Linking Particle Shape Simplification to Flowability: An Experimental Study

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Granular materials such as iron ore sinter are critical in steelmaking, where their bulk flow behaviour influences furnace efficiency. Sinter particles are typically in the size range of 20 to 50 mm and exhibit highly irregular, angular morphologies that govern packing and permeability. While Discrete Element Method (DEM) simulations are widely used to study bulk flows of granular materials, particle shapes are often simplified to spheres to reduce computational cost. This study quantifies how much geometric detail is needed to preserve flowability by transferring complexity from virtual models to physical experiments using 3D-printed polyhedral replicas at controlled mesh resolutions (400,000–40 faces) [1]. Shape fidelity was quantified via sphericity, convexity, and roundness; flowability was assessed using angle of repose (AoR), coefficient of static friction (μ_s), and Hausner ratio (HR). Results show a threshold near ~400 faces, where geometric fidelity stabilizes, and flow metrics remain within the same practical classifications. Cumulative effects become detectable only below ~100 faces, yet without reclassification of flow behaviour.

Methods

Three DEM shape modelling approaches (multi-sphere, polyhedral, super-ellipsoid) were evaluated; the polyhedral method was selected for its ability to represent angularity, flat faces, and sharp edges. Shape fidelity was quantified across mesh resolutions using sphericity, convexity, and roundness. Physical replicas were fabricated for bulk tests via Fused Deposition Modelling (FDM) at 400, 100, and 40 faces.

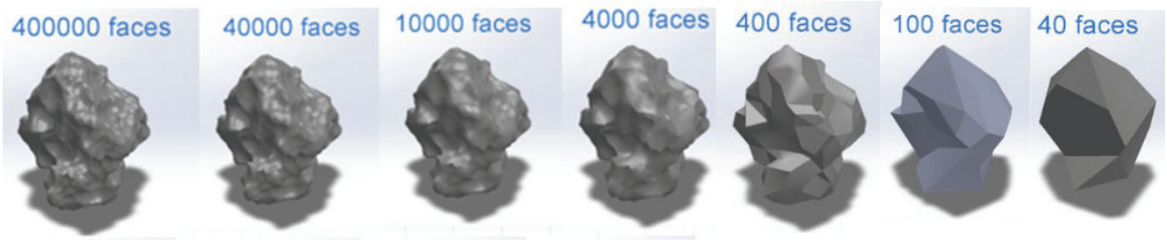

Figure 1: From left to right, sinter particles (size range 20-50 mm) represented by the number of faces from 400,000 to 40 faces. The 400, 100 and 40 face particles were printed for bulk tests.

All replicas (Figure 1) were homothetically scaled to match the original particle volume and empirically calibrated via infill to match the target mass of the original non-simplified particle (3.69 g; ±95% CI with 400,000 faces). AoR was measured with the ledge test and image-based slope extraction; μ_s was measured on an inclined plane for single particles (random and controlled placement) and bulk assemblies; HR was computed from bulk and tapped densities in a 2 L cylinder.

Results and Discussion

The evolution of the shape descriptors as a function of the number of faces is shown in Figure 2. Geometric deviation increases nonlinearly below ~400 faces: sphericity rises from 0.655 (original) to 0.788 (40 faces), convexity from 0.664 to 0.796, and roundness from 0.163 to 0.277. So roundness

shows the largest relative increase (~70%), while sphericity and convexity increase by about 20% each. AoR decreases from 43.4° (400,000 faces) to 38.4° (40 faces), bulk μ_s from 0.55 to 0.49, and HR from 1.45 to 1.32. Stepwise changes between adjacent resolutions generally show overlapping 95% CIs; cumulative differences become detectable only below ~100 faces. Sensitivity analyses indicate sphericity and convexity drive the modest reductions in AoR, μ_s, and HR, while roundness plays a secondary role.

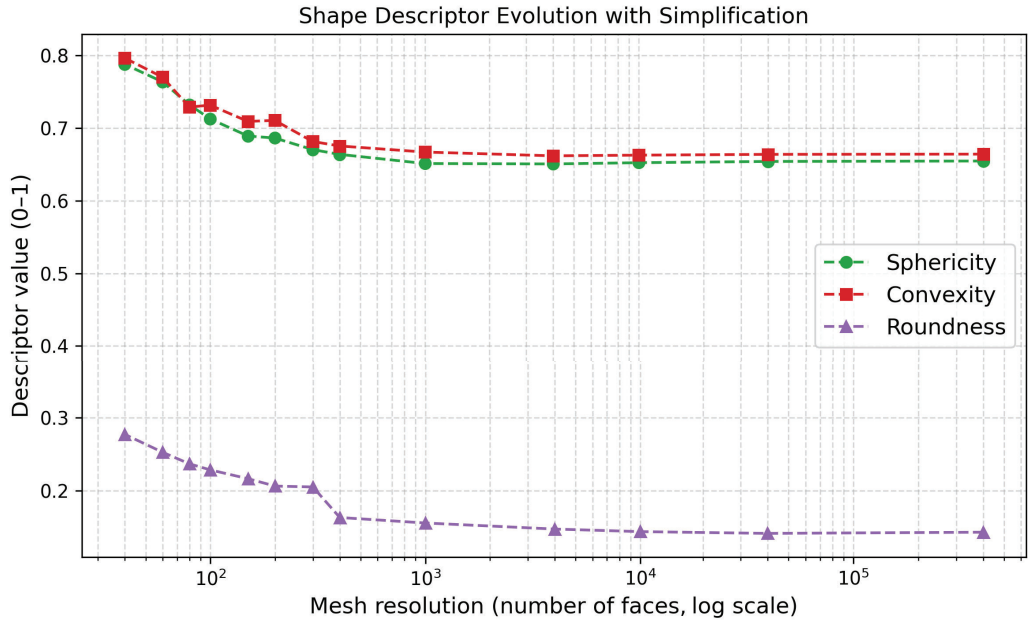

Figure 2: Shape descriptors increase as mesh resolution decreases, reflecting smoothing of angular shape features (400,000 faces represents the original particle).

Conclusions

Flowability of sinter particles is relatively insensitive to polyhedral shape simplification within the tested range. Models with ~400 faces preserve bulk flow metrics, enabling computationally efficient DEM without loss of practical fidelity; extreme simplification (<100 faces) yields minor, measurable changes that do not reclassify flow behaviour.

Future work should extend to size distributions, alternative simplification strategies, and extreme resolutions to refine fidelity thresholds.

Keywords: Sinter; 3D Printing; Shape Simplification; Flowability; Polyhedral DEM; Angle of Repose; Hausner Ratio

References

[1] E. Asad Pour, From Sinter to Print: Linking Particle Shape Simplification to Flowability, MSc thesis, TU Delft, 2026