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Description of selected practical properties of materials produced based on fine-fraction inorganic waste

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ABSTRACT

Purpose: The paper attempts to evaluate the materials produced by sintering fine fraction waste materials in terms of chemical inertness in the aquatic environment, as well as mechanical strength, scratch and abrasion resistance.

Design/methodology/approach: Slag from a solid waste incineration plant and broken packaging glass were used in studies. The tests were performed on cylindrical samples obtained in the process of pressing, with variable amount of raw materials and fraction (fine fraction < 63 μm, thick fraction 100-63 μm). Microscopic analysis (optical microscope) was carried out for obtained sinters, open porosity was determined via hydrostatic weighing, and also resistance to ions leaching in a water environment was studied using the method of specimens boiling in distilled water during 60 minutes followed by measurement of water pH. Abrasion resistance was also assessed via friction of the surface by a freely rotating metal ball (ball tester) as well as resistance to scratching with a diamond.

Findings: Microstructural analysis allowed to evaluate the morphology of the examined sinters specifying the size and shape of individual pores, which have a significant effect on the pH value. Definitely a much higher wear resistance of sintered materials showed fine particle and high slag content. This is confirmed by the results of scratch tests conducted on scratch-tester.

Research limitations/implications: The obtained results are very promising. Utilisation of such waste in the production of e.g. traditional tile lining is an alternative to natural raw materials. The technology of such products manufacture based on the studied waste is less complicated, economically and environmentally more favourable. However, additional studies are needed, which would enable selecting parameters for designing and producing ceramic floor and wall linings.

Practical implications: The research led to characterize slag as raw material, for which, despite diverse chemical composition, it is possible to obtain stable, reproducible levels of the final product properties, so that they are useful for the production of many glass-crystalline building materials.

Originality/value: The processes for the production of new products such as building materials and aggregates, will reduce the storage of waste and save natural resources.

Keywords: Fine fraction; Cullet; Slag; Dust; Sintering

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PROPERTIES

1. Introduction

A pro-ecological nature is an integral feature of each modern technology. Each manufacturing plant in European Union countries, where waste is generated due to carried out activities, is obliged to manage the waste in an ecological way. Waste landfilling in the ground or its dumping on an open space is a short-term solution, does not providing a guarantee of ecological safety of adjacent areas. Uncontrolled chemical reactions proceeding within a landfill and the influence of atmospheric precipitation may result in soil and groundwater pollution with heavy metals and their compounds at amounts higher than permissible. Therefore there is a real need to implement solutions leading to management of waste, both of industrial and of municipal [1]. In the case of the latter ones, incineration is one of methods for their initial volume reduction by a few dozen per cent. Unfortunately, by-products comprise slags, ashes and dusts, which chemical compositions – contrary to the power sector (power plants, CHPs) waste – feature a high instability and hence difficulty in using them in production of materials with strictly assumed chemical composition. In the case of other waste, e.g. broken glass, the oxide composition fluctuates in a much narrower range, therefore its use as a raw material is much more convenient [2]. Combination of various waste types in a high-temperature process of amorphous phase melting gives a possibility to obtain a material safe for the natural environment, due to an amorphous nature of the structure, in which small amounts of toxic elements left in the slag remain bound in the glass network. Hence the process of total or at least partial vitrification of such waste is a perfect solution, however, frequently difficult to execute [3-6].

Metallurgical process of glass melting from slags, ashes or dusts (even with addition of broken glass) is related to obtaining temperature of around 1600°C, which generates additional production costs. So it is more favourable to use the sintering technology, in which fine powders (crystalline, amorphous) bind with each other and condense, transforming into a mechanically strong solid polycrystal, at a temperature much lower than the glass melting temperature. The formed sinter, contrary to materials obtained through melting, features some porosity, which may be minimized by the addition of broken glass. The amorphous phase, introduced this way, softens with increasing temperature and fills voids in the sinter as the first, thereby decreasing its porosity [7,8].

The main objective of the presented study consisted of characterising specimens, obtained through sintering fine-fraction waste materials (slag from a municipal waste incineration plant and broken glass), in terms of chemical inertness in a water environment as well as mechanical resistance, i.e. to abrasion and scratching.

2. Materials material and experimental methods

Slag from a solid waste incineration plant and broken packaging glass were used in studies. Raw materials were grinded in a ball mill and the obtained powders screened through 63 and 100 μm sieves. Fine fraction < 63 μm and coarse fraction 100-63 μm were chosen for studies and then sets of varying raw material and fraction share were prepared:

Set I (90/10) – two variants:
- 90% of slag and 10% of broken glass (fine fraction);
- 90% of slag and 10% of broken glass (coarse fraction);

Set II (70/30) – two variants:
- 70% of slag and 30% of broken glass (fine fraction);
- 70% of slag and 30% of broken glass (coarse fraction);

Set III (50/50) – two variants:
- 50% of slag and 50% of broken glass (fine fraction);
- 50% of slag and 50% of broken glass (coarse fraction).

Powder blends were subject to uniaxial pressing on a hydraulic press at the pressure of 100 MPa and then finished cylindrical compacts were heat treated in an electric furnace with silicon carbide heaters during 24 hours. The sintering temperature of individual sets was selected experimentally: set I – 1150°C, set II – 1100°C, and set III – 950°C.

Microscopic analysis (optical microscope) was carried out for obtained sinters, open porosity was determined via hydrostatic weighing, and also resistance to ions leaching in a water environment was studied using the method of specimens boiling in distilled water during 60 minutes followed by measurement of water pH. Abrasion resistance was also assessed via friction of the surface by a freely rotating metal ball during 60 minutes (ball tester) as well as resistance to scratching with a diamond (Scratch Tech 4.0 CSM-Instruments). The surface was scratched on a section of 5 mm at a constant load of 5 N.

3. Results and discussion

Microstructural studies allowed assessing morphology of studied sinters, mainly the open and closed porosity (Figs. 1-3). The size and shape of individual pores and their arrangement change depending on the applied fraction of individual initial components. In the process of sintering the use of fine fraction both of slag and of broken glass leads to origination of a larger number of small open pores than in the case of applying a coarser fraction of both components. Increasing the glass content in a set results in origination of numerous spherical pores, having frequently a closed character.

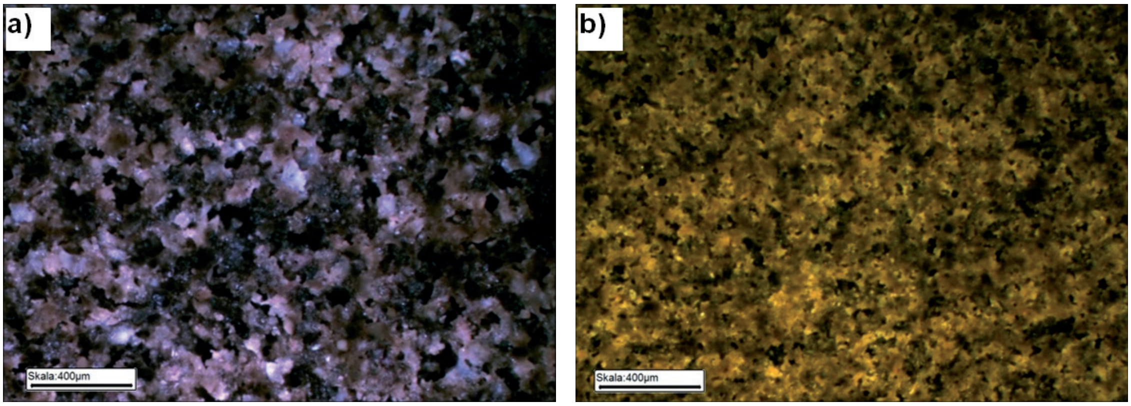

Fig. 1. Microstructure of sinter containing 90% slag and 10% cullet: a) thick fraction (100-63 µm), b) fine fraction (< 63 µm)

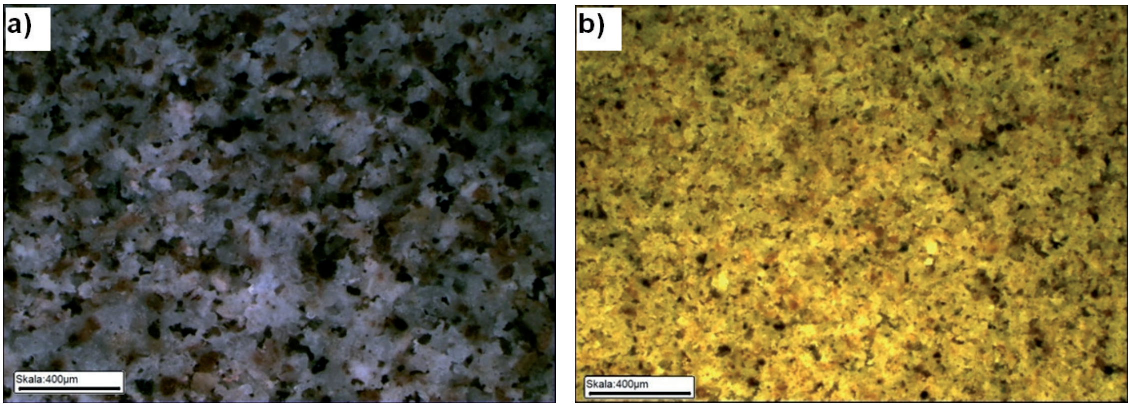

Fig. 2. Microstructure of sinter containing 70% slag and 30% cullet: a) thick fraction (100-63 µm), b) fine fraction (< 63 µm)

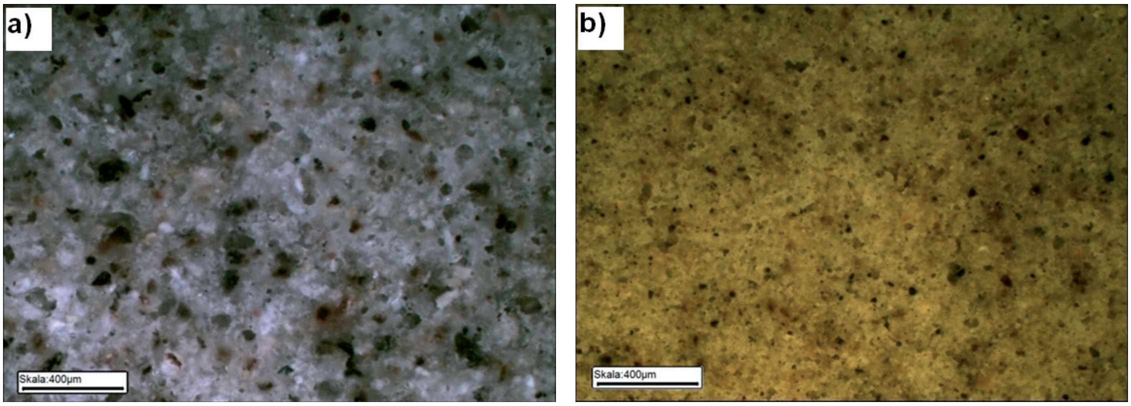

Fig. 3. Microstructure of sinter containing 50% slag and 50% cullet: a) thick fraction (100-63 µm), b) fine fraction (< 63 µm)

Determination of distilled water pH before and after individual specimens boiling allowed evaluating a possibility of ions leaching from the sinters structure, substantially affected by the open porosity. It has been observed that with increasing amount of open pores the pH value was growing, giving a slightly alkaline reaction (Fig. 4). It is necessary to draw attention also to the size of used initial raw materials. In the case of sinters containing the fine-fraction (< 63 μm) slag at the amount of 90% and 50%, the open porosity increased on average by nearly 40% as against sinters obtained from the coarser fraction (100-63 μm), parallel to a small increase in pH, reaching the value of 7. This means that in the case of fine-fraction sinters a better consolidation of raw materials was obtained during pressing, thereby a large area of individual grains contact, and then the heat treatment and increased share of broken glass resulted in a strong binding of individual ions in the material structure, making their leaching impossible.

To evaluate sinters' mechanical parameters an abrasion resistance test was performed, using the method of a steel ball freely rotating on the specimen surface. The effect of an hour long friction is illustrated in Figs. 5-7. The analysis of individual wear spots allows stating a much higher abrasion resistance of sinters based on fine-fraction raw materials and also those featuring a high slag content, which shows a high hardness of this waste.

This test results were also confirmed in the test of resistance to diamond cone scratching on a scratch-tester instrument. A comparative analysis was performed for results obtained from the scratching made on a section of 5 mm for all specimens (Figs. 8-10). At the applied load of 5 N for all specimens containing grains < 63 μm the obtained scratch depth did not exceed 50 μm. In the case of specimens from the 100-63 μm fraction (apart from the specimen containing 90% of slag) with increasing broken glass content the originated scratch was deepening, achieving nearly a three times higher value in the specimen containing 50% of slag. Considering such parameters as the scratch depth and width it is possible to state that, like in the case of abrasion resistance, materials obtained based on fine-fraction waste raw materials with a high slags share feature a high scratch resistance.

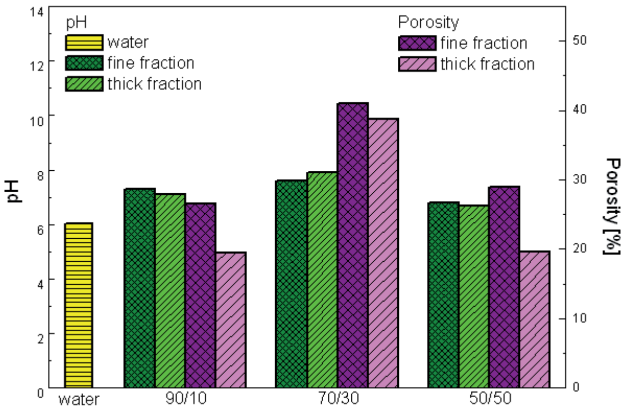

Fig. 4. Porosity and susceptibility to rinsing out of ions from the structure of sinter in pH value depending on the amount and size of individual fractions of starting materials (90/10 – 90% slag and 10% cullet; 70/30 – 70% slag and 30% cullet; 50/50 – 50% slag and 50% cullet)

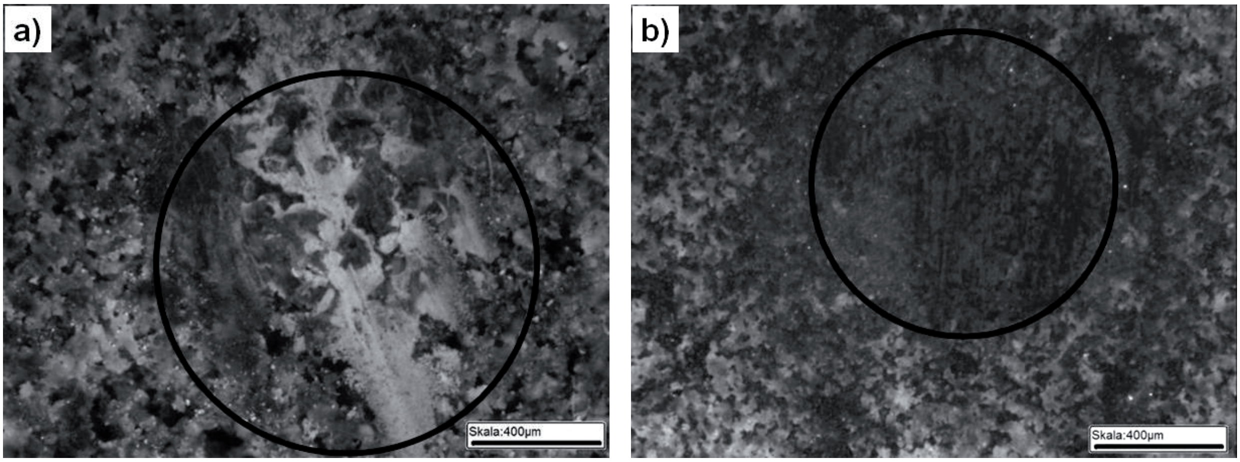

Fig. 5. Results of abrasion resistance tests carried out by means of Calotester for thick (a) and fine (b) fractions containing 90% slag and 10% cullet

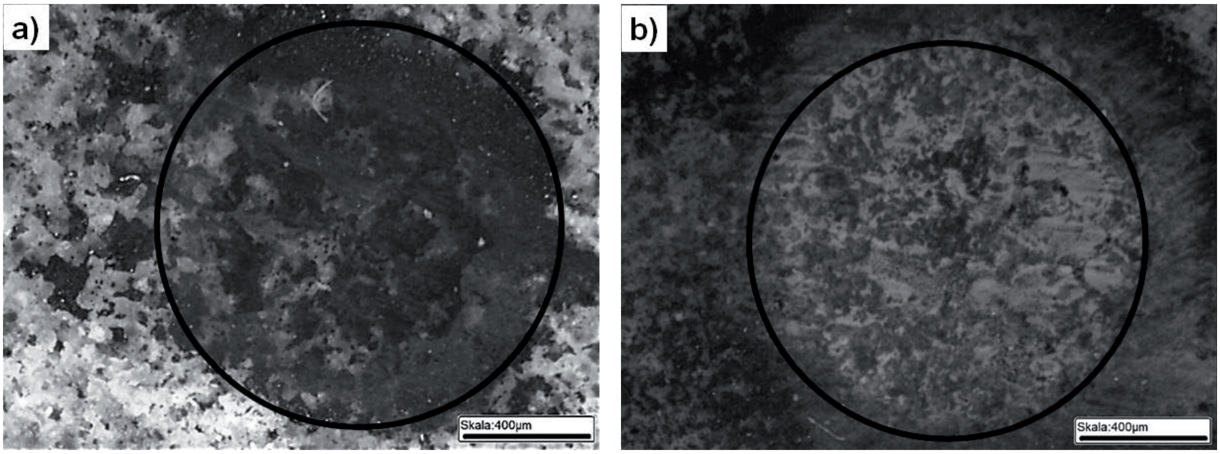

Fig. 6. Results of abrasion resistance tests carried out by means of Calotester for thick (a) and fine (b) fractions containing 70% slag and 30% cullet

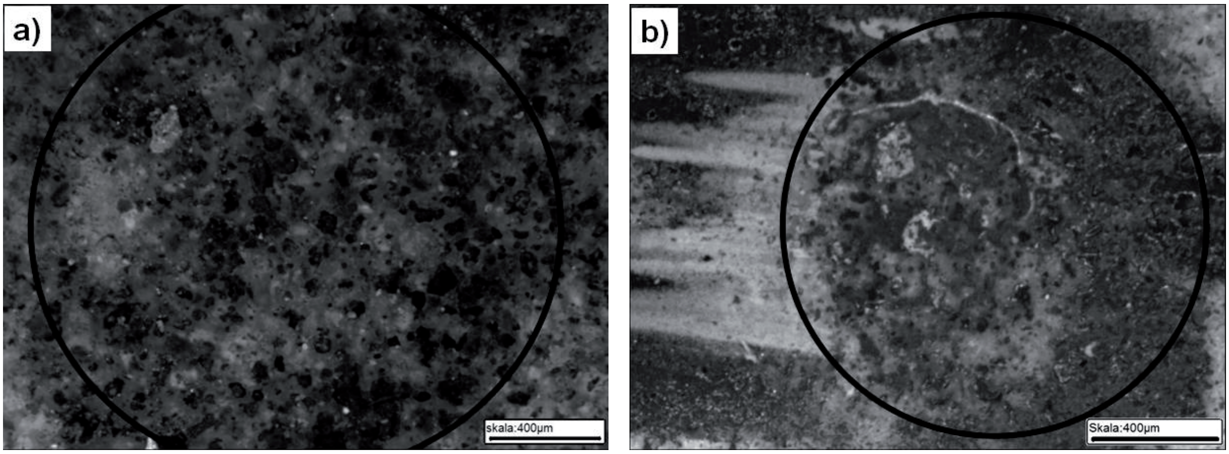

Fig. 7. Results of abrasion resistance tests carried out by means of Calotester for thick (a) and fine (b) fractions containing 50% slag and 50% cullet

4. Conclusions

The study made an attempt to evaluate materials produced through sintering of fine-fraction waste materials (slag from a municipal waste incineration plant and broken glass) in terms of chemical inertness in a water environment as well as mechanical resistance, i.e. resistance to abrasion and scratching. Obtained results allow stating that:

- the size and shape of pores and their arrangement change depending on the applied fraction of individual initial components,
- studied sinters feature a negligible leachability of alkaline ions from the material structure to the water environment, which can – as it should be presumed – be limited by appropriate selection of sintering parameters,
- in the case of abrasion or wear resistance the studies carried out have shown that a higher resistance to this type of mechanical wear was shown by specimens made from fine-fraction raw materials, as well as those with a high slag share.

The obtained results are very promising. Utilisation of such waste in the production of e.g. traditional tile lining is an alternative to natural raw materials. The technology of such products manufacture based on the studied waste is less complicated, economically and environmentally more favourable. However, additional studies are needed, which would enable selecting parameters for designing and producing ceramic floor and wall linings.

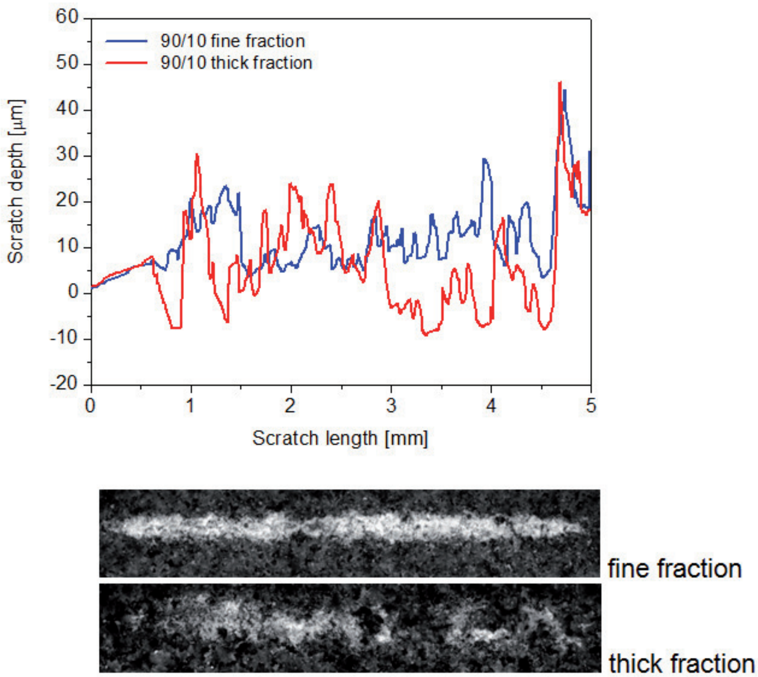

Fig. 8. Scratch depth changes graph along with scratches produced during the test on scratch-tester for fine and thick fractions containing 90% slag and 10% cullet

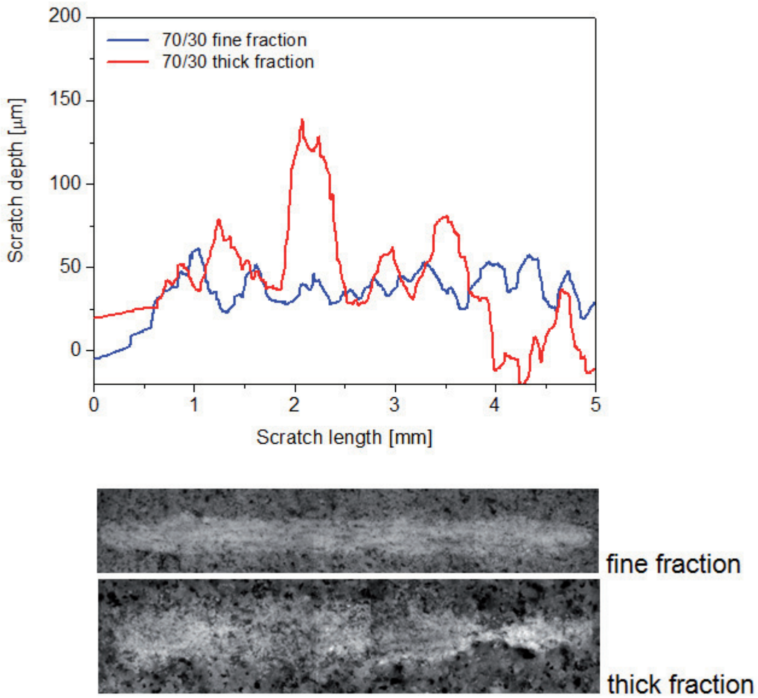

Fig. 9. Scratch depth changes graph along with scratches produced during the test on scratch-tester for fine and thick fractions containing 70% slag and 30% cullet

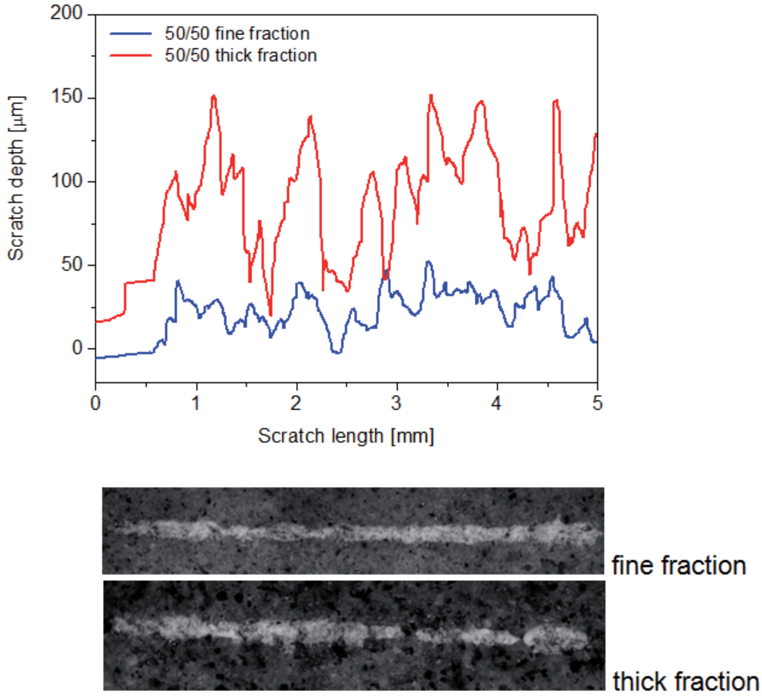

Fig. 10. Scratch depth changes graph along with scratches produced during the test on scratch-tester for fine and thick fractions containing 50% slag and 50% cullet

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