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SiLi SIGMUND LINDNER

High-density beads for more efficient grinding

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1. Introduction

The wet milling process is a widely used technique for processing dispersions across various industries, from simple dispersion processes to the production of micro and nano-sized products that meet the highest quality standards. In these applications, the choice of grinding media is crucial. Factors such as bead size, material, wear behavior, and milling time must be considered to meet specific product requirements. Beyond these factors, the grinding media also significantly impacts the optimization of the milling process, influencing necessary milling time and energy consumption. High-density ceramic beads, for example, can enhance milling performance by reducing required time and energy.

This study examines the milling efficiency of commonly used materials ZrO_2 and Al_2O_3 using three types of beads: state-of-the-art ZrO_2 beads, high-purity Al_2O_3 beads, and newly developed beads of a composite material made of tungsten carbide with ZrO_2. The objective is to compare and analyze the results concerning final product size, bead material, energy input, milling time, and wear behavior.

2. Experimental Setup

A Netzsch MiniPur laboratory bead mill with a 140 ml filling volume was used in circulation mode for all milling experiments. Each test was performed with the same filling rate and new beads, all the same size distribution. The three bead types used are detailed in Table 1:

- **SiLibeads® Type ZY 6.0:** The state-of-the-art beads (zirconium oxide/yttrium stabilized).
- **SiLibeads® Type A 99.99:** High purity alumina ceramic beads (99.99 % Al_2O_3 content).
- **SiLibeads® Type TC 9.5:** Newly developped special high-density beads (zirconium oxide/tungsten carbide).

ZrO_2 and Al_2O_3, common industrial materials, were milled until a target particle size d90 typical for production was reached (Table 2).

Table 1: Parameters of the used SiLibeads®

	ZY 6.0	A 99.99	TC 9.5
size / [mm]	0,4-0,6	0,4-0,6	0,4-0,6
density / [g/cm^3]	6,0	3,8	9,5
Hardness	1300 HV_{10}	n.a.	1600 $HV_{0,5}$
filling weight / [g]	510,0	321,5	816,0
Stress energy / [10^{-3} Nm]	0,091	0,071	0,085

Table 2: Milling Product definitions

	ZrO_2	Al_2O_3
Solid content / [%]	70	55
Solid content /[g]	2500	2000
target particle size d90 / [µm]	0,4	0,5

Various tip speeds were set for each bead type to achieve a sufficiently large but comparable amount of stress energy, with the upper limit determined by the laboratory mill's maximum permitted temperature of 40 °C or the highest possible tip speed. These values were determined through preliminary experiments. Particle size distribution was measured hourly using a Malvern 3000 Mastersizer until the target particle size d90 was reached (Table 1). Each milling experiment was repeated at least three times for each bead type and milling product. Additionally, milling time, energy input, and temperature were monitored during the experiments. The wear of the beads was calculated by measuring the weight loss of the spheres after each experiment compared to the initial filling weight.

3. Results and Discussion

Figure 1 illustrates the evolution of particle size d90 over specific energy for each bead type for both milling products until target fineness was achieved. Additional relevant parameters and associated results are summarized in Table 3.

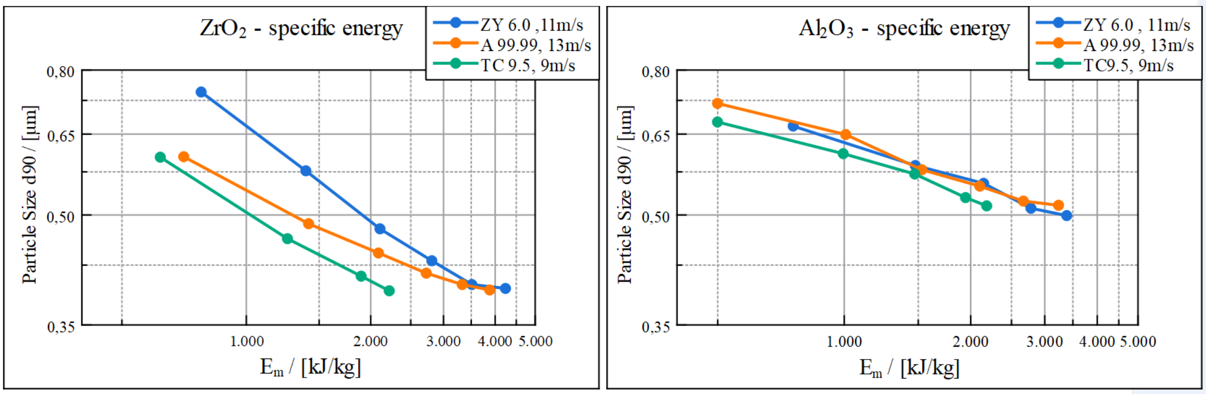

Figure 1: Evolution of particle size d90 of ZrO_2 (left) and Al_2O_3 (right) as function of specific energy for each bead type.

Table 3: Relevant parameters and associated results for each bead type and milling product

milling of ZrO_2 with:	ZY 6.0	A 99.99	TC 9.5
tip speed v_t / [m/s]	11	13	9
milling time / [min]	360	360	210
average energy input to reach final d90 / [kWh]	2,94	2,70	1,53
average bead wear / [%/h]	0,022	2,696	0,054

milling of Al_2O_3 with:	ZY 6.0	A 99.99	TC 9.5
tip speed v_t / [m/s]	11	13	9
milling time / [min]	300	360+	300
average energy input to reach final d90 / [kWh]	1,88	2,40	1,62
average bead wear / [%/h]	1,718	1,449	0,974

For both products, the shortest processing time to reach the final particle size d90 at comparable stress energy was achieved with **SiLibeads® Type TC 9.5.** This type also demonstrated reduced energy input, saving both energy and milling time while improving power input into the product.

The average wear was calculated by determining the percentage weight loss per milling time compared to the respective filling weight for each bead type. In comparison to the other beads, **SiLibeads® Type TC 9.5** exhibited superior wear behavior, particularly when milling highly abrasive Al_2O_3.

4. Conclusion

The results highlight the significant potential of **SiLibeads® Type TC 9.5** for established milling applications as well as for highly abrasive materials. Under comparable process conditions, these beads achieved not only comparable but better fineness in less time, significantly reducing energy consumption due to their material characteristics and the adapted milling parameters. Further improvements in milling performance of **SiLibeads® Type TC 9.5** are feasible by further optimizing specific energy input and stress energy for particular mills and process conditions.

TC 9.5