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⑤④ **Production of resin bonded abrasive products.**

⑤⑦ A method of producing resin bonded abrasive products particularly cut-off wheels is described. The method comprises firstly preparing a blend of a suitable abrasive material and a thermosetting resin bond which will soften on heating to a temperature at which the rate of cross-linking is not substantial. The blend is then heated to soften the resin bond and a compaction pressure of less than 3 kg/cm² is applied to the softened blend to effect consolidation thereof. The temperature of the blend is then raised to cure the bond and produce the resin bonded product.

The present invention relates to the production of resin bonded abrasive products.

Resin bonded abrasive products are conventionally produced by cold pressing a blend of particulate abrasive material and synthetic resins with or without fillers to give a green(uncured) product of the required shape, size and density and subsequently heating the green product to cure the synthetic resin thereby to provide a firm bond between the abrasive particles. The pressures normally required for the cold pressing are in the range of 35 - 500 kg/sq. cm., the exact value depending on the properties required for the bonded product.

Examples of resin bonded abrasive products manufactured by the above process are grinding wheels and especially cut-off wheels i.e. abrasive wheels having a high diameter to thickness ratio (e.g. from 40:1 to 200:1). An application of large diameter cut-off wheels is the cutting off of hot steel billets produced by the continuous casting process.

It will be appreciated that even at the lower end of the above pressure range, the manufacture of cut-off wheels having a diameter of 2 metres requires the use of a press capable of applying a total pressure of about 1000 metric tonnes. Such a press involves high capital expenditure.

A method of producing resin bonded abrasive products using a warm pressing operation is also known. For example, U.S. Patent No. 4,110,939 suggests that a blend of abrasive and resin may initially be pressed

under a pressure of at least 3 kg/cm² and at a temperature of 10-100°C prior to curing of the resin, although, as far as we are aware, such low pressures have not been used commercially for producing resin bonded abrasive products..

5 It has now been found that resin bonded abrasive products may be conveniently produced at pressures lower than those suggested for use in warm pressing operations, and substantially lower than those used in
10 cold pressing operations, thereby avoiding the need for the expensive presses used for cold pressing.

According to the present invention there is provided a method of producing a resin bonded abrasive product comprising preparing a blend of a particulate abrasive
15 material and a predominantly powdered thermosetting resin bond, which bond will soften by heating to a temperature below that at which the rate of cross-linking is substantial, heating the blend to soften the resin, applying a pressure below 3 kg/cm² to the heated blend to effect compaction
20 of the abrasive particles, and further heating the blend to cure the resin to produce the bonded abrasive product.

The invention also provides bonded abrasive products made in accordance with the process defined in the preceding paragraph.

25 The invention is particularly applicable to the production of grinding wheels and cut-off wheels.

The term "predominantly powdered resin bond" is used in the same sense herein as is normally

understood in the art. In other words, the bond comprises a liquid phase, which may itself be a thermosetting resin, and a major amount by weight of a powder which will include, or consist wholly of, a particulate thermosetting resin or resins. In addition to including the particulate resin, the powder may additionally include inorganic fillers, or organic modifiers such as epoxies, rubber, polyvinyl butyral, or the like, as is well known in the art, to give the desired properties for the finished product.

The important feature of the invention is the utilisation of the basic properties of predominantly powdered resin bonds which soften on heating to a degree which enables compaction of the composite under a low pressure, i.e. less than 3 kg/cm^2 . When a blend of such a resin bond and abrasive material is heated at a temperature at which the rate of cross-linking of the softened resin is low, the degree of this softening allows the abrasive particles to be compacted and consolidated together with the application of substantially lower pressures as compared to those which are used in the cold pressing operations described above. Although the same predominantly powdered resin bond could be used as the bond in the conventional cold pressing method, its flow characteristics are such that, without softening by heating, the high pressures of the cold pressing method are still required to achieve adequate consolidation of the uncured resin bonded abrasive product.

The exact pressure used in the method of the invention

will be dependent on the flow characteristics of the particular predominantly powdered resin bond system used. The pressure will however be less than 3 kg/cm^2 , preferably less than 2.5 kg/cm^2 and will most usually be less than 1.8 kg/cm^2 . In fact the preferred pressure range is 0.1 to 1.8 kg/cm^2 with a pressure of about 0.3 kg/cm^2 being suitable for most cases. The low pressures required may be applied by means of weights or compressed springs or by low pressure hydraulic or pneumatic methods, or by any other convenient method.

The predominantly powdered resin bond may be any such bond which softens on heating to a temperature lower than that at which the rate and degree of cross-linking will interfere with the compaction process. Within these criteria, the bond may have a wide variety of flow characteristics, and may soften at a greater or lesser temperature to suit the particular application, bearing in mind that the cured bond may have to withstand the forces encountered in high speed grinding or cutting operations.

The bond used may be based on powdered phenolic novalac resins, together with liquid phenolic resins (e.g. resoles) or wetting agents which can combine with the resins. Examples of such wetting agents are furfural or furfural in combination with cresols or xlenols, or plasticisers which are compatible with the resins at process temperatures. In the case of dense wheels utilising furfural or plasticiser based wetting agents, calcium oxide is added to combine with the volatiles produced in the bond during the curing process.

Powdered phenolic resins are available with a wide

range of flow characteristics, which makes such resins particularly useful for the invention. Typical examples of such powdered phenolic resins have flow characteristics varying between 15 mm (low flow) and 100 mm (high flow) as
5 determined by a common flow test used by phenolic resin manufacturers and grinding wheel Producers. The flow test uses a 0.5 g pellet of resin placed on a level glass plate in an oven, held at 120°C for 5 mins, and the plate is then tilted at an angle of 60°C. The length of the pellet in mm.
10 after 10 minutes is measured and constitutes the flow value.

Resins with flow values as specified above are readily available and can be utilised in the invention. In the case of bonds formulated with high flow resins it will be apparent that lower temperatures and pressures will be required to
15 consolidate the bond in the process of the invention, than would be required for low flow resins.

It is also common practice in producing resin bonded grinding wheels to include fillers which influence the strength of the wheel and contribute to improved grinding
20 performance. These materials reduce the flow of the bond to a degree which varies with the proportion of the filler used, and also the particle size of the filler. It will be readily apparent that the use of high filler contents for wheels made by the process of the invention necessitates the
25 use of higher flow resins to offset the restriction on flow of the high filler contents to maintain the pressure required in the compaction process at a low level.

Any particulate abrasive material of suitable grit size or combination of grit sizes may be used for the
30 invention. Examples of various types of abrasive are

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various types of fused alumina, silicon carbide, fused zirconia-alumina, and sintered abrasive either individually or in combination as commonly used

for the production of grinding wheels.

The blend of the particulate abrasive material and predominantly powdered resin bond may be produced in any convenient way. In one method, the abrasive material is firstly wetted with the liquid components of the bond, and then the powdered resin, optionally including fillers, is added and blended so that the powder adheres uniformly to the liquid coating on the abrasive. Alternatively in the production of dense or low porosity grinding wheels where the bond content is high, the formulation may be such that between the bond coated abrasive particles there exist resin particles wetted with a liquid which is a non-solvent for the resin at room temperature, but which combines with the resin during curing.

Once the blend has been prepared, the next step is to shape and compact the blend prior to curing of the resin. For this operation the blend may be introduced into a suitable mould, in which it is softened by heating and compacted to give a body of the required shape. The mould for producing a wheel may comprise a ring and a pin on a metal plate and, after the cavity is filled with the blend, a plunger is placed on the mould and the assembly heated to a temperature at which the bond softens and flows under the applied low pressure. Generally this temperature will be in the range of 30-100°C, the exact value depending on the flow characteristics and cross-linking rate of the bond.

Once the abrasive blend has been compacted, the

composite produced is heated to a higher temperature to cure the resin and produce a resin bonded abrasive product. Preferably the pressure applied during compaction is maintained during the curing operation.

5 In this case, the softening, compaction and curing are conveniently effected in a single oven with a programmed temperature control allowing the temperature of the oven to be raised firstly to the softening/ compaction temperature and, after a predetermined time,
10 secondly to the curing temperature which is again maintained for a predetermined time prior to cooling of the body. Alternatively, of course, the temperature of the oven may be slowly and continuously raised to the curing temperature, the oven being at a temperature
15 at which the resin is soft for a sufficient time to effect the desired compaction.

A number of variations may be applied to the basic principle described above.

The mould and also the plunger can be preheated
20 to the required temperature prior to adding the blend and the low pressure can be applied after the relatively short period required for the blend to attain the mould temperature.

Alternatively, the bottom plate of the mould
25 can be a thin metal plate and, after distributing the blend into the mould, the barrel and pin can be removed leaving the blend in a thin layer on the plate. A number of similar plates carrying evenly spread layers of blend can be stacked on top of each other and covered
30 with a plate on top of which are placed further plates

of a weight sufficient to provide the low pressure required for consolidation. The whole assembly is then heated in an oven initially at the temperature required for consolidation to take place, and once this
5 has been achieved the temperature is raised to completely cure the wheels. In order to ensure that all wheels receive the required degree of consolidation at least three spacers of a predetermined thickness may be placed between each pair of supporting plates in the
10 stack, so that when the required degree of consolidation has taken place the top plate rests on the spacers. By using spacers of identical thickness, a high degree of control of the thickness variation within the wheel can also be achieved.

15 Alternatively the blend can be distributed onto the mould base plate which is then placed in a microwave preheating oven for the period required to raise the temperature to the required degree. The plate is then removed from the microwave oven, a further
20 plate placed on top of the blend the required low pressure is applied to achieve the required degree of consolidation and the wheel is finally cured between the plates or bats.

In all of the above cases, the finally formed cured
25 wheel may be produced directly in the mould, or alternatively the cured disc may be machined to size.

Alternatively the blend may be spread onto a plate, similar in size to the desired wheel size, covered with a similar sized plate, and after the low
30 temperature and pressure have been applied to consolidate

the bond, the excess mix which exudes from between the plates is removed by a scraper whilst it is still soft and plastic before subsequently completing the curing cycle. By this process the bore of the wheel can be formed
5 by placing a pin through a hole in the plate to give the desired hole size. Metal bushes to give the desired arbor size can also be incorporated into the wheel arbor to eliminate the necessity for finishing the bore. The process described can be applied equally to
10 the production of both reinforced and non-reinforced resin bonded bodies, e.g. cut-off wheels. The reinforcement, which will be one or more fabric layers, may be placed externally and/or internally of the wheel. The reinforcing layers commonly used are discs of
15 phenolic resin impregnated woven or non-woven glass fabric.

In the conventional manufacture of cut-off wheels, modifications have been introduced to improve their cutting ability. For example the wheels are produced
20 with a taper from periphery to arbor or with moulded-in paper tapers to reduce the friction of the wheel faces during the cutting, as described in U.K. Patent No. 1,057,706

Alternatively it is known to produce rough faces for the wheel by the use of knurled or grooved mould
25 plates or bats or by moulding two open mesh reinforcing fabrics with a separating polyester film (such as Mylar (Trade Mark) polyester) or paper layer as in U.K. Patent No. 1,236,135, or by moulding and curing between PTFE coated glass fabrics to reproduce the fabric pattern
30 on the wheel faces. It is also known to use black

papers on the wheel faces to prevent sticking to moulds and to supporting bats during curing.

The above described modifications for cut-off wheels may be utilised in the method of the invention as applied to the production of cut-off wheels.

One of the problems experienced in the production of cut-off wheels according to processes of the prior art is that variability resulting from uneven distribution of the abrasive material in the blend is not eliminated by application of high pressure in the cold press process. In the process of the invention, where the blend will flow under the application of low pressures, there~~will~~^{for} be a tendency/flow to take place from the denser high pressure area into the less dense low pressure area, resulting in a reduction of the variations within the wheel as produced by uneven mould filling.

In the case of wheels produced by the cold pressing process and which contain reinforcing layers, variability is experienced due to the inadequate adhesion of the reinforcing layers to the blend, particularly where low density areas are produced in the wheel as a result of uneven mould filling.

This inadequate adhesion can result in low bursting speeds and rapid or irregular wheel break down in operation. In extreme cases wheel breakage results. In the case of wheels produced in accordance with the invention, the resin impregnation of the reinforcing fabric softens simultaneously with the predominantly powdered resin bond, which together with the application of the low pressure used for consolidation will result

in improved adhesion compared with the cold press process. This will result in an improvement in the strength and safety of the wheel.

It will be appreciated from the foregoing
5 description that the method of the invention provides a convenient and easy way of producing a wide range of resin bonded abrasive bodies without the need for expensive presses. It is a further advantage of the invention that the method allows the use relatively
10 inexpensive moulds with a high life expectancy. This is to be contrasted with the cold pressing process in which expensive heavy duty moulds are required in order to withstand the high pressures involved. Such moulds require frequent replacement due to a high wear rate
15 resulting from application of abrasive under high pressure to the mould surface.

The invention is illustrated by the following Examples describing the production of cut off wheels by the method of the invention and also by a conventional cold pressing method.

In both types of method the mould for producing the cut off wheels comprised a circular bottom plate, an annular ring (or barrel) located in a shallow peripheral annular recess on the upper surface of the bottom plate, a centre pin centrally located on the upper surface of the bottom plate, and a centrally apertured plunger plate locatable over the centre pin and slidable within the barrel. The plunger plate serves to apply pressure to the contents of the mould to effect consolidation thereof.

Example 1

This Example illustrates the production of a cut off wheel having a diameter of 1220 mm, a thickness of 10 mm, and an arborhole of 152.4 mm. by the method of the invention. The mould used had a bottom plate of diameter 1370 mm, a barrel having an inner diameter of 1235mm., and a centre pin of 150 mm diameter.

The cut off wheel was prepared from the following ingredients:-

30	grit white fused aluminium oxide	69.5 parts by weight
	325 mesh iron pyrites	16.0 parts by weight
	CS14 (medium flow powdered novolac resin)	10.0 parts by weight
25	CL50 (50 poise phenolic resole liquid resin)	4.5 parts by weight

The CS 14 and CL50 resins are produced by The Carborundum Co. Limited, Chemical Products Division.

A bond coated granular mix was prepared by first wetting the abrasive grain in a mixer with the liquid phenolic resin. The powdered resin and fillers were then added and mixing continued until the blended powdered bond
5 adhered to the abrasive grains to produce granular bond coated grains which could be readily separated but which adhered to each other under the influence of high pressure at room temperature.

The cut off wheel was prepared as follows.

10 A circular black tissue paper of 1235 mm diameter and with an aperture to locate over the centre pin was placed in the base of the mould followed by a 750 mm diameter phenolic resin impregnated glass fabric flange ply (external reinforcement for the finished wheel). One
15 third of the abrasive mix required to give a finished wheel of 10 mm thickness was distributed in the mould and levelled to give an even layer. A full diameter ply of phenolic resin impregnated glass fabric (internal reinforcement for the finished wheel) was placed on top
20 of the layer and flattened. A second layer of one third of the abrasive mix was distributed on top of the glass fabric and levelled. A further full diameter phenolic resin impregnated glass fabric was placed on the second mix layer followed by the final one third of the mix,
25 which was then levelled to form an even layer. Next, a flange ply similar to that used in the base of the mould was located on top of the upper mix layer and a circular black tissue paper laid over the flange ply. The plunger was then placed on the upper layer of tissue
30 paper, and the barrel and centre pin removed.

The assembly of unconsolidated wheel, plunger and bottom plate was transferred to a curing oven and a load was applied to the plunger so as to apply a pressure of 0.3 kg cm^{-2} to the wheel area. The load may for example
5 be applied by weights.

The oven was heated for a period of six hours at 70°C . During this heating the resin softened and the plunger moved downwardly to consolidate the bond. Consolidation was complete after six hours.

10 Curing of the resin was effected by raising the temperature of the oven to 175°C over a period of 20 hours and holding this temperature for 9 hours. Subsequently the wheels were cooled to room temperature over a period of 24 hours.

15 The arbor apertures of the cured wheels were then ground to the required diameter of 152.4 mm and the wheel periphery was ground concentric with the arbor to 1220 mm diameter.

Example 2

20 This Example describes the production of a cut off wheel of similar dimensions to that produced in Example 1 but using the conventional cold-pressing process.

The procedure of Example 1 was followed up to the point where the plunger is placed on the mould, which was
25 then transferred to a press capable of taking a mould of 1370 mm diameter. A pressure of 70 kg cm^{-2} of wheel area (approximate total pressure 800 tonnes) was applied for 15 seconds to consolidate the wheel.

After moulding, the centre pin and barrel were
30 removed, and the green wheel was transferred to an

aluminium supporting batt and covered with a steel plate of a thickness sufficient to give a load of 0.03 kg cm^{-2} of wheel area to maintain the wheel flat.

5 The wheel was cured in an oven in which the temperature was increased at a slow rate from room temperature to 70°C over a period of 8 hours and then to a temperature of 175°C over 20 hours. The oven was held at this temperature for 9 hours. As in Example 1 the wheel was cooled to room temperature over a period of 24 hours and then ground to
10 the required dimensions.

Properties of Cut Off Wheels

Wheels prepared by the methods of Examples 1 and 2 had similar densities of 2.33 grams/cc.

15 The wheels were evaluated by cutting through 20 cm diameter Incalloy ingots with a cutting speed of 80 m/sec.

The wheel produced in Example 1 gave a grinding ratio (i.e. ratio of area of metal cut to area of wheel worn) of 1.18 compared with a value of 1.00 for wheels produced by Example 2.

20 The freedom of cut was similar for both wheels. Additionally the "squareness of cut" was similar for both wheels. The "squareness of cut" is an indication of the extent to which the wheels cut the ingots at right angles to ingot axes. Any deviation from a right angled cut indicates
25 wheel breakdown with formation of a champhered periphery.

These tests demonstrate that the method of the invention produces cut off wheels having a performance at least equivalent to those produced by the conventional cold-pressing operation.

Example 3

This Example describes the production of a wheel using the method of the invention and having a diameter of 1800 mm, a thickness of 18 mm. and an arbor hole of 450 mm diameter. As previously a mould was used which gave an undersized arbor hole and oversize wheel diameter so that the wheel could be finished by grinding.

The wheel was prepared from the ingredients listed in Example 1 save that the 69.5 parts by weight of white fused aluminium oxide was replaced by the following mixture of abrasives.

Brown fused aluminium oxide	20 grit	34.8 parts by weight
Brown fused aluminium oxide	24 grit	20.8 parts by weight
Brown fused aluminium oxide	30 grit	13.9 parts by weight
		69.5 parts by weight

The wheel was to be externally reinforced with flange plies of 1220 mm diameter and internally reinforced with five plies of phenolic resin impregnated glass fabric (PRIGF). As full diameter PRIGF plies were not commercially available, semi-circular sections were cut from a roll of the fabric to fit into the mould with a 5 cm overlap. The position of the overlap on the five layers of PRIGF was staggered so that the overlays of each consecutive layer were positioned at an angle of 60 degrees in a clockwise direction.

The abrasive, resin and filler were mixed together as in Example 1.

The mould was filled using the following sequence of operations.

1. Two overlapping semicircles of black tissue paper.

2. One 1220 flange ply.
3. One sixth of the total granular abrasive mix required.
4. Two overlapping semicircles of PRIGF.
5. A further one sixth of the abrasive mix.
- 5 6. Two overlapping semicircles of PRIGF.
7. A further one sixth of the abrasive mix.
8. Two overlapping semicircles of PRIGF.
9. A further one sixth of the abrasive mix.
10. Two overlapping semicircles of PRIGF.
- 10 11. A further one sixth of the abrasive mix.
12. Two overlapping semicircles of PRIGF.
13. The final one sixth of the abrasive mix.
14. One 1220 mm diameter flange ply.
15. Two overlapping semicircles of black tissue paper.

15 The mould containing the uncompressed wheel was placed on a stand, the plunger placed in position and the barrel and centre pin removed.

The assembly was then transferred to a curing oven and a load applied to the plunger to give a weight of
20 0.3 kg/cm.^{-2} over the wheel area. The weighted wheel was then consolidated and cured under the conditions employed in Example 1. The arbor hole and the periphery were then ground to the required dimensions.

Three wheels prepared by the above method were test
25 speeded to destruction and burst at speeds of 170 to 174m/sec. This was well in excess of the minimum bursting speed of 140 m/sec. as specified for a maximum operating speed of 100 m/sec. by the German Grinding Wheel Committee is the accepted grinding wheel safety
30 standard authority in Europe.

A wheel as described was used to cut 80 mm diameter billets at a temperature of 800-900°C on a converted cold saw with a 250 KW motor. A cutting time of 1.7 seconds was obtained and a grinding ratio of 11.9 at an operating speed of 100 m/sec.

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CLAIMS

1. A method of producing a resin bonded abrasive product comprising preparing a blend of a particulate abrasive material and a predominantly powdered thermosetting resin bond, which bond will soften by heating to a temperature
5 below that at which the rate of cross-linking is substantial, heating the blend to soften the resin, applying a pressure below 3 kg/cm^2 to the heated blend to effect compaction of the abrasive particles, and further heating the blend to cure the resin to produce the bonded abrasive product.
- 10 2. A method as claimed in claim 1 wherein compaction is effected with a pressure of less than 2.5 kg/cm^2 .
3. A method as claimed in claim 2 wherein compaction is effected with a pressure of less than 1.8 kg/cm^2 .
4. A method as claimed in claim 3 wherein compaction
15 is effected with a pressure of about 0.3 kg/cm^2 .
5. A method as claimed in any one of claims 1 to 4 wherein the blend of the particulate abrasive material and the predominantly powdered thermosetting bond is softened at a temperature of 30 to 100°C .
- 20 6. A method as claimed in any one of claims 1 to 5 wherein the powder of the thermosetting resin bond is a phenolic novalac resin.
7. A method as claimed in any one of claims 1 to 6

wherein the liquid of the thermosetting resin bond is a liquid phenolic resin.

8. A method as claimed in any one of claims 1 to 6 wherein the liquid of the thermosetting bond comprises furfural.

9. A method as claimed in claim 8 wherein a xlenol or cresol is additionally present.

10. A method as claimed in any one of claims 1 to 9 wherein the temperature of the blend is raised continuously during the softening operation.

11. A method as claimed in any one of claims 1 to 10 wherein the pressure used for compacting the blend of abrasive material and resin is maintained during the curing operation.

12. A method as claimed in any one of claims 1 to 11 wherein external and/or internal reinforcement is provided for the bonded abrasive product.

13. A method as claimed in any one of claims 1 to 12 wherein the abrasive material is selected from fused alumina, silicon carbide and fused zirconia-alumina.

14. A method as claimed in any one of the claims 1 to 13 wherein the resin bonded abrasive product produced is a cut off wheel.