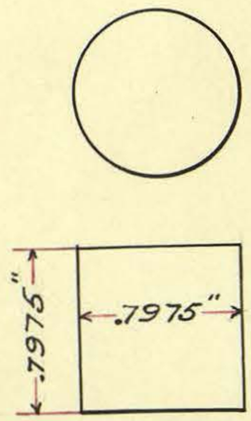
880
1760
2640
3520
4400
WATTS.



CASTING USED IN TESTS

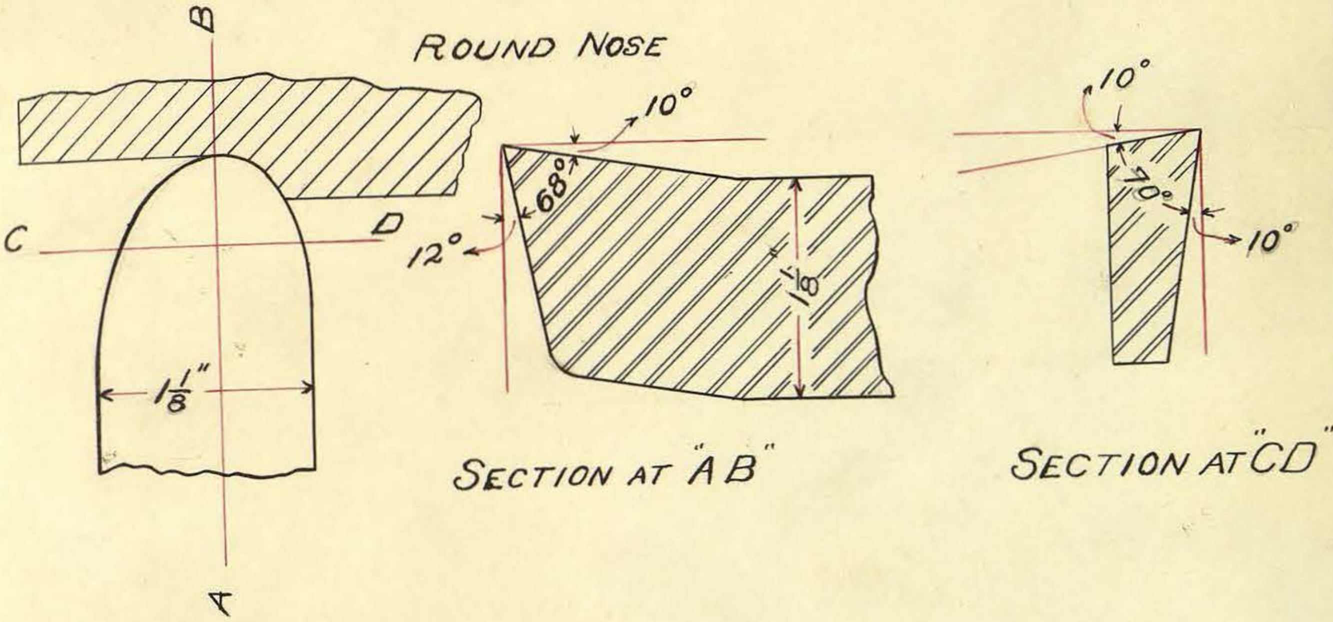


TENSION SPECIMEN.



COMPRESSION SPECIMEN

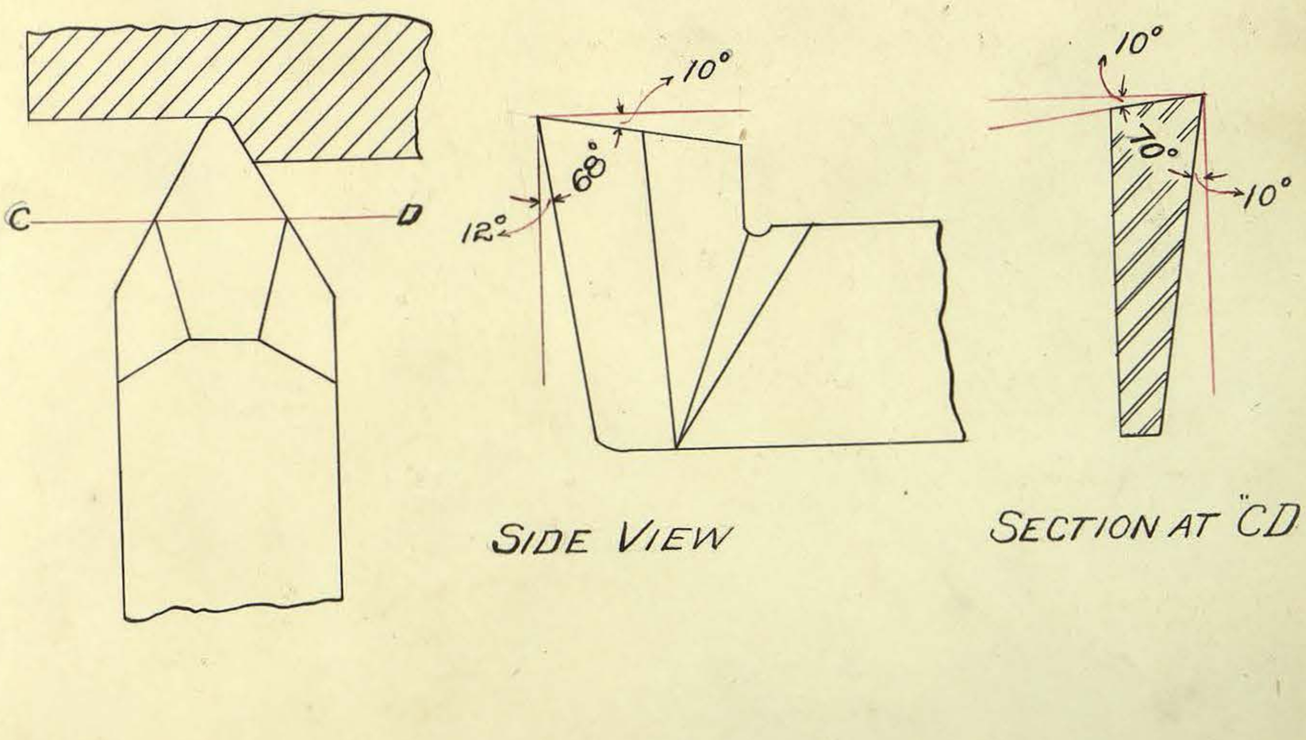
ROUND NOSE



SECTION AT "AB"

SECTION AT "CD"

DIAMOND POINT



SIDE VIEW

SECTION AT "CD"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The power to drive the machine was obtained from a 5 HP, 220 V DC shunt wound, "General Electric" motor. The motor was calibrated to determine useful power by the stray power method. The efficiency of the motor at different loads is shown by curve #1; in which watts are plotted as abscissae and efficiencies as ordinates.

The method of driving is shown in the accompanying photo. Power from the 5" drive pulley of the motor was communicated to the 20" tight and loose pulleys of the countershaft by means of a crossed belt. No trouble from slipping of the driving belt was experienced except when the machine was being started. A Weston, direct reading voltmeter and a 100 ampere Weston ammeter were used to measure the power consumed.

A 50" "Niles, Bement, Pond Co." boring mill was used for machining the specimens.. The revolutions of the table were recorded by a large "Crosby" engine register which was clamped to the frame of the machine so as to be easily seen from the front. By a system of levers actuated by a pin on the large gear which drives the table, five numbers were registered for each revolution of the table; which with the times taken for the cut gave data for the calculation of the surface speed..

The iron for the specimens was melted in a "Victor Collians Hot Blast" cupola of 18" diameter and two ton capacity. The air blast was furnished by a centrifugal fan at a pressure of about 5 oz. per square inch. The dimensions and shape of specimens are given in the following drawings. The test specimens for tension and compression tests we also made at each run and are shown on the same drawings. The molds were set up in large wooden flasks and the molten iron was served to them from a swinging crane.

A 100,000# Riehle testing machine was used for determining the tensile and compressive strengths of the specimens. For the hardness test we used a 3/16" "Noro" high speed drill, chucked in a small high speed drill press. A uniform and steady pressure was given to the drill by means of a 67# lead weight, turned true, and fitted over the drill spindle and supported on ball-bearing collars. The cutting steels used and prices per pound are shown in the following table.

Name.	Kind	Price per lb.
Rex A	high speed	60¢
Capital	" "	65
Sanderson	self-hardening	42 1/2
Jessop	annealed	16
Crescent	double-special	27
"	special	17
"	extra	12
"	cast	7

The tools were forged and hardened in a manner conforming as closely as possible to the manufacturer's directions. The shape of the tool used in the comparative tests as to the relative values of the different steels was of the round nose style as shown in drawing, experience having demonstrated the fact that this form will conduct heat away faster and stand the maximum amount of abuse with the minimum amount of care. The forging and hardening of the different steels was done as follows.

The Rex "A" was forged at a good red heat and was hardened at a white heat, or until a melted borax-like composition appeared on the point. It was then cooled in an air blast.

The Capital was worked the same as the Rex A, but was hardened in oil.

The Sanderson self-hardening was forged and hardened at an orange heat. Cooled in air.

The other steels, with the exception of the "Double Special Crescent" were given carbon-steel treatments.

The "Double Special" was heated only to a dull red heat instead of an orange. Hardened same as ordinary steel.

All tools were ground after hardening, and then measured with a bevel protractor to secure proper angles. The length projecting the tool holder was made as small as possible to avoid springing. The case iron specimens were made in the foundry, the details of the charging being carefully noted so that any unnatural results might be accounted for. The charging was as follows:

A bed of coke of about 250# was placed in the bottom of the cupola and when this was burned thru, a charge of iron of about 500# was thrown on and carefully leveled. Then followed 75# coke and the next charge of iron. After the bed had lowered sufficiently the charging was continued, 75# coke being placed between each charge of iron. Between the second and third charges a shovelful of limestone was thrown in to act as a flux and thin the slag.

Each specimen was numbered in the mold, as were also the tension specimens. The compression specimens were turned up out of the tension bars. Some of the castings were taken out of the sand at a red heat, while others were left in until practically cold. The object of this was to determine the effect of sudden cooling on machining. A complete record of castings is found in the following table:

Run. No.	Specimen number.	Composition.	Time after blast was started wheel poured.	Time in sand.	Condition when take out.
	1	50% scrap	23 min.	17 hrs.	hot
	2	50% #2,	23 min.	2 "	red hot
I	3	southern.	45 min.	17 "	hot
	4		51 min.	2 "	red hot
	5		51 min.	17 "	hot
	6		32 min.	2' 30"	red hot
II	7	66 2/3% #2	41 min.	17 hrs.	warm
	8	33 1/3% #1.	55 min.	2' 30"	red hot
	9		1 hr. 11 min.	17 hrs.	warm
	10		1 hr. 26 min.	2' 30"	red hot.
	11		35 min.	1 3/4 hrs.	red hot
	12	Remelt of	41 "	17 hrs.	warm
III.	13	Run #2.	47 "	1 3/4 hrs.	red hot
	14		53 "	17 hrs.	warm
	15		58 "	1 3/4 hrs.	red hot
	16		23 "	2 hrs/	red hot
	17		23 "	17 hrs.	warm
IV.	18	All scraps.	33 "	2 hrs.	red hot
	19		33 "	17 hrs.	warm
	20		43 "	2 hrs.	red hot

The drawing shows the size and shape of specimen used. They were first cast without the lugs, and were held in jaws on the boring mill about 4" above the table. Trouble was experienced due to the springing of the jaws. The castings were then cast with the lugs as shown and clamped directly to the table and the chattering ceased.

To obtain the depth of cut an inside micrometer was used between the tool post and the table. The feeds were obtained by setting the friction feed wheel in certain definite positions and then found, by measuring the distance the tool post moved when the table made fifty revolutions. The rack mentioned had eighteen teeth. We took every third tooth; found the corresponding feed per revolution of table.

The machine has extra feed. The ratio between the two feeds was found and then the fast feeds found by multiplying the slow by the ratio. By having the teeth on the rack numbered and with table of feeds, it proved to be an easy matter to obtain any desired feed.

Table of Feeds.

No. Tooth	Slow	Fast.
3	.035"	.098
6	.051"	.142
9	.068	.191
12	.085	.239
15	.103	.288
18	.119	.335

The surface speed was determined by having a Crosby Engine Register attached in such a manner that it registered 1/5 of a revolution of the table. By noting the reading of the register and time at beginning and end of a cut, the speed can be found: Speed in feet per minute equals $\frac{2\pi R \times \# \text{ Rv of table}}{12 \times \text{time}}$

Due to the shape of one of the specimens, and the manner in which the cut was taken, there was a gradual reduction in the surface speed from the beginning of the cut to the end. We have taken the maximum, average and minimum speeds.

The power consumed was measured by the Voltmeter Ammeter method. Readings were taken with the machine running empty except just before taking a cut, and then at short intervals during the cut. The average of these readings were taken. Having previously determined the efficiency of the motor at the different loads, the power required to drive the machine could easily be determined; also the power consumed in the cut.

The weight removed was figured from the depth of the cut. By experiment the weight per unit thickness was found and from this was figured the weight removed per cut. It was our intention to weigh the casting after each cut, and this would have caused no great inconvenience had it been possible to use the jaws, but when it was found that the specimen had to be bolted down, some other method had to be devised. Comparisons were made by weighing and measuring, and the results were almost identical.

Many different combinations of feeds, depths, and speeds were tried with the various tools and specimens, the aim being to test all tools under as nearly like conditions as possible, and to run them to the limit. The hardness test was simply a comparative test between the different combinations of cast iron used in this test. Three holes were drilled in each specimen by a 3/16" Novo H.S. drill having the constant weight of 67# on it and run for 500 revolutions in each case at a speed of 545 RPM. The drill was freshly ground to the standard shape after each casting was tested. An average of the three depths was taken and of course the metal into which the drill went the deepest, was the softest and was called hardness "100." From this the hardness of the other specimens were derived, the hardness in each case being inversely as the depth drilled.

As has been cited, it is of primary importance to secure steel which will stand high speeds. We have endeavored to determine the maximum speeds which the steels will stand when cutting the specimens which were used. The "Rex" and "Capital" high speed steels stood a setting speed of 60' per minute and were in good shape at the end of the runs in most cases. The fastest cut we took was with a Rex A tool in which we used a maximum speed of 101' per minute. The tool failed at this cut but the specimen had become heated from previous cuts and the tool was at a blue heat before commencing the cut, which fact may have influenced results.

The Jessop steel withstood a speed of 14' per minute, but would not stand a speed of 22' per minute; hence its limit must be between 14' and 22' per minute. The Sanderson self - hardening steel showed good results when used upon the machine soft castings, but would not stand cuts upon the hard, scrap castings. Its efficiency is very little above that of the better grades of Crescent steel.

The greatest weight of metal removed per minute was secured with a Rex A tool with a depth of .25" and a feed of .068" while running at a speed of 56' per minute. The Rex A, and Capital steels would no doubt have stood a much heavier cut with perhaps a faster speed, but the motor was not large enough to pull the load and the machine may not have been strong enough to stand it. The above cut was taken on a casting from Run #2 . The least power required per pound metal removed was taken with a Rex A tool with a light cut and slow speed on wheel No. 11.

Constant and equal speeds for comparative depths and feeds could not be secured because of a variation in the voltage of the current supplied: but for practical considerations the speed may be considered as constant.

From our tests we are satisfied that the Rex A and Capital high speed steels are enough more efficient and will allow of enough faster cutting to more than make up for their greater cost. If very hard castings are to be machined, the common steels will fail at almost any speed, no matter how small. The above mentioned high speed steels were found to leave a good smooth surface and remain in good shape even with a heavy cut and a speed between 20' and 30' per minute when machining all scrap iron.

In the tests on the shape of tools we found that diamond noses require about 7.5% less power for cutting than do the standard round noses when run at such speeds that they both hold their cutting edges, but the diamond point when dulled required as much power as the round nose. As the diamond point has less section for carrying away the heat it will dull before the round nose will.

In testing for angles of top rake , 15° was found to be too great because it left too little metal to support the cutting edge and carry away the heat. While the cutting edge remained intact, it required less power for the cut. The best results were secured with 10° top rake, this amount being sufficient to support the edge and give a nice smooth cut. With 5°, 0°, -5° and -10° rake the tool required constantly increasing power to drive it because of a scraping instead of cutting action of the teel. As would be expected the cutting edge stood up well, because strongly supported. A side rake of about 10° was used with all tools, this rake appearing to be about the best because small enough to support the cutting edge and large enough to give plenty of clearance. An end rake of 12° proved to be satisfactory.

Very little difference in the effect on the tools and the power required was noticeable in the machining of the castings of runs 1, 2, and 3, but the castings of run No. 4, were very hard and while not requiring a great deal more power per pound metal removed, required much longer time. It was found that the Rex A and Capital steels were the only ones which would cut them. The other steels failed at the start with the slowest speed possible. (13' per minute)

Taking an average of the power required per pound metal removed for the several wheels with the standard round none steel, we find that it takes 1.37, 1.58, 1.43, and 1.74 HP for runs 1, 2, 3, and 4, respectively, while by taking the average power per pound metal removed from the castings when a cut of .25" was used and as nearly the same speed as we could get, the following values were obtained: 1.57, 1.68, 1.51, and 1.84 for runs 1, 2, 3, and 4, respectively.

I.

Trial No.	Time, min.	Brand of steel.	Shape of tool.	Condition of tool. Before	After	Casting number.	Surface speeds. Max.	Av.	Min.
1	9	Rex A	Round nose.	New	Good	4	35.6	29.7	23.8
2	8.5	"	"	Good	"	4	34	28.3	22.7
3	8	"	"	"	"	4	34.6	28.8	23.1
4	8	"	"	"	"	4	39.9	33.3	25.4
5	8	"	"	hot	hot	4	37	30.8	24.7
6	4.5	"	"	"	failing	4	50.3	41.8	33.6
7	3.5	"	"	hot, blunted.	Bunched off.	4	101	84.2	67.5
8	5	"	"	new	good	4	60.5	50.3	40.3
9	5.5	"	"	good	"	4	56.5	47.1	37.7
10	4.5	"	"	hot	hot	4	58.8	48.8	39.2
11	16.25	Jessop	"	new	good	4	13.8	11.5	9.2
12	10.25	"	"	good	dubbed	4	20.6	17.2	13.7
13	10	"	"	"	failed	4	22.7	17.2	13.7
14	9.75	Rex A	"	new	good	4	23.3	19.4	15.5
15	6.25	"	"	good	"	4	34.9	29.1	23.3
16	20	"	"	"	dubbed	4	64.1		
17	6.5	"	"	"	hot	4	60.3	50.3	40.4
18	2.5	"	"	hot	dubbing	4	58.5	48.6	38.9
19	2.5	"	"	dulled	badly dulled.	4	61.4	51	40.8
20	14.5	"	"	new	good	4	36	30	24
21	23	"	"	good	good	4	35.3	29.4	23.5
22	28	Jessop	"	new	good	4	13	10.8	8.7
23		"	"	good	failed	4	22.6		
24	18	"	"	new	dulled	4	13.3	10.9	8.8
25	20	"	"	retempered.	"	4	12.6	10.5	8.4
26	10.5	"	"	fresh	dubbed	4	13.2	11.	8.8

Trial No.	Depth of cut.	Feed.	Wt. removed per minute.	Output of motor	Power to drive motor.	Power used in cut.	HP per Lb. until removed.	Comparative hardness of casting.
1	.094	.085	.558	1.74	.483	1.26	2.25	110
2	.156	"	1.02	2.08	.483	1.6	1.56	"
3	.25	"	2.05	3.43	.48	2.95	1.44	"
4	.25	"	2.04	3.	.33	2.67	1.31	"
5	.25	"	2.04	3.63	.33	3.30	1.62	"
6	.125	.119	1.82	4.1	.49	3.61	1.96	"
7	.125	.119	2.34	3.85	1.29	2.56	1.09	"
8	.125	.085	1.63	2.48	.5	1.98	1.22	"
9	.125	.085	1.49	2.83	.5	2.33	1.56	"
10	.125	.103	1.82	3.34	.5	2.84	1.56	"
11	.125	.119	.613	1.1	.17	.93	1.51	"
12	.094	.119	.465	1.06	.25	.81	1.74	"
13	.094	.119	.6	1.19	.25	.94	1.56	"
14	.187	.119	1.3	1.87	.25	1.62	1.24	100
15	.187	.119	1.92	2.63	.48	2.15	1.12	"
16	.187	.119						"
17	.187	.068	1.9	3.55	.52	3.03	1.59	"
18	.063	.191	1.64	2.89	.74	2.15	1.31	"
19	.063	.191	1.64	3.69	.63	3.06	1.86	"
20	.25	.051	1.13	2.05	.33	1.72	1.52	"
21	.375	.035	1.07	1.92	.39	1.53	1.43	"
22	.187	.068	.43	.73	.28	.45	1.04	"
23	.125	.103						"
24	.125	1103	.45	.72	.23	.49	.93	"
25	.125	.103	.41	.62	.17	.45	.99	"
26	.125	.191	.78	1.17	.17	1.	1.28	"

II.

Trial No.	Time, min.	Brand of steel.	Shape of tool.	Condition of tool Before	After	Casting No.	Surface speeds. Max.	Av.	Min.
27	10.5	Rex A	Round nose.	fresh	good	5	13.2	11.	8.8
28	17.3	"	"	fresh	hot	7	21.1	17.5	14.
29	10	"	"	hot	good	"	"	"	"
30	9	"	"	hot	good	"	34.2	28.5	22.8
31	6.5	"	"	good	dulled	"	56.	46.7	37.4
32	1.75	"	"	fresh	failed	"	56.2		
33	5	"	"	"	good	14	60.2	50.1	40.1
34	17	"	"	"	"	"	21.9	18.3	14.6
35	11	"	"	good	"	"	34.3	28.6	22.9
36	8.75	"	"	"	"	"	35.3	29.4	23.5
37		Dbl. Spec. crescent.	"	new	failed	"	23		
38	13.5	Sand.	"	"	"	"	23.1	21.1	15.4
39	10	"	"	"	fair	"	22.5	20.5	15.1
40		Cres. steel.	"	"	failed	11	12.9		
41		Cres. C. steel	"	"	"	"	"		
42	21	Rex A.	"	"	good	"	12.9	10.7	8.6
43		Crescent extra.	"	"	failed	"	13.2	11.	8.7
44	27.5	Sanderson	"	"	good	"	13.3	11.0	8.7
45		"	"	good	failed	"	23.1		
46	13.25	Rex A.	"	new	dulled	"	23.1	19.2	15.4
47	23.5	Crescent extra	"	"	bad. dulled.	"	13.6	11.3	9.1
48	23.5	C.C. Steel"	"	"	"	"	13.4	11.2	8.9
49	23.25	Dbl. Spec. crescent.	"	"	"	"	13.5	11.3	9.
50	15	Capital HS	"	"	good	"	21.4	17.8	14.3
51	12	"	"	good	"	"	22.3	18.4	14.7
52	13	"	"	"	"	10	19.3	16.1	12.9
53	6.5	"	"	"	"	10	33.1	27.6	22.1

Trial No.	Depth of cut.	Feed.	Wt. removed per minute.	Output of motor.	Power to drive motor.	Power used in cut.	HP per lb. until removed.	Comparative hardness of casting.
27	.125	.191	.78	.89	.17	.72	.93	100
28	.344	.068	1.3	2.72	.28	1.44	1.39	118
29	2203	.119	1.33	2.24	.33	1.91	1.42	"
30	.25	.085	1.82	3.65	.38	3.27	1.79	"
31	.25	.068	2.53	4.85	.58	4.27	1.69	"
32	.25	.068	2.69	5.08	.62	4.46	1.66	"
33	.25	.068	2.34	4.2	.62	3.58	1.53	"
34	.344	.068	1.33	1.99	.28	1.71	1.29	139
35	.25	.068	1.5	2.35	.25	2.1	1.4	"
36	.25	.085	1.89	2.9	.38	2.52	1.33	"
37	.25	.085						"
38	.25	.085	1.21	2.01	.4	1.61	1.33	"
39	.125	.119	.82	1.26	.26	1.	.84	"
40	.187	.085						197
41	.187	.085						"
42	.187	.085	.58	.83	.25	1.48	.82	"
43	.187	.068						"
44	.187	.068	.447	.7	.25	.45	1.05	"
45	.25	.085						"
46	.25	.085	1.23	1.9	.25	1.65	1.34	"
47	.125	.085	.349	.98	.28	.61	1.75	"
48	.141	.085	.393	.92	.27	.64	1.63	"
49	.14	.085	.4	.72	.25	.47	1.18	"
50	.25	.085	1.09	1.84	.25	1.59	1.46	"
51	.25	.103	1.37	2:22	.27	1.95	1.42	"
52	.281	.103	1.42	2.72	.24	2.48	1.74	153
53	.187	.119	1.89	3.44	.36	3.08	1.63	"

III.

Trial No.	Time, min.	Brand of steel.	Shape of tool.	Condition of tool. Before	After.	Casting, No.	Surface Speed. Max.	Av.	Min.
54	7	Cap. H. S.	Round Nose.	Good	Good	10	31.6	26.6	21.1
55	5	"	"	Good	Good	"	22	18.3	14.7
56	2	Rex A.	"	Fresh	failey	"	64		
57	5/16	Cap. H. S.	"	Good	slightly dulled	"	60.2	50.2	40.2
58	3.75	Cap H.S.	"	Good	"	"	50	56	40
59		Sanderson.	"	fresh	failed	"	60		
60	6.25	Rex A.	"	fresh	good	"	36.4	30.4	24.3
61	5	"	"	good	"	9	62.6	52.3	41.8
62	5	"	"	"	"	"	62.2	51.8	41.5
63	6.25	"	"	"	slightly dulled	"	62.4	52	41.6
64	5.3	Cap	"	"	good	"	59	49.4	39.6
65	8	"	"	"	"	"	58.8	49	39
66	7	"	"	"	"	"	57.8	48	38.4
67	7	"	"	fresh		"	58.4	48.7	39
68		Rex A.	"	fresh	failed	18	36		
69	29	Cap	"	dulled	dulled	"	13.2	10.9	8.7
70	30.2	Cap	"	fresh	dulled	"	13	10.8	8.7
71	71	Cres.Ex.	"	fresh	failed	"	13		
72		Cres.Sp.	"	fresh	"	"	13		
73		Jessop	"	fresh	"	"	13		
74	31	Sanderson	"	fresh	good	"	13.9	11.6	9.3
75	30	"	"	good	good	"	13.5	11.3	9.0
76	23.5	"	"	good	good	"	13.4	11.3	9.0
77	27.75	"	"	good	S.dulled.	"	13.3	11.1	8.9
78		"	"	good	failed	20			
79	26.25	Rex A.	"	fresh	good	20	14	11.8	9.5
80	32	R.A.&C.H.S.	"	"	"	20	21.2	17.7	14.2
81	19	"	"	"	"				

2III.

Trial No.	Depth of cut.	Feed.	Wt. removed per min.	Output of motor.	Power to drive machine.	Power used in cut.	HP per lb. metal removed.	Comparative hardness of casting.
54	.25	.119	2.38	4.44	.36	4.08	1.71	154
55	.156	.239	2.05	4.4	.36	4.04	1.97	"
56	.125	.085	2.05	3.72	.52	3.2	1.56	"
57	.187	.085	2.38	4.46	.62	3.84	1.61	"
58	.125	.119	2.08	4.27	.38	3.89	1.87	"
59	.125	.119						"
60	.218	.119	2.29	3.8	.47	2.33	1.01	"
61	.156	.085	2.05	3.53	.6	2.93	1.43	124
62	.203	.085	2.66	4.18	.65	3.53	1.33	"
63	.25	.068	2.63	4.37	.63	3.64	1.38	"
64	.203	.085	2.52	3.74	.63	3.11	1.23	"
65	.25	.068	2.05	4.46	.63	3.83	1.87	"
66	.25	.068	2.34	4.52	.62	3.9	1.67	"
67	.25	.068	2.34	4.75	.62	4.13	1.76	"
68	.156	.068						552
69	.156	.068	3.53	.958	.28	.68	1.93	"
70	.25	.068	.54	1.36	.28	1.08	2.00	"
71	.187	.051						"
72	.187	.051						"
73	.187	.051						"
74	.187	..051	.4	.82	.19	.63	1.57	"
75	.25	.068	.55	1.13	.19	.94	1.71	"
76	.25	.068	.7	1.34	.19	1.15	1.64	"
77	.25	.103	.79	1.57	.28	1.29	1.63	"
78	.187	.068						"
79	.143	.068	1.35	.84	.28	.56	1.59	1038
80	.5	.068	1.02	2.4	.38	2.02	1.98	"
81	.5	.068	1.73	3.18	.29	2.89	1.67	"

IV.

Trial No.	Time in min.	Brand of Steel	Shape of Tool.	Condition of tool before	after.	Casting No.	Surface Speed Max.	Av.	Min.
82	10	Rex A.	Round nose.	good	good	13	22.8	19.7	15.3
83	17.	"	" 15° top R.	good	dulled	"	22.5	18.7	15
84	17.5	"	Standard	good	"	"	22.3	18.6	14.8
85	17.2	"	R.N. 0° Top R.	"	"	"	22.9	19.1	15.3
86	18.	"	"	good	good	"	22.1	18.4	14.7
87	17.7	"	"	new	dulled	"	22.1	18.4	14.7
88	17	"	Standard	good	good	12	22.2	18.5	14.8
89	17	"	Round N. 0° top R.	fresh	good	"	22.4	18.7	14.9
90	17.7	"	"	good	good	"	22.1	18.4	14.7
91	17.7	"	-5° Top R.	fresh	good	"	22.4	18.7	14.9
92	17.7	"	"	good	good	"	22.4	18.7	14.9
93	17	"	Standard	good	good	15	22.3	18.6	14.8
94	17.5	"	-5° Top R.	fresh	good	"	22.4	18.7	14.9
95	18	"	-10° top R.	"	"	"	22.5	18.8	15
96	18	"	"	"	"	"	23 5	19.6	15.7
97	19.2	"	"	"	"	"	22.3	18 6	14.8
98	11	Cap HS.	Dia.Pt.	dull	dull	6	36.1	30.3	24.3
99	10.7	"	"	dull	dull	"	36.9	30.8	24.7
100	12	Rex A.	Standard	fresh	good	"	33.3	27.8	22.2
101	11.7	Cap.HS.	Dia. Pt.	"	"	"	34	28.3	22.7
102	12	"	"	"	"	"	33	27.5	22.1
103	9.5	"	"	"	"	8	32.8	27.4	21.9
104	9	"	"	"	"	"	34.5	28.9	23.2
105	9	"	"	"	dulled	"	34.5	28.9	23.2
106	9	"	"	"	good	"	35	29.1	23.3
107	9.5	Rex A.	Standard	"	"	"	33.2	28.5	22.8

Trial No.	Depth of cut.	Feed.	Wt. removed per min.	2IV. Output of motor.	Power to drive machine.	Power used in cut.	HP per lb. metal removed.	Comparative. hardness of casting.
82	.156	.119	1.03	2.29	.34	1.95	1.89	129
83	.253	.068	.98	1.65	.38	1.27	1.3	"
84	.267	"	1.00	1.78	.34	1.44	1.44	"
85	.266	"	1.01	1.93	.39	1.54	1.52	"
86	.254	"	.93	1.7	.39	1.31	1.41	"
87	.25	"	.92	1.71	.38	1.33	1.45	"
88	.25	"	.97	1.83	.28	1.55	1.6	126
89	.265	"	1.02	1.78	.28	1.5	1.47	"
90	.251	"	.92	1.67	.28	1.39	1.51	"
91	.263	"	.97	1.77	.28	1.49	1.54	"
92	.249	"	.92	1.57	.28	1.49	1.4	"
93	.258	"	.99	1.96	.28	1.68	1.7	145
94	.257	"	.99	2.17	.29	1.89	1.91	"
95	.26	"	.95	2.42	.29	2.13	2.24	"
96	.26	"	.95	2.18	.29	1.89	1.99	"
97	.256	"	.87	2.14	.28	1.86	2.14	"
98	.25	"	1.49	2.6	.37	2.23	1.5	196
99	.25	"	1.53	2.75	.4	2.35	1.53	"
100	.25	"	1.37	2.68	.4	2.28	1.66	"
101	.26	"	1.45	2.28	.41	1.87	1.29	"
102	.262	"	1.43	2.02	.41	1.61	1.13	"
103	.25	.085	1.73	3.56	.39	3.17	1.83	128
104	.25	.085	1.82	2.86	.46	2.4	1.32	"
105	.25	"	1.82	3.07	.46	2.61	1.43	"
106	.25	"	1.82	2.89	.46	2.43	1.33	"
107	.25	"	1.73	3.25	.46	2.79	1.61	"

Run No.	Test specimen No.	Tensile strength # sq.in.	Comp. strength, # sq.in.	Casting number.	Av. Depth drilled	Comparative hardness.	Time casting left in sand.
I.	1	19000	86880	4	1.13	110	2 hrs.
	2	19150	87260	5	1.25	100	17 hrs.
II.	1	20700	95610	6	.635	196	2.5 hrs.
	2	17800	93630	7	1.057	118	17 "
				8	.97	128	2.5 "
				9	1.003	124	17 "
				10	.812	153	2.5 "
				11	.633	197	1.75 "
III.	1	20500	97170	12	.986	126	17
	2	20600	100910	13	.967	129	1.75 "
				14	.894	139	17
	1	16620	116600	18	.226	552	2 "
IV.	2	25560	114240	20	.12	1038	2 "

The results of the tensile, compressive, and hardness tests show that the conbination of 50% scraps and 50% No. 2 Soutern iron has a lower tensile and compressive strength than any of the others, and the drill test for hardness reveals it to be the softest.

Run No. 3, a remelt of No. 2, is shown to have a higher tensile and compressive strength than No. 2, and the drill test shows it to be harder, a result to be expected.

Run No. 4, all scraps, shows a vast difference in the tensile strengths of the two test specimens. The difference must be due to an extra side strain set up in the test, because the compressive strengths are almost the same, and from the appearance of the iron specimen No. 1 was a little better than specimen No. 2. The hardness test shows that specimen No. 2 has almost twice the hardness of specimen No. 1, an unexpected result that might account for the low tensible strength of specimen No. 1.

A comparison between the castings as to the effects of leaving them in sand for unequal lengths of time, shows that in all cases, except one, the castings were harder. In some castings there was only a slight variation while in others the difference was quite marked. This is a result that would naturally be expected from our knowledge of the effects of sudden cooling upon irons containing cousi-durable carbon.

A comparison of the results of the tool tests shows that there is a definite ratio, between the depth of cut and the feed, that will produce the best results. A feed of from 1/4 to 1/5 of the depth of cut would probably give the best results.

It was found that the tool having a top rake of 15^0 required less power to remove one pound of metal than any other tried, although this angle was so great that the tool dulled quite badly , even at the low surface speed at which it was run, because the cutting edge was not sufficiently supported.

Conclusions to be drawn from this are that the top angle which the cutting edge makes with the machined surface, or in other words, the top rake should be as great as the conditions will allow, the limit being reached when there is insufficient backing to support the cutting edge and carry away the heat. Evidently the high speed steels can be run at from 3 to 5 times the surface speed allowable with carbon steel. The cost per pound is about four times as great. With this data at hand it should be an easy matter to determine the advantage gained from the use of high speed steel.

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'08.