US 20080160879A1

(19) United States

(12) Patent Application Publication

(10) Pub. No.: US 2008/0160879 A1

(43) Pub. Date: Jul. 3, 2008

Peterson et al.

(54) METHOD OF ABRADING A ZIRCONIUM-BASED ALLOY WORKPIECE

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(21) Appl. No.: **11/746,934**

(22) Filed: **May 10, 2007**

Related U.S. Application Data

(60) Provisional application No. 60/882,938, filed on Dec. 31, 2006.

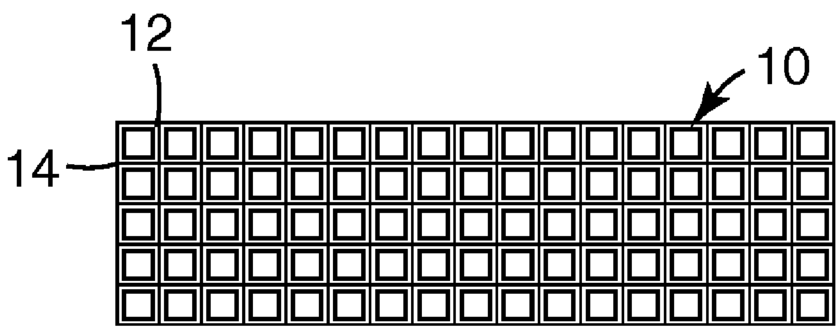
Publication Classification

(51) **Int. Cl.**
B24B 1/00 (2006.01)

(52) **U.S. Cl.** **451/28**

(57) **ABSTRACT**

A method of abrading a zirconium-based alloy workpiece including the steps of contacting a zirconium-based alloy workpiece with an abrasive article, wherein the abrasive article includes a flexible waterproof backing having a first surface bearing a cured primer coating; and a plurality of shaped structures, each structure having a distal end spaced from said backing and an attachment end attached to the primer coating on the backing, said shaped structures comprising a mixture of abrasive particles having a Knoop hardness greater than 2,200 kg/mm^2 and cured particulate binder, wherein the metal workpiece is contacted with the distal ends of the shaped structures to form an abrading interface; moving the abrasive article relative to the metal workpiece while providing sufficient force between the metal workpiece and the distal ends of the shaped structures of the abrasive article to abrade the metal workpiece; and applying liquid coolant proximate the abrading interface.



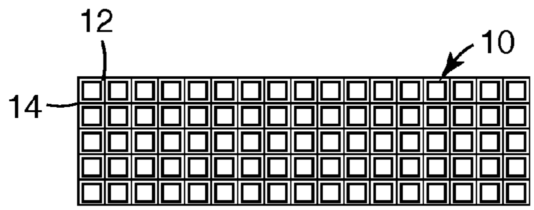


Fig. 1A

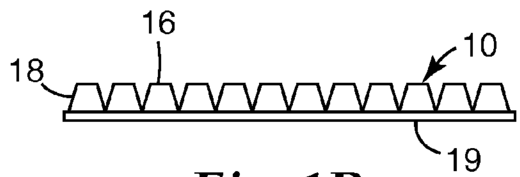


Fig. 1B

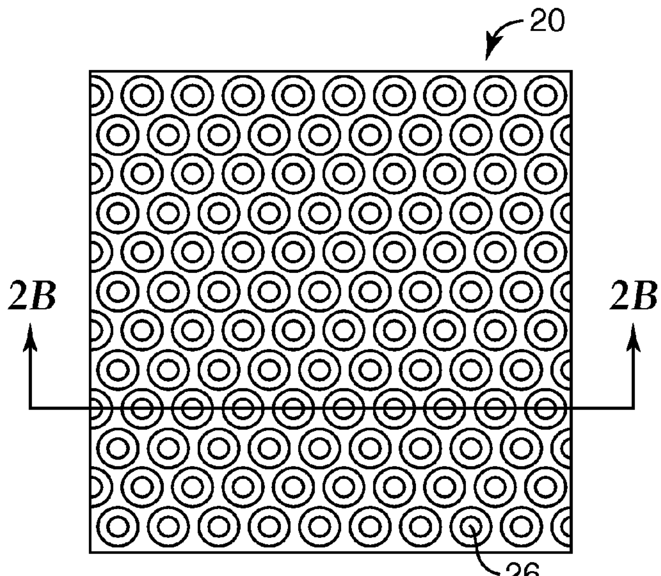


Fig. 2A

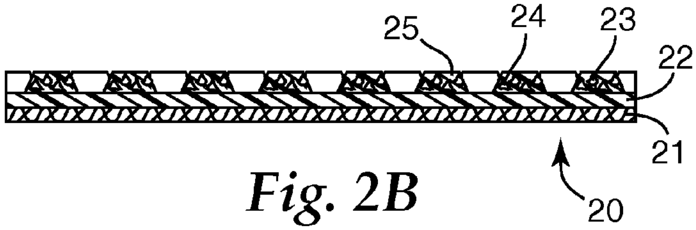


Fig. 2B

METHOD OF ABRADING A ZIRCONIUM-BASED ALLOY WORKPIECE

CROSS-REFERENCE

[0001] This application claims priority to previously filed U.S. Provisional Application No. 60/882,938, entitled "METHOD OF ABRADING A ZIRCONIUM-BASED ALLOY WORKPIECE" filed on Dec. 31, 2006.

FIELD

[0002] The present disclosure relates generally to a method of abrading a surface of a zirconium-based alloy workpiece.

BACKGROUND

[0003] Materials comprising zirconium based alloys have found utility in the nuclear power industry. One specific application in this industry is the use of zirconium-based alloy tubes as cladding for fuel pellets. The environment to which the tubes are exposed during this application can cause corrosion of the tube's exposed surface that often limits the duration of their use. Improving corrosion resistance is desirable and has been related to the tube's surface finish immediately prior to use. Improved corrosion resistance has been observed with a decreasing level of surface roughness, i.e., creating a smoother initial surface finish of the tube.

[0004] Several surface finishing processes have been employed to improve the surface finish of the tubes prior to use including a pickling method and a mechanical abrading method. The pickling method relies on strong acids to modify the surface finish of the zirconium based alloy. The mechanical abrading method allows at least portions of the surface of zirconium-based alloy workpiece to be modified by the urging of an abrasive article against the workpiece. The mechanical abrading method often employs a complicated, multi-step abrading process requiring a series of abrasive articles, of varying abrasive particle grit size, run in specific sequences for various times, pressures, and/or cycles.

[0005] The mechanical abrading method is often considered a better alternative that the chemical method. However, there is a continuing need for a mechanical abrading method that can simplify the surface finishing process, provide improved surface finish, provide improved process throughput, i.e., improved removal rate of the zirconium-based alloy, and/or lower the cost of the surface finishing process.

SUMMARY

[0006] The present disclosure relates generally to a method of abrading a surface of a zirconium-based alloy cylindrical workpiece. More specifically, the methods of the present disclosure have been shown to provide significant and unexpected performance advantages over conventional coated abrasives when used to abrade zirconium-based alloy cylindrical workpieces in the presence of a liquid coolant. Using methods of the present disclosure, an abrasive article can be used to achieve a desired finish with a higher cut rate than conventional coated abrasives. In some applications, the methods of the present disclosure reduce the necessity of using multiple abrasive article grades to achieve a target surface finish.

[0007] In one aspect, the present disclosure relates to a method of abrading a zirconium-based alloy workpiece that includes providing an abrasive article having a flexible waterproof backing having a first surface bearing a cured primer coating; and a plurality of shaped structures, each structure having a distal end spaced from said backing and an attachment end attached to the primer coating on the waterproof backing, said shaped structures comprising a mixture of abrasive particles having a Knoop hardness greater than 2,200 kg/mm^2 and cured particulate binder. The method includes contacting the zirconium-based alloy workpiece with the distal ends of the shaped structures to form an abrading interface, and moving the abrasive article relative to the zirconium-based alloy workpiece while providing sufficient force between the zirconium-based alloy workpiece and the distal ends of the shaped structures of the abrasive article to abrade the zirconium-based alloy workpiece. The method also includes applying liquid coolant proximate the abrading interface.

[0008] In some embodiments, the abrasive article is an abrasive belt.

[0009] In some embodiments, the abrasive particles comprise silicon carbide.

[0010] In some embodiments, the flexible waterproof backing is a treated woven polyester fabric.

[0011] In some embodiments, the liquid coolant is a mixture comprising an oil.

[0012] In some embodiments, the workpiece is rotated while the workpiece is abraded. An abrasive article can be mounted on a centerless grinding machine. In some embodiments, an abrasive belt can be mounted on a fixed center roll grinding machine.

[0013] In some embodiments, at least a portion of the shaped structures of the abrasive article comprise a cross-section selected from the group consisting of square, circular, rectangular, hexagonal, and triangular. The shaped structures can be arranged in a tessellated pattern. In some embodiments, the shaped structures can be formed by an embossing process.

[0014] In another aspect, the present disclosure relates to a method of abrading a zirconium cylindrical workpiece by providing an abrasive article having a flexible waterproof backing having a first surface bearing a cured primer coating; and a plurality of shaped structures, each structure having a distal end spaced from said backing and an attachment end attached to the primer coating on the waterproof backing, said shaped structures comprising a mixture of silicon carbide abrasive particles, and a cured thermoset particulate binder. The method includes contacting the zirconium cylindrical workpiece with the distal ends of the shaped structures to form an abrading interface and moving the abrasive article relative to the zirconium cylindrical workpiece while providing sufficient force between the zirconium cylindrical workpiece and the distal ends of the shaped structures of the abrasive article to abrade the zirconium cylindrical workpiece while applying liquid coolant proximate the abrading interface.

[0015] In some embodiments, silicon carbide abrasive particles having an average particle size in the range of 4 to 40 micrometers are used.

[0016] The methods of the present disclosure can be used to obtain at least 0.3 grams of material removal from the workpiece per 25.4 millimeter of belt width per minute, and a surface finish no greater than 0.22 micrometers Ra, or no greater than 0.20 micrometers Ra, or even no greater than 0.13 micrometers Ra.

BRIEF DESCRIPTION OF THE DRAWING

[0017] FIG. **1**A is a top view of a section of an abrasive article used in accordance with methods of the present disclosure;

[0018] FIG. **1**B is a side view of the section of the abrasive article shown in FIG. **1**A;

[0019] FIG. **2**A is a top view of a section of another abrasive article used in accordance with methods of the present disclosure; and

[0020] FIG. **2**B is an enlarged schematic cross-section of a portion of the abrasive article depicted in FIG. **2**A, taken at line **2**B-**2**B.

[0021] These figures, which are idealized, are intended to be merely illustrative of the abrasive article of the present disclosure and non-limiting.

DETAILED DESCRIPTION

[0022] The present disclosure refers to abrasive articles. The abrasive articles used in methods as disclosed herein have an endless abrasive surface (hereinafter "endless abrasive article"). Examples of endless abrasive articles include, but are not limited to, endless abrasive belts and endless abrasive bands. Endless abrasive articles also include assembled articles comprising abrasive sheets or strips endlessly disposed and removably or permanently affixed to the circumference of a rotatable cylinder so as to present an endless abrasive surface to a workpiece, when rotated. Examples of such assembled articles include, but are not limited to, sanding drums, wheels, and helically-wrapped cylinders. In an embodiment, the rotatable cylinder can have surface characteristics or surface constructions that can be chosen based at least in part on the desired use of the article. Examples of various surfaces include, but are not limited to, hard surfaces such as steel or high-durometer elastomeric surfaces, and soft surfaces such as foam or low-durometer elastomeric surfaces; or air-filled wheels.

[0023] The term "backing" refers to a flexible sheet material which will withstand use conditions of an abrasive product of the type herein described;

[0024] The term "shaped structures" refers to a structure having three dimensions including height, width and depth, such as, for example, a cube, rectangular block, right cylinder, rib, hexagonal based pyramid, truncated cone or truncated pyramid;

[0025] The term "temporary shaped structure" refers to a shaped structure comprising components in a transitory state that may be easily deformed by slight contact until it is converted to a permanent shaped structure;

[0026] The term "particulate curable binder" refers to binder materials that are solid at room temperature, have been processed to provide particles, and that may be softened and cured either upon heating and subsequent cooling, if thermoplastic, or upon sufficient exposure to heat or other suitable energy source, if thermosetting or cross-linkable;

[0027] The term "cured particulate binder" refers to a binder that was formerly particulate that has been softened and cured to form a cured mass of binder that no longer has particulate characteristics;

[0028] The term "permanent shaped structure" refers to a shaped structure that will not be altered by slight contact except when it is employed to abrade or otherwise modify the surface of a workpiece;

[0029] The term "softening" with reference to the particulate binder material refers to converting the particulate binder material from a solid having a defined particle shape to a physical form that no longer has the defined shape but instead is flowable as a liquid, viscous liquid, or semi-liquid mass;

[0030] The term "cured" with reference to the curable binder or primer material means that the material has been hardened to such a degree that the resulting product will function as an abrasive product;

[0031] The term "perforated-sheet patterning process" when referring to a process of forming the temporary shaped structures refers to any process that urges the particulate curable binder-abrasive particle mixture through a perforated sheet or cylinder and onto a backing, the holes in said sheet that form the perforations being shaped and configured to produce the desired shape and pattern of the temporary shaped structures.

[0032] The above summary of the abrasive article of the present disclosure is not intended to describe each disclosed embodiment of every implementation of the abrasive article of the present disclosure. The figures and the detailed description that follow more particularly exemplify illustrative embodiments. The recitation of numerical ranges by endpoints includes all numbers subsumed with that range (e.g., 1 to 5 includes 1, 1.5, 2, 2.75, 3, 4, 4.80, and 5).

[0033] FIG. **1**A, not drawn to scale, is a top view of an abrasive article useful in the methods of the present disclosure. It will be noted that cut lines **14** and **12** intersect to provide shaped abrasive structures **10** having distal ends **16** and sidewalls **18** on backing **19** as depicted in FIGS. **1**A and **1**B.

[0034] FIGS. **2**A and **2**B, not drawn to scale, show an abrasive product **20** that includes backing **21**, primer coating **22** and a plurality of shaped structures **23**. Each shaped body includes abrasive particles **24** that are bonded together by cured particulate binder material **25**. The shaped bodies in FIGS. **2**A and **2**B are truncated cones having flattened tops **26**.

[0035] Descriptions of apparatuses and methods useful for making the abrasive articles used in accordance with methods of the present disclosure are found in, for example, U.S. Pat. No. 6,833,014 (Welygan et al) and U.S. Pat. No. 7,044,989 (Welygan et al) and U.S. Pat. Pub. No. 2007/0074455 (Welygan et al), the disclosures of which are incorporated herein by reference. Abrasive articles employed in the method of the present disclosure comprise a flexible waterproof backing having a first surface bearing a cured primer coating and a plurality of shaped structures each structure having a distal end spaced from said backing and an attachment end attached to the primer coating on the waterproof backing, said shaped structures being comprised of a mixture of abrasive particles and cured particulate. Descriptions of the abrasive articles including abrasive belts can be found in, for example, U.S. Pat. No. 6,833,014 (Welygan et al) and U.S. Pat. No. 7,044,989 (Welygan et al) and U.S. Pat. Pub. No. 2007/0074455 (Welygan et al).

[0036] As used herein, the term "waterproof backing" refers to a backing with sufficient wet strength to resist tearing or other damage in wet abrading operations. Useful flexible waterproof backings include, for example, flexible polymeric film and primed polymeric film, metal foil, woven fabrics, knit fabrics, stitchbonded fabrics, coated paper, flexible vulcanized fibre, nonwoven fabric, calendared nonwoven fabric, open cell foam, closed cell foam, treated versions of the foregoing, and combinations thereof. The waterproof backing may be porous or nonporous.

[0037] As mentioned above, the waterproof backing may have one or more treatments thereon, which treatment(s) may cover at least a portion of a first major surface. Examples of such treatments include uncured, partially cured, or cured primers, tie layers, saturants (i.e., a barrier coat that is coated on all exposed surfaces of the waterproof backing), presizes (i.e., a barrier coat overlying the major surface of the waterproof backing onto which the abrasive layer is applied), and backsizes (i.e., a barrier coat overlying the major surface of the waterproof backing opposite the major surface on which the abrasive layer is applied). Useful presize, backsize and saturant compositions include glue, phenolic resins, latices, epoxy resins, urea-formaldehyde, urethane, melamine-formaldehyde, neoprene rubber, butyl acrylate, styrol, starch, and combinations thereof.

[0038] In some embodiments, the waterproof backing comprises a scrim. In such embodiments, it is typically desirable to support the scrim on a carrier to prevent the particulate curable binder precursor from passing through the scrim and creating processing problems.

[0039] The scrim may comprise an open mesh selected from the group consisting of woven, nonwoven, or knitted fiber mesh; synthetic fiber mesh; natural fiber mesh; metal fiber mesh; molded thermoplastic polymer mesh; molded thermoset polymer mesh; perforated sheet materials; slit and stretched sheet materials; and combinations thereof.

[0040] In some embodiments, the scrim may be made of natural or synthetic fibers, which may be either knitted or woven in a network having intermittent openings spaced along the surface of the scrim. The scrim need not be woven in a uniform pattern but may also include a nonwoven random pattern. Thus, the openings may either be in a pattern or randomly spaced. The scrim network openings may be rectangular or they may have other shapes including a diamond shape, a triangular shape, an octagonal shape or a combination of shapes.

[0041] Any of a variety of materials are suitable for use as the carrier, including for example heat resistant polymeric films, metal foils, woven fabrics, paper, calendared nonwoven fabrics, treated versions thereof, and combinations thereof. The thickness of a carrier is generally not important as long as it has sufficient integrity to be separated from the scrim.

[0042] Details concerning curable primers that can be useful for adhering the shaped structures to the waterproof backing may be found in, for example, U.S. Pat. No. 7,044,989 (Welygan et al). The primer coating may comprise a mixture of at least two different binder materials. In some embodiments, the primer material is a thermosetting binder. In some embodiments, primers are particulate mixtures of first particles of a thermosettable resin (e.g., a thermosettable polyester resin) and second particles of thermoplastic resin particles (e.g., thermoplastic polyester particles).

[0043] Abrasive articles useful in the methods of the present disclosure comprise at least one shaped structure that includes a plurality of abrasive particles dispersed in a cured particulate binder. The abrasive particles may be uniformly dispersed in a binder or alternatively the abrasive particles may be non-uniformly dispersed therein. In some embodiments, the abrasive particles are uniformly dispersed in the binder so that the resulting abrasive product has a more consistent cutting ability.

[0044] Exemplary abrasive particles include but are not limited to fused aluminum oxide, heat treated aluminum oxide, white fused aluminum oxide, black silicon carbide, green silicon carbide, titanium diboride, boron carbide, titanium carbide, diamond (both natural and synthetic), cubic boron nitride, and sol gel abrasive particles of appropriate hardness, and combinations thereof. Examples of sol gel abrasive particles can be found in U.S. Pat. No. 4,314,827 (Leitheiser et al.); U.S. Pat. No. 4,623,364 (Cottringer et al); U.S. Pat. No. 4,744,802 (Schwabel); U.S. Pat. No. 4,770,671 (Monroe et al.) and U.S. Pat. No. 4,881,951 (Wood et al.), the disclosures of which are incorporated herein by reference. In the context of the present disclosure, the term "abrasive particles" does not include agglomerated abrasive particles that contain an agglomerate binding material.

[0045] Abrasive particles may be coated with materials to provide the particles with desired characteristics. Abrasive particles may further comprise surface modification additives including wetting agents (also sometimes referred to as surfactants) and coupling agents. A coupling agent can provide an association bridge between the cured particulate binder and the abrasive particles. Additionally, the coupling agent can provide an association bridge between the cured particulate binder and filler particles. Examples of coupling agents include but are not limited to silanes, titanates, and zircoaluminates.

[0046] Alternatively, surface coatings can alter and improve the cutting characteristics of the resulting abrasive particle. Such surface coatings are described, for example, in U.S. Pat. No. 5,011,508 (Wald et al.); U.S. Pat. No. 3,041,156 (Rowse et al.); U.S. Pat. No. 5,009,675 (Kunz et al.); U.S. Pat. No. 4,997,461 (Markhoff-Matheny et al.); U.S. Pat. No. 5,213,591 (Celikkaya et al.); U.S. Pat. No. 5,085,671 (Martin et al.) and U.S. Pat. No. 5,042,991 (Kunz et al.), the disclosures of which are incorporated herein by reference.

[0047] The shaped structures of abrasive articles used in accordance with methods of the present disclosure are typically formed from a room-temperature solid, sinterable, particulate curable binder in a mixture with abrasive particles. The particulate curable binder typically comprises organic thermosetting and/or thermoplastic material, although this is not a requirement. Suitable particulate curable binders are typically capable of softening on heating to provide a curable liquid capable of flowing sufficiently so as to be capable of at least partially wetting either an abrasive particle surface or the surface of an adjacent particulate curable binder particle (e.g., sintering).

[0048] The particulate curable binder may be any suitable type as long as it is capable of providing satisfactory abrasive particle bonding and being activated or rendered tacky at a temperature which avoids causing substantial heat damage or disfiguration to the waterproof backing. Useful particulate curable binders meeting the criteria above include but are not limited to thermosetting particulate materials, thermoplastic particulate materials, thermosetting/thermoplastic hybrid particulate materials, mixtures of thermosetting particulate materials and thermoplastic particulate materials, thermoplastic elastomer materials, and mixtures thereof.

[0049] Thermosetting particulate materials involve particles made of a temperature-activated thermosetting resin.

Such particles are typically used in a solid granular or powder form. The first or short-term effect of a temperature rise sufficiently above the glass transition temperature is softening of the material into a flowable fluid-like state. This change in physical state allows the resin particles to mutually wet or contact the waterproof backing and abrasive particles. In this softened state, the cohesive layer may be modified in shape by, for example, calendering, cutting, or embossing. Prolonged exposure to a sufficiently high temperature triggers a chemical reaction, which forms a cross-linked three-dimensional molecular network. The thus solidified (cured) resin particle locally bonds abrasive particles and structures to the surface of the waterproof backing or the primed waterproof backing.

[0050] Useful thermosetting particulate curable binders include, for example, phenolic resins, epoxy resins, polyester resins, copolyester resins, polyurethane resins, polyamide resins, and mixtures thereof. Useful temperature-activated thermosetting materials include formaldehyde-containing resins, such as phenol formaldehyde, novolac phenolics including those with added crosslinking agent (e.g., hexamethylenetetramine), phenoplasts, and aminoplasts; unsaturated polyester resins; vinyl ester resins; alkyd resins, allyl resins; furan resins; epoxies; polyurethanes; cyanate esters; and polyimides. Useful thermosetting resins include but are not limited to the thermosetting powders disclosed, for example, in U.S. Pat. No. 5,872,192 (Kaplan, et al.) and U.S. Pat. No. 5,786,430 (Kaplan, et al.), the disclosures of which are incorporated herein by reference.

[0051] To prevent heat damage or distortion to the waterproof backing, the cure temperature of the thermosetting particle typically will be below a temperature that will cause damage or deformation of the waterproof backing constituents.

[0052] Useful thermoplastic particulate curable binders may include particulate forms of: polyolefin resins such as polyethylene and polypropylene; polyester and copolyester resins; vinyl resins such as poly(vinyl chloride) and vinyl chloride-vinyl acetate copolymers; polyvinyl butyral; cellulose acetate; acrylic resins including polyacrylic and acrylic copolymers such as acrylonitrile-styrene copolymers; and polyamides (e.g., hexamethylene adipamide, polycaprolactam), co-polyamides; polysulphones; polyethersulphones; aromatic polyethers; polycarbonates; polyarylates; and combinations thereof.

[0053] In the case of semi-crystalline thermoplastics (e.g., polyolefins, hexamethylene adipamide, and polycaprolactam, polyethylene terephthalate), the particulate curable binder may be heated to at least the melting point, whereupon they typically become molten to form a flowable fluid.

[0054] If non-crystallizing thermoplastics are used (e.g., vinyl resins and acrylic resins), they are typically heated above the glass transition temperature and rubbery region until the fluid flow region is reached.

[0055] Useful particulate curable binders also include mixtures and blends of the foregoing thermosetting and thermoplastic particulate curable binders.

[0056] The size of the particles of particulate curable binder is not particularly limited. In general, the average particle size is less than about 1000 micrometers in diameter, for example, less than about 500 micrometers in diameter. Generally, the smaller the size of the particles of particulate curable binder, the more efficiently they may be rendered flowable because the surface area of the particles will increase as the materials are more finely divided.

[0057] The amount of particulate curable binder used in the particulate curable binder-abrasive particle mixture generally will be in the range from about 5 weight percent to about 99 weight percent particulate curable binder, with the remainder about 1 weight percent to about 95 weight percent comprising abrasive particles and optional fillers. Typically, proportions of the components in the mixture are about 10 to about 90 weight percent abrasive particles and about 10 to about 90 weight percent particulate curable binder, and more typically about 40 to about 85 weight percent abrasive particles and about 15 to about 60 weight percent particulate curable binder, although this is not a requirement.

[0058] The particulate curable binder-abrasive particle mixture may include one or more optional additives, including, for example, additives selected from the group consisting of grinding aids, fillers, wetting agents, chemical blowing agents, surfactants, pigments, coupling agents, dyes, initiators, energy receptors, and mixtures thereof. The optional additives may also be selected from the group consisting of potassium fluoroborate, lithium stearate, glass bubbles, inflatable bubbles, glass beads, cryolite, polyurethane particles, cork particles, polysiloxane gum, polymeric particles, solid waxes, liquid waxes and mixtures thereof. Optional additives may be included to control a number of parameters, including particulate curable binder porosity and erosion characteristics. The optional additives can be added to the particulate curable binder, the abrasive particles, or the particulate curable binder-abrasive particle mixture.

[0059] Curing of the particulate curable binder may be accomplished by a suitable method including, for example, by IR heaters, heated rolls, platens, or ovens. Typically the choice of curing conditions are at least partially dictated by the particular curable binder and waterproof backing used. The choice of such conditions is well within the capabilities of one of ordinary skill in the art.

[0060] Abrasive articles used in accordance with methods of the present disclosure comprise shaped abrasive structures. The abrasive article may contain a plurality of such shaped abrasive structures in a predetermined array (ordered pattern) on a waterproof backing. Alternatively, the shaped abrasive structures may be in a random placement (random pattern) or an irregular placement on the waterproof backing. Typically, the shaped structures are closely packed in a tessellated arrangement across the surface of the waterproof backing, although this is not a requirement. The permanent shaped structures may include voids, which range from about 5 to about 60 percent by volume.

[0061] The form of the shaped structures (e.g., curable shaped structures and shaped abrasive structures) may be any of a variety of geometric configurations. For example, cross-sections of shaped structures taken parallel to the waterproof backing can be square, circular, rectangular, hexagonal, triangular, or a combination thereof. In some embodiments, shaped structures may have a shape selected from the group consisting of cones, truncated cones, three-sided pyramids, hexagon-based pyramids, truncated three-sided pyramids, four-sided pyramids, truncated four-sided pyramids, rectangular blocks, cubes, erect ribs, erect ribs with rounded distal ends, polyhedrons, and mixtures thereof. The cross-sectional shape of shaped structures at the base may differ from the cross-sectional shape at the distal end. For example, the sides forming shaped structures may be perpendicular relative to the waterproof backing, tilted relative to the waterproof backing or tapered with diminishing width toward the distal end. The transition between these shapes may be smooth and continuous or may occur in discrete steps. A shaped structure with a cross section that is larger at the distal end than at the attachment end may also be used, although fabrication may be more difficult. Shaped structures may also have a mixture of different shapes.

[0062] The height of each shaped structure is typically substantially the same, but it is possible to have shaped structures of varying heights in a single abrasive article. The height of the shaped structures generally may be less than about 10 mm, for example, in a range of from about 0.1 to 10 mm, or about 0.5 to about 5 mm, and even more typically about 0.7 to about 2 mm. The width of the shaped structure generally ranges from about 0.25 to 25 mm or more, for example, between about 1 to 5 mm, although other widths may also be used.

[0063] The base of the shaped structures may abut one another or, alternatively, the bases of adjacent shaped abrasive structures may be separated from one another by some predetermined, typically small, distance.

[0064] The areal density of the shaped abrasive structures is typically in a range of from 1,000 to 1,000,000 shaped structures/meter^2, for example, 25,000 to 500,000 shaped structures/meter^2, or 50,000 to 125,000 shaped structures/meter^2, although densities outside of these ranges may be used. The linear spacing may be varied such that the concentration of structures is greater in one location than in another. The linear spacing of structures typically ranges from about 0.3 to 10 structures per linear cm, for example, between 0.5 to about 8 structures per linear cm, although spacings outside of these ranges may be used.

[0065] The percentage bearing area may range from about 5 to about 95 percent, typically from about 10 percent to about 80 percent, for example, from about 25 percent to about 75 percent, or even from about 30 percent to about 70 percent. The percent bearing area is the sum of the areas of the distal ends times 100 divided by the total area, including open space, of the waterproof backing upon which the shaped abrasive structures are deployed.

[0066] The shaped structures may be arranged in rows, spiral, helix, or lattice fashion, or may be randomly placed.

[0067] The shaped structures can be formed by any method that creates the desired shaped structures. One method comprises softening a sheet of particulate curable binder-abrasive particle mixture, forming a temporary shaped structure by a cutting process and then curing the temporary shaped structure. Another useful method comprises softening a sheet of particulate curable binder-abrasive particle mixture, forming a temporary shaped structure by an embossing or molding process and then curing the temporary shaped structure. Yet another useful method comprises forming a temporary shaped structure by a perforated-sheet patterning process and then curing the temporary shaped structure.

[0068] The curable shaped structures comprise a plurality of abrasive particles mixed with particulate curable binder, but may include other additives such as coupling agents, fillers, expanding agents, fibers, antistatic agents, initiators, suspending agents, photosensitizers, lubricants, wetting agents, surfactants, pigments, dyes, UV stabilizers and powder flow additives. The amounts of these additives are selected to provide the properties desired.

[0069] Additional coatings may be applied over at least a portion of the shaped structures. Such coatings, also known as "size" coatings, may be compositionally the same as or different from that of the structures to which they are applied. Optional additional coatings may be: particulate or liquid in nature, thermoplastic or thermosetting, inorganic or organic. Such coatings may be applied from solution, or dispersion, or may be 100 percent solids coatings. Such coatings may or may not include additional abrasive particles, abrasive agglomerates, or abrasive composites. Examples of suitable coatings include reinforcing resins, lubricants, grinding aids, colorants, or other materials as such to modify the performance or appearance of the structures.

[0070] Optionally, the cured abrasive may be flexed, for example, to improve the flexibility of the resulting abrasive article by providing separation (e.g., cracking) between adjacent shaped abrasive structures.

[0071] Abrasive articles for use with methods of the present disclosure may be formed from sheet abrasives using any belt forming techniques known to those in the art, including, for example, adhering opposite ends of the sheet with a splicing tape and splicing adhesive.

[0072] Workpieces to be abraded in accordance with methods of the present disclosure are fabricated from zirconium in the form of zirconium-based alloys. The zirconium-based alloys typically comprise greater than 80% zirconium, or in some embodiments, even greater than 95% zirconium along with additives selected from, but not limited to, tin (Sn), iron (Fe), chromium (Cr), nickel (Ni), niobium (Nb) and oxygen (O). Specific ziconium-based alloys include those disclosed in U.S. Pat. No. 3,136,051 (Quinlan et al) and U.S. Pat. No. 5,383,228 (Armijo et al) and U.S. Pat. Pub. No. 2003/0098105 (Jeong et al), the disclosures of which are incorporated herein by reference. Exemplary zirconium-based alloys include a class of alloys referred to as "Zircaloy", including, "Zircaloy-2" and "Zircaloy-4".

[0073] The abrasive articles of the present disclosure can be used with any suitable machine. In embodiments where the abrasive article is an abrasive belt, it can be used with machines such as, for example, surface grinding machines fitted for abrasive belts, centerless grinding machines and fixed center roll grinding machines designed for abrasive belt use or modified for belt use. The abrasive belt is typically in the range of 5 to 35 cm wide and is typically urged against the rotating workpiece in increments suitable for the material being ground. Suitable roll grinding machines can readily be converted to accept abrasive belts and their concomitant contact wheels. Generally, a roll grinding machine will secure and rotate a cylindrical workpiece to systematically present its surface for modification. In operation, the cylindrical workpiece is typically rotated in the range of 15 to 92 meters/minute (50 to 300 surface feet per minute (sfpm)), and the abrasive belt is typically driven in the range of 762 to 2134 meters/minute (2,500 to 7,000 sfpm). In the case of zirconium and titanium workpieces, the abrasive belt is typically driven in the range of 762 to 1067 meters per minute (2,500 to 3,500 sfpm.)

[0074] The abrasive article of the present disclosure can also be used with centerless grinding machines. Suitable centerless grinding machines include, for example, Acme (Auburn Hills, Mich.) machine centerless belt grinders or Cincinnati Machine (now owned by Landis Grinding Systems, Waynesboro, Pa.), or Landis Grinding Systems (Waynesboro, Pa.) bonded wheel centerless machines that are readily converted to accept abrasive belts and their concomitant contact wheels. Generally, a centerless grinding machine will rotate and feed a cylindrical workpiece across a rotating abrasive belt to systematically present its surface for modification. In operation, the cylindrical workpiece is typically rotated in the range of 15 to 153 meters/minute (50 to 500 sfpm), and the abrasive belt is typically driven in the range of 762 to 2134 meters per minute (2,500 to 7,000 sfpm.) In the case of zirconium and titanium workpieces, the abrasive belt is typically driven in the range of 762 to 1067 meters per minute (2,500 to 3,500 sfpm.)

[0075] During the abrading operation of the present disclosure, a liquid coolant can assist in removing heat generated at the abrading interface. The liquid coolant can also aid in swarf or debris removal and lubrication. Examples of liquid coolants useful in the abrading operation of the present disclosure include water, aqueous mixtures, synthetic, semi-synthetic, and natural oils, water with a soluble oil, and the like, including "CT2552" commercially available from Chemtool Incorporate, Crystal Lake, Ill., with particular selection of the liquid coolant being within the level of one of skill in the art. Various additives can also be added such as lubricants, surfactants, grinding aids, dispersants, and the like. Selection and application rates of appropriate liquid coolants is typically dependent upon the selection of abrasive article, the particular metal being abraded, desired finishing results, and process limitations.

[0076] Using methods of the present disclosure, at least 0.3 (in some embodiments, at least 0.4 or even at least 0.5) grams of material can be removed from a workpiece per 25.4 millimeter of belt width per minute while obtaining a surface finish no greater than 0.22 (in some embodiments, no greater than 0.20, 0.18, 0.16, or even no greater than 0.13) micrometer Ra.

[0077] Advantages and other embodiments of the methods of the present disclosure are further illustrated by the following examples, but the particular materials and amounts thereof recited in these examples, as well as other conditions and details, should not be construed to unduly limit this method. All parts and percentages are by weight unless otherwise indicated.

EXAMPLES

[0078]

Materials

Identification	Description
Powder A	A thermoset copolyester adhesive powder, commercially available from EMS-CHEMIE (North America) Inc., Sumter, South Carolina, under the trade designation GRILTEX ™ D1644E P1
Powder B	A thermoplastic copolyester adhesive powder, commercially available from EMS-CHEMIE (North America) Inc., under the trade designation GRILTEX ™ D1441E P1
Powder C	A thermoset epoxy powder, commercially available from 3M Company, St. Paul, Minnesota under the trade designation SCOTCHKOTE ™ 6258
Powder D	A thermoset epoxy powder, commercially available from 3M Company, St. Paul, Minnesota under the trade designation SCOTCHKOTE ™ 413 Spray Grade
Filler A	Treated fumed silica from Cabot Corporation, Tuscola, Illinois, commercially available under the trade designation Cab-O-SIL ® CT-1221
Mineral A	Grade JIS 1200 Black silicon carbide mineral (UKSIC) commercially available from UK Abrasives Inc., Northbrook, Illinois
Backing A	A woven, polyester fabric, available from Milliken and Company, Spartanburg, SC commercially available under the designation 101 × 43, 1.06 Yd./Lb.(at 55% relative humidity), Polyester Sateen, High Tenacity, Dry Heat Set 1416 mm (55.755 in) Wide
Comparative Example A	A 4 inch wide by 54 inch long endless SiC abrasive belt, commercially available from the 3M Company under the trade designation 3M 464W grade 600
Comparative Example B	A 4 inch wide by 54 inch long (10.2 cm by 137 cm) endless SiC abrasive belt converted using conventional techniques from a larger endless abrasive belt commercially available from VSM Abrasives Company, O'Fallon, Missouri under the trade designation CK918 grade P800
Comparative Example C	A 4 inch wide by 54 inch long (10.2 cm by 137 cm) endless SiC abrasive belt converted using conventional techniques from a larger abrasive belt commercially available from Hermes Abrasives Ltd., Virginia Beach, Virginia under the trade designation RB515Y Grade P1200

Example 1

[0079] An abrasive belt was made as follows:

[0080] Backing A, 8 inches (20.3 cm) wide, was coated using ordinary means with a calcium carbonate filled phenolic backsize coating which was allowed to dry/cure by conventional means.

[0081] A primer mixture was prepared by combining Powder A, Powder B and Filler A in the weight ratio of 59.9:40.0:0.1. The primer mixture was thoroughly blended with an industrial mixer, a Twin Shell Dry Blender obtained from Patterson Kelly Co. Inc., East Stroudsburg, Pa., for 12 minutes.

[0082] The waterproof backing was then threaded through a particulate dispensing apparatus, comprising a reservoir and a knife coater, and a heating apparatus in order to coat and at least partially fuse the primer mixture to at least one of its major surfaces. The primer mixture was directed to the reservoir of a volumetric single screw powder feeder. A portion of the primer mixture from the feeder was deposited into a trough-like reservoir attached to, and behind, the knife coater of the particulate dispensing apparatus. The rate at which primer mixture was added to the reservoir allowed the formation of a bank of primer mixture behind the knife coater. The reservoir consisted of two teflon side walls that mated against the back of the knife coater creating a seal between the reservoir and knife coater. The width of the reservoir was narrower than the waterproof backing (about 4.5 inches), enabling the waterproof backing to be run under the reservoir sidewalls. The moving backing formed the bottom of the reservoir and, as primer mixture entered the reservoir, it landed on the moving backing, said moving backing conveyed the primer mixture to the knife coater. The knife coating blade was adjusted to a gap of 0.010 inches (0.254 mm) above the coated backing to allow a continuous layer of the primer powder to be deposited on the surface of the waterproof backing as the waterproof backing was carried forward at a speed of about 7 ft/min (2.13 meters/min). The heating apparatus comprised a 6 ft (1.83 m) long, 5 heat-zone platen which was located after the knife coater such that a continuous process of dispensing the primer via the dispensing apparatus, metering the primer via the knife coater and at least partially fusing the primer mixture via the heating apparatus could be maintained. A coating of the primer mixture, 3.4 grams per 24 square inches (0.0220 g/cm^2), was deposited on the side of the waterproof backing opposite the backsize coating and at least partially fused by passing over the heating platen having all zones set at a temperature of 265° F. (128° C.). After leaving the heating platen, the primer coated backing comprising the at least partially fused primer was air cooled and subsequently wound into a roll by a winder. During the at least partial fusing of the primer mixture, it may be possible for at least some curing of the primer mixture to occur.

[0083] A particulate curable binder-abrasive particle mixture was formed by placing Mineral A, Powder C and Filler A in the weight ratio of 51.5:48.0:0.5 into a plastic container. The container was sealed and placed on a paint can shaker, model number 5410-00, commercially available from the Red Devil Equipment Co., Plymouth, Minn. The particulate curable binder-abrasive particle mixture was thoroughly blended by shaking the container for 5 minutes.

[0084] The primer coated backing was then threaded through an apparatus designed to produce shaped structures. The apparatus included the particulate dispensing apparatus, knife coater, and heating apparatus described above, a compacting apparatus and an embossing apparatus, arranged such that they could be employed in a continuous process. The compacting apparatus was located above the heating apparatus and allowed to come into contact with the layer of the curable binder-abrasive mixture. The compacting apparatus comprised a 3.88 inch (9.9 cm) diameter silicone rubber covered aluminum roll that could spin freely on its shaft and was supported by pivot arms. The contact point of the compacting roll with the layer of curable binder-abrasive mixture was 32.5 inches (82.6 cm) from the end of the platen nearest the particulate dispensing apparatus. The downward load (i.e., dead weight) of the compacting roll was 6.5 kg.

[0085] The embossing apparatus was adjacent to the end of the heating apparatus furthest from the particulate dispensing apparatus. The embossing station was comprised of two synchronized rolls. The upper roll was a nickel plated, steel embossing roll that contained the desired embossing pattern for the shaped structures. The embossing pattern of the embossing roll was a series of hexagonal shaped cavities comprising a 5 inch (12.7 cm) wide continuous circumferential band in the middle of the 11 inch (27.9 cm) wide roll having a diameter of 5 inches (12.7 cm). The hexagonal cavities were packed in a tessellated hexagonal array. The tips of the hexagon patterns were tipped 10 degrees from the true axis of the roll, i.e. 10 degrees from the cross roll direction. The sides of the individual cavities were about 0.080 inches (0.20 cm) long at the outer extremity and the depth of the cavity was about 0.030 inches (0.076 cm) deep. The sides of the cavity were knife-like and had a 52 degree included angle. That is, the side was knife-like at the outside diameter of the embossing roll and then increased in width to the base of the cavity to form tapered sides that facilitated easy removal of the embossed feature after cooling. The embossing roll was capable of being temperature controlled and was held at a set temperature of 90° F. (32° C.). The shape of the base of the cavity was the shape of the top of the formed shaped structure after embossing. The bottom roll was a 5 inch (12.7 cm) diameter, chrome coated, steel roll of similar length as that of the embossing roll and was capable of being temperature controlled. The set temperature of the bottom roll was 60° F. (16° C.). The gap between the embossing roll and the bottom roll was about 0.015 inches (0.38 mm).

[0086] Particulate curable binder-abrasive particle mixture was directed to the reservoir of the dispensing apparatus by hand feeding using a plastic cup. The rate at which particulate curable binder-abrasive particle mixture was added to the reservoir allowed the formation of a bank of particulate curable binder-abrasive particle mixture behind the knife coater. The knife coating blade was adjusted to a gap of 0.055 inches (1.40 mm) above the primed backing to allow a continuous layer of the particulate curable binder-abrasive particle mixture to be deposited on the primed surface of the waterproof backing at a target thickness of 0.055 inches (1.40 mm) as the waterproof backing was carried forward at a speed of about 6 ft/min (1.83 meters/min). The set temperatures of the 5 zones of the heated platen were 300° F. (149° C.), 300° F. (149° C.), 275° F. (135° C.), 240° F. (116° C.) and 240° F. (116° C.), with the highest temperatures being near the knife coating apparatus and the lowest temperatures being near the embossing apparatus. After compacting and departing the heating platen, the layer of at least partially fused particulate curable binder-abrasive particle mixture entered the embossing apparatus and was embossed with the previously described hexagon array pattern. The structures, comprising the at least partially fused particulate curable binder-abrasive particle mixture, cooled upon the embossing roll, such that, they maintained the desired shape after being removed from the embossing roll. During the at least partial fusing of the particulate curable binder-abrasive particle mixture, it may be possible for at least some curing of the particulate curable binder to occur. Curing of the at least partially fused particulate curable binder-abrasive particle structures occurred by twice passing the waterproof backing containing the structures through a 60 ft (18.3 meters) long tunnel oven, having a first heat zone of 20 feet (6.1 meters) and a second heat zone of 40 feet (12.2 meters). The first pass through the oven was conducted at 10 feet per minute (3.05 meters/minute) with all zones set at a temperature of 190° F. (88° C.). The second pass was conducted at 6.6 feet per minute (2.0 meters/minute) with the first heat zone set at 330° F. (166° C.) and the second heat zone set at 400° F. (204° C.). After cooling, the abrasive belt was flexed using a 1 inch (2.54 cm) diameter bar using conventional techniques. After flexing, 4 inch (10.2 cm) wide by 54 inch (137 cm) endless belts were fabricated from the abrasive belt using conventional techniques.

Example 2

[0087] Example 1 was repeated with the following changes: The particulate curable binder-abrasive particle mixture was formed by using Mineral A, Powder A and Filler A in the weight ratio of 48.5:51.0:0.5. The knife coater blade was adjusted to a gap of 0.053 inches (1.35 mm) above the primed backing for a target coating thickness of particulate curable binder-abrasive particle mixture of 0.053 inches (1.35 mm). The compacting apparatus was not used. The process speed through the shaped structure forming apparatus was 3 feet per minute (0.91 meters/minute). The set temperatures of the 5 zones of the heated platen were 325° F. (163° C.), 325° F. (163° C.), 300° F. (149° C.), 300° F. (149° C.) and 300° F. (149° C.), with the highest temperatures being near the knife coating apparatus and the lowest temperatures being near the embossing apparatus. The second pass through the tunnel oven was conducted with the first heat zone set at 280° F. (138° C.) and the second heat zone set at 330° F. (166° C.).

Example 3

[0088] Example 1 was repeated with the following changes: The particulate curable binder-abrasive particle mixture was formed by placing Mineral A, Powder D and Filler A in the weight ratio of 58.5:41.0:0.5 into a 64 oz. plastic container along with 3 1" rubber balls. The mixture was thoroughly blended by shaking the container for 10 minutes using the paint can shaker. The contact point of the compacting roll with the layer of curable binder-abrasive mixture was 20 inches (50.8 cm) from the end of the platen nearest the particulate dispensing apparatus. The process speed through the shaped structure forming apparatus was 3 feet per minute (0.91 meters/minute). The set temperatures of the 5 zones of the heated platen were 325° F. (163° C.), 325° F. (163° C.), 325° F. (163° C.), 300° F. (149° C.) and 300° F. (149° C.), with the highest temperatures being near the knife coating apparatus and the lowest temperatures being near the embossing apparatus. Curing of the at least partially fused particulate curable binder-abrasive particle structures occurred by twice passing the waterproof backing containing the structures through a 30 ft (9.1 meters) long tunnel oven. The first pass through the oven was conducted at 5 feet per minute (1.52 meters/minute) with all zones set at a temperature of 190° F. (88° C.). The second pass was conducted at 3 feet per minute (0.91 meters/minute) with the oven set at 390° F. (198° C.).

Example 4

[0089] Example 4 was prepared as Example 3 with the exception that the composition was Mineral A, Powder D, Powder B, and Filler A in the weight ratio of 60.5:27.3:11.7:0.33. The knife coater blade was adjusted to a gap of 0.052 inches (1.32 mm) above the primed backing for a target coating thickness of particulate curable binder-abrasive particle mixture of 0.052 inches (1.32 mm). The contact point of the compacting roll with the layer of curable binder-abrasive mixture was 25 inches (63.5 cm) from the end of the platen nearest the particulate dispensing apparatus.

Example 5

[0090] Example 5 was prepared as Example 3 with the exception that the composition was Mineral A, Powder D, Powder B, and Filler A in a weight ratio of 60.5:15.6:23.4:0.33. The contact point of the compacting roll with the layer of curable binder-abrasive mixture was 27 inches (68.6 cm) from the end of the platen nearest the particulate dispensing apparatus. The knife coater blade was adjusted to a gap of 0.052 inches (1.32 mm) above the primed backing for a target coating thickness of particulate curable binder-abrasive particle mixture of 0.052 inches (1.32 mm). The set temperatures of the 5 zones of the heated platen were 325° F. (163° C.), 325° F. (163° C.), 325° F. (163° C.), 300° F. (149° C.) and 270° F. (132° C.), with the highest temperatures being near the knife coating apparatus and the lowest temperatures being near the embossing apparatus.

Abrasive Belt Test Procedure 1

[0091] The workpieces being abraded by the abrasive belts were about ⅜ inch (9.5 mm) by 30 inch (76 cm) long zirconium alloy tubes comprising Zircaloy. All tube preconditioning and testing was conducted on a Model M47 Centerless Grinding Machine available from Acme Manufacturing, Auburn Hills, Mich., run at the following conditions. The centerless grinding machine was run at a belt speed of 3155 surface feet per minute (962 surface meters per minute), a regulating wheel speed of 82 surface feet per minute (25 surface meters per minute), a tube thru feed speed of 4.8 feet/minute (1.5 meters/minute) with a 70 shore A smooth rubber contact wheel and an amp load over idle of 0.5 to 1.0 amps. A coolant, CT2552 commercially available from Chemtool Incorporate, Crystal Lake, Ill., diluted to 5% by weight in water was used at a flow rate of about 0.625 gallons per minute.

[0092] A test cycle consisted of the following:

[0093] First a 3M 464W grade 320, 4 inch (10.2 cm) wide by 54 inch (137 cm) endless belt, commercially available from the 3M Company, St. Paul, Minn., was mounted on the centerless grinding machine. A set of six zirconium alloy tubes were preconditioned by running each tube individually through the centerless grinding machine for a single pass, i.e., one time through the grinding machine, to generate an approximate 20-25 micro-inch Ra surface finish. After the preconditioning, all of the tubes were individually weighed and the surface finish was measured.

[0094] The 3M 464W grade 320 preconditioning belt was removed from the grinding machine and the specific belt to be tested was mounted. Tube 1 was run through the grinding machine. The surface finish was subsequently measured. Tube 1 was then run through the grinding machine an additional 4 passes. After the fifth pass, the tube was reweighed. The amount of zirconium alloy removed from the tube per pass, i.e., the average cut per pass, was calculated by taking the difference between the pre weight measurement (tube weight prior to running through the grinding machine) and post weight measurement (tube weight after 5 passes through the grinding machine) and dividing the value by 5.

[0095] Tube 2 was subsequently run five passes through the grinding machine. The tube was weighed after its fifth pass through the machine and the average cut per pass was again calculated. No surface roughness measurement was made on this tube. The belt now had achieved a total of ten tube passes.

[0096] Tubes 3 and 4 were then run through the centerless grinding machine in analogous fashion to tubes 1 and 2, respectively, including analogous measurements for surface finish and cut per pass.

[0097] Tubes 5 and 6 were then run through the centerless grinding machine in analogous fashion to tubes 1 and 2, respectively, including analogous measurements for surface finish and cut per pass.

[0098] The belt had now achieved a total of 30 tube passes which completed the test cycle. The test cycle was repeated an additional two times. At the end of the three test cycles, the belt had achieved a total of 90 tube passes.

Surface Finish Measurement Test Procedure

[0099] The resulting surface roughness of the workpiece was determined by using a surface finish testing device available under the trade designation MAHR® M4PI PERTHOMETER from Feinpruef Corp., Charlotte, N.C. Measurements were made transverse to the scratch patterns with the cut-off length set at 0.03 inches (0.76 mm). The finish indices of Ra, the arithmetic mean of the departures of the profile from the meanline and Rz (also known as Rtm), which is the mean of the maximum peak-to-valley values, were recorded for each test.

[0100] The abrasive belts of Examples 1 through 5 and Comparative Examples A, B and C, were tested according to the procedures outlined in Abrasive Belt Test Procedure 1. The "average cut per pass" was determined as described in this same test procedure and the "workpiece surface finish" was measured according to the Surface Finish Test Procedure. Results of this testing, including, the average cut per pass and workpiece surface finish are shown in Tables 1 and 2, respectively.

TABLE 1

		Average Cut per Pass (grams)							
Pass	Tube	Example 1	Example 2	Example 3	Example 4	Example 5	Comparative Example A	Comparative Example B	Comparative Example C
1-5*	1	1.02	0.67	1.03	1.12	0.67	0.52	0.51	0.57
6-10	2	0.82	0.75	1.10	0.96	0.71	0.59	0.53	0.64
11-15	3	0.81	0.78	0.96	0.92	0.59	0.48	0.58	0.64
16-20	4	0.81	0.58	0.84	0.89	0.68	0.47	0.48	0.67
21-25	5	0.90	0.74	0.91	0.92	0.69	0.34	0.51	0.61
26-30	6	0.85	0.74	0.80	0.90	0.61	0.39	0.48	0.62
31-35	1	0.81	0.60	0.79	0.97	0.64	0.49	0.42	0.54
36-40	2	0.91	0.62	0.98	0.93	0.63	0.50	0.38	0.55
41-45	3	1.12	0.70	0.96	0.85	0.62	0.50	0.46	0.66
46-50	4	0.91	0.70	0.95	0.86	0.56	0.45	0.45	0.62
51-55	5	0.85	0.66	0.86	0.89	0.63	0.39	0.39	0.68
56-60	6	0.85	0.58	0.82	0.83	0.63	0.39	0.46	0.64
60-65	1	0.70	0.59	n.d[1]	n.d.	n.d.	0.34	0.45	0.69
66-70	2	0.68	0.68	n.d	n.d	n.d	0.33	0.36	0.73
71-75	3	0.69	0.67	n.d	n.d	n.d	0.34	0.41	0.59
76-80	4	0.74	0.65	n.d	n.d	n.d	0.34	0.32	0.74
81-85	5	0.74	0.63	n.d	n.d	n.d	0.30	0.32	0.61
86-90	6	0.73	0.73	n.d	n.d	n.d	0.34	0.42	0.77
Average		0.82	0.67	0.91	0.90	0.64	0.41	0.44	0.65
Std. Dev.		0.11	0.06	0.09	0.04	0.04	0.08	0.07	0.06
n		17	17	11	11	11	17	17	17

[1]Not determined
*Data from passes 1-5 were not included in the calculation of the average cut and standard deviation, as this is considered to be part of the belt break-in period.

TABLE 2

		Workpiece Surface Finish: Ra [Rz] (all values in micrometers)							
Pass	Tube	Example 1	Example 2	Example 3	Example 4	Example 5	Comparative Example A	Comparative Example B	Comparative Example C
1*	1	0.34 [3.12]	0.21 [2.35]	0.38 [3.24]	0.19 [1.90]	0.21 [2.22]	0.33 [3.31]	0.57 [4.51]	0.42 [3.67]
11	3	0.23 [2.35]	0.19 [1.85]	0.23 [1.86]	0.19 [1.77]	0.14 [1.55]	0.27 [2.65]	0.29 [2.95]	0.21 [2.31]
21	5	0.25 [2.62]	0.17 [1.63]	0.24 [1.93]	0.17 [1.63]	0.13 [1.21]	0.23 [2.36]	0.26 [3.28]	0.25 [2.69]
31	1	0.17 [1.54]	0.14 [1.75]	0.23 [2.10]	0.17 [1.89]	0.17 [2.09]	0.19 [2.24]	0.25 [2.49]	0.28 [2.81]
41	3	0.19 [1.98]	0.13 [1.23]	0.22 [1.85]	0.17 [1.69]	0.15 [1.91]	0.24 [2.79]	0.24 [2.82]	0.21 [1.95]
51	5	0.21 [2.12]	0.14 [1.69]	0.16 [1.44]	0.17 [1.76]	0.12 [1.19]	0.21 [2.73]	0.24 [2.70]	0.24 [2.34]
61	1	0.18 [1.80]	0.13 [1.44]	n.d[2]	n.d	n.d	0.22 [2.84]	0.21 [2.02]	0.25 [2.29]
71	3	0.20 [1.99]	0.13 [1.48]	n.d	n.d	n.d	0.24 [3.15]	0.23 [2.60]	0.19 [1.85]
81	5	0.23 [2.06]	0.14 [1.66]	n.d	n.d	n.d	0.27 [3.20]	0.20 [2.40]	0.22 [2.20]
Average		0.21 [2.06]	0.14 [1.59]	0.22 [2.06]	0.17 [1.59]	0.14 [2.74]	0.23 [2.74]	0.24 [2.66]	0.23 [2.30]

TABLE 2-continued

		Workpiece Surface Finish: Ra [Rz] (all values in micrometers)							
Pass	Tube	Example 1	Example 2	Example 3	Example 4	Example 5	Comparative Example A	Comparative Example B	Comparative Example C
Std. Dev.		0.03 [0.33]	0.02 [0.20]	0.03 [0.24]	0.01 [0.10]	0.02 [0.40]	0.03 [0.34]	0.03 [0.38]	0.03 [0.33]
n		8 [8]	8 [8]	5 [5]	5 [5]	5 [5]	8 [8]	8 [8]	8 [8]

*Data from pass 1 was not included in the calculation of the average Ra and Rz, as well as their standard deviations, as this is considered to be part of the belt break-in period.
[2]Not determined

[0101] Surprisingly, Examples 1-3 show a significant improvement in the average cut per pass, i.e., an increase in the average cut per pass, while providing improvement in the workpiece surface finish, i.e., a decrease in the workpiece surface finish, compared to conventional coated abrasive products. This improvement in average cut per pass is unexpectedly obtained with a finer abrasive grade than Comparative Examples A and B and a similar abrasive grade to Comparative Example C. Similarly surprising, Example 2 shows improvement in the average cut per pass while providing significant improvement in the workpiece surface finish compared to conventional coated abrasive products. Incorporation of a thermoplastic resin shown in Examples 4 and 5 demonstrates the ability to maintain the abrasive average cut performance above the Comparative Examples while providing substantial improvements in the workpiece surface finish.

[0102] It is to be understood that even in the numerous characteristics and advantages of the abrasive article of the present disclosure set forth in above description and examples, together with details of the structure and function of the invention, the disclosure is illustrative only. Changes can be made to detail, especially in matters of shape, size and arrangement of the shaped structures and methods of making and using within the principles of the invention to the full extent indicated by the meaning of the terms in which the appended claims are expressed and the equivalents of those structures and methods.

What is claimed is:

1. A method of abrading a zirconium-based alloy workpiece comprising:
- contacting a zirconium-based alloy workpiece with an abrasive article, wherein the abrasive article comprises:
  - a flexible waterproof backing having a first surface bearing a cured primer coating; and
  - a plurality of shaped structures, each structure having a distal end spaced from said backing and an attachment end attached to the primer coating on the backing, said shaped structures comprising a mixture of abrasive particles having a Knoop hardness greater than 2,200 kg/mm^2 and cured particulate binder,
  - wherein the metal workpiece is contacted with the distal ends of the shaped structures to form an abrading interface;
- moving the abrasive article relative to the metal workpiece while providing sufficient force between the metal workpiece and the distal ends of the shaped structures of the abrasive article to abrade the metal workpiece; and
- applying liquid coolant proximate the abrading interface.

2. The method of claim **1** wherein the abrasive particles comprise silicon carbide.

3. The method of claim **1** wherein the flexible waterproof backing comprises treated woven polyester fabric.

4. The method of claim **1** wherein the liquid coolant comprises water and oil.

5. The method of claim **1** further comprising rotating the workpiece is being abraded.

6. The method of claim **1**, wherein the abrasive article is an abrasive belt.

7. The method of claim **6** wherein the abrasive belt is mounted on a centerless grinding machine.

8. The method of claim **6** wherein the abrasive belt is mounted on a fixed center roll grinding machine.

9. The method of claim **1** wherein at least a portion of the shaped structures of the abrasive article comprise a cross-section selected from the group consisting of square, circular, rectangular, hexagonal, and triangular.

10. The method of claim **9** wherein the shaped structures are arranged in a tessellated pattern.

11. The method of claim **9** wherein the shaped structured are formed by an embossing process.

12. The method of claim **9**, wherein the zirconium-based alloy workpiece is cylindrical.

13. A method of abrading a cylindrical zirconium-based alloy workpiece comprising:
- contacting a cylindrical zirconium-based alloy workpiece with an abrasive article, wherein the abrasive article comprises:
  - a flexible waterproof backing having a first surface bearing a cured primer coating; and
  - a plurality of shaped structures, each structure having a distal end spaced from said backing and an attachment end attached to the primer coating on the backing, said shaped structures comprising a mixture of silicon carbide abrasive particles and a cured thermoset particulate binder,
  - wherein the metal workpiece is contacted with the distal ends of the shaped structures to form an abrading interface;
- moving the abrasive article relative to the metal workpiece while providing sufficient force between the metal workpiece and the distal ends of the shaped structures of the abrasive article to abrade the metal workpiece; and
- applying liquid coolant proximate the abrading interface.

14. The method of claim **13** wherein the silicon carbide abrasive particles have an average particle size in the range of 4 to 40 micrometers.

15. The method of claim **13** wherein the flexible waterproof backing comprises treated woven polyester fabric.

16. The method of claim **13** wherein the liquid coolant comprises water and oil.

17. The method of claim **13** further comprising rotating the workpiece is being abraded.

18. The method of claim **13**, wherein the abrasive article is an abrasive belt.

19. The method of claim **18** wherein the abrasive belt is mounted on a centerless grinding machine.

20. The method of claim **18** wherein the abrasive belt is mounted on a fixed center roll grinding machine.

21. The method of claim **13** wherein at least a portion of the shaped structures of the abrasive article comprise a cross-section selected from the group consisting of square, circular, rectangular, hexagonal, and triangular.

22. The method of claim **21** wherein the shaped structured are formed by an embossing process.

23. The method of claim **18** wherein at least 0.3 grams of material is removed from the workpiece per 25.4 millimeter of belt width per minute, and a surface finish no greater than 0.22 micrometers Ra is obtained.

24. A method of abrading a zirconium-based alloy cylindrical workpiece comprising:

contacting a cylindrical zirconium-based alloy workpiece with an abrasive article, wherein the abrasive article comprises:

a flexible waterproof backing having a first surface bearing a cured primer coating; and

a plurality of shaped structures, each structure having a distal end spaced from said backing and an attachment end attached to the primer coating on the backing, said shaped structures comprising a mixture of abrasive particles having a Knoop hardness greater than 2,200 kg/mm^2 and a mixture of cured thermoplastic and thermoset particulate binder,

wherein the metal workpiece is contacted with the distal ends of the shaped structures to form an abrading interface;

moving the abrasive article relative to the metal workpiece while providing sufficient force between the metal workpiece and the distal ends of the shaped structures of the abrasive article to abrade the metal workpiece; and

applying liquid coolant proximate the abrading interface.

25. The method of claim **24** wherein the abrasive article is an abrasive belt.

26. The method of claim **25** wherein at least 0.3 grams of material is removed from the workpiece per 25.4 millimeter of belt width per minute, and a surface finish no greater than 0.22 micrometers Ra is obtained.

27. The method of claim **25** wherein at least 0.3 grams of material is removed from the workpiece per 25.4 millimeter of belt width per minute, and a surface finish no greater than 0.20 micrometers Ra is obtained.

28. The method of claim **25** wherein at least 0.3 grams of material is removed from the workpiece per 25.4 millimeter of belt width per minute, and a surface finish no greater than 0.13 micrometers Ra is obtained.

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