Investigation of the coating of hydrodynamic plain bearing contact surfaces by means of Extreme High-Speed Laser Material Deposition (EHLA)

Stephan Koß 1), Achill Holzer 2)[0000-0003-1190-18199], Sandra Megahed¹, Stephan Ziegler ¹, Johannes Henrich Schleifenbaum ¹, Katharina Schmitz 2)[0000-0002-1454-8267]

1) Digital Additive Production DAP, RWTH Aachen University, Campus Boulevard 73, 52074 Aachen
2) Institute for Fluid Power Drives and Systems ifas, RWTH Aachen University, Campus Boulevard 30, 52074 Aachen

*corresponding author: stephan.koss@dap.rwth-aachen.de

Abstract: In the field of drive technology, plain bearings are used in almost all drives. During operation these bearings have a very low load resistance and almost no wear. However, increased mixed friction can occur during starts, stops, low speeds and/or high loads. As a result of the increasing demands on the drive systems, such as in the automotive sector with the automatic start-stop system to reduce exhaust gases or in the area of the angular force, a greater mixed friction occurs, which increases wear. Extreme High-Speed Laser Material Deposition (EHLA) is a coating process that allows the application of corrosion and wear protection coatings in a resource-saving and productive manner. Furthermore, alternative materials and material combinations can be created. In the framework of this study two different Metal Matrix Composites (MMC) are tribologically investigated and characterized in the area of mixed friction against three friction contacts each.

Keywords: Extreme High-Speed Laser Material Deposition (EHLA), Tribology, Coatings, Metal Matrix Composite (MMC)

1. Introduction

In the field of drive technology, plain bearings are an essential component for the support of axial and radial loads. These are used for example in wind power plants, pumps, electric drives and combustion engines. For applications requiring a long service life and low energy consumption, plain bearings with liquid friction are preferable (e.g. in drives, in turbines). Due to the hydrodynamic pressure of the relative movement, an oil film forms between the contact surfaces. Plain bearings are used to support moving components and to transfer loads. The most prominent representatives are hydrodynamic bearings in internal combustion engines. The functionality of such bearings relies on two fundamental aspects, sufficient lubrication and design aspects resulting in hydrodynamic film formation as well as suitable bearing materials [1]. The latter is addressed with unique solutions for specific applications and material selection has been found to be a compromise between contradicting demands such as fatigue strength
and tribological properties (i.e., a material needs to be hard and soft at the same time), as well as chemical compliance [2]. To meet these requirements, plain bearings are usually designed with a layered structure and heterogeneous materials. Each layer and material has to fulfill a specific task addressing each demand. The main layers are defined as steel back for mechanical support, a bearing lining and optional overlay systems [3,4].

At high loads and/or low rotational speeds, hydrodynamic pressure cannot be built up sufficiently and mixed lubrication occurs, which accelerates the wear of bearings. This mixed lubrication occurs particularly with a large number of start-stop processes. One example of this is the start-stop function in modern cars in city traffic. This can reduce fuel consumption by up to 8%, but this causes an increased occurrence of solid contact between crankshaft and plain bearing. This increases wear and reduces the service life of the motor [2]. In order to reduce wear, material pairs are selected in friction contact, which show the lowest possible wear in contact. Typically, the hydrodynamic plain bearings are made of bronze, white metal, aluminium alloys, polymers or ceramics. The contact surfaces of the shaft are usually hardened against wear [5]. However, the service lifetime depends on the following [6]:

- Load coefficient depending on pressure [N/mm²]
- Rotation per minute depending on surface speed [m/s]
- Temperature [°C]
- Surface roughness
- Type of load (Point load/ Circumferential load)
- Factor depending on material/material combination
- Specific bearing load [N/mm²]
- Sliding speed [m/s]

These factors can vary greatly depending on the field of application. With the increasing loads and challenges in drive technology, it is necessary to extend the service life in plain bearings; especially as the service life of the engine is often equivalent to the service life of the slide bearings used. The highest wear occurs in mixed friction, for example due to start-stop processes, such as in the automotive sector, and/or due to high loads, such as in wind power. According to Stickel et al., the tribological properties do strongly depend on the surface topography, in particular in the very first time of operation. If the surface is smoother, the frictional properties are not always better [18]. In order to achieve the longest possible service life, material combinations with minimum wear and greatest conceivable sliding properties must be used in these plain bearings. As contact materials, brass and bronze are often used in plain bearings. These materials have a hardness in the range of approx. 150 to 230 HV and demonstrates a coefficient of friction of approx. 0.15 in wear tests at a contact pressure of 1 MPa [23].

The additive process Extreme High-Speed Laser Material Deposition (EHLA) offers new possibilities to generate metallurgically bonded coatings with low heat input to the substrate. Due to the process characteristics it is possible to coat unconventional material pairings such as Metal Matrix Composites (MMC). This provides new possibilities to increase durability. First tests investigating the tribological characteristics of EHLA 316L coatings on 42CrMoV4 (1.7225)-substrates have already been completed. The coatings are tested on a tribometer at 100 rpm and a contact pressure of 100 N for 30 min. The results showed little amount wear (0.097 g for a sliding distance of 1 km) [6]. Currently MMC coatings manufactured with EHLA are investigated to improve wear resistance of brake rotors. During the DYNO brake test, the brake rotor demonstrated wear of 0 to <0.5 g in the simulated test over 1000 km [7]. In this paper, various material pairings to use in plain bearings are tested and characterised. Furthermore, Blau and Jolley investigated the abrasive wear behaviour of several titanium carbide reinforced matrix composites using 240 grit aluminum oxide band as counterpart [15].
2. Methods and materials

2.1. EHLA process
EHLA offers new possibilities due to its unique process properties to reduce wear in plain bearings, especially for the frequently occurring mixed friction case. Figure 1 illustrates a schematic representation of the EHLA process. The powder material is fed to the deposition process via a continuous powder feed nozzle positioned coaxially to the laser beam. During conventional manufacturing of material combinations such as MMC, for example, the individual materials are mixed in-situ before the nozzle and fed into the process via a powder gas stream. The focus of the powder gas stream is positioned above the substrate. In this process, the majority of the laser energy is absorbed by the powder particles before they hit the substrate, which enables new materials and material combinations to be processed (e.g. MMC, coating of aluminium/copper with Fe/Ni/Co-based alloys, coating of substrates with Al/Cu and Al-/Cu-based alloys, etc.). The residual energy forms a small melt pool on the substrate surface. Since the energy input is directed into the coating material, the heat influence for the substrate is small. Process speeds of up to 500 m/min can be achieved. In combination with the track displacement, coatings with layer thicknesses ranging between 20 to 350 µm are produced. EHLA is resource efficient, because it reaches a powder efficiency of up to 95% [8,9]. Process characteristics allow for a high productivity coating process in which the risk of layer detachment under high loading conditions is very low or even non-existent. Furthermore the option of repairing coatings is given with the EHLA process.

![Figure 1: Schematic representation of Extreme High-Speed Laser Material Deposition (EHLA) including relevant process parameters](image)

2.2. Coating materials
MMC consist of at least two materials: one soft and ductile matrix material, in this case 316L, and one harder material, e.g. silicon carbide (SiC) and titanium carbide (TiC). TiC and SiC have a high hardness of 3200 HV (TiC) and 2800 HV (SiC) as well as high melting temperatures of 3065°C (TiC) and 2797°C (SiC) [10,11]. Compared to pure hard metal coatings, the coating is more ductile due to the softer matrix material.

![Figure 2: a) SEM image of 316L (Oerlikon Diamalloy 1003-1) with the magnification of 400x, b) Incident light microscope image of 316L cross sections with a magnification of 200x, c) measured particle size distribution of 316L particles](image)
Figure 2 shows SEM images and the powder size distribution of the 316L powder from Oerlikon. The particles are oval and dense (see Figure 2 a), b). The light blue area in the particle size distribution measurement highlights the manufacturer’s specifications of 20 to 53 μm. The blue line in the diagram shows the measured particle size distribution. These lies within the range of approx. 30 to 45 μm and thus in the range specified by the manufacturer. The chemical composition of 316L is given in Table 1.

The powder analysis of silicon carbides from GTV is shown in Figure 3 on the left-hand side. The particles are dense, no porosity can be identified in Figure 3b. The particle size distribution shows a size range of approx. 10 to 70 μm.

Table 1: Chemical composition of 316L (Oerlikon 1003-1)

| Material | Fe | Cr | Ni | Mo | Si | C |
|----------|----|----|----|----|----|---|
| Content  [wt.-%] | Bal | 17 | 12 | 2,5 | 2,3 | 0,03 |

The titanium carbide (TiC) used from GTV is dense, no porosity can be identified in Figure 3b. The measured particle size distribution is in the range of approx. 5 to 60 μm. Compared to 316L and SiC, TiC has the highest percentage of fine particles (see Figure 3 on the right-hand side). The chemical composition of the materials is given in Table 2 for SiC (left) and for TiC (right).

Table 2: Chemical composition of SiC (GTV 70.85.8)

| Material SiC | Si | C |
|--------------|----|---|
| Content [wt.-%] | 70,2 | 29,8 |

Table 2: Chemical composition of TiC (GTV 70.90.3)

| Material TiC | Ti | C |
|--------------|----|---|
| Content [wt.-%] | 80,8 | 19,2 |
2.3. Post processing
In order to obtain a smooth surface, all coatings are ground to a roughness of Ra 0.1 μm. For tribological examinations of lubricated contacts, Abbott-Firestone curves provide a summary of the roughness profile. High peaks increase the propensity of fretting, as the real pressure gets very high whereas deep valleys are expected to improve lubrication as valleys serve as fluid reservoir.

2.4. Tribometer
For the tribological investigation, a disc-on-disc tribometer test bench has been used. The tribometer test bench as shown in Figure 4, consists of two test discs, a stator and a rotor, which are pressed together by a hydraulic cylinder. The rotor is driven by an electric motor transmitting its torque to the stator. The stator is connected to the test bench by a torque sensor. Both test discs are placed in a temperature controlled oil basin. Air bearings make sure not to measure friction outside the disc-disc contact [14].

![Figure 4 CAD model of the test bench (left) and schematic drawing of the disc-disc tribometer test with stator coloured in red, and rotor coloured in green (right) [14]](image)

The tribological measurement took place at an oil temperature of 60°C which was maintained stable. For lubrication and cooling a fully additivated mineral-based hydraulic oil with the basis viscosity of 46 cSt has been used. Further technical parameters of the used test bench can be found in Table 3.

**Table 3 Technical properties of the used test bench**

| Parameter                  | Value          |
|----------------------------|----------------|
| Mean contact diameter      | 65 mm          |
| Friction track width       | 5 mm           |
| Area of contact            | 1021 mm²       |
| Surface pressure           | 1 to 30 MPa    |
| Temperature range          | 0 to 120 °C    |
| Gap measurement accuracy   | <0.065 μm      |

2.5. Used counterparts
In order to cover a wide range of application, the MMCs have been tested with three different counterpart materials. As a bearing steel, 100Cr6 has been used. To cover the materials of lower strength, S355 material has been tested. As third material, a brass material MS58 has been evaluated. All counterparts have been lapped to a roughness of Ra 0.1. Since lapping produces a stochastic surface, the specification of a one-dimensional Abbott curve is sufficient for the characterization (Figure 5) [22]. All surfaces have been lapped with the same parameter.
As shown in Figure 7 and Figure 5, the surfaces of the coated stator discs are slightly rougher than their counterparts. A comparison of the three Abbott curves shows that the 100Cr6 sample has slightly lower roughness peaks than the two other counterparts. It is assumed that this is due to the higher material hardness [22].

3. Results

3.1. Coating with MMCs
For the tribological tests, two MMC coatings were produced using EHLA, which are shown in Figure 6. The MMC produced from 316L + TiC contains no cracks or pores (see Figure 6 a)). Thereby, an average thickness of approx. 705 µm was produced with a mixing ratio of 1:1. SiC is considered to be a difficult material to weld, as the material only has a thermal stability up to 1300 °C. A SiC content of 30 vol-% with an average thickness of approx. 445 µm was achieved (see Figure 6 b)). During the deposition process of the MMC, a large content of SiC is dissolved in the matrix material, which increases its hardness. The cross section in Figure 5b shows cracks, which is characteristic for brittle materials. By means of the energy input into the coating material and the high process speed, the generated melt pool is small, so that the boundary between substrate and coating is clear.

3.2. Post processing
Figure 7 shows the Abbott curves of both as built and ground stator discs. It can be seen, that the roughness peaks perpendicular to the grinding direction are more than double the height compared to grinding direction. It is expected, that fluid lubrications suffers due to the tunnel effect, preventing a fluid pressure build-up. Nevertheless, ground surfaces like this can be found in hydraulic manufactured parts.
Figure 7 Abbott-Firestone curve of the coated and grinded SiC disc before tribological testing (left) as well as for the TiC coated disc (right)

It can be seen, that the SiC coated disc has, compared to the TiC coating, deep cavities perpendicular to the grinding direction, exceeding the depth about five times. Regarding the roughness peaks, both coatings are at the same level after the grinding process.

3.3. Tribological investigations

The aim of tribological testing is, one the one hand to analyse frictional behaviour. On the other hand, it is of special interest to investigate the bearing behaviour when insufficient oil pressure is maintained to support the bearing. This is the case, when the bearing is used at low speeds, without sufficient oil or at a very late state of life. The contact cannot be supported by the fluid, which results in damage, as mixed or even boundary lubrication occurs over a long time period.

A Strubeck curve has been plotted at a pressure of 1 MPa in a range from 0 to 14 m/s. As shown in Figure 8, the Strubeck curve can be seen as a superposition of solid state friction and fluid friction plotted over the sliding speed, where the solid friction is only applicable at low speeds until the contact gets fully supported by hydrodynamic pressure-build up. At higher speeds, fluid friction is an important parameter. Due to the temperature dependence of viscosity, the Hersey-Gümbel number is usually plotted on the y-axis [21]. In this case, temperature has been kept constant, allowing the sliding speed to be plotted.

The pairing has been forced in the state of mixed lubrication by repeated acceleration from zero to 3 m/s under constant pressure (see Figure 9). This process is repeated 50 times to analyse the resistance capability regarding wear.
Due to a not ideally stiff bearing of the stator, a slight wobbling motion occurs, which we can detect by means of inductive distance sensors. This wobbling motion leads to the occurrence of convergent lubrication gaps between the rotor and stator. Even though we can get into the range of liquid friction under good conditions and the present specimen geometry, in this case, also due to the prevailing wear, it can be assumed that the increase in the coefficient of friction is rather due to the wear caused by the larger energy input than by fluid lubrication as showed in Figure 8.

![Figure 9 Mixed lubrication test, where the pairing is forced in mixed lubrication for a high number of times](image)

3.4. Results MMC SiC+316L coating
In general, a very high level of friction has been observed for the SiC MMC against 100Cr6 discs. As shown in Figure 10, there is a noticeable drop of the friction coefficient at around 3 m/s and below. High friction coefficients on the right side of the curve (high speed range) may be explained with a run-in transition, as both discs were new, and the Strubeck curve has been captured from high-speed to low speed.

![Figure 10 Strubeck curve, plotting coefficient of friction over sliding speed in m/s of SiC coating against 100Cr6 test disc](image)

The 100Cr6 counterpart, as well as the coated stator disc showed a material loss of around 20 µm after performing Strubeck test and mixed lubrication test. In the Strubeck curve shown in Figure 11 a valley
can be seen on the left side (coated disc). A possible explanation for this behaviour is edge contact leading to a non-uniform pressure distribution.

In Figure 12, the Stribeck curve of the SiC MMC against the S355 steel disc is plotted. The behaviour at 3 m/s and less can be compared to the 100Cr6 material.

In contrast to the results of 100Cr6, the S355 disc showed less material loss than the SiC coated disc. Figure 13 shows the profile scan after performing both tribological tests.
Compared to the previous steel-based counterparts, brass has also been used which is much softer than the coated stator disc. The Stribeck curve (Figure 14) shows a drop at much higher velocity. The friction coefficient is slightly smaller, having its minimum at around 8 m/s with a value of 0.07.

Figure 14 Stribeck curve, plotting coefficient of friction over sliding speed in m/s of SiC coating against MS58 test disc

Figure 15 depicts, that the SiC MMC coated stator (left) has almost no material loss, whereas the brass material (right) lost about 150 µm of its original height.
The friction coefficients of the MMC 316L+SiC is fairly high (0.2-0.3) compared to the 100Cr6 and S355 samples (0.15-0.28 respectively). In the test against a brass contact, the friction coefficient lies within 0.08-0.15 at speeds up to 8 m/s. With a further increase in speed the friction coefficient increases to 0.3-0.36 is increased at speeds of ≥10 m/s against MS58. This behaviour is increased, as the mixed friction test passes through this area several times. The wear of MMC 316+SiC is in the range of 10 to 50 µm, whereby the greatest wear has occurred with S355. The wear of the opposite part is approx. 20 µm for 100Cr6 and S355 and approx. 150 µm for MS58. The wear data is listed in Table 4 for the respective pairings.

### Table 4 Material wear during mixed lubrication test of 316L+SiC

| Coating material | Counterpart material | Coating loss [µm] | Counterpart loss [µm] |
|------------------|----------------------|-------------------|-----------------------|
| SiC MMC          | 100Cr6               | 20                | 20                    |
|                  | S355                 | 50                | 20                    |
|                  | MS58                 | 10                | 150                   |

3.5. **Results MMC TiC+316L coating**

In Figure 16, the Stribeck curve of the TiC MMC against the 100Cr6 steel disc is shown. It can be seen, that the coefficient of friction is continuously increasing from 14 m/s to 5 m/s, where it reaches a value of over 0.4. As observed by previous contact partners, the curve lowers at low speeds at about 2 m/s.
After testing, the TiC coated disc lost about 20 µm of material, shown in Figure 17 (left side), whereas the counterpart made of 100Cr6 lost 200 µm (right).

Contrary to the behaviour of the SiC MMC coated disc, the measurement of the Stribeck curve started low, at a coefficient of friction around 0.2. From there on, the friction is continuously increasing until their peak of over 0.45 at around 3 m/s. At low speeds, under 2 m/s, the friction coefficient dropped to 0.2, and reached 0.3 in boundary lubrication (see Figure 18).
Figure 18 Stribeck curve, plotting coefficient of friction over sliding speed in m/s of TiC coating against S355 test disc

On the left side of Figure 19, the TiC coated disc is shown, having a material loss of 30 µm. The strain caused a bulge on both bodies. The results of the S355 disc showed a loss of almost 150 µm (Figure 19, right).

When running the TiC MMC coated disc against brass, rather low friction coefficients can be achieved, especially in the range between 2 m/s and 9 m/s (see Figure 20). Higher COF, as they occur at speeds above 10 m/s, and also the two peaks located at 6 m/s and 4 m/s are suspected to be transitions while run-in.
Due to the fact that the friction coefficient was the lowest measured of the whole test set, very few wear is expected. The corresponding material loss diagrams are shown in Figure 21, where the coated stator shows a material loss of around 10 µm (left) and the brass rotor suffered of 50 µm loss.

For tribological contact against 100Cr6, the friction coefficient is 0.15 at 2 m/s and then climbs to over 0.4 in the range of 2 to 6 m/s. With a further speed increase, the friction coefficient drops to 0.15 to 0.2 (see Figure 16). Against the friction partner S355 (see Figure 18) the greatest coefficient of friction is at a velocity of 2 m/s. A further increase in velocity reduces the friction coefficient to less than 0.1 at 12 m/s. The friction coefficient profile for the MS58 reaches the smallest friction coefficient of <0.15 at a speed between 4 to 8 m/s. The highest friction coefficient with 0.25 is achieved at a velocity of 13 m/s (see Figure 20).

The wear of MMC 316+TiC is in the range of 10 to 30 µm, whereas the wear for Cr6 is 200 µm and for S355 100 µm. The smallest wear occurs in the tribological contact of the MMC 316L+TiC with MS58, MS58 only has a wear of 50 µm (see Table 5).
Table 5 Material wear during mixed lubrication test of the MMC 316L+TiC

| Coating material | Counterpart material | Coating loss [µm] | Counterpart loss [µm] |
|------------------|----------------------|-------------------|-----------------------|
| TiC MMC          | 100Cr6               | 20                | 200                   |
|                  | S355                 | 30                | 100                   |
|                  | MS58                 | 10                | 50                    |

4. Discussion
The coatings produced show very different characteristics. The MMC of 316L + TiC is characterised by a homogeneous TiC particle distribution and no cracks. The TiC particles increase the strength of the MMC due to solid solution strengthening. MMCs with a hard material content of >30 vol.% show cracks. The increased number of hard particles going into solution increases the stress concentration within the material. The matrix cannot withstand unlimited stress causing cracks to form due to stress relief. The dissolved TiC precipitates form at the grain boundaries. These precipitates pin the grain boundaries increasing wear resistance. However, grain boundaries act as weak spots and reduce ductility. This explains the brittle behaviour observed. The processing of SiC is possible due to the direct energy input into the powder in combination with the high cooling rate (10⁶ °C/s). However, with larger volume percentages of SiC, the reaction with iron produces gases, which leads to strong pore formation. The SiC is almost completely dissolved in the matrix material during the deposition process. However, SiC is considered to be a difficult material to weld, as it reacts with iron at temperatures above approx. 1100 °C [12]. The reaction produces iron silicides and the carbon dissolves in the iron, which leads to an increase in hardness. However, if large volume percentages of SiC are added, carbon precipitation can also occur when the iron is saturated [12]. These carbides preferably form at grain boundaries weakening those. According to literature the structure of these precipitates is typical for increasing strength, however the structure itself is brittle, further impeding manufacturability and ductility. Saturation is a sign for segregation, leading to inhomogeneous material composition, an in turn mechanical properties. All test subjects showed a very high friction coefficient, where according to Blau et al., typical values are situated far below 0.1 for long time operation without severe wear [14]. Compared to the steel counterparts, both MMCs showed rather expectable friction coefficients. At higher speeds of more than 8 m per second, the measured coefficient of friction was too high. Peaks can be also seen at 4 m/s and 6 m/s, which may be explained as caused by transition and therefore a measurement error due to the not statically measurement method of Stribeck curve. Where the MMC with TiC showed very good results against the brass material (10 and 50 µm wear), SiC showed a significant loss at the brass counterpart (10 and 150 µm wear). Contrary to the results gained on brass, the SiC coated disc showed very few wear running against the 100Cr6 disc (20 and 20 µm). This pairing may be a very durable combination, enabling a high resistance against mixed friction and supporting emergency running properties for a longer time. Blau and Jolley investigated the abrasive wear behavior of several titanium carbide reinforced matrix composites like Ti64, 5TiB, 10TiC and 7.5W/TiC, using 240 grit aluminum oxide band as counterpart at a sliding speed of 10 m/s and an applied force of 9.6 N. However, the results cannot be compared in a direct manner, but at least a tendency can be seen. The TiC material achieved a wear volume of 1 mm³ after a sliding distance of 900 m, measuring a linear correlation between sliding distance and wear volume (low-stress abrasion) [15]. While doing the measurements, sliding distance has not been recorded. A calculation based on the speed profile gives an overall distance of each pairing of around 9 km. Compared to the 240 grid aluminum oxide, the wear against steel or brass is negligible. Brink studied the run in behaviour of lubricated steel – steel pairings, explaining that lower velocities are generally more suitable for the run-in transition of the materials [16]. As no run-in took place before performing the Stribeck test, all examined material had to run-in at high speeds of 14 m/s. This could possibly be an explanation of high COF, in particular at high speeds of the Stribeck curve. Often, a drop has been observed at 3 m/s or lower. Kragelski investigated the wear behaviour of lubricated steel – steel contacts on a similar geometry, obtaining wear rates of 0.015 mm/ km applying 0.1 MPa of pressure and around 1 mm/km applying 2 MPa of pressure [20].
Feser et al. measured the coefficient of friction in a lubricated steel – brass (CuZn5) contact between 0.02 and 0.4, at a sliding speed of 10 to 20 mm/s and 1 to 4 MPa \[1\]. According to Blau, steel on steel typically reaches a coefficient of friction of 0.6 \[18\]. Compared to the first tribological test, also performed on a disc on disc tribometer by the authors, the use of hard carbides integrated to the 316l coating material improved the wear resistance clearly \[7\].

5. Conclusion

Within the scope of this study two different MMCs made of 316L+TiC and 316L+SiC have each been successfully tribologically tested against three different counterparts made of 100Cr6, S355 and brass (MS58). The produced MMCs have varying coating properties in the cross section, while the TiC particles have only been dissolved to a small percentage and are present in the MMC in elemental form, whereas the SiC particles are almost completely dissolved into the matrix material. In the tribological tests the coatings show very different results. It was shown that MMCs, strengthened by Ti- or Si-Carbides, have a high tolerance against fretting and abrasive wear. Compared to their steel counterparts, the wear of the matrix material was just 10% of the steel wear. There is no connection between the hardness of the wear resistance and the hardness of the tested counterparts. It was not possible to abrade or destroy the coating in any way in the test. Even under high mechanical and thermal stress the weld between basis material (S355) and coating was firm. The MMCs, applied via EHLA are a promising way to strengthen the wear resistance of standard base steel.

The use of two hard contact partners compared to the classical system, the use of one hard contact partner against one soft contact partner, poses many new questions to tribology. It is now no longer necessary to regularly replace wear parts, usually bushings or bearing shells, which are made of soft brass. At the same time, of course, it can happen that housing parts that should actually be protected by the brass metal are now also subject to wear. Despite this solution, it must be carefully examined whether a hard-hard pairing should really be used and thus the risk of wear also exists in unintended places, or whether one would rather use the advantage of inexpensive “sacrificial” components. In further investigations, the results obtained must be examined metallurgically and tribologically in order to describe the wear behaviour. This includes an in-depth metallurgical analysis of the MMC to determine the microstructure and segregations within the alloy. In this way, suitable friction pairings with the lowest possible coefficient of friction as well as the lowest possible wear should be identified.

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