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POTENTIALS FOR POWDER METALLURGY PRODUCTS IN MILITARY APPLICATIONS

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13. ABSTRACT

The potentials for utilization of powder metallurgy by the Army are described in this paper in terms of:

1. Recent developments in the technology of the powder metallurgy process, including powder production, consolidation and sintering, and attainment of high performance properties.

2. Possible applications in Army Mission Areas.

3. Specific illustrations of research and development activities in the Army aimed at utilizing the process for military applications.

This paper concentrates primarily on the forging of low alloy steel preforms. Also it touches briefly on the status of titanium and superalloy powder metallurgy materials. (Authors)

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Monograph by

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POTENTIALS FOR POWDER METALLURGY PRODUCTS IN MILITARY APPLICATIONS

Foreword

This paper was prepared by the Army Materials and Mechanics Research Center, Watertown, Massachusetts, in coordination with Mr. Henry Handler, Army Materiel Command, Washington, D.C.

Introduction

The potentials for utilization of powder metallurgy by the Army touch upon a number of aspects associated with materiel performance requirements and economics.

In this paper, the potentials are described in part, at least, in terms of:

1. Recent developments in the technology of the powder metallurgy process, including powder production, consolidation and sintering, and attainment of high performance properties.

2. Possible applications in Army Mission Areas.

3. Specific illustrations of research and development activities in the Army aimed at utilizing the process for military applications.

The attainment of high performance properties and economies are a direct outcome of the technological advances or developments in the two principal areas of (1) powder production and (2) powder consolidation. Within the framework of the present considerations are the following classes of metals or alloys: ferrous, aluminum, titanium, superalloys, and refractory alloys. Closely related to the attainment of high performance properties for these materials are the latest developments in: "green" compaction, sintering, or pressure sintering of preforms, and the forging, rolling or extrusion techniques for final consolidation of such preforms.

This paper concentrates primarily on the forging of low alloy steel preforms. Also it touches briefly on the status of titanium and superalloy powder metallurgy materials.

Status of Steel Powder Production

The availability of suitable quality powder in tonnage quantities at low cost makes the powder metallurgy process inherently attractive. Inasmuch as the powder properties in themselves are basic to all the processing which follows and to the final attainment of properties in the consolidated material, it is important that the various processes for production of tonnage quantities of ferrous powders be noted. These are listed in Table I. Each of these processes produces powders of different characteristics, such as particle size, particle shape, porosity within the particle, and purity, that influence the character of the consolidation processes, and the properties of the final material.

Process 1, "Atomization", now provides the best combination of economy and powder properties, and for this reason provides a major part of the impetus for the current increase in use of low alloy steel powder metallurgy parts. This applies particularly to the water atomization (Domtar) process.

The atomization process, in summary, utilizes a stream of high velocity air or water to disintegrate a stream of molten metal to particles(1-4). The parameters are readily adjustable to provide the type of control needed to adjust powder characteristics, such as particle size distributions. A number of different nozzle arrangements are employed, and these variations comprise some of the various proprietary aspects in the industry. A key aspect, however, is in the introduction of excess carbon in the feed material to counter the oxidation which is normal to the process(1). In this way; the oxide and carbon content of the powder are controlled within reasonable limits. An important consequence of this approach is that the feed material need not be of high purity with respect to oxygen and carbon, though these levels must be known in order to adjust the added carbon. The atomization concept is known to have been under development and employed in the 1940's. It was not until the mid 1960's, however, that it was perfected to its present status of combined economy and quality of powder properties.

The other processes listed in Table 1 are summarized as follows:

In process 2, "Reduction of Oxides", iron oxide particles are reduced directly to iron particles by exposure to a stream of hot reducing gases, either CO or H_2. The product is familiarly known as sponge iron powder. Powders of this kind have been available since the 1940's or earlier.

In process 3, "Electrolytic Deposition", either iron chloride or iron sulphate are decomposed in an electrolytic bath. High purity iron is deposited at the anode as a spongy mass, which when attritioned provides a high purity iron powder. The product is known as electrolytic powder.

The chief utility of process 4, "Hydrometallurgical Precipitation", is in its application to low grade ore or scrap, which is leached to provide a precipitate of iron chloride. The chloride, in the form of briquettes, is reduced directly to sponge iron of reasonable purity by hydrogen gas, and the reduced mass is then attritioned.

In process 5, "Decomposition of Carbonyl", iron pentacarbonyl in vapor form is spontaneously decomposed by virtue of its chemical instability in that form, precipitating small high purity iron particles of spherical shape. This product, as well as electrolytic powder, was used by the Germans during World

TABLE I. POWDER PRODUCTION METHODS FOR TONNAGE QUANTITIES OF STEEL

1. Atomization

   Air (RZ) or Water (DOMTAR)

2. Reduction of Oxides

   CO Gas (HOEGANAES)

   H_2 (Pyron or Fluidized Bed)

3. Electrolytic Deposition

4. Hydrometallurgical Precipitation

   Reduction of Ferrous Chlorides

5. Decomposition of Carbonyl

War II in an early military application, the sintered iron rotating band for ballistic projectiles. This was done to conserve copper, which was in short supply.

Process 1, "Atomization", provides the best combination of economy and quality. However, development work carried out for the Army on a P/M forging to be discussed later, showed that attainment of optimum mechanical properties required pretreatment of the as-received powders.

Research and Development for Army Mission Areas

In general, all of the mission areas of the Army require support with respect to materials problems. This support is generally in the form of the development of new or improved materials, or improved processing that converts materials to the necessary components. The basic mission areas of the Army are listed in Table II. In each of these mission areas, pacing materials problems have been defined in context of the support mentioned above.

One form of depicting these problems is what is designated as the "Spider Chart", an example of which is shown in Figure 1 for the Aircraft Mission Area. This chart is not meant to cover the entire mission area, but only to serve as an example. The materials problems, or problem areas, as depicted here, are those which pace the advancement or improvement of the various subsystems so that the aircraft may perform its military functions as effectively as possible.

A number of these problems might fall into the area of powder metallurgy processing, for example:

Fabrication of Rotor Blade Spars
Fabrication of Rotor Hubs
Fabrication of Structural Armor Fuselages
Fabrication and Heat Treatment of Gears

Fabricators in these areas most certainly should remain abreast of the advancing powder metallurgy technology or potential for advancement, for cases such as these.

TABLE II. GENERAL MISSION AREAS OF THE ARMY REQUIRING SUPPORT IN MATERIALS AND PROCESSING

Aircraft	Craft
Armaments	Logistics
Armored Vehicles	Missiles
Communications	Mobility

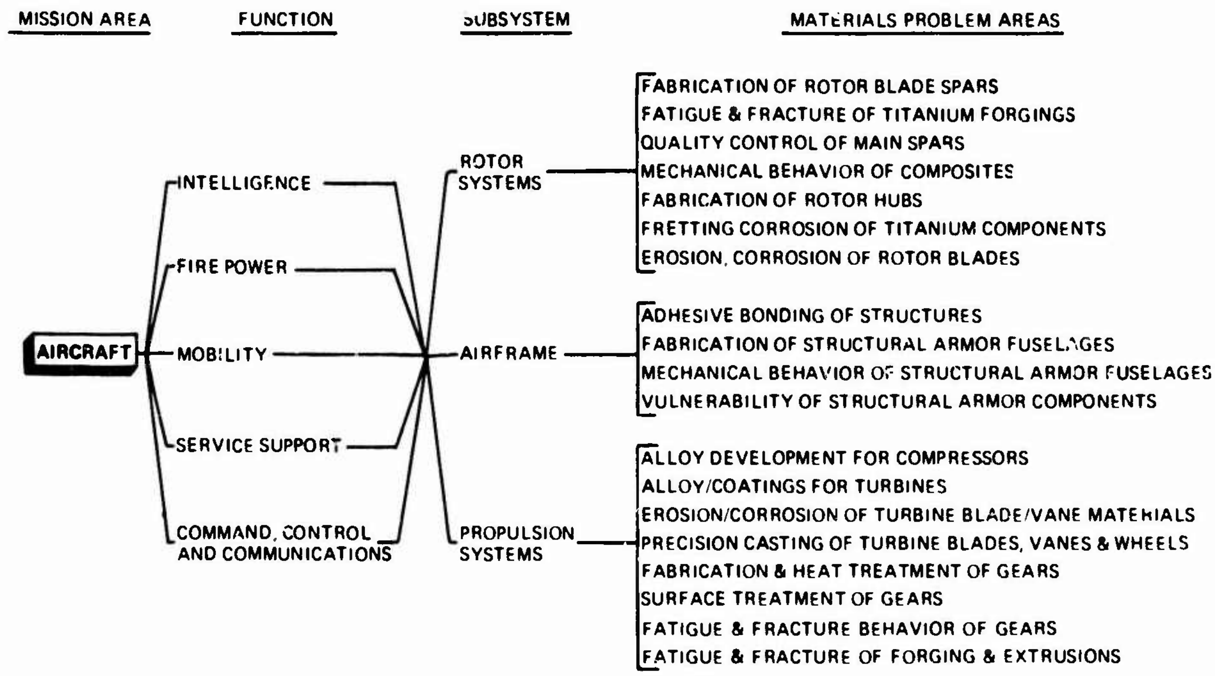


Figure 1. Spider chart relating materials problems to mission areas

In the mission area of Armaments some of the pacing materials problems are shown in Table III. Again this is not meant to indicate coverage of the entire mission area, but only to serve as an example.

Powder metallurgy approaches here might apply to:

Munitions for Hard Target Penetration
Low Pressure and Wear Bands in Munitions
Fabricability of Specific Weapons Components

Powder metallurgy approaches are in fact now being used for certain tungsten alloy projectiles for hard target penetration. Also, sintered iron rotating bands have been investigated but are not presently in production. Currently the application of the forged preform approach for production of a high performance weapons component, a machine gun trigger accelerator, is being investigated by the Weapons Command. More extensive application for these cases depends upon the outcome of the current developments.

More specifically, some of the current research and development programs in powder metallurgy carried on within the Army Materiel Command are listed in Table IV. Those activities already mentioned are included, as well as the development of controlled fragmentation materials, and some supporting studies of the fundamentals of materials migration and surface reactions in sintering. Also included is a study of some of the basic aspects of the forging of sintered alloy preforms.

In addition to this research and development there are programs for the development of manufacturing methods and related technology for specific components. Two current programs of interest are noted in Table V.

TABLE III. SOME PACING MATERIALS PROBLEM AREAS IN SUPPORT OF ARMAMENTS

Munitions	Weapons and Munitions
Hard Target Penetration	Sealing
Integrity of Case	Dynamic Response of Materials
Lethality	Environment and Corrosion
Hot Gas Erosion Control	Weight Reduction
Low Pressure and Wear Bands	Fabricability
	Friction and Wear

TABLE IV. CURRENT ARMY PROGRAM IN POWDER METALLURGY, RESEARCH AND DEVELOPMENT

Alloy Forging Preforms by Powder Metallurgy - AMMRC

Materials Migration During Sintering - AMMRC

Controlled Fragmentation Materials by P/M - AMMRC, MUCOM, Pittman-Dunn Labs

Tungsten Alloys for Penetrator Projectiles - AMMRC, MUCOM, Pittman-Dunn Labs

Sintered Iron for Rotating Bands - MUCOM, Pittman-Dunn Labs

Surface Reactions in Sintering - MUCOM, Pittman-Dunn Labs

TABLE V. CURRENT ARMY PROGRAM IN POWDER METALLURGY, MANUFACTURING METHODS AND TECHNOLOGY DEVELOPMENT

Compacting P/M Preforms for Forging (Machine Gun Accelerator Component) - WECOM, Contractor TRW

Automotive Components by P/M Preform Forging - ATAC, Contractor to be determined

Development and application of the forge preform approach to the mass production of a machine gun trigger accelerator component was singled out by the Weapons Command as a demonstration program for a mass production item requiring reasonable dimensional tolerances, and high performance properties. This program will be discussed in some detail.

The Army Tank and Automotive Command now plans to conduct an investigation on the powder metallurgy preform forging of components similar to the automotive gears recently developed by industry(5).

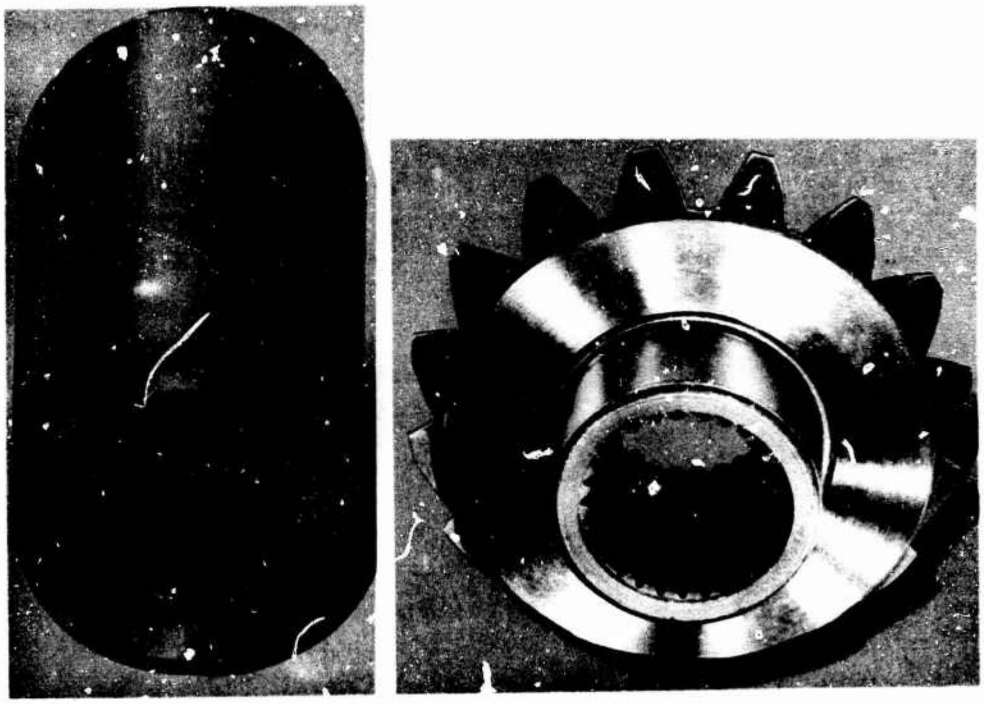
Status of Preform Forging - Technology and Economics

The current technology of low alloy steel powder metallurgy forgings is illustrated by the component shown in Figure 2, a differential side gear and the preform from which it is forged. Components such as these are now scheduled for production, though limited, in industry. The outlook is for eventual adoption throughout the automotive industry. Size of this component is of the order of one pound.

The properties and economies already demonstrated for components such as these comprise the basis for the planned work by the Army Tank and Automotive Command.

Development of components such as the gear shown in Figure 2, and the machine gun trigger accelerator which will be subsequently discussed, demonstrates that adaption of the process called "Powder Preform Forging" requires coordinated efforts in three areas: (1) the input powder, (2) design and fabrication of the preform, and (3) design and execution of the forging operation, as depicted in Figure 3. For example, powder alloy choice is based on the final required properties, but also on powder characteristics relative to processing, such as "green" compressibility, and sinterability. These, of course, relate to powder purity levels, and particle sizes and shapes. For the molding or "green" compaction operation, die design is unique to the final geometry. Compressibility depends significantly on the lubricants employed as well as the powder characteristics. Sintering temperature is designed to give precise sintered dimensions, with sintering atmosphere chosen to minimize oxidation and enhance the sintering operation. The preform is forged to provide a fixed degree of metal flow, either (1) by the so-called conventional method which produces some degree of "flash" within the die components, or (2) by the minimum deformation method by which the metal flows to fill the die cavity without "flash". The second method minimizes the machining required, but the larger amount of metal flow in the first method provides added assurance of obtaining high performance properties. The forging temperature is based largely on obtaining the metal flow required, and the pressing tonnage available, but also on minimizing the extent of die wear which is an important economic factor.

In considering the potentials for powder preform forging, it is essential that the size limitations be recognized. As indicated, the present technology handles sizes of the order of 1/8 to 5 pounds, though an 8-pound transmission gear is scheduled for limited production in the near future. Size limitations



PREFORM FINISHED PART

Figure 2. Differential side gear forged from powder preform. Courtesy of Cincinnati, Inc.

POWDER PREFORM FORGING

- Alloy Choice
- Particle Characterization
- Impurity Requirements
- Availability
- Cost

- "Green" Compaction
  - Lubricant
  - Die Design
- Sintering
  - Temperature
  - Atmosphere
- Sintered Characterization

- Technique
  - Conventional
  - Minimum Deformation
- Die Design
- Temperature
- Forged Characterization
  - Properties
  - Consistency

Figure 3. Factors in powder preform forging

are in press capacity, the requirements being of the order of 20 tons per square inch for preform molding and 30 to 65 tons per square inch for forging of the preform. Commercial presses in the industry as a rule do not exceed capacity of the 1000- to 2000-ton range.

For the future, large forgers visualize powder metallurgy forgings of up to the 250-pound size. Of course, feasibility needs to be demonstrated. If so, it is of interest to note that the largest press in the country, which has 50,000-ton capacity, would be capable of forgings up to the 2,000-pound or somewhat larger size.

Some of the problems of such large sizes, such as "green" compaction, handling the "green" compact, and die costs, might be solved by isostatic compaction techniques.

Assuming that acceptable properties can be obtained, the potential for powder metallurgy arises primarily from the economic consideration involved. The principal cost factors in the area of low alloy steel powder metallurgy forgings are given in Table VI.* Thus powder costs, for a given powder production method relate directly to the alloy content, the present range of 8 to 17 cents per pound being represented by welding rod steel at the low end and 4640 steel at the high end. Molding costs depend on press operating costs and press speeds, presenting a range of the order of 2.5 to 5 cents per part. The cost of sintering is reflected by the mass to be sintered which, based on furnace capacities and operating costs, is of the order of 10 cents per pound. The cost of forging depends upon press speed, presenting a cost of 4 to 5 cents per blow, based on a 12-hour work day. Die costs are a major factor, which vary with size, complexity and the need for redressing as a result of die wear. The associated costs vary widely, and may add from 2 to 25 cents to the cost per part.

TABLE VI. FACTORS IN STEEL POWDER METALLURGY PARTS COSTS

POWDER:	8 to 17 cents/pound. Lowest cost for welding rod. Highest cost for Alloy Steel (4640).
MOLDING:	Operating cost of Cincinnati Presses - $25/hour. Press speeds 600 to 1200 parts/hour, therefore 2-1/2 to 5 cents/part.
SINTERING:	Approximately 10 cents/pound.
FORGING:	4 to 5 cents/blow. Assumes 1-1/2 shifts/day.
TOOLS:	Dies cost $2,000 to $15,000 each. Redressing required after 20,000 parts. Total cost - Redressing and replacement: 2 to 25 cents/part.

*Personal Communication, Dr. Leander Pease, Sinterbond Corporation, Gloucester, Massachusetts.

When applying these factors to the cost of a 1/2-pound part, for example, a variation of the order of 17 to 35 cents per part is obtained, as shown in Table VII. In accordance with Table VI, the principal factors in the cost range are in the powder, and in the tooling.

Similarly, the cost range of a five-pound part, Table VIII, is found to be of the order 97 cents to $1.70 per part, which is 20 to 35 cents per pound. Again the principal factors in the cost range are in the powder, and in the tooling. The relatively high per part cost of sintering of course, relates to the mass of the part.

Though these cost analyses are not given in direct comparison with the costs of equivalent wrought forgings, it is known that the principal economies of the powder metallurgy approach are in (1) greater yield of finished part from the input material, and (2) elimination of most of the intermediate and finish machining. As shown in Table IX, conventional forging loses 35% to 40%

TABLE VII. COST ESTIMATE FOR A 1/2-POUND STEEL PART

	LOWER LIMIT	UPPER LIMIT
Powder	$.04	$.08
Mold	.025	.025
Sinter	.04	.05
Forge or Press	.04	.05
Tooling	.02	.15
	.165/Part	.355/Part

TABLE VIII. COST ESTIMATE FOR A 5-POUND STEEL PART

	LOWER LIMIT	UPPER LIMIT
Powder	$.40	$ .80
Mold	.05	.05
Sinter	.40	.50
Forge or Press	.08	.10
Tooling	.04	.25
	.97/Part	1.70/Part

TABLE IX. GOVERNING FACTORS IN COST SAVINGS

Conventional Forging Loses 35 to 40% of Material.

In P/M Process the Material Waste Factor is 3-1/2%.

Cost Savings are Primarily in Machining of Finished Part.

of the input material so that the yield is only about 60% to 65%. In contrast the yield for the powder metallurgy approach is 97% or more. The machining labor as a major contributing savings factor of course varies with the complexity of the part.

As a concrete example, the economies obtained for three transmission gears of the 0.4 to 7-pound size range are illustrated in Table X. Based on volumes of the order of 500,000 to 5,000,000 parts, as for the automotive industry, the dollar savings are found to be from 16 cents to $1.25 per part. The savings are about 30% to 50% over those of the conventional wrought forgings. Using all three types of gears in a single transmission the total savings is over $2.00 per vehicle, which in terms of mass production is a major savings. This forms a basis for potential savings in Army Materiel.

TABLE X. ESTIMATED COST SAVINGS ON POWDER METALLURGY STEEL TRANSMISSION GEARS

	Net Weight	Conventional Cost	P/M Cost	Estimated Saving
Pinion Gear	0.40 lb	$0.34	$0.18	$0.16
Differential Side Gear	1.03	0.80	0.50	0.30
Ring Gear	7.19	3.00	1.75	1.25

Based on automotive volumes of 500,000 to 5,000,000 pieces

Preform Forging of Machine Gun Trigger Accelerator

Based on developments that have been described for the gears, the Weapons Command has been investigating the powder metallurgy forging technique for a machine gun trigger accelerator component(6). An important factor in this is the necessity for maintaining close tolerances. The tolerance capabilities of the present technology are indicated in Table XI. For the trigger accelerator, the dimensional tolerances shown in Figure 4, of +0.020 inch, -0.020 inch, and +0.010 inch, are well within the indicated capability(7).

The three basic steps of the powder metallurgy approach as shown in Figure 5 are: (1) provision of the input powder, (2) sintering of the preform, and (3) forging of the preform. It should be appreciated however, that the molding and sintering steps required to fabricate the preform are not shown, though the forging operation is accomplished in a single step. In contrast, the conventional forging method requires a number of forging steps, and extensive machining, as illustrated in Figure 6.

TABLE XI. DIMENSIONAL TOLERANCES IN POWDER METAL FORGINGS

Can Hold to Within 0.002 Inch/Inch on a Diameter

No Draft is Necessary

Tolerance in Pressing Direction is 0.004 Inch on Lengths up to 2 Inches

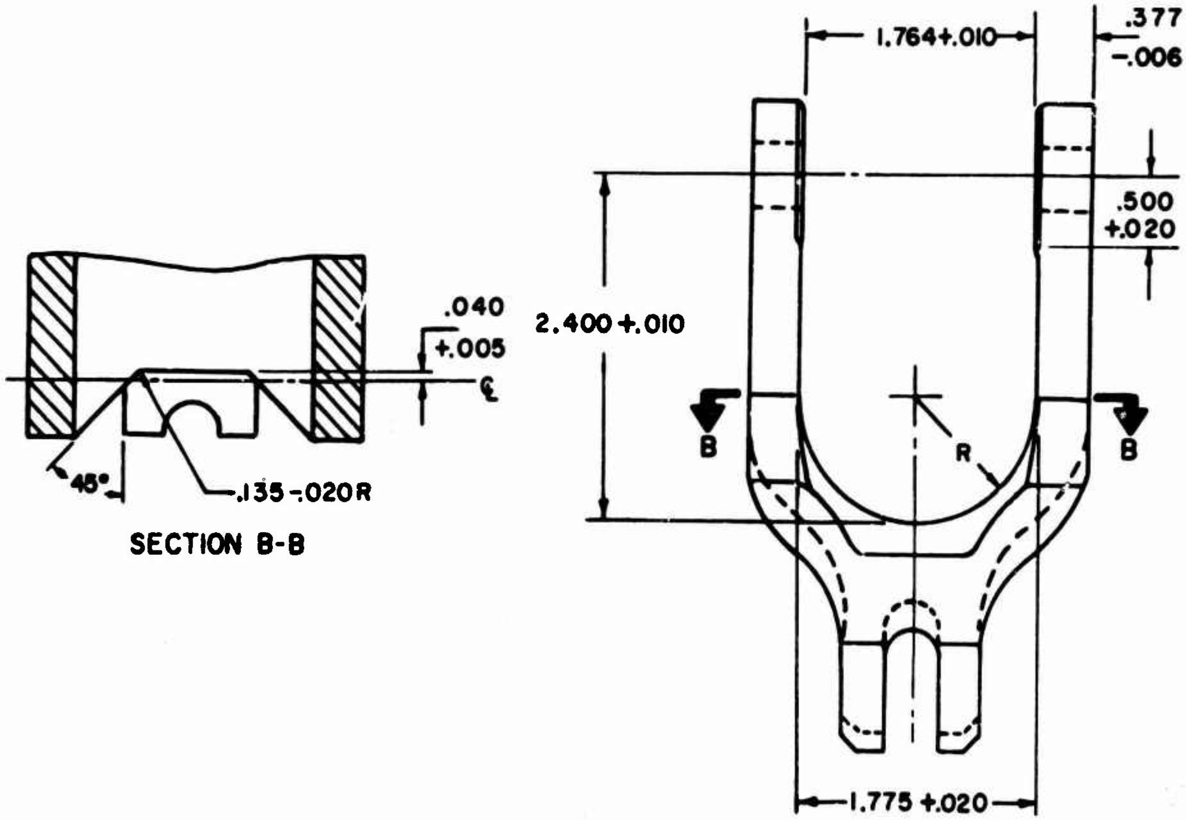


Figure 4. Di.mensional tolerances of trigger accelerator component

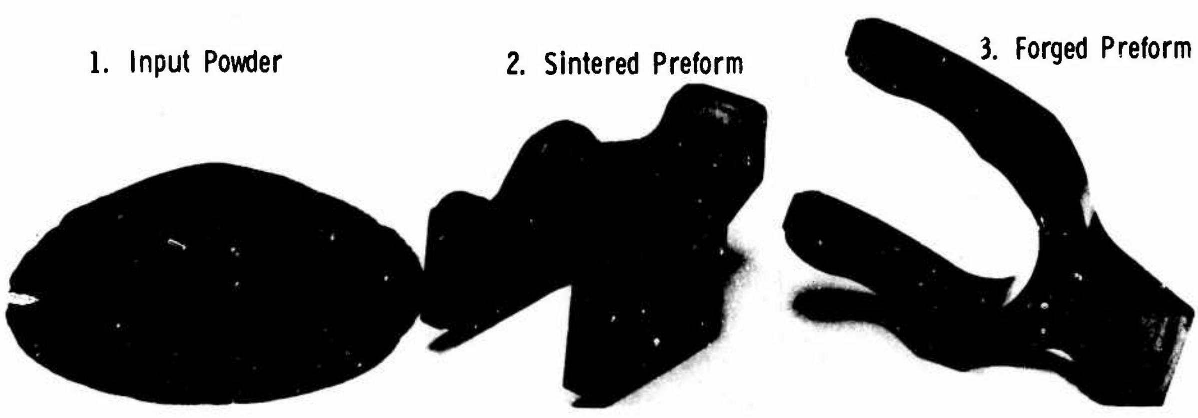
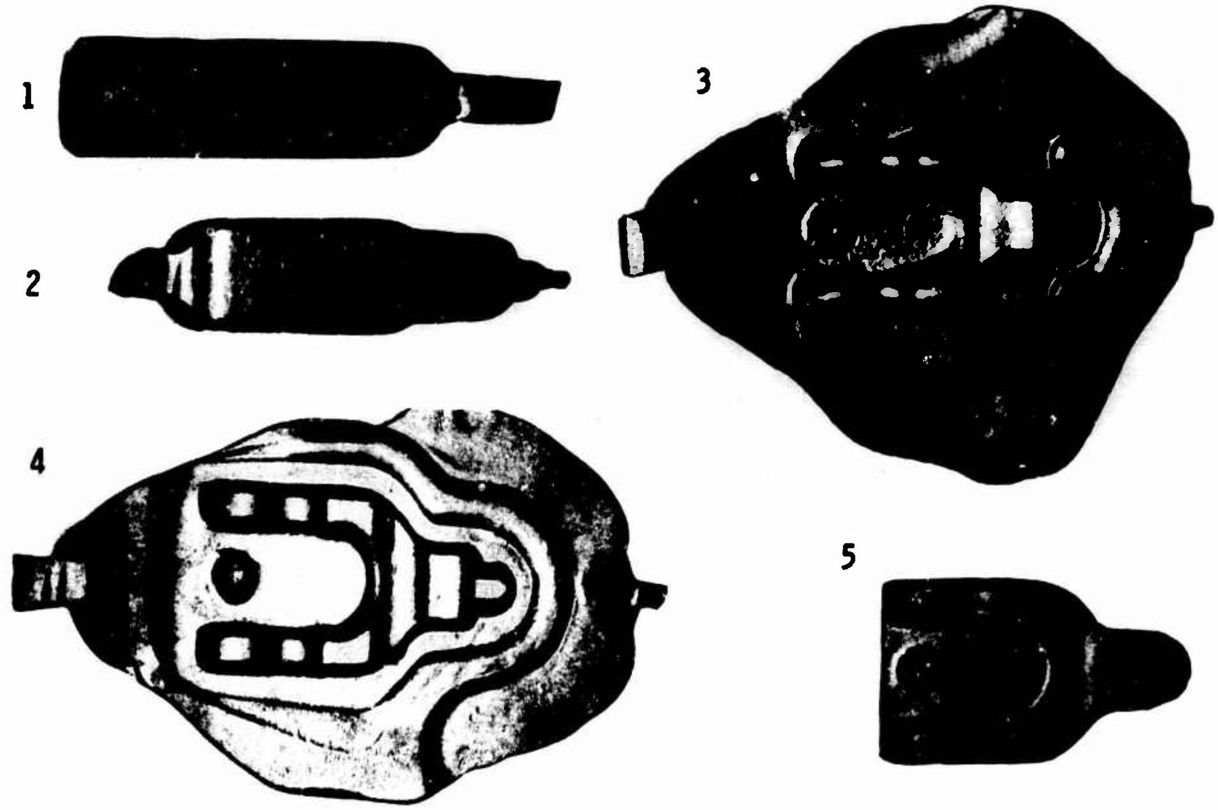


Figure 5. Machine gun accelerator by forging of powder preform



1. Input material - 2, 3, 4. Forging Steps - 5. Trimmed Forging

Figure 6. Machine gun accelerator by forging of wrought material

As stated previously the principal economies of the powder metallurgy approach are in the savings in material and machining, rather than in the number of forging steps alone. Original estimates of the savings for this component were of the order of 50% for mass production quantities.

Molding or "green" pressing of the preform is a key step in the powder preform forging process, since it must produce a preform of dimensions and density precisely suited to the final forging operation. Design of the die is not only unique to the particular part geometry, but also to the green compressibility characteristics of the particular powder employed. Once the die design is fixed, the powder characteristics must be held constant. The molding step for the subject accelerator component is shown schematically in Figure 7, and is accomplished with a single stroke of the press(7).

The forging die is not shown, but forging also is accomplished with a single stroke of the press. In this case, a minimum deformation forging technique is employed, for which the extent of deformation is calculated to obtain properties, without the formation of "flash". The machining requirements thus are minimized. The only finish machining required is indicated in Figure 8 by the dotted lines(7).

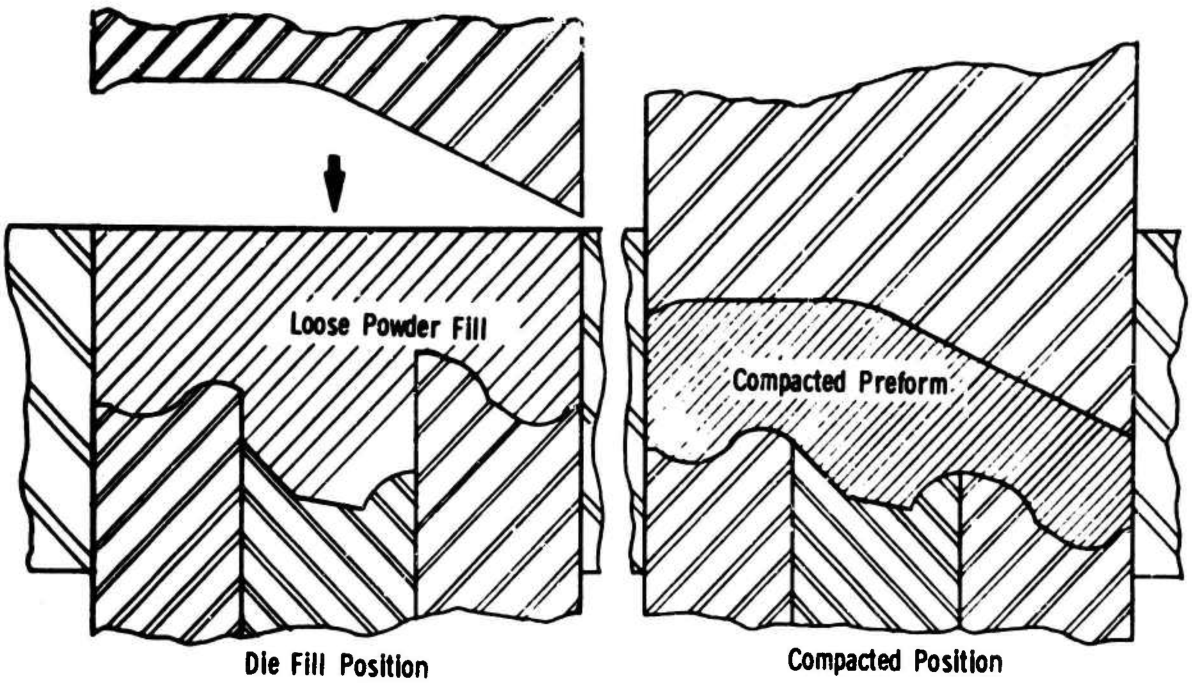


Figure 7. Schematic of die pressing action

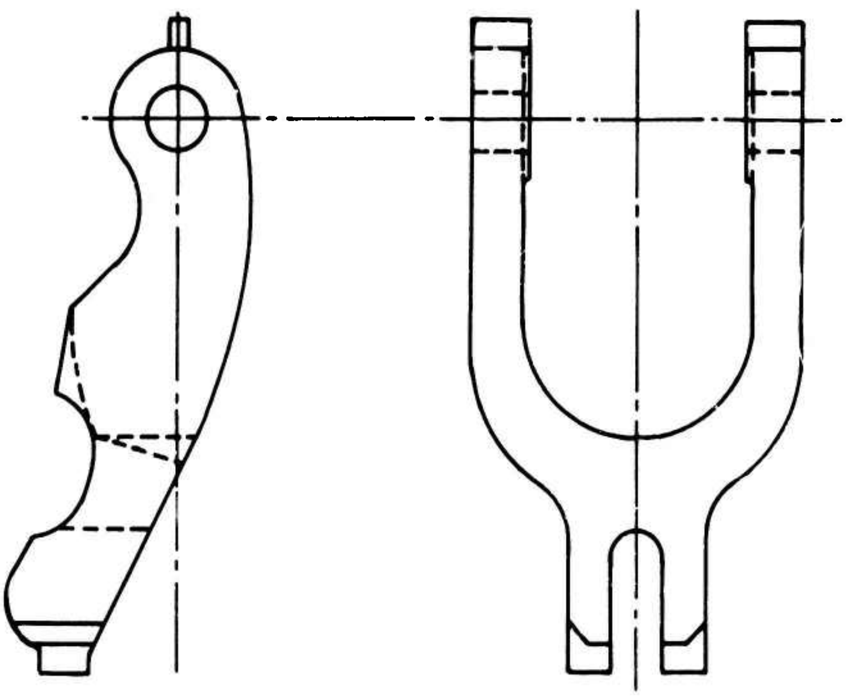


Figure 8. Machining required in component forged from powder preform

Fundamental to the utilization of the powder metallurgy approach for this component is the attainment of high performance mechanical properties, particularly tensile strength, ductility, and impact strength. These are indicated by conventional laboratory testing. Ductility is given by percent elongation or percent reduction in area of the tensile sample. Impact strength is given in terms of foot-pounds of energy required to fracture the standard V-notch Charpy test sample. Figure 9 shows some of the evaluations of the forged accelerator material, and shows that the tensile strength and ductility of the powder metallurgy forgings are equivalent to those of forgings from wrought material.

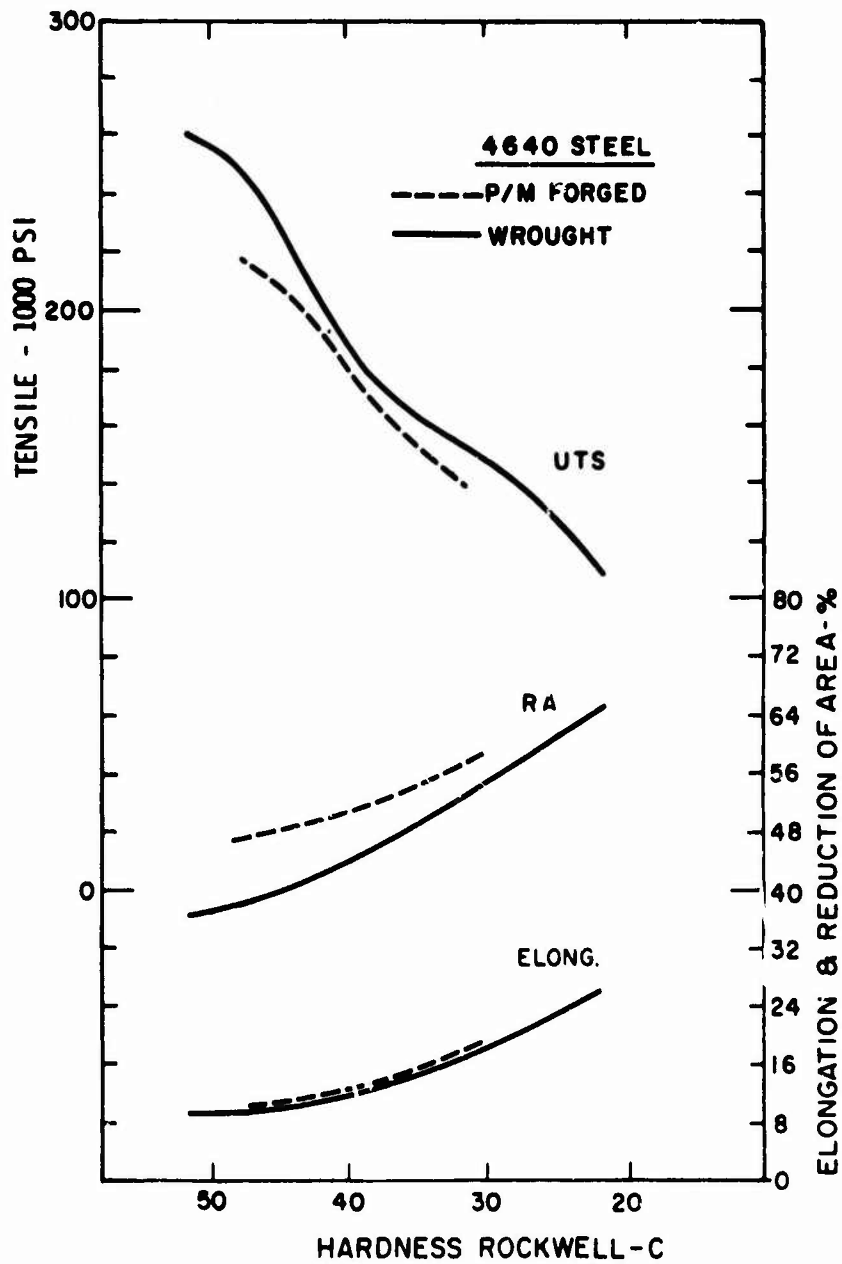


Figure 9. Tensile properties of powder forged material of machine gun trigger accelerator

However, the attainment of this equivalence in ductility is a most recent development in this instance. In the early phases of this work, components produced from as-received powders were deficient in both ductility and impact resistance. This low ductility is shown by the bottom curve in Figure 10. Later it was found that an additional pretreatment of powders in hydrogen enabled the ductility of the forged powder metallurgy material to be equivalent to that of the forged wrought material as shown by the upper two curves in Figure 10 and the corresponding curves in Figure 9. The pretreatment consisted of heating the powder in hydrogen at 1600°F for about 20 minutes, after which the normal cycle of powder metallurgy processing for fabrication of the component was carried on.

Impact resistance also was raised to the level of that of the wrought material as a result of this additional treatment of the powders, as shown in Table XII. This demonstration that the important toughness characteristic of powder metallurgy material can be equal to that of the wrought material adds greatly to the potential for powder metallurgy products in military applications.

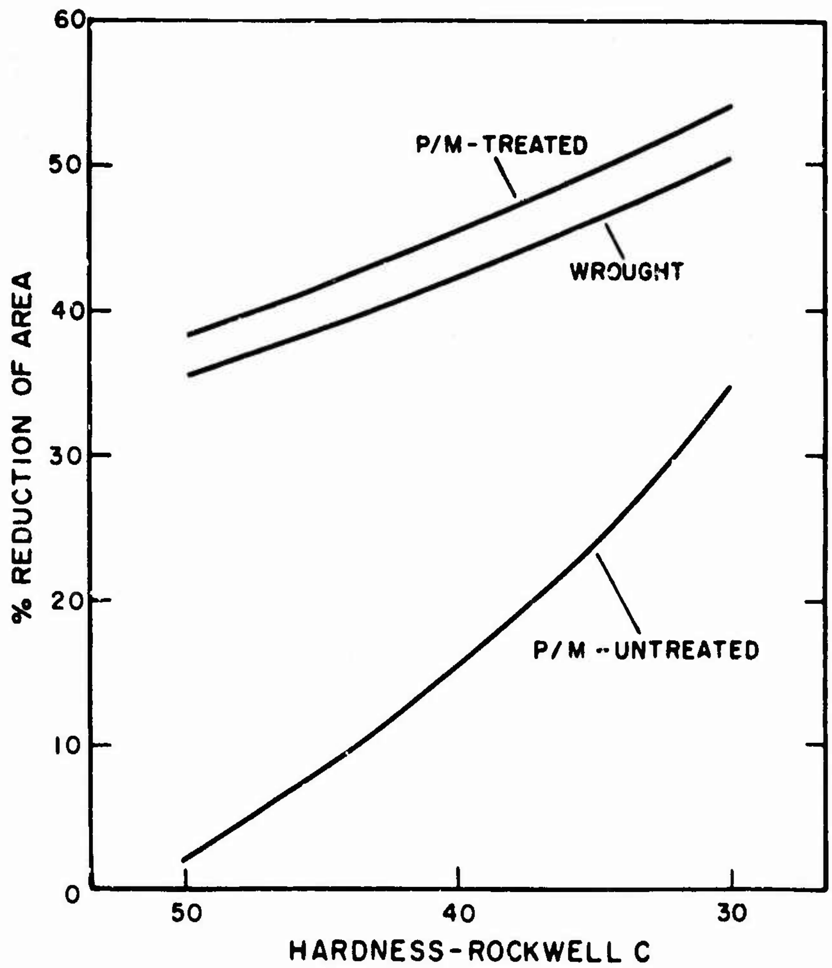


Figure 10. Effect of hydrogen pretreatment of 4640 steel powders on ductility of powder forged material

The traditional deficiency in ductility of 4600 steel powder metallurgy forgings is shown in Figure 11, based on a relatively wide survey of the current literature. It is suggested that this technology can now be improved by the above described pretreatment of powders.

TABLE XII. IMPACT RESISTANCE OF FORGED 4640 STEEL SHOWING EFFECT OF HYDROGEN TREATMENT OF POWDERS

Material	Room Temperature Charpy V-Notch Impact Energy in Foot-Pounds at R_c 30
Conventional Wrought Forging	56
P/M Compacts Forged from As-Received Powders	9 to 15
P/M Compacts Forged from Powders Treated in H_2 at 1600°F	46 to 59

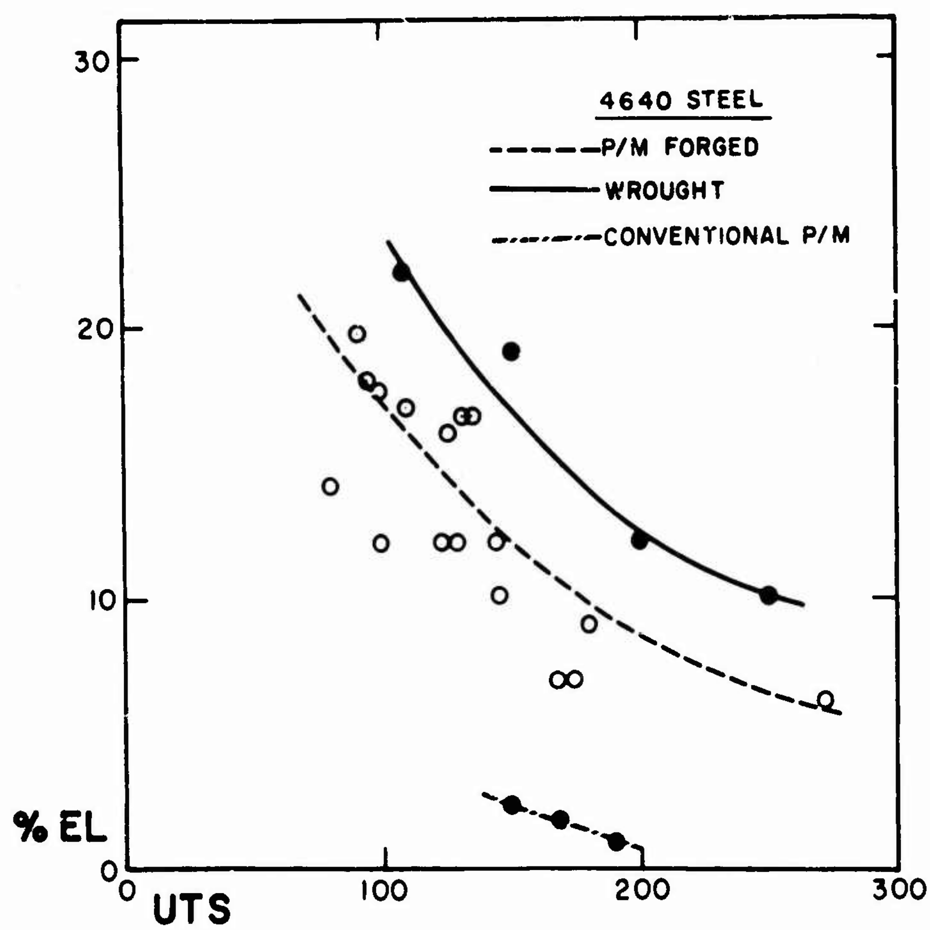


Figure 11. Current status of tensile ductility in 4640 steel comparing powder forged material to wrought material. (Courtesy of Dr. Leander Pease, Sinterbond Corporation)

Spark Sintering

It is now appropriate to mention the process known as Spark Sintering in context with the machine gun trigger accelerator component. Thus, the process has the potential to eliminate the preform fabrication step, shown in Figure 5, a major step in the forge preform approach. This process may be depicted further by the simplified schematic given in Figure 12. The die fill, consisting of a predetermined quantity of loose powder, is heated very rapidly by a surge of combined DC and RF current, and simultaneously pressed to final shape and density. The entire cycle may take place in a matter of seconds or minutes depending on component size, and equipment capacity. The process properly developed and automated has the potential for mass production economy, but many of the economic aspects and some of the technological aspects require further determination. Some of the research and development aspects are being investigated at the Army Materials and Mechanics Research Center.

Titanium Powder Metallurgy

The current technology of titanium alloy powder preform forging is in more preliminary stages of development than that of the low alloy steels. Problems stem largely from impurity pickup and ensuing embrittlement, though this has been overcome in some cases. Magnesium-reduced sponge provides raw material with the best combination of economy and purity. The iodide titanium is of higher purity but also of much higher cost. Powder is manufactured by (1) inert gas atomization of ingot, (2) conversion of ingot by the rotating electrode process, or (3) mechanical attritioning of the metal sponge or the hydrided sponge which is later dehydrided.

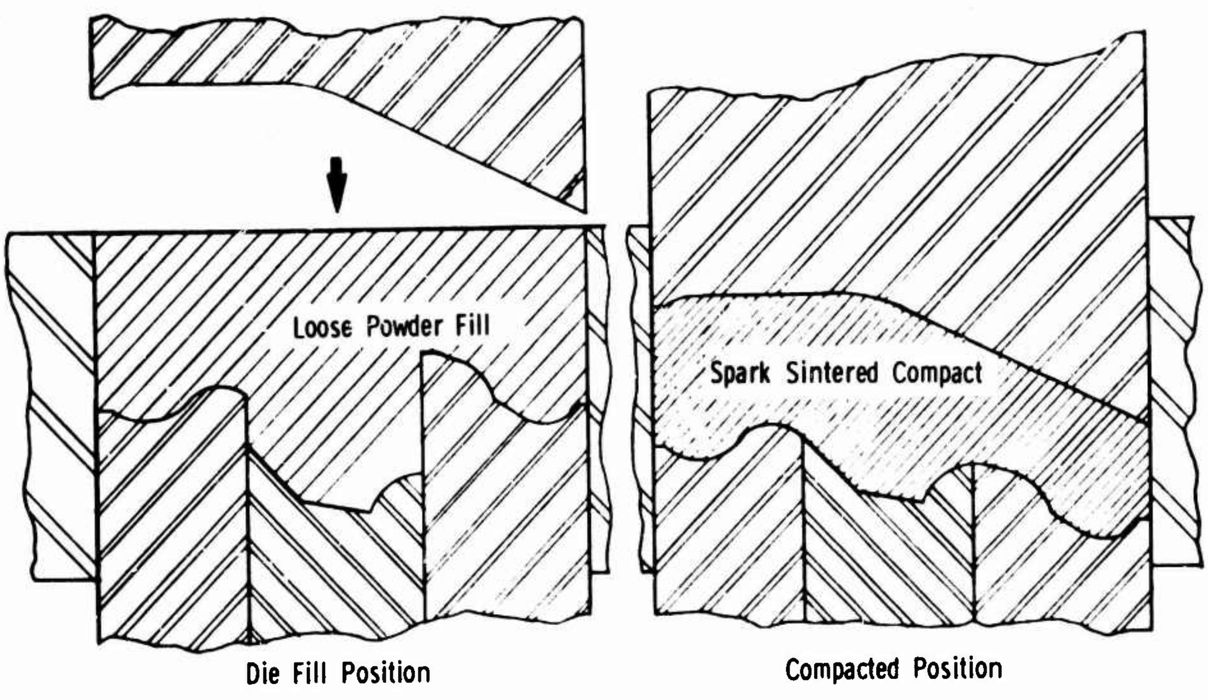


Figure 12. Schematic of spark sintering action

The status of the powder metallurgy forging of panels of the size shown in Figure 13 is given in reference 8 based on recent investigations of the Navy Air Systems Command and their contractor, Grumman Aerospace Corporation. In summary, experimental panels, obtained by the high energy rate forging approach exhibited low strength and low ductility, but panels obtained by isothermal forging exhibited some promise.

However, only those isothermally forged panels made from powders derived by the hydride-dehydride method and employed as elemental mixtures, rather than prealloyed powders, exhibited promising tensile strength and tensile elongation. These properties are summarized in Table XIII.

One problem of the high energy rate forging process was lack of metal flow to fill the die cavity. It is apparent that some of the results in Table XIII that show embrittlement reflect impurity pickup.

However, when the spark sintering process was applied to two-inch diameter compacts of prealloyed powders of Ti-6Al-4V by Lockheed Corporation, the tensile properties were attractive, as given in Table XIV. These spark sintered materials were further responsive to additional thermal or thermomechanical treatment to produce unusually high tensile strength together with good ductility.

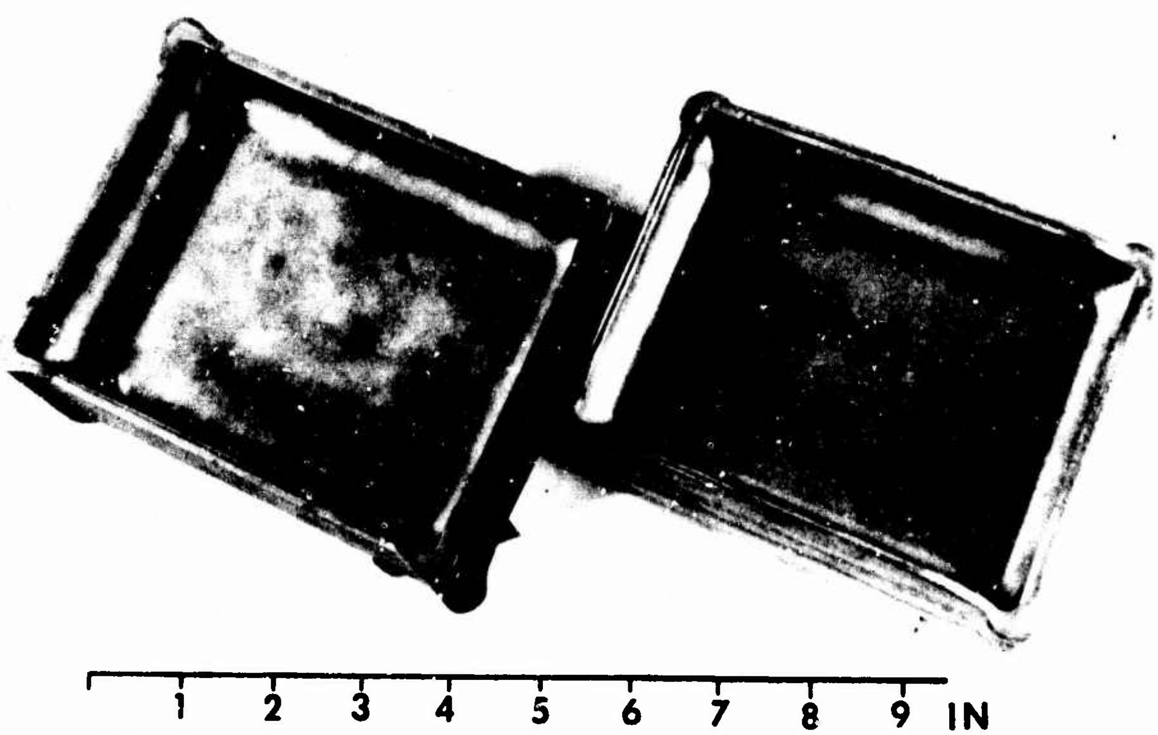


Figure 13. Experimental titanium alloy (Ti-6Al-4V) powder preform forged panels

TABLE XIII. PROPERTIES OF TITANIUM ALLOY (Ti-6Al-4V) ISOTHERMALLY FORGED POWDER PREFORMS*

Powder Source	Hydride-Dehydride and Attritioned	Mg-Reduced Sponge and Attritioned
Powder Type	Elemental Mixtures	Pre-Alloyed
Forging Temperature, °F	1650 to 1750	1650 to 1750
Porosity	None Detected	Some Detected
Tensile Strength (ksi)	150 to 152	115 to 125
Tensile Elongation (%)	13 to 14	Nil

*Preform size 7-1/2"x1-1/4"x1-1/4"
Approximately 45% forging reduction

TABLE XIV. PROPERTIES OF TITANIUM ALLOY (Ti-6Al-4V) SPARK-SINTERED POWDER (9)

Condition	Density (%)	UTS (ksi)	YS (ksi)	Elon. (%)
As Spark Sintered	98 to 100	145	128	7
Spark Sintered and Heat Treated	98 to 100	170	155	6
Spark Sintered and Forged	98 to 100	146	141	13
Spark Sintered, Forged and Heat Treated	98 to 100	170	160	15

NOTE: Prealloyed powders. Billets 2-1/2" diameter x 2" high.

Superalloy Powder Metallurgy

Nickel or cobalt base superalloy powders are produced by either (1) inert gas atomization of ingot, or (2) disintegration of ingot by the rotating electrode process. Control of oxygen impurity is important, and must be maintained below the level of 100 ppm, in order to finally obtain the optimum high temperature strength needed in turbine components.

The powder metallurgy approach in superalloys offers a very particular advantage, derived from the microstructural homogeneity and fine grain size of powder metallurgy compacts. As a result, the phenomenon of superplasticity is exhibited, as shown schematically in Figure 14. This permits the isothermal forging of large contoured turbine components, otherwise not feasible when the alloy is in segregated condition, and/or of large grain size.

An important result is that alloys such as IN-100, which are capable of higher temperature use than alloys normally employed as turbine components, and which otherwise are not forgeable, can now be used(10, 11).

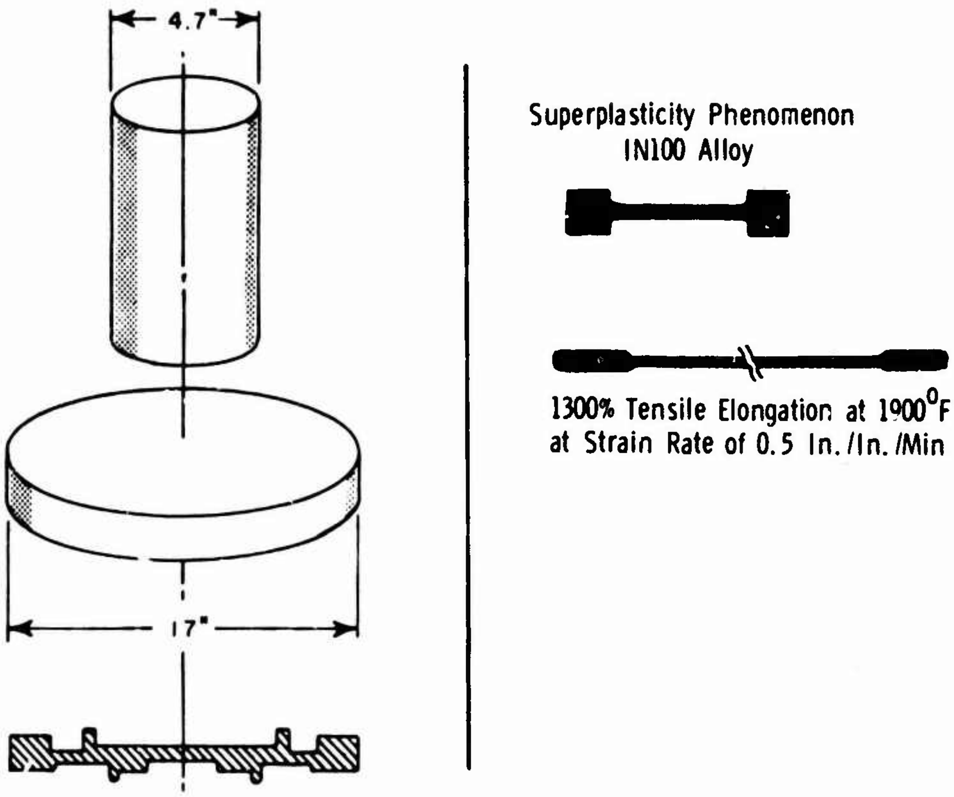


Figure 14. Isothermal forging of superalloy turbine disk (gatorizing)

Summary

1. Army pacing materials problems include many components potentially adaptable to powder metallurgy processing.

2. Economic availability of tonnage quantities of quality steel powders makes the powder metallurgy approach attractive for military applications.

3. Industry has demonstrated production feasibility for small (1- to 8-pound) powder metallurgy forgings of low alloy steels.

4. The Army Tank and Automotive Command (ATAC) plans to investigate the approach for similar components.

5. The Army Weapons Command (WECOM) is now demonstrating feasibility of the powder metallurgy approach for a typical small arms component.

6. Feasibility of application of the powder metallurgy process to larger components (for example, up to 250-pound size) requires demonstration.

7. Titanium alloy powder metallurgy is amenable to isothermal forging and to spark sintering. Scale-up and economics require further demonstration.

8. Large superalloy turbine components are isothermally forgeable from powders. This processing is unique to powder material as a result of the homogeneity which leads to superplastic behavior at specific temperatures.

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