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# The Influence of the Deposition Rate of Application on the Thickness of the Molybdenum Layer

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***Abstract:*** *Our research was based on the requirements of practice. The production organization asked us to solve the problem of application of molybdenum layer thermal spraying. In some samples, a large thickness was measured, making it impossible to produce the product of the required parameters. The product was a molybdenum lamella for brakes and clutches. The rate of application should be constant throughout the production of the lamella. Exceeded thickness is caused by the use of a large volume of additive material. Molybdenum is a very expensive metal, which ultimately results in a financial loss. In the paper we reviewed various causes of this problem and their consequences. Based on the research, we determined that the main cause of the large thickness of the applied layer was the non-compliance with the constant molybdenum wire feed rate. We have taken corrective measures to prevent it from happening again. Linking with practice and handling manufacturers' problems is very important for our research.*

***Keywords:*** *molybdenum layer, thermal spraying, exceeded thickness, quality production*

## INTRODUCTION

Molybdenum and its alloys, and composite materials that employ molybdenum metal, provide unique combinations of thermal and electrical conductivity, thermal expansion, high-temperature strength and creep resistance, vapor pressure, environmental stability, and resistance to abrasion and wear that make them ideal (Alló et al., 2013; Votava et al., 2014).

Even though alloying increases strength, the main way molybdenum is strengthened in all cases is by mechanical deformation. This is normally done by standard rolling, swaging, and forging processes. Deformation can increase molybdenum's strength by a factor of as much as four, depending on the amount of deformation applied (Kročko et al., 2011; Paulíček et al., 2014; Paulíček et al., 2013).

Carbide-stabilized alloys contain fine particles of reactive metal carbides in the molybdenum matrix. They also benefit from a small amount of substitutional alloying conferred by the reactive metals not present as carbides and additional interstitial hardening from carbon and oxygen atoms not contained in the carbide particles. This combination maintains molybdenum's strength to temperatures higher than possible with either pure molybdenum or simple substitutional alloys because the fine particles force recovery processes to take place at higher temperatures. Processing is a key element in the success of these alloys (Kováč et al., 2014; Chantaramanee et al., 2013).

Thermal spray equipment feeds the coating material into a high-temperature jet of inert or reducing gas, which melts and atomizes the coating material and impels it onto the surface. There the droplets solidify in "splats.' building up the surface coating. The coating material source can be wire. rod. or powder. Metals, ceramics, and cermet's are all processed using thermal spray technology. The heat source for spraying may be a flame, an electric arc. or even a controlled explosion. This variety of heat sources, carrier gases, materials, and material forms has led to the development of many different processes, including flame spray, wire spray, detonation gun deposition, high-velocity oxyfuel (HVOF) and plasma spray (Prístavka et al., 2014). The coatings themselves can be designed to impart corrosion resistance, wear resistance, friction control, and thermal insulation to the substrate. Thermal spray is also used in some cases to rebuild regions of a component that have been worn or eroded away in service (Bujna et al., 2013).

The aim of the paper is based on the requirements of the manufacturer of molybdenum lamellas. When applying the molybdenum layer to the lamella, the thickness of the layer applied was higher than that recommended, causing the part to be unusable for use and large financial losses. Our main goal was to find out why this thickness was exceeded (Prístavka and Beloev, 2015).

## MATERIALS AND METHODS

In the flame spraying process, molybdenum is fed in the form of spray wire to the spray gun where it is melted by a flammable gas. Droplets of molybdenum are sprayed onto the surface that is to be coated where they solidify to form a hard layer.

The process used is thermal spraying also known as flame spraying. Once this process is finished the final thicknesses and groove patterns are then machined to the surface to guarantee reliable friction behaviour. The following are properties that are associated with this type of material:

- good oil compatibility,
- good wear resistance,
- stable friction coefficient.

The steel lamella is coated with pure molybdenum. Thus, we can apply a thickness of 0.045 to 0.070 mm under optimal conditions.

Measurement Procedure of Prepared Samples. In case of steel parts the surface of which is covered with molybdenum, it is not required to measure the core hardness and part surface hardness. According to the technical documentation, an emphasis is on the thickness of molybdenum layer on the surface of the part. This thickness is clearly shown on the following technical drawing:

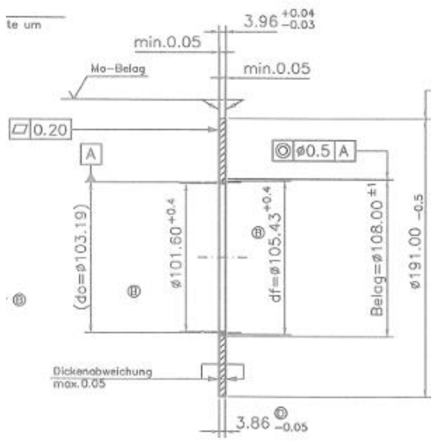


**Fig. 1** The tolerance of thickness specified in the technical documentation

First of all, we prepare a sample for microscopic measurement.

Procedure of Sample Preparation.

1. Optimum implementation of sample cut from a prepared part coated with molybdenum (Furka, 2012).
2. Vertical cutting with water cooling.
3. Sample cleaning with ethanol using ultrasonic.
4. Sample drying. Preparing the SimpliMet1000 machine and the application of epovit.
5. Checking the settings of the Sipmplemet3 device.
6. Preparing the moulding press.
7. Inserting the preparation into the Ecomet3 grinder.
8. Mambo disc polishing. Taking out the samples from the preparation. Rinsing. Cleansing with cotton wool. Ethanol spraying and desiccator drying.
9. Preparing the etchant in a glass container. The etchant is a chemical compound of $NH_3$ and ethanol. The sample identification data is written into the database (Bujna et al., 2016; Furka, 2012; DIN EN 657:2005-06).

Using a moulding press, the sample is prepared in a way that would enable an objective observation of part surface under the microscope.

We set the microscope at 100x magnification and then choose a section on the surface that would help us to perform an analysis. Using the Leica software, we take a picture of the studied surface with an emphasis on the sample to be well lit and the picture sharp and clear. We divide the surface of a sample into 100 µm sections according to Fig. 3. Afterwards, we perform the measurement of layer thickness for every 100 µm database (Bujna et al., 2016; Furka, 2012; DIN EN 657:2005-06).

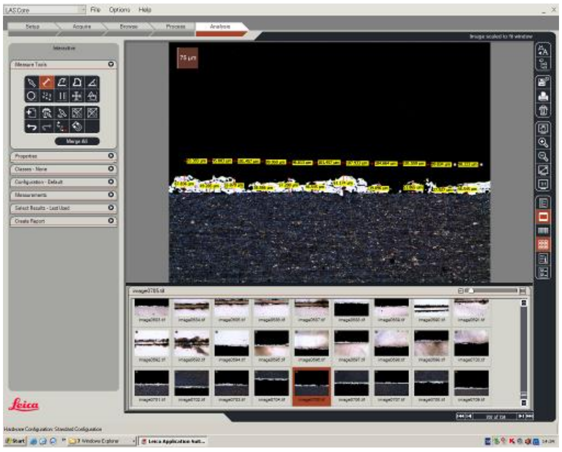

**Fig. 2** The surface of studied sample divided into sections with software Leica

We calculate the average value of molybdenum on the area being examined. The resulting value should not be less than the tolerance defined in the technical documentation of the part.

## RESULTS AND DISCUSSION

The task itself begins by checking the samples. The required control parameter is the thickness of the molybdenum layer applied on the steel lamella. The lamella is used in couplings for trucks, construction equipment and agricultural machinery.

The difference in the rate of application has a considerable impact on the thickness of the applied molybdenum in one part. The application process is affected by technological parameters. A technician sets the parameters for a particular part type. The part is currently undergoing a molybdenum coating process. The effect of the deposition on the molybdenum thickness is mainly ensured by the constant molybdenum wire feed rate. The wire is supplied to the nozzle and the rotational speed of the part under the nozzle, when the feed material is injected itself, is constant. The gas flow can, in exceptional cases, affect the quality or achieved thickness. The role of gases in the process is to melt the feeding wire.

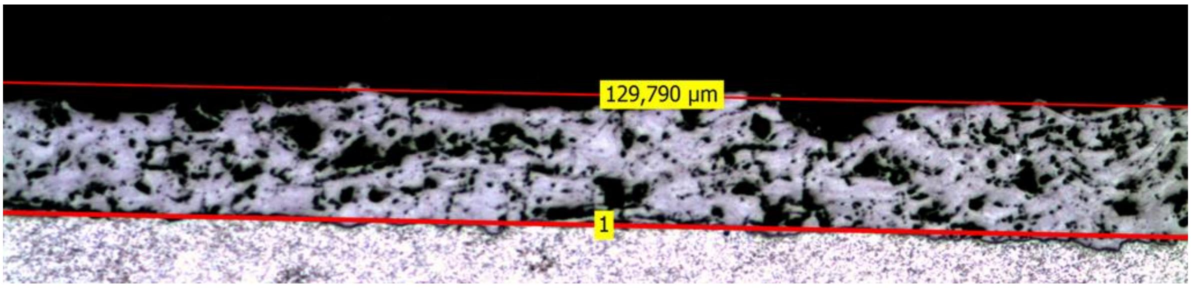


**Fig. 3** Molybdenum sample No. 5 / part No. 1

Magnification: 10x10, average value: 129,790 µm

The requirement for the thickness of the applied molybdenum layer was min. 50 μm. The laboratory measurement of the sample No. 5 (Figure 3) revealed that this value was at the most critical point exceeded by 80 μm.

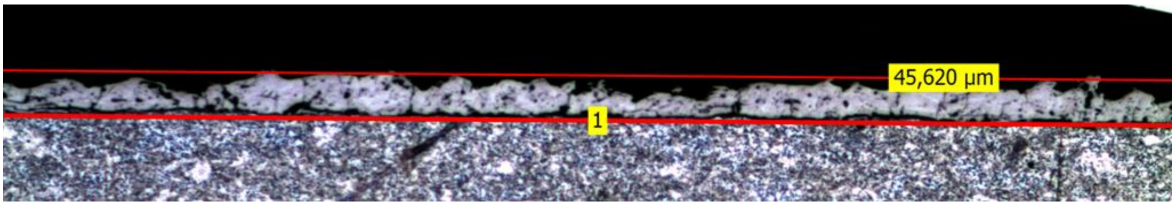


**Fig. 4** Molybdenum sample No. 5 / part No. 2
Magnification: 10x10, average value: 45,620 μm

The second measurement of sample No. 5 (Fig. 4), on the other hand, showed the value of 45,620 μm, which corresponded to the values achieved during the application of this particular type of part. The follow-up consultation of our team with the internal quality engineer and the technologist was as follows. There are several causes for this anomaly when different molybdenum thicknesses of 80 μm are present on one part. They are illustrated in the table 1.

***Table 1*** *Analysis of unacceptable molybdenum thickness*

| **Problem** | **Cause** | **Consequence** | **Assessment - acceptation** |
|---|---|---|---|
| molybdenum thickness of 80 μm | Incorrect attachment of the part to a rotary work table | The additional material is not applied circularly, but an elliptical movement is created. | Not accepted - it is not possible to achieve such an extreme difference in thickness |
| | The amount of oxygen and acetylene supplied | Exceeding the applied thickness of molybdenum | Not accepted - exceeding the thickness would be minimal |
| | Non-compliance with the constant speed of rotation of the parts during application | The table on which the part is placed slows down and then accelerates | Not accepted - after viewing the device |
| | Failure to maintain constant molybdenum wire feed rate | The wire slides through the worn-out and displaced feed wheels. | Confirmed |

The problem was caused by the molybdenum wire feed rate. The wire did not move at a constant speed to the nozzle, but it slid through the worn-out feed wheels. In this case, the required layer thickness would normally not be achieved. The displaced and worn-out feed wheels have been replaced and the action has been taken to introduce a regular inspection of the equipment and its integration into the maintenance system.

The car's brake disc is a very mechanically stressed component and heats up. It must therefore be wear-resistant and have a stability of its mechanical properties at elevated temperatures. It must also be resistant to abrasion. Properties of a brake disc must comply with prescribed mechanical properties. These properties are supplied by the applied molybdenum layer thermal spraying.

Pure molybdenum finds application as a spray coating for friction control on components in automotive, agricultural and aerospace industries. It is in this area that wire spraying is strongest, due to historical precedents and the fact that spray wire is available only as the pure metal. Journal and bearing shafts and piston rings are two major users of molybdenum coatings, applied using both wire and powder deposition processes.

## CONCLUSION

The global advancement and the impact of technologies have greatly affected the field of engineering technology, which has reached a high level in recent years.

For several years this trend has been part of our Slovak engineering industry. The trend of innovations and portfolio upgrading, and thus the dispersion of processing options, has introduced the technology of molybdenum coating on steel lamellae. This has raised new questions in terms of a quality and technology, which, of course, needed concrete answers to how to ensure high quality in the shortest possible time as customer demand is high. We recorded the impacts of individual parameters on the achieved level of application quality. The results of the long-term work have achieved the desired effect.

As a result of this effort, we were able to accurately describe all the accompanying parameters and fine-tune them and thus, within a few weeks, we have achieved the parameters of the applied molybdenum layer as required by the individual technical documentation. In many cases we have saved additive material, which is very expensive.

## ACKNOWLEDGEMENT

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