

A WIRE COATING APPARATUS, SYSTEM AND METHOD

Field of the Invention

The invention relates to a wire coating apparatus and method. In particular, the
5 invention relates to an efficient apparatus, system and method of manufacturing
abrasive wires.

Background

Wires coated with super-abrasives like diamond or Cubic Boron Nitride(CBN)
10 are important tools in the area of cutting, slicing and/or shaping of hard and
brittle materials, such as ceramics, glass, minerals, silicon and sapphire wafers,
etc.. These abrasive wires are useful cutting tools because they minimize
surface damage and kerf loss.

15 However, such abrasive wires are relatively more expensive compared to
conventional cutting tools. In addition, it is difficult to apply a uniform and
continuous metal coating to the abrasive particles using the apparatus and
processes available in the market. As a result, the diamond or CBN coated
wires available in the market lack consistency in their cutting capacity. This
20 adds to the cost of cutting due to the need for regular replacement.

In order to achieve a consistent cutting capacity, the layer/coat of diamond-
nickel or CBN-nickel deposited on the wire must have an extremely uniform
thickness and particle size distribution. Inconsistencies in thickness and particle

size distribution may cause surface damage, and result in lower yield and higher cutting cost.

Accordingly, there remains a need to develop an efficient apparatus and method for manufacturing abrasive wires with uniform surface thickness, and particle size distribution.

Summary of Invention

In a first aspect, the invention provides a system for coating wires comprising a first wire coating device according to any aspect and/or embodiment of the invention for applying a metal and metal coated grit to said wire; and a second wire coating device within a tank module according to any aspect and/or embodiment of the invention, said second wire coating device arranged to apply a metal coating over said metal and metal coated grit.

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In a second aspect, the invention provides a method for coating wire comprising the steps of guiding said wire to a first wire coating device; applying a metal and metal coated grit to said wire; guiding said wire to a second wire coating device; and applying a metal coating over said metal and metal coated grit.

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Relative to known devices and methods of coating wires, the system, device and apparatus according to any one aspect of the present invention efficiently deposits a coating with a highly consistent thickness and particle size distribution.

According to an embodiment, the first wire coating device may comprise a chamber having an electrolytic fluid therein, said chamber arranged to allow the passage of a wire through said chamber; a magnetising device for applying a magnetic field to said wire; at least one anodic electrode within said chamber; a cathodic electrical connection in electrical communication with said wire; a grit supply for introducing a supply of metal coated grit into the chamber; wherein the wire is arranged to magnetically attract the metal coated grit, with the anodic electrode and cathodic wire arranged to electrolytically apply a metal coating to said wire to encase said metal coated grit.

The chamber may be oriented vertically and the metal coated grit is introduced proximate the top of said chamber.

Accordingly, by introducing the metal coated grit proximate the top of a vertically oriented chamber, the metal ions and metal ions encasing the grit are brought into direct contact with said wire, while some are brought into close proximity to said wire. This advantageously shortens the plating time required for achieving a specified amount of deposits.

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In another embodiment, the device may include a tank module for allowing the passage of a wire. The tank module may comprise a weir at opposed ends, said weir having a slot for placing the wire, said slot having a width sufficient to allow

the passage of said wire, and; pulley arrays according to any embodiment of the invention at said opposed ends for electrically isolating said module.

The tank module may include a pair of air shields, each proximate to either an entry and exit point of said wire; each air shield comprising a nozzle assembly
5 arranged to radially direct an air supply to said entry or exit at a sufficient flow rate to repel fluid from said entry or exit.

In a further embodiment, the device may comprise a tensioning unit for
10 maintaining a tension in a wire engaged with said tensioning unit, the tensioning unit comprising a lever assembly comprising a first lever arm arranged to engage said wire from a wire drum, said lever assembly configured to move in response to a force corresponding to dynamic tension within said wire; a driving member operable with said movement for varying the extent of speed for
15 operating said wire.

The lever assembly may include a second lever arm comprising one or more counter-weights arranged to vary the dynamic tension for operating said wire.

20 According to a further embodiment, the metal and metal coated grit application step may include the steps of applying a magnetic field to said wire; introducing a mixture of electrolytic fluid and metal coated grit into the first coating device; guiding said wire through the first coating device comprising at least one anodic

electrode while applying an electrical connection to said wire and anodic electrode.

The guiding steps may include the step of guiding said wire from a first to
5 second to third pulley, said pulleys having corresponding pulley axles in a triangular pattern within a common plane.

Brief Description of Drawings

It will be convenient to further describe the present invention with respect to the
10 accompanying drawings that illustrate possible arrangements of the invention. Other arrangements of the invention are possible and consequently, the particularity of the accompanying drawings is not to be understood as superseding the generality of the preceding description of the invention.

15 Figure 1 is a flow chart showing a process according to one embodiment of the present invention.

Figure 2 is a schematic view of a diamond manufacturing process and/or system according to a further embodiment of the present invention.

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Figure 3 shows: (a) a detailed view of a pulley array according to one embodiment of the present invention; (b) an isometric view of a pulley array provided in a module according to another embodiment of the present invention; (c) a detailed view of a weir according to one embodiment of the present

invention; and (d) a detailed view of a metal pulley according to one embodiment of the present invention.

Figure 4 shows: (a) an isometric view of a tensioning unit according to one
5 embodiment of the present invention; and (b) an isometric view of a winding unit according to one embodiment of the present invention.

Figure 5 is an isometric view of a module for cleaning according to one embodiment of the present invention.

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Figure 6 is an isometric view of a surface coating section according to one embodiment of the present invention.

Figure 7 is a cross sectional view of a solvent tank according to one
15 embodiment of the present invention.

Figure 8 is an isometric view of a rinsing basket according to one embodiment of the present invention.

20 Figure 9 is an isometric view of a surface coating section according to a further embodiment of the present invention.

Figure 10 shows: (a) an isometric view of a housing arrangement according to one embodiment of the present invention; and (b) an isometric view of a

housing arrangement according to a further embodiment of the present invention.

Figure 11 is an isometric view of a load cell unit according to one embodiment
5 of the present invention.

Figures 12a and 12b are isometric detail views of a tension unit according to a further embodiment of the present invention.

10 Detailed Description

Overall Process and System

For convenience, the following description will refer to the invention applied to
15 the manufacture of diamond coated wires. It will be recognised that the invention may be applied to manufacture other types of abrasive wires or surface coated wires. Accordingly, the reference to diamond coated wires is not to be read as limiting the application of the invention but could equally apply to other suitable materials such as cubic boron nitride, iron carbide, tungsten
20 carbide, glass, minerals, silicon and ceramics.

Figure 1 shows a flow chart 5 for a process for coating wires according to a present embodiment of the invention. The process commences with a unwinding section 7 whereby manufactured wire is unwound from a wire drum.

Then, the wire is passed to a treatment section 10 whereby the wire undergoes treatment such as immersion into a cleaning solution, to remove unwanted particles, such as grease and dirt, prior to surface coating 15. The purpose of the treatment is to ensure that when the wire enters the surface coating section 5 15, unwanted particles do not contaminate the electrolyte solution used for surface coating thereby ensuring an effective electroplating process and uniform surface coating in which foreign particles may interfere.

The treated wire is then moved to a surface coating section 15 whereby the wire 10 is coated with a layer of abrasive material using an electroplating device. The coated wire is subsequently moved to a cleaning section 20 to remove residual electrolyte solution and/or unwanted chemicals from the coated wire. Following the surface coating 15 and cleaning section 20, the cleaned coated wire may be moved to another surface coating section 25 whereby the wire is coated with an 15 additional layer of material using an electroplating device. This is followed by a cleaning section 30 for removing residual electrolyte solution and unwanted chemicals to avoid contamination in the next section.

Subsequently, the wire may repeatedly pass through a further coating section 20 followed by a cleaning section until the coating on the wire reaches a desired thickness. Thereafter, the coated wire is passed through a drying section 35 whereby the wire is oven-dried to remove moisture dried prior to assembly and packaging 40.

Figure 2 shows a schematic view of a diamond wire manufacturing process and/or system 76 according to a further embodiment of the present invention. The process is a reel to reel process beginning from a first reel 80 and ending with an end reel 98. The wire 77 spanning between the reels 80, 98 is operated
5 under tension through a plurality of tensioning pulleys 78 with tension provide by a tensioning unit 82.

The wire 77 passes through a surface coating section 86 which is, in this embodiment, an electrolytic process whereby a supply of nickel coated diamond
10 particles 84 is provided to a chamber 86 with an electrolytic fluid supplied to the chamber 86 and recycled 88. Prior to the surface coating section 86, the wire may be passed through a treatment section similar to the aforementioned treatment section 10 of Figure 1 for removing unwanted materials from the wire surface.

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The wire 77, which is magnetized to attract the nickel coated diamond particles, passes through the electrolytic fluid and has adhered to it the diamond particles with a consequential thin nickel coating. The wire then passes through a wash and rinse arrangement 90 before arriving at the nickel coating stage 92 whereby
20 a further electrolytic process places a nickel coating of a specified thickness onto the wire. The electrolytic fluid is again supplied and recycled by a replenishing tank 94.

The diamond and nickel coated wire is then passed through a wash and rinse tank 96 before being spooled on the reel 98 for delivery to an end user.

Having described various embodiments of the overall process, the following is a
5 description of individual components within the overall process. Each component is further capable of being used separately and in themselves may be considered for separate use for unrelated applications.

Wire Tensioning Components

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The wire coating apparatus includes an array of components which together maintain tension in the wire throughout the process. These components include a tensioning unit, winding unit and an array of pulleys. The array of pulleys may be provided between each wire coating unit and section. The tensioning unit
15 serves to cooperate with the winding unit and array of pulleys so as to move the wire from end to end in a similar manner as discussed in Figure 2.

The geometric shape, contour, orientation and/or distance of the wire (work piece to be plated) relative to the anode determines the thickness and particle
20 distribution of the resulting layer of deposit. For example, insufficient tension distorts the orientation and/or distance of the wire relative to the anode and affects the quality of coating. On the other hand, putting the wire under tension would otherwise damage the wire and affect the quality of coating. To this end, the tensioning unit serves to regulate the tension applied to the wire at each

section, so as to maintain the tension within a specified range conducive for an effective electroplating process. An effective electroplating process helps to achieve a surface coating with uniform thickness and particle size distribution.

- 5 Any suitable pulley or a combination of pulleys may be used in the array of pulley systems. For example, suitable pulleys may include but are not limited to fixed pulley and/or rotatable pulley. In addition, the fixed and/or rotatable pulley may comprise one or more bearings. A pulley comprising more bearings serves to provide more rotational efficiency.

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The pulley or a combination of pulleys may be mounted at an angle and distance relative to a specific device or section of the wire coating to avoid putting the wire under tension, which would otherwise damage the wire and affect the quality of coating.

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Figure 3a shows an array of pulleys 190 comprising an electrically isolated metal pulley 205 mounted between two metal pulleys 195, 200. The metal pulleys 195, 200 are mounted at the same height while the electrically isolated pulley 205 is offset from metal pulleys 195, 200 so as to form an isosceles
20 triangle between the shafts of the pulleys. Further, the pulleys 195, 200, 205 are mounted within the same vertical plane.

In one embodiment of the present invention, either metal pulley 195 or 200 may be mounted to a block which in turn is connected to an "earth". In an alternative

embodiment, both metal pulleys 195, 200 may be mounted to a block which in turn is connected to an "earth".

The central pulley 205 achieves electrical isolation through having a coating or
5 ring, made of electrically insulating material, such as rubber or plastic, to the wire engaging groove of the pulley. To this end, such electrically isolated pulleys may also be referred to as "rubber pulleys".

The afore mentioned arrangement has the effect of electrically isolating a
10 station located between two of said pulley arrays, whereby either side of the station is an "earthed" connection and so preventing the wire from carrying current beyond the station.

In the present embodiment, the array 190 may be provided between the
15 treatment section 10 and surface coating section 15. Wire from the treatment section 10 is received and looped around the first metal pulley 195 prior to electrically isolated pulley 205 and followed by the second metal pulley 200. The same array of pulleys may be provided between the surface coating section 25 and cleaning section 30. Wire from the surface coating section 25 is received
20 and looped around the rubber and metal pulleys prior to the cleaning section 30 in the same manner as described for array 190. In this embodiment, the array of pulleys 190 serves to maintain the tension applied to the wire in the surface coating section within a specified range conducive for an effective electroplating process.

The array 190 may be mounted in a module 210 as seen in Figure 3b. In particular, a pair of openings 212, 217 is provided on opposed side surfaces of the module 210. The openings 212, 217 may be disposed at a pre-determined
5 height from the base of the module 210, and are aligned such that they fall on the same vertical plane as the array of pulleys 190.

Each opening may include a weir 215. Figure 3c is a detailed view of a weir 215 used in module 210. The weir 215 may include a pair of plates 220 disposed on
10 two opposed side surfaces 225, 230 and a channel 235 intermediate said plates 220. In one embodiment, the channel 235 may be of a specified width 240 (e.g. 6mm) which may correspond to a wire with thickness between 80um till 500um, plus a predetermined distance to allow for a tolerance about the wire to ensure the wire is only in intermittent contact, if any contact at all with the weir.

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A third pair of plates 245 may be provided on a third side surface 250 such that plates 220, 245 can be securely positioned in any one of the openings or apertures of module 210. In the present embodiment, wire from the treatment section enters module 210 via the channel 235 of weir 215, and exits at the
20 channel of weir 237.

While the weir may be securely positioned within any one of the openings of module 210, it will be appreciated that a specified allowance/distance between the plates 220, 245 and openings of module 210 may be created so as to permit

lateral adjustments of the weir within any one of the openings. As the position of the wire relative to the tank module is difficult to re-position, the weir provides adjustability by shifting the position of the wire to position the wire in the centre. It follows that the aperture in the tank module for receiving the weir must be
5 large enough to allow the adjustment of the weir. If the weir is, for instance an HDPE or polypropylene member which is arranged to fit within an aperture of the wall of the tank module, then the weir may have a slot into which it clips or slides over the tank wall. This slot may be dimensioned so as to allow re-positioning of the weir on the tank wall, whilst still having sufficient clearance to
10 firmly and securely attach to the wall.

The groove in the weir through which the wire passes will limit the amount of fluid that can escape passed the wire. By balancing sufficient tolerance for any lateral positioning of the weir but minimising the gap to limit the loss of fluid, the
15 designer can select a pump for recycling the fluid based upon the gap and so avoid overdesigning the recycling pump.

To this end, the weir is arranged to guide and align the moving wire during the wire coating process. As one efficient arrangement of the invention has the weir
20 entering the module beneath the surface of the entrapped fluid, the weir only allows a minimal amount of the fluid within the module to escape through the gap (tolerance) about the wire. By placing a collection area adjacent to the weir, this minimal escaping fluid can be readily collected and recycled.

Thus, a standard module, used for a variety of applications may comprise a chamber or tank, having weirs at each end of the tank to permit the passage of the wire beneath the surface of the entrapped fluid. The use of pulley arrays at either end of the tank then provides both a tension retaining feature as well as
5 electrical isolation of the module from adjacent stages both upstream and downstream. The tension retaining feature provided by the pulley arrays also control the passage of the wire along a designated linear path, and so prevent lateral movement of the wire despite movement of the wire upstream and downstream of the module.

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A further advantage is that the same module may be adapted and used for coating wires of varying thickness. This can be achieved by using weirs with channels that correspond to the desired thickness of the wire, as well as accommodating the tolerance previously mentioned.

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For economies of scale, the module may accommodate one or more arrays of pulleys for catering one or more wire coating production lines in parallel. For instance, whilst the foregoing discussion has discussed a single wire coating process, in fact the modular nature of the overall process also permits several
20 such lines of wire passing through the modules in parallel.

The surface coating sections 15, 25 must be electrically isolated from the rest of the wire coating process for protection against short circuits and electrical shocks. In the present embodiment of the invention, the surface coating section

15 may be isolated by grounding the array of pulleys that is supporting the wire between:

1. the treatment 10 and surface coating section 15; and
2. the surface coating 15 and cleaning section 20.

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As previously discussed, the array comprising two metal pulleys and an intermediate electrically isolated pulley are connected to "earth", whilst still supporting the moving wire. The bearings within the pulley provide poor contact between the moving wire and shaft of the pulley, and so fail to provide a reliable
10 electrical contact. As a result, conventional grounding methods cannot be applied because any grounded attachments would interfere with the moving parts and/or bearings of the pulley.

Figure 3d shows the metal pulley 260 electrically grounded according to one
15 embodiment of the present invention. A mercury attachment 265 is provided between the shaft 270 and ring 280 of the metal pulley. The ring 280 comprises moving parts such as one or more bearings depending on the intended purpose of the pulley. The liquid state of the mercury connection 265 provides a constant and reliable electrical connection between the rotating parts, such as the shaft
20 270, ring 280 and moving wire.

To this end, accumulated hazardous static electrical charges and unused electrical current from the surface coating section 25 may flow through the metal pulley and be grounded safely.

Figure 4a shows a tensioning unit 50 comprising a first lever arm 55 connected to a pulley 60 for receiving wire from a wire drum (not shown), and a second lever arm 65 comprising one or more counterweights 70. A fulcrum 77 connects
 5 the first lever arm 55 to the second lever arm 65, through a connecting arm, at opposed ends of the respective lever arms 55, 65 from the pulley 60 and counter-weight 70. The tensioning unit 50 may include a motor and a wheel 76 adjacent to the second lever arm 65.

10 The motor provides the driving force for moving the wire from the wire drum to downstream sections 10, 15, 20, 25, etc.. Counter-weights 70 produce a force F_w which counters the dynamic tension F_T , thereby reducing the driving force and effort required for moving the wire. Dynamic tension F_T is the net force applied on the wire at the pulley 60, and comprises the inertia from the wire
 15 drum as well as a combination of forces transmitted to the wire through downstream sections. In one embodiment of the present invention, the amount of counter-weights may vary so as to vary the tension for operating said wire. In another embodiment, the counter-weights may be shifted along lever arm 65 for varying the tension for operating said wire.

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The lever arm 55, fulcrum 77 and lever arm 65 form a unitary unit such that the lever arm 65 mirrors movement in lever arm 55. Dynamic tension F_T applied on the wire cause movements in lever arms 55, 65. This movement is captured by wheel 76 and converted to an electrical signal directly proportional to F_T . This

electrical signal is in turn used to determine the driving force required for moving the wire from the wire drum to downstream sections. This driving force exerted on the wire further determines the tension, and speed of the wire travelling through downstream sections such as the surface coating sections 15,

5 25.

As shown in Figure 11, the pulley 440 of the load cell unit 435 determines the degree of movement (for instance, up or down) of the tensioning unit. The lever 455 bears 445 against a load cell 450 in order to provide feedback as to the movement of the pulley 440.

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By moving the lever arm up, due to the dynamic tension F_T up, the motor has to go faster so as to consequentially move the tensioning unit down and so reduce F_T . This then results in the motor slowing down. Accordingly, this is a direct feedback loop, self-regulating F_T through motor control.

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Further, the load cell advantageously identifies spikes in the tension of the wire, which may be the result of broken bearings in one or more pulley arrays downstream.

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A feedback system may be provided to display the forces measured on a display screen or programmable logic controller. In addition, an alarm system may be installed to indicate situations when the forces applied on the wire exceed a pre-determined value. More importantly, the feedback and alarm

system collaborate to reflect departures from pre-determine ranges and so may assist in quality control, maintenance, and avoid bottlenecks at any of the sections downstream.

5 Figures 4a, 4b, 12a and 12b show various views of a winding device which may be provided at the assembly and packaging section 40. A winding device 100 is shown in Figure 4b and comprises a tensioning unit 105, and tensioning pulleys 110 (as shown in Figures 12a and 12b) similar to that described for Figure 4a, and hence not repeated for brevity. The winding device 100 may also comprise
10 a load cell 107. The pulleys 110 may be mounted at an angle and distance relative to the drying section and drum, so as to provide the rotational efficiency required for winding coated wires onto a drum.

To this end, the tensioning unit, winding device and array of pulleys collaborate
15 so as to move the wire at a pre-determined tension, and speed required for an effective electroplating process.

In general, the thickness and particle distribution of the surface coating may be a function of speed of the moving wire, residence time in the surface coating
20 section, electrolyte concentration, temperature, amperage and voltage of the power supply. The relationship between the aforementioned elements of the function will be detailed in the following paragraphs.

Washing & Rinsing Modules

As mentioned previously, ideally abrasive wires should have a uniform surface thickness and particle size distribution for utmost cutting capacity and performance. To achieve this, the wire must be treated to substantially remove unwanted particles, such as grease and oil which come from the fabrication and prefinishing operations, on the wire surface before surface coating 15 can begin. The object is to achieve a chemically clean surface so that the plating deposit will adhere.

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In the treatment section 10, wire from the wire drum enters a residue removal tank 285 containing cleaning solution, as seen in Figure 5, whereby the wire is submerged in cleaning solution for removing unwanted particles prior to surface coating 15.

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Any suitable cleaning method and cleaning solution may be employed for removing unwanted particles from the wire. For example, suitable cleaning methods may include, but are not limited to heat treatment, etching, chemical treatment or a combination thereof. In addition, examples of suitable cleaning solution include water, acid, alkaline or a combination thereof. Further, the residue removal tank may be provided with ultrasonic transducers so as to apply ultrasonic waves to said wire to assist with cleaning and removal of unwanted particles.

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The choice of cleaning method and cleaning solution depends on the cleaning requirements intended. In the present embodiment, the wire surface may be treated or cleaned using warm standard alkaline cleaners or inhibited alkaline cleaner at approximately 40 to 50°C (hereinafter referred to as "warm rinsing").

- 5 Alternatively, the wire surface may be cleaned using hydrochloric or sulphuric acid at room temperature (hereinafter referred to as "acid dipping") for removing oxide layers. In a further embodiment, the wire may be cleaned using warm rinsing in one residue removal tank followed by acid dipping in another residue removal tank.

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- In the present embodiment, the residue removal tank 285 may be provided with a pair of overflow holes 287, 289 on opposed side surfaces 295, 300 of the residue removal tank 285. The overflow holes may be disposed at a pre-determined height from the base of tank 285, and aligned such that they fall on
- 15 the same vertical plane. Each overflow hole may be adapted with a weir similar to that afore described for Figures 3b and 3c.

- The residue removal tank 285 may be surrounded by a collection area arranged to collect cleaning solution overflowed from the residue removal tank. The
- 20 collection area may be disposed between side surfaces 295, 300 and opposing side surfaces 297, 302. The collection area may be provided with a pair of openings 310, 315 disposed at a pre-determined height from the base of tank 285, and aligned such that they fall on the same linear path as the overflow

holes 287, 289 and their respective weirs and/or path of the moving wire. Wire from the unwinding section 7 enters the residue removal tank 285 via opening 310, overflow hole 289, and exits at overflow hole 287 via opening 315. The wire is thus exposed to the cleaning solution, and subjected to cleaning once it
5 enters the residue removal tank via overflow hole 289 and its corresponding weir.

The openings, overflow holes and collection area of the residue removal tank 285 may be selected to fully submerge the moving wire in the cleaning solution.
10 This helps to prevent contamination and collection of unwanted particles, such as dirt and dust, which may adversely affect the thickness and consistency in particle size distribution of the surface coating.

Cleaning solution flows through the overflow holes 287, 289 via channels of
15 weirs into the collection area. The overflowed cleaning solution may be recycled and routed back to the residue removal tank 285 for use again. Further, a pump may be provided for directing cleaning solution from the collection area to the residue removal tank 285 at a desired replenishment rate. Further still, a recycling tank may be provided whereby the cleaning solution is treated to
20 substantially remove any detritus and/or unwanted materials before it is routed back to the residue removal tank 285. A continuous supply of new and unused cleaning solution may be provided to the residue removal tank 285 to keep the cleaning solution at a level of purity sufficient to avoid contamination of the next tank.

Each opening 310, 315 may be adapted with an air shield comprising a recess for receiving the wire. The recess may include one or more apertures or nozzles in communication with an air supply. The air shield may be configured to eject
5 air in respective radial direction transverse to the direction of the moving wire entering 325, and exiting 330 the residue removal tank 285. The air supply may be directed at a sufficient flow rate to repel fluid from the entry 325 or exit 330. To this end, the air shield acts like a gasket which fills up the space between the wire, and recess to prevent leakage from the residue removal tank 285.

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In particular, the weirs at overflow holes 287, 289 guide, align or re-align the moving wire during the treatment 10 process. Further, the cleaning solution may flow through the weirs into the collection area at a controlled rate, which is further dependent on the width of the weir channel. Further still, the same
15 residue removal tank 285 may be adapted and used for cleaning wires of varying thickness simply by using weirs with channels that matches the desired wire thickness.

It will be appreciated that the residence time, that being the time in which the
20 wire is exposed to the cleaning solution and is subjected to cleaning, is sufficient such that detritus is substantially removed from the wire.

Following treatment in the residue removal tank, the wire may be moved to a subsequent rinsing tank for removing the cleaning solution or chemicals used in the treatment step 10. This is to avoid unwanted reactions on the wire surface as well as to avoid contamination in the next tank.

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It will be appreciated that merely submersing the wire in water does not sufficiently rinse the wire unless it is subjected to the water for a long period of time. Several methods of improving rinsing efficiency may be used, such as heated water and air agitation. Spray rinsing directly over the process tank may also be employed as a method of water conservation.

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For economies of scale, the residue removal tank 285 may accommodate and clean one or more wire coating production lines.

15 ***Wire Coating Process***

In the present embodiment, the treated wire may pass through a magnetizing station and then into an electroplating device 150, as seen in Figure 6, such that nickel coated diamond particles (grits) are adhered to the wire surface through magnetic attraction of the nickel to the wire, and consequently the diamond particles. The electroplating device 150 may be provided with one or more nickel plates 155 (anode) disposed in a hollow vertical column or pipe 160. The vertical column is arranged such that it encloses the nickel plate to prevent

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contamination, and collection of unwanted particles, such as dirt and dust, which may adversely affect the thickness and consistency in particle size distribution of the electroplating process. The nickel plate 155 and vertical column 160 may be supported in a housing or structure 170.

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Treated wire 165 is received at the bottom of the vertical column 160 and is positioned such that it moves in a path parallel to the nickel plate 155. This arrangement keeps the wire 165 (cathode) to nickel plate 155 (anode) distance constant, which is required in order to create diamond-nickel deposits with highly consistent thickness and particle size distribution. The electroplated wire then exits at the top of the vertical column 160. An effective method for good wire coating may include moving the wire opposite to the liquid flow, so forcing the wire to go through the liquid. By moving the wire in the same direction as the nickel sulfamate there is interference applied to the fluid, and so it may move with the wire instead of reacting with it.

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In this embodiment of the invention, the electrolyte solution comprising a mixture of nickel coated diamond grits and nickel sulfamate dissolved in a suitable solvent, is arranged to flow through the nickel plate 155 and wire 165 by gravity. A power supply and current of a pre-determined value may be passed through the wire 165 (cathode) and nickel plate 155 (anode) such that the nickel plate 155 is dissolved into the electrolyte in the form of nickel ions. Nickel ions encasing the diamond grits and dissolved nickel ions travel through the electrolyte solution, and deposits on the wire 165 (cathode). The diamond

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grits are thus bonded to the wire through the layer of electroplated nickel deposits.

For one embodiment of the present invention, the nickel plate may take any
5 form and shape that provides a consistent wire (cathode) to nickel plate (anode)
distance. In the present embodiment, the nickel plate is arranged in a cylindrical
shape. In an alternative embodiment, the nickel plate may comprise a metal tray
comprising nickel pallets. In a further embodiment, the nickel plate may
comprise at least two parallel nickel plates or parallel trays containing nickel
10 pallets.

Further, the nickel plate, supply of electrolyte solution and electroplating device
may assume any suitable configuration that allows a continuous and constant
contact amongst the electrolyte solutions, nickel plate and wire. In the present
15 embodiment, the nickel plate is disposed in a vertical column while the wire
arranged to move parallel to the nickel plate. The electrolyte solution is
arranged to flow through the nickel plate and wire by gravity. In an alternative
embodiment, the nickel plate may be immersed in an electrolyte bath whereby
the wire is arranged to enter the bath and move in a path parallel to the nickel
20 plate.

According to the present embodiment of the invention whereby electrolyte
solution is arranged to flow through the nickel plate and wire by gravity, the flow
of electrolyte solution brings the nickel ions and nickel coated diamond ions into

direct contact with the wire, while some are brought into close proximity to the wire. Upon application of electric current, the migration of electrons from the nickel plate to the wire are supplied to the nickel ions, and nickel coated diamond ions which are already in contact with the wire. As a result, a layer of nickel deposits with diamond grits dispersed throughout the nickel matrix may begin to form on the wire. This takes place at the initial stages of the electroplating process i.e. even before migration of the surrounding nickel ions completes. This advantageously shortens the plating time required for achieving a specified amount of deposits.

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In the alternative embodiment whereby the wire is arranged to move in a path parallel to a nickel plate immersed in an electrolyte solution bath, the nickel ions and nickel coated diamond ions in the electrolyte solution migrate to the wire after the application of an electric current. This is different from electroplating using the present embodiment whereby the nickel ions and nickel coated diamond ions are placed in direct contact with the wire during the initial stages of the electroplating process. When the same current and voltage is applied in this embodiment, the plating time required to achieve a specified amount of deposits would be relatively longer compared to the present embodiment.

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Following the principles of Faraday's law of electrolysis, an increase in current density applied to the cathode and anode would increase deposition per unit area. However, according to Ohm's Law, the amount of current flow will be proportional to the voltage. Therefore, the application of high current density

would mean an application of a correspondingly high voltage to the anodes and cathodes. The application of high voltage however leads to inefficiency and burning of the deposits, which is undesirable and unacceptable in the manufacture of abrasive wires.

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Alternatively, deposition per unit area may be increased by an increase in plating time. This would however affect the overall efficiency of the manufacturing process.

- 10 The present invention overcomes the aforementioned issues by shortening electroplating time without the need to increase current or voltage.

For any embodiment of the invention, the vertical column 160 may be made of any suitable material. For example, the column may include but is not limited to
15 polymers and plastics. In addition, suitable polymers may include acrylic.

Whilst certain efficiencies can be achieved, including residence time, for the wire plating chamber being a vertical column, it will be appreciated that a horizontal chamber may also serve the purpose. Such an arrangement may
20 require a recycling of the diamond particles on a more active basis.

For any embodiment of the invention, the electrolyte solution may be provided in a solvent tank. The solvent tank may be provided with one or more agitation pumps to keep the nickel coated diamond grits suspended in the nickel

sulfamate solution. Further, one or more pumps and one or more pipes may be provided in order to direct the electrolyte solution to the electroplating cell 150. Further still, the solvent tank may be arranged so as to collect and recycle the electrolyte solution flow from the electroplating cell 150.

5

A continuous supply of new and unused electrolyte solution may be provided to the solvent tank 180 to keep the electrolyte solution at a level of purity sufficient to avoid contamination during the electroplating process.

10 It will be appreciated that any suitable pumps may be used. For example, suitable pumps may include manual or automated pumps. In the present embodiment, a dual automated pump system is provided to direct the electrolyte solution to the electroplating cell 150. In a situation whereby one pump fails, this dual pump arrangement allows a switch from the faulty pump to
15 the back-up pump.

In the present embodiment, the solvent tank 180 may comprise a semi-spherical inner surface 185 as seen in Figure 7. An internal surface with large radius curves prevents diamond particles from accumulating in corners and
20 edge as, and thus prevents the formation of dead zones within the solvent tank.

For any embodiment of the present invention, any suitable electrolyte solution containing one or more dissolved metal salts (preferably comprising the metal to be deposited) and other ions that permit the flow of electricity may be used. For

example, suitable electrolyte solutions include but are not limited to nickel sulfamate, nickel sulfate and nickel chloride. The choice depends upon the desired properties of the deposit.

5 In a specific application using an embodiment of the present invention, a wire (e.g. hardened steel with brass coating) of thickness between 80 μ m to 500 μ m may be passed through a surfacing coating section comprising four electroplating devices. Each electroplating device comprises a nickel plate 800mm in height. 120 litres of nickel sulfamate solution comprising 300 grams
10 of nickel coated diamond grits is provided in the solvent tank. The mixture of nickel sulfamate solution and nickel coated diamond grits is then allowed flow through each of the electroplating device, wire and nickel plate at approximately 53 to 55°C. A power supply with an output of 5 volts and 1.5 amperage is applied to wire (cathode) and nickel plate (anode). Depending on the thickness
15 of the uncoated wire and moving/operating speed of the wire, a layer of nickel is coated over the wire and diamond powder with a thickness of 0.5 μ m to 1 μ m was coated onto the wire.

Following the surface coating section 15, residual nickel sulfamate solution
20 remains on the wire and gets transferred to the pulleys. In particular, the nickel sulfamate solution would harden in the groove of the pulleys and so prevent contact between the wire and grounded and/or electrically isolated metal pulleys pulleys. This adversely interferes with the grounding connections provided at

the metal pulleys. Without proper grounding, unused current and harmful electrostatic charges from the wire coating section 15 may leak to other sections and affect the quality of deposits at the wire coating section 15. Further, the wire coating apparatus in its entirety loses its protection against short
5 circuits and electrical shocks, which may in turn affect the electroplating processes downstream.

Figure 8 shows a rinsing basket 335 mounted relative to a pulley 340, according to the present embodiment of the invention. A consistent flow of clean water
10 may be supplied to the basket for rinsing the pulleys so as to remove residual nickel sulfamate solution present on the pulleys. Typically, residual nickel sulfamate solution from the wire gets transferred to the ring 345 of the pulley. Therefore, the basket of the present invention is disposed such that a portion of the ring 345 remains within the vicinity of the rinsing basket 335. To this end,
15 the nickel sulfamate solution is washed off when the pulley runs through the basket. This maintains electrical connection and/or contact between the wire and pulleys in the pulley array, which is required for grounding, isolating of the surface coating sections, surface coating, etc.. The rinsing basket advantageously reduces the need for regular replacement of the pulleys, which
20 consequently will significantly reduce the manufacturing costs of the diamond coated wire.

For economies of scale, the structure 170 comprising electroplating device 150 may accommodate one or more electroplating devices for catering one or more wire coating production lines.

5 ***Cleaning***

Further to the surface coating section 15, the coated wire must be cleaned to substantially remove residual nickel sulfamate solution and unwanted chemicals from the wire surface prior to the next section in the wire coating process. This
10 is to avoid unwanted reactions on the wire surface as well as to avoid solution contamination.

In the cleaning section 20, wire from the surface coating section 15 enters a residue removal tank whereby the wire is submerged in cleaning solution for
15 removing unwanted chemicals prior to the next section in the wire coating process. The residue removal tank may include features and steps similar to that afore described for Figure 5, and hence not repeated for brevity.

In the present embodiment, the coated wire may be treated or cleaned using
20 distilled water or deionized water. Further, several methods of improving rinsing efficiency may be used, such as heated water, air agitation and/or spray rinsing directly over the residue removal tank. It will be appreciated that the coated wire

may be passed through one or more residue removal tanks so as to minimize contamination in the next tank or wire coating section.

Further still, a rinsing basket similar to afore described Figure 8 may be
5 provided for rinsing the array of pulleys following the surface coating section 20 so as to remove residual nickel sulfamate solution present on the pulleys.

Nickel Electroplating Bath

10 Further to the surface coating 15 and cleaning 20 sections, the wire may pass through one or more nickel coating 25 and cleaning 30 sections until a coating of a specified thickness has been achieved.

In the present embodiment, the diamond coated and cleaned wire from sections
15 15, 20 may pass through an electroplating device 375, as seen in Figure 9, whereby a layer of nickel is deposited onto the surface of the diamond coated wire. The electroplating device 375 may include one or more parallel nickel plates 380 (anode) or one or more parallel trays containing nickel pallets immersed in an electrolytic bath 385. The electrolytic bath 385 may be provided
20 using the same standard module overflow holes and weirs 390, 395 as afore described Figure 3b.

The openings, overflow holes and collection area of the electroplating device 375 may be selected to fully submerge the moving wire in the electrolytic bath

385. This helps to prevent contamination and collection of unwanted particles, such as dirt and dust, which may adversely affect the thickness and consistency in particle size distribution of the surface coating.

- 5 Depending on the intended application, the module of the present embodiment may comprise one or more electroplating devices for one or more wire coating production lines.

The module may include a collection area 400 arranged to collect electrolytic
10 solution overflowed from the electrolytic baths 385, 415, 420. The collection area 400 may be provided with one or more openings 405, 410 and corresponding air shields similar to afore described residue tank 285 in Figure 5. The openings may be aligned with corresponding overflow holes and weirs such that they fall on the same vertical plane, and along the path of the moving wire.

15

In electrolytic bath 385, the diamond coated wire enters 425 the bath 385 via a first opening on one side surface of the collection area 400 and weir 390, travels along a path parallel to the nickel plate 380, and exits 430 from the bath 385 via weir 395 and a second opening on a second side surface of the collection area
20 400. As mentioned previously, this arrangement provides a consistent wire (cathode) to nickel plate (anode) distance, which is important for achieving a surface coating of uniform thickness and particle size distribution.

A power supply, supply of electrolyte solution, pump arrangement, agitation pumps, rinsing basket, recycling, similar to afore described surface coating section 15 may be provided in the surface coating section 25.

5 In a specific application using an embodiment of the present invention, a diamond coated wire having a thickness between 101 to 105 μ m is passed through an electrolytic bath comprising a nickel plate 600mm in length. The bath comprises 800 litres (nickel density of 1.35-1.36°Baume) at approximately 53 to 55 °C. Depending on the operating/moving speed and size of the wire, a power
10 supply with an output of 1 to 7 volts and 0.2 to 3 amperes may be applied to wire (cathode) and nickel plate (anode). A layer of nickel with a thickness of 0.5 μ m to 1 μ m, depending on thickness of the uncoated wire and moving/operating speed of the moving wire, was coated onto the diamond coated wire when electroplating was carried out for 7 seconds, with the wire
15 moving at 2 meters per minute.

Cleaning

Further to the surface coating section 25, the coated wire must be cleaned for
20 reasons similar to aforementioned cleaning section 20.

In the cleaning section 30, wire from the surface coating section 25 enters a residue removal tank whereby the wire is submerged in cleaning solution for

removing unwanted chemicals prior to the next section in the wire coating process. The residue removal tank may include features and cleaning steps similar to that afore described for Figure 5 and cleaning section 20.

5 ***Drying***

Following completion of the final surface coating and cleaning sections, the wire should be thoroughly dried. Complete drying is necessary to prevent staining and rusting.

- 10 For any embodiment of the invention, the drying section 35 may comprise one or more heaters for removing moisture from the coated wire, prior to assembly and packaging. Further, the heater may be operated individually or collectively. According to a particular embodiment, the drying section comprises six heaters for drying one or more wires at the same time. In this embodiment, the wires are
15 preferably spaced at least 89mm apart from one another.

Other components

- For any embodiment of the invention, a diameter measuring device may be
20 provided at one or more wire coating sections, such as at the surface coating sections 15, 25 and assembly section 40, for measuring the thickness/diameter of the coated wire. The measuring device may include a sensor set, transmitter and receiver. In particular, the diameter measuring device is useful for inspection and quality control purposes.

Further, an encoder may be provided at the rewinding device for measuring the length of the coated wire collected/assembled on the wire drum.

- 5 According to any embodiment of the invention, a suitable housing arrangement may be provided for housing the treatment 10, surface coating 15 and cleaning 20 sections. The housing arrangement may house each section individually or collectively depending on the work space available at the manufacturing site.
- 10 Figures 10a and 10b show embodiments of a suitable housing arrangements 350, 360. The housing arrangement 350 may include an enclosed structure comprising a ventilation system 355. The ventilation system 355 serves to remove unwanted vapour, such as nickel sulfamate vapour and/or water vapour from the nickel sulfamate, deionized water and/or alkaline cleaners. The
- 15 housing arrangements 350, 360 may include one or more access points, such as windows 365, hinged doors 370 and/or sliding doors, for inspection and maintenance of the equipment and devices within each section. It will be appreciated that the housing arrangement may be customized according to health and safety requirements and the nature of activities/reactions occurring
- 20 within each wire coating section.

For any embodiment of the invention, a temperature control unit may be provided in each of the treatment, surface coating, cleaning and drying sections. The temperature control unit may comprise a temperature sensor and

temperature controller operable with software. The temperature sensor assesses the temperature in each section of the wire coating apparatus, and controls a heater and/or cooler to adjust the temperature according to user-defined settings.

5

According to any embodiment of the invention, a fuse with a suitable operating characteristic may be provided in each electrical device of the wire coating apparatus. The fuse acts as a sacrificial device to provide overcurrent protection when too much current flows through it. To this end, each electrical device may
10 be isolated from the rest of the wire coating apparatus during short circuits, overloading, mismatched loads or device failure. It will be appreciated that the current operating characteristics such as the load let through by the fuse may be chosen to provide adequate protection without needless interruption.

Claims

1. A wire coating device comprising:
 - 5 a chamber having an electrolytic fluid therein, said chamber arranged to allow the passage of a wire through said chamber;
 - a magnetising device for applying a magnetic field to said wire;
 - at least one anodic electrode within said chamber;
 - a cathodic electrical connection in electrical communication with said
 - 10 wire;
 - a grit supply for introducing a supply of metal coated grit into the chamber;
 - wherein the wire is arranged to magnetically attract the metal coated grit, with the anodic electrode and cathodic wire arranged to electrolytically
 - 15 apply a metal coating to said wire to encase said metal coated grit.
2. The wire coating device according to claim 1, wherein the grit includes diamond particles and the metal includes nickel.
- 20 3. The wire coating device according to claim 1 or 2, wherein said chamber is oriented vertically and the metal coated grit is introduced proximate the top of said chamber.

4. The wire coating device according to any one of claims 1 to 3, further including a recycling system for recycling the electrolytic fluid; said recycling system including a recycling tank having an internal surface with large radius curves at corners and edges of said surface; 5 said recycling tank in fluid communication with said chamber.
5. A pulley array for guiding a wire, the pulley array comprising: three pulleys arranged such that corresponding pulley axles are arranged in a triangular pattern within a common plane; 10 a first and third of said pulleys being electrically conductive and in electrical communication with an earth; the second pulley having electrically insulative material in a groove for engaging said wire; wherein the pulleys are sequential arranged, along path of said wire, 15 from the first to second to third pulley.
6. The device according to claim 5, wherein at least one pulley of said pulley array includes a mercury attachment comprising liquid mercury, said mercury attachment arranged to electrically connect rotating parts of 20 said pulley with said wire.

7. A tank module for allowing the passage of a wire, the tank module comprising:
a weir at opposed ends, said weir having a slot for placing the wire, said slot having a width sufficient to allow the passage of said wire, and;
5 pulley arrays according to claim 5 to 6 at said opposed ends for electrically isolating said module.
8. The tank module according to claim 7, further including a pair of air shields, each proximate to either an entry and exit point of said wire;
10 each air shield comprising a nozzle assembly arranged to radially direct an air supply to said entry or exit at a sufficient flow rate to repel fluid from said entry or exit.
9. The tank module according to claim 7 or 8, further including at least one
15 anodic electrode within said tank module proximate to a path to be followed by said wire;
said module containing an electrolytic fluid
a cathodic electrical connection in electrical communication with said wire;
20 wherein the anodic electrode and cathodic wire arranged to electrolytically apply a metal coating to said wire.

10. A tensioning unit for maintaining a tension in a wire engaged with said tensioning unit, the tensioning unit comprising:
a lever assembly comprising a first lever arm arranged to engage said wire from a wire drum, said lever assembly configured to move in response to a force corresponding to dynamic tension within said wire;
5 a driving member operable with said movement for varying the extent of speed for operating said wire.
11. The device according to claim 10, wherein the lever assembly includes a
10 second lever arm comprising one or more counter-weights arranged to vary the dynamic tension for operating said wire.
12. A system for coating wires comprising:
a first wire coating device according to any one of claims 1 to 4 for
15 applying a metal and metal coated grit to said wire; and
a second wire coating device within a tank module according to any one of claims 7 to 9, said second wire coating device arranged to apply a metal coating over said metal and metal coated grit.
- 20 13. The system according to claim 12, further comprising a pulley array according to any one of claims 5 to 6.
14. The system according to claim 12 or 13 further comprising a tensioning unit according to claims 10 to 11.

15. A method for coating wires, the method comprising the steps of:

guiding said wire to a first wire coating device;

applying a metal and metal coated grit to said wire;

5 guiding said wire to a second wire coating device; and

applying a metal coating over said metal and metal coated grit.

16. The method according to claim 15, wherein the metal and metal coated grit application step includes the steps of:

10 applying a magnetic field to said wire;

introducing a mixture of electrolytic fluid and metal coated grit into the first coating device;

guiding said wire through the first coating device comprising at least one anodic electrode while applying an electrical connection to said wire and

15 anodic electrode.

17. The method according to claim 15 or 16, wherein the guiding steps

include the step of guiding said wire from a first to second to third pulley,

said pulleys having corresponding pulley axles in a triangular pattern

20 within a common plane.