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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:*

B331 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.

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3.1.2 **General:**

agglomerate, n—several particles adhering together.

cooling rate, n—the average temperature change per second between prescribed temperatures during the cooling phase of a thermal process.

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

particulate matter, n—see **powder**.

PM, n—the acronym for powder metallurgy.

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

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

3.1.3 **Processes to Produce Powder:**

air classification, n—the separation of powder into particle size fractions by means of an air 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.

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.

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.

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

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

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.

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:**

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.

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

comminuted powder, n—a powder produced by mechanical attrition of solid metal or powder.

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

composite powder, n—a powder in which each particle consists of two or more distinct constituents.

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.

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

hybrid-alloy powder, n—a pre-alloyed or diffusion-alloyed powder to which either elemental or master-alloy metal powders have been admixed.

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.

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.

mixed powder, n—see **powder mixture**.

nanopowder, n—a powder consisting of particles typically less than 100 nm in size.

partially alloyed powder, n—a powder in which the alloy addition or additions are metallurgically bonded to an elemental or pre-alloyed powder.

powder mixture, n—a powder made by mixing two or more powders of differing chemical composition, particle size distribution, particle shape, or a combination of these characteristics.

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**.

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

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).

sponge iron powder, n—ground and sized sponge iron, which may have been purified or annealed or both.

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

3.1.5 **Shapes of Powder Particles:**

acicular powder, n—needle-shaped particles.

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

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

irregular powder, n—particles lacking symmetry.

needles, n—elongated rod-like particles.

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

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.

spherical powder, n—globular-shaped particles.

3.1.6 **Additives to Powder:**

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.

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.

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

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:**

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

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.

mixing, n—the thorough intermingling of powders of two or more materials.

3.1.8 **Properties of Powder:**

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.

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).

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.

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 B331 and may be expressed numerically as the pressure to reach a specified density, or alternatively the density at a given pressure.[2]

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[2] See Test Method B331.

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**.

cut, n—see **fraction.**

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

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.**

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.

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

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.

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

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

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

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.")

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

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

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.

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

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.**

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:**

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:**

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.

briquet, n—see **compact.**

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.**

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.

heating rate, n—the average temperature change per unit time between prescribed temperatures during the heating phase of a thermal process.

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.

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.

soft magnetic composite, n—a compacted PM product in which individual ferrous powder particles are separated by a dielectric material.

3.2.2 **Processes for Compacting:**

cold pressing, n—the forming of a compact at room temperature.

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. ~~Synonymous with **molding**.~~

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

double-action pressing, n—a method by which a powder is pressed in a die between opposing moving punches.

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

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

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

hot isostatic pressing—subjecting a powder, compact, or sintered object to an elevated pressure, nominally equal from every direction, and an elevated temperature, the combination of which is sufficient to induce diffusion and creep, resulting in the densification of the material being processed.

molding, v—see **compacting.**

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

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

press, v—to apply force to a mass of powder, generally while confined in a die or container, to form a compact.

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

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.

warm compaction, n—the consolidation of a pre-heated powder in a pre-heated die.

warm-die compaction, n—the consolidation of an unheated powder in a pre-heated die.

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:**

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

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

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.

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.

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.

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.

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.

rotary press, n—a machine fitted with a rotating table carrying multiple dies in which a material is pressed.

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

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

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:**

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

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.

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

3.2.5 **Types of Cracks:**

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 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.

~~3.2.5.1~~

~~3.2.5.1.1~~*~~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.~~

~~3.2.5.2~~

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

~~3.2.5.3~~

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]

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

~~3.2.5.4~~

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).

~~3.2.5.5~~

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

~~3.2.5.6~~

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).

~~3.2.5.7~~

pressing crack, n—a defect occurring as a result of the forming operation.

~~3.2.5.8~~

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.

~~3.2.5.9~~

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

~~3.2.5.10~~

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:**

green density, n—the mass per unit volume of an unsintered compact. ~~Synonymous with **pressed density.**~~

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**.

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

pressed density, n—synonymous with **green density.** ~~springback, n—see **green expansion.**~~

3.2.7 **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.

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.**

PM forging, n—see **powder forging.**

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." ~~Synonymous with **PM forging**.~~

preform, n—a PM compact intended to be changed in shape through deformation and densification.

sinter forging, n—see powder forging. ~~springback, n—see **green expansion.**~~

3.2.8 **Metal Injection Molding:**

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**.

MIM—see **metal injection molding**.

~~[3] See Test Method B331.~~

[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 PM Compacts" by D. Zenger and H. Cai.