The Production and Applications of High Temperature Insulating Wool

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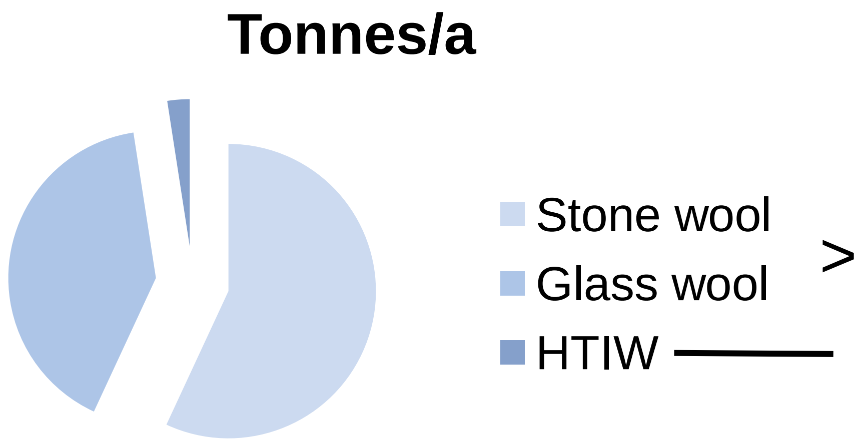
FIBRE

Bulk
Blanket
Modules
Converted
Paper

Scene Setting: HTIW in context

- HTIW = High Temperature Insulating Wool
- HTIW are inorganic insulating wools capable of use above 800ºC (others may say >1000ºC) in industrial processes.
- The vast majority of inorganic insulating wools are glass or stonewool and work at lower temperatures.
- The predominant use of glass and stone wool is in building insulation
- Order of magnitude volumes:



>10×10^6 Tonnes/a

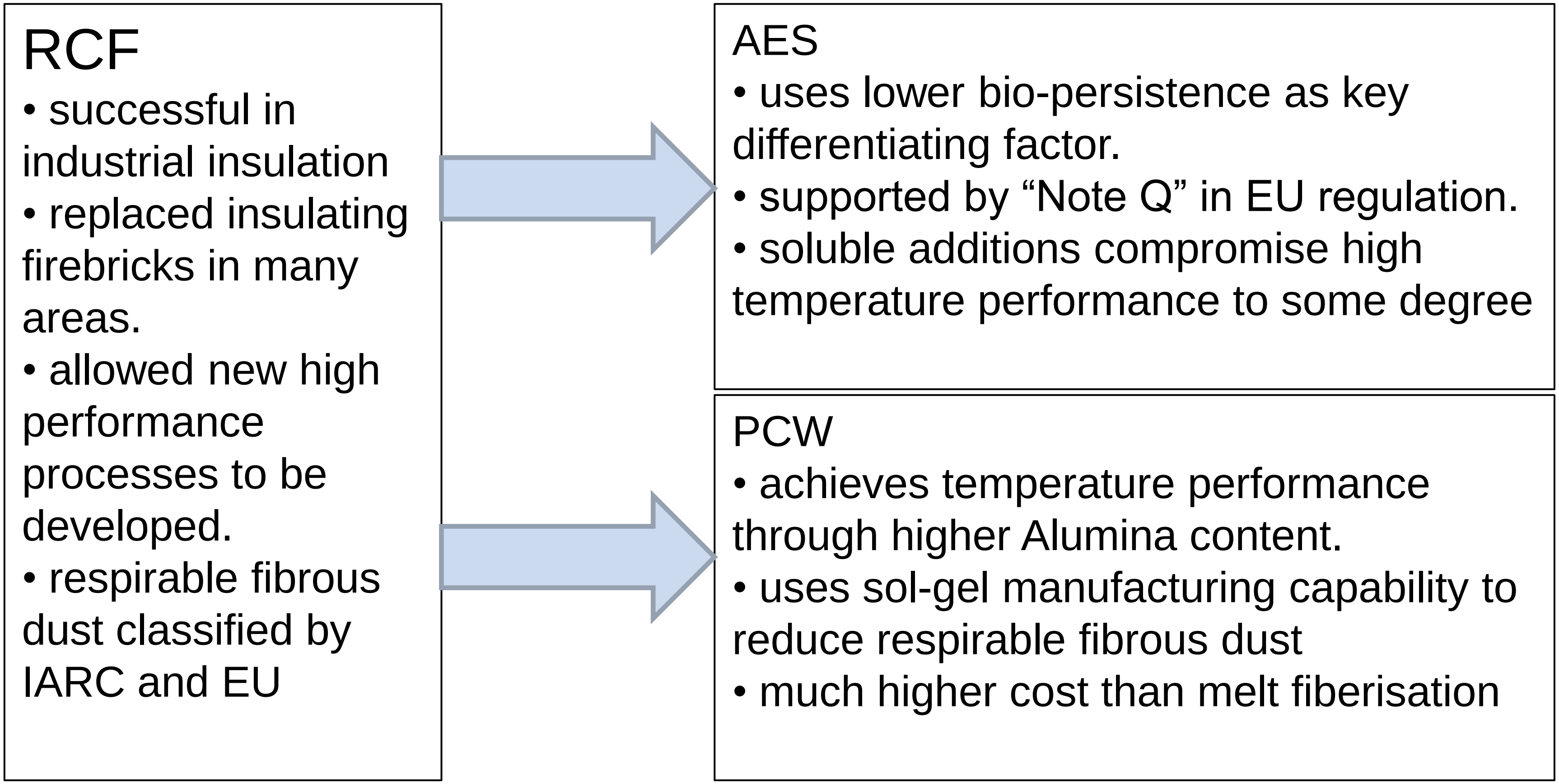
0.3×10^6 Tonnes/a

Breaking down the HTIW family into groups

HTIW sub-group	**AES**	**RCF**	**PCW**
% global tonnage (approximate)	25%	72%	3%
origins	1990’s	1950’s	1980’s
Typical constituents	CaO, MgO, SiO_2	ZrO_2, Al_2O_3, SiO_2	Al_2O_3, SiO_2
Use temperature	<1150ºC	<1250ºC	<1450ºC
IARC class	-	2b	2b
EU CLP	-	1b	-
Manufacturing process	Melt fiberisation	Melt fiberisation	Sol-gel fiberisation

Note: this table is given to create in impression of the global HTIW market. In each sub-group there are various fibre types and so this table is inevitably a simplification.

The evolution of HTIW reflects fibre toxicology results



RCF

- successful in industrial insulation
- replaced insulating firebricks in many areas.
- allowed new high performance processes to be developed.
- respirable fibrous dust classified by IARC and EU

AES

- uses lower bio-persistence as key differentiating factor.
- supported by “Note Q” in EU regulation.
- soluble additions compromise high temperature performance to some degree

PCW

- achieves temperature performance through higher Alumina content.
- uses sol-gel manufacturing capability to reduce respirable fibrous dust
- much higher cost than melt fiberisation

Example of an RCF application – steel heat treatment

The furnace lining and door seals use RCF – this is the everyday environment for HTIW products

Melt fiberisation – basic steps

1. Raw material powders are mixed in the correct proportions.
2. The powder is added to an electric arc melting furnace. Powder is added at the top at the same rate as molten material is drained from the bottom.
3. The “tap stream” leaves the furnace through a refractory nozzle and falls to the point of fiberisation.
4. The tap stream is atomised and then accelerated by air currents to draw out fibres. Atomisation can be done by high pressure air jets (blowing) or using steel rotors (spinning).
5. The fibres form with a diameter determined by viscosity, accelerating forces and cooling rate.

RCF fiberisation by blowing and spinning

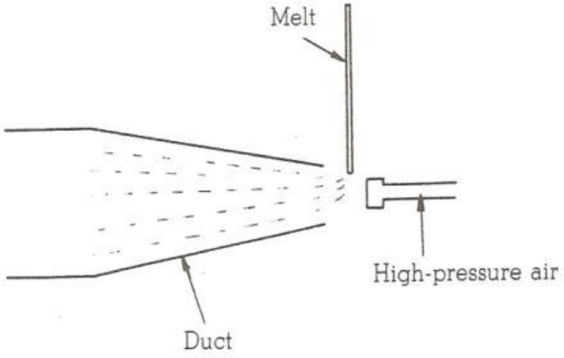


Fig. 1.2. Blowing process to make fiber

Characterised by very short atomisation period: eg 2 ms. This tends to create a relatively uniform fiberisation

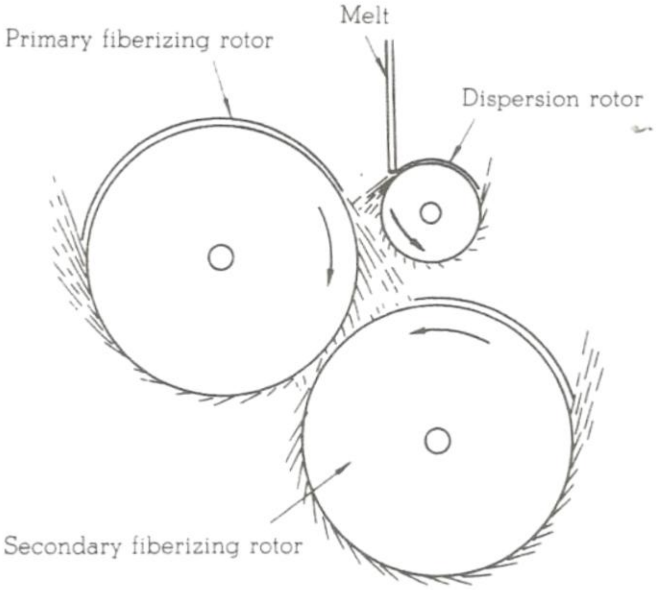
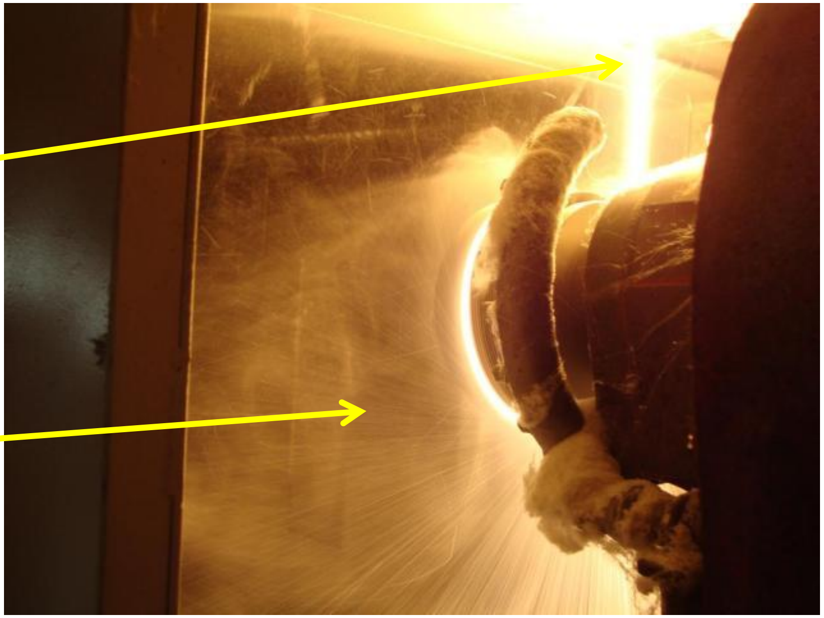


Fig. 1.3. Spinning process to make fiber

Characterised by a longer atomisation period: eg 10 ms during which the melt loses heat to the steel rotors

Pictures of fibre production (hiding the confidential bits!)

Raw material powder on top of melt pool. Electrodes clearly visible.



Tap stream

Spinning in action

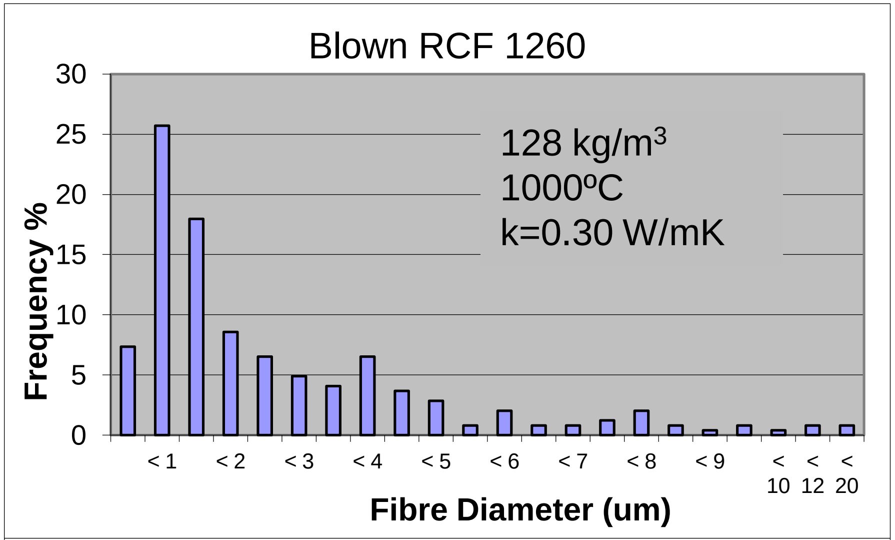
fibres

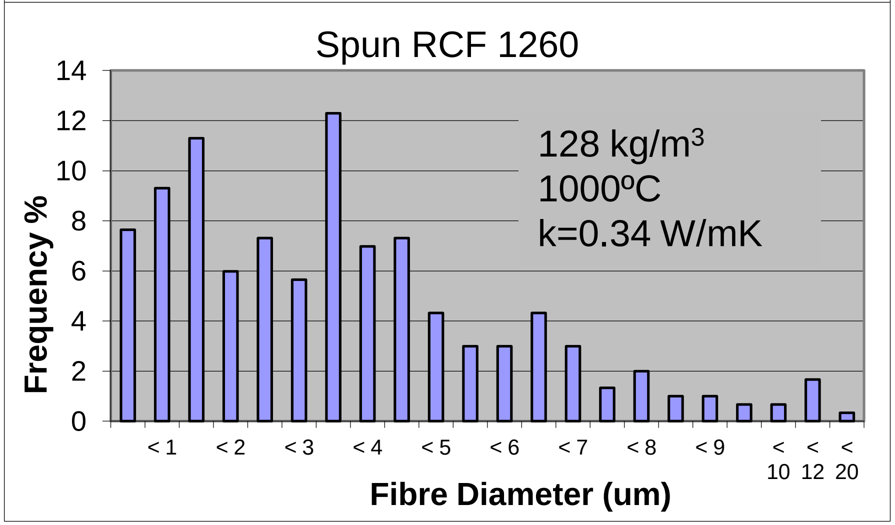
Typical downstream processing

Fibre fleece before needling

Blanket after needling, but before edge trimming

Fibre diameter distribution – spun and blown RCF





- Blown RCF is richer in fine fibres
- Spun RCF produces a broader spectrum of fibre diameter.
- In blown, finer fibres improve thermal conductivity
- Production of 1µm fibres is a natural consequence of tap stream viscosity and rapid acceleration forces.
- Spinning process produces more coarse fibres as the melt cools in contact with the steel rotors and the acceleration forces are less violent.

Mathematical model of fibre formation

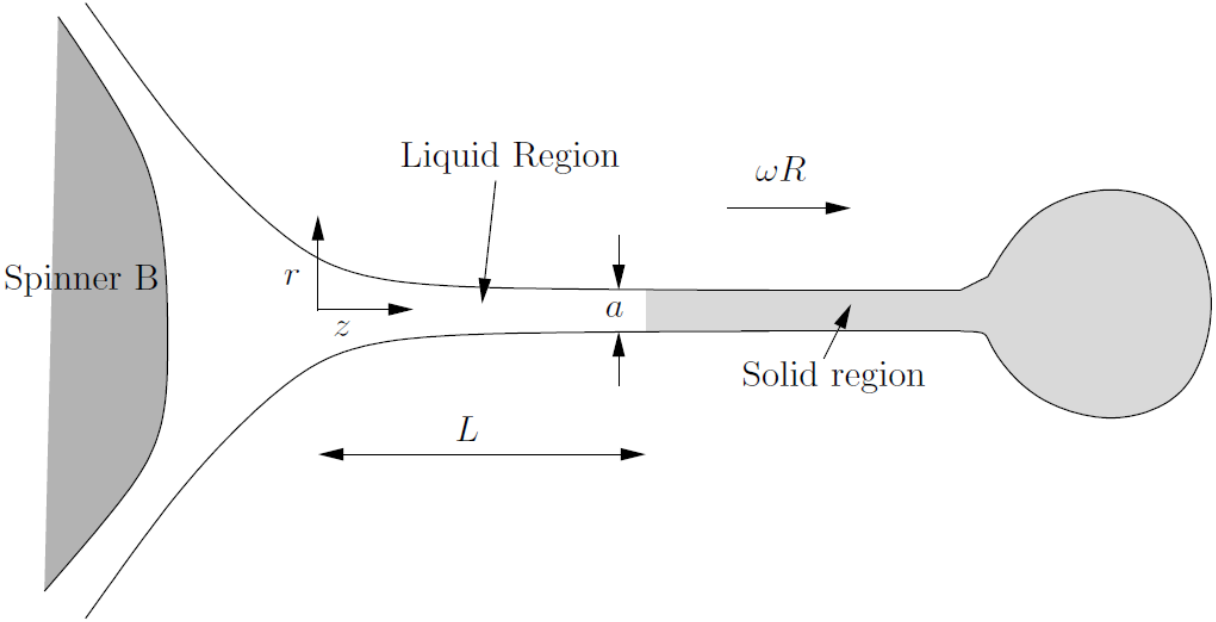
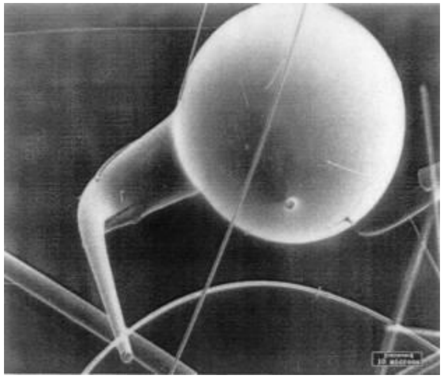


Figure 11: Schematic showing the shot and fibre leaving wheel B



Micrograph of shot particle with fibre attached

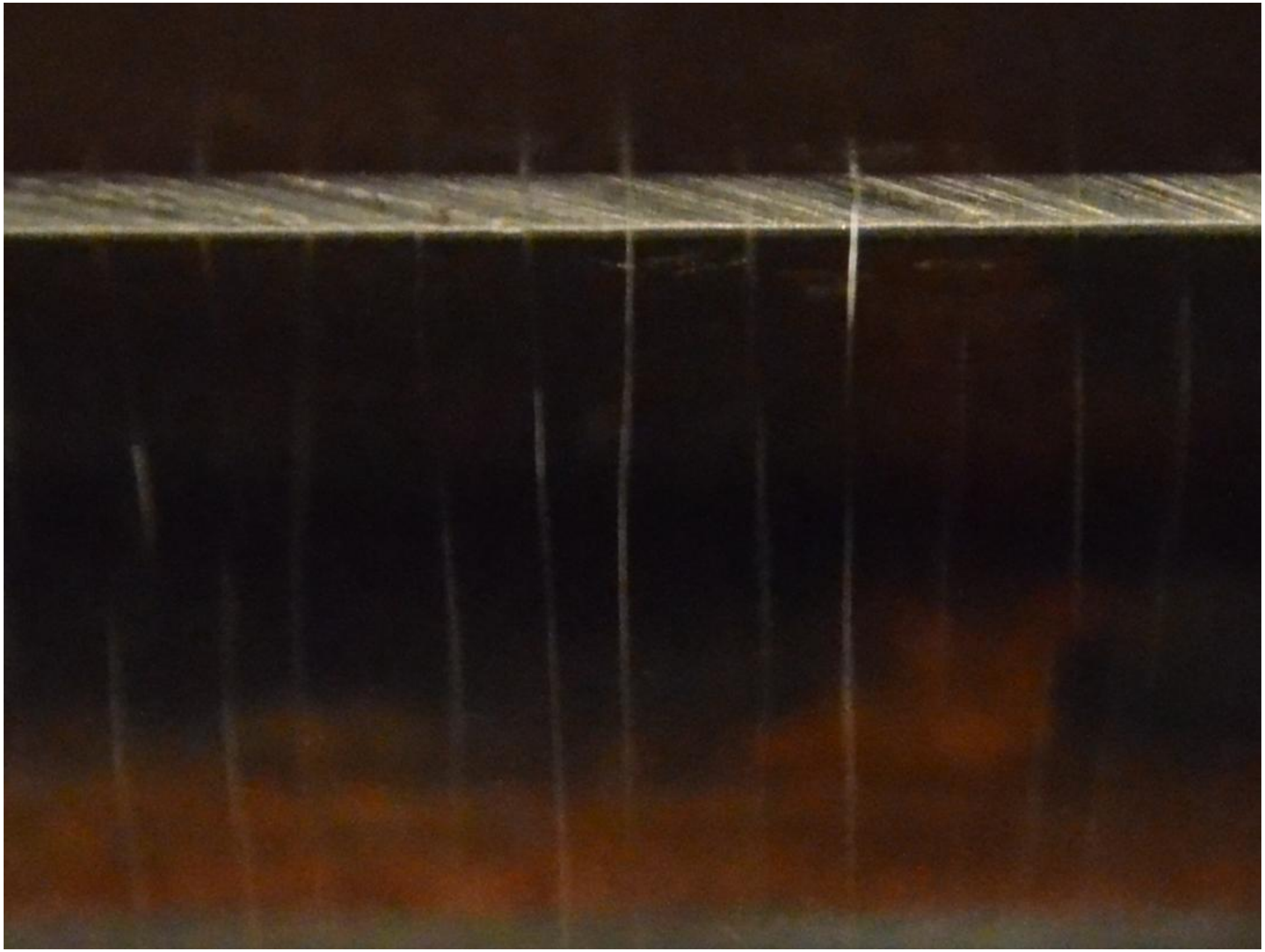
Parameters which give rise to varying fibre diameter:

1. Temperature and viscosity of melt
2. Mass and momentum of shot particle
3. Interaction with air flow: cooling and acceleration

Sol-gel fiberisation – basic steps

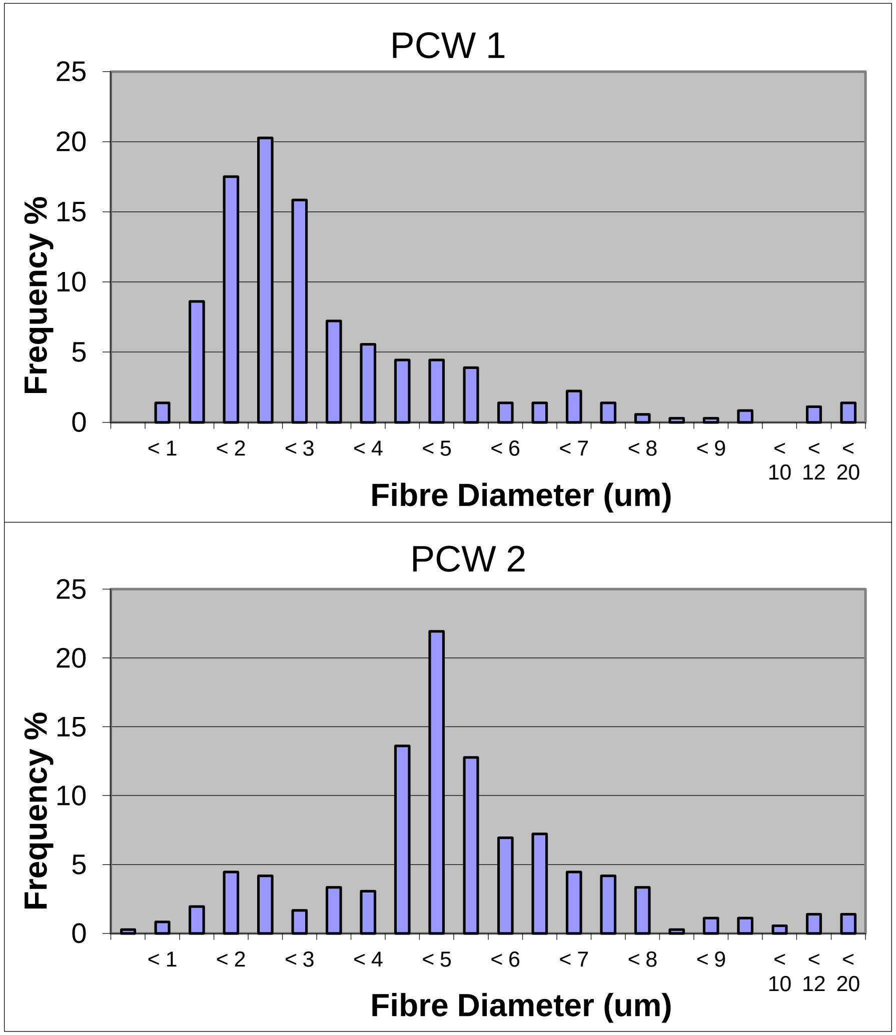
1. Mix precursor chemicals to produce a water based sol of the correct formulation.
2. Transfer to a holding vessel for degassing and aging.
3. Pump sol (at controlled viscosity) to the fiberising nozzles (a spinner system can also be used)
4. Sol is extruded through multiple fine nozzles and then accelerated away by an air flow. The fibres are formed at this stage.
5. Fibres fall through warm air losing water and gelling to fix their form.
6. The fibres are collected on a conveyor belt and transported for further processing.
7. The gel fibres are converted in subsequent heat treatment steps, which drive off all volatile components.

Magnified view of sol extruded from nozzles



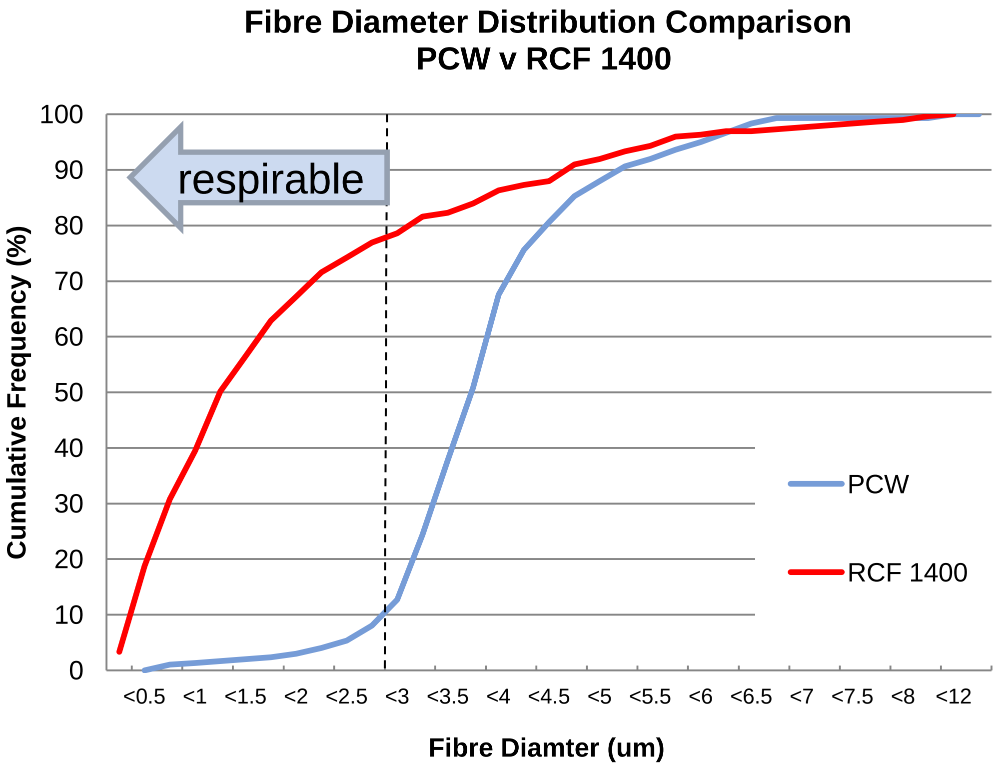
High speed photo: the jets appear bent as they are moving in the air stream

Fibre diameter distribution – nozzle formed PCW



- viscosity controlled at constant temperature.
- relatively gentle acceleration forces.
- production of respirable fibres very much reduced.
- 50% of fibres within a 1.5 micron band.
- water based sol allows mean diameter to be adjusted using sol-properties

Direct comparison PCW versus spun RCF



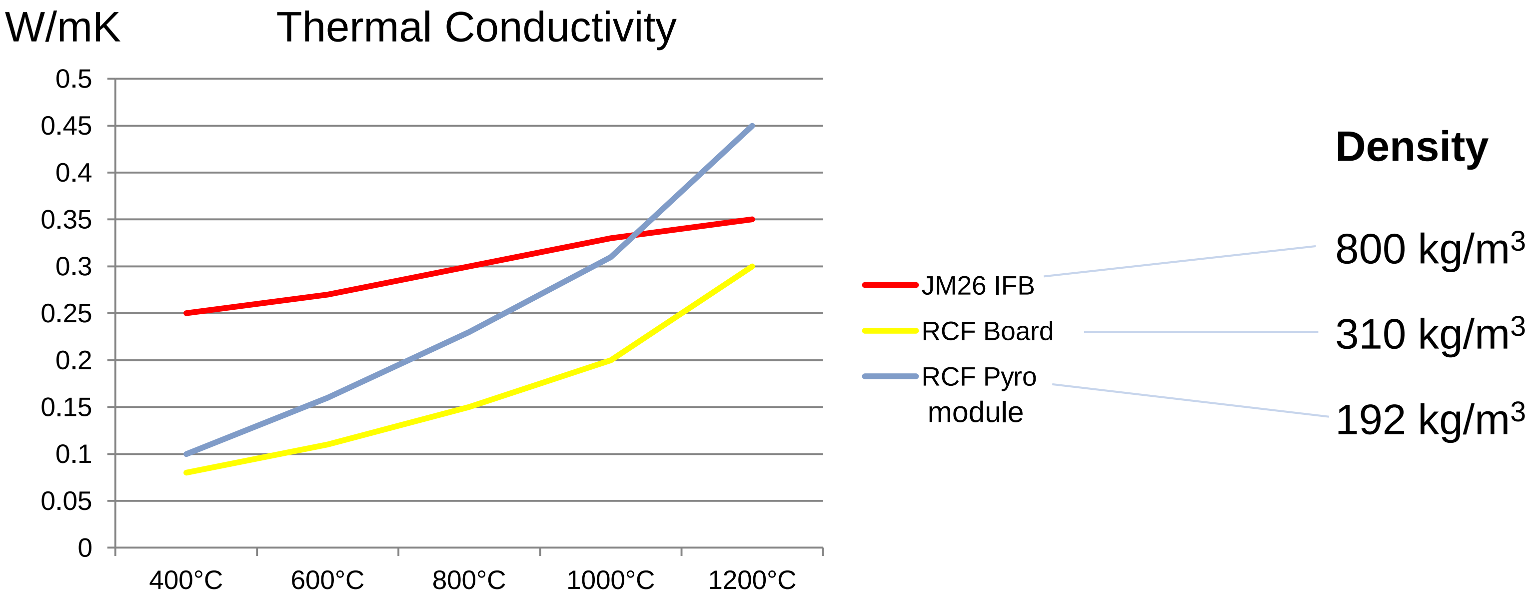
This comparison of a spun Zr-RCF versus PCW shows very clearly the reduction in respirable fibres which can be achieved.

Comparison of melt versus sol-gel fiberisation

Melt fiberisation	**Sol-gel fiberisation**
Output: 1,500 to 10,000 Tonnes p.a.	100 to 900 Tonnes p.a.
Fibre formulation directly affects fiberisation	Fiberisation controlled independently from fibre formulation
Temperature and viscosity vary through fiberisation unit	Temperature and viscosity controlled
Limited scope to adjust viscosity	Good control over viscosity
Depends on atomisation to initiate fibre	Fibre forms from continuous extrudate
Atomisation leads to shot formation	Inherently low shot content

Summary: Melt fiberisation is high output and low cost but has poor capability to avoid respirable fibre production. Sol-gel techniques are lower output and higher cost but give better control over fibre diameter.

The advantages of fibre insulation



- RCF fibre products have much lower density than Insulating Fire Bricks with the same temperature classification.
- Fibre insulation has less stored energy. Cycling furnaces are more efficient and can be cycled more quickly.
- Fibre products are much more insulating at lower temperatures making them ideal for “back up” insulation behind the hot face.

Another example of HTIW insulation

Sanitaryware: cyclic operation

In this case AES fibre

- Fibre is used in this type of furnace as it ensures the minimum energy use for each firing cycle.
- Fibre is used to insulate the furnace walls, roof and kiln car.
- The low density also means that the installation has a low mass and requires less structural support

Application Comparison of HTIW types

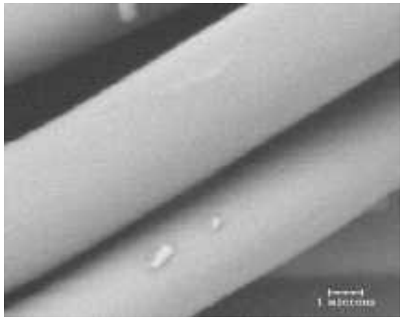
AES	RCF	PCW
Up to 1150°C	Up to 1250°C	Up to 1450°C
Sensitive to pollution	Less sensitive to pollution	Less sensitive to pollution
Capability increasing with R&D	Established technology	Higher capability than RCF
Similar cost to RCF	-	Much higher cost than RCF
Large volume availability	Large volume availability	Limited volume but growing

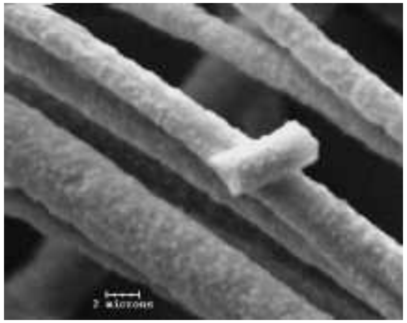
Increasing application capability
Trade off between useful lifetime and choice of fibre.

Crystallisation in HTIW

Fibre type	**Structure as sold**	**Silica content above Stoichiometric**	**Response to temperature >1000ºC**	**Is Crystalline Silica detected by XRD?**
AES	vitreous	Yes	Gradual crystallisation	Yes
RCF	vitreous	Yes	Gradual crystallisation	Yes
PCW	Pre-crystallised	No	Stable	No

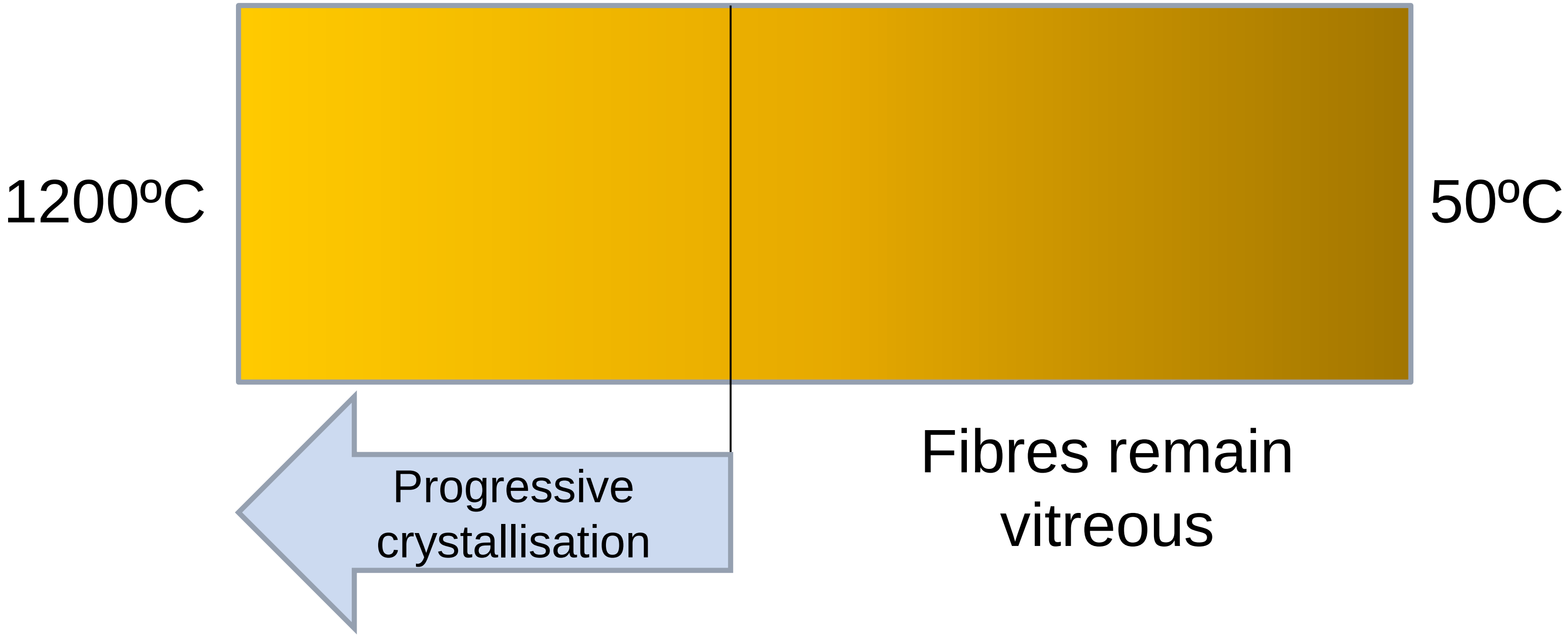
Zr-RCF vitreous





Zr-RCF highly crystallised

What happens in an RCF/AES furnace lining?



1200ºC

50ºC

Progressive crystallisation

Fibres remain vitreous

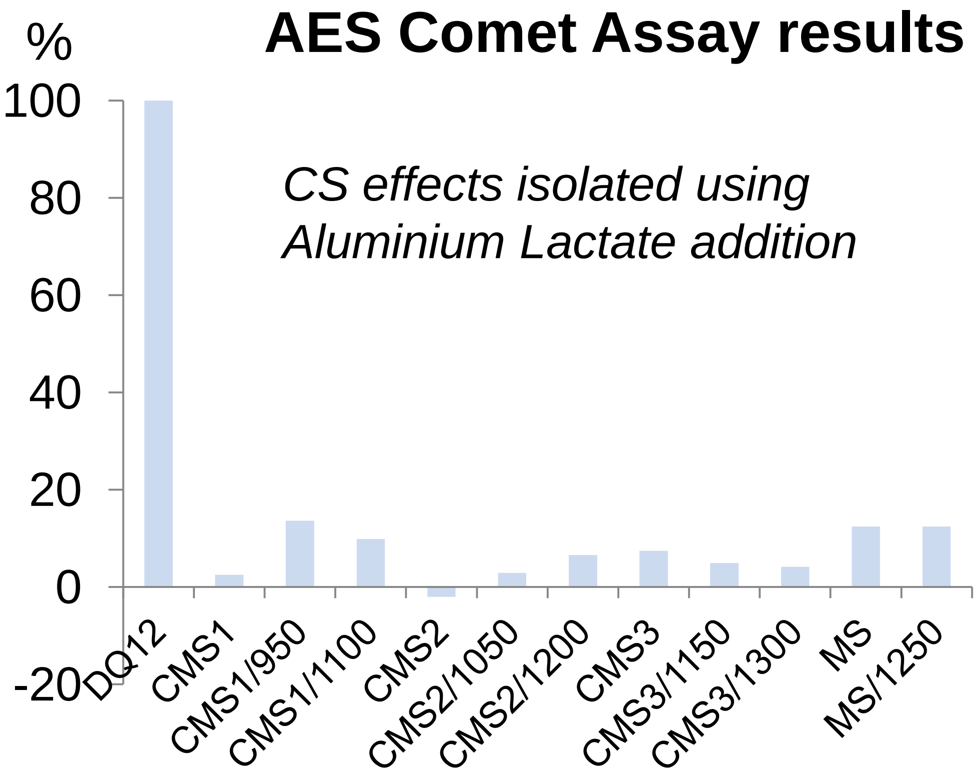
Small crystallites (eg <50nm) are not damaging to fibre performance. The growth of large crystals causes fibres to fragment and the lining is weakened. Large crystal growth can be promoted by pollutants or excessive temperatures. Generally RCF is more tolerant than AES to this effect.

ECFIA research into devitrified fibres

- AES fibres (4 types) were devitrified by laboratory heat treatment.
- Cytotoxicity (LDH activity) and genotoxicity (comet assay) tests were carried out in-vitro using rat macrophages at Fraunhofer ITEM to detect any crystalline silica activity.
- DQ12 Quartz was included as a positive control.
- Except for the positive control, no Silica activity was found. This may be the result of the Silica crystallising within a matrix of other crystalline and vitreous species.
- Now published: Ziemann et al. Inhalation Toxicology, 2014; 26(2): 113-127.

Example of Fraunhofer CMS comet assay results

Fibre type	CS%
CMS1	0
CMS1/950ºC	0.3
CMS1/1100ºC	18.4
CMS2	0
CMS2/1050ºC	10.4
CMS2/1200ºC	23.1
CMS3	0
CMS3/1150ºC	34.1
CMS3/1300ºC	32
MS	0
MS/1250ºC	17.9



CS effects isolated using Aluminium Lactate addition

Results show comet assay tail intensity relative to DQ12 control: no correlation with CS%

Summary of HTIW manufacture and application

1. Over the last 60 years, the gradual adoption of HTIW has revolutionised high temperature industrial processes.
2. The key advantages of fibre insulation are low density and the ability to cycle the temperature rapidly.
3. RCF is now classified carcinogenic and is subject to regulation.
4. New products have been developed which offer lower bio-persistence or less respirable fibre content.
5. Crystallisation at high temperature is often the ultimate reason why fibre linings deteriorate. No CS effects have so far been identified in crystallised fibres.