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PHYSICAL PROPERTIES AND TESTING OF SINTERED IRON ROTATING BANDS
Report No. 5

R. #6017,
PC #4643.

June 25,1947

SAM TOUR & CO., Inc.
44 TRINITY PLACE
NEW YORK 6, N. Y.

[illegible]
OFFICE OF THE CHIEF OF ORDNANCE
Washington, D.C.

25 July 1947

SUBJECT: Sintered-Iron Rotating Bands

TO: Commanding Officer
Watertown Arsenal
Watertown 72, Mass.

There is inclosed for your information and file Sam Tour and Company, Inc., Report Number 5 covering "Physical Properties and Testing of Sintered-Iron Rotating Bands".

BY COMMAND OF MAJOR GENERAL HUGHES:

A. ADELMAN
Assistant

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June 25,1947

PHYSICAL PROPERTIES AND TESTING OF SINTERED IRON ROTATING BANDS

Report No. 5

Introduction:

This report,which is the fifth in a series of reports being compiled under Contract No. W-30-069-ORD-4417 on German Sintered Iron Rotating Bands,contains a discussion of the physical properties desired in rotating bands, an outline of testing methods used and a brief discussion of some of the fundamental knowledge available on powder properties.

The section on Physical Properties contains an outline of those properties which the Germans found to be most desirable in rotating bands. These desired values were based on the sum of German experience at the close of the war. Opinions expressed by various German powder metallurgists as to other physical property values that might produce better results are also given.

The methods used by the Germans in the acceptance testing and process control testing of rotating bands are given in sufficient detail to permit duplication of the test methods. In some instances, the German test methods were most adequate. In other instances, they were inadequate. Where sufficient data were available to permit the formulation of opinions, the adequacy of the various test methods has been evaluated.

The discussion of the fundamental properties of powders has been based on a study of the discussions contained in some of the German documents in our possession and on the studies of a number of American technical papers. The information presented is not intended to represent a complete evaluation of the fundamental knowledge of powder properties that is available. Such a complete evaluation is not within the scope of the present series of reports.

A reference list of the documents that were consulted in compiling this report has been attached hereto. The German documents, together with translations, will be returned to the Ordnance Department upon conclusion of the work being carried out under this Contract.

Physical Properties and Testing:

The physical properties ranges of standard German sintered iron rotating bands were as follows:

Tensile Strength - - - - - 7 - 9 kg/mm^2
Circumferential Elongation - 2 - 3%
Hardness (Special test) - - 0.195-0.270 mm.
Specific Gravity - - - - - 5.7 - 6.0 gm/cc^3
Wax Absorption Capacity - - 2 - 3% by weight.

During the early stages of the development of the sintered iron band, acceptance was based on determinations of tensile strength, elongation and hardness, on a 1 percent sample of the bands after wax impregnation. It was believed that control of these properties would insure control of specific gravity and wax absorption capacity. Later, hardness testing was stopped. Excessive rejections because of failure to meet the hardness requirements led to extensive firing

tests that proved that there was no relationship between the apparent hardness of the rings and their performance in firing. This was probably because of the impossibility of determining the true hardness of the bands rather than because there is no relationship between hardness and performance.

Acceptance of the bands after setting in the band seat grooves was based on a hardness test of 2% of the bands, in which the hardness requirements were the same as for the unset bands, and on the proof-firing of a sample of about 0.5% of the projectiles. After the hardness tests were proved to be unreliable, acceptance of the set bands was based only on satisfactory proof-firing.

Proof Firing:

The criteria for satisfactory proof-firing were:

1. - Maintenance of normal muzzle velocity with normal powder charge.
2. - Adherence of the band to the projectile during flight.

In the discussion of the criteria for satisfactory proof-firing, no mention was made of control of powder pressure, requirements of accuracy, temperature correction or ranging errors. Although these factors were not mentioned, it must be assumed that their effects were taken into consideration in the evaluation of the results of proof-firing.

It was stated, in some of the German documents studied, that maintenance of normal muzzle velocity was at

least a partial indication that the bands were soft enough to conform to the rifling contours without undue pressure. Adherence of the band during flight and lack of evidences of shearing off of parts of the band in recovered projectiles, showed that the band had sufficient strength to perform satisfactorily and that the banding technique was adequate.

Although the inspection procedures set up were intended to maintain a reasonably close control of the physical properties of the bands in the range of properties that would produce the best possible band performance, it is doubtful that this objective was achieved. Results of physical tests made in this country on German bands showed that, in some cases, the actual physical properties of accepted bands were well below the specified minimums.

Testing:

These differences might be the result of the fact that the testing technique used in determining the physical properties were not satisfactory or that the Germans were accepting, for use, bands that did not meet the specified minimum physical properties.

They might also indicate that the sampling techniques or the sizes of the samples taken were inadequate. Proper sample sizes and maximum and minimum physical property levels can only be determined by statistical studies of physical property ranges and by correlation of physical properties

with comprehensive proof-firing test results. Lack of time and facilities prevented the Germans from carrying out such work.

Physical:

In the original development of the sintered iron rotating bands, a tensile strength range of 4 to 5 kg. per sq. mm. were arbitrarily chosen as the desirable strength range. Actual use of these bands, indicated that the relatively weak band had a tendency towards the chipping and cracking off both in the muzzle of the gun and during flight. To correct this tendency towards cracking, the physical property range of the band was increased to the currently standard 7 to 9 kg. per sq. mm. Even with the increased strengths there was some tendency towards cracking in certain of the larger calibers.

Bands for special aircraft projectiles, in which the prevention of muzzle debris was imperative, were made with strengths in the range of 10 to 14 kg. per sq. mm. Although no adequate firing records are available unofficial reports indicated that these higher strength bands were satisfactory. Based on these results, many of the German powder metallurgists believe that increasing the tensile strength of sintered iron bands to the range of 15 to 20 kg. per sq. mm. might produce better bands than those of the accepted standard strength range. However, the Germans had no adequate firing tests upon which to base any conclusions as to the optimum strengths of the sintered iron rotating bands.

Testing Methods:

A. - Tensile Testing Procedure:

Tensile tests were carried out on complete rotating bands by applying loads with conventional tensile testing machines while holding the bands in special loading grips. Fig. 1 shows the form of these grips and the method of placing the band for loading. Unit stresses were determined by dividing the applied load by twice the cross-sectional area of the band since the load was assumed to be evenly divided between the intersections of the plane AA with the rotating band.

This method of tensile testing presents a much better picture of the actual properties of the ring than could possibly be obtained by attempting to take conventional test specimens from such rings. Any possible effects of straightening or machining are avoided.

B. - Elongation Testing Procedure:

The elongation of sintered iron rotating bands was determined by forcing complete bands down over a tapered plug such as that shown in Fig. 2. The plug was calibrated along its length so that the position of the ring on the axis of the plug at the time of failure would indicate the percentage increase of the inner circumference of the ring. Thus, the gage length for elongation tests of sintered iron rotating bands was the total initial length of the inner circumference. The bands always showed initial fracture at the lower section as it was being forced over the plug gage. This was not considered disadvantageous.

This testing procedure also avoids the necessity of machining test specimens and at the same time provides a better evaluation of the true ductility properties than any test specimen. Although two complete rings are required for the determination of tensile and elongation properties by the Germans' procedure, it is undoubtedly more economical to destroy two rings than to obtain both values from a single ring by machining out suitable conventional test specimens.

C. - Hardness Testing Procedure:

For the hardness testing of rotating bands, the Germans used a standard Rockwell Hardness Tester with a 2.5 mm. diameter hardened steel ball as an indentor, a preload of 10 kg. and an additional applied test load of 125 kg. Because this particular combination of indentor and test load is not one of the standard Rockwell test combinations, the Rockwell scale readings were not applicable.

Hardness values were expressed in terms of millimeters of depth of impression of the indentor. The depth of penetration of the indentor was measured after removal of the 125 kg. test load.

Depth of penetration under load as measured by the Rockwell was specified to be between 0.195 and 0.270 mm.

Divisions in the standard Rockwell scale correspond to 0.002 mm. depth of impression, the total depth of impression of the penetrators could be determined by counting the divisions on the Rockwell scale. Some later models of

the hardness testing machine were provided with a scale calibrated directly in millimeters depth of impression so that the depth of penetration could be read directly from the scale.

German production of sintered iron rotating bands was seriously hampered by inability to meet the required indentation hardness specifications. Large quantities of bands were rejected because of this failure to meet hardness requirements. The situation finally became so serious that considerable investigations were run to determine the reliability of the hardness test. It was eventually proven that such hardness tests were not an adequate indicator of the properties of the bands. A number of tests on any one band would show a great range of value. The use of indentation hardness tests was eventually abandoned. The German experiences with the hardness testing of sintered bands bear out the general consensus of opinion in this country that hardness testing of sintered parts is of little value.

Detection of Cracks:

After being banded, all projectiles were run through a magnetic particle inspection test to assist in the detection of cracked bands or of any cracked projectiles that might have escaped prior inspection operations. The procedures used in magnetic particle inspection were the same as those commonly used in this country.

Projectiles whose bands showed any tendency towards cracks, especially cracks running in the longitudinal axis of the projectile, were rejected and returned for re-banding. There has been no evidence found, however, to indicate that such cracked bands would have any adverse effect on the performance of the projectile. In this connection, it is to be mentioned that some thought was given by the Germans to the possibility of producing three-piece bands. These would, of course, have in effect three longitudinal cracks through them.

Density Determinations:

For process control work, densities were determined by calculations based on the weight and dimensions of the bands. The density of each individual rotating band as it was taken from the press was determined by comparison of the dimensions and weight of the band to that of a standardized band made from the same powder lot.

More precise determinations of density required in research or development work were on the basis of weight in water and weight in air.

Work carried out at Sam Tour & Co., Inc. has indicated that substantial errors in determination of density may occur in the weight in air-weight in water method because of water penetration into the porous iron bands. It has been found that accurate determinations of density can be made only if the bands are coated with lacquer or sealed with some other

sealant which will prevent the absorption of water during the density determination. With such a technique, suitable corrections must be applied to compensate for the weight of the lacquer or other sealant.

Examination of the results of density determinations made in this country on German sintered iron rotating bands indicates a much greater spread in density values than those specified by the Germans. In general, these densities seem to be somewhat higher than those specified by the Germans. It is impossible to determine whether the greater spread in density values is due to experimental errors in the density determinations, or whether the bands as produced by the Germans had a much greater range of density than the Germans realized.

Wax Impregnation Control:

Determination of the quantities of wax that had been absorbed during the wax impregnation cycle were made by determining the increase in weight which occurred during impregnation. A small quantity of bands in each lot were weighed both before and after impregnation to maintain control of this process.

No attempts were made to determine the quantity of wax impregnation through extraction methods on a production control basis. In some instances, wax determinations on finished bands were made by refluxing in chloroform or similar solvent. These determinations were for research purposes only and were not adaptable to production control.

Some work carried out by Sam Tour & Co., Inc. on bands impregnated with known weights of wax, has shown that the percentage of wax content can be accurately determined by refluxing in Toluol in a Soxhlette apparatus for a period of approximately three hours. Calculations based on the weight of the band before and after extraction of the wax check closely the known weight of wax with which the band had been impregnated.

Chemical Analysis:

The chemical analysis of the iron powders used in rotating bands was specified as follows:

Carbon - - - -	0.25% max.
Silicon - - -	0.15 "
Sulphur - - -	0.05 "
Phosphorus - -	0.06 "
Oxygen - - - -	0.5 "

The contents of carbon, silicon, sulphur and phosphorus were determined by standard chemical analyses methods.

A suitable method for the determination of oxygen content of the iron powders was developed by the Germans. The details of this method are described in Appendix A of this report. Acceptance test for the powder also included sieve analysis and apparent specific gravity determination. There is no evidence available to indicate that the Germans were much concerned with the flow characteristics of the powder. Also, there is no mention of the use of addition agents to improve the flow characteristics.

Control of Physical Properties:

For rotating bands, there is an optimum combination of physical properties - tensile strength, compressive strength, density, elongation - that will produce the best type of band. High tensile strength is required to resist shearing by the lands while the projectile is in the gun and to resist the centrifugal forces set up by rotation of the projectile during flight. At the same time, low compressive strength will probably minimize wear and band pressures set up during engraving of the band.

In general with unimpregnated bands, tensile and compressive strengths are directly related so that a change in processing that causes an increase in tensile strength will cause a corresponding increase in compressive strength. Therefore, to determine the best processing cycle for use in the production of rotating bands, it is necessary to determine the effects on the rates of change of tensile and compressive strengths caused by changes in the processing steps.

Little information of value is available on the effects of changes in the processing cycle. Neither German nor American investigators have concerned themselves with the question of compressive strengths. Most of the American work was carried out with very fine particle sizes in attempts to produce the highest possible tensile strengths and densities (over 6.5 gm./cc^3.) The Germans developed the sintered iron rotating band of low density (under 6 gm./cc^3) using medium to coarse particle sizes on an empirical basis without

determining any fundamental data. In much of the work thus far carried out, the investigators determined only single properties. Thus, in some work, the effects of changes in sintering temperature on the tensile properties were determined but no data were recorded on the changes occurring in the density of the compacts. In other work, the effects of changes in pressure on the density were determined but no tensile strengths were determined.

Much of the investigative work has been contradictory in regard to the effects on the physical properties of changes in the processing steps. Squires (80)(x) shows a continuous increase in density as pressing pressure is increased from 40,000 to 200,000 p.s.i. Kelley (72) finds that density increases with pressure up to 60,000 p.s.i. and decreases with pressures above 60,000 p.s.i. Kuzmick (85) shows results that agree with those of Squires.

Kelley (72) shows that increased sintering temperatures cause increased density. Kuzmick (85) indicates that changes in sintering temperature cause no changes in density. Squires (80) states that increased sintering temperature causes increased density when low pressing pressures are used but decreased density when high pressing pressures are used.

Squires (80) states that increasing the sintering temperature causes increases in tensile strength. Kuzmick

(x) - Numbers in parentheses refer to reference list given at the end of this report.

shows that sintering temperature has no effect on tensile strength. Various data sheets show that tensile strength increases with sintering temperature up to 1050° C. (1920°F.), decreases at 1150° C. (2100°F.) and then increases as the temperature is raised above 1150° C. (2100°F.).

While some of these contradictory conclusions may be caused by differences in the conditions of the experiments, it is most probable that experimental errors are a major cause of the different conclusions. Thus, it is apparent that additional experimental work must be carried out to determine the effects of changes in processing steps on the properties of sintered iron rotating bands.

All this work was carried out on compacts that had not been impregnated with wax. Since wax impregnation lowers the compressive strength without changing the tensile strength, a major part of the investigation of the properties of iron powders for rotating bands should be done on wax impregnated compacts.

Conclusions:

The German methods for the testing of rotating bands, which have been described herein, appear to be entirely satisfactory. However, the suitability of any test method is largely dependent upon the size of the samples submitted for test. It appears that the Germans did not work out completely satisfactory sampling methods.

The brief resume of fundamental physical properties of powder metals, which has been included herein, was not intended as a complete summary of the available knowledge on fundamental properties. It does, however, represent the more readily available knowledge and indicates that more work along this line will be required to provide a full knowledge of the factors influencing the properties of powder metals.

Respectfully submitted,

SAM TOUR & CO., INC.

By: Sam Tour

Sam Tour,
President.

ST:AR

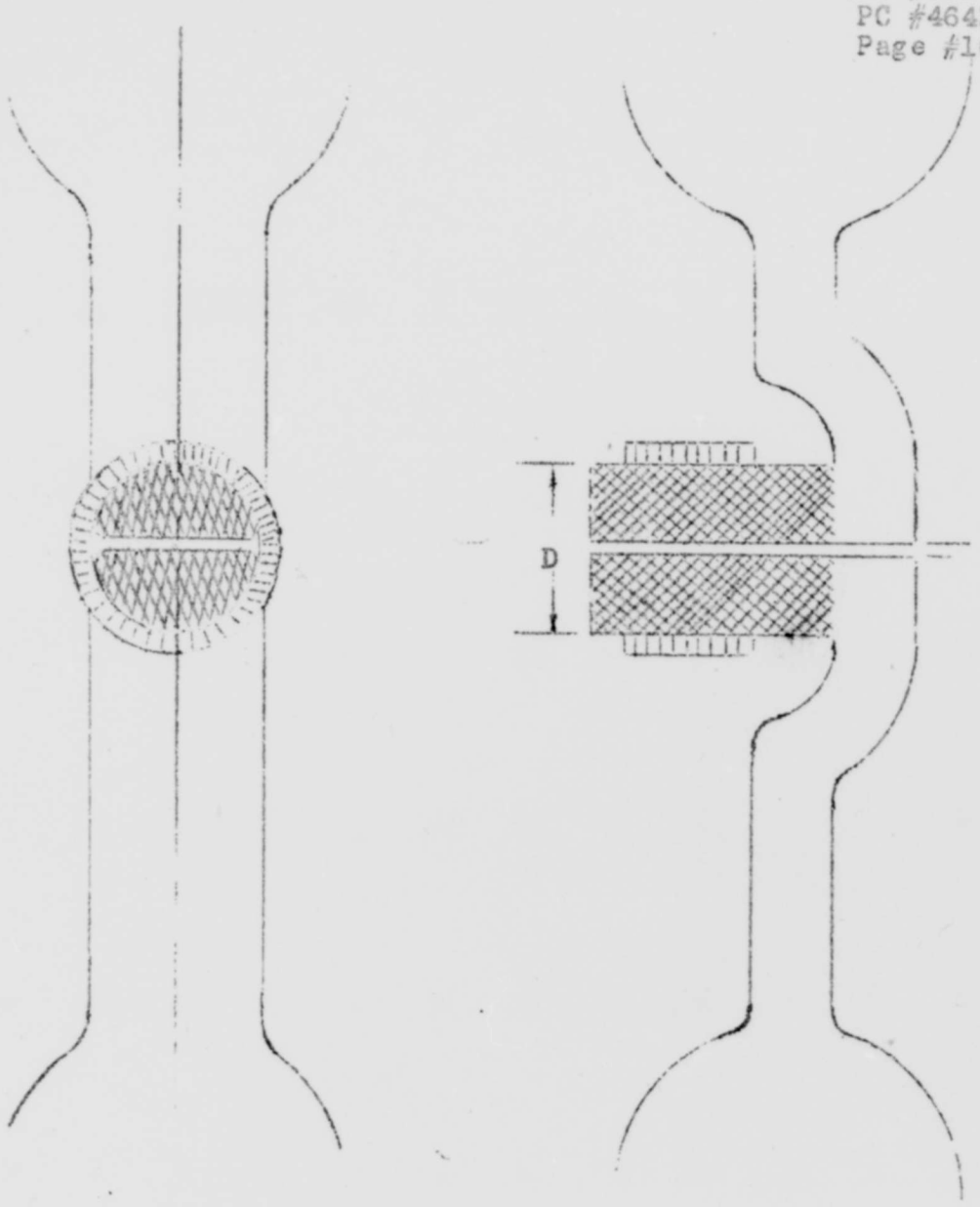
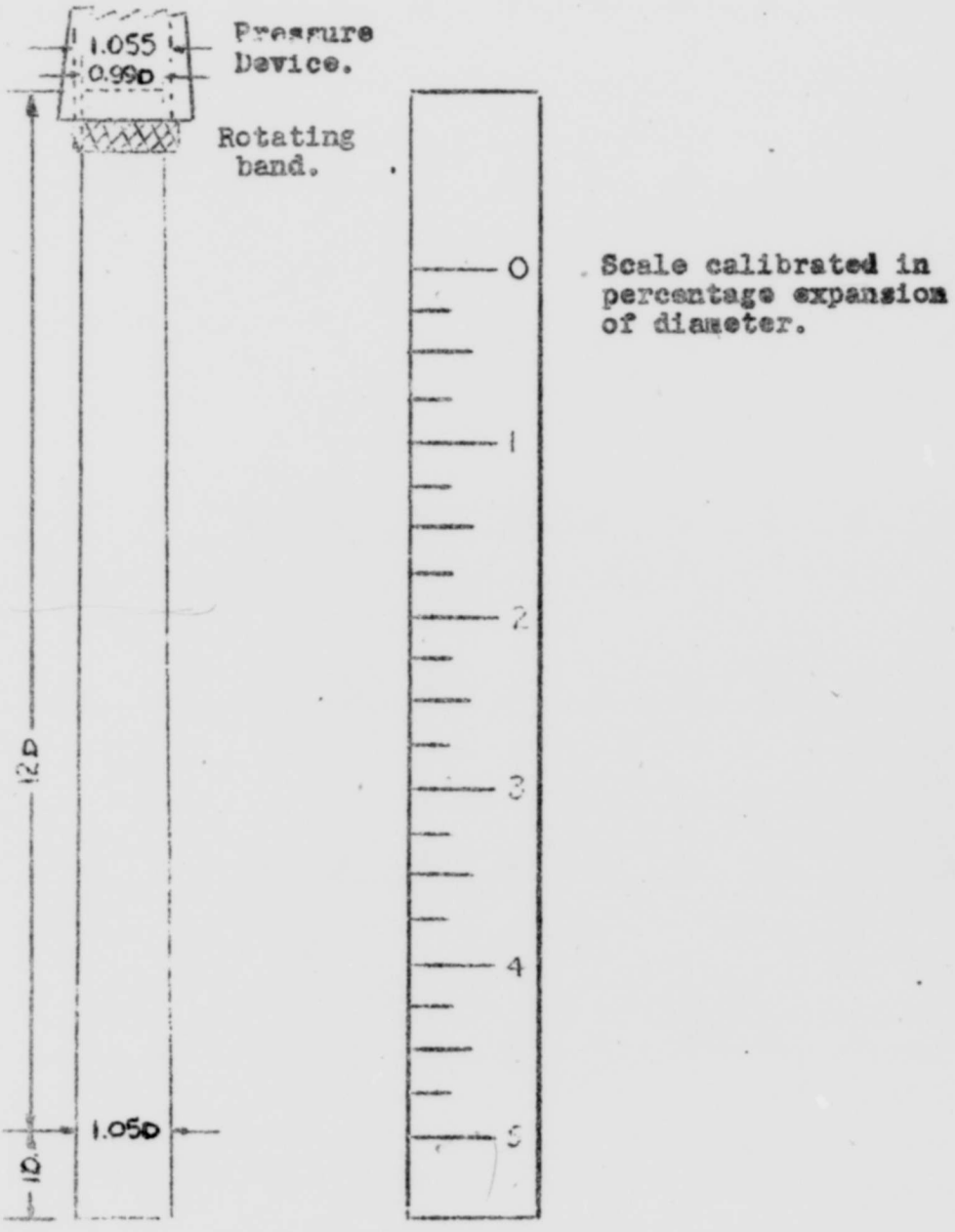


Fig. 1 - Special grips used in the tensile testing of sintered iron rotating bands.



SCALE: $\frac{1}{2}$" = D

Fig. 2 - Equipment used for determining the ductility of sintered iron bands.

APPENDIX A

M. W. Forschungsinstitute

Report on Investigation #25/44

Subject: A method for the determination of oxygen in iron and steel powder.

By Dr. Gerhard Naeser, Duisburg-Huckingen.

The large scale production of iron and steel powders called for a rapid and continuous determination of oxygen in powders that might be rather high in this element and in carbon. Since the usual analytical procedures included no such method, the latter had to be discovered and developed. Such a method has been developed and proved to be quite satisfactory.

Such methods as were known before (Gmelin's Hdb. der Anorganischen Chemie 8th edition #59 F.I. 18 41/103) were developed for steels and gray iron carrying from 0.02 to 0.1% oxygen. The first step was to find whether they would be suited to powders containing 0.3 - 0.4% O plus 0.03 - 0.08% C in addition.

The whole literature on this subject was recently surveyed so that there is no need to mention it here, except for the most recent article by A. Gotta (Archiv fuer Eisenhuettenverein 17 (1943/44, pages 53-55).

The most reliable method of oxygen determination used so far depends on an extraction in the hot state, but its precision is only ±10% of the total determined. It has

two drawbacks which make its practical use in the plants too difficult. The apparatus is quite complicated and the procedure is long. Furthermore, the possible precision is lowered by the necessity of taking very small samples. Powders containing over 0.5% oxygen have to be comminuted and they are likely to absorb more oxygen during this operation.

Reduction with hydrogen becomes practically impossible if the sample contains more than 0.2% of carbon, or if silica and silicates are present. At best it would require a 20-30 hours run to be nearly complete. The aluminum diffusion process is not suitable because the larger part of the oxygen contained is on the surfaces of the particles and does not enter the process.

The new process, like the hot extraction method, depends on a reduction with carbon and the determination of oxygen as carbon-monoxide. However, it requires no vacuum, therefore, a simple volumetric measurement is substituted for a complicated system of pumping and gas collecting. The 5-15% of carbon dioxide that usually would be present is reduced to monoxide in a simple manner.

The apparatus consists essentially of a furnace (fig. 1) which carries a tubing closed at the bottom and containing the carbon crucible and a gas burette for collecting the developed monoxide. The powdered sample is introduced into the crucible and the volume of the CO developed is read on the burette after 6 - 8 minutes. If the samples are standardized as to weight, the reading can be done directly in

% of oxygen. Just as with the old method slight corrections for temperature and pressure are required.

The furnace should develop a minimum temperature of 1300° C. Usually a silicon carbide furnace of the type used for the determination of sulphur will do. Far more convenient is a furnace with platinum winding as its control is easier and the power consumption much smaller. At present we are experimenting with furnaces having a carbon tube resistor which would permit considerably higher temperatures. The furnace isregulated by means of an ammeter, a series rheostat and a thermocouple with a millivoltmeter. The furnace is mounted adjustably as to height, so that it could be lowered in order to manipulate the tube. The latter is made either of sillimanite or of sintered alumina. It is 500 mm. long and 20 mm. i.d. The graphite crucible consists of three parts; the actual melting crucible, a conical intermediate funnel and a graphite cylinder (fig. 2). The conical part serves for the proper introduction of the sample, while the cylinder reduces to CO whatever CO_2 happens to form. The crucible has to be replaced after 5 - 10 determinations, but the other two serve much longer. The samples weighing 2 - 5 grams can be compacted to little rods or can be put in a small iron tubing (of iron containing no silicon). The tubing is closed with tin foil. A stock of such tubings must be annealed in hydrogen and kept ready. The gas burette is filled with paraffin oil. It is desirable to have two burettes one for samples containing much oxygen, the second for the lesser contents.

Procedure:

About two grams of pure iron containing no silicon is placed in the crucible first. This was found best in previous research work. Metal remaining from a previous test is satisfactory. It forms a pool of molten metal which accelerates the melting of the new sample. This is covered with about 1 gr. of graphite powder. This floats on the bath and reduces some of the CO_2 to CO. The conical part and the tube of graphite are placed upon the crucible next and the sillimanite tube connected to the burette.

In practice the sample should have a constant weight but, in our experiments, samples of 2 and 5 grs. were used. The burettes are graduated directly in % of oxygen. Corrections for temperature and pressure are taken from a table. The sample is placed in the sample compartment.

The apparatus is de-aired using a water pump and washing it out with pure, dry nitrogen. The pump is operated until the pressure reaches a minimum, then its stopcock is closed and nitrogen let in. This is repeated a number of times in order to eliminate all air. Next the furnace is switched on and run for at least an hour at 1300° C. or in the case of a platinum wound furnace at 1400° C. with a continuous checking of the volume in the burette every two minutes, until the latter stops changing or changes very slightly at a uniform rate which can be allowed for in exact analysis. The sample is thrown in with the help of a small magnet. A rapid formation of CO begins and is finished in 5 - 10 minutes. When

higher precision is needed the readings are corrected for the rate of change for two-minute intervals.

If, in cases of emergency, the burette and the chamber carrying the sample must be used without a protection by double wall tubings, the room-temperature must be kept closely constant.

After the burette is emptied of gas through opening b and brought back to zero (using the adjustable scale provided behind the burette), a second sample can be thrown in.

Precision of the method. The precision obtainable as well as the limits of applicability can be determined only after the whole apparatus is installed. The original equipment gave serviceable results even though it was a mere contraption. However, from the 300 analyses so far completed, the precision can be estimated to run ±5%, the error is consequently less than half than in the hot extraction process. Considerably greater errors occur, when the powder contains particles of slag or sand. They are reduced too, but the speed is low and it affects the speed of the determination and makes the end-point indistinct.

Fig. 3 presents a diagram in which the volume-time relationship was plotted each two minutes. Curve 1 obtained for pure powder shows the usual behavior, while curve 2 obtained for an impure powder is obviously composed of two overlapping isothermic processes. The steep part corresponds to the reduction of iron oxide, the second, shallower part, to that of the silicate. The presence of such silica carrying impurities can

be determined easily using a weak magnet, but the non-uniformity of their distribution through the mass of the powder can lead to additional errors. Tests have shown that the speed of reduction is materially affected by the presence of over 0.2% Si. Using a platinum wound furnace and running the test at 1400° C. might materially assist in the completeness of the reduction.

The described method was tested with pure iron oxide and the results compared with those obtained in the usual scheme of hot extraction. In all cases the agreement was quite good, frequently being much better than the 5% error mentioned above. The data of such tests are presented in Table 1. (The original apparatus is shown in the attached photograph and there is also added a list of the parts and chemicals needed.).

Resume. A new rapid method for the determination of oxygen in technical iron powder is described. It is based upon the formation of carbon monoxide when such powder is melted in the graphite crucible, under the cover of nitrogen. The use of an additional graphite tubing above the crucible permits to obtain a complete reduction of the CO_2 formed to CO. The oxygen content is determined directly from the volume of gas collected in a burette.

List of parts and chemicals needed to start oxygen determinations according to the new method:

1. - Furnace capable of giving a temperature above 1300° C.
2. - A bottom closed tubing of sillimanite or sintered alumina.
3. - Graphite crucible for melting.
4. - Graphite funnel to prevent the metal from spitting out.
5. - Graphite tubing for the reduction of the CO formed.
6. - Sample compartment.
7. - Sample shell of pure iron to take the sample of powder.
8. - Gas burette for collecting and measuring the CO formed.
9. - Level bottle for the adjustment of the level when reading the burette.
10. - Three-way stopcock.
11. - Hg. manometer.
12. - Three-way stopcock connecting the manometer.
13. - Stopcocks for the evacuation and for nitrogen inlet.
14. - "
15. - Thermoelement.
16. - Millivoltmeter.
17. - Thermometer for the room air temperature.
18. - Asbestos screen to prevent heat radiation.
19. - Gasholder with purified nitrogen.

Nitrogen to create a neutral atmosphere.
Cu or Fe chips for the purification of the nitrogen.
Furnace for the purification of the nitrogen.
Sulphuric acid for drying the nitrogen.
Washing bottle.
Paraffin oil as a burette liquid.
Pure Si-free iron to form a pool in the crucible.
Graphite powder.
Shells of pure Si-free iron for containers.
Tin foil for the closing of these shells.
Water-stream air pump.

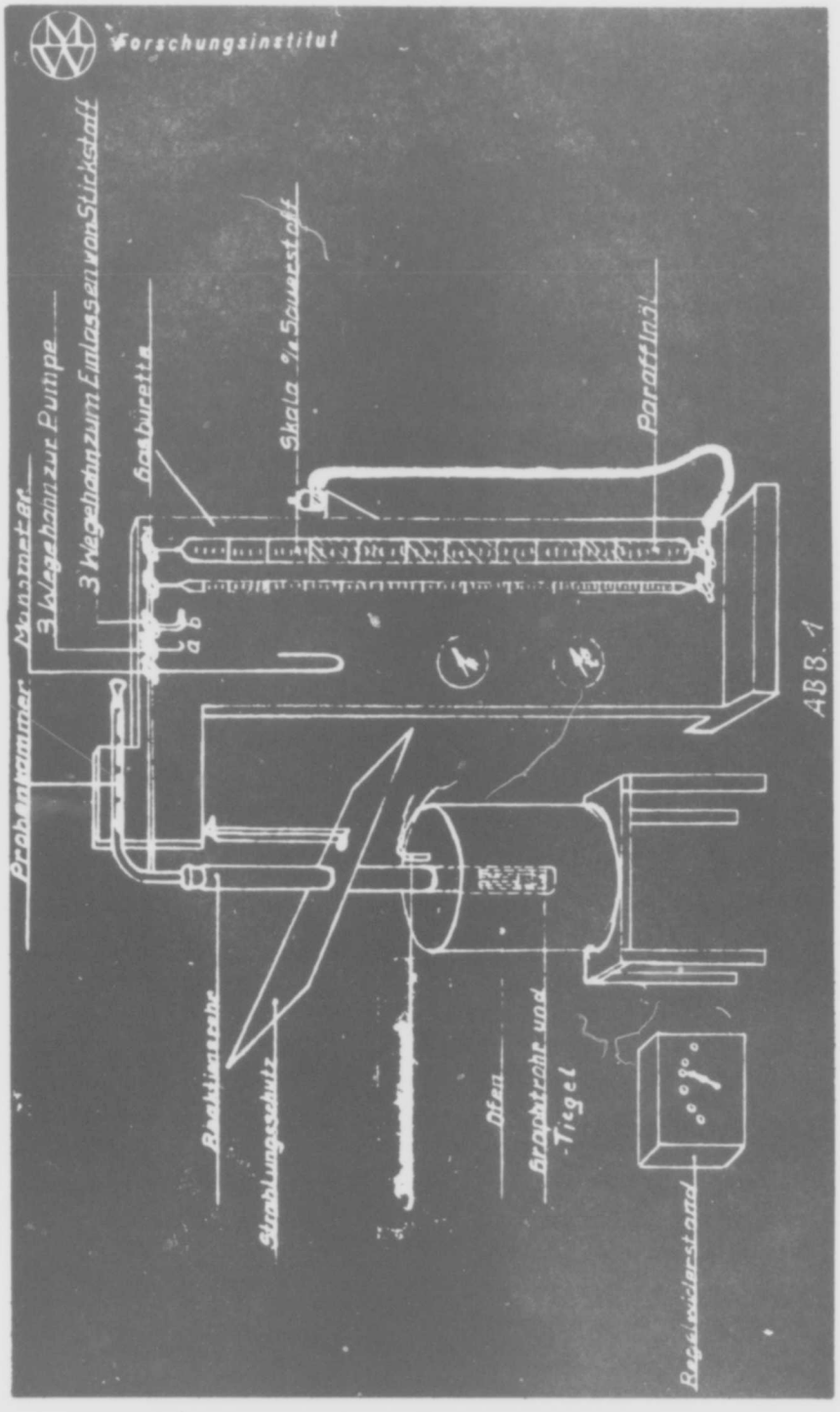


Fig. 1 - Sketch of apparatus used to determine Oxygen in Iron Powders.

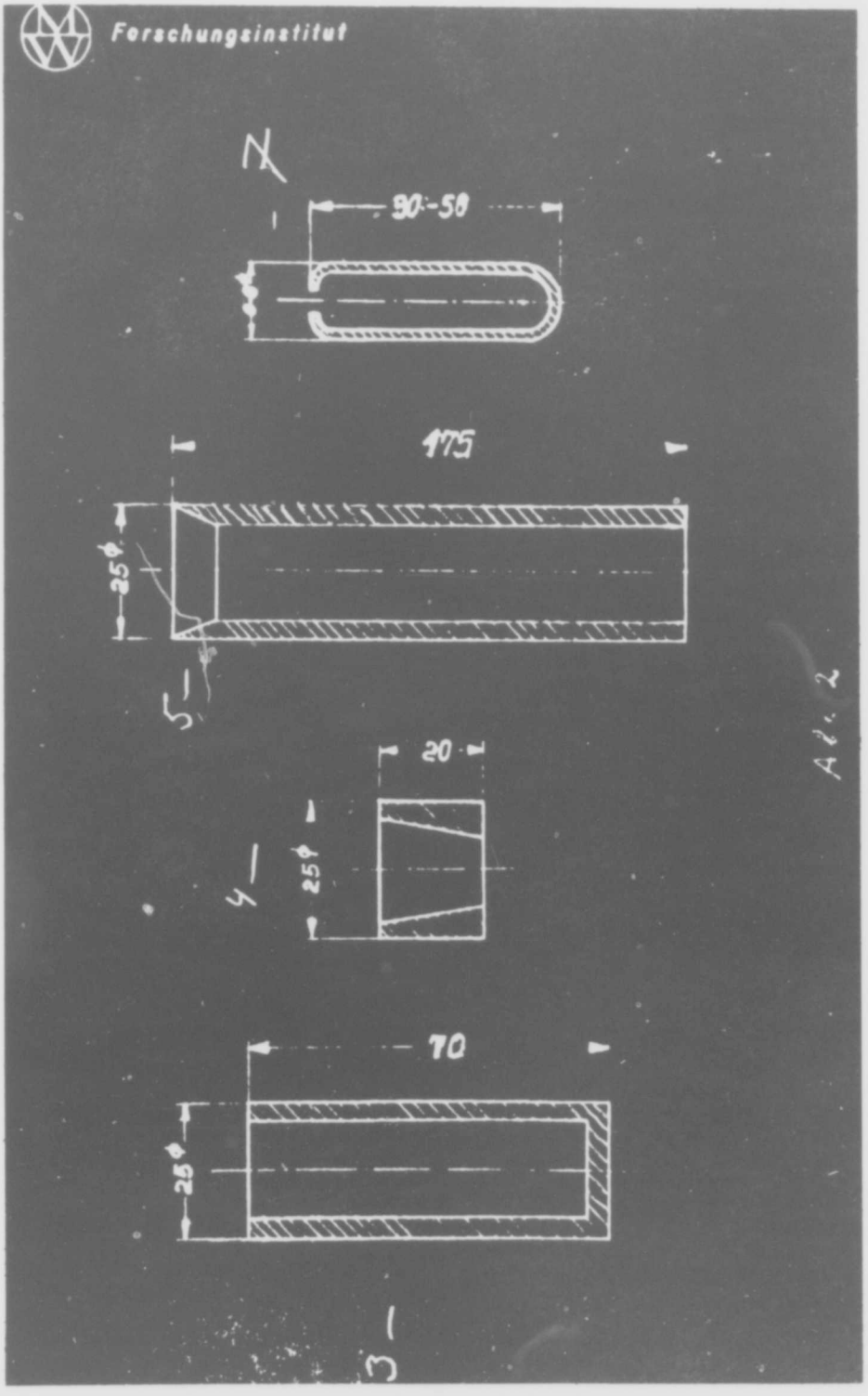


Fig. 2 - Details of Graphite Crucible used in determining Oxygen in Iron Powders.

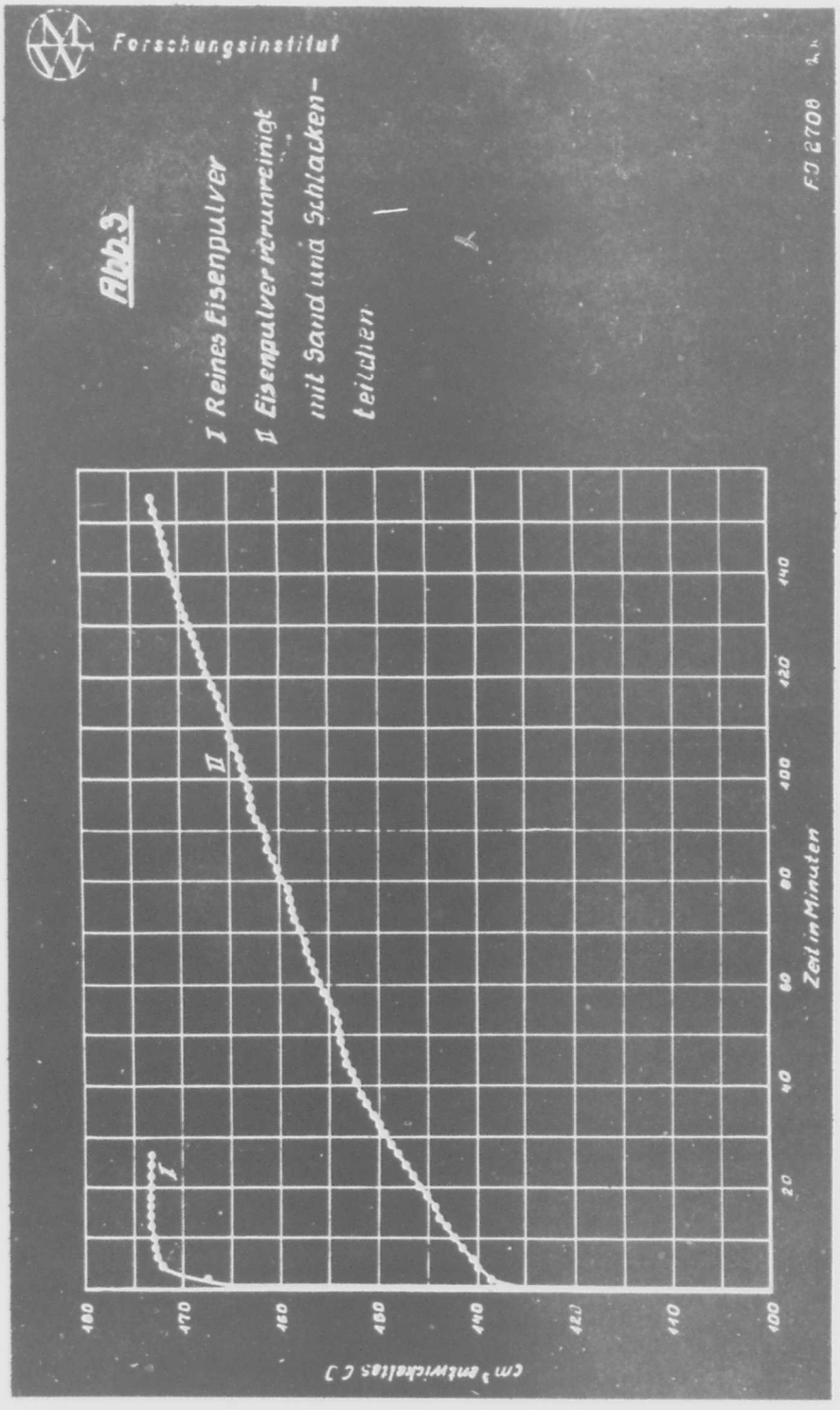


Fig. 3 - Relationship of Volume of Gas Evolved to Time of Evolution.

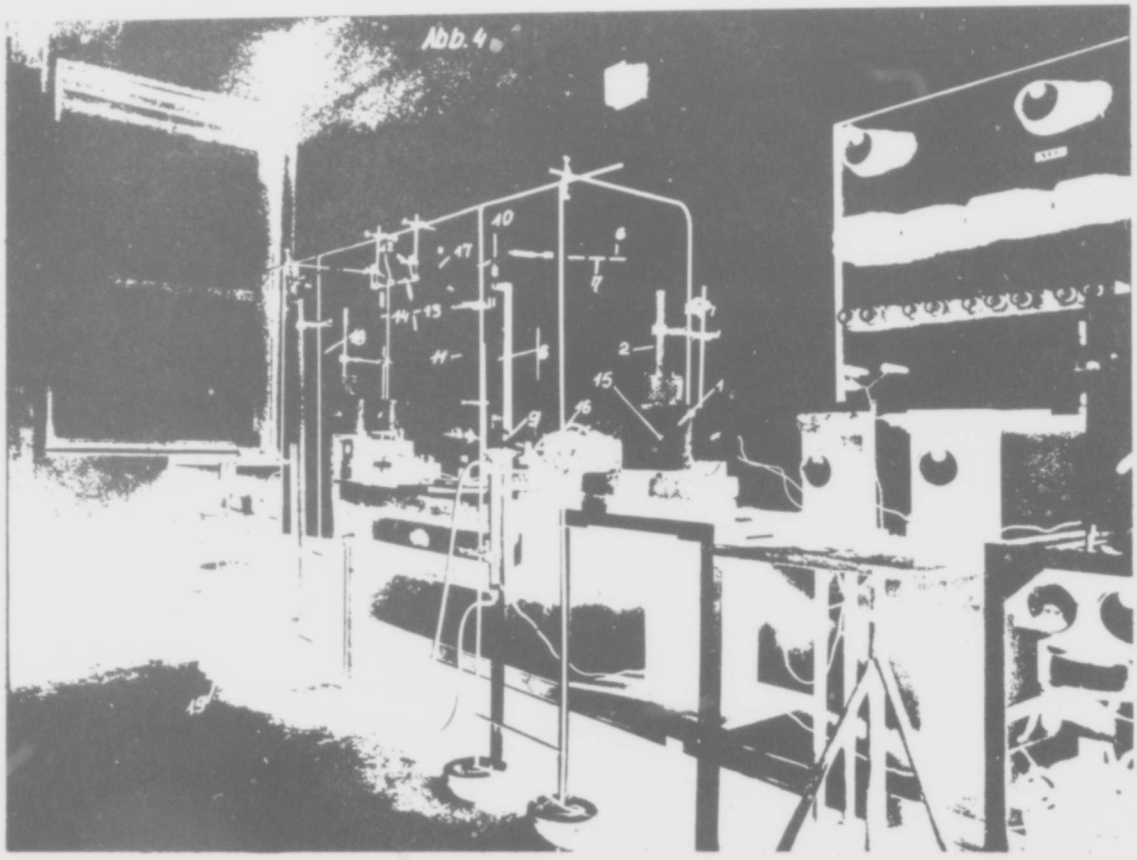


Fig. 4 - Apparatus Used in the Determination of Oxygen in Iron Powders.

REFERENCE LIST

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* #68 - Private Communication - H. H. Stout, Franklin Institute, to Sam Tour. 3 Dec., 1946. see ref #16

* #69. - Watertown Arsenal Laboratory Report WAL 671/24 - Metallurgical Examination of Two German Sintered Iron 75 mm. Rotating Bands. 16 April, 1945. see Ref. 73

#70. - File O.T.I.B. 2542 - Correspondence file on Acidity of Paraffin Baths and Tensile Strengths of Bands. 13, August, 1941. See Ref. 48 (Vol 5 of file)

#71. - File O.T.I.B. 2538 - Report of Difficulties in Acceptance Testing. Research Report No. 11. Army Inspection Station, Heddernheim-Ringsdorff, March 1941. See Ref 49 (Vol. 5 of file)

#72. - Wulff, Powder Metallurgy. American Society for Metals, 1945. (WAL Library)

**#73. - Watertown Arsenal Laboratory Report WAL 671/24 - Metallurgical Examination of Two German Sintered Iron 75 mm. Rotating Bands. 16, April, 1945. See Ref. 69

** #74. - National Defense Research Committee Report - M122 - Metallurgical Examination of Two German 8.8 cm. High Explosive Shells. Prepared by Battelle Memorial Institute. August 14,1943. WAL 763/52 L (on loan to Sam Tour).

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