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ARTICLE MADE FROM POWDERED MIXES AND ITS MANUFACTURE

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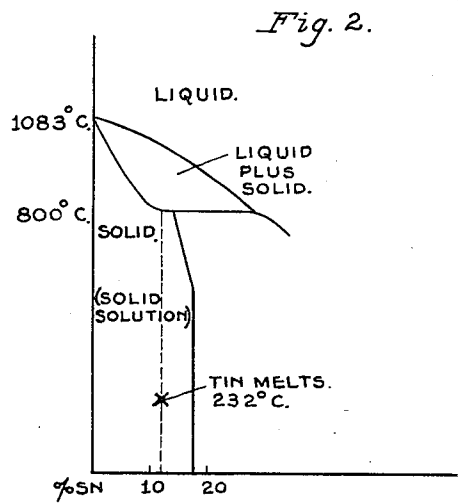
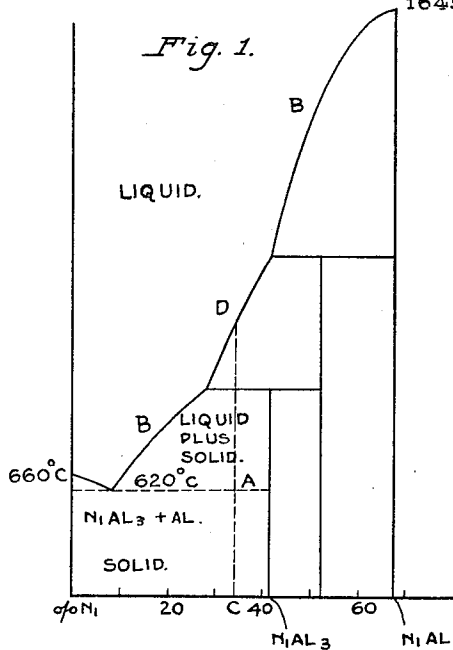


Fig. 3.

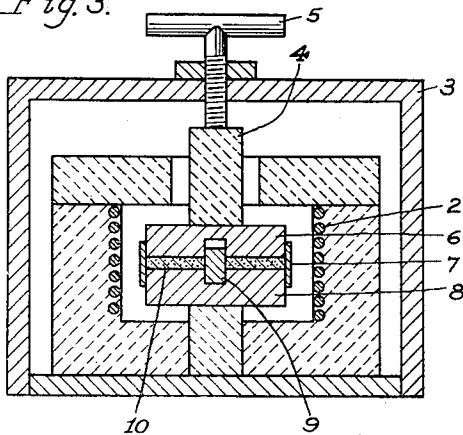


Fig. 4.

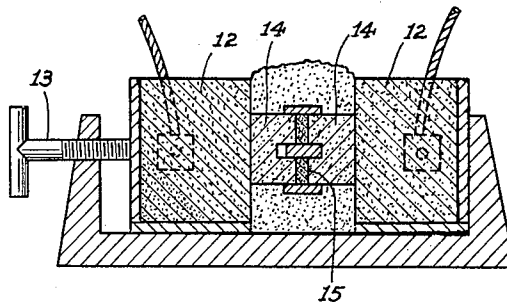
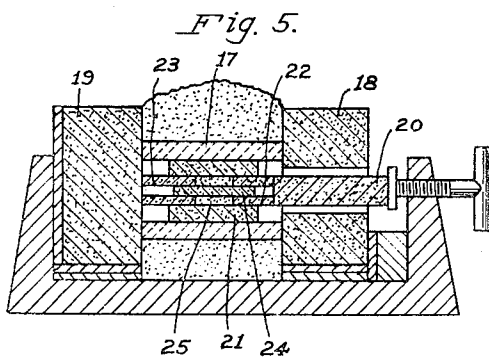
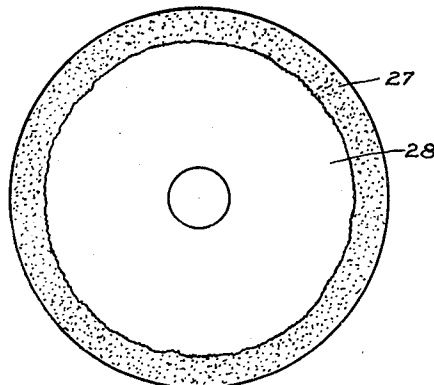


Fig. 6.



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ARTICLE MADE FROM POWDERED MIXES
AND ITS MANUFACTURE

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mesne assignments, to The Carborundum Com-
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6 Claims. (Cl. 51-278)

This invention relates to articles or composi-
tions formed by the consolidation of powdered
materials, and to their manufacture. The in-
vention relates particularly to the forming of ar-
ticles from powdered metals and to the metal
bonding of abrasives, but is also applicable to
other types of materials.

One of the objects of the invention is to fa-
cilitate the consolidation or diffusion of the parti-
cles of metal powder into a coherent mass without
complete fusion of the powder. Another object
is to provide an improved means for the bonding
of abrasive or other non-metallic particles.

In the sintering of metal powders as ordinarily
carried out, coherence of the particles to form a
metallic body is accomplished by diffusion of
the atoms of metal across the surface boundaries
of the particles while the metal is retained in
the solid state. This diffusion requires intimate
contact between the particles, and for this rea-
son, very high pressures, such as are obtained in
large hydraulic presses, are used. Even with high
pressures, difficulties are often encountered in
securing satisfactory coalescence of the particles
of powder.

In the process which I employ, I form a mix
of powdered metals which becomes plastic on
heating, as a result of the softening or melting
of one or more of the ingredients present. I have
found that diffusion takes place much more read-
ily throughout the mass when a small quantity
of liquid metal is present, then when the metals
as powders are merely held in mechanical con-
tact in the solid state. By employing certain
types of mixes, as will be hereinafter described,
it is possible to obtain a high degree of plasticity
without the material becoming fluid, and in cer-
tain instances the liquid diffuses into the solid
metal and the entire mass re-solidifies at a higher
temperature. The melting of a portion of the
material at a relatively low temperature, fol-
lowed by diffusion and resolidification at a higher
temperature, when combined with consolidation
under pressure during the heating process, pro-
duces a dense alloy material characterized by a
high degree of strength. Homogeneous metallic
solid solutions can be readily prepared by this
method, using the separate powdered compo-
nents.

The nature of the present invention will be
more clearly understood from a consideration of
the accompanying drawing.

In the drawing:

Figure 1 shows an equilibrium diagram of a
type of alloy which is plastic over a wide range

of temperatures without becoming fluid, the spe-
cific example being the alloy system of aluminum
and nickel.

Figure 2 shows a portion of the equilibrium
diagram of the copper-tin system, in which a
solid solution is formed having an incipient melt-
ing point considerably higher than one of the
components;

Figure 3 illustrates diagrammatically the meth-
od of sintering a thin circular article such as an
abrasive wheel under pressure;

Figure 4 illustrates a method of making an ar-
ticle such as metal bonded abrasive wheel, in
which the heating current is passed directly
through the mix and pressure applied during the
curing process;

Figure 5 illustrates a method of forming a cy-
lindrical article under pressure in a tube furnace;

Figure 6 shows a type of abrasive wheel which
can be made by the process herein described.

Considering the drawing in detail, Figure 1 is a
typical temperature-composition diagram of a
number of alloy systems in which the tempera-
ture of incipient melting and the temperature of
complete melting are widely divergent. In the
alloys of aluminum with nickel, cobalt and iron,
this property is very pronounced, and I have
found that these alloys are plastic or "pasty" over
a wide range of temperatures and compositions.
The alloys have a number of physical properties,
as for example, stiffness in thin sections, a high
degree of hardness, and the ability to chip under
impact without being fragile, which make them
suitable for many shaped metallic articles, and
particularly for metal bonded abrasives.

The properties of alloys of this type under heat
and pressure may be illustrated by considering the
aluminum-nickel alloy series, with particular ref-
erence to an alloy containing approximately 35
per cent nickel. As shown in Figure 1, the tem-
perature of incipient melting, indicated by the
line A, remains constant for all alloys up to
approximately 42 per cent nickel. The tempera-
ture of complete melting, however, rises rapidly,
as is shown by the curve B. In an alloy close to
the compound composition, as for example, that
indicated by the line CD, most of the aluminum
is combined in the form of the compound NiAl_3 ,
but at the same time, the alloy has an incipient
melting point of approximately 620°C . Upon
heating the alloy to temperatures above the in-
cipient melting point, sufficient melting takes
place to render the material plastic, although the
bulk of the alloy is unmelted. The plasticity of
the material can thus be varied over wide limits

without causing the material to become fluid. With lower nickel content, as for example, about 20 per cent nickel, the same degree of plasticity can be obtained at temperatures immediately above the incipient melting point as is produced with the 35 per cent alloy at somewhat higher temperatures. The powdered alloy can be readily molded to shape while plastic without the necessity of applying extremely high pressures.

Alloys of aluminum with cobalt and iron which contain up to 40 per cent cobalt or up to 30 per cent iron possess similar properties, and can be consolidated from powders in the same manner as the aluminum nickel alloys.

In making sintered compositions from powdered alloys where intermetallic compounds are formed, it is desirable to previously alloy the material and then reduce it to a powder. In the case of the aluminum alloys, this preliminary alloying greatly reduces the amount of liquid which would be present if compositions high in free aluminum were used, and also decreases the harmful effect of the chemical reactivity of aluminum in absorbing oxygen, nitrogen and carbon.

In an alloy series in which no compound is formed, but in which the temperatures of incipient and final melting are widely separated, the pure metal powders can be used, and the sintering temperature regulated so that the mass contains a small proportion of liquid. Alloys of copper with small percentages of bismuth, for example, can be consolidated by this method. Intermetallic compounds can also be mixed with powdered metals so as to form a plastic mass on heating. Mixtures of this type can be readily formed to shape by applying pressure either during the plastic stage or throughout the heating process.

When metallic objects of high strength and ductility are required, solid solution alloys can be formed under pressure from a mixture of their components. If one of these components melts at a temperature below the incipient melting point of the solid solution formed, a portion of the mix will become fluid on heating, thus rendering it plastic, but upon heating the mix to a higher temperature, the liquid will diffuse into the unmelted material and the entire mass will solidify to form a homogeneous solid solution alloy. Pressure can be applied during the partially liquid stage, or if desired, during the entire time of heating.

A composition of this type is illustrated in Figure 2, where the alloy is a solid solution of copper and tin. If a mixture of powdered copper and tin containing, for example, 10 per cent tin is heated to a temperature above 232° C. (the melting point of tin), the tin contained in the mix will melt, but as it is only a minor proportion of the mixture, the mass will become "plastic" rather than fluid. Upon raising the temperature to a point where diffusion of the tin into the copper is rapid, the tin will disappear as a separate constituent, and the mass will become solid, owing to the formation of the solid solution alloy. The partial liquefaction of the mix before alloying not only facilitates diffusion, but also makes the powdered material more readily deformable under pressure. For this reason, it is desirable to apply pressure during the heating process. The pressures required, however, are considerably less than those usually employed in the forming of sintered articles from metal powders.

Examples of other alloys of this type are the

solid solution alloys of copper with aluminum and zinc, and the solid solution alloys of nickel containing copper.

Even in cases where partial or incipient melting does not take place, I have found that there is a general relationship between the rate of diffusion or degree of coalescence of the metal powder at a given temperature and pressure and the presence of a low melting constituent or eutectic in the final alloy. For example, if two metals are employed which form a eutectic melting at a lower temperature than either component metal, alloys made from the original component powders can be readily produced by diffusion at temperatures just below the melting point of the eutectic, even when this temperature is considerably below the melting point of either powder making up the mix. As a specific illustration, copper and silver form a eutectic which melts at 778° C. and contains 72 per cent silver. Thus, if mixtures are formed from copper and silver powders and the mass sintered at temperatures slightly below the eutectic temperature, coalescence can be readily effected. The closer the eutectic composition is approached, the more readily can the particles of powder be consolidated into a dense metallic mass at temperatures slightly below the eutectic temperature. As in other previous examples, the mix becomes plastic as the eutectic temperature is approached, and the application of pressure during heating greatly facilitates coalescence.

In carrying out the sintering process, it is desirable to coat the metal particles with a solution of a fluxing agent, as described in my pending application Serial No. 93,037, filed of even date herewith. This is particularly true in the case of copper and copper base solid solution alloys, and also the nickel base alloys. The flux for these alloys can consist of a solution of borax and boric acid in the proportion of two parts of borax to one part of boric acid, or a solution of borax and an acid fluoride such as potassium acid fluoride. In the case of the aluminum alloys where the material at the final sintering temperature contains a certain proportion of liquid, satisfactory coalescence can usually be obtained without the use of a flux, but a dilute solution of aluminum welding flux can be used to moisten the powder if desired.

The compositions of the type above described are well adapted for the bonding of abrasives, and impart to the abrasive article certain characteristics which cannot be obtained with other types of bond. For example, the solid solution alloys are tough and resilient, and when abrasive articles in which these alloys are the bonding agents are made by the process herein described, the wheels will cut very hard materials rapidly, and at the same time the bond is so tough that the wheel loss is small or negligible compared with the usual abrasive wheel in which the bond is a ceramic or an organic material. These tough resilient bonds are especially adapted for abrasive wheels containing diamonds, for the diamond will retain its cutting qualities much longer than other abrasives, and with the usual diamond wheel the abrasive particles are separated from the wheel before their full cutting power has been utilized. The characteristics of the bond can also be varied over a much wider range than is possible with the usual abrasive bonds. For example, the solid solution alloys are very tough and resilient, and thin wheels sintered from these materials can even be made flexible if desired,

whereas the alloys approaching the composition of an intermetallic compound are very rigid and hard, and in many instances will break before bending. By controlling the composition of alloys containing intermetallic compounds, it is possible also to produce a bond which will break down under impact, and which at the same time will be very hard and rigid. This breakdown during the use of the wheel is important in maintaining a free-cutting surface, particularly in connection with abrasives softer than the diamond. In cutting certain materials with a metal bonded wheel in which the abrasive is silicon carbide or boron carbide, the wheel will often glaze over if a ductile resilient metal or alloy is used as the bond, but if a hard alloy is used, and particularly an alloy which will break under impact, glazing is prevented, and a wheel can be produced which is practically self-dressing.

In the case of metal bonded diamond wheels, I have found it to advantage to include in the mixture a certain proportion of a softer abrasive such as silicon carbide, boron carbide or fused alumina. This softer abrasive is preferably somewhat finer in grit size than the diamonds, and when it is distributed through the matrix, it stiffens the metal and makes it very resistant to wear or abrasion. Thus, even in cases when the softer abrasive does no cutting whatever, it greatly reduces the wheel loss, which is ordinarily due to "undercutting" or tearing out of the metal matrix surrounding the diamonds. The addition of materials such as silicon carbide to the mix makes possible the use of a comparatively small percentage of diamonds of fairly coarse grit to do the cutting, with practically no wearing or tearing out of the surrounding matrix. The action of the softer abrasive in making the matrix resistant to wear is of special importance in the use of cut off wheels for cutting glass, silicon carbide and other hard materials which in themselves have abrasive characteristics. During the cutting operation a considerable portion of the wheel is buried in the cut, and the detritus formed in the cut, being finely divided, has a lapping effect upon the metal in which the diamonds are embedded. This lapping or wearing away is prevented by the presence of the abrasive distributed throughout the matrix between the particles of diamonds.

The method of carrying out the invention, as illustrated in the accompanying drawing, is directed for the most part to the manufacture of metal bonded abrasive wheels, although it will be realized that practically any form of shaped article, composed entirely of metal or consisting of non-metallic particles embedded in or bonded by metal, can be produced by the methods indicated. Specific methods by which the sintering operation can be carried out are illustrated in Figures 3 to 5 inclusive. Referring to these figures in detail, Figure 3 shows a furnace with a wire heating element 2 embedded in the wall of the furnace chamber. A hand press supported by the steel frame 3 is placed over the furnace so as to engage with the plunger 4. The screw jack 5, when turned, applies pressure to the plunger 4, and hence to the plunger 6 of the mold. The mold is composed of an outer shell 7, which can be made of metal, and two plungers 6 and 8, which are preferably made of carbon or Acheson graphite. These two plungers are centrally bored to receive an insert or plug 9, which forms the arbor hole of the abrasive wheel. In placing the mix 10 in the mold, the outer ring 7 is

first positioned around the bottom plunger 8 so as to form a container, and the insert 9 is also inserted in the hole in the bottom plunger. The mix is then introduced into the mold and the top plunger inserted. After the mold is assembled, pressure can be applied during the heating operation by means of the screw handle 5.

Instead of applying the pressure continuously as indicated in Figure 3, the pressure can be applied by a sudden blow or a series of impacts, as in a forging or swaging operation. Such a procedure assists in eliminating the air film surrounding the unmelted metal particles or the non-metallic particles contained in the mix, and thus facilitates coalescence of the metal and adhesion of the metal to the non-metallic particles. Jolting the mix during application of pressure will also produce a similar effect.

Figure 4 illustrates a carbon electrode furnace in which the mold is placed between two large carbon electrodes 12 and pressure applied by means of the hand screw 13. The current is passed directly through the plungers 14 and the mix 15 so as to heat the material to the desired temperature.

Figure 5 illustrates a tube furnace in which a carbon tube 17 functions as the resistor, and is positioned between two carbon electrodes 18 and 19. Electrode 18 is hollow so as to admit the plunger 20 which transmits pressure to the mold plungers. The mold consists of an outer ring 21 and two plungers 22 and 23, which are bored to receive the plug 24. The mix 25 is placed around the plug so as to form a circular body with a hole through the center.

Figure 6 shows a type of abrasive wheel made by my process, which has been found satisfactory for the cutting of glass, bonded silicon carbide, refractory tile, and other extremely hard materials. The outer rim 27 is composed of diamonds which are embedded in sintered metal. Silicon carbide, boron carbide or other abrasive materials can be mixed with the diamonds in this outer rim. The inner portion 28 of the wheel can be composed entirely of metal or can be composed of a mixture of metal and an abrasive filler such as silicon carbide.

As a specific example of one method which can be used in making the wheel, the following procedure is given:

A mixture containing 10% diamonds of any desired grit size (as for example from 50 to 150 grid), 10% silicon carbide, 72% copper powder and 8% tin powder is moistened with an aqueous solution of borax and potassium acid fluoride. (This solution may also contain potassium carbonate and boric oxide.) Excess moisture is removed from the mixture, and after the lumps are disintegrated, the mix is introduced into the outer portion of a cylindrical mold so as to form the outer rim 27 of the wheel shown in Figure 6. A paper separator is used to separate the inner and outer portions of the wheel during the introduction of the mix into the mold. To form the inner portion of the wheel, a mixture of 20% silicon carbide (preferably of a grit size of approximately 150 grit), 72% copper powder and 8% tin powder is made. This mixture is also moistened with the flux and, after drying or removing at least most of the excess moisture, is introduced into the mold. The mold is then assembled as shown in Figures 3, 4 or 5 and the mixture subjected to pressure and at the same time heated to a temperature of approximately 750° C.

In addition to the metal bonding of abrasives, the process herein described is applicable to the charging of the surface of a metal wheel or grinding disc such as is used for the grinding of glass. For this purpose a mixture of diamonds or other abrasive and metal powder can be spread in a thin layer over the bottom surface of the mold, and the metal disc used as a plunger or inserted between the mold plunger and the layer of abrasive and metal powder. If a single layer of abrasive is desired, the abrasive grains can be coated on a paper or cloth which is covered with adhesive, the metal powder inserted between the coated paper or cloth and the disc to which the abrasive is to be joined, and the sintering operation carried out as above described.

I have found that sintered mixtures of abrasive particles and a metal powder as described in this application form excellent bearing surfaces, since the hard particles in the matrix are resistant to wear and the metal in which they are embedded is sufficiently ductile to withstand shock or impact. Abrasive materials such as silicon carbide, boron carbide or fused alumina are many times harder than the intermetallic compounds found in most bearing metals, so that the bearing will last almost indefinitely without appreciable wear. Fine silicon carbide or fused alumina particles embedded in a ductile matrix such as copper or bronze have excellent wear resistant properties when used for this purpose.

While the invention is primarily intended for the production of shaped articles, it can also be used for forming metal bonded abrasive aggregates. For example, fine grit diamonds or other abrasive can be bonded with metal by the process described, and the bonded mass broken into particles considerably coarser than the original grit size of the abrasive.

By the term "ingredient" in the appended claims I mean any component or constituent of the alloy in the form in which it is present in the powdered mix. I also include eutectics within the scope of this term, since a eutectic has a constant composition, melts at a constant temperature, and behaves as a single substance upon heating.

A few examples in connection with the aluminum-nickel alloys will make evident the meaning of the term "ingredient." An alloy containing 35 per cent nickel and 65 per cent aluminum, if powdered, would contain some free aluminum (in the form of aluminum nickel eutectic containing about ten per cent of nickel), as will be evident from a consideration of Figure 1 of the drawing. The powdered material, even if previously alloyed, would thus contain an ingredient having a melting point below the temperature of complete fusion of the alloy. If a composition corresponding to the pure compound NiAl were introduced into the mix in the form of the component powders, the mixture would also contain a low melting ingredient, namely, aluminum. However, an alloy of this composition, if powdered, would not contain an ingredient having a lower melting point than

the fusion temperature of the alloy, for in the latter case the aluminum would be combined as the high melting NiAl, and would not be present in the mix in any form which would melt at a low temperature.

The term "component" is used in its usual phase rule interpretation, in that it represents the elements or compounds from which the alloy system or equilibrium diagram is built up, regardless of their state of combination in the particular mixture or alloy in question. Thus in the aluminum-nickel system the components usually chosen are aluminum and nickel, and these elements remain the components even in alloy compositions where neither element is present in the free state.

A "constituent" may be defined as a phase which can be separately identified under the microscope. Thus, in a solid solution of tin in copper, there are two components (namely, copper and tin) but only one constituent, which is the solid solution.

Having thus described my invention, I claim:

1. The process of forming an abrasive article in which the abrasive is bonded by a metal alloy consisting essentially of a solid solution, which comprises forming a mix containing abrasive grain and at least two components of the said solid solution in finely divided form, one of said components being present in minor proportion and having a melting point substantially lower than the temperature of complete melting of the alloy, and sintering the metal powder by applying pressure to the mix and heating it until the metallic portion of the mix, after passing through a plastic condition, in which a portion of the metal is molten, resolidifies to form a compact solid solution alloy firmly holding the abrasive grain, the temperature at all times being below that temperature at which the alloy becomes completely molten.

2. The process as set forth in claim 1 in which the abrasive grain contains a substantial proportion of diamonds.

3. The process according to claim 1 in which the alloy of the bond is predominantly the ductile alpha solid solution of copper and tin and the metal components of the alloy in the mix are copper and tin.

4. The process according to claim 1 in which the alloy of the bond is predominantly a solid solution of aluminum in copper and the metal components of the alloy in the mix are aluminum and copper.

5. The process according to claim 1 in which the alloy of the bond is predominantly a solid solution of zinc in copper and the metal components of the alloy in the mix are zinc and copper.

6. The process according to claim 1 in which the alloy of the bond is predominantly a solid solution of tin in copper and the metal components of the alloy in the mix are tin and copper.

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