HANDLING OF FINE GRANULAR BULK MATERIAL: REDUCTION OF PARTICLE WALL FRICTION BY DIAMOND-LIKE CARBON COATING

[1]Christof LANZERSTORFER

[1]*University of Applied Sciences Upper Austria, Wels, Austria, EU, c.lanzerstorfer@fh-wels.at*

https://doi.org/10.37904/metal.2024.4865

Abstract

In the iron and steel industry large amounts of fine granular bulk material like iron ore fines, fluxes, foundry sands or residues from off-gas dedusting have to be handled. In storage, conveying and handling of such materials wall friction between the particles and the wall material is an important parameter. Recently, it was demonstrated that coatings made of diamond-like carbon (DLC) applied on the surface of the wall material can reduce the wall friction angle with fine granular bulk material substantially. In this study, wall friction angles of different wall materials with various fine granular bulk materials from steel mills were investigated. The results showed a significant reduction of the wall friction angle by the DLC coating in comparison to uncoated steel of up to more than 10°, while other coatings showed comparatively little reduction in wall friction.

Keywords: Steel mill, fine granular bulk material handling, wall friction reduction

1. INTRODUCTION

In steel mills large amounts of fine granular bulk materials have to be hadled, on the one hand the raw materials used in iron ore sintering or pelletizing as well as the auxiliary materials in ironmaking, steelmaking and casting processes, on the other hand residues from off-gas dedusting in ironmaking and steelmaking operations [1]. The friction between the particulate material and the wall material plays an important role in both the design and operation of granular bulk materials handling and conveying equipment. Wall friction can be quantified using the wall friction angle [2] which can be calculated from the wall shear stress and the wall normal stress:

$$\varphi_W = \arctan\left(\frac{\tau_W}{\sigma_W}\right) \tag{1}$$

where:

- φ_W – wall friction angle (°)
- τ_W – wall shear stress (N/mm²)
- σ_W – wall normal stress (N/mm²)

Due to the exceptional characteristics of diamond-like carbon (DLC) such as its high degree of hardness and chemical inertness DLC films have found many applications in various fields. They possess very good tribological properties [3] like low friction coefficients and low wear rates. Consequenzly, DLC coatings are applied to reduce friction and wear on sliding parts in numerous applications, including cutting tools, engine parts, gears, bearings, plastic injection molds, textile needles and compressor parts [4-6]. The benefit of DLC coatings in friction reduction for sliding and rotating parts has been widely investigated [7-9]. In contrast, literature focused on the impact of DLC coatings on wall friction of particulate materials is fairly limited. It is only recently that research indecated the potential of DLC coatings to reduce wall friction of granular materials [10].

The aim of the present study was the investigation of the effects of DLC films on wall friction lf fine granular bulk material used on large scale in the iron and steel industry. The wall friction angles were measured using an ring shear tester.

2. MATERIALS AND METHODS

2.1 Materials

Data of the fine granular bulk materials used in the wall friction tests - iron ore fines, fluxes, foundry sand or residues from off-gas dedusting - are summarized in **Table 1**. The materials tested varied in their mass median diameters, which ranged from 8.6 µm to 376 µm.Furthermore, the moisture content of the materials was generally low.

Table 1 Granular materials tested in the shear tests

	Material	**Mass median diameter (µm)**	**Moisture content (%)**
M1	Iron ore fines A	12.9	0.4
M2	Iron ore fines B	22.5	0.1
M3	Chromite sand	376	<0.05
M4	Silica sand	245	0.05
M5	Limestone	91.3	0.1
M6	Casting powder	265	1.6
M7	EAF dust	8.6	1.1
M8	BOF secondary dust	38.8	0,4
M9	BF casthouse dust A	10.6	0.7
M10	BF casthouse dust B	15.2	0.5

2.2 Methods

For the wall friction angle measurements an RST-XS ring shear tester from Schulze was used. The bottom ring of the wall friction shear cell is formed by a sample of the wall material tested. In the tests mild steel S235JR, a sample of an ultra-high molecular weight polyethylene (UHMWPE) and steel coated with diamond like carbon (DLC) were used. Data on the wall materials (roughness and hardness) can be found elsewhere [9]. The DLC coating consists of an amorphous hydrogenated carbon film modified in its properties by Si embedded into the carbon matrix (a-C:H:Si). Details about the production procedure of the DLC coating can be found in the literature [9,10]. Associated pairs of values, comprising the normal stress and the shear stress, were established, providing data points of the wall yield locus. The measurements were performed at five values of the wall normal stress: 240 Pa, 600 Pa, 2000 Pa, 6000 Pa and 20,000 Pa. The kinematic angle of wall friction results from the slope of a straight line running through the origin of the σ-τ-diagram and a point of the wall yield locus [2]. In the tests, each measurement was repeated four times. The results show the mean value of the wall friction angle accompanied by its standard deviation.

The particle size distribution of the fine granular bulk materials was evaluated using a Sympatec HELOS/RODOS laser diffraction instrument, utilizing dry sample dispersion. To maintain precision, the instrument's calibration was confirmed with a Sympatec SiC-P600'06 reference material. The moisture content of the granular bulk materials was determined by drying at 105°C.

3. RESULTS AND DISCUSSION

Figure 1 shows the wall friction angles of the fine granular bulk materials M1 to M8 as a function of the wall normal stress with the three different wall material tested.

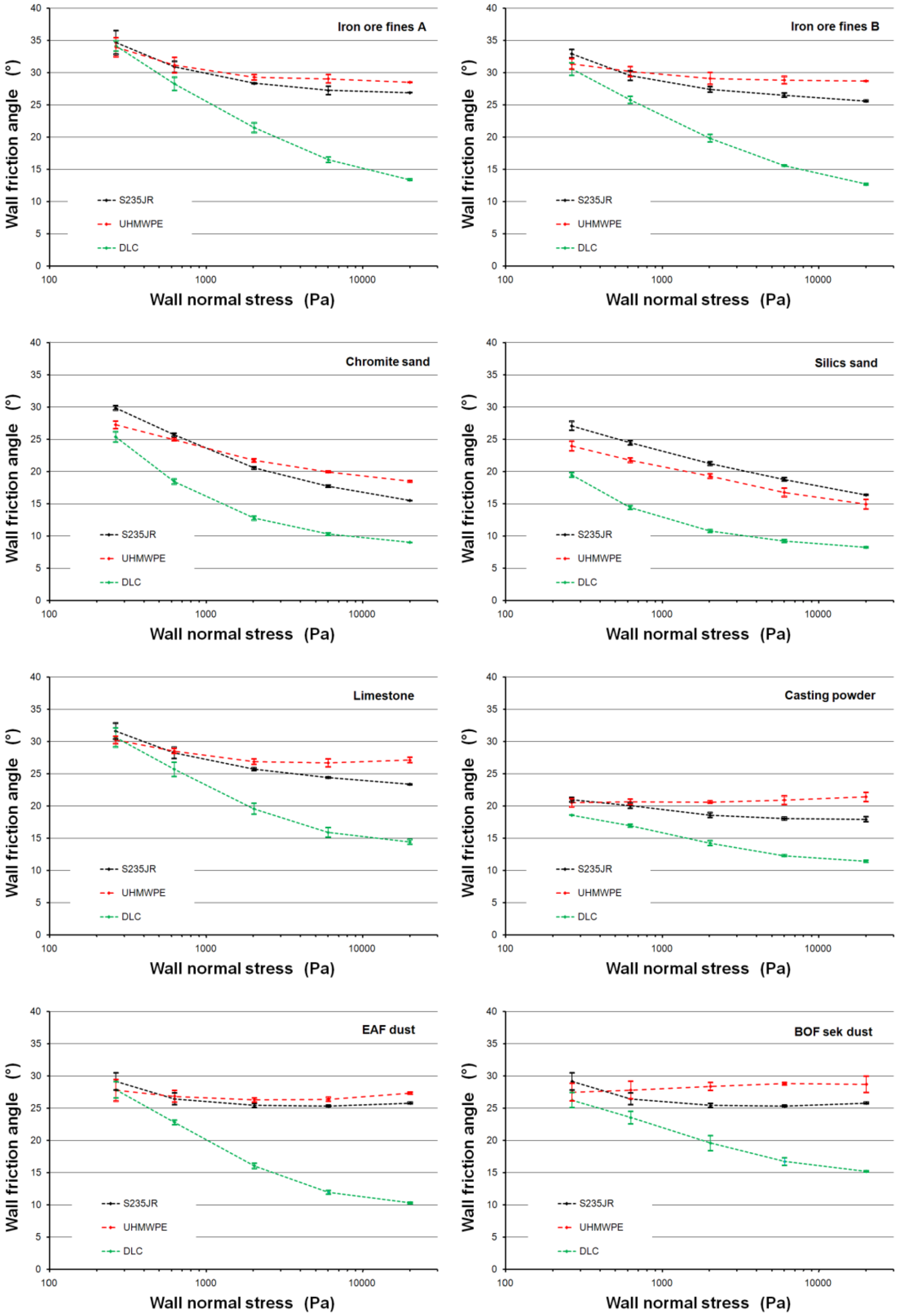

Figure 1 Wall friction angles for the fine granular bulk materials M1 to M8 as a function of the wall normal stress

For all materials the wall friction angles on the mild steel S235JR decreased with increasing wall normal stress. This decrease was markedly for the coarser foundry sands but only small for the casting powder and the dusts from EAF and BOF dedusting.

The wall friction angles on the UHMWPE material were slightly higher compared to the wall friction angles on the mild steel S235JR for all materials M1 to M8 with exception of the casting powder M6, for which the wall friction angle on UHMWPE was up to 3° lower.

Wall friction was lowest for all fine granular bulk materials M1 to M8 on the DLC coated wall material. In **Figure 2** the difference of the wall friction angle on the DLC coating in comparison that on the mild steel wall material. For the coarse sands the reduction of the wall friction angle was between 5° and 10° and the reduction was not very dependent on the wall normal stress. In contrast, for the other materials a distinct dependence of the reduction of the wall friction angle on the wall normal stress was found. The reduction was in the range of approximately 0.5° to 2.5° for the lowest wall normal stress and increased steadily with increasing wall normal stress. At high wall normal stress wall friction reduction was highest for the granular material with the smallest mass median diameter (EAF dust, iron ore fines A and B). For the coarser materials BOF dust, limestone and casting powder the reduction in wall friction was less.

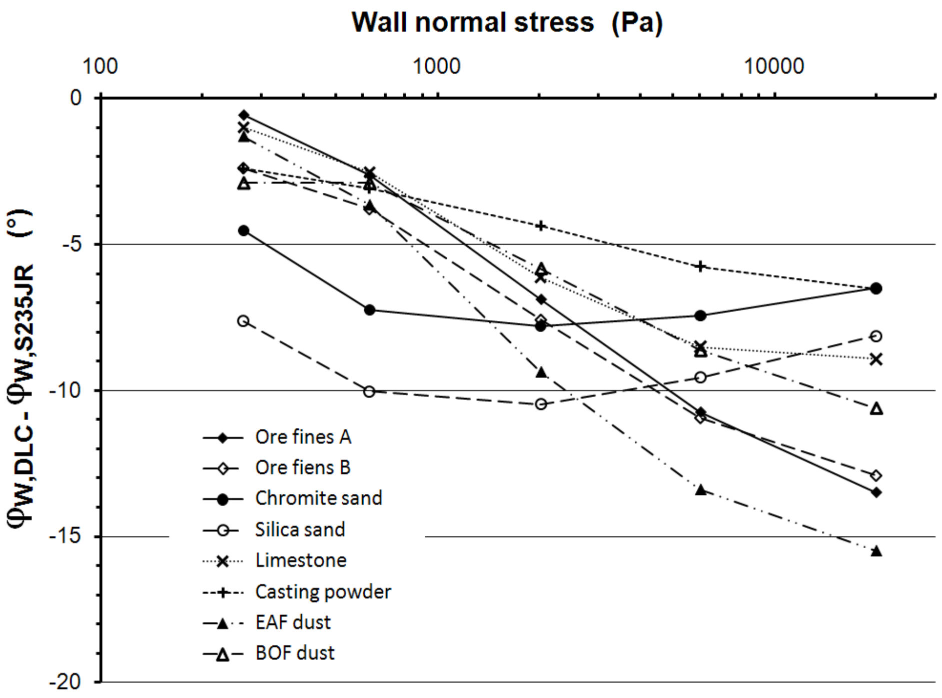

Figure 2 Wall friction angles for BF casthouse A and B as a function of the wall normal stress

However, it is important not to assume that a DLC coating inevitably leads to reduced wall friction. In the case of two BF casthouse dusts investigated, the wall friction angles on the DLC coating were slightly higher than those on the mild steel, as illustrated in Figure 3. Currently it is an unresolved query as to why the DLC coating did not achieve a reduction in wall friction for these BF casthouse dusts. Further investigations are required to find the explanation for the lack of friction reduction cy the DLC coating in certain cases.

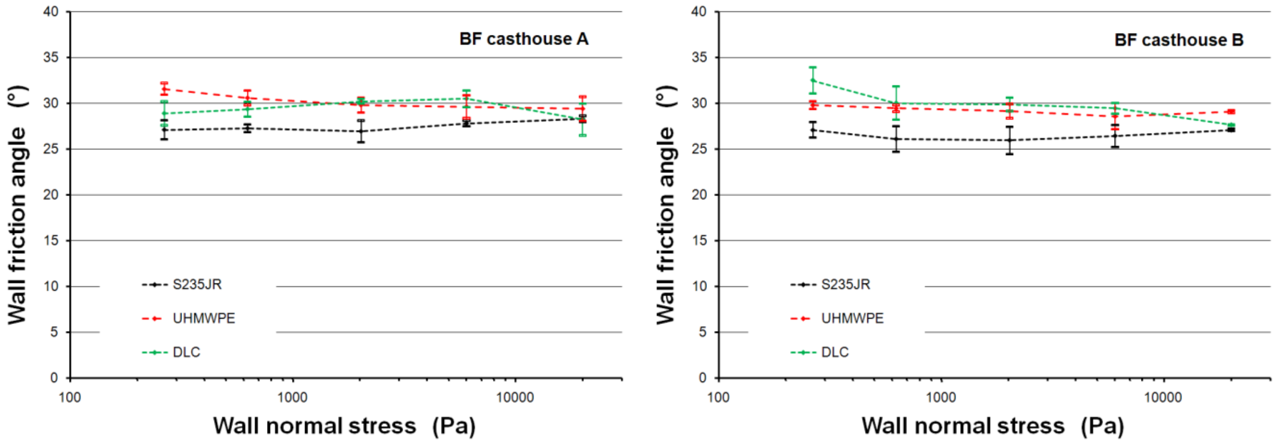

Figure 3 Wall friction angles for BF casthouse A and B as a function of the wall normal stress

4. CONCLUSION

DLC coatings demonstrate extensive potential for decreasing wall friction of fine granular bulk materials within the iron and steel industry. Depending on the wall normal stress, a reduction in the wall friction angle of up to 10° to 15° is achievable. However, this wall friction reduction through the use of DLC coating did not prevail across all tested fine granular bulk materials. Hence, further investigations are required to shed light on this effect.

ACKNOWLEDGEMENTS

Preparation of the DLC coated wall sample by C. Forsich is gratefully acknowledged.

REFERENCES

[1] REMUS, R., AGUADO-MONSONET, M.A., ROUDIER, S., SANCHO, L.D. *Best Available Techniques (BAT) Reference Document for Iron and Steel Production, Industrial Emissions Directive 2010/75/EU, Integrated Pollution Prevention and Control.* Luxembourg: Publications Office of the European Union, 2013.

[2] SCHULZE, D. *Powders and Bulk Solids - Behavior. Characterization. Storage and Flow.* Berlin: Springer, 2008.

[3] Meng, Y., Xu, J., Jin, Z., Prakash, B., Hu, Y. A review of recent advances in tribology. *Friction.* 2020, vol. 8, pp. 221–300.

[4] HEAU, C. DLC Films in Mechanical and Manufacturing Industry. In: *Tribology of Diamond-LIKE Carbon Films. Fundamentals and Applications*. DONNET, C., ERDEMIR, A., Eds. New York: Springer, 2008, pp. 469-483.

[5] VAN DER KOLK, G. J. Wear Resistance of Amorphous DLC and Metal Coating DLC in Industrial Applications. In: *Tribology of Diamond-LIKE Carbon Films. Fundamentals and Applications.* DONNET, C., ERDEMIR, A., Eds. New York: Springer, 2008, pp. 484-493.

[6] DONNET, C., ERDEMIR, A. New horizon in the tribology of diamond like carbon films. *Surface Engineering.* 2008, vol. 24, pp. 399-401.

[7] GANGOPADHYAY, A., SINHA, K., UY, D., MCWATT, D.G., ZDRODOWSKI, R.J., SIMKO, S.J. Friction, Wear, and Surface Film Formation Characteristics of Diamond-Like Carbon Thin Coating in Valvetrain Application. *Tribology Transactions.* 2011, vol. 54, pp. 104-114.

[8] BJÖRLING, M., ISAKSSON, P., MARKLUND, P., LARSSON, R. The Influence of DLC Coating on EHL Friction Coefficient. *Tribology Letters*. 2012, vol. 47, pp. 285-294.

[9] VETTER, J. 60 years of DLC coatings: Historical highlights and technical review of cathodic arc processes to synthesize various DLC types, and their evolution for industrial applications. *Surface and Coatings Technology*. 2014, vol. 257, pp. 213–240.

[10] LANZERSTORFER, C., FORSICH, C., HEIM, D. Reduction of wall friction of fine powders by use of wall surface coatings. *Coatings.* 2021, vol. 11, e427.