

SYSTEM AND PROCESS FOR PRODUCING A FLAME-RESISTANT MATERIAL**Field of the Invention**

The invention relates to a system and process for producing a flame-resistant material. The invention also relates to a wool material with flame-retardant properties that is produced by the system and process of the invention. The material may be an acoustic element, such as an acoustic tile or panel that comprises flame-retardant properties. The acoustic element may be used in any interior location where sound reverberation time is to be reduced, such as on walls or ceilings for example. The material may otherwise be a wool batting or felt and may be provided in or on an upholstered seat (such as a car seat, aircraft seat, boat seat, wheelchair, for example) an armchair, sofa, mattress, or other soft furnishing.

Background of the Invention

Excessive exposure to noise energy is harmful for human health. One such type of excessive noise may be caused by a long reverberation time in interior spaces. One solution to reduce the reverberation time is the use of acoustic absorption panels, which may sometimes take the form of acoustic tiles. Acoustic panels and tiles are commonly used to dissipate sound, such as in classrooms, restaurants, offices and other workplaces. Acoustic panels and tiles come in many different shapes and may be made from polyester, such as polyethylene terephthalate (PET), which is a thermoplastic polymer resin. However, the use of PET acoustic panels and tiles includes the disadvantage that PET contributes to plastic waste, leading to environmental pollution.

It has been found that wool panels and tiles have acoustic absorption characteristics similar to those of PET panels and tiles and can also mediate the interior environment of a room by its unique and inherent ability to regulate temperature and humidity, while also filtering the air and removing volatile organic compounds (VOC). As a natural, renewable fibre that can be produced sustainably and that has the ability to decompose over time, wool may also be considered to be an environmentally friendly product.

However, building regulations require acoustic panels and tiles to meet fire safety regulations also. On its own, wool does not meet the current fire safety regulations and so pure wool is not suitable for acoustic panels or tiles in a commercial setting in New Zealand and countries with the same or similar fire safety regulations.

Therefore, there is a need to provide an environmentally friendly, and effective acoustic panel or tile that also satisfies fire safety regulations.

There is also a need to provide a batting with flame-retardant properties to be used in soft furnishings, or to provide a soft furnishing that includes such a flame-retardant fabric. For example,

the risk of lethal fire may be reduced by providing mattresses and upholstered seating (for example) with a fabric having flame-retardant properties.

In addition, there is a need to provide a system and process to produce a flame-resistant wool material that may be used, for example, in an acoustic panel or as wool batting.

It is therefore an object of the invention to: (a) provide a flame-resistant wool material that may be used, for example in an acoustic element or as wool batting to go at least some way towards overcoming the disadvantages of known acoustic tiles and panels, or that goes at least some way towards overcoming the disadvantages of known materials used in soft furnishings;

(c) provide a system and process for applying a flame-retardant to wool material via spray application; or

(d) at least provide the public with a useful alternative to existing acoustic elements, wool material, or systems and processes for applying a flame-retardant to a wool material.

Summary of the Invention

In a first aspect, the invention provides a flame-resistant material comprising wool fibres onto which a flame-retardant fluid has been applied to at least one surface of the material, wherein the flame-retardant fluid comprises water and diammonium phosphate, at a concentration of between about 25% and about 50% to about 75% and about 50% water to give a dry weight covering of the material of about 10% to about 15% diammonium phosphate, and a wetting agent at a concentration of about 1% to about 5% by volume, and wherein the material has a density of between about 140kg/m³ and about 250kg/m³.

In some forms, the material comprises both wool fibres and low-melt bond fibres.

Preferably, the wetting agent comprises a surfactant.

Preferably, the flame-retardant fluid forms a coating on the surface of the material to which it has been applied.

In a second aspect, the invention provides an acoustic element formed from the flame-resistant material of the first aspect of the invention. The acoustic element may form a substantially flat panel or a three-dimensional tile.

In a third aspect, the invention provides a system for producing a flame-resistant material according to claim 1 from a web of needled wool fibres, the system comprising: a spray system comprising a sprayer comprising one or more spray nozzles in fluid communication with a fluid reservoir via at least one fluid conduit, wherein the fluid reservoir is configured to contain a flame-retardant fluid comprising water, diammonium phosphate and a wetting agent, wherein the flame-retardant fluid comprises water and diammonium phosphate, at a concentration of between about 25% and about 50% to about 75% and about 50% water to give a dry weight covering of the material

of about 10% to about 15% diammonium phosphate, and where the wetting agent is provided at a concentration of about 1% to about 5% by volume, and wherein the nozzles are arranged to spray the flame-retardant fluid onto a surface of the web; a drying system comprising a heat source to heat the web; and a finishing stage in which the web is prepared for delivery.

In some forms, the spray system comprises a bulk holding tank for containing the flame-retardant fluid and a pumping system to draw the flame-retardant fluid from the bulk holding tank to the fluid reservoir via a bulk fluid conduit, and wherein the fluid reservoir comprises an automatic fill system comprising one or more sensors that monitor a fluid level within the reservoir and that signal a control system to pump more fluid from the bulk holding tank to the fluid reservoir when the fluid level in the fluid reservoir falls below a first predetermined level, and to signal the control system to stop pumping fluid from the bulk holding tank to the fluid reservoir when the fluid level in the fluid reservoir reaches a second predetermined level, and wherein the volume of fluid in the fluid reservoir at the first fluid level is less than the volume of fluid in the fluid reservoir at the second fluid level.

In some forms, the system also comprises a metal detection system prior to the finishing stage. Preferably, the metal detection system is located after the drying system and prior to the finishing stage.

In some forms, the heat source comprises a heated roller and the drying system further comprises a pair of first and second pressure rollers to press the web around and against at least a portion of a circumferential surface of the heated roller.

In a fourth aspect, the invention provides a method of producing a flame-resistant material from a web comprising needled wool fibres and having a density of between about 140kg/m³ and about 250kg/m³, the method comprising the steps of: spraying at least one surface of the needled wool web with a flame-retardant fluid, wherein the flame-retardant fluid comprises water and diammonium phosphate, at a concentration of between about 25% and about 50% to about 75% and about 50% water to give a dry weight covering of the material of about 10% to about 15% diammonium phosphate, and where the wetting agent is provided at a concentration of about 1% to about 5% by volume, and a wetting agent at a concentration of about 1% to about 5% by volume; and drying the web.

Preferably, the flame-retardant fluid is sprayed onto the web at a pressure of between about 2 bar and about 6 bar.

Also disclosed herein is an acoustic element formed of a material comprising wool fibres and to which a flame-retardant solution containing water and diammonium phosphate, at a concentration of between about 25% and about 50%, has been applied to at least one surface of the acoustic element, to give a dry weight covering of 10% and 15%, the at least one surface being the largest of

all surfaces of the acoustic element, and wherein the at least one surface has a density of between about 140kg/m³ and about 250kg/m³.

Optionally, the material of the acoustic element comprises both wool fibres and low-melt bond fibres.

Optionally, the flame-retardant solution further comprises a wetting agent at a concentration of about 1% to about 5% by volume.

In some forms, the diammonium phosphate forms a coating on the surface to which it has been applied.

Preferably, the acoustic element is a substantially flat wool panel or tile.

Also disclosed herein is a method of producing an acoustic element with flame-retardant properties, the method comprising the steps of:

arranging layers of wool fibres and then needling the wool fibres to produce a substantially flat substrate having a density of between about 140kg/m³ and about 250kg/m³; and

spray coating at least one surface of the needled wool substrate with a flame-retardant solution of water and diammonium phosphate at a concentration of between about 25% and about 50% by weight.

In some forms, the wool fibres and low melt-bond fibres are arranged in layers and then needled to a desired density of between about 140kg/m³ and about 25kg/m³ to produce a substantially flat substrate.

Optionally, a wetting agent is added to the flame-retardant solution at a concentration of between about 1% and about 5% by volume.

In some forms, the flame-retardant solution is sprayed onto the substrate at a pressure of between about 2 bar and about 6 bar.

Also disclosed herein is a wool batting comprising wool fibres to which a flame-retardant solution containing water and diammonium phosphate, at a concentration of between about 10% and about 15% dry weight, has been applied to at least one surface of the wool batting.

Optionally, the wool batting comprises both wool fibres and low-melt bond fibres.

In some forms, the flame-retardant fluid further comprises a wetting agent at a concentration of about 1% to about 5% by volume.

In general, the acoustic element of the invention, such as a panel or tile, comprises wool or a wool blend and a flame-retardant, and is configured to achieve Group 1 or 2 performance under cone calorimeter testing.

In some forms, the diammonium phosphate is applied to the wool at a concentration of about 5% to about 15% dry weight.

Preferably, the diammonium phosphate forms a coating on the surface of the wool fibre which it has been applied.

In some forms, the acoustic element is a substantially flat wool tile or panel.

Unless the context clearly requires otherwise, throughout the description and the claims, the words “comprise”, “comprising”, and the like, are to be construed in an inclusive sense as opposed to an exclusive or exhaustive sense, that is to say, in the sense of “including, but not limited to”.

The word “acoustic element”, as used within this specification, includes “acoustic tile” and “acoustic panel”. A “panel” may differ from a “tile” in terms of size, such that a panel is typically larger than a tile, but the acoustic and flame-retardant features of a panel of the invention are the same as those of an acoustic tile of the invention.

Reference to any prior art in this specification is not, and should not be taken as, an acknowledgement or any form of suggestion that that prior art forms part of the common general knowledge in the field of endeavour in any country in the world.

The invention consists in the foregoing and also envisages constructions of which the following gives examples only.

Brief Description of the Drawings

Preferred forms of the invention will now be described by way of example and with reference to the accompanying drawings, in which:

Figure 1 is an isometric view of one form of substantially flat, acoustic panel comprising flame-resistant material according to the present invention;

Figure 2 is an isometric view of one form of three-dimensionally shaped acoustic tile comprising flame-resistant material according to the present invention;

Figure 2a is yet another form of three-dimensionally shaped acoustic tile comprising flame-resistant material according to the present invention;

Figure 3 is a schematic side view of an acoustic tile of the invention located on a supporting surface, such as a ceiling or wall;

Figures 4a to 4c show different forms and configurations of mounting elements to attach an acoustic element to a support surface, such as a wall or ceiling;

Figure 5 is a flow chart of one form of process for producing a flame-resistant material of the invention;

Figure 6 is a schematic image and partial cut-away view of one form of system for producing a flame-resistant material, such that the material may be used in an acoustic element or as wool batting;

Figure 6a shows a web moving through the system of Figure 6;

Figure 7 is an isometric view of one form of feed section for unwinding a raw material comprising a matrix of layered wool fibres such that the matrix may be fed into the flame-resistant material production system of the invention;

Figure 8 is an isometric view of one form of fluid reservoir and pumping system that may be used with a sprayer of the production system;

Figure 9a is an isometric view and partial cut-away view of one form of sprayer that may be used with the production system of the invention;

Figure 9b is a side view and partial cut-away view of the sprayer of Figure 9a;

Figure 10 is a schematic front view of one form of spray bar with a plurality of spray nozzles for use in a sprayer of the production system;

Figure 11 is a schematic isometric view of the spray bar of Figure 10 that is connected to a programmable control system and that is spraying flame-retardant fluid onto a web passing beneath the spray bar;

Figure 12a is an isometric and partial cut-away view of one form of drying system comprising a heater and dryer that may be used with the production system of the invention;

Figure 12b is an end view and partial cut-away view of the heater and dryer of Figure 12a;

Figure 13 is an isometric view from above of a pair of extraction hoods that may be located over the drying system of the production system to extract moisture from the web;

Figure 14 is an isometric view of one form of metal detection system that may be used with the production system, at any stage after the needling system and before the finishing stage; and

Figure 15 is an isometric view of one form of finishing stage that may be used with the production system of the invention, the finishing stage comprising a take-up roller resting on and being rotated by a pair of driven rollers; and

Figure 16 is a schematic side view of one form of mattress using the flame-resistant material of the invention.

Detailed Description of the Invention

The invention is further described with reference to the following examples. It will be appreciated that the invention as claimed is not intended to be limited in any way by these examples.

Experimental tests have shown that wool fibre provides sound absorption properties. Such properties may make the wool fibre suitable for use in acoustic elements. Acoustic elements comprise panels, tiles, or other elements that are configured to be attached to ceilings and/or walls of a room, or other support surface 200 to help dampen noise within the room or immediate area. However, tests have also shown that the use of pure wool fibre is not suitable for use as an acoustic element in a commercial environment in New Zealand at least because tests have shown that pure wool fibre

does not satisfy New Zealand's current fire safety requirements for ceiling and wall linings in commercial premises.

Therefore, the present invention has been developed to provide a flame-resistant wool material 1500 comprising flame-resistant properties that allow the material to be used in various products, such in a flame-resistant acoustic element for attachment to walls and ceilings in commercial spaces, or as wool batting in soft furnishings.

Tests have shown that the flame-resistant wool material 1500 of the invention maintains the acoustic performance, the moisture wicking and filtering properties, and the compostability at end-of-life of pure wool, and also provides the necessary flame-retardant properties required for an acoustic element that is suitable for use in a commercial setting. In some forms, the flame-resistant material of the invention may also have the necessary stiffness to be shaped and formed into a three-dimensional acoustic element, such as a three-dimensional acoustic tile, whereas pure wool material has been found to lack sufficient structure to hold a three-dimensional shape over time.

The flame-resistant wool material of the invention comprises wool fibre to which a flame-retardant fluid has been applied. The flame-retardant fluid comprises a mixture of water and diammonium phosphate (DAP) and may also comprise a wetting agent. The flame-resistant wool material is produced using a system and process of the invention to comply with the flame-resistant performance requirements of the current New Zealand fire safety regulations. The flame-resistant wool material may be formed into an acoustic element (such as an acoustic panel or tile) that provides acoustic absorption properties, or the flame-resistant wool material may form wool batting for use in soft furniture, such as couches, arm chairs, and mattresses for example. The flame-resistant wool material may also be put to other uses, as will be appreciated by a person skilled in the art.

Figures 1 to 3 show some forms of acoustic elements 100 comprising flame-resistant wool material of the invention.

Each of the acoustic elements 100 are configured to absorb noise in a space, such as in a room of a building, such as a commercial building. For example, an acoustic element 100 may be used in a commercial building comprising a classroom, a restaurant, an office, a factory, a retail store, or any other space that requires noise control. In some forms, the acoustic element 100 comprises a substantially flat wool panel. For example, Figure 1 shows an acoustic element 100 comprising a central portion 110 that is substantially planar/ flat, with shallow side walls forming the edges of the element. The acoustic element of Figure 1 therefore forms a substantially flat acoustic panel. Such an acoustic element 100 may consist of a sheet of flame-resistant material 1500 of the invention that has been cut to a desired size and shape.

In other forms, the acoustic element 100 comprises a three-dimensionally formed wool tile, as shown in Figures 2 and 2a. An acoustic element 100 comprising a three-dimensional tile may

comprise a non-flat, shaped central portion 110 and side walls 120 surrounding the central portion. Optionally, flanges 125 may surround the side walls 120. The central portion 110 of the acoustic element 100 has a front surface, and a rear surface and may be shaped to provide a three-dimensional structure, as exemplified in Figures 2 and 2a, where a star-like structure is exemplified.

In embodiments where the three-dimensional acoustic element 100 comprises flanges 125, the flanges may comprise a rear surface. The rear surfaces of the flanges 125 together provide a rear contact surface for the acoustic element 100. The rear contact surface may contact a support surface 200, such as a wall or ceiling, when the element 100 is installed, and the flanges may be used to attach the acoustic element to the support surface 200.

The acoustic element 100 of the invention (whether planar or three-dimensional) is attachable to a support surface 200, such as a ceiling or wall, by any suitable means of attachment. The acoustic element 100 may be removably attached to the support surface 200 or fixedly attached to the support surface.

For example, where the acoustic element comprises flanges at its sides, an attachment system may engage with one or more of the flanges to attach the acoustic element 100 to the support surface 200. For example, fasteners such as pins, screws, staples, or the like, may be pushed through the flanges to attach the acoustic element 100 to the support surface 200, or an adhesive fastener may be applied to the rear of the flanges, or the flanges may engage with fasteners comprising clips to attach the acoustic element 100 to the support surface 200.

Where the three-dimensional acoustic element 100 does not comprise flanges, as shown in Figures 1, 2, and 3, rear edges of the side walls 120 form a rear contact surface of the element 100 that may contact the support surface 200 when the acoustic element 100 is installed, as shown in Figure 3.

In some forms, rear edges or side edges of the acoustic element may be attachable to a mounting element 300 that is attached or attachable to a support surface 200, such as to a ceiling or wall. The mounting element may be attached to the support surface 200 by any suitable means, such as by fasteners (screws, nails, or the like), adhesive, or any other suitable form of attachment. In some forms, the mounting element 300 may comprise a body portion and may be adapted to receive a corner or an edge of at least one acoustic element 100 within an opening 310 (such as an aperture or recess) formed between two opposing walls 320 of the body portion to attach the acoustic element 100 to the support surface. In some forms, as shown in Figures 4a to 4c, the mounting element 300 comprises a clip mechanism that is secured to the support surface 200 and to which the acoustic element 100 may be removably attached. In some forms, as shown in Figures 4a to 4c, the mounting element 300 may comprise a modular arrangement of clips and may be configurable so that each clip receives a corner of one acoustic element. The modular nature of the mounting element 300 means

that two clips may be attached together to form the mounting element in order to receive a respective corner of two acoustic elements, or the mounting element may comprise three clips to receive corners of three acoustic elements, or the mounting element may comprise four clips to receive corners of four acoustic elements (as shown in Figure 4c). In some forms (as shown in Figure 4b), the mounting element 300 may be configured to receive an edge, such as a rear edge or a side edge, of at least one acoustic element 100 within an opening 310 formed between two opposing side walls 320 of the body portion of the mounting element 300.

Returning to the exemplifications shown in Figures 2, 2a, and 3, the side walls 120 of the three-dimensional acoustic element extend from the central portion 110 toward the rear of the acoustic element 100. A cavity is defined by the central portion 110 and the side walls 120. In some forms, the cavity allows the central portion 110 to move and vibrate and may increase sound absorption performance.

In some forms, the wool content of the acoustic element 100 provides the acoustic element with moisture-wicking, air filtering, and sound absorption properties.

In some forms, the three-dimensional acoustic element 100 of the invention may comprise non-woven wool material and may be formed into an acoustic tile of a desired shape by needle-punching or felting pure wool, or a wool blend, using any suitable known needle-punching or felting process. In some forms, the acoustic element 100 may be manufactured from carded wool, which is then needle-punched or felted and formed into the desired shape. A flame-retardant fluid comprising water, DAP, and optionally also a wetting agent, may then be sprayed onto the shaped tile.

However, in preferred forms, the acoustic element 100 is formed from a flame-resistant wool material or a wool blend that has been needle punched to form a needled web onto which a flame-retardant fluid is applied according to the process of the invention. The resulting flame-resistant material may then be formed into an acoustic element by cutting the material to the desired size for use as an acoustic panel, or the flame-resistant material may be shaped to form a three-dimensional acoustic tile.

In some forms, the acoustic element 100 may comprise wool and a (preferably biodegradable) low-melt bond fibre, such as polylactic acid, to enhance the stiffness of the acoustic element. Polylactic acid is derived from corn starch and is biodegradable. In other forms, polyester low-melt bond fibre may be used, although the resulting product will be non-compostable at its end-of-life. Preferred forms of low-melt bond fibre are configured to melt at between about 150°C to about 250°C, optionally between about 170°C to about 230°C, and preferably at around 200°C.

Using a combination of wool and a low-melt bond fibre helps the shape of three-dimensional acoustic tiles to be formed and retained. Preferably, the percentage of low melt fibre used is between about 40 – 50% of the total weight of the acoustic element 100.

In some forms, to manufacture an acoustic element 100 having a three-dimensional form, a sheet of flame-resistant material of the invention is cut to a desired size and shape, and may then be heated, such as by heating the material in an oven (preferably an infrared oven), to between about 130°C to about 250°C. The heated material is then pressed between male and female moulds to form the desired form, shape, and/or the final desired thickness of the three-dimensional acoustic element 100. The acoustic element 100 is then cooled, and any undesirable edges are trimmed off to obtain the desired size of panel or tile.

Where the acoustic element comprises wool and low-melt bond fibres, the step of heating melts the low-melt bond fibres, which then adhere to the wool. The acoustic element is pressed into shape whilst the low-melt bond fibres are in the melted state. As the low-melt bond fibres cool, these fibres adopt the new shape of the acoustic element and provide a matrix to hold the wool fibres of the acoustic element in the desired shape also.

In other forms of manufacturing a three-dimensional acoustic element, adhesive may be applied to the rear surface of the flame-resistant material, which has been cut to a desired size and shape. The material is then positioned over a secondary material that is pre-formed into the desired shape of the three-dimensional acoustic element. The adhesive causes the blank to attach to the secondary material and to adopt the shape of the secondary material to achieve a three-dimensional acoustic element. In some forms, the secondary material may comprise a perforated or non-perforated metal, such as aluminium or steel, or the secondary material may comprise a perforated or non-perforated polymer, such as polypropylene. The secondary material may be rigid or semi-rigid, in which the material has sufficient rigidity to hold its shape, but may be flexible enough to assist with removing the acoustic element from the secondary material after the acoustic element has been made into the desired form.

In some forms, the flame-resistant wool material of the invention is produced to have a thickness of between about 8mm – 24mm, and preferably about 9mm, and that has a weight of about 1000 – 4000gsm for use in an acoustic element. However, in other forms, the material may have a thickness of greater than 24mm and a weight of greater than 4000gsm. Where a two-dimensional acoustic element is formed from the material, such as an acoustic panel, the panel will have the same thickness and weight (density) as the flame-resistant wool material from which it is made. However, the thickness of a three-dimensional acoustic element may vary across the three-dimensional element as a result of the acoustic element being made into a three-dimensional form. For example, in some forms, a three-dimensional acoustic element 100 of the invention may have a thickness of about 5mm to about 10mm (after being pressed) at the central portion 110 of the element 100 and a weight of about 1000 to about 2000gsm. In some forms, the overall depth of the three-dimensional acoustic

element is between about 24mm to about 50mm from the front surface to the rear surface of the acoustic element.

In some forms, the three-dimensional acoustic element 100 may comprise folded edges or side walls, which provide an airgap between the acoustic element 100 and the wall or ceiling.

In some forms, the acoustic element 100 of the invention (whether the element is substantially flat or three-dimensional) may comprise an additive to modify the colour, texture or stiffness of the acoustic element. Optionally, the acoustic element 100 may be coloured to a desired colour or a coloured pattern, such as by using a dyed wool that is then manufactured using the system and process of the invention. In another form, colour may be applied to the flame-resistant material of the acoustic element after the material has been produced or after the acoustic element has been cut or formed to the desired size and shape. The colour may be applied using any suitable technique, such as by spraying the colour onto the acoustic element with an ink-jet apparatus.

In some forms, the acoustic element 100 is flexible to wrap around curves, but sufficiently resilient to support itself.

The acoustic element 100 may comprise different types of face finish. For example, the front surface of an acoustic element of the invention may be rolled to provide the front surface with a flat finish.

The acoustic element 100 is preferably porous for acoustic benefit.

In some forms, the acoustic element 100 comprises only bio-degradable material so that at the end of its life, the acoustic element 100 may be biodegradable and compostable.

The flame-resistant material of the invention may also be suitable for use as a batting in soft furnishings, such as mattresses 2000 (as shown in Figure 16), sofas, armchairs, and seats used in vehicles, such as cars and trucks, or on other forms of transport, such as trains, boats, and aeroplanes.

For example, flame-resistant wool material 1500 of the invention comprises a surface layer of flame-retardant fluid comprising water, DAP at a concentration of at least 25% by weight and applied to the material to provide a dry application weight of between about 10% and about 20% or between about 10% and about 15%), and optionally also comprising a wetting agent. The flame-retardant fluid is sprayed onto a web comprising needled wool fibres using the system and process of the invention, as described herein.

The flame-resistant wool material 1500 of the invention has been shown, through tests, to perform within at least Group 2, and preferably within Group 1, of a cone calorimeter test, in order to meet fire safety regulations for products used within commercial interiors, such as the current regulations in New Zealand.

A cone calorimeter test is a widely used small-scale test that can be used to determine the heat release rate (HRR) of building products and other materials. The cone calorimeter test is based

on the principle that the amount of heat released from a burning sample material is directly related to the amount of oxygen consumed during combustion of the sample material. The amount of heat a material generates is directly aligned with the severity of a fire, such as the fire growth rate.

From <https://www.sciencedirect.com/topics/chemistry/cone-calorimetry>: *Cone calorimetry is used to measure the decreasing oxygen concentration in the combustion gases of a sample subjected to a given heat flux. During testing, the sample is placed on a load cell to evaluate the mass loss over time. A conical radiant electrical heater uniformly irradiates the sample from above and combustion is triggered by an electric spark. Combustion gases produced pass through the conical heater and are captured by a ducting system where the gas flow, oxygen, CO, CO₂ concentrations and smoke density are measured.*

The measurements of gas flow and oxygen concentration are used to calculate the quantity of heat release per unit of time and surface area: heat release rate (HRR) is expressed in kW/m². The evolution of the HRR over time, in particular the value of its peak/maximum (pHRR or HRR_{max}), is usually taken into account to evaluate the flame-retardant properties of the sample. The integration of the HRR vs. time curve gives the total heat release (TRR) expressed in kJ/m².

Cone calorimetry testing also enables characterisation of the time to ignition (TTI), time of combustion or extinction (TOF), mass loss during combustion (MLR), quantities of CO and CO₂, and total smoke released (TSR).

The cone calorimeter test therefore provides various flammability parameters, including heat release rate (HRR), total heat release (THR), time to ignition (TTI), mass loss rate (MLR), total smoke release (TSR), and effective heat of combustion (EHC).

The cone calorimeter test (ISO 5660-1) for interior linings (such as acoustic panels) in New Zealand classifies sample materials according to the Building Code of Australia (BCA) groups, which are as follows:

- Group 1: no flashover within 20 minutes
- Group 2: flashover between 10 and 20 minutes
- Group 3: flashover between 2 and 10 minutes
- Group 4: flashover within 2 minutes.

The group number is a numeric representation of the performance of a material tested using a cone calorimeter and is a standardised benchmark for assessing the flammability of a material.

To meet New Zealand's current fire safety requirements for nearly unrestricted use in commercial interiors, for example, an acoustic element, such as an acoustic tile or panel, should at least perform at a Group 2 level. For unrestricted use in commercial interiors, the acoustic tile or panel must perform at a Group 1 level. Acoustic elements in Group 3 can be used in commercial

interiors, but there are strict limitations around wall coverage and location placement of those elements.

In some forms, the present invention provides a flame-resistant wool material, for use in an acoustic element or a wool batting, that performs at Group 2 level and may, in some forms, perform at Group 1 level.

The present invention also provides a system and process for producing the flame-resistant wool material of the invention. Figure 5 illustrates one form of process for producing a flame-resistant wool material, and Figures 6 to 15 illustrate some forms of production system and system components for producing a flame-resistant wool material.

Referring to Figures 5 and 6, initially, wool fibres or a wool blend that combines wool fibres with another material, such as a synthetic material (for example, wool fibres may be blended with low-melt bond fibres) or a natural material, are arranged in layers and are optionally woven together. The resulting material may comprise a loose web of layered or woven fibres. In some forms, the production system of the invention may comprise a web-forming section in which the loose fibres are layered or woven into a loose fibre web. In other forms, one or more lengths of a loose fibre web may be obtained from a separate production system and then fed into the production system of the invention.

As shown in Figures 5, in some forms, the production process of the invention comprises a needling system to produce a dense wool web. The needling system comprises a plurality of reciprocating needles that are punched into, and removed from, the loose fibre web to increase the interconnectivity of the fibres and produce a substantially flat wool web having a desired thickness and density. The process of needle punching is commonly referred to as the process of 'needling' and the resulting web may be referred to as being a 'needled' web.

The needling process may be carried out as part of the production system of the invention, or one or more lengths of needled wool web may be obtained from a separate production system and then fed into the production system of the invention to produce a flame-resistant wool material.

The density of the flame-resistant material of the invention affects the flame-resistant performance of the material. The less dense the fibres of the material, the lower the flame-resistant performance of the material. In preferred forms, the needling system is configured to produce a needled wool web having a density of about 1400gsm and a thickness of about 8 mm to about 10mm (about 140kg/m³ to about 175kg/m³). However, it is envisaged that, in other forms, the needled wool web may have a density of between about 140kg/m³ and about 250kg/m³. It is preferable that the density of the web is substantially consistent across its length and width.

The needled wool web may resemble felted wool and forms a substrate on which a flame-retardant fluid may be applied in a measured spray.

The unique structure of wool means that the exterior of the wool fibre is hydrophobic. When wool fibres are put through a bath process with a flame-retardant, there is a very low uptake of the retardant by the wool fibres. Tests showed that increasing the soaking time does not sufficiently improve the uptake of the flame-retardant without a wetting agent. Therefore, the process of producing a flame-resistant material of the present invention comprises spraying a flame-retardant fluid onto at least one surface of the wool web (which may be formed of pure wool or a wool blend, as described above) to apply a flame-resistant layer on that surface.

The wool web is then dried to form a flame-resistant web or material. Preferably, the drying step includes heating the web to expedite the drying process.

In some forms, the production process includes the step of cutting the flame-resistant web into desired lengths after it has dried. The selected length may be dependent on whether the flame-resistant material is to be used to produce an acoustic element, wool batting, or another product. Where the material is used to produce a three-dimensional acoustic element, the material may be cut to the desired length and then shaped by heat-setting the material over a mould, or by any other suitable shaping process, as described above. In other forms, the dry flame-resistant web is rolled onto a take-up roller and cut when the roll is full, or reaches a desired length, or the final edge of the roll may be cut or trimmed when the production run stops to provide the web roll with a tidy end.

Therefore, the process of the invention comprises spraying a needled wool web with a flame-retardant fluid comprising DAP; drying the wool web to produce a flame-resistant wool material, and optionally cutting the material to desired lengths and shapes.

The flame-resistant material may be produced via a continuous process or a batch process.

Preferably, the flame-resistant material is formed in a continuous process and passes through the needling system to form a continuous length of needled wool web. The needled web exits the needling system and enters a spray system at which the flame-retardant fluid is applied to the web. The web continues on its path from the spray system to the drying system in a continuous process before being wound onto a roll or cut into desired lengths at a finishing stage.

In another continuous production process, the web may be formed into discrete lengths immediately after needling by passing through a cutting station before entering the spray system (one or more pieces of web at a time) where flame-retardant fluid is applied to the web before it is moved to the drying system. Preferably, the web moves continuously through the various stages of the production system on a conveyor.

In yet another form, the web (whether cut in discrete lengths or formed as one long length) is continuously moved through the production system in a series of incremental steps. In this form, the system is configured to move the web forward a set distance and then to pause the web for a set period of time before the web is moved forward the set distance again.

In another form, a batch process may be used in which the web may be formed into discrete lengths at the needling stage by passing through a cutting section after needling, and then the cut web sheets may be placed in the spray system (one or more at a time) where flame-retardant fluid is sprayed onto at least one surface of the sheet(s), before the sheet(s) is/are placed in the drying system.

Figure 6 shows one form of production system for producing a flame-resistant material according to the invention. The production system comprises a needling system 400 (optional), and also comprises a spray system 500, a drying system 600, an optional metal detection system 700 (shown in Figure 14), and a finishing stage 800 (shown in Figure 15).

Optionally, the production system also comprises a web forming section, in which the wool web is formed from loose wool fibres or a wool fibre blend. The wool fibres are carded and lapped by a carder and lapper respectively, and are then needle punched in a needling system to produce a needled wool web.

In other forms, a loose web of wool fibres or a wool blend is obtained from a separate production line and the flame-resistant wool material production system of the invention comprises a needling system where loosely layered wool material is needled to form a dense, needled web.

In yet other forms, the needled web is obtained from a separate production line and is fed into the flame-resistant wool material production system of the invention.

The flame-resistant wool material production system of the invention may comprise a feed section. In some forms, the feed section 50 is located prior to the spraying system 500 and is configured to feed and guide the needled wool web to the sprayer 501. Alternatively, if the production system includes a needling system 400, then the feed section 50 may be located prior to the needling system to feed the loose fibre web into the needling system 400 to be needled.

As shown in Figure 7, the feed section 50 may comprise a frame 51 that supports a feed roller 55 on which is wound the loose or needled web (as the case may be). The feed roller 55 is configured to unwind the web and feed the web into the flame-resistant wool material production system. For example, the feed roller 55 may feed the loose fibre web into the needling system 400, or the feed roller may feed the needled wool web into the sprayer 501 (as the case may be).

In preferred forms, the flame-resistant wool material production system (referred to herein as the 'FRWM system') comprises a feed system, a needling system 400, a spray system 500 comprising a sprayer 501, a heater and/or dryer 600, a metal detector 700, and a finishing stage 800, as indicated in Figures 6 to 15. In such forms, the feed roller 55 of the feed section 50, as shown in Figure 7, is located prior to the needling system 400 and is configured to hold a bulk roll of layered wool fibres that have been carded and lapped to form a loose fibre web. The roll optionally holds between about 20 to about 400 lineal meters of loose fibre web. The feed roller 55 feeds and guides

the loose fibre web into the needling system 400 to form a needled web 1000 according to known methods.

The needling system 400 comprises a deck 410 for supporting the web thereon, and a plurality of needles (not shown) that reciprocate up and down and punch through the web to interconnect the fibres of the web and increase the density of the web.

The needled web 1000 is then moved to the spray system 500. In some forms, the FRWM system may be configured to move the web through the various stages of the FRWM system at a substantially constant speed to provide continuous movement of the web. Alternatively, the FRWM system may be configured to move the web incrementally through the system, such as by moving the web a short distance and then pausing for a period of time. In such a configuration, the web may be moved incrementally at approximately the same distance as, or a lesser distance than, the diameter of a spray cone created by the sprayer when spraying a flame-retardant fluid onto the web. For example, if the sprayer produces a spray cone having a diameter of 40cm, then the web may be moved a distance of 40cm, or less than 40cm, through the FRWM system before halting temporarily, such as for 10 seconds, as the sprayer sprays fluid onto the web.

The sprayer 501 of the spray system 500 comprises one or more spray nozzles 510. The spray system 500 also comprises a fluid reservoir 540 that contains flame-retardant fluid to be sprayed onto the web 1000. As shown in Figures 8 and 10, the one or more spray nozzles 510 are in fluid communication with the fluid reservoir 540 via one or more fluid conduits 515. Each nozzle 510 is adapted to emit a spray of flame-retardant fluid onto a selected surface of the web 1000.

The sprayer 501, as shown in Figures 8 to 10, comprises a substantially flat spray deck 505, having a length and width, that forms a placement surface for supporting the web 1000 thereon and that is supported by a frame 503 of the sprayer. In some forms, the deck 505 may be the upper surface of a conveyor belt that moves beneath the one or more spray nozzles 510 along the direction A of the production flowpath (from the sprayer 501 to the drying system 600), as shown in Figure 6. In other forms, the deck 505 may be a fixed surface of the sprayer 501 and the arrangement of spray nozzles 510 may be adapted to move along at least a portion of the length and/or the width of the deck 505. Preferably, the web 1000 is supported by the deck 505 and moves through the sprayer 501 toward the drying system 600 as the flame-retardant fluid is applied to the web or after the fluid has been applied.

In some forms, the spray system 500 comprises at least one forward guide roller 506 located before the spray nozzles and over which the web 1000 passes as the web enters the spray system. The spray system 500 may also comprise a pair of opposing aft guide rollers 507a, 507b located after the spray nozzles and between which the web 1000 passes as the web leaves the spray system 500. The

guide rollers 506, 507a, 507b help to hold the web 1000 taut and substantially flat on the deck 505 to allow for a substantially even spray coating to be applied to the upper surface of the web 1000.

The one or more spray nozzles 510 may be located above, and distanced from, the deck 505. In some forms, a shroud 502 at least partially encloses the nozzles to minimise spray drift. The spray nozzle(s) 510 are directed toward the spray deck 505 to spray flame-retardant fluid onto an upper surface of the web 1000. Preferably, the one or more spray nozzles 510 are configured to spray the flame-retardant fluid substantially evenly across the upper surface of the web 1000. The height of the spray nozzles 510 or spray bar 520 may be adjustable relative to the web 1000 to provide a suitable spray pattern, taking into account the thickness of the web, the fluid pressure at the nozzle(s) 510, and (where applicable) the line speed at which the web moves through the sprayer 501 and the FRWM system.

In some forms, the spray pressure (i.e. the fluid pressure at the nozzle(s)) may be adjustable to provide an even and controlled spray of flame-retardant fluid across the upper surface of the web. In some forms, the spray pressure is between about 2 bar to about 6 bar.

In some forms, as shown in Figure 10, the sprayer 501 comprises at least one elongate spray bar 520 that extends transverse to the direction of travel A of the web as the web passes through the sprayer 501. A plurality of nozzles 510 are located on the spray bar 520 and are configured to spray the flame-retardant fluid onto an upward facing surface of the web 1000. The spray bar 520 is configured to support the nozzles and at least one fluid conduit 515 through which fluid from a fluid reservoir 540 can be pumped to the nozzles 510 via a pumping system. The nozzles 510 are each configured to form a spray cone 590 of sprayed fluid. The nozzles may be configured (by positioning the nozzles and adjusting the spray pressure) such that spray cones produced by the nozzles cover substantially the entire width of the web 1000 in flame-retardant fluid. The spray bar 520 may be stationary, or the spray bar 520 may be moveable along at least a portion of the length and/or the width of the deck 505.

In another form, the sprayer 501 may comprise a single spray nozzle 510 located substantially centrally between opposing side edges of the web 1000 and may be configured to spray the flame-retardant fluid onto the upward facing surface of the web 1000. In such a configuration, the single nozzle 510 may be configured to have a wider spray area (i.e. may form a wider spray cone) than that of the individual nozzles 510 provided on the spray bar 520 in order to spray flame-retardant fluid across substantially the entire width of the web, or the nozzle may be moveable transverse to the direction of movement of the web and so as to spray across substantially the entire width of the web.

Typically, the flame-retardant fluid applied to the web 1000 by the sprayer 501 comprises a mixture of DAP and water and may optionally comprise a wetting agent also.

DAP may be provided at a concentration of between about 25% and about 50% DAP in relation to about 75% or about 50% water respectively, but higher concentrations of DAP have been found to leave an undesirable white residue on the acoustic element. Therefore, in preferred forms, the acoustic element 100 of the invention comprises DAP at a concentration of about 10% to about 15%, and most preferably at about 10% dry weight.

A wetting agent may optionally be added to the flame-retardant fluid. Wetting agents are a class of surfactants that lower the interfacial tension of a liquid such as water mixed with DAP. Water has a high interfacial tension, so a drop of water tends to “bead” on a hydrophobic surface such as wool. Without the wetting agent, DAP tends to leave a chalky residue on the surface of the web 1000 and, in some cases, some of the DAP may fall off the web in the later stages of manufacture.

Therefore, in preferred forms, the flame-retardant fluid comprises water, DAP (the DAP being provided at a concentration of between about 10% to about 15% dry weight), and a wetting agent. In some forms, the wetting agent comprises a surfactant. In some forms, the wetting agent comprises the surfactant, dioctyl sulfosuccinate. Another form of wetting agent may comprise butanedioic acid and ethanol. Tests showed that the wetting agent did not affect the flame-resisting performance of the flame-resistant material of the invention, but improved the extent to which the DAP attached to the wool fibres of the material. The use of a wetting agent also avoids a chalky white residue being left on the wool web after spraying the web with flame-retardant fluid. Therefore, the aesthetics of the resultant flame-resistant wool material are improved, or are at least better controlled, by using a flame-retardant fluid that comprises a mixture of DAP, water, and a wetting agent.

The wetting agent may be added to the flame-retardant fluid at a concentration of about 1% to about 5% by volume. The wetting agent allows the flame-retardant fluid to soak into the web to help ensure that the DAP doesn't sit on the surface of the web as a powdery residue or shake off the surface of the flame-resistant material as the material is moved or flexed.

As shown in Figure 8, the spray system 500 also comprises a pumping system 550 that draws the flame-retardant fluid from the fluid reservoir 540 using any suitable form of pump(s). In preferred forms, the spray system 500 comprises a bulk holding tank for containing a bulk quantity of the flame-retardant fluid, a fluid reservoir 540, and a pumping system 550 that draws the flame-retardant fluid from the bulk holding tank (not shown) to the fluid reservoir 540 via a bulk fluid conduit and using a first pump. In some forms, the first pump may comprise a diaphragm pump, but any suitable pump may be used. The fluid reservoir may be smaller than the bulk holding tank and may comprise an automatic fill system. The automatic fill system may comprise one or more sensors that monitor a fluid level within the reservoir and that signal a control system, such as the programmable control system 530, to pump more fluid from the bulk holding tank to the fluid reservoir 540 when the fluid level in the fluid reservoir falls below a first predetermined level, and to signal the control system to

stop pumping fluid from the bulk holding tank to the fluid reservoir when the fluid level in the fluid reservoir reaches a second predetermined level. The volume of fluid in the fluid reservoir at the first fluid level is less than the volume of fluid in the fluid reservoir at the second fluid level. The control system is configured to control the pumping system 550 to pump the flame-retardant fluid through the spray system 500. The pumping system may further comprise a second pump 550 to pump flame-retardant fluid from the fluid reservoir to the spray nozzle(s) 510 via at least one fluid conduit 515. In some forms, the second pump 550 may comprise a diaphragm pump, but any suitable form of pump may be used. Thus, the control system may be configured to control actuation of both the first pump and the second pump.

In preferred forms, the spray system 500 may comprise a programmable control system 530 having a user interface 535 and being adapted to control the spray pressure, nozzle height relative to the web, and optionally the production line speed based on user inputs received via the user interface 535. The programmable control system 530 may also control the operation of valves and one or more pumps within the pumping system 550 and the spray system 500 to move the flame-retardant fluid from the fluid reservoir 540 to the nozzles 510 and/or from the bulk storage tank to the fluid reservoir 540.

For example, the programmable control system 530 may be programmed to control the pumping system 550 so that each nozzle 510 is configured to spray a desired volume of flame-retardant fluid per second of operation. Each nozzle 510 may be configured to produce a continuous spray, or each nozzle 510 may be configured to produce individual bursts of spray in a series of pulses, between which no flame-retardant fluid is sprayed from the nozzle(s) 510. Therefore, operation of the nozzles 510 is actuated by the pumping system 550, which is controlled by the programmable control system 530.

In some forms, the sprayer 501 comprises one or more shut-off valves that are located along the fluid flowpath from the fluid reservoir 540 to the nozzle(s) 510. The shut-off valve(s) may be opened to allow fluid to flow to the nozzle(s) from the fluid reservoir, or the valve(s) may be closed to block fluid flow to the nozzle(s). The programmable control system 530 may be configured to control the opening and closing of the shut-off valves. In some forms, the spray system 500 may also comprise a manual override switch which, when actuated, may open or close the valve(s), or may be configured to simply close the valve(s) when actuated.

The programmable control system 530 may be remotely programmed via a remote user interface, such as via a personal computer connected to the programmable control system via a network, and/or the programmable control system 530 may comprise an onboard user interface 535 through which an operator can enter user inputs to control operation of the pumping system 550 and therefore of the nozzles 510. In some forms, the programmable control system 530 is programmed to

provide a variety of operating options that can be selected by an operator via the user interface. Typically, the programmable control system 530 comprises a non-transitory storage medium on which its operating programmes are stored.

In some forms, the spray nozzle(s) 510 may emit flame-retardant fluid in a series of intermittent pulses, or the nozzle(s) may produce a continuous spray. The nozzle(s) may be configured to spray intermittently regardless of whether the web is moved through the FRWM production system in incremental stages, or whether the web 1000 moves through the FRWM production system at a continuous speed, provided that the pulse time is set to synchronise with the line speed of the web 100 to substantially avoid creating areas on the web that have not been sprayed with fire-retardant fluid.

The volume of flame-retardant fluid applied to the web 1000 may be adjusted via the programmable control system 530 by adjusting any one or more of the following parameters: the spray atomising pressure, nozzle height, angle of application, and spray pulse time. In preferred forms, the spray atomising pressure of the nozzle(s) is set to between about 20 to about 90 bar; the spray height (i.e. the distance between the upward facing surface of the web and the nozzle(s)) is set to between about 250 mm and about 350 mm; the angle of application (i.e. the angle at which the spray nozzle(s) sprays the spray material onto the web) is set to between about 25° and about 40° from vertical; and the spray pulse time (the on/off time of the sprayer when the nozzles are set to spray intermittently) of the, or each, nozzle is set to between about 10 seconds and about 60 seconds per minute. A pulse time of 60 seconds per minute may be used for a continuous spray configuration, whereas a pulse time of less than 60 seconds per minute may be used for operations in which pulses of spray are emitted intermittently. The pulse time of the sprayer 501 may be input via the user interface 535. For example, a user may configure the sprayer to cause each nozzle to eject a spray of flame-retardant fluid onto the web substantially continuously, or via a series of pulsed sprays in which flame-retardant fluid is not ejected from the nozzle(s) between pulses.

In some forms, the atomising pressure of the nozzle(s) 510 may be set via the user interface 535, which provides input selections by which a user can input commands to the sprayer to provide the desired volume of flame-retardant fluid to the web 1000 relative to the line speed (the line speed being the speed at which the web passes through the sprayer).

In some forms, the line speed of the web 1000 may be selected depending on any one or more of: the drying time required for the concentration of the flame-retardant fluid, the volume of flame-retardant fluid applied to the web, and the density of the web. In some forms, the line speed is set to between about 0.7 to about 2 meters per minute, but other speeds may be used instead and as required.

In preferred forms, the spray deck 505 comprises a plurality of openings and any excess spray is collected by a drip tray that lies beneath the openings. The excess fluid collected in the drip tray may be recycled and fed back to the bulk holding tank of the spray system 500.

The flame-retardant fluid may be sprayed onto the front surface, the rear surface, or both the front and rear surfaces of the web 1000. Typically, the flame-retardant fluid is applied to only the front surface of the web. Where flame-retardant fluid is applied to both the front and rear surfaces of the web, then flame-retardant fluid may be applied to one of those surfaces and then dried, before turning the web to expose the other side of the web, and then feeding the web 1000 through the sprayer 501 again to apply flame-retardant fluid to that other side, before drying the web in the drying system 600.

In some forms, the flame-retardant fluid is sprayed onto the web at a volume of about 90ml to about 100ml per m², and preferably at about 98ml per m². Preferably, the one or more spray nozzles spray the flame-retardant fluid at a pressure of between about 2 bar and about 6 bar. Preferably, the web 1000 lies substantially flat beneath the spray nozzle(s) and moves beneath the nozzle(s) in a first direction A (as shown in Figure 6) and at a line speed of between about 0.7 to about 2 meters per minute. Preferably, the web 1000 is located at a distance of about 250mm to about 450mm, and preferably about 350mm, from spray outlets of the spray nozzle(s) 510.

Once the web 1000 has passed through the sprayer 501, the web 1000 moves to the drying system 600 where residual moisture from the flame-retardant fluid is removed from the web.

In some forms, the FRWM system comprises at least one guide roller to guide the web 1000 to the drying system 600. The guide roller(s) may be located between the spray system 500 and the drying system 600. In some forms, the sprayer 501 comprises a pair of opposing guide rollers 560a, 560b that are located after the nozzles 510 and through which the web 1000 passes as the web is fed to the drying system 600. In some forms, the drying system 600 comprises a pair of opposing guide rollers that are located at the beginning of the drying system and through which the web 1000 passes. In other forms, guide rollers may be supported by an independent unit located between the sprayer 501 and the drying system 600. In some forms, the guide rollers are located side by side in a horizontal plane and the web passes across top surfaces of the guide rollers from the sprayer to the drying system. In other forms, as shown in Figures 6, 6a, and 9b, the guide rollers 560a, 560b are located side by side in a vertical arrangement or an off-set vertical arrangement. The web 1000 passes between the rollers 560a, 560b from the sprayer 501 to the drying system 600. In some forms, the guide rollers 560a, 560b are rotatably driven by a motor that rotates the rollers 560a, 560b to move the web 1000 along the production flow path from the sprayer 501 to the drying system 600. In other forms, the guide rollers are passive rotating rollers that roll by movement of the web 1000 passing over or between the rollers, the web being moved by at least one other roller along the production flow path

that is driven to rotate by a motor. Alternatively, the web may be moved by another form of actuator such as by a gripping element that grips opposing edges of the web and pulls the web through the production system as the gripping element moves along a chain or track, for example.

In some forms, the web 1000 may be left to dry in the drying system 600 from natural conduction and convection, but this process is slow. Therefore, in preferred forms, the drying system 600 comprises a heat source to heat the web 1000 and cause more rapid evaporation of moisture from the web.

In some forms, as shown in Figures 12a and 12b, the drying system 600 comprises a frame 610 that supports a heat source comprising a heated roller 630 located between a first pressure roller 620a and a second pressure roller 620b. In some forms, the drying system 600 may also comprise at least one tension roller 615 that is supported by the frame and that tensions the web 1000 around the heated roller 630. Preferably, as shown in Figure 6, the drying system 600 comprises at least two tension rollers 615 that are located proximate to each other and close to a virtual vertical plane to tension and wrap the web 1000 around the circumference of the heated roller 630 as much as possible.

The first pressure roller 620a is located before the heated roller 630 and the second pressure roller 620b is located after the heated roller 630. Each of the pressure rollers 620a, 620b are positioned proximate to the heated roller and provide a small gap, preferably about the width of the web 1000, between the pressure roller 620a, 620b and the heated roller 630. In such an arrangement, the web 1000 enters the drying system 600 and is wrapped around the tension roller(s) 615 (where present) and around the heated roller 630, in a serpentine configuration. The first and second pressure rollers 620a, 620b are configured to press the web 1000 around and against at least a portion of a circumferential surface of the heated roller 630, to increase the heat transfer between the heated roller 630 and the web 1000. The heated roller 630 preferably comprises a larger diameter than each of the first and second pressure rollers 620a, 620b to maximise the heated surface area of the heated roller 630, and therefore to maximise the efficiency at which the web 1000 is heated. Both the first and second pressure rollers 620a, 620b may be rotationally driven by a first motor at a rotational speed that is synchronised with the production line speed of the web 1000.

In some forms, the heated roller 630 remains stationary and the web slides over the roller due to rotation of the pressure rollers 620a, 620b. In other forms, the heated roller 630 passively rotates with movement of the web 1000. In yet other forms, as shown in Figures 12a and 12b, the heated roller 630 is rotationally driven by a second motor 650 and the speed of rotation of the heated roller 630 is synchronised with the rotational speed of the pressure rollers 620a, 620b and the line speed of the web 1000.

In some forms, the programmable control system 530 controls the speed of rotation of the heated roller 630 and/or the speed of rotation of the pressure rollers 620a, 620b. In other forms, a separate programmable control system controls the speed of rotation of the heated roller 630 and/or the speed of rotation of the pressure rollers 620a, 620b. In some forms, the second motor 650 is a variable speed motor 650 that drives rotation of the heated roller 630 via a chain reduction system 655 or a gear system.

The heated roller 630 may be heated to between about 100° C to about 130° C, and preferably between about 100° C and about 130° C, such as about 120° C. The temperature of the heated roller 630 may be selected depending on the line speed of the web 1000 and the flame-retardant fluid application rate. The flame-retardant fluid application rate is the volume of flame-retardant fluid (in litres) as applied to the web (in m²). In some forms, the temperature of the heated roller 630 is controlled by the programmable control system 530 and may be set via the user interface 535, or the temperature of the heated roller may be controlled by a separate programmable control system.

As the web 1000 is heated on the heated roller 630, water from the flame-retardant fluid begins to evaporate. A hood 660 is optionally located above the heated roller 630 to collect the evaporated moisture, which is then extracted via an exhaust system 665.

It is not essential for the drying system 600 to comprise a heat source comprising a heated roller by which to heat and dry the web 1000. Instead, the web 1000 may be heated using any suitable heating system to encourage evaporation of moisture from the web. For example, the drying system may comprise a substantially flat, horizontal deck that comprises a heat source and across which the web may be moved to heat the web. In some forms, the drying system may comprise a heat source comprising at least two opposing heated rollers located below and above the web, such that the web may pass between the upper and lower heated rollers as the web moves through the drying system. In another form, the drying system may comprise a substantially flat, horizontal deck and a heat source may be located above or below the deck. For example, a blower may be employed above and/or below the deck to blow hot air onto the web to dry the web. Or a heating element may be employed above and/or below the deck to heat and dry the web. In yet another form, the web may pass substantially vertically through the drying system. For example, the drying system may comprise two pairs of adjacent rollers, one pair being located above the other and the web may pass between the rollers of each pair. Each pair of rollers may be heated to heat and dry the web, or a heat source, such as a heating element or blower, may be located between the roller pairs to heat and dry the web. In yet another form, the web may pass between a series of heated rollers in a serpentine configuration. As can be seen, the drying system 600 may comprise any suitable heat source to heat and dry the web 1000, and moisture evaporating from the web may optionally be captured in a hood 660, located in the drying system, and then removed via any suitable exhaust system 665.

The FRWM system of the invention also comprises a pair of opposing rotating nip rollers 670 that are rotationally driven by a nip roller motor. The nip roller motor may consist of the first motor, the second motor, or a third motor of the FRWM system. The nip rollers 670 are configured to grip the web 1000 and pull the web through the FRWM system as the nip rollers rotate. Where the drying system 600 comprises at least one rotatably driven heated roller 630, the rotational speed of the nip rollers 670 is synchronized with the rotational speed of the heated roller(s) 630, so that the nip rollers 670 and the heated roller(s) 630 rotate at the appropriate number of revolutions per minute to move the web 1000 through the drying system 600 at the desired line speed. In effect, the nip rollers 670 pull the web 1000 through the production system from the feed section 50. In some forms, the programmable control system 530 controls the rotational speed of the nip rollers 670. In other forms, a separate programmable control system controls the rotational speed of the nip rollers 670.

The nip rollers 670 may also be configured to set the line speed of the web 1000 through the production system. The nip rollers 670 pull the web from the feed section 50 through the sprayer 501 and around the heated roller 630. The rotational speed of the nip rollers 670 is selected to keep tension on the web 1000 and to set the line speed of the web 1000 in order to allow sufficient time in the drying system 600 for the web to reach 100% dryness or to approximate 100% dryness.

The nip rollers 670 are located downstream of the spray system 500 and are preferably located downstream of the drying system 600. In some forms, (as shown in Figure 6) the nip rollers form part of the drying system 600. For example, after the web 1000 is heated, the web may be fed between a pair of opposing nip rollers 570 that pull the web through the heated section of the drying system 600.

In some forms, as shown in Figures 6 and 13, the drying system 600 also comprises a drying conveyor 680. In such forms, the heated web 1000 moves off the heated roller 630 and is fed onto the drying conveyor 680 (preferably by passing through a pair of opposing nip rollers 670). At least one extraction hood 660 may be located over the drying conveyor 680. In preferred forms, two extraction hoods 660 are located over the conveyor 680, as shown in Figure 13. Excess moisture may be drawn upwardly through the, or each, extraction hood 600 by an extraction fan. Each extraction hood 600 comprises an exhaust outlet 650 that emits the captured moisture to the atmosphere. At a line speed of about 1 meter per minute, the extraction fan may extract about 369,039 m³ of moist air per hour, at a pressure of about 4,972 Pa. This flow rate can be varied depending on any one or more of: the line speed of the web, the flame-retardant application rate, and the desired final moisture content of the web 1000.

Occasionally, during needling the loose wool fibres, needles can break and imbed into the web 1000. Any broken needles should preferably be detected and removed to prevent injury. Therefore, the FRWM system optionally comprises a metal detection system 700 configured to identify any metal,

such as broken needles, in the web 1000, as shown in Figure 14. The metal detection system 700 may be located at any stage of the FRWM process and system subsequent to the needling stage or needling system 400. For example, in some forms the metal detection system 700 may be located after the needling system 400 and before the spray system 500. However, in preferred forms, the metal detection system 700 is located after the drying system 600 and before the finishing stage 800 at which the web 1000 is cut into selected lengths or wound onto a take-up roll.

The metal detection system 700 comprises a frame 710 that supports a sensor unit 720 comprising at least one metal detection sensor and a feed arrangement that feeds the web 1000 in front of the metal detection sensor(s). The feed arrangement may be a non-metal conveyor, such as a rubber conveyor, or a platform on which the web is supported. In some forms, as shown in Figure 14, the feed arrangement comprises at least two support rollers 715 that are distanced from each other and that are located at the front and rear of the sensor unit 720 along the production flowpath. The rollers 715 may be supported by the metal detection system frame 710. The web 1000 is supported by the rollers 715 so that a portion of the web extends between the rollers 715. The sensor unit 720 is located above the web 1000 and the metal detection sensor(s) face toward the web to scan the web to detect metal within the web. The metal detection system 700 comprises an alarm system. If metal is detected in the web 1000, the metal detection sensor(s) emit a signal to the metal detection unit 720, which comprises a controller that activates an alarm upon receiving the signal. The alarm may be any suitable alarm to alert an operator that metal is located in the web. For example, the alarm may be an audible alarm such as a beep or siren; a visual alarm, such as a flashing light or a light that presents a colour change when activated, or the alarm may include both an audible and visual alarm. At the same time as the controller activates the alarm, the controller signals the programmable control system to stop the rotation of the nip rollers 670 (by stopping the motor 650); stop the nozzles spraying the flame-retardant fluid (by stopping the pumping system or activating one or more shut-off valves to stop fluid flow to the nozzle(s) 510); and stop heating the heat source (such as the heated roller 630), in the drying system 600, thereby preventing the web 1000 from continuing to move along the production flow path.

In some forms, the programmable control system 530 forms the controller of the metal detection unit 720 and is configured to receive signals from the metal detection sensor(s) and to generate an alarm and stop the FRWM system when the sensor(s) signal that metal has been detected in the web. In other forms, a separate programmable control system may control the metal detection unit 720 and may be configured to receive signals from the metal detection sensor(s) and to generate an alarm and stop the FRWM system when the sensor(s) signal that metal has been detected in the web.

Once movement of the web 1000 is halted subsequent to the alarm being generated, an operator searches for and removes the metal from the web. Alternatively, if the metal cannot be located, the operator may cut the web to remove the section of the web that contains the metal.

In preferred forms, the programmable controller 530 controls the operation of the entire FRWM system, including the production line speed (and therefore the speed of rotation of the nip rollers 670), the needling system 400 (where present), the spray system 500, the drying system 600, the metal detection system 700, and the finishing stage 800.

The dry, metal-free web 1000 now forms the flame-resistant material 1500 of the invention and is fed to the finishing stage 800 to either be cut into desired lengths or wound onto a roll.

In some forms, the finishing stage 800 comprises a cutting element, such as a linear blade, a rotary blade, or any other cutting mechanism configured to make transverse cuts in the web 1000 to cut the web into discrete lengths to form sheets of flame-resistant material 1500, which may then be stacked and optionally packaged for delivery to the customer. In some forms, the material is cut into sheets of 1.2 metres wide x 2.4 metres long, but in other forms, the material may be cut to any suitable size and shape.

In other forms, the finishing stage may comprise a frame 810 that supports a pair of driven rollers 830a, 830b that are rotatably driven by a driven roller motor (not shown) and are synchronised with the line speed of the web through the production system. For example, the rotational speed of the driven rollers 830a, 830b may be synchronised with the rotational speed of the nip rollers 670 so that the web 1000 is pulled through the production system at a substantially constant speed.

In some forms, the programmable control system 530 controls the rotational speed of the driven rollers 830a, 830b and ensures that the speed of the driven rollers is synchronised with the speed of the nip rollers 670. In other forms, a separate programmable control system controls the rotational speed of the driven rollers 830a, 830b and ensures that the speed of the driven rollers is synchronised with the speed of the nip rollers 670.

A take-up roller 820 sits on top of the driven rollers 830a, 830b. The web 1000 is wound onto the take-up roller 820 as it is produced from the drying system 600 or the metal detection system 700 (as the case may be). The driven rollers 830a, 830b rotate the take-up roller 820 to wind the web of flame-resistant material 1500 onto the roller 820 at the line speed of the web through the FRWM system.

Rolls of woollen flame-resistant material 1500 produced by the system and process of the invention may be produced in varying lengths, as desired, such as between about 20 metres to about 300 metres.

The rolled web/flame-resistant material may then be packaged as a finished product or the material may be subject to further processing. For example, the roll may be transferred to a cutting

station where the material is unrolled and cut into shapes or sheets. In some forms, the material is cut into sheets of 1.2 metres wide x 2.4 metres long, but in other forms, the material may be cut to any suitable size and shape.

During development of the present invention, tests were conducted using different flame-retardants to establish whether it was possible to produce a flame-resistant material comprising wool fibre that had the required flame-resistant properties for use in a commercial environment. The flame-resistant material of the invention was found to achieve Group 1 performance under cone calorimeter testing using wool to which had been applied a flame-retardant fluid comprising DAP at a concentration of at least 10% to water.

Testing

Testing was undertaken to assess the performance of different flame-retardant fluids. Non-woven wool panels of about 8 - 10mm thickness and with various different flame-retardant additives were tested according to ISO 5660 to assess the resulting flame-resistant and noise absorption properties of the panels.

When testing the flame-resistant properties of a panel, test results were validated using a Cone Calorimeter test (ISO 5660-1).

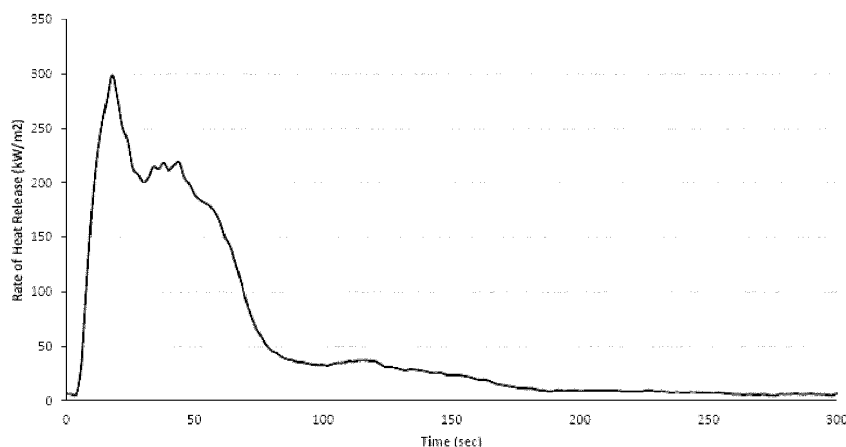
A cone calorimeter is a device used to study the fire behaviour of small samples of various materials in a condensed phase. It is widely used in the field of fire safety engineering, and is the standard test apparatus currently used in New Zealand, and some other countries, to assess fire compliance for interior linings in commercial spaces, including for acoustic panels.

For the present application, the parameters of most interest from the cone calorimeter testing were the heat release rate (HRR) and the time to ignition (TTI).

Flammability Test Results

Pure Wool

The flammability of a pure wool sample, without additives, was tested using the cone calorimeter test, which placed pure wool in Group 4, meaning that it did not meet current fire safety requirements for commercial interiors.



Graph 1: Rate of heat release over time for a pure wool sample having an initial mass of 11.3g under cone calorimeter testing at a heat flux of 50 kW/m².

Analysis based on this testing showed that to attain Group 2 performance, the total heat would need to be reduced by about 60%, or the time taken from first contact with a heat source until ignition would need to be delayed by about 60 seconds. To attain Group 1 performance, the total heat would need to be reduced by about 60%, and the time until ignition would need to be delayed by about 180 seconds or the rate of heat release would need to be below 50Kw/m².

Wool with a Diammonium Phosphate (DAP) Additive

Diammonium phosphate (NH₄)₂(HPO₄) is also known as ammonium monohydrogen phosphate, ammonium hydrogen phosphate, ammonium phosphate dibasic, Ammonium phosphate, dibasic, Diammonium acid phosphate, Diammonium hydrogen orthophosphate, Diammonium ydrogen phosphate, Diammonium hydrogen orthophosphate, Diammonium monohydrogen phosphate, Diammonium orthophosphate, Diammonium phosphate, Dibasic ammonium phosphate, secondary Ammonium phosphate.

The inputs required to produce one tonne of DAP are approximately 1.5 to 2 tonnes of phosphate rock, 0.4 tonnes of sulphur (S), to dissolve the rock, and 0.2 tonnes of ammonia.

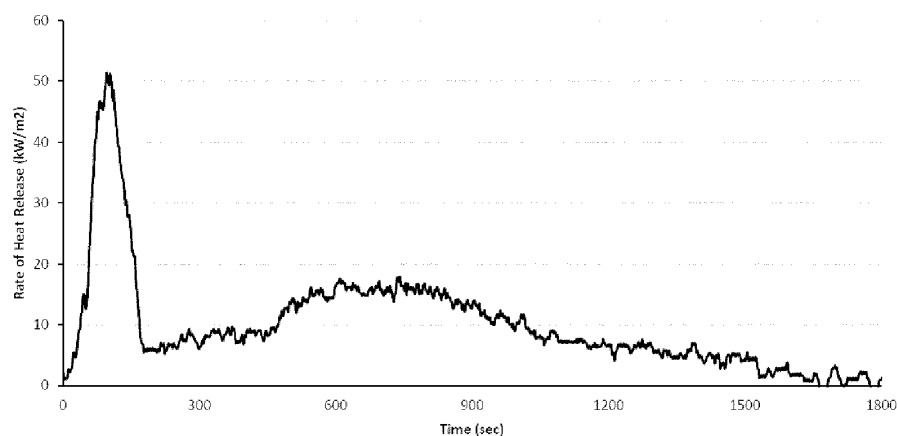
DAP (CAS number 7783-28-0) is a known fertiliser, wildfire retardant and food additive used as a nutrient in yeast cultivation which can be used in wine, food and pharmaceutical industries. It is also an ingredient in compounded bread improvers.

100% pure, food-grade Diammonium Phosphate was sprayed onto the front surface of a substantially flat wool sample at 10% dry weight concentration and the sample was tested using the cone calorimeter test.

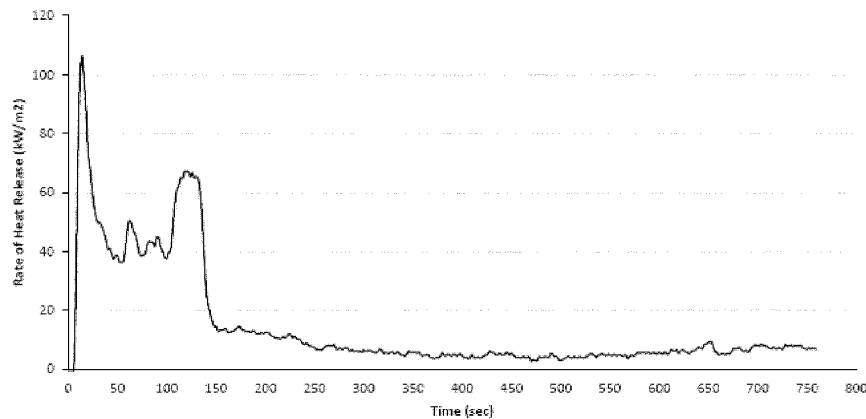
The cone calorimeter tests on a wool panel comprising DAP on the exposed surface/surfaces showed that the panel expands as it burns and forms a char layer. The low thermal conductivity of the char layer appears to cause the char layer to act as thermal insulation, absorbing some of the heat input and therefore reducing the heat flux and the heat release rate of the wool panel when compared to cone calorimeter test results on a pure wool panel.

For Group 1S performance each panel sample had a thickness of between 9-10mm and an initial mass of 73-77g (including a nominal 10mm thick plasterboard backer). Each sample had an overall apparent density of between 375 and 396 kg/m³ (including the plasterboard). The exposed sample area was 0.0088 m². The nominal heat flux applied by the test was 50 kW/m² with a nominal duct flow rate of 0.024 m³/s and a C-Factor of 0.041929 when the sample was positioned horizontally.

Tests showed that the inclusion of DAP on the face of the wool panel lowers the combustion temperature of the wool and increases the production of residue or char. A series of tests showed that aside from the addition of DAP, the density of the wool panel played a large part in the overall fire performance of the product. Where the wool was less dense (more loosely needled), the fire performance was adversely affected. With a less dense product, the charred layer leaves gaps and holes and allows fire to penetrate through the panel, whereas a panel of greater density creates a consistent char layer and thereby significantly impacts and reduces the overall heat release rate. The charring properties of the DAP was therefore shown to be more effective on a product of greater density and significantly improved fire performance.



Graph 2: More dense material: Rate of heat release over time for a 10mm sample material having an initial mass of 75.5 g and comprising 100% wool and 7-10% dry weight DAP sample under cone calorimeter testing at a heat flux of 50 kW/m². Apparent density (with plasterboard backer): 380kg/m³.



Graph 3: Less dense material: *Rate of heat release over time for a 9mm sample material having an initial mass of 70.8 g and comprising wool and 7% DAP dry weight sample under cone calorimeter testing at a heat flux of 50 kW/m². Apparent density (with plasterboard backer): 372kg/m³.*

A substantially flat wool panel comprising DAP at a concentration of about 7% dry weight sometimes achieved Group 1 performance, meaning that the panel satisfied the current fire safety requirements for commercial interiors, but when the concentration of DAP was increased to about 10%, consistent Group 1 results were obtained. However, a panel comprising wool and DAP at 5% concentration only achieved Group 4 performance, indicating that the flame-resistant performance of the panel increases as the concentration of DAP increases.

Therefore, testing showed that the concentration of the DAP on the panel is important to its performance as a flame-retardant. The concentration of DAP used in the panel affects the heat output and time to ignition, the DAP being shown to significantly delay ignition of the material.

In some forms, an acoustic element may comprise wool mixed with other fibres. For example, a substantially flat acoustic element comprising a wool and rayon flame-resistant fibre mix (needled together) and also comprising DAP applied at a concentration of 7% dry weight on the front surface of the acoustic element, has been shown to achieve Group 2 performance under testing.

Depending on the concentration used, DAP was found to have a minimal effect on the visual appearance of the tile or panel, apart from creating a very slight change to the texture of the product. In addition, it was found that DAP removes some of the lanolin smell from the wool, which is considered to be advantageous because the smell of new wool tiles and panels especially can be quite strong.

DAP is generally considered to have low toxicity. Under normal conditions of use, adverse health effects are not anticipated. DAP is not hazardous according to the criteria of the Globally Harmonised System of Classification and Labelling of Chemicals (GHS).

An acoustic element made from a combination of DAP and wool can be returned to the soil at the end of the product's useful life and, as the wool degrades, the product will release nutrients into the ecosystem.

Wool with phosphoric acid additive

Another form of acoustic element with flame-resistant properties combines phosphoric acid with wool.

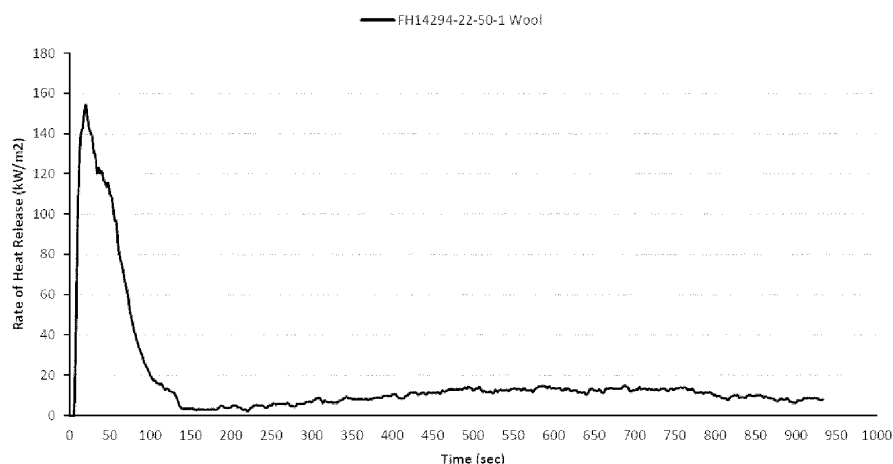
Phosphoric acid may be used on various surfaces as a flame retardant, such as with textiles, plastics, coatings, paper, seals, and building materials. The flammable volatile polyphosphoric acid, which eventually forms when heated, helps to produce a layer of charcoal that acts as a physical barrier to the formation of gases and the release of heat, which results in less a volatile fire reaction.

Phosphoric acid is hazardous according to criteria of the Environmental Protection Agency (EPA) New Zealand, although it is often added to food as an additive.

When phosphoric acid enters the environment, it can acidify soil and water. However, smaller quantities of phosphoric acid tend to be neutralised to form harmless phosphate salts or it can be diluted to harmless levels.

It was envisaged that phosphoric acid may be added to wool fibres or a combination of fibres including wool, or may be used to coat wool fibres or a combination of fibres including wool, to create a material with flame-resistant properties, but further testing found that the effectiveness of phosphoric acid was variable.

A flat wool sample comprising phosphoric acid sprayed at a 10% by dry weight concentration achieved Group 2 performance under cone calorimeter testing.

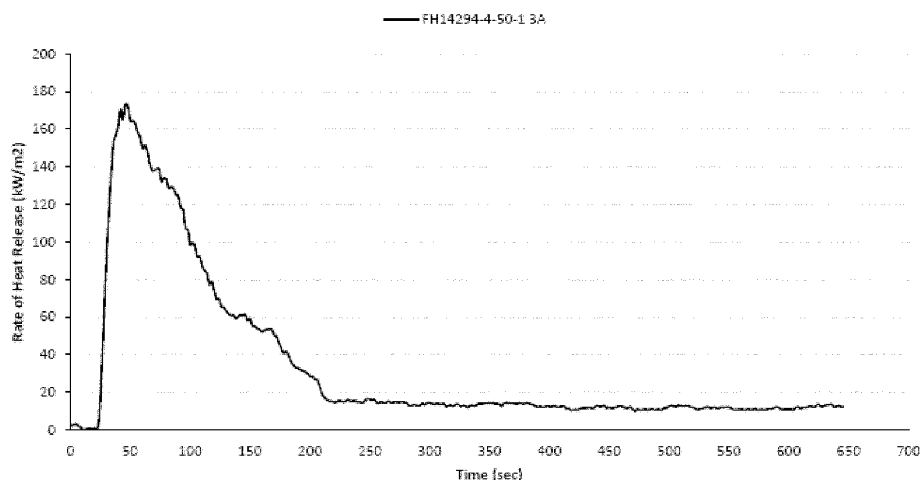


Graph 4: Rate of heat release over time for a sample material having an initial mass of 74.5 g and comprising wool bathed in phosphoric acid under cone calorimeter testing at a heat flux of 50 kW/m²

Alumina Trihydrate

Alumina trihydrate (AT) is a white, translucent powder that is also called aluminium hydroxide. Alumina trihydrate is obtained from Bauxite and commercially used as a flame retardant. When it is exposed to high heat, it releases water from its chemical structure. Alumina trihydrate is not water soluble and requires an emulsifier to adhere to wool.

Testing of a flat panel that included wool fibres and alumina trihydrate shows that alumina trihydrate delayed the time to ignition significantly beyond that of pure wool, because the alumina trihydrate created a soaking wet material when exposed to heat. The material appeared to boil before igniting at about one minute after exposure to the heat source. Initial testing showed that a wool sample comprising alumina trihydrate missed with an emulsifier and applied to the panel face achieved Group 2 performance, using cone calorimeter testing.



Graph 5: Rate of heat release over time for a sample material having an initial mass of 80.2 g and comprising wool coated with alumina trihydrate and an emulsifier under cone calorimeter testing at a heat flux of 50 kW/m². The AT and emulsifier was applied to the wool as a coating.

In summary, pure wool burns at around 300kW/m². ISO 5660-1 establishes that for the safe evacuation of a room during a fire, the heat output should not exceed 50kW/m².

DAP applied to an acoustic element comprising wool creates a char layer, which means that as the wool burns it releases heat at a much slower rate than without the addition of DAP, therefore the Heat Release Rate (kW/m²) is lower when DAP is applied to the acoustic element.

Additional testing of DAP applied to an acoustic element at concentrations of 3%, 5% and 7% dry weight respectively reduced the heat output (3% dry weight effectively halved it), but it was only at 10% dry weight concentration that the heat output dropped below 50kW/m². Similarly, acoustic elements produced with DAP concentrations above 10% provided effective flame-retardant properties, but tended to have a crunchy feel and included a white residue on the surface of the acoustic element and were therefore not aesthetically pleasing or pleasant to touch.

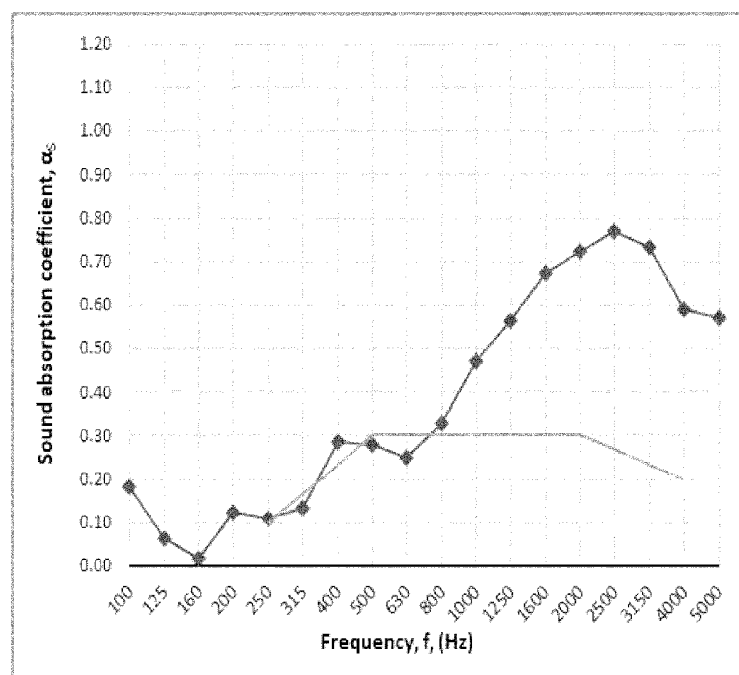
Therefore, tests showed that a wool substrate to which a DAP (at a concentration of at least about 10% dry weight) has been applied forms a char layer when burnt. The char layer drops the heat release rate from about 300kW/m² to about 36 kW/m², indicating an almost 90% reduction in the heat release rate as a result of the addition of DAP. The char layer reduces the ability of heat to penetrate the wool fibres and therefore significantly slows the rate at which the wool substrate burns – to the extent that the wool and DAP substrate was found to achieve at least Group 2 performance and, in some cases, was able to achieve Group 1 performance under cone calorimeter testing.

Acoustic Performance

In preferred forms, the acoustic element of the invention comprises a wool panel that comprises wool fibre, graded as being between about 50/100mm and about 75/110mm in length and having a thickness of about 33.0 μ m to about 36.5 μ m.

The acoustic element of the invention is felted by needling, which creates tangled and physically interlocked fibres to form a highly porous structure with a plurality of openings, such as air pockets, capillary channels, and interconnected openings in the micron and submicron scale. The porous structure provides high air permeability and accessibility of sound waves. Incidental sound waves that strike the acoustic element cause vibrations of air molecules accumulated within the openings between the fibres. The oscillating air molecules lose energy because of friction and thereby energy of the sound wave is transformed into thermal and viscous heat, which gives the acoustic element effective acoustic absorption properties.

Acoustic testing of the sound absorption of the acoustic element confirmed that the acoustic element was a highly dissipative and dispersive material with strong sound absorbing performance especially at higher frequencies.



For these materials the noise reduction coefficient (NRC), which is a quantitative measure of a material's potential for reverberation control, is above 0.40.

Rating according to ASTM C423

Single number ratings to ASTM - 99, ASTM C423 - 17	
Noise Reduction Coefficient (NRC)	0.40
Sound Absorption Average (SAA)	0.54

Therefore, the acoustic performance of wool to which DAP has been applied according to the invention is not negatively affected.

The invention may also be said broadly to consist in the parts, elements and features referred to or indicated in the specification of the application, individually or collectively, in any or all combinations of two or more of said parts, elements or features.

Where, in the foregoing description reference has been made to integers or components having known equivalents thereof, those integers are incorporated within this specification as if individually described.

It should be noted that various changes and modifications to the presently preferred embodiments described herein will be apparent to those skilled in the art. Such changes and modifications may be made without departing from the spirit and scope of the invention and without diminishing its attendant advantages. It is therefore intended that such changes and modifications be included within the scope of the invention.

Claims

1. A flame-resistant material comprising wool fibres onto which a flame-retardant fluid has been applied to at least one surface of the material, wherein the flame-retardant fluid comprises water and diammonium phosphate, at a concentration of between about 25% and about 50% to about 75% and about 50% water to give a dry weight covering of the material of about 10% to about 15% diammonium phosphate, and a wetting agent at a concentration of about 1% to about 5% by volume, and wherein the material has a density of between about 140kg/m³ and about 250kg/m³.

2. The flame-resistant material of claim 1, wherein the material comprises both wool fibres and low-melt bond fibres.

3. The flame-resistant material of claim 1 or 2, wherein the wetting agent comprises a surfactant.

4. The flame-resistant material of any one of the preceding claims, wherein the flame-retardant fluid forms a coating on the surface of the material to which it has been applied.

5. An acoustic element formed from the flame-resistant material of claim 1.

6. The acoustic element of claim 5, wherein the acoustic element forms a substantially flat panel or a three-dimensional tile.

7. A system for producing a flame-resistant material according to claim 1 from a web of needled wool fibres, the system comprising:

a spray system comprising a sprayer comprising one or more spray nozzles in fluid communication with a fluid reservoir via at least one fluid conduit, wherein the fluid reservoir is configured to contain a flame-retardant fluid comprising water, diammonium phosphate and a wetting agent, wherein the flame-retardant fluid comprises water and diammonium phosphate, at a concentration of between about 25% and about 50% to about 75% and about 50% water to give a dry weight covering of the material of about 10% to about 15% diammonium phosphate, and where the wetting agent is provided at a concentration of about 1% to about 5% by volume, and wherein the nozzles are arranged to spray the flame-retardant fluid onto a surface of the web;

a drying system comprising a heat source to heat the web; and

a finishing stage in which the web is prepared for delivery.

8. The system of claim 7, wherein the spray system comprises a bulk holding tank for containing the flame-retardant fluid and a pumping system to draw the flame-retardant fluid from the bulk holding tank to the fluid reservoir via a bulk fluid conduit, and wherein the fluid reservoir comprises an automatic fill system comprising one or more sensors that monitor a fluid level within the reservoir and that signal a control system to pump more fluid from the bulk holding tank to the fluid reservoir when the fluid level in the fluid reservoir falls below a first predetermined level, and to signal the control system to stop pumping fluid from the bulk holding tank to the fluid reservoir when the fluid level in the fluid reservoir reaches a second predetermined level, and wherein the volume of fluid in the fluid reservoir at the first fluid level is less than the volume of fluid in the fluid reservoir at the second fluid level.

9. The system of claim 7 or 8, further comprising a metal detection system prior to the finishing stage.

10. The system of any one of claim 7 to 9, wherein the heat source comprises a heated roller and the drying system further comprises a pair of first and second pressure rollers to press the web around and against at least a portion of a circumferential surface of the heated roller.

11. A method of producing a flame-resistant material from a web comprising needled wool fibres and having a density of between about 140kg/m^3 and about 250kg/m^3 , the method comprising the steps of:

- a. spraying at least one surface of the needled wool web with a flame-retardant fluid, wherein the flame-retardant fluid comprises water and diammonium phosphate, at a concentration of between about 25% and about 50% to about 75% and about 50% water to give a dry weight covering of the material of about 10% to about 15% diammonium phosphate, and where the wetting agent is provided at a concentration of about 1% to about 5% by volume, and a wetting agent at a concentration of about 1% to about 5% by volume; and
- b. drying the web.

12. The method of claim 11, wherein the flame-retardant fluid is sprayed onto the web at a pressure of between about 2 bar and about 6 bar.