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METAL BONDED ABRASIVE COMPOSITION

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The invention relates to metal bonds for abrasives and to metal bonded abrasive compositions for abrasive articles and the like. It finds its best present utility in the manufacture of diamond grinding wheels for the grinding of cemented carbide tools, particularly for sharpening milling cutters and for the grinding of chip breaker grooves in cemented carbide lathe tools. This application is a continuation-in-part of my copending application Serial No. 797,641, filed March 6, 1959, and now abandoned.

One object of the invention is to provide free cutting diamond grinding wheels which do not have excessive wheel wear. Another object is to eliminate or to reduce the use of abrasive dressing sticks because excessive dressing causes loss of good abrasive which is particularly undesirable in the case of expensive diamond abrasive. Another object is to provide wheels which do not crumble or spall yet which are free cutting.

Another object of the invention is to attain the desired freedom of cut in a diamond wheel without the use of soft inert fillers which cause the wheel to break down too readily during grinding. Such wheels usually have weak structures so that both diamond and filler are readily torn out causing the wheel to round and spall on the corners, necessitating frequent truing to preserve the desired contour of the wheel face and it is an object of my invention to reduce or to avoid this defect. Another object is to provide a metal bond which is strong and yet capable of being broken down under the stresses of use in a controlled manner, thus constituting and efficient bond in abrasive articles used for operations such as electrolytic grinding. Another object is to provide a metal bonded structure containing hard particulate inorganic material, having useful strength and wear resisting properties. Other objects will be in part obvious or in part pointed out herein.

I have found that phosphorous compounds added to metal bonds for abrasive products cause desirable gradual breakdown of the bond during use. The result of the gradual breakdown is freedom of cut achieved with relatively low wheel wear. Microscopic study indicates that the phosphorous appears to go into the metal grain boundaries.

EXAMPLE I

As an illustration of the way in which phosphorous compounds enter the grain boundaries, I took 15 grams of electrolytic iron powder of minus 325 mesh size and 0.79 grams of iron(ous) phosphate in purified finely divided precipitated powder form indicated to have the chemical formula $Fe_2(PO_4)_2 \cdot 8H_2O$. This phosphate was calculated to contain 33.5% Fe and 12.3% P. When heated in hydrogen, the ignited material was calculated to contain 73.1% Fe and 26.9% P, which means that the ignited mixture with iron powder contained about 0.6% P.

I mixed these dry powders together thoroughly by hand spatulation. The total mixture was then pressed in a steel mold of rectangular cavity approximately 1¼" long x ½" wide to a pressure of 40 tons per sq. in., producing a bar compact of 0.251" thickness. The bar was placed in a controlled hydrogen atmosphere furnace and fired

along with other test bars with a four hour soak at 800° C. The fired (sintered) bar was measured to determine shrinkage and weighed to permit calculation of sintered density. Rockwell hardness was determined and the bar was broken in cross-bending on 1" span with single point loading at a deformation rate of 0.25" per minute. Modulus of rupture was calculated by the conventional beam formula which reduces to:

$$\text{Mod. Rupt. (p.s.i.)} = \frac{1.5 \text{ load in lb.}}{(\text{width}) \times (\text{thickness})^2}$$

This is approximately an ASTM standard method for modulus of rupture tests of sintered metal compacts.

From half of the broken test bar, a metallographic sample was cut and mounted in Bakelite for polishing, etching and microscopic examination in the conventional manner. The microstructure showed black lines considered to represent an iron-phosphorous compound, which X-ray diffraction examination indicated to be iron phosphide, segregated at the iron grain boundaries, which boundaries were disclosed by further etching. A parallel experiment without any iron phosphate addition showed none of these heavy black lines.

EXAMPLE II

This illustrates the grain-by-grain breakdown that occurs in my compositions when subjected to stresses such as would be caused by the eroding action of grinding swarf in grinding use. As an incidental feature not believed to affect the breakdown characteristics, a small sulfide additive was present for reasons to be subsequently discussed. Bars were made according to Example I except that I added powdered copper sulfide in the amount of 5.0 weight percent of the total mixture weight, with subsequent thorough mixing, follower by sintering.

A polished and etched microsection of this sample after having been indented with a Rockwell hardness indenter showed a dark portion as the depressed area produced by the indenter and it could readily be seen that failure cracks had developed along the grain boundaries. These cracks are believed to have occurred along the grain boundaries which were weakened by the phosphorous containing compound.

A parallel experiment using electrolytic iron powder alone showed only a normal sintered ferritic structure and grain boundary weakening was not present. This was shown by a photomicrograph of a bar made and sintered in an experiment exactly parallel to Example I except that no phosphorous compound was added. As in the preceding case, a dark portion was the depressed area produced by a Rockdell hardness indentation. In the pure iron there was no evidence of grain-boundary failure and the product yielded in a ductile manner as would be expected for electrolytic iron.

In my new bond a measure of ductility remains due to the highly ductile nature of the electrolytic iron in spite of the presence of phosphorous and resulting grain boundary weakening. This is proved by the fact that I have data which shows that the deformation at rupture of typical bars was in the range of 20 to 40 mils, whereas that of similar bars made of a typical brittle bronze bond as used in many diamond grinding wheels of the prior art is in the range of only 2 to 6 mils. This ductility is considered to account for the resistance to spalling and consequent corner-holding ability of wheels made with my bond. It is to be realized that the inherent ductility of electrolytic iron powder prevails in spite of about 0.2% of residual impurities that it may contain.

As examples of the effect of different amounts of phos-

phorous compound on the physical characteristics of metal bonds, I have made bars similar to Example I except that they were sintered at 815° C., in which different amounts of iron phosphate were used in the mixture. Test results on 6 sintered bars of each mixture were as follows:

TABLE I

Physical Test Results on Metal Bonds (av. of 6 bars)

Example No.	Composition (percent by Wt.)		Density (gm./cc.)	Hardness (Rockwell F-scale)	Modulus of Rupture (p.s.i.)
	Total Fe [1]	P [2]			
III	99.4	0.6	6.15	60	85,000
IV	98.7	1.3	5.76	50	50,000
V	98.0	2.0	5.23	10	35,000
VI	97.2	2.8	4.95	5	30,000

[1] Total Fe = Fe added as Fe plus Fe added as iron phosphate.
[2] Added as $Fe_2(PO_4)_2 \cdot 8H_2O$ but calculated to Fe plus P.

These results show how I can vary the amount of grain-boundary weakening by varying the amount of phosphorous in the bond. The crossbending strength decreases as I increase the amount of phosphorous in the bond. Since I have observed that phosphorous compounds enter the grain boundaries, I interpret the decreasing strength to be correlated with a progressive weakening of the grain boundaries.

The following description of the making of a diamond wheel with Example III bond illustrates the use of my new metal bond composition in a grinding wheel. The wheel was a straight wheel of 6" diameter by ⅛" thickness. The diamond-containing layer of the wheel was the periphery and was 1/16" deep. I took 395 grams of electrolytic iron powder and molded a preform for the center of the wheel by putting this powder in a steel mold 6.024" inside diameter with a 1.250" arbor positioned centrally and pressing it to a thickness of 0.202 inches which required a pressure of about 26 tons per square inch. Then the preform was turned in a lathe to 5.889" diameter and replaced in the same mold band. The annular space between the periphery of the preform and the band was filled with the diamond mixture made by thoroughly mixing 22.8 grams of Example III bond mixture with 2.10 grams of size #100S diamond abrasive. The entire wheel was then pressed to a pressure of 40 tons per square inch. The mold was then stripped, the wheel removed, placed on a silicon carbide refractory batt and put in a furnace for firing, which was done with a soaking temperature of 815° C. for 4 hours in an atmosphere of hydrogen. After cooling to room temperature the wheel was trued to final dimensions and tested as will be described. Corresponding wheels with the other bonds of Table I are made in the manner just described. Wheels of other sizes, shapes, amount of diamond or other abrasive, grain size, kind of bond filler can be made, and other variations can be introduced into my bond composition and used to make wheels with procedures well known in the art.

To demonstrate the practical advantages of my new product in grinding wheels, I ground with the Example III wheel in comparison with two other wheels that are representative of current commercial wheels used for plunge cutting chip breaker grooves in cemented carbide tools. A grinding test was devised for carrying out this type of operation under standardized conditions that could be accurately measured and reproduced. The wheels were all metal-bonded diamond wheels of about the same grain size. They were 6" diameter and were sided to exactly 0.117" for all wheels. They were dressed by a standard method established for the test before grinding. The results of the test are given in Table II.

TABLE II

Grinding Results on Directly Comparable Metal-Bonded Diamond Wheels

	Grinding Time Req'd (min.)	Diametral Wheel Wear Resulting (mils on Diam.)	Wheel Corner Wear Resulting (mils radius of corner)
Comparison Wheel A	37.9	0.40	15
Comparison Wheel B	48.9	0.23	7
Wheel Example III bond	35.1	0.20	6

The above test shows superior performance for the invention wheel in all three categories. The time required to carry out the amount of grinding established in the test was less, the wheel wear measured by the difference in mils between the diameter of the wheel before the test and after the test was less and the wear on the wheel corners measured by the average radius in mils of the two wheel corners after the test was less.

In terms of the wheel value to the customer a lower grinding time means greater freedom of cut which means higher output of tools ground per shift with lower labor cost; a lower wheel wear means more tools ground per wheel and hence lower wheel cost; and a lower wheel corner wear adds to wheel life by reducing the amount of dressing necessary to hold the desired contour of the tool.

As further illustration of the utility of my bond, the results of a few field tests that are representative of many such tests made with my product are as follows.

Plant A uses a metal-bonded diamond wheel, 6" x ⅛", for plunge grinding the cemented carbide flutes of a two-flute end mill. An 80:1 dilution of soluble oil in water is used as coolant. The test wheel made in accordance with Example III bond was dressed at the start of the test and satisfactory wheel performance was noted throughout the test. No glazing occurred at any time. The wheel corners held up better than any wheel ever used previously. No appreciable wheel wear had occurred after grinding 400 flutes. The radius at the corner was still less than 1/32" and the wheel had not been dressed since the test started. The customer wanted free cut and long life and he was getting both.

Plant B uses a 6" x ⅛" diamond metal bond wheel for plunge grinding chip breakers on cemented carbide tools. The test wheel made in accordance with Example IV bond ground 20,888 chip breakers, had a satisfactory action and indicated a reduced grinding cost compared to the standard wheel used on the job.

Plant C uses a 3¾" x 1½" x 1¼" flaring cup shaped resinoid-bonded diamond wheel for resharpening cemented carbide inserts of milling cutters with soluble oil coolant. The test wheel made in accordance with Example IV bond was evaluated in an acceptance test by the customer consisting of 0.100" stock removal on a carbide blank ½" x 1" using a feed of 0.0003" per pass. The customer found the test wheel to be the best metal bonded cup wheel tested because of its cool and free-cutting action.

Plant D uses a 10" x 3/16" straight periphery-type diamond resinoid bond wheel for a combination of chip breaker grinding and surfacing of carbide tools with soluble oil coolant. The test wheel made in accordance with Example III bond lasted for a total of 1,936 hours on production work, during which 25,600 tools were ground. This is the best performance ever obtaind from any diamond wheel and reduced the overall tool cost from $3.04 per hour to 10 cents per hour.

It is my theory that the phosphorous addition acts advantageousy not only to establish a controlled breakdown rate in the bond by modifying the ferritic grain boundary but also in other ways. It reduces the ductility of the iron, thus reducing the tendency of the wheel to smear in grinding. I also consider that it imparts an af-

finity for oil to the bond. This is advantageous when grinding with straight oil or with soluble oil coolant and lubricant in that an adherent film of oil will reduce undesirable friction. As a supplement to the oil-holding characteristic of the phosphorous compound I may put sulphur compounds in the bond. This sulphur may form a phosphorous-sulphur complex at the grain boundary, but appears primarily to constitute a discrete sulphide phase.

To illustrate the use of sulphur additions, I took three mixtures of Example III composition and added sulphur compound as follows:

TABLE III

Physical Test Results on Iron-Phosphorous Bond of Example III plus 5% of Added Metal Sulfide (av. of several bars)

Example No.	Sulphur Compound Added	Percent S in Product	Density (gm./cc.)	Hardness (Rockwell F Scale)	Modulus of Rupture (p.s.i.)
VII	FeS	1.8	6.32	69	74,000
VIII	CuS	1.7	6.28	77	86,000
IX	MnS	1.8	6.22	71	69,000

By a photomicrograph at 400X of Example IX, darker grayish rounded areas were noted and considered to be manganese sulfide.

It will be seen from Table III that these products made with sulfides have a strength as measured by modulus of rupture that is not materially reduced compared with corresponding products made without sulfides, while the Rockwell hardness is slightly higher. I interpret these effects to means that smearing tendencies of the bond during grinding are reduced because of the sulfide inclusions and accompanying higher hardness, whereas wheel wear should remain essentially the same.

To investigate the effect of manganese sulfide addition in actual grinding tests, I made a diamond abrasive wheel in accordance with the procedures described for the making of Example III wheel except that as a bonding material I used the composition of Example IX, with 5% MnS in the bond mixture as well as the 0.6% phosphorous. This wheel was used to surface grind cemented tungsten carbide under fixed-feed conditions. Both wheel wear and power consumed were low and the performance was considered generally satisfactory, whereas bronze-bonded wheels of the prior art used for this type operation consume excessive power indicating failure to cut freely under surface grinding conditions.

To introduce phosphorus into my compositions I may use a varity of phosphorous-containing materials. I have given the example of ferrous phosphate. Ferric phosphates, pyrophosphates, phosphites, phosphides and other compounds can be employed. Phosphorus compound concentrates at the grain boundaries and weakens them. I may use phosphorous compounds other than those of iron, such as those of Ni, Co, Cu, Mn and Cr. I may use a phosphorous content in my sintered bonds from about 0.4% to about 5% by weight of the total metal bond composition after the furnacing which converts the bond to a "loss free" ignited basis and develops strength by the sintering operation, but I prefer bonds having in the range from about 0.6% to about 3% by weight of phosphorous of the total ignited metal bond composition.

To introduce sulphur into my compositions I may use metallic sulfides which are stable and do not dissociate or vaporize in the sintering range of my compositions. Sulfides of such metals as iron, nickel, cobalt, copper, manganese, chromium and mixtures thereof may be used. Sulphur compounds which are reducible in hydrogen, or other protective atmosphere used in sintering, to form sulfides may be used. The sulphur content of my bond composition may be from zero to 7% depending upon

the oil-holding characteristics desired, although about 4% is usually sufficient.

The sintering temperature can vary from about 750° C. to about 1100° C., but the exact temperature, soaking time, kind of atmosphere and other processing details will depend upon the composition used and other principles well known in the sintering art. My metal bond is an iron base bond which I define as containing at least 86% by weight of iron or iron strengthened with ferrite strengthening metal and having from no significant carbon up to .8% carbon and with from .4% to 5% phosphorous and with from no significant sulphur to 7% sulphur. However the iron base bond has at least 50% of iron. Metals which strengthen ferrite are manganese, silicon, nickel, cobalt, chromium, copper, molybdenum and tungsten. Mixtures can be used. My metal bond has a melting point above 750° C. and is sintered at between that temperature and 1100° C. The alloying metals can be present in the continuous iron phase in amounts that form solid solutions with the iron. In the preferred form of my invention by metal bond, which in most cases ought to be soft, has a hardness no greater than 100 on the Rockwell F scale. But I believe that useful abrasive compositions can be made in accordance with my invention, in which the ferrite strengthening metal is tungsten or silicon, having a hardness considerably greater than 100 on this scale.

Another way of defining my invention which will serve to qualify the previous definitions is that it is a metal bonded abrasive product consisting of abrasive grain bonded with metal bond essentially consisting of metal, phosphorous and permissible carbon and sulphur, having at least 50° iron, having at least 86% total metal, with from .4% to 5% of phosphorous, from no significant carbon up to .8% carbon, from no significant sulphur up to 7% sulphur, said metal having a melting point above 750° C. and having been sintered at a temperature of between 750° C. and 1100° C., said phosphorous producing grain boundary weakening.

Furthermore in a preferred form of the invention, the iron is strengthened by metal selected from Mn, Si, Nn, Co, Cr, Cu, Mo, W and mixtures thereof from .5% to the limit of solid solubility of such metal in iron. Also, my invention is a raw batch having the characteristics and material contents in the percentages stated.

With regard to the solid solubility in iron of the various metals which are ferrite strengthening metals, that of manganese is 3%, of silicon is 14%, of nickel is 6%, of cobalt is 49%, of chromium is 25%, of copper is 0.4%, of molybdenum is 6% and of tungsten is 6%.

The art of diamond wheel manufacture is now well developed and it is unnecessary to go into the details and permutations about such wheels and their manufacture which can be embodied in the invention wheels of the examples without departing from the scope of the invention. For diamond abrasive articles the amount of diamond may be from about 5 volume percent to about 38 volume percent of the article, whereas for ordinary abrasives the amount may be from about 35 to about 75 volume percent. The total range for all abrasives is therefore from about 5 to about 75 volume percent of the article. Pores may also be present, but are usually low such as less than 20%, and often are substantially absent.

It has become common practice in some types of metal bonded diamond wheels to use secondary abrasives or fillers in the metal bond, such as granular or powdered tungsten carbide and other hard carbides. Other materials such as silicon carbide, aluminum oxide, etc., may also be used. Sometimes powdered glass, mica, etc., is used as a filler.

While for some purposes one bond will give the best results, for other purposes another, and for other purposes still another, as grinding requirements vary, in order to comply with the statute, I select the bond of Example III as the best mode of the invention, and in the use of

diamond grinding wheels, a wheel made with the bond of Example III.

It will thus be seen that there has been provided by this invention a metal bonded diamond abrasive composition in which the various objects hereinabove set forth together with many thoroughly practical advantages are successfully achieved. As many possible embodiments may be made of the above invention and as many changes might be made in the embodiments above set forth, it is to be understood that all matter herein-before set forth is to be interpreted as illustrative and not in a limiting sense. Although I have explained my results in terms of observations and their interpretation by theories which represent my best opinions of processes and mechanisms which at best can only be interpreted and not completely measured, my claims are not restricted to the absolute correctness of these theories and opinions.

I claim:

1. A metal bonded abrasive product consisting of abrasive grain of from 5 to 75 volume percent bonded with metal bond consisting essentially of at least 86% by weight of metal selected from the group consisting of iron and ferrite strengthening metals, and mixtures thereof, at least 50% of the weight of the bond being iron, the bond also including from 0.4% to 5% by weight phosphorous, from a trace amount of carbon to 0.8% carbon, and from zero to 7% sulphur, said bond having a melting point above 750° C. and having been sintered at a temperature of between 750° C. and 1100° C., said phosphorous producing grain boundary weakening.

2. A metal bonded abrasive product according to claim 1 in which the ferrite strengthening metal is selected from the group consisting of Mn, Si, Ni, Co, Cr, Cu, Mo, W and mixtures thereof from 0.5% to the limit of solid solubility of such metal in iron.

3. A metal bonded product according ot claim 1 in which the metal bond contains from 1.5% to 7% sulphur.

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