Report of Investigations 7902

Spark-Shower Radiance of Metal Grinding Sparks

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UNITED STATES DEPARTMENT OF THE INTERIOR
Rogers C. B. Morton, Secretary

BUREAU OF MINES
Thomas V. Falkie, Director

This publication has been cataloged as follows:

Kelley, John E

Spark-shower radiance of metal grinding sparks, by John E. Kelley and Robert Blickensderfer. [Washington] U.S. Bureau of Mines [1974]

25 p. illus., tables. (U.S. Bureau of Mines. Report of investigations 7902)

Includes bibliography.

1. Spark tests. 2. Metals—Testing. I. U.S. Bureau of Mines. II. Blickensderfer, Robert, jt. auth. III. Title. (Series)

TN23.U7 no. 7902 622.06173

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SPARK-SHOWER RADIANCE OF METAL GRINDING SPARKS

by

John E. Kelley[1] and Robert Blickensderfer[2]

ABSTRACT

A method for measuring the spark-shower radiance of metals when abraded on a grinding wheel was developed by the Bureau of Mines for evaluating the sparking tendency of metals. The radiance was measured in units of emissive power per solid angle per area of the detector. Over 100 metals were tested and rated relative to commercially pure iron. The metals tested included elemental metals, iron binary and ternary alloys, iron-carbon ternary alloys, commercial steels, nonferrous alloys, and a few hard-metal compounds. Some alloys were synthesized; others were obtained commercially. Alloys that possessed good strength properties were emphasized for selection. The results indicate that the spark-shower radiance of plain carbon steels and carbon alloy steels was greater than that of pure iron. Certain elements, particularly vanadium and chromium, reduced the sparking tendency of iron. Stainless steels and particularly nickel alloys displayed low spark-shower radiance. Some metallic elements had much lower radiance than iron; others, much greater. Plain carbon steels, heat treated to a variety of hardnesses, gave radiance values that generally increased with increasing hardness.

The effect on sparking tendency of an increase in hardness of an alloy steel was studied. The sparking tendency increased with an increase in hardness to a maximum, then decreased with a further increase in hardness.

INTRODUCTION

One of the hazards of using many types of metals in explosive or flammable atmospheres is that frictional sparks from the metals can cause ignitions with subsequent loss of life and property. A serious ignition hazard sometimes occurs in coal mines, where "firedamp"--a mixture of methane and air--is ignited by frictional sparks or hot spots when steel mining machinery abrades hard rock strata or rock inclusions adjacent to or in coal seams. The Bureau of Mines, Albany Metallurgy Research Center, Albany, Oreg., is engaged in research to find alloys that will have the necessary strength and wear properties for use as coal-cutter picks and continuous-mining machines but will have

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a reduced tendency to ignite "firedamp" during mining operations. Funds for this research have been provided under the Coal Mine Health and Safety Research Program.

Coward and Ramsey (4),[3] Hartmann (6), Powell (9), and Titman (16) reported investigations of ignitions in coal mines by frictional sparks. Titman concluded that the ignition hazard depended upon the character of the sparks produced by friction between metals or metals and rocks. Discrete sparks flying through air-methane were not too dangerous unless they were arrested by some object, except when the particles burned rapidly enough to generate very high temperatures (about 1,800° C).

There have been many types of spark incendivity tests reported for sparks from steels and other metals abrading against rock. Powell (9) reports that low-carbon and high-chromium steels showed reduced sparking. However, Hartmann (6) and Titman (16) claimed that experiments in Germany and England showed that the metal was not the important factor in production of ignitions. In the case of abrasions or impacts of metal on rock, the type of mineral was reported to be the important factor in the production of dangerous sparks (1, 6-7, 10-11). The most dangerous types of rocks were quartzite, sandstone, and "sulfur balls," which are a calcium-magnesium carbonate containing some carbon and iron pyrites. Studies by Nagy and Kawenski (8) and Rae (12) showed that ignitions depended upon test conditions such as angle of impact and the velocity, pressure, and energy dissipated in the impact. Other factors, such as the temperature reached by frictional sparks, were reported (13). Riezler and Hardt (15) reported that grinding sparks from high-carbon steels reached as high as 1,720° C in air, and Wahl (17) found that about 1,850° C was reached by 1 pct carbon steel sparks in air. Rae (14) showed that the minimum ignition temperature of "firedamp" depended strongly upon the size of the ignition particle or body and on the concentration of methane in air; temperatures ranged from 1,050° to 1,468° C. Nowhere in the literature was any study found reporting a quantitative measure of the sparking tendency of abraded metals.

The spark-shower radiance test was developed to provide a quick screening test for a measure of the sparking tendency of a large number of metals. Earlier work in this laboratory (3) gave a good correlation between spark-shower radiance in air and incendivity of the sparks in an explosive mixture of hydrogen and air. Therefore the results of the spark-shower radiance test can be used to indicate the degree of hazard of sparks from a metal in a sensitive explosive atmosphere. The present work is an extension of the earlier work. The objective of this study was to use the radiance test to (1) determine the effect of composition of some iron alloys and steels on the sparking tendency, (2) determine the effect of hardness on the sparking tendency of steel, and (3) measure the spark-shower radiance of additional metals and alloys for aiding the selection of metals for further incendivity research.

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[3]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

ACKNOWLEDGMENTS

Appreciation is extended to Peter Romans, supervisory research physicist, for much help with the design and selection of the optical-electronic systems for measuring spark-shower radiance, and to Mark Copeland, metallurgist, for providing a great amount of assistance with alloy design and preparation. Lloyd Bazant is also greatly acknowledged for help with the many photographs.

EQUIPMENT AND EXPERIMENTAL PROCEDURE

The spark-shower radiance test equipment was described in reference 3. The metal sample was applied against a rotary abrasive wheel with a constant radial force while the radiance of the resulting spark shower was measured. The test conditions chosen to optimize reproducibility were as follows: 10-pound radial force between the specimen and the wheel, 1,750-rpm wheel speed, a 6-inch-diameter Alundum[4] wheel of 60 grit and medium bond, and a 150° conical point on the test specimen. Duplicate runs were made on each material investigated, and the radiance values were averaged. The radiance values are in units of emissive power per solid angle per unit area of the detector, microwatts per steradian per square centimeter ($\mu W/sr\text{-}cm^2$). The values indicate the average radiance integrated over the total spark shower and are not indicative of the radiance of an individual spark. Reproducibility of the radiance value was within ±5 pct of the mean.

A photographic record of each test was made by taking color pictures of the spark shower at the time the maximum radiance occurred. This maximum radiance was determined by observing the strip chart display, which was recording the radiant flux meter output and is the spark-shower radiance value used in the tables. The color photographs were reproduced in black and white for this report.

Reproducibility of the spark-shower radiance measurements was checked by making repeated tests on commercially pure iron specimens along with each group of metals tested. For all radiance measurements on commercially pure iron, the radiance was 787±50 $\mu W/sr\text{-}cm^2$.

The test procedure was as follows: A specimen was mounted in the holder on the lever arm and positioned to assure that the load force was radial. The specimen was rested on the grinding wheel, the wheel started, and a photograph taken at the maximum radiance. To prevent chatter of the specimen and subsequent erroneous data, the wheel was dressed and trued with a diamond nib before each test. When the wheel became worn to 5-5/8 inches diameter, it was replaced with a new wheel.

All of the test results in this report were established with a certain given set of test conditions. These conditions were established experimentally to give the most consistent reproducibility of radiance data. Spark-shower radiance tests were attempted on duplicate specimens at

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[4] Reference to specific equipment is made for identification only and does not imply endorsement by the Bureau of Mines.

5-, 10-, 15-, 20-, and 25-pound sample loads, and the 10-pound load was found to give the most consistent results. With a 5-pound load, the radiance was not high enough to measure with consistent results, and with 15-, 20-, and 25-pound loads, the grinding wheels filled with metal that caused erratic radiance results. The radial specimen load was controlled; however, the tangential specimen load varied as the coefficient of friction of the metal and the temperature varied in an unknown manner.

The 60-grit Alundum grinding wheel of moderate bond was chosen because it best fulfilled the overall requirements; it did not fill with metal as quickly as did a finer 120 grit wheel, and it gave more uniform spark showers than did a coarser 16 or 46 grit wheel. Hard bond wheels also tended to fill with metal rapidly, and soft bond wheels wore down too rapidly. The wheel used was a Norton 32A60-I8VBE.

A special specimen shape was developed by experimentation. First tests were made on 3/8-inch-square specimens with flat ends, but the spark-shower radiance results were not consistent. The tests were repeated with the same specimens after grinding the ends lightly on the 6-inch-diameter wheel to dress them into the wheel shape, but the results were only slightly more consistent. The concept of using a pointed specimen was tried, and after testing several point angles, the most consistent results were obtained with the 150° point. Also, less chatter of the specimen on the grinding wheel occurred with the pointed specimens.

The specimens that were synthesized in this laboratory were made by vacuum arc melting. Buttons of approximately 100 grams were melted by a tungsten electrode. The specimens were given a homogenization heat treatment prior to hot forging into approximately 3/8-inch-square cross section. Specimens were then annealed or heat treated for hardening and then machined to size.

RESULTS AND DISCUSSION

Relative Radiance of Metals and Alloys Tested

The relative spark-shower radiance values for 100 metals and metal alloys are depicted in the bar graph on figure 1. The radiance values have been normalized so that commercially pure iron has a value of 1.000. The alloy steels, tool steels, and plain carbon steels all produced greater spark-shower radiance than did commercially pure iron; some were two to three times greater.

Many of the metals produced less spark-shower radiance than did the commercially pure iron. Especially promising as low-sparking, high-strength metals are tungsten, 304 and 316 stainless steels, 17-4 PH stainless steel, chromium, molybdenum, nickel, and nickel-base alloys such as Inconel, Monel, and Rene 41. Softer, lower strength metals such as copper, brass, aluminum, zinc, magnesium, and beryllium-bronze produced no sparks under the test conditions described. However, one must not be misled into a false sense of security about the use of truly nonsparking metals. Garner (5) reports that

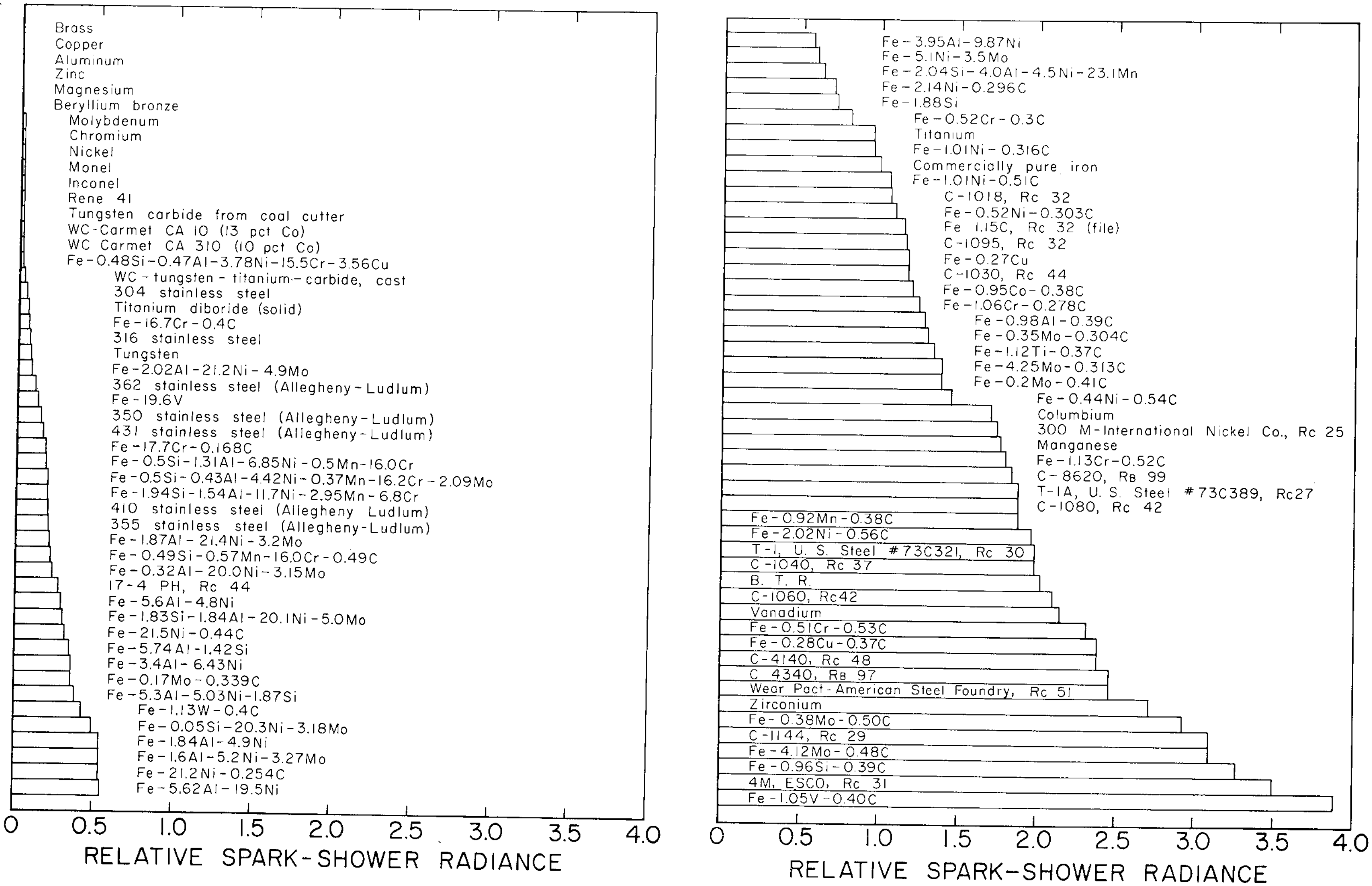

FIGURE 1. - Relative spark-shower radiance of metals.

under some conditions, nonsparking metals do give incendive impacts with stone or concrete in the presence of petroleum vapors and with steel in the presence of hydrogen. Anfenger and Johnson (2) warn that the term "nonsparking tool" is really a misnomer, because such tools can produce sparks under certain conditions, even if the metal itself cannot be sparked.

Effect of Composition

Elemental Metals

A group of elemental metals was tested, and the spark-shower radiance values are shown in table 1. Copper, aluminum, zinc, and magnesium showed no sparking at all under the test conditions described previously. Molybdenum, chromium, nickel, and tungsten showed very low sparking tendency, and titanium, vanadium, columbium, and manganese had a medium range of sparking radiance much similar to that of commercially pure iron. Only zirconium showed a high sparking tendency, about the same as that of some of the tool steels. It was obvious by naked eye and color photographs that the temperature of sparks from the reactive metals such as Ti, Cb, and Zr was much higher than the temperature of the steel sparks. Four photographs of the spark showers of elemental metals are reproduced in figure 2.

TABLE 1. - Spark-shower radiance of some elemental metals

Element	Spark-shower radiance, $\mu W/sr\text{-}cm^2$	Hardness, Rockwell
Aluminum	0	-
Chromium	<10	B 72
Columbium	1,333	B 95
Copper	0	-
Iron	787	B 22
Magnesium	0	-
Manganese	1,367	-
Molybdenum	<10	B 89
Nickel	<10	B 90
Titanium	743	B 88
Tungsten	60	C 45
Vanadium	1,758	B 51
Zinc	0	-
Zirconium	2,133	B 87

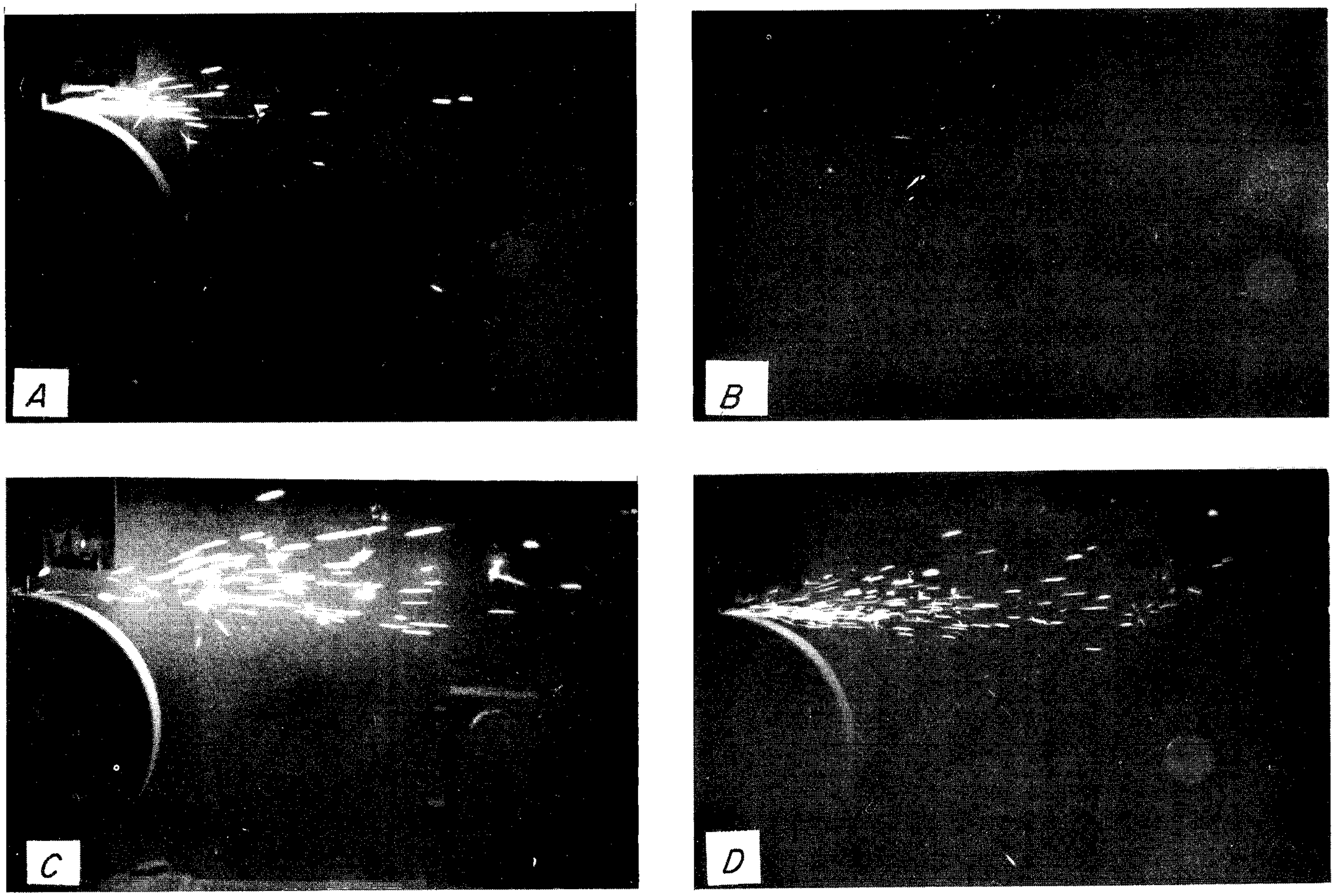

FIGURE 2. - Spark showers from elemental metals. *A*, Titanium; *B*, chromium; *C*, zirconium; *D*, vanadium.

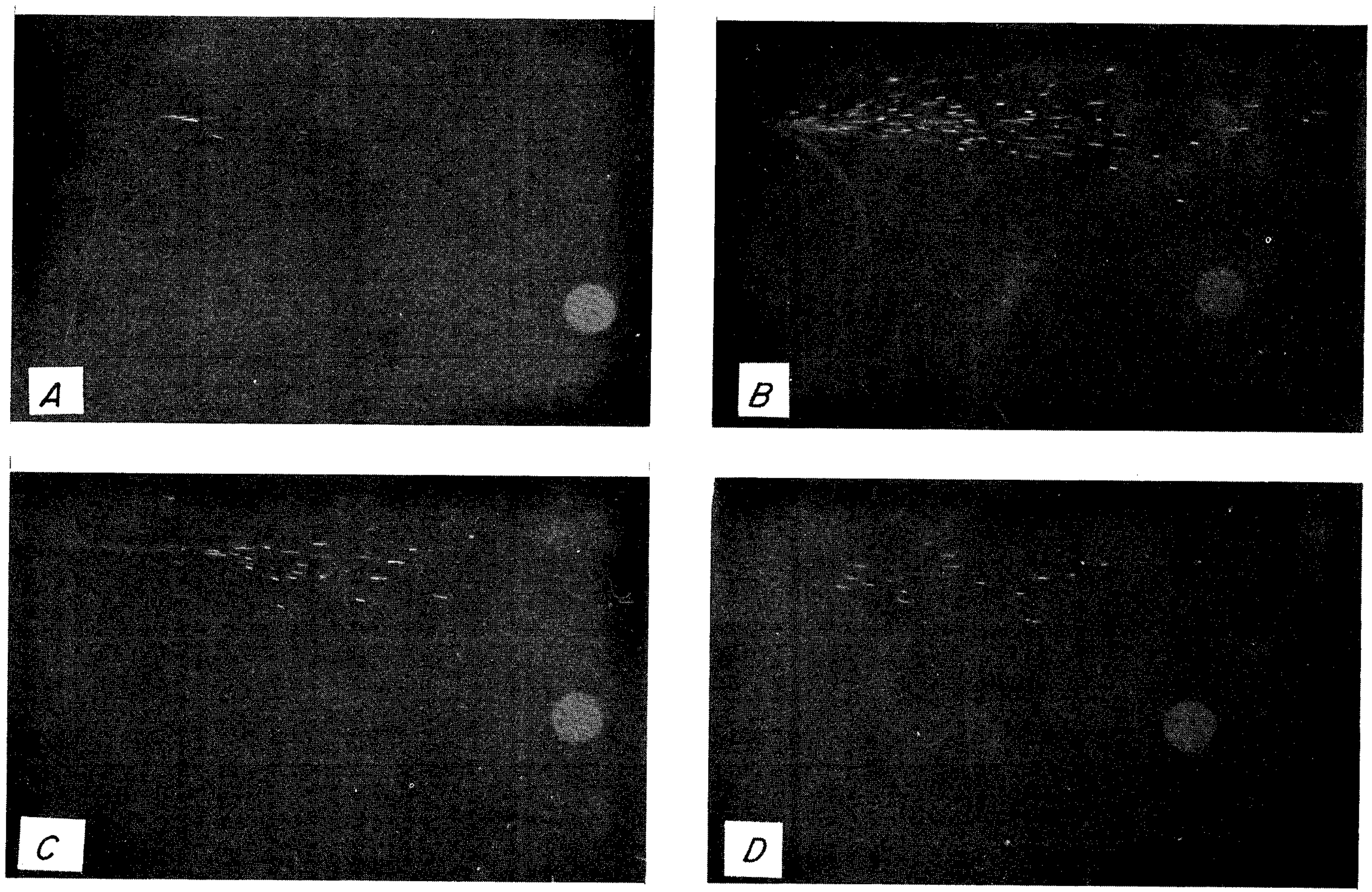

FIGURE 3. - Spark showers from iron-base alloys. *A*, Fe-20.0 V; *B*, Fe-2.0 Si; *C*, Fe-6.0 Al-2.0 Si; *D*, Fe-2.0 Si-1.5 Al-11.0 Ni-3.0 Mn-8.0 Cr.

Iron-Base Alloys

Three series of alloys were synthesized and tested to determine the effect of some alloying elements on the sparking tendency of iron. One series of binary alloys consisted of iron with Al, Si, Ni, Mo, V, Cu, Mn,Cr, Ti, Co, and W in amounts near their respective solubility limits in iron. The radiance results for these binary iron alloys are shown in table 2 and range over a factor of 30. Photographs of typical spark showers of these and the following alloys are illustrated in figure 3.

TABLE 2. - Spark-shower radiance of binary iron alloys

Nominal composition, wt-pct	Analyzed composition, wt-pct	Spark-shower radiance, $\mu W/sr\text{-}cm^2$	Hardness, Rockwell
Fe-20V.......	Fe-19.6V......	100	B 95
Fe-20Cr......	Fe-17.3Cr.....	162	A 53
Fe-20Ni......	Fe-22.5Ni.....	377	A 63
Fe-2Si.......	Fe-1.88Si.....	563	B 80
Fe-10Al......	Fe-10.0Al.....	593	A 61
Fe-6Si.......	Fe-5.77Si.....	701	A 66
Fe-0.3Cu.....	Fe-0.27Cu.....	913	B 37
Fe-20Co......	Fe-15.1Co.....	970	A 56
Fe-5W........	Fe-3.78W......	1,100	A 49
Fe-5Mo.......	Fe-2.34Mo.....	1,703	A 56
Fe-3Ti.......	Fe-3.23Ti.....	2,911	A 59
Fe-20Mn......	Fe-18.0Mn.....	3,180	A 67

The second and third series of iron alloys were synthesized with combinations of Al, Ni, Si, and Mo. The radiance values of the ternary alloys, as shown in table 3, were all less than that of pure iron. The radiance values of the quaternary alloys are given in table 4 and are generally less than the radiance of the ternary alloys.

TABLE 3. - Spark-shower radiance of ternary iron alloys

Nominal composition, wt-pct	Analyzed composition, wt-pct	Spark-shower radiance, $\mu W/sr\text{-}cm^2$	Hardness, Rockwell
Fe-6Al-5Ni.....	Fe-5.6Al-4.8Ni......	230	C 33
Fe-6Al-2Si.....	Fe-5.74Al-1.92Si....	270	C 22
Fe-4Al-7Ni.....	Fe-3.4Al-6.43Ni.....	280	C 41
Fe-2Al-5Ni.....	Fe-1.84Al-4.9Ni.....	415	C 33
Fe-6Al-20Ni....	Fe-5.62Al-19.5Ni....	440	C 51
Fe-4Al-10Ni....	Fe-3.95Al-9.87Ni....	445	C 45
Fe-5Ni-5Mo.....	Fe-5.1Ni-3.2Mo......	595	C 33

TABLE 4. - Spark-shower radiance of iron-nickel quaternary alloys

Nominal composition, wt-pct	Analyzed composition, wt-pct	Spark-shower radiance, μW/sr-cm²	Hardness, Rockwell
Fe-20Ni-2Al-10Mo......	Fe-21.2Ni-2.02Al-4.9Mo......	70	B 88
Fe-20Ni-2Al-5Mo.......	Fe-21.4Ni-1.87Al-3.2Mo......	170	C 52
Fe-20Ni-0.5Al-5Mo.....	Fe-20.0Ni-0.32Al-3.15Mo.....	185	C 42
Fe-5Ni-6Al-2Si........	Fe-5.03Ni-5.43Al-1.87Si.....	295	C 40
Fe-20Ni-2Si-5Mo.......	Fe-20.3Ni-0.05Si-3.18Mo.....	380	C 50
Fe-5Ni-2Al-5Mo........	Fe-5.2Ni-1.6Al-3.27Mo.......	415	C 38

Plain Carbon Steels

The effect of carbon content at several hardness levels on spark-shower radiance in plain carbon steels was studied. Specimens were machined from commercially available stock of C-1018, C-1030, C-1040, C-1060, C-1080, C-1095, and a high-carbon specimen that contained 1.15 wt-pct carbon. Prior to testing, the specimens were austenitized, quenched, and tempered to produce a desired hardness. As shown in figure 4, the spark-shower radiance increased about 1-1/2 times as the carbon content increased from 0.18 wt-pct to 0.60 wt-pct for a given hardness level. Further increases in carbon content produced a reduction in the spark-shower radiance as the carbon

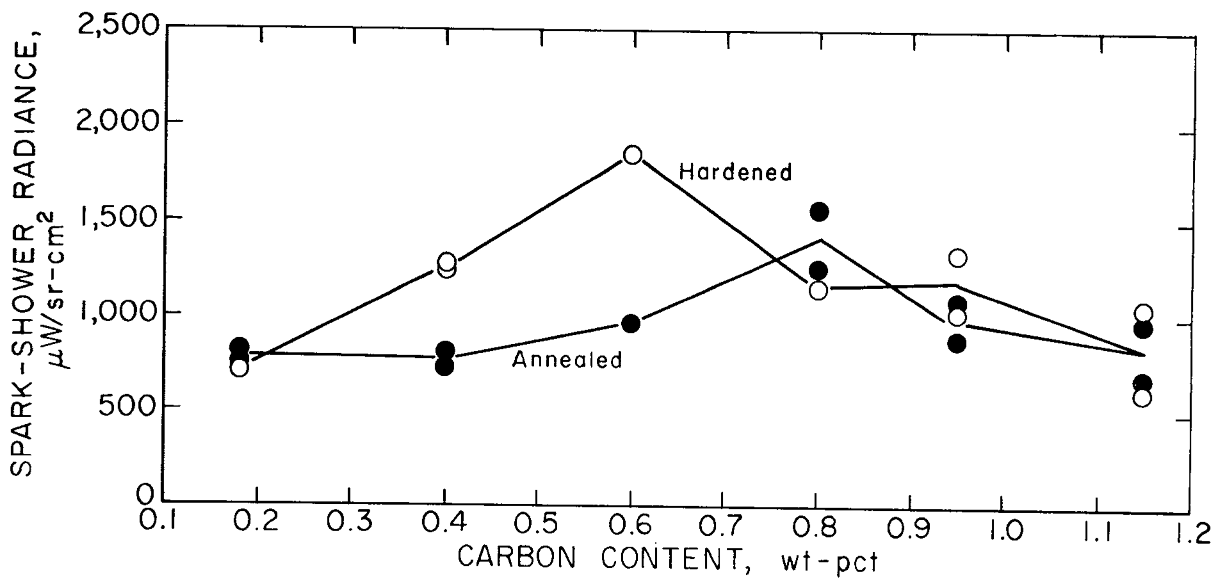

FIGURE 4. - Effect of carbon on spark-shower radiance of steel.

content reached 1.15 wt-pct. This same relationship can be seen in the photographs of the spark showers illustrated in figure 5. The cause of the peaks and reversal in spark-shower radiance versus carbon content curves could be many complex interacting factors such as spark temperatures, melting point changes in steel with varying carbon contents, particle size and surface area effects, and machinability. M'Combe (7) also reported a decrease in sparking in carbon steels with an increase of carbon above 0.6 wt-pct carbon.

Alloy Steels

The effect of certain alloying elements on the radiance of steels synthesized to contain a nominal 0.40 wt-pct carbon can be seen in table 5. Photographs of several spark showers are reproduced in figure 6. The sample containing tungsten produced the lowest radiance value. Several of the elemental additions caused radiance much greater than that of plain carbon steel. The effects of vanadium are especially interesting. As mentioned earlier, vanadium in pure iron resulted in the lowest radiance of the binary alloys tested. Vanadium in mild carbon steel, however, caused the greatest radiance among these ternary alloys. This shows that the effects of alloying ingredients on spark-shower radiance is not additive. Vanadium and carbon together in iron produce a synergistic effect on radiance.

TABLE 5. - Spark-shower radiance of ternary steel alloys with 0.40 wt-pct carbon

Nominal composition, wt-pct	Analyzed composition, wt-pct	Spark-shower radiance, $\mu W/sr\text{-}cm^2$	Hardness, Rockwell
Fe-0.40C-1.0W....	Fe-0.40C-1.13W....	332	B 86
Fe-0.40C-1.0Co...	Fe-0.38C-0.95Co...	942	B 48
Fe-0.40C-1.0Al...	Fe-0.39C-0.98Al...	996	B 82
Fe-0.40C-1.0Ti...	Fe-0.37C-1.12Ti...	1,050	B 41
Fe-0.40C-1.0Mn...	Fe-0.38C-0.92Mn...	1,467	B 92
Fe-0.40C-0.3Cu...	Fe-0.37C-0.28Cu...	1,880	B 52
Fe-0.40C-1.0Si...	Fe-0.39C-0.96Si...	2,575	B 92
Fe-0.40C-1.0V....	Fe-0.40C-1.05V....	3,050	C 30
Fe-0.40C[1]........	-	787	C 37

[1]Plain carbon steel is given for comparison.

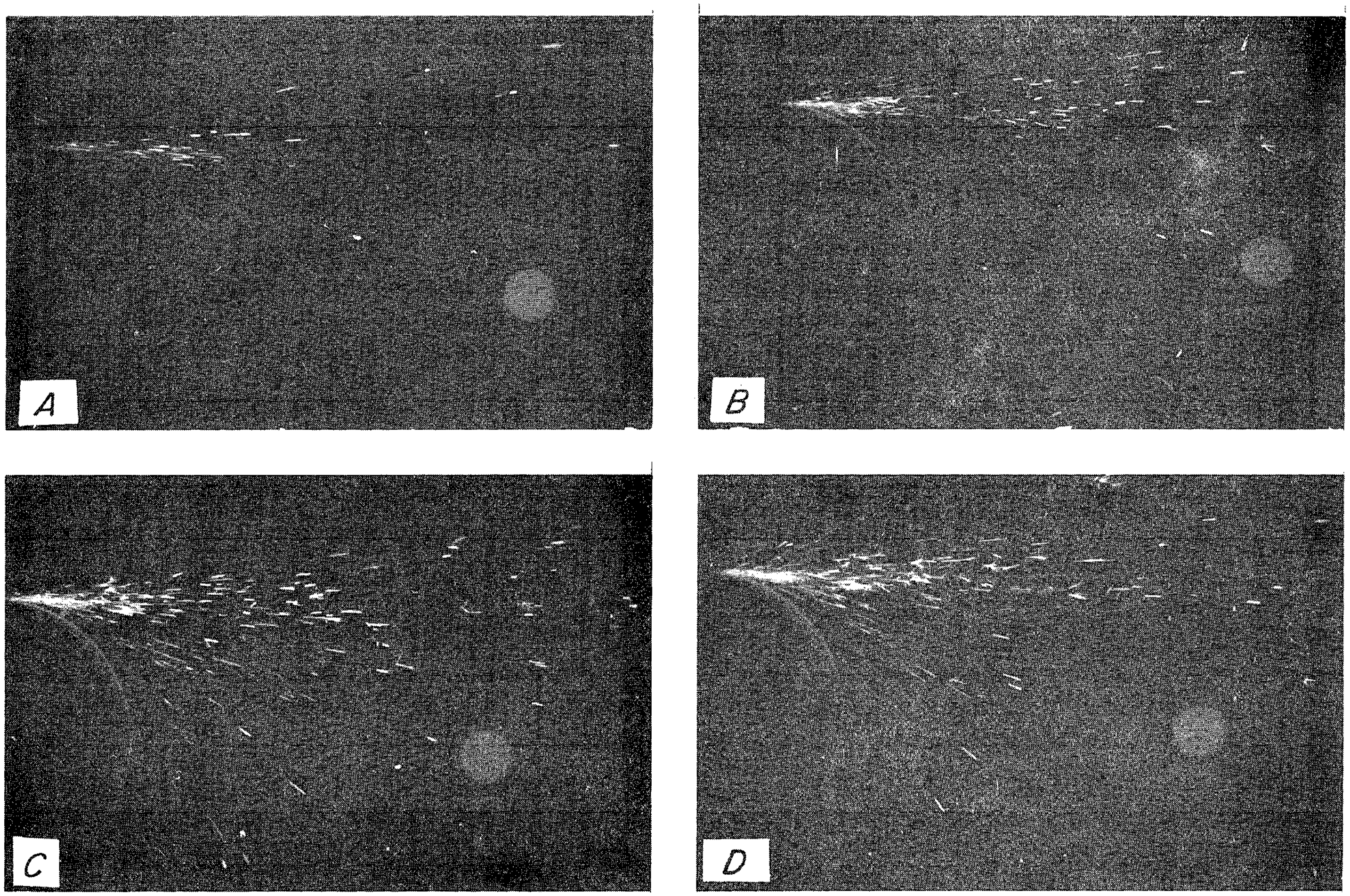

FIGURE 5. - Spark showers from plain carbon steels, Rockwell hardness about C 40. *A*, Commercially pure iron (0 wt-pct carbon); *B*, C-1018 (0.18 wt-pct carbon); *C*, C-1030 (0.30 wt-pct carbon); *D*, C-1040 (0.40 wt-pct carbon).

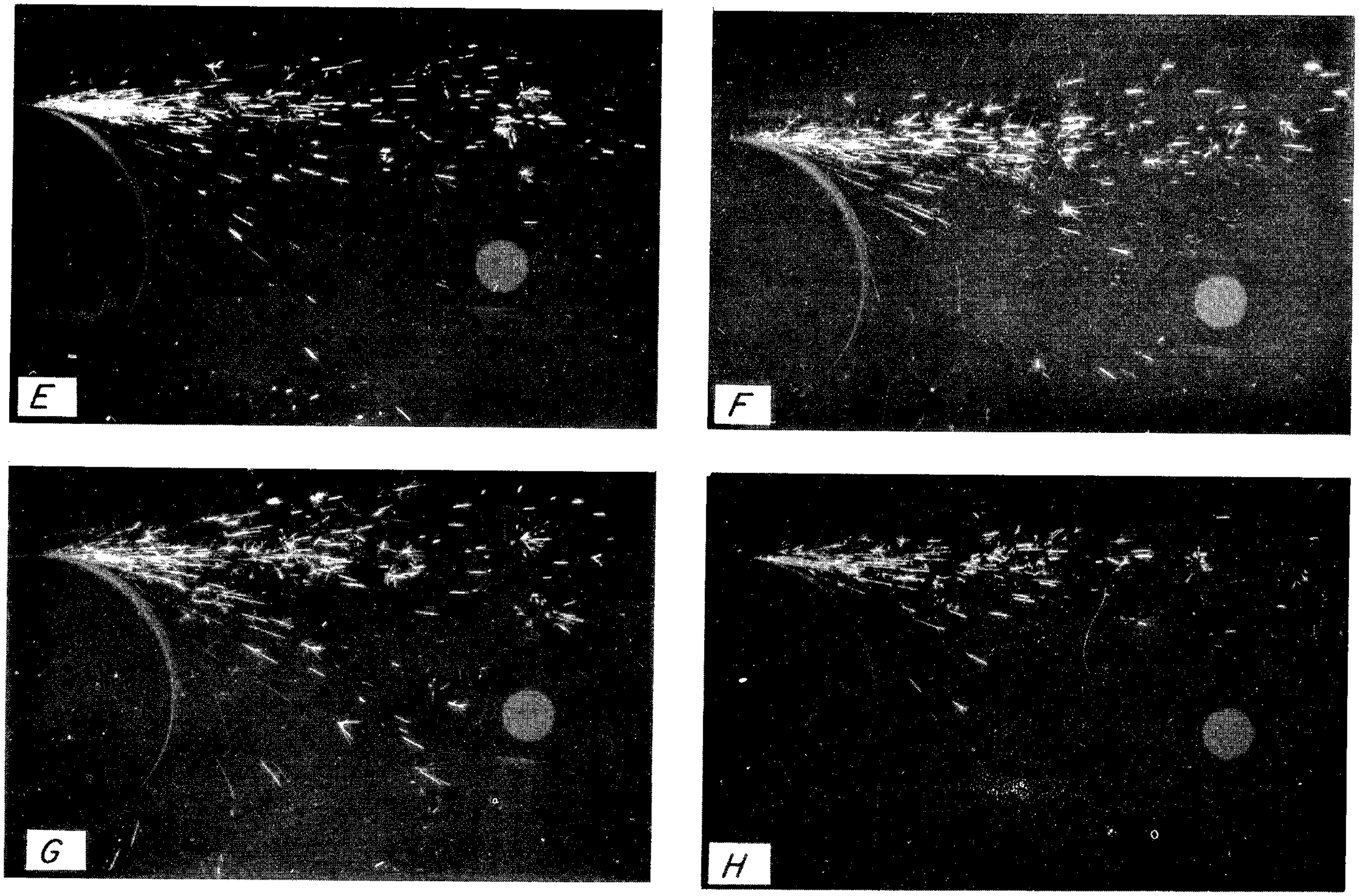

FIGURE 5. - Spark showers from plain carbon steels, Rockwell hardness about C 40.—Continued. *E*, C-1060 (0.60 wt-pct carbon); *F*, C-1080 (0.80 wt-pct carbon); *G*, C-1095 (0.95 wt-pct carbon); *H*, Fe (1.15 wt-pct carbon).

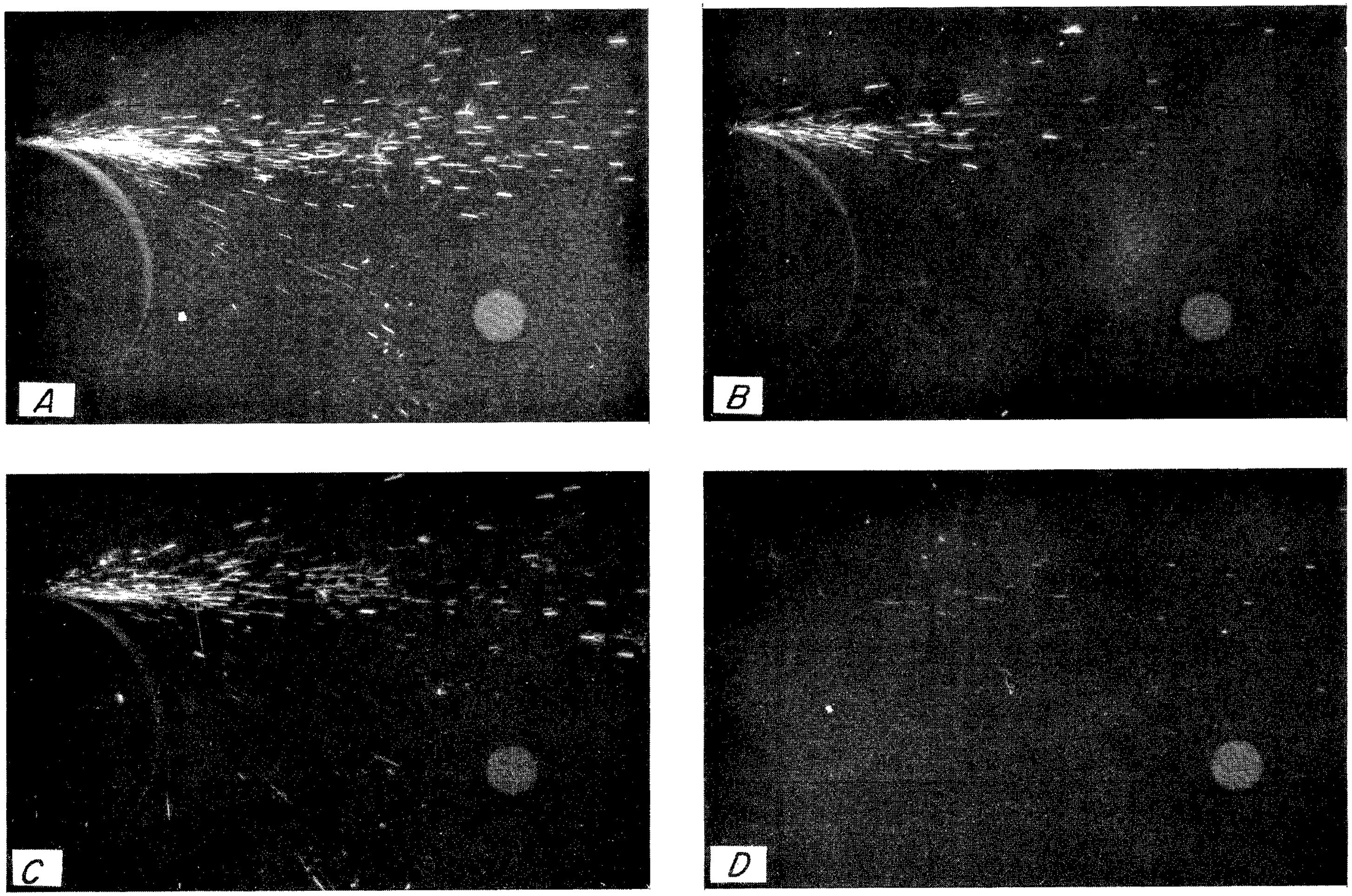

FIGURE 6. - Spark showers from iron-0.40 carbon ternary alloys. *A*, Fe-0.40 C-1.0 Si; *B*, Fe-0.40 C-1.0 Al; *C*. Fe-0.40 C-1.0 V; *D*, Fe-0.40 C-1.0 W.

The effects of Ni, Cr, and Mo on the spark-shower radiance of carbon steels were studied in greater detail. These elements were chosen because they are common ingredients in many of the alloy steels presently used in coal mining machinery. Twenty ternary alloys of iron with either 0.3 or 0.6 wt-pct carbon were prepared by vacuum arc melting. The analyzed compositions are given in table 6. The spark testing was done with the specimens in the annealed condition.

TABLE 6. - Composition of ternary steel alloys

Nominal composition, wt-pct	Analyzed composition, wt-pct
Fe-0.4Cr-0.3C..............	Fe-0.52Cr-0.3C.
Fe-1.0Cr-0.3C..............	Fe-1.06Cr-0.278C.
Fe-20.0Cr-0.3C	Fe-17.7Cr-0.168C.
Fe-0.4Ni-0.3C..............	Fe-0.52Ni-0.303C.
Fe-1.0Ni-0.3C..............	Fe-1.01Ni-0.316C.
Fe-2.0Ni-0.3C..............	Fe-2.14Ni-0.296C.
Fe-20.0Ni-0.3C.............	Fe-21.2Ni-0.254C.
Fe-0.15Mo-0.3C.............	Fe-0.17Mo-0.339C.
Fe-0.3Mo-0.3C..............	Fe-0.35Mo-0.304C.
Fe-5.0Mo-0.3C..............	Fe-4.25Mo-0.313C.
Fe-0.4Cr-0.6C..............	Fe-0.51Cr-0.53C.
Fe-1.0Cr-0.6C..............	Fe-1.13Cr-0.52C.
Fe-20.0Cr-0.6C.............	Fe-16.7Cr-0.47C.
Fe-0.4Ni-0.6C..............	Fe-0.44Ni-0.54C.
Fe-1.0Ni-0.6C..............	Fe-1.01Ni-0.51C.
Fe-2.0Ni-0.6C..............	Fe-2.02Ni-0.56C.
Fe-20.0Ni-0.6C.............	Fe-21.5Ni-0.44C.
Fe-0.15Mo-0.6C.............	Fe-0.20Mo-0.41C.
Fe-0.3Mo-0.6C..............	Fe-0.38Mo-0.50C.
Fe-5.0Mo-0.6C..............	Fe-4.12Mo-0.48C.

The results of the spark-shower radiance tests are shown in figures 7-9. Data are shown for nominal compositions of 0.5, 1.0, 2.0, and 20.0 wt-pct nickel; 0.5, 1.0, and 20.0 wt-pct chromium; and 0.15, 0.3, and 5.0 wt-pct molybdenum. In steels containing 0.3 wt-pct carbon, both chromium and nickel additions reduced sparking; chromium had a greater effect than nickel. At the 0.6 wt-pct carbon level, chromium had an even greater effect on reducing sparking. The effect of molybdenum additions was quite different. Molybdenum additions in the 0.3 wt-pct carbon steel made little significant change in the sparking behavior, but in the 0.6 wt-pct carbon steel, the radiance was nearly tripled with additions of more than 0.3 wt-pct molybdenum. These effects are illustrated by the photographs of the spark showers in figure 10.

The implications of these findings are clear. High chromium and nickel content in carbon steels will reduce the sparking behavior, but molybdenum will not. Stainless steels are therefore prime candidates for low-sparking, high-strength materials. These recommendations were substantiated by some of the results shown in figure 1.

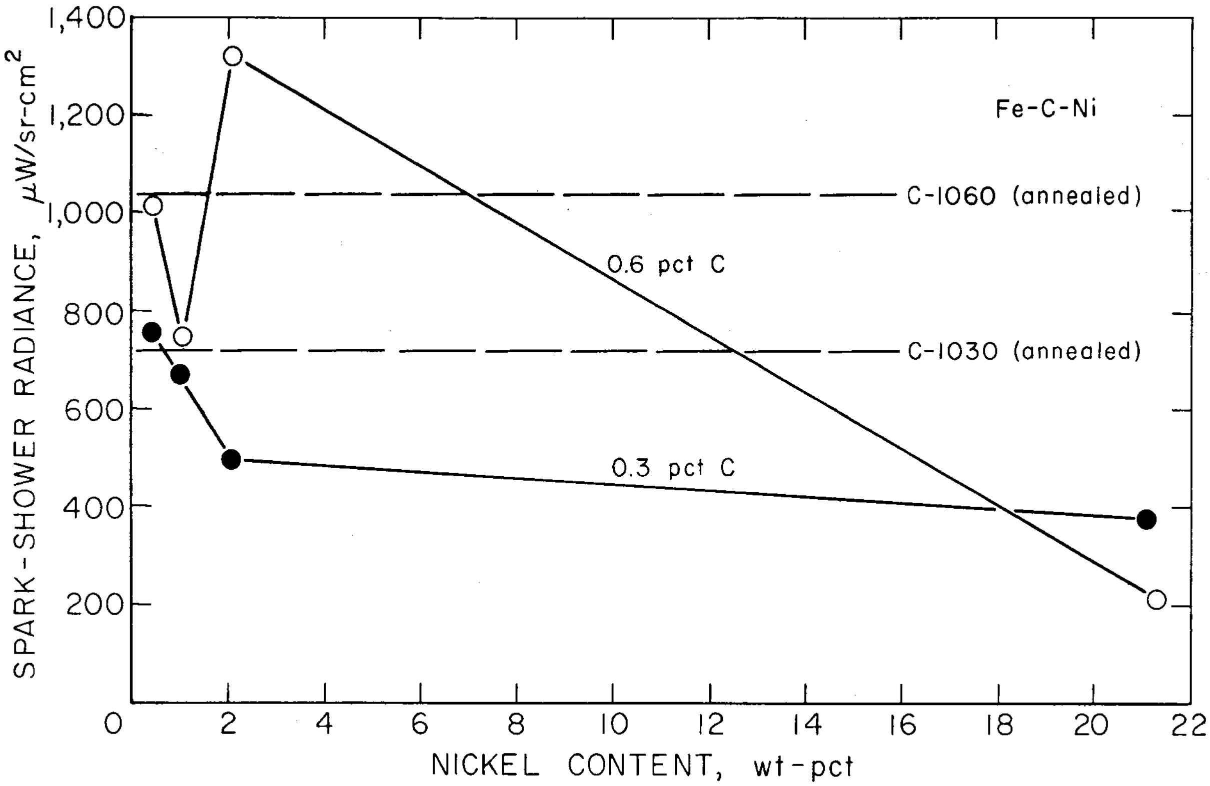

FIGURE 7. - Effect of nickel on spark-shower radiance of steel.

Seven steels containing high nickel or chromium as well as other elements commonly found in stainless steels were made and tested. Only one of these steels contained carbon. The compositions and spark-shower radiance are given in table 7. The precipitation hardening type of stainless steels gave relatively low radiance values, and these steels have the additional advantage of considerable strength and toughness.

TABLE 7. - Spark-shower radiance of alloy steels with high nickel-chromium

Nominal composition, wt-pct	Analyzed composition, wt-pct	Spark-shower radiance, μW/sr-cm²	Hardness, Rockwell
Fe-0.5Si-1.25Al-7Ni-0.5Mn-17Cr	Fe-0.5Si-1.31Al-6.85Ni-0.5Mn-16.0Cr.	145	C 39
Fe-0.5Si-0.5Al-4Ni-16.5Cr-4Cu.	Fe-0.48Si-0.47Al-3.78Ni-15.5Cr-3.56Cu.	150	C 40
Fe-2Si-1.5Al-11Ni-3Mn-8Cr.....	Fe-1.94Si-1.54Al-11.7Ni-2.95Mn-6.8Cr.	155	C 52
Fe-0.5Si-0.5Al-4.5Ni-0.5Mn-2.5Mo-17Cr.	Fe-0.5Si-0.43Al-4.42Ni-0.37Mn-2.09Mo-16.2Cr.	155	C 25
Fe-0.5Si-0.5Mn-18Cr-0.6C......	Fe-0.49Si-0.57Mn-16.0Cr-0.49C..	175	C 35
Fe-2Si-2Al-20Ni-5Mo...........	Fe-1.83Si-1.84Al-20.1Ni-5.0Mo..	235	C 51
Fe-2Si-4Al-4Ni-24Mn...........	Fe-2.04Si-4.0Al-4.5Ni-23.1Mn...	495	C 27

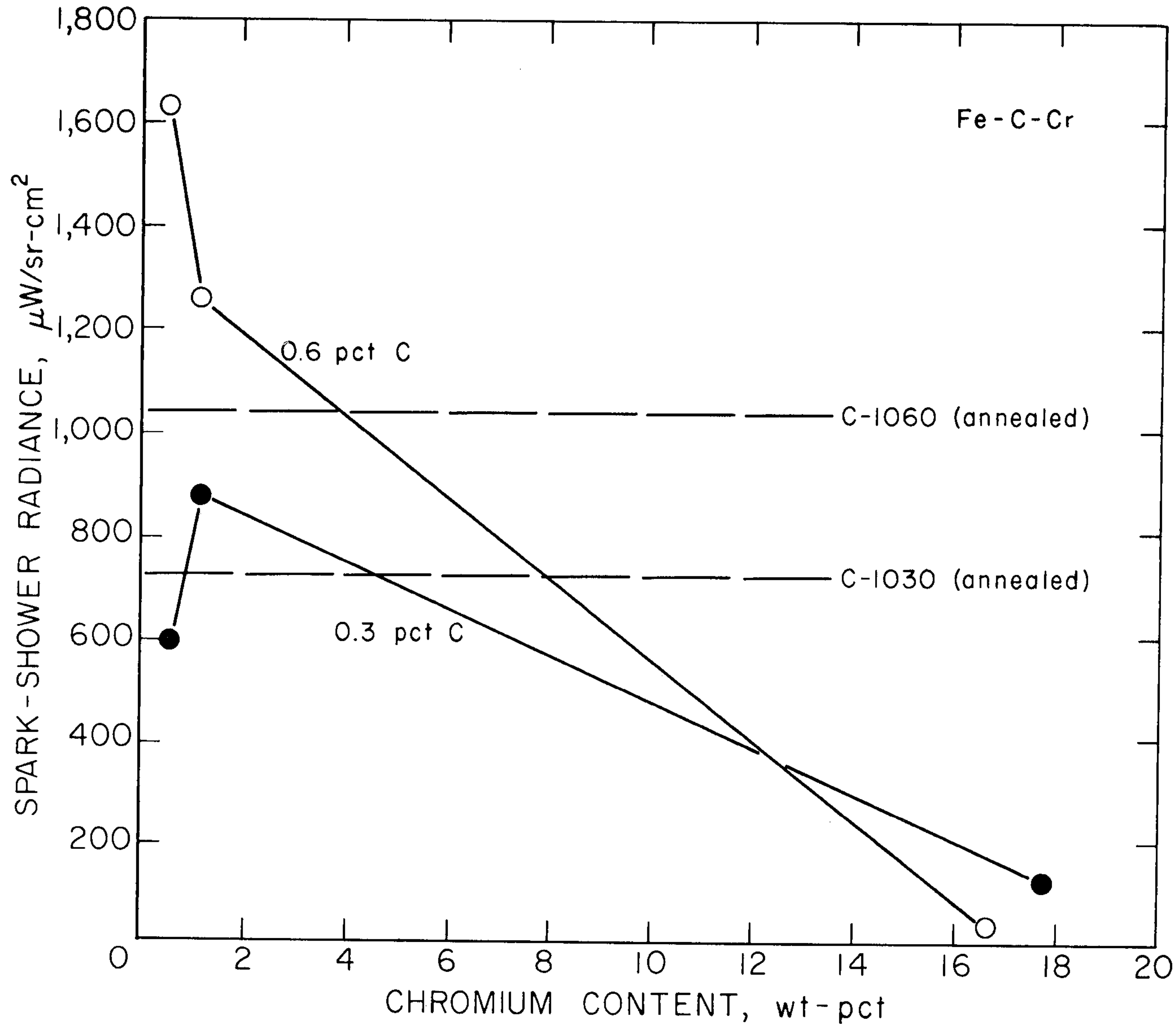

FIGURE 8. - Effect of chromium on spark-shower radiance of steel.

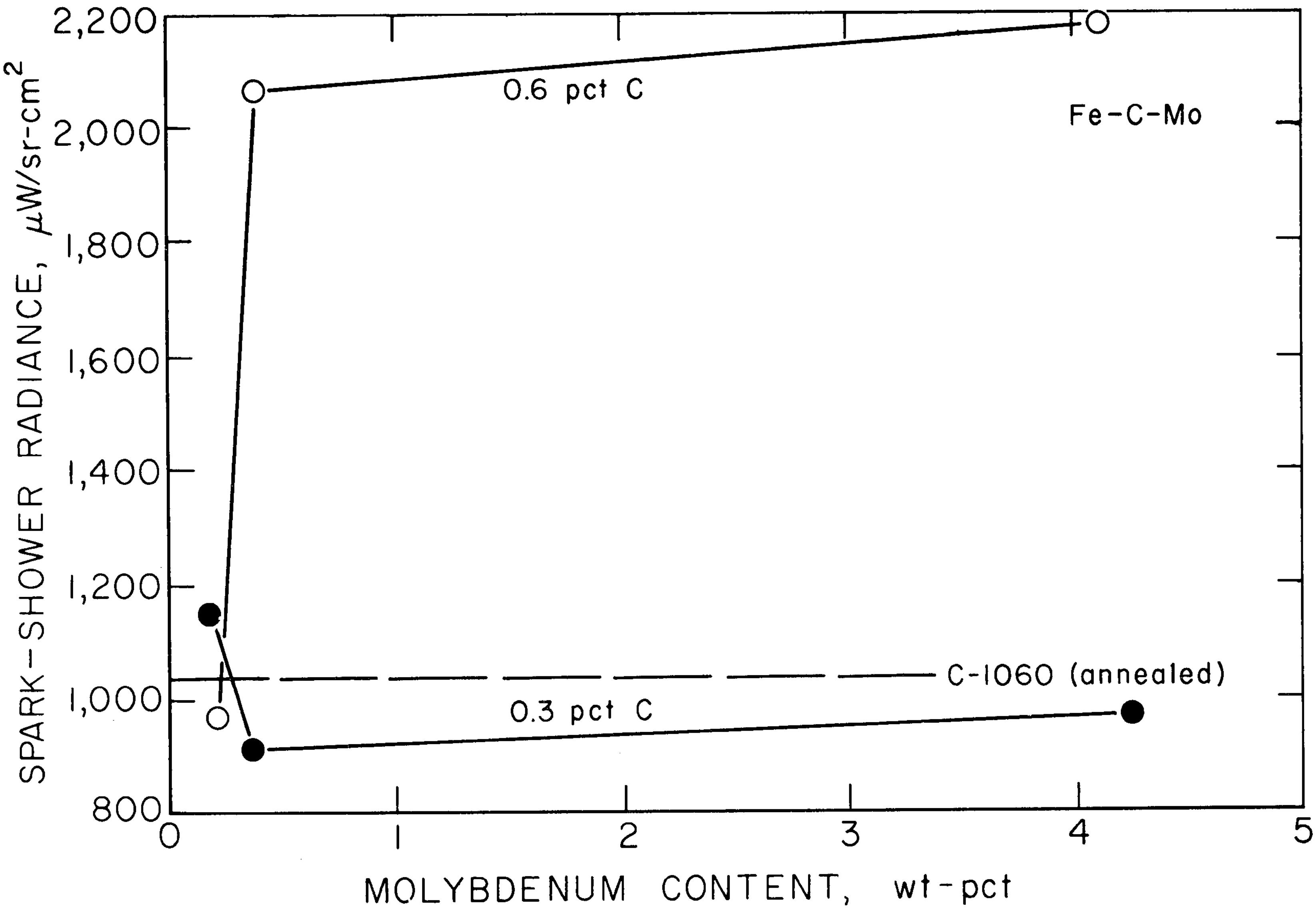

FIGURE 9. - Effect of molybdenum on spark-shower radiance of steel.

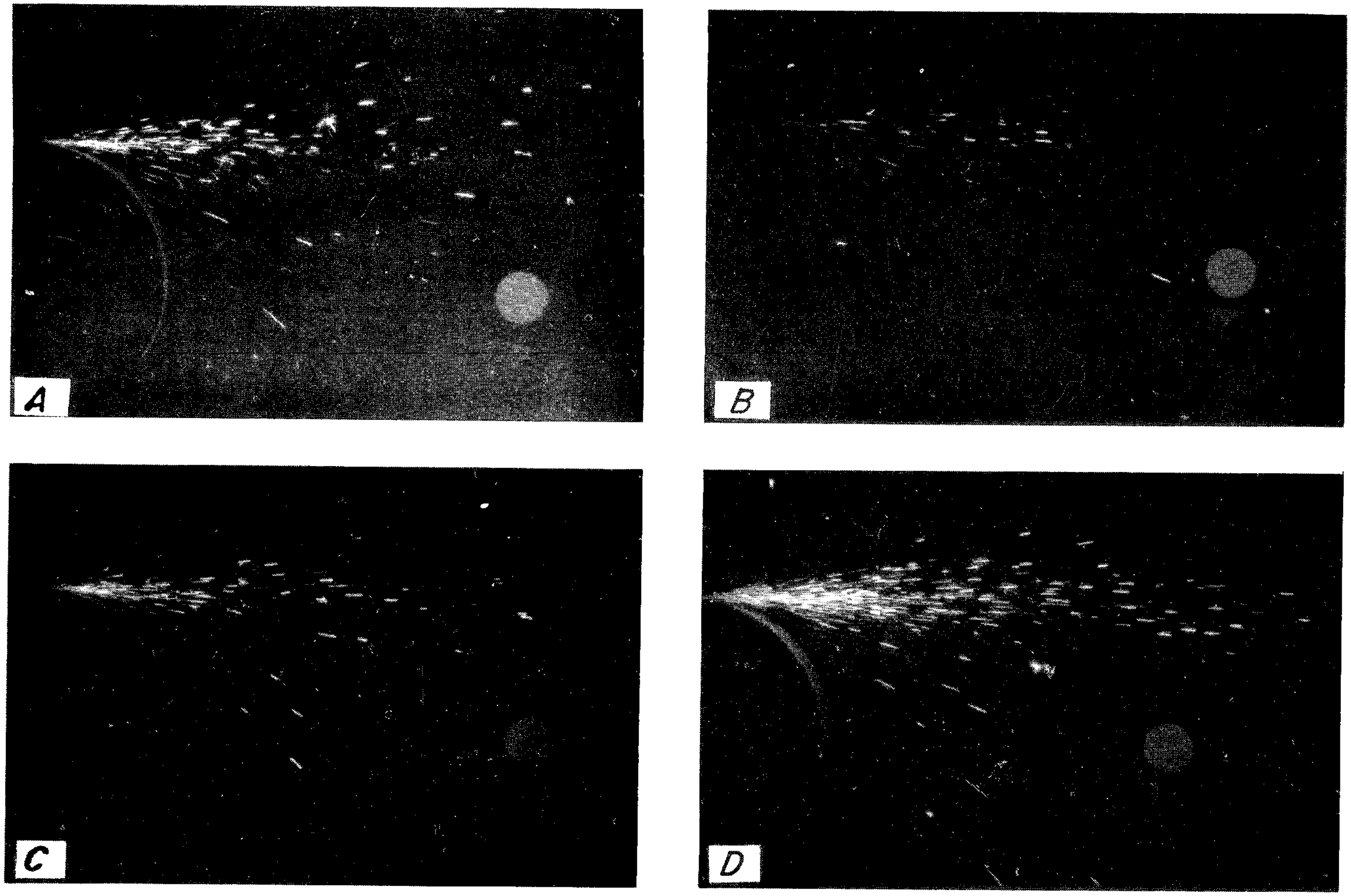

FIGURE 10. - Spark showers from carbon steel containing molybdenum and nickel. *A*, Fe-0.54 C-0.44 Ni; *B*, Fe-0.44 C-21.5 Ni; *C*, Fe-0.41 C-0.2 Mo; *D*, Fe-0.48 C-4.12 Mo.

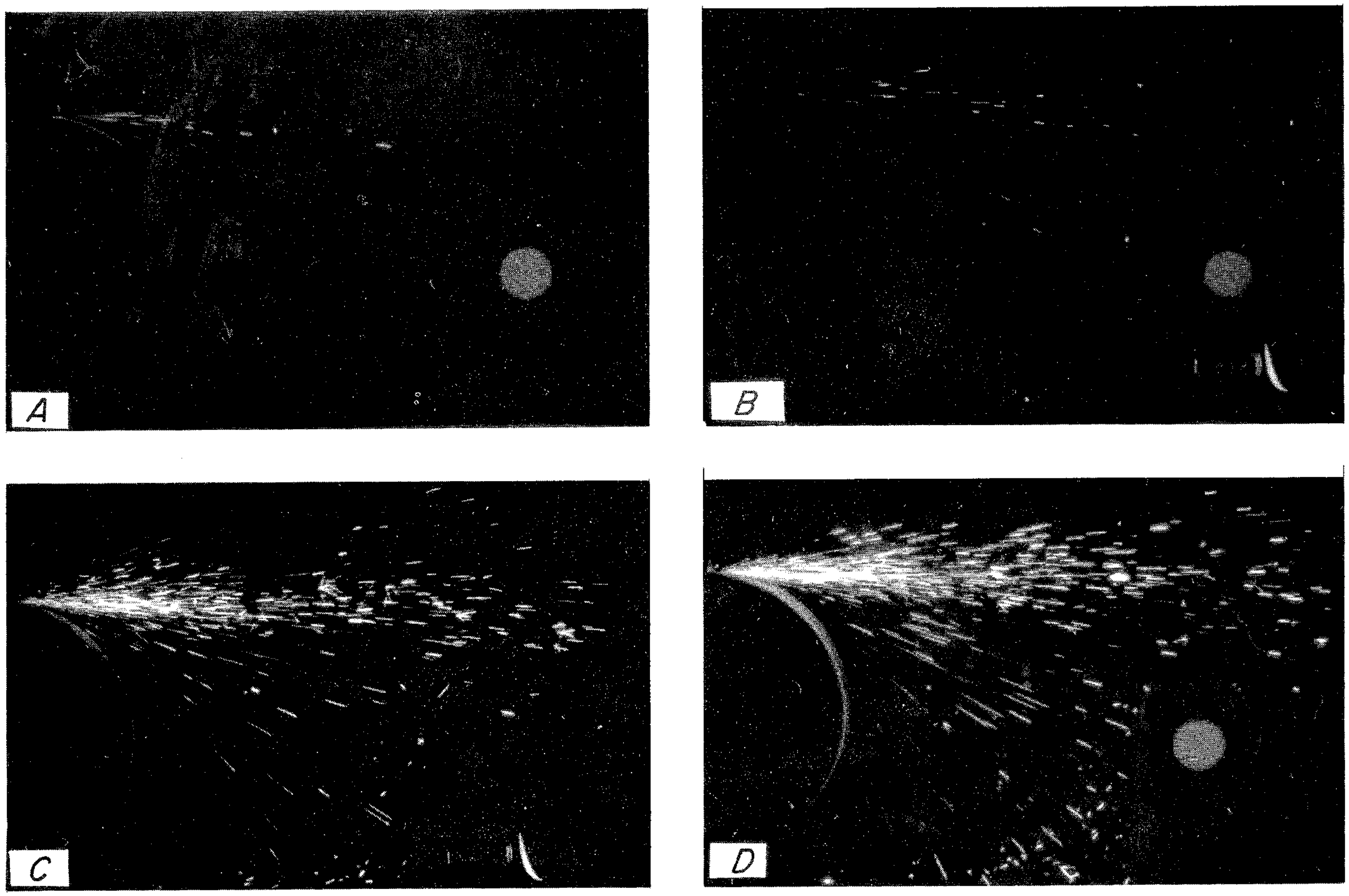

FIGURE 11. - Spark showers from commercial steels. *A*, 316 stainless steel; *B*, 17-4 PH stainless steel; *C*, C-4140, RC 48; *D*, 4M (Esco).

Commercial Alloys and Tool Steels

Eighteen commercial alloys including stainless steels, tool steels, and alloy steels were spark tested, and the results are shown in table 8. The stainless steels had very low sparking tendencies, but the tool steels and alloy steels had a very high sparking behavior. This is as expected from the results of the tests for compositional effects on sparking. Photographs of the spark showers from several of these alloys are shown in figure 11.

TABLE 8. - Spark-shower radiance of some common alloys and tool steels

Alloy or tool steel	Spark-shower radiance, μW/sr-cm²	Hardness, Rockwell
304 stainless steel	30	B 75
316 stainless steel	55	B 78
Almar 362, stainless steel, Allegheny Ludlum	85	C 45
AM-350 stainless steel, Allegheny Ludlum	118	C 36
431 stainless steel, Allegheny Ludlum	128	C 53
410 stainless steel, Allegheny Ludlum	160	C 45
AM-355 stainless steel, Allegheny Ludlum	164	C 41
17-4 PH stainless steel, Armco	218	C 33
300-M, International Nickel Co	1,365	C 25
C-8620	1,433	B 99
T-1A, U.S. Steel No. 73C389	1,443	C 27
T-1, U.S. Steel No. 73C321	1,550	C 30
BTR	1,567	C 26
C-4140	1,867	C 48
C-4340	1,933	B 97
Wear Pact, American Steel Foundry	1,938	C 51
C-1144	2,430	C 29
4M, Esco	2,748	C 31

Nonferrous Alloys

A group of five nonferrous alloys were tested, and all had little or no sparking tendencies. The nickel-base alloys, Monel, Inconel, and Rene 41 had a very low spark-shower radiance, and specimens of brass and beryllium-bronze did not spark at all. Results of these tests are shown in table 9.

TABLE 9. - Spark-shower radiance of nonferrous alloys

Alloy	Hardness, Rockwell	Spark-shower radiance, μW/sr-cm²
Brass	-	0
Beryllium-bronze	-	0
Monel	B 99	<10
Inconel	B 84	<10
Rene 41	B 98	<10

Hard-Metal Compounds

Specimens of cobalt-bonded tungsten carbide from coal-cutter bits, cast tungsten-titanium carbide, and titanium-diboride were spark tested and found to be extremely low in spark-shower radiance. These data are shown in table 10.

TABLE 10. - Spark-shower radiance of hard-metal compounds

Metal compound	Spark-shower radiance, μW/sr-cm²
Titanium-tungsten carbide, cast............	25
Tungsten carbide, cobalt bonded...........	30
Titanium-diboride, sintered...............	40

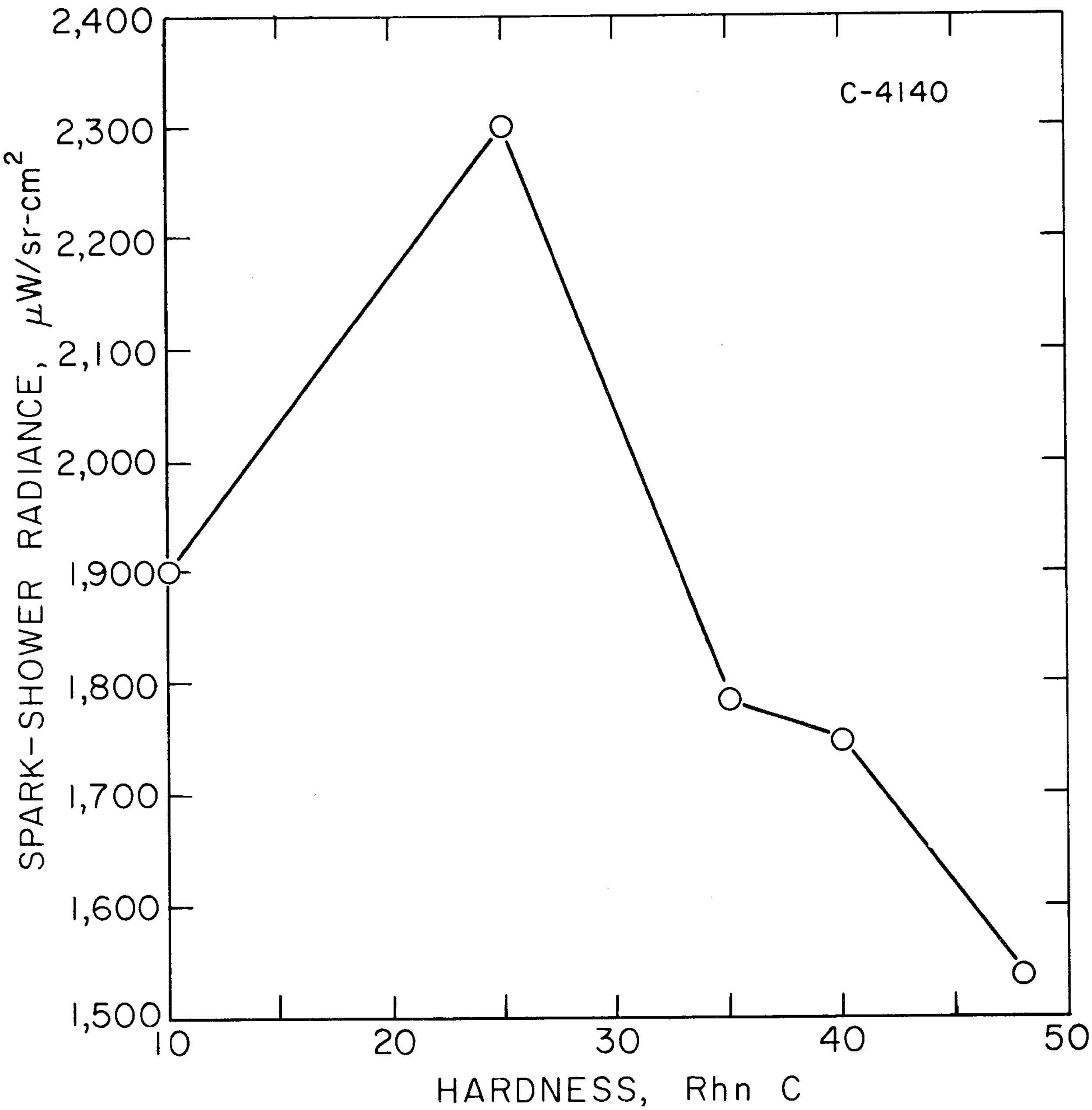

FIGURE 12. - Effect of hardness on spark-shower radiance of steel.

Effect of Hardness

The effect of hardness of a common alloy steel, C-4140, on spark-shower radiance was studied. Specimens of C-4140 alloy were austenitized, quenched, and tempered to selected hardness levels, then tested in the usual manner. The maximum spark-shower radiance occurred at a hardness of Rockwell C 25. The result is shown in figure 12.

SUMMARY AND CONCLUSIONS

A method for evaluating the sparking tendency of abraded metals was developed and used to study the effect of composition and hardness on some common alloy steels. Many other metals were examined for sparking tendency, and the results were displayed in a bar graph that gives the spark-shower radiance relative to commercially pure iron.

The spark-shower radiance test results showed the following:

1. Soft metals such as brass, copper, aluminum, zinc, magnesium, and beryllium-bronze do not spark when abraded on an Alundum grinding wheel.

2. Nickel and nickel-base alloys, stainless steels, molybdenum, chromium, and tungsten produce relatively little sparking. These metals are therefore high on the list of low-sparking, high-strength materials for use in hazardous atmospheres.

3. Carbon steels, alloy steels, tool steels, and reactive metals such as Zr, V, Cb, and Mn have dangerously high sparking tendency for use around explosive atmospheres.

4. Additions of carbon up to 0.6 wt-pct increases the spark-shower radiance of plain carbon steels. However, nickel and chromium contents of about 16 to 20 wt-pct were found to decrease the sparking tendency. Therefore, alloys high in chromium and nickel should be considered where low-sparking requirements are needed. These would include some of the stainless steels, which were also shown to have very low sparking tendencies.

5. The effect of more than one elemental addition on the spark-shower radiance is not necessarily additive. The effect on radiance may be synergistic as, for example, vanadium and carbon or molybdenum and carbon additions to iron. Consequently, the sparking tendency of a proposed alloy should be experimentally determined rather than predicted.

6. Effect of hardness--the sparking tendency in C-4140 steel was found to first increase with an increase in hardness, then decrease as the hardness was further increased.

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