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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 350

METHODS FOR THE IDENTIFICATION OF AIRCRAFT TUBING OF PLAIN CARBON STEEL AND CHROMIUM-MOLYBDENUM STEEL

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METHODS FOR THE IDENTIFICATION OF AIRCRAFT TUBING OF PLAIN CARBON STEEL AND CHROMIUM-MOLYBDENUM STEEL.

By W. H. Mutchler* and R. W. Buzzard*.

I. Introduction

The increasing use of chromium-molybdenum steel in the aircraft industry has resulted in the need for a simple method by means of which it may be accurately and rapidly differentiated from plain carbon steel. A study was accordingly made which had for its aim a general survey of the possibilities of a variety of such methods, rather than the development and perfection of any specific method. This survey was made by the authors at the Bureau of Standards and the results obtained form the basis of the present paper.

Chromium-molybdenum steel, S.A.E. No. 4130X, and plain carbon steel, S.A.E. No. 1025, are perhaps the two steels most extensively employed in the manufacture of present-day aircraft. Both steels are used principally in the form of seamless tubing for the construction of airplane fuselages. Inasmuch as the assembling is ordinarily done by welding, the strength of the tubing in the normalized condition serves as a criterion in design factors. The following physical properties of the two

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steels, in the normalized condition, have been given by Knerr (Reference 1):

	Steel S.A.E. 1025	Steel S.A.E. 4130X
Yield point (min.) $lb./in.^2$	36,000	60,000
Tensile strength $lb./in.^2$	55,000	95,000
Elongation in 2", per cent	22	12

It is evident that there is a considerable difference in the tensile properties of the two steels and that, if steel S.A.E. 1025 were to be used in aircraft construction where the design called for steel S.A.E. 4130X, the consequences might prove disastrous. It is imperative, therefore, that this should not occur, for a single tube so misplaced might give rise to considerable damage. No danger is to be expected, of course, if chromium-molybdenum steel were unknowingly substituted in place of plain carbon steel.

Opportunities for unintentionally mixing the two steels are not infrequent. Tubing of both kinds of steel are ordinarily produced in the same mill, often at the same time. Despite the greatest care it is virtually impossible to prevent an occasional mixup under conditions of manufacture. Subsequent transportation, handling and storage by the aircraft builder may result in further mixups.

It is evident that a rapid, accurate, and nondestructive method for differentiating plain carbon and chromium-molybdenum steel is needed by the aircraft industry. A means of differentiation which would permit the test to be carried out upon the completed aircraft would be highly desirable, for given such a method, a final inspection would definitely determine whether or not the proper steel had been used as called for in the specifications. The methods surveyed in the present investigation included hardness, magnetic, spark, and chemical tests.

II. Material

The material used in the investigation was obtained from two sources, which will be designated throughout this report as "A" and "B," respectively. All the material was in the form of seamless steel tubing.

Material "A" consisted of tubing 1-3/4 inches, 1 inch, and $\frac{1}{2}$-inch in diameter, each size being furnished in 20, 16, and 11 (B.W.G.) gauge material. Specimens of both chromium-molybdenum steel, S.A.E. 4130X, and plain carbon steel, S.A.E. 1025, were supplied in each size. Half of each kind of steel tubing was stated to be in the normalized condition; the remainder was in the cold-drawn condition.

Material "B" consisted of a miscellaneous assortment, with regard to dimensions and gauge, of both steels S.A.E. 1025 and S.A.E. 4130X. Information as to whether they were in the normalized or cold-drawn condition was not furnished. The materials on hand for investigation are listed in Table I.

TABLE I

Grades and Sizes of Steel Tubing Available for Study

Kind of steel	Source	Wall thickness	Diameter	Number of tubes: Normalized	Number of tubes: Cold-drawn	Number of tubes: Unknown
		gauge	in.			
Chromium-molybdenum S.A.E. 4130X	A	20	1-3/4	1	1	-
	A & B	16	"	1	1	1
	"	11	"	1	1	1
	A & B	20	1	1	1	1
	B	17	1	-	-	1
	A	16	1	1	1	-
	A & B	11	1	1	1	1
	A & B	20	1/2	1	1	1
	"	16	"	1	1	1
	A	11	"	1	1	-
Plain carbon, S.A.E. 1025	A	20	1-3/4	1	1	-
	A & B	16	"	1	1	1
	"	11	"	1	1	1
	A	20	1	1	1	-
	A & B	16	1	1	1	1
	A	11	1	1	1	-
	A	20	1/2	1	1	-
	A	16	"	1	1	-
	A	11	"	1	1	-

III. Hardness Tests as a Means of Identification

The physical properties of the two materials are dependent to a large extent upon their heat treatment. Therefore, unless the heat treatment were known definitely, hardness determinations would prove practically useless. The commonly employed methods of determining hardness, such as the Brinell, Rockwell, Vickers, Herbert (pendulum), and Shore (scleroscope) may also be regarded as somewhat unsatisfactory in that they can scarcely be applied upon the finished aircraft. The Brinell and scleroscope hardness tests, for example, are eliminated in any event as being inapplicable to thin tubing.

The use of hardness testing methods is practically limited to the tube manufacturer's mill, where first-hand information regarding the heat treatment of the materials is available. King and Knerr (Reference 1) have designed an apparatus for use in conjunction with the Rockwell Hardness Test, which has been in successful operation for more than a year in one manufacturer's tube mills for the differentiation of steels S.A.E. 1025 and S.A.E. 4130X, both in the normalized condition.

1. Herbert Pendulum Method

Aside from the Rockwell hardness testing method, the determination of hardness by the Herbert pendulum method appeared to offer the most promise among the various methods to determine hardness as a possible means of differentiating between the two kinds of steel when in the form of seamless tubing. This method was therefore studied to determine the feasibility of its use for this purpose.

The apparatus, or pendulum, consists essentially of a weight of 4 kilograms which can be balanced on a steel ball 1 millimeter in diameter and constitutes a compound pendulum 0.1 millimeter in length. When the pendulum is placed on a metal specimen and oscillated through a small arc, the "time hardness" number, that is, the number of seconds required for ten swings, is determined by means of a stop watch.

A number of "time hardness" determinations were made on each specimen of tubing which had been received from sources "A" and "B." The tests were first conducted on material in the "as received" condition, no effort being made to clean the surfaces of the tubes from scale. It was found that the values obtained failed entirely to differentiate between the two types of steel. On normalized material, in particular, it was noted that values of the order of 16.0 to 22.1 were obtained on portions of the metal comparatively free from scale, whereas values ranging from 35 to 45 were obtained on the scaled material. The values obtained on cold-drawn tubes, although spread over a smaller range than those obtained on the normalized tubes, were of about the same magnitude for plain carbon as for chromium-molybdenum tubes. "Time hardness" numbers of the plain carbon steel in the cold-drawn condition ranged from 18.8 to 28.2. The values ranged from 16.0 to 30.0 on chromium-molybdenum cold-drawn tubes. Table II, in which only the average values are reported, makes clear the failure of the pendulum "time hardness" numbers to distinguish between the two types of steel in the "as received" condition.

TABLE II

Average "time hardness" number of plain carbon (S.A.E. 1025 and chromium-molybdenum (S.A.E. 4130X) steel as determined by the Herbert pendulum method on tubing in the "as received" condition.

Gauge	Diameter	Normalized		Cold-drawn		Condition unknown	
		1025	4130X	1025	4130X	1025	4130X
	in.	sec.	sec.	sec.	sec.	sec.	sec.
11	1/2	22.1	22.8	24.7	27.4	-	-
	1	22.9	28.9	21.4	21.7	-	-
	1-3/4	29.7	22.4	22.0	22.5	22.0	23.7
16	1/2	23.7	29.5	25.4	25.7	-	23.2
	1	18.6	30.0	21.6	25.4	-	-
	1-3/4	33.3	28.7	24.4	21.3	22.3	23.7
17	1	-	-	-	-	-	25.0
20	1/2	23.3	27.6	26.9	27.5	-	27.1
	1	20.8	26.0	24.5	21.9	-	27.3
	1-3/4	22.0	35.0	22.9	26.3	-	-

Inasmuch as the Herbert method presumably gives a measurement of surface hardness, it was thought advisable to remove the scale thoroughly from the specimens and redetermine the hardness The "time hardness" numbers obtained on a series of 1-inch diameter tubes which had been cleaned free from scale, are given in Table III.

It will be noted that for material in the cold-drawn condition the values ranged from 19.8 to 24.1 for plain carbon tubing and from 21.0 to 27.2 for chromium-molybdenum tubing, the two ranges overlapping to such a degree as to make positive differentiation impossible. Material in the normalized condition, however, gave values which ranged from 16.0 to 20.5 for steel S.A.E. 1025 and for 21.9 to 28.8 for steel S.A.E. 4130X.

TABLE III

Ranges of "time hardness" numbers of 1-inch diameter plain carbon (S.A.E. No. 1025) and chromium-molybdenum (S.A.E. NO. 4130) steel as determined by the Herbert pendulum method on tubing freed from surface scale.

Gauge	Normalized		Cold-drawn		Condition unknown	
	1025	4130X	1025	4130X	1025	4130X
	sec.	sec.	sec.	sec.	sec.	sec.
11	17.4-19.2	21.9-23.6	19.8-21.4	21.4-23.1	-	24.1-28.8
16	16.0-17.6	27.8-28.8	21.4-23.3	26.0-27.2	-	24.3-26.5
20	19.7-20.5	26.4-28.2	23.2-24.1	21.0-22.6	-	28.7-30.4

It may be concluded, on the basis of these tests, that normalized, scale-free material might be identified very roughly by assuming the tubing to be steel S.A.E. 1025 if values less than 20.0 were always obtained, and as steel S.A.E. 4130X if values exceeding 22.0 were always obtained. The difference between these ranges for the two kinds of steel would seem to be much too small, however, to permit this method being used as a means of positive identification. Moreover, unless the heat treatment were definitely known, the Herbert pendulum method would prove entirely inadequate for purposes of differentiation. While it has some possibilities as a factory method, where the condition of the material might be known, it would prove impractical as a rapid test in the field.

IV. Magnetic Tests

Magnetic methods for the differentiation of the steel tubing under consideration appeared promising in view of the fact that they would be in no way destructive. The separation of mixed lots of steel by methods based upon their different magnetic properties has been practiced in the industry for several years. Owing to the many variables which come into play when magnetic methods are employed, it is usually necessary to devise a specific method of procedure for the positive differentiation of any given two types of steel. The procedure here reported upon, for the separation of steel S.A.E. 1025 and S.A.E. 4130X in the form of tubing, was developed during the present investigation by R. L. Sanford.*

Several factors had to be considered in the choice of a method for this particular separation. Inasmuch as the tubing ordinarily comes in various lengths, diameters, and gauges, the selection of a method was limited to one in which these factors do not play an important part.

A method based upon the comparison of the values of coercive force seemed to offer the most promise in the present case since the coercive force is independent of the cross-sectional area of the specimen. The coercive force may be defined as the reversed magnetizing force required to reduce the residual induction of a previously magnetized specimen to zero. This method was therefore chosen as the basis for experimentation.

Preliminary tests were first made in which the coercive force of each tube from the two sources was determined in an apparatus consisting of a straight solenoid in which was mounted a short test coil. The test coil was connected in a series with, and opposed to, the secondary of a variable mutual inductor whose primary was connected in series with the magnetizing solenoid. The primary circuit was connected with a storage battery through a reversing switch and control rheostats, the current being read by a variable range ammeter. The test coil system was connected through the usual adjustable resistance and a key to a ballistic galvanometer.

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When the mutual inductor was properly adjusted, there was no residual deflection of the galvanometer on reversal of the magnetizing current when no specimen was within the solenoid. Since only comparative results were required in the separation of the two kinds of steel, it was not necessary to determine the constants of the solenoid or the sensitivity of the galvanometer. The calibrating resistance was merely adjusted to give convenient deflections.

Comparative values of the coercive force measured in terms of current in the magnetizing solenoid, were made as follows. The reading of the galvanometer upon reversal of one ampere was noted. The current was then simultaneously reversed and reduced to such a value that the deflection was half the original value, the value of the reversed current thus determined being proportional to the coercive force. By experiments with a number of tubes, it was found that the coercive force for the tubes of the S.A.E. 4130X steel was practically always greater than for the S.A.E. 1025 steel tubes.

As the determination of the coercive force for each tube is a tedious and time-consuming operation, a modified procedure was tried. This consisted in always bringing the reduced reversed current to the same value, a value intermediate between those corresponding to the coercive forces for the two kinds of steel being used. Then, if the deflection was more than half that observed upon reversal of the total current, it indicated that the coercive force for the specimens was less than the set value, and that the material which was being tested was plain carbon steel. If the deflection was less than half, a greater coercive force was indicated, and thus identified the tubing as chromium-molybdenum steel. This determination could be made very rapidly, probably much more so than the determination of the hardness by any method.

After experiments had been made to determine the most suitable value for the coercive force current, tests were made on 57 specimens of both types of steel in various sizes and treatments. 52 of the tubes were correctly sorted, indications on three were uncertain, and two chromium-molybdenum tubes were classed as plain carbon steel. It was noted that, on the whole, material in the normalized condition was the more readily identified. After being normalized, the five tubes which were initially separated incorrectly were identified correctly by a second test.

From the results of these tests it seems safe to conclude that satisfactory differentiation of plain carbon and chromium-molybdenum steel tubing can be made by a magnetic method based upon the comparison of coercive force values. The method used required the insertion of tubes in a solenoid, but it seems probable that a method could be developed with an electromagnet small enough to be portable which in operation would need only to be placed against the tube to be tested. Further investigation would be required to determine whether or not this could be done. In any event, the development of such types of apparatus for use on fuselages was deemed beyond the scope of the present survey.

Very promising possibilities exist in the use of the magnetic method just outlined in providing a rapid and satisfactory nondestructive differentiation of the two types of steel. The apparatus might be compactly constructed so as to be portable and suitable for use not only in the factory but also for inspection. The starage battery would constitute the greater part of the weight of any portable apparatus. An electromagnet, switch, and galvanometer would be the remaining essential requirements, so that the initial outlay with regard to equipment should not be overly expensive aside from the time spent in getting it into working condition.

V. Spark Tests

The importance of this test as an inspection method is slowly coming to be recognized. It has long been known in the shops that steels of different carbon content give spark showers of different appearance when placed against a rapidly revolving abrasive wheel. Until recently, however, very little has been done toward introducing this test into the industry. Spark testing is now being used quite extensively in some large plants as a method for sorting mixed steels. It should not be expected to replace chemical analysis but is very useful for the rapid sorting of mixed steels.

There are two general methods of spark testing. In one, a 1/4 horsepower medium speed motor with a 6-inch abrasive wheel is used to produce the spark shower. The kind of steel is judged by the density of the shower, the color, the trajectory, and the peculiarity of the sparks which follow along the periphery of the wheel. In the other method, dependence is placed on the peculiarities of the trajectory of the sparks produced by small <u>high speed</u> motor. Equipment of the latter type was considered the more desirable for this study because of the ease with which it could be used on an assembled fuselage.

There is some controversy as to whether both the chromium and the molybdenum, of chromium-molybdenum steel, S.A.E. 4130X, impart peculiar characteristics to the spark stream that can be detected. Among those who claim a characteristic spark for chromium is Pitois (Reference 2), who has well stated these characteristics. According to him, chromium reduces the spark shower from a steel to a very short, but not dense, stream; while a short stream from a carbon steel is always dense. Chromium steel also produces finer and more separate "carriers" in the spark stream than carbon steel. The color also appears darker than that of the plain carbon steel shower.

Gat (Reference 2), and McCollam and Hildorf (Reference 3) observed a peculiar tip to the spark stream from steel containing molybdenum. The spark seems to die out and then flare up again. This was named an "arrow head" by Gat and a "detached spear point" by McCollam and Hildorf. Because of the greater ease with which the molybdenum characteristics may be observed, this was used as the basis of the identification in the spark tests made on the steel tubes.

Any report on the details of the spark-testing method is handicapped by the necessity of depending on oral or written descriptions of visual phenomena. The ease with which the molybdenum spark is distinguished in chromium-molybdenum steel makes the problem of differentiating chromium-molybdenum from plain carbon steel a relatively simple one. The characteristic "detached spear point" imparted to the shower by molybdenum is very easily discerned, that is, it is wide at the base and quickly tapers to a point. The name "spear point" was well chosen.

Efforts were made to obtain photographs to reveal the differences in the two spark streams. The photographs obtained are by no means as satisfactory as was hoped, but will serve to illustrate the general nature of the differences observed at the ends of the visible trajectories. They will help to emphasize that to carry out this method of identification properly, the eye must be focused on the end of the visible trajectory of the spark.

Figure 1 is a photograph of the "spark stream" from plain carbon steel. The tips of the visible trajectory are long and thin and taper off at the ends. Figure 2 is a photograph of the "spark stream" from chromium-molybdenum steel. Here it may be seen that the tips differ from that of the plain carbon steel (Fig. 1) in that the tips are short and "stubby" instead of being long and tapering. These tips appear to the eye to be completely detached. In the photograph, however, they are connected to the rest of the visible trajectory by a fine line. This detracts from the value of photographs as a means of instruction for beginners.

Observation reveals that every trajectory has the detached spear point. The beginner may be slightly confused at first because the plain carbon tubing will occasionally throw a particle whose trajectory apparently has a spear point tip. Its occurrence is not frequent and close observation shows that the "tip" is not detached. The molybdenum and chromium in steel S.A.E. 4130X apparently serve to retard the bursts of sparks. Because of this, the spark shower of the chromium-molybdenum tubing has a darker color than the plain carbon tubing and the explosions are fewer and less violent.

The equipment was relatively simple. A small (1/8 horsepower) motor, weighing about 8 pounds, operating at a shaft speed of 15,000 r.p.m. was used. An abrasive wheel of alundum, 1-1/4 inches in diameter and 3/8 inch thick was mounted on the shaft. The wheel had a peripheral speed of about 5000 feet per minute. The motor and wheel are shown in the photograph (Fig. 3) and the ease with which it may be handled is readily seen.

Colored glasses should be worn as constant observation of the spark streams with the unprotected eye is harmful. An ordinary light cobalt blue glass which transmits between 35 and 40 per cent of sunlight has been used with success although not entirely satisfactorily in all respects.

A few preliminary experiments to identify the steels by means of the spark were made with the use of a 6-inch abrasive wheel and a motor having 2800 r.p.m. This work was done in a very poorly lighted room. The characteristics of the molybdenum spark were found to be greatly "damped" by this type of wheel and the two steels could be separated only with difficulty. Experiments with the small motor indicated that the molybdenum spark was readily distinguished from that of the plain carbon steel, even in a well-lighted room.

A series of tests was then conducted to determine the ease with which wholly inexperienced operators could acquire proficiency, accuracy, and speed in distinguishing between chromium-molybdenum and plain carbon steel by the spark testing method. To this end, nine operators were selected at random from the members of the Bureau staff, none of whom had had any previous experience with the method.

Each operator was first given a sample of both chromium-molybdenum and plain carbon steel tubing. The characteristic differences between the two types of spark streams were pointed out by an experienced operator. After the new operator was sure he could tell the difference between the two spark streams, he was given 76 tubes, composition unknown to him, and told to separate them into two groups, chromium-molybdenum and plain carbon steels. This set consisted of 43 specimens of chromium-molybdenum steel tubing and 33 of plain carbon steel. Approximately half of each kind of steel was in the normalized condition and the remainder in the cold-drawn condition.

Each operator worked independently and separately from the others and 76 specimens were regarded as a unit "run." Four runs were made by each operator in order to obtain some idea of the increase in accuracy and speed as experience was acquired. These operators were allowed to use their standards as much as they pleased during a run. The results of the tests are summarized in Table IV. Three operators tested the total 304 specimens without making a single error in any of the four runs.

TABLE IV. Results of Tests of Nine Inexperienced Operators for Four Runs

Operator	Run 1 Time min.	Run 1 Number missed	Run 1 Accuracy %	Run 2 Time min.	Run 2 Number missed	Run 2 Accuracy %	Run 3 Time min.	Run 3 Number missed	Run 3 Accuracy %	Run 4 Time min.	Run 4 Number missed	Run 4 Accuracy %
A	14	4	94.7	9	2	97.4	6	1	98.7	6	2	97.4
B	45	6	92.1	35	3	96.1	14	1	98.7	20	0	100
C	15	11	85.5	9	1	98.7	7	0	100	6	0	100
D	$6\frac{1}{2}$	5	93.4	$6\frac{1}{2}$	2	97.4	4	0	100	5	0	100
E	15	2	97.4	10	0	100	8	0	100	7	0	100
F	40	1	98.7	14	0	100	9	0	100	5	0	100
G	20	0	100	8	0	100	4	0	100	$3\frac{1}{2}$	0	100
H	30	0	100	7	0	100	5	0	100	$3\frac{1}{2}$	0	100
I	20	0	100	12	0	100	9	0	100	9	0	100
Total tubes												
684	$195\frac{1}{2}$	29	–	$110\frac{1}{2}$	8	–	66	2	–	65	2	–

It will be noted from the table that practically all the operators required more than 15 minutes to complete the first run, the average time being about 20 minutes. On the final run, on the other hand, six of the operators required less than six minutes to complete the 76 specimens. As a matter of fact, this speed can be materially increased.

A more experienced operator correctly sorted the same 76 specimens in one and one-half minutes without an error. The records which were kept during the runs made by the nine operators show that there was no particular tendency for an operator to err in one direction. That is to say, of the 41 errors made, approximately half consisted in designating chromium-molybdenum steels as plain carbon steel or vice versa. This shows that although the personal equation is a factor, it is not normally an important one.

When it is considered that eight out of the nine operators were 100 per cent accurate on the fourth run, there can be no question concerning the ease with which relatively inexperienced operators can separate the two types of steel by spark-testing methods. If a man has been allowed to familiarize himself thoroughly with the standards, he should be able to make the last two runs of four successive ones without an error. Men who err on the fourth run would, in general, be considered as unsatisfactory for such work.

The damage done to the tubing by this test was very slight.

An experienced spark tester would leave a barely distinguishable mark. Figure 4 is a photograph of three chromium-molybdenum and three plain carbon steel tubes identified by the spark test. The wheel marks will be noted as light spots on the specimens, showing the scale was removed by the wheel and that was about all. For this particular test it is not necessary to grind below the decarburized surface. The decarburized surface materially aids the test in that it serves to emphasize the molybdenum spark. It is not necessary to grind below the decarburized surface on the plain carbon steel because the character of the tips is the distinguishing feature of this test, the nature of the "burst," color of shower, etc., being of only secondary importance.

It may be concluded that the spark-testing method is both accurate and rapid for the identification of chromium-molybdenum and plain carbon steels when the two are mixed. It is applicable to both field and factory use, and the test could be applied to the finished fuselage since the damage done to the steel tubing by this test is negligible. The test is simple and a man of ordinary intelligence and good vision quickly learns the method. The heat treatment may affect the general character of the spark stream as a whole but does not affect the characteristic feature upon which the identification is based.

VI. Chemical Tests

There are a number of qualitative tests applicable to steel filings or drillings which will detect the presence of small amounts of molybdenum. Among the reagents which may be used for the detection of molybdenum in solution are xanthic acid, pyrocatechol, diphenyl hydrazine, sodium xanthate, diphenyl carbozide, tannin, and potassium thiocyanate. All of these indicators will detect about one part of molybdenum per million parts of solution, thus being about equally effective. Iron and certain other elements interfere in the case of all the indicators excepting potassium thiocyanate, and must be removed before the test for molybdenum is made.

Attempts to distinguish chromium-molybdenum and plain carbon steels by means of chemical "spot tests" were unsuccessful because the small quantity of acid used (a few drops) does not dissolve sufficient molybdenum to permit of satisfactory tests by the available indicators. Inasmuch as a spot test would permit identification of the steel without making necessary the removal of filings or drillings, it should prove highly desirable.

Qualitative tests made upon portions removed from the original specimen are practically precluded in the present instance. It would not be feasible to cut out a small section of the tubing for test, even in the tube mill, since such a step would make necessary the further keeping of records for identification of the individual portions taken off, and hence introduce an added source of possible errors in causing mixups.

The xanthate test described by Malowan (Reference 4) has already found a limited use in practice for the identification of steels S.A.E. 1025 and 4130X. However, the potassium thiocyanate method appears more promising in view of the fact that iron need not be removed from the solution by precipitation and filtration, prior to testing for molybdenum. The investigation is being carried further at the Bureau of Standards to determine definitely whether or not a suitable chemical method can be developed.

VII. Summary

The survey of the possibilities for distinguishing between plain carbon and chromium-molybdenum steel tubing included the Herbert pendulum hardness, magnetic, spark, and chemical tests.

The Herbert pendulum test has the disadvantages of all hardness tests in being limited to factory use and being applicable only to scale-free, normalized material. The small difference in the range of hardness values between plain carbon and chromium molybdenum steels is likewise a disadvantage. The Rockwell hardness test, at present used in the industry for this purpose, is much more reliable.

Magnetic methods for identification of the two types of steel appear to offer considerable promise for both field and factory use and could probably be economically developed to the practical stage. The material to be separated need not be in the normalized condition and it is believed that positive identification could probably be made more rapidly than by methods based upon hardness.

Unless a chemical spot test can be successfully developed it is doubtful whether chemical methods would prove adaptable to the present problem. Even with the development of a reliable, although somewhat undesirable, method for the identification of drillings and filings, chemical methods would still have disadvantages in the matter of time consumed and damage to the material tested.

It may be concluded on the basis of the experiments performed that of all the methods surveyed, spark testing appears to be, at present, the most suitable for factory use from the standpoint of speed, accuracy, nondestructiveness and reliability. It is also applicable for field use.

Bureau of Standards,

September 5, 1930.

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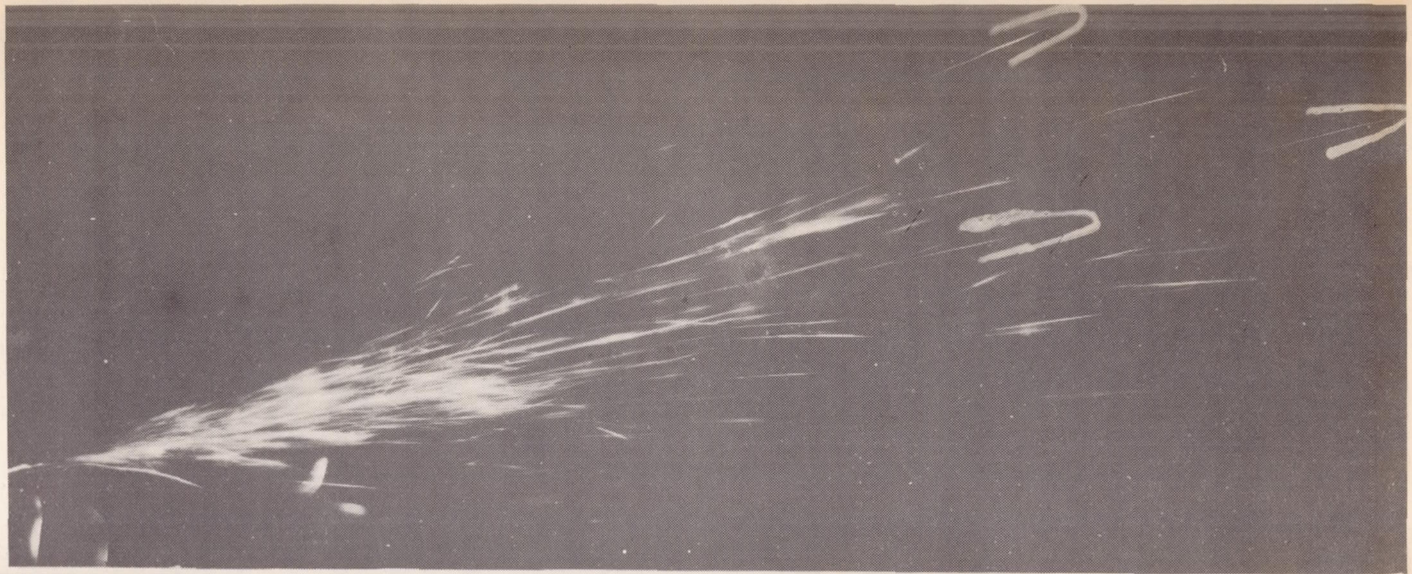

Figure 1.
Appearance of "spark stream" from plain carbon steel.

Note: The tapering of the visual trajectory indicated by white outline.

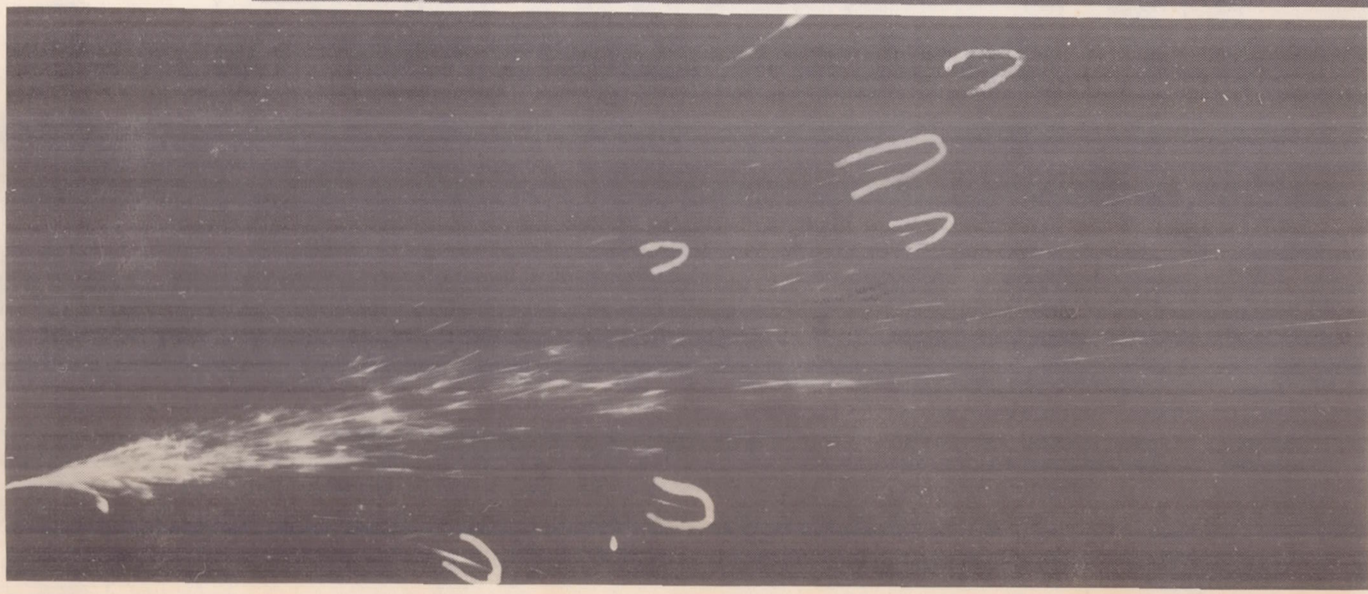

Figure 2.
Appearance of "spark stream" of chromium molybdenum steel.

Note: "Spear points" at end of visual trajectory indicated by white outline.

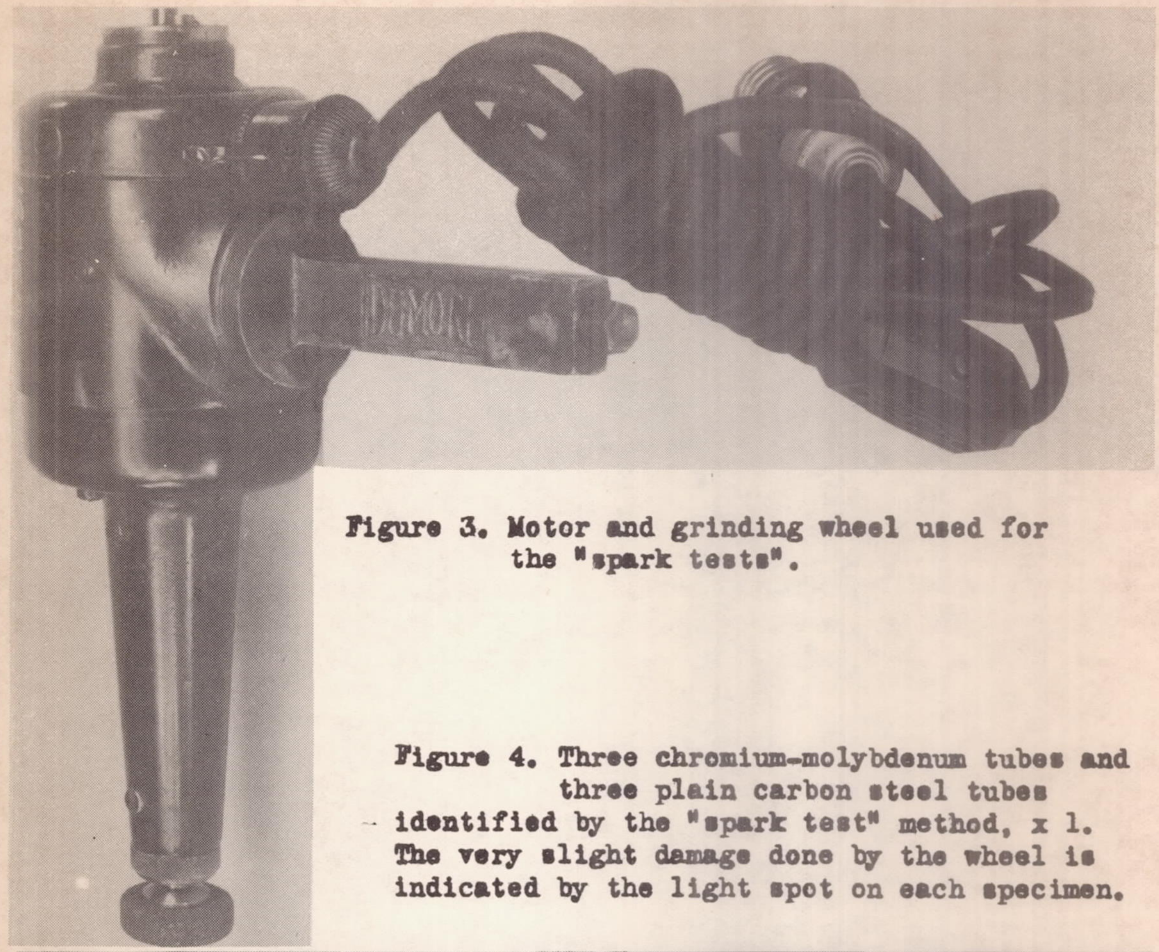

Figure 3. Motor and grinding wheel used for the "spark tests".

Figure 4. Three chromium-molybdenum tubes and three plain carbon steel tubes identified by the "spark test" method, x 1. The very slight damage done by the wheel is indicated by the light spot on each specimen.