RP 117

METALLOGRAPHIC POLISHING. I. AUTOMATIC METALLOGRAPHIC POLISHING MACHINE

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ABSTRACT

An automatic metallographic polishing machine, designed particularly for studying polishing methods, but which should be useful in any metallographic laboratory, is described. The metal specimen is mounted in a metal ring and held in an arm which moves it back and forth along a radius of the turning polishing disk. At the same time the specimen is rotated. There are three arms to a disk, so that three times as many specimens as there are disks in the machine can be polished at a time. A high quality polish, free from pitting and scratches, is obtained. An outline of the proposed study of polishing methods is given.

CONTENTS

I. INTRODUCTION

Polishing metal specimens for microscopic examination is an art not easily learned. The usual college course in metallography seldom gives the student sufficient experience to acquire the necessary skill, and even after long experience metallographers will find themselves spending a great deal of time in rectifying poor polishing results or in trying out various modifications, generally minor ones, in their polishing procedure. Such modifications seem to have consisted mainly in fluctuations about a norm, for the polishing procedure followed by a majority of metallographers to-day is not much different from that in use 10, 20, or 30 years ago. Although there has been continual concern over polishing methods, very little systematic study has been given to the subject since the early days of metallography. The bureau has recently undertaken such a study, the object of which is to make thorough trials of the important variables in the procedure, such as abrasives, the matrix for the abrasives (that is, cloths, metal laps, pitch polishers, etc.), speeds, pressures, etc. It is hoped that a recommended practice for metallographic polishing can be developed from the results of this study. Later, an inquiry into the theoretical matters involved may, perhaps, be desirable.

It was realized that, in the study of the polishing procedure, it would be necessary to eliminate, as far as possible, all irregularities and errors due to the personal equation such as would inevitably arise with the use of hand polishing. This desired condition would be obtained by means of a properly devised automatic polishing machine. Moreover, it was apparent that the building of a sucessful automatic polishing machine would, aside from its use in this study, be a sufficient end in itself. Hand polishing not only requires skill hard to attain, especially where a high quality polish is desired, but also is exceedingly tedious and time consuming. Every effort was made, in designing the machine, to construct it along such lines as would render it a highly serviceable piece of equipment in any metallographic laboratory with manifest advantages over hand polishing. It should be stated here that several models of automatic polishing machines were available in the market when this work was begun, but for various reasons they were regarded as not being fully suitable and the development of a new model was preferred. Such a machine has been developed, and it has proved very satisfactory after several months' operation under routine laboratory conditions. It was considered advisable to publish at this time a description of this machine without waiting for the study of polishing methods to be completed.

II. GENERAL REQUIREMENTS

In optical glass polishing automatic methods are practically universal and it might seem, therefore, that both the optical methods and machines could be adapted to metallographic work. However, there are radical differences between optical and metallographic polishing. In optical polishing, and this applies also to such operations as gage lapping where mechanical polishing is very successfully used, the material polished is always very hard, no special precautions have to be taken to prevent any flow or disturbance of the polished surface, and the main consideration is the contour or the dimensions of the finished object. In metallographic polishing, on the other hand, most of the specimens are relatively soft, the contour of the surface is of secondary importance as only a rough approximation to optical planeness is required, and the essential thing is the quality of the finished surface which must be undisturbed, with all the constituents left in place and not covered or removed. It may be mentioned in passing that an optically ground and polished lens, for instance, is of considerable and permanent value, whereas ordinarily a polished metallographic specimen is of only momentary value usually being discarded once the microscopic examination is over.

Because of the above differences metallographic polishing has followed a different course from that of optical polishing. In optical polishing machines, the work itself is usually moved over a slowly turning polisher and, in general, the speeds used are much slower than in metallographic polishing, especially during grinding where high speeds, of course, might cause cracking of the glass. The pressures are considerably greater in optical polishing, since there is little concern over disturbing or flowing the surface. Toward the end of the operation, as the work makes optical contact with the polisher, the forces between them become quite large and considerable viscous flow probably occurs. Hard metallic laps and pitch polishers are generally used instead of cloth-covered disks, as in metallographic polishing, in order to get more accurate contours. Such comparatively hard backings for the abrasives would be of advantage in metallographic polishing in decreasing rounding at edges, relief polishing of hard constituents, and pitting about cracks and inclusions, which effects are mainly due to the soft and yielding nature of the polishing cloth. However, the difficulty with pitch and other such polishing disks is that with all metals except hardened steel the specimen becomes impregnated with the abrasive and a matted, instead of a polished, surface is obtained. Unless some way of lubricating the hard polishing disks is devised which will entirely obviate this, the use of cloth-covered disks with their attendant disadvantages will have to be continued.

It may be emphasized here that it seemed essential to put high quality workmanship and material into the construction of the polishing machine. In the average laboratory the importance of having a good polishing machine appears to have been neglected or not sufficiently recognized. This has undoubtedly resulted in a deplorable waste of time in metallographic work as well as in lowering the quality of such work. In reality, the polishing machine is almost as important a piece of apparatus as the microscope itself. Ordinarily, a great deal more of the metallographer's time is spent in polishing, etching and repolishing the specimens than in examining them under the microscope and photographing them.

In designing the automatic polishing machine, the underlying principles employed did not depart in any essential respects from those in every-day use in metallographic hand polishing. The purpose of securing a high quality polish at least equal, or superior if possible, to that obtained by hand methods was kept uppermost. It might be mentioned that Pulsifer[1] has described a more rapid method of preparing microsections, by alternate grinding and etching, in which method the basic idea is that the preparation of a highly polished surface is unnecessary for revealing the structure. Aside from the

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[1] H. B. Pulsifer, Structural Metallography, Chemical Publishing Co., Easton, Pa.

fact that his method is not applicable to the study of inclusions and saves time only for the soft metals and not for iron or steel, it may be questioned on broad grounds whether such a rough method should be recommended for general use. The possibility of errors in judgment in microscopic work is very great, even with most painstaking preparation of specimens and after much experience, and it appears unwise, if only from the psychological standpoint, to advocate a method which for the sake of speed might seem to countenance carelessness and which might fail to instill the requisite pride in good looking and accurate work.

III. DESCRIPTION OF MACHINE

The details of the machine are given in Figures 1, 2, 3, 4, and 5. The machine consists essentially of a polishing disk mounted horizontally on a suitably designed table and a driving mechanism, actuated by an alternating current variable speed motor of 300 to 1,200 r. p. m., for rotating the disk at a speed of approximately 250 r. p. m.

The specimen to be polished is mounted in a metal ring, which will accommodate specimens up to 1¼ inches diameter and about 1½ inches high. This specimen holder, containing the specimen, is positively held in an arm, through which it is geared to an eccentric gear attached at the top of a shaft passing vertically through the axis of the polishing disk (fig. 3) and is slowly moved back and forth (about two times a minute) along a radius of the turning disk. At the same time the specimen is slowly rotated so that the direction in which it is polished changes continually. This rotating movement was deemed essential to prevent pitting and the formation of "comet tails" at inclusions. An intermittent gear for halting the oscillation of the arm for a brief interval during which the specimen holder was rotated through approximately 90° was tried out, but this arrangement proved to be superfluous. Three arms are supplied to one polishing disk, which is 9 inches in diameter, so that with one or more units (according to the number of polishing stages used) three times as many specimens as units employed can be polished at a time.

The shaft carrying the polishing disk is mounted in ball bearings to insure smooth working. Ample provision has been made to protect all bearings from abrasives and water. A belt drive, for connecting the driving mechanism to the motor, was chosen as being superior to a frictional drive, especially for this type of machine.

The abrasive may be continually supplied from a flask on a shelf placed above the polishing disk. The water containing the abrasive is agitated by an air stream, and the flow is regulated by a stopcock. A brass rod "wiper" attached to the wall of the pan, within which the polishing disk is placed, and resting upon the rim of the disk has

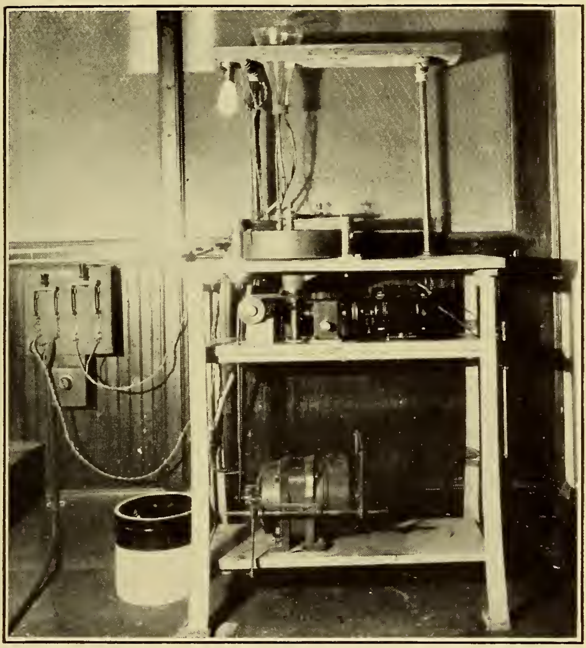

FIGURE 1.—*Side view of first model of automatic polishing machine*

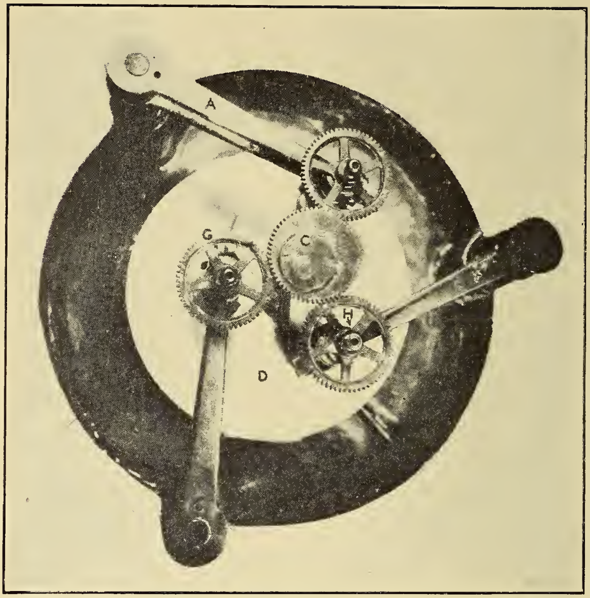

FIGURE 3.—*Plan view of the top of the machine*

A, Oscillating arm which carries the specimen and its holder; G, gear for rotating the specimen as it is moved across the polishing disk; D, C, cam gear by which the oscillation of the arms is brought about. Through the hole, H, a weighted pin may be inserted so as to rest upon the specimen.

been found useful in preventing the clogging of the disk with abrasive by distributing it more evenly over the disk.

A most important part of the machine is the means of holding the specimen flat on the polishing disk and applying the necessary light pressure. This is very conveniently accomplished by a spring arrangement attached to the end of the arm. This is shown in Figure 5. Pressure is applied to the "back side" (that is, on the side opposite to the direction of rotation of the polishing disk) of the specimen holder by means of a yoke to which the spring is attached, resting upon a flange at the bottom of the holder. Additional pressure may be applied through a sufficiently weighted pin which bears on the center of the mounted specimen. Before the spring arrangement was installed the pressure was applied from overhead only through this pin. The polishing results then obtained were very unsatisfactory because of the rounding of the surface, deep scratching, and slow polishing. The explanation seemed to be as follows: As the turning disk moves past the specimen a good deal of drag is set up between the "front side" and the cloth of the polishing disk. It

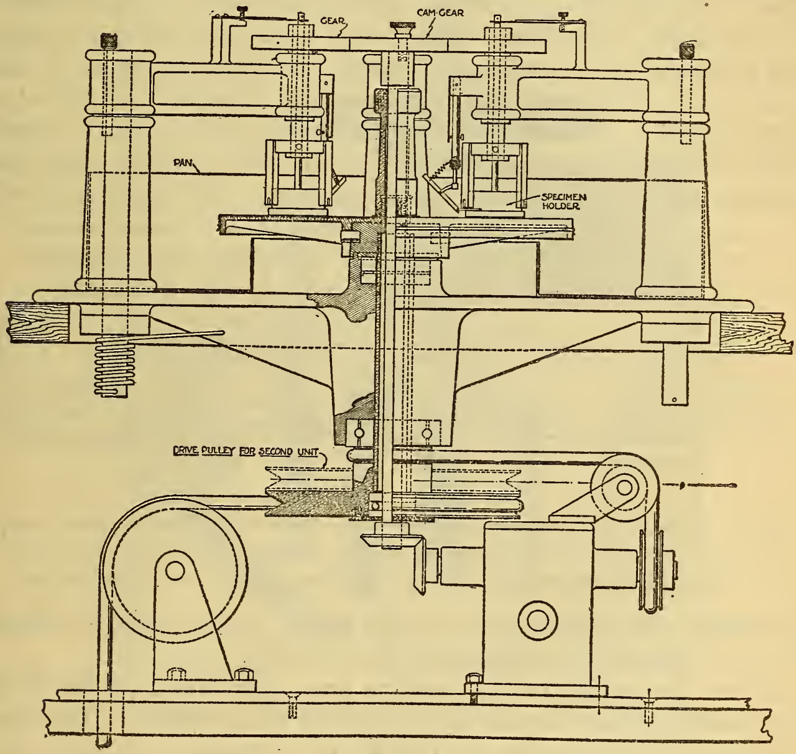

Figure 2.—*Assembly drawing of new model*

Some changes in dimensions were made for greater convenience in working. The spring arrangement placed at the side of the specimen holder for balancing it during polishing is shown.

is this frictional pressure which causes a specimen to fly out of the hand during hand polishing. In polishing by hand one instinctively compensates for the tendency to dig in at the "front" by a slight pressure on the "back"; this keeps the specimen balanced and eliminates the frictional pull. If something similar is not done in mechanical polishing, the specimen holder will jam tightly against the prongs of the support in which it is held and thereby be pressed hard against the disk so that deep scratches are formed. At the same time the holder no longer rests flatly on the disk but is tilted slightly. Most of the polishing, therefore, takes place at the circumference of the specimen, appreciable time elapses until the center is touched, and a rounded surface is the final result. With the spring at the side, however, the frictional drag is successfully balanced and the above difficulties are avoided. The spring is adjusted so that pressure downward and inward may be applied, the latter pressure preventing cocking against the prongs of the support. The specimen holder fits easily into the support and the spring is very readily adjusted in a few seconds for uniform and flat polishing.

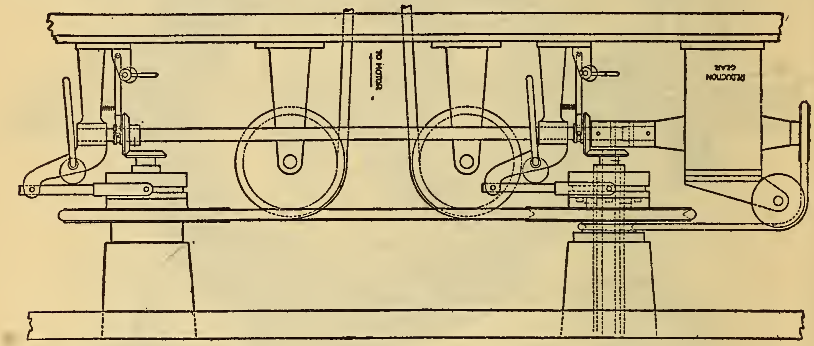

Figure 4.—*Transmission for two polishing units driven by one motor*

In the first model of the machine one motor was used for driving the polishing disk and another for rotating the specimens. The reason for the use of two motors was that for the purpose of studying polishing methods it was desired to have independent control of the speed of turning of the polishing disk and the speed of rotation of the specimen. A revolution counter for the polishing disk was also attached. Figure 1 shows a side view of this machine, before the spring attachment to the specimen holder was adopted. Another machine provided with two polishing disks is now being built along essentially the same lines, but with slight changes in dimensions for greater convenience. One motor will drive the two polishing disks, the same motor also rotating the specimens. Figure 2 shows an assembly drawing of this machine for one polishing disk. Figure 4 shows the transmission for the two polishing disks. Each disk may, of course, be turned on or off independently of the other.

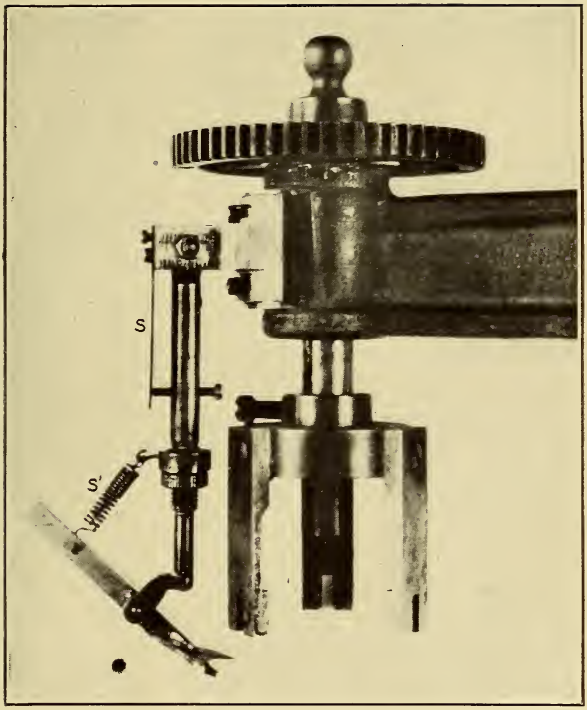

FIGURE 5.—*Specimen holder, somewhat smaller than actual size*

By means of the springs S and S′ pressure is applied to the specimen holder in two directions, perpendicular to each other. The specimen mounted in the ring is held by means of the slots in the "fingers" which form lower part of device.

IV. MOUNTING OF SPECIMENS

In hand polishing, specimens, such as filaments, sheets, or other odd shapes and small sizes, usually are mounted, but in this type of machine all specimens must be mounted. The question, therefore, of a suitable mounting medium becomes a very important one. Of course, materials usually employed for this purpose, such as the white metal alloys and litharge-glycerine cement, may be used, but these have decided disadvantages. They tend to smear and clog the polishing disk and may also scratch the specimen, but, above all, they seriously interfere with the subsequent etching of the specimen, since they are readily attacked by both acid and alkaline etching reagents.

In work recently done at the bureau on dental alloys sulphur was found to be a very convenient mounting medium. It has a sufficiently low melting point (120° C.), quickly hardens after solidifying, is clean, and is inert to acid etching solutions although it is attacked by alkaline sodium picrate and will disintegrate in the boiling solution of this reagent used for etching steel. However, the polished specimen is very readily knocked out of the surrounding sulphur without spoiling the surface and may then be etched without interference. A disadvantage of sulphur is that sometimes during the polishing, it forms tiny pits on the surface of steel which may be mistaken for inclusions; it also tarnishes copper and its alloys. It has been stated that the latter effect may be overcome by adding about 1 per cent of powdered graphite to the sulphur. A very useful precaution is to cut away the sulphur surrounding the specimen so that it does not come in contact with the polishing disk. This may be very readily done soon after the sulphur solidifies when it is comparatively soft. In mounting with sulphur the specimen and ring may first be ground flat and then laid face down on the glass side of an old photographic plate. By previously moistening the plate with glycerine the specimen and ring will stick to the plate and come out level with each other after the sulphur solidifies; this will save subsequent grinding to obtain a level surface. A slight amount of glycerine left in the ring before pouring in the molten sulphur will lift the sulphur from the glass and thus minimize the amount of cutting away required to keep the sulphur out of contact with the polishing disk. In general, sulphur makes a very convenient mounting medium if the above-mentioned precautions are taken.

Condensation products of phenol, such as bakelite, have even better properties than sulphur. Bakelite is very hard, can be molded at about 150° C., and is practically inert in both acid and alkaline reagents. The difficulty is that it must be molded under pressure so that some additional equipment is required. However, this is not prohibitive as a very small press is sufficient, the molding pressure needed being only 2,000 lbs./in.^{2}. A small electric furnace for obtaining the necessary temperature and a steel die for holding the metal ring may readily be made. The metal ring is fitted into the steel die, the specimen is inserted, and the bakelite in powdered form is poured around it. The die may advantageously be preheated to the required temperature of about 150° C. Pressure is then applied, and the molding is completed in about 10 minutes. Bakelite shrinks somewhat on cooling so that the molded specimen may become loose in the ring. This can be avoided by turning a few shallow grooves in the inner wall of the ring or else by drilling holes through the wall. There is no difficulty in knocking the bakelite out of the ring, which is then used over again. Figure 6 shows the press, steel die, and small furnace used for the molding operation. A good many other substances have been suggested as mounting materials, such as blocking wax, ozokerite, dumold (pyroxylin base), dental cement, plastic wood, balata, and paraffin. None of these seems to offer any special advantages. Some are soluble in alcohol, which is a great disadvantage in etching and cleaning the specimen.

V. METHOD OF POLISHING USED AND RESULTS OBTAINED

The stages in the automatic polishing procedure are exactly the same as those in hand polishing followed at the bureau. The specimens are first ground by hand with emery paper which is mounted on vertical disks directly attached to the armature shaft of a 500 to 1,200 r. p. m. direct-current motor. Mechanical means for the grinding stages appear to be unnecessary, since it is so rapidly done by hand. The papers used are emery paper 1/2 (American), Hubert (French) 1 G, 0, and 00. Recently, the quality of the finer papers available has not been of the best, and fairly deep grinding scratches have to be eliminated during the subsequent wet grinding with emery powder. This is a great disadvantage as it lengthens the time of polishing considerably and reduces the quality of the polish, for most of the pitting occurs during the wet grinding and polishing. Aloxite waterproof paper No. 400 is of excellent quality, although too coarse for the final grinding. It is unfortunate that a finer paper of this type, such as No. 600, is not manufactured.

After the final grinding the specimen is mounted in sulphur, bakelite, or white metal alloy. With the latter two materials, it is difficult to level the specimen with the mounting ring unless both are ground together after mounting. With sulphur, however, according to the procedure described, the specimen may be finally ground beforehand and then mounted perfectly level with the ring, no subsequent grinding on the emery papers being necessary; the precaution should be

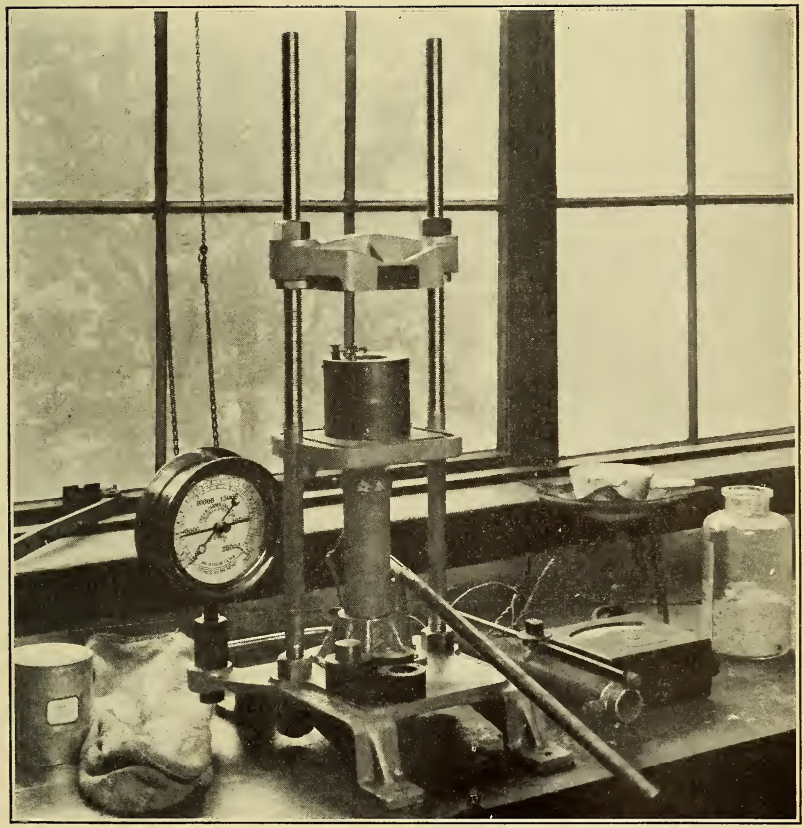

FIGURE 6.—*Press, steel die, and small electric furnace used for mounting specimens in bakelite*

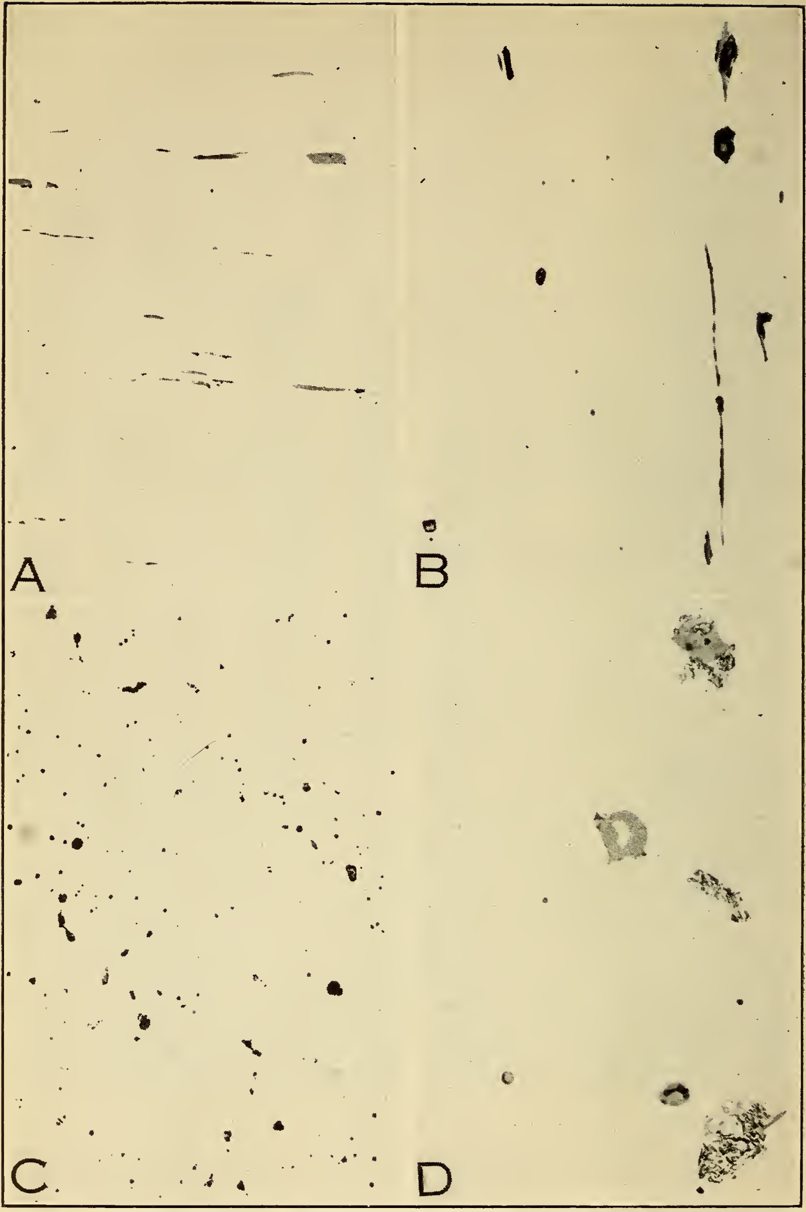

Figure 7.—*Representative micrographs of steel specimens polished in the machine, showing various types of inclusions. Not etched*

A, Sulphide inclusions in rail steel, × 100; B, alumina and sulphide inclusions in carburizing steel, × 500; C, large number of inclusions in experimental medium carbon steel ingot deoxidized with boron, × 100; D, same as C, but at × 500, silicate, sulphide and iron-boron-carbide inclusions are shown. These microsections appear to be practically free from "pitting."

taken, however, of testing for planeness by rubbing on the final emery paper, before proceeding further.

The mounted specimen is now polished automatically in the machine, first with 320 alundum suspended in water, then with either 500 or 600 alundum, and finally with Merck's reagent magnesia. For the alundum powders a strong cotton cloth, of about the same weave and weight as coarse linen, is used. Cotton cloth is superior to linen because of the knots and loose fibers usually present in the latter. The essential requisites of the cloth for wet grinding are a fairly coarse weave and absence of nap, otherwise pitting will occur. The emery powder and water should be used very sparingly. For the final polishing of the metal surface with magnesia the disk is covered with velvet. Care should be taken to brush the cloth-covered disks frequently with a stiff brush to clean them of débris and dirt. This applies especially to the magnesia disk, since wet magnesia hardens on exposure to air. The magnesia is not previously mixed with water, but is sprinkled dry on the moistened velvet cloth and then rubbed in with the fingers, water alone being supplied during the polishing. The support for the specimen holder may be easily wiped with a cloth or washed with water through a rubber tube. The spring is adjusted to press very lightly on the flange of the specimen holder, the amount of pressure being judged by lifting the holder. Auxiliary pressure is then applied through the pin which rests on the specimen, the pressure varying from about 3 to 6 ounces or more as desired.

For a high quality polish about 5 minutes polishing is generally given with the coarser alundum, 10 minutes with the finer alundum, and, finally, 15 minutes with the magnesia. Generally the total time of polishing in the machine is about a half hour or somewhat longer, the time consumed depending largely on the quality of polish desired. For merely revealing the structure, the pressure and speed may be increased and the polishing done more rapidly. Nevertheless, for any individual specimen automatic polishing in the machine is not any faster than polishing by hand. The saving in time only becomes considerable when a good many specimens are to be polished. With 3 specimens polishing on 1 disk, 9 specimens can be polished simultaneously on 3 polishing units, and 12 on 4, which would be available if 2 of the double disk machines described were used. Since the polishing is usually done in 3 stages 3 polishing units should be provided to obviate changing of disks and the difficulties attendant upon using more than one abrasive in a unit. Moreover, since the final polishing with magnesia takes the longest time, the best arrangement might be to have 4 disks; the final polishing could then be done on 2 of the disks, and the coarse and fine wet grinding on the other 2. As a matter of fact, the polishing machine has proved to be a great convenience, whenever a high-grade polish is desired, even when the number of specimens to be polished is small and practically no time is saved by using the machine. In the laboratory it was found that men inexperienced at polishing, quickly learned to get good results with the machine—very much sooner than they could have learned to polish by hand, which, of course, is a most valuable advantage.

A very high quality polish, fully the equal of that possible by hand, is obtained in the machine. The criterion of a good polish is not so much the absence of scratches, although that is, of course, important, as the freedom from pitting, especially in low-carbon steels. In fact, tests of the quality of steel based on the number and type of inclusions present are worse than useless unless a good quality polish free from pitting is to be had. Figure 7 shows a number of micrographs of inclusions in steel specimens polished in the machine; the microsections appear to be quite free from pitting. Figure 8 shows micrographs of a cracked piece of rail steel and of a specimen of gray cast iron. In examining cracks it is very desirable to get as little pitting as possible; gray cast iron is seldom well polished because of the dragging out of graphite flakes. As may be seen in these micrographs, the cracks in the steel do not appear to have been widened or pitted during the polishing, and the graphite flakes in the cast iron are sharply defined and intact. The softer metals may also be polished successfully in the machine. Figure 9 shows the results obtained on tin, wrought duralumin, and cast aluminum.

VI. PROPOSED OUTLINE OF STUDY OF POLISHING METHODS

As was stated in the introduction, the primary purpose in undertaking this work was to study the effect of the variables in the polishing procedure with a view to working out a recommended practice, and also, perhaps, to go into the theoretical aspects of the subject. Aside from developing the automatic machine, little progress has been made, but a brief outline of the proposed work may be given. The most obvious matters for study are the most suitable pressures and speeds for the various stages of polishing of the different metals. Here the use of an automatic machine, by which reproducible results should be obtainable, will be of value.

The subject of the best cloths has always been an uncertain matter. After a cloth has been chosen, a constant source of supply should be made available. Various disks have been suggested as improvements over cloth, such as paraffin, pitch, white metal alloy, cast iron, aluminum, etc. Such disks have been tried and discharged by many investigators, but it is, perhaps, possible that with proper lubrication

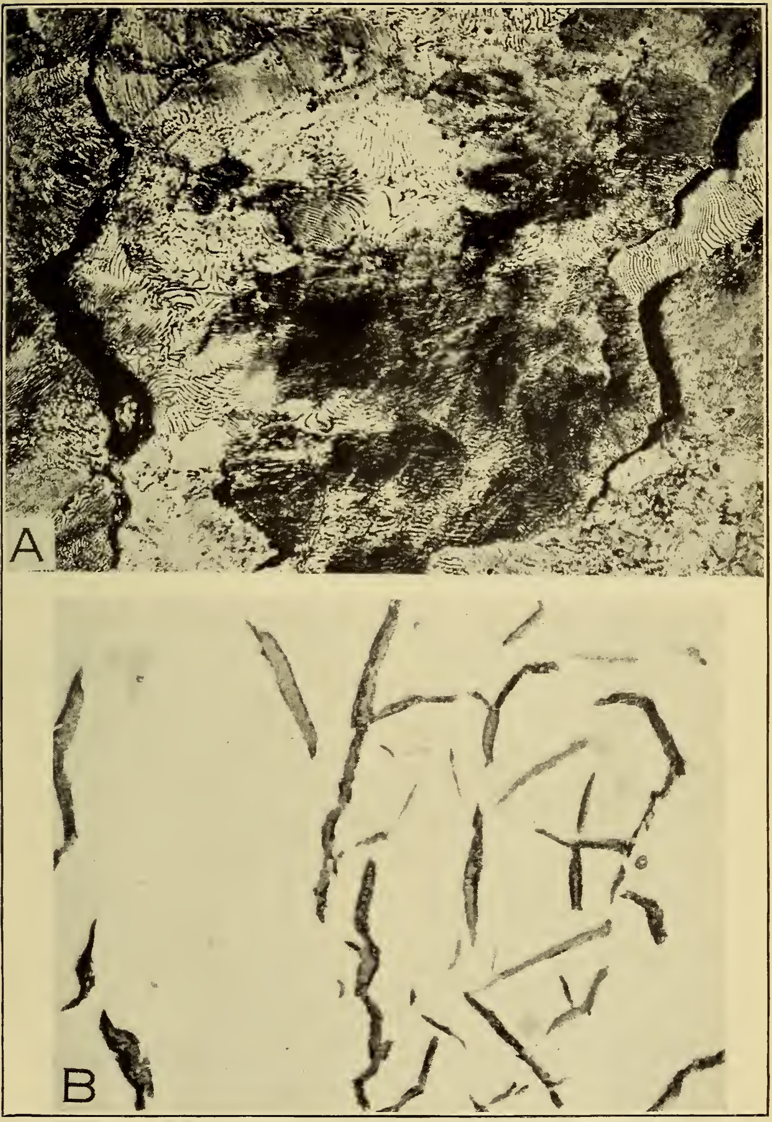

Figure 8.—*Micrographs of steel and cast-iron specimens polished in automatic machine*

A, Rail steel showing small cracks, × 500, etched with 5 per cent picric acid in alcohol; B, gray cast-iron showing graphite flakes and inclusions, × 500, not etched. Practically no pitting or rounding off of edges was produced at the cracks by the mechanical polishing. The graphite flakes also remained intact.

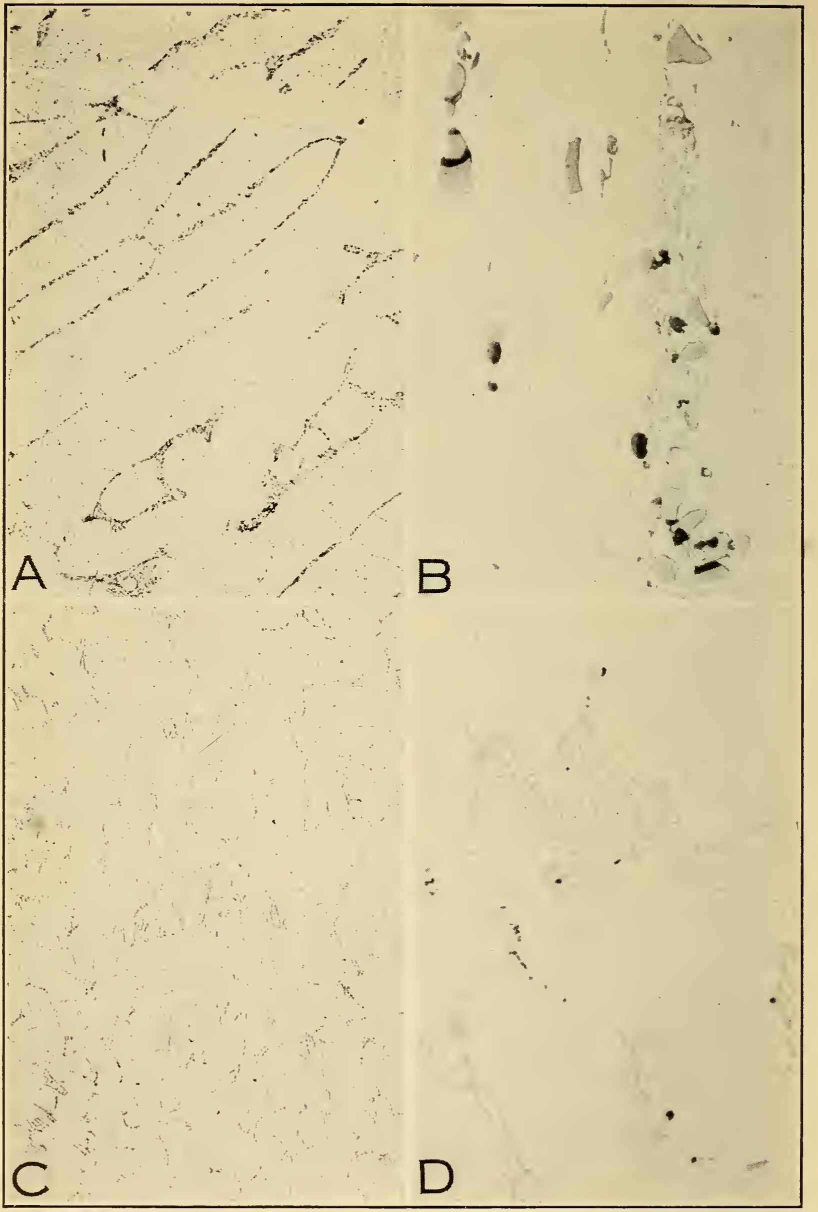

FIGURE 9.—*Micrographs of several specimens of softer metals polished in the machine*

A, Tin (0.25 Cu; 0.02 Pb; 0.02 Fe; Zn. not detected), showing dendritic structure and large twins, × 500, etched with 10 per cent aqueous solution of potassium hydroxide; B, segregated spot in wrought duralumin, × 500, not etched; C, cast aluminum, × 100, not etched; D, same as C, × 500 they may prove successful. The grinding and polishing powders have usually been suspended in water, although soap solutions and oil have been tried. Polishing powders are now marketed in which the abrasive is held in suspension in an oil or gum base liquid. Possibly such compounds may improve results and reduce the amount of abrasive consumed.

The question of grinding papers is an important one, especially the finer grades. If a satisfactory fine paper were available it would be possible to improve considerably the quality of polish and save time, and one of the steps in the wet grinding might even be eliminated. The main requirements of abrasive powders are their cutting quality and uniformity, and these might advantageously be studied with the microscope. A large number of grinding powders are available under different trade names; recently, due to the problem of polishing the hard tungsten carbide alloys, calcium boride and boron carbide have been added to the list. Titanium nitride is one of the hard materials to be tried out.

The number of polishing powders is also very great, among them being the oxides of iron, chromium, tin, zinc, manganese, aluminum, and magnesium. From the standpoint of cleanliness the last two, which are white powders, appear to be the most convenient. Tin oxide is also a white powder. Glazebrook[2] states that putty powder (SnO_2) was at one time extensively used as a polishing powder, but has been discarded for reasons of health. Magnesium oxide appears to be the most uniformly fine powder available. An objection to its use is its tendency to harden on exposure to air. The usual grade of levigated alumina contains traces of alkali, which are objectionable for polishing aluminum and its alloys, because the surface becomes tarnished. Alkali-free alumina of a fineness equal to magnesia would be preferable to the latter because of the tendency of magnesia to harden.

A microtome is available in this laboratory, and the question of the preliminary preparation of a plane surface of soft metals by means of this instrument will receive attention. An interesting proposal for preparing specimens with a cutting tool is that of turning with a diamond. This has been tried by the Bausch & Lomb Co., and may, perhaps, be considered further.

The question of the mechanism of the polishing action has long provided a topic of discussion to physicists, the principal issue being whether the action consists in removing the glass or metal from ridges or in flowing the material and filling in the grooves left by grinding. Apparently, measurements made on glass spheres during polishing[3] show an appreciable decrease in diameter indicating that material is

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[2] Glazebrook, Dictionary of Applied Physics, 4, p. 339.

[3] J. W. French, Some Notes on Glass Polishing, Trans. Opt. Soc. (London), 27, No. 2, p. 24; November, 1916.

removed. There is also evidence that surface flow occurs, so that probably both removal and flowing take place during polishing. Rosenhain has observed that all of the usual polishing materials are oxides and he, therefore, supposes that the polishing action may be partly chemical.

VI. SUMMARY

In order to obtain reproducible results in a projected study of polishing methods an automatic metallographic polishing machine was developed. A very high quality polish can be obtained, and the machine promises to be of great value for routine metallographic polishing. A description of the machine with photographs and drawings is given, some examples of the results obtained are shown, and the method of polishing used is discussed. A brief outline of the proposed study of polishing methods is also given.

ACKNOWLEDGMENT

Acknowledgment is gratefully made to Dr. H. W. Gillett, chief of the division of metallurgy, who initiated this study and whose encouragement made possible the building of the automatic polishing machine.

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