SAE The Engineering Society For Advancing Mobility Land Sea Air and Space® INTERNATIONAL
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SURFACE VEHICLE STANDARD

Submitted for recognition as an American National Standard

SAE J471d

REV. JUN66

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Superceding J471d AUG73

SINTERED POWDER METAL PARTS: FERROUS

1. ***Scope***—Powder metal (P/M) parts are manufactured by pressing metal powders to the required shape in a precision die and sintering to produce metallurgical bonds between the particles, thus generating the appropriate mechanical properties. The shape and mechanical properties of the part may be subsequently modified by repressing or by conventional methods such. as machining and/or heat treating.

While powder metallurgy embraces a number of fields wherein metal powders may be used as raw materials, this standard is concerned primarily with information relating to mechanical components and bearings produced from iron-base materials.

2. ***References***—There are no referenced publications specified herein.

3. ***Bearings***—Powder metal bearings are classified broadly in two groups: ferrous and nonferrous. While much of the basic information is common to both types, this standard is concerned only with the former. Information relating to copper- and aluminum-base materials is under development.

3.1 **Chemical Composition**—The chemical composition shall be determined on an oil-free basis and shall conform to the limits set out in Table 1. The analysis shall be performed in accordance with ASTM procedure, or any other approved method agreed upon by the manufacturer and the purchaser.

Subject to agreement between purchaser and manufacturer metallographic estimates of combined carbon values may be used.

In cases of disagreement in respect of composition, samples shall be submitted to independent umpire analysis.

3.2 **Physical and Mechanical Properties**—A most important characteristic of oil impregnated sintered bearings is their property of self-lubrication resulting from the internal oil reservoir created by the interconnected pore structure. The quantity of oil available is thus directly proportional to the pore volume of the bearing. The mechanical strength of bearings of the same composition produced under similar manufacturing conditions is inversely proportional to the pore volume. Although a tensile bar pressed and sintered under the same conditions as the bearing is sometimes used to evaluate materials, the generally accepted test is a radial crush test in which the load required to break the bearing is related to its physical dimensions via a constant, K, specified for each material.

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3.2.1 DENSITY—The density of the bearing, fully impregnated with lubricant (see Appendix B), shall conform to the limits set out in Table 1. If in one bearing the variation of density from any one section to any other is less than 0.3 g/CM3, the density of the bearing as a whole shall fall within the limits prescribed in Table 1. If this point-to-point variation exceeds 0.3 g/CM3, the manufacturer and purchaser shall agree upon a critical section of the part in which the density requirements of the specification must be fulfilled.

3.2.2 OIL CONTENT—The oil content of the bearing shall not be less than that specified in Table 1. (See Appendix B.)

3.2.3 RADIAL CRUSHING STRENGTH—Radial crushing strength (see Appendix A) shall not be less than the value calculated as follows:

$$P = \frac{KLT^2}{D - T} \quad \text{(Eq. 1)}$$

where:

P = radial crushing load, lb (N)
D = outside diameter of bearing, in. (nini)
T = wall thickness of bearing, in. (mm)
L = length of bearing, in. (mm)
K = strength constant shown in Table I

3.2.4 PERMISSIBLE LOADS—In calculating permissible loads, the operating conditions, housing conditions, and construction should be considered. Permissible bearing loads for various operating conditions are shown in Table 2. These are intended only as a general guide.

Certain conditions will increase the permissible loads, such as additional lubrication, pressure lubrication, hardening of the shaft, loads of short duration.

Certain conditions will tend to reduce the load-carrying capacity of bearings regardless of type or make: continued start-stop operation, oscillating and reciprocating motion, extremely high or low temperatures; excessively close or loose bearing clearances; deflection or misalignment of shaft; dust, grit, corrosive fumes, or poor shaft finish.

3.3 Dimensional Characteristics

3.3.1 TOLERANCES—Dimensional tolerances allowed shall conform to the limits prescribed in Tables 3 and 4, unless otherwise agreed between supplier and purchaser.

TABLE 1—PROPERTIES OF FERROUS P/M BEARINGS

SAE No.	Density, g/cm^3	Chemical Composition, % Cu	Chemical Composition, % C	Chemical Composition, % Others	Chemical Composition, % Fe	Minimum Oil Content by Volume, %	Strength Constant psi	Strength Constant MPa
850	5.7-6.1	—	0.25 max	2.0 max	Bal	18	25,000	172
851	5.7-6.1	—	0.25-0.60	2.0 max	Bal	18	30,000	207
862	5.8-6.2	7-11	0.30 max	2.0 max	Bal	18	40,000	276
863	5.8-6.2	18-22	0.30 max	2.0 max	Bal	18	40,000	276

TABLE 2—PERMISSIBLE BEARING LOADS

Shaft Velocity ft/min	Shaft Velocity m/min	Permissible Loads SAE 850/851 psi	Permissible Loads SAE 850/851 MPa	Permissible Loads SAE 862/863 psi	Permissible Loads SAE 862/863 MPa
Static (0)	0	7500	52	15,000	103
Slow and intermittent (25)	7.6	3600	25	8,000	55
50-100	15.2-30.4	1800	12	3,000	21
100-150	30.4-45.7	450	3.1	700	4.8
150-200	45.7-61	300	2.1	400	2.8
Over 200	61	225	1.6	300	2.1

For shaft velocities in excess of 200 ft/min (61 m/min), the permissible load may be calculated as follows:

$$P = 50,000/V$$

where:

P = safe load per square inch of projected area, psi
V = shaft velocity, ft/min
P = 105/V

or:

P = safe load per square metre of projected area, MPa
V = shaft velocity, m/min

TABLE 3—COMMERCIAL DIMENSIONAL TOLERANCES

Note: This table is intended for bearings with a 3:1 maximum length to inside diameter ratio and a 20:1 maximum length to wall thickness ratio. Bearings having a greater ratio than these are not covered by the table.

Inside Diameter and Outside Diameter in	Inside Diameter and Outside Diameter mm	Total Diameter Tolerance(1) Inside Diameter in	Total Diameter Tolerance(1) Inside Diameter mm	Total Diameter Tolerance(1) Outside Diameter in	Total Diameter Tolerance(1) Outside Diameter mm
Up to 0.760	Up to 19.31	0.001	0.025	0.001	0.025
0.761 to 1.510	19.32 to 38.36	0.0015	0.025	0.0015	0.04
1.511 to 2.510	38.37 to 63.76	0.002	0.05	0.002	0.05
2.511 to 3.010	63.77 to 76.46	0.003	0.08	0.002	0.05
3.011 to 4.010	76.47 to 101.86	0.004	0.10	0.004	0.10
4.011 to 5.010	101.87 to 127.26	0.005	0.13	0.005	0.13
5.011 to 6.010	127.27 to 152.65	0.006	0.15	0.006	0.15

1. Total tolerance on the inside diameter and outside diameter is a minus tolerance only.

Length in	Length mm	Total Length Tolernace(1) in	Total Length Tolerance(1) mm
Up to 1.495	Up to 37.97	0.010	0.25
1.496 to 1.990	37.98 to 50.54	0.015	0.38
1.991 to 2.990	50.55 to 75.96	0.020	0.51
2.991 to 4.985	75.97 to 126.61	0.030	0.76

1. Total tolerance is split into plus and minus.

Outside Diameter in	Outside Diameter mm	Wall Thickness, max in	Wall Thickness, max mm	Concentricity Tolerance(1) in	Concentricity Tolerance(1) mm
Up to 1.510	Up to 38.36	Up to 0.355	9.02	0.003	0.08
1.511 to 2.010	38.37 to 51.06	Up to 0.505	12.83	0.004	0.10
2.011 to 4.010	51.07 to 101.86	Up to 1.010	25.65	0.005	0.13
4.011 to 5.010	101.87 to 127.26	Up to 1.510	38.35	0.006	0.15
5.011 to 6.010	127.27 to 152.65	Up to 2.010	51.05	0.007	0.18

1. Total indicator reading.

TABLE 4—FLANGE AND THRUST BEARINGS DIAMETER AND THICKNESS TOLERANCES[1]

Flange Bearings, Flange Diameter Tolerances

Diameter Range in	Diameter Range mm	Standard in	Standard mm	Special in	Special mm
0 to 1-1/2	0 to 38	±0.005	±0.13	±0.0025	±0.06
Over 1-1/2 to 3	39 to 76	±0.010	±0.25	±0.005	±0.13
Over 3 to 6	77 to 152	±0.025	±0.64	±0.010	±0.25

1. Standard and special tolerances are specified for diameters, thickness, and parallelism. Special tolerances should not be specified unless required since they require additional or secondary operations and, therefore, are costlier.

Flange Bearings, Flange Thickness Tolerances

Diameter Range in	Diameter Range mm	Standard in	Standard mm	Special in	Special mm
0 to 1-1/2	0 to 38	±0.005	±0.13	±0.025	±0.06
Over 1-1/2 to 3	39 to 76	±0.010	±0.25	±0.007	±0.18
Over 3 to 6	77 to 152	±0.015	±0.38	±0.010	±0.25

Thrust Bearings (1/4 in (6.35 mm) Thickness, max), Thickness Tolerances, All Diameters[1]

Standard in	Standard mm	Special in	Special mm
±0.005	±0.13	±0.0025	±0.06

1. Outside diameter tolerances same as for flange bearings.

Parallelism on Faces, max

Diameter Range in	Diameter Range mm	Standard in	Standard mm	Special in	Special mm
0 to 1-1/2	0 to 38	0.005	0.13	0.003	0.03
Over 1-1/2 to 3	39 to 76	0.007	0.18	0.005	0.13
Over 3 to 6	77 to 152	0.010	0.25	0.007	0.18

3.3.2 RECOMMENDED PRESS FITS—Plain cylindrical journal bearings are commonly installed by press fitting the bearing into a housing using an insertion arbor. For housings rigid enough to withstand the press fit without appreciable distortion and for bearings with wall thickness approximately one-eighth of the bearing outside diameter, the press fits shown in Table 5 are recommended.

TABLE 5—RECOMMENDED PRESS FITS

Outside Diameter Bearing in	Outside Diameter Bearing mm	Press Fit Min in	Press Fit Min mm	Press Fit Max in	Press Fit Max mm
Up to 0.760	Up to 19.31	0.001	0.025	0.003	0.03
0.761 to 1.510	19.32 to 38.36	0.0015	0.04	0.004	0.10
1.511 to 2.510	38.37 to 63.76	0.002	0.05	0.005	0.13
2.511 to 3.010	63.77 to 76.45	0.002	0.05	0.006	0.15
Over 3.010	Over 76.45	0.002	0.05	0.007	0.18

3.3.3 RUNNING CLEARANCES— Proper running clearances for sintered bearings depend to a great extent upon the particular application. Therefore, only minimum recommended clearances are listed in Table 6. It is assumed that ground steel shafting will be used and that all bearings will be oil impregnated.

TABLE 6—RUNNING CLEARANCES

Shaft Size in	Shaft Size mm	Total Clearance, min in	Total Clearance, min mm
Up to 0.760	Up to 19.31	0.0005	0.01
0.761 to 1.510	19.32 to 38.36	0.001	0.025
1.511 to 2.510	38.37 to 63.76	0.0015	0.04
Over 2,510	Over 63.76	0.002	0.05

4. Mechanical Components

4.1 General Information—This section of the standard relates to mechanical or structural components such as cams, gears, levers, shock absorber parts, transmission parts, etc., which are produced by powder metallurgy methods. Many of these parts are used in the "as-sintered" or "as-sized" condition; however, in a large number of applications, additional processing of the parts is required. Additional processes include machining, heat treatment, sealing, or surface treatments, These notes are intended to provide a general guide on the application and use of some of these processes.

4.1.1 HEAT TREATMENT—P/M parts are porous and thus provide more surface area in any metal/gas reactions proceeding during heat treatment. In any given set of heat treating circumstances, the depth of carburization or decarburization will increase with decreasing density. Provided that the proper care is taken to maintain the appropriate carbon potential, carbonbearing iron-base P/M parts can be heat treated by conventional quenchhardening methods. It should be noted that the porous material will, on cooling, absorb some of the quench medium, perhaps resulting in some minor problems during tempering or further treatment.

The absorption of fluids by the porous materials usually precludes the use of liquid salt bath treatments.

4.1.2 STEAM TREATMENT—This process consists of heating ferrous parts to 1000-1100 °F (540-600 °C) and subjecting them to superheated steam under pressure. A layer of black iron oxide is formed on all external and internal (interconnected porosity) surfaces. This oxide layer improves wear resistance, surface hardness, compressive strength and, under some conditions, corrosion resistance. The presence of oxide within the pores tends to close these channels, reducing the volume of interconnected porosity and providing a measure of pressure tightness. Steam treatment usually results in a decrease in impact resistance. It should also be noted that oxidation can lead to the generation of internal stresses with a general degradation of mechanical properties.

4.1.3 PLATING—P/M parts can be electroplated by conventional techniques providing certain precautions are taken to prevent the absorption of the plating solution into the porous body. Trapped electrolyte will eventually exude, causing corrosion and flaking of the plate. The degree of surface preparation required is governed by the part density. Infiltrated parts and parts with a density in excess of 7.0 g/CM^3 can be plated by procedures normally employed for wrought materials. At lower densities the parts must be scaled by resin impregnation if the plating is to be deposited from a liquid electrolyte. Certain types of mechanical plating can be applied to porous materials without difficulty.

4.1.4 INFILTRATION—Infiltration is a process in which the residual interconnected porosity in an iron-base P/M part is filled with a metal of lower melting point. The infiltrant, normally copper or a copper-base alloy, is placed in contact with the part and the two are heated above the melting point of the infiltrant. In the liquid state the infiltrant is drawn into the interconnected porosity of the part by capillary action. The major disadvantage of the process is that it may result in some loss of dimensional accuracy.

The process has the following advantages:

a. Improved mechanical properties. Higher tensile strength and hardness values, together with improved impact and fatigue resistance, are obtained as a result of infiltrating the part.
b. Elimination of porosity. The sealing effect resulting from the filling of interconnected porosity eliminates problems associated with electrolyte entrapment in plating or gas permeation in heat treatment. Infiltrated parts can usually be used in most applications requiring pressure tightness.

4.1.5 IMPREGNATION—Impregnat ion is the process of filling the pores of a part with oil or a plastic resin. Oil is used primarily for self-lubricating parts or bearings; plastic resins may be used

a. To effect pressure tightness.
b. To seal porosity as a pretreatment prior to plating.
c. To provide an uninterrupted surface for machining. Impregnation improves tool life and surface finish.

Two basic techniques are in use for oil impregnation:

a. The parts are immersed in hot oil for a period varying between 30 min and several hours depending upon the size, shape, and type of part.
b. The parts are immersed in oil under vacuum in some suitable vessel.

The latter method ensures the removal of air pockets from within the component.

In the case of plastic impregnation, only the vacuum technique is employed.

4.1.6 MACHINING—It is not possible to give many useful rules or principles for the machining of P/M materials because of the diversity of materials, machining techniques, and objectives. In general, the machining characteristics of P/M materials are different from those of wrought materials of similar hardness or composition. It is obvious that a machining operation may close surface porosity and hence interfere with the intended function of a bearing surface. If possible, machining operations should be carried out dry since coolants may be retained in the pores subsequently leading to corrosion or act as an adulterant to the impregnating lubricant. Wet machining can be used without difficulty on infiltrated or impregnated parts. It is necessary to examine each individual application in detail to devise the optimum method and conditions for machining.

4.2 Properties

4.2.1 CHEMICAL COMPOSITION—The chemical composition shall be determined on an oil-free basis and shall conform to the limits prescribed in Table 7. The analysis shall be carried out in accordance with ASTM procedure or by any approved method agreed upon by the manufacturer and purchaser.

Subject to agreement between purchaser and manufacturer, metallographic estimates of combined carbon values may be used.

In cases of disagreement in respect of composition, samples must be submitted to independent umpire analysis.

4.2.2 DENSITY—In structural parts of complex shape, there may be variation in density from one section of the part to another. If this variation is less than 0.3 g/CM^3, the overall density of the part as a whole shall fall within the limits prescribed in Table 7. If the variation exceeds 0.3 g/CM^3, the manufacturer and purchaser shall agree upon a critical section of the part in which the density requirements of the specification must be fulfilled. This critical section would ordinarily be that at which the stresses are highest.

Density shall be determined on a dry basis, that is, on the unimpregnated component. (See Appendix B.)

TABLE 7—PROPERTIES OF STRUCTURAL COMPONENTS

SAE No.	Grade	Class	Type	Chemical Composition, % C	Chemical Compositiion, % Cu	Chemical Composition, % NI	Chemical Composition, % Others	Chemical Composition, % Fe	Density g/cm^3	Ultimate Yield Strength (typical) psi	Ultimate Yield Strength (typical) MPa	Yield Strength in Compression (typical) psi	Yield Strength in Compression (typical) MPa	Ultimate Yield Strength After Heat Treatment (typical) psi	Ultimate Yield Strength After Heat Treatment (typical) MPa
853		1	1	0.25 max	—	—	2.0 max	Bal	5.6-6.0	16,000	110	12,000	83	—	—
853		1	2						6.0-6.4	20,000	138	17,000	117	—	—
853		1	3						6.4-6.8	26,000	179	20,000	138	—	—
853		1	4						6.8-7.2	30,000	207	25,000	172	—	—
853		1	5						7.2 min	40,000	276	30,000	207	—	—
853		2	1	0.25-0.60	—	—	2.0 max	Bal	5.6-6.0	20,000	138	18,000	124	30,000	207
853		2	2						6.0-60.4	26,000	179	22,000	152	40,000	276
853		2	3						6.4-6.8	34,000	234	24,000	166	50,000	345
853		2	4						6.8-7.2	50,000	345	35,000	241	70,000	483
853		2	5						7.2 min	60,000	414	42,000	290	80,000	552
853		3	1	0.60-0.90	—	—	2.0 max	Bal	5.6-6.0	26,000	179	22,000	152	40,000	276
853		3	2						6.0-6.4	34,000	234	26,000	179	50,000	345
853		3	3						6.4-6.8	40,000	276	28,000	193	64,000	441
853		3	4						6.8-7.2	60,000	414	42,000	290	80,000	552
853		3	5						7.2 min						
864	1	3	1	0.60-0.90	1-3	—	2.0 max	Bal	5.6-6.0	30,000	207	—	—	40,000	276
864	1	3	2						6.0-6.4	41,000	283	—	—	49,000	338
864	1	3	3						6.4-6.8	58,000	400	—	—	89,000	614
864	1	3	4						6.8-7.2	76,000	524	—	—	124,000	955
864	1	3	5						7.2 min	105,000	724	—	—	154,000	1062
864	2	3	1	0.60-0.90	3-6	—	2.0 max	Bal	5.6-6.0	34,000	234	—	—	45,000	310
864	2	3	2						6.0-6.4	48,000	331	—	—	54,000	372
864	2	3	3						6.4-6.8	68,000	469	—	—	92,000	634
864	3	3	1	0.60-0.90	6-11	—	2.0 max	Bal	5.6-6.0	36,000	248	—	—	—	—
864	3	3	2						6.0-6.4	51,000	352	—	—	—	—
864	4	3	1	0.60-0.90	18-22	—	2.0 max	Bal	5.6-6.0	33,000	228	—	—	—	—
864	4	3	2						6.0-6.4	47,000	324	—	—	—	—
	1	1	3	0.3 max	2.5 max	1-3	2.0 max	Bal	6.4-6.8	28,000	193	—	—	—	—
?	1	1	4						6.8-7.2	38,000	262	—	—	—	—
	1	1	5						7.2 min	45,000	310	—	—	—	—
	1	2	3	0.3-0.6	2.5 max	1-3	2.0 max	Bal	6.4-6.8	37,000	255	—	—	82,000	565
?	1	2	4						6.8-7.2	50,000	345	—	—	110,000	689
	1	2	5						7.2 min	61,000	421	—	—	134,000	924
	1	3	3	0.6-0.9	2.5 max	1-3	2.0 max	Bal	6.4-6.8	48,000	331	—	—	100,000	689
?	1	3	4						6.8-7.2	65,000	448	—	—	135,000	931
	1	3	5						7.2 min	79,000	545	—	—	160,000	1103

TABLE 7—PROPERTIES OF STRUCTURAL COMPONENTS (CONTINUED)

SAE No.	Grade	Class	Type	Chemical Composition, % C	Chemical Compositiion, % Cu	Chemical Composition, % NI	Chemical Composition, % Others	Chemical Composition, % Fe	Density g/cm^3	Ultimate Yield Strength (typical) psi	Ultimate Yield Strength (typical) MPa	Yield Strength in Compression (typical) psi	Yield Strength in Compression (typical) MPa	Ultimate Yield Strength After Heat Treatment (typical) psi	Ultimate Yield Strength After Heat Treatment (typical) MPa
	2	1	3	0.3 max	2.0 max	3-5.5	2.0 max	Bal	6.4-6.8	36,000	248	—	—	—	—
?	2	1	4						6.8-7.2	49,000	338	—	—	—	—
	2	1	5						7.2 min	58,000	400	—	—	—	—
	2	2	3	0.3-0.6	2.0 max	3-5.5	2.0 max	Bal	6.4-6.8	45,000	310	—	—	112,000	772
?	2	2	4						6.8-7.2	62,000	428	—	—	154,000	1062
	2	2	5						7.2 min	74,000	510	—	—	180,000	1241
	2	3	3	0.6-0.9	2.0 max	3-5.5	2.0 max	Bal	6.4-6.8	57,000	393	—	—	—	—
?	2	3	4						6.8-7.2	77,000	531	—	—	—	—
	2	3	5						7.2 min	93,000	641	—	—	—	—
Infiltrated															
Materials															
870				0.25 max	15-25	—	4.5	Bal	7.1 min	65,000	448	70,000	483	—	—
872				0.6-0.9	15.25	—	4.5	Bal	7.1 min	85,000	586	90,000	621	120,000	827

NOTE—All properties given above are typical of materials produced from elemental powder mixes as distinct from prealloyed powders.

4.2.3 OTHER MECHANICAL PROPERTIES—The properties given in Table 7 are typical of materials within the specified density ranges and properly sintered.

Most P/M parts are too small to allow tensile bars to be cut from the actual component; thus, it is a common practice for the manufacturer and purchaser to agree upon an empirical acceptance test based upon the conditions of service of the part. This test may be an axial or radial crushing test, an impact test in which a weight is allowed to fall a specific distance onto a specified area of the part, a bending test, etc. The method of carrying out this test must be agreed upon, including the method of holding the specimen, the rate of application of the load, etc. Hardness tests are often used in conjunction with tests of this type. The actual metal hardness may be obscured by the collapse of the pore structure under the localized load of such a test. Consequently, it is usually impossible to correlate hardness measurements carried out by different methods as is often possible in wrought materials. In general, a particular hardness specification for a part should be developed by agreement of the supplier and customer. The familiar Rockwell scales such as B, C, and 15T are used to advantage.

The hardness values obtained for porous sintered materials on any scale should not be compared with the hardness readings yielded by wrought metals of similar composition because of the "pore effect" on hardness readings obtained on sintered materials and discussed earlier in this passage.

PREPARED BY THE SAE IRON AND STEEL TECHNICAL COMMITTEE

APPENDIX A

RADIAL CRUSHING STRENGTH—

Radial crushing strength shall be determined by compressing the test specimen between two flat- surfaces at a no load speed of 0.1 in./min (2.54 mm/min), the direction of the load being normal to the longitudinal axis of the specimen. The point at which the load drops due to the first crack shall be considered the crushing strength.

In the case of flanged bearings, the flange shall be cut off and the two parts tested separately. Each section shall meet the minimum requirement as calculated by the formula given in 1.2.3.