An Experimental Investigation on the Effect of Post-Shot Peening on Tribological Behaviors of Mo-Thermal Spray Coating in Synchronizer Rings

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Abstract

We have investigated the influence of post-shot peening on Mo-coating as compared to substrate steel 16MnCr5 (according to ZFN-413 A). Shot peening of carburized discs with and without Mo-coating was performed by using Shot size S230, Almen intensity 0.42mm'A' and exposure time 96 sec. Tribological properties were analyzed, using pin-on-disc tribometer apparatus, under dry sliding conditions at different specific applied loads, sliding velocities and distance. Typical standardized methods were used for studying of surface integrity parameters. Surface morphology of the substrate and Mo-coating specimens with and without Shot peening after wear was evaluated by Scanning Electron Microscope (SEM). The results showed that shot peening after Mo-coating has considerable effect on improving wear resistance and because of having low friction coefficient has showed better wear behavior and tribological properties over that of the un-peened Mo-coating.

Keywords: Shot peening, Carburized steel, HVOF, Tribological properties, Mo-coating

Introduction

Carburized steel is widely used for manufacturing of the automotive and transmission components such as synchronizing rings, synchronizing hubs, piston rings and selector forks, despite having good mechanical properties; this alloy doesn't indicate suitable wear resistance under automotive tribo- mechanical system conditions. Owning to special working condition in above mentioned automotive components, protective molybdenum coating has been extensively applied by thermal spray coating processes to improve the tribological behaviors of this alloy. Because thermal sprayed coatings possess an inherently rough surface between 5 and 20 µm that is not proper for the usual tribological application. Therefore, it will often be necessary to machine this component to achieve a final dimension and surface finish. Depending on the coating applied, the surface can be worked by conventional machining or can be ground and lapped to final dimension [15]. In most modes of long term failure the common denominator is tensile stress. These stresses can result from externally applied loads or be residual stresses from manufacturing processes such as grinding or machining. Tensile stresses attempt to stretch or pull the surface apart and may eventually lead to crack initiation. Compressive stress squeezes the surface grain boundaries together and will significantly delay the initiation of fatigue cracking. Because crack growth is slowed significantly in a compressive layer, increasing the depth of this layer increases crack resistance. Shot peening is the most economical and practical method of ensuring surface residual compressive stresses [16] and is considered a cold mechanical surface treatment in which the steel's surface is hitted with a flow of small balls with kinetic energy able to cause plastic deformation in the target surface for improving the mechanical behavior of metallic materials and structural parts and is used to increase static and dynamic strength of the working part. Not just a change of surface layers characteristics but also a change of tribological characteristics can be obtained by using this method [3, 6]. On the other hand, lubrication may be defined as a strategy of controlling friction and wear interposing a solid, liquid or gaseous media between interacting surfaces in relative motion under load. However, due to the complexity of the topic, the study of lubricated contacts needs more simplified approaches. Thus, a realistic approximation allows distinguishing three major lubrication regimes: hydrodynamic or full fluid, elasto hydrodynamic, and boundary [7]. One considerable advantage of peened surface is that they can induce an element of hydrodynamic lubrication (HL) between moving parts. Essentially, oil dragged into the dimples generates a load-carrying pressure [8] or the load is fully supported by a fluid film and consequently the surface stand completely separated [7]. This, in turn, reduces surface wear [8].

Experimental Procedure

In this study, 16 specimens were machined as substrate from carburized steel 16MnCr5 (DIN1.7131) in the disc shapes that a schematic picture with indicated dimensions is shown in Figure1. Chemical composition (wt. %) of this alloyed steel is; C: 0.155, Si: 0.269, Mn: 1.2, P: 0.002, S: 0.015, Mo: 0.026, Ni: 0.06, Cr: 0.85.

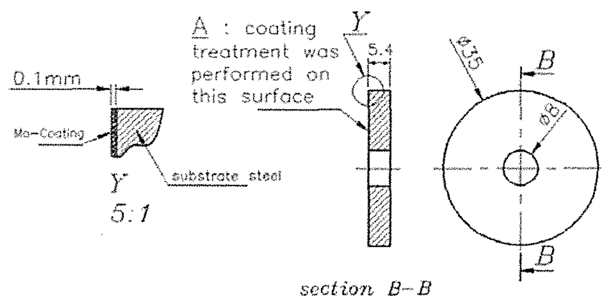

Fig.1: Schematic picture with indicated dimension in [mm]

Four groups of test specimens were used in this study. As the summery, the following treatments are shown in Table1 were designed to be performed on the test specimens:

Table 1: Design of experiment

Specimen Name	Treatments
T1	carburized + quenched + tempered
T2	T1 + shot peening with 0.6 mm
T3	T1+ abrasive blasting + Mo–coating
T4	T1+ abrasive blasting + Mo–coating+ shot peening with 0.6

In order to reduce the hardness slope between substrate and Mo-coating, before coating operation, substrate were heat treated in a furnace called RICHELIN (Austria) containing a carbon monoxide atmosphere under the industrial conditions. Shot peening was performed using impeller ejection type of machine and balls of d=0.6mm (S230) in diameter and 48-55 HRC hardness. The largest effects of shot peening occur when the whole area is covered [7]. Hence, coverage of 98% was selected at the peening time of 100 sec by the magnifying glass with 10X magnification. Because the adhesion of the coating to the substrate predominantly consist of mechanical bonding (interlocking)[15], the substrate surface was roughened and pitted to provide a foot-hold (splate-hold) for each splate of powder that impacts the substrate by using abrasive blasting machine. Then the surface cleaned from contamination that would fill the pits and prevent locking of the splates by using chemical method. Prepared disc samples were sprayed using HVOF method by machine called MET_JET III with the gun called MET-JET 4L. Experimental conditions of HVOF are shown in table2.

Table 2: Experimental conditions of HVOF

	Spray parameter	condition		Spray parameter	condition
1	Chemical composition	%98 Mo	4	Melting point of Mo ˚C	2660
2	Flame temperature ˚C	2500-3000	5	Distance of nozzle from component cm	34
3	Spraying velocity m/s	1000-1200			

Results and Discussion

The mean arithmetic deviation of surface (R_a) and mean asperity height (R_z) of the specimens were measured using a Mitutoyo, SJ.301, roughness tester. Figure 2 shows the comparison of surface roughness between Mo-coating and substrate after and before shot peening. The prominent increase on the surface roughness parameters for coating and substrate specimens were achieved by shot peening as compared with grounded ones. Worsening of the surface roughness parameter, which is more explicit for coating, is due to the existence of defect and porosity under the grounded surface layer. As illustrated, the roughness value of specimens before shot peening R_a is 0.28 and 0.36 µm and its R_z is 3.49 and 4.14 µm, respectively for Mo-coating and substrate specimens. However, the roughness of specimens after shot peening increases by R_a = 1.04 and 0.61µm and R_z=10.75 and 6.26 µm, respectively for Mo-coating and substrate ones.

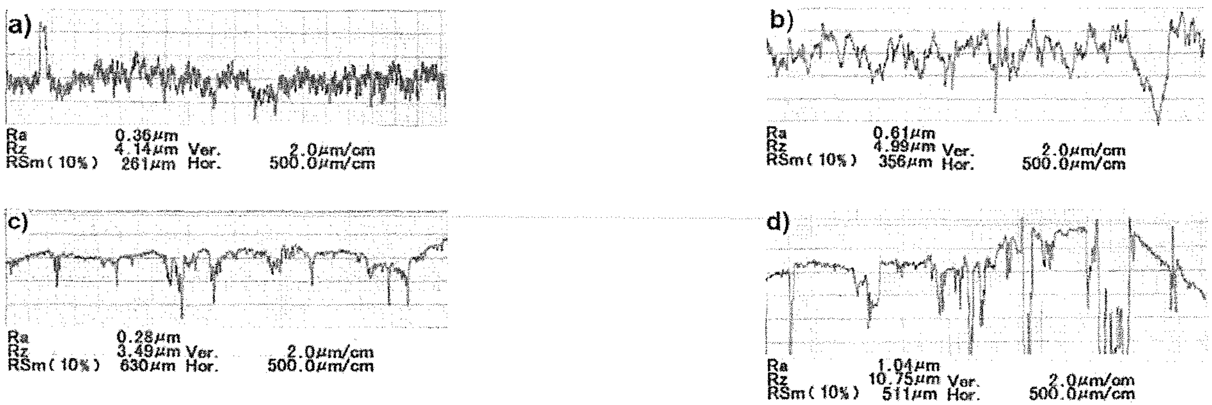

Fig.2: Surface profile of a) T1 b) T2 c) T3 and d) T4 state

To determine the micro-hardness of the specimens, the tests were carried out according to ASTM E384-11$^{\varepsilon 1}$. Hardness of polished sections of the specimens was measured at distance of 0.02 mm from surface. It is clear from the figure 3 that the hardness of shot peened specimens is greater than unpeened ones .The hardness increase of specimens coated by MO due to shot peening was 7% while for substrate specimens it was 15%.

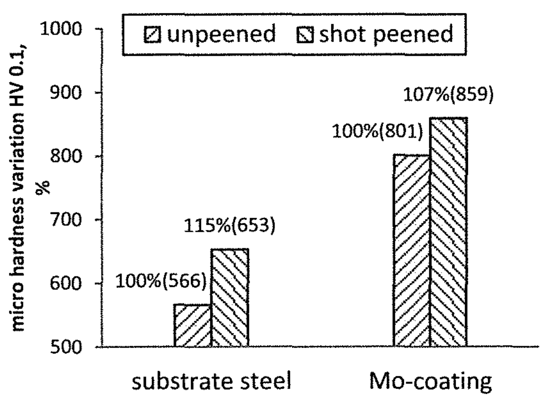

Fig.3: percentage change of hardness in surface layer

The friction coefficient was achieved automatically during the tests by means of data acquisition software. For instance, the graphical representation of the results of friction coefficient variation with applied load of 20 N and sliding speed of 0.22 m/s in dry sliding condition is illustrated in figure 4. As can be seen, shot peened Mo-coating showed a stable and lower friction coefficient value than the other test specimens up to the end of the sliding test. The unpeened Mo-coating, showed an irregular behavior during sliding distance. This was probably caused by the existence of porosity and ungrounded surface inside the wear track.

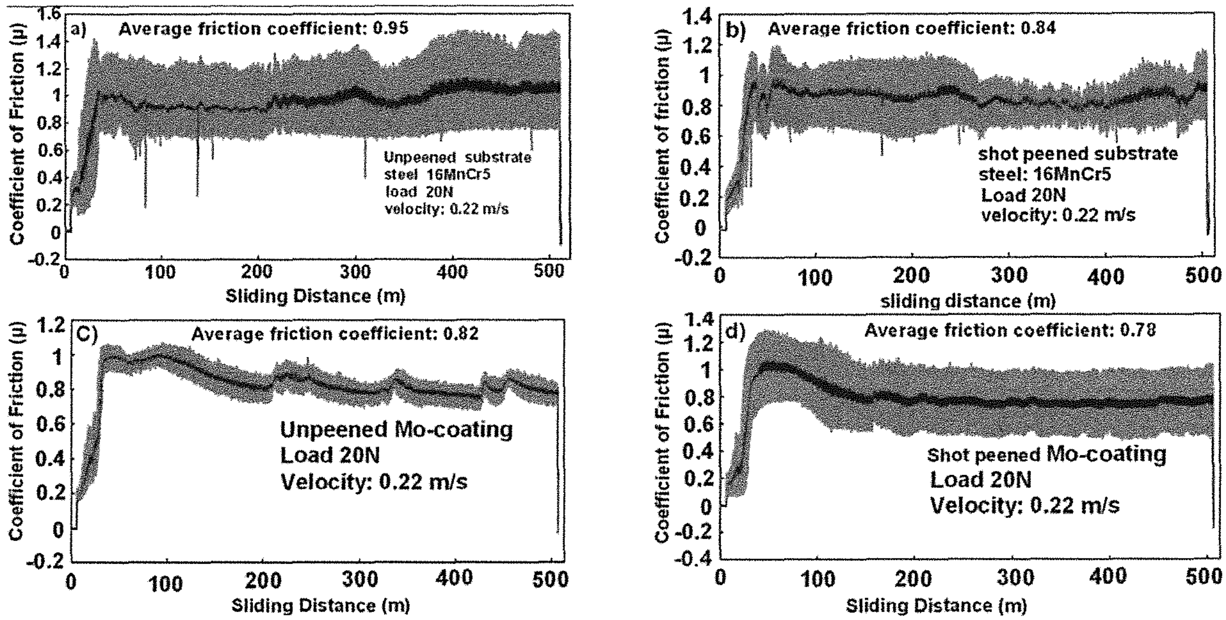

Fig.4: variations of friction coefficient against steel pin as a function of sliding distance for different surface treatment a) T1 b) T2 c) T3 and d) T4 state.

The test specimens were tested using a computer aided pin-on-disc tribometer apparatus. The counter face (pin of 5 mm in diameter) was made of steel 52100 of 800HV hardness with the roughness of R_a=0.1 μm. The test were performed continuously with a fixed sliding distance of 500 m under dry sliding conditions at different sliding speed(0.22 and 0.5 m/s) and applied loads (20 and 40 N) at room temperature (23°C). Each test was repeated three times. The Wear behavior of the specimens was calculated in terms of the wear rate (expressed in mg/m). Comparative bar graph of the wear rate under dry sliding condition of load and sliding speed is shown in figure 5. It was found that the wear rate increases with increase of load for both amounts of sliding speeds. In all sliding conditions the wear rate of unpeened substrate, was the maximum followed by shot peened substrate, unpeened Mo-coating and shot peened Mo-coating. Because wear is continuous unavoidable process that occurs as a consequence of direct contact of tribo-mechanical system elements [5] and the behavior of the material was highly influenced by the differences in hardness between the counter face and the coating [6]. Considerably higher wear resistance obtained by shot peening is the results of higher hardness induced on the surface layer of the specimens by shot peening treatment.
The variation of the friction coefficient for different treatment in the different sliding conditions of applied loads and sliding speeds is shown in figure 6. In dry sliding condition the friction coefficient amount of shot peened surface for substrate and Mo-coating is about 10%-18% and 5%-41% lower than unpeened surface, respectively. Generally, the bar graph shows that shot peened sample possess lower friction coefficient and high wear resistance than the unpeened specimens in dry sliding conditions.
The micrographs of the specimens were observed by a JEOL, JXA model, scanning electron microscope (SEM). Figure 7 shows the worn surface morphologies of the specimens after the sliding in condition of 20 N of applied load and 0.22 m/s of sliding speed. From figure 7b and d, unworn parts (cavities) can be clearly observed on the worn surface of the shot peened specimens (marked by cavity). By analyzing wear tracks we can say that, abrasive wear mechanism, what is verified by parallel scratches and displacement of material in direction of sliding. But in the wear track of shot peened Mo-coating the surface is smooth and without any indications of abrasion (Fig7d). In the case of the wear track produced in unpeened Mo-coating, an abrasion scar was clearly seen (Fig7c). the large distinct parallel and continuous grooves are formed on the substrate specimens can be observed from the figure

7a and b, while in the case of unpeened Mo-coating specimens large distinct grooves will reduced to fine scratches as shown in figure 7c.

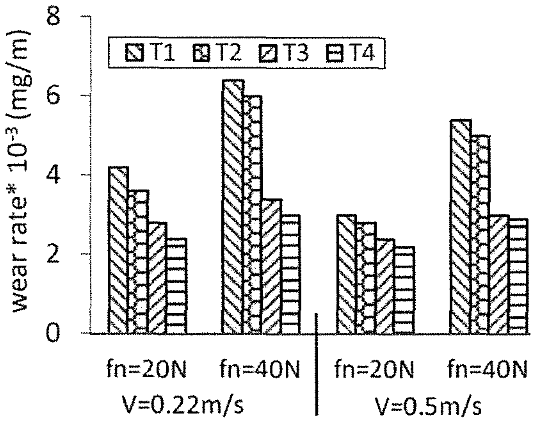

Fig.5: Variations of the percentage wear for different treatment in the different conditions of applied loads and sliding speeds in dry sliding conditions.

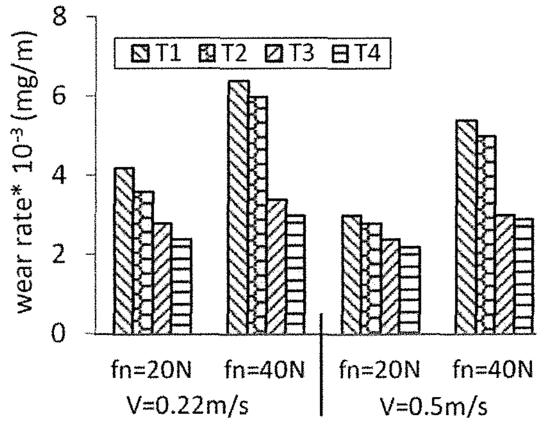

Fig.6: Variations of the friction coefficient for different treatment in the different conditions of applied loads and sliding speeds in dry sliding conditions.

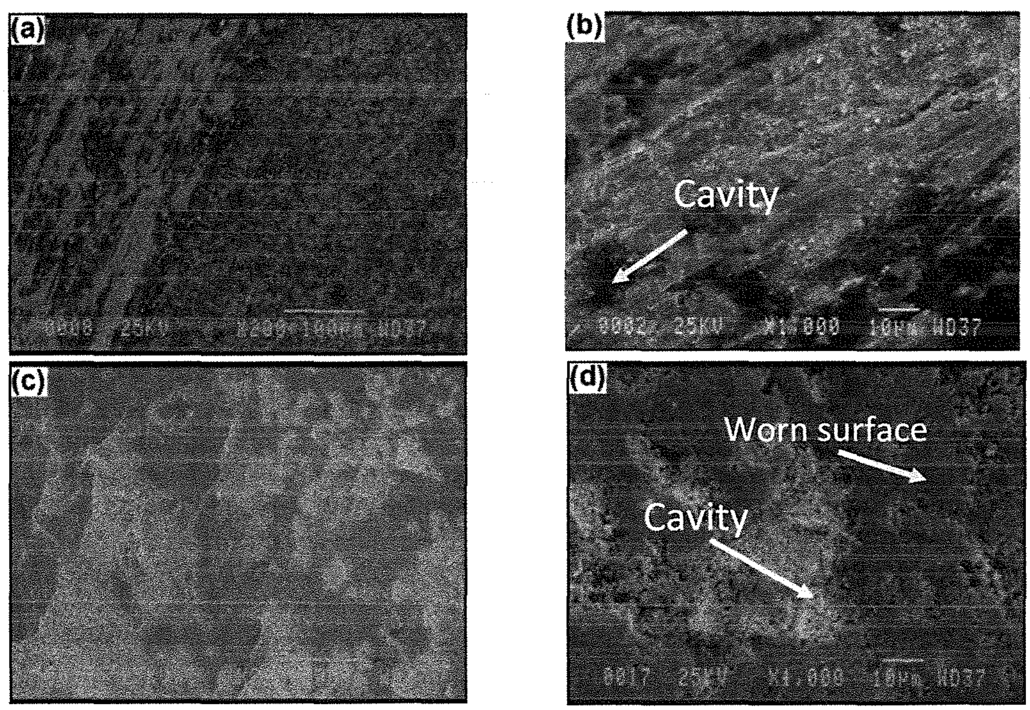

Fig.7: wear surface morphology by SEM of Mo-coating and substrate steel specimens in the dry sliding conditions for 20 N of applied load and 0.22 m/s of sliding speed for different surface treatment a) T1 b) T2 c) T3 and d) T4 state.

Conclusion

To enhance wear resistance of such a Mo-coating comprised with substrate steel, 16MnCr5, and the effect of post-shot peening on the tribological behavior of thus treatments were analyzed under the different sliding conditions. The following conclusions were obtained from the tests are listed below:

1) Result confirm that, the effect of shot peening on the worsening of surface roughness parameters on grounded surface of Mo-coating is higher than grounded surface of substrate.
2) Wear rate of shot peened specimens were found to be lower than grounded specimens due to surface work hardened layer and eliminating tensile stresses that attempt to stretch or pull the surface apart with inducing compressive residual stress by shot peening. T4 specimen possesses sufficient wear resistance as compared with T3 specimen and similar results was observed for T2 as compared with T1.
3) From friction behavior point of view, T4 specimen showed stable friction behavior as compared with other specimens in the same condition.
4) The amount of micro hardness is increased by 1.15 and 1.07 times for substrate and Mo-coating, respectively.
5) Range of wear rate achieved in dry sliding of Mo-coating, as well as the worn surface morphology indicate mild wear regime.

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