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LOOKING ULTRA FINE, GBFS

Loesche introduces its multicyclone plant for production of U/Fines, or ultra-fine materials. These ultra-fines can improve the early strength of low-CO_2 cements.

To reduce CO_2 emissions, the proportion of Portland clinker in cements should be minimised. While this lowers early strength, this can be boosted by using reactive fine materials. Loesche has developed a multicyclone plant that produces fine composites with low energy demand. Tests with granulated blast furnace slag (GBFS) showed that these so-called 'ultra-fines' (U/Fines) significantly improve the early strength of slag-rich cements, enabling their use in challenging applications like precast elements or shotcrete. The coarse fraction can still be used in conventional cements. Studies with other materials, such as calcined clay, steel slag and limestone also highlight the potential of these U/Fines for enhancing low-clinker cements.

Introduction

To reduce CO_2 emissions, the cement industry is focusing on high clinker substitution, and on carbon capture. However, clinker substitutes like GBFS have lower reaction rates, limiting their application. In Germany, the GBFS availability is expected to decline as the steel industry shifts to direct reduction. Additionally, it is likely that the slags from direct reduction will be converted into material like GBFS with comparable properties through various processes.

Currently, GBFS is mainly used in cement or concrete, typically with a fineness of 3000 - 6000cm^2/g, according to Blaine. However, producing finer GBFS (>10,000cm^2/g) could significantly improve the early strength of cements. Traditional ball mills achieve this fineness, but are highly energy-intensive, making the process costly and limiting widespread use to niche markets. In addition, contamination due to abrasion of the grinding media is a problem.

To address this, Loesche developed a more energy-efficient process to produce ultra-fine materials. This involves combining a conventional vertical roller mill (VRM) with a multicyclone plant. This progressive method offers a less expensive solution to produce extremely fine GBFS, unlocking its potential to improve the early strength of low-clinker cements, enabling broader use in various applications.

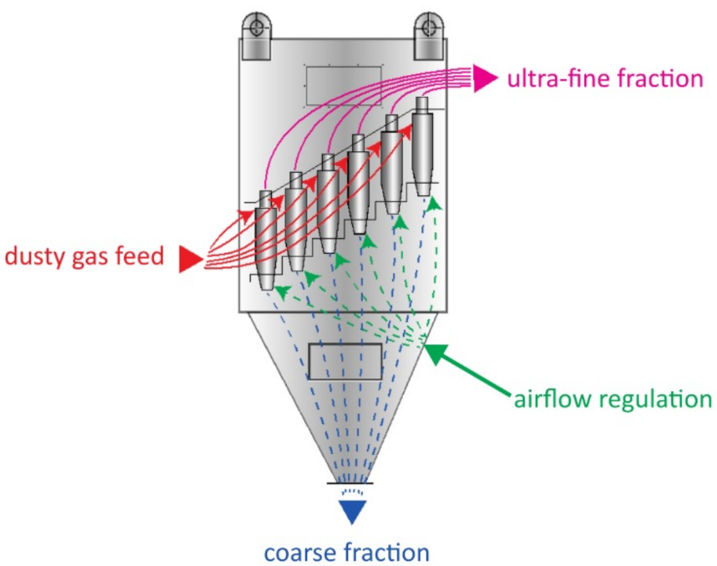

Figure 1: Schematic diagram of the multicyclone battery.

The principle of the multicyclone

Here, the focus is on GBFS, but the described plant can produce various types of ultra-fine materials. Slag ground in large-scale plants typically has a fineness of 3000 - 6000cm^2/g. Tests show that about 10-20% of the ground slag is in a range of >10,000cm^2/g. Loesche developed and patented EP3292912A1, a solution that uses special cyclone equipment originally designed for gas dust cleaning (See Figure 1). The multicyclone plant separates ultra-fine particles from the 'original' material.

The need for a multicyclone system arises from the small cyclone diameters (20 - 40 cm) required to produce ultra-fine materials with d50 values of 1.8 - 2.5µm. To achieve throughputs of several tonnes per hour, many cyclones must be connected in parallel,

Figure 2: View into a pre-assembled multicyclone battery (left), 3D model of an industrial multicyclone battery (right).

forming a multicyclone set-up (See Figure 2). This design allows for efficient separation and production of ultra-fine materials for various applications.

The multicyclone plant for processing GBFS is shown in Figure 3 overleaf. Ground slag from a grinding plant is fed into a vertical buffer (item 1) and then conveyed via an air conveyor trough or a screw feeder (item 2) through a flow meter (item 3). The material is introduced into a gas stream through a disperser (item 4), accelerated, and pneumatically conveyed to the multicyclone.

Gas flow and temperature are controlled by variable-speed blowers (item 5), ensuring optimal conditions for dispersion. Fresh air and re-circulated gas are mixed, with the ratio adjusted by a damper (item 6) to maintain system pressure. Re-circulated gas helps to reduce cold air intake and to control the separation process. To address potential uneven material distribution in the pipeline, two homogenisers (items 7 and 8) can be positioned upstream of the multicyclone entry.

The multicyclone itself (item 9) consists of several individual cyclones arranged geometrically, distributing the process gas evenly. The number of cyclones depends on the plant's throughput. In the multicyclone, coarse particles are separated and discharged via rotary gates (items 10 and 11). The airflow through the cyclone hopper (item 12) is adjusted to control the ratio of fine:coarse materials.

The ultra-fine material exits the multicyclone through a collection chamber connected to the cyclone dip tubes, and is transported to the filter (item 13). The ultra-fine material separated by the filter is continuously removed via a screw conveyor (item 14) and a rotary gate (item 15). After measuring the mass flow (item 16) to balance the fines/coarse ratio, the ultra-fine material is conveyed to a customer storage facility using a dust transport system (item 17). The multicyclone system allows precise control over the production of ultra-fine GBFS, enabling efficient material separation and optimisation for various applications. The findings in Table 1 from a series of tests illustrate the separation results achieved in the multicyclone plant. The energy required to produce the ultra-fine GBFS is considerably lower than that needed for a corresponding comminution. For example, a fineness of 12,000cm^2/g can be produced with an energy demand of <150kWh/t.

Table 1: Example performance of multicyclone plant.

	Input feed	Ultra-fine product	Coarse cyclone discharge
Proportion (%)		18	82
Fineness (cm^2/g)	6000	12,000	4650
D50 value (µm)	6	2.1	7.0

Cement performance of multicyclone GGBFS

The main goal of producing ultra-fine GBFS is to enhance the early strength of cements containing this material. Studies on early strength development in slag-containing cements reveal that particles ≤2µm are crucial in contributing to early reactivity in ground slag powders. However, early reactivity

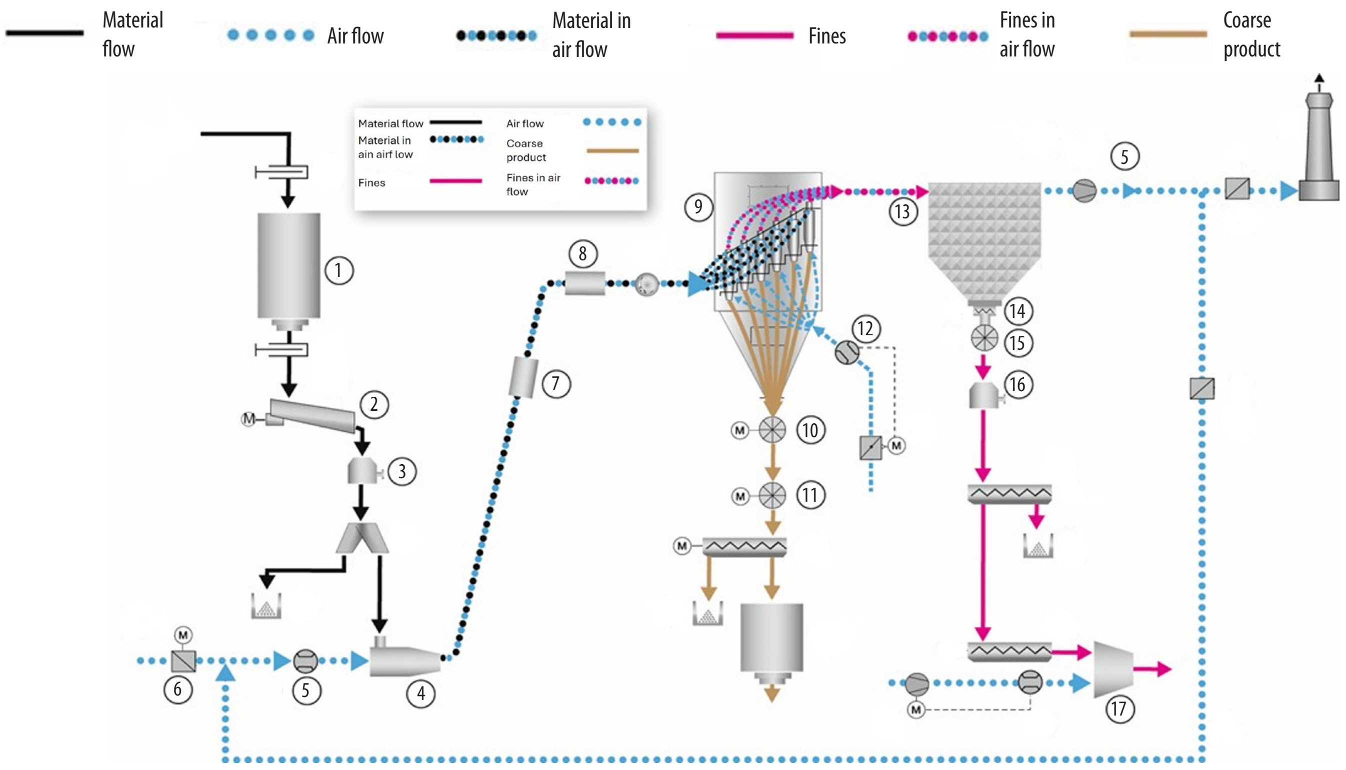

Figure 3: Loesche multicyclone plant (qualitative flow sheet).

is not linearly linked to particle size. Instead, there is a threshold below which slag particles begin to significantly contribute to cement strength within one to two days. Investigations with ultra-fine GBFS confirm these findings. Figure 5 displays the compressive strengths of blast furnace cement with 50% blast furnace slag, varying the slag's fineness. The materials used were slags ground to 3600 - 5000 cm^2/g in a Loesche VRM and an ultra-fine slag from the multicyclone plant with 17,000cm^2/g.

The results show minimal improvement in the early strength with increased fineness from 3600 - 5000cm^2/g. However, after seven and 28 days, higher fineness led to significant increases in strength. The ultra-fine GBFS nearly doubled in two-day compressive strength and considerably enhanced the final strengths, surpassing those achievable by conventional cements. This high-performance blast furnace cement, classified as CEM III/A 52.5 R, is suitable for all applications and serves as an ideal base for high-performance concretes.

Table 2 presents the particle size distributions of the ground granulated blast furnace slag (GGBFS), showing the volume fractions of particles ≤2μm in each variant.

With a feed fineness of approximately 4500 cm^2/g, the multicyclone plant produces only 5.5% by volume of the feed material at a product fineness of 17,000cm^2/g. This suggests that such settings will be used only for exceptional cases, like producing very high-performance speciality products. Discussions with potential users indicate that typical fineness settings will be 10,000 - 13,000cm^2/g for ultra-fine blast furnace slag. In this range, the volume fraction of particles ≤2μm is between 30% and 45%, meaning an enrichment from 15 - 20% in the original feed material.

Further results, not shown here, also indicate that both the early strength and the final strength can be significantly increased by using ultra-fine GBFS. In percentage terms, the increase rates are highest for the early strengths. A cement of strength class 52.5N can be produced with various GBFS contents. Within these test series, it was also found that the separation of the ultra-fine GBFS had only a minor effect on the performance of the remaining coarser material, compared to the initial GBFS. The early strengths remain completely unaffected, while the 28 day strengths are slightly

Table 2: Grinding fineness and volume fractions ≤2μm.

Manufacturing unit	Grinding fineness according to Blaine (cm^2/g)	Volume fractions ≤2μm (v%)
VRM		18
VRM	6000	12,000
Multicyclone	6	2.1

reduced by 2 - 3N/mm². These minor changes can be compensated by adjusting the feed fineness.

Overall, this means that corresponding cements, even with a drastically reduced clinker content, can now be used not only in the ready-mixed concrete sector, but also in the precast industry. In addition, it is now possible to use cements that are very rich in GBFS in shotcrete, which was previously problematic due to its slow setting and sub-optimal interaction with the accelerators.

Further benefits of ultra-fine GBFS

The use of ultra-fine GBFS in cement further positively impacts mortar and concrete properties:

Brightness: The high fineness of the slag significantly increases the whiteness of both the cement and the hardened concrete (see Figure 5). This enhancement allows for reduced pigment usage in coloured concretes and offers an alternative to white cement.

Durability: Ultra-fine GBFS lowers the capillary porosity in GBFS-rich concrete by up to 75%, which densifies the microstructure and improves resistance to external conditions;

ITZ Compaction: The interfacial transition zone (ITZ) between aggregate and cement paste, typically around 40µm thick, can become a weak point due to large calcium hydroxide crystals. Ultra-fine GBFS can replace silica dust to improve ITZ compaction, converting calcium hydroxide into C-S-H phases and achieving high performance in strength and durability.

Outlook

In addition to the production of fine GBFS, the multi-cyclone plant developed by Loesche offers other valuable applications, which are continuously being developed and tested in the company's own test centre.

One considerable focus of the investigations is increasing the early strength of cements with a low Portland cement clinker content by utilising ultra-fine supplementary cementitious materials. This includes the activation of pozzolanic or latent-hydraulic components such as calcined clays, steel slags and modified waste incineration ash. Future studies will also examine modified slags from direct iron reduction. In addition, the multicyclone plant is being used to investigate limestone powder, which can improve early strength as heterogeneous growth nuclei at very high fineness.

In general, ultra-fine materials are becoming increasingly important. This is not least due to the significantly better performance with comparatively low energy consumption during this cyclone process.

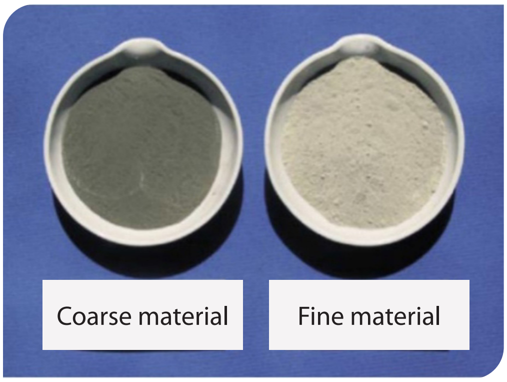

Figure 5: Change in brightness from coarse to ultra-fine.

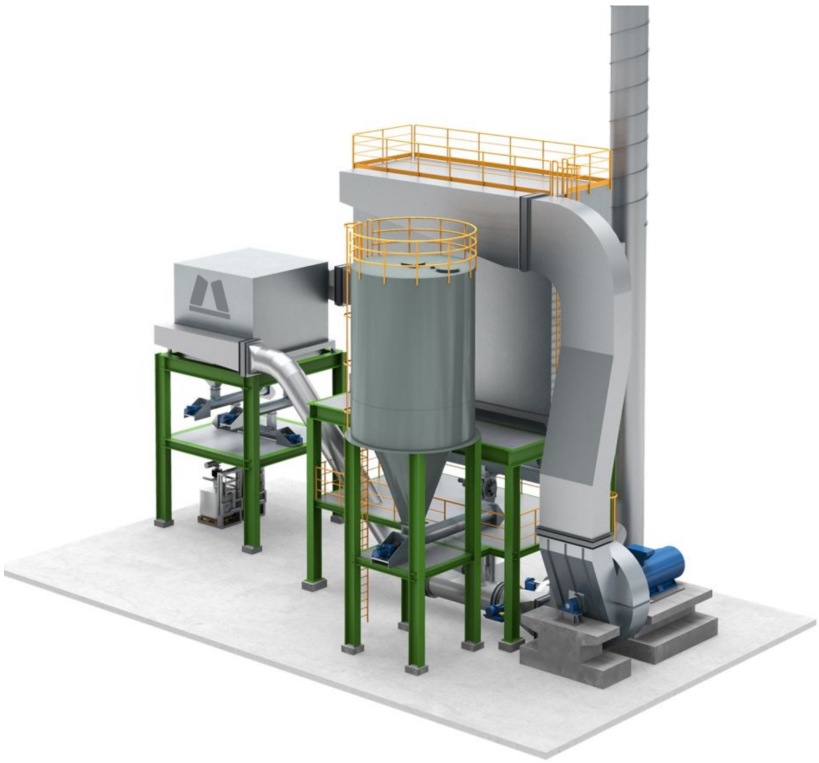

Figure 6: 3D model of a multicyclone plant.