

[54] EXOTHERMIC STRUCTURING OF ALUMINUM

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[56] References Cited

UNITED STATES PATENTS

3,353,954 11/1967 Williams 75/201

3,260,595 7/1966 Maier 75/200
3,068,016 12/1962 Dega 75/205 X
3,383,207 5/1968 Butts 75/222 X

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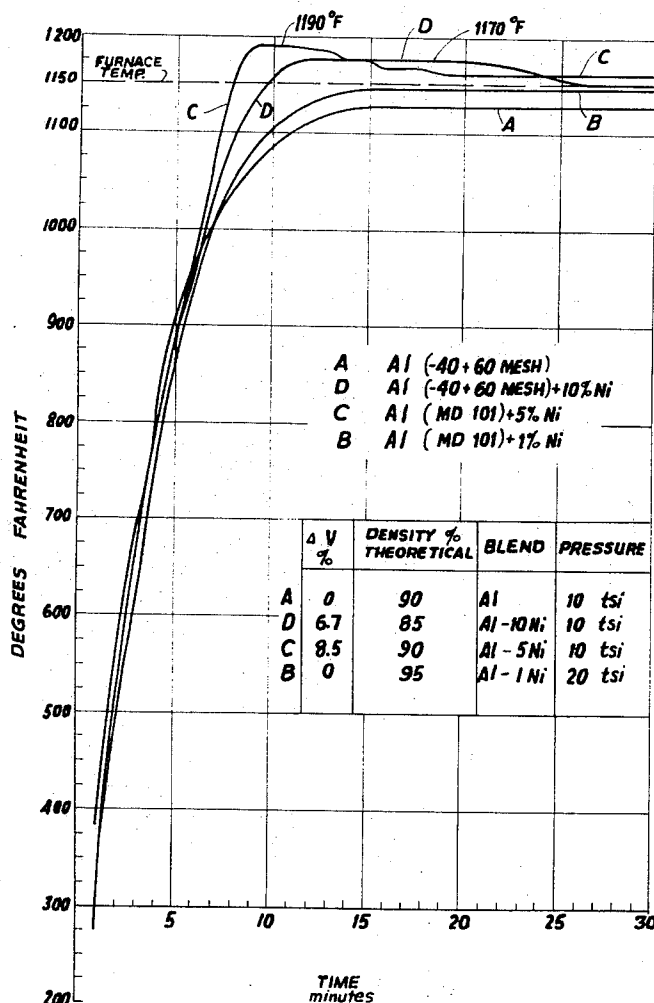
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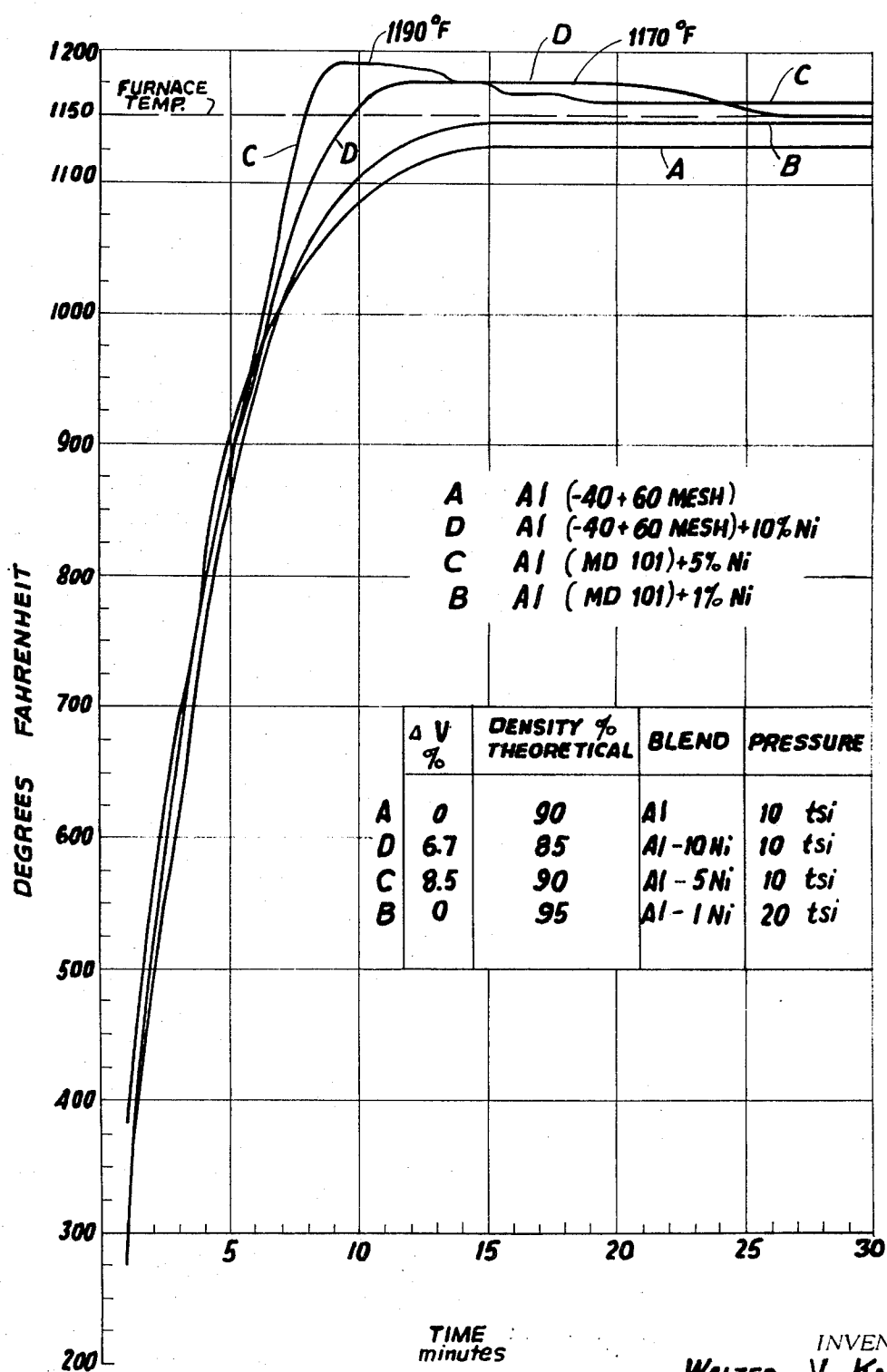
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[57] ABSTRACT

Strongly bonded aluminous bodies with produced by powder metallurgy by blending an amount of nickel powder with aluminum powder at least sufficient to effect the exothermic sintering of a pressed compact of the blended powder by heating the compact in a furnace maintained at a temperature below the eutectic temperature of the aluminum-nickel system and higher than the temperature at which nickel reacts exothermically with aluminum.

29 Claims, 1 Drawing Figure





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EXOTHERMIC STRUCTURING OF ALUMINUM

This invention relates to the powder metallurgy of aluminum and, in particular, to the production of sintered aluminous bodies containing an effective amount of nickel as an exothermic sintering agent.

STATE OF THE ART

It is known that aluminum particles generally have an oxide coating due to exposure to air, which coating acts as a deterrent to sintering. Thus, to assure adequate sintering, the usual practice has been to use relatively high compacting pressure in order to rupture the oxide coating and effect metal-to-metal contact as an aid to sintering. While the foregoing method has been useful in producing relatively high density powder metallurgy aluminum parts, it had its limitations in producing porous bodies, since the pressures employed in producing such bodies without over densification are not always sufficient to produce strongly bonded porous structures after sintering. This is also true in the situation where insoluble materials are mixed with aluminum, such as carbon (e.g., vitreous carbon), refractory carbides, borides and similar materials, to produce composite structures. The presence of such materials tends to deter sintering to the extent that strong sintering bonds are not obtained, even where high densification pressures are employed.

One method proposed for producing strong porous bodies of aluminum comprised adding 1 to 5 percent by weight of copper powder, compacting the mixture at a relatively low pressure, according to the porosity desired, and then heating the compact of the mixture to a temperature above the aluminum-copper eutectic temperature to promote liquid phase sintering. Thus, in U.S. Pat. No. 3,232,754, porous structures are provided by adding copper over the aforementioned range, e.g., from about 1 1/4 to 2 1/4 percent by weight, and pressing a compact of the mixture at about 3 to 7 t.s.i. (tons per square inch) to produce a porous body after sintering the compact at above the eutectic temperature (above 548°C), e.g., from 550°C to 625°C, and below the solidus temperature of the alloy system.

A disadvantage of the foregoing method is that particular care must be taken in controlling the sintering temperature above the eutectic temperature to avoid collapsing of the compact due to the formation of excess liquid phase.

In U.S. Pat. No. 2,155,651, a method is disclosed for producing powder metal parts of an aluminum alloy containing by weight at least 3 or 5 percent of silicon and at least 0.5 percent copper. About 0.5 to 5 percent nickel may be present. The sintering temperature ranges up to about 650°C, substantially above the aluminum-copper eutectic. Pre-alloyed powders may be employed in producing sintered bodies. Apparently, by employing both silicon and copper together with aluminum, the liquid phase sintering starts at even lower temperatures.

In U.S. Pat. No. 3,301,671, a three-component system of Al-Cu-Mg is disclosed comprising by weight 1 to 10 percent copper and 0.05 to 20 percent magnesium, the two additives copper and magnesium being relied upon to enable the formation of a liquid phase during sintering at temperatures even lower than the Al-Mg eutectic (450°C). However, particular care

must be taken to control the temperature to avoid distortion or collapsing of the body being sintered.

It would be desirable to provide a method of producing sintered aluminous bodies, be they porous or solid, the sintering of which can be controlled over a broader range of temperatures so long as the temperature of the environment, e.g., the furnace, is maintained at or below a maximum temperature which is below the eutectic temperature of the particular alloy system of interest, for example, the Al-Ni system.

By the term "aluminous" is meant sintered bodies of elemental aluminum and/or alloys in which aluminum is the major element. In the case of composite structures, e.g., aluminum and carbon, the term aluminous is meant to cover the metallic matrix surrounding the graphite particles, graphite being a non-metal, as are refractory carbides, borides, oxides, and the like.

OBJECTS OF THE INVENTION

It is thus the object of the invention to provide a method for producing sintered aluminous bodies in which sintering is effected through an exothermic reaction between aluminum or aluminum alloy particles and uniformly dispersed nickel particles.

Another object is to provide a method of producing strongly bonded composite structures comprising aluminum and a non-metal, e.g., carbon (for example, graphite), refractory carbides, borides, oxides, and the like materials.

A further object is to provide as an article of manufacture a sintered aluminous body.

These and other objects will more clearly appear from the following disclosure and the appended drawing which depicts heating curves during sintering of aluminum compacts with and without nickel.

STATEMENT OF THE INVENTION

One embodiment of the invention is directed to a method of producing by powder metallurgy a sintered strongly bonded aluminous body. Broadly, the method comprises blending with aluminum powder an amount of nickel powder ranging up to about 50 percent by weight, preferably up to about 30 percent, based on the sum of the nickel and aluminum contents, effective to react exothermically with aluminum when heated to an exothermic initiating temperature, forming a compacted body of the blend, placing the body in a furnace maintained at an average temperature below the aluminum-nickel eutectic temperature, and then allowing said compacted body to heat up in said furnace to at least the exothermic initiating temperature. Thus, as the blend reaches the exothermic initiating temperature and reacts, localized heating at above the eutectic temperature is effected at contact points between aluminum and nickel particles effective to cause bonding thereof, while the temperature of the furnace is maintained at below the eutectic temperature, such that any excess heat developed locally within the compact by the exothermic reaction is absorbed by the compact and the furnace, whereby the average temperature of the compact is maintained at below the eutectic temperature during the major portion of the sintering cycle. In this way, a substantially rigid compact is assured during sintering even though local areas or points within the compact are heated to a temperature above the aluminum-nickel eutectic.

Another aspect of the invention is directed to a sintered aluminous body having a cellular-like structure in which the cells may be pores (a porous structure) or occupied by a non-metallic material (composite structure), such as carbon or refractory carbides, borides, oxides and the like.

The nickel blended with aluminum may be in various forms. For example, it may be reduced nickel oxide, carbonyl nickel powder, or non-metallic particles coated with nickel. Thus, in producing an aluminum-carbon composite, nickel-coated graphite particles may be preferably employed, although both nickel and carbon particles may be blended with aluminum prior to compacting the mixture into a desired shape for sintering.

As stated hereinbefore, aluminum and aluminum alloy powders generally have a natural oxide coating which serves as a deterrent to sintering, that is, unless high compacting pressures are employed to rupture the coating to assure metal-to-metal contact between aluminum particles. However, the foregoing technique is not applicable to the production of porous bodies, since much lower pressures are required which are not sufficient to assure adequate metal-to-metal contact in the resulting compact prior to sintering.

According to the invention, the foregoing is overcome by adding an amount of nickel ranging up to about 30 percent or 50 percent by weight to the aluminum powder sufficient to effect an exothermic reaction between the aluminum and nickel particles at their contact points. Preferably, the amount of nickel may range by weight from about 1 to 20 percent and, more preferably, from about 1 or 2 percent to 10 percent. Apparently, the sintering bonds are due to the presence of an aluminum-nickel compound resulting from the exothermic reaction.

In carrying out the method, the temperature of the furnace is maintained at an average temperature below the aluminum-nickel eutectic temperature, that is, below 640°C (1184°F), the average temperature ranging anywhere from about 593°C (1100°F) to 630°C (1175°F). By having the furnace temperatures below the eutectic temperature but above the temperature at which the exothermic reaction proceeds, the temperature of the compact being sintered is thus controlled so that during exothermic sintering, the temperature of the compact will not substantially exceed the eutectic temperature, since, as the temperature of the compact during sintering reaches or tends to exceed the eutectic temperature, the furnace will provide a cooling effect and keep the average temperature of the compact from exceeding the eutectic temperature of the system Al-Ni over a prolonged residence period.

For example, during the initial portion of the sintering cycle, the temperature of the compact may exceed slightly the eutectic temperature for a very short period of time. However, this will not produce any immediate adverse effects in the light of the cooling effect of the furnace, the temperature of which is maintained below the eutectic temperature.

The amount of nickel employed may depend upon the particle size of the aluminum. Generally, the coarser the particle size of aluminum, the greater is the amount of nickel powder employed compared to that employed for a finer particle of aluminum. The importance of employing nickel as an exothermic sintering agent will be apparent from the drawing which shows

four heating curves or tests A, B, C and D employed in sintering aluminum compositions containing 0, 1, 5 and 10 percent by weight of nickel. Carbonyl nickel was employed having an average particle size ranging from about 4 to 7 microns, the nickel being added to two types of aluminum powder: (1) an aluminum powder of -40+60 mesh and (2) a type MD-101 powder of about 90 percent minus 325 mesh (U.S. Standard screen).

The furnace temperature was controlled at 1150°F (about 620°C) at a control differential of about $\pm 7.5^\circ\text{F}$ ($\pm 4.1^\circ\text{C}$). Compacts of tests A, C and D were compressed at 10 t.s.i. (tons per square inch), while the compact of test B which contained the least nickel (1 percent) was compressed at 20 t.s.i. The blending of the powders was carried out in the usual conventional manner.

Each of the compacted specimens was placed in the furnace and a thermocouple embedded in each in an axially aligned blind hole.

Referring to Curve A of the drawing, it will be noted that the compact without nickel reached a constant temperature of about 1,125°F, an amount 25° below the furnace temperature after 15 minutes of heating, the temperature remaining at that level after 30 minutes of total heating.

As regards Curve B in which the compact contained 1 percent nickel, a higher temperature of about 1145°F was reached. It will be noted that after about 6 or 7 minutes of heating, Curve B separated from Curve A, indicating the beginning of the exothermic reaction which raised the temperature within the compact to almost the furnace temperature (1150°F), the temperature being maintained at that level for from 15 to 30 minutes.

Referring now to Curve C based on 5 percent by weight of carbonyl nickel powder mixed with type MD-101 aluminum powder (90 percent minus 325 mesh), it will be noted that a more active exothermic reaction occurs due to the amount of nickel present such that the intrinsic temperature of the compact exceeds the furnace temperature and slightly exceeds the Al-Ni eutectic temperature, the temperature reaching briefly 1190°F compared to the eutectic temperature of 1184°F, the temperature quickly falling to below the eutectic temperature and reaching a constant temperature of about 1160°F, slightly above the furnace temperature during a 20 to 30 minute period following the initial heating. Because of the foregoing temperature conditions, the compact maintained its integrity and exhibited good sintering bonds.

As regards Curve D based on a 10 percent addition of nickel to aluminum, the curve did not reach as high as Curve C due to the fact that a coarser aluminum powder was employed (-40+60 mesh) which had less surface area for reaction with nickel. In any event, the compact had an intrinsic temperature of about 1175°F, that is about 25° higher than the furnace temperature, the temperature of the compact gradually falling to the furnace temperature due to cooling effect of the furnace.

Referring to curves A, B, C and D, it will be noted that all have the same heating rates of about 165°F per minute during the initial 6 or 7 minutes of heating, the exothermic reaction occurring at above 900°F, particularly above 1,000°F, the spread between the curves depending upon the amount of nickel in the compact, the particle size of aluminum, etc.

As stated herein, an advantage of exothermic sintering is that fairly strong porous bodies (e.g. filter plates) can be produced. Thus, a wide range of pressures can be employed depending upon whether various porosities are desired or a solid body. For example, the pressures may range from about 0.5 t.s.i. to 50 t.s.i.

Generally, a lubricant is added to the blend as a die lubricant. Usually, the amount of lubricant used is about 1 percent by weight. A typical lubricant is a waxy material corresponding to stearamide ($C_{17}H_{35}CONH_2$). The lubricant is preferably used as a powder of -200 mesh size.

The aluminum powder is generally -40 mesh and more preferably one in which at least 30 percent is less than 325 mesh. Where the particle size of the aluminum is near the 40 mesh range, a larger amount of nickel is employed than where the particle size of the aluminum is near the 325 mesh end of the size range. Thus, at a size range of -40 + 60 mesh aluminum, the amount of nickel may be 10 percent, while for a size range of aluminum of 90 percent less than 325 mesh, 5 percent nickel or less may suffice.

As has been stated, reduced nickel oxide or carbonyl nickel may be employed as the additive. The particle size is generally below 20 microns, preferably ranging up to 10 microns, for example 2 to 8 microns in size. Carbonyl nickel powder is preferred because of its activity in promoting exothermic sintering.

DETAILS OF THE INVENTION

As illustrative of the invention, the following example is given:

EXAMPLE 1

Aluminum compacts were produced containing 0, 1/4, 1 and 4 percent by weight of carbonyl nickel. Type MD-101 atomized aluminum powder was employed of minus 100 mesh in size, about 90 percent passing through 325 mesh. The carbonyl nickel powder had an average size range of about 4 to 7 microns and an apparent density of about 2 to 2.7 grams/c.c. The carbon content of the powder ranged from about 0.05 to 0.1 percent by weight.

Three blends with the aforementioned amounts of nickel were produced by placing each blend in a cylindrical container which was rotated for about one-half hour on a pair of rolls. Each blend contained about 1 percent by weight of stearamide ($C_{17}H_{35}CONH_2$) of minus 100 mesh size. The blends were each compressed into a flat type tensile bar (ASTM E-8) at 20 t.s.i. and then sintered in a furnace maintained at a constant temperature of about 1130°F for 1/2 hour. Following sintering, test pieces were evaluated and the test results were as follows:

TABLE 1

% Nickel	0	1/4	1	4
tensile strength	4100	10,000	12,600	14,700
yield strength	3300	4,400	5,000	6,000
% elongation	0.5	5.8	15.0	14.3

It will be noted from Table 1 that by employing 1 percent or more nickel in the blend, strong, ductile sintered products are obtained. Comparing 1 and 4 percent nickel with one-quarter of nickel, at least two and one-half times the ductility is obtained with an increase in tensile strength of over 25 percent. Compared to 0 percent nickel, it will be noted that the tensile strength

has more than tripled and the ductility increased almost thirty times.

It is quite evident that the use of at least 1 percent nickel promotes exothermic sintering between aluminum and nickel particles whereby strong sintering bonds are produced, the bonds being apparently due to the presence of an aluminum-nickel compound.

In the production of a porous aluminous body, the following example is given:

EXAMPLE 2

Type MD-101 aluminum powder as in Example 1 is mixed with 5 percent by weight of carbonyl nickel powder and 1 percent dry lubricant comprising stearamide. After blending the mixture as in Example 1, a flat disc of about 1 1/2 inches in diameter and one-eighth inch thick is compacted at a pressure of about 0.7 t.s.i. to produce a blank of about 50 percent porosity. The blank is then placed in a furnace maintained at about 1,050°F and allowed to heat up to its exothermic initiation temperature (above 900°F) following which exothermic sintering occurs. Following one-half hour of sintering, the flat disc is removed and examined. It is highly porous. The disc is placed in a vise and bent to an angle of about 40° before cracking. This test indicates that even though the disc was very porous, strong sintering bonds are obtained without distorting the shape, since the average temperature during sintering is generally maintained below the eutectic temperature of the aluminum-nickel system. Thus, a structure of good integrity is assured.

The presence of non-metallics mixed with aluminum generally hinders the sintering of aluminum, especially since aluminum powder itself has an oxide coating or film. However, sintered bodies of aluminum and graphite of good integrity can be obtained, provided nickel is employed as an exothermic sintering aid.

The invention is particularly applicable in the production of wear-resistant seals made of refractory vitreous carbon and aluminum. As illustrative of the production of an aluminum sealing element containing about 50 percent by weight of vitreous carbon, the following example is given.

EXAMPLE 3

About 60 parts by weight of nickel-coated vitreous carbon comprising about 50 percent carbon and 50 percent nickel are mixed with 50 parts by weight of atomized aluminum powder (MD-101). The aluminum powder was comprised of 80 percent minus 325 mesh, 10 percent plus 325 mesh, and 10 percent +200 mesh, the powder having a thin oxide coating which provides a total oxygen content ranging from about 0.1 to 0.4 percent by weight. The vitreous carbon had a particle size of about minus 100 and plus 325 mesh.

The two powders are blended as in Example 1 together with 1 percent of minus 200 mesh stearamide in a horizontal rotating bottle for about one-half hour, following which the uniformly mixed powder is compressed to a cylindrical shape of about 0.5 inch in diameter and 0.5 inch high at a pressure of 20 t.s.i. Excluding the lubricant, the final average composition of the system is about 25 percent carbon, 25 percent nickel, and the balance about 50 percent aluminum. The amount of nickel based on the nickel and aluminum content is about 33 percent by weight. The compact is placed in a furnace maintained at a temperature of

about 1,150°F and allowed to heat up to the exothermic temperature whereby the aluminum particles in contact with the nickel coated carbon react exothermically to provide sintering bonds. Metallographically, the product has a cellular-like structure in which the cells are occupied by particles of carbon, the sintered aluminum and nickel forming the matrix thereof.

Example of other compositions of aluminum, nickel and carbon are as follows:

TABLE 2

		Coated Carbon	Parts by Wt. Ni-C	parts by wgt. Al	Sintered Product		
No.	% Ni	%C			% Al	% Ni	% C
4	40 Ni	60 C	25	75	75	10	15
5	16.7 Ni	83.3 C	30	70	70	5	25
6	20 Ni	80 C	50	50	50	10	40
7	13.8 Ni	86.2 C	58	42	42	8	50
8	25 Ni	75 C	75	25	25	18.75	56.25
9	50 Ni	50 C	10	90	90	5	5
10	30 Ni	70 C	20	80	80	6	14

Other aluminum composites which may be produced using nickel as an exothermic sintering agent are composites formed by sintering aluminum with insoluble non-metallics, such as refractory carbides, borides and oxides, including carbides and borides of the refractory metals tungsten, chromium, molybdenum, titanium, hafnium, niobium, tantalum and vanadium; boron carbide, silicon carbide and refractory oxides, such as oxides of aluminum, magnesium, calcium, strontium, barium, thorium and the rare earth metals, e.g. oxides of cerium, lanthanum and the like. These refractory materials are characterized by melting points above 1,200°C.

These refractory materials, like carbon, may be nickel coated by the dissociation of a nickel carbonyl gas in a tower normally used for producing carbonyl nickel powder. Compositions which may be produced in accordance with the invention are as follows:

No.	Ni-coated refractory (R)	Parts by Wgt. of Ni Coated refractory	Al.	Sintered Product	
				% Al	% Ni
11	40 Ni - 60 WC	25	75	75	10
12	25 Ni - 75 MoC	50	50	50	12.5
13	50 Ni - 50 TiC	40	60	60	20
14	20 Ni - 80 NbC	30	70	70	6
15	30 Ni - 70 TiB	60	40	40	18
16	10 Ni - 90 SiC	35	65	65	3.5
17	40 Ni - 60 ThO ₂	70	30	30	28
18	50 Ni - 50 CeO	40	60	60	20
19	25 Ni - 75 Al ₂ O ₃	20	80	80	5
20	15 Ni - 85 TaC	20	80	80	3
21	30 Ni - 70 B ₂ C	20	80	80	6

* - R is the refractory material listed in the second column.

Tests conducted with compacts of aluminum and nickel have indicated that the exothermic reaction occurs in the neighborhood of about 900°F and generally about 950°F to 1,000°F. By maintaining the furnace temperature in the temperature range of about 1,100°F to 1,175°F and generally between about 1,125°F and 1,170°F, the compact, be it porous, or substantially dense, or a composite, such as shown in Tables 2 and 3, will sinter exothermically and provide strong structures.

Summarizing the foregoing, in carrying out the invention, the aluminous compacts containing nickel are generally produced by compacting at pressures ranging from over 0.5 t.s.i. to about 50 t.s.i., the lower pressure range being used to produce porous bodies of predetermined porosity. The porosity of the compact may

range from about 10 percent to 60 percent by volume. In carrying out the sintering, the temperature of the furnace is controlled at below the eutectic temperature of the aluminum-nickel eutectic, such as 1,100°F to 1,175°F, more preferably from about 1,125°F to 1,175°F.

While any nickel powder may be employed ranging in size up to about 20 microns, carbonyl nickel is preferred. The nickel should be in the unalloyed, unreacted form to assure exothermic reaction with aluminum, otherwise, pre-alloyed nickel loses its efficacy as an exothermic sintering agent.

As stated herein, the amount of nickel may range up to about 50 percent by weight based on the sum of the nickel and aluminum content, such as up to about 30 percent by weight, preferably 1 to 20 percent by weight, e.g. 1 or 2 to 10 percent, depending upon the particular application.

The invention is particularly applicable to the production of porous bodies preferably ranging in porosity from about 30 to 60 volume percent.

Where aluminum composites containing insoluble refractory material are produced, the amount of refractory may range from about 5 to 60 percent by weight and, preferably, from about 20 to 60 percent by weight, the amount of aluminum constituting at least about 30 percent by weight of the total composition.

In producing composites, the nickel and the refractory are blended with the aluminum. For best results, it is preferred to use nickel-coated refractory particles, such as nickel-coated vitreous carbon. The amount of nickel as the coating may range from about 5 to 60 percent by weight of the nickel-coated refractory and, more preferably, about 10 percent to 50 percent by weight.

Although the present invention has been described in conjunction with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention as those skilled in the art will readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and the appended claims.

What is claimed is:

1. A method of producing by powder metallurgy a sintered strongly bonded aluminous body which comprises:

blending with aluminum powder an amount of nickel powder ranging up to about 50 percent by weight based on the sum of the nickel and aluminum content effective to react exothermically with aluminum when heated to an exothermic initiating temperature,

forming a compacted body of said blend, placing said body in a furnace maintained at an average temperature below the aluminum-nickel eutectic temperature,

and allowing said compacted body to heat up in said furnace to at least the exothermic initiating temperature,

whereby as the blend reaches said exothermic initiating temperature and reacts, localized heating at above the eutectic temperature is effected at contact points between the aluminum and nickel particles effective to cause bonding thereof, while the temperature of the furnace is maintained at below the eutectic temperature,

such that any excess heat developed locally within the compact by the exothermic reaction is absorbed by the compact and the furnace while maintaining the average temperature of the compact at below the eutectic temperature during the major portion of the sintering cycle.

2. The method of claim 1, wherein the amount of nickel ranges from about 1 to 20 percent.

3. The method of claim 2, wherein the amount of nickel ranges from about 2 to 10 percent.

4. The method of claim 1, wherein the compact is heated to an exothermic initiating temperature of at least about 900°F and wherein the temperature of the furnace is maintained within the range of about 1100°F to 1175°F.

5. The method of claim 4, wherein the temperature of the furnace is maintained within the temperature range of about 1125°F to 1170°F.

6. The method of claim 2, wherein the aluminum powder has a particle size less than 40 mesh.

7. The method of claim 6, wherein the average size of the nickel powder ranges up to about 20 microns.

8. A method of producing by powder metallurgy a sintered strongly bonded porous aluminous body which comprises,

blending with aluminum powder an amount of nickel powder ranging up to about 30 percent by weight based on the sum of the nickel and aluminum content effective to react exothermically with aluminum when heated to an exothermic initiating temperature, forming a compacted body of said blend having a cellular-like structure in the form of porosity ranging by volume from about 10 percent to 60 percent,

placing said body in a furnace maintained at an average temperature below the aluminum-nickel eutectic temperature,

and allowing said compacted porous body to heat up in said furnace to at least the exothermic initiating temperature,

whereby as the blend reaches said exothermic initiating temperature and reacts, localized heating at above the eutectic temperature is effected at contact points between the aluminum and nickel particles effective to cause bonding thereof, while the temperature of the furnace is maintained at below the eutectic temperature,

such that any excess heat developed locally within the compact by the exothermic reaction is absorbed by the compact and the furnace while maintaining the average temperature of the compact at below the eutectic temperature during the major portion of the sintering cycle.

9. The method of claim 8, wherein the amount of nickel ranges from about 1 to 20 percent.

10. The method of claim 9, wherein the amount of nickel ranges from about 2 to 10 percent.

11. The method of claim 8, wherein the compact is heated to an exothermic initiating temperature of at least about 900°F and wherein the temperature of the furnace is maintained within the range of about 1,100°F to 1,175°F.

12. The method of claim 11, wherein the temperature of the furnace is maintained within the temperature range of about 1,125°F to 1,170°F.

13. The method of claim 9, wherein the aluminum powder has a particle size less than 40 mesh.

14. The method of claim 13, wherein the average size of the nickel powder ranges up to about 20 microns.

15. A method of producing by powder metallurgy a sintered strongly bonded composite aluminous body which comprises:

blending with aluminum powder an amount of an insoluble refractory material ranging from about 5 percent to 60 percent by weight, nickel ranging up to about 50 percent by weight based on the sum of the nickel and aluminum content effective to react exothermically with aluminum when heated to an exothermic initiating temperature, the aluminum making up substantially the balance of at least about 30 percent by weight, forming a compacted body of said blend,

placing said body in a furnace maintained at an average temperature below the aluminum-nickel eutectic temperature,

and allowing said compacted body to heat up in said furnace to at least the exothermic initiating temperature,

whereby as the blend reaches said exothermic initiating temperature and reacts, localized heating at above the eutectic temperature is effected at contact points between the aluminum and nickel effective to cause bonding thereof, while the temperature of the furnace is maintained at below the eutectic temperature,

such that any excess heat developed locally within the compact by the exothermic reaction is absorbed by the compact and the furnace while maintaining the average temperature of the compact at below the eutectic temperature during the major portion of the sintering cycle.

16. The method of claim 15, wherein the refractory material is selected from the group consisting of carbon, carbides and borides of refractory metals, silicon carbide, boron carbide and refractory oxides.

17. The method of claim 16, wherein the refractory material is carbon.

18. The method of claim 16, wherein the refractory material ranges in weight from about 20 to 60 percent, wherein the nickel ranges in weight from about 1 to 20 percent and wherein the aluminum as essentially the balance is at least about 30 percent by weight.

19. The method of claim 16, wherein the refractory material employed in producing the composite is nickel coated.

20. The method of claim 18, wherein the amount of nickel ranges from about 2 to 10 percent.

21. The method of claim 15, wherein the compact is heated to an exothermic initiating temperature of at least about 900°F and wherein the temperature of the furnace is maintained within the range of about 1,100°F to 1,175°F.

22. The method of claim 21, wherein the temperature of the furnace is maintained within the temperature range of about 1,125°F to 1,170°F.

23. The method of claim 18, wherein the aluminum has a particle size of less than 100 mesh and wherein the refractory material has a particle size of less than 100 mesh.

24. The method of claim 19, wherein the nickel-coated refractory contains an amount of nickel as the coating ranging from about 5 to 60 percent by weight of the nickel-coated refractory.

25. The method of claim 24, wherein the nickel making up the coating ranges from about 10 to 50 percent by weight of the coated material.

26. A sintered aluminous body formed from a blend of aluminum powder and up to about 30 percent by weight of nickel powder based on the sum of the aluminum and nickel content, said sintered aluminous body being characterized metallographically by a matrix comprising a cellular-like structure in which the cells occupy about 10 percent to 60 percent by volume of the body, the amount of nickel being at least sufficient such that the sintered bonds providing said cellular-like structure are characterized by the presence of an aluminum-nickel compound formed as a result of an exothermic reaction between aluminum and nickel during sintering.

27. The sintered aluminous body of claim 26, wherein the cellular-like structure comprises pores dispersed through said matrix.

28. The sintered aluminous body of claim 27, wherein said pores are occupied by a refractory material selected from the group consisting of carbon, carbides and borides of refractory metals, silicon carbide, boron carbide and refractory oxides.

29. A sintered aluminous body formed from a blend of aluminum powder and up to about 30 percent by weight of nickel powder based on the sum of the aluminum and nickel content, said sintered aluminous body being characterized metallographically by a matrix comprising a cellular-like structure in which the cells occupy about 10 percent to 60 percent by volume of the body, said cells containing carbon, the amount of nickel being at least sufficient such that the sintered bonds providing said cellular-like structure are characterized by the presence of an aluminum-nickel compound formed as a result of an exothermic reaction between aluminum and nickel during sintering.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,754,905

Dated August 28, 1973

Inventor(s) Walter V. Knopp

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

On the cover sheet, in the heading, item [54] and column 1, line 1, the title should read -- EXOTHERMIC SINTERING OF ALUMINUM --.

Signed and sealed this 7th day of May 1974.

(SEAL)

Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

UNITED STATES PATENT OFFICE
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