Abstract: The challenge related to waste management has become a serious worldwide environmental problem. Highly sustainable solutions, which do not involve reworking the material and are based on waste utilization, are sought. Such waste as used casting compounds, which so far has been used, among others, in construction, road construction, mining and cement production. Descriptions of the use of various waste moulding compounds, such as waste quartz compounds with water glass, quartz chamotte and quartz bentonite can be found in the literature. Due to the high content of quartz and low toxicity of bentonite sandmix, an attempt was done to use them for the production of sand-lime products.

The aim of this article is to determine the suitability of the waste material as a substitute for quartz sand in the production of sand-lime products. The usability of waste was determined by laboratory tests of physicochemical characteristics of the finished silicates. Sand, which is a carrier of silica, was replaced with used moulding compounds with fractions up to 0.5 mm, in the weight amounts of 5.5, 11 and 16.5%. Applying up to 11% of used casting materials as a substitute for quartz sand with a lime content of 5.5% in the raw material mixture has a clearly positive effect on compressive strength. However, the higher share of sand substitution in the mixture weakens the mechanical features of the obtained materials. The absorptivity of the finished products increases with the increase of the inserted additions' amounts. The influence of significant amounts of casting compound additives on the microstructure of calcium-silicate products was studied as well. It was stated, that they affect the location of the tobermorite in the volume of the autoclaved material.
diversity, both quantitative and qualitative, dependent on many factors, such as the landfill size, the amount and the type of deposited waste, as well as climatic conditions (in particular the amount and frequency of atmospheric precipitation), the landfill age and storage technology (the waste compaction degree and the insulating layers application). The leachate used in the experiment came from the municipal Barcza landfill near Kielce (Poland). Conducted research allowed formulating the conclusion that the used landfill leachate contributed to achieving slightly higher compressive strength of modified sand-lime products in comparison to the traditional product. Impact that is more significant was observed in bulk density and water absorption tests. Combination of the leachate and the water-resisting admixture did not produce an expected result of the higher compressive strength. Changes in the microstructure of the products with different composition were observed. In another study, [13] sand-lime products were examined with the use of high impact polystyrene (HIPS) and acrylonitrilebutadienestyrene (ABS). Additives in the form of recycled plastics have a considerable influence on the characteristics of the modified sand-lime products, which depends on the type of polymer, form of recycling and its quantity in the sample. The biggest impact on the compressive strength increase has HIPS regranulate [10], while ABS regranulate significantly reduces capillary action in the products. The analysis indicate that silicate masonry units with post-production and post-consumption plastic waste can possess interesting functional features, which bring a new potential possibility to dispose of still growing number of plastic waste.

Z. Pytel [14] presented in his work the possibility of the secondary usage of used casting masses in the process of producing sand-lime products. He used foundry masses with an organic binder in the form of a furan resin, foundry masses from Cold Box technology, with water glass, alkaline-phenolic, post-regenerative dust, which were gotten as a result of mass regeneration with furan resin and mixtures of various types of casting masses. However, each type of additive was processed by mechanical removal of binder residues from the grain surface. However, it has not been defined whether it is possible to use quartz bentonite masses for the production of sand-lime products. There is also no specification whether it is possible to apply the mass without mechanical processing. The main aim of this research work is to determine the possibility of partial replacement of quartz sand by waste casting masses, without any processing of used masses. The suitability of these sands for obtaining products was determined based on a comparative analysis in relation to the features of reference plastics, which do not contain waste materials.

2 Experimental

2.1 Materials

2.1.1 Quartz sand

Quartz sand of natural origin is the raw material, which is the source of silica and at the same time acts as an aggregate. It was obtained from deposits exploited at the Silicates Production Plant in Ludynia. Granulation was tested in accordance with the PN-EN 933-1 standard for control purposes. The analysis of granulomere composition was carried out using the sieve method. The weight of 0.5 kg of aggregate, after drying in a dryer at 105°, was sieved through sieves of 0.063, 0.125, 0.25, 0.5 and 1.0 mm. Based on this, it was stated that fine quartz sand of natural origin with a maximum grain size of less than 0.5 mm would be used for the test (Figure 1). According to the Unified Soil Classification System, this kind of sand with less than 5% fines is marked with the SW symbol. The distribution and shape of grains of sand are shown in the Figure 17.

![Figure 1: Sand grain size curve.](image-url)

2.1.2 Burnt lime

The function of the binder, which is a source of lime ions and at the same time acts as a plasticiser, by softly burnt lime, which comes from the Trzuskawica Production Plant. Declared values of functional features of lime are presented in the Table 1.
Table 1: Summary of functional features of high reactive burnt lime.

| Functional features of burnt lime | Declared value |
|----------------------------------|----------------|
| CaO+MgO [%]                     | ≥ 91           |
| MgO [%]                         | ≤ 2.0          |
| CO₂ [%]                         | ≤ 3.0          |
| SO₃ [%]                         | ≤ 0.5          |
| Screening through a 0.2 mm sieve [%] | ≥ 97          |
| Screening through a 0.09 mm sieve [%] | ≥ 90          |
| Reactivity 60°C                 | ≤ 2.0          |

Table 2: Quantitative composition of lime-silicate samples.

| Series number | Amount of lime (binder) [%] | Amount of sand (aggregate) [%] | Amount of the additive (post-mortem sand) [%] |
|---------------|----------------------------|-------------------------------|-----------------------------------------------|
| A             | 5.50                       | 94.50                         | 0.00                                          |
| B             | 5.50                       | 89.00                         | 5.50                                          |
| C             | 5.50                       | 83.50                         | 11.00                                         |
| D             | 5.50                       | 78.00                         | 16.50                                         |

2.1.3 Used casting compounds

The results of the analysis of the elemental composition of quartz-bentonite moulding masses used in the experiment by X-ray spectrophotometry are shown in Figure 3. The size of the grains does not exceed 0.5 mm, which is in line with the guidelines for the use of sand in sand-lime products. The shape of the grains of waste post-form sands is shown in Figure 2. Large amounts of silicon is a sign of possible use of the additives as a substitute for quartz sand.

2.2 Sample preparation procedures

The preparation of the sand-lime mixture for the individual sample series consisted of the following steps:

a) Weighing of particular quantities of materials, according to the Table 2.

b) Mixing high reactive burnt lime with quartz sand.

c) Addition of water, mixing of ingredients.

d) Placing the mixture in a sealed glass vessel in a drying oven at 65°C for 1 hour.

e) Cooling the mixture to ambient temperature.

f) Mixing of ingredient (2 minutes).

g) Addition of water in relation to the total weight of the mixture.

h) Sample forming by two-stage and double-sided pressing with interstage venting at 10 MPa and 20 MPa (cylinder-shaped samples with a diameter of 25 mm and a height of 25 mm).

i) Autoclaving under conditions:

- pressure of saturated water vapour - 1.002 MPa,
- water vapour temperature - 180°C,
- duration – 8 h (2.5 h heating + 5.5 h autoclaving).

The curve of temperature increase during heating of samples in autoclave and is shown in Figure 4. After 150
minutes the temperature stabilised and the samples were stored at 180°C for next 5.5 hours. After this period, the samples were left in an autoclave to cool for another 12 hours.

Four series of sand-lime samples, the quantitative composition of which is presented in Table 2, were carried out for the study. In the case of each series of samples a constant content of burnt lime was applied, and the amounts of quartz sand and post-formers sand were variable.

### 3 Testing methods

After the hydrothermal treatment process, the obtained samples of material were subjected to tests aimed at determining their basic functional properties. Tests of compressive strength, volumetric density and absorbability of the obtained samples were carried out in accordance with the range and methodology given in the following standards [15–17]. After 21 days, according to standard [15], of the autoclaving process, the compressive strength of silicate products was tested in laboratory conditions, using a hydraulic press (Tecnotest KC 300). Photos of the internal structure were made to observe hydrated calcium silicate morphology using scanning electron microscope (SEM-type Quanta 250 FEG) and EDS analysis (electron beam voltage - 5 kV, samples were not sputtered).

### 4 Results and discussion

By analysing the obtained research results, it should be stated that the share of used casting compounds has an influence on the features of autoclaved sand-lime materials.

This effect depends on the degree of substitution of quartz sand with waste material. According to (Pytel, 2010), the type and degree of processing of individual casting masses also have an impact on the parameters of sand-lime products.

The use of 5.5 and 11% of used casting compounds as a substitute for quartz sand has a clearly positive effect in terms of compressive strength (Figure 5). The use of 16.5% post-mortar sands causes a decrease in compression strength. Significant increase in the content of substitute in the raw material mixture weakens the mechanical properties of the obtained plastics. It was also observed that as the additive content in the raw material mixture increases, the absorbability of the finished products increases. Results of volumetric density indicate that the addition of up to 11% increases the tested parameter (Figure 6).

Figure 9 shows the microstructure of the reference sample. You can see on it the crystals of the tobermorite.
Figure 7: Sample after compressive strength test.

Figure 8: Results of volumetric density of sand-lime products with the use of used casting compounds.

Figure 9: Microstructure of the reference product. 1. Tobermorite 2. C-S-H phase.

Figure 10: EDS analysis. 1.

Figure 11: EDS analysis. 2.

Figure 12: Results of volumetric density.
embedded in a carbonated matrix. This is confirmed by the results of the EDS analysis (Figure 10, Figure 11).

Compared to the microstructure of the reference sample, a tobermorite (Figure 14) and a carbonated matrix (Figure 13) can also be observed in the sample. However, the crystals of the tobermorite are less and they are loosely located on the surface of the sample. Additionally, the uncoated surfaces of the aggregate are visible (Figure 15). This may suggest a lower degree of response of sample D components, resulting in a lower compressive strength compared to the samples.
5 Conclusion

The conducted research shows that there is a possibility of using waste quartz and bentonite moulding sand as a partial replacement of quartz sand in sand-lime products. Safe replacement, which is considered, is up to 11% of additives. Their use in amounts from 5.5 to 11% has a positive effect on the compressive strength and volumetric density of sand-lime products. In larger quantities, however, the compressive strength drops sharply. The use of the tested waste influences the increase in absorbability of finished products, which is a negative and undesirable phenomenon. However, the paper does not exhaust the research topic. Further studies should determine the phase, porosity and pore distribution of the products by XRD analysis and mercury porosimetry, as well as the frost resistance of the finished products. Other combinations of ingredients should also be studied, e.g. by increasing the amount of lime in the raw material mixture. Perhaps using more binder will increase the share of waste in the raw material mixture.

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