

ANTIMICROBIAL RESIN CURED RUBBER ARTICLES AND PRE-VULCANIZED COMPOSITIONS

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Field of the Invention

This invention relates to certain non-silicone resin cured rubber articles that are made from at least a majority by weight of non-silicone vulcanized rubber that include silver-based compounds to provide highly desirable long-term antimicrobial characteristics within the cured rubber articles. Such articles are in either solid or blown (foam or sponge) state (or combinations of both in multilayered forms) and can be utilized in a variety of different applications.

As silver-based compounds are deleteriously affected by utilization of standard curing agents and curing accelerators, such as sulfur-based compounds and/or systems, the ability to provide such an effective antimicrobial vulcanized rubber article is rather difficult. However, this invention encompasses the presence of different non-sulfur-based curing systems and agents, such as resin curing, that permit vulcanization and do not irreversibly bind silver ions thereto, thereby resulting in long-term antimicrobial performance of the ultimate rubber article itself. The rubber articles may also comprise fillers and/or plasticizers to provide desired characteristics of dimensional stability, stiffness, flexural modulus, tensile strength, abrasion resistance, elongation, and the like, for the ultimate rubber article, while simultaneously and surprisingly enhancing the control of antimicrobial efficacy of the rubber article as well. This invention also provides a simple method of producing such an antimicrobial vulcanized rubber-containing article. Furthermore, this invention encompasses certain non-silicone pre-vulcanized raw rubber formulations made from at least a majority by weight of non-silicone rubber that include silver-based components to provide highly desirable long-term antimicrobial characteristics within the ultimate resin cured rubber articles made therefrom.

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Discussion of the Prior Art

All U.S. Patents listed below are herein entirely incorporated by reference.

There has been a great deal of attention in recent years given to the hazards of bacterial contamination from potential everyday exposure. Noteworthy examples of such concerns include the fatal consequences of food poisoning due to certain strains of *Escherichia coli* being found within undercooked beef in fast food restaurants; *Salmonella enteritidis* contamination causing sicknesses from undercooked and unwashed poultry food products; and illnesses and skin infections attributed to *Staphylococcus aureus*, *Klebsiella pneumoniae*, yeast (*Candida albicans*), and other unicellular organisms. With such an increased consumer interest in this area, manufacturers have begun introducing antimicrobial agents within various everyday products and articles. For instance, certain brands of cutting boards, shoe soles, shoe inserts, medical devices and implements, liquid soaps, etc., all contain antimicrobial compounds. The most popular antimicrobial for such articles is triclosan. Although the incorporation of such a compound within liquid or certain polymeric media has been relatively simple, other substrates, specifically vulcanized rubber and surfaces thereof, have proven less accessible. Furthermore, such triclosan additives have proven to be difficult in use or ineffective for certain bacteria. For instance, triclosan itself migrates easily within and out of certain polymeric substrates and/or matrices (and thus is not very durable), lacks thermal stability (and thus readily leaches out of rubber and like materials at higher temperatures), and does not provide a wide range of bacterial kill (for instance does not exhibit any kill for *Pseudomonas aeruginosa*).

Antimicrobial rubber formulations are certainly highly desired for the production of vulcanized rubber articles and compositions to provide not only antibacterial benefits, but also antifungal, antimildew, antistaining, and odor control properties. Rubber articles are utilized in many different applications, from automobiles (hoses, tires, bumpers, etc.), to household items (toys, sink washers, gaskets, appliances, floor mats, door mats, carpeted rubber mats, gloves, and the like), and other areas in which bacterial growth is a potential problem. Thus, there remains a long-felt need to provide an effective, durable, reliable antimicrobial pre-vulcanized rubber formulation which will provide such long-term antimicrobial, antifungal, etc., effects within the final vulcanized article. Unfortunately, such a highly desired antimicrobial rubber formulation and/or vulcanized article containing silver-based antimicrobial agents has heretofore not been provided by the pertinent prior art.

The closest art includes Japanese Patent Application 1997-342076 which discloses the production of unvulcanized rubber formulations and articles exhibiting antibacterial properties due to the presence of silver complexes. Such formulations are formed through high temperature kneading in an oxygen-free atmosphere and are used as parts in a water disinfection system. Again, no vulcanized rubber is taught or obtained within or through this disclosure.

Antimicrobial rubber bands have been taught in Japanese Patent Application 1997-140034 in vulcanized form with silver antimicrobials therein. However, such compounds are rather limited in use and the vulcanization step must include a sulfur curing agent to effectuate the final vulcanized arrangement of the subject rubber. Such sulfur curing agents have a remarkably deleterious effect on certain silver-based antimicrobials such that the sulfur reacts with the silver ion to form silver sulfide, thereby rendering it ineffective as a bactericide. As such, the utilization of such specific rubber band formulations for and within large-scale antimicrobial articles is basically unworkable.

Certain types of antimicrobial peroxide-catalyst vulcanized rubber formulations have been produced in the past; however, such peroxide-cured rubbers are all silicone-based. It is well understood and accepted that silicone rubbers cannot be vulcanized by typical sulfur-based catalysts. Thus, the antimicrobial rubber formulations of Japanese Patent Applications 1997-026273 and 1995-065149 as well as U.S. Pat. No. 5,466,726 are standard vulcanized silicone rubber formulations and articles which also include certain antimicrobial compounds. Additionally, some types of rubber, such as butyl and its derivatives chlorobutyl and bromobutyl rubber, have a tendency to de-polymerize when cured with peroxide based curing systems.

Furthermore, rubber latexes (non-vulcanized) comprising antimicrobials have been disclosed (U.S. Pat. No. 5,736,591, for example), as have floor mats having silver-based antimicrobials incorporated within pile fiber components. These floor mats have non-antimicrobial rubber backings cured through peroxide-catalyzed vulcanization to protect the pile fiber antimicrobial compounds from attack by any sulfur compounds (as in Japanese Patent Applications 1993-3555168 and 1995-38991). Again, however, to date there have

been no disclosures or suggestions of producing a vulcanized non-silicone rubber formulation or article exhibiting excellent antimicrobial properties through the long-term effective utilization of silver-based antibacterial compounds. This invention fills such a void.

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Object of the Invention

It is therefore an object of this invention to provide an antimicrobial resin cured rubber-containing article exhibiting sufficient antimicrobial activity and structural integrity to withstand repeated use without losing an appreciable level of either antimicrobial power or modulus strength. Another object of the invention is to provide an antimicrobial vulcanized rubber article comprising silver-based antimicrobial compounds which include resin curing agents which do not deleteriously effect the antimicrobial activity of the finished vulcanized article (and thus is essentially free from sulfur-based curing agents and accelerators). Yet another object of this invention is to provide a resin cured rubber-containing article that exhibits log kill rates for *Staphylococcus aureus* and *Klebsiella pneumoniae* (and/or other types of bacteria as well) of at least 1.0 after 24 hours exposure at room temperature as well as prevents growth of certain fungi after at least 10 days of exposure. Still another object of this invention is to provide a resin cured rubber-containing article comprising structural integrity filler components and plasticizers (such as silica, metal salts, organic salts, pigments (such as carbon black), calcium carbonate, paraffinic oils, phthalate oils, metal oxides, and the like) that also provide enhancements in the control of antimicrobial efficacy of the article itself through regulated silver ion release to the article surface (e.g., exhibits higher log kill rates for *Staphylococcus aureus* and *Klebsiella pneumoniae* and prevents growth of fungi such as *Aspergillus niger*). Still another object is to provide an antimicrobial pre-vulcanized raw rubber formulation that ultimately provides a resin cured rubber article of sufficient antimicrobial activity and structural integrity to withstand repeated use without losing an appreciable level of either antimicrobial efficiency or modulus strength. Yet another object is to provide a simple method of producing such an antimicrobial resin cured rubber-containing article.

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Accordingly, this invention encompasses a dimensionally stable resin cured rubber-containing article exhibiting log kill rates for *Staphylococcus aureus* and *Klebsiella pneumoniae* of at least 1.0 each after 24 hours exposure at room temperature. Also, this

invention encompasses a dimensionally stable rubber-containing article exhibiting antifungal properties such that said article exhibits at least 60% inhibition of *Aspergillus niger* ATCC 6275, when tested in accordance with Test Method ISO 846, for at least 10 days at 30°C and at greater than 90% humidity. Furthermore, this invention encompasses such a resin cured rubber-containing article comprising at least one silver ion control release additive, such as those selected from the group consisting of fillers (such as carbon black, calcium carbonate, inorganic salts, organic salts, silica, and mixtures thereof) and plasticizers (oils such as phthalate oils and paraffinic oils). This invention also encompasses a pre-vulcanized rubber formulation comprising at least one rubber constituent, the majority of which must be a non-silicone rubber, at least one silver-based antimicrobial compound and at least one resin curing compound, wherein all of said resin curing compound present within said formulation does not include an appreciable amount of sulfur-based compounds, and wherein said rubber formulation optionally comprises at least one blowing agent, at least one silver ion release control additive, and at least one antifungal additive other than said silver-based antimicrobial compound. Additionally, this invention encompasses a method of producing a vulcanized rubber-containing article comprising the steps of providing a rubber formulation of uncured rubber, at least one non-sulfur based resin curing agent, and at least one silver-based antimicrobial compound, and vulcanizing said rubber formulation at a temperature of at least 150°C and at least at a pressure of 3 bars, wherein said rubber formulation is substantially free from sulfur curing agent and accelerator.

Detailed Description of the Invention

The term “dimensionally stable” is intended to encompass a vulcanized rubber article that is structurally able to be handled without disintegrating into smaller portions. Thus, the article must exhibit some degree of structural integrity and, being a rubber, a certain degree of flexural modulus.

Such a specific antimicrobial resin cured rubber-containing article has not been taught nor fairly suggested within the rubber industry or prior art. As noted above, the avoidance of sulfur-based curing agents and accelerators to any appreciable degree thus permits the retention of silver antimicrobials within the final product in amounts sufficient to provide long-lasting log kill rates for *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Pseudomonas*

aeruginosa, and *Escherichia coli*, at the very least. Furthermore, due primarily to high costs, non-sulfur curing agents have not been prevalent within vulcanized rubber formulations and articles. As such, there has been no teaching or fair suggestion of coupling non-sulfur curing agents (and most preferably resin curing agents) with silver-based antimicrobial agents within pre-vulcanized rubber formulations to form effectively antimicrobial vulcanized rubber articles.

Additionally, certain fillers and oils (such as silica, carbon black, stearates as fillers, and phthalate and paraffinic oils) are generally, although not necessarily, required to provide both flexural modulus and structural integrity to vulcanized rubber articles. The rubber component alone generally does not exhibit proper dimensional stability without such additives. Surprisingly, the presence of such additives also provides the ability to control silver-ion release at the target article surface. Without intending to be bound to any specific scientific theory, it appears that such fillers as silica and such oils as paraffinic oil (as some examples), act in such a way as to draw moisture into the article which then transports silver ions from within the article to the surface. In such a situation, then, the rubber article may exhibit enhanced silver release resulting in higher log kill rates for certain bacteria due to the presence of larger amounts of available surface silver ions.

Other hydrophobic fillers, such as pigments (for example, carbon black) and calcium carbonate appear to work in the opposite manner by keeping water out of the target article and prevent silver-ion migration to the article surface. Thus, the reduction of such silver-ion availability decreases the antibacterial efficacy of the rubber article. In effect, then, the actual antibacterial efficacy of the entire rubber article can be controlled through the presence of certain amounts of such generally required fillers and oils (some hydrophilic antistatic agents also appear to act in the same manner as silica as well).

As a result, the necessary filler and/or oil constituents required to provide dimensional resiliency and/or flexural modulus (and thus actual usefulness) of the finished article serve a dual purpose heretofore unrecognized within the rubber industry. Rubber articles can be produced with specific end-uses in mind depending upon the duration of antimicrobial activity desired through the addition of specific amounts of such additives. Again, such a

targeted duration antimicrobial vulcanized article and the benefits thereof have heretofore been unknown and unrecognized within the rubber industry. These rubber components are thus hereinafter referred to as "silver ion release control additives".

5 The term rubber, as noted above, is intended to cover any standard rubber which must be vulcanized to provide a dimensionally stable rubber article. The specific types of rubber are listed below and have been utilized previously within the rubber industry for a variety of applications and are generally well known and taught throughout the prior art. Such inventive rubber formulations and cured articles may also possess a chemical plasticizer which aids in
10 the breakdown period of the elastomer during compounding and processing (and provides flexural modulus properties to the finished article) as well as fillers required for reinforcement (e.g. calcium carbonate, carbon black, silica, and clays). Optionally, to form a blown (foam or sponge) rubber article, a blowing agent may be added to the inventive formulation.

15 The rubber component or components of the inventive rubber formulation and cured article is therefore selected from the group consisting of nitrile rubber [such as acrylonitrile-butadiene rubber (NBR)], styrene-butadiene rubber (SBR), natural rubber, chloroprene rubber, polychloroprene rubber, ethylene propylene rubber, ethylene propylene diene monomer (EPDM) rubber, fluoroelastomer rubber, polyurethane rubber, butyl rubber,
20 halogenated butyl rubber [such as chlorobutyl rubber and bromobutyl rubber], isoprene rubber, epichlorohydrin rubber, polyacrylate rubber, chlorinated polyethylene rubber, hydrogenated NBR, carboxylated NBR, polybutadiene rubber, and the like.

 Other types of rubber may also be mixed with the base rubber type in order to provide
25 different strengths, flexibilities, or other properties. Such other components may then include, without limitation, nitrile rubber [such as acrylonitrile-butadiene rubber (NBR)], styrene-butadiene rubber (SBR), natural rubber, chloroprene rubber, polychloroprene rubber, ethylene propylene rubber, ethylene propylene diene monomer (EPDM) rubber, fluoroelastomer rubber, polyurethane rubber, butyl rubber, butyl rubber, halogenated butyl
30 rubber [such as chlorobutyl rubber and bromobutyl rubber], isoprene rubber, epichlorohydrin rubber, polyacrylate rubber, chlorinated polyethylene rubber, hydrogenated NBR, carboxylated NBR, polybutadiene rubber, and the like.

Although the presence of silicone rubber is discouraged within the inventive formulation, there remains the possibility of adding certain low amounts of such specific unvulcanized rubber components without adversely affecting the overall antimicrobial rubber formulation itself. Thus, up to 25% by total weight of the formulation may be silicone rubber; however, the vast majority of the rubber formulation must be non-silicone rubber. Furthermore, the non-silicone rubber portion must not possess an appreciable amount of sulfur-based curing agent or residue (in the finished article) and thus must be vulcanized through curing with primarily non-sulfur-based compounds (such as resins, peroxides, and/or metal oxides, for example). The rubber component is present in an amount of from about 10 to about 1,000 parts of the entire composition, more preferably from about 50 to about 500 parts, and most preferably from about 70 to about 200 parts of the entire composition. Thus, with a total number of parts between about 100 and about 2,000 parts throughout the target vulcanized rubber article, the rubber constitutes from about 25 to about 70% of the percentage by parts of the entire article. The remainder comprises additives such as fillers, oils, curing agents, the desired antimicrobial agents, optional blowing agents, and the like (as discussed more thoroughly below).

The antimicrobial agent of the inventive raw rubber formulation may be of any standard silver-based compounds. Such compounds, in contrast with organic types, such as triclosan, for example, do not exhibit low thermal stability and typically remain within the target matrix or substrate at different temperatures. Thus, such an antimicrobial is more easily controlled, as discussed above, for surface release as desired. Such agents include, without limitation, silver salts, silver oxides, elemental silver, and, most preferably ion exchange, glass, and/or zeolite compounds. Of even greater preference are silver-based ion exchange compounds for this purpose due to the low levels of discoloration and enhanced durability in the final product provided by such compounds, the efficacy provided to the final formulation with such a compound, and the ease of manufacture permitted with such specific compounds. Thus, the antimicrobial agent of this invention may be any type which imparts the desired log kill rates as previously discussed to *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Escherichia coli*, and *Pseudomonas aeruginosa*, as merely representative organisms. Furthermore, such antimicrobial compounds must be able to withstand elevated

processing temperatures for successful incorporation within the target non-sulfur (resin, for example) cured rubber-containing articles. Again, such antimicrobial agents comprise, preferably, silver-containing ion exchange, glass, and/or zeolite compounds. Most preferably, such a compound is a silver-based ion-exchange compound and particularly does not include any added organic bactericide compounds (thereby not permitting a release of volatile organic compounds into the atmosphere during processing at high temperatures, etc.).

The preferred silver-based ion exchange material is an antimicrobial silver zirconium phosphate available from Milliken & Company, under the trade name ALPHASAN®. Such compounds are available in different silver ion concentrations as well as mixtures with zinc oxide. Thus, different compounds of from about 0.01 to 15% of silver ion concentration, more preferably from about 3 to about 10%, and most preferably amounts of about 10% by total amount of components (e.g. of the total amount of silver ions and zirconium phosphate) are possible. Other potentially preferred silver-containing solid inorganic antimicrobials in this invention are silver-substituted zeolite available from Sinanen under the tradename ZEOMIC®, or a silver-substituted glass available from Ishizuka Glass under the tradename IONPURE®, which may be utilized either in addition to or as a substitute for the preferred species. Other possible compounds, again without limitation, are silver-based materials such as MICROFREE®, available from DuPont, as well as JMAC®, available from Johnson Mathey.

Generally, such an antimicrobial compound is added to a rubber formulation in an amount of from about 0.1 to 10% by total weight of the particular total rubber formulation preferably from about 0.1 to about 5%, more preferably from about 0.1 to about 2%; and most preferably about 2%.

Furthermore, with regard to silver-based inorganic antimicrobial materials, these particular antimicrobial rubber articles are shown to be particularly suitable for the desired high levels of efficacy and durability required of such articles. It has been found that certain silver-based ion exchange compounds, such as ALPHASAN® brand antimicrobials available from Milliken & Company, (U.S. Patent 5926238, U.S. Patent 5441717, U.S. Patent 5698229 to Toagosei Chemical Industry Inc.), exhibit impressive bio-efficacy. After a period of time,

alternative antimicrobial compounds (e.g. triclosan, microchek, OBPA, Zn-omadine) initially suffer from decomposition under the high processing temperatures, which is followed by depletion of the biocide through leaching into the surrounding environment and finally through depleted bactericidal activity. However, silver-containing ion exchange, glass, and/or zeolite compounds do not suffer from these shortcomings. Such antimicrobial agents exhibit high temperature stability ($>1000^{\circ}\text{C}$), do not leach into the environment and provide substantial amounts of the oligodynamic silver ion to provide for the desired extensive durability.

The inventive antimicrobial articles should exhibit an acceptable log kill rate after 24 hours for *Staphylococcus aureus* when tested in accordance with the ATCC Test Method 6538 and for *Klebsiella pneumoniae* when tested in accordance with ATCC Test Method 4352. Such an acceptable level log kill rate is tested for *S. aureus* or *K. pneumoniae* of at least 0.1 increase over baseline (represented by the control antimicrobial-free rubber article). Alternatively, an acceptable level will exist if the log kill rate is greater than the log kill rate for non-treated (i.e., no solid inorganic antimicrobial added) rubber articles (such as about 0.5 log kill rate increase over control, antimicrobial-free vulcanized non-silicone rubber article). Preferably, these log kill rate baseline increases are at least 0.3 and 0.3, respectively for *S. aureus* and *K. pneumoniae*; more preferably these log kill rates are 0.5 and 0.5, respectively; and most preferably these are 1.0 and 1.0, respectively. Of course, the high end of such log kill rates are much higher than the baseline, on the magnitude of 5.0 (99.999% kill rate). Any rate in between is thus, of course, acceptable as well.

However, log kill rates which are negative in number are also acceptable for this invention as long as such measurements are better than that recorded for correlated non-treated rubber articles. In such an instance, the antimicrobial material present within the rubber article at least exhibits a hindrance to microbe growth. Furthermore, such rubber articles should exhibit log kill rates of the same degree for other types of bacteria, such as, *Pseudomonas aeruginosa* and *Escherichia coli*.

Of great surprise within this invention is the ability for the finished inventive articles to provide antifungal benefits as well as antibacterial characteristics. Such versatility is rare

among antibacterial compounds; however, without intending to be limited to any particular scientific theory, it appears that the silver ions, and particularly the silver ions present at the article surface in great abundance, provide excellent antifungal properties. Thus, another embodiment of this inventive rubber formulation provides fungal kill durability of at least 10 sequential days for such organisms as *Aspergillus niger* and possibly for mixtures of fungi including *Aspergillus niger* ATCC 6275, *Paecilomyces variotii* ATCC 18502, and *Trichoderma virens* ATCC 9645, when tested in accordance with Test Method ISO 846. In order to provide a greater array of potential antifungal benefits, other compounds may be incorporated within the target pre-vulcanized rubber formulation (and subsequent article), such as zinc oxide, as one example.

Of great importance to the effectiveness of the inventive articles in terms of antimicrobial and antifungal activity is the omission of deleterious amounts of sulfur-based curing agents, accelerators, and additives which bind silver (such as barium sulfate filler) from the rubber article. As noted above, it is believed, without intending to be bound to any specific scientific theory, that sulfur reacts with the preferred silver-based antimicrobials and irreversibly binds the silver ions (as silver sulfides, for example) within the rubber composition and/or article itself. As such, the resultant silver sulfides, etc., are ineffective as antimicrobial agents and their presence renders the final product antimicrobially inactive. Thus, it has been necessary to produce a vulcanized rubber article lacking any appreciable amount of sulfur curing agents and accelerators therein. It should be appreciated that the term "appreciable amount" permits a small amount to be present. It has been found that, as a molar ratio, a 1:1 ratio (and above) between sulfur molar presence and silver molar presence results in a clear loss of antimicrobial activity within the desired ultimate vulcanized article. However, greater molar amounts of silver in relation to sulfur provide at least some antimicrobial properties to the desired article. A molar ratio range of from about 0.25:1 to about 0.000000001:1 of sulfur to silver ions is thus at least acceptable. The primary curing agent, however, must be of non-sulfur nature (and is preferably, though not necessarily, a resin-based compound) in order to provide the desired antimicrobial activity for the subject rubber. Furthermore, the primary curing agent may be already incorporated into the unvulcanized rubber during the manufacturing process.

Although resin curing agents have been utilized for vulcanization of rubber previously, such a different type of curing agent is not widely utilized as a suitable vulcanization catalyst for rubber for a number of reasons. Foremost, such curing agents are much more costly than standard sulfur-based agents and thus the utilization of such resins, and the like, as a replacement for the sulfur-based compounds have been rather limited to mostly silicone-based rubbers or, at the very least, non-antibacterial rubber articles. However, due to the problems associated with antimicrobial activity when such compounds are reacted with sulfur-based curing agents, alternatives to such sulfur-based cured articles was to permit utilization of such effective antimicrobial compounds within raw and vulcanized rubber for long-term high log kill rate effects. Thus, although non-sulfur-based compounds are not readily utilized within the non-silicone industry as vulcanization curing agents, utilization of such curing agents was necessary to provide an effective, ultimate antimicrobial vulcanized rubber article.

Additionally, the curing of certain non-silicone rubbers, such as butyl and its derivatives chlorobutyl and bromobutyl, is generally difficult with peroxide-based curing systems since peroxides tend to depolymerize these rubber types. An alternative method of curing butyl rubber and its derivatives is with resin-based curing systems. Some examples of resin-based curing systems includes phenol formaldehyde resins having reactive methylene groups and additional activators, as well as systems having small amounts of chlorinated polymers, such as chloroprene. These resin-based curing systems enable the use of silver-based antimicrobials in non-silicone rubbers, such as, for example, in butyl rubber (IIR – isoprene isobutylene rubber). Furthermore, these resin-based curing systems may be used in both black and non-black non-silicone rubber applications, and more specifically, in black and non-black butyl rubber applications.

Surprisingly, it has now been found that the inventive rubber articles listed above are available without such sulfur-based curing agents in any appreciable amounts; most importantly, with the introduction of certain additives, the structural integrity and/or flexural modulus of the rubber formulation is improved to an acceptable level, and the efficacy of the antimicrobial components can be controlled simultaneously.

Thus, the curing agent present within the raw rubber formulation to be vulcanized to form the inventive article must be at least a majority, and preferably at least about 75% by weight of a non-sulfur-based curing agent. As discussed above, traditional sulfur and sulfur-based catalysts will not work with the inventive antimicrobial formulations due to chemical reactions between the sulfur atoms and the biocidal Ag⁺ ion. However, non-sulfur-based catalysts, such as, for example, and without intending to being limited to resin curing systems, provide effective curing for the inventive raw rubber formulations. Such a curing agent should be present in amount of from about 0.5 to about 100 parts per hundred parts of rubber (pphr), more preferably from about 1 to about 50 pphr, and most preferably from about 1 to about 10 pphr, all either as one curing agent alone, or as the combination of any number of different types of curing agents.

Other additives present within the inventive vulcanized rubber article may include any of the aforementioned silver ion release control additives, accelerators, accelerator activators, antidegradants, softeners, abrasives, colorants, flame retardants, homogenizing agents, internal lubricants, and deodorants. Such components should be present, if at all, in rather low amounts, of from about 0.1 to about 50 pphr.

It has further been contemplated that a substantial increase in the antibacterial and antifungal efficacy may be provided upon washing the finished inventive article. Abrading the surface of such an article may also permit increases in such characteristics due to an increase in Ag⁺ release; however, industrial laundering of certain rubber products (mats, and the like) may provide improved antimicrobial, antifungal, etc., efficacy through a simple washing. In fact, such an increase may steadily improve with greater numbers of consistent washes such that a rubber article, as first vulcanized, may exhibit lower overall antibacterial and antifungal activity than one that has been washed one, two, three, and up to at least 20 times (in a standard industrial rotary washing machine). Such a surprising benefit may permit utilization of such rubber articles as floor coverings (mats, as one example, such as those with carpeted portions or those which are rubber alone; particularly foamed rubber mats for antifatigue properties and reduced specific gravity so as to reduce the chances of machinery damage during such industrial rotary launderings and dryings), and other articles which can be easily washed within standard laundry machines.

Furthermore, as alluded to above, friction with the subject rubber article surface can remove very slight layers of rubber from the article surface thereby permitting "fresh" silver-comprising crystallites at the surface to act as desired in their antibacterial and/or antifungal capacities. Basically, then, the inventive article produced from the inventive raw rubber formulation exhibits an even dispersion of antimicrobial particles throughout the entire rubber article. Such an even dispersion of the biocide throughout the rubber article thus provides a reservoir of fresh crystallites containing the biocidal metallic ion. As layers of the rubber are worn and abraded away, antimicrobial particles containing untapped silver ions become available.

The preferred resin cured rubber articles of this invention containing the antimicrobial agent can be processed into rubber articles which exhibit excellent antimicrobial qualities as well as antimicrobial efficiency throughout the rubber article's lifetime. Examples of other such rubber articles encompassed within this invention include, but are not limited to, hard rubber mats, static dissipative rubber mats, anti-fatigue rubber mats, rubber mats which include a face fiber, rubber link mats, rubber seals and gaskets, rubber medical goods, rubber gloves, rubber medical devices, rubber conveyor belts, rubber belts and rubber wheels used in food processing, rubber clothing, rubber shoes, rubber boots, rubber tubing, and rubber automotive fuel hoses. Such inventive formulations may also be incorporated into a multilayered rubber article in which the antimicrobial agent can be incorporated into any surface layer and still provide the desired antimicrobial efficiency.

Of particular interest is the formation of multilayered rubber articles wherein at least one of such rubber layers exhibits the desired antimicrobial activity and thus is made from an inventive non-silicone rubber-containing article. Such layered articles may be adhered together through co-vulcanization, gluing, and the like. Furthermore, layers of other types of materials may be placed between rubber layers as well to provide, as one non-limiting property, better structural stability to the desired multilayered article.

The non-limiting, preferred embodiments of these rubber formulations and articles are discussed in greater detail below.

Description of the Preferred EmbodimentsInventive Raw Rubber Formulations**(INVENTIVE) RUBBER BASE FORMULATION 1**

	<u>Component</u>	<u>Amount</u>
5	Polychloroprene Rubber (Neoprene WRT from Dupont)	100 parts
	FEF N550 Black (CABOT carbon black filler)	30 pphr
	Mistron Vapour (magnesium silicate filler from Luzanac)	30 pphr
	Di-isodecyl phthalate (DIDP) (plasticizer oil from AKM)	15 pphr
10	Aflux 54 (pentaerythritol tetrastearate process aid from Rhein-chemie)	2 pphr
	Zinc Oxide Active (available from Bayer)	5 pphr
	Stearic Acid (available from AKM)	1 pphr
	Antimicrobial (ALPHASAN® RC2000 from Milliken & Company)	2% by weight

15 (INVENTIVE) RUBBER BASE FORMULATION 2

	<u>Component</u>	<u>Amount</u>
	Natural Rubber (SMRCV60 from Simmington)	90 parts
	Neoprene W Rubber	10 parts
	SP 1045 (curing resin from Schenectady Chemicals)	10 pphr
20	Zinc Oxide Active	5 pphr
	Stearic Acid	1 pphr
	Antimicrobial (ALPHASAN® RC2000 from Milliken & Company)	2% by weight

(INVENTIVE) RUBBER BASE FORMULATION 3

	<u>Component</u>	<u>Amount</u>
25	EPDM Rubber (Dutral 4038 from Enichem)	90 parts
	Neoprene W Rubber	10 parts
	SP 1045	15 pphr
	Mistron Vapour	30 pphr
30	Zinc Oxide Active	5 pphr
	Stearic Acid	1 pphr
	Antimicrobial (ALPHASAN® RC2000 from Milliken & Company)	2% by weight

(INVENTIVE) RUBBER BASE FORMULATION 4

	<u>Component</u>	<u>Amount</u>
35	Nitrile Butadiene Rubber (Breon N36C80 from Zeon Chemicals)	90 parts
	Neoprene W Rubber	10 parts
	SP 1045	10 pphr
	Zinc Oxide Active	5 pphr
40	Stearic Acid	1 pphr
	Antimicrobial (ALPHASAN® RC2000 from Milliken & Company)	2% by weight

(INVENTIVE) RUBBER BASE FORMULATION 5

<u>Component</u>	<u>Amount</u>
Styrene Butadiene Rubber (SBR 1502 from Enichem)	90 parts
Neoprene W Rubber	10 parts
5 SP 1045	10 pphr
Zinc Oxide Active	5 pphr
Stearic Acid	1 pphr
Antimicrobial (ALPHASAN® RC2000 from Milliken & Company)	2% by weight

(INVENTIVE) RUBBER BASE FORMULATION 6

<u>Component</u>	<u>Amount</u>
Bromobutyl Rubber (Bromobutyl 2244 from Exxon)	100 parts
FEF N550 Black	50 pphr
SP 1045	10 pphr
15 Brisopar 300 (paraffinic oil)	7 pphr
Zinc Oxide Active	5 pphr
Stearic Acid	1 pphr
A/O 2246 (antioxidant)	1 pphr
Antimicrobial (ALPHASAN® RC2000 from Milliken & Company)	2% by weight

(INVENTIVE) RUBBER BASE FORMULATION 7

<u>Component</u>	<u>Amount</u>
Bromobutyl Rubber (Bromobutyl 2244 from Exxon)	90 parts
Chloroprene Rubber	10 parts
25 FEF N550 Black	20 pphr
Mistron Vapour	20 pphr
SP 1045	10 pphr
Zinc Oxide Active	5 pphr
Antimicrobial (ALPHASAN® RC2000 from Milliken & Company)	5% by weight

These inventive raw rubber formulations were created using ALPHASAN® RC2000 (available from Milliken & Company), a silver ion-exchange zirconium phosphate salt, exhibiting 10% Ag⁺ concentration and including Ag_xNa_yH_zZr₂(PO₄)₃, where x+y+z=1, as other components (% by weight).

The compounding of ingredients within each formulation can be carried out in an open mill, an internal mixer, or an extruder where intensive mixing within the polymer matrix of each component will take place. During the mixing operation, the control of temperature rise, due to high shear incorporation of the ingredients, is crucial to ensure that pre-vulcanization (scorch) does not take place during processing. Generally, a maximum

temperature of 120°C is reached on single stage (pass) mixing through an internal mixer. The compounds can be further processed after mixing into specific forms to allow adequate presentation for manufacturing into products. This could be calendaring, extrusion, granulation/pelletization, strip form, fabrication and preforming into specific shaped blanks.

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The vulcanization of the compounds can be in the form of molding (compression, transfer, injection), continuous extrusion (LCM, UHF[where permissible], autoclave and hot air), and coatings. The vulcanization (cure) temperatures can range from 150°C to 250°C. In this specific situation, the rubber articles were calendared into rough mat structures and then subjected to vulcanization under high temperature and pressure.

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Testing of Vulcanized Rubber Articles

The following Tables list the silver elution, antibacterial activity, and antifungal activity of these inventive and comparative samples.

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Table 1 illustrates silver-ion extraction (or, silver elution) results from the inventive rubber articles. The rubber articles were immersed in an aqueous salt extraction solution (sodium phosphate) for 24 hours; the extract was then analyzed by inductively coupled plasma measurements for a measurement of available silver removed from the article surface.

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EXPERIMENTAL TABLE 1

Available Surface Silver Ions of Inventive Rubber Articles

		Available Ag ⁺ ions (ppb/cm ²)
<u>Sample ID</u>	<u>Rubber ID</u>	
25 Rubber Formulation 1	Polychloroprene	0.103
Rubber Formulation 2	Natural rubber	0.001
Rubber Formulation 3	EPDM	0.128
Rubber Formulation 4	Nitrile butadiene	0.056
Rubber Formulation 5	Styrene butadiene	0.028
30 Rubber Formulation 6	Bromobutyl	0.329
Rubber Formulation 7	Bromobutyl	0.196 (after 20 washes)

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Thus, the inventive articles exhibited controlled release of silver ions. Accordingly, it is believed that the silver elution results shown above provide highly desirable long-term antimicrobial characteristics within the cured rubber article.

Antimicrobial efficacy was assessed using ATCC Test Method 6538 for *Staphylococcus aureus* and ATCC Test Method 4352 for *Klebsiella pneumoniae*. The antifungal tests followed were ISO 846 for *Aspergillus niger* in accordance with ATCC 6275. The internal control was created using a polypropylene plaque.

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EXPERIMENTAL TABLE 2

Antimicrobial Performance of Inventive Rubber Articles for Staphylococcus aureus and Klebsiella pneumoniae

	<u>Sample ID</u>	<u>Rubber ID</u>	log kill reduction vs. internal control	
			<u><i>S. aureus</i></u>	<u><i>K. pneumoniae</i></u>
10	Rubber Formulation 1	Polychloroprene	2.04	3.11
	Rubber Formulation 2	Natural rubber	0.06	-1.27
	Rubber Formulation 3	EPDM	2.89	3.11
	Rubber Formulation 4	Nitrile butadiene	2.89	1.92
15	Rubber Formulation 5	Styrene butadiene	1.97	0.47
	Rubber Formulation 6	Bromobutyl	3.07	3.11
	Maximum Log Kill		3.73	3.11

Thus, the inventive formulations provided inventive vulcanized rubber articles that exhibited improved antimicrobial activity over the same formulations without any antimicrobial compounds present. Specifically, the polychloroprene, EPDM, and bromobutyl articles reached maximum log kill reduction for *K. pneumoniae*.

Efficacy against fungi was assessed using ISO Method 846 against *Aspergillus niger* in accordance with ATCC 6275. Samples were placed on Mineral Salts Agar (MSA) and inoculated with 10 droplets (10ul each, 100ul total) of 10E5 fungal spores/ml in a synthetic nutrient medium followed by incubation for 35 days at 30°C and >90% relative humidity. Efficacy was measured by visual observation of the samples according to the following scale:

30	<u>Observed Growth in Applied Droplets</u>	<u>Category</u>
	Droplets have dark growth, many spores	A
	Droplets have light growth, few/no spores	B
	Droplets have no growth or scarce growth	C

The results in Table 3 show the number of droplets that match A, B, and C. For example, results such as (3,5,2) illustrate better antifungal performance than results such as (9,1,0).

EXPERIMENTAL TABLE 3*Antifungal Performance of Inventive Rubber Articles*

	<u>Example</u>	<u>Rubber ID</u>	<u>Fungal Growth After # Days</u>			
			<u>0</u>	<u>10</u>	<u>21</u>	<u>35</u>
5	Rubber Formulation 1	Polychloroprene	0,0,0	0,0,10	0,0,10	0,0,10
	Rubber Formulation 2	Natural rubber	0,0,0	10,0,0	10,0,0	10,0,0
	Rubber Formulation 3	EPDM	0,0,0	1,4,5	4,6,0	4,6,0
	Rubber Formulation 4	Nitrile butadiene	0,0,0	3,7,0	10,0,0	10,0,0
10	Rubber Formulation 5	Styrene butadiene	0,0,0	10,0,0	10,0,0	10,0,0
	Rubber Formulation 6	Bromobutyl	0,0,0	0,0,10	0,0,10	7,0,3

These results indicated that the inventive formulations were indeed effective at inhibiting fungal growth over the exposure period. The samples exhibited 60% inhibition of growth after 10 days, 43% inhibition of growth after 21 days, and 22% inhibition of growth after 35 days.

Having described the invention in detail, it is obvious that one skilled in the art will be able to make variations and modifications thereto without departing from the scope of the present invention. Accordingly, the scope of the present invention should be determined only by the claims appended hereto.

CLAIMS

1. A dimensionally stable resin cured rubber article comprising at least one silver-based antimicrobial compound, wherein said rubber article exhibits log kill rates in accordance with
5 ATCC Test Method 6538 for *Staphylococcus aureus* and ATCC Test Method 4352 for *Klebsiella pneumoniae* of at least 1.0 each after 24 hours exposure at room temperature, and wherein said article optionally comprises at least one silver ion release control additive and at least one antifungal additive other than said silver-based antimicrobial compound.
- 10 2. The rubber article of Claim 1 wherein said article exhibits log kill rates for *Staphylococcus aureus* and *Klebsiella pneumoniae* of at least 2.0 each after 24 hours exposure at room temperature.
3. The rubber article of Claim 1 wherein said rubber article is comprised of a
15 majority of rubber selected from the group consisting of nitrile rubber, nitrile butadiene rubber (NBR), styrene butadiene rubber, natural rubber, chloroprene rubber, polychloroprene rubber, ethylene propylene rubber, ethylene propylene diene monomer rubber, fluoroelastomer rubber, polyurethane rubber, butyl rubber, halogenated butyl rubber, isoprene rubber, epichlorohydrin rubber, polyacrylate rubber, chlorinated polyethylene rubber,
20 hydrogenated NBR, carboxylated NBR, polybutadiene rubber, and any mixture thereof.
4. The rubber article of Claim 1 wherein said silver-based antimicrobial compound is selected from the group consisting of elemental silver, silver oxides, silver salts, silver ion exchange compounds, silver zeolites, silver glasses, and any mixtures thereof.
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5. The rubber article of Claim 2 wherein said silver-based antimicrobial compound is selected from the group consisting of elemental silver, silver oxides, silver salts, silver ion exchange compounds, silver zeolites, silver glasses, and any mixtures thereof.
- 30 6. The rubber article of Claim 1 wherein said at least one silver ion control release additive is present.

7. The rubber article of Claim 1 wherein said antifungal additive other than said silver-based antimicrobial compound is present.

8. The rubber article of Claim 6 wherein said at least one silver ion control release additive is selected from the group consisting of fillers, oils, pigments, salts, antistatic agents, and any mixtures thereof.

9. The rubber article of Claim 8 wherein said at least one silver ion control release additive is a hydrophilic filler selected from the group consisting of silica, stearates, and any mixtures thereof.

10. The rubber article of Claim 8 further comprising at least one hydrophilic oil selected from the group consisting of paraffinic oil, phthalate oil, and any mixtures thereof.

11. The rubber article of Claim 3 wherein said rubber article is comprised of butyl rubber.

12. The rubber article of Claim 3 wherein said rubber article is comprised of halogenated butyl rubber.

13. A dimensionally stable resin cured rubber-containing article comprising at least one silver-based antimicrobial agent, wherein said article exhibits antifungal properties such that said article exhibits at least 60% inhibition in accordance with Test Method ISO 846 of *Aspergillus niger* ATCC 6275 for at least 10 days at 30°C and at greater than 90% humidity, and wherein said article optionally comprises at least one silver ion release control additive and at least one antifungal additive other than said silver-based antimicrobial compound.

14. The rubber article of Claim 13 wherein said silver-based antimicrobial compound is selected from the group consisting of elemental silver, silver oxides, silver salts, silver ion exchange compounds, silver zeolites, silver glasses, and any mixtures thereof.

15. The rubber article of Claim 13 wherein said at least one silver ion control release additive is present.

16. The rubber article of Claim 13 wherein said antifungal additive other than said silver-based antimicrobial compound is present.

17. The rubber article of Claim 13 wherein said at least one silver ion control release additive is selected from the group consisting of fillers, oils, pigments, salts, antistatic agents, and any mixtures thereof.

18. The rubber article of Claim 17 wherein said at least one silver ion control release additive is a hydrophilic filler selected from the group consisting of silica, stearates, and any mixtures thereof.

19. The rubber article of Claim 17 further comprising at least one hydrophilic oil selected from the group consisting of paraffinic oil, phthalate oil, and any mixtures thereof.

20. The rubber article of Claim 1 wherein said article is a mat structure.

21. The rubber article of Claim 13 wherein said article is a mat structure.

22. A pre-vulcanized rubber formulation comprising at least one rubber constituent, the majority of which must be a non-silicone rubber, at least one silver-based antimicrobial compound and at least one resin curing compound, wherein all of said resin curing compound present within said formulation does not include an appreciable amount of sulfur-based compounds, and wherein said rubber formulation optionally comprises at least one blowing agent, at least one silver ion release control additive, and at least one antifungal additive other than said silver-based antimicrobial compound.

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23. The rubber formulation of Claim 22 wherein said rubber constituent is selected from the group consisting of nitrile rubber, nitrile butadiene rubber, styrene butadiene rubber, natural rubber, chloroprene rubber, polychloroprene rubber, ethylene propylene rubber, ethylene propylene diene monomer rubber, fluoroelastomer rubber, polyurethane rubber, butyl rubber, halogenated butyl rubber, chlorobutyl rubber, bromobutyl rubber, isoprene rubber, epichlorohydrin rubber, polyacrylate rubber, chlorinated polyethylene rubber, hydrogenated NBR, carboxylated NBR, polybutadiene rubber, and any mixture thereof.

24. The rubber formulation of Claim 22 wherein said silver-based antimicrobial compound is selected from the group consisting of elemental silver, silver oxides, silver salts, silver ion exchange compounds, silver zeolites, silver glasses, and any mixtures thereof.

25. The rubber formulation of Claim 22 wherein said at least one blowing agent is present.

26. The rubber formulation of Claim 22 wherein said at least one silver ion control release additive is present.

27. The rubber formulation of Claim 22 wherein said antifungal additive other than said silver-based antimicrobial compound is present.

28. The rubber formulation of Claim 26 wherein said at least one silver ion control release additive is selected from the group consisting of fillers, oils, pigments, salts, antistatic agents, and any mixtures thereof.

29. The rubber formulation of Claim 28 wherein said at least one silver ion control release additive is a hydrophilic filler selected from the group consisting of silica, stearates, and any mixtures thereof.

30. The rubber formulation of Claim 28 further comprising at least one oil selected from the group consisting of paraffinic oil, phthalate oil, and any mixtures thereof.

31. The rubber formulation of Claim 23 wherein said rubber constituent is
5 polychloroprene rubber.

32. The rubber formulation of Claim 23 wherein said rubber constituent is natural rubber.

33. The rubber formulation of Claim 23 wherein said rubber constituent is ethylene
10 propylene diene monomer rubber.

34. The rubber formulation of Claim 23 wherein said rubber constituent is nitrile rubber.

35. The rubber formulation of Claim 23 wherein said rubber constituent is styrene
15 butadiene rubber.

36. The rubber formulation of Claim 23 wherein said rubber constituent is butyl rubber.

37. The rubber formulation of Claim 23 wherein said rubber constituent is bromobutyl
20 rubber.

38. A method of producing a rubber article exhibiting long-lasting, regenerable
antimicrobial characteristics, comprising the steps of compounding together the unvulcanized
rubber formulation of Claim 22, molding said rubber formulation into a preselected shape,
25 and vulcanizing said rubber formulation under high pressure and exposure to high
temperature.

39. A method of producing a rubber article exhibiting long-lasting, regenerable
antimicrobial characteristics, comprising the steps of compounding together the unvulcanized
30 rubber formulation of Claim 23, molding said rubber formulation into a preselected shape,

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and vulcanizing said rubber formulation under high pressure and exposure to high temperature.

40. A method of producing a rubber article exhibiting long-lasting, regenerable antimicrobial characteristics, comprising the steps of compounding together the unvulcanized rubber formulation of Claim 25, molding said rubber formulation into a preselected shape, and vulcanizing said rubber formulation under high pressure and exposure to high temperature.

41. A method of producing a rubber article exhibiting long-lasting, regenerable antimicrobial characteristics, comprising the steps of compounding together the unvulcanized rubber formulation of Claim 26, molding said rubber formulation into a preselected shape, and vulcanizing said rubber formulation under high pressure and exposure to high temperature.

42. A method of producing a rubber article exhibiting long-lasting, regenerable antimicrobial characteristics, comprising the steps of compounding together the unvulcanized rubber formulation of Claim 27, molding said rubber formulation into a preselected shape, and vulcanizing said rubber formulation under high pressure and exposure to high temperature.

43. A rubber composition comprising at least one rubber component, at least one resin curing agent, and at least one silver-based antimicrobial agent, and optionally comprising at least one blowing agent, at least one silver ion release control additive, and at least one antifungal additive other than said silver-based antimicrobial compound.