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THE PREPARATION OF "AS POLISHED" METALLOGRAPHIC FINISHES IN NON-FERROUS METALS

by

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ABSTRACT

Various methods that have been shown to give consistently good results in the preparation of metallographic samples are described. The selection and application of these techniques to the various alloys is discussed relative to the class of examination required. The avoidance of certain pitfalls is discussed and information is given on a number of minor points that collectively can lead to a considerable improvement in technique.

RÉSUMÉ

Les auteurs décrivent les divers procédés qui ont constamment donné de bons résultats dans la préparation des échantillons métallographiques. Ils analysent le choix et l'utilisation de ces procédés pour les divers alliages selon le genre d'examen oui doit être fait. Ils indiquent comment éviter certaines erreurs et donnent des renseignements sur nombre de points d'importance mineure qui, pris dans leur ensemble, peuvent améliorer considérablement la technique.

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INTRODUCTION

This report is a condensation of the procedures used in the Non-Ferrous Section of the Physical Metallurgy Division of the Mines Branch to obtain polished surfaces adequate for the intended purposes. Those already familiar with metallographic techniques will be aware that there is no unique way that must be used to obtain a perfect finish. Sample preparation is still much of an art and a skill, and the "best" method not only must fill certain technical requirements but also must fit the limitations and idosyncrasies of the equipment and the operators. Thus, the techniques to be described herein have been found, with a wide range of personnel, to give consistent results when intelligently applied under normal laboratory conditions. Because enquiries are frequently received as to polishing techniques, and because people from other departments and industry have been given metallographic training by our laboratories in the past, it is considered desirable at this time to make a complete resumé of our present techniques. It is hoped that this report may considerably reduce training time in the future, both for our own technicians and for others; that it will serve to update those who have been trained in the past; and that when kept up to date it will speed the acceptance of new and improved methods by increasing the ease of reference and comparison of techniques developed for the different metals.

A relatively large number of samples of a variety of materials pass through the metallographic preparation phase each day and it has been necessary to break the work down into three distinct groups according to the quality of finish required, each group being treated in a different manner.

The first group, classed as "grain size" polished, is subjected to a rapid rough preparation, sufficient for counts of inclusions and porosity and for determination of grain size for control purposes. Because some inclusions are removed, relief is marked, and a great many scratches remain, this first type of polish is unsuitable for other purposes. The second group is "routine" polished, with more steps used in the preparation and a little more time consumed at each step. The surface resulting has only a small number of scratches present, and inclusions are intact but with some relief. This second type of preparation is suitable for most purposes, such as micro-hardness surveys, comparison of structures, etc., and is quite adequate for relatively low-power monochromatic photomicrography using incident illumination. It is unsuitable for high magnification work or colour photomicrography and illumination other than incident. The third group is a "finish" polish, a great deal of care being taken to ensure a polish revealing the true structure of the material, with inclusions intact, edges sharp, and relief minimized. These samples are nearly always mounted in a suitable plastic before polishing and, when finished, are suitable for any examining technique. This preparation is mandatory for colour photomicrography and phase contrast work.

The metals commonly polished include magnesium, aluminum, copper, nickel, zinc, tin, lead, and their alloys; galvanized and plated coatings; and lesser quantities of other materials such as zirconium, niobium, cadmium, etc.

MOUNTING SAMPLES FOR METALLOGRAPHY; MOUNTING MATERIALS

The main reasons for mounting a sample to be polished might be summarized as follows:

1. It is too small to be held conveniently in the hand and polished.
2. It is friable.
3. It is fragile.
4. A corrosion product or scale must be retained.
5. The edges must be preserved.
6. It is to be automatically polished by machine and must be of standard size to fit fixtures.

Usually, samples large enough to be held in the hand, and which are to be polished only for hardness, density or grain size determinations, are not mounted.

The mounting materials used fall into three classes: thermosetting, which requires heat and pressure for curing; thermoplastic, which requires heat to soften, followed by cooling under pressure; and room-temperature curing, without additional heat or pressure. An ideal mounting compound would be one that would keep indefinitely until ready to be used and would then set in a few minutes at room temperature without pressure into a hard, dense, chemically inert free-machining substance completely investing all irregularities on the sample. Mineral-filled diallyl phthalate and phenolic resins are representative of the thermosetting materials and give hard, readily polished mounts with good filling (particularly with diallyl phthalate), but they tend (particularly the phenolics) to pull away from surfaces after curing.

Polyvinyl chloride is thermoplastic, flows and bonds very well, and is extremely tough and abrasion-resistant when moulded. It appears to be inert to the chemicals used in polishing and etching. On the other hand, methyl methacrylate, also thermoplastic, while having good flow characteristics, tends to smear or polish in relief and, at the same time, is brittle, sensitive to moisture adsorption before processing, and sensitive to alcohols when moulded. Epoxy and dental acrylics can be used without heat or pressure but are the softest materials when cured, and tend to be porous.

Further, if improperly mixed, they tend to be subject to excessive shrinkage, leading to poor bonding between sample and plastic.

Satisfactory as a room-temperature curing plastic is a proprietary hybrid - - thought to be basically polyester modified with some other type of resin - - that is supplied under the trade name of C-32*. After catalysing, this casting resin sets overnight, without pressure and without any temperature increase, into a hard, water-clear, porosity-free solid completely investing all parts of the encapsulated sample. The bond with the sample is good. It is inert to most chemicals and is free-machining. However, alcohol should be used with caution, since it will slowly dissolve the plastic.

Mineral-filled diallyl phthalate is supplied as blue granules and is used wherever a prime requirement of the mounting material is flowability in the gel stage with good bonding in the cured mount. It is also used in some cases where edge retention is of first importance, but always with a sealant and sometimes with an edge support. Since the glass fibres in the glass-filled resin tend to be removed from the mount during the final polishing stages and thus ruin laps, the asbestos-filled material is the one of choice. Premoulds may be made by placing the granules in a cold mould and applying a pressure of about 8 kpsi for a few seconds. The resultant compact may be handled in the usual manner or stored for a few days.

Phenolics (Bakelite) are supplied as unfilled amber powders, and black, red or green mineral-filled granules and premoulds. The amber powder makes the hardest cured mount of this type, with the green being almost as hard and the black the softest. The granules and premoulds are used with the majority of samples and process into hard, dense, chemically inert material that is easy to grind and polish. However, they do not flow as well as does diallyl phthalate and, as previously mentioned, they tend to pull away from surfaces after processing. If retention of the edges is important, the samples are sealed before mounting.

Polyvinyl chloride and methyl methacrylate are supplied as fine white powders. Although there appears to be no particular precaution required for the storage of polyvinyl chloride, methyl methacrylate must be kept in sealed enclosures to prevent moisture adsorption; failure to do this may result in a finished mount with a porous centre and, in extreme cases, a mount that is completely porous or that will not fuse.

Room-temperature curing materials are supplied as double component packs that are mixed together and poured into a suitable enclosure containing the sample. With the exception of C-32, all

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* Some suppliers of the various materials are listed in the Appendix.

have perceptible heat of reaction with resulting increase in temperature of the mould as curing progresses. They are used in those cases where the specimen structure might be altered by heat or pressure or both; for example, pure tin, metallic foils, corrosion products, pieces of sand moulds, etc. Because of its desirable properties, C-32 had at one time almost completely displaced epoxies or dental acrylics for such purposes in these laboratories. However, recent improvements in epoxy formulations have now shifted the balance of preference back to the epoxies.

Another material found useful in preparing metallographic mounts is Eastman 910 adhesive. This is a thin, water-clear liquid which changes into a clear, hard solid when drawn out into a thin film by smearing, swabbing, or pressing between two surfaces. It has excellent adhesion and chemical resistance.

SPECIFIC MOUNTING TECHNIQUES

One of the common difficulties associated with polishing material in which edge preservation is of importance is the previously mentioned separation at the plastic-sample interface, which leaves a seam from which liquids may oooze after the specimen has otherwise been dried. The harder the mount the more likely it is that this will happen. Another, and similar, seam may occur when two or more sheet specimens are mounted together in a single mould. Here, again, a hard mount is desirable but the harder plastics usually have poorer flowability in the gel stage, thus increasing the likelihood of voids between adjacent samples. The use of Eastman 910 adhesives provides an aid in overcoming these defects. The 910 may be used in a number of ways. For sheet specimens, a sandwich of two or more samples fastened together with adhesive is made, wrapped in metallic foil, and mounted. When edges are important the sandwich is made with adhesive-saturated lens tissue, Kleenex, or filter paper, interleaving the samples, the choice of the different papers being governed by the degree of separation desired between adjacent samples.

When handling plated material it is sometimes an advantage if the apparent thickness of the plate be increased as an aid to observation or measurement. This may be readily accomplished by the following procedure of taper sectioning. A known angle is let into one side of a piece of flat stock and the sample is fastened to this angle with 910 adhesive. The composite is then mounted in one of the granular plastics, or in epoxy, with the back face of the flat stock exposed on the base of the mount. After curing, the mount is carefully ground back from this face until the sample is exposed. This procedure will give an increase in apparent magnification, since in effect the true vertical height of the triangle is extended to become the hypotenuse. For example, a recessed angle of 5.5 deg will give an apparent increase in magnification of X10. In practice, foot-long strips are machined

with known angles recessed into one side, and small pieces cut from these are used as the disposable jig.

When preparing wires larger than about 20 gauge, holes about twice the diameter of the wire are drilled into a premould, the wire is inserted, and amber bakelite is tamped in around it. This assembly is processed in the normal way. This technique not only supplies a band of very hard plastic around each wire, which aids edge retention, but ensures that the wire is mounted in true cross-section. Wires smaller than 20 gauge are usually made up into small bundles and each bundle is treated as a single larger wire. A variation may be used for sheet specimens where a true cross-section is desired. In this case, the sheet is inserted in a saw cut in a premould and amber bakelite is tamped in before processing.

Chunky samples where edge preservation is not important are mounted by placing them on the bottom ram of the press with a premould on top, then closing, and processing. If edges are important, a small annulus is made inside the moulding chamber with granular plastic, the sample is placed in the centre, and amber bakelite is poured into the space between the sample and the plastic liner. A premould is placed on top of this and the assembly is processed.

Fragile materials or odd-shaped pieces, which might be distorted if premoulds were used, are processed with powdered or granular plastics or with epoxy. The sample may be treated first with 910 or epoxy, particularly if there are friable coatings present.

Mounts that are made with heat and pressure come from the process hot and must be allowed to cool to room temperature. This should not be hurried by quenching, for it is almost certain that cracks will then develop.

Should voids or seams remain in mounts or should the sample be very porous when polished, a drop of 910 adhesive or epoxy may be placed on the sample face to overlap onto the mount, which is then placed in a vacuum chamber and the pressure lowered until bubbles stop coming through the adhesive. Air is then admitted to the chamber; the sample and mount are removed and the face is smeared gently with a glass slide or piece of metallic foil, which is immediately removed; and the mount is set aside to cure. Subsequent polishing will show complete filling and sealing in most cases. The treatment may be repeated as often as required.

Success with either the epoxy or the 910 adhesive is proportional to the degree of cleanliness of the sample, particularly the presence of either grease or moisture. For this reason, it is important that samples be clean and dry before any mounting procedures are attempted. In particular, should the necessity for vacuum sealing become apparent at any stage after polishing has started, it is imperative that the sample be thoroughly cleaned and

dried before sealing is attempted. Final drying is usually accomplished by placing the mounted sample in a good vacuum for about half an hour before applying the adhesive.

SUMMARY OF PLASTICS USED AND CURING PROCEDURES

1. Phenolic

(a) Granules and premoulds	-	Mould pressure, 4.3 kpsi; Mould temperature, 150°C (300°F); Time: granules, 8 min.; premoulds, 5 min.
(b) Amber powder	-	Used only as filler or edge preserver with other thermosetting materials.

2. Diallyl Phthalate

Supplied as granules only	-	Mould temperature, 150°C (300°F); Time, 9 min. During the first two minutes of this time the pressure should be applied and released a number of times.

3. Polyvinyl Chloride

Supplied as unfilled white powder	-	Mould pressure: just closed; Mould temperature: until contents reach 120°C (250°F); Cool under 5 kpsi pressure to below 60°C (140°F); Total time, about 10 min.

4. Methyl Methacrylate

Supplied as unfilled white powder	-	Mould pressure: just closed; Mould temperature: until contents reach 150°C (300°F); Cool under 3 kpsi pressure to below 60°C (140°F); Total time, about 15 min.

5. C-32 Plastic

Supplied as two liquids - Mix 1 ml or less hardener per 15 ml resin.
For mounting powders and fine particles, pour a little catalysed resin in mould cavity, add sample, and when sample sinks fill mould with resin.
For solid samples, pour catalysed resin over sample in mould cavity. (Rubber moulds are useful for easy stripping).
Pressure, none;
Temperature, ambient;
Temperature rise during cure, none detected;
Cure time, overnight. Do not remove from mould until completely hard. If the mould is sticky on surface, wash with warm water.

6. Eastman 910 Adhesive - Apply by dipping or dropping;
Set by smearing, squeezing, or rubbing;
Time, a few seconds.
Caution: Irritating to eyes. Also, if two skin surfaces, such as fingers, should be pressed together with adhesive between, they will seal together and may be separated only with some difficulty.

7. Epoxy

Supplied as two liquids - Mix components as directed on pack and pour over sample in mould cavity;
Pressure, none;
Temperature, ambient;
Temperature rise during cure: less than 50°C (90°F).
Do not remove until cooled.
Time, several hours.

8. Dental Acrylic

Supplied as fine powder and liquid - Mix components as directed on pack and pour over sample in mould cavity;

Pressure, none;
Temperature, ambient;
Temperature rise during cure: should reach not more than 60°C (140°F).
Time, about 30 min.

CAUSE AND EFFECT OF DEFECTIVE MOUNTING PROCEDURES

A. THERMOSETTING RESINS

1. Moisture adsorption on raw plastics	-	1. Porous mould. 2. Mount breaks away from sample or cracks at right angles to major faces.
2. Too much release agent	-	1. Porous mould around outside faces and usually at specimen-mount interface.
3. Pressure too high	-	1. Mount splits or cracks parallel to major faces. 2. Specimen-mount interface separated.
4. Pressure or temperature too low	-	1. Porous mount. 2. Compacted rather than cured mount. 3. Soft mount. 4. Cold shuts on mount.
5. Temperature too high	-	1. Mount cracked. 2. Mount splits on ejection. 3. Mount discoloured or charred.
6. Curing time too short	-	1. Mount bulges in centre on ejection. If time cut much too short, entire mount may swell.
7. Mount quenched after ejection	-	1. Mount cracked. 2. Poor bond. 3. Liquid seepage at specimen mount interface.

8. Sample positioned too close to side of melt or has sharp corner near edge	-	1. Mount cracks at this point.
9. Greasy or damp sample	-	1. Resin will not bond, but cracks do not form from this cause alone. A damp sample may be vacuum sealed, but a greasy one must be removed from the mount, cleaned, and remounted.

B. THERMOPLASTIC RESINS

(a) Polyvinyl Chloride:

1. Applying pressure too early	-	1. Mount has opaque white centre.
2. Releasing pressure too early	-	1. Mount swells on ejection.
3. Pressure too high	-	1. No apparent effect on finished mount.
4. Temperature too low	-	1. Poor bond 2. Cold shuts on mount 3. Opaque white mount
5. Temperature too high	-	1. Mount will be clear straw colour to opaque dark brown, by which time it is useless, depending on how high the temperature was and how long held at temperature. May also be a zone of opaque white in the centre of the mount.
6. Greasy or damp sample	-	1. Same effects as for thermosetting resins.

Note: Attempts to remove samples mounted in this material by breaking the mount have proved hazardous because of the great force required to crack the mount. Samples may be picked out with tongs if the mount is gently heated to about 110°C (230°F).

(b) Methyl Methacrylate:

1. Moisture adsorption on raw plastic	-	1. Mount has porous centre.

2. Applying pressure too early	-	1. Mount has powdery centre.
3. Releasing pressure too early	-	1. Mount swells on ejection.
4. Pressure too high	-	1. Mount cracks on ejection. 2. Mount-specimen interface separated. 3. Mount very sensitive to alcohol or acetone and will craze or even disintegrate.
5. Temperature too low	-	1. Poor bond. 2. Cold shuts on mount. 3. Translucent mount.
6. Greasy or damp sample	-	1. Same effects as for thermo-setting resins.

C. COLD SETTING RESINS

(a) C-32:

1. Too much hardener	-	1. Resin will gel too rapidly, resulting in entrapped air, lack of investment of sample, and incompletely filled mould. 2. Brittle mount which may crack spontaneously. 3. Excessive shrinkage during cure.
2. Too little hardener	-	1. Excessive time to cure. 2. Increased sensitivity to alcohol.

Note: This material does not appear to be sensitive to stirring time unless continued into the gel stage, which should not be reached until at least 30 min after adding hardener.

(b) Epoxy and Dental Acrylic:

1. Improper proportioning or insufficient mixing	-	1. Porous mount. 2. Gummy mount. 3. Soft or brittle mount. 4. Mount may not set at all, or may react at a rate high enough to develop enough heat to make the material swell out of the mould cavity.

2. Over-mixing	-	1. Lack of flow, with ridges and voids. 2. Poor bond.
3. Greasy or damp sample	-	1. No bond.

DISCUSSION OF GRINDING AND POLISHING

In the preparation of a satisfactory polish on any metallic material, it has been found that there are a number of common factors. Perhaps the most important, and most often overlooked, is cleanliness, particularly of hands and utensils. Hands and samples must be thoroughly cleaned between each step. Laps must be kept covered except when in actual use. It is futile to cover laps only at night. Some polishing laboratories are the "orphans" of an establishment and are crowded into a corner no one else particularly wants and laps cannot be kept free from contamination unless constant vigilance is exercised. Because the polishing rooms are actually precision laboratories, they should be out-of-bounds to all personnel not employed there.

Emery abrasive papers are no longer used. It has been found that, with harder materials, the grit tends to fracture, becoming progressively finer in use and eventually glazing the sample. With the softer metals, emery particles will become embedded in the matrix, where they may be mistaken for inclusions. Because this abrasive is not as hard as some other materials, there tends to be a rapid dulling action with heat generated and an increase in the thickness of the layer of worked metal which must be removed before true structures are revealed.

On the other hand, silicon carbide keeps a sharp cutting edge for its life and it does not fracture, glaze the sample, or embed itself in soft matrices to the same extent. There is also no doubt when it is worn out, as it will simply no longer cut. The silicon carbide papers do not load readily, and, used with a lubricant in most instances, grinding is cooler and cleaner. For these reasons, this abrasive grinding material is used exclusively.

It has been found by experience that the use of "cheap" materials often leads to inconsistent results and nearly always turns out to be an expensive saving. For instance, denatured alcohol, used as a rinse or for making up reagents, will yield stains and pseudo-structures that have nothing to do with the true structure of the sample. Inferior magnesium oxide, aside from yielding scratches, will stain and pit most materials similarly. "Cheaper" diamond abrasives may be satisfactory for other purposes, such as die polishing, but often are poorly graded, have low diamond content, or have both defects; they may also not be the same from one batch to the next, and often have poor cutting characteristics, or a tendency to generate scratches after a short period of use. For metallographic purposes, Buehler "Metadi" has been found to be the most consistently successful.

Hot-water rinsing of the sample after polishing can lead to more difficulties than is generally appreciated. For example, in lead-bearing coppers this will turn the lead particles black; and in magnesium alloys it will react with the sample, trapping polishing debris rather than washing it away. Cold water is the preferred rinse for those materials that can tolerate water, but warm (not hot) water may be used at times with caution.

It has been found that ultrasonic cleaning is an efficient method for removing polishing debris from polished surfaces. There are, however, some notes of caution associated with the use of this technique. It is capable of removing a thin line of plastic at the interface between metal or oxide and impregnated plastic, leaving a fine seam from which reagents may seep over a polished surface. When used on friable materials it may remove small particles of the sample, and on very soft metals such as pure lead it may work the polished surface. However, by and large, ultrasonic specimen cleaning is one of the major advances in metallographic preparation in recent years since it precludes coarse grits being carried over into the later stages of polishing. This not only improves the surface finish but extends the life of the final polishing-cloths, leading to increased efficiency and economy.

Because of their good corrosion resistance, bronze laps are normally supplied with polishing equipment. However, it has been found that, in some instances, galvanic couples can develop between the sample and the lap, resulting in staining or pitting of the sample. For this reason, at times,magnesium or aluminum laps are preferred. The possibility of galvanic corrosion must also be kept in mind when mounting composite materials such as plated ware, galvanized material, etc., and when introducing supports for delicate samples or for positioning purposes. This possibility can be minimized by using non-electrolytes, such as kerosene, for lubrication or by making supports out of materials similar to, or less noble than, the sample.

Unless otherwise stated, in all polishing operations the samples are firmly held between the thumb and first two or three fingers and are rotated around the lap in a direction counter to its rotation. This rotary motion is fairly rapid when polishing commences, but slows to say 20 r.p.m. in the final polishing stages.

The use of automatic polishing machines has become prevalent in recent years, and there is much to recommend in the current models. In the Physical Metallurgy Division, automatic rotary polishers are used, such as the Buehler "Automet" for grinding and the Buehler "Whirlimet" for all routine and some finish polishes, together with "Syntron" vibratory polishers for the highest quality finishes. The "Syntrons" are vibrated by a magnetic device operating on mains frequency. The uses of the "Automet" and the "Whirlimet" are not discussed in the following sections, since they essentially duplicate the motion of the hand-held sample, and therefore would be operated with the same types of polishing media,

cloths, lubricants, etc., as are described for hand polishing. All automatic machines have the advantages that several specimens can be polished simultaneously; the machine can be covered during the polishing operation, excluding grit and maintaining moisture or lubricant in the polishing compound; and extended polishing times can be used without operator fatigue. Vibratory machines are often left polishing unattended over a weekend, for example. With these machines it has been found advantageous to surround the polishing area with Teflon tube bumpers in order to avoid excessive sample motion caused by contact with the vertical sides.

GRINDING PROCEDURES (GRINDS A to G)

Grinding is carried out on wet or dry silicon carbide papers, with grits 120, 180, 320, 400 and 600 being stocked. The papers may be lubricated with liquids such as plain water, water with soap or neutral detergents added, or kerosene; or they may be filled with paraffin wax, graphite,or talc. These abrasives are normally used on power-driven horizontal laps at either 550 or 1150 rpm. Occasionally they are used, with or without lubricants or fillers, on vertical laps.

After sectioning and/or mounting, the sample is flattened on 120 grit paper with running water lubricant until evidence of saw marks or other previous operations is no longer apparent and all grinding marks are running in one direction. This pre-grind is carried out at 550 rpm.

Grinding is done on successively finer grades of abrasive, with each step being continued more than long enough to remove all preceding scratches. In order that this may be readily observed the sample is rotated 90 deg between each paper.

Following is a list of procedures, with comments on the metals or alloys for which they are most suitable. This list is not intended to be an absolute dictum of grinding technique, inasmuch as each operator will use variations which best suit his working habits. There is also a group of metals, including antimony and bismuth, that do not respond well to any of these techniques and which are treated elsewhere under their own heading.

Grind A

Grits 320 and 600 with running water lubricant at 1150 rpm.

Generally this will be used for samples of aluminum, magnesium, copper and their alloys where the determination of grain size is the objective. It will also be used as a preparatory step for the finish polish, where edge preservation is not important, of magnesium, lead, tin, cadmium, and their alloys, and of those alloys of aluminum, nickel, copper, gold, niobium, tungsten and cobalt which contain relatively large quantities of other

non-reactive elements.

Grind B

Grits 180, 400 and 600 with running water lubricant at 1150 rpm, followed by grit 600 (a) dry, or (b) talc filled at 550 rpm.

Grind (a) is used for the same materials as grind A but where edge preservation is important, and (b) has been found useful for some galvanized and other coated materials.

Grind C

Grits 180, 320 and 400 with kerosene lubricant, followed by grit 600 dry, all at 550 rpm.

This grind is used as an alternative to either A or B where water-reactive constituents are present in the sample.

Grind D

Grits 180 and 400 glazed with paraffin, lubricated with kerosene, followed by grit 600 with (a) graphite glaze or (b) talc filled at 550 rpm throughout.

Both of these are useful for zinc and its alloys and for some types of galvanized ware. It is also useful for pure copper and aluminum. The choice of graphite or talc is a personal one, but talc gives a slightly finer finish.

Grind E

Grits 180, 400 and 600 with water lubricant to which has been added 10% neutral detergent or green soap, at 550 rpm.

This is particularly useful for copper, aluminum, tin, and silver, and for their alloys which are homogeneous or have only small amounts of constituent. It is also useful for those metals that tend to fill or load the papers, such as some of the zinc alloys.

Grind F

Grits 180, 400, 600 dry at 550 rpm, followed by graphite-filled 600 grit at 1150 rpm with very light pressure. Normal amyl alcohol used to wash samples between laps. Samples turned 180 deg between laps so all scratches run lengthwise.

This is the procedure of choice for galvanized sheet and taper sections, and for other samples with an

exaggerated length-to width ratio -- such as chromium-plated material -- in which it is desired to preserve edge detail.

Grind G

Grits 320 and 600 and 600 soft with running water lubricant at 1150 rpm. The 600 soft paper should not be used for more than 2 or 3 samples, each making one pass from centre to periphery of wheel.

This is a special grind for those copper alloys containing lead where it is necessary to make a porosity count as the lead remains intact and light coloured and is thus easily distinguished from holes. It is also suitable for the same purposes as Grind A.

DETAILED PREPARATION TECHNIQUES FOR VARIOUS MATERIALS

Aluminum and Its Alloys

(a) Grain Size Determination of Aluminum Casting Alloys

The aluminum casting alloys fall into two distinct groups, based on the silicon content. In those alloys having less than 3% Si the samples are prepared with Grind A and etched by immersion in HF-HCl-HNO_3 mixtures. When the alloys contain more than 3% Si, grinding should not be finer than 320 grit and the samples should be etched by swabbing with 30% cupric chloride in water, followed by immersion in concentrated nitric acid to clear. All surfaces are best examined by oblique illumination.

Preparation should not be carried beyond the steps given, because etch pits will obliterate the grain structure. Also, should the metal have a dendritic structure, this will be preferentially revealed by etching -- particularly if the reagent is one of the acid mixtures. The cupric chloride etchant may be used on any aluminum casting alloy. However, contrast decreases with lower silicon content. The reaction becomes more violent and less readily controlled as the copper content of the alloy increases.

(b) Finish Polish of Aluminum Casting Alloys

Following Grind A or B, the sample is polished on two diamond laps at 180 rpm, using 8 micron and ¼ micron diamond successively, with n-amyl alcohol* as the lubricant. The 8 micron

* This material is toxic and its use should be restricted to a fume hood. The liquid and vapour are dangerous to the eyes and contact with the skin should be avoided as far as possible. It is a moderate fire hazard and smoking or other open flame should be avoided.

diamond is dispersed on a Metron cloth. Moderately heavy pressure is used until all grinding marks have been removed, when pressure is reduced and polishing continued for about as long again as it took to remove the grinding marks. The sample is rotated counter to the direction of wheel rotation at all times. The sample is cleaned in n-amyl alcohol in an ultrasonic tank, rinsed with ethyl alcohol, and blown dry. The polish with the finer diamond, also dispersed on a microcloth, follows in the same manner, after which the sample is ready for routine examination.

A finish polish is secured by the use of a Rayvel cloth fastened to the platten of a vibratory polisher. The abrasive is a slurry made by boiling together to half its original volume 1 part by weight of magnesium oxide and 9 parts water. When cool, this is dumped, without scraping, from the beaker onto the cloth. (This dumping process appears to leave the coarser or gritty particles behind, stuck to the wall of the beaker). A weight of about 100g is added to the sample, and the machine amplitude is adjusted until the sample travels at a velocity of about 12 in. per minute. Polishing is finished in about five minutes, but in no case should it be extended beyond fifteen minutes or the sample will pit and inclusions will etch. The sample is removed while the machine is still running, rapidly transferred to a fast-moving stream of cold water, rinsed with ethyl alcohol, cleaned ultrasonically, again rinsed with ethyl alcohol, and blown dry. Provided the last diamond polish has been carried far enough and the vibrating polish not too far, the specimen will be ready for the most critical examination unless it contains water-reactive constituents. Should this be the case, a good finish polish may be obtained by a careful ¼ micron diamond polish followed either by a short critical electrolytic polish in a perchloric acid-ethanol mixture or by a long-time polish on a Pellon Pan K disc fastened to a vibratory polisher, using ¼ micron diamond and pure kerosene lubricant with no additional weight on the sample. Again, machine amplitude is adjusted to give a sample velocity of about 12 in. per minute. The mechanical polish-electrolytic finish technique takes only a few seconds but will always result in some relief, whereas the wholly mechanical polish, although resulting in the highest quality of surface, may take several days.

(c) Grain Size Determination of Aluminum Wrought Alloys

In most cases the grain size will be of the order of 0.004 to 0.030 in. average grain diameter, and will not be revealed by the techniques used for the casting alloys. A routine polish is required in most cases. Those alloys which have only small amounts of alloying additions have been found to be difficult to etch after the usual polish; a modified polish and electrolytic treatment is required to reveal the grain structure.

After the grinding operation is completed (either A or B), the sample is rough-polished on a Microcloth or Rayvel-covered lap rotating at 1150 rpm, using heavy pressure and a water suspension

of Linde B abrasive until all evidence of grinding is removed. Contrary to what might be expected, this treatment will usually not relief polish or remove inclusions, and will leave edges sharp and flush with the mount. A light finishing of short duration, on a Gamal cloth fastened to a lap rotating at 1150 rpm, and using the same abrasive, will complete the procedure, leaving a bright smooth surface with a few shallow scratches. Grain sizes will be revealed in most alloys after an etch in an acid mixture.

Those alloys which contain little alloying additions are treated electrolytically to form an anodic film which, when viewed under polarized light, will show grain contrast. This treatment is carried out in a cell with a massive aluminum cathode, using a 1.8% aqueous fluoboric acid solution at room temperature as the electrolyte. The specimen is made the anode and about 20 volts of direct current is applied across the cell for about one minute. It will be noted that very little current flows after the first few seconds, indicating the formation of an anodic film which is increasing the resistance across the cell. After the first minute the voltage may be gradually increased to 50 volts, provided the amperage does not increase. Rising amperage indicates a film breakdown, with attack of the sample. Reducing the voltage will occasionally correct this, but usually the sample will have to be repolished. After anodizing for a total time of about four minutes, the sample is removed from the cell with the power on, washed in a running stream of cold water, and blown dry. Success is indicated by colour fringes travelling across the face of the sample as it dries, and confirmed by examination under polarized light. Since the effect is cumulative the procedure may be repeated if there is insufficient contrast in the sample. This technique is not so successful on finely finished aluminum, for reasons which are not clear, the sample tending to etch rather than anodize.

(d) Finish Polish of Aluminum Wrought Alloys

Those wrought alloys of aluminum which do not contain water-reactive constituents may be readily polished to an excellent finish with aluminum oxide abrasives suspended in water. Following grind A or B, rough polishing is carried out on a Gamal cloth covered lap rotating at 1150 rpm, using 600X alundum abrasive suspended in distilled water, until all evidence of grinding has been removed. Following washing in cold water and drying in air stream, the final polish is done on another Gamal cloth covered lap rotating at 550 rpm, using relevigated Linde B in distilled water. This operation must be done with care because the aqueous polishing suspension tends to stain many of the microconstituents. This can be an advantage inasmuch as some compounds, such as Mg_2Si, are almost invisible in the unetched state after a diamond finish, but the technique may result in pitting if carried too far. The use of aluminum laps for the backing of all papers and cloths is recommended as an aid to satisfactory results.

For those alloys which contain water-reactive particles, or where a minimum of relief and staining is desired, polishing procedures as described for the casting alloys are used.

Antimony, Bismuth, and Their Alloys

One of the characteristics of both of these metals, and of some of the alloys in which either is the major metal, is their friability. Antimony is far more troublesome in this respect than any other metal encountered. For this reason these materials can only be prepared using soft abrasives in the polishing operation. Since they both tend to load grinding discs, and large pieces will be removed from the sample by a loaded disc, grinding is not carried too far on any one paper.

Tests with room-temperature curing resins, and with diallyl phthalate or phenolics, have indicated no structural changes caused by their use.

Grinding is carried out at 550 rpm on silicon carbide discs, in successive grits of 180, 320, 400 and 600, with a copius supply of cold running water as the lubricant and coolant. On the final grit, only one pass from the centre to the edge of a new disc may be made, using light pressure. If scratches from the 400 grit disc remain after this, a new 600 grit disc must be used. Re-use of this last disc will invariably mean that a return to, at least, 320 grit is required to remove the holes and cracks resulting. Bismuth is not as sensitive in this respect as is antimony.

Efforts to use diamond polishing abrasives on antimony have been completely unsuccessful, and only partly successful with bismuth. However, good polishes on these materials can be readily obtained by means of polish-attack methods and softer abrasives.

After the final grind, the sample is washed with soap and water, rinsed with ethyl alcohol, and blown dry. Ultrasonic cleaning is quite capable of removing particles of metal from the surface and, for this reason, is not used at any stage. The sample is then deeply etched (acid ferric chloride for antimony and hydrochloric acid for bismuth) and the etch is removed by gentle polishing on a Gamal cloth lap rotating at 550 rpm, using a water suspension of 600X alundum as the abrasive. The sample is re-etched and repolished until the operator is satisfied that all work from the grinding operation is removed. Initially on etching, the first structure to appear is the pattern of the grinding marks from the 600 grit disc. When this pattern no longer appears, polishing may proceed, after thorough washing of the sample, on another Gamal cloth lap revolving at 550 rpm. The abrasive is a water suspension of Linde B. Alternate etching and polishing are again carried out using the same technique and reagent as for the rough polish, but in this case the pressure applied to the sample is somewhat lighter and the etching is considerably reduced.

After a dozen or more polishing-etching cycles on this lap have been completed, no traces of rough polish should remain and the sample should have a high gloss and only very light scratches.

The success of the method is dependent on (a) not polishing beyond the point where the previous etch is just removed, (b) light pressure at all times, and (c) copious supplies of abrasive suspension on the lap.

The sample is washed in soap and water, rinsed with ethyl alcohol, and gently blown dry. The polish is quite satisfactory for all but the most critical examination, with the structure fully developed and a few fine scratches present.

A finish polish is obtained on a Rayvel cloth fastened to the platten of a vibratory polisher, using a slurry made by boiling together 1 part by weight reagent-grade magnesium oxide and 6 parts by weight water until boiled to one-third its original volume. This slurry is cooled and dumped without scraping from its container onto the cloth. Polishing continues without additional weight for 16 to 24 hours, with the machine amplitude adjusted for a sample velocity of about 15 in. per minute. After being washed and dried, the sample is ready for any examination.

Copper, Nickel and Their Alloys

Preparation of all types of samples from these materials may be carried out according to grind B(a) or C, depending on whether or not the sample contains water-reactive constituents. Grinds A or C are adequate for grain size or hardness determinations. However, if grain contrast is not developed after etching, it may be necessary to finish the sample on a Gamal cloth lap rotating at 550 rpm, using a thick water suspension of 600X alundum. This rough polishing is carried out until all grinding marks have been removed; then the lap is flooded with water to remove most of the abrasive, and polishing is continued for a few seconds with light pressure. The sample is then removed, washed under cold running water, and blown dry in a rapidly moving stream of air.

An alternate rough polish of somewhat better quality can be obtained with the use of a Metron lap rotating at 550 rpm, using a water suspension of Linde A as the abrasive, applied copiously to the cloth. The pressure on the sample is light, usually only enough to ensure even contact with the cloth. The thickness of the slurry is determined by the hardness of the material and the ease with which grinding scratches may be removed. Finishing of this stage on this lap should not require more than five minutes, when the surface should be bright and fairly clean, with well-defined constituents; there should be little relief although some light scratches will be present. The sample is washed in running water, rinsed in ethyl alcohol, and dried in an air stream.

Routine polishing may be carried out, after either of the rough polishes, on a Gamal cloth lap rotating at 550 rpm, using a relevigated water suspension of Linde B as the abrasive. Polishing continues, using light pressure, until all evidence of the rough polish is removed. This will require five or ten minutes, after which the sample is removed, washed in running water, rinsed with ethyl alcohol, and blown dry. Inclusions will be intact and bright, and there will be numerous fine black spots and some scratches on the polished face. There will usually also be some relief, and lead particles will be dark grey to black in colour and rough surfaced. However, the polish will be adequate for preliminary critical examination.

If a sample of these materials is to be given a finish polish, diamond abrasives with n-amyl alcohol or pure odourless kerosene lubrication are used at all stages subsequent to the grinding operation. For most samples, diamond of 8, 3 and ¼ micron grades are used in succession on Metron or Microcloth, respectively, all laps rotating at 175 rpm. A firm pressure is maintained on the sample on each lap, except the ¼ micron grade where pressure is firm at first and decreases to very light as polishing is finished. Counter rotation of the sample against the lap is used at all times. The sample is washed ultrasonically in n-amyl alcohol between each step and at the end of the process, rinsed with ethyl alcohol, and blown dry. If the sample is very hard, 25 micron grade diamond abrasive charged on another Metron cloth is introduced between the grind and the 8 micron diamond. If oxide or scale on the edge of a hard sample is important, Pellon discs PaK are substituted for Metron cloths. However, if the sample is of the usual hardness for these metals, the 25 and 8 micron grade may be by-passed and polishing commenced with a napless cotton broadcloth loaded with 3 micron diamond, immediately after the grinding operation. In all cases, the sample will usually come off the ¼ micron diamond lap still containing some fine dots in the matrix and with colours of the inclusions not fully developed. There may also be some relief and some fine scratches.

The next step is by vibratory polishing, using ¼ micron diamond as the abrasive, with the machine amplitude adjusted to give a sample velocity of 12 to 24 in. per minute. The actual kind of cloth used does not appear to be important provided it has some nap, is hard wearing, and has a closely woven back to take adhesives and remain fastened to the platten of the polisher. Metron, Microcloth, Pellon discs, Gamal and Rayvel all meet these requirements. The weight used will depend on the time available to complete the job and the amount of relief that may be tolerated, and is usually a compromise. No additional weight yields far superior results but the time required is considerable, being of the order of days rather than minutes or hours. Increasing weight shortens the time required, but also increases relief effects. Too much weight will also result in numerous fine zig-zag scratches on the polished face. Pure,odourless kerosene is preferred as lubricant for the longer polishes but is sometimes quite difficult to completely remove from the sample. Normal amyl alcohol is generally

used for the shorter polishes but it has a tendency to become contaminated with use, resulting in stained or pitted samples if left too long. At the end of the cycle the sample is removed from the running machine, washed for a few seconds ultrasonically in n-amyl alcohol, rinsed with ethyl alcohol, and blown dry. It will be bright and free from black specks; inclusions will be full coloured, including lead, which will be watery, pale metallic grey colour; edges will be sharp; and relief should be negligible.

In some instances a further step may be involved, when it is desired that the contrast between various constituents be enhanced or that some constituents be very lightly outlined without etching the matrix. This technique is generally reserved for those samples that are to be photographed in the as-polished condition, and must be done with caution, because, if carried too far, it has much the same effect as over-etching, or etching with an unsuitable reagent. The procedure uses a slurry made by boiling together 1 part of magnesium oxide and 6 parts by weight water until the original volume has been halved. This slurry is allowed to cool, then is dumped, without scraping, from its container onto a Metron cloth or Microcloth fastened to the platten of a vibratory polisher, and about an equal volume of distilled water is added. After the slurry mixture has been distributed over the cloth by turning the machine on, the sample is added without any additional weight and the machine amplitude is adjusted until the sample has a velocity of about 12 in. per minute. Polishing continues for not less than five nor more than fifteen minutes, after which the sample is removed, rinsed quickly under cold running water, rinsed with ethyl alcohol, washed ultrasonically in n-amyl alcohol, flushed with ethyl alcohol, and blown dry.

Galvanized Coatings

Grind F is the step preparatory to polishing and is the one used on all but a very few samples. Occasionally, and for special coatings, grind D will be found more satisfactory.

Normal amyl alcohol is used for all cleaning operations on this material and for lubricating all polishing laps. Water polishing of galvanized samples has been discontinued as being unreliable because of staining (due to the galvanic corrosion couple between the coating and the steel base) and bevelling of the zinc coat.

Rough polishing is carried out on a Gamal cloth lap rotating at 175 rpm, using 8 or 3 micron diamond as the abrasive, with medium pressure until grinding marks are removed. The sample is cleaned by rinsing with pure ethyl alcohol. This treatment will be adequate for routine examination, with a few scratches present but with edges sharp and inclusions intact. The choice of 8 or 3 micron diamond is determined by the thickness and hardness of the coating, the coarser diamond being chosen for the harder or thicker coat.

For a finish polish, a Metron cloth, or Microcloth charged with ¼ micron grade diamond is fastened to the platten of a vibratory polisher. The sample is placed, without additional weights, on this cloth and the amplitude of the machine is adjusted to give a sample velocity of about 12 in. per minute. After one half to one hour the sample is removed from the running machine, swabbed, rinsed with pure ethyl alcohol, and blown dry in a fast-moving stream of air.

Because galvanized samples are normally polished in packs, success in polishing these samples is much dependent on well made mounts, cleanliness throughout, and the complete absence of water contamination. Laps used for galvanized samples should be reserved strictly for that material.

Lead, Tin, Cadmium, Zinc, and Their Alloys

Before the advent of reliable grades of hard abrasives the preparation of these metals for metallographic examination was tedious and unreliable, involving the use of a microtome, or of filing and polish-attack methods. However, since silicon-carbide-covered discs, and pastes loaded with graded diamond, became available, it has been found that all of these materials may be conveniently polished to a high finish, using only slightly modified procedures.

If mounting of the specimen is required, the usual heat and pressure curing resins may be used, but it must be kept in mind that this may introduce changes in the structure. If in doubt, a hot and cold mount can be polished to a rough finish and examined. If both structures are the same, then finishing can continue on the sample mounted in heat and pressure-cured resin. Otherwise, cold-mounting techniques must be used.

The samples are ground using an extension of grind A, with each step being carried out in two stages. After the scratches from the preceding grit are removed, the sample is again rotated through 90 deg and reground on the same disc, but with lighter pressure, for as long again as it took to remove the previous scratches. Water is flooded on the discs at all times. After a thorough washing in water, and drying, the samples are polished with diamond abrasives of 8, 3 and ¼ micron grades on Metron or Microcloth fastened to a lap rotating at 175 rpm, using n-amyl alcohol as lubricant and washing fluid.

The finish polish is obtained by placing the samples, without additional weight, on a Rayvel cloth fastened to the platten of a vibratory polisher, using magnesium oxide 1 part and water 3 parts by weight mixed, but not boiled, settled for one minute, and decanted onto the cloth as the abrasive, the machine amplitude being adjusted to give a sample velocity of about 6 in. per minute. The polish is usually finished after an overnight run on the machine, when the sample is rapidly transferred from the polisher

to a cold water rinse, flushed with pure ethyl alcohol, immersed for a few seconds in an ultrasonic cleaner (again containing n-amyl alcohol) flushed with pure ethyl alcohol, and blown dry in a rapidly moving stream of air.

The ultrasonic cleaner must be used with caution. This device is quite capable of cold-working some of the softer materials and changing their microstructures without any gross evidence of having done so. For this reason it should not be used for more than 10 sec on the softest metals nor more than 20 sec on even the hardest metals in this group.

Magnesium and Its Alloys

Polishing procedures from "grain size" to "finish" for these metals are virtually the same, each being simply an extension of the preceding one. However, diamond polishing or finishing is not recommended, except in very special cases.

Grinding is carried out as detailed in grind A or B (a) depending on whether edges are important or not.

Rough polishing is done on a Gamal cloth lap rotating at 1150 rpm, using a slurry of 600X alundum in water, with constant rotation opposed to the polishing direction until all evidence of previous grinding has been removed. The lap is then flushed with a copious stream of water while polishing continues for a few seconds, and the sample is then blown dry in an air stream. At this stage, porosity counts may be taken as only a few scratches remain and, after appropriate etching, grain sizes may easily be determined. Inclusions will be intact with only slight relief apparent, except in those samples having massive, very hard particles, such as for example, sand grain inclusions.

Polishing is carried to a further stage on another Gamal cloth lap, again rotating at 1150 rpm, using a water suspension of Linde B as the abrasive, and constant rotation opposed to the polishing direction. Polishing is started with copious quantities of the slurry but no more is added as the treatment continues, allowing the cloth to dry, and polishing is finished just before the sample has a tendency to grab. With a little experience the operator can feel this point as a distinct gliding sensation of the sample on the cloth. The sample is quickly removed from the lap, rinsed under cold running water for about ten seconds, and blown dry in a high-speed stream of air. Two things are particularly important at this stage and the success of the method will depend to a large extent on the attention paid to them. Firstly, the interval between removal of the sample from the cloth and drying should be as short as possible, and no time should be taken during this part of the technique to look at the wet sample. Secondly, only cold water should be used, inasmuch as warm water appears to react with the material, trapping polishing debris leading to stains and other artifacts, particularly after etching. After this procedure a very few light scratches may remain, inclusions will be flat and

intact, and the sample will in most cases be ready for critical examination. If the sample is to be examined in the etched state, these light scratches will be removed during etching.

In those few samples in which, for one reason or another, a better finish is desired, a further step will be required. This is accomplished by making a thick slurry of magnesium oxide 1 part and water 3 parts by weight, boiled to half its original volume and cooled to room temperature. This is dumped, without scraping, onto a Rayvel cloth fastened to the platten of a vibratory polisher. A 100-g weight is added to the sample, which is then placed on the cloth of the running machine, and the amplitude of vibration is adjusted until the sample travels at a velocity of about 12 in. per minute. Samples may be left several hours with constant improvement, but most of the advantage is gained in the first twenty minutes. Staining is an indication that the weight is not heavy enough, and this stain will be removed if more weight is added and polishing is continued. Relief polishing is evidence that the weight is too great, but the sample will flatten itself if some weight is removed and the polishing is continued. The sample is removed from the running machine and immediately flushed with cold water, rinsed with pure ethyl alcohol, transferred to an ultrasonic cleaner filled with n-amyl alcohol, cleaned for 30 sec, again rinsed with pure ethyl alcohol, and blown dry in a fast-moving stream of air. Properly carried out, this technique will yield intact polished inclusions and a flat, scratch-free surface which will etch in less than half the time normally required. Under no circumstance is methyl alcohol used on magnesium or its alloys, as they are attacked by this reagent.

As previously mentioned, magnesium and its alloys do not lend themselves to polishing with diamond abrasives, since it appears almost impossible to obtain a scratch-free surface. In addition, contrary to experience with most other materials, diamond polishing of these metals is slower than wet polishing with softer abrasives. However, in those rare cases where massive hard particles are present and scratches may be tolerated, diamond techniques may be used. In these instances n-amyl alcohol is the exclusive lubricant. Extensive tests with special pastes or other lubricants for diamond polishing have shown no advantage.

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RIH/EFC/gm

A P P E N D I X

SOURCES OF SUPPLY

The following information is intended to help those who may be setting up a metallographic laboratory for the first time, or who may wish to obtain specific materials.

It does not purport to be a complete or comprehensive list of sources of supply, nor does it imply any exclusiveness of the product. Undoubtedly, in many cases the same product could be obtained from alternative sources, or equivalent products from the same or alternative sources.

Material	Supplier
Thermosetting granules and premoulds	Tech-Met (Canada) Ltd., Scarborough, Ont. Micro Metallurgical Ltd., Thornhill, Ont.
Acrylic	Any dental supply house. North Hill Plastics, London, England.
Epoxies	Tech-Met (Canada) Ltd., Scarborough, Ont. Micro Metallurgical Ltd., Thornhill, Ont. Canus Equipment Ltd., Ottawa, Ont.
PVC	Micro Metallurgical Ltd., Thornhill, Ont.
C-32	Canus Equipment Ltd., Ottawa, Ont.
Eastman 910 adhesive	Armstrong Cork (Canada) Ltd., Montreal, P.Q.
Casting rubber (for making mould cavities)	Canus Equipment Ltd., Ottawa, Ont.
Grinding and polishing machines and SiC discs.	Tech-Met (Canada) Ltd., Scarborough, Ont. Micro Metallurgical Ltd., Thornhill, Ont.

Sources of Supply, concluded -

Material	Supplier
Diamond abrasives (Buehler)	Tech-Met (Canada) Ltd., Scarborough, Ont.
" " (Geo-Science)	Micro Metallurgical Ltd., Thornhill, Ont.
SiC abrasive powders	Tech-Met (Canada) Ltd., Scarborough, Ont.
Alumina abrasive powders	Micro Metallurgical Ltd., Thornhill, Ont.
Magnesium oxide abrasive powders	Fisher Scientific Co., Montreal, P.Q. Linde Co., Crystal Products, East Chicago, Ind., U.S.A.
Metron and Astromet cloths and Pellon discs	Micro Metallurgical Ltd., Thornhill, Ont.
Gamal cloths	Fisher Scientific Co., Montreal, P.Q.
All other cloths	Tech-Met (Canada) Ltd., Scarborough, Ont.
Ultrasonic cleaner	Micro Metallurgical Ltd., Thornhill, Ont.
Paper cement	Tech-Met (Canada) Ltd., Scarborough, Ont. Behr-Manning Co., Troy, N.Y., U.S.A.
Lubricants and chemicals	Any distributor such as Fisher, Cenco or Canlab.

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