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THE UTILITY OF THE SPARK TEST AS APPLIED TO COMMERCIAL STEELS

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ABSTRACT

Typical spark streams of plain carbon steels, a variety of alloy steels including S.A.E. steels, nitrided steel and cast iron are described and illustrated. Definite spark stream characteristics were found in the steels studied for each of the alloying constituents, chromium, manganese, molybdenum, nickel, tungsten, and vanadium.

A supplementary study was made of the appearance of the metal pellets collected from the spark streams of the various types of steel. The presence in the steel of chromium, molybdenum, silicon, or vanadium in some cases imparts characteristics to the pellets which may aid in the identification of the steel.

The spark test may be depended upon as a means for classifying steels into groups of similar composition, but cannot be successfully used as a means of identifying an unknown steel.

On the basis of the data given by the combined spark test and pellet test a sorting chart has been prepared. This chart indicates the possibility of sorting by the spark and pellet tests over 2,100 combinations of two steels of a total of 2,500 possible combinations of any two steels in the chart.

CONTENTS

I. INTRODUCTION

The difference in the sparks produced by applying steels of different compositions against a revolving abrasive wheel was first described in 1804.[1] Relatively little detailed information, however, has since been published. The published records which have appeared, with two exceptions,[2 3] have used written descriptions or drawings to record the results of the study of this phenomenon. It is the purpose of this paper, which summarizes the results of the application of this method of testing to a wide variety of steels, to emphasize points often overlooked in the use of the spark test, to present photographs of representative spark streams,[4] as well as to discuss some new aspects of the subject.

The spark test is limited to two fields of application; namely, (1) for inspection and, (2) for sorting of unknown steels from a lot of steel of known chemical composition. The test cannot be depended upon for identifying steels of unknown composition; such determinations can be made only by chemical analysis.

II. METHOD

1. EQUIPMENT

The equipment required is relatively simple. A ⅛-horsepower motor, weighing about 8 pounds, operating at a shaft speed of 15,000 rpm was used in this work. An abrasive wheel of alundum (41S) 1¼ inches in diameter and ⅜-inch thick was mounted on the shaft. The working peripheral speed of the wheel was about 5,000 fpm.

Colored glasses should be worn, as constant observation of spark streams with the unprotected eye is harmful. The color of the glass is not so important. It must be of sufficient density to relieve eye strain, but as light as possible so it will not obscure the characteristics of the spark stream.

2. PHOTOGRAPHY

Either a motion-picture camera or an ordinary camera for single exposures can be used successfully for such photographs as are reproduced in this paper. Since a good photograph was more a matter of chance than of skill, a motion-picture camera was regularly used so that more individual records could be made with greater ease and speed, and thus give a larger number of photographic records from which to choose. It was necessary to use a fast lens with a fast panchromatic film. Extremely rapid exposures were out of the question as it was desired to record the entire trajectory of some of the particles. Short time-exposures were made against a dark background to allow the stream to expose itself.

3. NOMENCLATURE OF SPARK TRAJECTORY

In describing spark streams various investigators have used different terms. To make it easier to follow this description, the outstanding characteristics have been indicated on typical photographs as follows:

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[1] de Manson, Jacques, Traité du Fer et de l'Acier, Paris, 290 pp., 1804.
[2] E. Pitois and J. D. Gat, Sparking of Steel. Chemical Publishing Co., 1929.
[3] W. G. Hildorf and C. H. McCollam, Classifying Steels by Sparking, Metal Progress, Feb. 1933. (The author refers the reader to this paper for recommended practice for the routine application of the spark test.)
[4] Photographs for record only, all routine spark testing is by visual examination.

The general spark stream characteristics typical of carbon in steel as shown in figure 4, the "flower burst" in figure 10, the "spearpoint" in figure 21 and the "jacketing effect" in figure 25.

The plain carbon steels were studied in groups classified on the basis of similar spark streams. These groups are designated as brackets. Three such brackets were used; the lower carbon bracket including open hearth iron, and carbon steels through S.A.E. 1045 (Society of Automotive Engineers); the medium carbon bracket, steels from S.A.E. 1045 through S.A.E 1070; and the high carbon bracket, the high carbon steel, S.A.E. 1070, and above.

4. THEORY OF SPARK STREAM

The characteristic appearance of the spark stream is apparently to be attributed chiefly to the oxidation of the carbon in the steel. Alloying elements may contribute minor characteristics to the stream. It appears probable that as the grinding wheel tears off small particles of steel the work done causes the temperature to rise. This rise in temperature may also be increased by a "pyrophoric" oxidation effect resulting from the rapid surface oxidation of small particles which are torn away from the steel specimen with perfectly clean oxide-free surface. The particles of steel are heated to such a degree that they become fused, at least superficially, and tend to become spherical. Oxygen and carbon react in the heated portions of the particles to produce CO_2 and perhaps CO.

The oxide scale formed on a plain carbon steel is not very tenacious and easily flakes off. The gas which forms within the heated spherical particles escapes through this easily fractured skin and gives rise to the "series spark bursts." A comparatively smooth pellet which shows a slight pattern on the surface remains after the particle cools. Alloying elements in the steel may change the characteristics of the oxide film in such a manner as to give the various spark characteristics.

The entire spark stream consists of the trajectories of a multitude of glowing particles with the accompanying "bursts." As the carbon content of the steel is increased, the number and intensity of the "carbon bursts" increase.

5. METHOD OF STUDY

The study of the spark stream is simplified if the trajectory is considered to be divided into four sectors as shown in figure 4. The first sector is located directly adjacent to the abrasive wheel. A characteristic color, not necessarily the same as the spark stream color, is sometimes observed here, and the spark of nickel can often be detected in this portion. The second sector covers the dense portion of the stream between the first sector and the carbon bursts. The only pronounced characteristic observed in this sector is that of color. The third sector includes the well-formed carbon bursts at the end of the stream and it is in this sector that the characteristics imparted to the spark by the alloying constituents chromium, molybdenum, manganese, carbon, sulphur, nickel, vanadium, tungsten, and silicon are best observed. The invisible portion of the trajectory following the "bursts" may, for sake of completeness, be considered as the fourth sector although it is not really a part of the spark. The study of the "burnt out" particles or pellets colected from this fourth sector gives some information concerning steels containing chromium, vanadium, molybdenum, or high alloy content in general.

III. MATERIALS AND RESULTS

A large variety of steels were examined. These consisted of representative steels of the various classes in the S.A.E. series, together with many others donated by different manufacturers. In the accompanying tables are listed the compositions of the steels which gave the typical spark streams illustrated in the figures of this paper. Steels of many additional compositions were studied in each group. The entire range of chemical compositions of steels upon which was based the selection of typical spark stream photographs is indicated in the following sections which summarize the observations made on the different materials. In these observations, a distinction has been made between two kinds of "carbon bursts." This distinction can readily be made and the characteristics of two types are indicated by the designations used, namely, the "series" bursts, and the "flower" bursts.

TABLE 1.—*Composition of plain carbon steels studied*

Designation	C	Mn	P	S	Si	Ni	Cr	Fig. no.
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Open hearth iron	0.01	0.003	0.02	0.020	0.01	0.02	0.01	1, 2
S.A.E. 1010	.09	.30	.011	.026	.02	.12	.02	1
S.A.E. 1015	.16	.51	.017	.026	.15	.20	.06	1
S.A.E. 1020	.20	.43	.006	.041	------	.008	.008	1
S.A.E. 1030	.32	.53	.01	.036	.064	------	------	3, 4
S.A.E. 1045	.44	.68	.016	.025	.23	.27	.06	3
S.A.E. 1050	.46	.57	.036	.042	.20	------	------	3
S.A.E. 1070 [1]	.70	.22	.023	.011	.23	------	.03	3
S.A.E. 1080 [1]	.76	.50	.028	.026	.28	.23	.28	5
S.A.E. 10100 [1]	1.06	.24	.014	.016	.18	------	------	5
S.A.E. 10120 [1]	1.22	.22	.015	.016	.25	------	------	5
S.A.E. 10130 [1]	1.29	.23	.017	.017	.23	------	.05	5

[1] Designated in accordance with S.A.E. numbering system for plain carbon steels; not official S.A.E. steels.

1. PLAIN CARBON STEELS

In table 1 are listed the compositions of the plain carbon steels which produced the representative spark streams shown in figures 1, 3, and 5. Six plain carbon steels in addition to those of table 1 were studied. These steels, all of carbon contents within the range of 0.23 to 1.12 percent, revealed no additional spark stream characteristics. In figure 4, the notations define the various terms used in describing the sparks. The simplest stream observed was that of open hearth iron. The stream was full, but on account of the absence of carbon not very brilliant. In general, the stream was dull red and the burst consisted simply of a swelling of the main line or carrier with occasional sprigs at the base of the enlargement. In steels containing as little as 0.10 percent carbon, the carbon burst was distinctly visible, usually as a terminal forked tongue. With the appearance of the forked tongue the stream brightened throughout.

The true "series burst" typical of this type of steel first appeared in steels containing approximately 0.15 percent carbon. The simplest

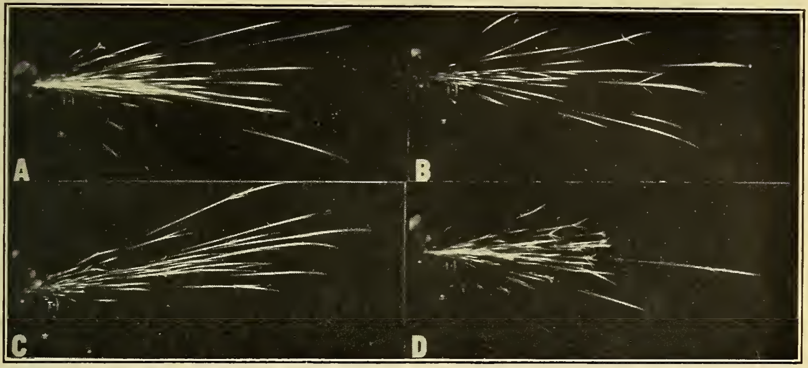

FIGURE 1.—*Typical features of spark streams of low-carbon steel.*

A, Open-hearth iron, single sprig bursts, dark tips; B, S.A.E. 1010 steel, two or three ray bursts, dark tips; C, S.A.E. 1015 steel, series bursts of sprigs; D, S.A.E. 1020 steel, series burst of sprigs and rays, buds.

FIGURE 2.—*Spark stream of open-hearth iron. Enlargement of 1A.*

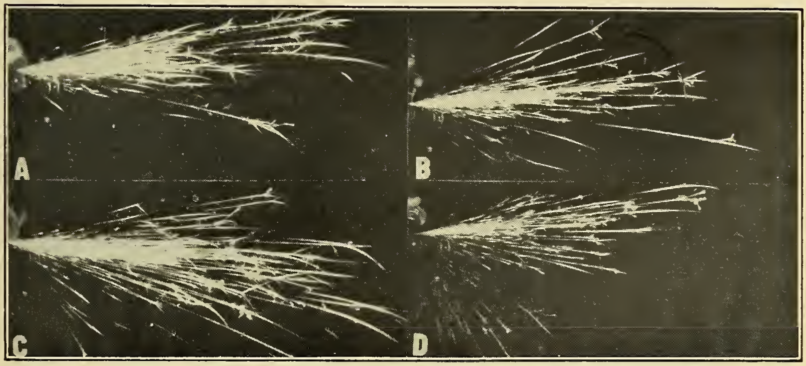

FIGURE 3.—*Typical features of spark streams of medium-carbon steel.*

A, S.A.E. 1030 steel, long tongues, series burst, buds and stars; B, S.A.E. 1045 steel, bright stream, series burst having preliminary bursts, buds, stars of the secondary type; C, S.A.E. 1050 steel, darkened sprigs and secondary carriers; D, S.A.E. 1070 steel, high carbon burst, finer carrier, shorter tongue. No sprigs and few rays. Full development of all carbon characteristics.

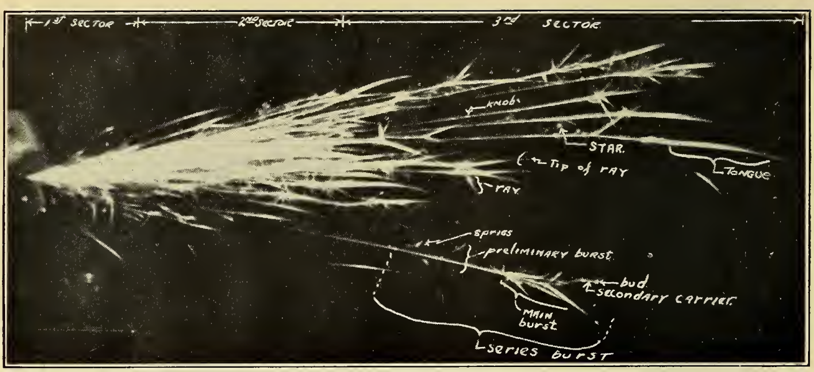

FIGURE 4.—*Spark stream of S.A.E. 1030 steel showing the various characteristics of the carbon burst.*

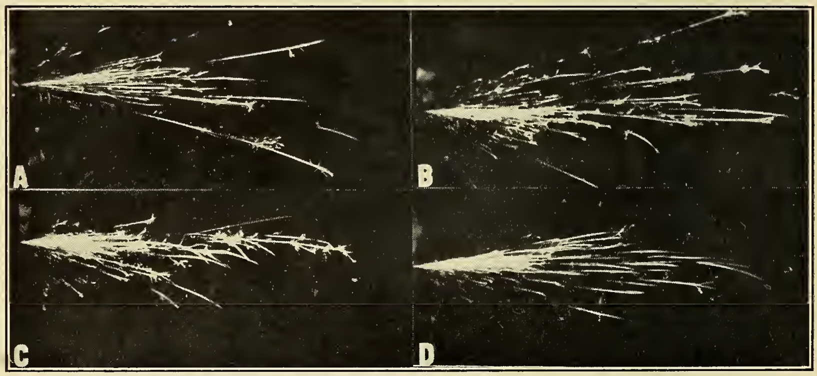

FIGURE 5.—*Typical features of spark streams of high-carbon steel.*

A, S.A.E. 1080; B, S.A.E. 10100; C, S.A.E. 10120; D, S.A.E. 10130: Shows development of all carbon characteristics and streams darker in general.

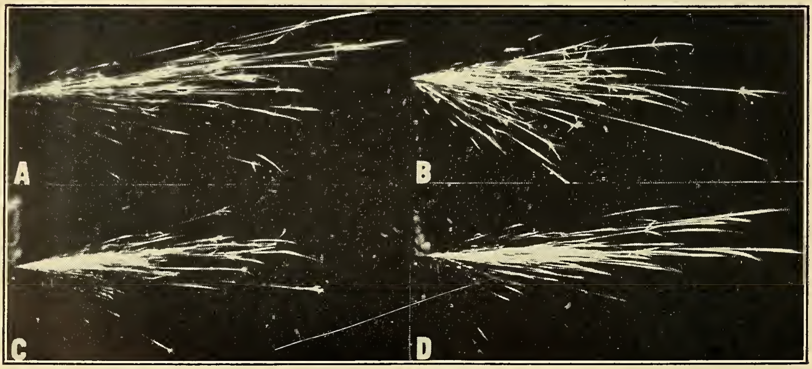

FIGURE 6.—*Typical features of spark streams of S.A.E. nickel steels.*

A, S.A.E. 2315 steel, forked tongues, slightly suppressed and compact burst; B, S.A.E. 2335 steel, forked tongues, slightly suppressed and compact burst; C, S.A.E. 2350 steel, forked tongues, slightly suppressed and compact burst; D, S.A.E. 2512 steel, forked tongue bursts, nickel spark.

form of the series burst consisted of a number of simple sprigs. With increase in carbon content above 0.15 percent, the length of the series burst was increased and buds and then stars appeared, all of which increased in number as the carbon content was increased. The maximum tongue length was obtained in steel containing about 0.30 percent carbon, and the maximum length of burst at 0.45 percent carbon. This was also the most spectacular stream observed.

The entire spark stream lightened in color as the carbon content was increased up to 0.45 percent and then gradually darkened in the steels of progressively higher carbon content, this being very pronounced in steel containing 1.00 percent carbon or more. In testing all of the steels of the high carbon class, a marked tendency for the spark to be carried entirely around the periphery of the abrasive wheel was noted.

2. NICKEL STEELS

The nickel steels listed in table 2, and in addition those corresponding to S.A.E. Nos. 2320, 2330, 2340 and 2345, were studied. Photographs representative of the spark streams are given in figures 6, 7, and 8.

TABLE 2.—*Composition of nickel steels studied*

Designation	C	Mn	P	S	Si	Ni	Cr	Fig. no.
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
S.A.E. 2315	0.16	0.68	0.014	0.03	0.26	3.45	0.09	6
S.A.E. 2335	.36	.64	.018	.031	.24	3.41	--------	6–7
S.A.E. 2350	.47	.65	.021	.025	.25	3.45	.06	6
S.A.E. 2512	.13	.45	.019	.023	.22	5.03	.16	6
N 1	.39	.55	.016	.032	.17	1.25	.62	8
N 2	.29	.74	.025	.017	.17	3.52	.14	8
N 3	.08	.31	.020	.016	.10	5.12	.15	8
N 4	.14	1.70	--------	--------	.16	47.40	--------	------
	.05	.21	--------	--------	.31	34.27	--------	8

Nickel was found to impart to the spark stream two characteristics which are useful in the sorting of a lot of mixed steels of known composition. The first, the "nickel spark", designated here as a "jacket", can be observed in either the first sector on the short carriers, or in the third sector at the base of the well-developed carbon bursts, but it is probably the most difficult alloy characteristic to observe. The second characteristic is the split tongue observed within many of the bursts instead of the usual single tongue.

The characteristics of the nickel spark can probably be attributed to the fact that the surface oxide layer on a particle of nickel steel is more tenacious than that on a plain carbon steel. It may follow that the formation of this layer on a nickel steel is so rapid and the film so tenacious that it is distended by the pressure developed within the molten pellet. Thus, the molten sphere may enlarge before bursting and at the high rate of speed of travel will produce a constantly broadening streak of light in its path and result in the oval flare at the base of the burst known as the nickel spark.

In the steels of the S.A.E. series, containing 3.00 to 3.60 percent nickel, the color of the stream was slightly darker than, but otherwise similar to, that of the spark stream of the corresponding plain carbon steels. The bursts were compact and the tongues slightly shorter, the split tongue effect being a common occurrence. The characteristic nickel spark was readily observed in the steels low in carbon (0.15 percent) but became progressively fainter with increasing carbon content until, at 0.35 percent, it was practically unobservable. In general, the spark stream of a steel containing 5 percent nickel and 0.15 percent carbon was very similar to that of the corresponding plain carbon steel. The principal differences were the slightly suppressed burst, the darkening of the stream, and the nickel spark.

All of the alloy steels of high nickel content produced spark streams. An alloy of the invar type containing 34.27 percent nickel gave a stream of yellow streaks, whereas one containing 47.4 percent nickel produced a stream too dark to permit photographing it. A specimen of commercial nickel gave a spark stream, but one of monel metal gave none.

3. CHROMIUM STEELS

Table 3 gives the compositions of the chromium steels which pro-

TABLE 3.—*Composition of chromium steels studied*

Designation	C	Mn	S	P	Si	Ni	Cr	Fig. no.
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
S.A.E. 5120	0.21	0.70	0.018	0.029	0.18	0.19	0.73	9
S.A.E. 5130 [1]	.32	.63	.021	.019	.33		1.06	
S.A.E. 5140	.45	.61	.023	.018	.24		.91	9–10
S.A.E. 5150	.51	.72	.031	.024	.23		.86	9
S.A.E. 52100	1.02	.37	.027	.014	.42		1.40	9
C 3	.39	.64	.040	.026	.42		.80	11
C 7	.92	.33	.027	.015	.31		1.68	11
C 10	.72	.49	.025	.008			2.18	11
C 11	.90	.35			.22		3.40	11
C 12	.71	.34			.37		4.88	12
C 13	.10	.41	.004	.019	.33		11.50	12
C 17	2.25	.60					13.00	12
C 18	.34	.34	.017	.024	.29	.30	13.00	12
C 23	.35	.25	.029	.016	.22	.28	14.36	12
C 25	.10	.40	.03	.03	.50		17.00	12
C 26	1.00						17.00	12
C 30	.25	.50	.03	.03	.75		25.00	12

[1] Designated in accordance with S.A.E. numbering system for chromium steels; not an official S.A.E. steel.

duced the representative spark streams illustrated in figures 9, 11, and 12. The spark streams of some 20 chromium steels were studied in addition to those listed in table 3. The composition of these steels, however, are all closely approximated by the selected steels of table 3.

The spark stream of chromium steels differed from that of plain carbon steels in that the carrier lines were finer and slightly darker. The bursts were of the flower type. These characteristics may be assumed to be associated with a strong oxide film which forms over the surface of the particles. The particle shatters under high internal pressure and a flowerlike burst results.

In the S.A.E. chromium steels whose carbon content did not exceed 0.45 percent, the spark stream resembled that of the plain carbon steels with the outstanding exception of the flower-like burst. In steels containing more than 0.45 percent carbon, the stream very closely resembled that of the corresponding plain carbon steel with the exception that the carrier lines were finer and somewhat darker.

FIGURE 7.—*Spark stream typical of nickel steel showing the nickel spark and the forked tongue effect. Type S.A.E. 2335 c.f. (fig. 4).*

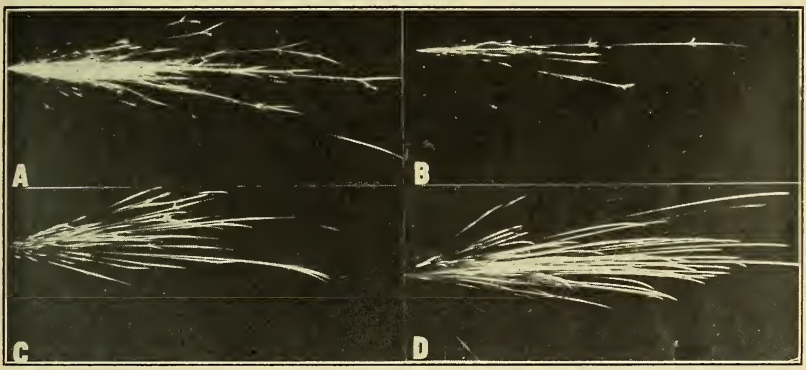

FIGURE 8.—*Typical features of spark streams of special nickel steels.*

A, Steel N1 (0.39 C, 0.62 Cr, 1.25 Ni), forked tongues; B, steel N2 (0.29 C, 3.52 Ni), nickel spark; C, steel N3 (0.03 C, 5.12 Ni), carbon burst absent, dark tips; D, invar, dark-red blunt carriers.

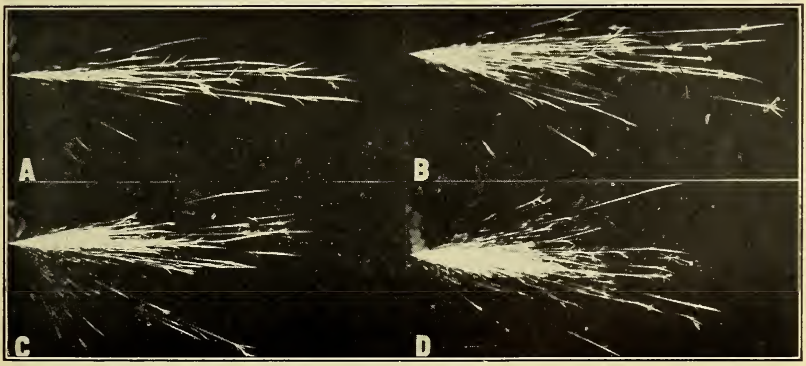

FIGURE 9.—*Typical features of spark streams of S.A.E. chromium steels.*

A, S.A.E. 5120 steel, flower bursts, slightly darker color; B, S.A.E. 5140 steel, flower bursts, more rays in burst; C, S.A.E. 5150 steel, flower bursts, more rays in bursts, fine carriers; D, S.A.E. 52100 steel, high carbon burst, fine carriers, slightly dark in color.

FIGURE 10.—*Spark stream of typical chromium steel showing the flower burst. Type S.A.E. 5140, c.f. (fig. 4).*

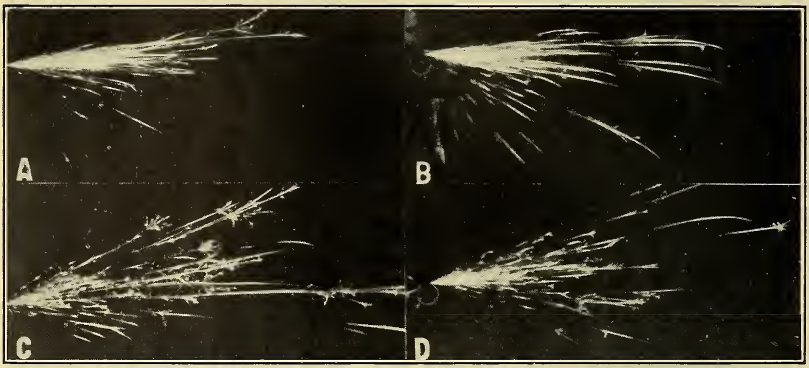

FIGURE 11.—*Typical features of spark streams of low-chromium steels.*

A, Steel C3 (0.39 C, 0.30 Cr), flower burst; B, steel C7 (0.92 C, 1.68 Cr), compact high carbon burst; C, steel C10 (0.72 C, 2.18 Cr), compact high carbon burst, fine carriers; D, steel C11 (0.90 C, 3.40 Cr), compact high carbon burst, fine carriers.

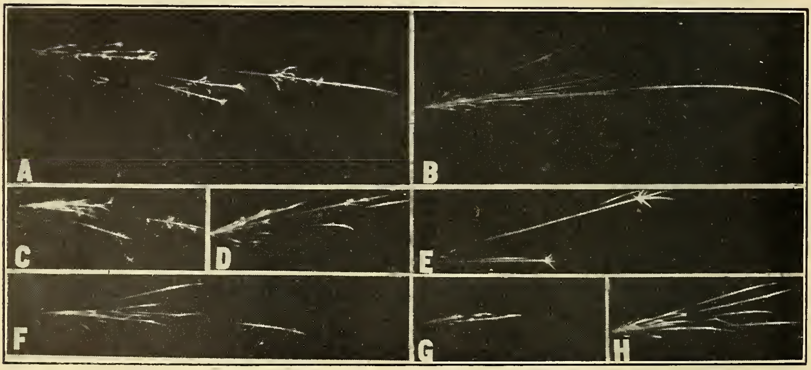

FIGURE 12.—*Typical features of spark streams of high-chromium steel.*

A, Steel C12 (0.71 C, 4.80 Cr), scant stream, typical carbon burst; B, steel C13 (0.10 C, 11.50 Cr), scant stream, disjointed red lines, suppressed carbon burst; C, steel C17 (2.25 C, 13.00 Cr), scant, short stream, occasional typical carbon burst; D, steel C18 (0.34 C, 13.00 Cr), scant, short stream, suppressed carbon burst; E, steel C23 (0.35 C, 14.36 Cr), scant, short stream, suppressed carbon burst; F, steel C25 (0.10 C, 17.00 Cr), scant, short stream, suppressed carbon burst; G, steel C26 (1.01 C, 17.00 Cr), scant, very short stream, carbon burst suppressed; H, steel C30 (0.25 C, 25.00 Cr), scant, very short stream, carbon burst suppressed.

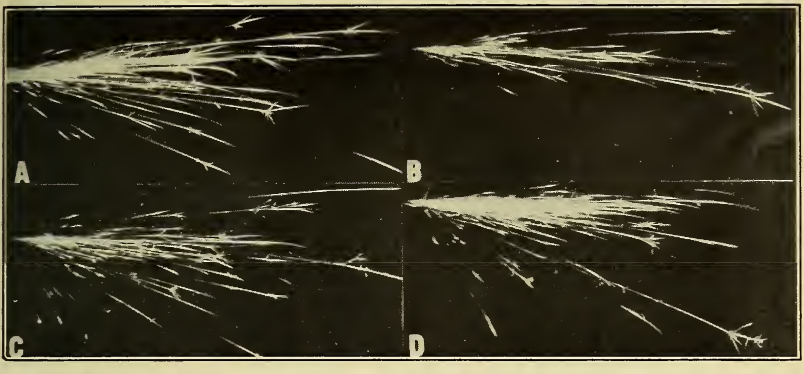

FIGURE 13.—*Typical features of spark streams of S.A.E. chromium-nickel steels.*

A, S.A.E. 3115 steel, nickel spark, flower burst, c.f. (fig. 1C); B, S.A.E. 3120 steel, flower burst, c.f. (fig. 1D); C, S.A.E. 3130 steel, flower burst, c.f. (fig. 3A); D, S.A.E. 3140 steel, flower burst, c.f. (fig. 3B).

FIGURE 14.—*Spark stream typical of chromium-nickel steel. Type S.A.E. 3130, c.f. (fig. 4).*

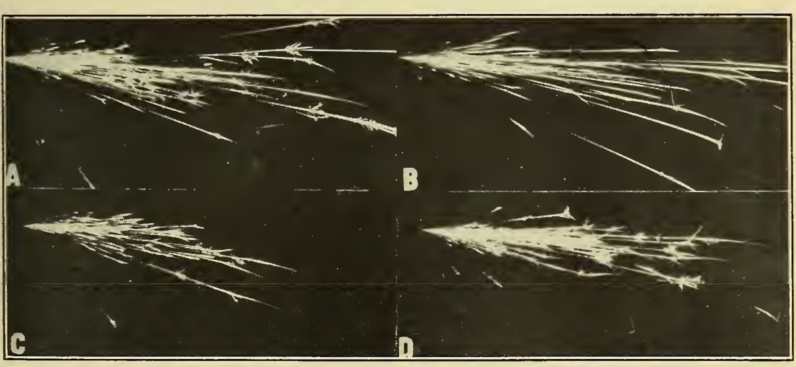

FIGURE 15.—*Typical feature of spark streams of S.A.E. chromium-nickel steels.*

A, S.A.E. 3240 steel, flower bursts; B, S.A.E. 3312 steel, small bursts, nickel spark, dark stream; C, S.A.E. 3340 steel, flower burst, dark stream; D, S.A.E. 3435 steel, dark streams, flower burst.

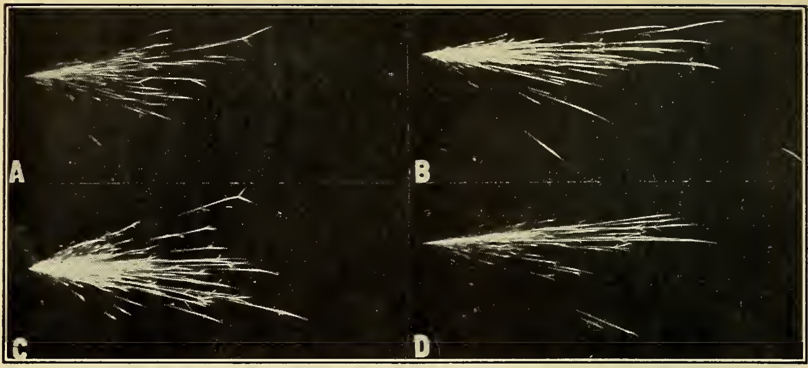

FIGURE 16.—*Typical features of spark stream of special chromium-nickel steels.*

A, Steel NC1 (0.19 C, 1.35 Ni, 0.51 Cr), flower bursts; B, steel NC4 (0.48 C, 1.65 Ni, 1.04 Cr); C, steel NC5 (0.28 C, 2.50 Ni, 2.50 Cr), flower burst; D, steel NC7 (0.24 C, 5.80 Mn, 10.04 Ni, 1.78 Cr), flower burst, jackets.

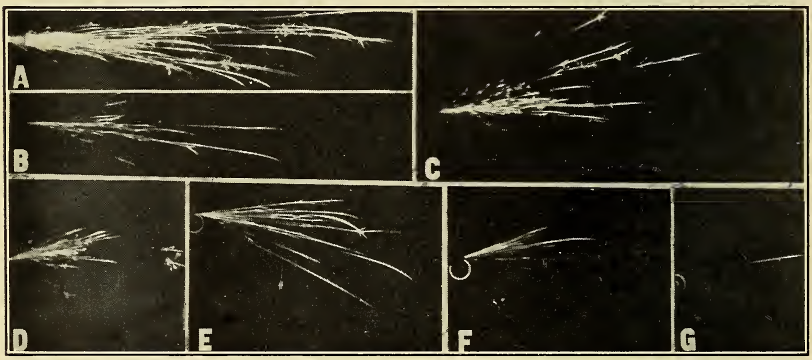

FIGURE 17.—*Typical features of spark streams of special chromium-nickel and chromium-vanadium steels.*

A, Steel V1 (0.45 C, 0.90 Cr, 0.20–0.25 V), carbon burst; B, steel V4 (0.40 C, 13.00 Cr, 1.00 V), no spearpoints, suppressed carbon burst; C, steel V2 (0.94 C, 1.44 Cr, 0.20 V), carbon burst; D, steel V3 (2.20 C, 12.00 Cr, 0.75 V), short scant stream; E, steel NC8 (0.15 C, 11.80 Ni, 13.00 Cr), banded wheel, scant stream, red disjointed lines, spearpoints; F, steel NC16 (0.10 C, 8.26 Ni, 18.82 Cr), banded wheel, scant stream, red disjointed lines, some spearpoints; G, steel NC20 (0.15 C, 11.00 Ni, 21.00 Cr), banded wheel, single carrier stream.

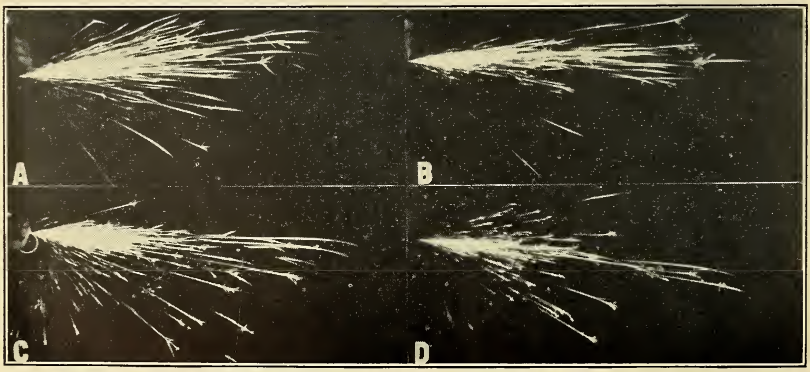

FIGURE 18.—*Typical features of spark streams of S.A.E. chromium-vanadium steels.*

A, S.A.E. 6120 steel, flower bursts, occasional spearpoint; B, S.A.E. 6140 steel, flower burst; C, S.A.E., 6150 steel, carbon burst; D, S.A.E. 6195 steel, carbon burst.

Only by very close examination could the flower bursts, which seem to be characteristic of chromium steels of lower carbon content, be detected in the spark stream.

Many of the special alloys studied (table 3) had high carbon content. All the steels (except C 3) containing less than 5 percent chromium contained at least 0.70 percent carbon. The spark streams produced were all typical of the carbon contents. The steels of highest chromium content were of the stainless type. A steel of this kind with a low carbon content gave a very short spark stream in which tongues showed a tendency to be tipped with spearpoints as is shown in the photographs. The periphery of the rotating abrasive wheel was brightly banded. A short, dark spark stream was obtained with the high chromium steels of higher carbon content. Although the stream was greatly suppressed, the carbon bursts were full and typical of the high carbon content. In the steels of highest chromium content (15 to 30 percent chromium) the spark stream was inconspicuous, and was entirely lacking in the steel containing about 30 percent chromium or more.

TABLE 4.—*Composition of nickel-chromium steels studied*

Designation	C	Mn	P	S	Si	Ni	Cr	Fig. no.
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
S.A.E. 3115	0.15	0.46	0.017	0.024	0.20	1.31	0.60	13
S.A.E. 3120	.19	.47	.020	.029	.18	1.26	.62	13
S.A.E. 3130	.32	.46	.019	.031	.23	1.12	.63	13–14
S.A.E. 3140	.39	.62	.033	.036	.26	1.18	.62	13
S.A.E. 3240	.41	.44	.028	.022	.26	1.73	1.10	15
S.A.E. 3312	.10	.44	.019	.023	.22	4.14	1.49	15
S.A.E. 3340	.40	.50	.021	.021	.23	3.39	1.56	15
S.A.E. 3435	.36	.45	.028	.023	.22	4.14	1.49	15
NC 1	.19	.52	.012	.024	.15	1.35	.51	16
NC 4	.48	.46	.015	.009	.18	1.65	1.04	16
NC 5	.28					2.50	2.50	16
NC 7	.24	5.80				10.04	1.78	16
NC 8	.15	.50			.45	11.80	13.00	17
NC 15	.14	.70	.009	.017	2.02	8.42	18.06	
NC 16	.10	.34	.019	.023	.49	8.26	18.82	17
NC 20	.15	.60			.95	11.00	21.00	17

4. NICKEL-CHROMIUM STEELS

In table 4 are the compositions of the nickel-chromium steels whose spark streams are illustrated in figures 13 to 17 inclusive. The spark streams shown (figs. 13 and 15) are typical of the entire group of simple nickel-chromium steels examined. Steels of many compositions in addition to those listed in table 4 were studied and their spark streams compared with those selected as typical. The additional compositions included S.A.E. 3125, 3135, 3235, and 3250 steels as well as 24 special nickel-chromium steels. The carbon content of these special steels ranged from 0.8 to 2 percent. The maximum alloy content was as follows: Manganese, 1.28 percent; nickel, 35 percent; chromium, 25 percent; and silicon, 2.8 percent. One composition contained 0.2 percent molybdenum; another, 1.7 percent vanadium; and a third, 1.35 percent copper.

The combination of the two alloying elements, nickel and chromium, resulted in a suppression of the nickel effects and a strengthening of the chromium effects. In the S.A.E. steels the spark streams were similar to those of the corresponding carbon chromium steels already discussed, though slightly darker in color. In the low-carbon steels of this type the nickel spark was detected but not in steels containing 0.30 percent carbon or more. As the combined nickel-chromium content was increased, a tendency for the stream to darken was observed.

Spark streams typical of a group of special alloy steels (NC 1 to NC 20, table 4) are shown in figures 16 and 17. It was found that steels of low nickel-chromium content produced spark streams in which the bursts were well developed. In steels of higher nickel-chromium content, 12 percent or more chromium, the carriers were darkened and the stream scanty. Only a few bright carriers, many of which were tipped with a spear point, were present in the spark stream, and it consisted largely of dull red streaks. In the steels high in both carbon and nickel-chromium content the stream was short, scanty, and dark, with bursts characteristic of the high carbon content. As in the high chromium steels, the periphery of the wheel was brightly banded.

In general, as the nickel-chromium content increased the character of the spark stream changed from bright carrier lines to dull red, disjointed lines. A high nickel-chromium content tended to suppress the stream entirely. This result was obtained when the combined percentages of nickel and chromium totaled approximately 30 percent. Steel NC 7, relatively high in manganese, gave a bright stream; evidently the manganese counteracted the effect of the chromium. Steel NC 15, containing 2 percent silicon, gave a stream of disjointed red lines.

Table 5.—*Composition of chromium-vanadium steels studied*

Designation	C	Mn	P	S	Si	Ni	Cr	V	Fig. no.
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
S.A.E. 6120	0.21	0.70	0.019	0.034	0.45	0.18	0.73	0.13	18
S.A.E. 6140	.45	.66	.020	.011	.23	----	.88	.16	18
S.A.E. 6150	.50	.50	.040	.040	----	----	.90	.17	18
S.A.E. 6195	1.06	.34	.017	.022	.27	.12	1.44	.17	18
V 1	.45– .50	.45– .55	.025	.025	.25– .35	----	.90	.20– .25	17
V 2	.94	.34	.017	.009	.26	.09	1.44	.20	17
V 3	2.20	----	----	----	----	----	12.00	.75	17
V 4	.40	----	----	----	----	----	13.00	1.00	17

5. CHROMIUM-VANADIUM STEELS

The spark streams of all the S.A.E. steels (including 6125, 6130, 6135, and 6145 not listed in table 5 and the special steels studied (table 5)) were characterized by the chromium content rather than the vanadium (figs. 17, 18, and 19). Vanadium as an alloying element caused spear points to appear in the stream at the terminals of some of the carrier lines. This phenomenon, however, could not be depended upon as a reliable means of identification, although it is useful as an aid.

6. MOLYBDENUM STEELS

In addition to the molybdenum steels listed in table 6, spark streams were studied of compositions corresponding to S.A.E. steel 4140, and the so-called "4130X", as well as of seven special molybdenum steels containing 0.15 to 0.40 percent carbon, 0.15 to 3.6 percent nickel, 0.04 to 0.9 percent chromium, and 0.25 to 0.45 percent molybdenum.

FIGURE 19.—*Spark stream typical of chromium-vanadium steel. Type S.A.E. 6130 steel, c.f. (fig. 4).*

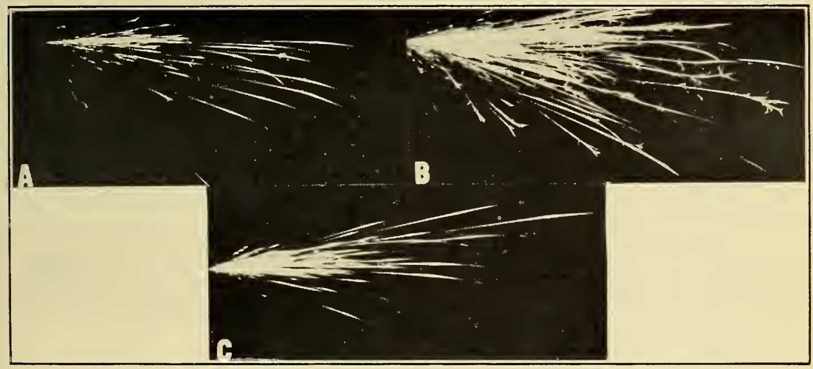

FIGURE 20.—*Typical features of spark streams of S.A.E. molybdenum steels.*

A, S.A.E. 4130 steel, spearpoints; B, S.A.E. 4150 steel, spearpoints, compact burst; C, S.A.E. 4615 steel, spearpoints, nickel spark, suppressed carbon burst.

FIGURE 21.—*Spark stream typical of molybdenum steel, showing spearpoints. Type S.A.E. 4130, c.f. (fig. 4).*

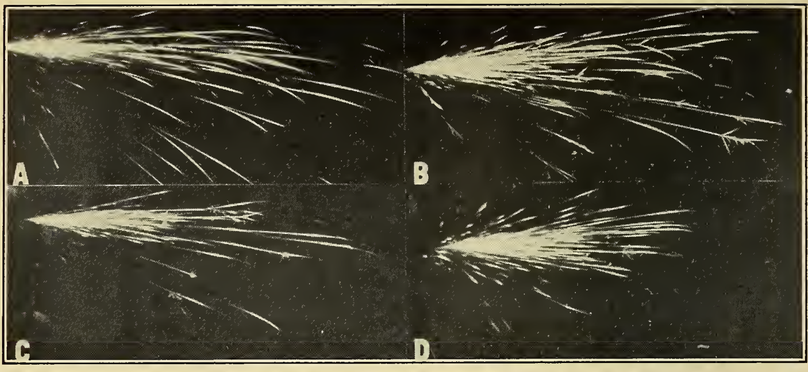

FIGURE 22.—*Typical features of spark streams of special molybdenum steels.*

A, 0.15 C Mn-Mo steel, suppressed carbon burst, spearpoints; B, steel M1 (0.20 C, 3.64 Ni, 0.07 Mo), spearpoint; C, steel M11 (0.53 C, 1.02 Si, 0.40 Mo), spearpoint, suppressed carbon burst; D, steel M16 (0.71 C, 5.75 Mo), spearpoints, suppressed carbon burst.

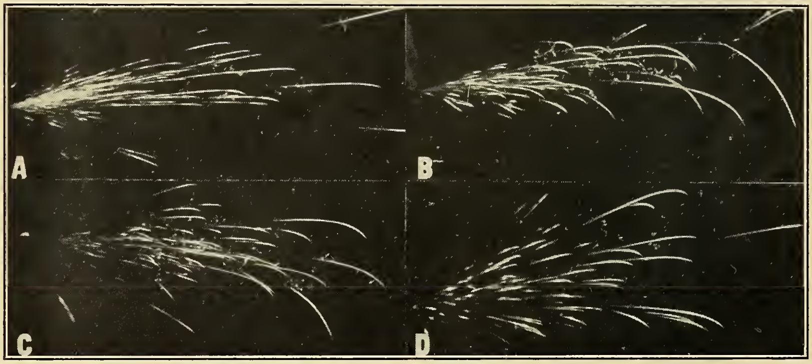

FIGURE 23.—*Typical features of spark streams of low-tungsten steels.*

A, Steel W1 (0.85 C, 0.45 W), heavy tips, suppressed carbon burst, dark carriers; B, steel W5 (1.25 C, 1.00 W), downward curve of tongues, heavy-tip wild bursts, suppressed carbon burst, red color; C, steel W10 (1.20 C, 1.60 W), downward curve of tongues, heavy tips, dark-red color, secondary carriers very dark, carbon burst suppressed; D, steel W12 (0.50 C, 2.00 W), carriers very dark, tongues bright, downward curve to tongues, suppressed carbon burst, very dark secondary carriers, bright buds and stars.

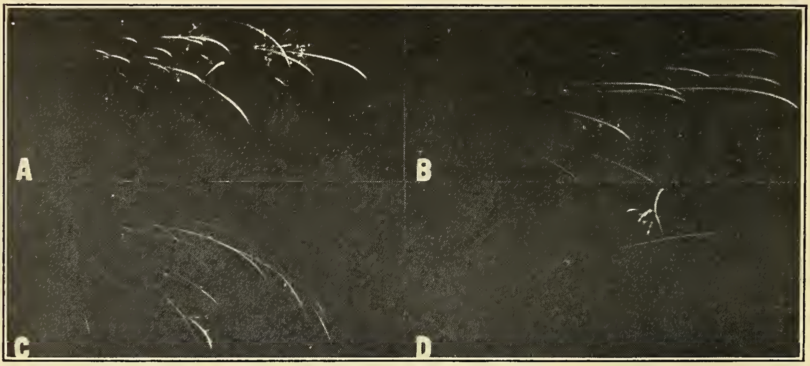

FIGURE 24.—*Typical feature of spark streams of high-tungsten steels.*

A, Steel W22 (1.54 C, 1.00 Cr, 4.98 W), dark-red carriers, suppressed bursts, very dark secondary carriers, heavy tips, curved downward; B, steel W27 (0.68 C, 4.47 Cr, 2.20 V, 14.57 W), dark-red disjointed lines with an occasional swelling forming a tongue; C, steel W29 (0.73 C, 4.50 Cr, 1.22 V, 17.50 W), dark-red disjointed lines with an occasional carbon burst; D, same as C showing a very good example of a wild burst characteristic of tungsten.

TABLE 6.—*Composition of molybdenum steels studied*

Designation	C	Mn	P	S	Si	Ni	Cr	Mo	V	Cu	Fig. no.
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
S.A.E. 4130	0.29	0.62	0.019	0.031	0.21		0.69	0.22			20, 21
S.A.E. 4150	.47	.77	.022	.022	.23		.97	.19			20
S.A.E. 4615	.15	.62	.017	.024	.20	1.82	.30	.23			20
M 1	.20	.50	.011	.024	.10	3.64	.11	.07			22
M 2	.78	1.74	.016	.010	.47	.06		.08	0.22		
M 3	.14	.94			.66	19.75	25.48	.16			
M 9	1.00	.25			.25		1.00	.35			
M 11	.53	.41	.018	.015	1.02	.14	.13	.40			22
M 13	1.42	.25	.013	.034	.50		4.20	.78		0.37	
M 14	1.50					12.00		1.00			
M 15	.06	.47	.016	.018	.42	9.84	19.65	3.07		.11	
M 16	.71	.28			.28			5.75			22

All of the molybdenum steels studied showed a peculiar flare at the end of each ray. This was completely detached from the ray tip and is referred to here as the "spearpoint" (figs. 20 and 22). The color of the spearpoint varies with the steel. In the S.A.E. steels the spearpoint appeared in all cases in which the carbon content did not exceed 0.50 percent. The identification of such steels is simple and sure.

In the chromium-molybdenum steels the flower-like burst characteristic of chromium was evident. In other cases the carbon content appeared to be the factor which determined the predominating characteristic of the spark.

Of the 16 special molybdenum steels examined, all but 6 (M 2, M 3, M 9, M 13, M 14, M 15) showed the characteristic spearpoints in the spark stream. The failure of these six to show this feature can be attributed either to excess chromium, nickel, or carbon. The influence of carbon on the spearpoint is dependent on the molybdenum content; for example, in the steel (M 2) containing 0.78 percent carbon and 0.08 percent molybdenum, no spearpoints were observed in the spark stream, whereas steel M 16 (0.71 percent carbon and 5.75 percent molybdenum), showed spearpoints in the spark stream as did also steel M 1, containing 0.20 percent carbon and 0.07 percent molybdenum.

TABLE 7.—*Composition of tungsten steels studied*

Designation	C	Mn	Si	Cr	Ni	V	W	Fig. no.
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
W 1	0.85		0.25	1.55			0.45	23
W 5	1.25			.20			1.00	23
W 10	1.20			.40		0.10	1.60	23
W 12	.50			1.65		.25	2.00	23
W 22	1.54	0.39	.25	1.00			4.98	24
W 27	.68	.24		4.17	0.28	2.20	14.57	24
W 29	.73	.27	.23	4.15	.02	1.22	17.50	24

7. TUNGSTEN STEELS

Table 7 lists the compositions of the tungsten steels which produced the representative spark streams illustrated in figures 23 and 24. Thirty additional steels containing tungsten were also studied, some

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containing 0.5 to 2.5 percent tungsten, and manganese up to 1.5 percent; some with 1 to 2 percent tungsten and 2 percent carbon and others with 1 to 4 percent tungsten and 10 to 20 percent chromium. A special tungsten alloy examined contained 62 percent nickel, 12.5 percent chromium, 2.57 percent tungsten, 1.5 percent manganese, and 0.29 percent carbon.

Tungsten was found to impart a very characteristic red color to the spark stream in which the main carbon bursts were suppressed and the secondary carriers which were dark and inconspicuous were tipped with buds and stars the brilliance of which depended on the carbon content. The short, stubby tongues having a pronounced downward curvature were also characteristic. The spark streams of the steels having a low alloy content were full and dark and showed the characteristics just described. In steels containing 1.50 percent tungsten or more, the intensity of the carbon burst was diminished and the stream was dark red. In the steels of 2 percent tungsten content the carbon burst was variable even in the high carbon steels, in which the burst varied from one typical of a high carbon content to one associated ordinarily with a low carbon content. The presence of chromium in amounts of approximately 1.5 percent did not appear to affect the display, but larger amounts, for example, 10.5 percent, tended to "kill" the spark stream.

An increase in tungsten content above approximately 2 percent resulted in "wild" bursts in the spark stream which were sometimes so violent that the path of the pellet was entirely changed in direction. The carriers appeared as disjointed red lines.

The presence of 5-percent tungsten caused the spark shower to decrease rapidly in volume and steels containing 5 to 15 percent tungsten seldom showed more than dull red lines, the brilliance of which apparently depended largely on the chromium present. Steels containing 20 percent tungsten or more showed almost no spark stream. The combined chromium-tungsten content necessary for the elimination of the spark stream was much lower than that of nickel and chromium for producing a similar effect, the summation being approximately 20 percent.

8. SILICON-MANGANESE STEEL

Only one steel of the silico-manganese series was examined (S.A.E. No. 9250, containing 0.52 percent carbon, 0.83 percent manganese, 2.10 percent silicon). The spark stream (fig. 25) was dark red with club-shaped tongues and the carbon bursts were suppressed. This can be attributed largely to the influence of silicon. The manganese imparted a brilliant jacket to the burst.

9. MANGANESE STEELS

All the manganese steels considered (table 8) showed heavily "jacketed" bursts in the spark stream (fig. 26). The jacket was similar to that observed in spark streams of the nickel steels, although somewhat more brilliant. The carbon burst was apparently affected very little by the presence of manganese. The stream was full and even brighter than that of a corresponding plain carbon steel.

FIGURE 25.—*Spark stream typical of silico-manganese steel, showing jacketing effect. Type S.A.E. 9250.*

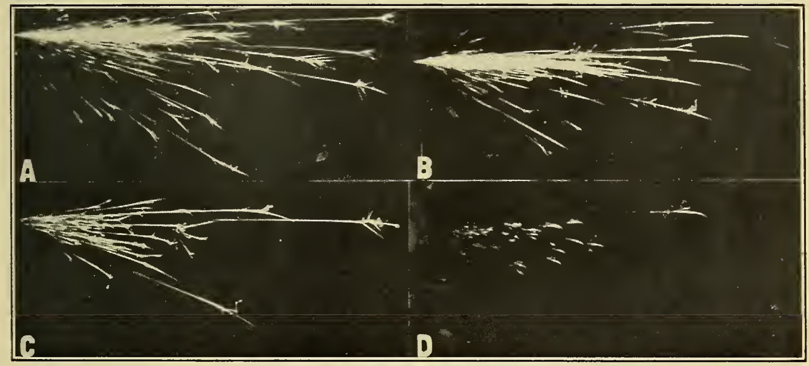


FIGURE 26.—*Typical features of spark streams of manganese steel and cast iron.*

A, Steel Mn1 (0.21 C, 1.00 Mn), jacket, compact burst; B, steel Mn5 (0.92 C, 1.60 Mn), jacket, compact burst, bright; C, steel Mn7 (1.00 C, 12.00 Mn), jacket, compact burst, bright; D, cast iron, very dark carrier, bright burst.

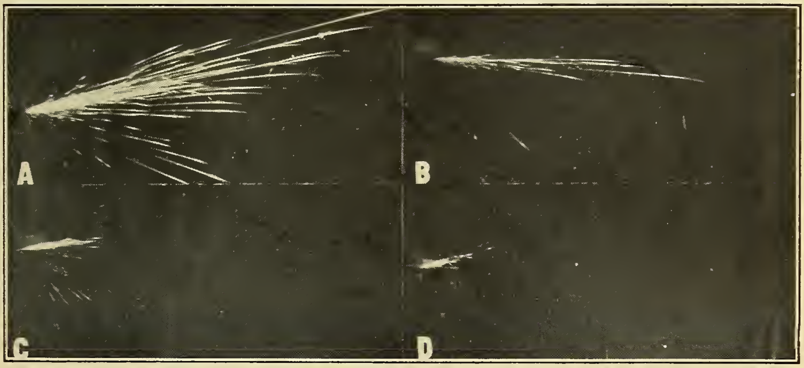


FIGURE 27.—*Spark streams showing the influence of nitriding time on type spark stream produced.*

A, Original steel, long full stream with spearpoints; B, same steel nitrided for 24 hours, stream shortened with a different burst; C, same steel nitrided for 48 hours, stream short, no burst; D, same steel nitrided for 72 hours, stream almost entirely suppressed, no burst.

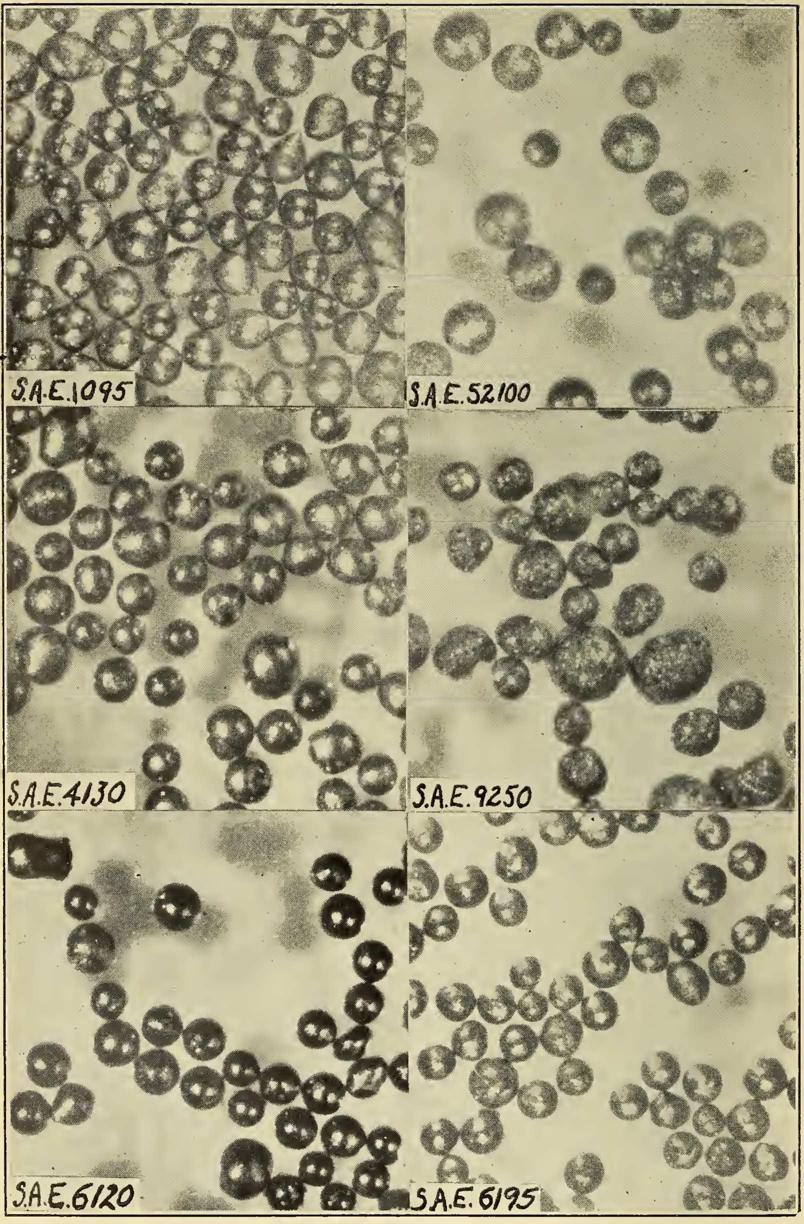


FIGURE 28.—*Typical pellet specimens* × *35.*

TABLE 8.—*Composition of manganese steels studied*

Designation	C	Mn	S	P	Si	Cr	Ni	Fig. no.
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Mn 1	0.21	1.00	0.054	0.059	0.22	0.19	0.06	26
Mn 2	.39	.95	.090	.056	.21	.25	.10	------
Mn 3	.50	1.07	.033	.018	.21	.57	.14	------
Mn 4	.35	1.50	.040	.025	.45	--------	--------	26
Mn 5	.92	1.60	.012	.024	.21	.11	.12	------
Mn 6	.45	1.89	--------	--------	--------	--------	--------	------
Mn 7	1.00	14.00	--------	--------	--------	--------	--------	26

10. CAST IRON

Four plain cast irons were studied, with chief consideration given to their combined carbon contents (table 9). No marked differences were observed in the spark streams. In general, the stream consisted of very dark carriers with a comparatively light burst (fig. 26, *D*).

TABLE 9.—*Composition of cast irons studied*

Specimen number	Total carbon	Free carbon	Combined carbon	Mn	P	S	Si	Cr
				Percent	*Percent*	*Percent*	*Percent*	*Percent*
1-55	3.31	2.94	0.19	--------	--------	--------	2.53	--------
3-56	3.39	3.11	.28	--------	--------	--------	2.51	--------
4-56	3.45	3.08	.37	--------	--------	--------	2.45	0.04
4-55	3.36	3.10	.26	0.72	0.515	0.039	2.30	.04

11. NITRIDED STEEL

A brief study of steels which has been nitrided, that is, "case hardened" by nascent nitrogen formed by the decomposition of ammonia, showed that the character of the spark stream was changed by nitriding and that this change was dependent upon the degree of nitriding. The photographs of figure 27 show the spark streams of the steel used (0.19 C, 0.38 Mn, 0.014 P, 0.012 S, 0.16 Si, 1.88 Al, 0.83 Mo) before nitriding and after 24, 48, and 72 hours nitriding, respectively. The possible usefulness of this method for determining differences in the thickness of the surface layer on nitrided steel products is apparent.

12. MISCELLANEOUS ALLOYS

A number of ferrous alloys were found to give no spark stream when tested in the ordinary manner. The compositions are shown in table 10.

TABLE 10.—*Composition of ferrous alloys showing no spark*

Manufacturer's designation	C	Mn	Si	Cr	Ni	Mo	V	W	Co
	Per-cent	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*
CN 2	------	------	------	------	------	------	------	------	------
Dreadnaught	0.68	0.27	0.30	3.48	------	------	1.03	17.08	------
G A	.55	------	------	15.00	35.00	------	------	------	------
F	.55	------	------	15.00	25.00	------	------	------	------
B 28	.66	------	------	26.00	8.00	------	------	------	------
B	1.20	------	------	20.00	8.00	------	------	------	------
C	.55	------	------	20.00	8.00	------	------	------	------
B LC	.55	------	------	20.00	8.00	------	------	------	------
N	.55	------	------	17.00	68.00	------	------	------	------
CP 12	------	------	------	------	------	------	------	------	------
V 3	.30	------	------	3.50	------	------	.50	10.00	------
Cru EX 12	.75	------	------	3.50	.50	------	1.00	18.00	------
A	.75	------	------	4.80	------	.80	.50	18.00	0.42
Cyclops B6	.68	.30	------	4.00	------	------	------	18.00	------
WL 6	.67	.50	.126	1.49	.62	------	.17	------	------
2825	.24	.35	.35	28.00	------	------	------	------	------
55	.25	.70	------	28.96	.334	------	------	------	------
44	.43	1.37	------	23.50	11.10	------	------	------	------
V 2	.70	------	------	4.00	------	------	1.00	18.00	4.50
B 1	.70	------	------	4.00	------	------	1.00	18.00	4.50
Clarite	------	------	------	------	------	------	------	------	------
Vulcan	.70	.40	.30	4.00	------	------	1.00	18.00	------
Mercury	1.54	.39	------	1.00	------	------	------	5.00	------
Rezistal 4	.20	.57	2.79	17.24	25.20	------	------	------	------
Nichrome	.20	2.00	------	16.00	60.00	------	------	------	------
Nichrome IV	.15	------	.25	19.50	77.50	------	------	------	------
RE 3	.19	.58	1.34	24.50	20.00	------	------	------	------

13. PELLET TEST

The possible identification of a steel by examination of the metal "pellets" which are formed during the spark testing of steel was first discussed by Hildorf and McCollam.[5] This test is supplementary to the spark test and not a complete one in itself. It has been found on examining the metallic "dust" from the spark stream of a steel that the individual burned particles are globules or pellets and that the pellets from one steel often differ quite characteristically from those of another kind of steel.

The "dust" from the spark streams in the foregoing examinations was collected and the spherical pellets separated from the more irregular particles by rolling on a sheet of paper. The spherical pellets were then sieved. All of the pellets which did not pass a 100-mesh screen were collected and examined under the microscope (x 35, fig. 28).

The pellets from plain carbon and nickel steels were shiny and black with indistinct patterns showing over the surface. The carbon content apparently did not affect the character of the surface of the pellet.

The pellets of chromium steels were rough and light gray in color. Those from molybdenum steel were very smooth and jet black. A scattering of elongated pear-shaped pellets was found among those collected from some vanadium steels. Silico-manganese steel produced badly blown pellets which, although spherical in shape, had holes blown entirely through them (table 11).

[5] Hildorf, W. G., and McCollam, C. H., Metal Pellets Produced by Spark Tests Used to Identify Alloy Steels, Iron Age, vol. 126, p. 1, 1930.

TABLE 11.—*Summary of pellet characteristics of S.A.E. steels*

Kind of steel	Pellet characteristics	
	Color	Shape and surface appearance
Plain carbon	Shiny black	Round and faintly patterned on a portion of the surface.
Nickel	do	Do.
Chromium	Light gray	Round and generally rough over entire surface.
Nickel-chromium	do	Do.
Chromium-vanadium	do	Round and generally rough over entire surface with a scattering of elongated pear-shaped pellets.
Molybdenum	Jet black	Round and very smooth having a tendency to be blown out on one side but still retaining round shape. An occasional elongated pear-shaped pellet appears.
Silicon-manganese	Dull black	Round but badly blown. Some holes entirely through the pellets.

IV. SUMMARY

1. SORTING CHART FOR S.A.E. STEELS

The data obtained in the study of the carbon and alloy steels, including S.A.E. steels, have been used as the basis of a sorting chart (fig. 29). In assembling this chart only the outstanding characteristics which can be depended upon as a basis of sorting groups of steels of known composition have been used. The character of the carbon burst has been used as much as possible. Cases where sorting is possible but may be difficult have been designated as "*D*". In all cases labeled "*Y*", there should be no difficulty in sorting the two steels if reasonable care is used. The alloy characteristics listed at the end of the chart apply only in a general way. They are the most probable characteristics, in addition to the carbon burst.

Half of this chart is devoted to the possible usefulness of the pellet test in the sorting of steels. It will be seen that in a number of cases the combination of the two tests will give conclusive evidence of the nature of the steel, whereas the indications of the spark test alone might be doubtful.

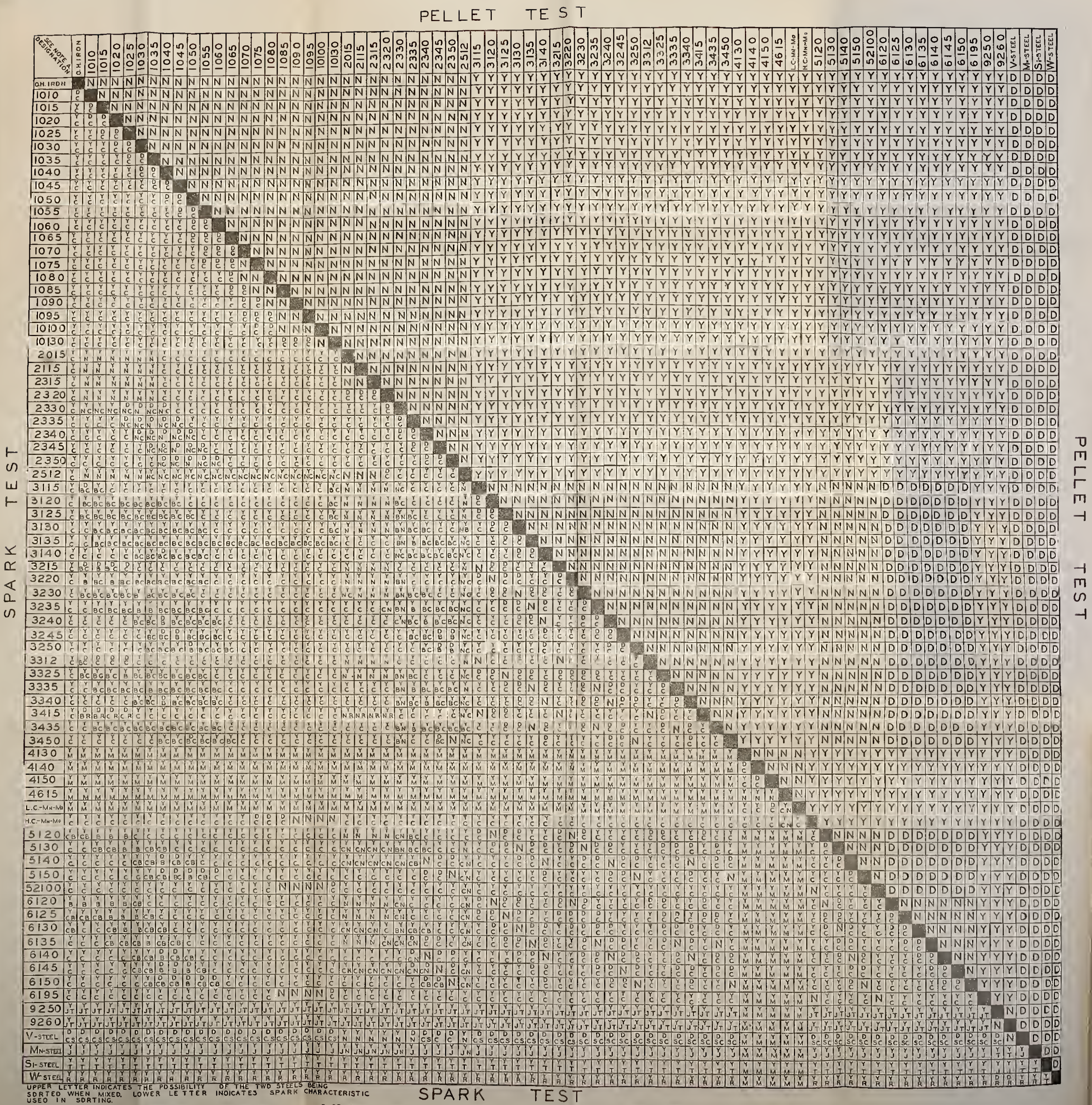
In general, it can be shown that out of possibly over 2,500 combinations of any two of the steels shown in this chart the identity of over 2,100 can be established. In addition, it may be possible to establish the identity in 390 additional combinations (listed under doubtful) and in the case of only 83 combinations are the results of the test entirely negative. The characteristics upon which this chart is based refer only to spark streams produced by the grinding wheel described and may not always apply if a distinctly different testing procedure is followed.

2. CONCLUSIONS

The spark test may be depended upon as a means for classifying steels into groups of similar composition, but cannot be successfully used as a means of identifying an unknown steel.

The spark test is probably the most rapid method for sorting mixed lots of steels containing two or three different compositions.

Definite spark stream characteristics were found in the steels studied for each of the alloying constituents; chromium, manganese, molybdenum, nickel, tungsten, and vanadium. The "carbon burst", however, is the most prominent feature of the spark stream.



UPPER LETTER INDICATES THE POSSIBILITY OF THE TWO STEELS BEING SORTED WHEN MIXED. LOWER LETTER INDICATES SPARK CHARACTERISTIC USED IN SORTING.

Y-YES THE TWO STEELS INDICATED MAY BE SORTED.

N-NO THE TWO STEELS INDICATED CAN NOT BE SORTED.

D-MAY BE SORTED WITH DIFFICULTY.

A- NUMERICAL DESIGNATIONS ARE BASED ON THE S.A.E NUMBERING SYSTEM. NOT ALL STEELS SO DESIGNATED ARE OFFICIAL S.A.E COMPOSITION.

B-CR BURST EFFECT

R-COLOR

T- SI EFFECT ON TONGUE

J-JACKET.

C-CARBON BURST

M-DETACHED SPEARPOINT

N-NI SPARK

S-SPEARPOINT (NOT DETACHED)

SORTING CHARACTERISTICS OF STEEL FOR THE SPARK AND PELLET TESTS

FIGURE 29.—*Spark stream sorting characteristics*

The presence of chromium, molybdenum, silicon, or vanadium in some cases imparts characteristics to the fused particles or pellets resulting from the spark test which may be used in the identification of such steels.

V. ACKNOWLEDGMENTS

The author gratefully acknowledges to the steel companies the aid given in furnishing the various brands of special alloys; to Dr. V. Homerberg, of the Massachusetts Institute of Technology, in furnishing and nitriding the nitrided specimens, and to W. S. Rice, of the Bureau of Standards, for aid and advice in photographing the spark streams. Special acknowledgment is made of the cooperation and help given by C. H. McCollum, of the Timken Steel and Tube Co.

WASHINGTON, August 1, 1933.