MAN-MADE MINERAL FIBRES

1. Chemical and Physical Data

'Man-made mineral fibres' is a generic term that denotes fibrous inorganic substances made primarily from rock, clay, slag or glass. These fibres can be classified into three general groups: glass fibres (comprising glasswool and glass filament), rockwool and slagwool, and ceramic fibres.

'Mineral wool' is a term that has been used to describe rockwool, slagwool and, in some publications, also glasswool. In this monograph, the terms 'rockwool', 'slagwool' and 'glasswool' are used rather than 'mineral wool', whenever possible.

The term 'wool' is used synonymously with fibre when describing vitreous or glassy material that has been attenuated without the use of a nozzle. Fibres that are drawn through nozzles are referred to as filaments or continuous fibres (Loewenstein, 1983; World Health Organization, 1983).

Synonyms and trade names[1]:

Glasswool: JM (Johns Manville) 100; JM 102; JM 104; JM 110
Glass filament: ES 3; ES 5; ES 7
Rockwool: G + H
Slagwool: RH; ZI
Ceramic fibre: Fiberfrax; Fibermax; Fireline Ceramic; Fybex; MAN; Nextel; PKT; Saffil

1.1 Glass fibres

Glass fibre is produced either as glasswool or glass filament. Glasswool is produced by drawing, centrifuging or blowing molten glass and comprises cylindrical fibres of relatively short length (compared to filaments) (Boyd & Thompson, 1980; McCrone, 1980). Glass filaments are continuously drawn or extruded from molten glass. This class of materials includes longer, large-diameter filaments for textile and reinforcing applications as well as fine-diameter filaments (Mohr & Rowe, 1978).

[1]Only those synonyms and trade names used in this monograph are listed.

In the production of glass fibres, finely-powdered sand is used as the major source of silica, and kaolin clay and synthetic aluminium oxides are the most common sources of aluminium. Boric oxide is introduced primarily from colemanite (a natural calcium borate), boric acid and boric acid anhydride. Powdered dolomite [$CaMg(CO_3)_2$] or burnt dolomite ($MgO.CaO$) is used to introduce magnesium oxide (magnesia) and calcium oxide. Uncalcined and calcined limestone are used as magnesia-free sources of calcium oxide. Fluorspar (CaF_2) is used to introduce fluoride. Sodium sulphate is added to the glass mixture as a firing agent and to assist in dissolving residual grains of sand. Iron oxide (Fe_2O_3) may be added to assist the fibre-drawing process (Loewenstein, 1983; Harben & Bates, 1984).

Compositions of some types of glass used in fibre manufacture are shown in Table 1.

Table 1. Composition (% by weight) of glasses[a] used in fibre manufacture[b]

Component	Glass type					
	E	C	A	S	Cemfil	AR
SiO_2	55.2	65	72.0	65.0	71	60.7
Al_2O_3	14.8	4	2.5	25.0	1	–
CaO	18.7	14	9.0	–	–	–
MgO	3.3	3	0.9	10.0	–	–
B_2O_3	7.3	5	0.5	–	–	–
Na_2O	0.3	8.5	12.5	–	11	14.5
K_2O	0.2	–	1.5	–	–	2.0
ZrO_2	–	–	–	–	16	21.5
Li_2O	–	–	–	–	1	1.3
F_2[c]	0.3	–	–	–	–	–
Fe_2O_3	0.3	0.3	0.5	trace	trace	trace

[a]E, electrical fibre component; C, chemical glass (used in, e.g., surfacing mats for corrosion resistance); A, common soda lime type; S, high-strength, high-modulus (for high-performance structures); AR, alkali resistant (for reinforcement of concrete)

[b]From Loewenstein (1983)

[c]Fluorine present in glass presumably as fluorides

'E' glass was first developed for electrical applications, but currently over 99% of all continuous filament produced is of this type. 'E' glass is generally not defined by composition, but rather by its electrical properties, which are related to its low alkali oxide content (less than 1% sodium, potassium or lithium oxide) (Loewenstein, 1983). 'E' glass is insoluble in hydrochloric acid (Miller, 1975).

'C' glass is characteristic of the glass types used to produce glasswool. It is chemically resistant and is also used in composites that come into contact with mineral acids and as a reinforcement material in bituminous roofing sheet (Loewenstein, 1983).

'A' glass, produced from inexpensive glass scrap, is a soda-lime–silica glass. It currently represents an insignificant proportion of world fibre production (Loewenstein, 1983) and is used only in glass fibre insulation (Watts, 1980).

'S' glass is a high-strength glass developed in about 1960 for applications such as rocket motor cases. Produced only in the USA, it is difficult and costly to make and is therefore limited to very sophisticated, high-technology use (Loewenstein, 1983).

'Cemfil' and 'AR' glass are used for cement reinforcement. These fibres, designed to impart strength and support, can reinforce 20–30 times their weight of cement (Loewenstein, 1983). 'Cemfil' and 'AR' glass differ in composition from other glasses by the inclusion of zirconium oxide, which provides the alkali-resistant property necessary for cement reinforcement but also renders the glass more difficult to process (Lee, 1983).

Table 2 presents the composition of some typical commercial glass fibres based on another classification of glass types (low alkali, lime-alumina borosilicate [I]; soda-lime borosilicate [II, III]; soda-lime [IV]; lime-free borosilicate [V]; and high lead silicate [VI]).

Table 2. Composition (% by weight) of some typical commercial glass fibres[a]

Component	Glass type					
	I	II	III	IV	V	VI
SiO_2	54.5	65.0	59.0	73.0	59.5	34.0
Al_2O_3	14.5	4.0	4.5	2.0	5.0	3.0
CaO	22.0	14.0	16.0	5.5	–	–
MgO	–	3.0	5.5	3.5	–	–
B_2O_3	8.5	5.5	3.5	–	7.0	–
Na_2O	0.5	8.0	11.0	16.0	14.5	0.5
K_2O	–	0.5	0.5	–	–	3.5
ZrO_2	–	–	–	–	4.0	–
TiO_2	–	–	–	–	8.0	–
PbO	–	–	–	–	–	59.0
F[b]	–	–	–	–	2.0	–

[a]From National Institute for Occupational Safety and Health (1977a)

[b]Fluorine present in glass presumably as fluorides

Type IV is used very frequently in glass fibres. Table 3 presents some of the characteristics and physical properties of fibrous glass made from these six glass types (National Institute for Occupational Safety and Health, 1977a).

Glass filaments are primarily made from 'E' glass with the following typical composition (% by mass): SiO_2, 53.5–55.5; CaO, 21.0–24.0; Al_2O_3, 14.0; B_2O_3, 5.0–8.0; alkaline oxides, 0.5–1.5; CaF_2, 0.0–0.8; MgO, 0–2; minor oxides, <1.0. Glass filaments exhibit the following properties: high tensile strength, dimensional stability, high heat resistance, resistance to chemical attack, high thermal conductivity, low moisture absorption, high dielectric strength and flame resistance. One type of glass filament has a softening point of 849°C and a specific gravity of 2.63 g/cm^3 (PPG Industries, 1984).

Table 3. Characteristics and physical properties of some commercial fibrous glass[a]

Glass type	Form	Fibre diameter range (μm)	Specific gravity (g/cm³)	Refractive index
I	Textiles, mats	6–9.5	2.596	1.548
II	Mats Textiles	10–15 6–9.5	2.540	1.541
III	Wool (coarse)	7.5–15	2.605	1.549
IV	Packs (coarse)	115–250	2.465	1.512
V	Wool, fine ultrafine	0.75–5 0.25–0.75	2.568	1.537
VI	Textiles	6–9.5	4.3	–

[a]From National Institute for Occupational Safety and Health (1977a)

The fibre size of bulk fibrous glass is characterized by the nominal diameter (the median distribution of length-weighted diameters in random bulk samples of the product). Table 4 shows a system that is used to designate glass fibre materials by their nominal diameter ranges. Tables 5 gives the nominal fibre diameters and the types of binders used for a number of commercial products. The most common resins are phenol-formaldehyde and melamine-formaldehyde (Dement, 1975). More recent data suggest that somewhat lower nominal fibre sizes are associated with building insulation; 3.75–7.5 μm for low-density products and up to 15 μm for roof boards (Owens-Corning Fiberglas Corp., 1987).

Table 4. US glass fibre size designations and associated diameters[a]

Fibre size designation	Nominal diameter (μm)		Fibre size designation	Nominal diameter (μm)	
	Min	Max		Min	Max
AAAAA	0.05	0.20	J	11.43	12.70
AAAA	0.20	0.50	K	12.70	13.97
AAA	0.50	0.75	L	13.97	15.24
AA	0.75	1.50	M	15.24	16.51
A	1.50	2.52	N	16.51	17.78
B	2.52	3.81	P	17.78	19.05
C	3.81	5.08	Q	19.05	20.32
D	5.08	6.35	R	20.32	21.58
E	6.35	7.62	S	21.58	22.86
F	7.62	8.89	T	22.86	24.13
G	8.89	10.12	U	24.13	25.40
H	10.12	11.43			

[a]From Corn (1979)

Table 5. Nominal fibre diameters and binders for commercial fibrous glass products[a]

Product	Nominal fibre diameter (μm)	Type of binder
Wool products		
General thermal insulation	6–15	Resin
Moulded pipe insulation	7–9	Resin
Lightweight aircraft insulation	1.0–1.5	Resin
High-temperature insulation and filter paper	0.05–3.0	Resin
Textile products		
Continuous filament electrical insulation	6–9.5	Coatings
'Silver' type electrical insulation	7–9.5	Lubricant
Plastic reinforcing mat	6–9.5	Resin
Wrap-on pipe insulation	3.5	Resin

[a]From Dement (1975)

Individual fibres in a given product have a range of diameters. The range is generally small for continuous filaments and much wider for wool-type fibres.

1.2 Rockwool and slagwool

Rockwool and slagwool are produced by blowing, centrifuging or drawing molten rock or slag.

Rockwool is typically made from igneous rocks such as diabase, basalt and olivine, and carbonate rocks containing 40-60% calcium and magnesium carbonates (Mansmann *et al.*, 1976; Fowler, 1980; World Health Organization, 1983). Rockwool remains in the glassy state because it is cooled so rapidly that it does not recrystallize. It dissolves in dilute hydrochloric acid (Miller, 1975).

Slagwool is made from the fused agglomerate by-products of certain metal smelting processes (Mansmann *et al.*, 1976; Fowler, 1980; World Health Organization, 1983) and its composition is thus a reflection of the range of components in the different slags used in the melt (Stettler *et al.*, 1982). The properties of the fibre vary not only according to the sources of raw material but also from batch to batch. One typical composition (%) is: SiO_2, 41; Al_2O_3, 11; CaO, 35; MgO, 6; Fe_2O_3, 5; miscellaneous, 2 (some sulphur is present). Slagwool made from Alabama furnace slags had the following composition (%): SiO_2, 33–36; Al_2O_3, 11–14; CaO, 35–42; MgO, 6–13; Fe_2O_3, 0–23; S, trace–1.66. The absence of significant amounts of sodium and boron is typical of slagwool; it is essentially a calcium aluminium silicate with varying amounts of magnesium and iron, and is usually slightly soluble in hydrochloric acid (Miller, 1975).

The composition of some European and US rockwool and slagwool insulation materials is given in Table 6 (Mansmann *et al.*, 1976; Owens-Corning Fiberglas Corp., 1987). The nominal diameters of rockwool and slagwool products are typically 3–8 μm (Cherrie *et al.*, 1986).

Table 6. Composition (% by weight) of insulation-type rockwool and slagwool fibres[a]

Component	Rockwool[a]			Slagwool[a]		Darkwool[b]		Diabase or basalt fibres[b]		
	1	2	3	1	2	USG Tacoma dark steel slagwool	Rockwool industries	Gullfibre	Fibre in low density tile	German basalt fibres
SiO_2	52.92	47.5	45.54	41.0	40.58	40.97	39.11	42.92	46.94	44.31
Al_2O_3	6.52	13.0	13.38	11.8	12.52	5.09	7.44	12.56	13.40	12.53
MgO	–	–	–	–	–	7.54	8.92	6.79	10.34	10.49
CaO	30.28	16.0	10.80	40.0	37.50	19.69	31.89	29.65	16.85	11.46
FeO	1.01	7.0	5.75	0.9	1.0	21.10	8.97	2.15	6.56	11.07
TiO_2	0.51	1.5	1.99	0.4	0.44	0.28	0.35	2.47	1.83	2.43
MnO	0.06	0.5	0.24	0.6	0.30	0.06	0.47	0.68	0.15	0.20
Na_2O	2.29	2.5	2.52	0.2	1.45	0.71	0.34	1.24	2.34	3.75
K_2O	1.57	1.0	1.36	0.4	0.30	0.73	0.76	0.67	0.87	1.66
SO_3	–	–	–	–	–	3.29	0.46	0.46	0.04	–
P_2O_5	0.15	–	0.06	0.3	0.21	0.29	0.30	0.08	0.27	1.17
Fe_2O_3	1.48	0.5	8.22	–	–	–	–	–	–	–
CaS	–	–	–	–	1.04	–	–	–	–	–
S	–	–	–	0.4	0.46	–	–	–	–	–
F[c]	–	–	–	0.4	–	–	–	–	–	–

[a]From Mansmann *et al.* (1976)

[b] From Owens-Corning Fiberglas Corp. (1987)

[c]Fluorine present in glass presumably as fluorides

1.3 Ceramic fibres

Ceramic fibres comprise a wide range of amorphous or crystalline, synthetic mineral fibres characterized by their refractory properties (i.e., stability at high temperatures). Ceramic fibres are typically made of alumina, silica and other metal oxides or, less commonly, of nonoxide materials, such as silicon carbide (Arledter & Knowles, 1964). Most ceramic fibres are composed of alumina and silica in an approximate 50/50 mixture. Monoxide ceramics, such as alumina and zirconia, are composed of at least 80% of one oxide, by definition; usually, they contain 90% or more of the base oxide, and specialty products may contain virtually 100%. Other ceramic fibres prepared for special applications may incorporate thoria, magnesia, berylia, titania, hafnia, yttria or potassium titanate. Nonoxide specialty ceramic fibres, such as silicon carbide, silicon nitride and boron nitride, have also been produced (Arledter & Knowles, 1964; Miller, 1982; US Environmental Protection Agency, 1986; Anon., 1987a).

Alumina-silica ceramic fibre may be manufactured in two types: ceramic refractory fibre and ceramic textile fibre. The main distinction between the two fibre types is their size. Ceramic textile fibres are typically longer, ranging from about 155 to 250 mm in length, and have diameters that range from 11 to 20 μm. Refractory fibres are smaller and shorter than textile fibres, with average diameters of 2.2–5.0 μm and lengths varying from 40 to 250 mm. Over 90% of ceramic fibres produced in the USA are refractory fibres (US Environmental Protection Agency, 1986).

Table 7 presents typical composition and Table 8 chemical and physical properties of some commercial ceramic fibres (Zircar Products, 1978a,b; Sohio Carborundum Co., 1986; Fireline, undated; 3M Center, undated; Zircar Products, undated).

Table 7. Typical composition of some commercial ceramic fibres[a]

Component (% by weight)	Fiberfrax® bulk	Fiberfrax® long staple	Fibermax® bulk	Fiberfrax® HSA	Alumina bulk (Saffil®)	Zirconia bulk	Fireline ceramic	Nextel® 312 fibre
Al_2O_3	49.2	44.0	72.0	43.4	95.0	–	95 and 97.25	62.0
SiO_2	50.5	51.0	27.0	53.9	5.0	<0.3		24.0
ZrO_2	–	5.0	–	–	–	92.0	–	–
Fe_2O_3	0.06	–	0.02	0.8	–	–	0.97 and 0.53	–
TiO_2	0.02	–	0.001	1.6	–	–	1.27 and 0.70	–
K_2O	0.03	–	–	0.1	–	–	–	–
Na_2O	0.20	–	0.10	0.1	–	–	0.15 and 0.08	–
CaO	–	–	0.05	–	–	–	0.07 and 0.04	–
MgO	–	–	0.05	–	–	–	Trace	–
Y_2O_3	–	–	–	–	–	8.0	–	–
B_2O_3	–	–	–	–	–	–	0.06 and 0.03	14.0

Table 7 (contd)

Component (% by weight)	Fiberfrax® bulk	Fiberfrax® long staple	Fibermax® bulk	Fiberfrax® HSA	Alumina bulk (Saffil®)	Zirconia bulk	Fireline ceramic	Nextel® 312 fibre
Leachable chlorides (ppm [mg/kg])	<10	<10	11	<10	–	–	–	–
Organics	–	–	–	–	–	–	2.47 and 1.36	–

[a]From Zircar Products (1978a,b); Sohio Carborundum Co. (1986); Fireline (undated); 3M Center (undated); Zircar Products (undated)

Table 8. Chemical and physical properties of some typical ceramic fibres[a]

Fibre trade name	Description	Melting-point (°C)	Specific gravity (g/cm³)	Fibre diameter (mean; μm)	Fibre length (mean; mm)	Fibre surface area (m²/g)
Fiberfrax® bulk[b]	White	1790	2.73	2–3	Up to 102	0.5
Fiberfrax® long staple[b]	White	1790	2.62	5 and 13	Up to 254	NA
Fibermax® bulk[b]	White, mullite polycrystalline	1870	3	2–3.5	NA	7.65
Fiberfrax® HSA[b]	White to light-grey	1790	2.7	1.2	3	2.5
Alumina bulk (Saffil®)[c]	White	2040	0.096	3	3	NA
Zirconia bulk[d]	White	2600	0.24–0.64	3–6	1.5	NA
Fireline ceramic[e]	White to cream	1700	NA	NA	NA	NA
Nextel® 312 fibre[f] (filament)	White, smooth, transparent, continuous polycrystalline metal oxide	1700	>2.7	8–12	Continuous	<1

[a]From Zircar Products (1978a,b); Sohio Carborundum Co. (1986); Fireline (undated); 3M Center (undated); Zircar Products (undated)

[b]Resistant to attack from most corrosive agents, except hydrofluoric acid, phosphoric acid and strong alkalies; resistant to oxidation and reduction; high temperature stability, low thermal conductivity, low heat storage, thermal shock resistance, light weight, excellent sound absorption

[c]Corrosion resistant; light weight, low thermal conductivity, low thermal mass, thermal shock resistance, high dimensional stability, high temperature resilience, refractoriness

[d]Resistant to oxidation and reduction; low thermal conductivity, great refractoriness

[e]Highly resistant to attack from most corrosive agents, except hydrofluoric acid, phosphoric acid and certain strong alkalies; low thermal conductivity, light weight, thermal shock resistance, moisture resistance

[f]Corrosion resistant, except for phosphates, alkali metal salts, colloidal silica, colloidal alumina and castable refractory cements and mortars; compatible with silicone, epoxy, and phenolic and polyimide matrix materials; high temperature stability, dimensional stability, low specific heat, thermal shock resistance, low thermal conductivity, high electrical resistance, moisture resistance, abrasion resistance

NA, not available