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R. F. CLINE
DIAMOND ABRASIVE
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2,476,699

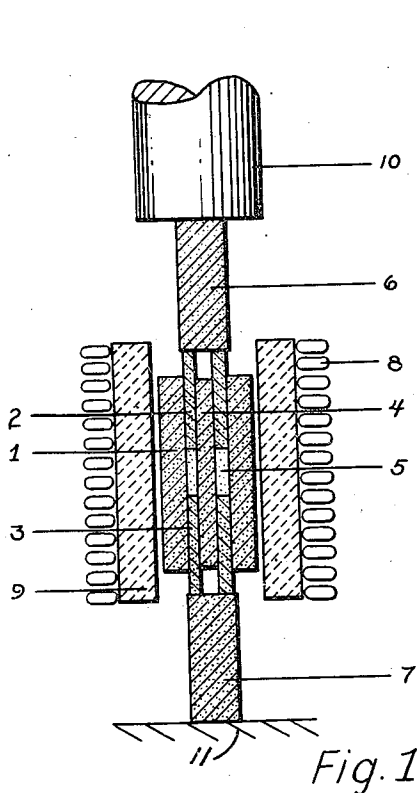


Fig. 1

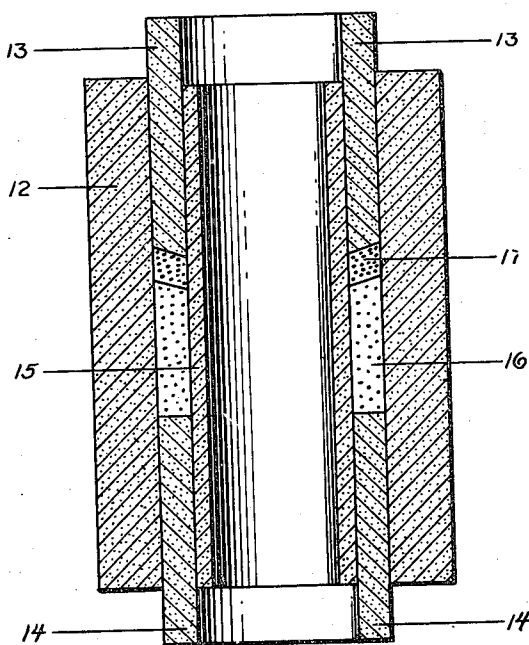


Fig. 4

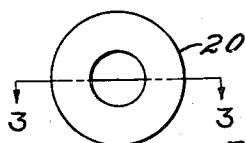


Fig. 2

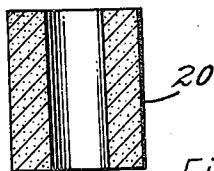


Fig. 3

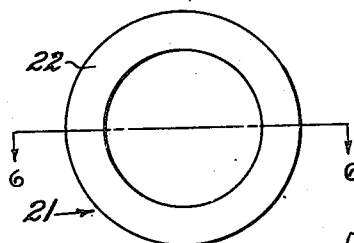


Fig. 5

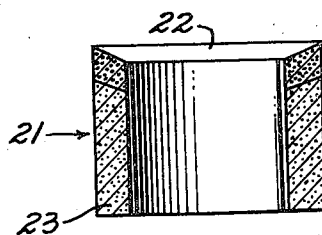


Fig. 6

ROBERT F. CLINE Inventor

By  Attorney

UNITED STATES PATENT OFFICE

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DIAMOND ABRASIVE

Robert F. Cline, Niagara Falls, Ontario, Canada,
assignor to Norton Company, Worcester, Mass.,
a corporation of Massachusetts

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1 Claim. (Cl. 51—309)

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The invention relates to diamond abrasives.

One object of the invention is to provide a diamond grinding wheel bonded with a hard, heat-resistant bond. Another object of the invention is to produce a sintered metal type bond of great hardness. Another object of the invention is to provide a method for the manufacture of diamond abrasives yielding a hard metallic bond under such conditions that the diamonds are neither oxidized nor graphitized nor otherwise impaired.

Another object of the invention is to provide for diamonds a bond of the metallic class which is harder acting than the non-ferrous metal bonds and also harder than most sintered steel bonds now known. Another object of the invention is to provide a diamond abrasive useful in new types of grinding operations. Another object of the invention is to provide a grinding wheel having one or more of the above characteristics and which is nevertheless free-cutting.

Another object of the invention is to produce a diamond grinding wheel especially for cutting or grinding of hard, brittle substances. Another object of the invention is to provide a hard and somewhat friable bond which will allow dull diamond grains readily to break away from the wheel to permit new sharp edges of diamond to be presented to the working face. Another object of the invention is to provide a whole range of bonds varying in hardness from about Rockwell A 85 or higher down to the hardness of bronze and varying from quite friable or brittle to fairly ductile.

Another object of the invention is to provide a well bonded diamond grinding wheel. Another object of the invention is to provide a combination of elements which, in powder form, will quickly sinter to produce a uniform composition to bond diamond abrasive grains. Other objects will be in part obvious or in part pointed out hereinafter.

The invention accordingly consists in the features of construction, combinations of elements, and in the several steps and relation and order of each of said steps to one or more of the others thereof, all as will be illustratively described herein, and the scope of the application of which will be indicated in the following claim.

In the accompanying drawings illustrating two

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of many possible embodiments of the mechanical features of this invention.

Figure 1 is an axial sectional view of a graphic mold assembly and induction heating apparatus;

Figure 2 is an end view of a diamond wheel made in the mold of Figure 1;

Figure 3 is an axial sectional view taken on the line 3—3 of Figure 2;

Figure 4 is an axial sectional view of another graphite mold assembly for the production of a hollow cylindrical wheel including a non-abrasive portion;

Figure 5 is an end view of the wheel made in the mold of Figure 4; and

Figure 6 is an axial sectional view, taken on the line 6—6 of Figure 5.

For the grinding of different materials and under different conditions and to produce specific results, many different kinds of abrasives and bonds have been used. Diamond abrasive bonded with synthetic resin fulfills particular needs while vitrified bonded diamond wheels are preferred for certain operations. Where hard bonded diamond wheels have been wanted, resort has usually been had to metal bonds. Sintered copper-tin bond has been used with great success to bond diamonds making, relatively speaking, a hard bonded diamond wheel. Sintered steel has been used to some extent to provide a still harder acting bond for diamonds. I have discovered a composition and a method for the production of diamond abrasives with a still harder bond which is specifically useful and gives improved performance in certain operations. The composition can be readily formed in situ around the diamond particles by a sintering operation involving temperature and time factors which are readily obtainable and which will not harm the diamonds.

I provide a quantity of boron carbide in powdered form. This may be boron carbide made in accordance with U. S. Letters Patent No. 1,897,214 to Raymond R. Ridgway. In a particular case the boron carbide powder had the following chemical composition:

	Per cent
B.....	77.32
C.....	21.62
Fe.....	0.03
Undetermined.....	1.03

From microscopic examination it was observed that a large percentage of the crystals were clear, indicating a high quality B₄C. The actual particle size distribution in this B₄C powder was as follows:

Microns	Percentage by Weight
35-50.....	1
25-35.....	2
15-25.....	4
7-15.....	25
3-7.....	50
1-3.....	15
Finer than 1.....	8

I provide a quantity of iron powder. The iron powder that was actually used would pass through a 325 mesh screen and analysis indicated it to be more than 98% iron. It was obtained from a commercial source on the open market.

I made a mixture of these powders to give a volume percentage of 23 B₄C to 77 iron. Actually, to provide this percentage ratio, I took 17.8 grams of B₄C and 182.2 grams of iron. The two powders were mixed together in a standard type of pan mill for a period of about 18 hours to insure uniform mixing. A weight of 15.7 grams of this dry mixture was then taken as bond for the wheel. To this was added 2.77 grams of diamond grain of 100 grit size to produce a resulting wheel containing 25 volume per cent of diamond. This small amount of mixture which totalled 18.47 grams was mixed with a spatula by hand to reasonable uniformity and then loaded into a graphite mold.

Referring now to Figure 1, the mold consisted of an outer hollow cylinder 1 of graphite with a $\frac{5}{8}$ " bore fitted with hollow cylindrical graphite plungers 2 and 3 which would just slide in the bore and themselves having a $\frac{1}{4}$ " bore in which a cylindrical graphite core rod 4 fitted. The wheel mixture was placed in the annular zone 5 between the core rod 4 and the outer cylinder 1. The plungers 2 and 3 moved from both ends to compress the mixture in the annular zone 5. The mixture, which was dry, was compacted in the mold by a moderate cold pressing operation under a pressure slightly less than 1000 pounds to the square inch.

The mold was then placed between graphite rods 6 and 7 and inside of a high frequency induction furnace coil 8 having a refractory lining. While heating the mold it was subjected to a pressure of 2260 pounds per square inch by a press ram 10 acting against the rod 6, the rod 7 being supported by the press platen 11. The heating and pressing were continued until the required contraction shown by a press gage had been obtained to yield the desired length of wheel. The mold assembly was then removed from the furnace and allowed to cool slowly in diatomaceous earth powder.

It is usually desirable to make a diamond grinding wheel integral with a back or center of non-abrasive properties so that all or substantially all of the diamond material may be used in grinding, leaving little or none in the discarded stub. Figure 4 illustrates a mold to make such a wheel. An outer cylinder 12 of graphite is fitted with hollow cylindrical graphite plungers 13 and 14 which will just slide in the bore of the cylinder 12 and in the bores of the plungers 13 and 14 is a hollow core 15, also of graphite. The

annular zone 16 of this mold is partly filled with a mixture such as already described, and partly with such mixture without the diamonds, i. e. with iron and boron carbide. The two mixtures are cold pressed in the mold as already described and then the mold is placed between pressure elements and in a high frequency induction furnace of a size to receive it and the mixtures are compacted under heat and pressure of the order of and as already described. A feature of the mold of Figure 4 is that the core 15 is hollow and thin-walled so that the piece can cool from the inside as well as from the outside to prevent fracture of the product due to cooling stresses. This is important for relatively large diameter wheels.

The grinding wheel 20 made in the mold of Figure 1 is shown in Figures 2 and 3. When the cold mold was broken apart and the wheel 20 cleaned of graphite, it was mounted on a $\frac{1}{4}$ " mandrel and found to rotate with remarkable truth. While rotating it was dressed with fine boron carbide grain of about 200 grit size to cause the diamond grains to project above the surface of the bonding material.

This wheel 20 had a good distribution of diamond grains around its periphery and across its ends. The diamonds themselves were undamaged by the heat treatment due to the short time during which they were above 1000° C. (about five minutes). The actual temperature on the outside of the mold was 1085° C. The diamonds were well stuck or attached in the wheel, indicating that good bonding had been achieved.

Grinding tests were made with the wheel 20 in comparison with a standard metal bonded diamond wheel containing the same concentration of diamonds, the bond being 18.5% tin and 81.5% copper (by weight), and also in comparison with a standard resinoid (phenolic resin) bonded diamond wheel, also having the same concentration of diamonds. The grinding machine was a Heald 72a internal grinder, wheel speed 25,000 R. P. M. The following tables give the grinding results for particular materials.

TABLE I

Grinding porcelain pipe sections

[Size 3 $\frac{3}{4}$ " O. D. x 2" I. D. x $\frac{3}{4}$ " length]

Wheel	Wheel Wear on Diameter Mils	Material Removed on Diameter Mils
Of the invention.....	0.0	61.0
Standard Metal bonded.....	0.3	59.0
	0.1	61.0

TABLE II

Grinding tungsten carbide

[Size 1 $\frac{1}{2}$ " O. D. x 1 $\frac{1}{2}$ " I. D. x $\frac{3}{4}$ " length]

Wheel	Wheel Wear on Diameter Mils	Material Removed on Diameter Mils
Of the invention.....	0.2	12.0
	0.2	12.0
Standard Resinoid Bonded.....	1.9	13.5
	1.4	12.5

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TABLE III

Grinding Sanderson's cartridge die steel

Wheel	Wheel Wear on Diameter Mills	Material Removed on Diameter Mills
Of the invention.....	0.1	12.0
Standard Metal Bonded.....	0.7	12.0

Referring now to Figures 5 and 6, the grinding wheel 21 made in the mold of Figure 4 has an abrasive portion 22 which is a cylinder bounded by two conical surfaces, and an integral non-grinding portion 23 made from boron carbide and iron without any diamonds. This wheel is an example of a relatively thin zone of abrasive-bearing bond molded integrally with another zone having the same alloy composition but no abrasive. A wheel such as the wheel 21 or any other integral shape can be mounted on a steel shank or any other suitable mounting. It can be brazed to a shank by a subsequent heating operation and the bond will not be deleteriously affected as long as the brazing temperature is less than 100° C.

The above chemical analysis should not be considered as a limiting case since, in the commercial preparation of boron carbide, the boron content may, if desired, be raised to 95% with the balance mainly carbon. The presence of the carbon was considered to be of doubtful value. Since 17.8 grams of boron carbide plus 182.2 grams of iron adds up to 200 grams of mixture, the proportion is 8.9% of boron carbide to 91.1% of iron by weight. Since there was but 21.62% of carbon in the boron carbide, there was only 1.94% of carbon in the mixture.

In an attempt to find out the true nature of the bonding material of the invention, I prepared a sample of 25% by volume of boron carbide of the foregoing analysis and 75% by volume of Fe (this differs only slightly from the proportions used in making the wheels described).

This mixture was heated under pressure as already set forth and the compacted sample was then powdered and subjected to X-ray analysis. Then another mixture was made of 40% B₄C and 60% Fe by volume, likewise heated under pressure, powdered and subjected to X-ray analysis. The first of these will be called sample No. 1 and the second will be called sample No. 2. Excellent powder photographs were obtained from both samples. The following conclusions are believed to be correct:

(a) The principal phase present in both samples No. 1 and No. 2 was Fe₂B, sometimes referred to as FeB₂, which contained little or nothing in solid solution.

(b) Sample No. 1 contained little or no B₄C or Fe.

(c) Sample No. 2 seemed to contain a small amount of each of B₄C and Fe.

(d) No indication of FeB or of B could be found in either of sample No. 1 or sample No. 2.

(e) Graphite was indicated by the X-ray photographs to a slight extent in sample No. 2. From all considerations graphite should be present in both of the samples and to a greater extent in sample No. 2 than in sample No. 1.

(f) From all considerations there is doubt as to the presence of Fe₃C in either sample. The X-ray photographs failed to indicate any. Fur-

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thermore, the sintering time was too short to make the formation of Fe₃C likely.

It is, therefore, considered that the principal sintering reaction may be indicated by the formula:



This would indicate that to combine all of the iron and boron and provided the boron carbide is represented by the formula B₄C, 11% B₄C to 89% Fe by weight should be used. But, as indicated, an excess of boron over that required by the formula B₄C may be present (in solid solution) in the boron carbide powders. In such cases more iron may be provided to combine all of the boron to Fe₂B.

In order that the various weight and volume percentages already mentioned may be seen at a glance, the following table is provided:

TABLE IV

Volume per cent	B ₄ C	Weight per cent
10.0		3.87
23.0	Formula from	8.9
which were prepared wheels of the two examples given		
25.0	Sample No. 1	9.67
28.4	Ratio for	11.0
	B ₄ C + 8Fe	→ 4Fe ₂ B + C
30.0		11.6
40.0	Sample No. 2	15.5
	Fe	
90.0		96.13
77.0	Formula from	91.1
which were prepared wheels of the two examples given		
75.0	Sample No. 1	90.3
71.6	Ratio for	89.0
	B ₄ C + 8Fe	→ 4Fe ₂ B + C
70.0		88.4
60.0	Sample No. 2	84.6

The composition of sample No. 1 appears to yield the highest hardness values, indicated by tests to be in the range of Rockwell A scale 80 to 85. This is very hard. Rockwell A 87 is about 600 times as hard as plate glass in wear resistance. Commercial cemented tungsten carbide has a hardness range on the Rockwell A scale of around 86 to 91. It may be desirable in some cases to provide a bond which, while much harder than the widely used copper-tin bonds, is yet not so hard as the above. In general, the hardness and brittleness of the bond can be reduced by decreasing the proportion of boron carbide. For example, with 10% by volume of B₄C and 90% by volume of Fe (see Table IV), the resulting metallic material becomes more ductile and actually can be deformed without snap fracturing. This is doubtless due to a substantial proportion of iron as ferrite in the composition. Assuming all of the boron combined with iron to form Fe₂B, this composition is by weight:

	Per cent
Free iron	71.86
Combined iron	24.27
Combined boron+carbon	3.87
Total	100.00

Inasmuch as the invention may be carried out with the use of pure boron (if and when available) and since this composition gives useful properties as a bond for diamonds, the upper limit of iron may be put at 75% iron by weight calculated as beyond that required for the reactions B₄C+8Fe→4Fe₂B+C and B+2Fe→Fe₂B.

While boron carbide, B₄C, is of great hardness, and is in fact considered next to the diamond itself in hardness, it has been noted that 90.3% iron, the remainder B₄C, produced the hardest bond. This is doubtless because the particular time-temperature factor for sintering does not cause the boron carbide grains readily to bond

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to each other. When a quantity of B_4C appreciably greater than 30% by volume is added to the iron powder, the resulting metallic material shows, upon metallographic inspection, discrete crystals of B_4C . These tend to weaken the structure somewhat. Yet for certain grinding results it is desirable to have a "friable" bond. So, therefore, I may use as much as 40% B_4C by volume (see Table IV) or, stated in another way, as little as 84.58% by weight of iron (sample No. 2). The low limit of iron is, therefore, stated, in an even percentage, as 84% by weight.

Instead of sintering the mixture of boron carbide and iron under combined heat and pressure, the grinding wheel or other abrasive body may first be cold pressed under a relatively high pressure and subsequently sintered without pressure. To substantiate this, a test bar was made by pressing a mixture of 23 volume per cent of B_4C and 77 volume per cent of iron under a pressure of 70,000 pounds per square inch without any heat. Later this test bar was heated in an induction furnace in a vacuum for four hours at a temperature of 1000° C. This process made a strong bar and accordingly is deemed to be useful for the manufacture of grinding wheels containing diamonds. From certain tests made by my associates it is clear that the diamonds will not be detrimentally graphitized by such heat treatment in the presence of the range of compositions according to the present invention, provided carbon is present even in combined form to the extent of at least .7% by weight of the bond, as will usually be the case. In either method of preparing the product the bond is a silvery metallic product having a density of from 6.0 to 7.0. Accordingly if for manufacturing reasons it is desired to do the heating in a furnace which cannot be associated with pressure apparatus, cold pressing and subsequent sintering may be resorted to.

While the utility of the invention is now known in connection with diamond abrasives, it is contemplated that the bonding ingredients may be used to bond other hard materials such as aluminum oxide, and especially silicon carbide, not

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only for abrasive purposes but also for the manufacture of tool bits or other hard objects. Furthermore, the alloy of boron and iron herein described will have useful properties when made without the admixture of any abrasive or other material and I wish to claim the same separately.

It will thus be seen that there has been provided by this invention an article and a method in which the various objects hereinabove set forth together with many thoroughly practical advantages are successfully achieved. As various possible embodiments might be made of the mechanical features of the above invention and as the art herein described might be varied in various parts, all without departing from the scope of the invention, it is to be understood that all matter hereinbefore set forth or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

I claim:

An abrasive composition comprising diamond grains bonded with a sintered mixture containing from 25% to 100% Fe_2B by weight and from 91% to 97.8% iron by weight, including both free and combined iron.

ROBERT F. CLINE,

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The following references are of record in the file of this patent:

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