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(54) AGGLOMERATED STAINLESS STEEL POWDER COMPOSITIONS AND METHODS FOR MAKING SAME

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(57) **ABSTRACT**

An agglomerated stainless steel powder composition for use in rigid-die powder metallurgy is provided. The composition preferably comprises a pre-alloyed water atomized stainless steel powder and a water-soluble binder. It exhibits minimal dusting, segregation, and die galling, has good compressibility and flow rate, and produces a finished part essentially free of non-metal residues. Methods for making this agglomerated stainless steel powder composition are also provided. Improved stainless steel rigid-die powder metallurgical parts are also provided.

AGGLOMERATED STAINLESS STEEL POWDER COMPOSITIONS AND METHODS FOR MAKING SAME

BACKGROUND OF THE INVENTION

[0001] The present invention relates to the field of powder metallurgy. More particularly, the present invention relates to binder systems that may be used with stainless steel powders.

[0002] Powder metallurgy, or P/M, processing is a useful approach for producing a wide range of parts that may be used in products such as lock hardware, automobile engines and transmissions, auto brake and steering systems, power tools and hardware, sporting arms, copiers, postage meters, knives, hydraulic assemblies, x-ray shielding, oil and gas drilling wellhead components, and wrist watches. Powder metallurgy parts are typically made by consolidating or pressing metal powders into a compact and then sintering the compact at a high temperature in a protective atmosphere wherein metallurgical bonds are formed. The temperature is controlled so that either no melting or only a limited amount of melting occurs. This control of the temperature ensures that the particles form metallurgical bonds while retaining the overall shape of the compact.

[0003] Another common metal forming technique is casting, which is based on pouring molten metal into a mold where it is allowed to solidify and forming wrought parts by hot or cold deformation of metal bodies and machining. However, P/M is a more efficient process than casting; P/M typically utilizes more than 97% of the starting material in the finished part.

[0004] There are several manufacturing techniques based on the basic principles of powder metallurgy. One technique is metal injection molding or MIM. MIM is used to manufacture small parts of complex shapes. The MIM process uses fine powders, which contain particles that are typically less than 20 microns in diameter and that are mixed with polymer binders in the form of thermoplastics, waxes or other organics, and heated. After cooling, the mixture is granulated and fed into an injection-molding machine. The granulated mixture is then heated to the consistency of a paste and injected into a closed mold to form a green compact. A "green compact" is a mass of compacted metal powders that are held together by mechanical bonds and/or one or more binders. The binder content of the green MIM compact may be as high as 40% by weight.

[0005] According to MIM techniques, the green compact is cooled and removed from the mold. Chemical and/or thermal methods may be used to remove the majority of the binder from the compact so that the compact does not deform during the sintering process. This is known in the art as, "debinding" a cumbersome process that often takes several days. The remainder of the binder is removed from the compact by heating the compact at an intermediate temperature, then elevating the temperature for sintering. During sintering, diffusion of atoms takes place due to the need to reduce surface energy of the powder mass. Interdiffusion of atoms between particles leads to formation of metallurgical bonds. This process is useful in the production of small, intricate parts, but because of its relatively high costs, it is not economical for the production of a large majority of powder metallurgical parts.

[0006] Another technique based on the principles of powder metallurgy, known as the "strip process," involves producing a strip from metal powder. In this process, in which metal powder and resin are admixed to form a slurry, the slurry is fed into and compacted between two rollers and then sintered. This technique does not use molds or dies and therefore cannot be used to produce three-dimensional parts like rigid-die P/M and MIM. Rigid-die P/M differs from both of these other techniques in that rather than employing a dry powder, both metal injection molding and the strip process require that the powder metal be formed into a plastic-like slurry, and they either be extruded into a mold, or fed between two rollers to form a green compact.

[0007] Although both MIM and the strip process have found commercial success, the oldest powder metallurgy technique, "rigid-die powder metallurgy" is still the most widely used. This technique, also called "rigid-die P/M," compacts a powder or powder composition in a rigid-die to form a green compact and then mechanically ejects the green compact from the die for further processing. Green compacts produced by rigid-die P/M, unlike those produced by MIM or the strip process, are held together almost entirely by mechanical bonds and these typically contain many fewer additives than green compacts produced by these two other processes. In rigid-die P/M, the removal of the non-metal components such as lubricants is accomplished during sintering without the need for a separate de-binding step as is necessary for the MIM and the strip casting process.

[0008] Unlike the other two aforementioned variations of powder metallurgy techniques, rigid-die P/M comprises filling the die, or mold, with dry powder, rather than a slurry. Thus, although MIM and the strip process techniques were derived from rigid-die P/M, their methods, equipment, and pre-mold material compositions differ greatly from and are typically not compatible with rigid-die P/M.

[0009] Persons skilled in the art for rigid-die P/M generally prepare powders either as powder mixtures or as fully pre-alloyed powders. Powder mixtures are prepared by mixing the iron or steel powder with powder containing the desired alloying element or elements, either in the elementary form or as master alloys. Fully pre-alloyed steel powders are manufactured e.g., by is atomizing a steel melt containing the desired alloying elements to a powder.

[0010] One of the drawbacks of using powder mixtures is that such powders consist of particles that often differ considerably in size, shape and density, and that are not mechanically interconnected. Consequently, such powder mixtures are susceptible to segregation during their transport and handling. This segregation leads to varying composition of the green compacts manufactured from the powder, and in turn, to varying dimensional changes during the sintering operation and to varying mechanical properties in the as-sintered product.

[0011] Another drawback of powder mixtures is their tendency to dust, especially if an additive or alloying agent is present in the form of very small particles. This can lead to difficult environmental problems when the powder mixture is handled.

[0012] Prior art has taught that by producing pre-alloyed powders with uniformly coarse particle size, the risk of dusting is eliminated. However, such pre-alloyed powders do not form high-density green compacts and as a result lead to finished parts that are not sufficiently dense or strong. The inclusion of fine and superfine particles in a pre-alloyed powder composition produces a stronger and denser finished parts, but it creates the problem of segregation and dusting.

[0013] The use of a small amount of binder with certain powders containing fine and superfine particles, such as when one uses an oil as a binder for iron powder, is known to reduce these problems greatly. In addition, the use of a small amount of binder improves the flow rate of powders containing large amounts of fine and super fine particles, thus increasing the efficiency of the production of intricate parts. The inclusion of fine and superfine powders increases the strength, and density of finished parts, but without a binder to agglomerate these particles, flow rate may suffer to the point that the powder may not be useful for rigid-die P/M. The presence of loose super-fine particles also leads to galling of the compaction tooling as these very small particles find their way into the clearance between the die and the punch. Reduction of segregation of particles, dusting, and die galling combined with increased flow rate of powders permits greater amounts of fine and super fine particles to be used, and in turn, results in the safe and efficient production of stronger and denser parts.

[0014] If the amount of binder is limited to a small volume fraction as is the case in traditional rigid-die P/M, the small amount of binder present in the green compact is easily burned off along with the lubricant at an early stage of sintering. Depending on the type and amount of binder used however, there may be residual elements or compounds, such as carbon and oxygen, left behind when the binder is burned off. Residual elements may be problematic because they may change the properties of the finished part. For example, binders such as oils, emulsions, and some organic compositions may be acceptable for use with carbon steel and its alloys, but such binders cannot be used with stainless steel because they leave high levels of carbon in the stainless steel, thereby decreasing the desired corrosion resistance of the stainless steel part.

[0015] However, if no binder is used when stainless steel powders that contain large amounts of fine and superfine particles are subjected to rigid-die PIM, there may be problems such as dusting, segregation, and/or die galling, or the flow rate of such powders may be so poor that the powder is unable to flow into the die in a satisfactory manner. In theory, one could minimize these problems by excluding fine and superfine particles, but their exclusion would produce parts with reduced density and strength. The amount of fine and superfine particles that can be incorporated into a stainless steel powder P/M composition has hereto now been limited either by residual carbon left by the concomitant addition of binder or by dusting, segregation, die galling, and reduced flow rate if the necessary amount of binder is not added. Accordingly, there remains a need for a substantially carbon-free, binder-agglomerated stainless steel powder composition for use in rigid-die powder metallurgy that incorporates fine and superfine particles and exhibits minimum die galling, dusting and segregation.

[0016] The present invention addresses these problems and provides binder-treated stainless steel powder compositions for use in rigid-die P/M, as well as methods for their production. These compositions maintain high flow rates and compressibility, exhibit low dusting and segregation properties, and produce a rigid-die powder metallurgical stainless steel part with minimal residual elements and increased strength and density due to the incorporation of fine and superfine particles.

SUMMARY OF THE INVENTION

[0017] The present invention provides compositions and methods for producing rigid-die powder metallurgical parts from stainless steel powder. These compositions and methods provide agglomerated powders that are both free-flowing and exhibit minimal dusting and segregation. It has also been found that powder metallurgical parts made from the methods and compositions of the present invention have improved strength, higher density and corrosion resistance when compared to parts made from previously known methods and compositions, due in part to the incorporation of greater amounts of fine and superfine particles than was possible in previously known techniques.

[0018] In one embodiment, the present invention provides an agglomerated stainless steel powder composition comprising an atomized stainless steel powder and a water-soluble binder, wherein the water-soluble binder is between about 0.05% and about 0.2% by weight, based on the weight of the agglomerated stainless steel powder composition. Preferably, the atomized stainless steel powder has been water atomized and is pre-alloyed.

[0019] In another embodiment, the present invention provides a process for preparing a dry agglomerated stainless steel powder composition comprising the steps of mixing an atomized stainless steel powder with a water-soluble binder and water to form an admixture and drying the admixture to form the dry agglomerated stainless steel powder composition.

[0020] In a preferred embodiment, the present invention provides a stainless steel part made from the compositions of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0021] The present invention provides compositions for use in rigid-die powder metallurgy. The compositions comprise an atomized pre-alloyed stainless steel powder and a water-soluble binder. The present invention also provides a process for the preparation of an agglomerated stainless steel powder composition comprising fine particles while exhibiting low dusting and segregation properties and high flow rates and compressibility. Further, the present invention provides a rigid-die powder metallurgical stainless steel part made from a composition of the present invention, which part exhibits high strength, hardness and density.

[0022] The present disclosure is not intended to be a treatise on powder metallurgy, binders or the manufacturer of stainless steel parts. Readers are referred to appropriate, available texts and other materials in the field for additional and detailed information on any aspect of practicing this invention as necessary.

[0023] An atomized stainless steel powder is a powder comprising stainless steel produced by a well-known process called atomization. Preferably, the atomized stainless steel powder is a water-atomized stainless steel powder. The production of atomized stainless steel powder and its use in the field of rigid-die powder metallurgy are well known to persons skilled in the art. Water-atomized stainless steel powder is commercially available from various manufacturers, including OMG Americas, Inc.

[0024] For the purposes of rigid-die P/M, powders having a wide range of particle sizes, from 200 microns down to a few microns are found suitable. The wide range of particle size, which is naturally produced via water atomization, facilitates the production of high green density compacts. These screened powders are referred to as "minus N mesh powders," where N is the size of opening in the mesh through which the powder is passed. The description of powders in reference to the size of mesh openings is well known to persons skilled in the art. The powders most commonly used for rigid-die compaction typically comprise −60 mesh powders and contain between approximately 35-50% by weight −325 mesh particles, though have been know to contain up to 90% by weight −325 mesh particles and could in theory contain up to 100% by weight −325 mesh particles. Preferably, they will contain between about 35% and 70% by weight −325 mesh particles, and more preferably between about 50% and about 70% by weight −325 mesh particles.

[0025] Preferably, water-atomized powders, and more preferably water-atomized pre-alloyed powders are used for press and sinter processes employing a rigid-die since such powders offer good green strength and compressibility and are cost effective. Water-atomized powders particles typically have an irregular shape. Such powders are often preferred, because they interlock with each other, enabling them to develop sufficient inter-particle bonds upon cold compaction. This in turn results in compacts that have sufficient green strength to withstand ejection from the die and during subsequent handling.

[0026] The stainless steel of the atomized powder of the present invention is preferably a metal alloy composed primarily of iron alloyed with at least 9.0% chromium. Other elements, including but not limited to elements such as silicon, nickel, manganese, molybdenum and carbon, may be present in specific grades. As used herein, the phrase "stainless steel" refers to any low-carbon iron-chromium alloy.

[0027] Most commonly, rigid-die powder metallurgy utilizes AISI 300 and 400 series alloys of stainless steel. The former series are referred to as austenitic and the latter are referred to as ferritic or martensitic—depending mainly on the carbon content. To a small extent, a family of stainless steels known as Precipitation Hardened Stainless Steels are also used in rigid die powder metallurgy. The stainless steels are well known to persons skilled in the art.

[0028] The 300 series stainless steel alloys are also referred to as austenitic stainless steels, because of their crystal structure. Austenitic stainless steels have the highest level of corrosion resistance in the stainless steel family, cannot be hardened by heat treatment, and are non-magnetic for practical purposes. An example of a 300 series stainless steel alloy is 316L stainless steel.

[0029] The 400 series stainless steel alloys are either martensitic or ferritic in structure. Martensitic stainless steel refers mainly to stainless steel types **410**, **416**, and **420**, and have high carbon content, which reduces corrosion resistance, but allows a sharp increase in tensile strength after heat treatment. Martensitic stainless steel is magnetic. Its corrosion resistance is not as good as austentic stainless steel or ferritic stainless steel. The use of martensitic stainless steels in rigid-die powder metallurgy is very limited since the process does not produce full-dense parts and hence the high hardness martensitic materials become brittle.

[0030] Ferritic stainless steel refers mainly to type **409**L, **410**L, **430**L and **434**L. The "L" designation refers to low carbon. These are magnetic and not able to be hardened by heat treatment. Ferritic stainless steels provide greater corrosion resistance than martensitic stainless steel but much less than austenitic stainless steel.

[0031] Except for some martensitic stainless steel products, most rigid-die powder metallurgy stainless steel parts require a low residual carbon content (typically less than 0.03%) in order to provide good corrosion resistance and satisfactory ductility. In order to achieve this goal the starting powder also needs to have a low carbon content.

[0032] The steel used to manufacture stainless steel is either low in carbon content or is decarburized to produce a low carbon metal. The deposit of carbon by the typical binders used in powder metallurgy is detrimental to these important properties of stainless steel. Particular powders that are suitable for use according to the present invention include powders made from the materials and by the procedure described above, as well as other powders that from reading this disclosure appear useful according to the present invention.

[0033] A "water-soluble binder" is a binding agent with a solubility of greater than 0.1 mol/L of water at 25° C. and standard pressure. Binding agents, including water-soluble binders, are well known in the industry. The present invention employs any water-soluble binder known in industry or that from reading this disclosure would appear to one skilled in the art to be useful in connection with the present invention. Preferred water-soluble binders useful in the present invention are methylcellulose and alginates. Methylcellulose and alginates are used commercially as food additives and binders. Methylcellulose is a water-soluble polymer of cellulose. Alginates are naturally occurring polysaccharides isolated e.g., from brown seaweed. Sodium salts of the alginates are especially preferred binders. One example of such binder is sold under the trade name Kelcosol® by ISP, Inc. These binding agents are soluble in water and are commonly used as emulsifiers, lubricators, binders and thickeners in a variety of manufacturing fields. When used as binders in these and other fields, methylcellulose and alginates are added to a viscous slurry to form a semi-solid plastic material that must be extruded or injected into molds. In contrast, the present invention provides unexpectedly free-flowing dry powder by employing a binder to metal ratio much smaller than ratios known in industry. The unexpected effectiveness of the small amount of binder of the present invention allows the production of agglomerated metal powders substantially free of carbon and other binder residues.

[0034] According to the present invention, the binding agent agglomerates mainly the fine particles, which have an average diameter of less than about 45 microns (−325 mesh particles), and the superfine particles, which have an average diameter of less than about 20 microns (−635 mesh particles). Although it is known in the art to use water soluble binders in conjunction with stainless steel powder, their use has been limited to instances where they are mixed with stainless steel and water to form a viscous slurry, or gel-like matrix, for use in other types of powder metallurgy such as MIM or the strip method. A viscous slurry does not exhibit the flow properties necessary for use in rigid-die P/M. Thus, binder treated stainless steel known in the art is not compatible with the widely used technique of rigid-die P/M.

[**0035**] The methods of the present invention provide compositions agglomerated by an amount of binder smaller than amounts known in industry to be effective. The optimum amount of binder used is between about 0.05% and 0.2% by total weight, although an amount up to 2.0% may also be effective. The small quantities of water and binder used in the present invention make it possible to dry the admixture to a dry composition with good flow properties. The resulting composition may incorporate larger amounts of fine (and superfine) particles than is used conventionally in rigid-die powder metallurgy. It can be used in rigid-die P/M with less binder than agglomerated metal powder compositions previously known in the art. Thus, the compositions of the present invention may be used to produce powder metallurgical stainless steel parts stronger and denser than those previously known in the art.

[**0036**] Preferably, the compositions of the present invention will include a lubricant. It is common practice in rigid-die P/M to blend a lubricant together with the metal powder. The use of lubricants is well known to persons in the art. The amount of lubricant is preferably 1% by weight. The use of a lubricant reduces friction between the pressed compact and the die walls during compaction which in turn, lowers the required ejection force necessary to remove the compact from the die, lessening tool wear. Preferably, the lubricant may be chosen from the group consisting of waxes and stearates, but other lubricants known in the art may be used as well. The lubricant may advantageously be the commercially available Acrawax®, which is an anti-static internal lubricant available from EMS Company.

[**0037**] The present invention also provides processes for making agglomerated stainless steel powder compositions. This process involves mixing water-atomized stainless steel powder with small amounts of binder to form an admixture. In the present invention, it is preferred to use between about 0.05% and 0.2% of binder by weight of total composition. It is also preferred to use between about 5% and 20% of water by weight of total composition. "Mixing" refers to any method for combining the stainless steel powder with the binder. Preferably, the mixing is mechanical mixing in a double-cone blender. According to this method, the binder mixes with the water and metal powder to form an agglomerated mixture. The agglomerated mixture is then dried until the water of the mixture is evaporated, leaving a dry, free-flowing powder composition referred to as a "dry agglomerated stainless-steel powder." As used herein, "dry" means substantially free of water, although it is recognized that a small residual amount of water may remain in the "dry" powder. The drying step is preferably performed at about 85° F. The resulting agglomerated stainless steel powder composition is useful in rigid-die powder metallurgy and has a carbon level substantially the same as the carbon level of the water-atomized powder used in its manufacture. The improved powder composition of the present invention can be used in rigid-die powder metallurgy by any method now known or that will come to be known in the art for using powders in rigid-die P/M.

[**0038**] After drying, one optionally employs the step of screening the agglomerated stainless steel powder composition through a mesh. It is well known in the art that screening powders and especially agglomerated powders through a mesh prior to filling a rigid-die breaks up large particles, resulting in more contact surface area among particles and in turn, a stronger finished part.

[**0039**] The compositions of the present invention may also be used to manufacture novel, rigid-die powder metallurgical stainless steel parts. The parts made from the compositions or by the methods of the present invention exhibit greater strength, hardness, and density, due to the incorporation therein of a greater amount of fine and superfine particles, than is possible in stainless steel rigid-die powder metallurgical parts manufactured with prior art stainless steel powder compositions. The methods of creating finished rigid-die powder metallurgical parts from an agglomerated free-flowing powder composition are well known in the art, and can be employed using the agglomerated stainless steel powder composition of the present invention.

[**0040**] The following examples are presented to provide a more complete understanding of the invention. The specific techniques, conditions, materials, proportions and reported data set forth to illustrate the principles and practice of the invention are exemplary and should not be construed as limiting the scope of the invention.

EXAMPLES

Example 1

[**0041**] Water atomized −100-mesh stainless steel powder, grade 410L (ferritic) was used in this set of experiments. The particle size distribution and properties of this powder (without any addition of a binder or a lubricant) are shown in the "Control" column of Table 1. The powder was separately blended with three different types of binders. The binders were: (A) Methocell [A4M], (B) Methocell [J75MS-N], and (C) Kelcosol®[62068A]. The binder amount was 0.10%, by weight, in each case. To each mix, a small amount of water was added to form an admixture. The amount of water was approximately 5% by volume. Blending was then carried out using a double cone blender for ten minutes. After blending, water was removed by drying in an oven at a temperature of 85° F. The dried powders had undergone some degree of agglomeration, yet they behaved as free flowing particulate materials.

[**0042**] The dried powders were screened through a 60-mesh screen. The oversize agglomerates were broken up by squeezing through the 60-mesh screen. The agglomerated −60 mesh stainless steel powders were tested for particle size distribution and physical properties. The results are shown in Table 1. As may be seen here the amount of fines (i.e., percent −325 mesh) is significantly reduced for all three binder treated powders. Each powder was then lubricated with 1% Acrawax® and tested for green properties (Table 2). Green compacts were delubricated at 1000° F. in a dissociated ammonia atmosphere, and then sintered at 2350° F., in a hydrogen atmosphere for 30 minutes. The properties of the sintered samples are shown in Table 3. As may be seen here the residual carbon contents are desirably low (less than 0.02%) for all three binder treated samples, and their sintered properties are similar to those obtained with the standard, un-treated powder except for strength, which is greater for the stainless steel treated in accordance with invention.

TABLE 1

Particle Size Distribution and Properties of 410L grade Stainless Steel (unlubricated)

	Control	Blend A1	Blend B1	Blend C1
wt. % of +60 mesh powder	0.0	0.1	0.9	0.4
wt. % of −60/+100 mesh powder	1.6	11.5	15.9	13.4
wt. % of −100/+140 mesh powder	9.1	13.0	28.6	18.0
wt. % of −140/+200 mesh powder	15.3	22.2	27.4	20.7
wt. % of −200/+325 mesh powder	30.4	25.2	15.4	22.4
wt. % of −325 mesh powder	43.6	28.0	11.8	25.1
A.D. (g/cm^3)	2.65	2.36	2.11	2.36
Flow Rate (s/50 g)	28.0	35.8	40.0	33.5
C (%)	0.003	0.071	0.025	0.059
N_2 (ppm)	323	306	309	300
O_2 (ppm)	1588	2197	2058	2134
S (%)	0.003	0.002	0.003	0.002

[0043]

TABLE 2

Properties of Powders After Lubrication (0.75% Acrawax ® addition)

	Control	Blend A1	Blend B1	Blend C1
A.D. (g/cm^3)	2.87	2.63	2.54	2.31
Flow Rate (s/50 g)	no flow	36.9	40.9	43.5
Green Density, (g/cm^3)*	6.29	6.27	6.25	6.29
Green Strength (psi)*	1040	940	1150	830

*Compaction Pressure 40 TSI

[0044]

TABLE 3

Sintered Properties

	Control	Blend A1	Blend B1	Blend C1
C (%)	0.004	0.005	0.004	0.004
N_2 (ppm)	264	255	308	231
O_2 (ppm)	1282	1307	1218	1384
Sintered Density (g/cm^3)	6.91	6.91	6.99	6.95
Dimensional Change (%)	−3.47	−3.55	−4.1	−3.64
Sintered Strength, TRS (psi)	168,500	175,500	202,200	189,800

Example 2

[0045] Water atomized −100-mesh stainless steel powder, grade 410L (ferritic) was used in this set of experiments. The particle size distribution and properties of this powder (without any addition of a binder or a lubricant) are shown in the "Control" column of Table 4. The powder was separately blended with three different types of binders. The binders were: (A) Methocell [A4M], (B) Methocell [J75MS-N], and (C) Kelcosol®[62068A]. The binder amount was 0.20%, by weight, in each case. To each mix, a small amount of water was added to form an admixture. The amount of water was approximately 5% by volume. Blending was then carried out using a double cone blender for ten minutes. After blending, water was removed by drying in an oven at a temperature of 85° F. The dried powders had undergone some degree of agglomeration, yet they behaved as free flowing particulate materials.

[0046] The dried powders were screened through a 60-mesh screen. The oversize agglomerates were broken up by squeezing through the 60-mesh screen. The agglomerated −60 mesh stainless steel powders were tested for particle size distribution and physical properties. The results are shown in Table 4. As may be seen here the amount of fines (i.e., percent −325 mesh) is significantly reduced for all three binder treated powders. Each powder was then lubricated with 1% Acrawax® and tested for green properties (Table 6). Green compacts were delubricated at 1000° F. in a dissociated ammonia atmosphere, and then sintered at 2350° F., in a hydrogen atmosphere for 30 minutes. The properties of the sintered samples are shown in Table 5. As may be seen here the residual carbon contents are desirably low (less than 0.03%) for all three binder treated samples, and their sintered properties are similar to those obtained with the standard, un-treated powder except for strength, which is greater for the stainless steel treated in accordance with invention.

TABLE 4

Particle Size Distribution and Properties of 410L grade Stainless Steel (unlubricated)

	Control	Blend A2	Blend B2	Blend C2
wt. % of +60 mesh powder	0.0	2.8	7.0	0.6
wt. % of −60/+100 mesh powder	1.6	31.2	36.7	45.9
wt. % of −100/+140 mesh powder	9.1	20.1	14.6	21.6
wt. % of −140/+200 mesh powder	15.3	25.0	22.4	19.9
wt. % of −200/+325 mesh powder	30.4	20.9	19.2	12.0
wt. % of −325 mesh powder	43.6	0.0	0.0	0.0
A.D. (g/cm^3)	2.65	2.34	2.41	2.18
Flow Rate (s/50 g)	28.0	33.9	34.2	37.4
C (%)	0.003	0.087	0.051	0.098
N_2 (ppm)	323	347	346	362
O_2 (ppm)	1588	2296	2275	2284
S (%)	0.003	0.002	0.003	0.002

[0047]

TABLE 5

Properties of Powders After Lubrication (0.75% Acrawax ® addition)

	Control	Blend A2	Blend B2	Blend C2
A.D. (g/cm^3)	2.87	2.47	2.53	2.23
Flow Rate (s/50 g)	No flow	39.6	39.9	43.3

TABLE 5-continued

Properties of Powders After Lubrication (0.75% Acrawax ® addition)

	Control	Blend A2	Blend B2	Blend C2
Green Density, (g/cm^3)*	6.29	6.28	6.29	6.30
Green Strength (psi)*	1160	880	1180	820

*Compaction Pressure 40 TSI

[0048]

TABLE 6

Sintered Properties

	Control	Blend A2	Blend B2	Blend C2
C (%)	0.007	0.022	0.029	0.013
N_2 (ppm)	357	386	447	363
O_2 (ppm)	2116	2173	6699	1670
Sintered Density (g/cm^3)	6.77	6.84	6.95	6.87
Dimensional Change (%)	−2.9	−3.1	−3.8	−3.13
Sintered Strength, TRS (psi)	154,200	161,500	163,300	172,800

Example 3

[0049] Water atomized −100-mesh stainless steel powder, grade 410L (ferritic) was used in this set of experiments. The particle size distribution and properties of this powder (without any addition of a binder or a lubricant) are shown in the "Control" column of Table 7. The powder was separately blended with three different types of binders. The binders were: (A) Methocell [A4M], (B) Methocell [J75MS-N], and (C) Kelcosol®[62068A]. The binder amount was 0.05%, by weight, in each case. To each mix, a small amount of water was added to form an admixture. The amount of water was approximately 5% by volume. Blending was then carried out using a double cone blender for ten minutes. After blending, water was removed by drying in an oven at a temperature of 85° F. The dried powders had undergone some degree of agglomeration, yet they behaved as free flowing particulate materials.

[0050] The dried powders were screened through a 60-mesh screen. The oversize agglomerates were broken up by squeezing through the 60-mesh screen. The agglomerated −60 mesh stainless steel powders were tested for particle size distribution and physical properties. The results are shown in Table 7. As may be seen here the amount of fines (i.e., percent −325 mesh) is significantly reduced for all three binder treated powders. Each powder was then lubricated with 1% Acrawax® and tested for green properties (Table 8). Green compacts were delubricated at 1000° F. in a dissociated ammonia atmosphere, and then sintered at 2350° F., in a hydrogen atmosphere for 30 minutes. The properties of the sintered samples are shown in Table 10. As may be seen here the residual carbon contents are desirably low (less than 0.02%) for all three binder treated samples, and their sintered properties are similar to those obtained with the standard, un-treated powder except for strength, which is greater for the stainless steel treated in accordance with invention.

TABLE 7

Particle Size Distribution and Properties of 410L grade Stainless Steel (unlubricated)

	Control	Blend A3	Blend B3	Blend C3
wt. % of +60 mesh powder	0.0	0.1	0.4	0.2
wt. % of −60/+100 mesh powder	1.6	6.9	7.2	6.8
wt. % of −100/+140 mesh powder	9.1	13.3	27.8	14.5
wt. % of −140/+200 mesh powder	15.3	16.9	22.6	17.0
wt. % of −200/+325 mesh powder	30.4	28.3	22.3	27.0
wt. % of −325 mesh powder	43.6	34.5	19.3	34.5
A.D. (g/cm^3)	2.65	2.63	2.35	2.67
Flow Rate (s/50 g)	28.0	28.8	30.6	25.4
C (%)	0.003	0.024	0.020	0.034
N_2 (ppm)	323	325	325	298
O_2 (ppm)	1588	1990	2099	2019
S (%)	0.003	0.003	0.003	0.003

[0051]

TABLE 8

Properties of Powders After Lubrication (0.75% Acrawax ® addition)

	Control	Blend A3	Blend B3	Blend C3
A.D. (g/cm^3)	2.87	2.81	2.51	2.8
Flow Rate (s/50 g)	No flow	35.5	40	36
Green Density, (g/cm^3)*	6.27	6.30	6.27	6.32
Green Strength (psi)*	1112	953	1180	830

*Compaction Pressure 40 TSI

[0052]

TABLE 9

Sintered Properties

	Control	Blend A3	Blend B3	Blend C3
C (%)	0.012	0.009	0.015	0.012
N_2 (ppm)	638	620	808	596
O_2 (ppm)	1991	2014	1993	2010
Sintered Density (g/cm^3)	6.48	6.52	6.51	6.58
Dimensional Change (%)	−1.27	−1.44	−1.57	−1.57
Sintered Strength, TRS (psi)	136,100	140,800	155,000	150,000

Example 4

[0053] Water atomized −100-mesh stainless steel powder, grade 316L (austenitic) was used in this set of experiments. The particle size distribution and properties of this powder (without any addition of a binder or a lubricant) are shown in the "Control" column of Table 10. The powder was separately blended with three different types of binders. The binders were: (A) Methocell [A4M], (B) Methocell [J75MS-N], and (C) Kelcosol®[62068A]. The binder amount was

0.10%, by weight, in each case. To each mix, a small amount of water was added to form an admixture. The amount of water was approximately 5% by volume. Blending was then carried out using a double cone blender for ten minutes. After blending, water was removed by drying in an oven at a temperature of 85° F. The dried powders had undergone some degree of agglomeration, yet they behaved as free flowing particulate materials.

[0054] The dried powders were screened through a 60-mesh screen. The oversize agglomerates were broken up by squeezing through the 60-mesh screen. The agglomerated −60 mesh stainless steel powders were tested for particle size distribution and physical properties. The results are shown in Table 10. As may be seen here the amount of fines (i.e., percent −325 mesh) is significantly reduced for all three binder treated powders. Each powder was then lubricated with 1% Acrawax® and tested for green properties (Table 11). Green compacts were delubricated at 1000° F. in a dissociated ammonia atmosphere, and then sintered at 2200° F., in a hydrogen atmosphere for 30 minutes. The properties of the sintered samples are shown in Table 12. As may be seen here the residual carbon contents are desirably low (less than 0.05%) for all three binder treated samples, and their sintered properties are similar to those obtained with the standard, untreated powder except for strength, which is greater for the stainless steel treated in accordance with invention.

TABLE 10

Particle Size Distribution and Properties of 316L grade Stainless Steel (unlubricated)

	Control	Blend A4	Blend B4	Blend C4
wt. % of +60 mesh powder	0	n	n	n
wt. % of −60/+80 mesh powder	0.1	0.1	0.1	0.1
wt. % of −80/+100 mesh powder	2.6	3.8	5.7	5.6
wt. % of −100/+140 mesh powder	8.3	12.0	213	18.1
wt. % of −140/+200 mesh powder	14.6	18.8	27.5	21.1
wt. % of −200/+325 mesh powder	28.5	29.3	24.0	25.3
wt. % of −325 mesh powder	45.9	36.0	21.4	29.8
A.D. (g/cm^3)	2.65	2.67	2.44	2.36
Flow Rate (s/50 g)	28	27.5	31.8	29.1
C (%)	0.029	0.077	0.057	0.076
N_2 (ppm)	363	341	362	375
O_2 (ppm)	2108	2509	2373	2399
S (%)	0.012	0.012	0.012	0.012

[0055]

TABLE 11

Properties of Powders After Lubrication (0.75% Acrawax ® addition)

	Control	Blend A4	Blend B4	Blend C4
A.D. (g/cm^3)	2.8	2.73	2.51	2.68
Flow Rate (s/50 g)	37.2	37.60	41	41.8

TABLE 11-continued

Properties of Powders After Lubrication (0.75% Acrawax ® addition)

	Control	Blend A4	Blend B4	Blend C4
Green Density, (g/cm^3)*	6.52	6.54	6.49	6.53
Green Strength (psi)*	997	764	874	712

*Compaction Pressure 40 TSI

[0056]

TABLE 12

Sintered Properties

Chemistry	Control	Blend A4	Blend B4	Blend C4
C (%)	0.040	0.045	0.049	0.045
N_2 (ppm)	1585	1592	1526	1597
O_2 (ppm)	1969	1958	1872	1843
Sintered Density (g/cm^3)	6.67	6.70	6.64	6.71
Dimensional Change (%)	−0.81	−0.81	−0.77	−0.86
Sintered Strength, TRS (psi)	146,400	161,200	168,500	147,900

Example 5

[0057] Water atomized −100-mesh stainless steel powder, grade 409LE (ferritic) was used in this set of experiments. The particle size distribution and properties of this powder (without any addition of a binder or a lubricant) are shown in the "Control" column of Table 13. The powder was separately blended with Kelcosol®[62068A]. The binder was added to four stainless steel powder mixes each containing 55%, 60%, 65% and 70%-325 mesh respectively. The binder amount was 0.10%, by weight, in each case. To each mix, a small amount of water was added to form an admixture. The amount of water was approximately 10% by weight. Blending was then carried out using a double cone blender for ten minutes. After blending, water was removed by drying in an oven at a temperature of 185° F. The dried powders had undergone some degree of agglomeration, yet they behaved as free flowing particulate materials.

[0058] The dried powders were screened through a −30-mesh screen. The oversize agglomerates were broken up by squeezing through the −30-mesh screen. The agglomerated −30-mesh stainless steel powders were tested for particle size distribution and physical properties. The results are shown in Table 13. As may be seen here, the amount of fines (i.e., percent −325 mesh) is significantly reduced for all four binder treated powders. Each powder was then lubricated with 0.75% Acrawax® and tested for green properties (Table 14). Green compacts were delubricated at 1000° F. in an air atmosphere and then sintered at 2400° F., in a hydrogen atmosphere for 60 minutes. The properties of the sintered samples are shown in Table 15. As may be seen here, the residual carbon contents are desirably low (less than 0.03%) for all four binder treated samples, and their sintered properties are similar to those obtained with the standard, untreated powder except for strength, which is greater for the stainless steel treated in accordance with the invention.

TABLE 13

Particle Size Distribution and Properties of 409LE grade Stainless Steel (unlubricated)					
	Control	Blend A5 55% −325 mesh	Blend B5 60% −325 mesh	Blend C-5 65% −325 mesh	Blend D5 70% −325 mesh
wt. % of +30 mesh powder	/	/	/	/	/
wt. % of −30/+40 mesh powder	/	7.7	5.2	7.6	8.1
wt. % of −40/+60 mesh powder	/	4.2	4.5	8.3	7.5
wt. % of −60/+80 mesh powder	0.1	3.6	3.5	4.6	4.8
wt. % of −80/+100 mesh powder	1.3	3.0	2.9	2.6	2.9
wt. % of −100/+200 mesh powder	16.1	18.5	17.4	16.0	13.8
wt. % of −200/+325 mesh powder	26.9	26.7	25.7	21.8	19.9
wt. % of −325 mesh powder	55.6	36.3	40.8	39.1	42.6
C	0.028	0.035	0.045	0.495	.6484
N	343	530	470	450	460
O	2410	3010	3100	3018	3243
S	0.015	0.015	0.015	0.015	0.015

[0059]

TABLE 14

Properties of Powder After Lubrication (0.75% Acrawax ® Addition)					
	Control	Blend A5 55% −325 mesh	Blend B5 60% −325 mesh	Blend C5 65% −325 mesh	Blend D5 70% −325 mesh
A.D. (g/cm^3)	2.77	2.66	2.66	2.65	2.58
Flow (s/50 g)	37	46	44	47	49
Green Density: (g/cm^3)*	6.49	6.43	6.46	6.46	6.43
Green strength: (psi)*	2800	2600	2720	2790	2650

*Compacted Pressure 45 TSI

[0060]

TABLE 15

Sintered Properties					
	Control	Blend A5 55% −325 mesh	Blend B5 69% −325 mesh	Blend C5 65% −325 mesh	Blend D5 70% −325 mesh
C (%)	0.0064	0.0088	0.0105	0.0093	0.0079
N_2 (ppm)	33	31	25	63	47
O_2 (ppm)	3595	3735	3347	3634	3975
Sintered Density (g/cm^3)	7.26	7.26	7.28	7.30	7.30
Dimensional Change (%)	−4.1	−4.2	−4.3	−4.4	−4.5
Yield Strength (psi)	31,600	30,600	31,400	31,200	33,300
UTS (psi)	56,600	57,700	57,500	58,300	58,900
Elongation (%)	20	21	23	20	23

Example 6

[0061] Water atomized −100-mesh stainless steel powder, grade 409LE (ferritic) was used in this set of experiments. The particle size distribution and properties of this powder (without any addition of a binder or a lubricant) are shown in the "Control" column of Table 16. The powder was separately blended with Kelcosol®[62068A]. Binder was added to two stainless mixes containing 75% and 100%-325-mesh respectively. The binder amount was 0.10%, by weight, in each case. To each mix, a small amount of water was added to form an admixture. The amount of water was approximately 10% by weight. Blending was then carried out using a double cone blender for ten minutes. After blending, water was removed by drying in an oven at a temperature of 185° F. The dried powders had undergone some degree of agglomeration, yet they behaved as free flowing particulate materials.

[0062] The dried powders were screened through a −40-mesh screen. The oversize agglomerates were broken up by squeezing through the −40-mesh screen. The agglomerated −40-mesh stainless steel powders were tested for particle size distribution and physical properties. The results are shown in Table 16. As may be seen here, the amount of fines (i.e., percent −325 mesh) is significantly reduced as a result of binder treatment. Each powder was then lubricated with 0.75% Acrawax® and tested for green properties (Table 17). Green compacts were delubricated at 1000° F. One set of specimens was delubricated in air, while the other set was delubricated in dissociated ammonia (D.A.) atmosphere. All parts were sintered at 2200° F., in a hydrogen atmosphere for 40 minutes. The properties of the sintered samples delubricated in air are shown in Table 18. The properties of the sintered samples delubricated in D.A. are shown in Table 19. As may be seen here, the residual carbon contents are desirably low (less than 0.03%) for all four binder treated samples, and their sintered properties are similar to those obtained with the standard, un-treated powder except for strength, which is greater for the stainless steel treated in accordance with the invention.

TABLE 16

Particle Size Distribution and Properties of 409LE grade Stainless Steel (unlubricated)

	Control	Blend B6 75% −325 mesh	Blend C6 100% −325 mesh
wt. % of +40 mesh powder	/	/	/
wt. % of −40/+60 mesh powder	/	5.0	4.7
wt. % of −60/+80 mesh powder	0.1	13.9	5.9
wt. % of −80/+100 mesh powder	1.3	9.0	5.1
wt. % of −100/+200 mesh powder	16.1	18.4	17.5
wt. % of −200/+325 mesh powder	26.9	13.9	8.0
wt. % of −325 mesh powder	55.6	39.8	58.8
C, wt %	0.022	0.055	0.054
N, (ppm)	421	548	478
O, (ppm)	2825	3462	3332
S, wt %	0.015	N/A	N/A

[0063]

TABLE 17

Properties of Powders After Lubrication (0.75% Acrawax ® Addition)

	Control	Blend B6 75% −325 mesh	Blend C6 100% −325 mesh
A.D. (g/cm^3)	2.77	2.38	2.52
Flow (s/50 g)	40	39	45.5
Green Density: (g/cm^3)*	6.24	6.22	6.19
Green strength: (psi)*	2135	1944	2013

*Compaction Pressure 40 TSI

[0064]

TABLE 18

Sintered Properties of Specimens Delubricated in Air

After Sinter Chemistry	Control	Blend B6 75% −325 mesh	Blend C6 100% −325 mesh
C (%)	0.016	0.017	0.016
N_2 (ppm)	2037	2062	1989
O_2 (ppm)	4260	4658	4859
Sintered Density (g/cm^3)	6.33	6.40	6.47
Dimensional Change (%)	−0.55	−1.15	−1.67
Sintered Strength, TRS (psi)	142,100	155,200	181,500

[0065]

TABLE 19

Sintered Properties of Specimens Delubricated in Dissociated Ammonia

After Sinter Chemistry	Control	Blend B6 75% −325 mesh	Blend C6 100% −325 mesh
C (%)	0.023	0.023	0.025
N_2 (ppm)	2319	2132	2048
O_2 (ppm)	3104	3177	3259
Sintered Density (g/cm^3)	6.37	6.53	6.60
Dimensional Change (%)	−0.86	−1.70	−2.31
Sintered Strength, TRS (psi)	149,200	181,700	212,600

What is claimed is:

1. An agglomerated stainless steel powder composition comprising:

(a) a pre-alloyed water atomized stainless steel powder; and

(b) a water-soluble binder, wherein the water-soluble binder is between about 0.05% and about 2.0% by weight of the agglomerated stainless steel powder composition based on the weight of the agglomerated stainless steel powder.

2. A composition according to claim 1, wherein the composition is substantially free of water.

3. A composition according to claim 1, wherein the atomized stainless steel powder comprises a 400 series stainless steel alloy or a 300 series stainless steel alloy.

4. A composition according to claim 1, wherein the atomized stainless steel powder comprises at least 35% by weight −325 mesh particles.

5. A composition according to claim 4, wherein the atomized stainless steel powder comprises between about 35% and about 70% by weight −325 mesh particles.

6. A composition according to claim 5, wherein the atomized stainless steel powder comprises between about 50% and about 70% by weight −325 mesh particles.

7. A composition according to claim 1, wherein the water-soluble binder is an alginate.

8. A composition according to claim 1, wherein the water-soluble binder is methylcellulose.

9. A composition according to claim 1, further comprising a lubricant.

10. A composition according to claim 9, wherein the lubricant is selected from the group consisting of waxes and stearates.

11. A composition according to claim 9, wherein the lubricant is an anti-static internal lubricant.

12. A method of preparing a dry agglomerated stainless steel powder composition comprising the steps of:

(a) mixing an atomized stainless steel powder with a water-soluble binder and water to form an admixture; and

(b) drying the admixture to form the dry agglomerated stainless steel powder composition.

13. A method according to claim 12, wherein the atomized stainless steel powder is obtained by atomizing a stainless steel melt-stock with water to produce the atomized stainless steel powder.

14. A method according to claim 12, wherein the atomized stainless steel powder comprises a 400 series stainless steel alloy or a 300 series stainless steel alloy.

15. A method according to claim 12, wherein the atomized stainless steel powder comprises at least 35% by weight −325 mesh particles.

16. A method according to claim 15, wherein the atomized stainless steel powder comprises between about 35% and about 70% by weight −325 mesh particles.

17. A method according to claim 16, wherein the atomized stainless steel powder comprises between about 50% and about 70% by weight −325 mesh particles.

18. A method according to claim 12, wherein the water-soluble binder is an alginate.

19. A method according to claim 12, wherein the water-soluble binder is methylcellulose.

20. A method according to claim 14, wherein the water-soluble binder is between about 0.05% and about 2% by weight of the agglomerated stainless steel powder composition.

21. A method according to claim 14, wherein the amount of water mixed is between about 5% and about 20% by weight of the atomized stainless steel powder.

22. A method according to claim 14, further comprising the step of screening the dry powder composition through a mesh.

23. A stainless steel part made from the composition of claim 1.

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