The assessment and treatment of waste from glass fibre production for use as a filler in composites

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Abstract. Waste glass from fibreglass production is waste that is generated at various stages of production. In nature, it is a combination of glass fibres, fine dust, but also larger glass grains, for example also from leakages during production. This material is or may be contaminated by impregnation, lubricants or some impurities that prevent its recovery during production. The main objective of this study is to assess the suitability of glass fibre waste and to optimise the pre-treatment of the raw material for use in the composite. This paper describes the determination of chemical composition, mineralogical composition by X-ray diffraction analysis, determination of bulk density, water absorption and specific surface area. The results obtained are compared with the primary raw material - glass fibre. The results showed that the waste from glass fibre production is primarily composed of silica, calcium, alumina and boron. Minor components include magnesium oxide, sodium oxide, fluorine, iron oxide, strontium oxide, potassium oxide, titanium dioxide, sulphur dioxide and chromium oxide. The specific surface area of treated glass fibre waste correlates with the specific surface area of cement, which is a prerequisite for the use of this waste as a partial substitute for cement in the production of building materials.

1 Introduction

1.1 Waste from glass fibre production

Waste glass from fibreglass production is waste that is generated at various stages of production. It is a combination of glass fibres, fine dust, but also larger glass grains, for example also from leakages during production. This material is, or may be, contaminated by impregnation, lubricants or certain impurities which prevent its recovery during production [1].

Primary glass is a solid with a high content of amorphous SiO_2. It is a substance formed by solidification of a melt without crystallisation processes. The hardness of glass on the Mohs hardness scale is 5-7. The term glass recyclate refers to container glass, especially bottle glass, made from 50 % silica sand, 10 % Na_2CO_3 (soda), 12 % $CaCO_3$ (limestone), 18 %

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crushed waste glass shards and 4 % other substances. The glass melt, in the form of a red-hot viscous mass, is produced at a temperature of 1500-1700 °C when it is fed into blowing or press-blowing machines for bottle production. The glass thus produced may be clear or coloured [2,3].

Due to its properties, composition and versatility, so-called E-glass occupies a major share (>90 %) in the production of glass fibres. The approximate composition of E-glass is 52-56 % silica, 16-25 % calcium oxide, 12-16 % alumina, 5-10 % boron oxide, 0-5 % magnesium oxide and <1 % alkali (Na_2O, K_2O) [4].

The production of glass fibres consists primarily in the preparation of the charge and its transport to the melting furnace. This is followed by melting, shaping by mechanical drawing or centrifugation and sufficiently rapid cooling to prevent crystallisation.

In the production of glass fibres, various wastes are generated at different stages of production. In nature, it is a combination of glass fibres, fine dust but also larger glass grains, for example, also arising from leakages during production [2,5].

1.1 Purpose and issues of the research

Recycling of construction waste is one of the steps of sustainable construction, which leads to a reduction of environmental pollution as well as a reduction in the cost of building materials. In this regard, the aim of this work is to assess the suitability of waste fiberglass and to optimize the pre-treatment of the raw material for use in the composite.

The following properties are to be determined:

- Investigate the composition and properties of construction waste from the production of glass fibre.
- Determine the technological criteria for the suitability of the pre-treatment of the waste.
- Identify the possibilities of using the waste in construction materials in relation to its designated properties.

The results obtained are compared with the primary raw material - glass fibre. The annual production of glass waste including waste from glass fibre production in the Czech Republic is 3.45 tonnes (for 2017) [6].

Due to its composition and high SiO_2 content, waste from glass fibre production shows high pozzolanic activity, which in combination with cement promotes the formation of CSH gels in the cement matrix. Finely ground soda-lime glass shows high pozzolanic activity, consuming portlandite to form CSH phases. These coat the reaction edge of the glass grains and reduce the monosulphate level. This ability of fine glass can in turn reduce the risk of ACP. A prerequisite for such glass properties is the fineness of the grinding.

Pozzolans, are natural siliceous substances, silica-clay substances, or a combination of both. When mixed with water, pozzolans do not harden or set themselves, but when ground finely and suitably, they react in the presence of water and calcium hydroxide ($Ca(OH)_2$) to form silicate or calcium aluminate compounds, which are the carriers of strength. These compounds are similar to those formed during the hardening of hydraulic substances (e.g. cements). Pozzolans must contain at least 25 % silica (SiO_2) and also contain alumina (Al_2O_3), smaller amounts of iron oxide (Fe_2O_3) and other oxides. According to EN 197-1, pozzolans include, for example, natural calcined pozzolans, which are substances of volcanic origin, clays, shales or sedimentary rocks activated by heat treatment and which comply with the above. Furthermore, pozzolans include fly ash and silica fume [7–9].

Research studies indicate that if the glass grain size is less than 75 μm, the material exhibits sufficient pozzolanic activity. However, with the use of ground glass and glass in concrete in general, the problem of alkali-silica reaction (ASR) arises, a reaction whereby the reaction of alkali (cement) and amorphous silicates (glass) in the cement matrix results in the formation of new and larger volume formations over time, which can lead to structural failure of the entire structure. It is known from research that when the glass is ground to a higher specific surface area and the mean particle size is below 300 μm, ASR no longer occurs [10].

Limiting the recyclability of glass fibre waste is the possible contamination by impregnation, lubricants or some impurities that prevent its reuse in production. Impregnation or lubrication of glass fibres is a surface treatment of the fibres which provides surface protection during further processing and also ensures that the individual elementary fibres are bonded together. The most used chemicals for fibreglass lubrication are synthetic resins, waxes, oils or silicones [11].

2 Metods and Experiment

2.1 Determination of the pre-treatment of glass fibre waste

Within this part of the research, waste pre-treatment methodologies were developed together with the assumption of optimization of the sorting, crushing and grinding process.

2.1.1 Verification of pre-treatment capabilities with commonly available laboratory and production facilities

Figure 1 shows the grain size curve of the untreated waste glass, which was determined by sieving the raw material through a set of standard sieves. Pre-treatment of the waste glass fibre production was carried out first in a jaw crusher, then in a vibrating and ball mill. The specific surface area of the glass waste thus pretreated was then determined by the permeability method with a value of 330 $m^2 \cdot kg^{-1}$ using a Blain apparatus.

Pre-treated waste glass was of 0-0.8 mm fraction. The maximum grain size of 0.8 mm waste glass ensures better cohesiveness of the mass and also prevents the formation of silica gel in such a form that it damages the structure.

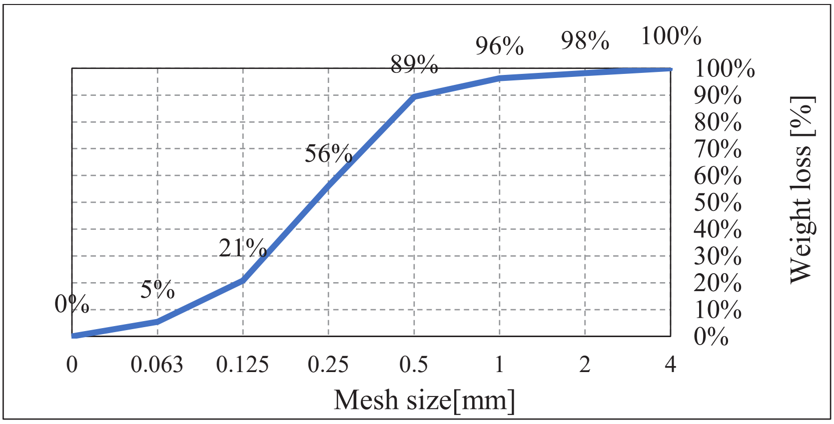

Fig. 1. Grain size curve of untreated waste glass.

2.1.2 Optimization of pretreatment processes to achieve suitable grain size curves

When grinding glass, care must be taken to select an appropriate grinding time, as the time for additional grinding to a higher fineness increases exponentially with higher fineness. The optimum fineness of glass waste for partial cement replacement was determined by determining the specific surface area by the permeability method with a value of 330 $m^2 \cdot kg^{-1}$ using the Blain apparatus.

The use of waste glass as a substitute for the fine fractions of aggregate and sand in the production of composite materials is limited and may show negative results, mainly because of the risk of alkali-silica reaction between cement and waste glass aggregate and also because composite materials with higher amounts of glass replacing aggregate have lower flexural and compressive tensile strengths. The shape of the waste glass particles determines the degree of adhesion in the cement paste and therefore affects the compressive and flexural strengths.

In the optimisation of the pre-treatment processes, it was found that the use of pre-treated waste glass fibre production waste of 0-0.8 mm fraction as a filler to replace fine aggregate of the same fraction in the amount of 10-15 % of the total ballast, using a maximum grain size of 0.8 mm of waste glass, results in better cohesiveness of the mass and also does not lead to the formation of silica gel in such a form that it damages the structure. The resulting aggregate grain size curve used in the silicate composite is shown in Fig. 2 compared to the ideal grain size curve according to Fuller.

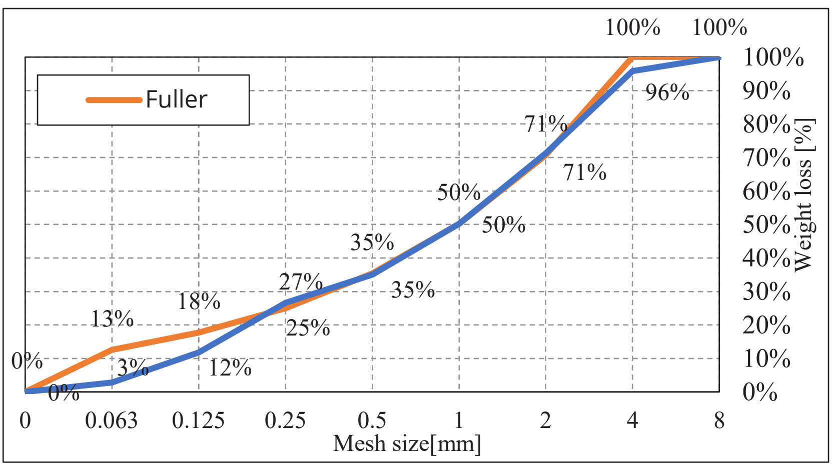

Fig. 2. Comparison of the ideal grain size curve according to Fuller and the used aggregate grain size curve in the composite rain size curve of untreated waste glass.

2.2 Research on glass fibre waste

The chemical composition was determined on a sample of the raw material - waste from glass fibre production. From the results of the chemical composition (Table 1) it can be seen that the waste from glass fibre production consists mainly of silica (SiO_2), calcium oxide (CaO), aluminium oxide (Al_2O_3) and boron oxide (B_2O_3). Minor constituents include magnesium oxide (MgO), sodium oxide (Na_2O), fluorine (F), iron oxide (Fe_2O_3), strontium oxide (SrO), potassium oxide (K_2O), titanium dioxide (TiO_2), sulphur oxide (SO_3) and chromium oxide (Cr_2O_3). From chemical analysis, it was possible to determine that this is so-called E-glass. E-glass occupies a major share (>90 %) in the production of glass fibres due to its properties, composition and versatility. The approximate composition of E-glass is 52-56 % silica, 16-

25 % calcium oxide, 12-16 % alumina, 5-10 % boron oxide, 0-5 % magnesium oxide and <1 % alkali (Na_2O, K_2O).

Table 1. Chemical composition of waste glass.

SiO_2	CaO	Al_2O_3	B_2O_3	MgO	Na_2O	F	Fe_2O_3	SrO	K_2O	TiO_2	SO_3	Cr_2O_3
52,25	23,10	14,16	7,18	0,97	0,77	0,56	0,365	0,245	0,23	0,11	0,039	0,005

The results of the mineralogical composition show that the waste from the production of glass fibres is completely amorphous, which can also be confirmed by the presence of a typical curvature between the angles 2θ in the range 15-35°. The presence of iron oxides can also be confirmed from the results due to the typical interference between iron oxides when using a copper anode (CuKα), which appears as a discontinuous line in the resulting diffractogram.

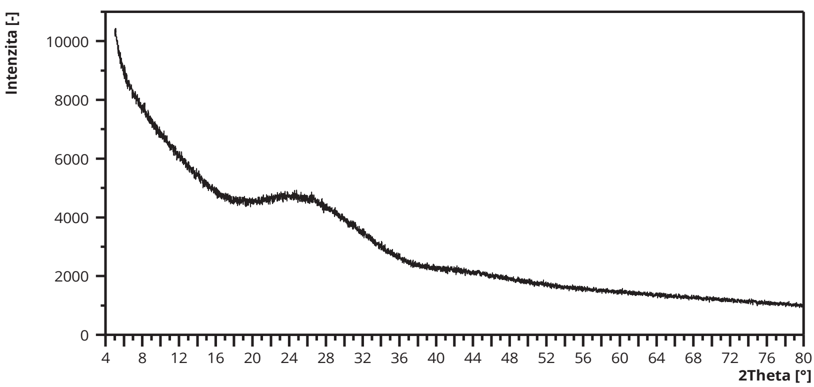

Fig. 3. X-ray diffraction analysis of raw material .

The results of the tests for the determination of bulk density, specific gravity, water absorption and specific surface area are given in Table 2 below. Since the raw material does not contain pores, the values for bulk density and specific gravity are the same. The raw material, waste from glass fibre production, is also non-absorbent. Pre-treatment of the raw material was carried out in a jaw crusher, vibrating and ball mill and then its specific surface area was determined by the Blaine method.

Table 2. Results of measured material properties of the raw material.

Parameter	Value
Volume weight	$2.62\ g\cdot cm^{-3}$
Specific gravity	$2.62\ g\cdot cm^{-3}$
Absorbency	0 %
Specific surface area	$330\ m^2\cdot kg^{-1}$

The bulk density and specific gravity correlate with the density of ordinary glass. Because of the way the glass fibres are produced, which are completely amorphous, there are no pores in them and the absorbency of this waste from the production of glass fibres is therefore zero. The specific surface area of pre-treated glass fibre waste correlates with that of cement (300-350 $m^2\cdot kg^{-1}$), which is a prerequisite for the use of this waste as a partial replacement for cement in silicate composites.

3 Results and Discussion

The research was carried out to determine the material properties of glass fibre production waste by means of a set of laboratory tests. The results of the chemical composition of the raw material are presented in Table 1, and the results of the mineralogical composition by X-ray diffraction analysis are presented in Figure 3.

The chemical composition was determined on the waste glass sample (Table 1), it was found that the waste glass fibre is primarily composed of silica, calcium, aluminium and boron. Minor constituents include magnesium oxide, sodium oxide, fluorine, iron oxide, strontium oxide, potassium oxide, titanium dioxide, sulphur dioxide and chromium oxide. Thus, it was possible to determine that the glass fibres are made of so-called E-glass.

The mineralogical composition was also determined by X-ray diffraction analysis (Fig. 3), from which it was found that the waste from glass fibre production is completely amorphous. As the raw material does not contain pores, the values of bulk and specific gravity are the same and also due to the absence of pores the raw material is also non-absorbent (Table 2). The specific surface area (Table 2) of the treated glass fibre waste correlates with that of cement, which is a prerequisite for the use of this waste as a partial substitute for cement in the production of building materials.

At the same time, a determination was made as to the method of pretreatment of waste from fibreglass production to maximise its use in the production of building materials. As part of the optimisation of the pretreatment process, it was found that the most advantageous is the pretreatment of waste from fibreglass production first in a jaw crusher, then in a vibrating or ball mill.

It was found that the pretreated waste glass can be used as a partial cement substitute due to its pozzolanic properties. The optimum value of specific surface area of pretreated waste glass fibre production is 330 $m^2 \cdot kg^{-1}$.

4 Conclusions

The study dealt with the testing and expert analysis of waste from glass fibre production. As part of the testing, the chemical composition of the raw material was determined. It was found that the waste from glass fibre production is primarily composed of silica, calcium, alumina and boron. From the determination of the mineralogical composition by X-ray diffraction analysis, it was found that the glass fibre waste is completely amorphous. Since the raw material does not contain pores, the values of bulk density and specific gravity are identical, and the absence of pores also makes the raw material non-absorbent. The specific surface area of the treated glass fibre waste correlates with that of cement, which is a prerequisite for the use of this waste as a partial substitute for cement in the production of building materials.

The second objective was to determine the optimum method of pretreatment of waste from fibreglass production to maximise its use in the production of building materials. It was found that the most advantageous method was pretreatment of waste from fibreglass production first in a jaw crusher, followed by grinding in a vibrating and ball mill. Waste glass can be used as a partial cement substitute due to its pozzolanic properties and the optimum specific surface area of the pre-treated fibreglass waste is 330 $m^2 \cdot kg^{-1}$. It was also found that the use of pre-treated glass fibre waste with a fraction of 0-0.8 mm as filler to replace fine aggregate of the same fraction in the amount of 10-15 % of the total ballast, better cohesiveness of the mass is achieved and the formation of silica gel in such a form as to damage the structure is avoided.

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