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Standard Terminology of Powder Metallurgy[1]

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1. Scope

1.1 This terminology standard includes definitions that are helpful in the interpretation and application of powder metallurgy terms.

2. Referenced Documents

2.1 *ASTM Standards:*

B 331 Test Method for Compressibility of Metal Powders in Uniaxial Compaction

3. Terminology

3.1 *Powder*—Terms associated with production, characterization, use, and testing of metal powders.

3.1.1 *Table of Contents*

1. Powders:
1.0 General, 3.1.2
1.1 Processes to Produce Powder, 3.1.3
1.2 Types of Powder, 3.1.4
1.3 Shapes of Powder Particles, 3.1.5
1.4 Additives to Powder, 3.1.6
1.5 Treatment of Powder, 3.1.7
1.6 Properties of Powder, 3.1.8
1.7 Procedures to Evaluate Powder, 3.1.9
1.8 Equipment to Evaluate Powder, 3.1.10

2. Forming:
2.0 General, 3.2.1
2.1 Processes for Compacting, 3.2.2
2.2 Conditions of Compacting, ~~3.2.3~~
2.3 Tools Used for Compacting, ~~3.2.4~~ 3.2.3
2.4 Phenomena Resulting from Compaction, ~~3.2.5~~ 3.2.4
2.5 Properties of Compacts, ~~3.2.7~~ 3.2.6
2.6 Forging, ~~3.2.8~~ 3.2.7
2.7 Metal Injection Molding, ~~3.2.9~~ 3.2.8

3. Sintering:
3.1 Process for Sintering, 3.3.1
3.2 Conditions During Sintering, 3.3.2
3.3 Phenomena Resulting from Sintering, 3.3.3
3.4 Properties of Sintered Parts, 3.3.4
3.5 Procedure to Evaluate Sintered Parts, 3.3.5
3.6 Removal of Binders, 3.3.6

4. Postsinter Treatments :

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4.1 Processes, 3.4.1

5. Miscellaneous :
5.1 Definitions, 3.5.1
5.2 Processes, 3.5.2
5.3 Materials, 3.5.3

3.1.2 **General:**

~~*1001 agglomerate, n*~~agglomerate, n —several particles adhering together.

~~*1002 particulate matter, n*~~metal powder, n —particles of elemental metals or alloys, normally less than 1000 μm (1 mm) in size.

particulate matter, n—see **powder**.

~~*1003 P/M, n*—the acronym representing powder metallurgy. Used as **P/M Part**, **P/M Product**, **P/M Process**, and so forth.~~ PM, n—the acronym for powder metallurgy.

~~*1004 powder metallurgy, n*—the production and utilization of metal powders.~~

~~*1005 powder, n*~~powder, n—particles that are usually less than 1000 μm (1 mm) in size.

~~*1006 metal powder, n*—particles of elemental metals or alloys, normally less than 1000 μm (1 mm) in size.~~

~~3.1.3*Processes to Produce Powder:*~~ powder metallurgy, n—the production and utilization of metal powders.

3.1.3 **Processes to Produce Powder:**

~~*1101 atomization, n*—the dispersion of a molten metal into particles by a rapidly moving gas or liquid stream or by mechanical means.~~

~~*1102 granulation, n*—the production of coarse metal particles by pouring the molten metal through a screen into water (shotting) or by violent agitation of the molten metal while solidifying.~~

~~*1103 classification, n*—separation of a powder into fractions according to particle size.~~

~~*1104 air classification, n*~~air classification, n—the separation of powder into particle size fractions by means of an air stream of controlled velocity.

~~*1105 gas classification, n*—the separation of powder into particle size fractions by means of a gas stream of controlled velocity.~~ atomization, n —the dispersion of a molten metal into particles by a rapidly moving gas or liquid stream or by mechanical means.

~~*1106 chemical deposition, n*~~—the precipitation of one metal from a solution of its salts by the addition of another metal or reagent to the solution.

~~*1107 chemically precipitated metal powder, n*~~—powder produced by the reduction of a metal from a solution of its salts either by the addition of another metal higher in the electromotive series or by other reducing agent.

~~*1108 reduced metal powder, n*—metal powder produced, without melting, by the chemical reduction of metal oxides or other compounds.~~ classification, n—separation of a powder into fractions according to particle size.

~~*1109 disintegration, n*~~disintegration, n—the reduction of massive material to powder.

~~*1110 milling, n*~~ gas classification, n—the separation of powder into particle size fractions by means of a gas stream of controlled velocity.

granulation, n —the production of coarse metal particles by pouring the molten metal through a screen into water (shotting) or by violent agitation of the molten metal while solidifying.

milling, n—the mechanical treatment of metal powder, or metal powder mixtures, as in a ball mill, to alter the size or shape of the individual particles or to coat one component of the mixture with another.

~~*1111 pulverization, n*—the reduction in particle size of metal powder by mechanical means, a specific type of disintegration.~~

~~3.1.4~~*pulverization, n* —the reduction in particle size of metal powder by mechanical means, a specific type of disintegration.

reduced metal powder, n—metal powder produced, without melting, by the chemical reduction of metal oxides or other compounds.

3.1.4 **Types of Powder:**

~~*1201 atomized metal powder, n*~~—metal powder produced by the dispersion of a molten metal by a rapidly moving gas, or liquid stream, or by mechanical dispersion.

~~*1202 electrolytic powder, n*—powder produced by electrolytic deposition or by the pulverization of an electrodeposit.~~

~~*1203 dendritic powder, n*—particles, usually of electrolytic origin, having the typical pine tree structure.~~

~~*1204 carbonyl powder, n*~~carbonyl powder, n—a metal powder prepared by the thermal decomposition of a metal carbonyl.

~~*1205 master-alloy powder, n*—a powder with high alloy concentration, designed to be diluted when mixed with a base powder to produce the desired composition.~~ comminuted powder, n—a powder produced by mechanical attrition of solid metal or powder.

~~*1206 pre-alloyed powder, n*—powder composed of two or more elements that are alloyed in the powder manufacturing process in which the particles are of the same nominal composition throughout. Synonymous with **completely alloyed powder**.~~

~~*1207 completely alloyed powder, n*~~completely alloyed powder, n—see **pre-alloyed powder**.

~~*1208 partially alloyed powder, n*—a powder in which the alloy addition or additions are metallurgically bonded to an elemental or pre-alloyed powder.~~ composite powder, n—a powder in which each particle consists of two or more distinct constituents.

*1209 diffusion-alloyed powder, n*dendritic powder, n—particles, usually of electrolytic origin, having the typical pine tree structure.

diffusion-alloyed powder, n—a partially alloyed powder produced by means of a diffusion anneal.

1210 mechanically alloyed powder, n—a composite powder produced by mechanically incorporating other constituents which are generally insoluble within the deformable particles of the matrix metal. electrolytic powder, n—powder produced by electrolytic deposition or by the pulverization of an electrodeposit.

*1211 matrix metal, n*hydrogen-reduced powder, n—powder produced by the reduction of a metal oxide in an atmosphere containing hydrogen.

master-alloy powder, n—a powder with high alloy concentration, designed to be diluted when mixed with a base powder to produce the desired composition.

matrix metal, n —the continuous phase of a polyphase alloy or mechanical mixture; the physically continuous metallic constituent in which separate particles of another constituent are embedded.

1212 composite powder, n—a powder in which each particle consists of two or more distinct constituents. mechanically alloyed powder, n—a composite powder produced by mechanically incorporating other constituents which are generally insoluble within the deformable particles of the matrix metal.

1213 spongy, n—a porous condition in metal powder particles usually observed in reduced oxides. mixed powder, n —a powder made by mixing two or more powders as uniformly as possible. The constituent powders will differ in chemical composition or in particle size or shape, or a combination thereof.

1214 sponge iron, n—a coherent, porous mass of substantially pure iron produced by solid-state reduction of iron oxide (for example, iron ore or mill scale). nanopowder, n—a powder consisting of particles typically less than 100 nm in size.

1215 sponge iron powder, n—ground and sized sponge iron, which may have been purified or annealed or both. partially alloyed powder, n—a powder in which the alloy addition or additions are metallurgically bonded to an elemental or pre-alloyed powder.

1216 mixed powder, n—a powder made by mixing two or more powders as uniformly as possible. The constituent powders will differ in chemical composition or in particle size or shape, or a combination thereof. pre-alloyed powder, n—powder composed of two or more elements that are alloyed in the powder manufacturing process in which the particles are of the same nominal composition throughout. Synonymous with **completely alloyed powder**.

*1217 premix, n*premix, n—a uniform mixture of ingredients to a prescribed analysis, prepared by the powder producer, for direct use in compacting powder metallurgy products.

1218 comminuted powder, n—a powder produced by mechanical attrition of solid metal or powder. sponge iron, n —a coherent, porous mass of substantially pure iron produced by solid-state reduction of iron oxide (for example, iron ore or mill scale).

1219 nanopowder, n—a powder consisting of particles typically less than 100 nm in size. sponge iron powder, n—ground and sized sponge iron, which may have been purified or annealed or both.

1220 hydrogen-reduced powder, n—powder produced by the reduction of a metal oxide in an atmosphere containing hydrogen.

3.1.5*spongy, n*—a porous condition in metal powder particles usually observed in reduced oxides.

3.1.5 **Shapes of Powder Particles:**

1301 acicular powder, n—needle-shaped particles.

1302 needles, n—elongated rod-like particles. flake powder, n —flat or scale-like particles whose thickness is small compared with the other dimensions.

1303 granular powder, n—particles having approximately equidimensional nonspherical shapes.

1304 nodular powder, n—irregular particles having knotted, rounded, or similar shapes.

*1305 irregular powder, n*irregular powder, n—particles lacking symmetry.

1306 spherical powder, n—globular-shaped particles. needles, n—elongated rod-like particles.

1307 flake powder, n—flat or scale-like particles whose thickness is small compared with the other dimensions. nodular powder, n—irregular particles having knotted, rounded, or similar shapes.

*1308 plates, n*platelet powder, n—a powder composed of flat particles having considerable thickness (as compared with flake powder).

plates, n—flat particles of metal powder having considerable thickness.

1309 platelet powder, n—a powder composed of flat particles having considerable thickness (as compared with flake powder).

3.1.6*spherical powder, n*—globular-shaped particles.

3.1.6 **Additives to Powder:**

*1401 binder, n*binder, n—a cementing medium; either a material added to the powder to increase the green strength of the compact, and which is expelled during sintering; or a material (usually of relatively lower melting point) added to a powder mixture for the specific purpose of cementing together powder particles which alone would not sinter into a strong body.

*1402 feedstock, n*dispersion-strengthened material, n—a material consisting of a metal and finely dispersed, substantially insoluble, metallic or nonmetallic phase.

feedstock, n—in metal injection molding (MIM), a moldable mixture of metal powder and binder.

1404 dispersion-strengthened material, n—a material consisting of a metal and finely dispersed, substantially insoluble, metallic

~~or nonmetallic phase.~~ lubricant—material used to reduce inter-particle friction and the friction between the powder mass and the tooling.

~~*1405 pore-forming material, n*~~lubricant (admixed), n—a lubricant incorporated into a powder mixture.

lubricant (die-wall), n—a lubricant applied to the tooling surfaces to facilitate ease of movement of the tooling and the removal of the compact or part from the tooling.

pore-forming material, n—a substance included in a powder mixture that volatilizes during sintering and thereby produces a desired kind and degree of porosity in the finished compact.

3.1.7 **Treatment of Powder:**

~~*1501 blending, n*~~ blending, n—the thorough intermingling of powders of the same nominal composition (not to be confused with mixing).

~~*1502 equalizing, n*~~cross-product contamination, n—the unintentional mixing of powders with distinct differences in either physical characteristics or chemical composition or both.

equalizing, n—see blending.

~~*1503 mixing, n*~~mixing, n—the thorough intermingling of powders of two or more materials. ~~1504 cross-product contamination, n—the unintentional mixing of powders with distinct differences in either physical characteristics or chemical composition or both.~~ ~~3.1.8~~

3.1.8 **Properties of Powder:**

~~*1601 apparent density, n*~~angle of repose, n—the basal angle of a pile formed by powder when freely poured under specified conditions onto a horizontal surface.

apparent density, n—the mass of a unit volume of powder, usually expressed as grams per cubic centimetre, determined by a specified method.

~~*1602 bulk density, n* —~~the mass per unit volume of a powder under nonstandard conditions, for example, in a shipping container (not to be confused with apparent density).

~~*1603 tap density, n*—the apparent density of the powder in a container that has been tapped under specified conditions.~~

~~*1604 flow rate, n*—the time required for a powder sample of standard weight to flow through an orifice in a standard instrument according to a specified procedure.~~

~~*1605 specific surface, n*—the surface area of one gram of powder, usually expressed in square centimetres.~~

~~*1606 compactibility, n*~~compactibility, n—a conceptual term, encompassing the *powder* characteristics of compressibility, green strength, edge retention, and lamination tendency, that relates to the ability of a powder to be consolidated into a usable green compact.

~~*1607 compressibility, n*~~compressibility, n—the capacity of a metal powder to be densified under a uniaxially applied pressure in a closed die.

DISCUSSION—Compressibility is measured in accordance with Test Method B 331 and may be expressed numerically as the pressure to reach a specified density, or alternatively the density at a given pressure.[2]

~~*1608 compression ratio, n*~~—the ratio of the volume of the loose powder to the volume of the compact made from it. Synonymous with **fill ratio**.

~~*1609 fill ratio, n*—~~see **cut, n**—see **fraction.**

fill ratio, n—see **compression ratio**.

~~*1610 oversize powder, n*—particles coarser than the maximum permitted by a given particle size specification.~~

~~*1611 plus sieve, n*—the portion of a powder sample retained on a standard sieve of specified number. (See **minus sieve.**)~~

~~*1612 minus sieve, n*—the portion of a powder sample which passes through a standard sieve of specified number. (See **plus sieve**.)~~

~~*1613 fines, n*~~fines, n—the portion of a powder composed of particles which are smaller than a specified size, currently less than 44 μm. See also **superfines.**

~~*1614 superfines, n*—the portion of a powder composed of particles that are smaller than a specified size, currently less than 10 μm.~~ flow rate, n—the time required for a powder sample of standard weight to flow through an orifice in a standard instrument according to a specified procedure.

~~*1615 fraction, n*~~ fraction, n—the portion of a powder sample that lies between two stated particle sizes. Synonymous with **cut.**

~~*1616 cut, n*—see **fraction.**~~ hydrogen loss, n —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.

~~*1617 subsieve fraction, n*—the portion of powder passing through a 45-μm (no. 325) sieve.~~ minus sieve, n —the portion of a powder sample which passes through a standard sieve of specified number. (See **plus sieve**.)

[2] See Test Method B 331.

1618 sieve fraction, n—that portion of a powder sample that passes through a standard sieve of specified number and is retained by some finer sieve of specified number. oversize powder, n—particles coarser than the maximum permitted by a given particle size specification.

1619 particle size, n—the controlling lineal dimension of an individual particle as determined by analysis with sieves or other suitable means.

1620 particle size distribution, n—the percentage by weight, or by number, of each fraction into which a powder sample has been classified with respect to sieve number or microns. (Preferred usage: "particle size distribution by frequency.")

1621 hydrogen loss, n—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. plus sieve, n—the portion of a powder sample retained on a standard sieve of specified number. (See **minus sieve.**)

*1622 segregation, n*segregation, n—the separation of one or more constituents of a powder, for example, by particle size or chemical composition.

1623 angle of repose, n—the basal angle of a pile formed by powder when freely poured under specified conditions onto a horizontal surface.

3.1.9*Procedures to Evaluate Powder:* sieve fraction, n—that portion of a powder sample that passes through a standard sieve of specified number and is retained by some finer sieve of specified number.

1701 sieve analysis, n—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.** specific surface, n—the surface area of one gram of powder, usually expressed in square centimetres.

*1702 screen analysis, n*subsieve fraction, n—the portion of powder passing through a 45-µm (no. 325) sieve.

superfines, n—the portion of a powder composed of particles that are smaller than a specified size, currently less than 10 µm.

tap density, n —the apparent density of the powder in a container that has been tapped under specified conditions.

3.1.9 **Procedures to Evaluate Powder:**

screen analysis, n—see **sieve analysis.**

1703 sieve classification, n—the separation of powder into particle size ranges by the use of a series of graded sieves.

3.1.10*Equipment to Evaluate Powder:* sieve analysis, n—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, n—the separation of powder into particle size ranges by the use of a series of graded sieves.

3.1.10 **Equipment to Evaluate Powder:**

1801 powder flow meter, n—an instrument for measuring the rate of flow of a powder according to a specified procedure.

3.2 *Forming*—Terms associated with consolidation of metal powders and mixes, including tooling, equipment, and characterization of sintered compacts.

3.2.1 **General:**

2001 green—unsintered (not sintered); for example, green compact, green density, green strength.

2002 preforming—the initial pressing of a metal powder to form a compact that is subjected to a subsequent pressing operation other than coining or sizing. Also, the preliminary shaping of a refractory metal compact after presintering and before the final sintering.

*2003 blank, n*blank, n—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.

2004 briquet, n briquet, n—see **compact.**

2005 compact, n compact, n—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.**

*2006 pressed bar, n*composite compact, n—a metal powder compact consisting of two or more adhering layers, rings, or other shapes of different metals or alloys with each material retaining its original identity.

compound compact, n—a metal powder compact consisting of mixed metals, the particles of which are joined by pressing or sintering or both, with each metal particle retaining substantially its original composition.

green—unsintered (not sintered); for example, green compact, green density, green strength.

preforming—the initial pressing of a metal powder to form a compact that is subjected to a subsequent pressing operation other than coining or sizing. Also, the preliminary shaping of a refractory metal compact after presintering and before the final sintering.

pressed bar, n —a compact in the form of a bar; a green compact.

2007 rolled compact, n—a compact made by passing metal powder continuously through a rolling mill so as to form relatively long sheets of pressed material.

3.2.2 **Processes for Compacting:**

2008 composite compact, n—a metal powder compact consisting of two or more adhering layers, rings, or other shapes of

different metals or alloys with each material retaining its original identity. cold pressing, n —the forming of a compact at room temperature.

2009 compound compact, n—a metal powder compact consisting of mixed metals, the particles of which are joined by pressing or sintering or both, with each metal particle retaining substantially its original composition.

3.2.2*Processes for Compacting:* compacting, n—a process in which a powder held in a die or other container is subjected to an external force in order to densify the powder and produce a compact of prescribed shape and dimensions.

2101 molding, v —see **compacting.** compacting pressure (uniaxial), n—applied force divided by the projected area of contact with the punch(es).

2102 press, v—to apply force to a mass of powder, generally while confined in a die or container, to form a compact. double-action pressing, n—a method by which a powder is pressed in a die between opposing moving punches.

2103 double press-double sinter, n—to repress and sinter a previously presintered or sintered compact.

DISCUSSION—Used to describe a four-step manufacturing process.

2104 single-action pressing, n—a method by which a powder is pressed in a stationary die between one moving and one fixed punch.

DISCUSSION—Only during ejection does either the stationary die or punch move. explosive compaction, n—high-energy consolidation of powders by means of a detonation shock wave.

2105 double-action pressing, n—a method by which a powder is pressed in a die between opposing moving punches. molding, v—see **compacting.**

2106 withdrawal pressing, n—a powder consolidation method in which the die moves downward in relation to the lower punch(es) during compaction. It further descends over the fixed lower punch(es) for ejection, so that the compact may then be pushed off the tooling at this point.

*2107 multiple pressing, n*multiple pressing, n—a method of pressing whereby two or more compacts are produced simultaneously in separate die cavities.

2108 roll compacting, n—the progressive compacting of metal powders by the use of a rolling mill. Synonymous with **powder rolling.**

*2109 powder rolling, n*powder rolling, n—see **roll compacting.**

2110 cold pressing, n—the forming of a compact at room temperature. press, v—to apply force to a mass of powder, generally while confined in a die or container, to form a compact.

2111 compacting, n—a process in which a powder held in a die or other container is subjected to an external force in order to densify the powder and produce a compact of prescribed shape and dimensions. roll compacting, n—the progressive compacting of metal powders by the use of a rolling mill. Synonymous with **powder rolling.**

2112 compacting pressure (uniaxial), n—applied force divided by the projected area of contact with the punch(es). single-action pressing, n—a method by which a powder is pressed in a stationary die between one moving and one fixed punch.

DISCUSSION—Only during ejection does either the stationary die or punch move.

2113 explosive compaction, n—high-energy consolidation of powders by means of a detonation shock wave.

3.2.3*Conditions for Compacting:*

2202 die-wall lubricant, n—synonymous with **die lubricant.**

3.2.4*withdrawal pressing, n*—a powder consolidation method in which the die moves downward in relation to the lower punch(es) during compaction. It further descends over the fixed lower punch(es) for ejection, so that the compact may then be pushed off the tooling at this point.

3.2.3 **Tools Used for Compacting:**

2301 mold, n—in metal or powder injection molding, the member of the tooling into which the powder and binder mixture is forced, and the configuration of which forms the surfaces of the green part. In isostatic compacting, a mold is also the confining form in which powder is isostatically compacted.

*2302 compacting tool set, n*compacting tool set, n—an assembly of tooling items in which powder is pressed.

DISCUSSION—May include a die, punches, and core rods.

2303 die, n—a member of the compacting tool set forming the cavity in which the powder is compacted or a P/M compact is repressed. core rod, n—a member of the compacting tool set that forms internal features such as splines, diameters, keyways, or other profiles in a PM compact.

2304 die body, n die, n—a member of the compacting tool set forming the cavity in which the powder is compacted or a PM compact is repressed.

die body, n—the stationary or fixed part of a die.

2305 die set, n die insert, n—a removable liner or part of a die body.

die set, n—the parts of a press that hold and locate the die in proper relation to the punches.

2306 core rod, n —a member of the compacting tool set that forms internal features such as splines, diameters, keyways, or other profiles in a P/M compact. feedshoe, n—a part of the compacting press that delivers powder to the die cavity, usually by sliding

an open-bottomed powder container over the open top of the die.

2307 punch, n—a member of a compacting tool set used to close the die cavity and transmit the applied pressure to the powder or P/M compact. mold, n—in metal or powder injection molding, the member of the tooling into which the powder and binder mixture is forced, and the configuration of which forms the surfaces of the green part. In isostatic compacting, a mold is also the confining form in which powder is isostatically compacted.

punch, n—a member of a compacting tool set used to close the die cavity and transmit the applied pressure to the powder or PM compact.

DISCUSSION—Multiple upper or lower punches may be needed to compact multilevel parts.

2308 stripper punch, n—a punch that, in addition to forming the top or bottom of the die cavity, later moves further into the die to eject the compact. rotary press, n —a machine fitted with a rotating table carrying multiple dies in which a material is pressed.

2309 split die, n—a die made of parts that can be separated for ready removal of the compact.

2310 die insert, n—a removable liner or part of a die body.

*2311 segment die, n*segment die, n —a die fabricated by the assembly of several die sections within a retaining bolster or shrinkage ring.

2312 rotary press, n—a machine fitted with a rotating table carrying multiple dies in which a material is pressed. split die, n—a die made of parts that can be separated for ready removal of the compact.

2313 feedshoe, n —a part of the compacting press that delivers powder to the die cavity, usually by sliding an open-bottomed powder container over the open top of the die.

3.2.5*Phenomena Resulting from Compaction:* stripper punch, n—a punch that, in addition to forming the top or bottom of the die cavity, later moves further into the die to eject the compact.

3.2.4 **Phenomena Resulting from Compaction:**

2401 bridging, v bridging, v—the formation of arched cavities in a powder mass.

2402 green, adj —unsintered (not sintered); for example, green compact, green density, green strength. cold welding, n —cohesion between two surfaces of metal, generally under the influence of externally applied pressure, at room temperature.

DISCUSSION—Often used to describe the mechanism by which powder particles develop initial bonds and a pressed compact develops green strength.

*2403 springback, n*springback, n—see **green expansion.** green expansion.

3.2.5 **Types of Cracks:**

2404 cold welding, n—cohesion between two surfaces of metal, generally under the influence of externally applied pressure, at room temperature. blister crack, n—typically small defects (star burst) over or around a bump or blister.

DISCUSSION—Often used to describe the mechanism by which powder particles develop initial bonds and a pressed compact develops green strength.

3.2.6*Types of Cracks:* —These may occur during sintering as a result of rapid outgassing of the lubricant. The rapid outgassing may be caused by the specified amount of lubricant being subjected to an excessive heating rate. The defects may also be caused by "concentrated balls" of lubricant, or moisture. During the sintering of the copper base PM parts, hydrogen gas from the furnace atmosphere can diffuse into the compact and react with residual oxygen, producing steam that can form blisters and cracks. In that industry, this is also called embrittlement, and is not to be confused with the hydrogen embrittlement of high strength steel.

2405 cracks (rigid die system (RD)), n—the following names and definitions apply only to items produced in a rigid die system (RD) as opposed to those cracks produced by other systems, that is, metal injection molding, vacuum hot pressing, and so forth.

*2406 crack (RD), n*crack (RD), n—generally a planar defect.

2407 green crack, n—a defect that occurs prior to sintering. cracks (rigid die system (RD)), n—the following names and definitions apply only to items produced in a rigid die system (RD) as opposed to those cracks produced by other systems, that is, metal injection molding, vacuum hot pressing, and so forth.[3]

2408 pressing crack, n—a defect occurring as a result of the forming operation. densification crack, n—a defect caused by differential stresses in a region of a part that has experienced large differences in shrinkage during sintering.

2409 slip (rupture) crack, n—a defect that occurs typically at the junction between levels of a multilevel part (occurs during the pressing cycle while powder is transferring from one level (area) to another). ejection crack, n—a defect that occurs during the removal of the compact from the tooling (usually occurs in multilevel parts that are not supported uniformly on all lower surfaces).

*2410 lamination crack, n*green crack, n—a defect that occurs prior to sintering.

lamination crack, n—a defect(s) roughly parallel to the punch faces of the part (these defects usually occur when powder is compressed to high density and the relaxation forces during pressure release exceed the binding force between the particles).

2411 ejection crack, n—a defect that occurs during the removal of the compact from the tooling (usually occurs in multilevel parts that are not supported uniformly on all lower surfaces). pressing crack, n—a defect occurring as a result of the forming operation.

[3] There is detailed information on numerous cracks, their location, cause, and prevention in a handbook published by Metal Powder Industries Federation, Princeton, New Jersey, "The Common Cracks in ~~P/M~~PM Compacts" by D. Zenger and H. Cai.

2412 push-off crack, n—a defect or crushed surface caused by the action of the feed shoe or other mechanism removing the compact from the area above the lower punch.

2413 handling crack, n—a defect that occurs in a green part after removal from the press, and prior to sintering.

*2414 sintering crack, n*sintering crack, n—a defect that occurs during the sintering operation.

2415 blister crack, n—typically small defects (star burst) over or around a bump or blister.

DISCUSSION—These may occur during sintering as a result of rapid outgassing of the lubricant. The rapid outgassing may be caused by the specified amount of lubricant being subjected to an excessive heating rate. The defects may also be caused by "concentrated balls" of lubricant, or moisture. During the sintering of the copper base P/M parts, hydrogen gas from the furnace atmosphere can diffuse into the compact and react with residual oxygen, producing steam that can form blisters and cracks. In that industry, this is also called embrittlement, and is not to be confused with the hydrogen embrittlement of high strength steel.

2416 densification crack, n—a defect caused by differential stresses in a region of a part that has experienced large differences in shrinkage during sintering.

3.2.7*slip (rupture) crack, n*—a defect that occurs typically at the junction between levels of a multilevel part (occurs during the pressing cycle while powder is transferring from one level (area) to another).

3.2.6 **Properties of Compacts:**

2501 green density, n —the mass per unit volume of an unsintered compact.

2502 pressed density, n—synonymous with **green density.**

*2503 green expansion, n*green expansion, n—the increase in dimensions of an ejected compact relative to the die dimensions, measured at right angles to the direction of pressing. Synonymous with **springback**.

xxxx green strength, n—stress required to break an unsintered compact.

3.2.8*green strength, n*—stress required to break an unsintered compact.

pressed density, n—synonymous with **green density.**

3.2.7 **Forging:**

2601 powder forging, n—densification (generally hot) of a P/M preform by forging.

DISCUSSION—In the case in which the preform has been sintered, the process is often referred to as "sinter forging." hot repress powder forging, n—hot densification of a PM preform by forging where the material flow is mainly in the direction of forging.

*2602 P/F, n*hot upset powder forging, n—hot densification of a PM preform by forging where there is a significant amount of lateral material flow.

PF, n—the acronym for powder forging. See **powder forging.**

*2603 P/M forging, n*PM forging, n—see **powder forging.**

2605 preform, n —a P/M compact intended to be changed in shape through deformation and densification. powder forging, n—densification (generally hot) of a PM preform by forging.

DISCUSSION—In the case in which the preform has been sintered, the process is often referred to as "sinter forging."

2606 sinter forging, n—see powder forging. preform, n—a PM compact intended to be changed in shape through deformation and densification.

2610 hot upset powder forging, n—hot densification of a P/M preform by forging where there is a significant amount of lateral material flow.

2611 hot repress powder forging, n—hot densification of a P/M preform by forging where the material flow is mainly in the direction of forging.

3.2.9*sinter forging, n*—see powder forging.

3.2.8 **Metal Injection Molding:**

2701 metal injection molding (MIM), n—a process in which a mixture of metal powders and a binder system is forced under pressure into a mold. See also **powder injection molding**.

*2702 MIM*MIM—see **metal injection molding**.

*2703 powder injection molding (PIM), n*PIM—see **powder injection molding**.

powder injection molding (PIM), n—a process in which a mixture of powders and a binder system is forced under pressure into a mold. See also **metal injection molding**. 2704 PIM—see **powder injection molding**.

3.3 *Sintering*—Terms associated with forming a metallic bond among particles including processes, equipment, and characterization of sintered compacts.

3.3.1 **Processes for Sintering:**

3101 sinter, v—to increase the bonding in a mass of powder or a compact by heating below the melting point of the main constituent.

3102 solid-state sintering, v—sintering of a powder or compact without formation of a liquid phase.

3103 presintering, v—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 before sintering.

*3104 activated sintering, v*activated sintering, v—a sintering process during which the rate of sintering is increased, for example,

by addition of a substance to the powder or by changing sintering conditions.

3105 continuous sintering, v—presintering, or sintering, in such manner that the objects are advanced through the furnace at a fixed rate by manual or mechanical means. Synonymous with **stoking.**

3106 stoking, v —see **continuous sintering.** cored bar, n—a compact of bar shape heated by its own electrical resistance to a temperature high enough to melt its interior.

*3107 liquid phase sintering, v*infiltration, n —a process of filling the pores of a sintered, or unsintered, compact with a metal or alloy of lower melting point.

liquid phase sintering, v—sintering of a compact, or loose powder aggregate, under conditions in which a liquid phase is present during part of the sintering cycle.

3108 infiltration, n—a process of filling the pores of a sintered, or unsintered, compact with a metal or alloy of lower melting point. nitrogen alloying, n—the transfer of nitrogen from a furnace atmosphere to powder or a PM part, in such a way as to increase the nitrogen content of the material within controlled limits.

3109 nitrogen alloying, n—the transfer of nitrogen from a furnace atmosphere to powder or a P/M part, in such a way as to increase the nitrogen content of the material within controlled limits. presintering, v —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 before sintering.

3110 cored bar, n—a compact of bar shape heated by its own electrical resistance to a temperature high enough to melt its interior.

3.3.2Conditions During Sintering: sinter, v—to increase the bonding in a mass of powder or a compact by heating below the melting point of the main constituent.

3201 packing material, n—any material in which compacts are embedded during the presintering or sintering operation. solid-state sintering, v—sintering of a powder or compact without formation of a liquid phase.

3202 sintering time, n—the total elapsed time during which the P/M part/specimen is within (±) a specified percentage of the stated sintering temperature. stoking, v—see **continuous sintering.**

3.3.2 **Conditions During Sintering:**

*3203 dissociated ammonia, n*cracked ammonia, n—see **dissociated ammonia**.

dissociated ammonia, n—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.

*3204 exothermic atmosphere (gas), n*endothermic gas, n—a reducing gas atmosphere used in sintering, produced by the reaction of a hydrocarbon vapor and air over a catalyst with the use of an external heat source. It is low in carbon dioxide and water vapor while containing combustibles of about 60 atomic percent hydrogen and carbon monoxide combined.

exothermic atmosphere (gas), n—a reducing gas atmosphere used in sintering, produced by partial or complete combustion of hydrocarbon fuel gas and air with the associated generation of heat. The maximum combustible content is approximately 25 atomic percent.

3205 endothermic gas, n—a reducing gas atmosphere used in sintering, produced by the reaction of a hydrocarbon vapor and air over a catalyst with the use of an external heat source. It is low in carbon dioxide and water vapor while containing combustibles of about 60 atomic percent hydrogen and carbon monoxide combined. packing material, n—any material in which compacts are embedded during the presintering or sintering operation.

3206 cracked ammonia, n—see **dissociated ammonia**.

3.3.3Phenomena Resulting from Sintering: sintering time, n—the total elapsed time during which the PM part/specimen is within (±) a specified percentage of the stated sintering temperature.

3.3.3 **Phenomena Resulting from Sintering:**

3301 powder metallurgy part, n—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. Synonymous with **P/M part**.

3302 P/M part, n —see **powder metallurgy part**.

3303 fully dense material, n—a material completely free of porosity and voids. blistered compact, n—a sintered object characterized by having blisters or eruptions on the surface.

DISCUSSION—This is a conceptual term. In practice, complete densification is difficult to achieve and some microporosity will generally be present. The measured density of a material depends on its specific chemistry, thermomechanical condition, and microstructure. —In ferrous materials, this effect is often caused by *in situ* gas decomposition and soot formation that forces particles apart and causes the compact to blister.

*3304 cake, n*cake, n—a bonded mass of unpressed metal powder.

DISCUSSION—Often refers to the form of powder as it exits a furnace.

3305 closed pore, n—a pore not communicating or connected with an exterior surface.

3306 open pore, n—a pore communicating with an exterior surface.

*3307 communicating pores, n*communicating pores, n—see **interconnected porosity.**

3308 interconnected porosity, n—a network of pores in and extending to the surface of a sintered compact. Usually applied to

~~powder metallurgy materials in which the interconnected porosity is determined by impregnating the specimens with oil. Synonymous with **communicating pores**.~~

~~*3309 exudation, n*~~exudation, n—the action by which all or a portion of the low melting constituent of a compact is forced to the surface during sintering. Sometimes referred to as "bleed out." Synonymous with **sweating** .

~~*3310 sweating, n* —see **exudation**.~~ fluid permeability, n—see **permeability**.

~~*3311 infiltration erosion, n*~~fully dense material, n—a material completely free of porosity and voids.

DISCUSSION—This is a conceptual term. In practice, complete densification is difficult to achieve and some microporosity will generally be present. The measured density of a material depends on its specific chemistry, thermomechanical condition, and microstructure.

infiltration erosion, n—the pitting, channeling, and coarsening of the surface porosity that results from the dissolution of the base metal by the liquid infiltrant, as the infiltrant flows into the matrix.

~~*3312 infiltration residue, n*~~—material that remains on the surface of the part after infiltration.

~~*3313 blistered compact, n*—a sintered object characterized by having blisters or eruptions on the surface.~~

~~DISCUSSION—In ferrous materials, this effect is often caused by *in situ* gas decomposition and soot formation that forces particles apart and causes the compact to blister.~~ interconnected porosity, n—a network of pores in and extending to the surface of a sintered compact. Usually applied to powder metallurgy materials in which the interconnected porosity is determined by impregnating the specimens with oil. Synonymous with **communicating pores**.

~~*3315 neck formation, n*~~—during sintering, the development of a neck-like bond between particles.

~~*3316 slumping, n* —the lack of shape retention of a molded part, during subsequent processing, because of the effect of gravity.~~ open pore, n—a pore communicating with an exterior surface.

~~*3317 warpage, n* —distortion that may occur in a compact during sintering.~~

~~*3318 oxide network, n*~~oxide network, n —continuous or discontinuous oxides that follow prior particle boundaries.

~~*3319 surface finger oxide, n*—the oxide that follows prior particle boundaries into a part from the surface and cannot be removed by physical means, such as rotary tumbling.~~ PM part, n—see **powder metallurgy part**.

~~*3320 pore, n*~~pore, n—an inherent or induced cavity within a particle or within an object.

~~*3322 fluid permeability, n*—see **permeability**.~~

~~*3.3.4Properties of Sintered Parts:*~~ powder metallurgy part, n—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. Synonymous with **PM part**.

slumping, n—the lack of shape retention of a molded part, during subsequent processing, because of the effect of gravity.

surface finger oxide, n—the oxide that follows prior particle boundaries into a part from the surface and cannot be removed by physical means, such as rotary tumbling.

sweating, n—see **exudation**.

warpage, n—distortion that may occur in a compact during sintering.

3.3.4 **Properties of Sintered Parts:**

~~*3401 dimensional change of a compact, n*~~apparent hardness, n—the hardness of a P M material (including the effects of porosity), measured using macroindentation hardness equipment.

DISCUSSION—See general description of production, properties, and uses of sintered metal powder bearings and structural parts, paragraph on density and mechanical properties, information on hardness measurement, Volume 02.05, gray pages.[4]

apparent porosity, n—specific to cemented carbides, microstructural features that appear to be pores in a properly prepared, unetched surface; these features may result from uncombined carbon or nonmetallic inclusions as well as actual porosity.

density (dry), n—the mass per unit volume of an unimpregnated powder metallurgy part.

density (wet), n—the mass per unit volume of a powder metallurgy part impregnated with oil or other nonmetallic materials.

density ratio, n —the ratio, often expressed as a percentage, of the density of a porous material to the density of the same material completely free of porosity. Synonymous with **relative density**.

dimensional change of a compact, n—the difference, at room temperature, between the size of the sintered specimen and the die size.

DISCUSSION—The difference in dimensions is usually reported as a percentage of the die size. It should include a (+) when the sintered part is larger than the die size and a (−) when the sintered part is smaller than the die size.

~~*3402 growth, n*~~growth, n—an increase in dimensions of a compact which may occur during sintering. (Converse of **shrinkage**.)

~~*3403 shrinkage, n*—a decrease in dimensions of a compact which may occur during sintering. (Converse of **growth**.)~~

~~*3404 infiltrant efficiency, n*~~infiltrant efficiency, n—the ratio of the mass of infiltrant absorbed by the part to the mass of infiltrant originally used, expressed as a percentage.

[4] For a discussion of apparent hardness, see the section on Density in General Description of Production, Properties, and Uses of Sintered Metal Powder Bearings and Structural Parts, which appears in the *Annual Book of ASTM Standards*, Vol 02.05.