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Sintered Parts Section of The

Wakefield Manual

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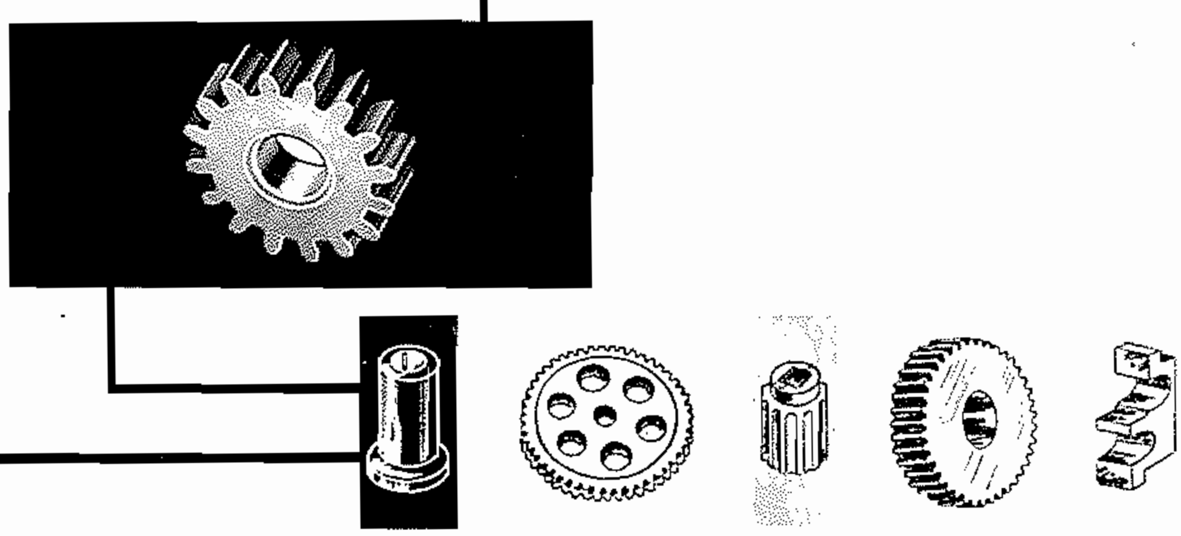
WAKEFIELD

Dependable Sintered Metal Parts

BEARINGS • BUSHINGS • STRUCTURAL PARTS



Foreword

This catalog demonstrates the reliability of products manufactured by the Wakefield Bearing Corporation, now in its 60th year of operation. You will observe that the sequence of laboratory testing which occurs in our process and that of the manufacturers of our raw material powders is much more advanced than the quality control practiced in the recent past. For this reason, the user of sintered metal products must be constantly aware of the progress of the art, and of the succession of improvements in physical properties leading to increasing dependability.

While research up to 1964 resulted in much progress, we are in no way satisfied that all the work has been accomplished. We feel there are very large areas for new investigation, some of which will lead to properties as yet unknown, but which reach beyond the realm of wrought material. However, such research cannot be meaningful until the basic fundamentals and values are well established. In publishing this information, we are attempting to show the foundation on which we presently produce our products, and on which we hope to build for the future.

We call your attention, in the following pages, to our capability in processing bearings and parts, which stems from an abundance of recently acquired capital equipment and an extremely competent group of employees.

One of the most important features to be considered in selecting a sintered metal source is size. There is very definitely a point where a too small company will not support the necessary production and mechanical engineers with advanced metallurgists. On the other hand, a very large producer does not give the immediate and personal attention needed for speedy results, especially where volumes are modest.

We at Wakefield find ourselves in the happy situation of being neither too large nor too small. We do have extremely competent people, who are not involved in red tape to the extent that they cannot give proper attention to each situation promply. Your contact will be direct and personal.

To use our services to full advantage, we suggest you present your problem to us by mail or directly to our sales representatives. The review by design engineers, metallurgical engineers and production specialists follows. In the event that some points are still obscure, we hope you will allow the specialist in question to visit you, or as frequently happens, have your appropriate specialist visit us. In any event, we do offer great competence in conference work.

When the situation has been assessed as to product, a price is determined. In almost all cases, the savings are astonishing. You will find we are skilled in offering the best value for your dollar, which should not be confused with the lowest price in every instance.

Finally, the very nature of the growth statistics of our industry forbid a negative approach. We feel nothing but optimism for the future.

TABLE OF CONTENTS

PHYSICAL PROPERTIES OF SINTERED AND SOLID MATERIALS

Comparison of Physical Properties of Sintered and Solid Materials.

We feel the beginning point is not in terms of generalities in the use of sintered products but starts with a factual approach to the relative values found in the various available materials. We list below a quick reference table, so that all concerned may decide at once whether sintered metal use is possible and desired. If there is an obvious decision to proceed, we invite closer study of the data which follows throughout the contents of this catalog.

WAKEFIELD SINTERED MATERIALS

ALLOY	MATERIAL	TENSILE STRENGTH PSI	% ELONGATION
39C	Nickel Steel	60,000 - 100,000	.4 - 2.9
39L	Leaded Nickel Steel	40,000 - 55,000	.5 - 2.4
65	Nickel Steel	70,000 - 144,000	1.0 - 2.8
72	Nickel Steel	62,000 - 188,000	1.8 - 7.0
61	Iron-Copper	50,000 - 105,000	.6 - 2.7
14	Bronze	15,000 - 20,000	.5 - 7
22	Bronze & Graphite	10,000 - 15,000	3.5 - 4

Data compiled by SKC Research Associates

WROUGHT MATERIALS

ALLOY	TENSILE STRENGTH PSI	% ELONGATION
#101 Nylon	10,500	90.0
Cast Iron	18,000 - 60,000	0
Wrought Iron	45,000 - 55,000	35 - 25
Commercially pure iron-annealed	42,000	48
Hot rolled	48,000	30
Cold rolled	100,000	—
Structural Steel, ordinary	50,000 - 65,000	40 - 30
Low alloy, high strength	65,000 - 90,000	30 - 15
Steel, SAE 1300, annealed	70,000	26
Steel, SAE 4340, annealed	80,000	25
Cold Rolled Steel, SAE 1112	84,000	18
Free Machining, leaded	79,000	16
Screw Machine Stock	80,000 - 95,000	10 - 20
Stainless Steel, 18-8	85,000 - 95,000	60 - 55
Steel castings, heat-treated	60,000	33 - 14
Aluminum, pure, rolled	13,000 - 24,000	35 - 5
Aluminum-copper alloys, cast	19,000 - 23,000	4 - 0
Wrought, heat-treated	30,000 - 60,000	33 - 15
Aluminum die castings	30,000	2
Aluminum Alloy 17ST	56,000	26
Aluminum Alloy 51ST	48,000	20
Copper, annealed	32,000	58
Copper, hard drawn	68,000	4
Brasses, various	40,000 - 120,000	60 - 3
Phosphor Bronze	40,000 - 130,000	55 - 5
Tobin Bronze, rolled	63,000	40
Magnesium alloys, various	21,000 - 45,000	17 - 0.5
Monel Metal, 70Ni, 30Cu	100,000	35

CHARACTERISTICS OF SELF-LUBRICATING BEARINGS

Again, in evaluating bearing applications, we resort at once to the data listed below to establish the useful role of sintered bearings, as compared to other materials. We think this is important, due to the promotional efforts published from time to time in favor of a particular miracle product.

Type of Bearing	Operation	Coefficient of Friction	Load	Maximum Operating Temperature °F	Approx. PV Factor
Rubber	water lubrication	0.01	Moderate	180	11,000
Laminated Phenolics	water lubrication	0.02	Heavy	200	30,000
Lignum Vitae	water lubrication	0.12	Moderate	150	13,000
Glass-to-rubber sleeve on shaft	process liquid lubrication	0.18	Moderate	180	11,000
Porous Bronze	impregnated with lubricant	0.01	Heavy	200*	50,000
Hard Wood	impregnated with lubricant	0.12	Moderate	160	12,000
Plastic Alloys	impregnated with synthetic & dry lubricants	0.06	Heavy	375	30,000
Sintered Nylon	impregnated with lubricant	0.20	Moderate	200	8,000
Molded Nylon	dry	0.20	Light	200	1,000
Molded Teflon	dry	0.04	Light	500	1,000
Teflon & Lead	dry	0.04	Moderate	400	20,000
Delrin	dry	0.20	Light	212	1,000
Carbon Graphite	dry	0.10	Moderate	800	12,000
Plastic Roller Bearing	Plastic bearing cage impregnated with dry lubricant	?	Heavy	?	—
Gas Film	dry — no metal-to-metal contact	gas drag	Moderate	?	?
Magnetic	dry — no metal-to-metal contact	air drag	Light	?	?

*Wakefield alloy #11 500° F

* Wakefield alloy #4 700° F

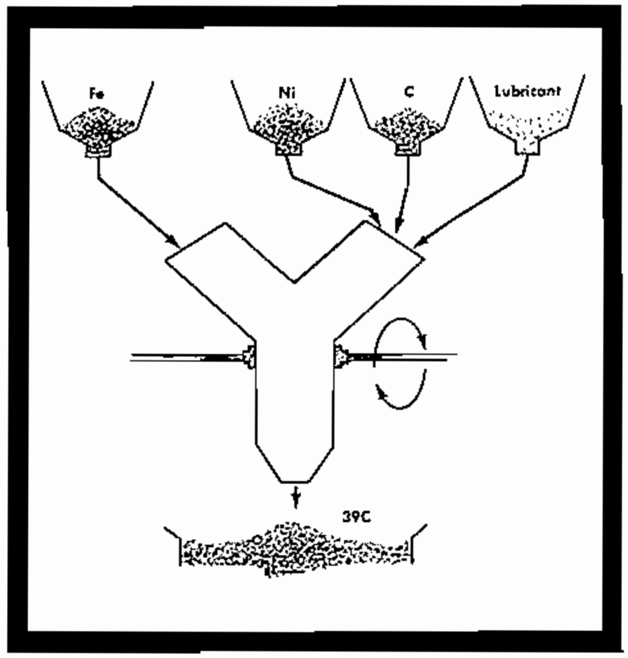
* Both light to medium loads
Wakefield Bearing Corp., — Findings.

Reprinted courtesy of *Mill & Factory*, November 1962

INTRODUCTION TO THE POWDER METALLURGY PROCESS

Presuming, then, the reader has found grounds for proceeding in the previous data, we open our discussion with the basic framework of how the end result is obtained. We express some of the basic definitions, and endeavor to transmit a feeling for the product.

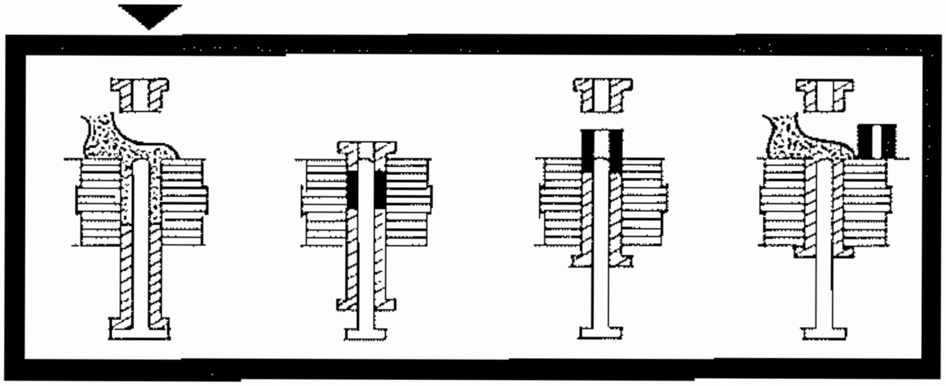
Finely divided metal powders are the raw materials of sintered metal parts. Pure powders, produced from high grade raw materials, may be combined to produce alloys of standard composition and often of unusual compositions for special properties. Some combinations can only be made by powder metallurgy. Powders are blended together and carefully tested for chemical and physical properties before being placed in production.



To form a shape from powdered metal, blended powder is poured into a rigid die, and pressure is applied from top and bottom by movable punches. Pressures range from 5 to 50 tons per square inch. The pressure forces particles together, so that they interlock and form bonds. The shape then has sufficient coherence and strength to be ejected from the die. The degree to which the powder is compressed controls the density, or weight per unit volume, of the pressed part.

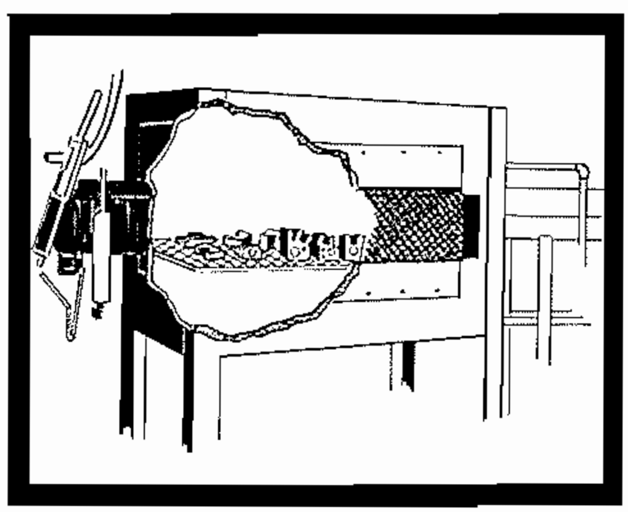
Exact control of density is extremely important, as most of the physical properties of a part depend upon it.

All compacts produced from a particular die are identical in dimensions. Very complex shapes can be formed repeatedly and accurately in this single step.



Sintering is the heat treatment of a pressed shape to strengthen and increase the bonds between metal particles. These bonds grow with increasing time and temperature of sintering; however, the temperature is held below the melting point of the major metallic constituent so that the pressed shape is retained. During this heat treatment parts are protected from oxidation by controlled atmosphere.

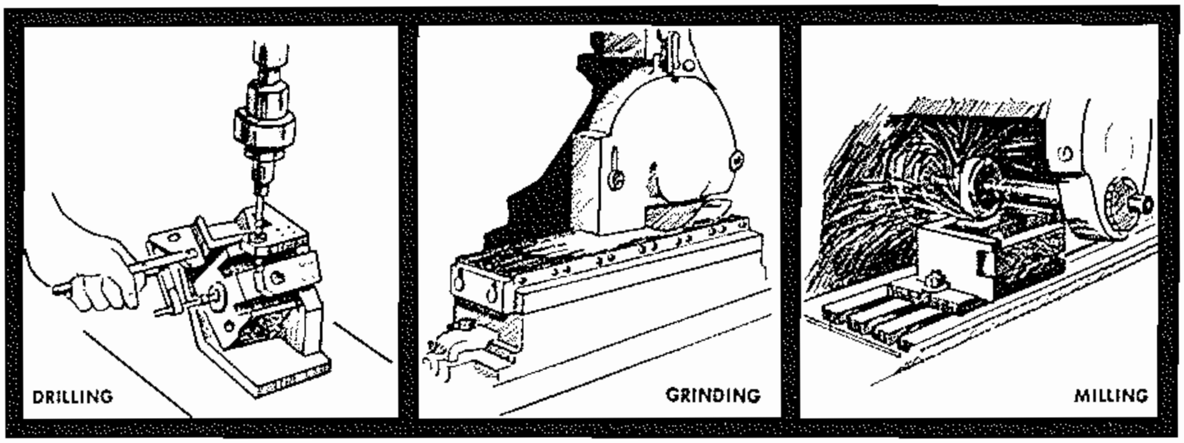
After sintering many parts are ready for use, but various further finishing operations may be applied to sintered parts.



Some of these, such as sizing or oil impregnation, are specific to sintered metal, others such as machining, heat treatment, barrel finishing and plating are operations common to other metal fabricating methods.

Sizing is frequently included in the process. This consists of a repressing operation in precision dies, during which surface finish and dimensional accuracy are improved. Some increase in density and strength may also occur.

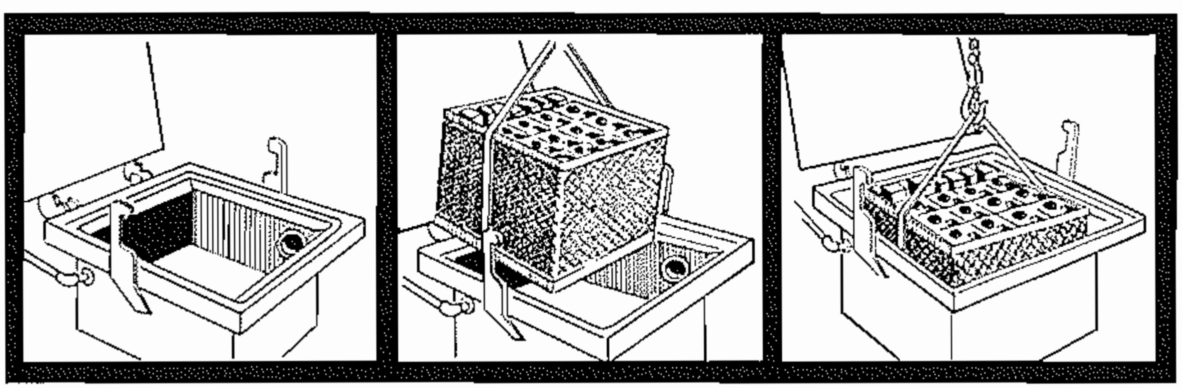
Machining on sintered parts completes those portions which cannot be directly molded in pressing, for example undercuts or tapped threads. We specialize in parts 100% complete.



Heat treatment of sintered steels compares with conventional steel heat treatment. Hardness and strength are increased by quenching and tempering. On high density sintered steels, case carburizing is also possible.

Commonly used surface finishing treatments include black oxide steam treatment, barrel finishing and plating.

One finishing treatment unique to powdered metal is oil impregnation. The pores or spaces between the metal particles are usually interconnected. Lubricating oil can be absorbed and retained by these pores by capillary action. In application, when a bearing or moving part is warmed by friction in operation, the oil flows out of the pores and lubricates the bearing surfaces.



OIL IMPREGNATION OF SINTERED PARTS IN A VACUUM TANK

Unfortunately, we cannot dismiss the subject quickly, but must proceed to cover at some length the details which follow. At this point, however, the potential user would do well to consider a visit to our plant, as we welcome the opportunity to convey first hand the graphic presentation of actual production and discussion of the materials, a review of which follows.

ALLOYS AND APPLICATIONS

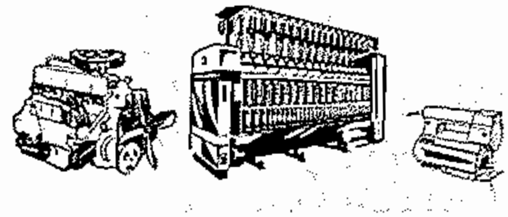
Over a period of many years' experience in successful field applications, we have acquired a more than usual number of alloys. In spite of pressure from our production management, we retain them, although the very number complicates our manufacturing a great deal.

However, to serve our customers best, we feel the fine points of the art should be preserved, not curtailed, and we plan to add to, rather than subtract from, our capability to produce dependable products.

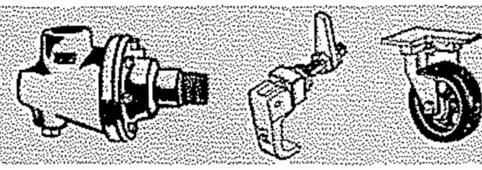
IRON, AND ALLOY STEEL COMPOSITIONS

Alloys No. 16, 17, 18, 19, 26, 27, 28, 29 represent the early work in sintered iron, and have established uses and good historical background in suitable applications. In general, they are used as oil retaining bearings, cast iron substitutes, and applications where high strength is not important. Fabrication costs are low. Use of the particular alloy will be determined as the description of the application appears.

We also find in this group certain military specifications, listed on page 10

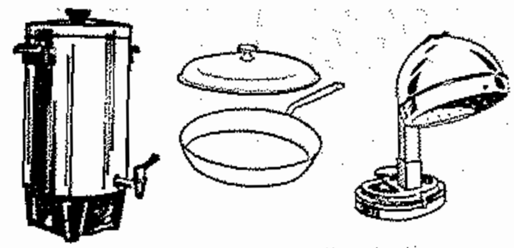


Alloy No. 35 covers copper infiltrated parts. It is a long standing material of higher strength values. To some extent it has been superseded by more sophisticated alloys, but nevertheless represents important basic usage in gears, structural parts, and areas where hardened or plated parts are desired.



Alloys No. 38 are the stainless steel group, under which the various analysis are described by the usual AISI numbers. Their corrosion resistance is important, but due care must be taken not to expect exact duplication of the wrought material, as scratch corrosion takes place more easily. We should be consulted on specific applications, if this question is important. Generally, there is a rising use of the stainless alloys for decoration, and heat resistance metals.

You will note many variations in fabrication, which add to the usefulness of this product. Therefore, they are especially engineered products.

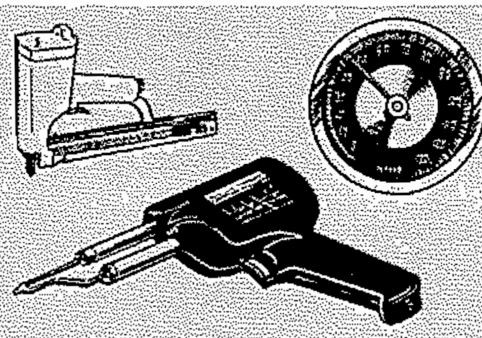


Alloy No. 39 represents one of the first usages of nickel, with and without carbon, to improve sintered compacts. Wakefield Bearing Corp. pioneered much of this work, and established facts which have become guide lines.

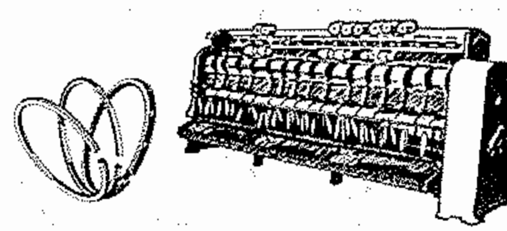
The best application is in the medium to high tensile strength range, particularly useful in gears under high wear and impact conditions. Further, where additional wearability of a part, such as a cam, is desired, this material is suitable without resorting to carburizing, in some cases.

Measured in material use, the alloy is one of our largest, unquestionably based on the fact that it has been successful over a long period of time.

A note of caution here is that correct fabrication on our part is the key to success.



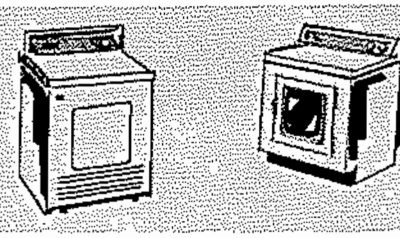
We are very interested in the new usage of our No. 58 alloy, which contains 2% Aluminum Oxide covered by U. S. Patent #3,118,272. We have observed high wear resistance, low friction values, high heat strength and other properties unusual in powdered metal. Our data on bearings is most impressive, showing an extremely large number of cycles under test. Further, as a cam, we do have field experience which is of great value. All applications need careful consideration, and we welcome the opportunity to discuss them.



We find No. 65 heading well into the areas formerly considered beyond the capability of sintered metal. The outstanding usages are gear applications, under extreme wear and shock load conditions. At this point, fabrication costs begin to rise.

IRON, AND ALLOY STEEL COMPOSITIONS

Alloy No. 72, either as sintered or heat treated, represents the ultimate in tensile strength, elongation, toughness, and hardness. In cost, this alloy should not be compared with lower but useful grades. Only where the optimum is desired should you specify this material. Examination of the data will properly place the area in question.

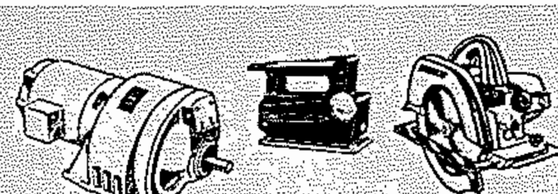


NON-FERROUS ALLOYS

BRONZE

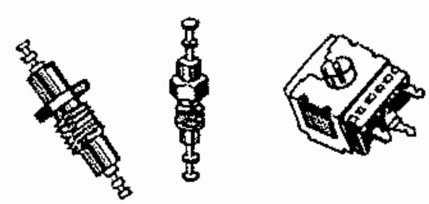
Alloy No. 14 is a very popular and widely used porous type bearing, containing NO GRAPHITE. Used on light duty applications, where oiling is scheduled, and applied mainly to automotive type bearings. The equivalent of popular bronze oilless bushings.

Alloy No. 12 is the same as #14, except there is a 2% lead content, which doubles the elongation values, and improves the tensile strength by approximately 25-28%. Therefore, this alloy has no graphite, but is adaptable to heavier loads. We also find a lower friction value. Used commonly in power tools and fractional motors.



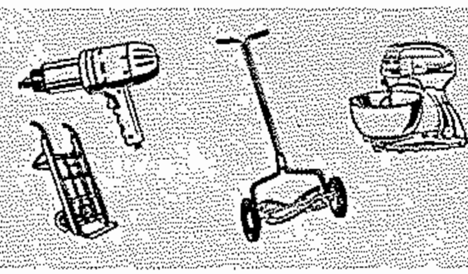
COPPER

Alloys No. 52 and 54 are suitable for terminals, contacts and other electrical conductor components, and have a distinct advantage in excellent appearance at low cost. They also lend themselves to more complex shapes and closer tolerances than sand-cast pieces.

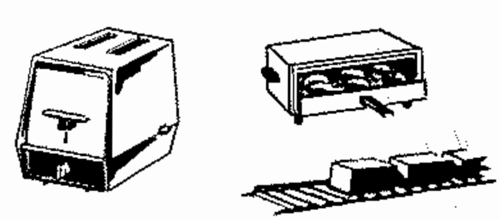


GRAPHITED BRONZE COMPOSITIONS

Alloys No. 22, 23 and 24 contain copper and tin plus a small amount of graphite embedded in the metal itself. There is no chance for free graphite to appear. Most usual applications are those where infrequent or unreliable oiling cycles rule. Household appliances, hand trucks and casters, automotive, lawnmowers, machine tools, hand tools and small fractional motors.

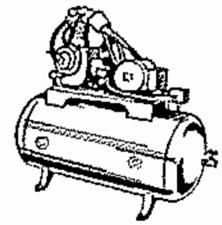


Alloy No. 11 contains copper and tin, plus a larger amount of graphite retained in the same manner as #22. However, the oiling cycles can be omitted under some loads and speeds. Our recommendation is advised on the usage, as it is based on wide and successful experience. This alloy also is adaptable to high temperature, above the burn off point of oil and for heavy loads. Ovens, household equipment, cameras, outdoor applications, conveyors, calender rolls.



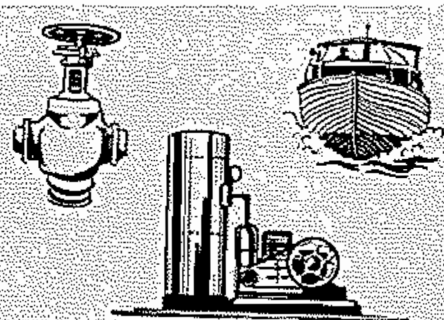
NON FERROUS ALLOYS

LEADED BRONZE COMPOSITIONS

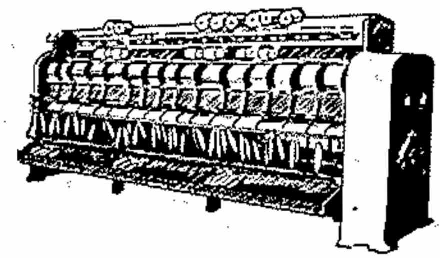


Alloys No. 13 and 12, Leaded bronzes, with and without graphite, have many excellent properties for self-lubrication and resistance to shock loads. Certain high speeds are well served by these alloys, for example, compressors.

LEADED GRAPHITED BRONZE COMPOSITIONS

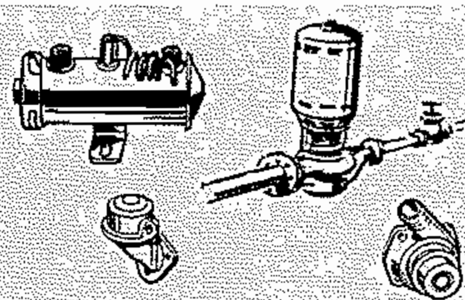


Alloys No. 4 and 10 are special graphited bronzes designed for water lubricated applications such as pumps, agitated vats, ship installations, and washing machines. Extremely corrosion resistant. They neither gall shafts, nor allow shafts to be scored by foreign material and will not squeak when dry. Special recommendations on request. Recommended for use in water meters, pumps, washing machines, and marine applications.



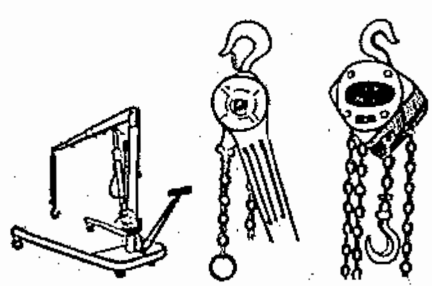
Alloy No. 3. A Graphited bronze of lower porosity developed especially for the textile trade to overcome the effect of lint and fly, and to provide self-lubrication. Field usage over a period of years indicates this alloy is outstanding, and accepted by many of the textile machine manufacturers.

SPECIAL LEADED GRAPHITED BRONZE COMPOSITIONS



Alloys No. 6, 8, 9, and 25. These are special leaded graphited bronzes. The outstanding bearing in the field for liquid fuel pumps, where trouble free operation is essential. They operate with liquid as a lubricant.

BRONZE MOLYBDENUM DISULPHIDE COMPOSITIONS

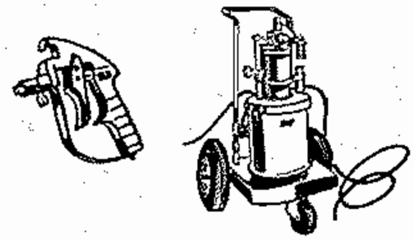


Alloys No. 1 and 2 are a new bronze development using molybdenum disulphide with excellent laboratory and field results, for higher speeds and heavier loads, than #11. It shows remarkably consistent results. Priced higher, due to material costs. Test samples furnished on request. For use in spindles, hoist pulleys, and electric motors.

NON FERROUS ALLOYS

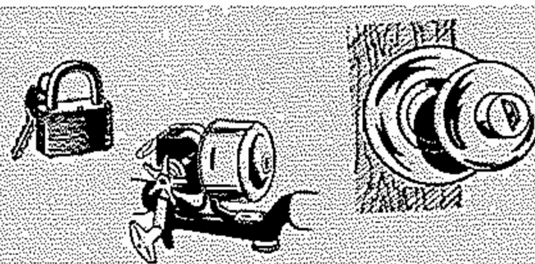
COPPER-NICKEL ALLOY COMPOSITIONS

Alloy No. 21 is a copper nickel alloy for use on regular and special alloy shafts. It will not gall, is corrosion resistant and exceedingly efficient in temperatures to 900 degrees F. Can be adapted to machine parts. This is a relatively new and important development. Salt water applications, chemical handling equipment, catalytic cracking plants.



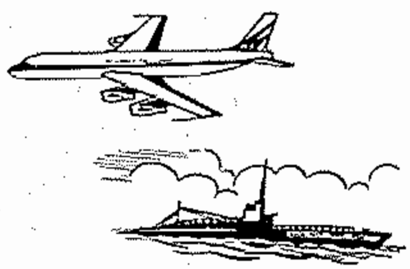
BRASS ALLOY COMPOSITIONS

The brass alloys No. 36 and 37 are exceptionally clean and free from surface blemishes or discoloration. With our improvements in furnace treatment, extremely high strengths and densities are possible. Ideally suited for low cost and high production items of intricate design. Extremely close tolerances possible by coining.



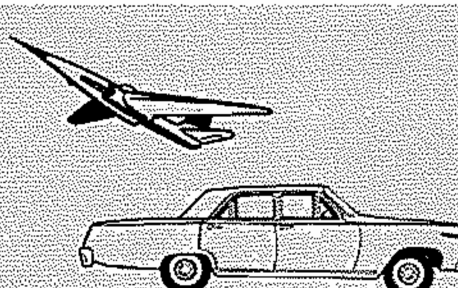
GRAPHITED TIN-LEAD COMPOSITIONS

Alloy No. 15 is a graphited Babbitt metal highly favored by some pump manufacturers. Also is particularly valuable where Babbitt bearings are desired, and where certain self-lubricating properties are needed for safety factors in the event of oil failure. It has the advantage of removable Babbitt bearings, and can be installed on the job. Specially suited for aircraft and marine applications.



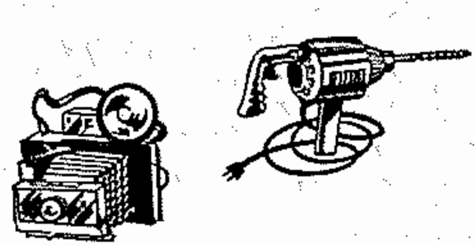
TITANIUM COMPOSITION

Alloy No. 55, Titanium — light-weight, high-strength sintered parts which approach very closely the properties of the solid material. Moulding Titanium saves waste and expensive machine time, and in some cases is the only practical method of making low cost pieces. Alloys with increased physical properties are also available on request.



No. 48 NICKEL SILVER ALLOY

Alloy No. 48 is a nickel-copper-zinc material useful for corrosion resistance. It has good physical properties and is non-magnetic. We find a particular usage in food handling equipment. With chrome plating directly on the sintered and polished surface, the appearance is attractive.



STANDARDS AND SPECIFICATIONS

SINTERED BEARINGS

	M.P.I.F.	A.S.T.M.	S.A.E.	OTHERS	WAKEFIELD ALLOY #
Bronze — 5.8 - 6.2 g/cc + Less	BT-0010-N	—	840		14, 23
Bronze — 6.4 - 6.8 g/cc	BT-0010-R	B-202-60T Type I Class A	841	AMS-4805-B MIL B 5687 Type I Comp. A	14, 23
Bronze — 6.8 - 7.2 g/cc	BT-0010-S	—	842		14, 23
Iron — 5.7 - 6.1 g/cc	F-0000-N	B-202-60T Type II Class A1	850	MIL-B-5687-B Type II Comp. A1	41*
Iron-Alloy 5.8 - 6.2 g/cc	FC-1000-N	B-202-60T Type II Class B	862	MIL-B-5687-B Type II Comp. B	*

SINTERED METAL PARTS

STRUCTURAL PARTS & MECHANICAL COMPONENTS

	M.P.I.F.	A.S.T.M.	S.A.E.	OTHERS	WAKEFIELD ALLOY #
Bronze — 6.8 - 7.2 g/cc	BT-0010-S	B-255-61 Class B	842		14, 23
Brass — 7.2 g/cc min.	BZ-0218-T	B-282-60 Class A	890	MIL-12128-A — Comp. 3	37
Brass — 7.7 g/cc min.	BZ-0218-U	B-282-60 Class B	891	MIL-12128-A — Comp. 3	37
Brass — 8.0 g/cc min.	BZ-0218-W	—	—		37
Iron — 5.7 - 6.1 g/cc	F-0000-N	B-310-58T Type I Class A	850	MIL-M-13749	41
Iron-Alloy 5.8 - 6.2 g/cc	FC-0710-N	—	—		45, 19
Iron-Carbon 6.1 - 6.5 g/cc	F-0010-P	B-310-58T Type II Class C	855		42
Iron-Metal Infiltrated	FX-2000-T	B-303-61 Class A	870		35
Iron-Carbon Metal Infiltrated	FX-2010-T	B-303-61 Class C	872		35

Note that in our tables of physical properties on pages 64–70 we have many alloys which are not presently covered by specifications but whose properties far exceed those referred to in the above specifications.

*We will gladly make material to the specification FC-1000-N and F-0000-N as we normally make a group of iron-copper-carbon alloys whose compositions are near that of the specifications.

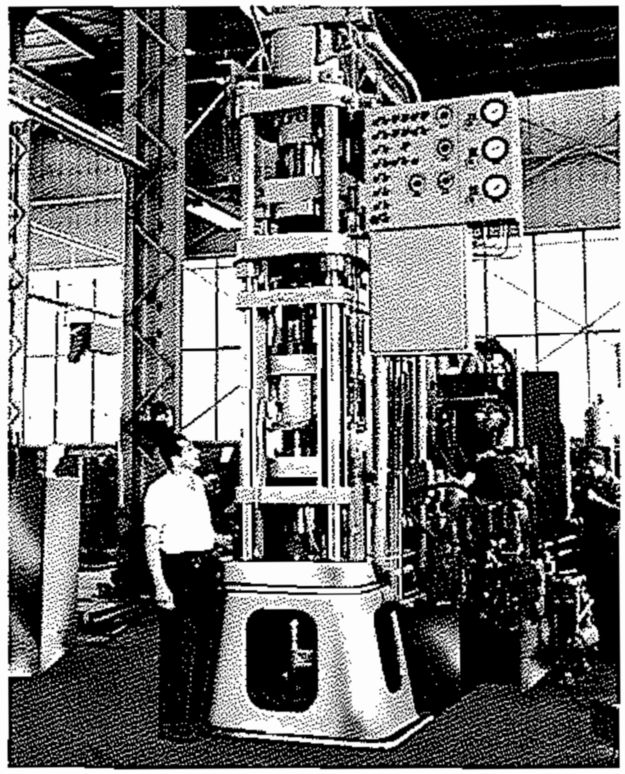
PRODUCTION CAPABILITIES

In writing this material, we well recall the arrival of the first automatic briquetting press. The results were fantastic in those days, but pointed a direction and policy which has been followed since that time.

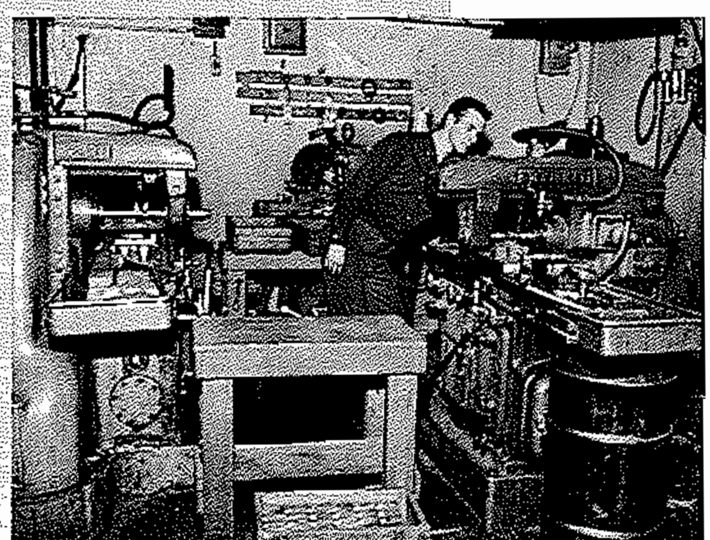
First, only the best equipment, bought from Kux, Stokes and others, brand new, has been added.

Secondly, before the actual need arose, the equipment was acquired in order to keep pace with projected growth, and fulfill needs as they arose. We will continue to do so. We have placed no limits.

Third, no expense is spared in keeping equipment in top operating condition.

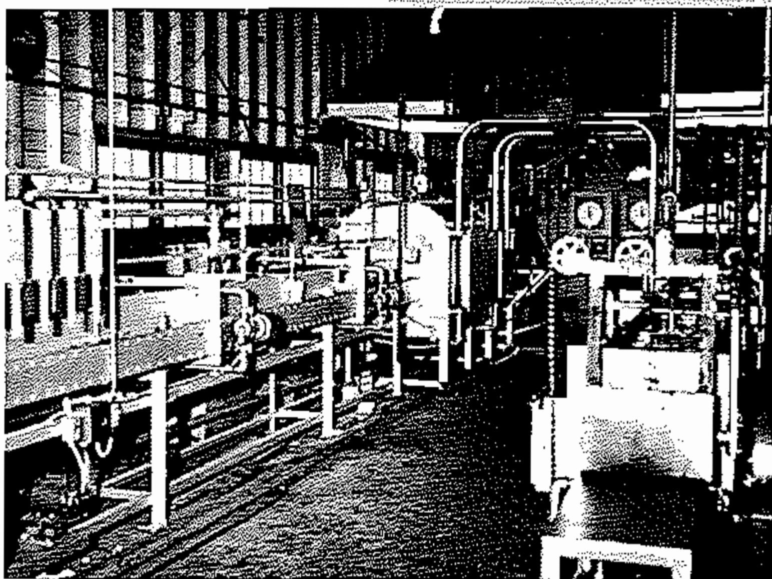


Fourth, the entire assembly of equipment is as nearly complete as possible for the needs of our customers, from the smallest to largest size parts. We specialize in all secondary machining operations, performed on our own equipment, and under one inspection. You can get dependable completed parts.



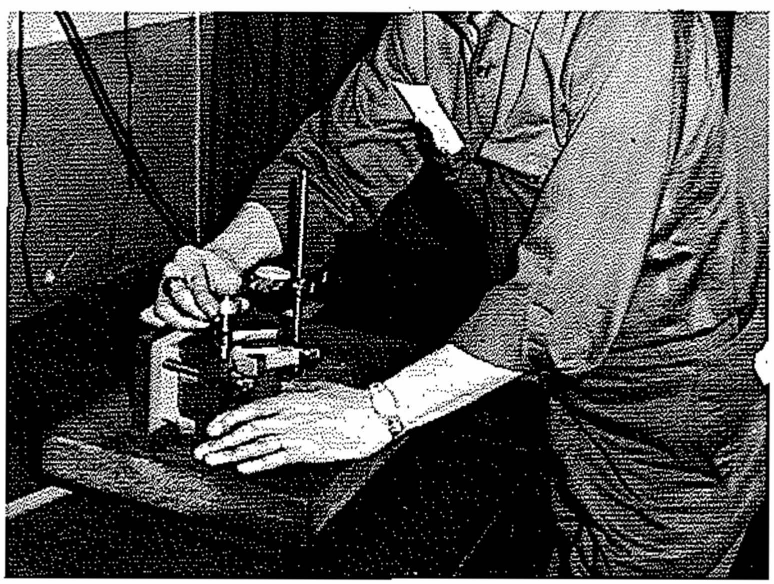
Fifth, and finally, we have on hand thousands of sets of tools in inventory.

As a matter of fact, we are very pleased to list equipment which currently is very new, as a good portion of the growth in sintered metal has only been in recent years.



All of these facilities are worthless without competent operators, and we find we have an extremely aggressive group, constantly seeking new levels of production. Relations are excellent throughout.

Also important during this period has been the emphasis on quality control. The very real problem of high quality and low price is one which demands close understanding with our customer. Our process, like all others, is directly related. The more we spend fabricating and tooling a job, the higher the quality and the higher the price. In this situation, therefore, reliability is by mutual definition.



To assure reliability, we do maintain a very high percentage of inspectors to production workers.

Our Wakefield and Route 128 area is one rich in people with mechanical skills, which is tremendously helpful in quick expansion and rapid rises in production demands.

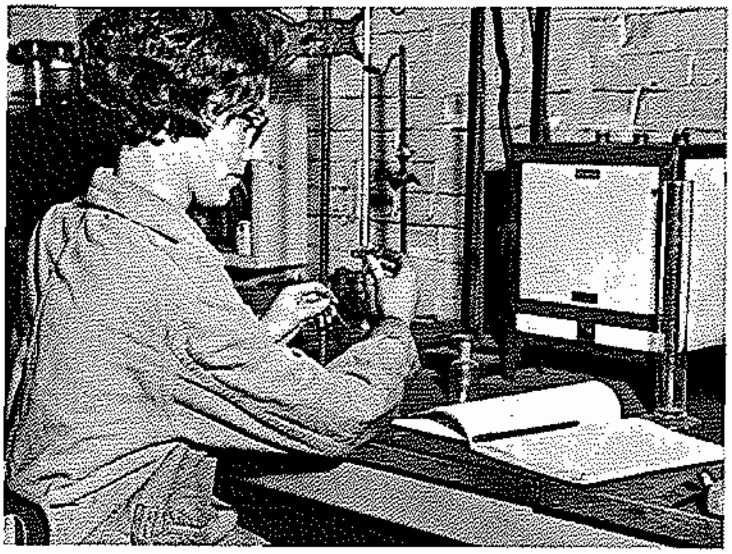
Finally, our raw material suppliers are an extraordinarily efficient group, whose delivery and quality are dependable, which allows us to plan production without reservation.

ENGINEERING

Elaborating on our initial statement on engineering, we find three principal divisions.

The first is *mechanical,* in which all geometry of the product is handled. Included are plant equipment, methods, tools, and product design. Under one head, therefore, is continuous thinking, without interference. The action can be very fast.

Without doubt, product design is the principal occupation, as we deal with our customers on a very close basis. Changes and suggested improvements are frequent, as are recommendations based on past successful field service, or from data known to be reliable.



At all times, competent design engineers are available for field trips, or to receive visits at the plant. Using this service saves many hours or even weeks of time in reaching conclusions. We can best summarize by saying we have produced parts satisfactorily that no one else wanted, due to design problems.

Our second engineering activity is *metallurgy,* where we perform all the necessary laboratory tests. At times, we supplement this work with the use of outside sources. We feel that our laboratory facilities and staff place us among the leaders in the field.

This statement is best judged by results, which are extremely satisfactory. We are currently conducting over fifty separate research projects.

Here again, design work on a given project is performed, with the recommendations for materials based on growing lists of data. Historical records are maintained to follow up the appropriate situation.

The third phase of engineering is *metallurgical research,* which has a large field of opportunity. We do research both with a specific objective, and also where there is no apparent commercial end use. In any event, we hope that full use of this facility will be made, as we feel the customer may have an opportunity for product improvement.

Where a customer has companion people and laboratory equipment, we like to exchange observations and suggestions. Research proceeds on a broader basis, as there are more minds at work, more ideas flowing. You can use this service with the greatest confidence, as a customer's plans, hopes and ideas are never disclosed elsewhere.

Here again, we are prepared to have the appropriate metallurgist visit with you.

CHECK LIST — QUOTATION INFORMATION

To facilitate our prompt reply to your request for quotation, we list below the information which we need for accurate price analysis.

1. **Drawing of the part showing minimum acceptable tolerances. Generally speaking, looser tolerances mean lower price.**

2. **Material specifications and physical properties required in the part. (Tensile strength, impact resistance, porosity, elongation, hardness).**

3. **Operations which the customer intends doing to complete the part for use.**

4. **Function of the part, and assembly, with indication as to whether design changes are possible.**

5. **Quantities for which prices are required, and estimated annual usage.**

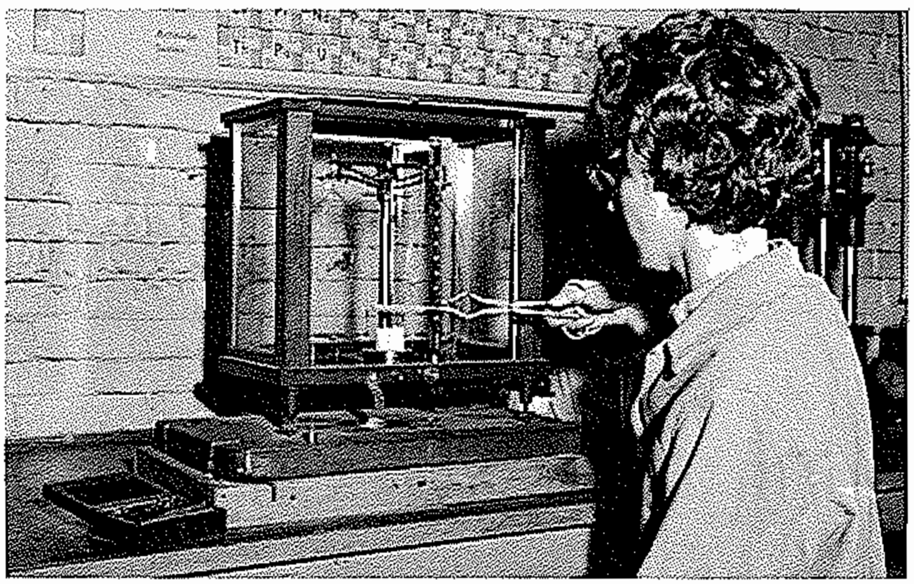
On the following pages appears a discussion of the Powder Metallurgy Process. In the course of this we have given a description of the mechanics of the process, the physical and chemical principle which are basic to powder metallurgy, and the various controls and tests which are applied during manufacturing to assure a dependable and consistent product.

A. METAL POWDER

The control of the properties of finished sintered metal parts begins with close control of the raw materials by the metal powder manufacturers.

Raw materials for powdered metals are ingot, high grade scrap, and ore. The powders are produced by atomization of molten metal, by reduction of crushed oxide, by electrolysis, or by a combination of these processes. Our supplies offer many different grades of powder with distinct properties, which allows us to choose the grade of material most favorable to the properties of the final part.

Chemical composition is as important in powder metal as in other metallic and non-metallic materials. Not only is the starting chemistry of the raw material specified, but throughout the melting or reduction cycles controls are applied which result in a product with close chemical tolerances. Electrolytic powders are the most pure. Impurities can lower final strength and ductility, and affect our processing by causing unexpected dimensional distortion and reduced compressibility which results in a low density part. On the other hand, some trace elements present in the powder are helpful alloying agents, and result in better properties. Some are useful for particular reasons, i.e. sulfur in iron increases machinability.



Of equal importance are the physical characteristics of powdered metal; the size and shape of the particles. A distribution of particle size is normally desirable. Consistency from lot to lot of powder is necessary to insure uniformity of pressing, dimensional changes during sintering, and as a result, final properties. The size distribution is tested by screen analysis during manufacturing as well as on the final powder product. If it is not within specifications, the powder can be ground or milled to the proper size, or size fractions may be separated out and reblended in the correct proportions. If mechanical working is necessary, the powder is annealed to remove work hardening strains which could impair compressibility.

Particle shape is controlled by the manufacturing process. Reduction of oxide produces an irregular or sponge powder. Electrolytic powder is characteristically dendritic and atomized powder is spherical. Figures 3 and 4 illustrate the appearance of uncompacted powder. These characteristics affect the flow rate of the powder into a cavity, and also the apparent density, (weight of a volume of loose powder). Control of both these properties is vital for speed in filling the die cavity during the pressing cycle, and more important, for consistency in the weight of powder which fills the die cavity. Consequently both properties are tested by the supplier and, if outside specification limits, may be corrected by further grinding or blending. Since only minor changes can be made on the particle shape by these methods, powder may have to be completely reprocessed to bring it within tolerance. Particle shape has a substantial effect on the behavior of the powder under pressure. Irregularly shaped powder particles interlock when compacted to form a strong unsintered or green part, whereas spherical powders must depend solely on cold welding for green strength. On the other hand, such regularly shaped powders pack together to form a more dense compact than do sponge powders under similar pressure.

Our suppliers do not limit themselves to testing just the properties of the loose powder, but actually press and sinter test samples from every lot, to assure their customers that the powder will perform correctly in production. These tests are repeated by us, and results correlated, so that no powder of substandard quality ever enters the production process. The tests performed are described fully below.

THIS INFORMATION WAS SUPPLIED BY:

Easton Metal Powder Company

The Glidden Company

Greenback Industries Inc.

Hoeganaes Sponge Iron Corporation

The New Jersey Zinc Company

The mixing of metal powders with alloying elements and other constituents can be performed either by the powder manufacturer or consumer. Alloys are often made by mixing and sintering elemental powders. Examples include copper and tin powders which produce sintered bronze, and iron and graphite mixtures which form steel after sintering. The correct percentage of each constituent is weighed out and charged into a rotating drum or double cone blender. A small percentage of solid lubricant is mixed into the powder and serves to reduce friction and die wear during pressing. The lubricant volatilizes and disappears during sintering. During the mixing cycle, samples are withdrawn to check the degree of mixing attained and the apparent density and flow characteristics of the mix.

Powder is now ready for use in production, but before release, it must pass the tests established by us to insure perfect uniformity and high quality in our finished parts. The mixed powder undergoes a final check for flow rate and apparent density. Samples are then made and tested in our laboratory facilities, which approximate as closely as possible our production conditions, and are controlled to assure standard conditions for each test. Test bars first are pressed to our standard density for the particular alloy. (Fig. 2) The pressure required to attain that density is recorded, and if it is excessive the powder is rejected, since there is danger either of tool breakage or sub-standard density in production.

The test bars are then sintered under standard conditions. Dimensional stability during sintering, breaking strength, and hardness are checked. Deviation from our standard tolerances on any one of these tests is cause for rejection of the entire lot of powder.

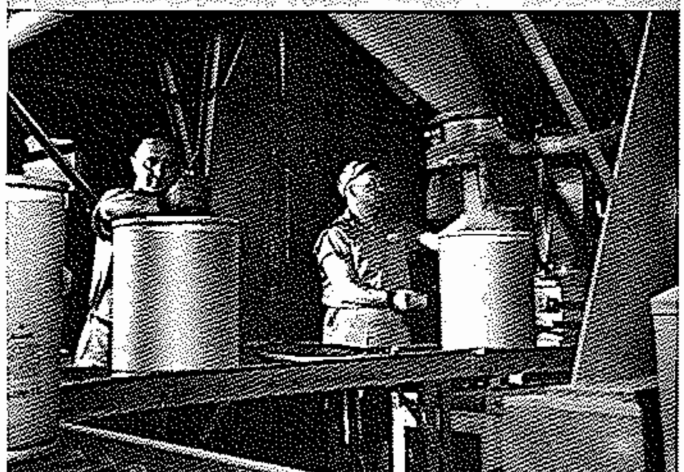


Fig. 1 POWDER BLENDING
Photo courtesy of Hoeganaes Sponge Iron Corp., Riverton, New Jersey.

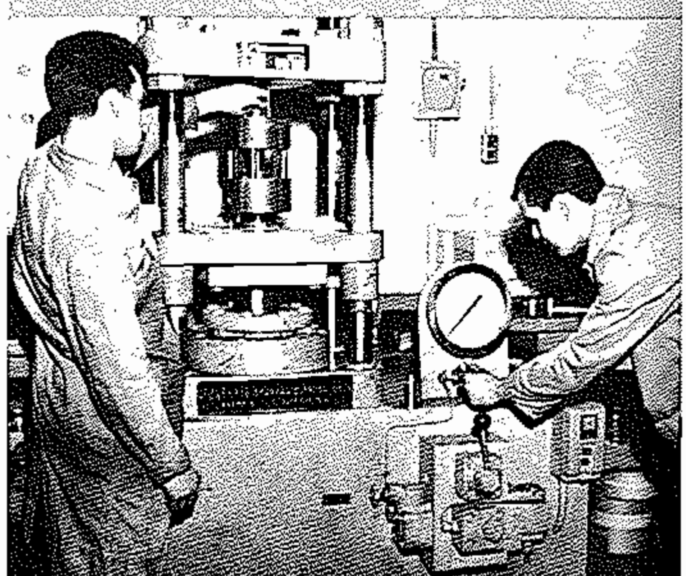


Fig. 2 LABORATORY PRESSING OF TEST BARS

C. PRESSING

Mixed metal powder is poured into a die cavity and then compressed by punches moving simultaneously from above and below. After ejection from the die the compact has sufficient strength to be handled and has approximately the same dimensions and density as it will have when finished.

The green powder compacts have strength because the particles of material are enmeshed and joined by cold welds during the pressing. Fig. 3 shows highly magnified views of uncompressed powders. The irregular shape contributes to the intermeshing effect. Spherical powders such as those in Fig. 4 have very little green strength, (strength in the unsintered condition).

Cold welding describes the adhesion or bonding that can take place between two very clean metal surfaces. If there are no oxide or lubricant films, surfaces can be brought so close that the attractive forces between atoms can bridge the gap and attract or bind one particle to another. The galling and seizing which can take place in an improperly lubricated bearing is simply the cold welding that results from break down of the lubricating film.

Mixed powders always contain a lubricant which lowers friction between the compact and the die wall. If there were no lubricant, the powder would tend to gall and seize, ejection would be difficult, and the pressure applied to each end of the compact would not be properly transmitted to the center.

Metal powders under pressure do not behave as a liquid. Some of the pressing force is absorbed in moving the powders along the die wall as shown in Fig. 5 . Lubricants minimize this problem, but a non-uniform pressure along the length of the piece will result in some degree of non-uniform density.

Figure 6 (from Jones, "Powder Metallurgy" — P. 299) shows the variation in density throughout a compact. Proper die design and part design can aid in attaining a uniform density. It should be realized that the lowest density region in a part will be the region of minimum strength. For this reason we hold the overall density of our parts as high as possible, consistent with the need for porosity for oil retention.

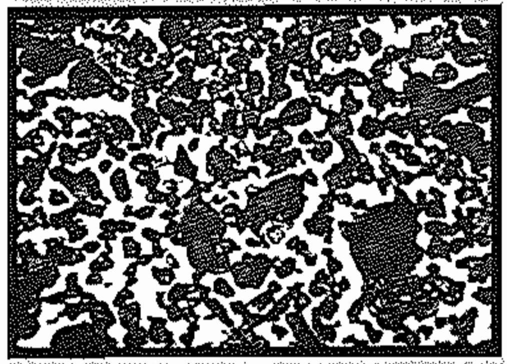


Fig. 3 100X Electrolytic Copper Powder

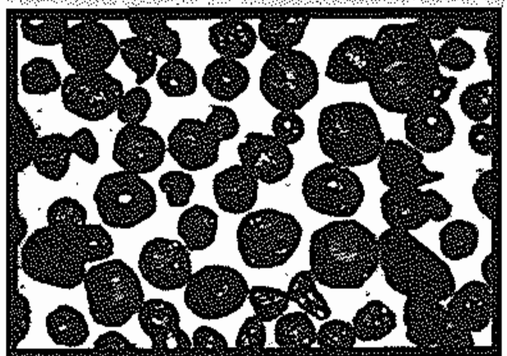
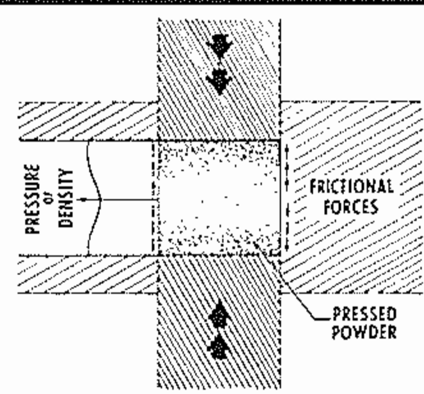
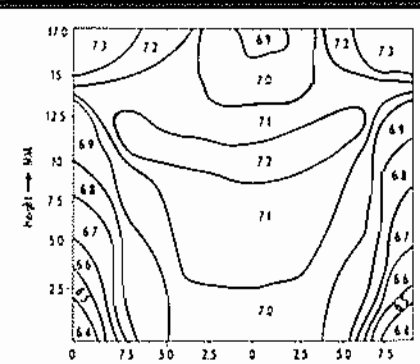


Fig. 4 100X Spherical Bronze Filter Powder



Pressure Loss Because of Die Wall Friction

Fig. 5



Distribution of densities in a nickel compact, pressed from one end at 52 TSI

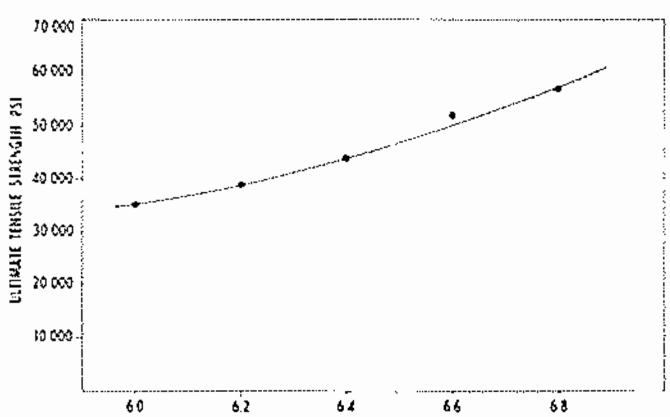
Fig. 6

D. DENSITY : Key to physical properties

The density of a part pressed from powdered metal determines most of the physical characteristics. For this reason, we regularly check the density of production pieces after pressing and after finishing. The density of a part is defined as the weight of a unit volume. Typically, the weight is measured in grams and the volume in cubic centimeters. If all parts were cylinders or cubes we could measure the dimensions with micrometers, which would give volume in a straight-forward way. The majority of our structural pieces, however, have irregular shape, and the volume is measured by the amount of water they displace. Details of this technique are given on page 51.

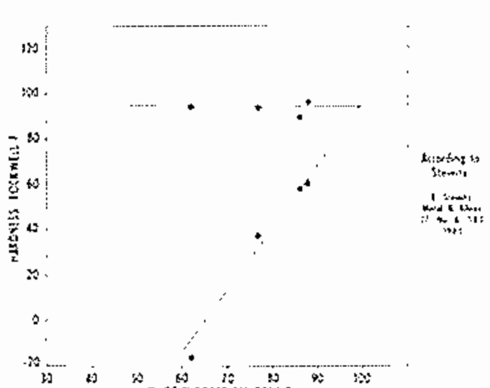
Let us consider briefly the way in which several important physical properties depend upon density. As one might suspect, if the cross sectional area of a tensile test specimen is reduced by introducing porosity the specimen will be weaker. The ultimate tensile strength of one of our alloys is shown in Figure 7 for several densities.

For solid steels, there is a (rough) relationship between Rockwell hardness and the ultimate tensile strength. For this reason, it is natural to prescribe a hardness standard for porous materials as an indication of strength. There is no objection to the procedure as long as the value of a hardness test for sintered materials is understood. We publish, in the section beginning on page 63, an exhaustive list of our alloys with hardness and tensile values. If the strength required is known, then the hardness value of the material may be read from our table and used for inspection or quality control. Density may vary slightly in any one part which will give high and low hardness readings. The reason for the variation of hardness with density is easy to understand. When the diamond point or steel ball of a Rockwell hardness tester is pressed against a surface with a certain force, the more porous material offers less resistance to indentation and gives a lower hardness reading. Rockwell hardness testing averages the effect of solid material and pores.



EFFECT OF DENSITY ON ULTIMATE TENSILE STRENGTH

Fig. 7



% OF THEORETICAL DENSITY
EFFECT OF DENSITY ON MICRO HARDNESS AND MACRO HARDNESS

Fig. 8

If a material must be hard to promote wear resistance, the micro-hardness of the material is the significant property. Wear situations normally do not involve the loads which are found in static structural applications. The wear resistance is therefore determined by the hardness of the solid material between the pores. In micro-hardness testing, a small diamond point is placed on an area of solid material and the length of the indentation measured with the aid of a high powered microscope (400X). The readings so obtained do not average the strength of pores and solid material but are characteristic of the metal itself. The dependence of micro-hardness and macro-hardness on density are shown quantitatively in Fig. 8*. As would be expected, the micro-hardness is not sensitive to porosity and macro-hardness approaches micro-hardness at full density.

The modulus of elasticity of iron decreases from 30 x 10^6 psi in a fully dense material to 6 x 10^6 psi at 36% porosity or 64% of full density.

The last physical property to be considered is porosit. Studies have shown* that, up to 92% of theoretical density, the porosity is all interconnected and available for accepting oil. The percent porosity is just 100 minus the percent of theoretical density of the part.

The effect of density on physical properties has been indicated in the preceding paragraphs. Because density is so important, powder pressing becomes one of the most important steps in the process. The density obtained at pressing is very nearly the density of the final part. Density is very rarely increased by more than 10% in subsequent processing. Uniform and high density can only be obtained through adequate tool design and sufficient press capacity.

*This data is taken from Goetzel's Treatise Powder Metallurgy.
*G. Arthur Jnl. Inst. of Metals 1955, 83 (7), p. 329-336.

E. PRESSING TOOLS

Fig. 9 pictures a complete set of powdered metal briquetting tools. The product is a two level part. Levels are defined as the number of thicknesses in the pressing direction.

In most cases, separate punches and compacting motions in the tools or press are required for each level, thereby limiting the number of levels that can be pressed without sacrificing density and related properties of the part.

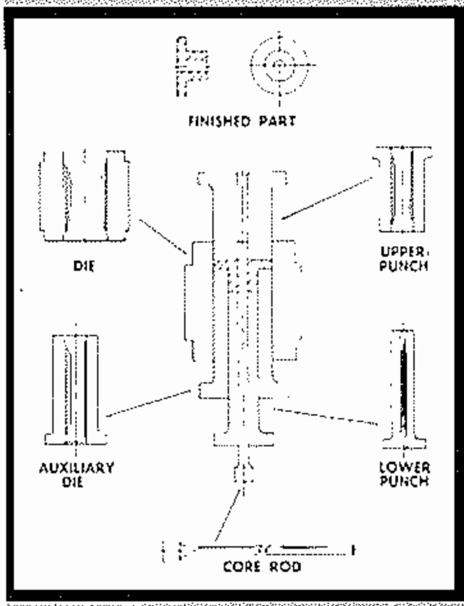


Fig. 9 TOOLS FOR PRESSING A 2 LEVEL BEARING

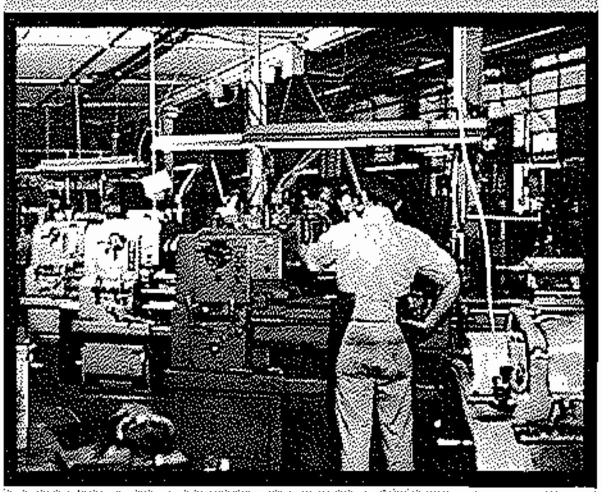


Fig. 10 TOOL SHOP

The part as shown has one hole, however, additional holes in the pressing direction can be included by adding core rods.

The cross sectional configuration of the part in the pressing direction is practically unlimited.

One set of powdered metallurgy compacting tools will replace several jigs, fixtures, cutters, etc., necessary for producing parts by conventional machining methods. All dimensions are established by the precision die and parts are then reproduced uniformly from one lot to the next.

All tools are designed by Wakefield Bearing Corp. and are manufactured in our own well equipped tool shop or by reputable outside sources. Fig. 10.

Only those tool shops specializing in powder metal tool manufacture are employed.

F. PRESSING CYCLE

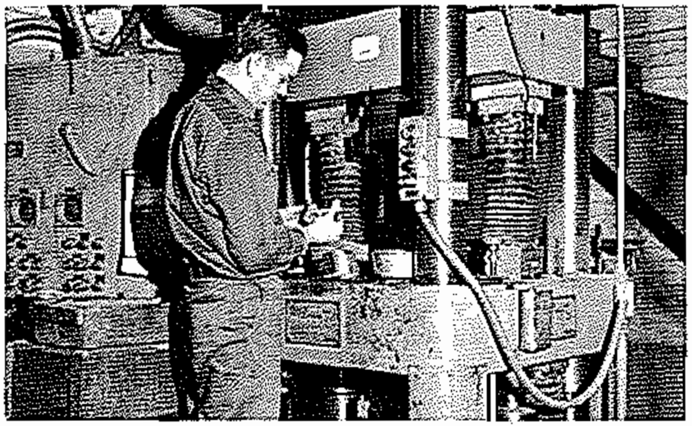
At the start of each production run, the weight of powder is calculated which will, when compacted, produce a part of the correct density and length. The tools are adjusted in the press so that the die cavity is exactly the right depth to contain the required weight of loose powder. The powder is fed into the die from a hopper or shoe, which, as it swings to one side, also levels off the powder at the top of the die. The upper punch moves down to close the die, then both the upper and lower punches apply the compacting force. After compaction, the upper punch withdraws and the lower punch moves upwards to eject the part from the die. A new cycle begins as the powder shoe moves across the die cavity, pushing the pressed part to the side, and the lower punch retracts to receive the next charge of powder.

The first parts from the press are checked at once for density. Most parts are pressed to a predetermined length, so that the volume is constant. The importance of the apparent density of the powder becomes obvious. If the weight of powder charged into the die cavity varies, the weight of the pressed part, and its density, also varies.

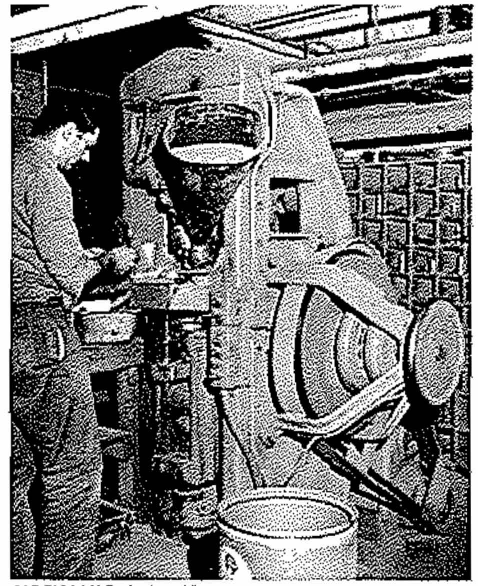
Tool breakage can occur if excessive pressure is required to compress powder into a certain volume. This condition arises with hard powders which resist deformation and compaction, or with an excessive amount of powder in the die cavity. Tooling for very complex parts is often fragile and cannot be used to attain high densities. At the end of a production run, tooling is inspected for wear and is repaired if necessary.

Our presses, both mechanical and hydraulic, are all automatic and double acting. 70% of them have been purchased in the last 8 years. They range in capacity from 4 to 400 tons, allowing for great versatility in the size of parts we can produce.

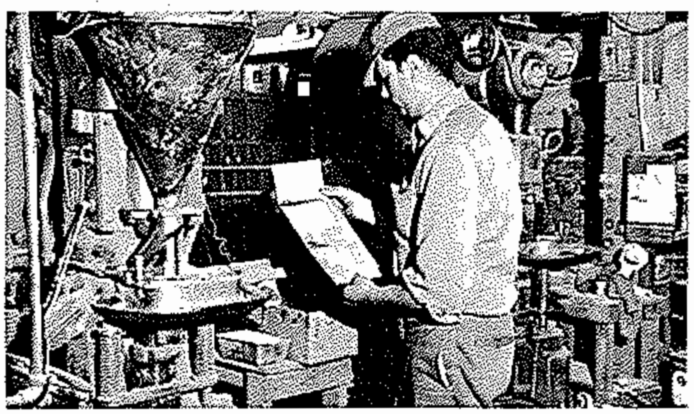
F. PRESSING CYCLE



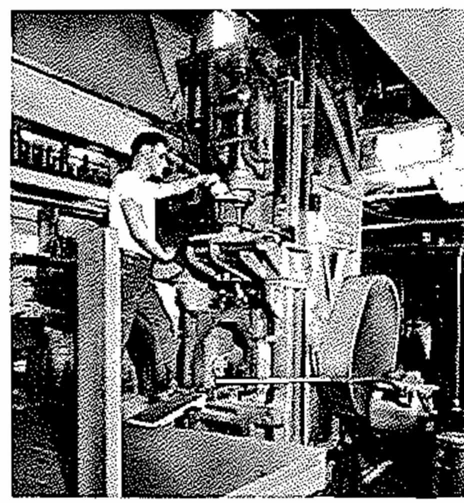
300 TON HYDRAULIC PRESS



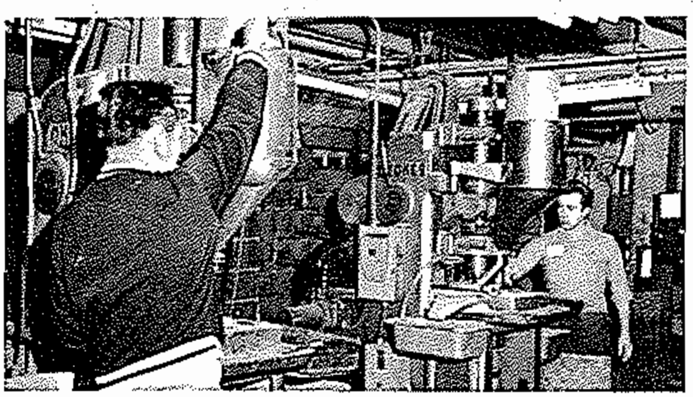
MECHANICAL PRESS



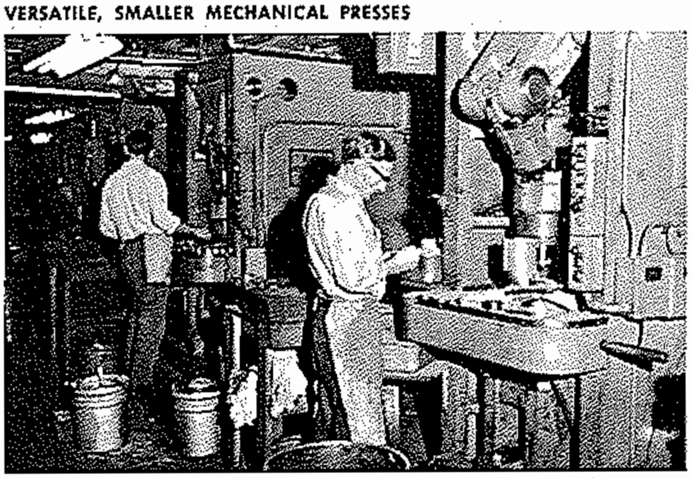
CHECKING DETAILS ON A SHOP ORDER



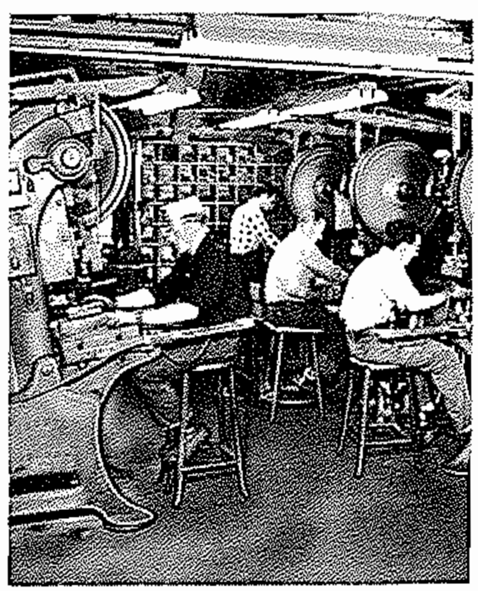
ANOTHER SECTION OF OUR LARGE PRESS DEPT.



VERSATILE, SMALLER MECHANICAL PRESSES



125 TON MECHANICAL PRESSES



SECTION OF OUR SIZING DEPT.

SINTERING

Sintering is the heat treatment of green compacts to convert them into stronger, more ductile components. The green parts have their strength by virtue of cold welds and mechanical interlocking. During sintering the areas of cold welding are enlarged and perfected so that no division is visible between powder particles. At the same time the irregular voids between particles are rounded and filled in by the surrounding material. To the extent that voids are filled in, the external dimensions shrink. If voids are created, the external dimensions grow.

There are basically two forms of sintering: solid phase and liquid phase. In solid phase sintering, no liquid is formed, whereas, a molten metal is created in liquid phase sintering. We shall consider these two types of sintering separately.

G. SOLID PHASE SINTERING

An example of solid phase sintering would be the heat treatment of pure compacted iron powder to form sintered iron, or a mixture of iron, nickel and carbon (our #39 alloy) to form sintered steel. We will consider the single component sintering first. A pure iron compact might appear as shown in Fig.11 before sintering. The particles are crushed together with some cold welding. There is some residual entrapped lubricant. As the compact is preheated in the furnace the lubricant added for pressing purposes vaporized at 720°F and helps to clean the particle surfaces of oxide.

At higher temperatures the atoms near the cold welds begin to rearrange themselves by moving from regions of strain to regions of less strain (from high to low energy areas). This movement often occurs on the surface of a pore whose shape is as shown in Figs. 12 and 13. The atoms move toward the sharp corners of the pore and cause the pore to become rounded. In so doing, the areas of cold weld are expanded and strong bonds are formed between the metal particles. The metal particles recrystallize and the new grains that are formed can grow across the original division between metal particles. When this grain growth occurs, there is no longer any evidence of the original separate metal particles, so that the material is strong and homogeneous.

The usual sintered metal structure will contain some porosity and a great many bonds between particles. If the material is sintered for a longer time, the

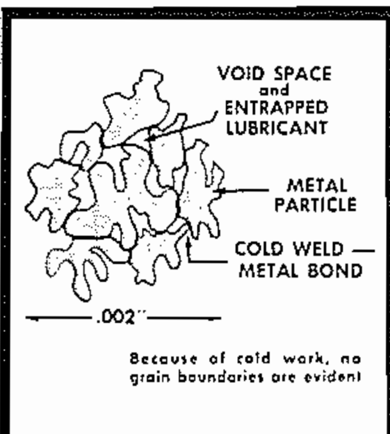


Fig. 11
SCHEMATIC APPEARANCE OF AN UNSINTERED (green) COMPACT

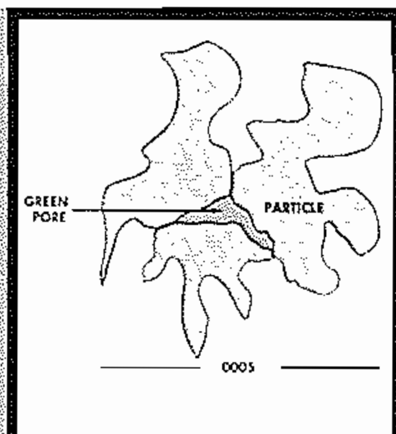


Fig. 12
ANGULAR APPEARANCE OF A PORE IN AN UNSINTERED COMPACT

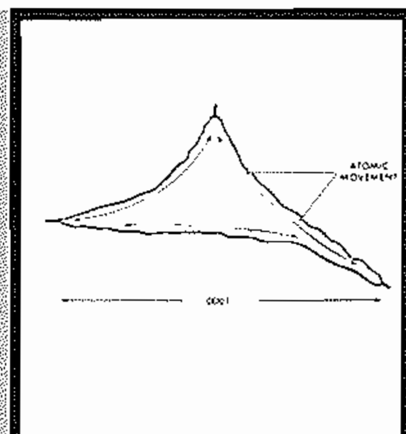


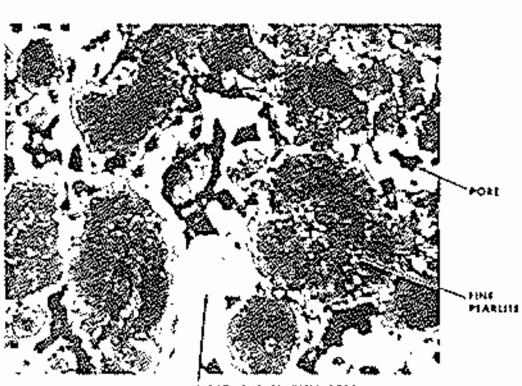
Fig. 13
ATOMIC MOVEMENTS RESULTING IN FORMATION OF SPHERICAL VOIDS

G. SOLID PHASE SINTERING

voids tend to disappear. Essentially, atoms from the surface of the material move along grain boundaries to fill the voids. The grain boundaries are rather open regions in the material and are an easy path along which atoms can move. This void filling effect is illustrated in Fig. 14.

If we are sintering the iron-nickel-carbon steel, the same sintering effects occur as for the pure iron but with one additional complication. The atoms from the nickel and carbon particles must diffuse or move into the particles of iron while the iron particles are forming bonds. The situation at the joint between an iron and nickel particle is shown in Fig. 15. At the sintering temperature the nickel atom indicated by the arrow may be vibrating strongly enough to jump into the vacant iron site. An iron atom can jump into the vacant nickel sites. With other vacant sites in the rows of atoms, nickel can diffuse into iron and vice-versa. The same thing happens with carbon. It is only at the proper sintering temperatures that the atoms can move across boundaries and change sites.

The object of this diffusion and sintering is to form a homogeneous iron solution in which some iron sites are occupied by nickel atoms and others by carbon. There should be a minimum of nickel and carbon rich areas when the sintering is completed. In addition to diffusion we of course experience bond formation with void shape change and shrinkage during sintering.



39C 200X, properly sintered

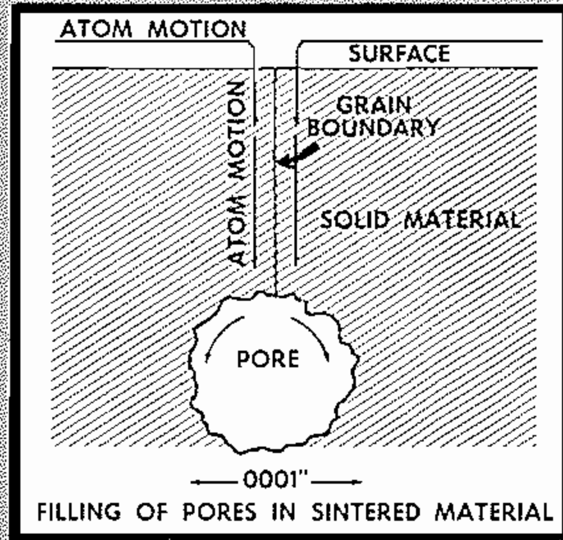


Fig. 14

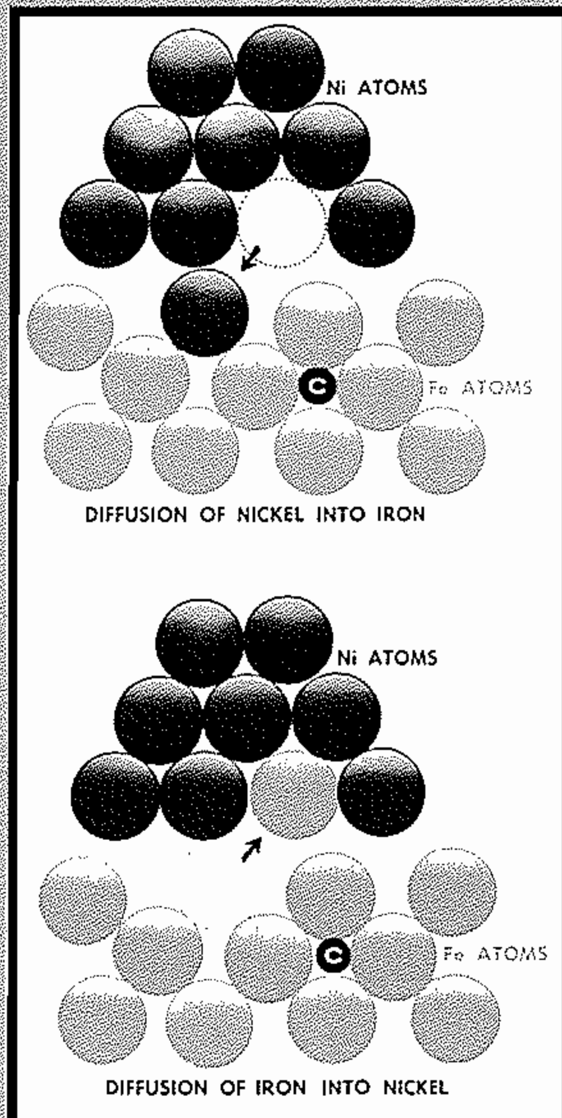


Fig. 15

H. LIQUID PHASE SINTERING

In sintering a bronze alloy composed of approximately 90% copper and 10% tin, the tin melts and forms a liquid phase. The tin is not present in sufficient quantity to cause the compact to sag while the tin is molten. The principal advantage of liquid phase sintering is speed. Since the tin is molten, voids are more readily rounded than in the case of solid state diffusion. In addition, the tin atoms are extremely mobile in the liquid state and move into the copper quite readily to form bronze. Eventually all of the tin diffuses into the copper and there is no liquid left. The grain structure of the bronze changes from very small clusters as it is first formed to good size, strong, and readily machined grains when the sintering is completed properly. The sequence of stages in sintering bronze is shown in the color microphotos of figures 16 through 21 at 200X.

Figure 16 shows the appearance of an unsintered compact of copper and tin. The tin is present as silvery particles while the copper is red colored. The dark areas are pores or holes in the compact.

Figure 17 illustrates the very beginning of the sintering process. Some tin has diffused into the copper, resulting in the formation of yellow colored alpha bronze at the boundary between tin and copper. The tin atoms actually move into the copper and occupy sites formerly occupied by copper. This process is called forming a solid solution.

In Figure 18, all the free tin has dissolved in the bronze, but it has not yet distributed itself uniformly. The red areas contain less than 10% tin and the yellow areas more than 10% tin. A uniform tin content will occur by diffusion of tin during a longer sintering treatment. As the tin dissolves in copper, the copper grains recrystallize as clusters of small alpha bronze grains.

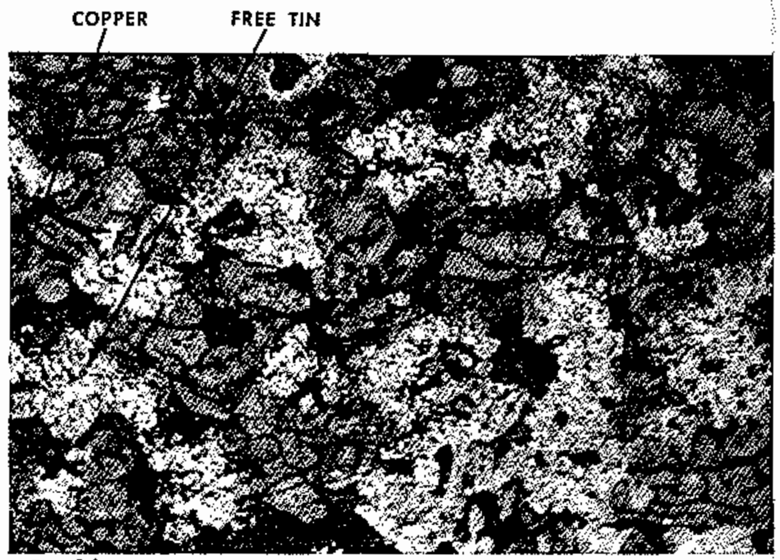


Fig. 16

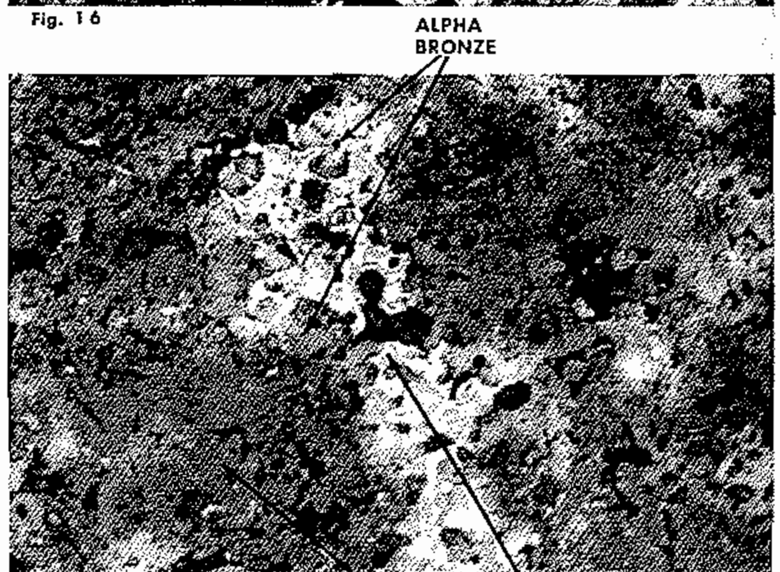


Fig. 17

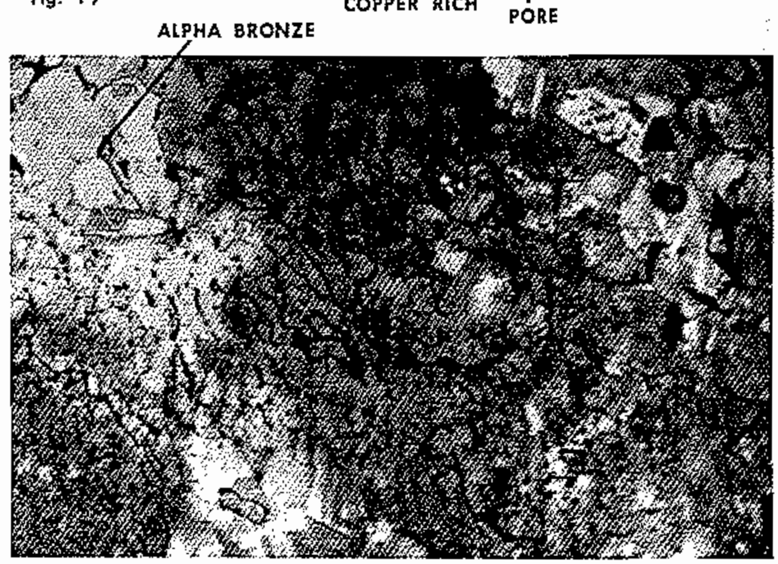
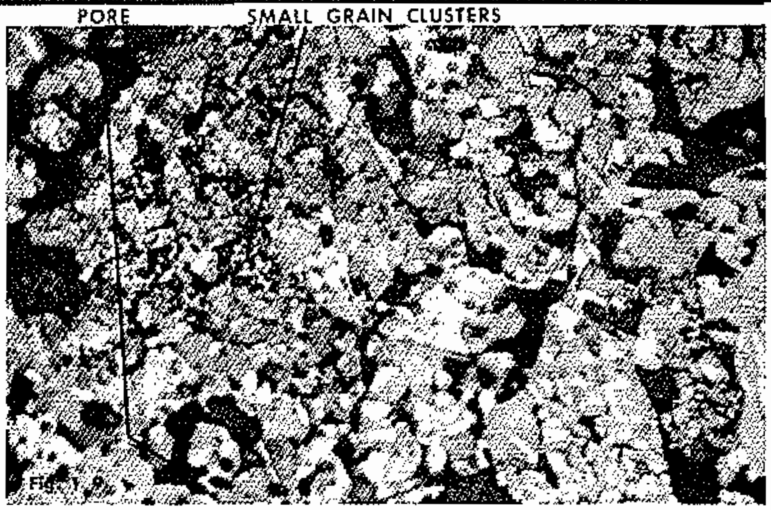
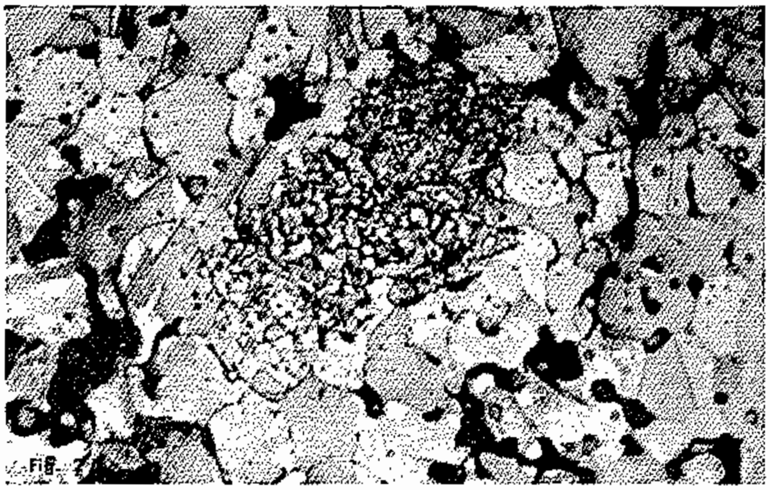


Fig. 18

H. LIQUID PHASE SINTERING (cont.)



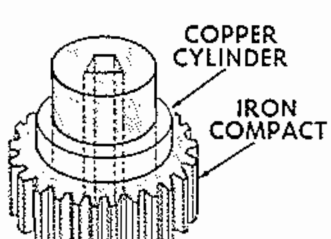


The first copper particles to recrystallize show a reasonable grain size in Figure 18.

Longer heat treatments results in the removal of all copper rich areas, and the growth of small grain clusters into large grains as shown in Figures 19-21. Our average sintering is similar to Figure 19, with special treatments resulting in the structure of Figure 20. The larger grain size means easier machining and should be requested where secondary machining operations are to be performed.

In sintering bronze, the copper does not melt, but remains as a solid skeleton. In our iron-copper alloys, the copper melts and diffuses into the iron. Just above the melting point of copper, 7-8% Cu will dissolve in the iron, the rest of the copper remaining in the free state. The dissolved copper exerts a considerable strengthening effect on the iron, increasing ultimate tensile strength from 25,000 to 50,000 psi.

Copper infiltration of iron results in a much stronger part. We normally accomplish this form of liquid phase sintering by pressing the iron powder, sintering, putting a wafer of copper on the sintered part (Fig. 22) and resintering. The copper melts, and runs in the pores by capillary action. The resulting structure is very dense (7.3 gr/cc) and has the appearance of 400X shown in Figure 23.



Copper And Iron Assembly, Prepared For Infiltration

Fig. 22 INFILTRATION OF IRON WITH COPPER

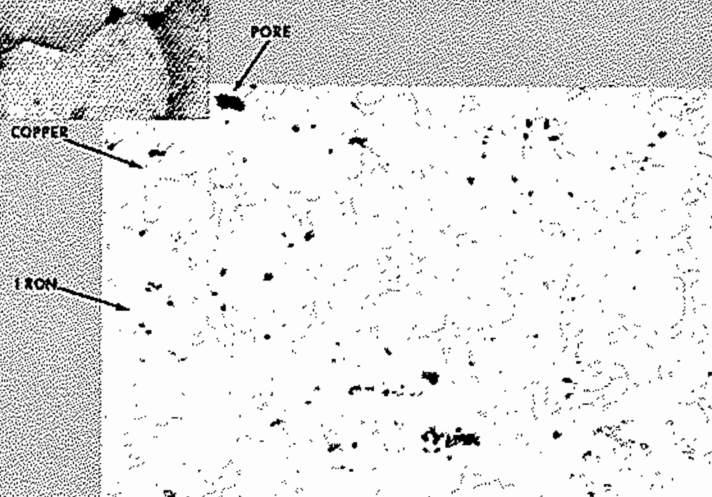


Fig. 23 400X MICROPHOTOGRAPH INFILTRATED IRON

Sintering time and temperature

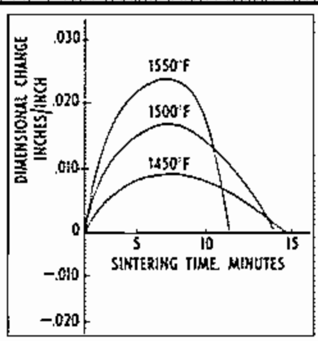
The formation of sintered bonds by the rearrangement of atoms is dependent on both time and temperature. Atomic mobility increases with increasing temperature, allowing atoms to move more freely and more quickly to form strong bonds. Increased time increases the number and size of these bonds. Usually recrystallization takes place, so that the structure becomes completely different from the original configuration of particles squeezed together during pressing. (Figs. 16-21).

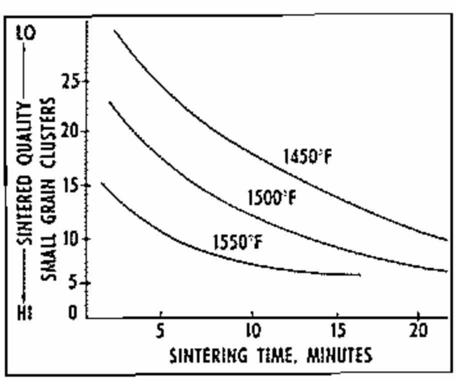
Upper limits in temperature are dictated by the melting point of the alloy in question, and the capacity of the furnace equipment. High temperature and/or long times of sintering can also ruin the dimensions of a part through excessive change in the size, shape and number of voids, although the metallurgical structure of the part may be excellent.

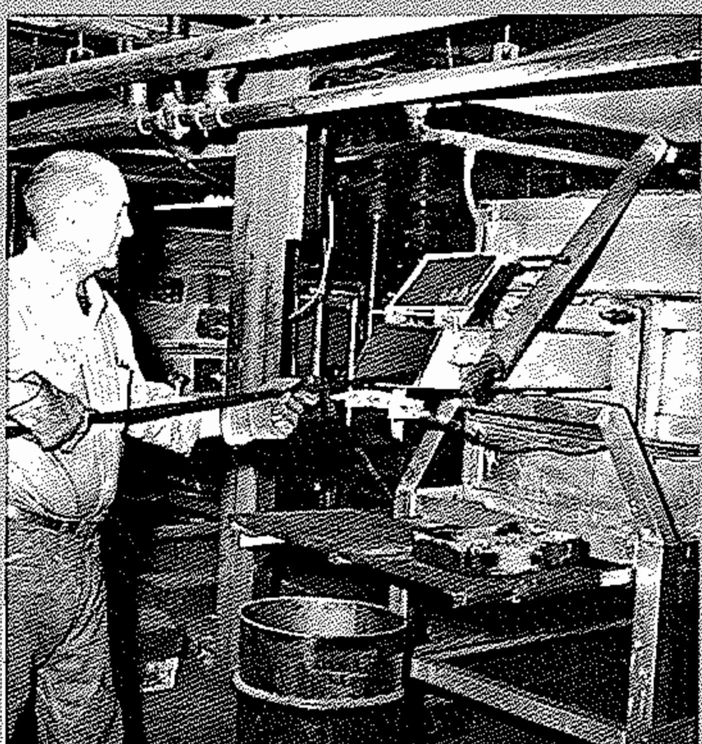
Lower limits are usually set by experience, by which we know that less than a certain temperature, or less than minimum time, will result in too few and too weak bonds, and a finished part which will not meet specifications.

In the case of an alloy, which is formed by liquid phase sintering, the low temperature limit is set by the melting point of the liquid phase; in other alloys, by a change in crystalline structure which will allow bonding and diffusion of alloying elements to proceed at a more rapid rate.

Parts sintered between the upper and lower limits of time and temperature will have microstructures homogeneous in nature, with the particles strongly bonded. At the same time, dimensional distortion from the shape as pressed is held to a minimum.

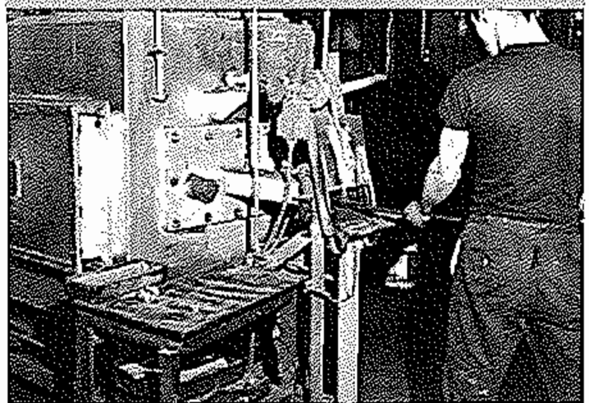




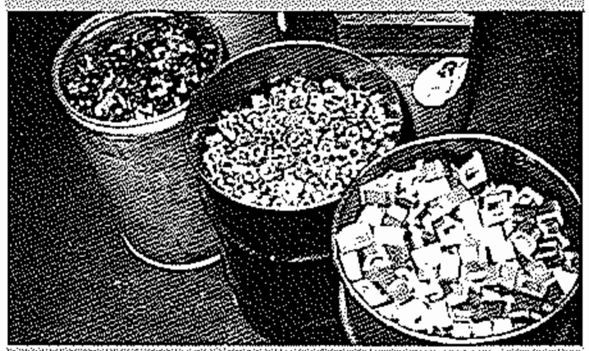


BRONZE SINTERING

Sintering of parts must be carried out under controlled atmosphere conditions. If solid materials are heated in air, the resulting skin of oxide formed can usually be removed. A porous product, however, becomes oxidized throughout due to the numbers of pores open to the surface.



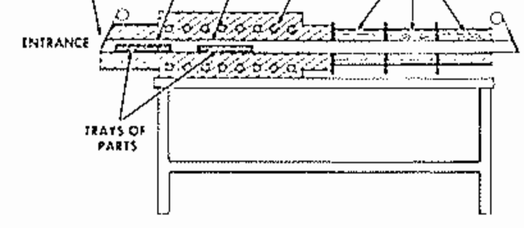
Atmospheres containing H_2 or CO, such as pure hydrogen, dissociated ammonia, and partially burned hydrocarbon gases, reduce oxide already present in the powder, and prevent oxidation during sintering. Inert atmospheres, such as nitrogen and completely burned hydrocarbon gas, merely prevent oxidation at sintering temperatures.



In the case of sintered steels, a second consideration during sintering is the maintenance of the desired carbon level. Low levels of oxygen, CO_2 and water vapor insure against decarburization.

The composition of hydrocarbon gases may be controlled by varying the degree of combustion, which affects the moisture content and CO-CO_2 ratio. Oxygen and water vapor may also be removed by scrubbing and drying units before the atmosphere enters the furnace. Quantitative analysis is made of the various components of the atmosphere, as is frequent measurement of the dew point, which indicates the amount of moisture present. Thus we are assured of a controlled atmosphere of correct composition in contact with the parts.

Sintering is performed in continuous furnaces. Parts placed in the front end enter the heating chamber and after sintering is completed move into a water jacketed cooling zone without leaving the protective atmosphere. When cool they are removed from the back end. The ends are sealed off by doors, or flame curtains so that air cannot enter to oxidize the work.



DESIGN PRINCIPLES OF A PUSHER TYPE FURNACE

I. QUALITY CONTROL


Fig. 24


Fig. 25

We have emphasized that quality control of the final product begins with the powder manufacturer. We continue this effort by performing extensive testing of incoming powder ourselves. If the powder does not have the proper sintering and pressing characteristics, the lot is rejected.

The other aspect of quality control which is performed prior to sintering is a check on the green or unsintered density of the part. The importance of density has been described in detail under the section on pressing, page 18

If the previous measures may be called process quality control, the product quality control begins after sintering. This is the first point in the production process at which a part is produced which could be considered finished.

The manufacturing process, which includes careful design of tooling, selection and control of alloy, and pressed green density, is planned so that the optimum part characteristics are achieved with close control of dimensions.

A separate inspection department is maintained for the purpose of assuring the dimensional accuracy of all pieces which we ship.

Our equipment for dimensional inspection includes precision gage blocks, dial bore gages, an electro limit gage, and a comparator, as well as standard measuring equipment such as micrometers, plug gages, dial indicators and surface plates. Frequent calibration of these devices is performed by the inspection department or outside sources. Samples are withdrawn from various stages of the manufacturing process, including sintering, sizing and machining, as well as from the completed parts ready for shipment.

The sampling plan for inspection is designed for the particular Acceptable Quality Level (AQL) of the customer. The required AQL on each critical dimension should be indicated in the request for quotation and in the purchase order. The amount of inspection required will be reflected in the price of the parts.

Strength of materials

The best test of the overall strength and sintering of a particular part is a destructive break test. The required breaking strength is either agreed upon with the customer, or is left to our discretion. The ASTM Radial crushing strength is often used for cylindrical shapes. On setting up specifications, 30 to 100 pieces of the first production lot should be broken by a test mutually agreeable to us and the customer. If this production lot performs satisfactorily in application, the breaking strengths are used to set up a sampling plan for checking strengths of future production lots. We routinely break an average of 0.1% of the production pieces which has proved a successful method of preventing field failures. We would be pleased to discuss the statistical methods of sampling plans in detail at the customer's convenience. Strength tests are performed on a dynamometer which measures with a precision of 2% of the applied load. The maximum load applied is either 1,000 or 10,000 pounds. Figure 26 shows the machine set up to measure the breaking strength of a production bearing.

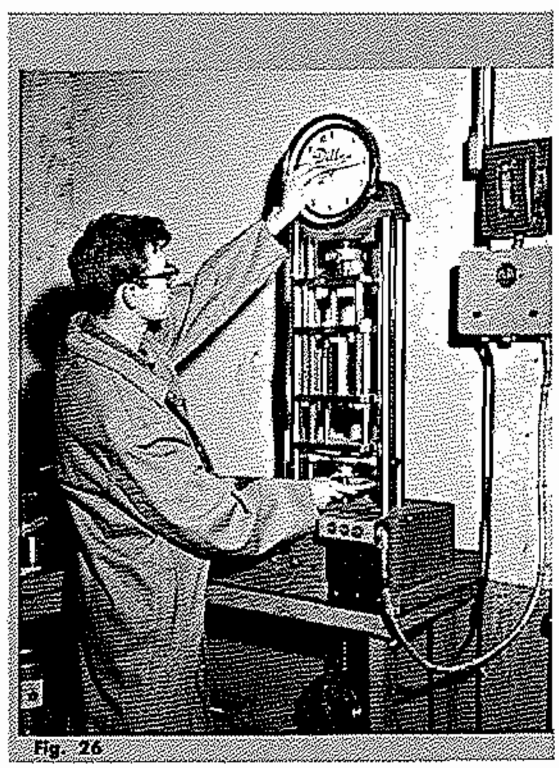


Fig. 26

Hardness testing is a quick method for evaluating the strength of sintered material. The hardness of the material, as measured by a Rockwell tester, depends upon the alloy, the density, and the condition of heat treatment. The customer should not set up a hardness specification based upon the hardness of a wrought material which has proved successful in his application. Ideally the customer should know the required tensile strength, elongation, and impact strength required and either let us recommend a material or choose a material himself from the extensive listing of physical properties beginning on page 63. If we have a material that meets the strength requirements, then the hardness of that material should be specified as a means of testing for strength.

If the customer specifies a hardness test, the pieces of the first acceptable production run can be checked for hardness. This data can be used to set up a sampling plan to assure required hardness and strength. If such a program of testing is anticipated, it should be mentioned in the request for quotation.

High hardness is often desirable for wear resistance, both to galling and abrasion. For wear resistance, the hardness of the individual particle is the determining factor. This microhardness or particle hardness is measured with a special machine, of the type made by Wilson, which is shown in Fig. 29. A polished metallurgical specimen is viewed at 400X magnification. A diamond point is then lowered at a controlled rate, under a fixed load (often 50g) onto a particular area of the surface. This diamond makes a small diamond shaped indentation in the surface, whose length is typically .001 - .002 inches for a hardened steel. A picture of one of these indentations is shown in Fig. 28. The length is measured to the nearest .1 micron (.000004 inches) and the result converted to Knoop hardness (or the equivalent Rockwell hardness). Typical values of microhardness for our products are given in the tables of physical properties beginning on page 63. If microhardness testing for quality assurance is desired it should be stated in the request for quotation and we will set up a sampling and testing plan. The microhardness of a part can often be related to macrohardness by measuring both on the same sample. This technique would allow an initial standardization of hardness by microhardness readings followed by an actual production control process of macrohardness testing (normal Rockwell testing).

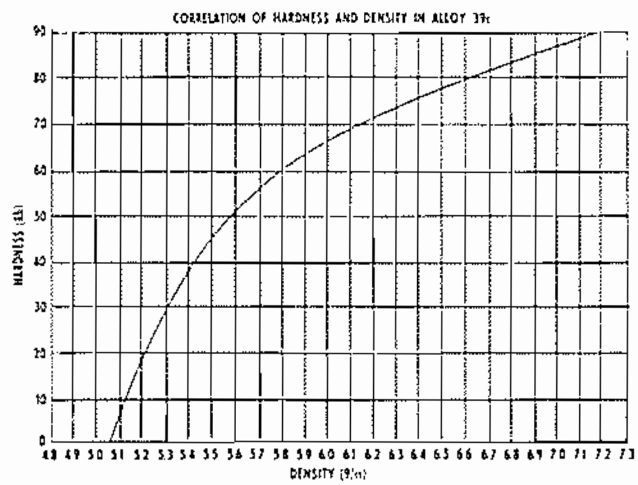


Fig. 27

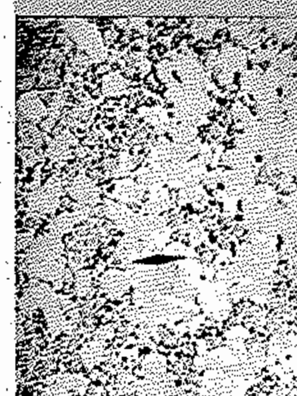


Figure 28
Microhardness
Indentor 75X

Figure 29
Microhardness
Testing
Apparatus

Metallography

We use metallography as a test of the quality of critical parts, but it is much more economical to do routine destructive break tests in determining the overall quality of sintering. Metallography is used in the initial stages of a production run to establish the best sintering practice. We maintain the standard metallographic facilities shown in Figure 30 for this purpose. If, during a production run, breaking tests indicate a problem in sintering, metallography then is used to find out what is wrong with the piece and what changes should be made in sintering practice. A recent development, however, has been routine metallography on all bronze in process.

The metallographic facilities are always available to answer customer questions about a specific part or to carry out research on new alloys and processes.

Fig. 30

J. FINISHING OPERATIONS : SIZING

The usual method of obtaining high dimensional accuracy in sintered parts is to repress them in a die whose dimensions are those of the final product. This operation, called sizing, slightly compresses the sintered piece and improves the surface finish. The compression into the sizing die tends to work harden the surface of the piece and increase wear resistance.

The sizing operation does not close the surface pores as a machining operation might. For comparison, Figs. 31 and 32 show pictures of the surface of a part after sizing and after machining.

The dimensional accuracy to be obtained from sizing is excellent, typically a total of .001" per inch of cross section, and .010" per inch of length.

The sizing operation and sizing presses are shown in Figs. 33 and 34. Some alloys change dimensions so greatly on sintering that two sets of tools are necessary, one for compacting and one for sizing. In practice, for those alloys that do change dimensions we make sizing tools to the print and compacting tools with dimensions compensated for growth or shrinkage in sintering, so that the part will be of approximately the proper dimensions after sintering. The finished dimensions are then obtained by sizing the parts in the set of tools which produce the dimensions required.

We can advise the customer before final selection of an alloy, whether his tolerances are such that one or two sets of tools are needed.

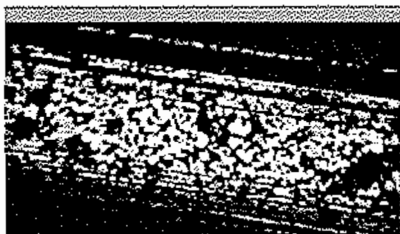


Fig. 31 — 60X, as sized

Fig. 32 — 60X, as machined

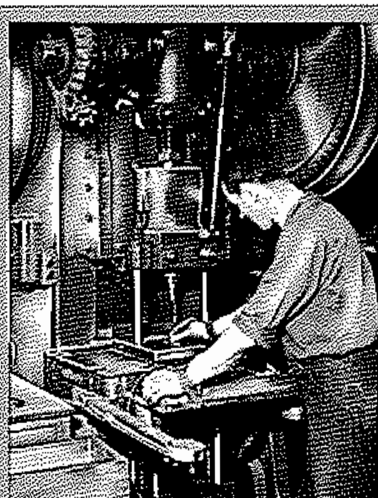


Fig. 33

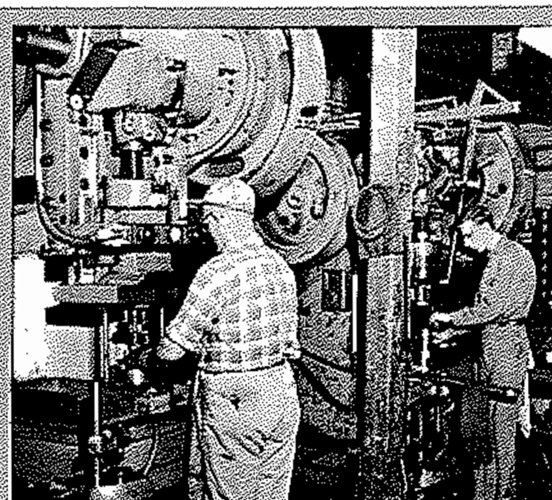
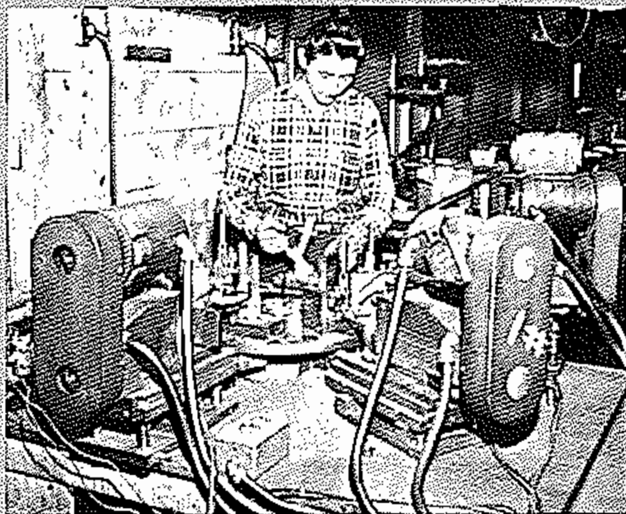
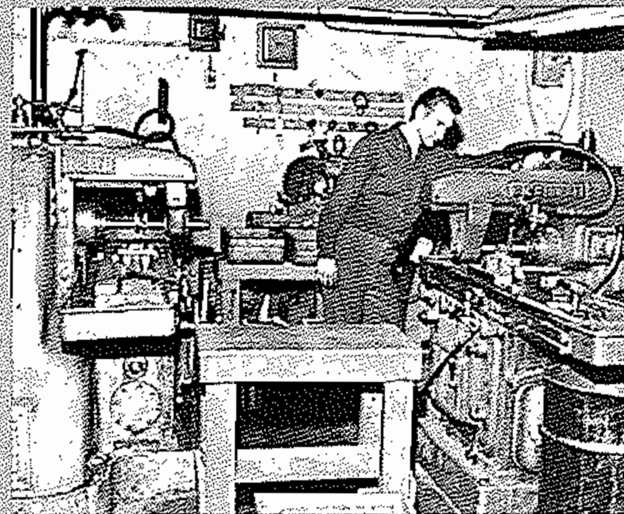
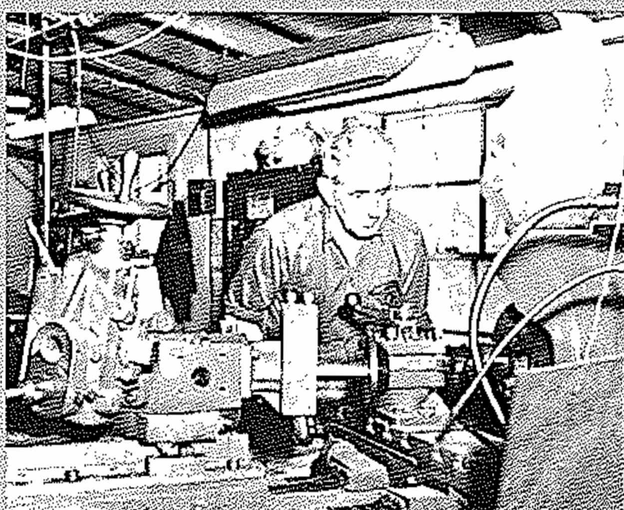


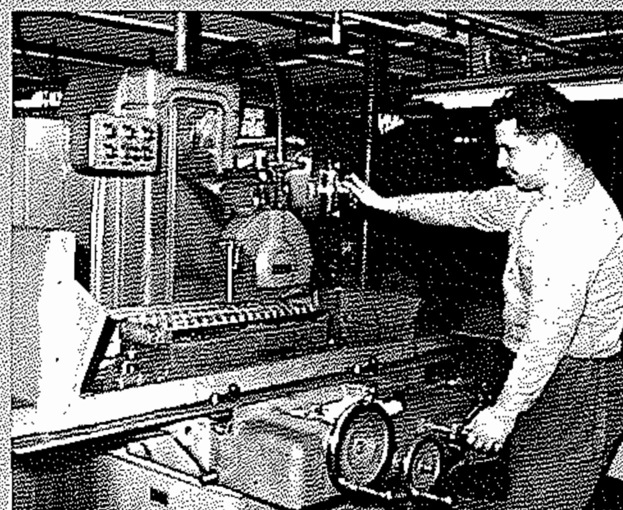
Fig. 34

Machining









The section on design illustrates how threads, undercuts etc. cannot be molded but must be machined.

Wakefield Bearing Corp. has many years of valuable experience in machining sintered parts.

We have recognized the fact that most customers do not wish to purchase a semi-finished part for reasons of economy and split responsibility. Therefore we have increased the capacity of our secondary machining facilities in milling, drilling, tapping, precision boring and grinding, to meet increasing demands for completed parts.

Heat treatments

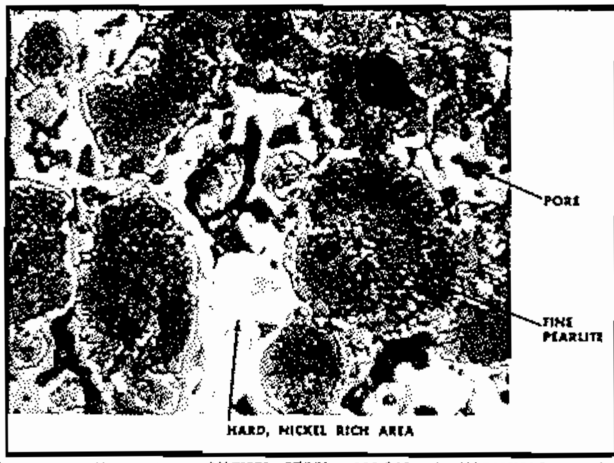


Fig. 35 — 200X NICKEL STEEL, ALLOY 39 SHOWING PEARLITE AND NICKEL RICH MARTENSITE

PACK CARBURIZING

The heat treatment of sintered steels is in general similar to that of wrought steels, but the exceptions to this general statement are extremely important. The customer who wishes to heat treat sintered material himself is referred to the special section on heat treatment on Page 56

Many of our nickel steels are partially air hardening, which means that in the "as sintered" condition, very hard areas of martensite will be encountered in the structure, Fig. 35 For some applications this condition is undesirable, especially when machining to finished configuration is necessary. In such cases we can supply parts in an annealed condition. The parts can be heat treated subsequently for high strength and hardness.

Hardening can be accomplished by the usual quenching and tempering methods for steels for increased strength, hardness and wear resistance.

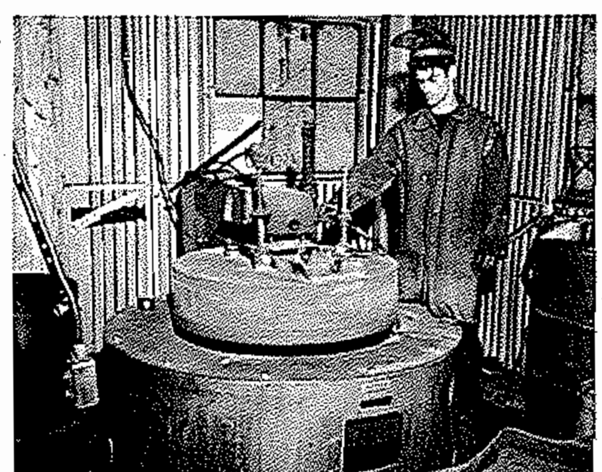
The hardness values obtained are equivalent to those of hardened steel on the microhardness test, however, the effect of density lowers values found by Rockwell or other macrohardness tests. A more detailed discussion of this point appears on Pages 18 and 60

The addition of carbon to a piece may be accomplished by gas carburizing. However, the carburizing gases are able to penetrate the pores in the material and reach the interior of the part as well as the outside surface. Unless a density of over 7.0 g/cc is used, no definite case will be obtained, since carbon pickup throughout the piece will occur. At extremely high densities (7.0+) it is possible to case carburize sintered material, but the depth of case is still sensitive to minor density fluctuations.

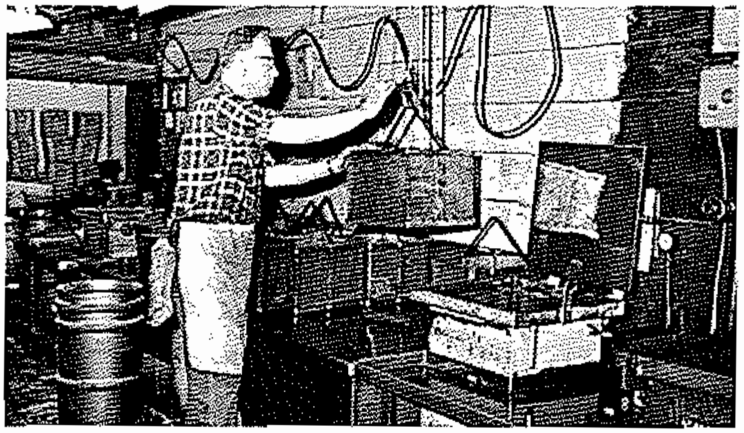
Some of the sintered steels with high copper content are suitable for an age hardening treatment, in which a fine dispersion of copper is precipitated from solution over a period of time at elevated temperature, resulting in higher strength and hardness.

Steam blackening

A black oxide steam finish Fe_3O_4 may be applied to ferrous sintered materials. This coating gives an attractive black matte finish and enhances corrosion resistance, tensile strength, and hardness. However, it does impair slightly some physical characteristics, such as machinability and ductility, so that our engineering staff should be consulted before it is specified.



Oil impregnation



Most powdered metal parts are porous to some degree. This porosity may be impregnated with oil for lubrication and corrosion protection.

At normal bearing densities (bronze 6.4-6.8 gm/cc, Iron 5.8-6.2 gm/cc) porosity is interconnected. Oil flows freely by capillary action throughout the structure and provides lubrication to bearing surfaces as the heat generated by friction causes the oil to thin and expand.

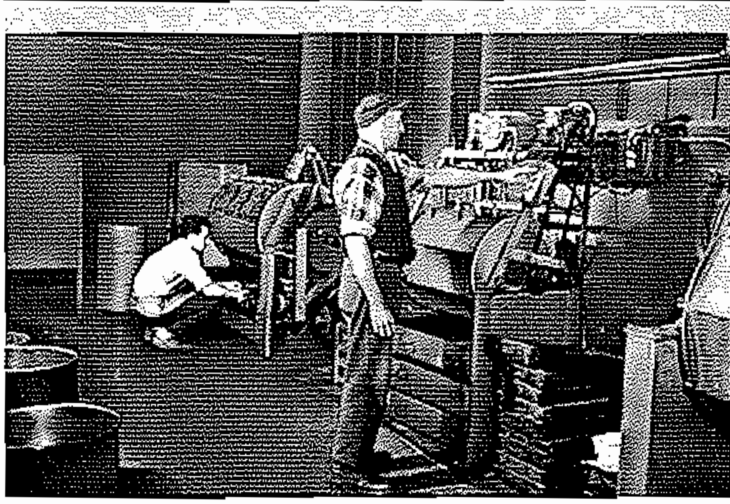
As densities approach 90% of theoretical, the interconnecting pores diminish in number and size so that complete oil impregnation becomes more difficult. As densities increase above 90% of theoretical, oil impregnation becomes unreliable and eventually impossible.

Our facilities for oil impregnation include several vacuum tanks in which parts are completely immersed in oil. The tanks are sealed, then a vacuum is drawn and held for several minutes until the air within the parts has been completely evacuated. On returning to atmospheric pressure, the oil surrounding the parts is forced into the interconnected pores.

Although our facility can easily accommodate and impregnate with any special oil at a customer's request, our standard oils include two viscosities; 300 and 600 sec. and are the highest quality, all purpose cylinder oils.

Percent oil content by volume of finished parts is checked in our laboratory prior to shipment as part of our in process inspection and quality control. Oil content is normally in the range of 20 to 25% for standard bearing densities but can be increased by lowering part density. For higher density materials the oil content is naturally lower. For customers wishing to test oil content of sintered materials, the standard method appears on pg. 51.

Barrel finishing



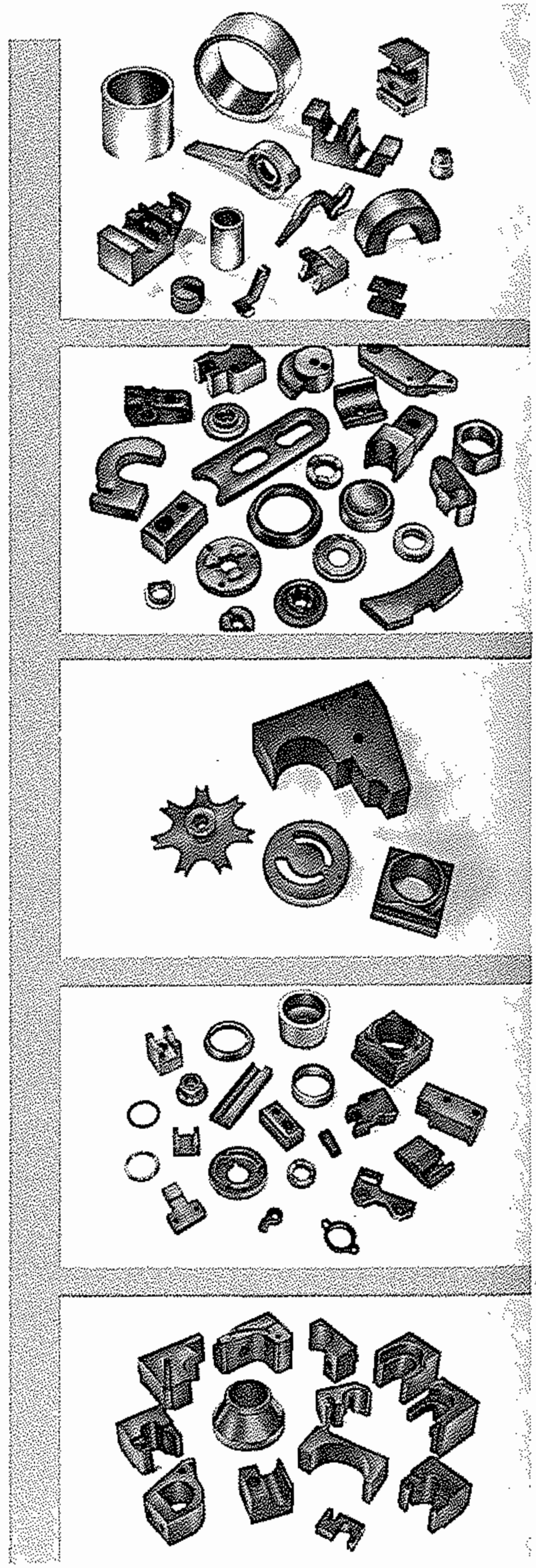
Barrel finishing is a frequently used method of deburring and rounding sharp edges of parts to assure proper fit and easy assembly. The appearance of parts which are exposed to view may also be improved. By selecting loads, speeds and media we are able to finish a part that is clean, free of burrs and flash, consistent in surface color and texture or, if required, polished.

Plating

Powder metal parts can also be finished by electroplating, providing that sufficiently high density parts are used to eliminate absorption of the plating liquid. Another device to avoid this difficulty is infiltration of parts before plating with copper, brass or plastic.

With the brief discussion of plating, we end the detailed description of the manufacturing of parts by power metallurgy. In the following pages we will discuss specific structural parts and bearings which we offer.

STRUCTURAL PARTS AND BEARINGS



Wakefield's specialty is the production of structural parts custom made for an individual application and often of geometry and materials unusual in powder metallurgy. Parts can range in size from less than a gram to eight or ten pounds each.

In ordinary metal working practice, complex shapes require many machining operations, each one a source of possible error and additional expense. But once a powder metal die is made and approved, the same parts are reproduced each time accurately and at less expense than by machining methods. Savings on quantities as low as 250-500 pieces are often enough to justify the purchase of tooling. Elsewhere (page 50) we have explained some of the limits on shapes, but many of these limits can be overcome by minor changes in part design, or one or two simple machining operations. Often several components can be combined into one powder metal part at considerable saving.

Materials also are selected for the properties necessary for the specific job, leading to superior part performance. Many of our powder alloys have compositions and properties impossible to achieve in other materials. If necessary, new materials are developed for specific needs. Our engineering staff is always ready to design a "tailor made" part for your particular needs. Send us your requirements.

The capacity of sleeve bearings is rated in terms of the PV factor which is a measure of the load and speed at which the shaft or bearing operates.

P is the pressure on the bearing and is given by

$$P = \frac{\text{Load (lb)}}{\text{Length} \times \text{I.D.}} = \text{lb}/\text{in}^2$$

Length and I.D. are measured in inches.

V is the surface velocity in feet/min:

$$V = \frac{(\text{RPM}) \times (\text{I.D.}) \times \pi}{12''}$$

RPM = Revolutions per minute of shaft.

$$\text{Thus PV} = \frac{\text{Load} \times \text{RPM} \times \pi}{12 \times \text{length}} \qquad (1)$$

In principle, there is a PV value for a bearing for any given lifetime. This is shown graphically in Fig. 36.

For a given PV value, any combination of load and rpm may be used in Equation (1). If the load is chosen, Equation (1) may be solved for the speed in rpm:

$$\text{RPM} = \frac{(\text{PV}) \times 12 \times \text{length (inches)}}{\pi \times \text{load (lbs)}}$$

or the allowed load may be calculated from

$$\text{loads (lbs)} = \frac{(\text{PV}) \times 12 \times \text{length (inches)}}{\pi \times \text{RPM}}$$

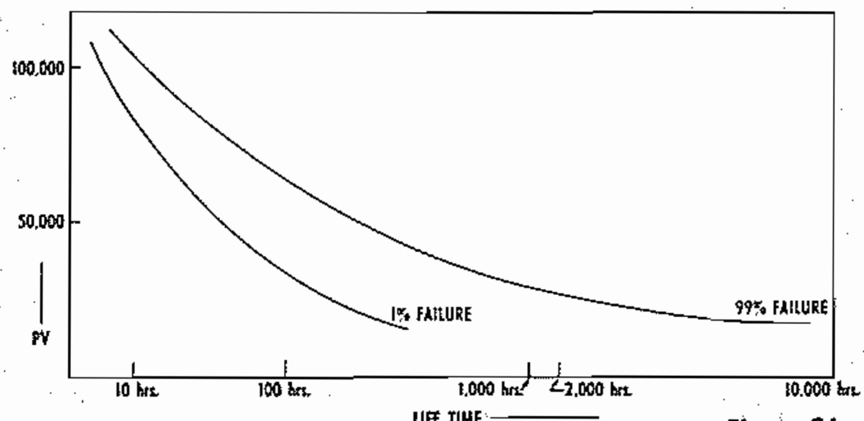


Figure 36

The range of loads and speeds that give a constant PV value is limited. Loads which exceed the elastic limit of the material are too high, whereas the maximum speed in rpm is uncertain. Most bearing tests are performed at 1750 rpm, but this is not the upper limit for speeds. Our laboratory is currently engaged in research into the nature of PV vs. life curves for various alloys, and at the same time, checking the limits of load and rpm that give a constant PV. We would be pleased to send test results as they become available to anyone who is interested.

For purposes of comparison, Table II, page 3 , contains a listing of various bearing materials and their PV values.

B. BEARINGS — ALLOYS

Wakefield Bearing offers more than twenty different bearing alloys. Many of them were developed to meet a particular customer need. We would be pleased to recommend one for your specific application or develop a new one if the circumstances warrant.

As a guide line to our bearings, alloys 14, 23, and 22 are 90-10 bronzes with 0, .5, and 2.5% graphite added. Graphite adds extra lubricating ability when the oil film breaks down under high loads. Tensile and compressive strengths are lowered by graphite, however, limiting the amounts which can be added. Each bearing represents a compromise between strength and lubrication.

Alloy 2 contains 4% MoS_2, a compound with a layered structure like graphite which aids considerably in boundary lubrication situations.

Iron base bearings are less expensive than bronze but offer higher strength and a PV value of about 35,000, compared to that of bronze at 50,000. Typical iron base alloys suitable as bearing materials are 19 and 28. Iron bearings are not as corrosion resistant as bronze.

Our alloy 58, iron with 1% Al_2O_3, has proved to be an outstanding bearing in laboratory testing. The wear resistance of this material is described on page 60. The aluminum oxide helps to prevent adhesive wear while resulting in only a limited amount of abrasive wear. The bearing has worked well in applications where fretting corrosion was previously a problem.

C. SPECIAL BEARING DESIGNS

In addition to conventional sleeve, flange and thrust bearings, we offer certain novel designs, covered by patents, which show improved performance.

The combination of oil impregnated wood, capable of retaining almost 50% lubricant by weight, and sintered bronze has been successful. In this case the metal is the load carrying member, while the wood acts as a lubricant reservoir. Various examples of this combination are shown in Fig. 37.

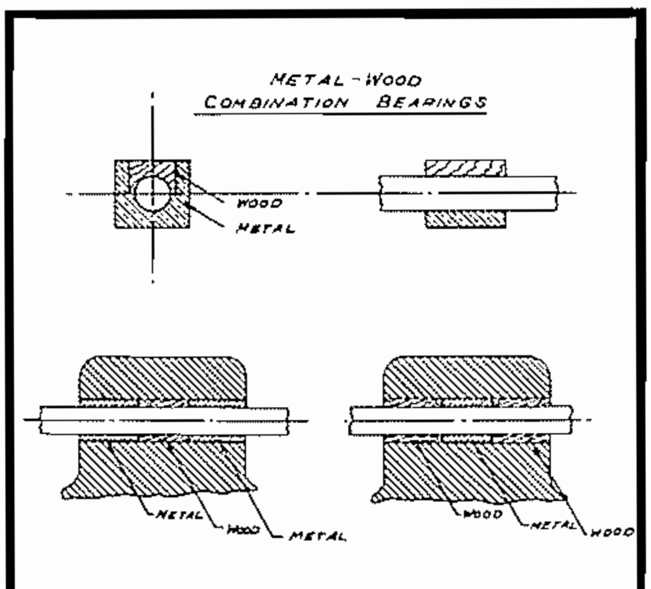


Fig. 37

Another successful design innovation is the placing of a groove in the I.D. of a bearing such that foreign material and gumming products of overheated oil are removed from the shaft and prevented from causing premature failure. This device has been successful especially in dirty or high heat situations at low torque values.

D. SINTERED SHAFTS

We have been actively investigating the bearing properties of a porous, oil containing sintered shaft. The usual objections raised against the shafts are strength, size limitations, and cost. Our strengths can be from 30,000 psi tensile strengths to over 100,000. By pressing at right angles to the axis of the shaft we can produce shafts up to three feet long and an inch or more in diameter. These rough pressings are then turned and ground to an excellent finish. The final cost is competitive with polished and ground alloy steel. Having dealt with the objections to shafts, let us next consider the many potential advantages.

1. Porous shafts allow oil impregnation in such quantities that a 1 x 6 inch shaft contains 11 times the oil in a 1" x 1¼" x 1" long sleeve bearing. The oil moves along inside the pores of the shaft and is emitted at the warm bearing surface.

2. The flow of oil from the shaft is aided by centrifugal force.

3. During periods of rest, the shaft will transfer oil to the mating porous bearing.

4. The shaft can contain inbedded solid lubricants such as WS_2, $Mo\ S_2$, graphite, or B N, Al_2O_3.

5. The shaft can be hollowed out to contain a reservoir of oil which is metered to the bearing surface through the pores.

6. A shaft can run against a solid housing without the need of an additional bearing in the housing.

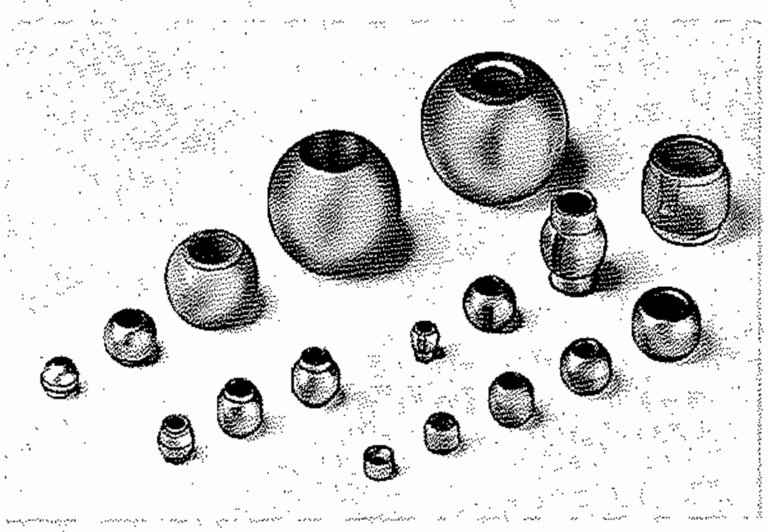
7. Shafts of alloy 39C will have the wear resistant nickel rich particles. Shafts of alloy 58A will have particles of Al_2O_3 which have high wear resistance and low coefficient of friction.

8. Loss of oil away from the bearing can be controlled by closing the pores in the shaft surface at that point.

9. Wider temperature ranges for operation could be produced by using two oils of different viscosities, one in the shaft, and one in a porous bearing.

Because of the novelty of the idea of a sintered shaft, and the many advantages noted above, we have applied for a patent on the shaft. We invite your inquiry about the use of sintered shafts in your products. We feel that there are many applications in which the sintered shaft will be superior to a solid one.

E. SPHERICAL BEARINGS



Spherical bearings are often the answer where alignment of two sleeve bearings would be troublesome or expensive. Since these bearings rotate in a spherical holder They are perfectly aligned with the shaft Perfect alignment coupled with the liquid and solid lubricants contained in the material results in a superior bearing system. Our spherical bearings have been used with notable success in fractional horsepower electric motors.

F. BEARING TOLERANCES

Standard and special bearings are held to the following tolerances:

BEARINGS	DIMENSIONS	TOLERANCES
Plain and Flanged Bearings	Inside and Outside Diameters	–.001" for bearings up to 1½" in ID. –.0015 for bearings 1½" to 2½" in ID. –.002" for bearings over 2½" in ID.
	Length	±.005 for bearings up to 1½" in length. ±.0075 for bearings over 1½" up to 3" in length. ±.010 for bearings over 3" in length.
All	Concentricity	.0015 (0.003" total indicator reading) for bearings up to 1½" in ID. Total reading can be .001 at slight additional cost. .002" (0.004" total indicator reading) for bearings over 1½" in ID.
Thrust Bearings	Inside Diameter	±.0015" for bearings up to 1¼" in ID. ±.005" for bearings over 1¼" in ID.
	Outside Diameter	±.005" for bearings up to 1½" in OD. ±.010" for bearings over 1½" in OD.
	Thickness	±.0025".

These tolerances represent the coined condition. If looser tolerances can be specified, the coining operation may be eliminated and, in any case, a lower cost will result.

G. PRESS FIT OF BEARINGS

When a sintered bearing is pressed into a housing, the degree of interference partly determines the amount that the I.D. closes in. The I.D. close-in also depends upon the wall thickness and the elastic strength of the bearing, and Youngs Modulus of the bearing and the housing. Thin wall bearings tend to close in more than thick wall.

Based on measurements of our own bearings we recommend the allowance for close-in shown in the accompanying table as a practical guide.

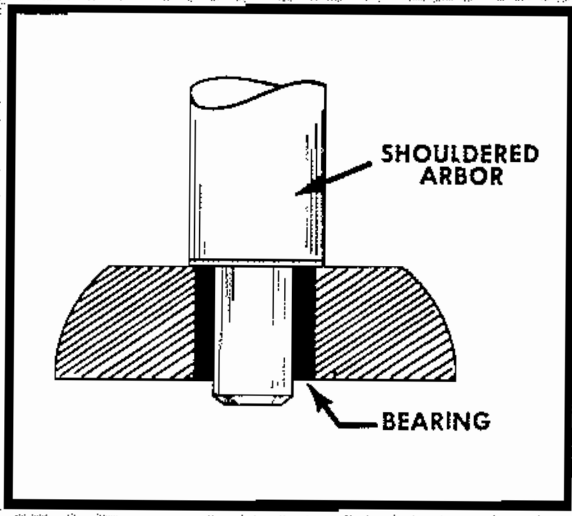
PRESS FIT

In general close-in is .0007 per .001" press fit.

OUTSIDE DIAMETER	PRESS	CLOSE IN I.D.
Up to .750"	.001 - .003"	.0006 - .002"
.750 - 1.500"	.0015 - .0035"	.001 - .002"
over 1.500"	.002 - .004"	.0015 - .003"

Variations in density or wall thickness will affect these figures slightly.

H. INSTALLING BEARINGS



Bearing should always be pressed into place with a shouldered arbor. The final I.D. of the installed bearing is determined by the type of arbor employed. If the arbor is smaller than the final I.D. of the bearing, the bearing will close in an amount determined by the degree of press fit as discussed on P. 37. If desired, the arbor can be .0003" bigger than the final size. As the bearing is inserted into its housing, the I.D. will be compressed against the arbor. Upon removal of the arbor the I.D. will close in about .0003". This procedure will give installed bearings with a high degree of concentricity and straightness.

Installed bearings can be bored or reamed but a very sharp carbide or diamond tool should be used. A slightly dull tool will close the surface porosity and prevent the appearance of lubricating oil. We would be pleased to furnish arbors, reamers, or burnishing tools with an order for bearings.

I. BEARING LUBRICATION

The majority of the bronze and iron bearings which we produce are impregnated with a high quantity 300 or 600 SUS turbine oil. This oil is strongly fortified with oxidation and corrosion inhibitors and will operate for very long periods of time at temperatures up to 180-200°F.

We have recently investigated a group of synthetic oils that promise to provide lubrication in the temperature range from 250-1000°F. We invite inquiries on applications in this temperature range because we would like further evidence of the usefulness of these lubricants. It is interesting to note that although a bearing may have an overall temperature of 150°F, the interface temperature may locally approach 500°F or higher for short periods of time. This effect can cause deterioration of oils that are not oxidation resistant at high temperatures.

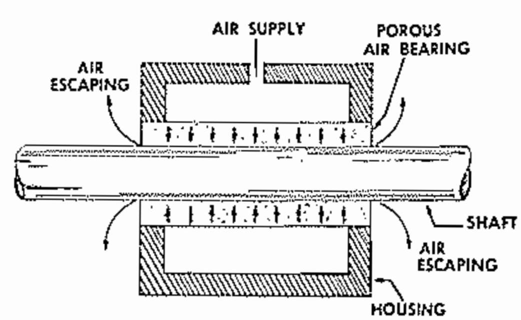
In addition to liquid petroleum or silicone lubricants we offer a wide range of solid lubricants for use under conditions of boundary lubrication, including graphite, MoS_2, WS_2, and Al_2O_3. We are now investigating additions of Boron Nitride for high temperatures or severe conditions of lubrication.

We do not claim that our bearings never require oiling. It is true, though, that at lower speeds and loads, the bearings often will run longer than the lifetime of the equipment in which they are installed without additional lubrication. In our testing, we run bearings without additional lubrication until they fail. We are in the process of determining how long a given alloy will run at various PV values. This information should be of considerable use in future design work.

J. AIR BEARINGS

It is possible to direct an air flow at a shaft by means of the interconnected porosity of a sintered bearing of a low density, or a filter material. A uniform air pressure distribution is created around the shaft as shown in Fig. 38.

At very high speeds a form of hydrodynamic lubrication exists, while the air pressure tends to create hydrostatic lubrication at all speeds. Inquiries are invited concerning the development of these bearings. We would be pleased to supply sample bearings to the customer's design for such experimental development.



POTENTIAL USE OF POROUS MATERIAL IN AN AIR BEARING

Fig. 38

K. STANDARD BEARING SIZES

The following list represents the tooling which we maintain to produce standard sizes of bearings. Orders for these bearings are filled without tool charge.

Our inventory includes many special non-standard bearing tools as well, so that we may be able to supply your special bearing needs likewise without tool charge. Please send us your requirements. ASTM Standard sizes are indicated by a *

STANDARD SLEEVE BEARINGS

I.D. Nominal	I.D. Actual	O.D. Nominal	O.D. Actual	Any Length Up to
* 1/8	.127	3/16	.189	1/4
1/8	.127	7/32	.220	5/16
* 1/8	.127	1/4	.252	3/8
1/8	.127	5/16	.314	3/8
1/8	.127	3/8	.377	3/8
5/32	.158	7/32	.220	1/4
* 5/32	.158	1/4	.252	5/16
* 3/16	.189	1/4	.252	7/16
* 3/16	.189	5/16	.314	5/8
3/16	.189	3/8	.377	5/8
7/32	.220	5/16	.314	3/8
7/32	.220	7/16	.439	3/4
1/4	.252	5/16	.314	1/2
* 1/4	.252	3/8	.377	1
* 1/4	.252	7/16	.439	1
1/4	.252	1/2	.502	1
5/16	.314	3/8	.377	3/4
* 5/16	.314	7/16	.439	1
* 5/16	.314	1/2	.502	1
* 3/8	.377	1/2	.502	1-1/4
* 3/8	.377	9/16	.565	1-1/4
3/8	.377	5/8	.627	1-3/8
3/8	.377	11/16	.690	1-1/2
3/8	.377	3/4	.753	1-1/2
7/16	.439	9/16	.565	1
7/16	.439	5/8	.627	1-1/2
* 1/2	.502	5/8	.627	1-1/2
1/2	.502	11/16	.690	1-1/2
* 1/2	.502	3/4	.753	1-3/4
1/2	.502	13/16	.815	1-3/4
1/2	.502	7/8	.753	1-3/4
9/16	.565	11/16	.690	1-1/4
9/16	.565	3/4	.753	1-3/8
9/16	.565	13/16	.815	1-3/8
9/16	.565	7/8	.878	1-1/2
* 5/8	.627	3/4	.753	1-5/16

*ASTM Standard

STANDARD SLEEVE BEARINGS

I.D. Nominal	I.D. Actual	O.D. Nominal	O.D. Actual	Any Length Up to
5/8	.627	13/16	.815	1-5/16
• 5/8	.627	7/8	.878	2
5/8	.627	15/16	.940	2
5/8	.627	1	1.003	2
11/16	.690	13/16	.815	1
11/16	.690	7/8	.878	1-1/4
11/16	.690	15/16	.940	1-1/2
• 3/4	.753	7/8	.878	1-1/2
3/4	.753	15/16	.940	1-1/2
• 3/4	.753	1	1.003	2
3/4	.753	1-1/16	1.066	2
3/4	.753	1-1/8	1.128	2
3/4	.753	1-1/4	1.253	2
13/16	.815	1	1.003	1-3/4
7/8	.878	1	1.003	1-1/2
7/8	.878	1-1/16	1.066	1-1/2
7/8	.878	1-1/8	1.128	2
7/8	.878	1-1/4	1.253	2
15/16	.940	1-1/16	1.066	1-1/4
15/16	.940	1-3/16	1.191	1-1/2
15/16	.940	1-1/4	1.253	1-1/2
1	1.003	1-1/8	1.128	1-1/2
1	1.003	1-3/16	1.191	1-1/2
•1	1.003	1-1/4	1.253	1-3/4
1	1.003	1-5/16	1.316	2
•1	1.003	1-3/8	1.378	2
1	1.003	1-1/2	1.503	2
1-1/16	1.066	1-5/16	1.316	1-1/2
1-1/8	1.128	1-1/4	1.253	1-1/4
1-1/8	1.128	1-5/16	1.316	1-1/2
1-1/8	1.128	1-3/8	1.378	1-3/4
1-1/8	1.128	1-1/2	1.503	2
1-3/16	1.191	1-5/16	1.316	1-1/4
1-3/16	1.191	1-3/8	1.378	1-1/2
1-3/16	1.191	1-7/16	1.441	2
1-3/16	1.191	1-1/2	1.503	2

I.D. Nominal	I.D. Actual	O.D. Nominal	O.D. Actual	Any Length Up to
1-1/4	1.253	1-7/16	1.441	1-1/2
•1-1/4	1.253	1-1/2	1.503	1-3/4
1-1/4	1.253	1-9/16	1.566	2
•1-1/4	1.253	1-5/8	1.628	2
1-1/4	1.253	1-3/4	1.753	2
1-5/16	1.316	1-1/2	1.503	1-1/2
1-5/16	1.316	1-5/8	1.628	2
1-3/8	1.378	1-9/16	1.566	1-1/2
1-3/8	1.378	1-5/8	1.628	1-3/4
1-3/8	1.378	1-3/4	1.753	2
1-7/16	1.441	1-5/8	1.628	1-1/4
1-7/16	1.441	1-3/4	1.753	1-3/4
1-1/2	1.503	1-11/16	1.691	1
•1-1/2	1.503	1-3/4	1.753	2
1-1/2	1.503	1-13/16	1.816	2
•1-1/2	1.503	1-7/8	1.878	3
1-1/2	1.503	2	2.004	3
1-5/8	1.628	1-7/8	1.878	1-1/2
1-5/8	1.628	2	2.004	2
1-11/16	1.691	2-3/16	2.191	3
1-3/4	1.753	1-5/16	1.941	1-1/2
1-3/4	1.753	2	2.004	2
1-3/4	1.753	2-1/8	2.129	2-1/4
1-13/16	1.816	2-3/16	2.191	2
1-7/8	1.878	2-1/4	2.254	2
1-15/16	1.941	2-5/16	2.317	2
2	2.004	2-1/4	2.254	2
2	2.004	2-3/8	2.379	2-1/4
•2	2.004	2-1/2	2.504	3
2-1/4	2.254	2-5/8	2.629	2
2-1/4	2.254	2-3/4	2.754	3
2-3/8	2.379	2-3/4	2.754	3
•2-1/2	2.504	3	3.005	3
2-3/4	2.755	3-1/4	3.255	3
•3	3.005	3-1/2	3.505	3

*ASTM Standard

STANDARD FLANGE BEARINGS

I.D. Nominal	I.D. Actual	O.D. Nominal	O.D. Actual	Overall Length	Flange O.D.	Flange Length
1/8	.127	1/4	.252	1/4	5/16	1/16
3/16	.189	5/16	.314	3/8	7/16	1/16
3/16	.189	3/8	.377	3/8	7/16	1/16
1/4	.252	3/8	.377	1/2	1/2	1/16
1/4	.252	3/8	.377	1/2	15/32	1/16
1/4	.252	7/16	.439	1/2	1/2	1/16
1/4	.252	1/2	.502	1/2	5/8	1/16
5/16	.314	7/16	.439	1/2	9/16	1/16
5/16	.314	1/2	.502	1/2	9/16	1/16
3/8	.377	1/2	.502	1/2	5/8	1/16
3/8	.377	1/2	.502	1/2	5/8	3/32
3/8	.377	1/2	.502	1/2	3/4	3/32
3/8	.377	5/8	.627	5/8	7/8	1/16
7/16	.439	9/16	.565	1/2	11/16	1/16
7/16	.439	5/8	.627	5/8	7/8	1/8
1/2	.502	5/8	.627	3/4	31/32	3/32
1/2	.502	5/8	.627	3/4	3/4	3/32
1/2	.502	5/8	.627	1/2	7/8	1/16
1/2	.502	11/16	.690	3/4	31/32	3/32
1/2	.502	11/16	.690	1/2	13/16	1/16
1/2	.502	3/4	.753	3/4	15/16	1/8

*ASTM Standard

STANDARD FLANGE BEARINGS

I.D. Nominal	I.D. Actual	O.D. Nominal	O.D. Actual	Overall Length	Flange O.D.	Flange Length
5/8	.627	3/4	.753	3/4	1	3/32
5/8	.627	3/4	.753	1/2	7/8	1/16
5/8	.627	13/16	.815	3/4	1	1/8
5/8	.627	13/16	.815	3/4	1-1/4	1/8
5/8	.627	7/8	.878	3/4	1	1/8
3/4	.753	7/8	.878	1/2	1	1/16
3/4	.753	15/16	.940	3/4	1-1/8	3/32
3/4	.753	15/16	.940	3/4	1-5/16	1/8
3/4	.753	1	1.003	1	1-7/16	1/8
3/4	.753	1	1.003	1	1-1/2	1/8
3/4	.753	1	1.003	1	1-5/16	1/8
3/4	.753	1	1.003	1	1-1/8	1/8
3/4	.753	1-1/16	1.066	1	1-3/16	1/8
7/8	.878	1	1.003	1	1-1/4	1/8
7/8	.878	1-1/8	1.128	1	1-1/2	1/8
1	1.003	1-1/4	1.253	1	1-1/2	1/8
1	1.003	1-1/4	1.253	1	1-7/8	1/8
1	1.003	1-1/4	1.253	1	1-5/8	1/8
1	1.003	1-5/16	1.316	1-1/4	1-3/4	7/32
1	1.003	1-5/16	1.316	1-1/4	1-7/8	1/8
1	1.003	1-3/8	1.378	1-1/4	1-3/4	3/16
1-1/8	1.128	1-3/8	1.378	1-1/2	1-3/4	1/8
1-1/4	1.253	1-1/2	1.503	1-1/2	1-11/16	1/8

STANDARD THRUST WASHERS

I.D.	O.D.	Length
1/4	7/16	1/16
1/4	1/2	1/16
1/4	5/8	1/16
5/16	5/8	1/16
5/16	3/4	1/16
3/8	5/8	1/16
3/8	3/4	1/16 - 1/8
7/16	3/4	1/16
1/2	3/4	1/16
1/2	7/8	3/16
1/2	1	1/16 - 1/8
9/16	1-1/4	1/16 - 1/8
5/8	1	1/16 - 1/8
5/8	1-3/16	1/16 - 1/8
5/8	1-1/4	1/16 - 1/8
5/8	1-1/2	1/16 - 1/8
3/4	1-1/4	1/16 - 1/8
3/4	1-3/8	1/16 - 1/4
3/4	1-9/16	3/32
3/4	1-3/4	1/16 - 1/8
7/8	1-1/2	1/16 - 1/8
7/8	2	1/8
7/8	2-1/8	1/8

I.D.	O.D.	Length
1	1-1/2	1/16 - 3/16
1	1-5/8	1/16 - 1/4
1	1-3/4	1/16 - 1/8
1	2	1/8 - 3/16
1	2-7/8	1/8
1-1/16	2-3/8	1/16 - 1/8
1-1/8	1-7/8	1/8
1-1/4	1-11/16	1/8
1-1/4	2	1/16 - 1/8
1-1/4	2-3/8	1/16 - 1/8
1-1/4	3-5/16	1/16 - 1/8
1-3/8	1-15/16	1/8
1-1/2	2	1/8
1-1/2	3-1/2	3/16
1-9/16	2-7/16	1/8
1-3/4	2-7/16	1/8
1-3/4	2-5/8	1/8
1-15/16	2-5/8	1/8
2	3	3/16 - 1/4
2	3-5/8	3/16
2-1/16	4	1/8 - 1/4
2-1/2	3-1/4	1/8
2-3/4	3-7/8	1/4

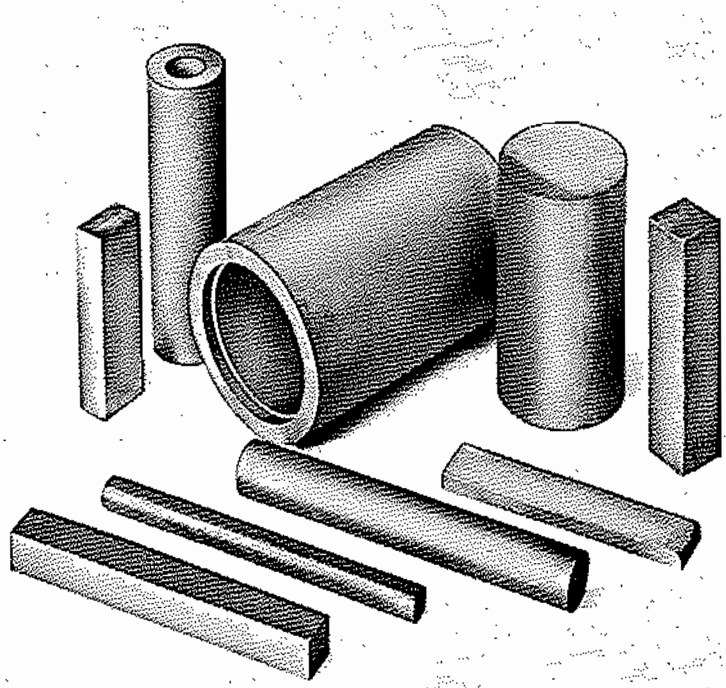
L. BAR STOCK

Wakefield Bearing Co., produces bar stock in all standard alloys as solid and cored bars of various sizes. This material is available from us or our distributors for immediate delivery off the shelf, which allows you to machine replacement parts, with minimum delay. Bar stock of unusual or special alloy or density can be made up in 24 hours. Machined bar stock is also used to test prototypes of new parts, although care must be taken that material of appropriate density is used, so that performance will be the same as that of a part pressed to shape.

Optimum machining techniques for powdered metal should be used in machining bar stock, to avoid smearing and closing off the oil retaining pores.

Refer to the section on machining p55.

All dimensions are oversize such that the stock will clean up to the nominal dimension upon turning.



CORED BAR STOCK

Will finish to dimensions shown

I.D.	O.D.	Length
1/2	1 1-1/8 1-1/4 1-1/2 2	6-1/2
5/8	1 1-1/8 1-1/4 1-1/2 1-3/4 2	
3/4	1-1/4 1-1/2 1-3/4 2 2-1/4 2-1/2 2-3/4	
7/8	1-3/8 1-1/2 2 2-1/4	
1	1-1/2 1-5/8 1-3/4 2 2-1/4 2-1/2 3	
1-1/4	1-3/4 2 2-1/4 2-1/2 3	
1-1/2	2 2-1/4 2-1/2 2-3/4 3 3-1/2 4	

I.D.	O.D.	Length
1-3/4	2-1/4 2-1/2 2-3/4 3 3-1/2	6-1/2
2	2-3/4 3 3-1/4 4 4-1/2	
2-1/4	3 3-1/4 3-1/2 3-3/4 4 4-1/2	
2-3/8	3 3-1/2 4 4-1/2	
2-1/2	3-1/2 3-3/4 4 4-1/4 4-1/2	
2-3/4	3-3/4	
3	3-3/4 4 4-1/2 5 6	
3-1/4	4-1/4	
3-1/2	4-3/4 5 6	
4	5-1/2 6	
4-1/2	5-1/2	
5	7	

M. SOLID BAR STOCK

Will finish to dimensions shown

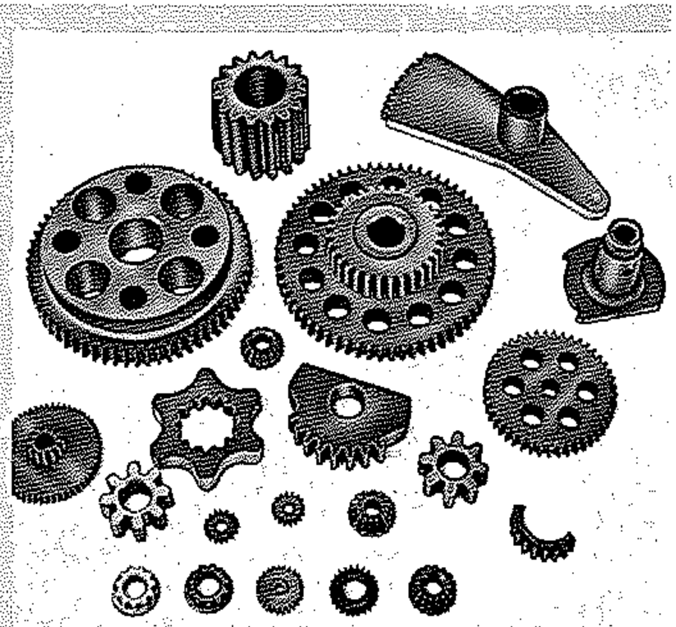
O.D.	Length
1/4	2
3/8	3
1/2	6-1/2
5/8	6-1/2
3/4	6-1/2
7/8	6-1/2

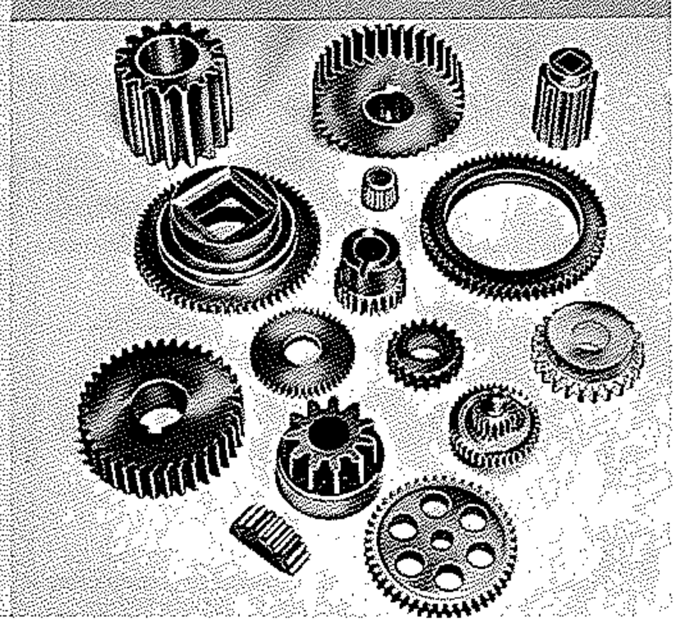
O.D.	Length
1	6-1/2
1-1/8	6-1/2
1-1/4	6-1/2
1-3/8	6-1/2
1-1/2	6-1/2
1-5/8	6-1/2

O.D.	Length
1-3/4	6-1/2
1-7/8	6-1/2
2	6-1/2
2-1/4	6-1/2
2-1/2	6-1/2
2-3/4	6-1/2

O.D.	Length
3	6-1/2
3-1/4	6-1/2
3-1/2	6-1/2
4	6-1/2

N. GEARS





Powdered metal gears are being used increasingly in various types of applications. They offer not only a cost saving, but often improved performance over cut gears.

The powder metal process makes possible design advantages not found in cut gears. Cluster gears can be made as a single piece, at considerable saving over machining and assembling two gears. A true involute tooth form, resulting in a stronger tooth, can be formed without the excessive undercuts produced by other methods. Tooth strength is also enhanced by designing the gear so that maximum density is obtained in the tooth root. Our Engineering Department should be consulted for help in designing gears especially for powdered metal.

Once design is established and tools are made, all gears produced are identical. This is especially important for special or non standard gears, as errors can creep in from lot to lot when they are cut from bar stock.

Tolerances on gears are specific to the individual job, due to design and material variations. In general, however, the following limits are maintained:

Outside diameter	.003", +.001" per inches diameter
Root diameter	.003", +.001" " " "
Measurement over wires	.002", +.001" " " "
Taper over wires	.001" per inch length
Involute profile 10 to 64 Pitch	.001"
Tooth to tooth error	
0 to 20 teeth	.0014"
20 or more	.0010"
Concentricity of I.D. to teeth	
up to 2" pitch diameter	.003 TIR
2" to 4" " "	.004 TIR
over 4" " "	.005 TIR

The properties necessary for satisfactory gear operation vary widely. Some applications have relatively low strength and wear requirements, and for these sintered metal offers a low cost and entirely satisfactory gear. In addition, our gears have recently begun replacing and out-performing cut steel gears in applications previously considered too severe for powdered metal. These gears are made from our high density nickel steel alloys, which offer good wear resistance combined with impact and fatigue strength. This combination of wear resistance and toughness is attributable to the partial air hardening of these nickel steel alloys.

Hard areas of martensite increase wearability, while softer pearlite contributes toughness. A microphotograph of this structure appears on p 31.

For situations in which impact loads exist, our #35 and 72 alloys, both of high density, offer a great improvement over other sintered steels. See page 58 for Tensile impact data.

On designing gears for powdered metal and selecting satisfactory materials for them, the dynamic and static loads on the gear tooth and the limit load for wear should be computed. The designer is referred to Professor Earle Buckingham's *Manual of Gear Design*, section two, pp 141-149 in which complete formulae and definitions are available. The formulae also appear in *Machinery's Hand Book*, pp 715-720, 13th edition. Our engineering staff will be happy to assist you in your gear design problems.

There are three material dependent factors necessary for the computation of the load carrying ability of a gear. For Dynamic Load the elastic modulus must be known. Table II shows elastic modulus values for Wakefield alloys most commonly used in gear applications. It will be observed that the values depend a great deal on density. In computing the Static Beam Strength of teeth, the safe static bending stress for the material is required. Values for this are given in Table III.

The Limit Load for Wear involves both elastic modulus and surface endurance limit of the material. These values appear in Table III.

O. REINFORCED GEARS

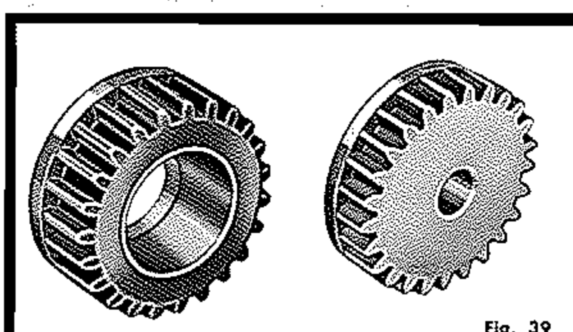


Fig. 39

The process of powder metallurgy offers a definite strength advantage in the production of a reinforced gear. The gear teeth can be made with an interconnecting reinforcing web as shown in Figure 39. This web could not be used in the standard gear cutting practice. Gears with left and right hand webs can be conveniently used in matched pairs. Depending on the ratio of gear thickness to the tooth length, we estimate an increased tooth loading of 50%.

MATERIAL PROPERTIES FOR GEAR DESIGN

TABLE I

Density	Elastic Modulus, psi × 10^6
7.6	26 × 10^6
7.5	25
7.4	23.8
7.3	22.7
7.2	21.5
7.1	20.5
7.0	19.5
6.9	18.5
6.8	17.6
6.7	16.7
6.6	15.9
6.5	15
6.4	14

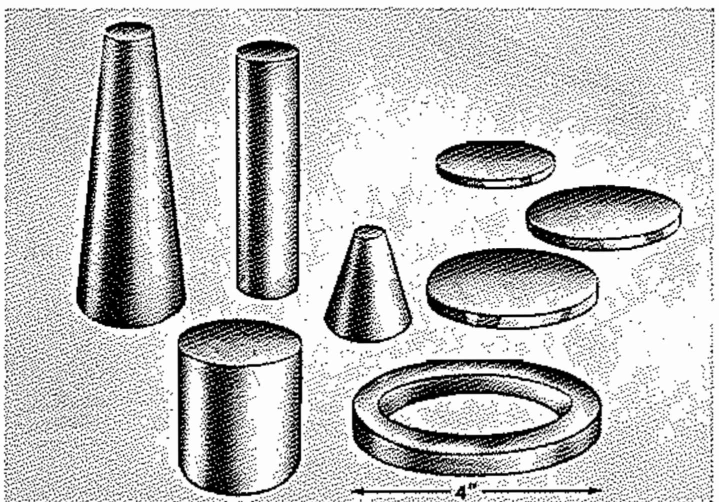
TABLE II

Alloy	Density gr/cc	Modulus × 10^6 psi
39c	6.5 - 6.9	15 - 18.5
65	6.7 - 7.2	16.7 - 21.5
72	7.2 - 7.5	21.5 - 25
35	6.9 - 7.3	18.5 - 22.7
61	6.4 - 6.8	14 - 17.6

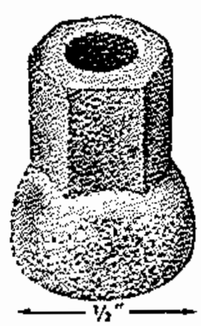
TABLE III
SAFE STATIC BENDING STRESS ST
AND SURFACE ENDURANCE LIMIT, SC

Alloy	St psi	Sc psi
39c	18000-31000	26000-40000
65	23000-44000	33000-65000
72	26000-60000	37000-90000
35	25000-37000	35000-54000
61	23000-33000	33000-47000

P. FILTERS



Actual size 4"



Actual size ½"

Sintered bronze and stainless steel filters can be used to remove particles from 5-100 microns or larger from a wide variety of fluids. Impurity particles are easily filtered from air, water, petroleum products, acids, or bases at high or low temperatures.

The metal particles that are used in making bronze filters are very small, perfect spheres, closely graded in size. The regular packing arrangement of these particles produces pores of regular and known dimensions. The filter will remove particles larger than the known pore size. Close control of filtering properties is possible with our wide range of filter grades available. By using table IV, to select filter materials, the customer can obtain the degree of filtration he requires.

Bronze Filter Grades and Particle Sized Removed

TABLE IV

Grade	Average Particle Size Removed (microns)*	Minimum Size Completely Removed (microns)*	Removed about 50% of Particles Coarser Than (microns)*
A	170	500	100
B	100	300	50
C	80	240	40
D	57	170	30
E	39	120	20
F	28	85	15
G	21	60	10
H	12	35	5

Our stainless steel filters are made from irregularly shaped powders which create a tortuous network through which the fluid must flow. Particles of a size larger than 5-10 microns are easily removed, in addition to which, many particles as small as .1 micron are also stopped.

Bronze filters are normally made by gravity sintering uncompacted spherical particles. Individual molds of graphite or stainless steel are filled with loose powder and passed through the sintering furnace. Because multiple tooling is required, filter designs should be kept simple. The advantage of the graphite tooling and a simple design is that filters can be easily and inexpensively made in our laboratory for your test and approval.

Stainless steel filters are made by a light pressing of the irregularly shaped powders in conventional powdered metal tooling. The density and particle size of the filter is adjusted to give the specified pressure drop and particle size removal.

Rather than present specific data charts and tables for calculating filter design, we would prefer to have the following information on the intended filter application submitted to our engineering department.

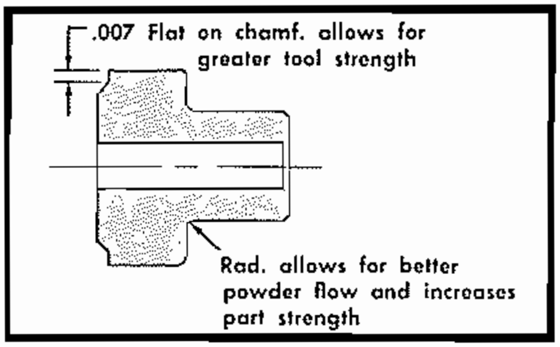
1. **Drawing of filter and structure into which filter will be assembled.**
2. **Type of fluid being filtered.**
3. **Operating temperature.**
4. **Allowable pressure drop.**
5. **Maximum rate of flow required.**
6. **Type of material to be removed, (gummy, solid, etc.)**
7. **Minimum particle size to be removed.**
8. **Number of pieces and delivery required.**
9. **Wide dimensional tolerances mean lower costs.**

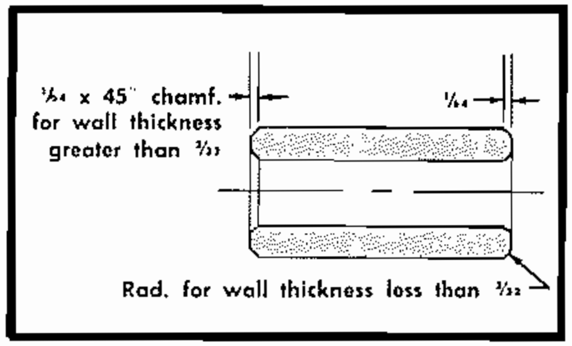
*25 microns = .001"

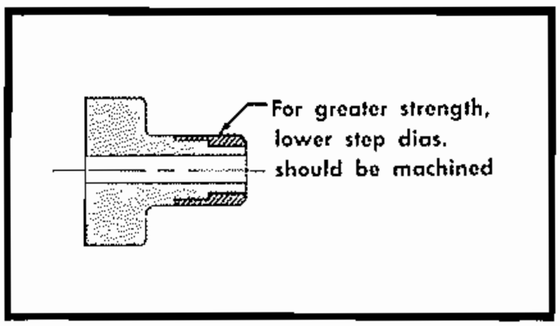
Q. DESIGNING FOR POWDER METALLURGY

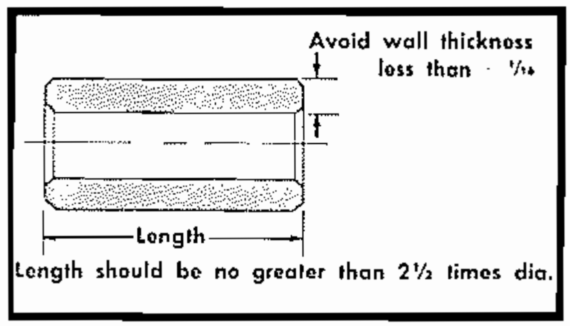
To derive the greatest benefits from the powdered metal process, both in cost and performance, the designer should observe the basic rules of powdered metal part design.

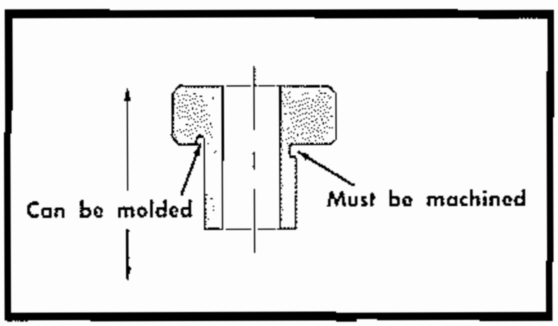
These rules insure better tool strength, higher part density and physical properties, uniformity, and reliability. The following sketches will be helpful.

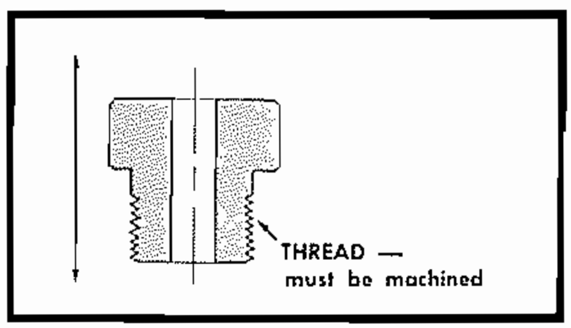


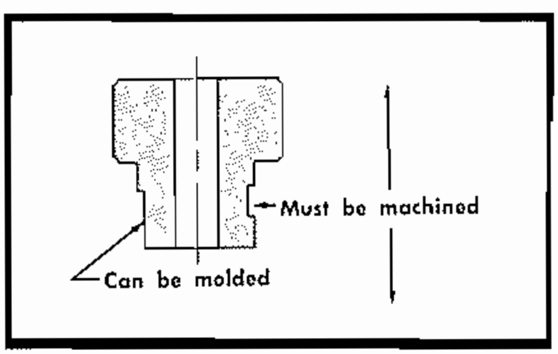


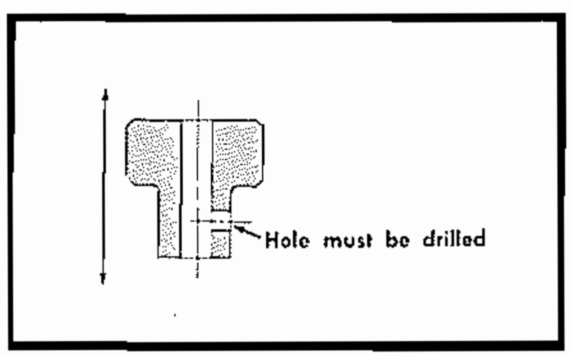












When pressure is applied to powder in the die cavity, the powder does not flow freely in all directions as would a liquid, but will move only in the pressing direction.

The die must be constructed to allow free movement in this direction. All sharp corners, and projections, restricting powder flow should be eliminated. Threads, undercuts, holes at right angles to the pressing direction can not be molded. However, they can be easily machined and the cost of machining a sintered blank is in many cases lower than other methods of manufacture.

In the above sketches the pressing direction is indicated by ↕

R. TOLERANCES

The following table gives general rules for the tolerances, which can be expected in powdered metal parts. For specific types of parts, such as bearings or gears, more detailed tolerances are published under the appropriate section in this catalog.

Cross section .... **.001 per inch**

Length .... **.010 per inch**

Center location
from hole to hole .... **.004 per inch**

These figures apply to parts finished by a sizing operation.

Depending on the configuration of the part, it may be possible to hold closer tolerances. Our engineering staff should be consulted before firm figures are set.

If cost is a factor, the designer should bear in mind that any relaxation of these tolerances may represent a substantial saving. Tools can be less expensive, and one set of tools may serve when ordinarily two would be necessary. Production rates can be accelerated, and even entire operations eliminated with no sacrifice in physical properties, if dimensional tolerances are broad.

PHYSICAL PROPERTIES OF SINTERED METALS

A. DENSITY AND OIL CONTENT

1. The density of a sintered metal product should be checked in accordance with the Metal Powder Industries Federation specification 8-50, "Acceptance Tests on Structural Parts Made from Metal Powders", or American Society for Testing Material specification B 328-60 "Density and Interconnected Porosity of Sintered Metal Structural Parts and Oil-Impregnated Bearings".

The density of a part may be calculated as follows:

$$D = \frac{A}{B-C}$$

where:

A = weight of the part in air in grams

B = weight of the part in air (after coating with a transparent lacquer) in grams.

C = weight of the part in water (as coated with the transparent lacquer) in grams

D = density in grams per cubic centimeter

We find in practice that it is usually not necessary to use the lacquer if the weight B is the weight of the sample after having been weighed in water and with the excess water drops wiped off. The steps involved in taking a sample density are illustrated in Fig. 40-41. On all samples, care should be exercised in making certain that no bubbles adhere to the sample surface. Ordinarily, the sample is supported on a thin thread or wire as shown. The thin thread does not cause noticeable inaccuracy on balances with a sensitivity of .01 gram.

A. DENSITY AND OIL CONTENT (cont.)

2. The measurement of available porosity or oil content is also described in the two specifications mentioned above. The percent by volume of the sample which represents porosity can be calculated from the relation:

$$P = \frac{B - A}{(B - C)S} \times 100$$

where:

A = weight of the *oil free* sample in grams

B = weight of the oil impregnated sample in grams

C = weight of the oil impregnated sample immersed in water.

P = intercommunicating porosity, by volume in percent

S = specific gravity of the impregnant at the temperature of the test.

The oil should be removed by the Soxhlet solvent extraction method. It may also be successfully removed by heating the parts for 10 minutes at 1450°F in a protective atmosphere.

The oil content is numerically equal to the volume percent of interconnected voids. Table V lists the oils that we regularly use for impregnating, and their specific gravities.

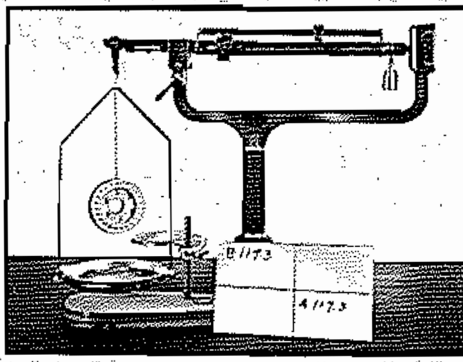


Fig. 40 — Density Checking

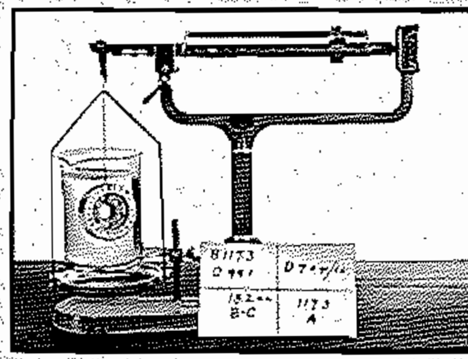


Fig. 41 — Density Checking

TABLE V

Oil	Specific Gravity
300SUS	.875
600SUS	.885

B. RADIAL CRUSH TEST

The Radial Crush test is described in M.P.I.F. specification 35-61 — "Materials Standard and Specification".

The Radial Crush is a strength test that can be applied to cylindrical bushings and bearings. The bearing is compressed between two flat platens as shown in Fig.42. The load, P, at which the bearing first cracks is called the Radial Crushing Strength. This load may be determined from the dimensions of the bearing and a factor K, called the strength constant:

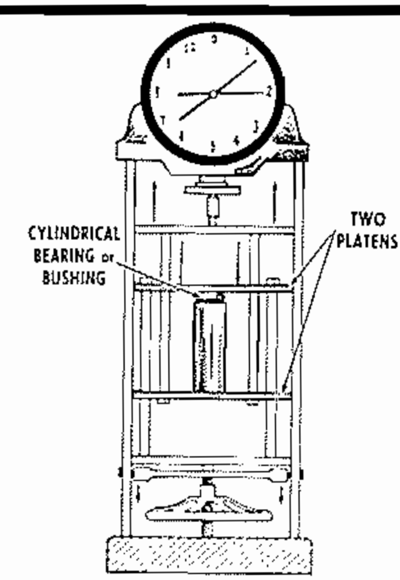


Fig. 42

COMPRESSION TESTING A CYLINDRICAL BEARING

B. RADIAL CRUSH TEST (cont.)

$$P = \frac{KLT^2}{D-T}$$

P=radial crushing load, pounds

D=outside diameter of bearing in inches

T=wall thickness of the bearing, in inches

L=length of the bearing, in inches

K=strength constant, pounds/in²

The strength constant is approximately related to the tensile strength as follows:

K psi = 1.87 Tensile Strength (psi)

In this way, strength constants can be determined from the tensile strengths given in the table of physical properties beginning on page 63. They are also specified in MPIF and ASTM standards.

C. EMPIRICAL STRENGTH TESTS

The best method for handling the inspection of overall sintered quality is the empirical strength test. In a preproduction program we produce enough parts for the customer to evaluate by life test or other means and also set up a destructive strength test. A fixture suitable for breaking the particular part is constructed and at least 30 pieces are broken. From this sample, control limits for production are established by graphical technique on probability paper. Sampling of subsequent production lots by us or the customer should yield parts with breaking strengths greater than the minimum, giving a high degree of assurance that these production pieces are as strong as those that proved successful in the preproduction run. Even if life testing of a preproduction lot is impossible, measurements taken on the first production lot that is successful in the field will allow continued control of production and satisfactory performance.

D. HARDNESS TESTING

Hardness testing may be used as a substitute for an empirical strength test or as a test of the wear resistance of a thin, hard case. Hardness ranges that are to be used for acceptance sampling should be determined as described above for the empirical crushing strengths. That is, the hardnesses on the first successful production lot should be used to set up standards for subsequent production and acceptance. The values of the hardness given in the tables of physical properties beginning on page 64 may be used as a guide to the hardnesses to be expected. In general, the customer should choose the alloy for tensile strength and use our value of hardness as a test for that tensile strength.

A more detailed discussion of hardness testing was given on page 28.

Hardness values are measured on a macroscopic scale with the series of testing machines that employ the Rockwell scale. The ASTM specification B-347-59T is appropriate, even though directed specifically at friction materials.

Case hardening by carburizing or nitriding should properly be evaluated with a microhardness tester. The general operation of such a machine was explained on page 28. It is very likely that we can relate microhardness to Rockwell A or superficial hardness and to the service life on a given part. Thus, the first few production pieces could be checked by microhardness and Rockwell A testing to ascertain what value of Rockwell A should constitute acceptable hardness of production pieces.

E. METALLOGRAPHY

Metallography can be used both as a tool for analysis of failure and for continuous production quality control or acceptance sampling. If the customer would like to perform metallographic examination, we recommend the following procedure.

1. Extract all oil from the sample by a solvent or heating in protective atmosphere. Retained oil makes examination difficult because it flows from the pores and causes spots on the polished surface. These spots can, however, be temporarily removed with alcohol.

2. Mount sample in Bakelite if the sample is too small to hold while polishing.

3. Rough grind, preferably wet, on an 80 mesh belt.

4. Finish grind on emery papers #1, 1/0, 2/0, 3/0 and 4/0 dry.

5. Polish on a rotating wheel, using Al_2O_3 1μ in water suspension. A Buehler Metlcloth is satisfactory.

6. Etch to remove smearing
   - A. Iron base — 5-10 seconds by swabbing in 2% Nital.
   - B. Copper base — 20 seconds in a solution of 5 parts NH_4OH 2 parts H_2O and 2-5 parts H_2O_2, by swabbing or immersion.

7. Final polish on Buehler microcloth with $.1\mu$ alumina in water.

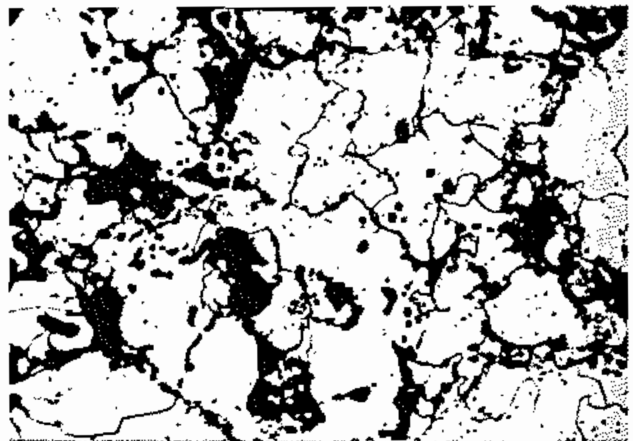
8. Etch lightly, 1-5 seconds, in solution of step 6.

9. Examine under suitable reflecting light (metallurgical) microscope (100-600X).

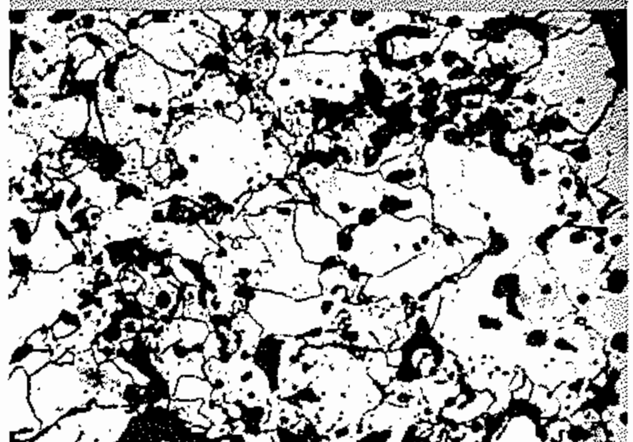
Many micro-photographs of properly and improperly sintered materials have been included in the catalog. Following is a list of such photographs for reference and comparisons: P 22, 23, 24, 31.

F. DIMENSIONAL INSPECTION

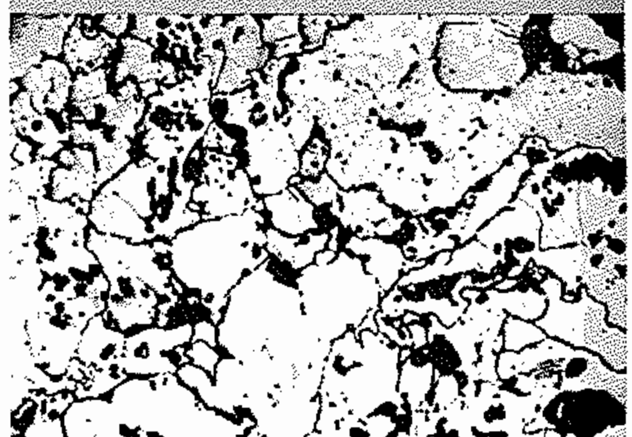
The best way to carry out dimensional inspection is described in MIL STD 105D on acceptance sampling. If the customer can specify an Acceptance Quality Level (AQL) in the request for quotation, we can set up our production inspection to guarantee this level. The low AQL required for the more critical parts will be reflected in the prices we are able to quote. It is economically advantageous for the customer not to request an AQL lower than is really needed for the part.



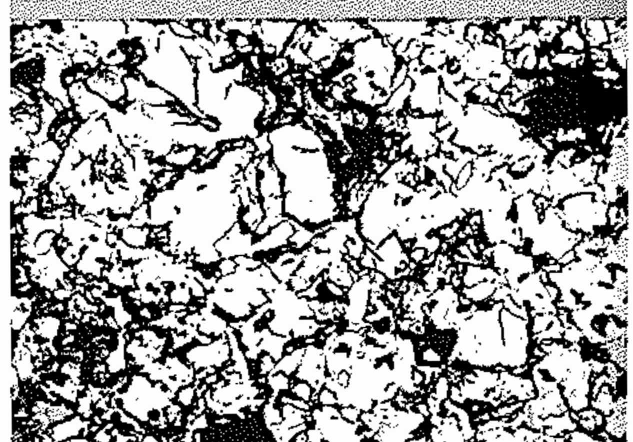
ALLOY 28 5 minutes at 1900°F Magnification 330X



ALLOY 28 45 minutes at 2050°F Magnification 330X



ALLOY 19 5 minutes at 1900°F Magnification 330X



ALLOY 19 45 minutes at 2050°F Magnification 330X

G. MACHINING

Machining practice for sintered materials is not greatly different from that used on the same material in wrought form. In general very sharp cutting tools are recommended, and to maintain their edge, they should be a good grade of carbide. The dead sharp edge is needed for two reasons:

1. In boring a bearing I.D., a dull tool will smear the metal and close the porosity thus preventing oil flow during operation.

2. In machining sintered steel, or even bronzes, the material is not perfectly homogeneous; that is there is porosity and variation in composition. Composition variations cause hard and soft spots whose effects are minimized by the sharp tool.

It is a simple matter to check for closure of porosity by examining the machined surface at 50-100X magnification or by observing a uniform oil film on the surface when heated to 150-200°F.

Finishing cuts should be made with a feed of .002-.005", a depth of cut of .002-.004 and a surface speed that depends on the material. Bronzes should be machined at 200-400 sfm and steels or irons at about 200.

Drilling can be done with high speed steel at 70 sfm or with carbide at 200 sfm. Care must be exercised on breaking through, in order to obtain a sharp edge on the hole.

If secondary machining is important in the production of a particular part, we are in a position to offer some alloys in an annealed condition which markedly increases the machinability. In addition we can improve machinability by increasing density and by alloy substitution. It is well to mention subsequent machining in your initial inquiry so that we can recommend an alloy with optimum machinability.

For reference, Figures 43 and 44 show the preferred tool design for high speed steel and carbide tooling.

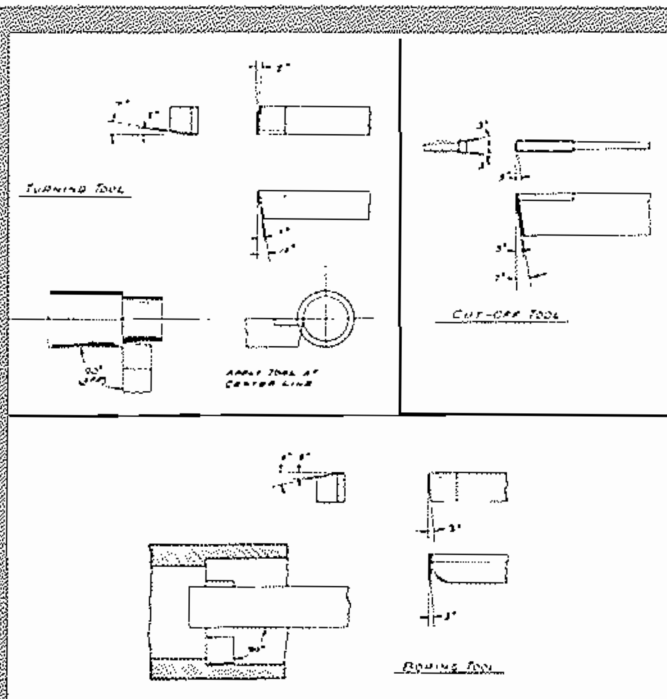


Fig. 43

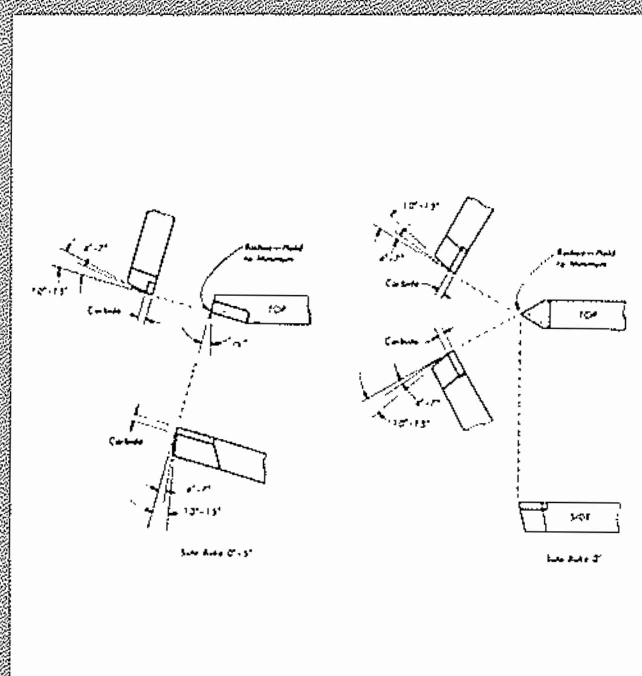


Fig. 44

H. RECOMMENDED HEAT TREATMENT PRACTICE

PURE IRON, CASE CARBURIZED 150X

Wakefield Sintered Steel alloys suitable for heat treatment include Nos. 39, 65, 72, 61.

The nickel steels of this group are partially air hardening and consequently have areas of martensite and bainite (see P. 31) in the sintered condition due to the cooling rate in the water jacketed cooling zone of the sintering furnaces. The advantage of such a structure is wear resistance, but a disadvantage is that machining is made difficult by these hard spots. If machining is difficult the parts may easily be annealed. The most successful cycle consists of holding the parts at 1500°-1550°F for an hour, followed by a slow furnace cool either to room temperature or to 1200°-1300°F, at which point they may be rapidly cooled to room temperature. Care must be taken to protect the pieces with a non-oxidizing atmosphere throughout the cycle. Most customers prefer to have us supply the parts in the annealed condition, thereby avoiding this additional step in their own processing.

Ferrous sintered materials may be carburized for increased hardness and strength. This must be accomplished by a carburizing gas or a solid carburizing pack, as a liquid medium could enter the pores of the part and create problems in cleaning. Parts are held at 1700°F for various time cycles, depending on the degree of carburization desired (typically 1-2 hours).

In massive steels, carburization implies the formation of a high carbon case on a core of softer steel. However, this is often not the result of carburizing sintered material. The important factor is, again, density.

At densities below 7.0 g/cc porosity is mostly interconnected and open to the surface. Therefore, the carburizing gases can penetrate into the interior of the piece, resulting in the diffusion of carbon into the interior of the part as well into the outer surface. Carbon is distributed evenly throughout the parts, and no case results. At densities above 7.0, porosity is no longer interconnected completely, so that gas cannot penetrate throughout the piece. A case can then be formed. However, the depth of case is extremely sensitive to the density, as the few remaining surface pores allow carbon to penetrate more quickly as gas than it could by diffusing through the solid steel. Case depth depends on the combination of density and time of carburization, and must be determined by experimentation for the individual job. For this reason many customers prefer to leave this critical step in our hands.

Dimensional stability during carburization depends on density also, as the introduction of carbon throughout a part will cause more expansion than would a thin case. Again, the dimensional change can be determined for the density of the specific part. Due to minor density fluctuations within a part, however, tolerances should be as broad as possible.

Quench hardening of our steel alloys, whether carburized or in the sintered condition is most successfully accomplished by holding the work at 1550°F. for ½ hour and quenching into agitated oil at 140-275°F. Parts should be heated in a non-oxidizing atmosphere which is neutral to the carbon content of the parts. If possible they should be heated and quenched in racks to reduce the chance of distortion.

Quenching should be followed by a tempering treatment, usually for an hour. The temperature depends on the desired final properties of the part. If maximum hardness is necessary, a treatment at 400°F. increases toughness with the sacrifice of only one or two points of hardness. If, as is usually the case, an increase in tensile strength and toughness is the object of hardening, a tempering temperature of 750°F. will yield excellent results, although with some loss of hardness.

I. PLATING

The usual processes for plating non-porous metals can be applied to powder metal parts as well. However, care must be taken that there is no interconnected porosity within the part as the plating liquids may impregnate the part by capillary action and subsequently bleed out and destroy the plated finish.

Parts can be supplied by us in a condition suitable for plating, or the customer can have parts infiltrated with plastic before plating by his own shop or a local supplier, which will fill the open porosity satisfactorily.

J. TENSILE IMPACT TESTING

The impact strength of sintered materials is usually not presented with other physical property data. In the past, values have been low and would only serve to show the material in an unfavorable light. The question of impact strength cannot be avoided in the more severe applications of sintered steels for which we receive inquiries. For this reason we have measured the tensile impact strength of our sintered steels and compared them with familiar wrought materials. Tensile impact testing is described in ASTM Specification D1822-61T. The tensile bar specimen is gripped as shown in Fig.45 in a TMI machine (Fig.46). The pendulum carries the specimen down against an anvil. The trailing grip catches on the anvil while the forward grip continues on and breaks the specimen in tension. The energy in foot pounds is read directly on the upper scale. Data are normalized by dividing the energy to fracture by the cross section area.

In Table VI are presented the data on our best materials in several heat treated conditions. For ease of comparison, data on the wrought materials, cold rolled steel, stainless steel, copper, brass, and aluminum are also presented.

Note that our best materials, alloy 72 and annealed infiltrated iron, are in the same range of strength as copper, brass, and aluminum, which are certainly not brittle materials. Even our 39C alloy as sintered, with the relatively low impact strengths of 64 ft. lbs. has been used with tremendous success on a wide variety of gears and structural parts. The wide range of impact allows considerable latitude in material selection.

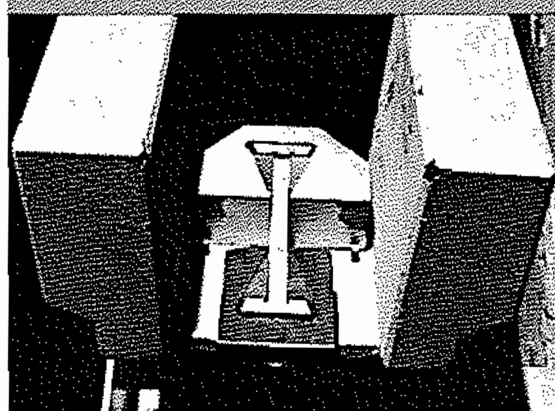


Fig. 45

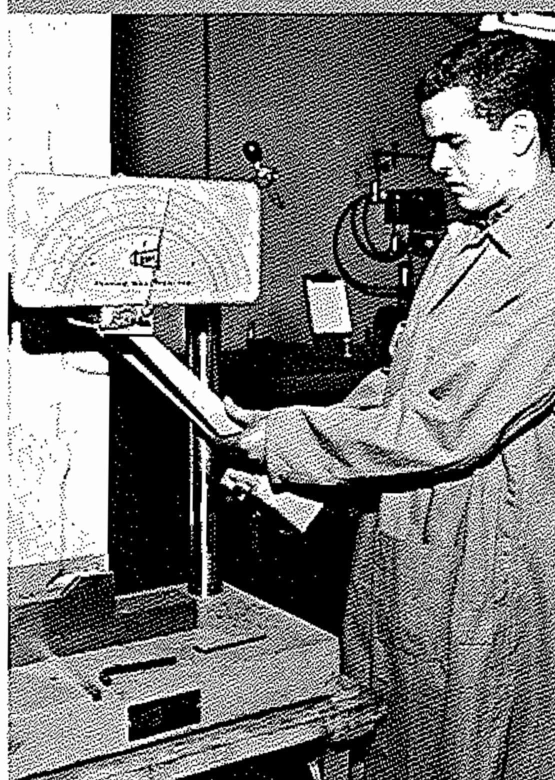


Fig. 46

TABLE VI
TENSILE IMPACT STRENGTH, SINTERED AND WROUGHT MATERIALS

SINTERED MATERIALS		Impact Strength Foot lbs./in.			
Alloy	Density g/cc	Sintered	Quenched	Quenched and Tempered	Annealed
39C	6.35	27	23	16	108
	6.83	64	45	37	161
58	6.34	0	27	20	54
	6.55	7.5	33	18	38
65	6.86	92	31	58	330
	7.01	210	25	360	555
72	7.06	550	24	405	315
	7.39	590	49	530	695
Infiltrated Iron	7.52	204	19	107	905

WROUGHT MATERIALS

wrought Materials	Impact Strength ft.-lb./in.
316 Stainless Steel	4600
Cold Rolled Steel	1905
Brass, half hard	1450
Copper	1280
Aluminum	805
Cast Iron (Grey)	45

K. WEAR RESISTANCE

There are two common forms of wear to be distinguished:

a. Adhesive wear
b. Abrasive wear

Adhesive wear results from the transfer of small pieces of metal from one surface to another. Two surfaces are always rough or hilly on a microscopic scale. As the hills collide during rubbing of the surfaces, lubricant or films are broken away and metal to metal contact occurs. On metal to metal contact, cold welding occurs. As these cold welds break when the surfaces move along, small pieces of metal are pulled out of one surface and adhere to the other. This sequence is illustrated in Fig. 47. The wear particle subsequently breaks loose from the new surface and is lost from the system.

It is interesting to note that one can make an estimate of the rate of adhesive wear. The formula which describes the volume of wear products formed is due to E. Rabinowicz and is:

$$V = \frac{K \times L \times l}{4260 \times P}$$

V = volume of wear products, (in^3)

K = wear coefficient, equals the probability that when two asperities collide, there will be a wear particle created

L = Load on one surface bearing on another (pounds)

l = length that one surface moves relative to the other (inches)

P = Knoop or Vickers hardness, kg/mm^2

The wear volume is independent of contact area because a larger area would spread the load and create less pressure at any one point.

Typical values of K are given in Table VII.

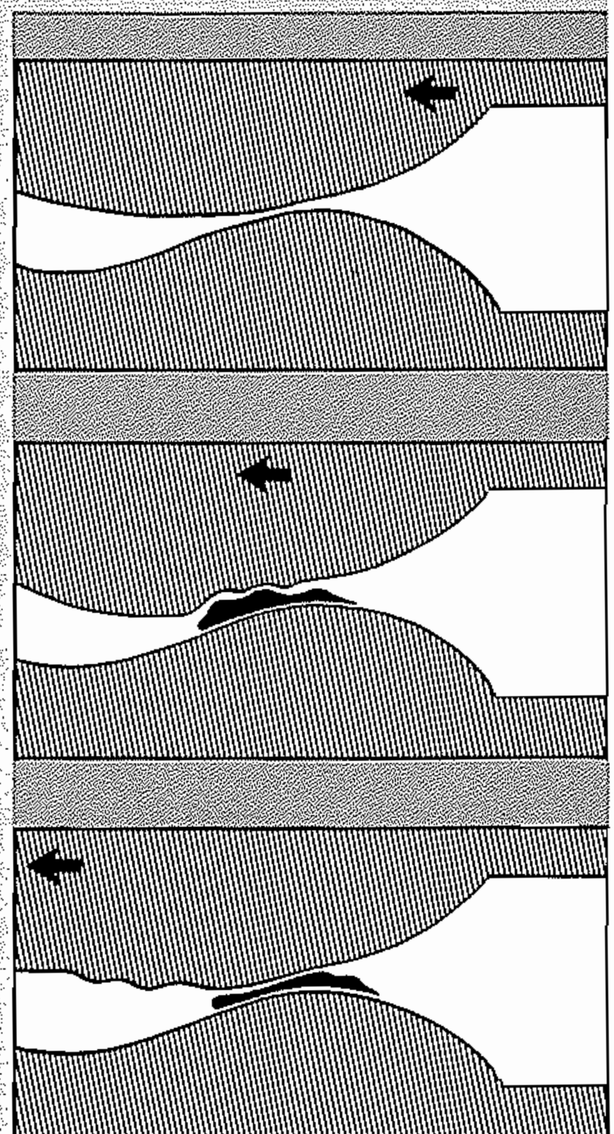


Fig. 47 — ADHESIVE WEAR

K. WEAR RESISTANCE (cont.)

TableVII, Values of K, the Wear Coefficient

Lubrication	Like Metals in Contact	Unlike Metals in Contact	Non metals in Contact
Clean Surfaces	5×10^{-3}	2×10^{-4}	5×10^{-6}
Poor lubrication	2×10^{-4}	10^{-4}	5×10^{-6}
Average lubrication	10^{-5}	10^{-5}	5×10^{-6}
Excellent lubrication	10^{-6}-10^{-7}	10^{-6}-10^{-7}	10^{-6}

In an automobile engine, the piston-cylinder system has a K of 10^{-7}. From the table we see that like materials give a very high wear rate when they are clean. (note, the best way to clean a metal is to abrade it lightly with dry, fine, emery paper). Non metals seem to have the edge under no lubrication" conditions. It must be remembered that P, the hardness, enters into the evaluation of material lost by wear. P for nylon is about 1/20 that of steel so that under conditions of average lubrication, the material loss for metal is less than for nylon, the higher K value of the metal notwithstanding.

What is meant by like metals or unlike metals with respect to the above table? Pure metals like Cu/Cu or Zn/Zn are examples of like metals that seize easily, and have a high K value. Most alloys act as unlike metals, even when bearing and journal are of the same alloy. Thus steel on steel is an acceptable combination with low K. Similarly brass/brass or bronze/bronze act as unlike metals. Apparently having two phases in an alloy helps it to act as "unlike" even toward itself. In carburizing or nitriding to form Fe_3C or iron nitride we get non metal constituents that help to make the steel act in the "unlike" manner toward itself. High hardness is helpful in adhesive wear resistance.

Abrasive wear results from sharp, hard particles plowing up the surfaces in contact and creating small chips or wear particles. This form of wear is illustrated in Fig. 48.

The rate of abrasive wear can be estimated by a formula similar to that for adhesive wear:

$$V = \frac{K \times L \times l}{6680 \times P}$$

The letters all have the same significance as for adhesive wear except that K has a new physical meaning. Here K equals the tangent of the angle A in Fig. 49.

If A is greater than 45°, K can be greater than 1. Typical values for K are given in Table VIII.

Table VIII

K values for Abrasive Wear

Application	K
Sharp File	0.1
Emery Paper	.01
Loose Particles	.001

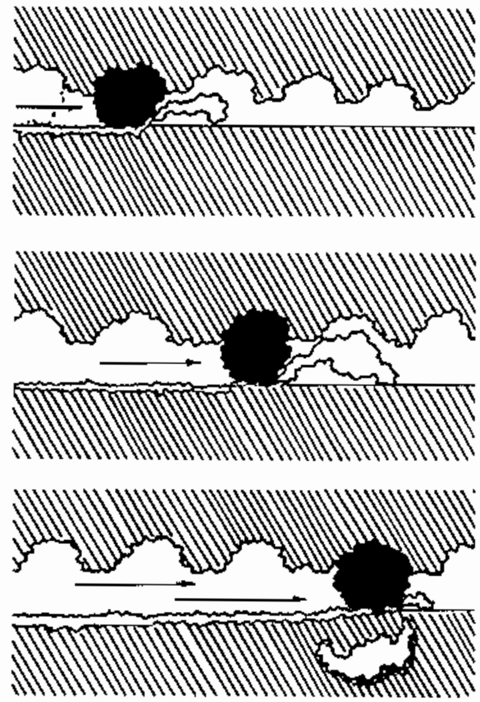


Fig. 48

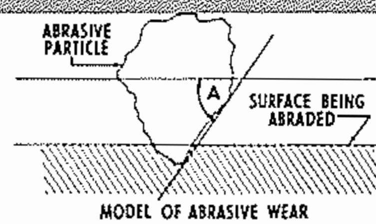
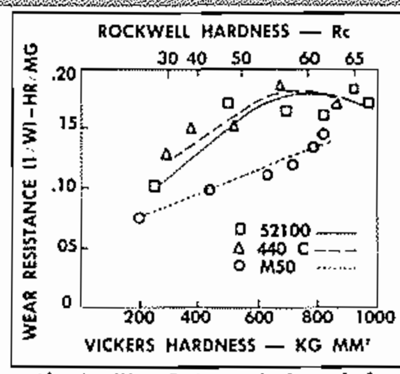


Fig. 49



Abrasive Wear Resistance (reciprocal of wear rate) as a Function of Hardness.

Fig. 50

Since K values tend to be much greater for abrasive wear than for adhesive wear, we try to eliminate abrasive wear first.

It is interesting to note that high hardness pays a diminishing return when attempting to combat abrasive wear. Figure 50 shows that increasing hardness from Rc 50 to Rc 65 does not decrease the wear rate very much. This result *does not* apply to adhesive wear, as was shown by Olson & Chapman (ASM Transactions Vol 53, P 359, 1961.) For adhesive wear, high hardness gives high wear resistance.

L. WEAR RESISTANCE OF ALLOY 58

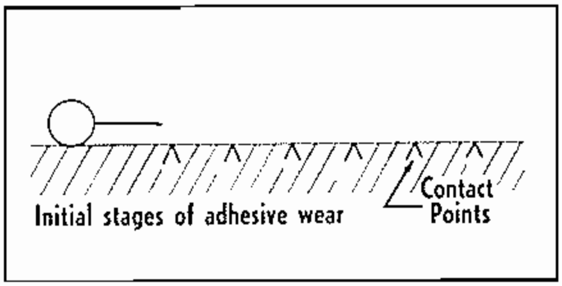


Fig. 51a.

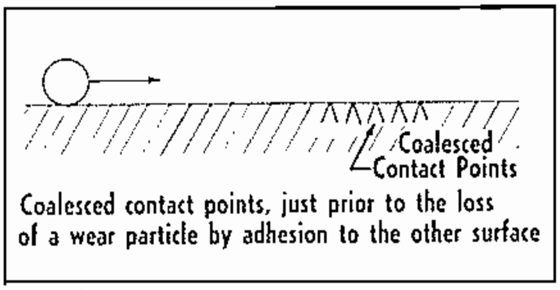


Fig. 51b.

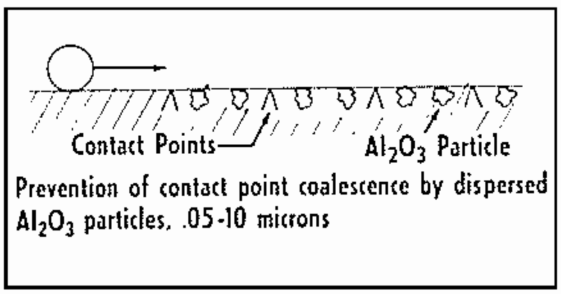


Fig. 51c.

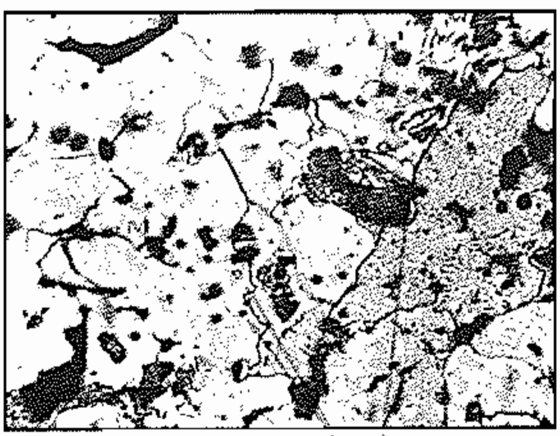


Fig. 52 — Alloy 58,300X Al_2O_3 pore

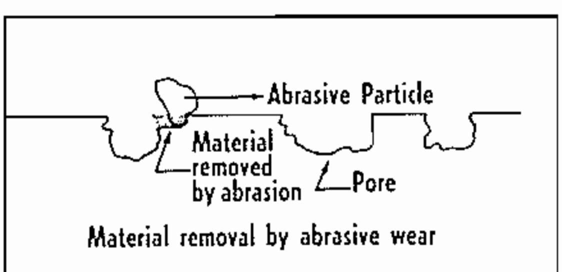


Fig. 53

Our alloy 58 is an iron matrix with fine Al_2O_3 particles included. The aluminum oxide may cause some abrasive wear, but the particles are so small that the wear rate is very low. The Al_2O_3 particles actually help prevent adhesive wear by the following mechanism. Initially in the interaction between two surfaces, the points of contact are evenly distributed over the surface. (Fig. 51a)

During continued motion, the contact points coalesce and form a region with many contact points. (Fig. 51b)

It is this coalesced contact point region which then can be transferred, as an adhesive wear particle, from one surface to the other. Apparently the Al_2O_3 particles in the matrix physically prevent coalescence. (Fig. 51c)

We thus reduce adhesive wear at the expense of a little abrasive wear. This would suggest that a combination of Al_2O_3 for adhesion prevention plus a hard, carbonitrided surface for abrasion resistance would be excellent for over-all wear resistance. A microphoto of alloy 58 at 300X is shown in Fig. 52.

Wear of a soft Bearing on a hard shaft.

One remedy for wear that has often been employed in the past is to use a soft bearing on a hard shaft. In principle the soft bearing will imbed any hard abrasive particles and remove them from the system so that no wear can occur. E. Rabinowicz stated at an ASM meeting October 3, 1963, that for this system to work successfully, the hard material must be five times as hard as the soft material. Both hardnesses should be measured on an absolute scale such as Vickers or Knoop, and not Rockwell C or B.

M. WEAR RESISTANCE AND HARDNESS

We maintain that microhardness is the best measure of resistance to wear for a porous surface. With microhardness testing one investigates the resistance to deformation of the matrix material itself and excludes the effect of porosity. For example, in considering resistance to abrasion, we are concerned with the plowing away of matrix material by a hard particle. There is nothing to be lost from voids on the surface. Wear by abrasion of a sintered porous surface is shown in Fig. 53.

We can then state that a surface with a microhardness of Rc 65 is as resistant to abrasion as a wrought material of the same hardness. For adhesive wear, which can be more greatly affected by hardness, the same considerations apply. We are not worried about loss of material from pores but only from the matrix.

N. EFFECT OF DENSITY ON ELASTIC MODULUS

We have only estimated the elastic modulus of powdered metal parts in our own laboratory. There is a very limited amount of data in the literature on this matter.

V. T. Morgan (Powder Metallurgy No. 12, P. 72, 1963) has measured the elastic modulus for iron. His data is given in Table IX.

TABLE IX
Youngs Modulus & Poisson's Ratio for Iron

Porosity %	Youngs Modulus lb/in² x 10⁶	Poisson's Ratio (± .02)
36	6	.20
29.8	10	.22
23.9	12.5	.23
18.2	14	.22
10.2	23	.25
00	30	

The value given for a 28% porosity, bronze material was 1.29 x 10⁶ psi.

This work is consistent with that of U. V. Skorokhod (ibid P. 188). He shows that the Youngs modulus goes to 0 at a porosity greater than 55%. This is probably only true for sintered powders, because foamed materials with 90% porosity have been produced which have a finite elastic modulus.

A graph showing existing data relating density to modulus is reproduced in Fig. 51 from Jones. (Fundamental Principals of Powder Metallurgy, P841). This can be used to obtain a modulus of elasticity for an iron base alloy whose density is known.

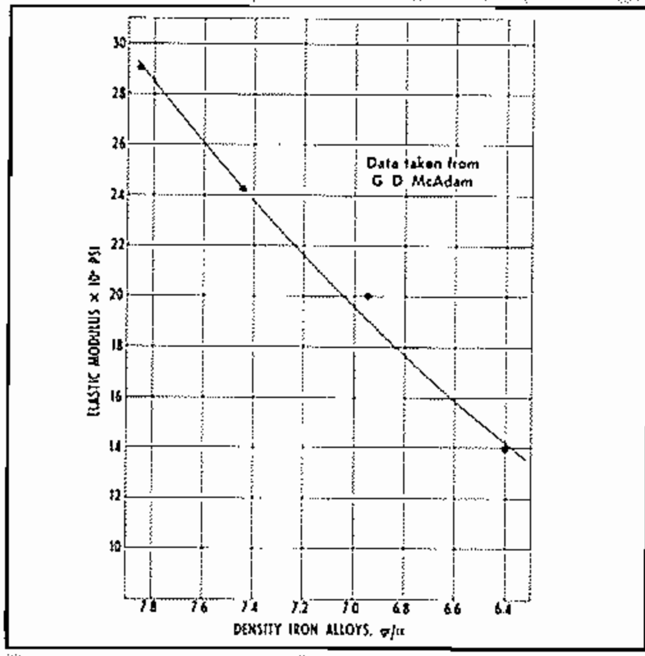


Fig. 51

O. CORROSION RESISTANCE OF STAINLESS STEEL

Stainless Steel

Sintered stainless steel has in the past been sold with more optimism than confidence in its corrosion resistance. Customers ordering sintered stainless steel of a standard composition have been surprised and disappointed to discover that corrosion resistance does not equal that of the wrought material. However this fact is readily understood when one remembers that the surface of a sintered component is interrupted by pores. These pores act as notches which provide a starting point for corrosion. If wrought stainless steel is similarly notched corrosion can result.

However the fact that sintered stainless steel is somewhat inferior to wrought stock in corrosion resistance does not mean it is not useful. It offers a great improvement in corrosion resistance over that of other steels, sintered and massive alike. Fig. 52 shows samples subjected to identical corrosive conditions for the same length of time. The superiority of sintered stainless steel is clear.

If a customer is concerned that sintered stainless steel will not meet his requirements for corrosion resistance, the best solution is to test samples under conditions as closely approximating actual service conditions as possible. Failure under the salt spray test is often not a valid reason for rejecting sintered material, as even wrought stainless is attacked by the chloride ion. Under less severe conditions sintered stainless steel will display entirely satisfactory corrosion resistance.

Current research indicates that improved properties in corrosion resistance of sintered stainless will soon be available.

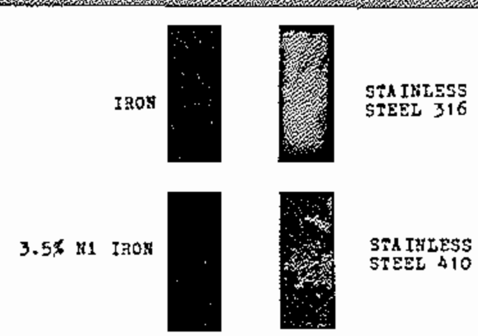


Fig. 52 — Salt spray results

P. FRETTING CORROSION

Fretting corrosion is a persistent problem in some applications. It is characterized by the generation of a red or black powder, accompanied by roughening of the metallic surfaces. The factors which seem to contribute to the situation include humidity in the atmosphere, vibration, and too small clearances between the fretting parts.

In the field fretting corrosion situations have often been corrected by using oil impregnated powdered metal parts. Additional success has been experienced with our alloy #58, containing aluminum oxide. It is believed that this material wears in and adjusts the running clearance so that fretting will not occur. In addition the aluminum oxide prevents adhesive wear particles from forming and oxidizing.

Q. HIGH TEMPERATURE PROPERTIES

Lubricants for temperatures of 250-1000°F were discussed on page 38, but lubrication is not the only limiting factor at elevated temperatures. Sintered steels and bronzes are also susceptible to oxidation, like wrought materials of the same composition. We have tested our stainless steel, 316 grade, and found a weight of only 300 mg/dm² after one week at 700°F in still air. Fig.53 shows a photograph of stainless steel samples after 1 week at 700°F and 1400°F in still air.

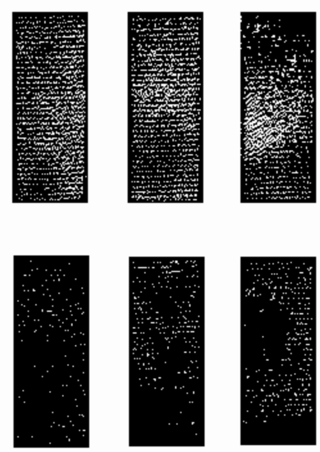


Fig. 53

The latter gained 3800 mg/dm² and would probably not be suitable for most applications.

Oxidation resistance at temperatures up to 2000°F can be imparted by a proprietary process called Chromallizing (Chromalloy Corp.). The process consists of the diffusion of chromium into the surface and formation of an integral layer of high chrome content about .002" thick.

This treatment applied to our #58 alloy (containing a fine dispersion of Al_2O_3) would yield a material with superior hot strength, creep resistance and oxidation resistance. We do not yet have quantitative data from stress rupture tests on this material.

We are also interested in fabricating metals or cermets containing Boron Nitride for high temperature lubrication on a developmental basis.

R. FATIGUE PROPERTIES

Very little data is available on the fatigue strength of sintered materials. We have not yet measured fatigue strengths of our materials but we can estimate values from published work where the material is of the same density and composition.

Our ferrous alloys (39, 65, 72, 61, 28, 19, etc.) should have a fatigue strength of about 20,000-25,000 psi for 10,000,000 cycles. This stress is the stress in the outer fiber in bending. Our bronzes (14, 22, 23, etc.) should have flexural fatigue strengths of 5,000-10,000 psi.

It appears from data in the literature (*Powder Metallurgy #12*, G. C. Smith, P. 141) that the pores are too large to act as the notches which initiate fatigue cracks. The material fatigues at the surface first and the cracks proceed inward. This has been demonstrated by removing the surface layer of a fatigued specimen and observing a doubling of the expected life. Reducing the number of pores makes fatigue crack propagation more difficult so that for iron densities of 7.0 g/cc or greater are recommended for fatigue situation.

S. MAGNETIC AND ELECTRONIC MATERIALS

Our high density (7.0-7.5 gr/cc) iron has proved successful as a soft magnetic material. Although we have not measured magnetization curves (B vs H), our customers find it to be only slightly inferior to wrought material in its flux density. We would recommend that you test a billet of our high density iron for permeability, or machine a component for testing in application.

We are willing to fabricate alloys for electronic materials and devices on a developmental basis and in production. We have access to a high temperature (2400°F) vacuum furnace in which more exotic and reactive alloys can be sintered without introducing significant interstitial impurities.

T. ELECTRICAL CONDUCTIVITY OF SINTERED MATERIALS

We have listed below the electrical conductivity of several of our alloys. The values are presented in the form of the percentage of the electrical conductivity of the wrought material of the same composition.

ALLOY	DENSITY gr/cc	PERCENT Conductivity
Electrolytic Cu	7.2	79.1
	7.7	85.8
	8.0	86.6
	8.13	86.2
	8.73	86.0
410 Stainless Steel	6.91	.65
	7.06	1.73
	7.33	1.36
316 L Stainless Steel	7.0	1.00
	7.39	1.50
Electrolytic Iron	7.35	6.4
	7.44	7.6

U. PROPERTIES OF SINTERED METAL COMPOSITIONS DETERMINED BY TESTS

In the following pages the alloys we find useful for most applications are listed. They are arranged in "family groups" according to general alloy constitution. At the head of each group there is an alloy in bold face type: namely, that material which, of its group, we have found most satisfactory in a majority of applications. The other alloys of the group vary somewhat from the principal alloy in composition and properties, and are designed to fit applications which require special properties.

It should be emphasized that the figures published here are laboratory test results, and as such represent the average properties of a group of test pieces. They are intended as guides to the typical properties of the materials, but should not be construed as specifications or minimum standards. Such is not the intention of publishing this data.

The properties for our alloys are given in most cases for several densities which represent the range of density and dependent physical properties normally obtainable with the alloy in question. For a full discussion of the dependence of properties on density, see Page 18. All tests were made on standard MPIF test samples which are simple in shape and of uniform density. Often, however, due to the configuration of a part, high or uniform densities cannot be obtained in practice. Some reasons for this are explained on pages 18 and 50. For the density range found within a part, a comparable range of properties will be characteristic of the different sections of the part.

PROPERTIES OF SINTERED METAL COMPOSITIONS DETERMINED BY TESTS

Before selecting a specific alloy or density from this listing, our engineering staff should always be consulted. We may advise you of a more appropriate alloy or density for your particular part, or suggest a design change which would allow us to obtain the properties you require at lower cost.

Although we have published physical data varying with density, all other variables were held constant in these tests. Therefore the effects of using different grades of powder, of varying the alloy constituents, of sintering times, temperatures and atmospheres, are not shown. These variables can be used to change properties from those published here. For some alloys we list the effects of finishing operations, such as coining and heat treatment. Most of them, however, were tested in the as-sintered state. The improvements of various finishing operations are substantial and should be borne in mind.

No.	Composition	Condition	Density g/cc	Porosity %	Tensile Strength lbs./sq. in.	Elongation %	Compressive Strength .2% yield	Hardness Rockwell	Microhardness converted from Knoop
					NICKEL STEELS				
39C	93.25 Fe-4 Ni 2 Cu-.75 C	as sintered	6.53 6.80 6.89	16.3 12.9 11.7	69,700 74,300 78,700	1.0 2.2 2.5	49,300	B85 B84 B87	B88-C43
		annealed	6.54 6.82 6.90	16.3 12.8 11.4	59,800 62,700 69,400	2.0 2.5 2.9		B76 B76 B78	B56-94
		heat treated	6.53 6.79 6.90	16.3 13.0 11.4	92,000 93,600 99,200	0.4 1.1 1.7	87,300	B86 B92 B95	B86-C33
		case carburized	6.50 6.96					C22 C36	C54-60 C54-60
65	93.25 Fe-4 Ni 2 Cu-.75 C	as sintered	6.75 7.09 7.19	13.5 9.1 7.9	76,200 87,600 90,700	1.6 1.7 2.1	56,800	B88 B95 B97	B94-C22
		annealed	6.82 7.07 7.23	12.8 9.4 7.3	69,000 76,100 88,800	2.1 2.2 2.8		B79 B81 B88	B80-97
		heat treated	6.77 7.10 7.18	13.1 9.0 8.0	101,200 137,700 144,500	1.1 1.5 1.4	71,800	C15 C24 C29	C24-37
		case carburized	6.55 6.95					C34 C36	C58-60 C58-60
72	95.25 Fe-4 Ni .75 C	as sintered	7.24 7.41 7.48	6.6 4.5 3.5	83,300 92,500 101,700	4.4 5.4 5.3	41,800	B80 B88 B90	
		annealed	7.22 7.42 7.52	7.0 4.4 3.0	62,300 74,300 75,200	5.0 5.9 7.0		B67 B76 B78	B75-94

Continued on next page

PROPERTIES OF SINTERED METAL COMPOSITIONS DETERMINED BY TESTS

No.	Composition	Condition	Density g/cc	Porosity %	Tensile Strength lbs./sq. in.	Elong-ation %	Compressive Strength .2 % yield	Hard-ness Rockwell	Micro-hardness converted from Knoop
72	95 .25 Fe-4 Ni .75-C	heat treated	7.19 7.39 7.50	7.3 4.7 3.3	131,000 168,300 188,200	1.8 3.3 3.6	78,500	C20 C31 C34	C42-45
		case carburized	7.5					C40	C56-58
39L	93.75 Fe-4 Ni 1 Cu-.75-C-.5 Pb	as sintered	6.37 6.59 6.69	18.0 15.2 13.9	43,200 57,500 56,500	0.2 0.5 0.6		B77 B83 B85	B67-94
		annealed	6.39 6.63 6.75	17.7 14.6 11.8	41,000 42,500 53,400	2.1 2.2 2.4		B59 B69 B72	B71-75
		heat treated	6.30 6.57 6.67	19.0 15.5 14.1	51,600 51,100 51,500	1.0 1.4 1.2		B81 B87 B89	C28-47
		case carburized							C47-49
39A	96 Fe-4 Ni	sintered	6.59	16.6	31,250	5.0		H97	
				COPPER - FE					
28	98 Fe-2 Cu	sintered	5.69 6.19	28.0 21.5	18,100 23,900	2.5 2.5	12,300 21,300	H75 H86	
		case carburized							C47
29	97.5 Fe-2 Cu-.5C	sintered	5.59 6.04	27.6 21.8	19,800 27,400	2.5 2.5	25,400 26,900	H83 H92	
44	95.5 Fe-3 Cu 1.5C	sintered	5.57 5.76 5.96	26.1 23.8 21.1	37,400 49,300 56,200	0.8 1.6 0.7		B62 B61 B65	
26	95 Fe-5 Cu	as sintered	5.78 5.91	24.1 22.5	21,500 21,800	0.5 0.5	26,900 27,700	H83 H84	
61	94 Fe-5 Cu 1C	as sintered	6.43 6.68 6.82	15.7 12.4 10.6	75,200 86,900 95,000	1.6 0.6 0.7		B83 B86 B90	B98-C35
		annealed	6.42 6.70 6.84	15.7 12.2 10.3	52,900 61,000 66,000	2.5 2.6 2.7		B59 B68 B69	B89-C44
		age hardened	6.48 6.69 6.82	15.1 12.4 10.6	78,400 97,900 105,600	1.6 1.3 1.5		B89 C20 C22	C28-42
		case carburized	6.6					C31	C63-65
43	93 Fe-7 Cu	sintered	5.50 5.73 5.81	30.7 27.8 26.8	26,600 26,600 31,500	1.6 0.0 1.7		H81 H87 H90	
45	92 Fe-7 Cu-1C	sintered	5.65 5.86 5.99	26.1 23.3 21.6	35,800 37,500 42,600	1.3 1.6 1.0		B60 B69 B69	
19	91 Fe-8 Cu-1C	sintered	5.70 6.05	26.2 21.6	38,000 46,500	0.0 0.0	40,400 46,000	H105 H109	
17	85 Fe-15 Cu	sintered	5.92 6.20	26.0 22.6	30,200 36,700	0.0 1.3	25,300 28,400	H85 H89	
16	80 Fe-20 Cu	sintered	5.65 5.99	29.5 25.1	29,300 36,300	2.5 2.5	16,700 18,200	H84 H93	
18	75 Fe-23.5 Cu 1.5C	sintered	5.66 6.14	27.4 21.4	21,800 25,500	2.0 2.0	43,700 45,100	H99 B65	
27	70 Fe-30 Cu	sintered	5.77 6.08	29.1 25.5	26,300 30,800	2.5 2.5	23,300 29,200	H79 H86	
46	50 Fe-50 Cu	sintered	6.78 6.61 6.64	18.9 20.9 20.6	34,400 34,500 35,600	1.2 1.6 0.7		H88 H91 H88	
41	Fe	sintered	5.79 6.05 6.17	26.4 23.1 21.6	10,900 15,100 16,100	2.9 4.7 4.7		H44 H56 H59	

PROPERTIES OF SINTERED METAL COMPOSITIONS DETERMINED BY TESTS

No.	Composition	Condition	Density g/cc	Porosity %	Tensile Strength lbs/sq. in.	Elongation %	Compressive Strength .2% yield	Hardness Rockwell	Micro-hardness converted from Knoop
41	Fe	case carburized	6.6					C36	C58-64
42	98.5 Fe-1.5C	sintered	5.82	23.2	39,500	1.9		B47	
			5.98	21.1	44,500	1.0		B57	
			6.18	18.4	46,300	2.2		B66	
INFILTRATED Fe									
35	80 Fe-20 Cu .75-1.00C	sintered	6.98		78,800	1.2		B85	
			7.16		94,000	1.7		B92	
			7.32		102,300	1.7		B95	
		annealed	6.90		54,900	4.0		B63	
			7.17		68,700	4.8		B71	
			7.30		79,500	4.5		B75	
		heat treated	6.95		89,000	1.5		B96	
			7.10		105,700	1.7		B93	
			7.18		117,800	1.0		B97	
STAINLESS STEEL									
38A	304L18 Cr-8Ni balance Fe	sintered	6.64	16.0	38,200	19.0		B40	
38B	316 L 18 Cr-8Ni 2 Mo balance Fe	sintered	6.80	15.0	40,000	13.3		B39	
38C	302B 18 Cr-8Ni	sintered	6.56	17.0	41,700	12.6		B44	
SPECIAL WEAR RESISTANT MATERIAL									
			6.11	20.4	12,400§	3.7		H63	
58-41	98 Fe-2A1$_2$O$_3$	sintered	6.33	17.5	14,200	4.7		H69	B62-64
			6.46	15.8	15,900	4.2		H73	
		sintered	6.35	16.6	52,300	1.1		B77	
			6.51	14.5	54,800	1.7		B82	B86-100
			6.64	13.0	59,400	1.5		B86	
58-39	91.25 Fe-4 Ni 2 Cu-2A1$_2$O$_3$ .75C	annealed	6.34	16.9	43,200	2.0		B66	
			6.54	14.2	47,500	1.8		B71	B81-C28
			6.67	12.5	48,800	2.2		B75	
		heat treated	6.30	17.4	55,900	1.2		B82	
			6.57	13.8	61,100	1.4		B90	
			6.63	13.0	66,900	2.1		B91	

BRONZE

No.	Composition	Former Designation	Density	Porosity	Tensile Strength	Elongation	Compressive Strength	Hardness Rockwell	Micro-hardness
14	90 CU-10 Sn	Coprex	6.27	28.5	15,500	6.7	14,000	H41	
			6.73	23.4	19,800	5.5	15,300	H59	
23	90 CU-10 Sn +.5C	Graphex	5.74	33.5	15,000	5.0	7,700	H40	
			6.20	28.0	19,200	7.5	10,500	H53	
22A	92 Cu-8 Sn +2.5C	Graphex	6.12	25.3	10,400	3.7	9,000	H34	
			6.57	19.7	13,500	3.5	10,200	H50	
			6.67	18.5	15,300	4.0	10,500	H55	
23A	92 Cu-8 Sn +.5C	Graphex	6.18	28.6	11,500	5.0	10,400	H36	
			6.78	21.7	15,400	5.7	14,000	H55	
			6.85	20.9	16,300	5.0	14,400	H56	
24	90 Cu-10 Sn +1.5C	Graphex	6.08	27.5	10,200	4.0	8,650	H23	
			6.19	26.2	10,800	5.5	9,250	H30	
			6.46	22.8	12,500	5.8	10,600	H41	
22	90 Cu-10 Sn +2.5C	Graphex	5.42	33.6	9,400	5.0	5,150	xx	
			6.01	26.4	13,500	5.0	8,600	H36	
3	91 Cu-9 Sn +3C	Graphex	5.89	27.5	8,800	5.0	7,350	H10	
			5.98	26.4	9,300	4.0	7,500	H12	
			6.30	22.5	11,100	4.5	8,500	H29	
11	92 Cu-8 Sn +4C	Graphex	5.67	28.1	6,900	1.5	4,200	xx	
			5.87	25.5	7,600	2.0	5,650	xx	
			6.15	22.0	8,900	4.0	7,650	H19	
2	90 Cu-10 Sn +4MoS$_2$	Graphex 4M	6.15	30.1	11,700	5.0	9,500	H29	
			6.55	24.5	15,900	7.0	12,200	H54	
2A	92 Cu-8 Sn +4MoS$_2$	Graphex 4M	6.33	28.0	10,900	4.8	10,400	H31	
			6.44	26.8	11,200	5.0	11,400	H13	
			6.76	23.1	14,100	4.9	14,200	H55	
1	90 Cu-10 Sn +2MoS$_2$	Graphex 2M	6.43	27.0	14,000	5.6	10,800	H44	
			6.85	22.2	18,000	9.0	12,000	H59	
1A	92 Cu-8 Sn +2MoS$_2$	Graphex 2M	6.46	26.4	12,600	3.3	11,300	H49	
			6.64	24.5	12,900	3.3	12,600	H56	
			6.82	22.4	14,800	4.2	13,800	H62	

PROPERTIES OF SINTERED METAL COMPOSITIONS DETERMINED BY TESTS

No.	Composition	Former Designation	Density	Porosity	Tensile Strength	Elongation	Elastic Limit	Hardness Rockwell	Micro-hardness
				LEADED BRONZE					
12	88 Cu-10 Sn —2 Pb	Coprex	6.84 7.24	22.3 17.8	19,000 26,400	10.0 13.2	14,200 16,100	H54 H64	
8	86 Cu-9 Sn —5 Pb + 2 C	Graphex	6.75 7.01	19.4 16.2	13,000 13,900	6.9 6.9	7,900 8,100	H34 H45	
10	77 Cu-8 Sn 15 Pb + 4.5 C	Graphex	5.78 6.20	28.0 22.7	4,400 6,200	2.7 4.5	3,300 4,350		
13	88 Cu-10 Sn —2 Pb + 3.5 C	Graphex	5.81 6.38	27.2 20.1	9,700 14,200	00 00	7,000 9,700	H21 H47	
25	86 Cu-10 Sn —4 Pb + 1.5 C	Graphex	6.55 6.80	22.5 19.5	11,900 13,700	3.5 9.0	10,100 11,400	H32 H44	
6	87 Cu-7.5 Sn —5.5 Pb + 2.5 C	Graphex	6.28 6.78	24.5 18.5	8,900 12,100	6.3 7.5	6,100 8,050	H26	
4	86 Cu-5 Sn 9 Pb-4 C	Graphex	6.09 6.49	24.5 19.5	5,200 7,500	1.6 3.5	4,650 6,250	H26	
9	68 Cu-10 Sn —22 Pb + 2 C	Graphex	6.70 7.06	22.3 18.3	9,700 11,700	5.0 5.0	5,250 6,400	H19	
				NICKEL BRONZE					
21	33 Ni-65 Cu —2 Sn + 2 C	Graphex Cu-Ni	5.74 6.03	33.3 29.3	8,800 9,500	2.8 2.8	5,550 8,750	H22	
				OTHER NON-FERROUS					
37	78.5 Cu-20 Zn —1.5 Pb	Brass	7.40 7.83	13.3 8.5	24,200 28,500	11.0 17.2		H72 H80	
48	64 Cu-16.5 Zn 18 Ni 1.5 Pb	Nickel Silver	7.35	15.0	23,000	7.5			
52	Cu	Copper	6.81 7.53	23.7 15.7	18,500 23,500	15.9 26.8		H18 H35	
53	Ag	Silver	8.10 8.30	22.8 20.8	11,300 12,600	10.5 13.1		H12 H25	
55	Ti	Titanium	4.08	10.0	74,000	6.0		B50	
5	94 Cu-6 Sn		8.25-8.40	4.5	40,000	5		B45	
15	70 Cu-25 Ni-5 Sn		7.70-7.80	11	45,000-50,000	5			

COEFFICIENT of FRICTION

No.	Composition	Test Range	Recommended Figure	Angle of Repose
39C	93.25 Fe-4 Ni 2 Cu-.75 C	.230	.230	13°
65	93.25 Fe-4 Ni 2 Cu-.75 C	.210	.210	12°
72	95.25 Fe-4 Ni .75 C	.210-.230	.215	12.25°
39L	93.75 Fe-4 Ni 1 Cu-.75 C-.5 Pb	.210-.220	.215	12.25°
28	98 Fe-2 Cu	.225-.250	.225	13°
29	97.5 Fe-2 Cu-.5 C	.225-.250	.225	13°
44	95.5 Fe-3 Cu-1.5 C	.210-.230	.220	12.5°
26	95 Fe-5 Cu	.250	.250	14°
61	95 Fe-5 Cu	.205-.215	.210	11.75°
43	93 Fe-7 Cu	.250	.250	14
45	92 Fe-7 Cu-1 C	.230	.230	13
19	91 Fe-8 Cu-1 C	.225-.250	.225	13
17	85 Fe-15 Cu	.225-.250	.225	13
16	80 Fe-20 Cu	.225-.250	.225	13
18	75 Fe-23.5 Cu-1.5 C	.225-.250	.225	13
27	70 Fe-30 Cu	.300	.300	17.5°
46	50 Fe-50 Cu	.230	.230	13°
41	Fe	.250-.285	.265	14.75
42	98.5 Fe-1.5 C	.210-.230	.220	12.5
38	Stainless Steel	.240	.240	13.5
58.41	98.5 Fe-2 Al_2O_3	.260-.280	.265	14.75
58.39	91.25 Fe-4Ni .75 C	.230	.230	13
	Steel on steel	.150-.200		8.5-11.5

COEFFICIENT OF FRICTION

No.	Composition	Test Range	Recommended Figure	Angle of Repose
BRONZE COMPOSITIONS				
14	90 Cu-10 Sn	.275-.300	.275	16.0
23	90 Cu-10 Sn + .5 C	.250-.275	.250	14.5
22A	92 Cu-8 Sn + 2.5 C	.300-.325	.300	17.5
23A	92 Cu 8 Sn + .5 C	.275-.300	.275	16
24	90 Cu-10 Sn + 1.5 C	.275-.300	.275	16
22	90 Cu-10 Sn + 2.5 C	.275	.275	16
3	91 Cu-9 Sn + 3 C	.225-.250	.225	13
11	92 Cu-8 Sn + 4 C	.250-.275	.250	14.5
2	90 Cu-10 Sn + 4 MoS_2	.250	.250	14.5
2A	92 Cu-8 Sn + 4 MoS_2	.225-.250	.225	13
1	90 Cu-10 Sn + 2 MoS_2	.275-.300	.275	16
1A	92 Cu-8 Sn + 2 MoS_2	.250-.300	.250	14.50
12	88 Cu-10 Sn-2 Pb	.225-.250	.225	13
8	86 Cu-9 Sn-5 Pb + 2 C	.225-.250	.225	13
10	77 Cu-8 Sn-15 Pb + 4.5 C	.200-.225	.200	11.5
13	88 Cu-10 Sn-2 Pb + 3.5 C	.225-.250	.225	13
25	86 Cu-10 Sn-4 Pb + 1.5 C	.225-.250	.225	13
6	87 Cu-7.5 Sn-5.5 Pb + 2.5 C	.225-.250	.225	13
4	86 Cu-5 Sn-9Pb + 4 C	.225-.250	.225	13
9	68 Cu-10 Sn-22 Pb + 2 C	.200	.200	11.5
NON FERROUS				
21	33 Ni-65 Cu-2 Sn + 2 C	.275-.300	.275	16
37	78.5 Cu-20 Zn-1.5 Pb	.230-.250	.240	13.5
52	Cu	.285	.285	15
53	Ag	.250	.250	14
55	Titanium	.230	.230	13

*This figure decreases rapidly after break-in period as shown by No. 2 Alloy which coefficient of friction reduced to approximately .07 after slight coating of molybdenum disulphide has had time to be dispersed on shaft.

CALCULATED PROPERTIES OF BRONZE COMPOSITIONS AT 6.6 G/CC DENSITY

		Tensile Strength	Compressive Strength	Porosity
14	90 Cu-10 Sn	15,900	14,900	23.8
23	90 Cu-10 Sn+.5 C	22,900	12,900	23.4
22A	92 Cu-8 Sn+2.5 C	14,000	11,300	19.5
23A	92 Cu-8 Sn+.5 C	14,200	12,900	23.8
24	90 Cu-10 Sn+1.5 C	13,400	11,400	21.2
22	90 Cu-10 Sn+2.5 C	17,600	10,200	19.3
3	91 Cu-9 Sn+3 C	12,800	9,500	18.6
11	92 Cu-8 Sn+46	12,500	10,900	16.4
2	90 Cu-10 Sn+4 MoS_2	15,500	11,400	24.9
2A	92 Cu-8 Sn+4 MoS_2	12,600	12,800	24.8
1	90 Cu-10 Sn+2 MoS_2	15,700	11,400	24.9
1A	92 Cu-8 Sn+2 MoS_2	12,900	12,300	24.8
12	88 Cu-10 Sn-2 Pb	14,600	12,800	25.0
8	86 Cu-9 Sn-5 Pb+2 C	12,500	7,750	21.2
10	77 Cu-8 Sn-15 Pb+4.5 C	7,900	5,200	17.8
13	88 Cu-10 Sn-2 Pb+3.5 C	15,900	10,700	17.5
25	86 Cu-10 Sn-4 Pb+1.5 C	12,300	10,400	22.0
6	87 Cu-7.5 Sn-5.5 Pb+2.5 C	10,900	7,350	20.7
4	86 Cu-5 Sn-9 Pb+4 C	8,100	7,500	18.2
9	68 Cu-10 Sn-22 Pb+2 C	9,100	4,900	23.5

CALCULATED PROPERTIES OF FERROUS COMPOSITIONS AT 6.0 G/CC DENSITY

		Tensile Strength	Compressive Strength	Porosity
28	98 Fe-2 Cu	21,700		24.0
29	97.5 Fe-2 Cu-.5 C	26,700		22.3
26	95 Fe-5 Cu	22,000	28,200	21.4
19	91 Fe-8 Cu-1 C	45,300	45,000	22.3
17	85 Fe-15 Cu	32,100	26,200	25.2
16	80 Fe-20 Cu	36,500	19,300	25.0
18	75 Fe-23.5 Cu-1.5 C	24,400	45,600	23.1
27	70 Fe-30 Cu	29,600	26,600	26.5

CALCULATED PROPERTIES OF COMPACTS AT 70% OF THEORETICAL DENSITY

BRONZE COMPOSITIONS

No.	Composition	Density	Tensile Strength	Compressive Strength	Porosity
14	90Cu-10Sn	6.15	12,400	13,500	30.0
23	90Cu-10Sn+.5C	6.03	17,600	9,450	30.0
22A	92Cu-8Sn+2.5C	5.74	7,800	6,650	30.0
23A	92Cu-8Sn+.5C	6.06	10,600	9,650	30.0
24	90Cu-10Sn+15C	5.87	9,500	7,550	30.0
22	90Cu-10Sn+2.5C	5.72	11,700	6,900	30.0
3	91Cu-9Sn+3C	5.68	7,600	6,600	30.0
11	92Cu-8Sn+4C	5.52	6,400	3,700	30.0
2	90Cu-10Sn+4MoS_2	6.16	11,800	9,550	30.0
2A	92Cu-8Sn+4MoS_2	6.15	9,500	8,900	30.0
1	90Cu-10Sn+2MoS_2	6.16	11,400	10,000	30.0
1A	92Cu-8Sn+2MoS_2	6.15	9,200	9,200	30.0
12	88Cu-10Sn-2Sn-2Pb	6.16	11,200	10,100	30.0
8	86Cu-9Sn-5Pb +4.5C	5.90	9,900	7,200	30.0
10	77Cu-8Sn-15Pb+4.5C	5.62	3,600	2,950	30.0
13	88Cu-10Sn-2Pb+3.5C	5.60	8,000	6,050	30.0
25	86Cu-10Sn-4Pb+15C	5.92	7,300	6,650	30.0
6	87Cu-7.5Sn-5.5Pb+2.5C	5.82	6,900	4,350	30.0
4	86Cu-5Sn-9Pb+4C	5.65	4,000	2,800	30.0
9	68Cu-10Sn-22Pb+2C	6.04	6,000	3,050	30.0

FERROUS COMPOSITIONS

No.	Composition	Density	Tensile Strength	Compressive Strength	Porosity
28	98Fe-2Cu	5.52	14,000		30.0
29	97.5Fe-2Cu-.5C	5.40	16,600		30.0
26	95Fe-5Cu	5.34	20,400	24,300	30.0
19	91Fe-8Cu-1C	5.40	30,700	35,000	30.0
17	85Fe-15Cu	5.61	23,000	22,000	30.0
16	80Fe-15Cu	5.61	28,300	16,400	30.0
18	75Fe-23.5Cu-1.5C	5.46	20,300	43,100	30.0
27	70Fe-30Cu	5.71	25,400	22,300	30.0

1. Composition format:

Compositions are listed in two ways. Materials in which the addition agents (graphite, MoS_2, etc.) do not alloy are listed with the metallic components totalling 100% and the addition agent as an added percentage. For example: Alloy 22A is 92% Cu-8% Sn + 2.5% Graphite (all percentages are by weight). Metallurgically, the bronze matrix is a typical 92-8 bronze alloy. For materials in which the additives alloy with the base metal, all constituents add up to 100%. For example: alloy 45 contains 92% Fe, 7% Cu, 1.0% C. The carbon indicated in these alloys is the amount of graphite added. The combined carbon is about 65% of the amount of carbon shown by the composition.

2. Theoretical densities of sintered alloys are calculated from the densities of the components and their weights if a comparable wrought material does not exist. The theoretical densities may be calculated from the formula:

$$D_{\text{theoretical}} = \frac{D_{\text{measured}}}{1 - \frac{P}{100}}$$

D theoretical = theoretical density

D measured = the density value listed in the table

P = % porosity listed in the table for the particular measured density.

Example: Alloy 23

D measured = 6.20 gr/cc

P = 28%

$$D_{\text{theoretical}} = \frac{6.20}{1 - \frac{28}{100}} = \frac{6.20}{.72} = 8.61 \text{ gr/cc}$$

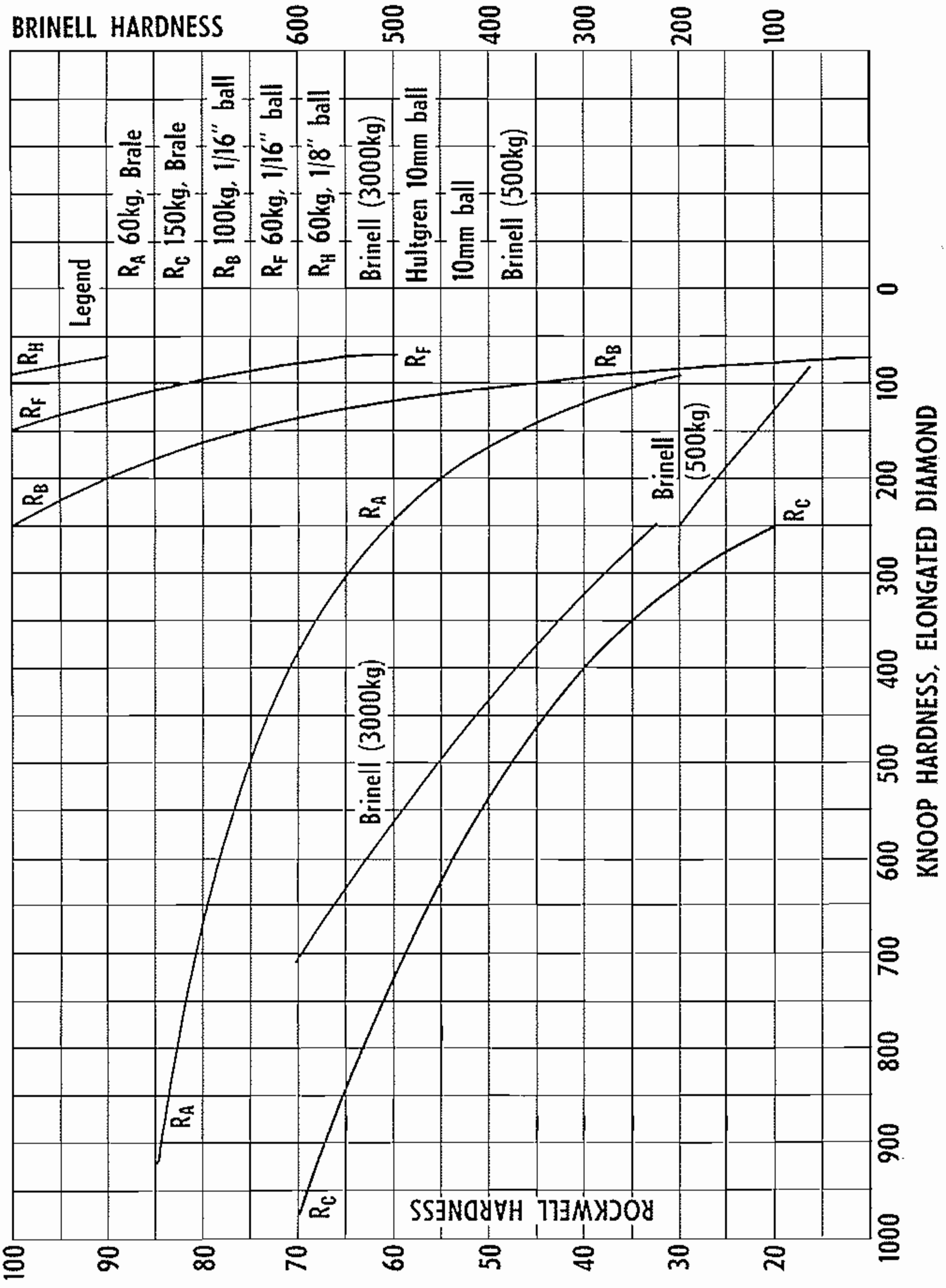
We do not list theoretical densities in the tables because the porosity figure, 28%, imparts a better physical feeling for the structure of the material and its oil holding capacity.

3. Tensile tests were measured on standard MPIF tensile bars on our Dillon Dynamometer or at the facilities of SKC Research Associates.

4. Hardness measurements were made with the Wilson "Rockwell" tester and with Knoop microhardness tester. To compare the various Rockwell scales employed, we have plotted Rockwell hardness versus Knoop hardness, (elongated diamond indenter) on page 72.

5. The porosity listed in the preceding table is total porosity. The porosity available for oil holding is 2 - 5% less.

6. The elastic limit in compression is measured by compressing a cylinder of the material and determining at what stress .2% permanent deformation occurs.


BRINELL HARDNESS
600
500
400
300
200
100
Legend
R_A 60kg, Brale
R_C 150kg, Brale
R_B 100kg, 1/16" ball
R_F 60kg, 1/16" ball
R_H 60kg, 1/8" ball
Brinell (3000kg)
Hultgren 10mm ball
10mm ball
Brinell (500kg)
R_H
R_F
R_B
R_A
R_C
Brinell (500kg)
Brinell (3000kg)
KNOOP HARDNESS, ELONGATED DIAMOND
0
100
200
300
400
500
600
700
800
900
1000
ROCKWELL HARDNESS
100
90
80
70
60
50
40
30
20

GLOSSARY OF TERMS USED IN POWDER METALLURGY

The following definitions are according to MPIF standard 9-62 and are those most applicable to this manual.

APPARENT DENSITY —

The weight of a unit volume of powder, usually expressed as grams per cubic centimeter, determined by a specified method.

ATOMIZED METAL POWDER —

Metal powder produced by the dispersion of molten metals into particles by the impingement of a rapidly moving gas or liquid stream.

BLANK —

A pressed, presintered or fully sintered compact, usually in the unfinished condition, requiring cutting, machining, or some other operation to give it its final shape.

BLENDING —

The thorough intermingling of powders of the same nominal composition (not to be confused with mixing).

BRIQUET —

See Compact.

BURN OFF —

That stage of a sintering cycle referring to the time or temperature necessary to remove ingredients used to assist the forming of a powder metallurgy part.

CARBONYL POWDER —

A metal powder prepared by the thermal decomposition of a metal carbonyl.

CLASSIFICATION —

Separation of a powder into fractions according to particle size.

COINING —

The pressing of a sintered compact to obtain a definite surface configuration (not to be confused with repressing or sizing).

COLD PRESSING —

The forming of a compact at room temperature.

COLD WELDING —

Cohesion between two surfaces of metal, generally under the influence of externally applied pressure at room temperature.

COMPACT —

An object produced by the compression of metal powder, generally while confined in a die, with or without the inclusion of nonmetallic constituents. Synonymous with Briquet.

COMPACTING TOOL SET —

See Die.

COMPRESSIBILITY —

A density ratio determined under definite testing conditions.

COMPRESSION RATIO —

The ratio of the volume of the loose powder to the volume of the compact made from it. Synonymous with Fill Ratio.

CONTINUOUS SINTERING —

Sintering in such a manner that objects are advanced through the furnace at a fixed rate, by manual or mechanical means.

CORE ROD —

The member of the compacting tool set or die that forms a through hole in the compact.

CRACKED AMMONIA —

See Dissociated Ammonia.

DENDRITIC POWDER —

Particles, usually of electrolytic origin having the typical pine tree like structure.

DENSITY (DRY) —

The weight per unit volume of an unimpregnated powder metallurgy part.

DENSITY (WET) —

The weight per unit volume of powder metallurgy part impregnated with oil or other non-metallic material.

DIE —

The part or parts making up the confining form in which a powder is pressed. The parts of the die may be some or all of the following: die body, punches, and core rods. Synonymous with Mold and Compacting Tool Set.

DIE BODY —

The stationary or fixed part of a die.

DIE LINER —

A removable liner or part of a die body or punch. Synonymous with Die Insert.

DIE LUBRICANT —

A lubricant mixed with the powder or applied to the walls of the die and punches to facilitate the pressing and ejection of the compact.

DISSOCIATED AMMONIA —

A reducing gas produced by the thermal decomposition of anhydrous ammonia over a catalyst, resulting in a gas of 75% hydrogen and 25% nitrogen. Synonymous with Cracked Ammonia.

ELECTROLYTIC POWDER —

Powder produced by the pulverization of an electro-deposit.

EXOTHERMIC ATMOSPHERE (GAS) —

A reducing gas atmosphere used in sintering and produced by partial or complete combustion of a hydrocarbon fuel gas and air. Maximum combustibles approximately 25%.

ENDOTHERMIC ATMOSPHERE (GAS) —

A reducing gas atmosphere used in sintering and produced by the reaction of a hydrocarbon fuel gas and air over a catalyst with the aid of an external heat source. It is low in carbon dioxide and water vapor with relatively large percentage of hydrogen and carbon monoxide. Maximum combustibles approximately 60%.

FINES —

The portion of a powder composed of particles which are smaller than a specified size, currently less than 44 microns.

FLOW RATE —

The time required for a powder sample of standard weight to flow through an orifice in a standard instrument according to a specified procedure.

GREEN —

Unsintered (not sintered); for example: green compact, green density, green strength.

GROWTH —

An increase in dimensions of a compact which may occur during sintering (converse of shrinkage).

HOT PRESSING —

The simultaneous heating and molding of a compact.

HYDROGEN LOSS —

The loss in weight of metal powder or of a compact caused by heating a representative sample for a specified time and temperature in a purified hydrogen atmosphere — broadly a measure of the oxygen content of the sample, when applied to materials containing only such oxides as are reducible with hydrogen and no hydride forming element.

HYDROGEN REDUCED POWDER —

Powder produced by the hydrogen reduction of a metallic compound.

IMPREGNATION —

A process of filling the pores of a sintered compact, usually with a lubricant; also a process of embedding particles of a non-metallic substance in a metal powder matrix, as in diamond impregnated tools.

INFILTRATION —

The process of filling the pores of a powder metallurgy part with a metal or alloy of a lower melting point.

INTERCOMMUNICATING POROSITY —

That type of porosity in a sintered compact in which the pores are connected to each other and the surfaces so that a fluid may pass from one to the other completely through the compact.

K-FACTOR —

The strength constant in the formula for "Radial Crushing Strength." (See Radial Crushing Strength.)

LIQUID PHASE SINTERING —

Sintering of a mass of powders consisting of two or more constituents, at a temperature below the melting point of the high-melting constituent, but above the melting point of the low-melting constituent.

LOWER PUNCH —

The member of the compacting tool set or die that determines the powder fill and forms the bottom of the part being produced. Secondary or subdivided lower punches may be necessary to facilitate filling, forming and ejecting of multiple level parts.

LUBRICATING —

Mixing with, or incorporating in, a powder, some agent to facilitate pressing and ejecting the compact from the die body; applying a lubricant to the die walls and punch surfaces.

MATRIX METAL —

The continuous phase of a polyphase alloy or mechanical mixture; the physically continuous metallic constituent in which separate particles of another constituent are embedded.

MECHANICAL COMPONENT —

A shaped body pressed from metal powder and sintered wherein self-lubrication is not a primary property. A powder metallurgy part but not an oil-impregnated bearing. See Powder Metallurgy Part.

MESH —

The screen number of the finest screen through which substantially all of the particles of a given sample will pass. The number of screen openings per linear inch of screen.

METAL FILTER —

See Porous Metal.

METAL POWDER —

Discrete particles of elemental metals or alloys normally within the size range of 0.1 to 1000 microns.

MIXING —

The thorough intermingling of powders of two or more materials.

MOLDING —

The pressing of powder to form a compact.

PARTICLE SIZE —

The controlling lineal dimension of an individual particle as determined by analysis with sieves or other suitable means.

PARTICLE SIZE DISTRIBUTION —

The percentage by weight, or by number, or by volume of each fraction into which a powder sample has been classified with respect to sieve number or microns. (Preferred usage: "particle size distribution by weight" or "particle size distribution by frequency".)

PERMEABILITY —

A property measured as the rate of passage of a liquid or gas through a compact; measured under specified conditions.

POROSITY —

The amount of pores (voids) expressed as a percentage of the total volume of the powder metallury part.

POROUS METAL —

A metal structure having controlled interconnected porosity and uniform pore openings produced to meet filtration or permeability requirements. Synonymous with Metal Filter

POWDER FLOW METER —

An instrument for measuring the rate of flow of a powder according to a specified procedure.

POWDER LUBRICANT —

An agent mixed with or incorporated in a powder to facilitate the pressing and ejecting of the compact.

POWDER METALLURGY —

The arts of producing metal powder and of the utilization of metal powders for the production of massive materials and shaped objects.

POWDER METALLURGY PART —

A shaped object that has been formed from metal powders and bonded by heating below the melting point of the major constituent. A structural or mechanical component, bearing or bushing, made by the powder metallurgy process.

PRE-ALLOYED POWDER —

An alloy in powder form in which each particle is of alloy composition.

PRE-MIXED POWDER

A uniform intermingling of powders of two or more materials performed by the powder producer (not to be confused with pre-blending — see Blending).

PRESINTERING —

The heating of a compact at a temperature below the normal final sintering temperature, usually to increase the ease of handling or shaping the compact, or to remove a lubricant or binder prior to sintering.

PRESSED BAR —

A compact in the form of a bar; a green compact.

PRESSED DENSITY —

The weight per unit volume of an unsintered compact. Synonymous with Green Density.

PUNCH —

Part of a die or compacting tool set which is used to transmit pressure to the powder in the die cavity. See Upper Punch and Lower Punch.

RADIAL CRUSHING STRENGTH —

The load capacity, expressed in pounds, of a hollow cylindrical specimen made by powder metallurgy, to resist fracture induced by a force applied between flat parallel plates in a direction perpendicular to the axis of the specimen.

RATE-OF-OIL-FLOW —

The rate at which a specified oil will pass through a sintered porous compact under specified test conditions.

REDUCED METAL POWDER —

Metal powder produced, without melting, by the reduction of metal oxides or other compounds with hydrogen, carbon, carbon monoxide or mixtures thereof.

REPRESSING —

The application of pressure to a previously pressed and sintered compact, usually for the purpose of improving some physical property.

SHRINKAGE —

A decrease in dimensions of a compact which may occur during sintering (converse of growth).

SIEVE ANALYSIS —

Particle size distribution; usually expressed as the weight percentage retained upon each of a series of standard sieves of decreasing size and the percentage passed by the sieve of finest size. Synonymous with Screen Analysis.

SIEVE CLASSIFICATION —

The separation of powder into particle size ranges by the use of a series of graded sieves.

SINTERING —

Bonding of particles in a mass of metal powder by molecular (or atomic) attraction in the solid state, through the application of heat, causing strengthening of the powder mass and normally resulting in densification and recrystallization due to material transport. (Sintering (Noun) — See Powder Metallurgy Part)

SIZING —

A final pressing of a sintered compact to secure desired size.

SPONGE IRON POWDER —

Iron powder of porous structure usually produced by the reduction of iron oxide.

SPHERICAL POWDER —

Globular shaped particles.

STRIPPER PUNCH —

A punch, which in addition to forming the top or bottom of the die cavity, later moves further into the die to eject the compact.

SUPERFINES —

The portion of a powder composed of particles which are smaller than a specified size, currently less than 10 microns.

TAP DENSITY —

The apparent density of a powder obtained when the receptacle is tapped or vibrated during loading under specified conditions.

UPPER PUNCH —

The member of the compacting tool set or die that closes the die and forms the top of the part being produced.

WARPAGE —

Distortion which may occur in a compact during sintering.

BIBLIOGRAPHY

The current Bibliography represents only a very small portion of the articles available on Powder Metallurgy. The articles selected herein have been chosen as representative of those felt to be of most interest to the readers of this catalog. The books and periodicals listed in this Bibliography cite many other articles on the subject for the reader who wishes to investigate other phases of Powder Metallurgy in detail. Those articles listed in the Bibliography published in our previous catalog are not included in the current Bibliography, but are available for reference.

BOOKS

GOETZEL, C. G. — Treatise on Powder Metallurgy — Vol. I — 1949; Vol. II — 1950; Vol. III — 1952 — (Interscience Publishers, Inc., New York).

JONES, W. D. — Fundamental Principles of Powder Metallurgy — 1960 — (Edward Arnold, Ltd., London).

KINGSTON, W. E. — The Physics of Powder Metallurgy — 1951 — (McGraw-Hill Book Company, Inc., New York).

LESZYNSKI, W. Powder Metallurgy — Proceedings International Conference — New York — June 13 - 17, 1960 — (Metal Powder Industries Federation & Powder Metallurgy Committee, A.I.M.E.) — (Interscience Publishers, Inc., New York).

SCHWARZKOPF, P. — Powder Metallurgy — Its Physics and Production — 1947 — (The Macmillan Co., New York).

WULFF, J. — Powder Metallurgy — 1942 — (American Society for Metals, Cleveland, Ohio).

______Symposium on Production and Design Limitations and Possibilities of Powder Metallurgy Parts — 1945 — (American Society for Testing Materials, Philadelphia).

______Symposium on Powder Metallurgy — 1943 — (American Society for Testing Materials, Philadelphia).

______Special Report No. 38 Ed 2 — Symposium on Powder Metallurgy — 1947 — (Iron & Steel Institute — London).

______Symposium on Powder Metallurgy — 1954 — (Iron & Steel Institute — London), 1956.

LITERATURE REFERENCES

A.S.M. Review of Metal Literature — 1946 - 1965 Inclusive — (American Society for Metals, 7301 Euclid Avenue, Cleveland 3, Ohio).

Engineering Index Service — (Engineering Societies Library, 29 West 39th Street, New York 18, New York).

STANDARDS AND SPECIFICATIONS

Metal Powder Industries Federation, 60 East 42nd Street, New York 17, New York.

American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pennsylvania.

BULLETINS, PERIODICALS, ANNUALS

(Specifically Devoted to Powder Metallurgy)

Metal Powder Association Proceedings of Annual Meetings — (Metal Powder Industries Federation, 60 East 42nd Street, New York 17, New York) — 2nd (1946) Through 20th (1964) Annual Proceedings.

Powder Metallurgy — (Powder Metallurgy, Ltd., Joint Group of the Iron & Steel Institute and Institute of Metals, London, S.W. 1, England). — 1957 — 1965.

Powder Metallurgy Bulletin — (Powder Metallurgy Bulletin, 320 Yonkers Avenue, Yonkers, New York).

Metal Powder Report (Powder Metallurgy Ltd. of London, Paramount House, 75 Uxbridge Road, Ealing W. 5 England).

AIME Powder Metallurgy Committee Newsletter (Institute of Metals Division, Metallurgical Society of AIME, 345 East 47th Street, New York 17, New York).

ARTICLES

W. R. Anderson — Process Controls for Quality and Quantity in Powder Metallurgy — Proceedings — Metal Powder Industries Federation — 16th Annual Meeting — April 25-27, 1960, pg. 42-49.

W. R. Anderson, W. F. Bissett, & P. R. Kalischer — Powder Metallurgy Operations at Maytag — Precision Metal Molding *19,* March, 1961, pg. 43-46.

H. E. Barkan — Powder Metallurgy Parts — Their Advantages in Design — Electrical Manufacturing *65,* March 1960, pg. 139-147.

V. D. Barth — Selected References on Making High-Temperature Alloys by Powder Metallurgy — Defense Metals Information Center — Memo No. *47,* March 18, 1960, 3P.

W. L. Batten — How to do More with Prealloyed Powders — Metal Progress *75,* April 1959, pg. 105-112.

W. L. Batten — Application of Stainless Steel Powder Metallurgy — Proceedings — Metal Powder Industries Federation — 16th Annual Meeting — April 25-27, 1960, pg. 120-129.

W. L. Batten — Developments Extend Market for Stainless Powders — Iron Age *186,* September 1, 1960, pg. 64-66.

G. R. Bell & L. M. Maricchi — Powder Metallurgy as an Aid to Production Engineer — Engineer and Foundryman *22,* August 1957, pg. 54-60.

G. R. Bell, F. B. Webb, & R. Woolfall — Pressing and Sintering Characteristics of Certain Copper and Tin Powder Mixes — Metallurgia *58,* November 1958, pg. 233-241.

E. Betz — Metal Powders — Boon for Industry — Canadian Metalworking *24,* July 1961, pg. 21-22.

H. R. Biehl — Acceptance Inspection for Quality Assurance of Powder Metallurgy Parts — Proceedings — Metal Powder Industries Federation — 18th Annual Meeting — April 23-25, 1962, pg. 74-84.

L. J. Bonis & N. J. Grant — Structure and Properties of Dispersion Strengthened Internally Oxidized Nickel Alloys — Met. Soc. of A.I.M.E. Trans. *224,* No. 2, April 1962, pg. 308-316.

B. Bovarnick — New Basis for Inspection Method for Sintered Metal Components — Proceedings — Metal Powder Industries Federation — 15th Annual Meeting — April 20-22, 1959, Part I, pg. 72-81.

S. Bradbury — Complex Powder Metal Parts for Higher Density — Iron Age *181,* June 5, 1958, pg. 124-125.

R. Burgess — Realistic Tolerances for Sinterings — Precision Metal Molding *16,* October 1958, pg. 52-53.

C. Burley, Jr. — New Methods Spur Metal Powder Use — American Machinist *103,* July 13, 1959, pg. 108-109.

A. Clayton & G. Brewer — Sintered Porous Media — Engineering Materials & Design Conference — 2nd. Proc. 1961, pg. M1-5.

W. Coursen — Use Quality Control to Lower Costs — Precision Metal Molding *20,* December 1962, pg. 32-34.

S. R. Crooks — What Carbon and Alloys do for Iron Powder — Metal Progress *74,* December 1958, pg. 68-73.

G. W. Cunningham — Powder Metallurgy — State of Art — Battelle Technical Review *11,* No. 8, August 1962, pg. 3-9.

F. J. DeMaine — Prototype Tooling for Powdered Metal Parts — Precision Metal Molding *19,* December 1961, pg. 28-32.

J. E. Elliott — Porous and Infiltrated Metal Pt. 1 — Powder Metallurgy Applications, Bearings, Fundamentals of the Process; Pt. 2 — Iron-Copper Materials, Sintered Iron Bearings, Sintered Components — Metal Industry *92,* April 11, 1958, pg. 293-296, *92,* April 18, 1958, pg. 307-309.

J. E. Elliott — Porous and Infiltrated Metal — Metal Industry *92,* April 25, 1958, pg. 334-336.

M. Eudier — Mechanical Properties of Sintered Low-Alloy Steels — Powder Metallurgy, No. 9, 1962, pg. 278-290.

P. E. Evans & G. C. Smith — Rolling of Strip from Metal Powders — Sheet Metal Industries *32,* No. 340, August 1955, pg. 589-592.

J. L. Everhart — Designing for Metal Powder Structural Parts — Materials in Design Engineering *49,* Manual No. 158, April 1959, pg. 113-124.

P. J. Failla — How Design Affects Quality of Powdered Metal Parts — Iron Age 188, July 6, 1961, pg. 76-78.

E. J. Fitzgerald — Powder Metallurgy — 1962 — Journal of Metals *15,* No. *5,* May 1963, pg. 338.

F. Giordano — Roll Peen Powder Metal Parts for Size and Finish — Tool & Mfg. Engr. *48,* No. *5,* May 1962, pg. 125-126.

E. Gleixner — How to Specify Powdered Metal Parts — Precision Metal Molding *18,* No. *4,* April 1962, pg. 36-39.

F. T. Gray & P. V. Schneider — Application of Quality Controls to Powder Metallurgy — Proceedings — Metal Powder Industries Federation — 18th Annual Meeting — April 23-25, 1962, pg. 58-66.

R. E. Green — Some Current Applications of Powder Metallurgy — Machinery (London) *101*, No. 2603, October 3, 1962, pg. 760-765.

E. Gregory — Extruding Metal Powders — Metal Progress *75*, No. 4, April 1959, pg. 113-116, 150-152, 154, 156, 158.

L. Griffin — High Density Sintered Iron Components for Fuze Assemblies — Proceedings — Metal Powder Industries Federation — 18th Annual Meeting — April 23-25, 1962, pg. 139-155.

J. Haller — Sizing and Coining of Metal Powder Parts — Machinery (New York) *65*, No. 8, April 1959, pg. 135-138.

L. Harrison — Powder Metallurgy — Engineering Materials and Design Conference Proceedings — February 1960, pg. S1-S12.

L. Harrison & R. H. T. Dixon — Some Experiments in Production of Low-Alloy Steel by Powder Metallurgy — Powder Metallurgy — No. 9, 1962, pg. 247-264.

W. Hillyer — How to Solve Small Parts Production Design Problems — Precision Metal Molding *15*, No. 7, July 7, 1957, pg. 42-43; 69.

B. I. Horton — Improving Quality, Performance, and Economy in Postage Meters Through Powder Metallurgy — Proceedings — Metal Powder Industries Federation — 18th Annual Meeting — April 23-25, pg. 67-73.

R. S. Jamieson & E. Geijer — Machinability of Sintered Iron — Proceedings — Metal Powder Industries Federation — 15th Annual Meeting — April 20-22, 1959 (Part 1), pg. 82-93; Supplement — 16th Annual Meeting — April 25-27, 1960, pg. 19-33.

I. Jenkins — Recent Developments in Powder Metallurgy — Iron & Steel Inst. Journal *189*, Part I, May 1958, pg. 15-18.

H. F. Johnson — How to Make Structural Parts from Powdered Metals — Canadian Metalworking *24*, July 1961, pg. 26-27.

W. V. Knopp — Sintered Nickel Steels — Precision Metal Molding *18*, No. 9, September 10, 1960, pg. 55-61.

N. Kothari — Heat-Treated Powder — Iron Parts — Machine Design *30*, No. 22, October 30, 1958, pg. 93-96.

J. Kovacs — Porous Metal Filter Media Solve Tough Operating Problems — Materials in Design Engineering *47*, No. 1, January 1958, pg. 126-128.

A. J. Last — Powder Metallurgy and Sintering of Iron — British Chemical Engineer 2, No. 8, August 1957, pg. 433-436.

H. Lefer — Sintered Insert Shaves Cost of Die Cast — Engine Flywheel — Precision Metal Molding *19*, September 1961, pg. 79.

F. V. Lenel, G. S. Ansell, & E. C. Nelson — Metallography of Aluminum Powder Extrusions — Journal of Metals 9, January 1957, pg. 117-124.

F. V. Lenel, A. B. Backensto, Jr. & M. V. Rose — Properties of Aluminum Powders and of Extrusions Produced from Them — Journal of Metals *9*, January 1957, pg. 124-130.

J. A. Lund — Roll Compacting Produces Pure Nickel Strip — Journal of Metals *10*, November 1958, pg. 731-734.

J. E. Miller — Furnace Upgrades Powder Parts to Meet Design Challenge — Iron Age *191*, No. 11, March 14, 1963, pg. 92-93.

J. F. C. Morden — Powder Metallurgy — Metal Industry *90*, No. 6, February 8, 1957, pg. 103-105, 108; April 5, 1957, pg. 265-268.

J. F. C. Morden — Powder Metallurgy — Metal Industry 92, No. 3, January 17, 1958, pg. 43-46.

H. C. Mouwen & T. R. Fruda — Forms and Properties of Porous Metal Products — Proceedings — Metal Powder Industries Federation — 18th Annual Meeting — April 23-25, 1962, pg. 166-171.

W. A. Olep — Powder Metal Products — Wisconsin Engineer 65, October 1960, pg. 14-15, 38, 42.

D. Peckner — Today's Five Trends in Powder Metallurgy — Materials in Design Engineering *53*, No. 4, April 1961, pg. 111-115.

R. L. Pettibone — Powder Metallurgy — Engineering Forum 20, June 1959, pg. *5*.

V. Pryer — Iron Powder Part Hardness Gains Through Carbonitriding — Steel *149*, No. 3, July 17, 1961, pg. 134-135.

C. Rector — Powder Metallurgy, New Factor in Manufacturing Technology — A.S.T.M. Creative Mfg. Seminars — Tech. Paper SP63-37, November 1962, pg. 9.

E. W. Reinsch — Sintered Metal Brake Linings for Automotive Applications — Proceedings — Metal Powder Industries Federation — 18th Annual Meeting — April 23-25, 1962, pg. 131-138.

E. H. Rennhack — Strengthening Effect of Copper in Infiltrated Sintered Iron Parts — Proceedings — Metal Powder Industries Federation — 17th Annual Meeting — April 24-26, 1961, pg. 12-18.

E. H. Rennhack — Copper-Cobalt Alloy Strengthens Iron Powder Parts — Metal Progress *83*, No. 4, April 1963, pg. 93-96.

T. L. Robinson — Designing for Powder Metallurgy — Precision Metal Molding 19, No. 5, 6, 7, 8, 9, 10, 11 — May 1961, pg. 56-59; June 1961, pg. 24-26; July 1961, pg. 25-27; August 1961, pg. 36-38; September 1961, pg. 80-83; October 1961, pg. 69-70; November 1961, pg. 58-60.

K. H. Roll — What to Consider in Choosing Powder Metallurgy — Materials in Design Engineering *47*, No. 4, April 1958, pg. 106-109.

O. V. Roman & H. H. Hausner — Shrinkage of Copper and Iron Powder Compacts During Sintering — Metal Progress *83*, No. 2, February 1963, pg. 104-108, 126, 130.

A. E. S. Rowley — Porous Bronze Effects of Some Powder Characteristics on Pressing and Sintering Properties — Powder Metallurgy — No. 7, 1961, pg. 204-217.

R. L. Sands & J. F. Watkinson — Sintered Stainless Steel — Powder Metallurgy, No. 5, 1960, pg. 85-115.

P. V. Schneider — Producing Powder Metallurgy Parts — Tool & Mfg. Engr. *46*, No. 5, April 1961, pg. 81-86.

J. D. Shaw & W. V. Knopp — Current Developments in the Rolling of Both Ferrous and Non-Ferrous Powders — Proceedings — Metal Powder Industries Federation — 13th Annual Meeting — April 30 - May 1, 1957, pg. 33-41.

J. D. Shaw & W. V. Knopp — Current Status of Aluminum Powder Metallurgy — Proceedings — Metal Powder Industries Federation — 15th Annual Meeting — April 20-22, 1959, pg. 67-71.

A. W. Shearer — Powder Metallurgy Scores Impressive Gains — Automotive Industries *118*, April 15, 1958, pg. 54-56; 116-118; 120.

J. G. Solomir — Progress in Sintered Aluminum Alloys — Metal Progress *83*, No. 1, January 1963, pg. 105-108.

F. L. Spangler & M. E. Lackey — Strengthen Powdered Iron Parts with Steam — Iron Age *180*, No. 5, August 1, 1957, pg. 98-99.

J. H. Speck — Controls Used in Powder Metallurgy — Precision Metal Molding *15*, No. 11 — November 1957, pg. 82-83.

F. W. Starratt — Dispersion Strengthened Alloys Become Commercial — Journal of Metals *14*, August 1962, pg. 561, 562.

S. Storchheim — Aluminum Powder Metallurgy Finally Made Commercially Practical — Proceedings — Metal Powder Industries Federation — 18th Annual Meeting — April 23-25, 1962, pg. 124-130.

C. H. Sump — New Horizons in Powder Metallurgy — Metal Progress *72*, July 1957, pg. 95-96; 116; 118.

R. Talmage — Primary Considerations in the Design and Use of Sintered Metals Parts — Proceedings — Metal Powder Industries Federation — 13th Annual Meeting — April 30 - May 1, 1957, pg. 49-57.

R. Talmage & J. Kolb — Design for Metal Powder Parts — Product Engineering *28*, No. 8, August 1957, pg. 183-190.

R. Talmage — Get Tailor-Made Properties with Sintered Steel — Iron Age *181*, No. 14, April 3, 1958, pg. 104-106.

R. Talmage & R. L. Lee — Guide to Specifying Metal Powder Parts — Product Engineering *31*, July 25, 1960, pg. 56-59.

R. Talmage — Sintered Iron Piston Rings — Metal Progress *79*, No. 5, May 1961, pg. 89-91.

R. Talmage — Producing High-Quality Parts by Powder Metallurgy — Metal Progress 82, No. 6, December 1962, pg. 96-100; 100B; 122; 124; 126; 128; 131; 131-A; 131-B.

P. V. Tarr — Production of Nuts and Washers from Brass Powder — Proceedings — Metal Powder Industries Federation — 14th Annual Meeting — April 21-23, 1958, pg. 107-111.

H. G. Taylor — Influence of Tooling Methods on Density Distribution in Complex Metal Powder Parts — Powder Metallurgy — No. 6, 1960, pg. 87-124.

H. G. Taylor — Powder Metallurgy as Production Technique for Mechanical Components — Machinery (London), *101*, No. 2606, 2608, October 24, 1962, pg. 942-952; November 7, 1962, pg. 1056-1060.

H. G. Taylor — Case Histories of Typical Structural Components Made from Metal Powders — Machinery (London), *102*, No. 2630, April 10, 1963, pg. 832-838.

R. B. Thomson — Application Engineering Applied to Powder Metallurgy Parts — Proceeding — Metal Powder Industries Federation — 16th Annual Meeting — April 25-27, 1960, pg. 130-140.

R. B. Thomson — Redesigning for Powder Parts — American Machinist/Metalworking Manufacturing *105*, April 17, 1961, pg. 113-115.

R. B. Thomson — Performance Reliability of Powder Metallurgy Parts — Proceedings — Metal Powder Industries Federation — 18th Annual Meeting — April 23-25, 1962, pg. 48-57.

V. A. Tracy, G. T. Pyner, & J. F. Watkinson — Sintered High-Temperature Alloys — Journal of Metals 13, No. 5, May 1961, pg. 363-369.

J. R. Van Orsdel — Powder Metallurgy — Journal of Metals 12, January 1960, pg. 50-51.

T. J. Whalen & M. Humenik, Jr. — Mechanisms and Microstructural Aspects of Liquid Phase Sintering — Proceedings — Metal Powder Industries Federation — 18th Annual Meeting — April 23-25, 1962, pg. 85-98.

J. Wilcock & R. J. Woolfall — The Manufacture of Coins by Powder Metallurgy — Proceedings — Metal Powder Industries Federation — 18th Annual Meeting — April 23-25, 1962, pg. 115-123.

______Strong, Ductile, Tough Stainless Sinterings — Precision Metal Molding 15, No. 8, August 1957, pg. 43; 69.

______How to Give Powdered Metals Strength — Steel 141, No. 22, November 25, 1957, pg. 110-111.

______Bigger Powdered Bearings — Steel 141, December 1957, pg. 72.

______Powder Metallurgy — Technique and Applications — Metallurgia 56, No. 338, December 1957, pg. 271-275.

______Sintered Metals Approach Properties of Wrought Alloys — Iron Age 181, January 23, 1958, pg. 88-90.

______Powder Parts Add Sell to Tools — Steel 142, No. 21, May 26, 1958.

______A.S.T.M. Standards on Metal Powders and Metal Powder Products (With Related Information) — American Society for Testing Materials, Philadelphia, Pennsylvania, September 1958.

______Design Properties of Sinterings — Precision Metal Molding 16, No. 10, October 11, 1958, pg. 54-56; November 1958, pg. 30-33.

______Continuous Sintering of Quality Powdered Parts in Mechanized Furnace — Industrial Heating 25, October 1958, pg. 1964-1966; 1968.

______Who Uses Sinterings — Precision Metal Molding 16, November 1958, pg. 24-27.

______For Lower Costs and Unique Properties Sinterings are Choice — Precision Metal Molding 17, January 1959, pg. 43.

______Powder Metallurgy Growing — Chemical and Engineering News 37, March 16, 1959, pg. 46; 48-49.

______Design with Non-Ferrous Sinterings — Precision Metal Molding 17, No. 4, April 1959, pg. 32-33.

______Designing for Powder Metallurgy — Precision Metal Molding 17, No. 5, May 1959, pg. 60-63.

______Selected References on Making High-Temperature Alloys by Powder Metallurgy — Defense Metals Information Center — Battelle Memorial Institute, PB 161197, March 1960, 6P.

______Powder Metal Parts — Machine Design 32, July 7, 1960, pg. 112-122.

______Make Better Use of Powder Metallurgy Parts — Precision Metal Molding 19, April 1961, pg. 27-30.

______Powder Metals Increase Profits — Design Engineer 7, June, 1961, pg. 42-44

______Powder Metallurgy — Machine Production 20, June 1961, pg. 17-19; 23.

______Brass Gears and Cams Win Prize — Precision Metal Molding 19, June 1961, pg. 42-43.

______Preferred Design in Metal Sinterings — Metalworking Production 105, July 5, 1961, pg. 67-70.

______How Design Affects Quality of Powdered Metal Parts — Iron Age 187, July 6, 1961, pg. 76-78.

______Small Stainless Steel Camera Components Produced by Powder Metallurgy — Machinery (London) 99, August 16, 1961, pg. 365.

______Don't Overlook Powdered Metal Parts — Product Engineering (Design Digest Issue) 32, September 4, 1961, pg. 65-67.

______Is Powder Metallurgy Your Answer — Precision Metal Molding 20, January 1962, pg. 48-49.

______The Sintering Process for Small Components — Engineering Materials & Design 5, January 1962, pg. 34-36.

______Checking Bending Strength of Powder Metallurgy Parts — Precision Metal Molding 20, No. 4, April 1962, pg. 27-29.

______Powder Metallurgy Specifications — Materials in Design Engineering 55, May 1962, pg. 145.

______Tailor Made Alloys — Precision Metal Molding 21, No. 4, April 1963, pg. 27-29.

______Powder Metallurgy in Space Age — I.M.D. Powder Metallurgy Committee of Met. Soc. A.I.M.E. — Fall Meeting 1962 — Journal of Metals 15, No. 5, May 1963, pg. 352-358.

INDEX

D

E

F

G

H

I

K

L

M

N

O

P

Q

R

S

T

U

V

W

Y

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