(12) 按照专利合作条约所公布的国际申请

(72) 发明人: 章林 (ZHANG, Lin); 中国浙江省桐乡市经济开发区文华南路 669 号巨石科技大楼, Zhejiang 314500 (CN)。曹国荣 (CAO, Guorong); 中国浙江省桐乡市经济开发区文华南路 669 号巨石科技大楼, Zhejiang 314500 (CN)。张毓强 (ZHANG, Yuqiang); 中国浙江省桐乡市经济开发区文华南路 669 号巨石科技大楼, Zhejiang 314500 (CN)。邢文忠 (XING, Wenzhong); 中国浙江省桐乡市经济开发区文华南路 669 号巨石科技大楼, Zhejiang 314500 (CN)。顾桂江 (GU, Guijiang); 中国浙江省桐乡市经济开发区文华南路 669 号巨石科技大楼, Zhejiang 314500 (CN)。

(74) 代理人: 北京名华博信知识产权代理有限公司 (BOXIN CHINA INTELLECTUAL PROPERTY); 中

(54) Title: HIGH PERFORMANCE GLASS FIBRE COMPOSITION, AND GLASS FIBRE AND COMPOSITE MATERIAL THEREOF

(54) 发明名称: 一种高性能玻璃纤维组合物及其玻璃纤维和复合材料

(57) Abstract: A high performance glass fibre composition, and a glass fibre and a composite material thereof. The content, given in weight percentage, of each component of the glass fibre composition is as follows: 53-64% of SiO_2, more than 19% and less than 25% of Al_2O_3, 0.05-7% of $Y_2O_3 + La_2O_3 + Gd_2O_3$, less than or equal to 1% of $Li_2O + Na_2O + K_2O$, 10-24% of $CaO + MgO + SrO$, 1.5-12% of CaO, less than 2% of TiO_2, and less than 1.5% of Fe_2O_3. The composition significantly improves the elastic modulus and the chemical stability of glass, and on this basis, overcomes the problem that traditional high performance glass has a high risk of crystallisation and a high clarification difficulty, and the problem of it being difficult to perform high efficiency tank furnace production. The composition significantly reduces the liquidus temperature and the forming temperature of high performance glass, and under equal conditions, significantly reduces the crystallisation rate of glass. The composition is particularly suitable for the tank furnace production of a high performance glass fibre having excellent chemical stability.

(57) 摘要: 一种高性能玻璃纤维组合物及其玻璃纤维和复合材料。其中，玻璃纤维组合物各组分的含量以重量百分比表示如下：SiO_2 为 53-64％，Al_2O_3 为大于 19％且小于 25％，$Y_2O_3+La_2O_3+Gd_2O_3$ 为 0.05-7％，$Li_2O+Na_2O+K_2O$ 为小于等于 1％，$CaO+MgO+SrO$ 为 10-24％，CaO 为 1.5-12％，TiO_2 为小于 2％，Fe_2O_3 为小于 1.5％。该组合物能大幅提高玻璃的弹性模量和化学稳定性，在此基础上，克服了传统高性能玻璃析晶风险高、澄清难度大，难于进行高效率池窑生产的问题，能显著降低高性能玻璃的液相线温度和成型温度，同等条件下大幅降低玻璃的析晶速率，特别适合用于池窑化生产化学稳定性优异的高性能玻璃纤维。

WO 2016/165530 A3

HIGH-PERFORMANCE GLASS FIBER COMPOSITION, GLASS FIBER AND COMPOSITE MATERIAL THEREFROM

This application claims the priority of Chinese Patent Application 201610147905.0, filed March 15, 2016 and titled "High-Performance Glass Fiber Composition, Glass Fiber and Composite Material Therefrom", the disclosure of which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

The present invention relates to a glass fiber composition, specifically to a glass fiber composition that can be used as a reinforcing base material for composites, and to a glass fiber and composite material therefrom.

BACKGROUND OF THE INVENTION

Glass fiber is an inorganic fiber material that can be used to reinforce resins to produce composite materials with good performance. As a reinforcing base material for advanced composite materials, high-performance glass fibers were originally used mainly in the aerospace industry or the national defense industry. With the progress of science and technology and the development of economy, high-performance glass fibers have been widely used in civil and industrial fields such as wind blades, pressure vessels, offshore oil pipes and auto industry.

The original high-performance glass compositions were based on an MgO-Al_2O_3-SiO_2 system and a typical solution was S-2 glass of American company OC. The modulus of S-2 glass is 89-90GPa; however, the production of this glass is excessively difficult, as its forming temperature is up to about 1571 °C and its liquidus temperature up to 1470 °C, and therefore it is difficult to realize large-scale industrial production. Thus, OC stopped production of S-2 glass fiber and transferred its patent to American company AGY.

Thereafter, OC developed HiPer-tex glass having a modulus of 87-89GPa, which were a trade-off for production scale by sacrificing some of the glass properties. However, as the designed solution was just a simple improvement over that of S-2 glass, the forming and liquidus temperatures remained high, which caused difficulty in attenuating glass fiber and consequently in realizing large-scale industrial production. Therefore, OC also stopped production of HiPer-tex

glass fiber and transferred its patent to the European company 3B.

French company Saint-Gobain developed R glass that is based on an MgO-CaO-Al_2O_3-SiO_2 system, and its modulus is 86-89GPa; however, the total contents of SiO_2 and Al_2O_3 remain high in the traditional R glass, and there is no effective solution to improve the crystallization performance, as the ratio of Ca to Mg is inappropriately designed, thus causing difficulty in fiber formation as well as a great risk of crystallization, high surface tension and fining difficulty of molten glass. The forming temperature of the R glass reaches $1410^{\circ}C$ and its liquidus temperature up to $1350^{\circ}C$. All these have caused difficulty in effectively attenuating glass fiber and consequently in realizing large-scale industrial production.

In China, Nanjing Fiberglass Research & Design Institute developed an HS2 glass having a modulus of 84-87GPa. It primarily contains SiO_2, Al_2O_3 and MgO while also including certain amounts of Li_2O, B_2O_3, CeO_2 and Fe_2O_3. Its forming temperature is only $1245^{\circ}C$ and its liquidus temperature is $1320^{\circ}C$. Both temperatures are much lower than those of S glass. However, since its forming temperature is lower than its liquidus temperature, which is unfavorable for the control of glass fiber attenuation, the forming temperature has to be increased and specially-shaped tips have to be used to prevent a glass crystallization phenomenon from occurring in the fiber attenuation process. This causes difficulty in temperature control and also makes it difficult to realize large-scale industrial production.

To sum up, we find that, at present stage, the actual production of various high-performance glass fibers generally faces the difficulty of large-scale production with refractory-lined furnaces, specifically manifested by comparably high liquidus temperature, high crystallization rate, high forming temperature, fining difficulty of molten glass and a narrow temperature range (ΔT) for fiber formation and even a negative ΔT value. Therefore, most companies tend to reduce the production difficulty by compromising some of the glass properties, thus making it impossible to improve the properties of the above-mentioned glass fibers with the growth of production scale. The problem of an insufficient modulus has long remained unresolved in the production of S glass fiber.

SUMMARY OF THE INVENTION

The present invention aims to solve the issue described above. The purpose of the present invention is to provide a high-performance glass fiber composition which can not only significantly

improve the elastic modulus and chemical stability of the glass, but also overcome the technical problems in the manufacture of traditional high-performance glasses including high risk of crystallization, fining difficulty of molten glass and low efficiency of production in refractory-lined furnaces, and significantly reduce the liquidus temperature, forming temperature and crystallization rate under the same conditions, thus making it particularly suitable for production of high-performance glass fiber with excellent chemical stability in refractory-lined furnaces.

According to one aspect of the present invention, a glass fiber composition is provided comprising the following components expressed as percentage by weight:

SiO_2	53-64%
Al_2O_3	>19% and <25%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.05-7%
$R_2O=Li_2O+Na_2O+K_2O$	≤1%
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%

wherein, the restricted weight percentage ratio $C1= RE_2O_3/R_2O$ is greater than 0.5;

wherein, the restricted content range of Li_2O is 0.05-0.85% by weight;

wherein, the restricted content range of $R_2O=Li_2O+Na_2O+K_2O$ is lower than 0.97% by weight;

wherein, the restricted content range of Li_2O is at least 0.05% and lower than 0.55% by weight;

wherein, the restricted content range of Li_2O is 0.1-0.5% by weight;

wherein, the restricted weight percentage ratio $C2= Al_2O_3/MgO$ is greater than 1.8;

wherein, the restricted weight percentage ratio $C2= Al_2O_3/MgO$ is greater than 1.95;

wherein, the restricted content range of $SiO_2+Al_2O_3$ is lower than 80.4% by weight;

wherein, the restricted content range of $RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$ is 0.5-6% by weight;

Wherein, the said composition comprises the following components expressed as percentage by weight:

SiO_2	53-64%
Al_2O_3	>19% and <25%

$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.05-7%
$R_2O=Li_2O+Na_2O+K_2O$	$\leq 1\%$
Li_2O	0.05-0.85%
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%

In addition, the weight percentage ratio $C1= RE_2O_3/R_2O$ is greater than 0.5.

Wherein, the said composition comprises the following components expressed as percentage by weight:

SiO_2	53-64%
Al_2O_3	>19% and <25%
$SiO_2+Al_2O_3$	<82%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.05-7%
$R_2O=Li_2O+Na_2O+K_2O$	$\leq 1\%$
Li_2O	0.05-0.85%
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%

In addition, the weight percentage ratio $C1= RE_2O_3/R_2O$ is greater than 0.5.

Wherein, the said composition comprises the following components expressed as percentage by weight:

SiO_2	53-64%
Al_2O_3	>19% and <25%
$SiO_2+Al_2O_3$	<80.4%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.05-7%
$R_2O=Li_2O+Na_2O+K_2O$	<0.97%
Li_2O	0.05-0.85%

CaO+MgO+SrO	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%

In addition, the weight percentage ratio $C1 = RE_2O_3/R_2O$ is greater than 0.5.

wherein, the restricted content range of $R_2O = Li_2O + Na_2O + K_2O$ is not greater than 0.95% in percentage by weight;

wherein, the restricted content range of $R_2O = Li_2O + Na_2O + K_2O$ is not greater than 0.85% in percentage by weight;

Wherein, the said composition comprises the following components expressed as percentage by weight:

SiO_2	53-64%
Al_2O_3	>19% and <25%
$RE_2O_3 = Y_2O_3 + La_2O_3 + Gd_2O_3$	0.05-7%
$R_2O = Li_2O + Na_2O + K_2O$	≤1%
Li_2O	0.05-0.85%
CaO+MgO+SrO	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%

In addition, the weight percentage ratio $C1 = RE_2O_3/R_2O$ is greater than 0.5, and the weight percentage ratio $C2 = Al_2O_3/MgO$ is greater than 1.8.

Wherein, the said composition comprises the following components expressed as percentage by weight:

SiO_2	53-64%
Al_2O_3	>19% and <25%
$SiO_2 + Al_2O_3$	<82%
$RE_2O_3 = Y_2O_3 + La_2O_3 + Gd_2O_3$	0.5-6%
$R_2O = Li_2O + Na_2O + K_2O$	≤1%

Li_2O	$\geq 0.05\%$ and $<0.55\%$
$CaO+MgO+SrO$	$10\text{-}24\%$
CaO	$1.5\text{-}12\%$
TiO_2	$<2\%$
Fe_2O_3	$<1.5\%$

In addition, the weight percentage ratio $C1= RE_2O_3/R_2O$ is greater than 0.5, and the weight percentage ratio $C2= Al_2O_3/MgO$ is greater than 1.8.

Wherein, the said composition comprises the following components expressed as percentage by weight:

SiO_2	$53\text{-}64\%$
Al_2O_3	$>19\%$ and $<25\%$
$SiO_2+Al_2O_3$	$<82\%$
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	$0.5\text{-}6\%$
$R_2O=Li_2O+Na_2O+K_2O$	$<0.97\%$
Li_2O	$0.05\text{-}0.85\%$
$CaO+MgO+SrO$	$10\text{-}24\%$
CaO	$1.5\text{-}12\%$
TiO_2	$<2\%$
Fe_2O_3	$<1.5\%$

In addition, the weight percentage ratio $C1= RE_2O_3/R_2O$ is greater than 0.5, and the weight percentage ratio $C2= Al_2O_3/MgO$ is greater than 1.95.

Wherein, the said composition comprises the following components expressed as percentage by weight:

SiO_2	$54\text{-}62\%$
Al_2O_3	$>19\%$ and $\leq 23\%$
$SiO_2+Al_2O_3$	$<80.4\%$
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	$0.5\text{-}6\%$
$R_2O=Li_2O+Na_2O+K_2O$	$\leq 1\%$
Li_2O	$0.05\text{-}0.85\%$

CaO+MgO+SrO	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%

In addition, the weight percentage ratio $C1 = RE_2O_3/R_2O$ is greater than 1, and the weight percentage ratio $C2 = Al_2O_3/MgO$ is greater than 1.95.

wherein, the restricted content range of Na_2O+K_2O is lower than 0.7% by weight;

wherein, the restricted content range of TiO_2 is not greater than 0.75% by weight;

wherein, the restricted content range of Al_2O_3 is greater than 19% and not greater than 19.4% by weight;

wherein, the restricted content range of Al_2O_3 is greater than 19.4% and not greater than 23% by weight;

wherein, the restricted content range of SrO is 0.1-2% by weight;

wherein, the restricted content range of Gd_2O_3 is 0.05-1% by weight;

Wherein, the said composition comprises the following components expressed as percentage by weight:

SiO_2	53-64%
Al_2O_3	>19% and <25%
$SiO_2+Al_2O_3$	<82%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.05-7%
$La_2O_3+Gd_2O_3$	0.1-3%
$R_2O=Li_2O+Na_2O+K_2O$	≤1%
Li_2O	0.05-0.85%
CaO+MgO+SrO	10-24%
CaO	1.5-12%
TiO_2	≤0.75%
Fe_2O_3	<1.5%

In addition, the weight percentage ratio $C1 = RE_2O_3/R_2O$ is greater than 0.5.

Wherein, the said composition comprises the following components expressed as percentage

by weight:

SiO_2	53-64%
Al_2O_3	>19% and <25%
$SiO_2+Al_2O_3$	<82%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.05-7%
Y_2O_3	0.5-5%
$R_2O=Li_2O+Na_2O+K_2O$	<0.97%
Li_2O	0.05-0.85%
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%

In addition, the weight percentage ratio $C1= RE_2O_3/R_2O$ is greater than 0.5, and the weight percentage ratio $C2= Al_2O_3/MgO$ is greater than 1.8.

wherein, the restricted weight percentage ratio $C1= RE_2O_3/R_2O$ is 1.5-5.

wherein, the restricted weight percentage ratio $C2= Al_2O_3/MgO$ is 2-2.45.

wherein, the restricted content range of CaO is 5-10% by weight;

wherein, the restricted content range of MgO is 8.1-12% by weight;

wherein, the restricted content range of La_2O_3 is 0.1-2% by weight;

Wherein, said high-performance composition comprises F_2 with a content range of 0-1.2% in percentage by weight;

Wherein, said high-performance composition comprises B_2O_3 with a content range of 0-2% in percentage by weight;

Wherein, said high-performance composition comprises CeO_2 with a content range of 0-1% in percentage by weight.

According to another aspect of this invention, a glass fiber produced with said glass fiber composition is provided.

According to yet another aspect of this invention, a composite material incorporating said glass fiber is provided.

The main inventive points of the glass fiber composition according to this invention include: introducing one or more rare earth oxides from the group consisting of Y_2O_3, La_2O_3 and Gd_2O_3 while including a high content of alumina and a low content of alkali metal oxides, utilizing the synergistic effect among rare earth oxides, alkali metal oxides and alumina, controlling the ratios of RE_2O_3/R_2O and Al_2O_3/MgO, reasonably configuring the content ranges of Al_2O_3, R_2O, Li_2O, Y_2O_3, La_2O_3, Gd_2O_3, CaO and CaO+MgO+SrO respectively and utilizing the CaO, MgO and SrO mixed alkali earth effect, and a selective introduction of F_2, B_2O_3 and CeO_2 at appropriate amounts.

Specifically, the high-performance glass fiber composition according to the present invention comprises the following components expressed as percentage by weight:

SiO_2	53-64%
Al_2O_3	>19% and <25%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.05-7%
$R_2O=Li_2O+Na_2O+K_2O$	≤1%
CaO+MgO+SrO	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%

The effect and content of each component in said glass fiber composition is described as follows:

SiO_2 is a main oxide forming the glass network and has the effect of stabilizing all the components. In the glass fiber composition of the present invention, the restricted content range of SiO_2 is 53-64%, preferably 54-62%.

Al_2O_3 is another main oxide forming the glass network. When combined with SiO_2, it can have a substantive effect on the mechanical properties of the glass and have a significant effect on water and acid resistance. In order to obtain sufficiently high mechanical properties and water and acid resistance of the glass, the content of Al_2O_3 should be desirably high. However, too high of a content will cause the glass viscosity to be excessively high thereby resulting in melting and fining issues, together with a risk of glass crystallization and phase separation. In one embodiment, the inventors have unexpectedly found that when the content range of Al_2O_3 is kept to be greater than 19% and lower than 25%, the content range of $Li_2O+Na_2O+K_2O$ to be not greater than 1%, and an

appropriate amount of rare earth oxides is introduced, the glass can have excellent elastic modulus, chemical stability and crystallization resistance as well as a broad temperature range ($\triangle$T) for fiber formation. Therefore, in the glass fiber composition of the present invention, the restricted content range of Al_2O_3 is greater than 19% and lower than 25%, preferably greater than 19% and not greater than 23%. Furthermore, in one embodiment, the restricted content range of Al_2O_3 can be greater than 19% and not greater than 19.4%; in another embodiment, the restricted content range of Al_2O_3 can be greater than 19.4% and not greater than 23%. In addition, the restricted content range of $SiO_2+Al_2O_3$ can be lower than 82%, preferably lower than 80.4%.

In the glass structure, Al_2O_3 is generally present in two coordination states, i.e., four-coordinated state (AlO_4) and six-coordinated state (AlO_6). The inventeors find that, by introducing not only a high content of Al_2O_3 and a low content of alkali metal oxides, but also one or more rare earth oxides from the group consisting of Y_2O_3, La_2O_3 and Gd_2O_3 so as to utilize the high alkali properties of rare earth oxides to produce a significant non-bridging oxygen effect, the amount of Al_2O_3 in tetrahedral coordination would become noticeably high, thus promoting more Al^{3+} ions to enter the glass network and accordingly help to enhance the compactness of the network. Moreover, it is difficult for each of the fore-mentioned three rare earth ions to enter the glass network, and they usually exist as external ions at the gaps of the glass network. These ions have large coordination numbers, high electric charge and field strength, and high accumulation capability, and therefore can help to improve the structural stability of the glass and increase the mechanical properties and chemical stability of the glass. Meanwhile, they can also effectively prevent the movement and arrangement of other ions so as to minimize the glass crystallization tendency and improve its chemical stability.

The inventors also find that, when used separately, Y_2O_3 has better effects than La_2O_3 or Gd_2O_3 in improving the glass modulus and prohibiting crystallization. Moreover, when two or more rare earth oxides are used simultaneously and the ratios therebetween are appropriately controlled, an unexpectedly remarkable synergistic effect will be achieved, i.e. the effect in improving the glass modulus and prohibiting crystallization is better than that when only one rare earth oxide is used at a time. The inventors believe that this is because, one the one hand, two or more rare earth oxides used simultaneously can provide more external ions of the network for the coordination, thus helping to improve the structural stability of the glass and increase the glass modulus and, on the other hand, the rare earth ions of various radiuses are less likely to give rise to regular arrangements,

which is conducive to significantly reducing the growth rate of crystals and thus improving the crystalllizaiton resistance of the glass.

In the glass fiber composition of the present invention, the restricted range of the weight percentage $RE_2O_3 = Y_2O_3 + La_2O_3 + Gd_2O_3$ can be 0.05-7%, preferably 0.5-6%. Furthermore, the restricted range of the weight percentage $La_2O_3 + Gd_2O_3$ can be 0.1-3%. Furthermore, the restricted range of the weight percentage Y_2O_3 can be 0.5-5%. Furthermore, the restricted range of the weight percentage La_2O_3 can be 0.1-2%. Furthermore, the restricted range of the weight percentage Gd_2O_3 can be 0.05-1%.

Both K_2O and Na_2O can reduce glass viscosity and are good fluxing agents. Compared with Na_2O and K_2O, Li_2O can not only significantly reduce glass viscosity thereby improving the glass melting performance, but also help greatly improve the mechanical properties of glass. In addition, a small amount of Li_2O provides considerable non-bridging oxygen, which helps more aluminum ions to form tetrahedral coordination and enhances the network structure of the glass. However, as too many alkali metal ions in the glass composition would signigficantly reduce the chemical stability of the glass, the introduced amount should be limited. Therefore, in the glass fiber composition of the present invention, the restricted content range of $Li_2O + Na_2O + K_2O$ can be not greater than 1%, preferably lower than 0.97%, more preferably not greater than 0.95%, and still more preferably not greater than 0.85%. Furthermore, the restricted content range of Li_2O can be 0.05-0.85%, preferably at least 0.05% but lower than 0.55%, and more preferably 0.1-0.5%. Furthermore, the restricted content range of $Na_2O + K_2O$ can be lower than 0.7%.

Furthermore, for the purpose that the non-bridging oxygen produced by alkali metal oxides can be effectively accumulated by rare earth ions and thus more aluminum ions can enter the glass network in the form of AlO_4, in the glass fiber composition of the present invention, the restricted range of the weight percentage ratio $C1 = RE_2O_3/R_2O$ can be greater than 0.5, preferably greater than 1, and more preferably can be 1.5-5.

CaO, MgO and SrO mainly control the glass crystallization and regulate the glass viscosity. Particularly on the control of the glass crystallization, the inventors have obtained unexpected effects by controlling the introduced amounts of them and the ratios between them. Generally, for a high-performance glass based on the $MgO-CaO-Al_2O_3-SiO_2$ system, the crystal phases it contains after glass crystallization include mainly diopside ($CaMgSi_2O_6$) and anorthite ($CaAl_2Si_2O_8$). In

order to inhibit the tendency of these two crystal phases to crystallize and reduce the liquidus temperature and crystallization rate of the glass, this invention has rationally controlled the content range of CaO+MgO+SrO and the ratios therebetween to utilize the mixed alkali earth effect for a more compact stacking structure, so that more energy will be needed for the crystal nucleus to form and grow and therefore the tendency of glass cystallizaiton will be inhibited. Moreover, the strontium oxide introduced with an appropriate amount can help to make a more stable glass structure, thus further improving the properties of the glass. In the glass fiber composition of this invention, the restricted content range of CaO+MgO+SrO can be 10-24%. As a network modifier, too much CaO would increase the crystalllization tendency of the glass that lead to the precipitation of crystals such as anorthite and wollastonite from the glass melt. Therefore, the content range of CaO can be 1.5-12%, preferably 5-10%. MgO has the similar effect in the glass network as CaO, except that the field strength of Mg^{2+} is higher, which plays an important role in increasing the glass modulus. Furthermore, the content range of MgO can be 8.1-12%. Furthermore, the content range of SrO can be lower than 3%, and preferably can be 0.1-2%.

Furthermore, in the glass fiber composition of the present invention, in order to effectively control the crystallization of the glass, the resticted range of the weight percentage ratio C2= Al_2O_3/MgO can be greater than 1.8, preferably greater than 1.95, and more preferably can be 2-2.45.

TiO_2 not only has a fluxing effect, but also can siginificantly improve the chemical stability of glass. It also has a certain effect of reducing the surface tension of the molten glass. However, since an excessive amount of Ti^{4+} ions could have an undesired coloring effect, the introduced amount should be limited. In the glass fiber composition of the present invention, the restricted content range of TiO_2 is lower than 2%, preferably not greater than 0.75%.

Fe_2O_3 facilitates the melting of glass and can also improve the crystallization performance of glass. However, since ferric ions and ferrous ions have a coloring effect, the introduced amount should be limited. Therefore, in the glass fiber composition of the present invention, the resticted content range of Fe_2O_3 is lower than 1.5%.

In the glass fiber composition of the present invention, an appropriate amount of F_2, B_2O_3 or CeO_2 can be introduced to further improve the crystallization and fining performance of glass. In the glass fiber composition of the present invention, the resticted content range of F_2 can be 0-1.2%;

the resticted content range of B_2O_3 can be 0-2%; and the resticted content range of CeO_2 can be 0-1%.

In addition, the glass fiber composition of the present invention can include small amounts of other components with a total content not greater than 2%.

In the glass fiber composition of the present invention, the beneficial effects produced by the aforementioned selected ranges of the components will be explained by way of examples through the specific experimental data.

The following are embodiments of preferred content ranges of the components contained in the glass fiber composition according to the present invention. The elastic modulus of the glass fiber made from the compositions according to these embodiments is more than 90 GPa.

Preferred embodiment 1

The high-performance glass fiber composition according to the present invention comprises the following components expressed as percentage by weight:

SiO_2	53-64%
Al_2O_3	>19% and <25%
$SiO_2+Al_2O_3$	<82%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.05-7%
$R_2O=Li_2O+Na_2O+K_2O$	≤1%
Li_2O	0.05-0.85%
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%

In addition, the range of the weight percentage ratio $C1= RE_2O_3/R_2O$ is greater than 0.5.

Preferred embodiment 2

The high-performance glass fiber composition according to the present invention comprises the following components expressed as percentage by weight:

SiO_2	53-64%

Al_2O_3	>19% and <25%
$SiO_2+Al_2O_3$	<80.4%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.05-7%
$R_2O=Li_2O+Na_2O+K_2O$	<0.97%
Li_2O	0.05-0.85%
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%

In addition, the range of the weight percentage ratio $C1= RE_2O_3/R_2O$ is greater than 0.5.

Preferred embodiment 3

The high-performance glass fiber composition according to the present invention comprises the following components expressed as percentage by weight:

SiO_2	53-64%
Al_2O_3	>19% and <25%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.05-7%
$R_2O=Li_2O+Na_2O+K_2O$	≤1%
Li_2O	0.1-0.5%
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%

In addition, the range of the weight percentage ratio $C1= RE_2O_3/R_2O$ is greater than 0.5, and the range of the weight percentage ratio $C2= Al_2O_3/MgO$ is greater than 1.8.

Preferred embodiment 4

The high-performance glass fiber composition according to the present invention comprises the following components expressed as percentage by weight:

14

SiO_2	53-64%
Al_2O_3	>19% and <25%
$SiO_2+Al_2O_3$	<82%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.5-6%
$R_2O=Li_2O+Na_2O+K_2O$	≤1%
Li_2O	≥0.05% and <0.55%
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%

In addition, the range of the weight percentage ratio C1= RE_2O_3/R_2O is greater than 0.5, and the range of the weight percentage ratio C2= Al_2O_3/MgO is greater than 1.8.

Preferred embodiment 5

The high-performance glass fiber composition according to the present invention comprises the following components expressed as percentage by weight:

SiO_2	53-64%
Al_2O_3	>19% and <25%
$SiO_2+Al_2O_3$	<82%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.5-6%
$R_2O=Li_2O+Na_2O+K_2O$	<0.97%
Li_2O	0.05-0.85%
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%
Gd_2O_3	0.05-1%

In addition, the range of the weight percentage ratio C1= RE_2O_3/R_2O is greater than 0.5, and the range of the weight percentage ratio C2= Al_2O_3/MgO is greater than 1.95.

Preferred embodiment 6

The high-performance glass fiber composition according to the present invention comprises the following components expressed as percentage by weight:

SiO_2	54-62%
Al_2O_3	>19% and ≤23%
$SiO_2+Al_2O_3$	<80.4%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.5-6%
$R_2O=Li_2O+Na_2O+K_2O$	≤0.95%
Li_2O	0.05-0.85%
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%

In addition, the range of the weight percentage ratio C1= RE_2O_3/R_2O is greater than 1, and the range of the weight percentage ratio C2= Al_2O_3/MgO is greater than 1.95.

Preferred embodiment 7

The high-performance glass fiber composition according to the present invention comprises the following components expressed as percentage by weight:

SiO_2	53-64%
Al_2O_3	>19% and <25%
$SiO_2+Al_2O_3$	<82%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.05-7%
$La_2O_3+Gd_2O_3$	0.1-3%
$R_2O=Li_2O+Na_2O+K_2O$	≤0.85%
Li_2O	0.05-0.85%
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%

TiO$_2$ ≤0.75%

Fe$_2$O$_3$ <1.5%

In addition, the range of the weight percentage ratio C1= RE$_2$O$_3$/R$_2$O is greater than 0.5.

Preferred embodiment 8

The high-performance glass fiber composition according to the present invention comprises the following components expressed as percentage by weight:

SiO$_2$	53-64%
Al$_2$O$_3$	>19% and <25%
SiO$_2$+Al$_2$O$_3$	<82%
RE$_2$O$_3$=Y$_2$O$_3$+La$_2$O$_3$+Gd$_2$O$_3$	0.05-7%
Y$_2$O$_3$	0.5-5%
R$_2$O=Li$_2$O+Na$_2$O+K$_2$O	<0.97%
Li$_2$O	0.05-0.85%
CaO+MgO+SrO	10-24%
CaO	1.5-12%
TiO$_2$	<2%
Fe$_2$O$_3$	<1.5%

In addition, the range of the weight percentage ratio C1= RE$_2$O$_3$/R$_2$O is greater than 0.5, and the range of the weight percentage ratio C2= Al$_2$O$_3$/MgO is greater than 1.8.

Preferred embodiment 9

The high-performance glass fiber composition according to the present invention comprises the following components expressed as percentage by weight:

SiO$_2$	53-64%
Al$_2$O$_3$	>19% and ≤19.4%
SiO$_2$+Al$_2$O$_3$	<82%
RE$_2$O$_3$=Y$_2$O$_3$+La$_2$O$_3$+Gd$_2$O$_3$	0.5-6%
R$_2$O=Li$_2$O+Na$_2$O+K$_2$O	<0.97%

Li$_2$O	0.05-0.85%
CaO+MgO+SrO	10-24%
CaO	1.5-12%
TiO$_2$	<2%
Fe$_2$O$_3$	<1.5%

In addition, the range of the weight percentage ratio C1= RE$_2$O$_3$/R$_2$O is greater than 0.5, and the range of the weight percentage ratio C2= Al$_2$O$_3$/MgO is greater than 1.95.

Preferred embodiment 10

The high-performance glass fiber composition according to the present invention comprises the following components expressed as percentage by weight:

SiO$_2$	54-62%
Al$_2$O$_3$	>19.4% and ≤23%
SiO$_2$+Al$_2$O$_3$	<80.4%
RE$_2$O$_3$=Y$_2$O$_3$+La$_2$O$_3$+Gd$_2$O$_3$	0.5-6%
R$_2$O=Li$_2$O+Na$_2$O+K$_2$O	≤1%
Li$_2$O	0.05-0.85%
Na$_2$O+K$_2$O	<0.7%
CaO+MgO+SrO	10-24%
CaO	1.5-12%
TiO$_2$	<2%
Fe$_2$O$_3$	<1.5%

In addition, the range of the weight percentage ratio C1= RE$_2$O$_3$/R$_2$O is greater than 1, and the range of the weight percentage ratio C2= Al$_2$O$_3$/MgO is greater than 1.95.

Preferred embodiment 11

The high-performance glass fiber composition according to the present invention comprises the following components expressed as percentage by weight:

SiO$_2$	53-64%

Al_2O_3	>19% and <25%
$SiO_2+Al_2O_3$	<82%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.05-7%
$La_2O_3+Gd_2O_3$	0.1-3%
$R_2O=Li_2O+Na_2O+K_2O$	≤1%
Li_2O	0.05-0.85%
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%
TiO_2	≤0.75%
Fe_2O_3	<1.5%
SrO	0.1-2%
F_2	0-1.2%

In addition, the range of the weight percentage ratio C1= RE_2O_3/R_2O is 1.5-5.

Preferred embodiment 12

The high-performance glass fiber composition according to the present invention comprises the following components expressed as percentage by weight:

SiO_2	53-64%
Al_2O_3	>19% and <25%
$SiO_2+Al_2O_3$	<82%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.05-7%
$La_2O_3+Gd_2O_3$	0.1-3%
$R_2O=Li_2O+Na_2O+K_2O$	≤1%
Li_2O	0.05-0.85%
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%
TiO_2	≤0.75%
Fe_2O_3	<1.5%
B_2O_3	0-2%

CeO$_2$	0-1%

In addition, the range of the weight percentage ratio C1= RE$_2$O$_3$/R$_2$O is greater than 0.5, and the range of the weight percentage ratio C2= Al$_2$O$_3$/MgO is 2-2.45.

Preferred embodiment 13

The high-performance glass fiber composition according to the present invention comprises the following components expressed as percentage by weight:

SiO$_2$	53-64%
Al$_2$O$_3$	>19% and <25%
SiO$_2$+Al$_2$O$_3$	<80.4%
RE$_2$O$_3$=Y$_2$O$_3$+La$_2$O$_3$+Gd$_2$O$_3$	0.05-7%
R$_2$O=Li$_2$O+Na$_2$O+K$_2$O	<0.97%
Li$_2$O	0.05-0.85%
CaO+MgO+SrO	10-24%
CaO	5-10%
MgO	8.1-12%
TiO$_2$	<2%
Fe$_2$O$_3$	<1.5%
La$_2$O$_3$	0.1-2%

In addition, the range of the weight percentage ratio C1=RE$_2$O$_3$/R$_2$O is greater than 0.5.

According to the preferred embodiment 13, the elastic modulus of the glass fiber formed from the composition is greater than 95GPa.

DETAILED DESCRIPTION OF THE INVENTION

In order to better clarify the purposes, technical solutions and advantages of the examples of the present invention, the technical solutions in the examples of the present invention are clearly and completely described below. Obviously, the examples described herein are just part of the examples of the present invention and are not all the examples. All other exemplary embodiments obtained by one skilled in the art on the basis of the examples in the present invention without

performing creative work shall all fall into the scope of protection of the present invention. What needs to be made clear is that, as long as there is no conflict, the examples and the features of examples in the present application can be arbitrarily combined with each other.

The basic concept of the present invention is that the components of the glass fiber composition expressed as percentage by weight are: 53-64% SiO_2, greater than 19% and lower than 25% Al_2O_3, 0.05-7% $Y_2O_3+La_2O_3+Gd_2O_3$, not greater than 1% $Li_2O+Na_2O+K_2O$, 10-24% $CaO+MgO+SrO$, 1.5-12% CaO, lower than 2% TiO_2 and lower than 1.5% Fe_2O_3. Said composition can not only significantly improve the elastic modulus and chemical stability of the glass, but also overcome the technical problems in the manufacture of traditional high-performance glasses including high risk of crystallization, fining difficulty of molten glass and production efficiency difficulty with refractory-lined furnaces, significantly reduce the liquidus and forming temperatures, and greatly reduce the crystallization rate under the same conditions, thus making it particularly suitable for production of high-performance glass fiber with excellent chemical stability in refractory-lined furnaces.

The specific content values of SiO_2, Al_2O_3, CaO, MgO, Li_2O, Na_2O, K_2O, Fe_2O_3, TiO_2, SrO, Y_2O_3, La_2O_3, Gd_2O_3, F_2 and CeO_2 in the glass fiber composition of the present invention are selected to be used in the examples, and comparisons with S glass, traditional R glass and improved R glass are made in terms of the following six property parameters,

(1) Forming temperature, the temperature at which the glass melt has a viscosity of 10^3 poise.

(2) Liquidus temperature, the temperature at which the crystal nucleuses begin to form when the glass melt cools off -- i.e., the upper limit temperature for glass crystallization.

(3) ΔT value, which is the difference between the forming temperature and the liquidus temperature and indicates the temperature range at which fiber drawing can be performed.

(4) Peak crystallization temperature, the temperature which corresponds to the strongest peak of glass crystallization in a DTA testing. Generally, the higher this temperature is, the more energy is needed for crystal nucleuses to grow and the lower the glass crystallization tendency is.

(5) Elastic modulus, the longitudinal elastic modulus defining the ability of glass to resist elastic deformation, which is to be measured as per ASTM2343.

(6) Powder weight loss, to be determined in a procedure set out as follows: Crush and grind the

prepared glass appropriately and then sieve the powder to collect those sized 0.4-0.6mm (that can pass 60-mesh but cannot pass 80-mesh sieves). Weigh to prepare three samples from the collected powder, 3g for each sample, and place each sample respectively into a 10% HCL solution with a preset amount to be water bathed at 95 °C for 24 hours. Calculate the average weight loss of the sample powder to characterize the chemical stability of the glass.

The aforementioned six parameters and the methods of measuring them are well-known to one skilled in the art. Therefore, these parameters can be effectively used to explain the properties of the glass fiber composition of the present invention.

The specific procedures for the experiments are as follows: Each component can be acquired from the appropriate raw materials. Mix the raw materials in the appropriate proportions so that each component reaches the final expected weight percentage. The mixed batch melts and the molten glass refines. Then the molten glass is drawn out through the tips of the bushings, thereby forming the glass fiber. The glass fiber is attenuated onto the rotary collet of a winder to form cakes or packages. Of course, conventional methods can be used to deep process these glass fibers to meet the expected requirements.

The exemplary embodiments of the glass fiber composition according to the present invention are given below.

Example 1

SiO_2	58.0%
Al_2O_3	19.1%
CaO	7.9%
MgO	9.4%
Y_2O_3	3.6%
Na_2O	0.18%
K_2O	0.31%
Li_2O	0.45%
Fe_2O_3	0.44%
TiO_2	0.43%

In addition, the weight percentage ratio C1= RE_2O_3/R_2O is 3.83, and the weight percentage ratio C2= Al_2O_3/MgO is 2.03.

In Example 1, the measured values of the six parameters are respectively:

Forming temperature	1300°C
Liquidus tempetature	1204°C
ΔT	96°C
Peak crystallization tempetature	1030°C
Elastic modulus	95.7GPa
Powder weight loss	0.98%

Example 2

SiO_2	58.0%
Al_2O_3	19.1%
CaO	7.2%
MgO	9.4%
Y_2O_3	3.6%
Na_2O	0.18%
K_2O	0.31%
Li_2O	0.45%
Fe_2O_3	0.44%
TiO_2	0.43%
SrO	0.7%

In addition, the weight percentage ratio C1= RE_2O_3/R_2O is 3.83, and the weight percentage ratio C2= Al_2O_3/MgO is 2.03.

In Example 2, the measured values of the six parameters are respectively:

Forming temperature	1302°C
Liquidus temperature	1201°C
ΔT	101°C
Peak crystallization temperature	1032°C
Elastic modulus	96.5GPa

Powder weight loss   0.95%

Example 3

SiO$_2$	56.9%
Al$_2$O$_3$	21.0%
CaO	5.3%
MgO	10.4%
Y$_2$O$_3$	3.5%
La$_2$O$_3$	0.5%
Na$_2$O	0.11%
K$_2$O	0.24%
Li$_2$O	0.61%
Fe$_2$O$_3$	0.44%
TiO$_2$	0.74%

In addition, the weight percentage ratio C1= RE$_2$O$_3$/R$_2$O is 4.17, and the weight percentage ratio C2= Al$_2$O$_3$/MgO is 2.02.

In Example 3, the measured values of the six parameters are respectively:

Forming temperature	1306°C
Liquidus temperature	1216°C
ΔT	90°C
Peak crystallization temperature	1023°C
Elastic modulus	97.6GPa
Powder weight loss	0.95%

Example 4

SiO$_2$	56.1%
Al$_2$O$_3$	21.6%
CaO	6.2%
MgO	9.0%

Y_2O_3	3.8%
La_2O_3	0.4%
Na_2O	0.12%
K_2O	0.28%
Li_2O	0.54%
Fe_2O_3	0.44%
TiO_2	0.62%
SrO	0.5%

In addition, the weight percentage ratio $C1 = RE_2O_3/R_2O$ is 4.47, and the weight percentage ratio $C2 = Al_2O_3/MgO$ is 2.40.

In Example 4, the measured values of the six parameters are respectively:

Forming temperature	1305°C
Liquidus temperature	1220°C
ΔT	85°C
Peak crystallization temperature	1022°C
Elastic modulus	99.2GPa
Powder weight loss	0.8%

Example 5

SiO_2	58.1%
Al_2O_3	19.2%
CaO	7.3%
MgO	9.3%
Y_2O_3	2.0%
La_2O_3	1.6%
Na_2O	0.18%
K_2O	0.21%
Li_2O	0.51%
Fe_2O_3	0.44%

TiO_2	0.95%

In addition, the weight percentage ratio C1= RE_2O_3/R_2O is 4.0, and the weight percentage ratio C2= Al_2O_3/MgO is 2.06.

In Example 5, the measured values of the six parameters are respectively:

Forming temperature	1296°C
Liquidus temperature	1199°C
ΔT	97°C
Peak crystallization temperature	1033°C
Elastic modulus	94.7GPa
Powder weight loss	0.85%

Example 6

SiO_2	58.3%
Al_2O_3	19.3%
CaO	7.3%
MgO	8.9%
Y_2O_3	3.7%
La_2O_3	0.4%
Na_2O	0.23%
K_2O	0.18%
Li_2O	0.54%
Fe_2O_3	0.44%
TiO_2	0.51%

In addition, the weight percentage ratio C1= RE_2O_3/R_2O is 4.32, and the weight percentage ratio C2= Al_2O_3/MgO is 2.17.

In Example 6, the measured values of the six parameters are respectively:

Forming temperature	1303°C
Liquidus temperature	1204°C
ΔT	99°C
Peak crystallization temperature	1030°C

Elastic modulus	97.4GPa
Powder weight loss	0.9%

Comparisons of the property parameters of the aforementioned examples and other examples of the glass fiber composition of the present invention with those of S glass, traditional R glass and improved R glass are further made below by way of tables, wherein the component contents of the glass fiber composition are expressed as weight percentage. What needs to be made clear is that the total amount of the components in the examples is slightly less than 100%, and it should be understood that the remaining amount is trace impurities or a small amount of components which cannot be analyzed.

Table 1A

		A1	A2	A3	A4	A5	A6	A7
Component	SiO_2	58.0	58.0	58.0	58.0	58.3	58.0	57.8
	Al_2O_3	19.1	19.1	19.1	19.1	19.1	19.4	20.0
	CaO	7.9	7.2	7.2	7.6	8.3	8.0	8.1
	MgO	9.4	9.4	9.4	9.2	10.2	9.0	9.2
	Y_2O_3	3.6	3.6	3.3	4.1	1.8	3.6	-
	La_2O_3	-	-	0.5	-	-	-	1.7
	Gd_2O_3	-	-	-	-	-	-	0.3
	Na_2O	0.18	0.18	0.18	0.18	0.22	0.18	0.13
	K_2O	0.31	0.31	0.31	0.31	0.20	0.31	0.22
	Li_2O	0.45	0.45	0.45	0.45	0.54	0.45	0.61
	Fe_2O_3	0.44	0.44	0.44	0.44	0.44	0.44	0.44
	TiO_2	0.43	0.43	0.43	0.43	0.71	0.43	1.2
	SrO	-	0.7	0.5	-	-	-	-
Ratio	C1	3.83	3.83	4.04	4.36	1.88	3.83	2.08
	C2	2.03	2.03	2.03	2.08	1.87	2.16	2.17
Parameter	Forming temperature/°C	1300	1302	1298	1298	1295	1304	1308
	Liquidus temperature /°C	1204	1201	1199	1197	1212	1202	1210
	△T /°C	96	101	99	101	83	103	98
	Peak crystallization temperature/°C	1030	1032	1034	1034	1024	1032	1028
	Elastic modulus /GPa	95.7	96.5	97.0	97.9	93.1	95.8	92.8
	Powder weight loss/%	0.98	0.95	0.93	0.9	1.05	0.95	0.98

Table 1B

		A8	A9	A10	A11	A12	A13	A14
Component	SiO$_2$	58.1	58.1	56.1	58.3	58.3	58.5	57.4
	Al$_2$O$_3$	19.2	19.2	21.6	19.1	19.3	19.3	20.3
	CaO	6.7	7.3	6.2	6.8	7.3	7.0	7.0
	MgO	9.3	9.3	9.0	9.2	8.9	8.9	9.2
	Y$_2$O$_3$	1.6	2.0	3.8	4.0	3.7	3.7	2.4
	La$_2$O$_3$	2.0	1.6	0.4	0.4	0.4	0.4	-
	Na$_2$O	0.18	0.18	0.12	0.26	0.23	0.12	0.12
	K$_2$O	0.26	0.21	0.28	0.40	0.18	0.29	0.29
	Li$_2$O	0.51	0.51	0.54	0.30	0.54	0.54	0.54
	Fe$_2$O$_3$	0.44	0.44	0.44	0.44	0.44	0.44	0.44
	TiO$_2$	0.41	0.95	0.62	0.60	0.51	0.41	0.75
	SrO	1.1	-	0.5	-	-	-	1.4
	F$_2$	-	-	-	-	-	0.2	-
Ratio	C1	3.79	4.0	4.47	4.58	4.32	4.32	2.53
	C2	2.06	2.06	2.40	2.08	2.17	2.17	2.18
Parameter	Forming temperature/°C	1297	1296	1305	1298	1303	1300	1301
	Liquidus temperature /°C	1201	1199	1220	1199	1204	1197	1205
	ΔT /°C	96	97	85	99	99	103	96
	Peak crystallization temperature/°C	1032	1033	1022	1034	1030	1034	1028
	Elastic modulus /GPa	94.3	94.7	99.2	98.5	97.4	97.1	94.8
	Powder weight loss/%	0.95	0.85	0.8	0.9	0.9	0.95	0.9

Table 1C

Component		A15	A16	A17	A18	S glass	Traditional R glass	Improved R glass
Component	SiO$_2$	58.2	58.2	58.0	56.9	65	60	60.75
	Al$_2$O$_3$	19.2	19.2	19.1	21.0	25	25	15.80
	CaO	8.1	7.8	6.4	5.3	-	9	13.90
	MgO	9.4	9.7	9.1	10.4	10	6	7.90
	Y$_2$O$_3$	-	2.0	4.5	3.5	-	-	-
	La$_2$O$_3$	2.0	-	-	0.5	-	-	-
	Na$_2$O	0.14	0.11	0.14	0.11	trace amount	trace amount	0.73
	K$_2$O	0.31	0.30	0.30	0.24	trace amount	trace amount	
	Li$_2$O	0.40	0.50	0.50	0.61	-	-	0.48
	Fe$_2$O$_3$	0.44	0.44	0.44	0.44	trace amount	trace amount	0.18
	TiO$_2$	0.75	0.49	0.46	0.74	trace amount	trace amount	0.12
	SrO	0.7	0.7	0.7	-	-	-	-
	CeO$_2$	-	0.2	-	-	-	-	-
Ratio	C1	2.35	2.20	4.79	4.17	0	0	0
	C2	2.04	1.98	2.10	2.02	2.5	4.17	2
Parameter	Forming temperature/°C	1302	1298	1297	1306	1571	1430	1278
	Liquidus temperature /°C	1204	1200	1198	1216	1470	1350	1210
	ΔT /°C	97	98	99	90	101	80	68
	Peak crystallization temperature/°C	1027	1031	1033	1023	-	1010	1016
	Elastic modulus /GPa	92.2	93.4	98.6	97.6	89	88	87
	Powder weight loss/%	0.85	0.9	0.9	0.95	-	1.25	1.5

It can be seen from the values in the above tables that, compared with the S glass and traditional R glass, the glass fiber composition of the present invention has the following advantages: (1) much higher elastic modulus; (2) much lower liquidus temperature, which helps to reduce crystallization risk and increase the fiber drawing efficiency; relatively high peak crystallization temperature, which indicates that more energy is needed for crystal nucleuses to form

and grow during the crystallization process, i.e. the crystallization risk of the glass of the present invention is smaller under the same conditions;

Meanwhile, compared with the improved R glass, the glass fiber composition of the present invention has the following advantages: (1) much higher elastic modulus; (2) relatively high peak crystallization temperature, which indicates that more energy is needed for crystal nucleuses to form and grow during the crystallization process, i.e. the crystallization risk of the glass of the present invention is smaller under the same conditions; (3) Much lowered weight loss showing that the chemical stability of the glass is significantly improved.

Both S glass and traditional R glass cannot enable the achievement of production with refractory-lined furnaces and, with respect to improved R glass, part of the glass properties is compromised to reduce the liquidus and forming temperatures, so that the production difficulty is decreased and the production with refractory-lined furnaces could be achieved. By contrast, the glass fiber composition of the present invention not only has a sufficiently low liquidus temperature and lower crystallization rate which permit the production with refractory-lined furnaces, but also significantly increases the glass modulus and chemical stability, thereby resolving the technical bottleneck that the performance of S and R glass fibers cannot be improved with the growth of production scale.

The glass fiber composition according to the present invention can be used for making glass fibers having the aforementioned excellent properties.

The glass fiber composition according to the present invention in combination with one or more organic and/or inorganic materials can be used for preparing composite materials having excellent performances, such as glass fiber reinforced base materials.

Finally, what should be made clear is that, in this text, the terms "contain", "comprise" or any other variants are intended to mean "nonexclusively include" so that any process, method, article or equipment that contains a series of factors shall include not only such factors, but also include other factors that are not explicitly listed, or also include intrinsic factors of such process, method, object or equipment. Without more limitations, factors defined by such phrase as "contain a…" do not rule out that there are other same factors in the process, method, article or equipment which include said factors.

The above examples are provided only for the purpose of illustrating instead of limiting the

technical solutions of the present invention. Although the present invention is described in details by way of aforementioned examples, one skilled in the art shall understand that modifications can also be made to the technical solutions embodied by all the aforementioned examples or equivalent replacement can be made to some of the technical features. However, such modifications or replacements will not cause the resulting technical solutions to substantially deviate from the spirits and ranges of the technical solutions respectively embodied by all the examples of the present invention.

INDUSTRIAL APPLICABILITY OF THE INVENTION

The glass fiber composition of the present invention not only has a sufficiently low liquidus temperature and crystallization rate which enable the production with refractory-lined furnaces, but also significantly increases the glass modulus and chemical stability, thereby resolving the technical bottleneck that the performance of S glass fiber and R glass fiber cannot be improved with the enhanced production scale. Compared with the current main-stream high-performance glasses, the glass fiber composition of the present invention has made a breakthrough in terms of elastic modulus, crystallization performance and chemical stability of the glass, with significantly improved modulus, remarkably reduced crystallization risk and noticeably improved chemical stability. Thus, the overall technical solution of the present invention is particularly suitable for the production of high-performance glass fiber with excellent chemical stability in refractory-lined furnaces.

CLAIMS

1.A high-performance glass fiber composition, comprising the following components expressed as percentage by weight:

SiO_2	53-64%
Al_2O_3	>19% and <25%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.05-7%
$R_2O=Li_2O+Na_2O+K_2O$	$\leq 1\%$
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%

2.The high-performance glass fiber composition according to claim 1, wherein the range of the weight percentage ratio $C1= RE_2O_3/R_2O$ is greater than 0.5.

3.The high-performance glass fiber composition according to claim 1, wherein the content range of Li_2O by weight percentage is 0.05-0.85%.

4.The high-performance glass fiber composition according to claim 1, wherein the content range of $R_2O= Li_2O+Na_2O+K_2O$ by weight percentage is lower than 0.97%.

5.The high-performance glass fiber composition according to claim 1, wherein the content range of Li_2O by weight percentage is at least 0.05% and lower than 0.55%.

6.The high-performance glass fiber composition according to claim 1, wherein the content range of Li_2O by weight percentage is 0.1-0.5%.

7.The high-performance glass fiber composition according to claim 1, wherein the range of the weight percentage ratio $C2= Al_2O_3/MgO$ is greater than 1.8.

8.The high-performance glass fiber composition according to claim 1, wherein the range of the weight percentage ratio $C2= Al_2O_3/MgO$ is greater than 1.95.

9.The high-performance glass fiber composition according to claim 1, wherein the content range of $SiO_2+Al_2O_3$ by weight percentage is lower than 80.4%.

10.The high-performance glass fiber composition according to claim 1, wherein the content range of $RE_2O_3= Y_2O_3+La_2O_3+Gd_2O_3$ by weight percentage is 0.5-6%.

11.The high-performance glass fiber composition according to claim 1, comprising the following components expressed as percentage by weight:

SiO_2	53-64%
Al_2O_3	>19% and <25%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.05-7%
$R_2O=Li_2O+Na_2O+K_2O$	≤1%
Li_2O	0.05-0.85%
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%

wherein, the range of the weight percentage ratio $C1= RE_2O_3/R_2O$ is greater than 0.5.

12.The high-performance glass fiber composition according to claim 1, comprising the following components expressed as percentage by weight:

SiO_2	53-64%
Al_2O_3	>19% and <25%
$SiO_2+Al_2O_3$	<82%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.05-7%
$R_2O=Li_2O+Na_2O+K_2O$	≤1%
Li_2O	0.05-0.85%
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%

wherein, the range of the weight percentage ratio $C1= RE_2O_3/R_2O$ is greater than 0.5.

13.The high-performance glass fiber composition according to claim 1, comprising the following components expressed as percentage by weight:

SiO_2	53-64%
Al_2O_3	>19% and <25%

$SiO_2+Al_2O_3$	<80.4%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.05-7%
$R_2O=Li_2O+Na_2O+K_2O$	<0.97%
Li_2O	0.05-0.85%
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%

wherein, the range of the weight percentage ratio C1= RE_2O_3/R_2O is greater than 0.5.

14.The high-performance glass fiber composition according to claim 1 or 11, wherein the content range of $R_2O= Li_2O+Na_2O+K_2O$ by weight percentage is not greater than 0.95%.

15.The high-performance glass fiber composition according to claim 1 or 11, wherein the content range of $R_2O= Li_2O+Na_2O+K_2O$ by weight percentage is not greater than 0.85%

16.The high-performance glass fiber composition according to claim 1, comprising the following components expressed as percentage by weight:

SiO_2	53-64%
Al_2O_3	>19% and <25%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.05-7%
$R_2O=Li_2O+Na_2O+K_2O$	$\leq$1%
Li_2O	0.05-0.85%
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%

wherein, the range of the weight percentage ratio C1= RE_2O_3/R_2O is greater than 0.5, and the range of the weight percentage ratio C2= Al_2O_3/MgO is greater than 1.8.

17.The high-performance glass fiber composition according to claim 1, comprising the following components expressed as percentage by weight:

SiO_2	53-64%

Al_2O_3	>19% and <25%
$SiO_2+Al_2O_3$	<82%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.5-6%
$R_2O=Li_2O+Na_2O+K_2O$	$\leq$1%
Li_2O	$\geq$0.05% and <0.55%
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%

wherein, the range of the weight percentage ratio $C1= RE_2O_3/R_2O$ is greater than 0.5, and the range of the weight percentage ratio $C2= Al_2O_3/MgO$ is greater than 1.8.

18. The high-performance glass fiber composition according to claim 1, comprising the following components expressed as percentage by weight:

SiO_2	53-64%
Al_2O_3	>19% and <25%
$SiO_2+Al_2O_3$	<82%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.5-6%
$R_2O=Li_2O+Na_2O+K_2O$	<0.97%
Li_2O	0.05-0.85%
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%

wherein, the range of the weight percentage ratio $C1= RE_2O_3/R_2O$ is greater than 0.5, and the range of the weight percentage ratio $C2= Al_2O_3/MgO$ is greater than 1.95.

19. The high-performance glass fiber composition according to claim 1, comprising the following components expressed as percentage by weight:

SiO_2	54-62%
Al_2O_3	>19% and $\leq$23%

$SiO_2+Al_2O_3$	<80.4%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.5-6%
$R_2O=Li_2O+Na_2O+K_2O$	≤1%
Li_2O	0.05-0.85%
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%

wherein, the range of the weight percentage ratio $C1= RE_2O_3/R_2O$ is greater than 1, and the range of the weight percentage ratio $C2= Al_2O_3/MgO$ is greater than 1.95.

20.The high-performance glass fiber composition according to claim 1 or 4, wherein the content range of Na_2O+K_2O by weight percentage is lower than 0.7%.

21.The high-performance glass fiber composition according to claim 4 or 19, wherein the content range of TiO_2 by weight percentage is not greater than 0.75%.

22.The high-performance glass fiber composition according to claim 4 or 18, wherein the content range of Al_2O_3 by weight percentage is greater than 19% and not greater than 19.4%.

23.The high-performance glass fiber composition according to claim 4 or 19, wherein the content range of Al_2O_3 by weight percentage is greater than 19.4% and not greater than 23%.

24.The high-performance glass fiber composition according to claim 1 or 4, wherein the content range of SrO by weight percentage is 0.1-2%.

25.The high-performance glass fiber composition according to claim 1 or 11, wherein the content range of Gd_2O_3 by weight percentage is 0.05-1%.

26.The high-performance glass fiber composition according to claim 1, comprising the following components expressed as percentage by weight:

SiO_2	53-64%
Al_2O_3	>19% and <25%
$SiO_2+Al_2O_3$	<82%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.05-7%
$La_2O_3+Gd_2O_3$	0.1-3%
$R_2O=Li_2O+Na_2O+K_2O$	≤1%

Li_2O	0.05-0.85%
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%
TiO_2	≤0.75%
Fe_2O_3	<1.5%

wherein, the range of the weight percentage ratio $C1= RE_2O_3/R_2O$ is greater than 0.5.

27.The high-performance glass fiber composition according to claim 1, comprising the following components expressed as percentage by weight:

SiO_2	53-64%
Al_2O_3	>19% and <25%
$SiO_2+Al_2O_3$	<82%
$RE_2O_3=Y_2O_3+La_2O_3+Gd_2O_3$	0.05-7%
Y_2O_3	0.5-5%
$R_2O=Li_2O+Na_2O+K_2O$	<0.97%
Li_2O	0.05-0.85%
$CaO+MgO+SrO$	10-24%
CaO	1.5-12%
TiO_2	<2%
Fe_2O_3	<1.5%

wherein, the range of the weight percentage ratio $C1= RE_2O_3/R_2O$ is greater than 0.5, and the range of the weight percentage ratio $C2= Al_2O_3/MgO$ is greater than 1.8.

28.The high-performance glass fiber composition according to claim 13 or 26, wherein the range of the weight percentage ratio $C1= RE_2O_3/R_2O$ is 1.5-5.

29.The high-performance glass fiber composition according to claim 13 or 26, wherein the range of the weight percentage ratio $C2= Al_2O_3/MgO$ is 2-2.45.

30.The high-performance glass fiber composition according to claim 13, wherein the content range of CaO by weight percentage is 5-10%.

31.The high-performance fiber glass composition according to claim 1 or 30, wherein the content range of MgO by weight percentage is 8.1-12%.

32.The high-performance fiber glass composition according to claim 1 or 13, wherein the content range of La_2O_3 by weight percentage is 0.1-2%.

33.The high-performance glass fiber composition according to claim 1 or 26, comprising F_2 with the weight percentage of 0-1.2%.

34.The high-performance glass fiber composition according to claim 1 or 26, comprising B_2O_3 with the weight percentage of 0-2%.

35.The high-performance glass fiber composition according to claim 1 or 26, comprising CeO_2 with the weight percentage of 0-1%.

36.A glass fiber, characterized by, being produced from any of the glass fiber compositions described in claims 1-35.

37.A composite material, characterized by, incorporating the glass fiber described in claim 36.