Tribological Optimised CFC-Gliding Elements and Ceramic-Coatings on the Gliding Strip for the Transrapid System

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ABSTRACT: In the unlikely case of the magnetic levitation of the Transrapid vehicle being disabled at a levitation frame support skids and gliding strips are used for mechanical support. This support shall have the full function for speeds up to 500 km/h. Therefore, a system consisting of high performance fibre reinforced ceramic gliding elements in combination with a wear resistant surface coating was already developed and qualified. Based on this system further improvements with regard to the application and maintenance can be achieved with an Al_2O_3-ceramic surface coating applied by flame gunning. Extensive tribological laboratory tests showed excellent properties of this new coating.

1 INTRODUCTION

As the basic concept of high-speed magnetic-levitation trains, the regular operation of the Transrapid vehicle is contact free (Löser et al 2004). That is, the vehicle is levitated and guided by magnets. In particular, each levitation frame is supported by two levitation magnets according to the redundant dimensioning of the undercarriage. If one of the levitation magnets is being temporarily or permanently disabled, the levitation frame will be supported by a single magnet. However, in the unlikely case of both levitation magnets being disabled at the same time, the magnet levitation is replaced by mechanical support (Miller 2004, Diekmann 2004, Löser 2004).

This system consists of support skids (figures 1 and 2) with gliding elements made of high performance ceramics and tribologically optimised coating on the basis of polyurethane (PU) on the gliding strip of the guide way. The gliding elements were developed on the basis of a special carbon fibre reinforced carbon (CFC). In extensive laboratory tests the components of this special tribological system were developed, analyzed and optimized. In Shanghai (China) the PU-coating was applied to the steel gliding strips of the hybrid guideway and were tested under operation conditions with the novel CFC gliding elements. A similar PU coating system was developed for concrete gliding strips and tested on the TVE. The laboratory results could be fully confirmed and/or exceeded. The surface coating of the gliding strip showed practically no wear. The new CFC support skids and the tribological optimised topcoat were qualified for the Transrapid system (Diekmann et al 2004, Bauer et al 2004, Löser 2004, Miller 2004).

The technical requirements for the support skid and the gliding strip are extremely high. For example, considering the 30 km long Transrapid link from Shanghai Pudong International Airport to the Metro station Long Yang Road in the financial district of Shanghai. Both, support skid and gliding strip, have to withstand safely the mechanical and thermal loads even if both magnets are disabled directly after leaving the Pudong station (Diekmann et al 2004).

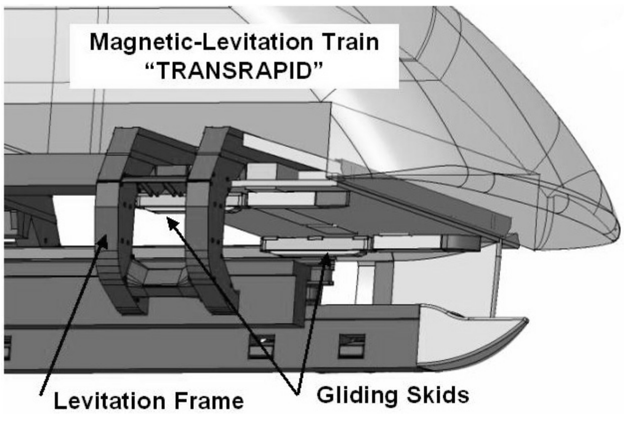


Figure 1: Arrangement of the sliding skids.

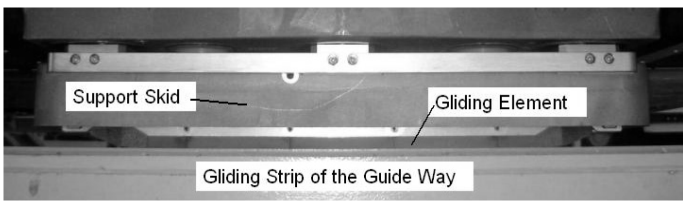


Figure 2: Support skid with gliding elements.

2 REQUIREMENTS

The task of the coating system of the concrete gliding strip is to prevent from extensive contact between CFC and concrete or steel respectively ensuring permanently a well-defined tribological process for the gliding of a support skid on the gliding strip.

Demands on the gliding elements:

- High temperature stability (>1000 °C) and high shock resistance,
- high resistance to wear and a good corrosion resistance as well as
- small coefficient of friction (while gliding on the special coated gliding strip).

Demands on the properties of the coating of the gliding strips:

- Good applicability for the tribological use with the employed gliding material, in particular regarding the specified friction coefficient and a limited temperature development.
- High adhesive tensile strength of the coating on concrete and also on steel subsurfaces.
- Small wear of the coating if a support skid glides on the gliding strip.
- Standardized and non-complex application method with regard to quality assurance.
- Resistance against influence from climate conditions such as temperature changes, solar radiation or humidity.
- Corrosion prevention in case of a steel gliding strip (steel or hybrid guideway).

Besides this, demands with regard to the application and maintenance of the coating are important:

- A short production time is required for a high production yield of guideway girders in the factory.
- The on site application of the coating should be independent of weather conditions.
- In case of maintenance, the operational limitations for the Transrapid as well as maintenance vehicles should be minimal.
- Inspection and maintenance of the coating may only be executed in large time intervals.

The typical inspection interval for the PU-coating is one per year in accordance with the mentioned demand of large time intervals. However, the application of PU-polymer-layers requires a temperature above approximately 5°C and dry conditions. Every layer has to dry at least several hours before the next layer can be applied and afterwards the system needs several days to harden before a load can be applied.

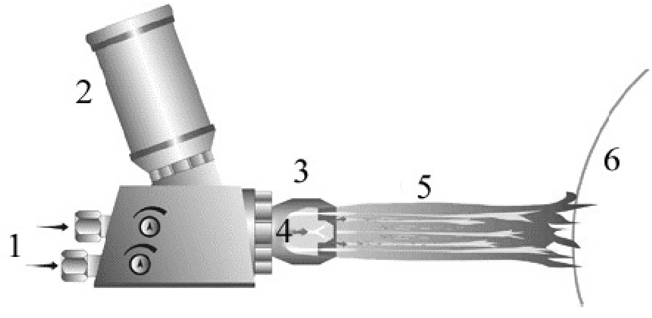
This indicates that polymer-layers are not the optimum solution with regard to the application and maintenance. Therefore, a new coating with a special Al_2O_3-ceramic layer applied by the technology of flame gunning or thermal spray was tested.

3 CERAMIC COATING OF THE GLIDING STRIP BY THERMAL SPRAY

Thermal spray is a process group of surface modification technologies where materials are deposited on the substrate in a molten or semi-molten state. The substrate surface - in this case a part of the guideway - is thermally much less influenced than in welding processes. Typically coatings with a thickness of 100 – 500 µm are produced. Plasma spraying in different surroundings, flame and high-velocity oxy-fuel spraying (HVOF) as well as arc spraying are the most important processes in this group. Advanced thermal spray coatings are characterized by low porosity and high bond strength.

In this case the surfaces of the specimen for the tribological tests where coated by high-velocity oxy-fuel spraying (HVOF). The principle of this technology is pictured in figure 3. Figure 4 shows a photo of HVOF.

This method can be used independent of weather conditions and load can be applied immediately, as the coating does not have to dry or harden. Therefore, HVOF is a preferential method with regard to application and maintenance.



Caption:

1 Gas (acetylene, oxygen)
2 Powder box
3 Burner nozzle
4 Conveyor gas and powder
5 Flame with particles
6 Substrate

Figure 3: Principle of high-velocity oxy-fuel spraying (HVOF).

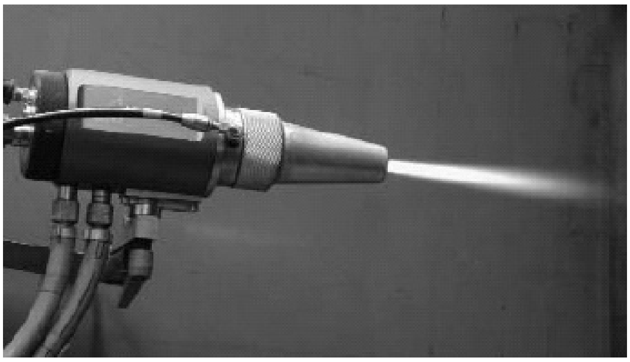


Figure 4: High-velocity oxy-fuel spraying (HVOF).

4 TRIBOLOGICAL TESTS

The tests were made by two steps as follows: basic test by pin-on-disc facility and high speed test by a special pin-on-disc facility.

First development step: basic test by pin-on-disc facility

To determine the friction and wear rate of the modified CFC composites and the special coatings this tribology test rig was adapted according to DIN 50 322 and DIN ISO 7148 (figure 5 and figure 6).

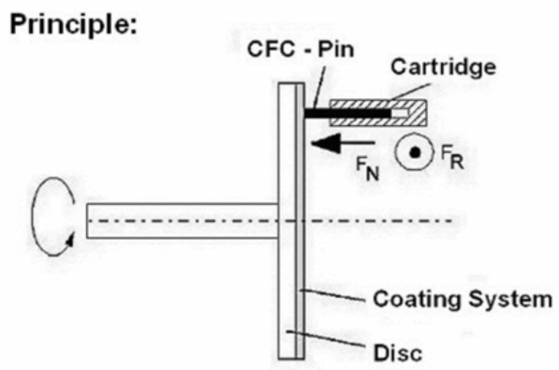


Figure 5: Pin-on-disc facility (principle).

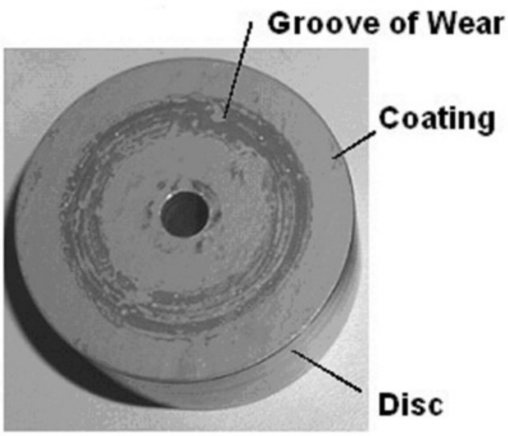


Figure 6: Example for disc with polyurethane coating system tested by pin-on-disc facility.

The tests gave first results of the characteristics of several coating systems in a sliding contact with a CFC-pin with regard to the friction coefficient (figure 7 and 8) and wear resistance (table 1).

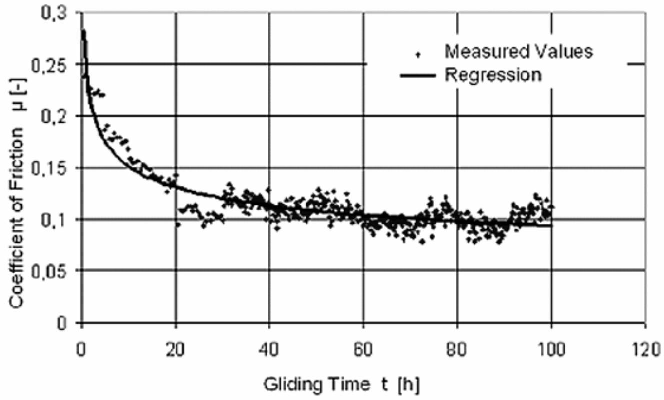


Figure 7: Coefficient of friction of Al_2O_3 coating system (layer on steel) in contact with CFC.

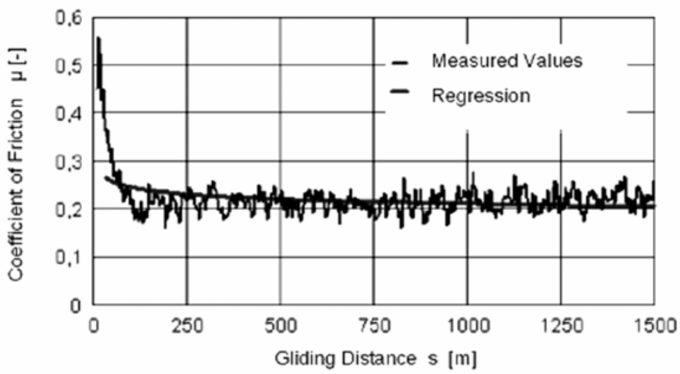


Figure 8: Coefficient of friction of Al_2O_3 coating system (layer on concrete) in contact with CFC.

After a comparably high coefficient of friction during the first rotations of the disk, the Al_2O_3-coatings show a small coefficient of friction in tribo-contact with the CFC-pin. Unlike the wear mechanism of the polymer layers the ceramic coatings shows practically no wear (table 1 and figure 9 and 10).

Table 1: Wear properties of gliding strip coatings and CFC gliding elements.

Surface of the Gliding Strip (Coating)	Linear Wear Rate [µm/km]	
	CFC-Pin	Gliding Strips
Polymer (Polyurethane)	no wear	97
Concrete / Al_2O_3	71	no wear
Steel / Al_2O_3	87	no wear
Concrete (without a coating)	150	150

Figure 9: Specimen surface of a polymer coating.

Figure 10: Specimen surface of a ceramic coating.

Second development step: high speed test by pin-on-disc facility

With the aid of a special high speed test equipment (figure 11 and 12) the CFC-gliding elements of the support skids was tested in contact with different tribological layers.

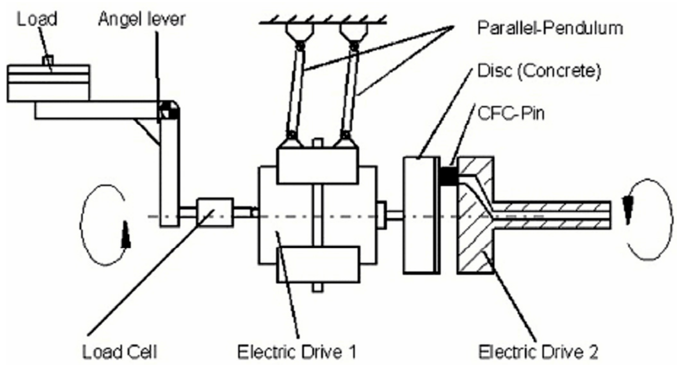


Figure 11: Principle of the high speed test by pin-on-disc facility.

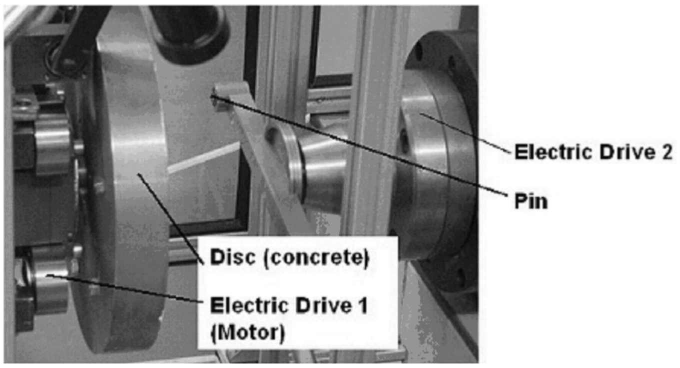


Figure 12: Photo of the high speed test by pin-on-disc facility.

This special tribological test equipment allows gliding speeds up to 112 m/s. It is possible to get online dates about the friction temperature (figure 13), the absolute value of wear (figure 14), the actual normal force and other dates by a special telemetric measurement. The measured average value of the linear wear rate of the CFC-Pin (110 µm/km) is comparable to the value that we measured on the low speed test facility (table 1). The wear is higher than on the PU-coating where no wear was measurable. The surface temperature of the Al_2O_3-coated concrete disc (figure 13) is lower than the temperature which we determined on the polymer coatings (> 450 °C).

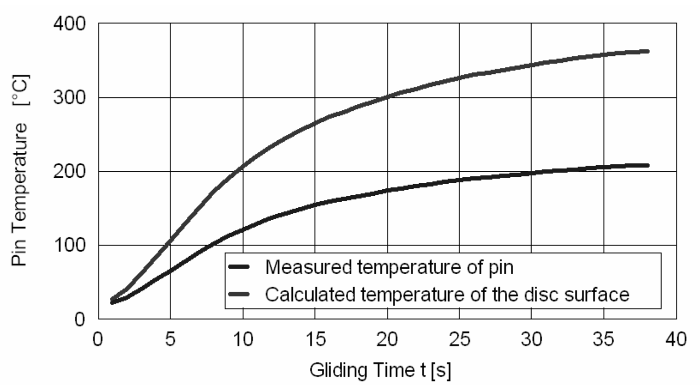


Figure 13: Temperature of the CFC-Pin and calculated temperature of the Al_20_3 coated concrete disk.

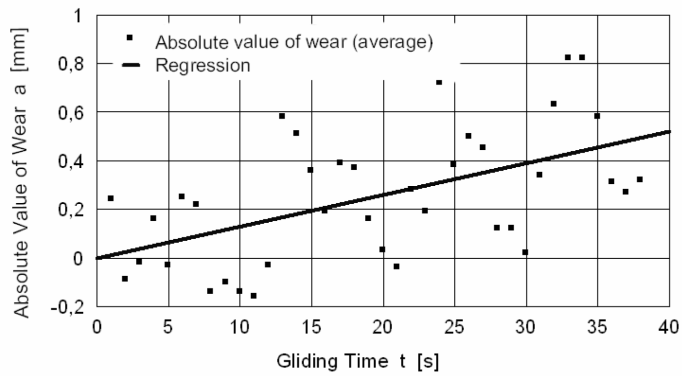


Figure 14: Absolute value of wear of the CFC-Pin (online-printout).

5 CONCLUSION / PERSPEKTIVE

The new coating has several advantages with regard to application and maintenance. The laboratory tests gave first results of the characteristics of the new ceramic coating systems with regard to the friction coefficient and thermal development. These results are compatible with the demands on the coating of the gliding strip. The wear of the CFC gliding element is higher than on the PU-coating.

Next Development Steps

The next steps for qualification of the new coating are climate tests and the test at the Transrapid Test Facility TVE (in Emsland, Germany). For this purpose it will be necessary to develop equipment for the thermal spray of Al_2O_3-ceramic layers on the concrete gliding strip

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