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(54) Titre : FIBRES VITREUSES SYNTHETIQUES
(54) Title: MAN-MADE VITREOUS FIBRES

(57) **Abrégé/Abstract:**

Man-made vitreous fibres have a solubility at pH 4.5 of at least 20 nm per day and a melt viscosity of 10-70 poise at 1,400 °C. A composition which will provide these properties is selected for their manufacture and contains at least 10 % by weight Al_2O_3 . Novel fibres contain at least 6 % by weight $Na_2O + K_2O$.



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(54) Title: MAN-MADE VITREOUS FIBRES (57) Abstract Man-made vitreous fibres have a solubility at pH 4.5 of at least 20 nm per day and a melt viscosity of 10-70 poise at 1,400 °C. A composition which will provide these properties is selected for their manufacture and contains at least 10 % by weight Al ₂ O ₃ . Novel fibres contain at least 6 % by weight Na ₂ O + K ₂ O.														

Man-Made Vitreous Fibres

This invention relates to man-made vitreous fibres (MMVF) which are durable in use but which can be shown to
5 be biologically advantageous.

MMV fibres are made from vitreous melt, such as of rock, slag, glass or other mineral melts. The melt is formed by melting in a furnace a mineral composition having the desired analysis. This composition is generally
10 formed by blending rocks or minerals to give the desired analysis. The mineral composition often has an analysis, as oxides, which includes at least 32% SiO₂, below 30% Al₂O₃ and at least 10% CaO. The elemental analyses in the specification are by weight and calculated as oxides. The
15 iron oxide may be a mixture of FeO and Fe₂O₃ but is quoted herein as FeO.

Efficient and cost-effective formation of the melt in the furnace and of the fibres from the melt requires that the composition should have a suitable liquidus temperature
20 and should have a suitable viscosity during the fibre-forming process. These requirements impose constraints on the selection of the composition that is to be melted.

Although there is no scientific evidence establishing that there is a health risk associated with the manufacture
25 and use of MMV fibres, commercial interests have led manufacturers to provide MMV fibres that retain the required physical properties of MMV fibres (e.g., durability at elevated temperatures and under humid conditions) but which can also be alleged to be of improved
30 biological safety.

This allegation of improved safety is usually made on the basis of an in vitro test that examines the dissolution rate or degradability of the fibres in a liquid which is intended to simulate lung liquid, such as Gamble's solution
35 with pH 7.4 to 7.8. A consequence of enhanced dissolution rate at pH 7.5 is that the fibres will normally have reduced resistance to humidity.

Numerous patent applications have been published describing fibres that give enhanced dissolution rate in such an in vitro test, such as WO87/05007, WO89/12032, EP 412878, EP459897, WO92/09536, WO93/22251 and WO94/14717.

5 A characteristic of many of these patent applications, and of fibres which are alleged to have enhanced dissolution rate in such in vitro tests, is that the fibre should have reduced aluminium content. For instance it is stated in WO87/05007 that the Al_2O_3 amount must be below
10 10%. The aluminium content of rock wool and slag wool is generally in the range 5 to 15% (measured as Al_2O_3 by weight) and many of these allegedly biologically suitable fibres have an aluminium content of below 4%, and often below 2%. It is known to include phosphorous in these
15 low- Al_2O_3 compositions in order to increase the dissolution rate in this pH 7.5 dissolution rate test.

A problem with many of these low- Al_2O_3 fibres (in addition to uncertainty as to whether they do have enhanced biological suitability) is that the melt properties are not
20 entirely satisfactory for manufacture in conventional or easily adapted melting and fibre-forming apparatus. For instance the melt viscosity at convenient fibre-forming temperatures may be rather low. Another problem is that a high dissolution rate at pH 7.5 may tend to result in
25 reduced durability under humid conditions which may be experienced after installation.

In addition to the in vitro tests, in vivo research testing has been conducted. For instance Oberdörster in VDI Berichte 853, 1991, pages 17 to 37 showed that two
30 basic mechanisms are involved in the clearance of fibres from the lungs, namely dissolution in the near-neutral lung fluid and dissolution in the acidic environment (maintained at pH 4.5 to 5) created around fibres surrounded by macrophages in the lung. It is believed macrophages
35 promote removal of the fibres from the lung by promoting local dissolution of the surrounded fibre area leading to weakening and breaking of the fibres so as to reduce the

average fibre length, thereby enabling macrophages to engulf and transport the shorter fibres out of the lung. This mechanism is illustrated in the article by Morimoto et al in Occup. Environ. Med 1994, 51, 62-67 and especially
5 Figures 3 and 7 and articles by Luoto et al in Environmental Research 66 (1994) 198-207 and Staub-Reinhaltung der Luft 52 (1992) 419-423.

Traditional glass fibres and many of the MMV fibres claimed to have increased solubility in lung fluid (at pH
10 7.5) have a worse solubility at pH 4.5 than at pH 7.5 and so presumably attack by macrophages would not contribute significantly to the shortening and final removal of the fibres from the lung.

Existing MMV fibres formed from rock, slag and other
15 relatively high alkaline earth mixtures can have a higher dissolution rate at pH 4.5 than pH 7.5 but tend to have a low melt viscosity. Existing fibres which are promoted as being biologically acceptable do not have a satisfactory combination of dissolution rate at pH 4.5 with melt
20 properties. Fibres which are currently alleged to be preferred on the basis of in vitro tests tend to have low melt viscosity when they have the required low aluminium content. The low melt viscosity inevitably reduces production efficiency compared to normal production.

25 It would be desirable to provide MMV fibres which can be shown to be biodegradable in the lung, have melt properties which allow for normal, high, production efficiency and which can be made from inexpensive raw materials. Preferably they have good weathering resistance
30 when exposed to ambient humid conditions in use.

In the invention we use, as fibres having satisfactory biological solubility, fibres which have a dissolution rate measured at pH 4 to 5 of at least 20nm per day and which are formed of a composition having a melt viscosity at
35 1,400°C of 10-70 poise. For instance the dissolution rate at pH 4.5 can be at least 30 or even at least 50 nm per day or more.

The combination of the melt viscosity and the solubility at pH 4.5 means that we can use a melt which is convenient to fiberise by conventional techniques and can produce fibres which are biologically soluble at pH 4.5.

5 It is new to formulate or select fibres according to this combination, and many such fibres have a novel composition.

In a preferred aspect of the invention we determine the melt viscosity and the fibre dissolution rate at a pH in the range 4-5 of one or more compositions, we select a
10 composition which has a melt viscosity at 1400°C of 10 to 70 poise and provides fibres which have a dissolution rate at pH 4.5 of at least 20nm per day and which has an analysis, measured as weight of oxides, which includes

	SiO ₂	32 to 48%
15	Al ₂ O ₃	10 to 30%
	CaO	10 to 30%
	MgO	2 to 20%
	FeO	2 to 15%
	Na ₂ O + K ₂ O	0 to 12%
20	TiO ₂	0 to 6%
	Other Elements	0 to 15%

and we make fibres from this composition.

It is surprisingly possible, in accordance with the invention, to provide fibres which have a good dissolution
25 rate at pH 4.5 thereby facilitating clearance from the lungs by macrophages (thus promoting genuine biodegradability), even though the fibres can have low or moderate dissolution rate at pH 7.5. This allows maintenance of good stability under humid conditions
30 (without loss of biodegradability). The fibres can have reasonably conventional melt characteristics such as liquidus temperature, crystallisation rate and melt viscosity. The fibres can be formed using inexpensive raw materials.

35 Another advantage of the fibres is that when they are exposed to humidity and condensed water, the resultant solution that is formed containing dissolution products has

increased pH but the fibres may have reduced solubility at increased pH and so they may dissolve less and have increased durability.

The invention broadly includes all MMVF products made from a composition having the melt viscosity at 1,400°C of 10-70 poise and wherein the manufacture, promotion or sale or use involves measurement of, or reference to measurement of, solubility at about pH 4.5 (e.g., 4 to 5) and/or in the environment of macrophages in the lung irrespective of whether the dissolution rate is measured during the actual production of such products. The fibres preferably have an analysis as stated above.

The invention includes the use of the stated composition to promote the removal of MMVF fibres from human lungs. The invention also includes the use of the stated fibres to impart the ability to be rejected from human lungs.

The invention includes MMVF products, including MMV fibres, made from a composition which has been selected in order to provide the stated solubility. For instance it includes the measurement of pH 4-5 solubility and the melt viscosity of one or more compositions and selecting a composition partly or wholly on the basis of observing melt viscosity and solubility value at pH 4-5, and utilising compositions having the same or substantially the same analysis for making MMVF products. Any deviations in the analysis must be sufficiently small that they do not significantly alter the pH 4-5 solubility. When conducting the measurements to allow a selection of fibres to be made, the solubility can be determined at any pH (usually in the range 4-5) which correlates to the pH at 4.5. The melt viscosity can be determined either by deduction from data or by measurement and/or calculation, for any temperature (usually in the range 1,370-1,450°C) which gives a value which correlates with the value at 1,400°C.

The selection of the composition does not have to be conducted at the same location or at about the same time as

carrying out the commercial production using the selected composition. Thus a manufacturer may conduct tests, or sponsor others to conduct tests, to determine solubility and use the information from these tests as part of the basis for selecting the composition which is used for making the fibres commercially.

The invention includes products having the quoted analysis and are formed from a composition having the quoted melt viscosity and which are labelled or sold as having the defined dissolution rate at pH 4-5. The invention includes packages which contain MMV fibres and which carry a label or insert, or which are sold with advertising, which refers to solubility at pH in the range 4-5 or in the environment of macrophages or which refers to a test method which measures such solubility.

The invention includes novel MVVF products. These include horticultural MMVF growth media and fibre reinforcement wherein the fibres are as defined in the invention.

One class of fibres which are novel are fibres having the solubility, melt viscosity and composition analysis given above except that the amount of Al_2O_3 is at least 18%. Other useful fibres have Al_2O_3 above 16%. Often it is above 19 or 20%, for instance up to 26 or 28%. In fibres having Al_2O_3 above 16% the combined amount of alkali ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) is usually at least 1% and preferably at least 2%, up to 7% or 10% or more. The amount of alkali is usually below 5% and preferably below 3% when the amount of Al_2O_3 is above 16%. These fibres can have good fire resistance and other mechanical properties. When these properties are of less importance, fibres having useful pH 4.5 solubility can be obtained with amounts of Al_2O_3 below 16% and amounts of $\text{Na}_2\text{O} + \text{K}_2\text{O}$ above 6 or 7%, for instance 8 to 12%, usually 8-10%.

Another class of fibres which are novel are fibres which preferably have the solubility and melt viscosity given above and which have the general analysis given above

except that the alkali ($\text{Na}_2\text{O}+\text{K}_2\text{O}$) is above 6% and the amount of Al_2O_3 is usually 12-18%, and is often not more than 16% preferably 13-16%. Often the composition contains 0.5-4% TiO_2 , usually 1-2% TiO_2 . The alkali is usually provided by
5 at least 5% and often at least 7%, Na_2O . The total amount of alkali ($\text{Na}_2\text{O}+\text{K}_2\text{O}$) is preferably 8-12%, often 8-10%.

It is possible to select elemental analyses within the general ranges given above so as to obtain the defined combination of melt viscosity and dissolution rate at pH
10 4.5. Also, it is easily possible to select the composition such that the composition and the fibres comply with other desirable properties, such as liquidus temperature and sintering temperature.

For instance, if it is found that the viscosity at
15 1400°C of any particular melt is too high, it may be possible to reduce it by reducing the total amount of $\text{SiO}_2 + \text{Al}_2\text{O}_3$. Similarly, if the melt viscosity is too low, it may be possible to increase it by raising the total amount of $\text{SiO}_2 + \text{Al}_2\text{O}_3$, generally within the range of 55 to 75%,
20 often 60 to 75%, or by increasing the amount of alkali oxide. Similarly, it may be possible to decrease the viscosity by increasing the total amount of alkaline earth metal oxide components and FeO .

If the rate of dissolution at pH 4.5 is too low it may
25 be possible to increase it by decreasing the amount of SiO_2 , but it may then be necessary to increase the amount of Al_2O_3 (and/or to add a component such as P_2O_5) in order to maintain melt properties.

The amount of SiO_2 is normally at least 32%, often at
30 least 34% and preferably at least 35%. It is normally below 47% and preferably below 45% and is often 38-42%. However amounts of 42 to 47% are preferred when the amount of Al_2O_3 is not more than 16%.

The amount of Al_2O_3 is normally at least 12% and
35 preferably at least 13%. When the amount of alkali is relatively low, good solubility at pH 4.5 can be obtained with Al_2O_3 amounts above 16 or 17%, especially at least 18%,

but preferably at least 20% and often at least 24%. It is normally below 28% and preferably below 26%. Amounts of 20-23% are often preferred. However when the amount of alkali is relatively high (for instance at least 7% Na₂O+K₂O) good solubility at pH 4.5 can be obtained with Al₂O₃ amounts below 16%, eg 13-15%.

The combined amount of SiO₂ + Al₂O₃ is normally 55 to 75%, usually at least 56% and preferably at least 57%. In preferred products it is often above 60%, most preferably at least 61 or 62%. It is normally below 70% or 68% and preferably below 65%. When the amount of Al₂O₃ is not more than 16%, the amount of SiO₂+Al₂O₃ is often 56-60%.

The amount of CaO is normally at least 14% and preferably at least 18%. It is normally below 28% and preferably below 25%. Amounts of 14-20% are often preferred.

The amount of MgO is normally at least 5%, preferably at least 6% and most preferably at least 8%. It is normally below 15%, preferably below 11%. When the amount of Al₂O₃ is not more than 16%, the amount is preferably 5-11%.

The amount of FeO is normally at least 3% and preferably at least 5%. It is normally below 12%, preferably below 10% and most preferably below 8%. Amounts of 5-7% are often preferred. Preferably CaO + MgO + FeO is 25 to 40%.

The composition often includes TiO₂ in an amount of up to 3% or 4%, usually up to 2%. The amount of TiO₂ is usually at least 0.2%, often at least 0.5 or 1%.

A variety of other elements can be present in the composition in any amount that does not detract from the desired properties. Examples of other elements that can be included are P₂O₅, B₂O₃, BaO, ZrO₂, MnO, ZnO and V₂O₅.

It is often desirable to include P₂O₅ and/or B₂O₃ for instance to adjust melt properties or to adjust solubility. The total amount of P₂O₅ and B₂O₃ is generally not more than 10%. The amount of P₂O₅ is usually more than the amount of

B_2O_3 and is usually at least 1% or 2%. Often B_2O_3 is absent. Preferably there is 1 to 8%, usually 1 to 5%, P_2O_5 and 0 to 5% B_2O_3 (often 1 to 4% B_2O_3).

5 The total amount of these various other elements is usually below 15% and often below 10% or 8%. Each of the other elements which is present is normally present in an amount of not more than 2%, except than P_2O_5 and/or B_2O_3 may be present in larger amounts as mentioned above.

10 The melt can have normal crystallisation characteristics, but when it is desired to minimise crystallisation this can be achieved by including magnesium in a rather low amount for instance 2 to 6% MgO.

15 When it is desired to provide fibres having improved fire resistance, it is generally desired to increase the amount of FeO, which preferably is then at least 6%, for instance up to 8% or higher, for instance 10%, and the MgO should then be at least 8%.

20 The analysis of the composition is preferably such that the fibres have a dissolution rate at pH 4.5 of at least 25, and preferably at least 40, nm per day. It is desirable for the dissolution rate to be as high as possible (consistent with retention of adequate humidity and heat resistance properties) but it is generally unnecessary for it to be above 150 or 100nm per day and it
25 is usually below 80nm per day.

Although a high dissolution rate at pH 7.5 has been proposed as a desirable property (as an indication of alleged biodegradability), in fact it is often an undesirable property since it is an indication of poor
30 weathering resistance when exposed to humidity. Dissolution in the lungs at pH 7.5 is not exclusively necessary for the fibres to be biodegradable. Preferably the fibres have a dissolution rate in Gambles solution at pH 7.5 of below 25, and most preferably below 15, nm per
35 day.

The viscosity of the composition at 1400°C is usually at least 12 or 15 poise and is preferably at least 18

poise. Although it can be as high as, for instance, 60 poise it is generally below 40 poise and preferably it is not more than 30 poise.

When it is desired that the fibres should have good
5 fire resistance, the analysis is preferably such that the sintering temperature is at least 800°C and preferably at least 1,000°C.

The liquidus temperature is usually at least 1200°C but often at least 1240°C. It can be as high as, for
10 instance, 1400°C but preferably it is not more than 1340°C.

An advantage of the use of the moderate aluminium melts defined for use in the invention is that it permits the inclusion in the composition of readily available materials having a moderate aluminium content such as rock,
15 sand and waste. This therefore minimises the need to use expensive, high alumina materials such as bauxite or kaolin, and minimises at the same time the need to use expensive very low alumina materials such as silica sand or olivine sand, iron ore, etc. These more expensive
20 materials may however be useful if desired. Typical, readily available, medium alumina materials that may be used as part or all of the composition include anorthosite and phonolite and gabbros.

The composition is typically formed by blending
25 appropriate amounts of naturally occurring rock and sand materials such as anorthosite, gabbros, limestone, dolomite, diabase, apatite, boron-containing materials, and waste materials such as mineral wool waste, alumina silicates, slag, in particular high alumina (20-30%) slags
30 such as ladle slag, foundry sand, filter dust, fly ash, bottom ash and high alumina waste from the production of refractory materials.

The composition can be converted to a melt in conventional manner, for instance in a gas heated furnace
35 or in an electric furnace or in a cupola furnace. An advantage of the invention is that the composition can easily have a reasonably low liquidus temperature (while

maintaining adequate viscosity at 1400°C) and this minimises the amount of energy that is required for forming the melt.

The melt can be converted to fibres in conventional manner, for instance by a spinning cup process or by a cascade rotor process, for instance as described in WO92/06047.

The fibres of the invention can have any convenient fibre diameter and length.

In this invention, dissolution rate is determined using the following test protocol.

300mg of fibres are placed in polyethylene bottles containing 500ml of a modified Gamble's solution (i.e., with complexing agents), adjusted to pH 7.5 or 4.5, respectively. Once a day the pH is checked and if necessary adjusted by means of HCl.

The tests are carried out during a one week period. The bottles are kept in water bath at 37°C and shaken vigorously twice a day. Aliquots of the solution are taken out after one and four days and analysed for Si on a Perkin-ElmerTM Atomic Absorption Spectrophotometer.

The modified Gamble's solution has the following composition:

		g/l
25	MgCl ₂ .6H ₂ O	0.212
	NaCl	7.120
	CaCl ₂ .2H ₂ O	0.029
	Na ₂ SO ₄	0.079
	Na ₂ HPO ₄	0.148
30	NaHCO ₃	1.950
	(Na ₂ -tartrate).2H ₂ O	0.180
	(Na ₃ -citrate).2H ₂ O	0.152
	90% lactic acid	0.156
	Glycine	0.118
35	Na-pyruvate	0.172
	Formalin	1 ml

The fibre diameter distribution is determined for each sample by measuring the diameter of at least 200 individual fibres by means of the intercept method and a scanning electron microscope or optical microscope (1000 x magnification). The readings are used for calculating the specific surface of the fibre samples, taking into account the density of the fibres.

Based on the dissolution of SiO_2 (network dissolution), the specific thickness dissolved was calculated and the rate of dissolution established (nm/day). The calculations are based on the SiO_2 content in the fibres, the specific surface and the dissolved amount of Si.

In this specification, the sintering temperature is determined by the following test protocol.

A sample (5 x 5 x 7.5 cm) of mineral wool made of the fibre composition to be tested is placed in a furnace preheated to 700°C. After 1.5 hours exposure the shrinkage and the sintering of the sample were evaluated. The method is repeated each time with a fresh sample and a furnace temperature 50°C above the previous furnace temperature until the maximum furnace temperature, at which no sintering or no excessive shrinkage of the sample is observed, was determined.

In this specification, the viscosity in poise at 1400°C is calculated according to Bottinga and Weill, American Journal of Science Volume 272, May 1972, page 455-475.

The following are examples of the invention.

Compositions were formed by blending appropriate proportions of raw materials as shown in the table and each was melted in a crucible furnace and was fiberised by the cascade spinner technique. The melt viscosity and solubility of each was determined. The analyses of the compositions and their properties are quoted in the following tables. In the invention, any of compositions A to X are judged to be suitable and are selected for the

subsequent manufacture of MMVF products which are labelled as having good biological solubility. Those having viscosity above 20 and pH 4.5 solubility above 30 are preferred.

5 Product 1 is similar to, commercial slag wool and gives a poor viscosity. Product 2 is a high aluminium product but the proportions of all the components are such that the melt viscosity is too high for convenient spinning. Product 3 is similar to a conventional rock wool
10 product with normal good product properties but has a very low dissolution rate at pH 4.5. Accordingly products 1, 2 and 3 are not selected for use in the manufacture of biologically soluble MMV fibre products.

Fibre Types	SiO ₂ %	Al ₂ O ₃ %	TiO ₂ %	FeO %	CaO %	MgO %	Na ₂ O %	K ₂ O %	SUM	Vis poise 1400°C	Diss rate pH 7.5 (st) nm/day	Diss rate pH 4.5 (st) nm/day	Sintering temp °C
A	34.5	28.0	1.8	3.3	25.4	5.6	0.6	0.8	100.0	21.2	9.5	34.8	>800
B	36.2	26.3	1.9	4.9	17.7	10.8	1.0	1.1	100.0	19.4	6.8	45.1	>800
C	38.3	25.0	1.7	3.0	24.9	5.6	0.7	0.8	100.0	24.7	7.4	53.8	>800
D	38.1	24.7	1.8	4.6	17.4	11.3	1.2	0.8	100.0	20.0	7.9	64.2	>800
E	43.2	20.0	1.6	5.0	16.6	11.5	1.2	0.8	100.0	22.8	5.0	57.9	>800
F	43.2	19.8	1.5	3.4	24.7	5.6	1.0	0.8	100.0	27.1	4.8	47.0	>800
G	47.7	19.4	0.8	3.7	16.6	10.8	0.4	0.4	100.0	34.7	3.0	21.0	>800
H	43.7	18.8	3.6	5.4	16.4	9.7	1.8	0.7	100.0	25.1	5.8	38.6	>800
I	45.6	18.1	1.5	5.3	16.5	9.7	2.5	0.7	100.0	30.8	3.1	44.4	>800
J	46.9	18.9	0.5	3.3	17.0	9.5	3.4	0.5	100.0	44.0	0.9	35.2	>800
K	44.1	18.7	1.6	5.2	16.5	9.8	3.3	0.7	100.0	30.3	2.6	41.1	>800
L	39.6	24.3	1.8	3.2	21.7	6.7	1.8	0.8	100.0	30.8	5.7	49	>800
M	43.8	20.4	1.2	10.3	15.6	8.3	0.2	0.3	100.0	21.9	3.9	39.7	>1000
N	42.9	23.2	0.7	8.8	17.5	5.1	0.6	1.4	100.0	36.8	-	45.9	>900
O	43.1	19.9	1.6	10.1	15.0	9.3	0.6	0.4	100.0	19.8	4.6	51.9	>1000
P	37.8	18.3	0.9	12.0	15.8	10.1	4.7	0.3	100.0	15.0	10.2	61.5	>1000
Q	40.0	22.2	2.0	7.5	15.2	10.7	1.5	0.8	100.0	19.4	7.1	61.1	>1000
R	45.4	14.5	1.6	5.6	15.3	7.2	9.0	0.9	100.0	39.9	3.1	48.1	>1000
S	45.3	17.5	1.1	5.7	20.3	7.8	1.7	0.6	100.0	25.9	1.8	48.6	>1000
T	43.1	14.0	0.7	0.5	34.3	5.2	0.7	1.5	100.0	15.2	1.5	59.8	>700
U	37.2	16.1	1.6	3.3	21.5	10.1	9.3	1.0	100.0	29.2	5.2	48.0	>800
V	42.9	16.6	1.7	6.4	16.8	9.6	5.2	0.8	100.0	25.3	3.1	21.9	>1000
W	38.9	16.4	1.4	8.4	20.0	7.9	6.4	0.6	100.0	20.2	9.5	33.0	>1000
X	42.5	16.4	1.7	5.8	21.1	6.3	5.4	0.8	100.0	27.1	4.1	32.9	>1000
1	42.7	8.8	0.3	0.4	36.9	9.4	0.7	0.3	100.0	8.2	13.9	41.1	>700
2	39.7	32.8	1.7	7.0	15.7	2.1	0.3	0.7	100.0	100.0	7.8	59.3	>1000
3	46.9	13.2	3.0	6.4	17.1	9.4	2.6	1.3	100.0	23.7	2.0	3.0	>1000

The selected fibres may be provided in any of the forms conventional for MMV fibres. Thus they may be provided as a product consisting of loose, unbonded fibres.

5 More usually they are provided with a bonding agent, for instance as a result of forming the fibres and connecting them in conventional manner. Generally the product is consolidated as a slab, sheet or other shaped article.

10 Products according to the invention may be formulated for any of the conventional purposes of MMV fibres, for instance as slabs, sheets, tubes or other shaped products that are to serve as thermal insulation, fire insulation and protection or noise reduction and regulation, or in appropriate shapes for use as horticultural growing media, or as free fibres for reinforcement of cement, plastics or
15 other products or as a filler.

CLAIMS

1. A method of making man-made vitreous fibre products comprising forming one or more mineral melt compositions and
5 forming fibres from the or each melt composition characterised in that

the melt viscosity and the fibre dissolution rate at a pH in the range 4-5 are determined for the or each composition,

10 a composition is selected which has a viscosity at 1400°C of 10 to 70 poise and provides fibres which have a dissolution rate of at least 20nm per day when measured at a pH of 4.5, and which includes, by weight of oxides,

	SiO ₂	32 to 48%
15	Al ₂ O ₃	above 16 up to 28%
	CaO	10 to below 28%
	MgO	2 to 20%
	FeO	2 to 15%
	Na ₂ O + K ₂ O	0 to 12%
20	TiO ₂	0 to 4%
	Other Elements	0 to 8%

and the selected composition is utilised for making the man-made vitreous fibres.

2. Use of a product formed of man-made vitreous fibres as
25 an insulation product in an environment where it is exposed to ambient humid conditions and where it is required to be shown to be biologically soluble, wherein the fibres are formed of a composition which includes, by weight of oxides,

	SiO ₂	32 to 48%
	Al ₂ O ₃	above 16 up to 28%
	CaO	10 to below 28%
	MgO	2 to 20%
5	FeO	2 to 15%
	Na ₂ O + K ₂ O	0 to 12%
	TiO ₂	0 to 4%
	Other Elements	0 to 8%

and the composition has a viscosity at 1400°C of 10 to
10 70 poise,

and the fibres have a dissolution rate of at least 20nm
per day when measured at a pH of 4.5.

3. A package containing a man-made vitreous fibre product
wherein the fibres are formed of a composition having an
15 analysis which includes, by weight of oxides,

	SiO ₂	32 to 48%
	Al ₂ O ₃	above 16 up to 28%
	CaO	10 to below 28%
	MgO	2 to 20%
20	FeO	2 to 15%
	Na ₂ O + K ₂ O	0 to 12%
	TiO ₂	0 to 4%
	Other Elements	0 to 8%

and the composition has a viscosity at 1400°C of 10 to
25 70 poise,

and the fibres have a dissolution rate at pH 4.5 of at least 20nm per day,

and the package includes a label or insert referring to solubility at pH 4 to 5 and/or in the environment of
5 macrophages in the lung fluid.

4. The invention according to any one of claims 1 to 3 in which the dissolution rate at pH 4.5 is 25 to 100nm per day.

5. The invention according to any one of claims 1 to 4 in which the composition has a viscosity of at least 12 poise at
10 1400°C.

6. The invention according to any one of claims 1 to 5 in which the fibres have a dissolution rate at pH 7.5 below 15nm per day.

7. The invention according to any one of claims 1 to 6 in
15 which the fibres have a sintering temperature of at least 800°C.

8. The invention according to any one of claims 1 to 7 in which the composition provides a liquidus temperature of 1240 to 1340°C.

20 9. The invention according to any one of claims 1 to 8 in which $\text{Na}_2\text{O} + \text{K}_2\text{O}$ is not more than 10%.

10. The invention according to any one of claims 1 to 9 in which Al_2O_3 is 18-28%, $\text{SiO}_2 + \text{Al}_2\text{O}_3$ is 60-75%, FeO is 2-12% and $\text{Na}_2\text{O} + \text{K}_2\text{O}$ is 0-7%.

25 11. The invention of any one of claims 1 to 9 in which the amount of Al_2O_3 is below 19%.

12. The invention according to claim 4 in which the

dissolution rate at pH 4.5 is 40 to 80nm per day.

13. The invention according to claim 7 in which the fibres have a sintering temperature of at least 1000°C.

14. The invention according to any one of claims 1 to 13 in
5 which MgO is at least 5%.

15. The invention according to any one of claims 1 to 14 in which FeO is below 10%.

16. The invention according to any one of claims 1 to 15 in which FeO is at least 5% but below 10%.

10 17. The invention according to any one of claims 1 to 16 in which the composition has a viscosity at 1400°C of 15 to less than 40 poise.

18. The invention according to any one of claims 1 to 16 in which the composition has a viscosity at 1400°C of 18 to 40
15 poise.

19. The invention according to claims 1 to 18 in which SiO₂ is below 45%.

20. The invention according to claims 1 to 19 in which SiO₂ + Al₂O₃ is below 68%.

20 21. The invention according to any one of claims 1 to 20 in which Al₂O₃ is at least 18%.

22. The invention according to any of claims 1 to 10 and 14 to 21 in which Al₂O₃ is at least 18%.

23. The invention according to claim 22 in which Al₂O₃ is up
25 to 26%.

24. The invention according to any one of claims 1 to 23 in which TiO_2 is at least 0.5%.

25. Use of a melt composition to make man-made vitreous fibres which are shown to be biodegradable in the lung
5 wherein the composition has an analysis, measured as weight of oxides, which includes

	SiO_2	32 to 45%
	Al_2O_3	above 16 up to 28%
	CaO	10 to 30%
10	MgO	2 to 20%
	FeO	2 to 15%
	$\text{Na}_2\text{O} + \text{K}_2\text{O}$	0 to 12%
	TiO_2	0 to 4%
	Other Elements	0 to 8%

15 and the composition has a melt viscosity at 1400°C of 10 to 70 poise, and in which the fibres have a dissolution rate at pH 4.5 of at least 20nm per day.

26. Use according to claim 25 in which the fibres are the fibres of a bonded product.

20 27. Use according to claim 25 or claim 26 in which the fibres are the fibres of a bonded product which is used as thermal insulation, fire insulation or protection, or noise regulation or protection.

25 28. Use according to claim 25 or claim 26 in which the fibres of a bonded product which is used as horticultural growth medium.

29. Use according to claim 25 in which the fibres are used

in free form as reinforcement or as a filler.

30. Use according to any one of claims 25 - 29 in which the fibres are shown to be biodegradable in the lung by determination of solubility in the environment or macrophages
5 in the lung.

31. Use according to any one of claims 25 - 30 wherein the sintering temperature of the fibres in mineral wool formed from the fibres is at least 800°C.

32. Use according to any one of claims 25 - 31 in which the
10 amount of $\text{SiO}_2 + \text{Al}_2\text{O}_3$ is below 68%.

33. Use according to any one of claims 25 - 32 in which the amount of magnesium expressed as MgO is at least 5% up to 20%.

34. Use according to any one of claims 25 - 33 in which the
15 amount of iron, expressed as FeO , is below 10%.

35. Use according to any one of claims 25 - 34 in which the amount of iron, expressed as FeO , is at least 5%.

36. Use according to any one of claims 25 - 35 in which the amount of aluminum, expressed as Al_2O_3 is at least 18%.

20 37. A use according to claim 36 in which the amount of Al_2O_3 is at least 20%.

38. A use according to claim 36 in which the amount of Al_2O_3 is 20% to 26%.

39. A use according to any one of claims 25 - 38 in which
25 the amount of SiO_2 is below 42%.

40. A use according to any one of claims 25 - 39 in which

the amount of titanium, express as TiO_2 is at least 0.5%.

41. A use according to any one of claims 25 - 40 in which the fibres have a dissolution rate at pH 7.5 below 15nm per day.

5 42. A use according to any one of claims 25 - 41 in which the composition provides a liquidus temperature of 1240 to 1340°C.

43. A method of making a shaped article formed of bonded man-made vitreous fibres comprising

10 forming one or more mineral melt compositions,

determining the melt viscosity for the or each composition,

forming fibres from the or each melt,

15 determining the solubility of the fibres in the environment of macrophages in the lung,

selecting, on the basis of these determinations, a composition which has a viscosity at 1400°C of 10 to 70 poise and provides fibres which have a dissolution rate of at least 20nm per day calculated from the amount of Si in solution in
20 modified Gambles solution at a pH of 4.5 after one day's immersion and after four days immersion, and which includes, by weight of oxides,

SiO_2 32 to below 45%

Al_2O_3 above 16 to 23%

25 CaO 10 to below 28%

MgO 2 to 20%

FeO 2 to 15%

Na ₂ O + K ₂ O	0 to 12%
TiO ₂	0 to 4%
Other Elements	0 to 8%
SiO ₂ + Al ₂ O ₃	below 68%

5 making man-made vitreous fibres from the selected composition,

providing the fibres with a bonding agent and

consolidating the fibres into the shaped article.

10 44. A method according to claim 43 wherein the sintering temperature of the fibres in mineral wool formed from the fibres is at least 800°C.

45. A method according to claim 43 or claim 44 in which the amount of magnesium expressed as MgO is at least 5% up to 20%.

15 46. A method according to any one of claims 43 - 45 in which the amount of iron, expressed as FeO, is below 10%.

47. A method according to any one of claims 43 - 46 in which the amount of iron, expressed as FeO, is at least 5%.

20 48. A method according to any one of claims 43 - 47 in which the amount of aluminum, expressed as Al₂O₃, is at least 18%.

49. A method according to claim 48 in which the amount of Al₂O₃ is at least 20%.

50. A method according to any one of claims 43 - 49 in which the amount of SiO₂ is up to 42%.

25 51. A method according to any one of claims 43 - 50 in which

the amount of titanium, expressed as TiO_2 , is at least 0.5%.

52. A method according to any one of claims 43 - 51 in which the fibres have a dissolution rate at pH 7.5 below 15nm per day.

5 53. A method according to any one of claims 43 - 52 in which the composition provides a liquidus temperature of 1240 to 1340°C.

54. Use as biodegradable man-made vitreous fibres of man-made vitreous fibres formed of a composition which includes,
10 by weight of oxides,

	SiO_2	32 to 48%
	Al_2O_3	above 16 to 28%
	CaO	10 to 30%
	MgO	2 to 20%
15	FeO	2 to 15%
	$\text{Na}_2\text{O} + \text{K}_2\text{O}$	0 to 12%
	TiO_2	0 to 6%
	Other Elements	0 to 15%

and the composition has a viscosity at 1400°C of 10 to
20 70 poise.

55. Use in mineral fibre products as biodegradable fibres of man-made vitreous fibres formed of a composition which includes, by weight of oxides,

	SiO_2	32 to 48%
25	Al_2O_3	above 16 to 28%
	CaO	10 to 30%

	MgO	2 to 20%
	FeO	2 to 15%
	Na ₂ O + K ₂ O	0 to 12%
	TiO ₂	0 to 6%
5	Other Elements	0 to 15%

and the composition has a viscosity at 1400°C of 10 to 70 poise.

56. Use in mineral fibre products of man-made vitreous fibres which are shown to be biodegradable in the lung, wherein the fibres are formed of a composition which includes, by weight of oxides,

	SiO ₂	32 to 48%
	Al ₂ O ₃	above 16 to 28%
	CaO	10 to 30%
15	MgO	2 to 20%
	FeO	2 to 15%
	Na ₂ O + K ₂ O	0 to 12%
	TiO ₂	0 to 6%
	Other Elements	0 to 15%

20 and the composition has a viscosity at 1400°C of 10 to 70 poise.

57. Use of fibres as biodegradable products, wherein the fibres are man-made vitreous fibres formed of a composition which includes, by weight of oxides,

25	SiO ₂	32 to 48%
	Al ₂ O ₃	above 16 to 28%

	CaO	10 to 30%
	MgO	2 to 20%
	FeO	2 to 15%
	Na ₂ O + K ₂ O	0 to 12%
5	TiO ₂	0 to 6%
	Other Elements	0 to 15%

and the composition has a viscosity at 1400°C of 10 to 70 poise.

58. A use according to any one of claims 55 - 57 in which
10 the product is a bonded product.

59. A use according to claim 57 in which the bonded product is used as thermal insulation, fire insulation or protection, noise regulation or protection, or as a horticultural growth medium.

15 60. Use according to any one of claims 54 - 59 in which the fibres are shown to be biodegradable in the lung by determination of solubility in the environment or macrophages in the lung.

20 61. Use according to any one of claims 54 - 60 in which the fibres have a dissolution rate of at least 20nm per day calculated from the amount of Si in solution in modified Gambles solution at pH 4.5 after one day's immersion and after four days' immersion.

25 62. Use according to any one of claims 55 - 61 wherein the sintering temperature of the fibres in mineral wool formed from the fibres is at least 800°C.

63. Use according to any one of claims 54 - 62 in which the fibres have an analysis, measured as weight of oxides, which

includes

	SiO ₂	32 to below 45%
	Al ₂ O ₃	above 16 to 28%
	CaO	10 to 30%
5	MgO	2 to 20%
	FeO	2 to 15%
	Na ₂ O + K ₂ O	0 to 12%
	TiO ₂	0 to 4%
	Other Elements	0 to 8%

10 and the amount of SiO₂ + Al₂O₃ is below 68%.

64. Use according to any one of claims 54 - 63 in which the amount of magnesium expressed as MgO is at least 5% up to 20%.

65. Use according to any one of claims 54 - 64 in which the
15 amount of iron, expressed as FeO, is below 10%.

66. Use according to any one of claims 54 - 65 in which the amount of iron, expressed as FeO, is at least 5%.

67. Use according to any one of claims 54 - 66 in which the amount of aluminum, expressed as Al₂O₃, is at least 18%.

20 68. A use according to claim 67 in which the amount of Al₂O₃ is at least 20%.

69. A use according to claim 67 in which the amount of Al₂O₃ is 20 to 26%.

70. A use according to any one of claims 54 - 69 in which
25 the amount of SiO₂ is below 42%.

71. A use according to any one of claims 54 - 70 in which the amount of titanium, expressed as TiO_2 , is at least 0.5%.

72. A use according to any one of claims 54 - 71 in which the fibres have a dissolution rate at pH 7.5 below 15nm per
5 day.

73. A use according to any one of claims 54 - 72 in which the composition provides a liquidus temperature of 1240 to 1340°C.

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