Title: PERMEABLE CONSTRUCTION MATERIAL CONTAINING WASTE RUBBER TYRES

Abstract: The present invention relates to a lightweight and permeable construction material and a process for the manufacture thereof by mixing cement, rubber aggregate, silicate based aggregated (gravely) and water. When cured, the rubber and silicate aggregates are bonded together in a porous and permeable matrix by the cementitious material. In addition, it is preferred that polymer fibres and/or rubber powder derived from waste rubber tyres is added to material and acts as an elastic binding material which improves the physical properties of the constructional material. Depending on the particular engineering application, material can be cast-in-place or formed into precast blocks.
PERMEABLE CONSTRUCTION MATERIAL CONTAINING WASTE RUBBER TYRES

BACKGROUND OF THE INVENTION

[0001] The present invention relates to a concrete based constructional material and in particular to permeable cementitious materials containing rubber aggregates derived from waste rubber tyres.

[0002] Each year about 1 billion pieces of used vehicle rubber ties are generated in the world. Over 40 percent of waste rubber tyres are being disposed into sanitary landfills, and tens of millions are left in empty lots and illegal tyre dumps. These dumps have the potential to cause serious fire and environmental hazards. Because rubber tyres do not easily decompose, economically feasible and environmentally sound alternatives for scrap tyre disposal must be found.

[0003] Rubber chips derived from waste rubber tyres can be used as a lightweight aggregate for the production of concrete constructional materials, while rubber powder and polymer fibres derived from waste rubber tyres can be used as an elastic binder to improve the ductility and strain compatibility of hardened cement gel in bonding of rubber aggregates and silicate based aggregates in concrete production. In addition, by making the concrete constructional materials with an open and porous internal matrix structure, the preferred embodiment can provide an improved concrete material having beneficial mechanical and hydraulic properties, and it also provides an environmentally sound way of disposing of waste rubber tyres.

SUMMARY OF THE INVENTION

[0004] According to the present invention there is provided a method of manufacturing porous concrete constructional material, the method comprising the steps of:

a) mixing a cementitious material, rubber aggregates derived from waste rubber tyres, silicate based aggregates and water to form slurry; and

b) curing the slurry to form a porous material with interconnected pore spaces which allows free drainage, and wherein the rubber and silicate aggregates are bonded together by the cementitious material.

[0005] An advantage of the present invention is that the slurry can be used as cast-in-place porous and permeable construction material or the slurry can be moulded into precast construction blocks. The construction material/blocks can be applied to various civil engineering applications which include but are by no means limited to: retaining structures, slope stabilization, highway pavement road-base/subbase, railway track support material,
thermal insulating material, impact energy absorption material, as well as sound and vibration absorption and insulating material.

[0006] According to the present invention there is also provided a construction material in which water, cementitious material, rubber aggregates derived from waste rubber tyres and silicate based aggregates have cured so as to bond the rubber and silicate aggregates together in a porous configuration that allows free drainage of fluid therethrough.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0007] In broader terms, the present invention provides a process for manufacturing a porous and permeable concrete material, comprising mixing a cementitious material, rubber bits derived from waste rubber tyres, gravelly silicate aggregates, elastic binder and water and curing the mixture to form a porous matrix with interconnected pore spaces in which the rubber bits and aggregates are bonded together by the cementitious material. In general, the bonding between the rubber bits and aggregates are mainly achieved by the hardened cementitious material (cement gel). The resulting rubberized concrete material has a permeable and porous matrix structure which has long-term chemically and mechanically stable constituents which allow it to be used for normal applications in civil and geotechnical works. The porous nature of the rubberized concrete material is also advantageous as it allows free drainage of water and eliminates the development of pore water pressure.

[0008] The cementitious material preferably substantially covers the silicate and rubber based aggregates and bonds them into the matrix having a porous structure with interconnected pore spaces. The spaces between the bonded aggregates provide the possibility to permit free drainage through the construction material. The high porosity and high rubber content of the new concrete material also make the new material highly tolerant to drying shrinkage and volumetric changes. Furthermore, the said material can withstand a high degree of deformation before rupture and ultimate failure, thus the newly invented material can also be used as a high impact energy adsorption material.

[0009] The bits of rubber aggregate used in the said concrete material may be of any size, but they are preferably granules, such as crumb and/or chips. In order to improve the porosity of the cured rubberized concrete material, it is further preferred that bits of nearly uniform grade or gap-graded particle sizes are used. Rubber granules of uniform size or gap-graded size will tend to form an open matrix structure, in contrast to randomly sized particles, which tend to settle into a closed matrix structure.

[0010] It is further preferred that a binding compound is included in the rubberized construction material to improve the strain compatibility of the cementitious material and the rubber aggregate. Once cured, the cementitious material is relatively brittle, in contrast to the
rubber bits which remain relatively deformable and elastic; thus, the strain characteristics of the two materials are incompatible. The binding compound functions as an elastic binder to increase flexibility of the hardened cementitious material and, therefore, to improve the strain compatibility of the rubberized construction material. Preferably the binding compound is a rubber powder, a polymer fibre, or a combination thereof. Both rubber powder and polymer fibre are derived from waste rubber tyres.

[0011] A preferred ratio of cementitious material to rubber aggregates, by weight, is one part cementitious material to 0.3 to 2.5 parts rubber aggregate, inclusive. By varying the ratio, the mechanical and hydraulic properties of the rubberized concrete material may be varied, as required. For example, if the ratio is one part cementitious material to 0.3 parts rubber bits, a high strength material having low porosity is obtained. In contrast, a ratio of one part cementitious material to 2.5 parts rubber aggregates produces a lower strength, highly porous material. A ratio of one part cementitious material to less than 0.3 parts rubber aggregates results in a concrete material having a low coefficient of permeability because the voids between the rubber aggregates are filled with cementitious material, resulting in a non-porous internal structure. While preferred ratios are disclosed, any range of ratios of cementitious material to rubber bits may be employed, depending on the desired properties of the constructional material.

[0012] A preferred ratio of cementitious material to water, by weight, is one part cementitious material to 0.3 to 0.8 parts of water, inclusive. Again by varying the ratio, the mechanical and hydraulic properties of the rubberized concrete material may be varied. For example, if the ratio is one part cementitious material to 0.3 parts water, a high strength material is obtained but which has low workability prior to curing. In contrast, a ratio of one part cementitious material to 0.8 parts water produces a lower strength material that is highly workable prior to curing. Of course, any intermediate ratio of cementitious material to water may be employed depending on the desired material properties.

[0013] A preferred ratio of cementitious material to binding compound, by weight, is one part cementitious material to up to, and inclusive of, 0.3 parts binding compound. Again by varying the ratio the mechanical and hydraulic properties of the rubberized concrete material may be varied. In applications where ductility of the rubberized concrete material is not the primary concern, binding compound is not required in the mixture. If ductility of the material is important, 0.3 parts of binding compound substantially increases the ductility thereof. Of course, intermediate ratios of cementitious material to binding compound may be employed, depending on the desired material properties.

[0014] By varying the composition of the rubberized concrete material its density may also be varied. Typically, the density of the said rubberized concrete material may be only about
one-third to two-third of that of that of conventional concrete. Alternatively, the density of the said material can be reduced by substituting a portion of rubber bits and/or gravelly aggregate with lightweight aggregate filler, such as volcanic pumice, expanded polystyrene pellets, cellulose fibre, expanded and dehydrated clay pellets, dehydrated and cemented biomass pellets, furnace bottom ash and pellets or the like, or any combination thereof.

[0015] Preferably the construction material according to the present invention may contain a range of 5% to 90% of rubber aggregate being replaced by silicate based (gravelly) aggregates, such as sand, gravel or the like. Alternatively, aggregates recycled from construction and demolition (C & D) wastes can be used in replacement of conventional fresh silicate based aggregates. If a small percentage of not less than 5% of silicate based aggregate is used, this would benefit the lightweight and low density properties of the material. If higher strength and stiffness of the rubberized concrete material is required, up to 90% by weight of the rubber bits can be substituted by the silicate based aggregates; however, this could result to a higher unit weight of the cured material.

[0016] Preferred cementitious materials are Portland cement, hydraulic cement or slag cement. To reduce production costs, fly ash, pulverized fly ash (PFA), or equivalent materials may be used in place of some of the Portland or slag cement. The gain in strength of the rubberized concrete material with time will significantly slow down with a high percentage of fly ash or PFA in place of Portland cement.

[0017] The rubberized concrete material according to the present invention may be cast-in-place at the construction site and allowed to cure in situ; or it may be poured into block-forming moulds and allowed to cure prior to transportation to, and use at, the construction site.

[0018] Through testing, a slurry in which the rubber and silicate based aggregates are thoroughly coated with cementitious material, but in which the voids between adjacent aggregates are not filled with cementitious material can be achieved. Such slurry results in a construction material having the desired drainage and density characteristics. If there is too much cementitious material, the voids are filled. In many cases, experimentation is required to arrive at the correct ratios for a given set of raw materials.

[0019] Irrespective of the method employed for the production of the said rubberized concrete constructional material, the placement density is preferably controlled during casting by vibration or static compression means i.e., weight placed on the slurry. The desired void ratio and placement density dictate the methods used during casting/placement. Experimentation may be used during casting/placement. Experimentation may be required to achieve the desired attributes for a given set of raw materials or casting conditions. The resulting density, void-ratio, and mechanical behaviours of the said rubberized concrete can
be consistently achieved than in known equivalent materials, such as in-situ compaction fill or backfill soils, which are imprecise and variable. Vibration and/or static compression can be applied to the said rubberized concrete under fresh and un-hardened condition to a void ratio ($e$) in the range of 0.05 to 2.0. The void ratio ($e$) of the said material is defined as in the following equation:

$$e = \frac{V_v}{V_s}$$

where $V_v$ is the total volume of void space of the said material, and $V_s$ is the total volume of solid phase of the said material.

[0020] The aggregate of rubber used in the said rubberized concrete material are preferably granules, such as crumb and/or chips. In order to improve the porosity and interconnection of the void spaces in ensuring permeable internal structure of the material, it is further preferred that rubber bits or silicate based aggregates of nearly uniform graded or gap-graded particle sizes as defined in [0022] are used. The amount of energy induced by the vibration and/or static compression shall be calculated beforehand so that the change in the total volume of void spaces induced by the imposed energy shall result in the void ratio of the said material within the preferred void ratio range of 0.05 to 2.0.

[0021] Experimentation may be required to properly define the attributes of compaction efforts in terms of static compression or vibration or a combination hereof. It is generally found that the magnitude of static compression of not greater than 500 kPa, or a vibration frequency of not more than 200 Hz, or a combination thereof, can achieve the targeted range of the final compacted void ratio ($e$) of 0.05 to 2.0. If the compaction effort is too high, the resulting void ratio of the compacted material could be too low, which will render the material to be impermeable and beyond the art of the present invention. On the other hand, if the compaction effort is too low and resulting the compacted void ratio of the material higher than 2.0, the material could be too lose and too compressible, which deprive the mechanical characteristics of the material. The compaction energy can be applied, for example, by the following means: hydraulic actuator, pneumatic actuator, static or vibrating tamper, static or vibrating rammer, static or vibrating plate compactor, static or vibrating roller, smooth wheeled drum roller, vibration table, vibration probe, or the like.

[0022] Another important aspect in ensuring the interconnecting void spaces in resulting permeable internal structure of the said material is the specific ranges of particle size distribution as defined in [0021]. Rubber bits, gravely aggregates or lightweight aggregates
are said to be well-graded when it has a good representation of particle sizes over a wide rage, and its particle size distribution curve is smooth and generally concave upward. On the other hand, a poorly graded rubber bits (gravelly or lightweight) aggregates would be one where there is either an excess or deficiency of certain sizes (gap-graded) or if most of the particles are about the same size (uniformly graded). In the present invention, it is preferred that the rubber bits or gravelly or lightweight aggregates be either uniformly graded or gap-graded. In classifying such graduation of particle size distributions, it is preferred that either the coefficient of uniformity \( C_u \) of the rubber bits or gravelly or lightweight aggregates distribution is smaller than 6 or the coefficient of curvature \( C_c \) of the rubber bits or gravelly or lightweight aggregate distribution is outside the range of 1.5 to 2.5 (i.e. \( C_u < 6 \) or \( C_c < 1.5 \) or \( C_c > 2.5 \)). The coefficient of uniformity \( C_u \) is defined as:

\[
C_u = \frac{D_{60}}{D_{10}}
\]

where:

\( D_{60} = \) particle diameter corresponding to 60% passing (by weight) as obtained from the sieve analysis, and

\( D_{10} = \) particle diameter corresponding to 10% passing (by weight) as obtained from the sieve analysis.

While the coefficient of uniformity \( C_u \) is defined as:

\[
C_c = \frac{D_{30}^2}{(D_{10})(D_{60})}
\]

where:

\( D_{30} = \) particle diameter corresponding to 60% passing (by weight) as obtained from the sieve analysis.
The following table summarizes the engineering performance of the resulting rubberized construction material in comparison with conventional concrete.

<table>
<thead>
<tr>
<th>Engineering Performance</th>
<th>Proposed Rubberized Construction Material</th>
<th>Conventional Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniaxial Compressive Strength ($q_u$)</td>
<td>400 kPa to 10 MPa</td>
<td>20 MPa to 30 MPa</td>
</tr>
<tr>
<td>Axial Strain at Failure</td>
<td>1% to 10%</td>
<td>&lt; 0.5%</td>
</tr>
<tr>
<td>Mohr-Coulomb Strength:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cohesion ($c$)</td>
<td>100 kPa to 5MPa</td>
<td>~5 MPa</td>
</tr>
<tr>
<td>Internal Angle of Friction ($\phi$)</td>
<td>30° to 40°</td>
<td>35° to 40°</td>
</tr>
<tr>
<td>Elastic Modulus ($E$)</td>
<td>100 kPa to 5 GPa</td>
<td>10 to 20 GPa</td>
</tr>
<tr>
<td>Compacted Bulk Density ($\rho$)</td>
<td>800 to 1900 kg/m$^3$</td>
<td>2400 to 2500 kg/m$^3$</td>
</tr>
<tr>
<td>Coefficient of Earth Pressure at Rest ($K_a$)</td>
<td>Less than 0.05</td>
<td>0.2 to 0.4</td>
</tr>
<tr>
<td>Coefficient of Permeability ($k$)</td>
<td>$10^{-1}$ to $10^{-4}$ cm/sec</td>
<td>$&lt;10^{-8}$ cm/sec</td>
</tr>
</tbody>
</table>

The rubberized concrete constructional material according to the present invention may be employed for any number of construction projects, such as retaining structure, slope stabilization material, highway pavement road-base/sub-base, sport court surface and base layer, railway track support material, thermal insulating material, as well as sound and vibration absorption and insulating material, or any other construction projects in replacement of conventional concrete or compacted fill materials.

Viewed from another aspect, the rubberized concrete constructional material according to the present invention provides an effective and inexpensive particle bonding technology to bond rubber crumb/chips together into a new rubberized lightweight and porous construction material providing free drainage therethrough. The bonding agent mainly comprises of cementitious materials such as Portland/hydraulic/slag cement, fly ash or PFA, and binding compound of rubber powers and/or polymer fibres derived from waste rubber tyres.
BRIEF DESCRIPTION OF THE FIGURES

[0026] Some preferred embodiments of the present invention will now be described, by way of example only, and with reference to the accompanying drawings, in which:

[0027] FIG.1 shows a general flow diagram of the process for producing a rubberized concrete constructional material according to the present invention and its casting into block form;

[0028] FIG.2 shows a general flow diagram of the process for producing a slurry mixture of the rubberized concrete constructional material and possible casting methods thereof;

[0029] FIG.3 shows the photograph of the said rubberized concrete constructional material; and

[0030] FIGS. 4 to 10 show general examples of possible uses of the said rubberized concrete constructional material in civil engineering applications.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT

[0031] FIG.1 is a block diagram schematically showing the steps followed to create rubberized concrete block in accordance with the present invention.

[0032] The first stage in the process is to remove the steel beads around the inner rim of the rubber tyres by mechanical means before chopping the rubber tyres into chunks (step 1). The tyre chunks are then fed into a granulation machine and granulated into rubber bits in the form of rubber crumb/chips (step 2) and then any steel wires and polymer fibres embedded in the chips are removed by magnetic and mechanical separation and removal techniques leaving almost pure rubber bits (step 3). However, it should be noted that, in Step 3, the removal of the steel wires can be avoided if the fill thickness is less than 3 meters as specified in ASTM Designation: D6270-98.

[0033] If needed as indicated in step 4, rubber crumb/chips are grinded down into rubber powder as part of the basic ingredients for the making of the binding compound.

[0034] A predetermined proportion of cementitious materials, such as Portland / hydraulic slag cement, fly ash or PFA (if required), and water are then thoroughly mixed with the rubber bits, silicate base aggregates or other lightweight aggregates (step 5) to form a slurry mixture. The rubber bits and aggregates in the resulting slurry are substantially coated by the cement gel.
[0035] Transfer the slurry mixture into block-forming moulds with predetermined shapes and configurations (step 6). Care must be taken to avoid excessive segregation of the cement from the rubber bits during placement in the moulds. The required placement density of the hardened material can be achieved by placing a pre-defined mass of the slurry mixture into a block-forming mould of a specific volume and subjecting it to a predetermined energy of vibration or using static compression means (step 7). A vibration table or vibration probe(s) can be used to impart the vibration energy to the mixture under a specific vibration amplitude and time interval. Alternatively, static compression can be used to control the placement density of the slurry mixture in the mould. In order to achieve uniformity of the slurry during the moulding process, static compression can be conducted in multiple lifts so that the multiple layers of the slurry are compressed in the mould into a predetermined thickness. The compacted rubberized slurry mixture is preferable to have an internal void ratio ($e$) between 0.05 and 2.0. The compaction efforts in achieving the given range of void ratio is given in the methods as prescribed in [0021] to [0022].

[0036] Then, after initial curing, the forming moulds can be disassembled as “green” blocks (step 8) which in turn are cured under humid conditions for additional curing (step 9). The strength of the rubberized construction blocks will continue to increase with time but after the additional curing period they are suitable for use in construction applications (step 10). The matured design strength of the block will be reached at about 28 days after initial casting. If fly ash or PFA is used to substitute a portion of the Portland cement, the mature strength of the construction blocks could be reached at about three months after initial casting.

[0037] As an alternative to casting the rubberized concrete material into blocks, the slurry mixture can be used directly as a cast-in-place material which cures in situ, as shown in FIG. 2. This alternative production method increases the number of engineering applications in which the said rubberized concrete may be employed.

[0038] In order to maintain the porosity of the cured rubberized construction material and blocks, rubber bits of nearly uniform grade or gap-graded particle sizes are recommended. The compressive strength of the hardened said construction material can be increased or decreased by adjusting the cement/gravely aggregates/rubber aggregates ratio and the workability of the slurry can be adjusted by changing the water/cement ratio. Substituting a portion of rubber bits with lightweight aggregate filler, such as volcanic pumice, expanded polystyrene pellets, cellulose fibre, expanded and dehydrated clay pellets, dehydrated and cemented bio-mass pellets, furnace bottom ash and pellets or the like, or any combination thereof, which can further reduce the density of the rubberized construction material. The cost of the cementing agent can be reduced by substituting a portion of the Portland cement with fly ash or PFA.
[0039] When the rubberized concrete material is mixed without a-binding compound and allowed to cure, the hardened pure cement gel is relatively brittle in comparison to the high ductility and elasticity of the rubber bits, where the strain compatibility of the two materials is inconsistent. By adding tyre derived rubber power and/or polymer fibbers to the cementing agent to act as an elastic binder (binding compound), step 5 of FIG.1, the flexibility of the cement mixture is increased and the strain compatibility of the cementing agent with the rubber bits is improved.

[0040] A specific preferred formula for the rubberized concrete constructional material (Example Material 1) is as follows: Portland cement: PFA: tyre rubber bits: sand: tyre derived rubber power: tyre derived polymer fibre: water (by weight) =1: 0.5: 1.7: 0.2: 0.167: 0.002: 0.6

[0041] This formula results in a rubberized concrete (suitable to use as a lightweight permeable backfill) having the following properties:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unconfined Compressive Strength</td>
<td>500 kPa</td>
</tr>
<tr>
<td>Axial Strain at Failure</td>
<td>( \sim 10% )</td>
</tr>
<tr>
<td>Elastic Modulus</td>
<td>100 MPa</td>
</tr>
<tr>
<td>Compacted Dry Density</td>
<td>900 kg/m(^3)</td>
</tr>
<tr>
<td>Cohesion Intercept (defined by Mohr-Coulomb Failure Envelope)</td>
<td>150 kPa</td>
</tr>
<tr>
<td>Internal Angle of Friction (defined by Mohr-Coulomb Failure Envelope)</td>
<td>(10^\circ)</td>
</tr>
<tr>
<td>Coefficient of Earth Pressure at Rest</td>
<td>0.02</td>
</tr>
<tr>
<td>Coefficient of Permeability</td>
<td>(10^{-1} \text{ to } 10^{-2} \text{ cm/sec})</td>
</tr>
<tr>
<td>Void ratio</td>
<td>(\sim 0.3)</td>
</tr>
</tbody>
</table>
[0042] Such a material can be considered a low to moderate strength, highly porous lightweight concrete constructional material when compared to conventional concrete. The construction material is relatively weak compared with concrete and is not intended as a direct substitute therefor. When compared to conventional soil fills, however, the construction material is less dense, high strength, exerts markedly less earth pressure, and it is much more permeable and very stable due to its porosity and compressive strength.

[0043] Another specific preferred formula for the rubberized concrete material (Example Material 2) is as follows: Portland cement: PFA: tyre rubber bits: sand: gravel: tyre derived polymer fibre: water (by weight) = 1.0: 0.5: 1.0: 1.5: 3.5: 0.002: 0.62

[0044] This formula results in a rubberized concrete material (suitable for use as a highway pavement subbase/road-base material) having the following properties:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unconfined Compressive Strength</td>
<td>5000 kPa</td>
</tr>
<tr>
<td>Axial Strain at Failure</td>
<td>1 – 3%</td>
</tr>
<tr>
<td>Resilient Elastic Modulus</td>
<td>1500 MPa</td>
</tr>
<tr>
<td>Compacted Dry Density</td>
<td>1850 kg/m³</td>
</tr>
<tr>
<td>Cohesion Intercept (defined by Mohr-Coulomb Failure Envelope)</td>
<td>~1500 kPa</td>
</tr>
<tr>
<td>Internal Angle of Friction (defined by Mohr-Coulomb Failure Envelope)</td>
<td>~35°</td>
</tr>
<tr>
<td>Coefficient of Earth Pressure at Rest</td>
<td>0.05</td>
</tr>
<tr>
<td>Coefficient of Permeability</td>
<td>$10^{-3}$ to $10^{-4}$ cm/sec</td>
</tr>
<tr>
<td>Void ratio</td>
<td>~0.15</td>
</tr>
</tbody>
</table>

[0045] Another specific preferred formula for the rubberized concrete material (Example Material 3) is as follows: Portland cement: PFA: tyre rubber bits: gravel: tyre derived rubber powder: tyre derived polymer fibre: water (by weight) = 1.0: 0.5: 1.3: 1.5: 0.1: 0.001: 0.6. This formula results in a porous concrete material having excellent noise and vibration
absorption abilities. A thin panel of 40mm thick of the said material can attenuate at least 60dB of noise under intermediate to high frequency range, and it can attenuate at least 30dB of noise even under a very low frequency vibration range of less than 10Hz. On the other hand, the damping ratio of the said material is in the range of 5% to 15% and a dynamic shear modulus of over 200MPa.

[0046] Another specific preferred formula for the rubberized concrete material (Example Material 4) is as follows: Portland cement: PFA: tyre rubber crumb (1 to 3mm): sand: fine gravel (5mm): tyre derived polymer fibre: water = 1: 0.5: 1.2: 1.0: 2.0: 0.0015: 0.70. The formula results in a porous concrete material having a smooth and permeable surface, which is highly suitable for the construction of sport court surface. The sport court surface constructed by the said material is elastic and rebounding, and most importantly, it is highly permeable to rainwater. Thus, the court surface constructed by the said material can maintain a levelled and flat surface (without the requirement of falling gradient for rainwater), while rainwater can be drained vertically across the said material and discharge at the subbase level and it does not cause any ponding water developed on the sport court surface after heavy rainfall.

[0047] Another specific preferred formula for the rubberized concrete material (Example Material 5) is as follows: Portland cement: tyre rubber crumb (1 to 3mm): sand: water = 1.0: 0.5: 0.5: 0.3. The formula results in a porous, free drainage, high strength, and non-shrinkage material, which is suitable for use as a binding layer or interfacing layer material. The material is also highly suitable for use as a surface protection layer against erosion and surface instability of sloping grounds during temporary excavation.

[0048] FIG.3 is a photograph showing a close up view of the said rubberized concrete material. The bonding mechanism of the tyre rubber bits 2 with the gravelly aggregate 3 and hardened rubberized cement gel 4 can be observed. The porous nature and interconnected void spaces 5 of the rubber concrete material is clearly visible.

[0049] FIG.4 shows an example of a retaining wall 6 constructed on a sloping ground to create a platform for roadway or building construction. A heavier and stronger version of the rubberized concrete material (Example Material 2) is constructed as a gravity type retaining structure 7 on top of a concrete binding layer 8 excavated on the sloping ground. A lightweight version of the rubberized concrete material (Example Material 1) is used as the backfill material 9 between the retaining wall 7 and the existing sloping ground surface. Road pavement or building platform 10 is then constructed on materials 7 and 9 to form the extended and elevated land surface.
[0050] FIG. 5 shows a possible use of the said rubberized concrete materials to stabilize a soil slope 11 composed of loss soil 12. Example Material 5 is used as an interface material 13 to provide a one-way drainage layer and surface erosion protection layer on the soil slope surface. Porous rubberized concrete 14 either in the form as Example Material 1 or as Example Material 2 is used as a drainage and reinforcement layer to stabilize the soil slope 12. The stabilized slope is then covered with Example Material 5 as a surface rainwater run-off layer/binding layer 13 and precasted concrete surface protection grid units 15 are installed on the binding material 13. The openings in the precasted concrete surface protection grids are filled with planting soil 16 and grass/vegetation 17 growths on the planting soil surface. Such a slope surface protection system is very effective in controlling surface erosion and rainwater infiltration due to heavy rainfall 18.

[0051] FIG. 6 shows an example of a highway pavement 19 constructed on sub-grade soil 20. Example Material 2 is used as a permeable and elastic subbase/road-base layer 21 to support the overlying bituminous base-course 23 and bituminous wearing-course 22 of the highway pavement. The high strength, high stiffness and high resiliency characteristics of Example Material 2 of the preferred embodiment provide a competent road base support, thus reducing the required design thickness of the overlying bituminous layers. Furthermore, the noise and traffic vibration levels generated by the vehicles riding on the bituminous layers 22 and 23 can be significantly reduced by the underlying rubberized concrete layer as described in the present invention. Thermal insulating effect can also be provided by the proposed subbase/road-base layer 21.

[0052] FIG. 7 illustrates a possible way of constructing a levelled sport court surface 24 on sub-grade ground 25. Example Material 2 is used as a subbase and drainage layer 26 for the construction of sport court. Example Material 4 is constructed on the sub-base layer to provide a smooth and level court surface 27. Permeable surface coating material 28, such as polyurethane or epoxy coating, or artificial turf, can be applied as surface protection and colour coating. Alternatively, artificial turf can be used as court surface cover. Since both Example Material 2 and Example Material 4 are permeable materials, rainwater can percolate freely across the surface layer 27 into the sub-base drainage layer 26. Thus, drainage of rainwater can be provided by the permeable nature of the said rubberized concrete material and falling gradient across the court surface is not required, which results in a flat and elastic sport court surface.

[0053] FIG.8 illustrates a possible way of constructing a bridge abutment wall 29 utilizing the said rubberized concrete material. As show in FIG. 8, the abutment 31 is constructed either by Example Material 1 or by Example Material 2 and it is located on a concrete foundation 30. Precasted interlocking concrete facing panel 32 is constructed on the surface of the abutment to protect the rubberized concrete backfill, and the bridge deck structure 33
located on top thereof. A road pavement 34 is constructed on top of the abutment wall and levelled with the bridge deck 33.

[0054] FIG. 9 illustrates a possible way of constructing a vibration insulation curtain wall/diaphragm wall 34 using Example Material 3 in protecting a building 36 against traffic induced noise and vibration 35.

[0055] FIG. 10 shows an example of using the said rubberized concrete material as a noise and vibration damping material beneath a railway track system 37. The said concrete material is manufactured as precasted blocks 40 and put underneath the railway tracks 42 and railway sleepers 41 as a cushion layer to reduce noise and vibration generated by passing trains. Levelling of the rubberized precasted concrete blocks 40 is provided by the levelling bed 39 located on top of the sub-grade 38. Gravely ballast 43 can be used to fill beneath the railway tracks in order to protect the said material 40.

[0056] In summary, a new lightweight and porous concrete constructional material is created, the material mainly comprises of rubber crumbs/chips derived from waste rubber tyres, silicate based aggregates, cementitious materials such as Portland, hydraulic and/or slag cement, fly ash or pulverized fly ash (PFA), elastic binding compound such as rubber powder and/or polymer fibres derived from waste rubber tyres. These basic ingredients are mixed with water to form slurry. The slurry can be placed as cast-in-place lightweight and porous concrete material. Alternatively, the material when still in slurry stage can be moulded into lightweight construction blocks. The construction material/blocks can be applied to various civil engineering works instead of conventional concrete or fill soils. The applicability of the construction material/blocks includes, but not limited to, the following engineering applications: retaining structure, slope stabilization material, highway pavement roadbase/subbase, railway track support material, sport court pavement surface, thermal insulating material, impact energy absorption material, as well as a sound and vibration absorption and insulating material.

[0057] Although the description herein contains many specific embodiments and references, these are not intended to limit the scope of the invention but merely to provide illustrations of some of the presently preferred embodiments thereof. For example, the cementing mixture may contain other chemicals, admixtures and/or additives as commonly adopted in concrete technology to improve its engineering performance; or the construction blocks can have other shapes and configurations, or a portion of rubber bits and/or silicate based aggregates are to be substituted by lightweight aggregate filler, such as volcanic pumice, expanded polystyrene pellets, cellulose fibre, expanded and dehydrated clay pellets, dehydrated and cemented biomass pellets, furnace bottom ash and pellets or the like, or any combination thereof.
[0058] In the claims which follow and in the preceding description of the invention, except where the context requires otherwise due to express language or necessary implication, the word "comprise" or variations such as "comprises" or "comprising" is used in an inclusive sense, i.e. to specify the presence of the stated features but not to preclude the presence or addition of further features in various embodiments of the invention.
THE CLAIMS

1. A method of manufacturing porous concrete constructional material, the method comprising the steps of:
   a) mixing a cementitious material, rubber aggregates derived from waste rubber tyres, silicate based aggregates and water to form a slurry; and
   b) curing the slurry to form a porous material with interconnected pore spaces which allows free drainage, and wherein the rubber and silicate aggregates are bonded together by the cementitious material.

2. The method according to claim 1, wherein said rubber aggregates are granules.

3. The method according to claim 1 or 2, wherein the rubber or silicate aggregate have a uniformity coefficient of less than 6 according to the formulae:

\[ C_u = \frac{D_{60}}{D_{10}} \]

wherein \( D_{60} \) and \( D_{10} \) represent particle diameters corresponding to 60 and 10% by weight on a sieve analysis.

4. The method according to any one claims 1 to 3, wherein the rubber or silicate aggregate have a coefficient of curvature \( (C_c) \) that is less than 1.5 or greater than 2.5 according to the formulae:

\[ C_c = \frac{D_{30}^2}{(D_{10})(D_{60})} \]

wherein \( D_{60}, D_{30} \) and \( D_{10} \) represent particle diameters corresponding to 60, 30 and 10 % by weight on a sieve analysis.

5. The method according to any one of claims 1 to 4, wherein the step of mixing comprises combining the cementitious material and rubber aggregates at a ratio of 1 : 0.3 to 2.5 inclusive on a weight basis.
6. The method according to any one of claims 1 to 5, wherein the step of mixing comprises combining the cementitious material and water at a ratio of 1 : 0.3 to 0.8 inclusive on a weight basis.

7. The method according to any one of claims 1 to 6, wherein from 5 to 90% of the rubber aggregate and/or silicate aggregate is substituted with a lightweight aggregate filler including volcanic pumice, expanded polystyrene pellets, cellulose fibre, expanded and dehydrated clay pellets, dehydrated and cemented bio-mass pellets, furnace bottom ash and pellets or the like, or any combination thereof.

8. The method according to any one of claims 1 to 7, wherein from 5 to 90% of rubber aggregates by weight is replaced with silicate aggregates derived from construction and demolition wastes.

9. The method according to any one of claims 1 to 8, wherein the step of mixing comprises adding an elastic binding compound for improving the strain compatibility of the construction material.

10. The method according to claim 9, wherein the elastic binding compound comprises rubber powder and/or fibres derived from waste rubber tyres.

11. The method according to claim 9 or 10, wherein the ratio of the cementitious material to the binding compound is 1 : 0 to 0.3 inclusive on a weight basis.

12. The method according to any one of claims 1 to 11, wherein the cementitious material comprises a material selected from the group consisting of: Portland cement, hydraulic cement, slag cement, fly ash and pulverized fly ash.

13. The method according to any one of claims 1 to 12, further comprising the step of casting said slurry in place on a construction site; and said curing step comprises allowing said slurry to cure in place.

14. The method according to any one of claims 1 to 12, further comprising the step of casting said slurry in block forming moulds.

15. The method of claim 13 or 14, wherein said step of casting comprises controlling the density and porosity of the slurry by static compression and/or vibration to a void ratio in the range of 0.05 to 2.0.
16. The method according to any one of claims 1 to 15, wherein the slurry formed by step a) has, before step b) a void ratio \( e \) in the range of 0.05 to 2.0 defined by the following formulae:

\[
e = \frac{V_v}{V_s}
\]

wherein, \( V_v \) is the total volume of void space of the said material, and \( V_s \) is the total volume of solid phase of the said material.

17. A construction material in which water, cementitious material, rubber aggregates derived from waste rubber tyres and silicate based aggregates have cured so as to bond the rubber and silicate aggregates together in a porous configuration that allows free drainage of fluid therethrough.

18. The construction material according to claim 17, wherein water can drain therethrough.

19. The construction material according to claim 17, including a binding compound that increases flexibility of the cementitious material.

20. The construction material according to claim 19, wherein the binding compound is a rubber powder, a polymer fibre, or a combination thereof derived from waste rubber tyres.

21. The construction material according to claim 17, wherein the ratio of the cementitious material to rubber aggregates is 1 : 0.3 to 2.5 inclusive on a weight basis.

22. The construction material according to claim 17, wherein the ratio of the cementitious material to water is 1 : 0.3 to 0.8 inclusive on a weight basis.

23. The construction material according to claim 19 or 20, wherein the ratio of the cementitious material to the binding compound is 1 : 0 to 0.3 inclusive on a weight basis.

24. The construction material according to any one of claims 17 to 23, wherein from 5 to 90% of the rubber aggregate and/or silicate aggregate is substituted with a lightweight aggregate filler including volcanic pumice, expanded polystyrene pellets, cellulose fibre, expanded and dehydrated clay pellets, dehydrated and cemented bio-mass pellets, furnace bottom ash and pellets or the like, or any combination thereof.
25. The construction material according to claim 21, wherein from 5 to 90% of the rubber aggregate is substituted with silicate aggregates.

26. The construction material according to claim 17, wherein the cementitious materials includes any one or a combination of Portland cement, hydraulic cement, slag cement, fly ash, pulverized fly ash.

27. The construction material according to claim 17 whereby when in an uncured state, the material has a void ratio \( e \) in the range of 0.05 to 2.0 defined by the following formulae:

\[
e = \frac{V_v}{V_s}
\]

wherein \( V_v \) is the total volume of void space of the said material, and \( V_s \) is the total volume of solid phase of the said material.

28. The construction material according to any one of claims 17 to 27, wherein the rubber or silicate aggregate have a uniformity coefficient of less than 6 according to the formulae:

\[
C_u = \frac{D_{60}}{D_{10}}
\]

wherein \( D_{60} \) and \( D_{10} \) represent particle diameters corresponding to 60 and 10% by weight on a sieve analysis.
29. The construction material according to any one of claims 17 to 28, wherein the rubber or silicate aggregate have a coefficient of curvature ($C_c$) that is less than 1.5 or greater than 2.5 according to the formulae:

$$C_c = \frac{D_{30}^2}{(D_{10})(D_{60})}$$

wherein $D_{60}$, $D_{30}$ and $D_{10}$ represent particle diameters corresponding to 60, 30 and 10 % by weight on a sieve analysis.

30. Use of the construction material according to any one of the preceding claims in the following situations:

- a structural and backfill material for the construction of retaining structures;
- a reinforcement and surface protection materials for stabilization of soil slopes;
- a road-base/sub-base layer to support asphaltic concrete for the construction of flexible highway pavement structures;
- a permeable and elastic material for the construction of sport court pavement surfaces;
- a structural and backfill material for the construction of abutment wall for bridge structures;
- a noise and vibration adsorption material for the construction of curtain walls or diaphragm walls to insulate buildings against traffic induced noise and vibration energies; or
- a noise and vibration adsorption material located underneath railway tracks in order to reduce and control the noise and vibration generated by the passing trains.
FIGURE 1

Step 1
Cut waste rubber tyres into chunks

Step 2
Granulate rubber tyre chunks into rubber crumb/chips

Step 3
Removal and separation of steel wires and polymer fibres from rubber crumb/chips

Step 4
Grinding of rubber crumb/chips into rubber powder for use as a binding compound

Step 5
Mixing of following ingredients into slurry:
- Portland/hydraulic/slag cement
- Pulverized fly ash (PFA)
- Rubber crumb/chips aggregates
- Silicate based aggregates
- Binding compound of rubber powder and polymer fibres derived from waste rubber tyres
- water

Step 6
Feed slurry of mixture into block-forming moulds

Step 7
Placement density control by vibration/static compression of slurry in mould

Step 8
Disassembly of mould after initial curing

Step 9
Curing of precast rubberized concrete blocks

Step 10
Construction
FIGURE 2

Uniform graded or gap-graded rubber crumb/chips aggregates

Uniform graded or gap-graded silicate based aggregates

Mixing with:

Portland slag / hydraulic cement
Pulverized Fly Ash (if required)

Binding compound makes of:
- rubber powder
- polymer fibre
(both ingredients derived from waste rubber tyres)

Water

Rubberized concrete Slurry

Placement density control by vibration/static compression of slurry to the specified void ratio

Cast-in-place:

Molding into precast blocks:

Rubberized Porous Concrete Constructional Material
Rubberized Porous Concrete Construction Blocks
Figure 3

Construction of Highway or Building Platform on Sloping Ground

Figure 4
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

See extra sheet

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 8 C04B 28/+, 18/+ 

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database consulted during the international search (name of database and, where practicable, search terms used)

CNKI, CNPAT, WPI, EPODOC, PAJ 

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
  
  "A" document defining the general state of the art which is not considered to be of particular relevance
  
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Date of the actual completion of the international search


Date of mailing of the international search report

06·FEB 2006 (06·02·2006)

Name and mailing address of the ISA/CN

The State Intellectual Property Office, the P.R.China
6 Xitucheng Rd., Jining Bridge, Haidian District, Beijing, China 100085
Facsimile No. 86-10-62019451

Authorized officer

Xu, Dongying

Telephone No. 86-10-62084686

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CLASSIFICATION OF SUBJECT MATTER

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C04B 18/22 (2006.01) i
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