GENERAL SURVEY OF THE UTILITY OF THE SPARK TEST AS APPLIED TO COMMERCIAL STEELS

THESIS FOR DEGREE OF METALLURGICAL ENGINEER

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by

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Introduction

The difference in sparks produced by applying steels of varying carbon contents against a revolving abrasive wheel was first described in 1804 by Jacques de Manson.

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de Manson, Jacques, Traité du Fer et de l'Acier, Paris, 290 pp., 1804.

Since then little tabulated information has been published. With one exception such records depend on written description or hand drawings to record this phenomenon. It is the purpose of this paper which summarizes results of an intensive study of this phenomenon, to emphasize points often overlooked in its use, to present some new aspects hitherto unavailable in the literature and to present photographs of representative spark streams.

Uses of Spark Testing

Contrary to general opinion, the steel chemist need fear no competition from the spark test, but instead, the spark test will prove to be one of his best tools if properly applied.

The spark test has often fallen from grace due to the fact that its limitations were not considered. With only a general idea of the spark test available, it has been misapplied causing a general distrust for its value to arise.

The identification of a steel to be of a definite chemical composition is only for a chemical laboratory to determine. With the use of standards it is possible to determine the approximate carbon content of a plain carbon steel. But for accurate work, this is not recommended, such information being available only through the medium of a chemical analysis.

The presence of special alloying elements under certain conditions may be hazarded at.

Obtaining such information as thus outlined by means of the spark test may be useful for the small shop, where no chemist is available and only when such information may be of help but no great importance in the finished product.

The real application of the spark test comes in the sorting of large lots of mixed steels and as an inspection method for detecting foreign steel in a lot of steel products of uniform chemical composition.

This application of the spark test takes it out of the field of competition with the chemical laboratory and places it in a field of application where it is an outstanding test and has no near competitor.

Likely the most outstanding applications of this test are in cases where the chemical composition varies widely such as high and low-carbon steels which can also be sorted by hardness. In such cases the mixtures more likely to occur are of heat-treated material where the hardness method requires annealing and removal of scale. The spark test is not limited by either scale, heat treatment or shape of surface to be tested. Care must be taken in testing heat-treated material in that decarburized surfaces will give a false carbon spark and must be ground through to get the true carbon spark.

It cannot be over emphasized that the future of the spark test lies in the field of sorting mix-ups and as an inspection method. Let the past experience in the field of identification of unknown specimens be a warning that all unknown steel must be identified by the ordinary chemical analysis.

Equipment

The equipment is relatively simple. A small (1/8 horsepower) motor, weighing about 8 pounds, operating at (a shaft speed of) 15,000 r.p.m. is used (I J G Dumore). An abrasive wheel of alundum, 1-1/4 inches in diameter and 3/8 inch thick, is mounted on the shaft. The wheel has a peripheral speed of about 5,000 feet per minute.

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 color to relieve the eye strain to the operator and as light as possible so as not to blot out the characteristics of the stream.

Two types of glass have been used with success: An ordinary light cobalt blue glass which transmits between 35 to 40 per cent sunlight or an American Optical Company safety goggle, Saniglass B, Superamorplate Calobar (the light or dark shade may be used).

Photography

It has been conceded by the advocates of the spark test that any written description of this phenomenon is sadly lacking due to insufficient mechanical illustrations of the phenomenon. Most human eyes see the streams slightly different, making it difficult for two investigators to agree on the smaller details of the stream.

The efforts to record photographically the spark stream have been doomed with failure due to lack of detail.

E. Pitois is the only investigator who has published

E. Pitois and J. D. Gat, Sparking of Steel. Chemical Publishing Company, 1929.

any photographic records of spark streams. His photographs are quite satisfactory but do not cover a very large field.

For this investigation both a movie camera and a still camera were tried. Either may be used with equal success for such reproductions as are shown in this paper.

It was found necessary to use a fast lens and a fast panchromatic film. Due to the fact that the obtaining of a good photograph is more a matter of chance (which increases with the speed of the lens and the film) than of skill, a movie camera was used because more individual records could be made with greater ease and speed giving a larger variety of photographic records to choose from.

Rapid exposures are out of the question as it is necessary to record the entire visible trajectory of each particle. Short-time exposures were made against a dark background to allow the stream to expose itself.

Nomenclature of Spark Trajectory

In describing spark streams various investigators use different terms. To make it easier to follow this description, a brief outline of the terms used herein is presented.

The trajectory is the entire path traveled by a single particle of steel and consists of two parts, the visible and invisible trajectory. The particle is the small piece of steel removed from the steel by the abrasive wheel. The pellet is the particle after it has traversed the visible trajectory. That part of the trajectory preceding the actual burst is known as the carrier line, this often has small swellings on it known as knobs. Usually the actual burst is preceded by small hair-like projections known as sprigs, and small bursts called preliminary bursts. The final burst is the main burst being the most complicated. The tongue is the main ray of this burst usually following the path of the trajectory. A ray is really a swollen sprig, brilliant in color as compared with the rest of the stream. Its shape is long, swollen in the center and coming to a sharp tip at the end, referred to as the tip of the ray. In the case of some alloys the carrier line apparently swells before actually bursting. This effect is called a jacket, always appearing at the base of the main burst. The main burst is of two types, the "series burst", where the burst is distributed along the trajectory and the "flower burst" which is compact and takes place at a point on the trajectory. The analysis of a burst is the key to the carbon content, the first step is the sprig and ray bursts,as the carbon content increases the following develop in order named, buds which are little ball-like tips appearing on the sprigs. The "bud-tipped" sprigs are called secondary carriers. These buds burst to give secondary bursts or stars. The sprigs of the secondary bursts are often "bud-tipped" and so become tertiary carriers; the buds of secondary bursts may burst to give tertiary bursts or secondary stars. Certain alloys cause the tip of the rays to enlarge forming a shape:- enlarged and blunt at the base and pointed at the tip called spear points. This entire display is known as the spark stream or shower.

The plain carbon steels are studied in sets of similar showers. These sets are known as brackets. There are three brackets: the lower carbon; ingot iron to S.A.E. 1035, medium carbon; S.A.E. 1035 to S.A.E. 1070 and the high carbon S.A.E. 1070, up.

Theory of Spark Stream

The spark s tream, as produced by the contact of steel with a high speed grinding wheel, apparently is caused by oxidation of the carbon. When the steel is placed against a high-speed grinding wheel small particles are torn off. The work done by the wheel in removing these particles causes their temperature to rise. The surface of these particles is clean and unoxidized but as they are thrown into the atmosphere they rapidly oxidize at the surface. The heat of this oxidation added to the heat resulting from the work done on the particles in tearing them from the specimen is sufficient to cause part of these particles to become plastic. This bit of metal by virtue of its motion and surface tension tends to form a sphere. The surface oxides may diffuse into the molten particle and form CO and CO_2. The spheres when molten within are still encased in a scale of non-volatile (at this temperature) oxides. The scale formed on a plain carbon steel is not of a tenacious character and is easily flaked off.

The gas developed within the molten particle makes its escape through this easily fractured skin. This gives rise to the 'series' burst and gives a comparatively smooth pellet which is slightly patterned on the surface. Different alloying elements may change the characteristics of this surface oxide film in such a manner as to give the various spark characteristics.

The spark stream itself consists of a multitude of trajectories and the carrier lines preceding the bursts are illuminated by the preheating effect. As the carbon content increases the number and intensity of these carbon bursts increase.

Method of Study

To satisfactorily carry out a study of a spark stream the trajectory must be divided into four sectors. The first sector is located directly off the abrasive wheel. The second sector covers the dense area of the stream between the first sector and the actual carbon burst. The third sector takes in the carbon burst to the end of the visible trajectory. The fourth sector consists of the invisible portion of the trajectory.

In the first sector two characteristics appear. Some steels give a practically colorless stream in this portion of the trajectory, while others very from a very dull red to a white. The second characteristic is the nickel spark. This appears as an oblong flare in the stream and is very blunt at the ends. Due to the fact that it is quite questionable as to what position the nickel spark occupies on the trajectory, it is well to bear in mind that a sector refers to the whole stream in general although it is necessary to define the sectors as to the general position on the trajectory.

In the second sector but one characteristic is found. It is here that the color of the stream is observed.

The third sector is rich in alloy characteristics. It is in this sector that the characteristics of chromium, molybdenum, manganese, carbon, sulphur, nickel, vanadium, tungsten and silicon are best observed.

The fourth sector gives the pellets,which although a part of the spark stream,may be used as a separate test. Here, chromium, vanadium, molybdenum and high alloy contents may be detected.

Before reviewing the alloy characteristics it is best to state that this paper introduces two distinct types of carbon bursts on which the findings of this investigation are based. These are the series burst and the flower burst, which have been described.

Plain carbon steels (Table 1)

It is in the third sector of the stream the carbon burst is best observed. The most simple stream is that produced by ingot iron (commercially pure iron). This

Table 1 - Chemical Analyses of Plain Carbon Steels Studied.

S.A.E. Number	C	Mn	P	S	Ni	Cr	Si
Ingot Iron	.01	.003	.02	.020	.02	.01	.01
1010	.09	.30	.011	.026	.12	.02	.02
1015	.16	.51	.017	.026	.20	.06	.15
1020	.20	.43	.006	.041	.008	.008	---
1025	.23	.51	.008	.025	--	.01	.01
1030	.32	.53	.01	.036	--	---	.064
1035	.34	.38	.037	.019	.14	.10	.18
1040	.42	.67	.044	.036	.18	.05	.22
1045	.44	.68	.016	.025	.27	.06	.23
1050	.46	.57	.036	.042	--	---	.20
1060	.59	.40	.017	.027	--	.05	.05
1070	.70	.23	.023	.011	--	.03	.23
1080	.76	.50	.028	.026	.23	.28	.28
1090	.96	.29	.023	.02	--	---	.18
10100	1.06	.24	.014	.016	--	---	.18
10110	1.12	.23	.019	.013	--	.06	.23
10120	1.22	.22	.015	.016	--	---	.25
10130	1.29	.23	.017	.017	--	.05	.23

stream is comparatively full, but due to lack of carbon bursts it is not very showy. The carrier in the first sector is a very dull red but brightens as it enters the second sector and continues to brighten and widen throughout this sector. Due to the very low carbon content the burst consists almost entirely of a swelling of the carrier line to form what might be called a tongue. Very few actual carbon bursts can be seen in this stream. These few bursts consist of only two or three fine short sprigs at the base (wheel end) of the tongue. Such bursts are difficult to see and still more difficult to photograph. Only one such burst is shown in the photograph (Fig. 1A). The larger and more distinct carriers are dull red-tipped, and may be easily confused with the spearpoint type. A suggestion of this may be observed on the lower (long) carrier in the photograph. This tip should not be confused with the spearpoint type as a close examination will prove it distinctly different.

The stream brightens with a slight increase in the carbon content so that in the S.A.E. 1010 steel (Fig. 1) the tips conform more to the color of the rays. The effect of the increased carbon content is apparent in the burst, which consists of two or three sprigs often of the magnitude of rays which due to the low carbon content are grouped.

The true plain carbon burst first appears between 0.10 per cent carbon and 0.15 per cent carbon. S.A.E. 1015 steel (Fig. 1) shows the true series burst. This stream is similar in color to S.A.E. 1010 steel. Scattering preliminary bursts appear along the carrier. The sprigs in general are undecorated. An occasional bud appears and at times a star is observed, but these phenomena are not common. This steel has a completely illuminated stream in all three sectors. A phenomenon often observed in this steel is that of the split tongue which is more commonly found in nickel steels.

In S.A.E. 1020 steel (Fig. 1) these characteristics are slightly emphasized, the series burst being longer and the buds and stars appearing more frequently. The appearance of the split tongue is more or less a common factor in the plain carbon steels, the frequency of its appearance being only slightly increased with an increase of carbon content in the first two brackets and decreasing in the last or high carbon bracket.

The increase of carbon content tends to complicate and lengthen the bursts. In S.A.E. 1030 steel (Fig. 2A) the stream commences to lighten noticeably. Comparing the photographs of S. A. E. 1015 and 1020 steel

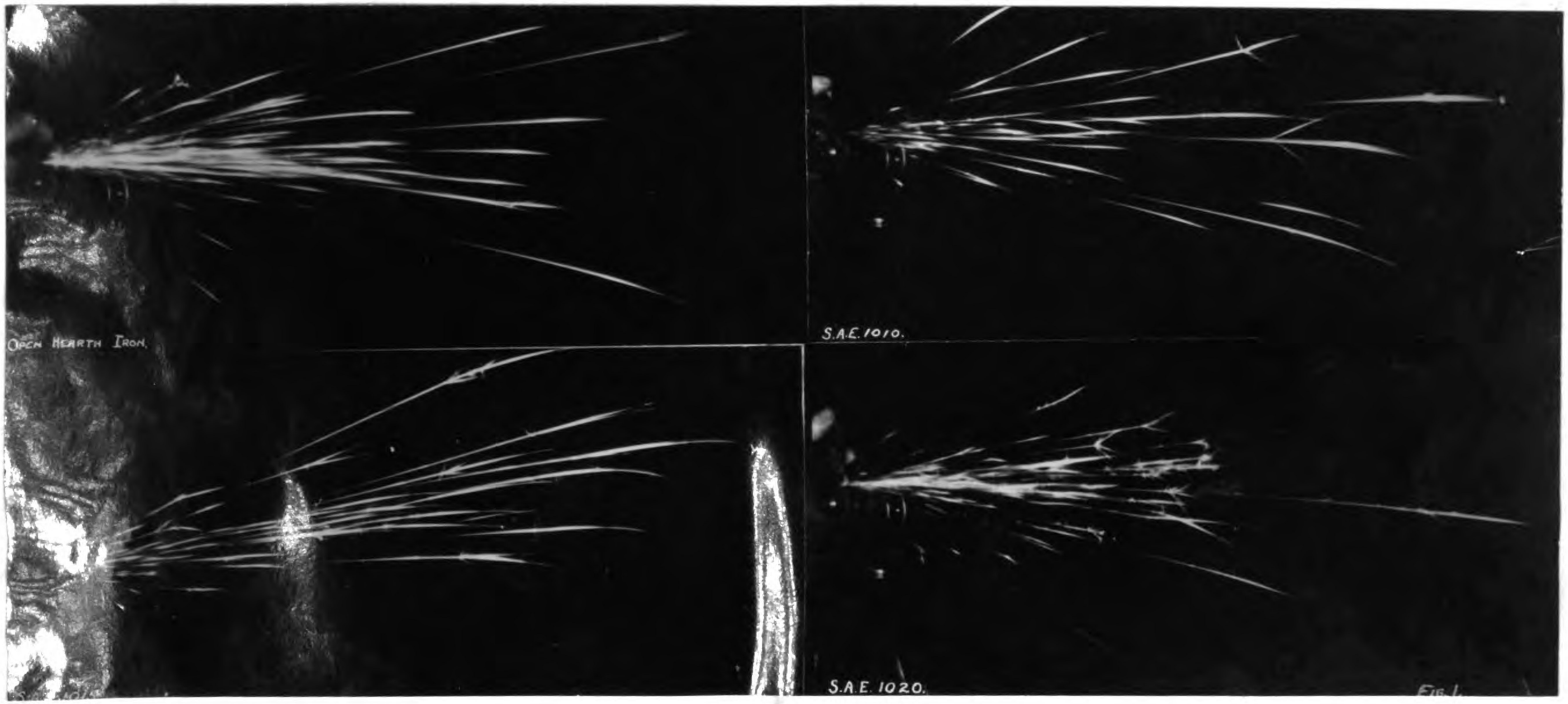

Fig. 1 - Spark streams typical of low carbon steel

Fig. 2A - Spark stream of S.A.E. 1030 steel showing the various characteristics of the carbon burst

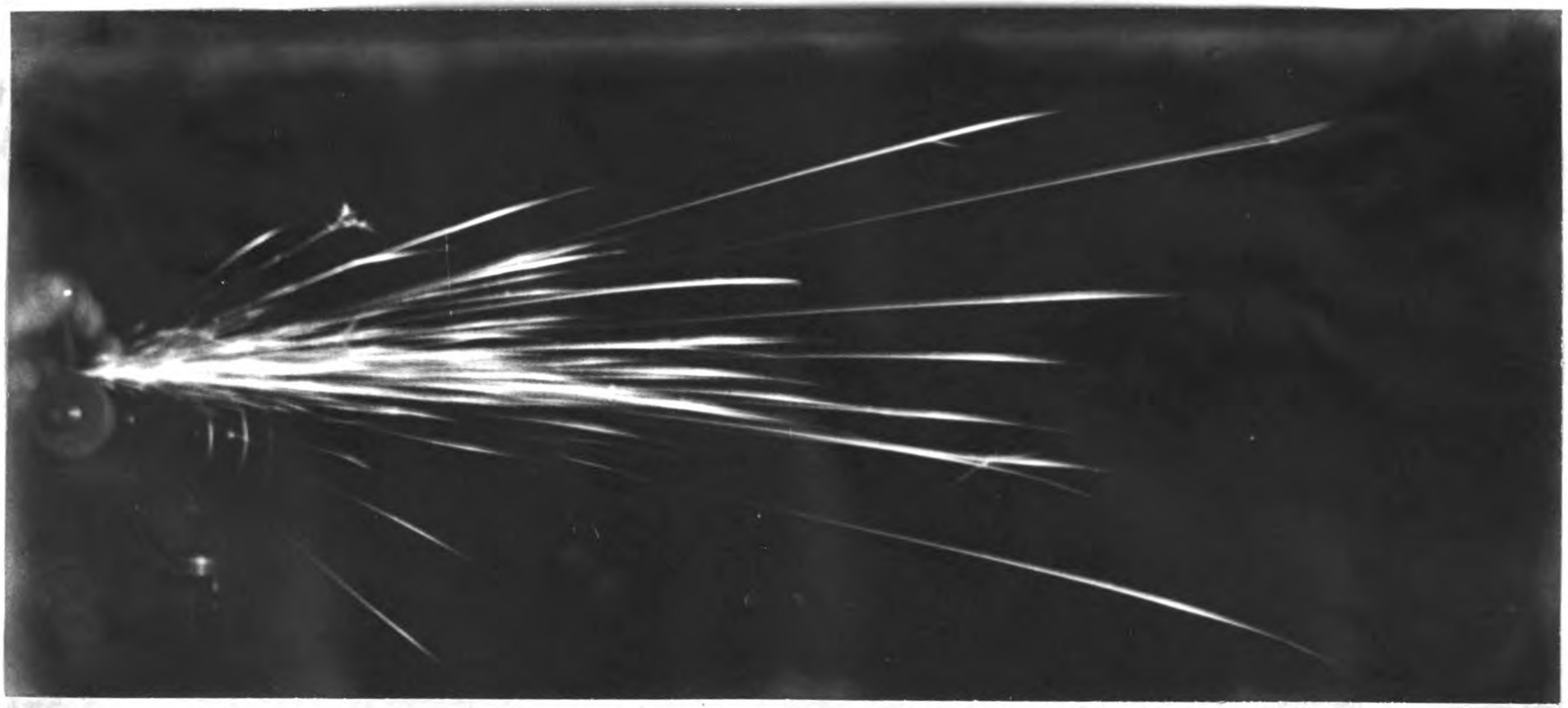

Fig. 1A - Spark stream of ingot iron

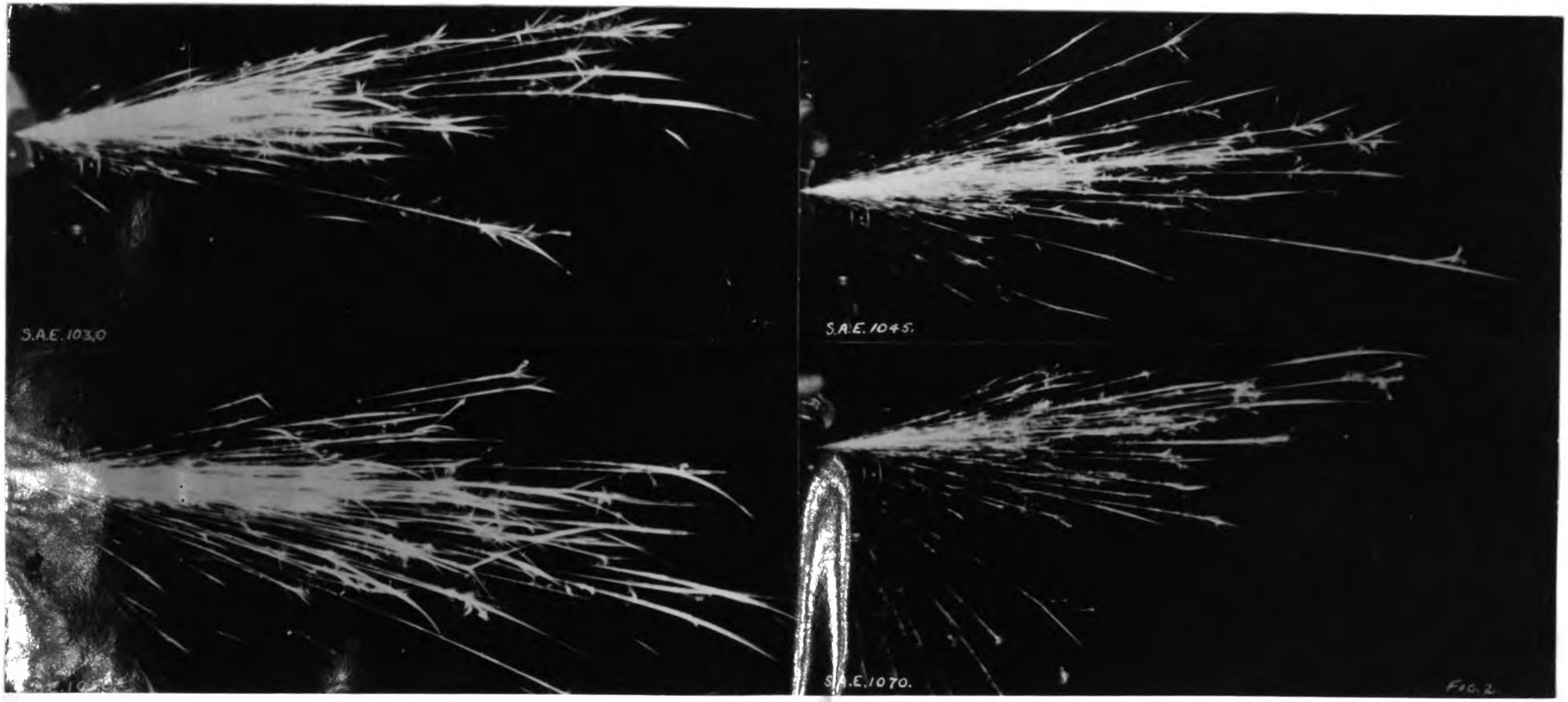

Fig. 2 - Spark streams typical of medium carbon steel

(Fig. 1) to S.A.E. 1030 steel (Fig. 2) the increase in length of the series burst will be seen. This stream is full and showy in all three sectors. The general appearance is that of a row of sprigs along the carrier line, among which with increasing intensity are sprinkled two or three small ray bursts. The display is climaxed with a large flower type burst. The final burst consists of a multitude of bud-tipped sprigs and a few rays. A number of stars are not uncommon in this shower. The steels in this portion of the plain carbon series are characterized by the long tongues.

The bursts commence to bunch as the carbon content increases and the preliminary bursts become more pronounced. It is essential that a close examination be made of the carrier to identify the burst as a series type. The key to the carbon content remains in the main carbon burst. That is, as the carbon increases the secondary and tertiary bursts increase and the burst becomes more complicated in general.

The display reaches its peak at approximately 0.45 per cent carbon. In S.A.E. 1045 steel (Fig. 2) the shower is light golden in color and very showy. The preliminary bursts at this carbon content are very violent, apparently expending all the energy causing the scattered sprigs which so easily identify a series burst to disappear. Buds top almost every sprig and secondary bursts are very common with a scattering of tertiary bursts.

With a slight increase in carbon content the stream shows signs of darkening. S.A.E. 1050 steel (Fig. 2) is very similar to S.A.E. 1045 steel. The series burst is only discerned by close examination. The stream commences to darken and the tongue to shorten, as is characteristic of the higher carbon bracket.

The change in characteristics for the next 0.20 per cent carbon is very gradual. In S.A.E. 1070 steel (Fig. 2) a pronounced change of type is seen. This steel marks the change from the medium carbon bracket to the high carbon type. As is seen by comparing the photographs, the entire structure of the spark stream has changed. The characteristics of the high carbon bracket prevail. The color is noticeably darker. Good bursts follow clear around the wheel. The stream shortens and the tongues commence to disappear. The carriers are finer and show a greater tendency to scatter. The bursts develop all of the characteristics possible in a plain carbon burst.

Figure 3 shows the steels of the higher carbon contents. These streams differ only slightly in spark characteristics, they show the highest possible development

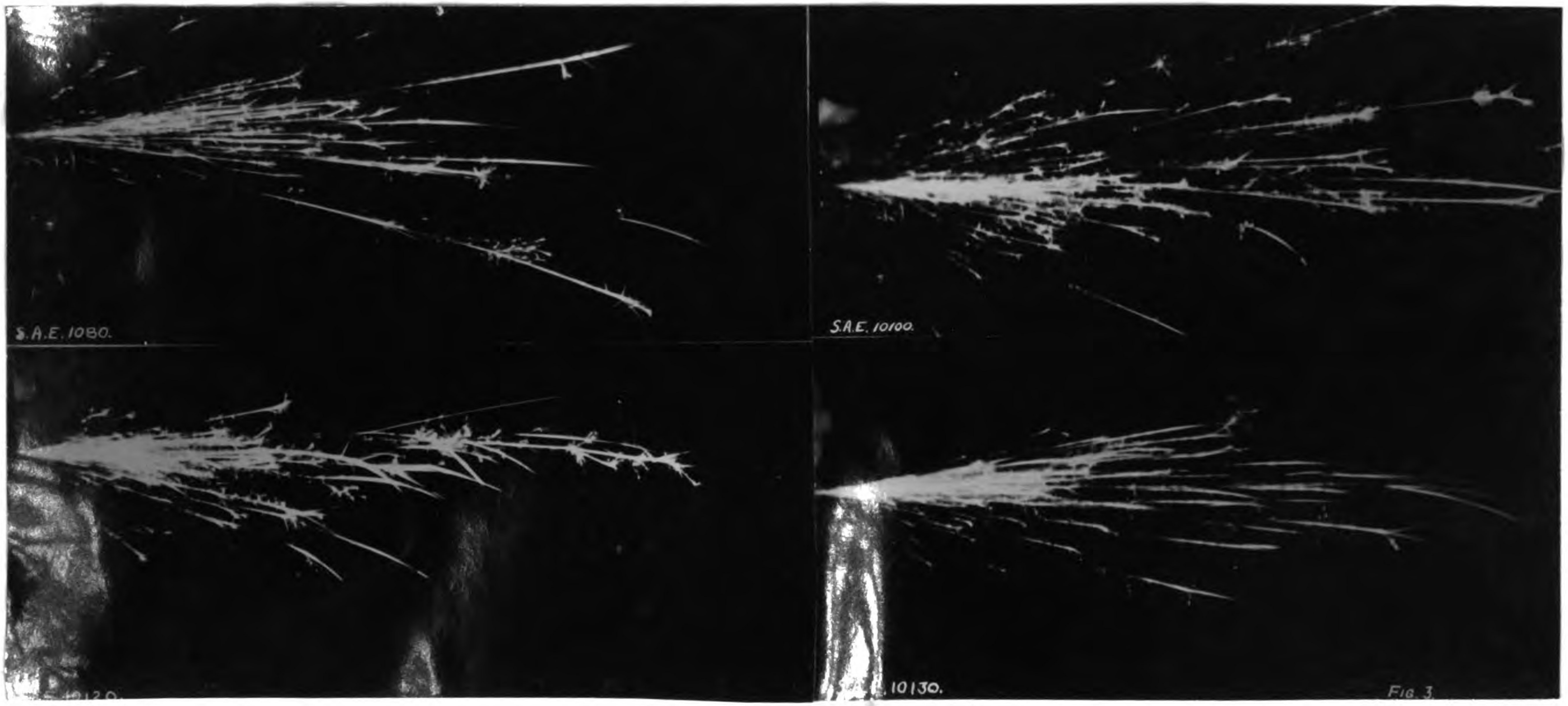

Fig. 3 - Spark streams typical of high carbon steel

Table 2 - Chemical Analysis of S.A.E. Nickel Steels Studied.

S.A.E. Number	C	Mn	P	S	Ni	Cr	Si
2315	.16	.68	.014	.03	3.45	.09	.26
2320	.23	.63	.016	.025	3.63	.09	.26
2330	.28	.65	.016	.025	3.60	--	.27
2335	.36	.64	.018	.031	3.41	--	.24
2340	.40	.67	.034	.039	3.35	--	.23
2345	.44	.66	.031	.026	3.38	--	.26
2350	.47	.65	.021	.025	3.45	.06	.25
2512	.13	.45	.019	.023	5.03	.16	.22

Table 2A - Chemical Analysis of Special Nickel Steels.

Manufacturers' Number	C	Mn	S	P	Cr	Ni	Si	BS No.
13	.39	.55	.032	.016	.62	1.25	.17	N 1
12	.29	.74	.017	.025	.14	3.52	.17	N 2
10	.08	.31	.016	.020	.15	5.12	.10	N 3
AMF-HF1-369	.14	1.70	---	---	--	47.4	.16	N 4
Invar	.05	.21	---	---	--	34.27	.31	---

in carbon bursts. What can be said of one (S.A.E. 1070) will apply to the rest. The increase of carbon tends to complicate the stream and it is only on a very careful comparative study of such streams that any difference can be seen.

Nickel Steels (Table 2)

Nickel imparts two characteristics to the spark stream which may be used in sorting. The first, the "nickel spark" which may be studied in either the first or third sector, and the other the "split tongue" effect which, of course, is best observed in the third sector.

Many advocates of the spark test describe the nickel spark as an enlargement on the carrier line found in the first sector. It is true that this spark characteristic appears in the first sector but after a careful study of this phenomenon, the author wishes to advance the theory that the nickel spark is a jacket. The nickel tends to shorten the spark stream so that a number of short carriers burst within the first sector and cause the appearance to be that of the long carriers having an enlargement at their base when in reality this phenomenon is merely the jacket of these suppressed or shortened carriers.

The formation of the nickel spark can likely be attributed to the surface oxide layer of a particle of

Fig. 4 - Spark streams typical of S.A.E. nickel steel

nickel steel being more tenacious than that on a plain carbon steel. It may follow that the formation of this layer on a nickel steel is of such a rapidity and the film is of such tenacity as to allow its being 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 leave a stream of light in its path. This would be emphasized by the glowing effect produced by the rapidly burning mass, and would produce the oval flare.

In the low-carbon, low-nickel steels the color of the stream is slightly darker, but otherwise similar to the corresponding plain carbon steel.

S.A.E. 2315 steel (Fig. 4) appears slightly darker than 0.15 per cent carbon steel. This difference in color is best observed in the first sector. The burst is more compact than the plain carbon burst, being between a series and a flower burst. This cannot be used in characterizing the stream. The tongues of these bursts are shorter. The split tongue effect is quite prevalent. The nickel spark can be seen in both the first and third sectors of this stream. In this particular steel, it can be used as an absolute proof of the presence of nickel.

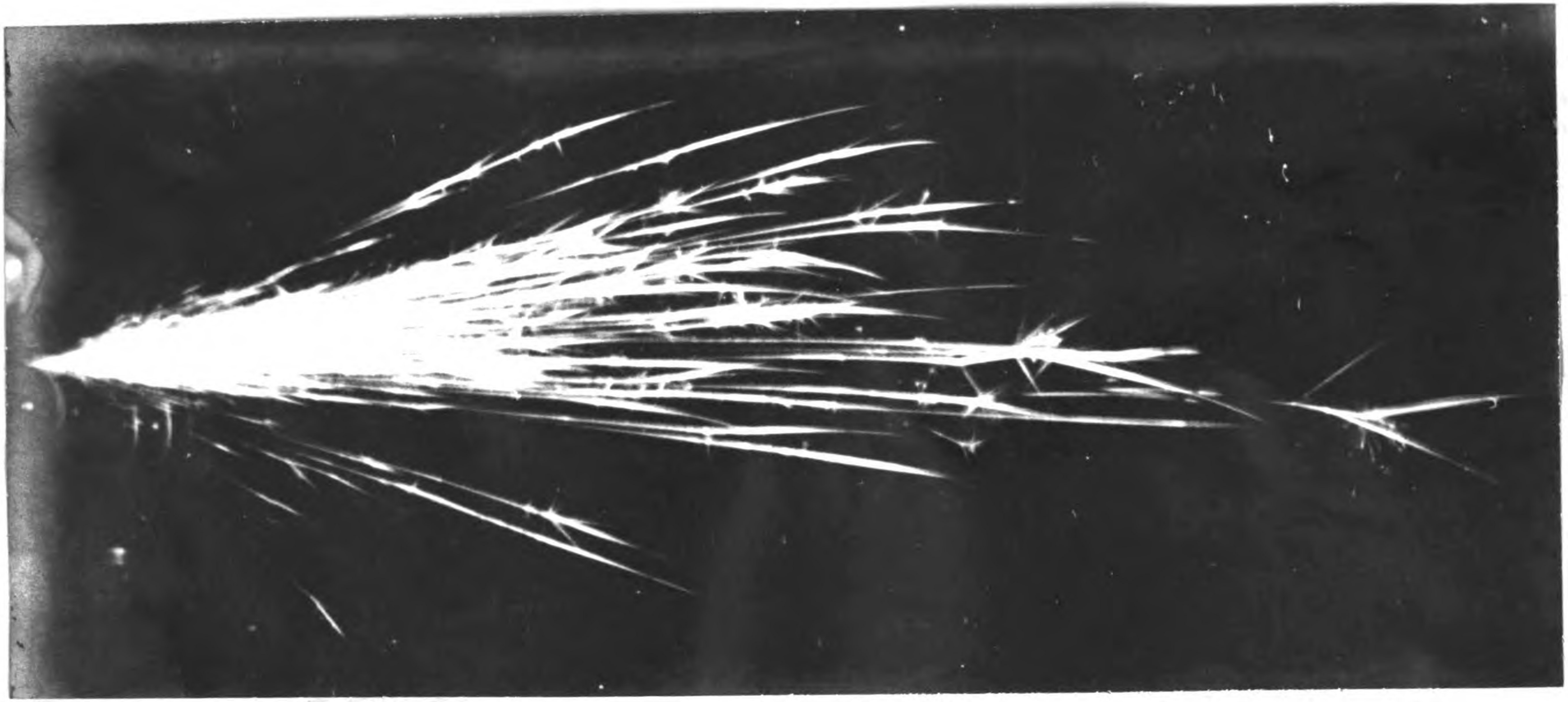

Fig. 4A - Spark streams typical of nickel steels

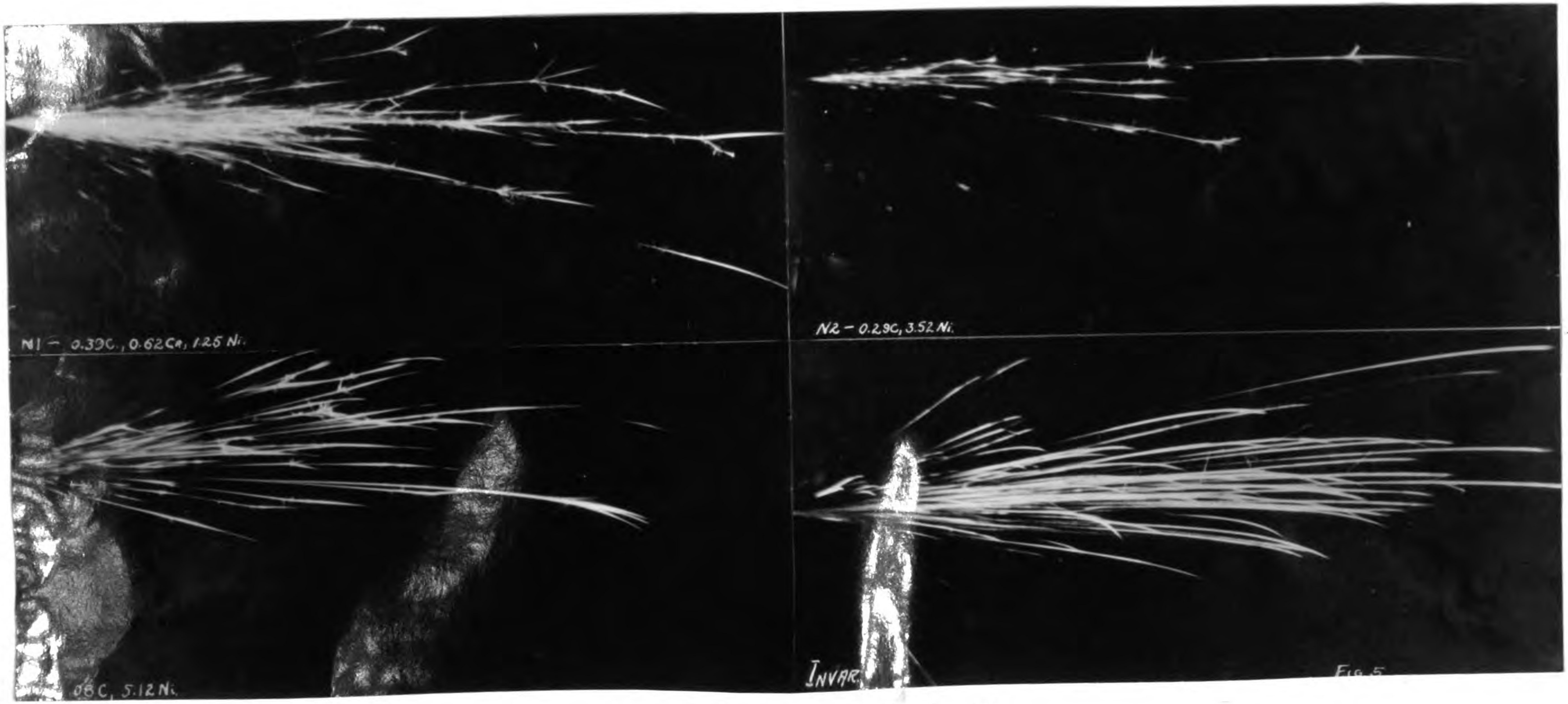

Fig. 5 - Typical streams of special nickel steels

As the carbon content is increased, the stream darkens. S.A.E. 2335 steel (Fig. 4A) gives a noticeably darker stream. The stream is short and the forked tongues are quite numerous. Two or three preliminary bursts appear on the carriers. On close examination the nickel spark may be seen in the first sector, but in this case it is more easily observed in the third sector.

A further increase in carbon content kills the nickel characteristics. In S.A.E. 2350 steel (Fig. 4) the stream is quite similar to that of the same plain carbon steel. The stream is but slightly darker and the nickel slightly shortens the stream. The nickel jacket appears but due to the high carbon content is practically hidden from view.

An increase of nickel content as seen in S.A.E. 2512 steel (Fig. 4) darkens the stream and slightly dampens the bursts. On the whole, the stream is very similar to the like plain carbon. The stream is characterized by its nickel spark.

Four special nickel steels (Table 2A) were studied. N1 (Fig. 5) contained enough chromium to kill the nickel spark. N2 and N3 (Fig. 5) gave streams similar to the S.A.E. steels of that type. N4, an alloy high in nickel, gave a stream which was too dark to photograph. This stream consisted of dark red streaks with occasional heavy tongues and no bursts.

Table 3 - Chemical Analysis of S.A.E. Chromium Steels Studied

S.A.E. Number	C	Mn	S	P	Ni	Cr	Si
5120	0.21	0.70	0.018	0.029	0.19	0.73	0.18
5130	.32	.63	.021	.019	---	1.06	.33
5140	.45	.61	.023	.018	---	0.91	.24
5150	.51	.72	.031	.024	---	.86	.23
52100	1.02	.37	.027	.014	---	1.40	.42

Table 3A - Chemical Analysis of Special Chromium Steels

Mfgrs. Number	C	Mn	S	P	Cr	Ni	Si	Mo	V	Cu	Co	B S No.
SKF13	1.05	--	-	-	0.85	--	--	--	-	--	--	C 1
SKF9	1.10	--	-	-	.50	--	--	--	-	--	--	C 2
W2	0.39	.64	.040	.026	.80	--	.42	--	-	--	--	C 3
18	1.03	.40	.012	.025	1.39	.17	.31	--	-	--	--	C 4
A117	1.12	.33	.017	.007	1.41	--	.23	--	-	--	--	C 5
SKF3	1.00	.25	-	-	1.50	--	.30	--	-	--	--	C 6
A83	0.92	.33	.027	.015	1.68	--	.31	--	-	--	--	C 7
Cr MAG	.92	.32	-	-	2.08	--	.24	--	-	--	--	C 8
M62	.91	.33	-	-	2.08	--	.24	--	-	--	--	C 9
A83	.72	.49	.025	.008	2.18	--	--	--	-	--	--	C 10
220	.90	.35	-	-	3.40	--	.22	--	-	--	--	C 11
A110	.71	.34	-	-	4.88	--	.37	--	-	--	--	C 12

Table 3A - continued

Mfgrs. Number	C	Mn	S	P	Cr	Ni	Si	Mo	V	Cu	Co	B S No.
St12	0.10	.41	.004	.019	11.50	--	.33	--	-	--	--	C 13
5	.12	.37	.007	.008	11.70	.47	.20	--	-	--	--	C 14
Ex3452	.08	.09	.015	.010	12.00	.23	.09	--	-	--	--	C 15
33	.11	.47	-	-	12.66	.22	--	--	-	--	--	C 16
VH63	2.25	.60	-	-	13.00	---	--	--	-	--	--	C 17
EM4273	0.34	.34	.017	.024	13.00	.30	.29	--	-	--	--	C 18
DEFIRUST	.10	.40	.03	.03	13.00	---	.50	--	-	--	--	C 19
RE4	.09	.37	.015	.019	13.45	.86	.34	--	-	--	--	C 20
9	.10	.49	.289	.010	14.04	.11	.55	--	-	--	--	C 21
6	.34	.42	.016	.013	13.53	.33	.40	--	-	--	--	C 22
M41	.35	.25	.029	.016	14.36	.28	.22	--	-	--	--	C 23
V6	.30	--	--	--	14.50	---	---	--	-	--	--	C 24
Sp. DEFIRUST	.10	.40	.03	.03	17.00	---	.50	--	-	--	--	C 25
F2	1.00	--	--	--	17.00	---	---	--	-	--	--	C 26
RE2	0.08	.38	.014	.019	17.10	---	.61	--	-	--	--	C 27
St18	.12	.67	.012	.013	18.92	---	.29	--	-	--	--	C 28
7	.31	.37	.005	.024	20.40	.35	.50	--	-	1.23	--	C 29
DEFIHEAT	.25	.50	.03	.03	25.00	---	.75	--	-	--	--	C 30
H1	---	---	---	---	27.00	--	---	--	-	--	--	C 31

Invar (Fig. 5) gives a dark red stream almost devoid of bursts. As is seen by the photograph the carriers end abruptly and have a decided tendency to curve downward. The increase in nickel content tends to darken the stream. A specimen of commercial nickel received gave a spark stream, while a like specimen of monel gave no spark.

Chromium Steels (Table 3)

Three characteristics are outstanding in the spark stream of the chromium steels. First:- below 0.45 carbon in these steels a typical flower burst appears. This characteristics, as in the case of the nickel steels, may be assumed to be due to a strong oxide film on the surface of the molten particle. This film is apparently very tenacious and has very little elasticity. These properties cause it to shatter readily in the presence of a high internal pressure giving a flower-type burst. Secondly, the streams of steels highly alloyed with chromium are darker than plain carbon streams of like carbon contents. The third characteristic most useful in the high carbon steels is the tendency of chromium to produce a fine carrier, which gives a full but not dense stream as is the case when the chromium is not present.

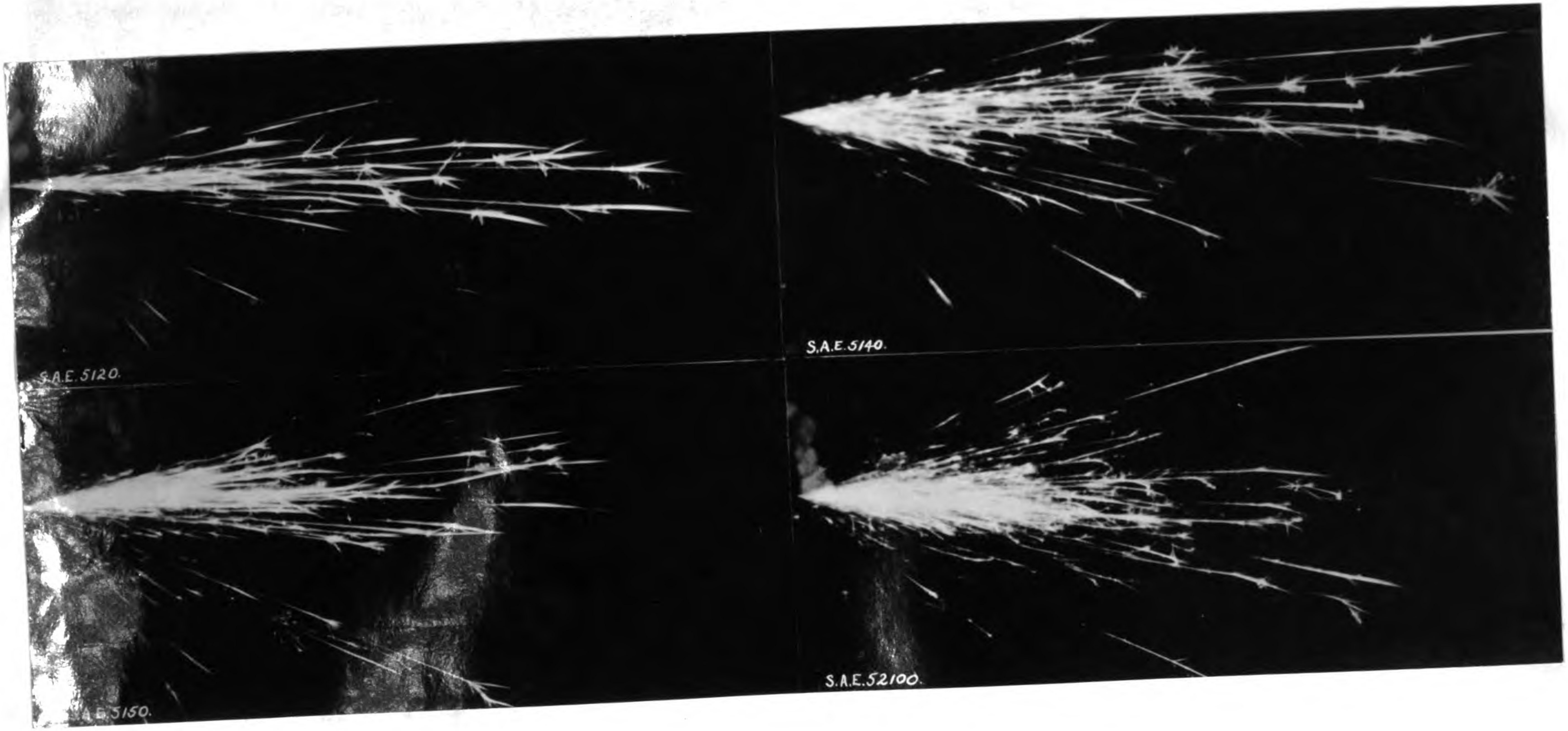

Fig. 6 - Spark streams typical of S.A.E. chromium steels

Up to 0.45 carbon (Figure 6) the spark stream produced by the S.A.E. series of chromium steels resembles the plain carbon steels with one outstanding exception, that is, in the case of chromium steels the flower burst prevails (Fig. 6A) while in the plain carbon steels the series bursts prevail. At 0.50 carbon (Fig. 6) the stream is very similar to the plain carbon stream and it requires a close examination with the use of the combination of all three chromium characteristics to sort it from a 0.50 per cent carbon steel. With the increase of the carbon content as in S.A.E. 52100 steel (Fig. 6) the fine stream and the tendency to form the compact bursts are the distinguishing characteristics. It is difficult to distinguish it from that of a plain carbon steel of the same carbon content and the supplementary pellet test which will be discussed later is the deciding factor in this case.

In a study of the high alloy chromium steel an investigation of the effect of chromium on the spark shower in the lower chromium ranges is greatly hampered by the prevalence of high carbon. The first twelve chromium steels (Table 3A) include all the steels with the chromium content of 5 per cent or under while all the carbon contents are over 0.70 carbon. This has a tendency to kill all alloy characteristics. The characteristics stream over

Fig. 7 - Spark streams of low chromium steels

Fig. 8 - Spark streams of high chromium steels

this range are shown by photographs of Figures 7 and 8. The streams are typical of the carbon contents, with a tendency to show the influence of their chromium content. As the chromium content approaches 5 per cent, there is a tendency for the thinning out of the stream as is shown by the photograph (Fig. 8 - C12).

Steel C13 (Fig. 8) contains 11.50 per cent chromium and the stream is very similar to that found produced by stainless steel with the exception of the brightly banded wheel.

Steel C17 (Fig. 8) is very similar to the steel C13 in composition, the chromium being but slightly higher, but the carbon content is 2.25 per cent as compared with 0.10 per cent for steel C13. The stream is very short and suppressed. Only a few carriers are produced in contact with the wheel but high carbon type bursts are formed.

Steel C18 (Fig. 8) has a lower carbon content than C17 and much the same condition exists in the stream with *the* carbon burst typical of the carbon content.

Steel C23 (Fig. 8) shows a slight increase of chromium content over steel C18 and the stream is suppressed to only a very few carriers. These carriers still contain typical carbon bursts but appear of quite a lower carbon content than they actually are.

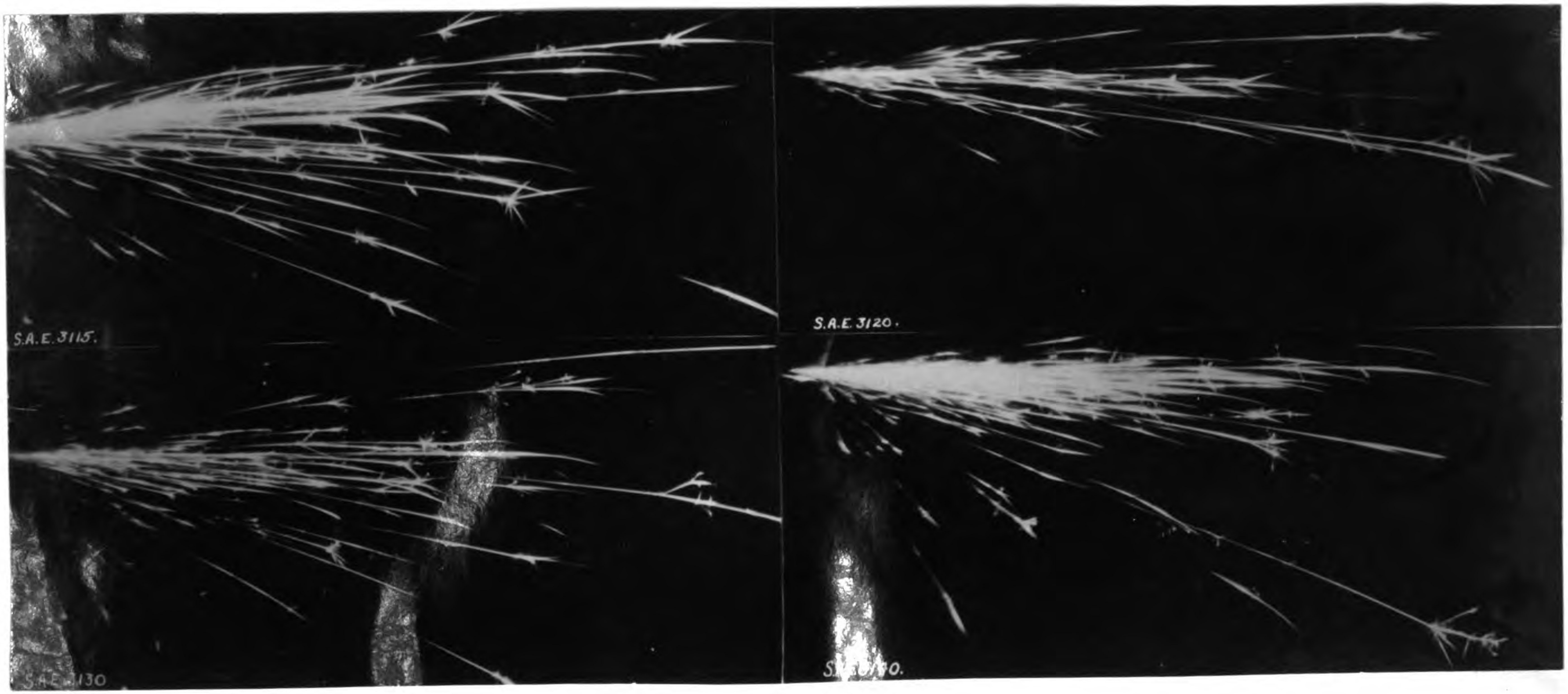

Fig. 9 - Spark streams of S.A.E. chromium-nickel steels

Table 4 - Chemical Analysis of S.A.E. Nickel-Chromium Steels Studied

S.A.E. Number	C	Mn	P	S	Ni	Cr	Si
3115	0.15	0.46	0.017	0.024	1.31	0.60	0.20
3120	.19	.47	.020	.029	1.26	.62	.18
3125	.28	.48	.017	.026	1.35	.55	.28
3130	.32	.46	.019	.031	1.12	.63	.23
3135	.36	.51	.026	.039	1.31	.58	.29
3140	.39	.62	.033	.036	1.18	.6[illegible]	.26
3235	.35	.41	.032	.018	1.87	1.21	.24
3240	.41	.44	.028	.022	1.73	1.10	.26
3250	.50	.51	.022	.026	1.69	1.12	.27
3312	.10	.44	.019	.023	4.14	1.49	.22
3340	.40	.50	.021	.021	3.39	1.56	.23
3435	.36	.45	.02[illegible]	.025	4.14	1.49	.22

Steel C25 (Fig. 8) is typical of the increased chromium content, the spark stream gradually disappears. As the carbon content is low, very little burst is seen. The tongues are tipped with spearpoints.

Steel C26 (Fig. 8) is a suppressed type stream, dark in color, giving a small high carbon burst. The stream is very thin and scattering, with the typical fine chromium carrier.

Steel C30 (Fig. 8) is at about the upper limit of chromium range allowable for formation of a spark stream. The stream is of the ingot iron type, although 0.25 per cent carbon is present.

Referring to Table 9, it is seen that no stream was obtained for a steel containing 28 per cent chromium so the limit of allowable chromium present to produce a spark stream must be in the neighborhood of 25 to 30 per cent.

Nickel-Chromium Steels (Table 4)

The combination of these two alloys tends to suppress the nickel spark and to emphasize the chromium effect. The color of the spark stream produced by these steels is generally slightly darker than that of a like plain carbon steel, but has all the carbon characteristics.

Fig. 9A - Spark streams typical of chromium-nickel steels - Type S.A.E. 3130

Table 4A - Chemical Analysis of Special Nickel-Chromium Steels

Mfgrs. Number	C	Mn	S	P	Si	Ni	Cr	B S No.
11	0.19	0.52	0.024	0.012	0.15	1.35	0.51	NC 1
W3	.42	.64	.038	.025	.38	1.56	.70	NC 2
WL2	.64	.63	.026	.020	.30	1.20	.51	NC 3
14	.48	.46	.009	.015	.18	1.65	1.04	NC 4
A338	.28	--	--	--	--	2.50	2.50	NC 5
5	.12	.37	.007	.008	.20	0.47	11.70	NC 6
88	.24	5.80	--	--	--	10.04	1.78	NC 7
12-12	.15	0.50	--	--	.45	11.80	13.00	NC 8
24	2.02	.43	.007	.020	.47	0.54	13.70	NC 9
JX2110	0.11	.39	.018	.020	.25	9.38	18.60	NC 10
Defistain	.18	.50	.03	.03	.50	8.0	18.0	NC 11
W4	.11	.42	.029	.014	.70	8.00	19.94	NC 12
RE1	.08	.38	.013	.019	.57	9.17	17.52	NC 13
AM	.14	.43	--	--	--	8.17	18.51	NC 14
Rezistal 20	.14	.70	.017	.009	2.02	8.42	18.06	NC 15
18-8	.10	.34	.023	.019	0.49	8.26	18.82	NC 16
KA23	.07	.50	.020	.010	.35	8.97	18.22	NC 17
140	--	--	---	---	--	8.00	18.00	NC 18
8	.10	.33	.008	.009	.58	9.69	18.25	NC 19
2112	.15	.60	---	---	.95	11.00	21.00	NC 20
173	.15	.70	---	---	1.10	19.50	7.80	NC 21

Table 4A - continued.

Mfgrs. Number	C	Mn	S	P	Si	Ni	Cr	Mo	V	Cu	B S No.
17A	0.40	0.70	--	--	1.10	19.50	7.80	--	---	--	NC 22
2020	.18	.50	--	--	0.45	20.00	20.00		-		NC 23
NYHF121	.48	.97	--	--	1.00	21.90	8.26		-		NC 24
66	.06	.35	--	--	--	0.49	20.08		-		NC 25
ATV1HF143	.41	1.28	--	--	1.28	35.2	10.20		-		NC 26
AHF141	.13	0.73	--	--	0.77	32.0	19.00		-		NC 27
Ultradie	2.31	.42	.015	.018	.23	0.20	12.00	0.19	-	--	NC 28
M55	0.80	.30	.004	.021	1.88	.47	14.17	.07	-	--	NC 29
976E3023	.44	.42	--	--	1.42	1.49	10.30	--	1.69	--	NC 30
Rezistal 2600	.35	.77	.020	.012	1.38	22.40	7.77	--	-	1.34	NC 31
Rezistal 7	.23	.61	.016	.009	2.80	21.35	24.32	--	-	--	NC 32

In the low alloy end of this series as in S.A.E. 3115 steel (Fig. 9) the nickel spark is present but not clear. The burst is of the flower type and contains all the characteristics of its carbon content. The tongues are short and the tips very very little in color from that of the rays. The rays are darker than the bursts. The stream as a whole is finer, less dense and generally reduced. A slight increase in carbon content (S.A.E. 3120 (Fig. 9)) tends to emphasize the flower burst. The nickel spark can still be seen. Further increase in carbon content, S.A.E. 3130 steel (Fig. 9A) causes the nickel spark to practically disappear. The shower in general is definitely darker than that of S.A.E. 1030 steel. Further increase of the carbon content causes the nickel spark to disappear and the stream remains comparatively dark. The flower burst predominates the stream. In S.A.E. 3140 steel (Fig. 9) the stream is shorter, finer and darker than a like plain carbon stream. The tongues are stubby and darkened at the tips. The bursts contain more rays than are present in plain carbon steels and this characteristic in the medium carbon range is important in comparing the two streams.

An increase in alloy content as in S.A.E. 3240 steel (Fig. 10) shows little change from the stream produces by S.A.E. 3140 steel other than it might be called slightly darker in color.

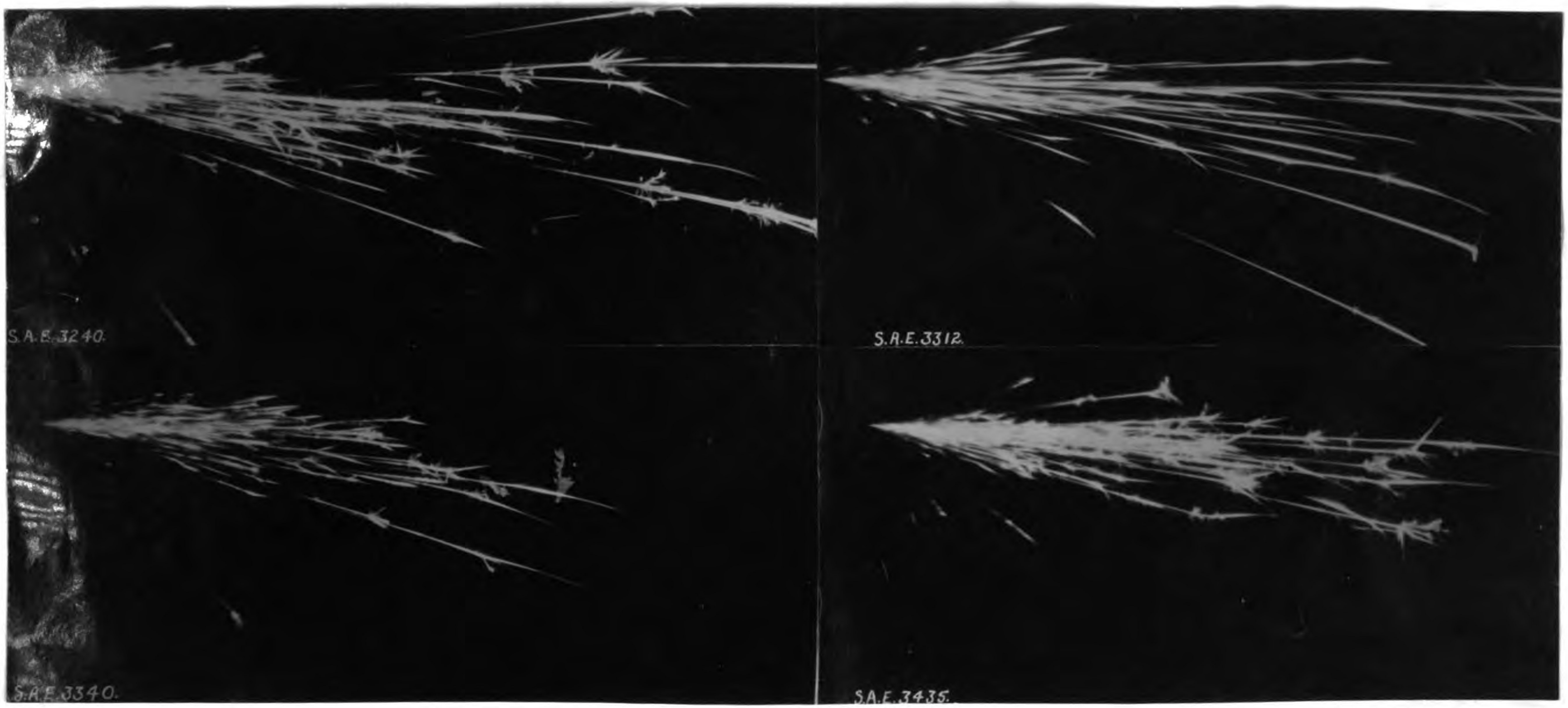

Fig. 10 - Spark streams of S.A.E. chromium-nickel steels

Further increase in alloy content only causes further darkening of the stream. A fairly representative series of this type steel was obtained. It is of interest to note that this series consists of both high chromium and low nickel and low chromium and high nickel steels, also at intervals are steels of equal nickel-chromium content (Table 4A).

Steels NC 1-2-3 are very nearly the same chemically, varying only in carbon content. In the first two steels the difference in the spark streams varied only as might be expected for the varying carbon contents. The nickel spark is present but darker than usual. The stream is full and in general that which would be expected for the carbon content. The stream differs from the plain carbon steel in that the carriers are heavily jacketed and the stream as a whole is generally darker, together with the chromium bursts. Fig. 11 shows the stream of NC1. Steel NC3 varies slightly in composition from NC2, contains about 0.20 per cent more carbon. A characteristic spark stream quite the same as the plain carbon steel of the same carbon content is produced, bearing out the fact that carbon tends to kill the alloy characteristics.

Steel NC4 (Fig. 11) has a higher chromium content than NC2. A thin stream is produced with scattering flower bursts. The stream is darker than usual. In spite of the

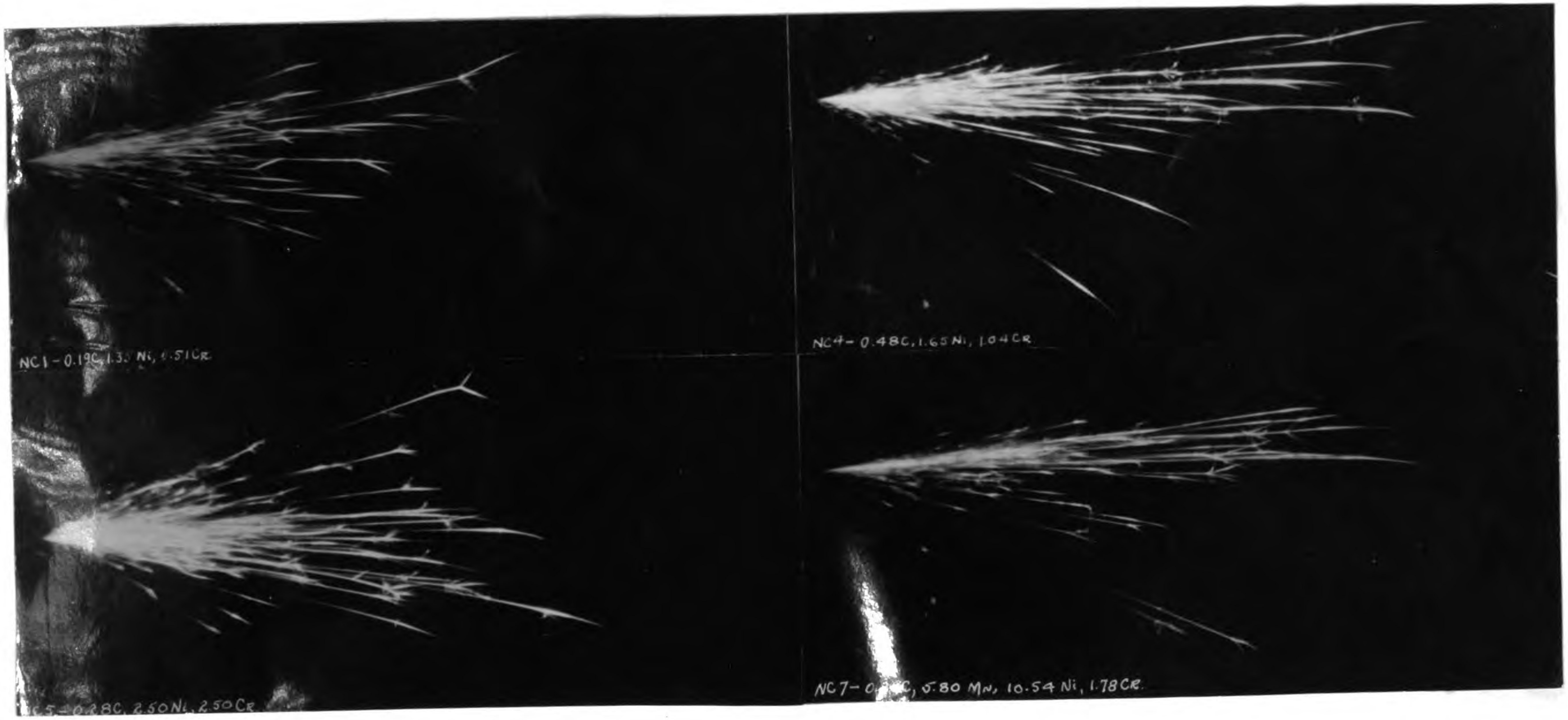

Fig. 11 - Spark streams of special chromium-nickel steels

fact that the carbon effect is dampened by the alloying elements present the carriers are long.

Steel NC5 (Fig. 11) in comparison with NC4 demonstrates how difficult it is to predict what should be expected in the spark stream. This steel contains 2.5 per cent of both chromium and nickel or about twice the quantity of alloying elements as NC4, yet with a much lower carbon content a spark stream display is given almost equal that to be expected in a plain carbon steel. The flower burst typical of chromium is well defined in this stream. Many forked tongues are present which may be attributed to the nickel. The stream as a whole is darker in color.

As the alloying elements are increased, the general tendency seems to be toward a suppression of the spark stream and a darkening of the carriers. In NC7 (Fig. 11) a peculiar reversal of this order is found due to the high manganese content which has a tendency to rejuvenate the stream. This causes the stream to appear similar to the type stream of the same plain carbon content, having jackets of nickel and manganese, flower bursts of chromium and forked tongues very likely caused by nickel.

In NC9, with high chromium, low nickel and high carbon content, the stream has practically lost all its carbon characteristics. The stream in this case consists mostly of dull red lines, being very short and small with an occasional high carbon carrier and burst.

With steel NC8 (Fig. 12) this series enters into nickel-chromium range known as the stainless steels. A phenomenon appears quite characteristic of this type steel which is that of the bright band around the grinding wheel. This is not found in all cases. It cannot be said that the stream does not follow around the grinding wheel in the case of other steels but the bright band on the grinding wheel in the case of the stainless steels once actually observed will not be confused with the dark band usually found in the case of other steels. The photograph (NC 16, Fig. 12) shows well this spark stream characteristic. This stream is thin and short in comparison with the plain carbon steels. The carbon bursts are suppressed and scattering. All are of the flower type so typical of chromium. Attached spearpoints are observed at frequent intervals in the stream.

In general this type of steel produces a stream consisting of only a few low carbon type carriers, among which are usually scattered some dark red disjointed lines, the quantity of which varies slightly with the different steels of this type. The carbon burst itself is very similar to that formed for ingot iron, although occasional bursts of a higher order may be seen at intervals. Very few carriers are discharged other than at the point of contact

Fig. 12 - Spark streams of special chromium-nickel and chromium-vanadium steels

Table 5 - Chemical Analysis of S.A.E. Chromium-Vanadium Steels Studied

S.A.E. Number	C	Mn	P	S	Ni	Cr	V	Si
6120	0.21	0.70	0.019	0.034	0.18	0.73	0.13	0.45
6125	.25	.61	.016	.026	.19	.89	.17	.19
6130	.30	.30	.040	.040	--	.90	.17	---
6135	.37	.70	.017	.020	.25	.98	.18	.15
6140	.45	.66	.020	.011	--	.88	.16	.23
6145	.50	.66	.017	.021	.13	1.03	.20	.26
6150	.50	.50	.040	.040	--	0.90	.17	---
6195	1.06	.34	.017	.022	.12	1.44	.17	.27

Table 5A - Chemical Analysis of Special Chromium-Vanadium Steels

Mfgrs. Number	C	Mn	S	P	Cr	Ni	V	Si	Co	DS No.
Vulcanl	.45-.50	.45-.55	.025	.025	0.90	---	.20-.25	.25-.35	---	V 1
19	0.94	0.34	.009	.017	1.44	.09	0.20	0.26	---	V 2
V10	2.20	--	--	--	12.00	---	.75	--	.75	V 3
F 5	0.40	--	--	--	13.00	---	1.00	--	---	V 4

and only a few here as this stream is one of very few carriers.

Steel NC15 varies slightly from this type; in that it contains 2 per cent silicon. This alloying element tends to kill the carbon burst entirely leaving only the disjointed red lines in the stream.

Steel NC20 (Fig. 12) with 11 per cent nickel and 21 per cent chromium has a very small stream and outside of an occasional flare contains nothing but a series of disjointed red lines. As the quantity of these two alloying elements are increased over this limit the red lines increase and the carriers decrease till the stream disappears. The spark stream is entirely eliminated when the sum of the alloy content of chromium and nickel is in the neighborhood slightly above 30 per cent. The chromium has a greater tendency to eliminate the spark stream than does the nickel. Nickel by itself does not completely suppress the shower, whereas chromium will. Consequently, with a high nickel content and low chromium the spark shower will appear at a higher chromium-nickel summation than it will with high chromium and low nickel.

<u>Chromium-Vanadium Steels</u> (Table 5)

Characteristics peculiar to both alloying elements may be observed in the spark stream of this steel. The

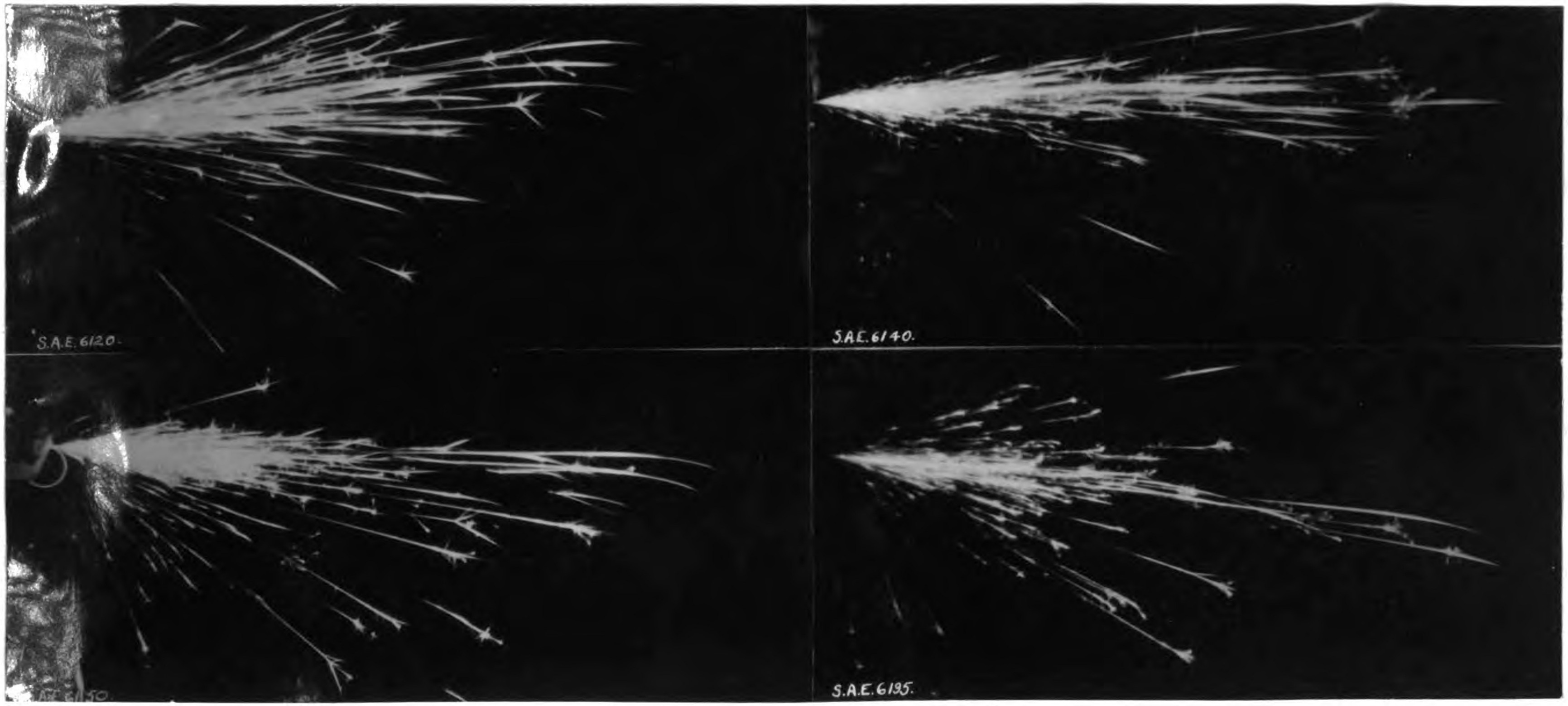

Fig. 13 - Spark streams of S.A.E. chromium-vanadium steels

Fig. 13A - Spark streams typical of chromium-vanadium steels -

Type S.A.E. 6130

flower burst typical of chromium is the outstanding characteristic of the stream. The alloy vanadium causes spearpoints to appear in the stream, but this phenomenon is not reliable and can be used only as an aid to the identification.

In S.A.E. 6120 steel (Fig. 13) the flower bursts are characteristic and the stream resembles the stream of the chromium steel of the same carbon content. Spearpoints appear throughout the stream and are attached to the ray tips. In general the same statements hold for this entire series. As the carbon increases as in S.A.E. 6130 steel (Fig. 13A) through S.A.E. 6195 steel (Fig. 13) the streams resemble the like chromium streams with a scattering of attached spearpoints in the low and medium carbon ranges.

Of the special steels only four of the chromium-vanadium type were examined (Table 5A). Two of high carbon content gave the high carbon type burst, V3 being highly alloyed gave a very scant stream, V1 gave a characteristic carbon burst with an occasional spearpoint, while V4 though heavily alloyed with chromium gives a spearpoint of dark red with a suppressed carbon burst. All four spark streams of these are shown in Figure 12.

Table 6 - Chemical Analysis of S.A.E. Molybdenum Steels Studied

S.A.E. Number	C	Mn	P	S	Ni	Cr	Mo	Si
4130	0.29	0.62	0.019	0.031	--	0.69	0.22	0.21
4130X	.31	.67	.031	.028	--	.96	.18	.26
4140	.37	.53	.017	.013	--	1.04	.45	.14
4150	.47	.77	.022	.032	--	0.97	.19	.23
4615	.15	..62	..017	.024	1.82	.30	.23	.20

Table 6A - Chemical Analysis of Special Molybdenum Steels

Mfgrs. Number	C	Mn	S	P	Si	Ni	Cr	Mo	Cu	V	BC No.
A303	0.20	0.50	0.024	0.011	0.10	3.64	0.11	0.07	--	--	M 1
A87	.78	1.74	.010	.016	.47	0.06	--	.08	--	0.22	M 2
E3931-25-20	.14	0.94	--	--	.66	19.75	25.48	.16	--	--	M 3
SKS77	.15	.49	.020	.015	.23	3.41	0.04	.25	--	--	M 4
KX7104	.27	.46	--	--	.12	3.59	.76	.32	--	--	M 5
JX2133	.15	1.42	.018	.015	.17	0.12	.07	.34	--	--	M 6
28X428	.35	1.10	.038	.036	.44	.15	---	.35	--	--	M 7
FX4181	.41	0.26	.016	.017	.29	2.35	.86	.35	--	.37	M 8
SKF22	1.00	.25	--	--	.25	--	1.00	.35	--	--	M 9
A132	0.36	.64	.030	.023	.22	--	0.88	.38	--	--	M 10
15	.53	.41	.015	.018	1.02	0.14	.15	.40	--	--	M 11
KX7102	.31	.51	.014	.014	0.11	3.57	.82	.45	--	--	M 12
A78	1.42	.25	.034	.012	.50	--	4.20	.78	.37	--	M 13
F6	1.50	--	--	--	--	12.00	--	1.00	--	--	M 14
MA2M	0.06	.47	.018	.016	.42	9.84	19.65	3.07	.11	--	M 15
A111	.71	.28	--	--	.28	--	--	5.75	--	--	M 16

Molybdenum Steel (Table 6)

The most interesting and easily studied spark characteristic is that produced by molybdenum. It is a very sensitive characteristic appearing in steels having as low as .07 per cent molybdenum.

Molybdenum steels all have a peculiar flare-up at the end of each ray completely detached from the ray tip known as a spearpoint. This characteristic was observed in all the molybdenum steel spark streams studied in this investigation of the S.A.E. steels. This detached spearpoint appears as a return of color to the particle after it has cooled off.

Apparently the particle cools at the surface too quickly for all of the gas at the center to escape. As the sphere cools the solubility of this entrapped gas decreases, causing pressure to build up in the cooling particle. The gas in escaping carries the red hot or still molten center with it which quickly cools to give the spearpoint effect.

As the carbon content is increased the burst becomes more violent causing a more complete shattering of the sphere and allowing all the gas to escape. This explains the absence of the spearpoint in the high-carbon molybdenum steels.

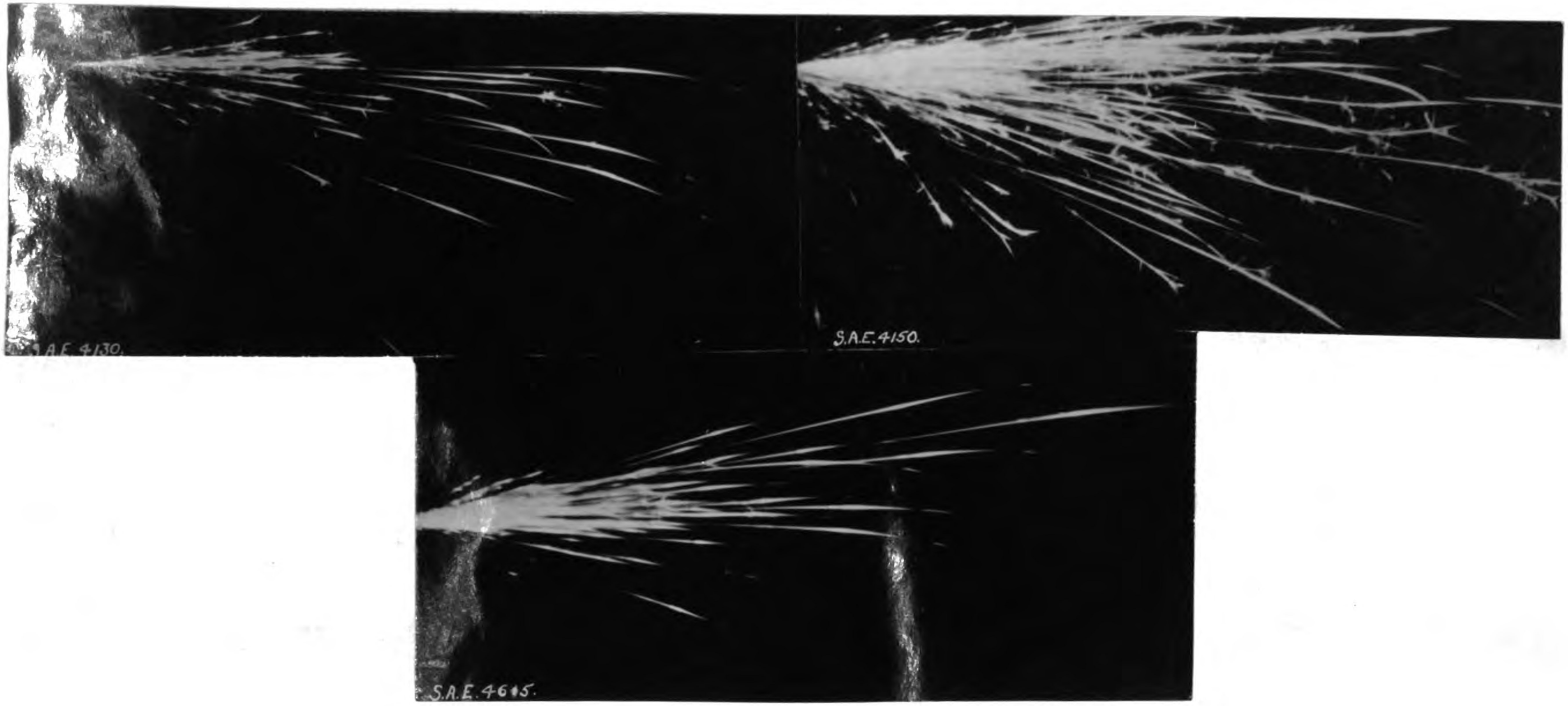

Fig. 14 - Spark streams typical of S.A.E. molybdenum steels

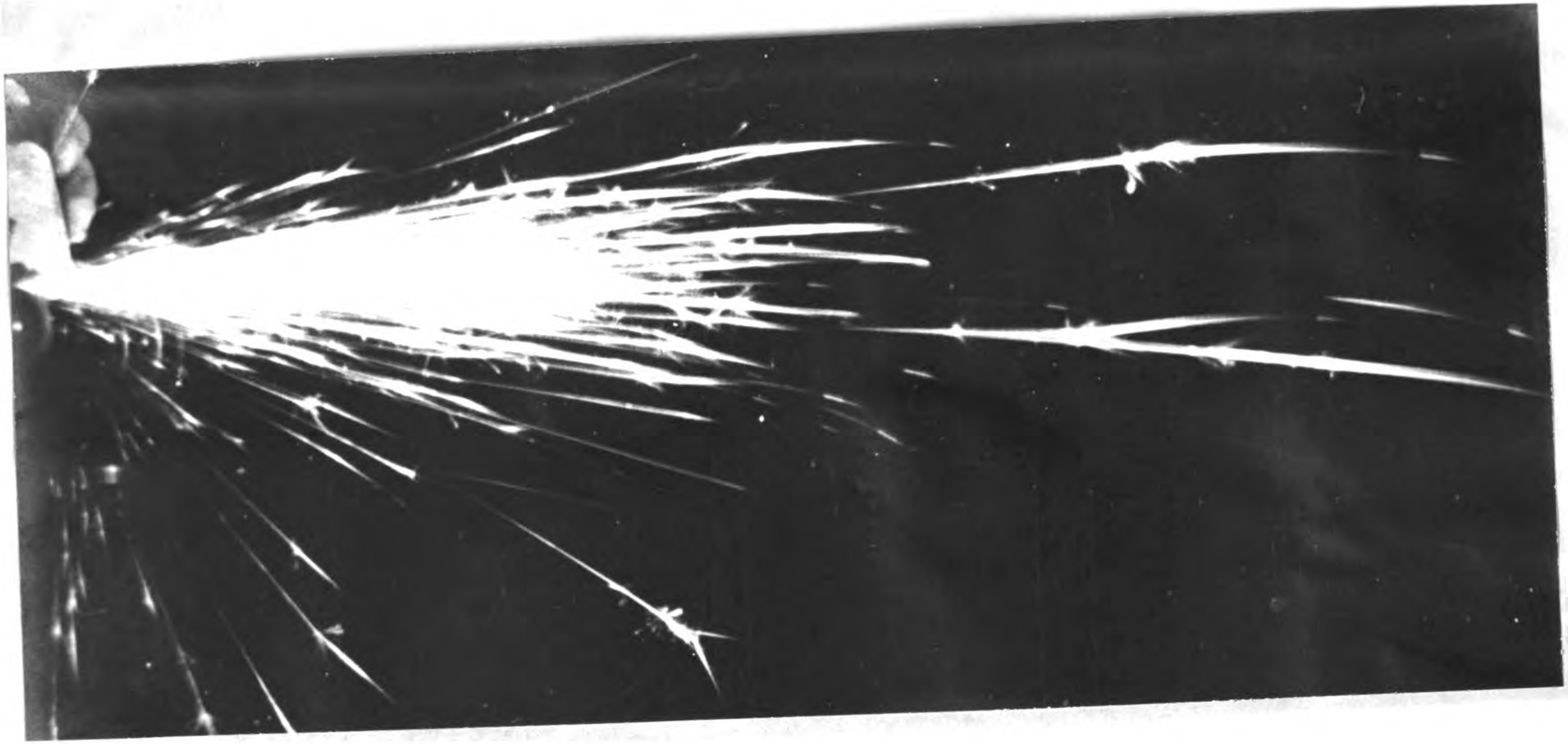

Fig. 14A- Spark streams typical of molybdenum steel showing spearpoints - Type S.A.E. 4130

Fig. 15 - Spark streams of special molybdenum steels

In the chromium-molybdenum steels both the flower bursts of chromium and the molybdenum spearpoints are present. In structure, the carbon burst is similar to that of the plain carbon type. In S.A.E. 4130 steel (Fig. 14A) the stream is slightly darkened and the spearpoints are the outstanding characteristic. The increase of carbon content tends to suppress both these characteristics. In S.A.E. 4150 steel (Fig. 14) the burst is a typical chromium burst. The spearpoints are still present but close observation is required for thier detection on account of the high carbon display blanketing them.

One of the prettiest displays of the molybdenum spearpoint is seen in S.A.E. 4615 steel (Fig. 14) in which both nickel and molybdenum are found in the presence of low carbon. The combination of these two alloys causes the carbon burst to be almost entirely suppressed and both the displays of the nickel and molybdenum spark stream characteristics are near perfect. The long glowing tongue due to nickel is tipped by a detailed spearpoint in every case. As shown in Table 6A sixteen molybdenum steels were submitted for this test; of these all but five showed the molybdenum spearpoint. Of the five that did not show the spearpoint, two are heavily enough alloyed with chromium-nickel to practically kill the stream and the other three contained too much carbon. These specimens showed molybdenum spearpoints up to .75 carbon and as low as .07 molybdenum. Steel M1 (Fig. 15) with high nickel and low molybdenum showed heavy spearpoints. Steel M2 with .78 carbon and .08 molybdenum did not show a spearpoint but M16 (Fig. 15) with .71 carbon and 5.75 molybdenum did show spearpoints. High chromium-nickel concentrations seem to kill the spearpoint. Concentrations of nickel to about 4 per cent did not affect the molybdenum spearpoint. The chromium-molybdenum specimens showing spearpoints were all below 1 per cent chromium as no intervening specimens between the low chromium and the high chromium specimens were studied, it is not possible to approximate the maximum chromium limit required to kill the spearpoint. 1 per cent silica did not affect the molybdenum spark as seen in steel M11 (Fig. 15) but the stream was very dark and the carbon bursts of low order due to the silicon.

It appears that carbon kills the spearpoint. Just how dominant this effect is, is difficult to approximate due to lack of special alloys. With the molybdenum kept constant as the carbon content increases the molybdenum spark is smothered but it is evident from the facts at hand an increase in molybdenum content will increasethe carbon maximum. Further than this, it is difficult to place limits.

Table 7 - Chemical Analysis of Special Tungsten Steels

Mfgrs. Name	C	Mn	Cr	Ni	Si	V	W	B S No.
Oildia	0.85	--	1.55	--	0.25	--	0.45	W 1
V9	.90	1.25	0.50	--	--	0.15	.50	W 2
Wando	.95	1.18	.52	--	.29	.22	.57	W 3
RT1733	.80	1.00	.60	--	.20	--	.60	W 4
Taddis	1.25	--	.20	--	--	--	1.00	W 5
Superdie	2.20	--	10.50	--	.80	--	1.00	W 6
10-0	1.15	0.30	--	--	.20	--	1.20	W 7
37	1.20	.28	0.45	--	.14	--	1.42	W 8
Vulcan2	1.10	--	.50	--	.15	.20	1.60	W 9
V5	1.20	--	.40	--	--	.10	1.60	W 10
Cyclops Para	1.04	.28	.39	--	.27	.23	1.68	W 11
V7	0.50	--	1.65	--	--	.25	2.00	W 12
Buster Brand	.60	--	1.25	--	..25	.10	2.20	W 13
Cyclops Alco	.46	.29	1.42	--	.28	.23	2.15	W 14
711	.50	.30	1.00	--	.70	.20	2.50	W 15
BTG-E1565	.29	1.50	12.50	62.00	.13	--	2.57	W 16
Double Special	1.30	--	0.55	--	.40	--	3.25	W 17
36	1.31	0.23	.10	--	.31	--	3.55	W 18
Saturn	1.24	.33	.14	--	.35	--	3.75	W 19
Midvale ATV3E 2836	0.40	1.49	14.07	25.90	1.32	--	4.20	W 20
Midvale HR-HF 1316	.41	0.45	19.98	7.66	1.53	--	4.26	W 21

Table 7 - continued

Mfgrs. Name	C	Mn	Cr	Ni	Si	V	W	Co	B S No.
Mercury	1.54	0.39	1.00	--	0.25	---	4.98	--	W 22
Tungsten Mag.	0.68	.38	0.34	--	.25	---	5.35	--	W 23
KR	.55	.70	7.23	--	.99	0.17	6.66	--	W 24
34	.47	.28	2.99	--	.21	---	8.43	--	W 25
V3	.30	---	3.50	--	---	.50	10.00	--	W 26
KM6022	.68	.24	4.17	0.28	---	2.20	14.57	--	W 27
L.C.T.	.45	.29	2.76	--	.27	0.45	14.96	--	W 28
KV3155	.73	.27	4.15	.02	.23	1.22	17.50	--	W 29
Dreadnaught	.68	.27	3.48	--	.30	1.03	17.08	--	W 30
35	.71	.23	3.77	--	.13	1.16	17.78	--	W 31
GruMX 12	.75	---	3.50	.50	--	1.00	18.00	--	W 32
GruMX 22	.75	---	4.80	--	.80	0.50	18.00	--	W 33
Vulcan 3	.70	---	4.00	--	.20	1.00	18.00	--	W 34
V1	.70	---	4.00	--	--	1.00	18.00	--	W 35
V2	.70	---	4.00	--	--	1.00	18.00	4.50	W 36
B6	.68	.30	3.95	--	.10	0.99	18.27	--	W 37
JJ124	.86	1.17	0.51	--	.21	--	0.41	--	

In general, the spark stream is very sensitive to the alloy molybdenum and it is likely the most outstanding spark. Due to the presence of this spearpoint an individual discussion of each steel was not made as the photographs speak for themselves.

Tungsten Steel (Table 7)

In the study of the some thirty-seven steels containing tungsten submitted, the outstanding feature is that: the bursts of the high tungsten steels are quite different from that generally expected. The carrier or sprig on which the buds and the secondary bursts appear is very dark as compared with the secondary bursts and stars, which cause all phenomena of this type to appear very white and to stand out very prominently. This effect seems to be so very prominent in connection with these steels, that it can be called a characteristic of the alloy tungsten. Furthermore a phenomenon of this type did not appear on any of the other alloys studied. Other characteristics of tungsten are the short stubby tongues which are named the "W-tip". The most generally accepted characteristic of tungsten is the dark red color it imparts to the stream.

Steel JJ124 has a low tungsten content but the influence of tungsten is readily seen on the stream. Not

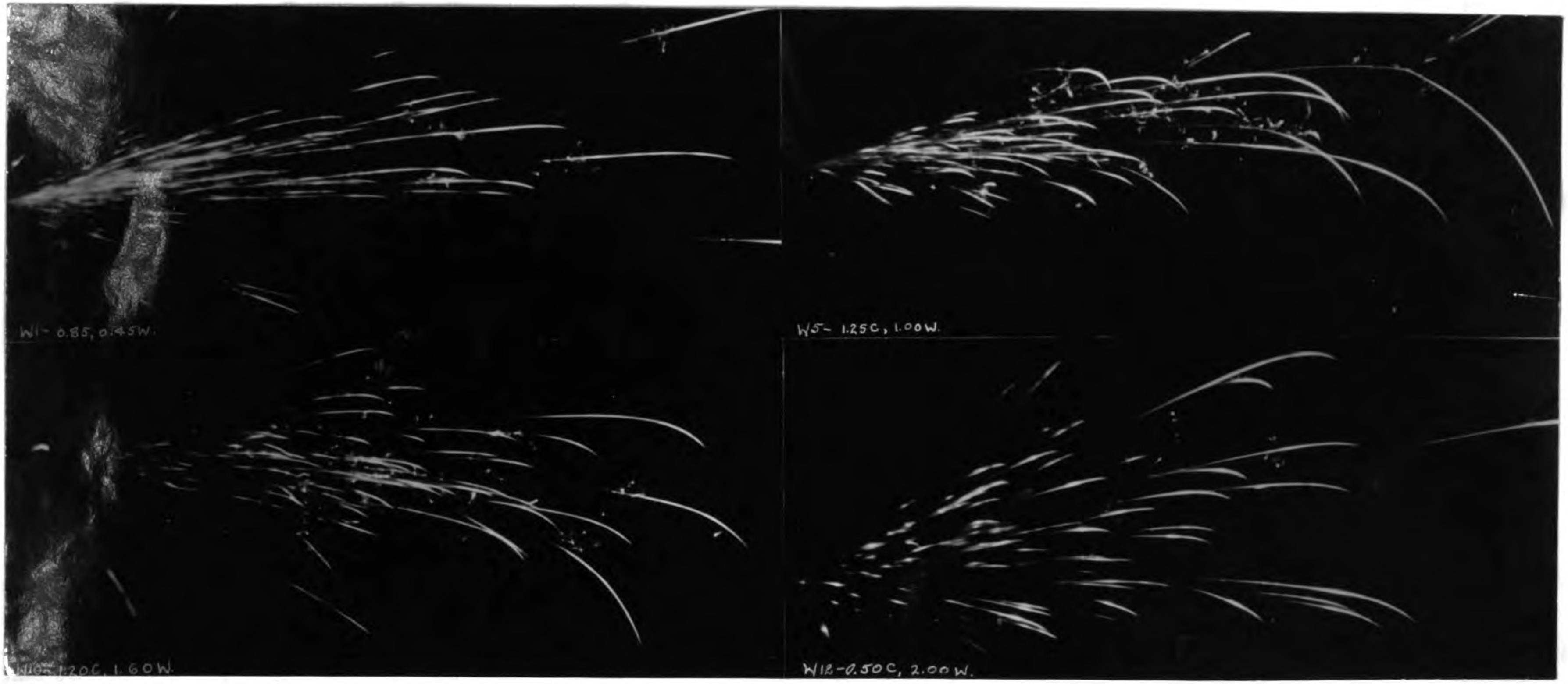

Fig. 16 - Spark streams of low-tungsten steels

only is the stream as a whole darkened in color but the carbon bursts are suppressed, the burst appears as spots connected to the trajectory by darkened secondary carriers. The effect of even this small amount of alloy shows on the tongues which are shortened and heavier assuming a stubby appearance.

Steels W1 through W10 cover this type steel to 1.6 per cent tungsten. Steel W1, Steel W5 and Steel W10 (Fig. 16) show characteristics of spark streams for .45 per cent, 1.00 per cent and 1.60 per cent tungsten, respectively. All these steels have ordinary tungsten bursts very much the same as described for Steel JJ124. As the percentage of tungsten is increased the carbon burst decreases and the stream becomes redder and darker, the tungsten characteristics in the burst being emphasized with the increase of alloy content. As the tungsten content approaches 2 per cent the carbon burst becomes very erratic in its behavior, in that a high carbon burst will vary from a high order burst to a series of sprigs. The 1.5 per cent chromium in W1 does not appear to exert a very great influence on the spark stream, but in W6 the 10.5 per cent chromium tends to kill the stream and gives the effect of about half ordinary carriers in the stream and about half disjointed red lines. The photograph of steel W5 (Fig. 16) shows the peculiar tendency of the alloy tungsten to cause wild bursts. This

Fig. 17 - Spark streams of high-tungsten steels

is emphasized as the percentage of the alloy is increased. The bursts are very violent causing the direction of the trajectory to be changed. The tips are heavy and curve downward. With the increase of tungsten to 2 per cent, the actual carriers become scarce and the stream scant, populated more by the heavy red disjointed lines characteristic of heavy alloying. A typical stream of this type is shown by steel W12 (Fig. 16). This steel contains one-half per cent of carbon but it will be noticed by the photograph the stream is thin and not well filled out and the bursts appear of a very low carbon type. The carrier lines have become so dark that they appear on the photograph only at the base of the tongue.

As the tungsten increases to 5 per cent the shower rapidly loses its identification as a spark shower, only showing carriers at times depending largely on the other alloying elements present. Steel W22 (Fig. 17) illustrates this type shower. The carriers present in this case may be easily counted. Only a few of those present have bursts. The dark red secondary carriers are very evident in this steel as the buds appear as light spots on the photograph with no connecting line.

In this series of steels from 5 to 14 or 15 per cent tungsten the steels seldom show more than dull red lines, the degree of which apperently depends on the chromium

Table 8 - Chemical Analysis of Special Manganese Steels

Mfgrs. Number	C	Mn	S	P	Cr	Ni	Si	B S No.
WL1	0.21	1.00	0.054	0.059	0.19	0.06	0.22	Mn 1
WL3	.39	0.95	.090	.056	.25	.10	.21	Mn 2
WL1	.30	1.07	.033	.018	.57	.14	.21	Mn 3
W1	.35	1.50	.040	.025	---	---	.45	Mn 4
17	.92	1.60	.012	.034	.11	.12	.21	Mn 5
68290	.45	1.89	---	---	---	---	---	Mn 6
Hatfield	1.00	14.00	---	---	---	---	---	Mn 7

present. In this high range, two steels gave interesting streams. Steel W27 (Fig. 17) gave bright tongues on the carriers with an occasional suggestion of a carbon burst. Another steel in this series W29 (Fig. 17) gave a series of disjointed red lines and an occasional burst. The peculiar burst as often found in tungsten steel was very evident in this steel. The photograph shows two characteristic bursts of this type, in which the bursts are shown by only one secondary carrier tipped with a good burst leaving the main carrier. The disjointed lines so common in the tungsten steels are well-known in the photograph.

The chromium-tungsten summation for eliminating the spark stream seems to be much lower than the chromium-nickel summation. The summation tungsten-chromium of 17 per cent still gave red lines while the summation of 20 per cent seldom gave any spark. With tungsten steel the summation which entirely kills the stream seems to be in the vinicity of 20 - 25 per cent.

<u>Silicon-Manganese Steel</u>

Only one steel of this series was obtained (S.A.E. 9250). Here both silica and manganese lead spark characteristics to the stream (Fig. 18). The silica causes the stream to assume a dark dirty red and suppresses the carbon burst so that in this steel only a very few secondary carriers develop with sprigs almost entirely absent. This secondary

Fig. 18 - Spark streams of typical silica-manganese steel, showing jacketing effect - Type S.A.E. 9250

S.A.E. No.	C	Mn	P	S	Ni	Cr	Mo	Si
9250	0.52	0.83	0.035	0.029	0.16	0.14	0.02	2.10

Table 9 - Chemical Analysis of Cast Iron Specimens

Specimen Number	Total Carbon	Free Carbon	Combined Carbon	Mn	P	S	Si	Cr
1 - 55	3.13	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

carriers are very dark and fine. The tongue is suppressed by the silica giving it a clubbed appearance. Manganese forms a bright jacket, as in the case of nickel only this jacket forms more of a √-shape. The bright manganese jackets are very plainly seen in the photograph.

Manganese Steel (Table 8)

Steel Mn1 (Fig. 20) shows the type stream for .20 per cent carbon steel with the heavy manganese jacket. Steel Mn5 (Fig. 20) shows the same effect in a high carbon steel. While steel Mn7 (Fig. 20) with 14 per cent manganese appears like one of 1.6 Mn content. In general, the typical spark characteristics of this alloy is the light color of the stream and the light jacket it imparts to the carrier.

Specimens are considered from 0.95 per cent to 14.00 per cent manganese containing from 0.21 to 1.00 per cent carbon and the jacket is quite prevalent on the carriers of all the combinations and there is little or no effect on the carbon burst.

Cast Iron (Table 9)

Four cast irons are considered, the combined carbon content of which is the main consideration. No great difference can be observed in the spark stream of these. In general the stream consisted of very dark red carriers with a comparative light burst, as shown in Fig. 20.

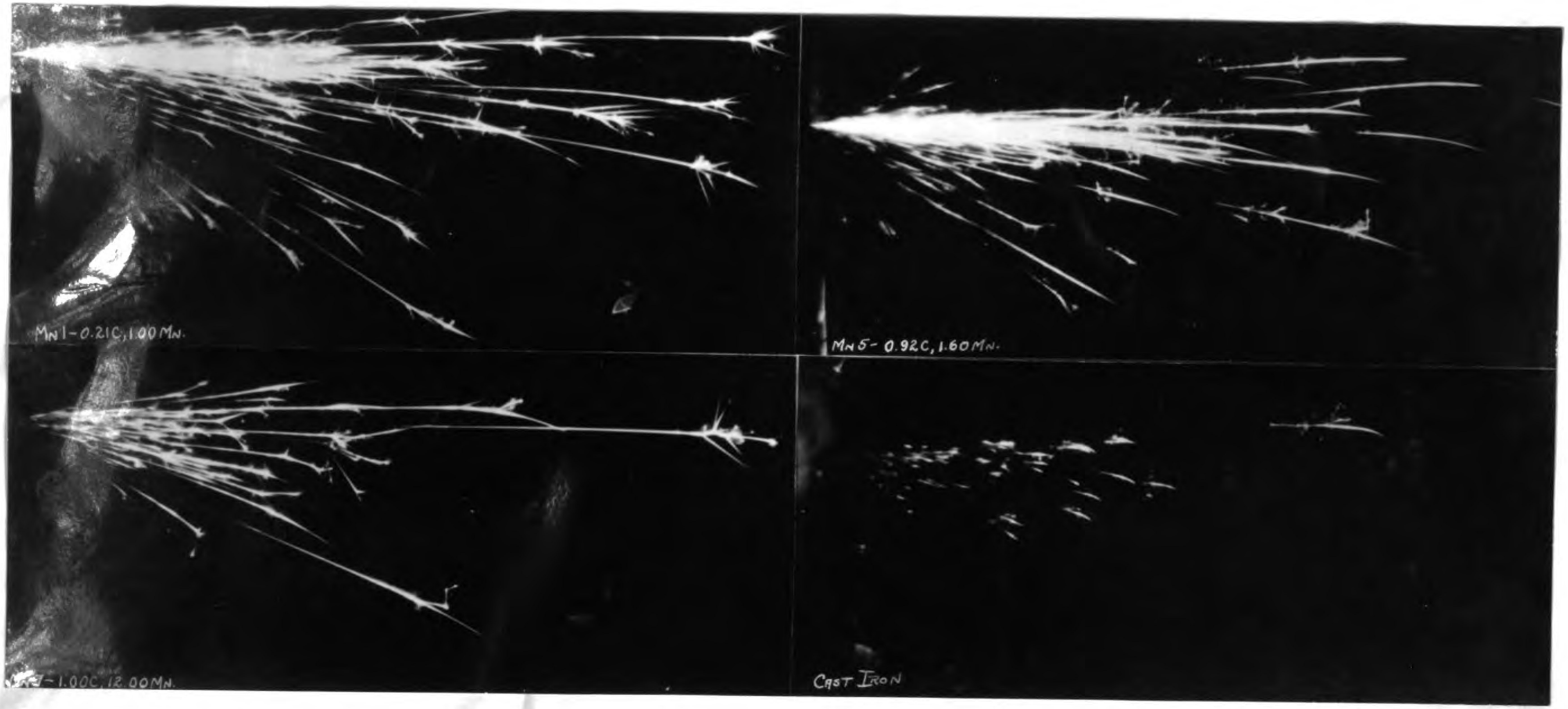

Fig. 20 - Spark streams of manganese steel and cast iron

Fig. 21 - Spark streams showing the influence of nitriding time on type spark stream produced

Nitrided Steels

A brief study of the relation of the nitriding of steel to the spark stream showed that the spark stream was changed by nitriding, and that this change is a function of the amount of nitriding. Fig. 21 shows the spark streams of a piece of steel before nitriding, after nitriding for 24 hours, after 48 hours' nitriding, and after 72 hours' nitriding time.

The steel itself gives a very nice molybdenum spark. After 24 hours' nitriding the stream is shortened and darkened. The burst gives the effect of a high carbon but is of a long series type taking place close to the carrier. The spearpoints have almost lost their characteristic shape. After 48 hours of nitriding, the stream loses all semblance of a burst and is noticeably shorter than that of the 24-hour specimen. An additional 24 hours' nitriding only makes the stream still shorter and less dense.

A number of the alloys received gave no spark stream. These are collected in a group and given in Table 10.

Table 10 - Chemical Analysis of Alloys Showing No Spark

Mfgrs. Number	C	Mn	Cr	Ni	Si	Mo	V	W	Co
CN2	--	--	--	--	--	--	--	--	--
Dreadnaught	0.68	0.27	3.48	--	0.30	--	1.03	17.08	--
G A	.55	--	15.00	35.0	--	--	--	---	--
F	.55	--	15.00	25.0	--	--	--	---	--
B28	.66	--	26.00	8.0	--	--	--	---	--
B	1.20	--	20.00	8.0	--	--	--	---	--
C	0.55	--	20.00	8.0	--	--	--	---	--
B LC	.55	--	20.00	8.0	--	--	--	---	--
N	.55	--	17.00	68.0	--	--	--	---	--
CP 12	---	--	---	---	--	--	--	---	--
V3	.30	--	3.50	---	--	--	0.50	10.00	--
Cru EM 12	.75	--	3.50	0.50	--	--	1.00	18.00	--
A	.75	--	4.80	---	--	.80	0.50	18.00	0.42
Cyclops B6	.68	.30	4.00	---	--	--	--	18.00	--
WL6	.67	.50	1.49	.62	.126	--	.17	---	--
2825	.24	.35	28.00	---	.35	--	--	---	--
55	.25	.70	28.96	.334	--	--	--	---	--
44	.43	1.37	23.50	11.10	--	--	--	---	--
Cl - 139	--	--	--	---	--	--	--	---	--
Xite	--	--	--	---	--	--	--	---	--
[illegible] alloy	--	--	--	---	--	--	--	---	--
Fyson 18	--	--	--	---	--	--	--	---	--

Table 10 - continued.

Mfgrs. Number	C	Mn	Cr	Ni	Si	Mo	V	W	Co
V2	0.70	--	4.00	--	--	--	1.00	18.00	4.5
V1	.70	--	4.00	--	--	--	1.00	18.00	4.5
Clarite	---	--	---	--	--	--	---	--	---
Vulcan	.70	0.40	4.00	--	0.30	--	1.00	18.00	---
Mercury	1.54	.39	1.00	--	--	--	--	5.00	---
Rezistal 4	0.20	.57	17.24	25.20	2.79	--	--	--	---
Nichrome	.20	2.00	16.00	60.00	--	---	--	--	---
Nichrome V	.15	--	19.50	77.50	0.25	---	--	--	---
RE3	.19	0.58	24.50	20.00	1.34	----	--	--	---

Pellet Test

This test was first reported by McCollam and Hildorf.

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.

The test is not complete in itself but finds its application as a supplementary test when used with the spark test. All the particles torn from a specimen by a grinding wheel do not burn. As previously explained only a part of the specimens burn to give the spark stream. It has been found on examining the "ash" from the spark stream that the burned particles exist as globules or pellets and that the pellets from some steels differ quite decidedly from those of others.

Preparation of Pellets for Examination

To obtain a pellet specimen, a baffle is placed at the end of the visible trajectory with a clean sheet of paper at its base. The spark stream is thrown against the baffle and the particles are collected on the paper. After the sheet of paper is well covered with a dust, it is collected at one end of the paper by folding the paper, thus sliding the particles together. The dust is then jarred to distribute it the entire width of the folded paper. The paper is then flattened and by gently shaking the paper it is found that a portion of this dust will roll faster than the rest. The paper is then inclined and these faster rolling particles are rolled off by gently shaking the paper. This portion is the pellet sample. This is then put through a 100 mesh screen and the portion retained by the screen is examined under the microscope at x 50. Any unfused particles should be removed by a sharp pointed instrument.

It is possible to photograph these pellets, but due to the fact that the colors of the particles vary only in shades it is very difficult to show these differences photographically and photographs of these pellets when reproduced are very misleading. Only a few characteristic pellets are shown to give a general idea of their appearance. (Fig. 22). The steels from which these pellet specimens were obtained are indicated in the figure by the S.A.E. number of the steel.

Plain carbon and nickel steels give pellets faintly patterned on the surface and shiny black in color. In the plain carbon series the lower the carbon content the harder it is to collect a pellet specimen.

All the steels containing chromium gave a very characteristic pellet. The surface of the pellet is rough and the entire pellet is a light grey in color.

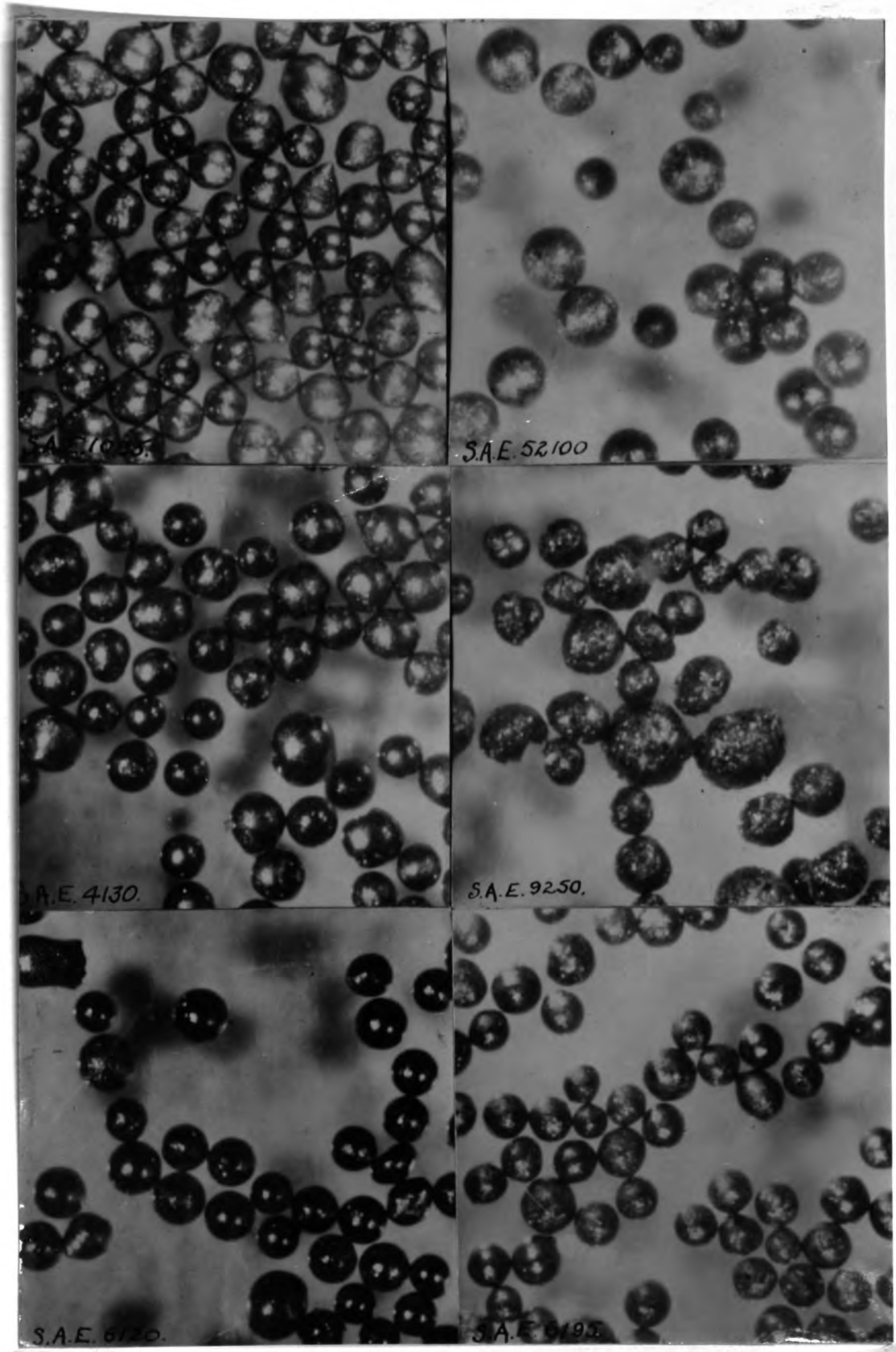

Fig. 22 - Typical pellet specimens, x 50

The pellets of the molybdenum steels are very smooth and a shiny jet black. Some of the pellets are blown out. This phenomenon is best observed by gently tapping the pellet specimen while examining, causing the pellet to roll, these pellets having a tendency to come to rest on the blowhole. The pellets of high carbon molybdenum-manganese steel were badly shattered and half shells appeared as well as more shattered pieces. Some of the pellets retained their round shape but had holes entirely through their diameter.

Chromium-vanadium pellets have the chromium characteristic but may be sorted from the nickel-chromium and straight chromium steel pellets by the characteristic of having blown out their center evidently caused by the alloy, vanadium. These pellets elongate when they blow out causing a pear shaped pellet, the blow hole being at the small end. This tendency to blow out is greater in S.A.E. 6195 than it is in S.A.E. 6120 and the number of blown pellets increases from S.A.E. 6120 to S.A.E. 6195.

The silicon-manganese steel had badly blown pellets which retained their round shape but had holes blown out entirely through the pellet.

Sorting Chart for S.A.E. Steels

The data on the characteristics of the S.A.E. steels studied have all been combined in a sorting chart presented in Figure 23. In compiling this chart only the outstanding sorting characteristics have been used and the carbon burst has been used as much as possible. Cases where sorting is possible but liable to be confusing have been labeled "doubtful". In all cases labeled "yes", there should be no difficulty in sorting the two steels if reasonable care is used. The general alloy characteristics listed at the end of the chart may not always apply. They are, however, the characteristics other than the carbon burst most likely to appear. In the case of silicon and tungsten the presence of a high or low amount of the alloy will change the appearance of the stream so as they may be sorted from each other. Half of this chart is devoted to the possibilities of the pellet test. It will be observed that in a number of cases the combination of the two tests will give conclusive evidence of the nature of an alloy, whereas the spark test in itself is doubtful. This is especially true with high carbon steels. In general, it is seen that out of possibly 2520 combinations (mixtures) of any two steels shown on this chart, 2108 of these steels may readily be sorted from each other while it may be possible (listed under

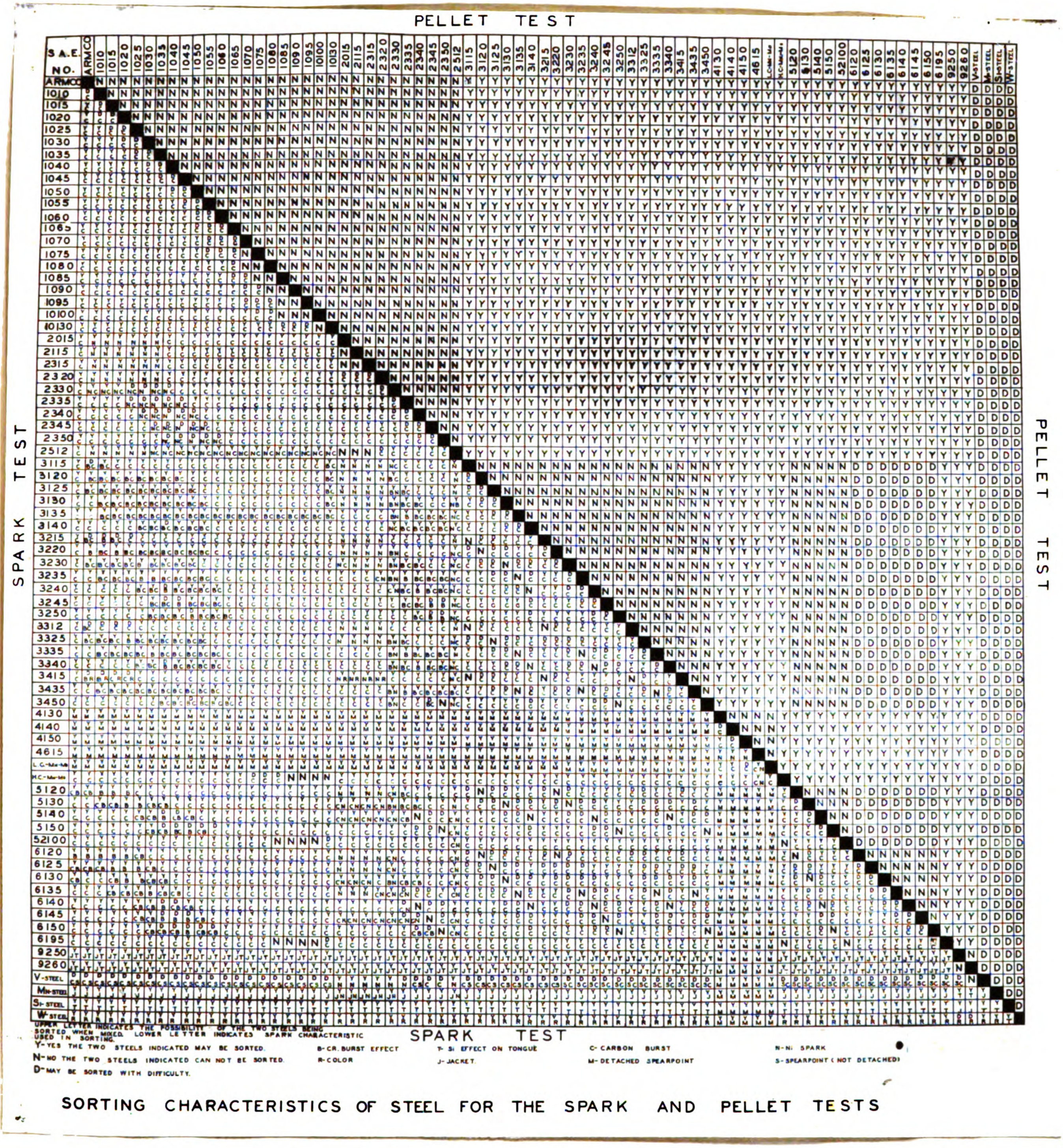

Fig. 23 - Spark test sorting characteristics

doubtful) for 326 additional steels to be sorted and only 72 steel combinations may not be sorted by the spark test. The information contained by this chart refers only to spark streams produced by the small fast revolving grinding wheel as described at the beginning of this discussion.

A word as to naming the chart a sorting chart may be in line. The word of warning was sounded in the introduction that this test is recommended only as a means of sorting foreign steels from a lot of known material and should not be used as a means of identifying a steel of unknown chemical composition, thus the name, sorting chart, instead of identification chart.

Summary

Various elements introduced into iron as alloys cause the hot sparks produced by contact with a grinding wheel to give various shades of yellow and red, to produce characteristics peculiar to the element contained.

Carbon causes the stream to have bursts along the carrier line which develops with increasing intensity as the carbon content increases. In the low-carbon ranges these changes are so pronounced that steels differing only five points or less in carbon may be differentiated from each other. As the carbon increases above 0.45 per cent this difference decreases until above 0.75 per cent it is very difficult to tell the spark streams one from the other.

The introduction of nickel into a steel causes the spark stream to shorten and darken. As the nickel is increased the carbon burst is suppressed. A small spark stream can even be obtained from nickel.

In the lower alloyed steels of the S.A.E. type heretofore discussed there is a swelling or glowing effect at the base of the burst called the nickel spark. This shows nicely in nickel steels of less than 0.30 per cent carbon and can be seen in steels as high as 0.45 per cent carbon. This does not appear in high nickel-iron alloys.

Chromium in a steel causes the bursts to bunch to give flower type bursts. This characteristic can be readily observed as high as 0.45 per cent carbon. Above that this tendency is still present but harder to detect. Chromium also causes the stream to be finer and less dense. With an increase of chromium content the stream darkens and disappears until in the neighborhood of 30 per cent chromium the stream disappears.

When nickel is added with chromium to a steel the stream is quite characteristic of the chromium content equivalent to the summation of the nickel and chromium present.

The stream varies little from a typical chromium stream when vanadium is added with the chromium. Some spearpoints appear in the stream due to the vanadium.

Molybdenum in the quantities regularly added causes the rays to be tipped with spearpoints. This effect can be killed with raising of the carbon content, but by increasing the molybdenum content the phenomenon can be made to appear in steels of as high as 1 per cent carbon. Of the steels examined in the presence of 0.15 per cent carbon, .07 per cent molybdenum will cause spearpoints.

Manganese has an effect on the stream similar to nickel in that of jacketing the burst. Otherwise, its action is very opposite. It whitens the stream and increases the display in general.

Silica causes a club-shaped tongue to appear and suppresses and darkens the stream in general. It requires but a comparatively small amount of silica to kill the stream.

Tungsten causes the stream to darken and as the percentage increases the stream gradually disappears until in general above 18 per cent tungsten no spark stream appears. Tungsten also gives a characteristic burst and tongue.

The pellet test may be applied to steels in special cases to differentiate one analysis from another. In the S.A.E. steels each series has the same type pellet with but few exceptions. An increase of carbon content tends to emphasize the alloy characteristics. Nickel pellets resemble plain carbon pellets while chromium, molybdenum, silica and vanadium impart shades and shapes to the pellets whereby they may be told one from the other. Unlike the spark test the pellet test cannot be used to show the carbon content. Using ordinary equipment for the examination of pellets, daylight is the best source of illumination.

Conclusion

The spark test may be used for classifying steels as to like analysis, but cannot be successfully used as a means of identifying an unknown steel.

The spark test is likely the most rapid sorting method for mixed lots of steel containing two or three different analysis.

Each alloy investigated showed a different spark stream characteristic.

Pellets of chromium, molybdenum, silica and in some cases vanadium, may be identified as such.

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