Vol. 39, No. 1 (2017) 100-109

Tribology in Industry

www.tribology.fink.rs

RESEARCH

Effect of Shot Peening on Tribological Behaviors of Molybdenum-Thermal Spray Coating using HVOF Method

H. Mohassel[a], F. Malekabadi[b], M. Jebreili[c], M. Zehsaz[c], F. Vakili-Tahami[c]

[a] *Iran Gear Research Center(IRGRC), Charkheshgar Co., Tabriz, Iran,*
[b] *Faculty of Mechanical Engineering, Sahand University of Technology, Tabriz, Iran,*
[c] *Faculty of Mechanical Engineering, University of Tabriz, Tabriz, Iran.*

Keywords:

Shot peening
Tribology
Molybdenum-Thermal Spray Coating
Almen Saturation Curve

Corresponding author:

H. Mohassel
Iran Gear Research Center(IRGRC), Charkheshgar Co., Tabriz, Iran
E-mail: hoseinmohassel@gmail.com

A B S T R A C T

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 steel discs with and without Mo-coating was performed by using Shot size S230, Almen intensity 0.42 mm '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 (micro-hardness, topography and surface roughness). Surface morphology of the Mo-coating specimens with and without Shot Peening before and after wear was evaluated by Scanning Electron Microscopy. 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 tribologi cal properties over that of the un-peened Mo-coating.

1. INTRODUCTION

Current global industry witnesses quick development in all fields. Engineering and mechanical industries are considered the essential foundation in fabrication and high-efficiency engineering designs to achieve the required goal of building highly dependable industry at reasonable cost. It is mandatory that machines components of steel are of specific mechanical properties; its surface shall be hard and wear resistance with high resistance fatigue [1] and lower friction coefficient. 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. Owing 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.

Thermal spray is defined as …" applying these coatings takes place by means of special device/ systems through which melted or molten spray material is propelled at high speed onto a cleaned and prepared component surface"[2,3].

There are several different processes used to apply a thermal sprayed coating. They are:

- Conventional flame spray
- Electric arc wire spray
- Plasma spray
- High velocity oxy-fuel spray (HVOF) [3,4].

The high velocity oxy-fuel spray (HVOF) process that is the purpose of this investigation is a relatively recent addition to the family of thermal spray process. As it uses a hypersonic jet, setting it apart from conventional flame spray, the speed of particle impact on the substrate is much higher, resulting in improved coating characteristics. The mechanism differs from flame spraying by on expansion of the jet at the exit of the gun. The coating feedstock material is melted by a heat source. This liquid or molten material is then propelled by process gases and sprayed onto a base material, where it solidifies and forms a solid layer [3].

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 [3]. 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. Since 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 [5] 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 [6,7]. 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, Elastohydrodynamic, and Boundary [6]. 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 [9]. This, in turn, reduces surface wear [8].

Many researchers strived and many studies were conducted to improve the automotive tribo-mechanical system for the purpose of increasing of wear resistance and decreasing of friction coefficient in the surface layer of components to attain better properties for the metal. Previously done studies by M. Babić et al. [9] suggest that after being subjected to shot peening treatment various types of steels like alloyed steel 36NiCrMo16 have shown positive influence on tribological behavior of machined parts a that they can contribute to improvement of tribological level of tribomechanical elements, Mc Sharma and Sc Modi [10] have reported shot peening after coating has shown considerable improvement on abrasive wear resistance. Plasma spray coating is primarily used in applications that require excellent wear resistance.

Shot peening has proven effective as a base material preparation prior to plasma applications that are used in cyclic fatigue applications. Shot peening has also been used after the plasma spray application to improve surface finish and close surface porosity [5]. But very less investigation has been done to study the tribological behavior of shot peened coating. The current study aims at investigating and comparing the tribological behavior of Mo-coating before and after being subjected to shot peening treatment. In this work, we claimed that shot peening treatment after Mo-coating has the excellent wear resistance and lower friction coefficient that was the determinant factor for its good performance in synchronizer rings, synchronizing hubs, piston rings and selector forks.

2. 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 Fig. 1. Coating treatment was performed on the surface A. To determine the exact alloy of specimens, specimens were analyzed by Quant meter device, SPECTROLAB M8, at temperature of 20 ºC ±3 and the pressure of 1 atm ±0.2 that 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, while mechanical properties of the test substrate steel of specimens are yield stress (RE) of 880-1180 Mpa, Elongation (A) of Min 9 %, hardness after tempering of 61 HRC, Reduction of are (Z) of Min 35 %.

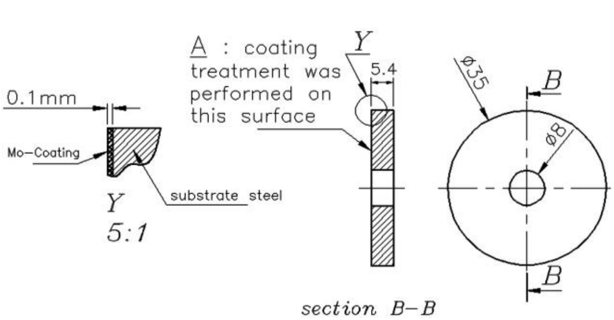


Fig. 1. schematic picture with indicated dimension in [mm].

2.1 Design of Experiment

Four groups of test specimens were used in this study. As the summery, the following treatments are shown in Table 1 were designed to be performed on the test specimens:

The first group was unpeened substrate that was subjected to conventional heat treatment, the second ones were shot peened substrate after conventional heat treatment, the third group of test specimens after heat treatment and abrasive blasting of substrate were sprayed of molybdenum with HVOF method and the fourth group were shot peened molybdenum coating. Each treatment was performed on three specimens. Note, that the shot peening with shot size of 0.6 mm (S230) in diameter are applied to automotive component.

Table1. 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	T3+ Shot peening with 0.6

2.2 Heat Treatment of Substrate Steel

After completing fabrication of samples, for the reduction of hardness slope between substrate and MO-coating, before coating operation, substrates were heat treated in a furnace called RICHELIN (Austria) containing a carbon monoxide atmosphere under the industrial condition in the cycle consist of carburizing at the temperature of 930 ˚C (1203 K) for 360 minutes and kept at 820 ˚C (1092 K) for 120 minutes and then quenched in oil at 110 ˚C (383 K) for 20 minutes, finally were tempered at 180 ˚C (453 K) for 90 minutes. Surface hardness and case depth with EHT610 of 16MnCr5 after carburizing was measured by REICHERTER, C.STIEFELMAYER are 61 HRC and 0.8 mm, respectively. In order to minimize the effect of heat treat scale (oxidized material) on the test results, after heat treatment, the surface of substrates were polished with P2000 grit emery paper to remove oxide scale which was done with care.

2.3 Shot Peening Treatment

Shot peening was performed using impeller ejection type of machine called GUTTMAN, Germany, and balls of d=0.6 mm. Shot peening intensity was quantified by means of the standardized Almen measurement. The residual compressive stresses from the one-side peening are convexly towards the peened side. The Almen test strip arc height is a function of the energy of the shot stream and is very repeatable. Other details of Almen intensity measurements can be found in [5,11].

The largest effects of shot peening occur when the whole area is covered. Hence, coverage of 98 % was selected at the peening time of 96 sec by the magnifying glass with 10x magnification.

Following standardized procedures and by peening a series of Almen test strips of "A" type, are made from plain carbon steel SAE 1070 and have hardness about 45 HRC, using increasingly longer peening times, with all other condition maintained constant, the saturation curve for shot size S230 was constructed with peening times selected between 50 to 270 sec. Peening intensity is measured by Almen Test and gauged is shown in Fig. 2.

Fig. 2. Peening intensity is measured by Almen Test and gauge

A plot of peening exposure time versus arc height is shown in Fig. 3.

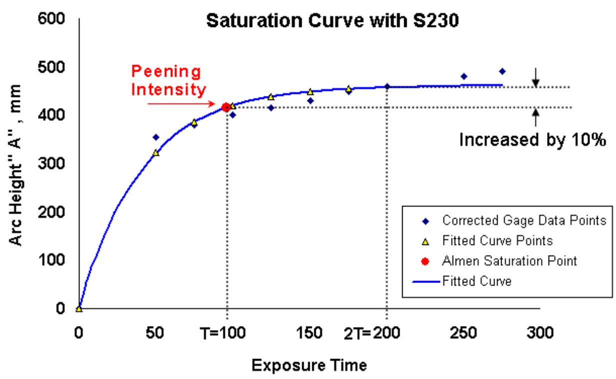


Fig. 3. Almen Saturation Curve constructed for shot size of S230.

As can be seen, at T=100 seconds using the shot size of S230 leads to the most optimum a mount of Almen intensity and according to SAE J443 the arc height increases by 10 % when the peening time is doubled and surface coverage on shot peened sample was observed by the magnifying glass with 10x magnification. It was determined the coverage was 98 % (complete coverage) with shot peening time of 100. Prior to shot peening, following standarzed procedures and by using type 'A', GEORGE FISCHER, Almen test strips the saturation curve for shot size (S230) were constructed and based on this curve the peening time selected 96sec. Cast steel shots with a hardness of approximate 510 HV with maximum hardness deviation ±25 HV [2] and a diameter of 0.6 mm (S230) were used.. Experimental conditions on shot peening are shown on Table 2. A special fixture was used for fixing the specimens on a rotating table which speeds is controlled by a motor system. [8,12-16].

Table 2. Shot Peening condition.

Shot Peening Parameters	Condition
Shot type	Cast Steel Shot
r.p.m	1450 r.p.m
Peening angle (deg.)	90º
Temperature (˚C)	30
Coverage (%)	98
Projection Velocity (m/s)	72

2.4 Mo-thermal spraying operation by HVOF process

Because the adhesion of the coating to the substrate predominantly consist of mechanical bonding (interlocking) [17], 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. Aluminum oxide and sharp chilled iron particles were used for abrasive blast operation. The arithmetic average surface roughness (Ra) after abrasive blasting was at least 8 μm. In addition, the surface was cleaned from contamination that would fill the pits and prevent locking of the splats by using chemical cleaning machine called DÜRR ECOCLEAN®. After the removal of surface impurities by chemical method, prepared disc samples were sprayed using HVOF method by the machine called MET-JET III with the gun called MET-JET 4L. Experimental conditions of HVOF are shown in Table 3. Molybdenum powder form with 98 % purity and 15-45 μm grading was used in this process. Thermal sprayed coating possesses a rough surface that is between 5 to 20 μm. Therefore, it will often be necessary to post process the surface of component to achieve a final dimension and surface finish. Depending on the coating applied, the surface can be worked by conventional machining or can ground and lapped to final dimension. In addition, specification procedures can call for other methods, such as post-coating diffusion, nitrating, hot isostate pressing or shot peening,as required. Calibration and measurement of MO-coatings thickness is shown in Fig. 4 [18-21].

Table 3. Mo-thermal spray coating (HVOF) parameters on substrate steel.

Spray parameters	Condition
Chemical composition	% 98 Mo
wire diameter (mm)	3.175
Wire charge speed (m/min)	0.7
Wire consumption rate	3.4
Oxygen flow rate	50
Cooling component while	Without
Distance of nozzle from	10 - 15
Rotating speed of	50
Pre-heating temperature of	80 °C

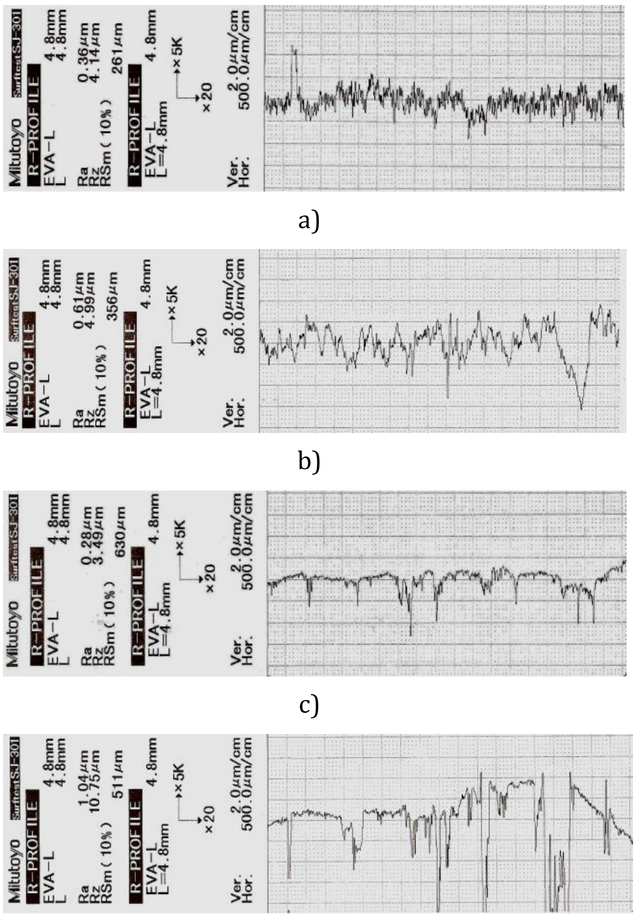
a) b)

Fig. 4. a) Calibration of coating thickness measurement meter, b) Measurement of MO-coatings thickness (μm).

3. Result

3.1 Surface integrity testing

The shot peened and unpeened specimens before the subsequent tribological testing, was evaluated in terms of surface integrity [22] by using standard metallographic method, micro hardness and roughness testing. The surface microgeometery is defined by: mean arithmetic deviation of surface (Ra) and mean asperity height (Rz) of the specimens that were measured by using a Mitutoyo, SJ.301, and roughness tester. Figure 6 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 Ra 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 Ra=1.04 and 0.61 μm and Rz=10.75 and 4.99 μm, respectively for Mo-coating and substrate ones. [23-24].



a) b) c) d)

Fig. 5. Surface profile of a) T1, b) T2, c) T3 and d) T4 State.

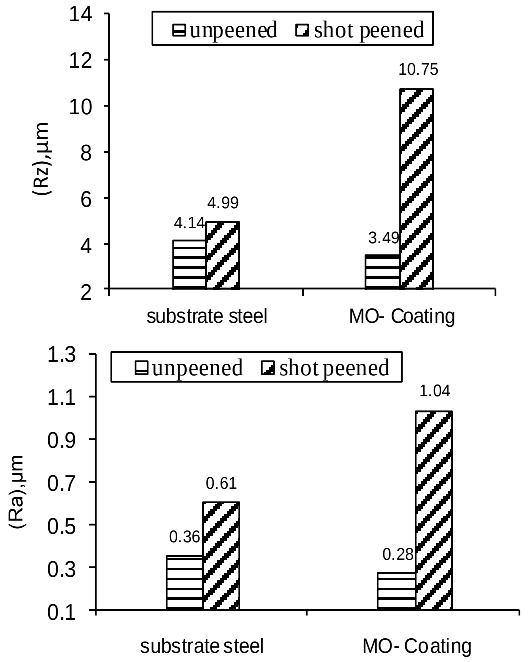


Fig. 6. Percentage change of surface roughness for the shot peened and un-peened surface of specimens.

3.2 Micro hardness investigation

Knoop hardness test is a micro hardness test method that is defined in ASTM E384. This Hardness measurement method enables measurements at very short distance between the pits and very close to the surface, what is not possible to realize by the Vickers method and particularly are used for very brittle materials or thin sheets, where only a small indentation may be made for testing purposes. To determine the micro-hardness of the specimens, the test was carried out with Knoop Hardness Tester at room temperature with a rhombic-based pyramidal diamond indenter for all specimens and the results thus obtained were recorded. Hardness of polished section of specimens was measured at distance of 0.02 mm in three rows; with lateral displacement under the applied load of 100 gr. Surface micro-hardness values for all specimens are shown in Fig. 7. It is clear from the figure that the average hardness of shot peened MO-coating (T4 specimens) is greater than other specimens (T1, T2, T3) and based on these measurements, the average hardness of T4 specimens is 859 HK while for specimens T1, T2, T3 is 801 HK, 653HK, 566 HK, respectively. The results indicate that near surface of different shot peened specimens (T2, T4) hardness has been significantly increased up to 25 % in comparison with unpeened ones and the hardness values of the HVOF-sprayed coatings strongly depend on porosity, oxidized, un-melted/semi-melted particles [25]. Note that Substrate steel was carburized for reducing the slope of hardness between MO-coating and substrate steel.

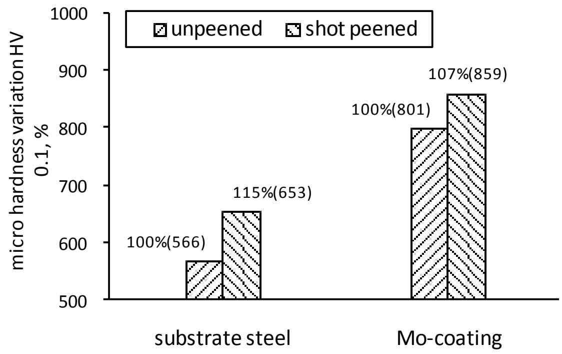
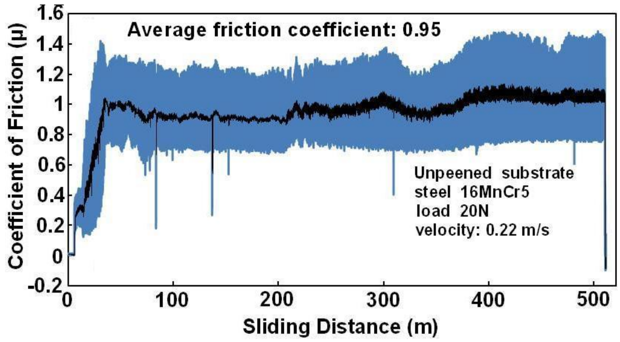


Fig. 7. Percentage change of hardness in surface layer

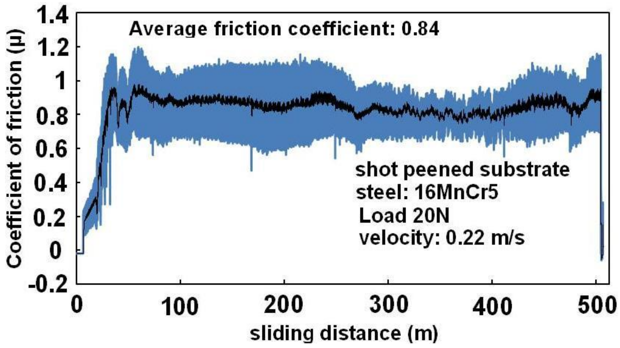
3.3 Wear

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 Ra=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) [26]. Each test was repeated three times. 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 loads of 20 and 40 N and sliding speed of 0.22 and 0.5 m/s in dry sliding condition is illustrated in Fig. 8. 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 behaviour during sliding distance. This was probably caused by the existence of porosity and ungrounded surface inside the wear track.

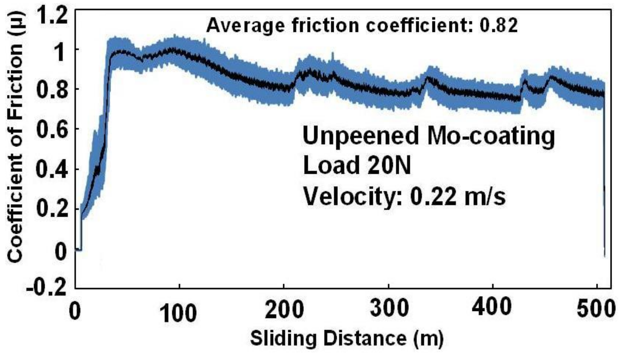
The Wear behaviour of the specimens was calculated in terms of the wear rate (expressed in mg/m). Comparative bar graph of the wear rate under dry sliding condition of load and sliding speed is shown in Fig. 9. It was found that the wear rate increases with increase of load for both amounts of sliding 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 behaviour of the material was highly influenced by the differences in hardness between the counter face and the coating [6].



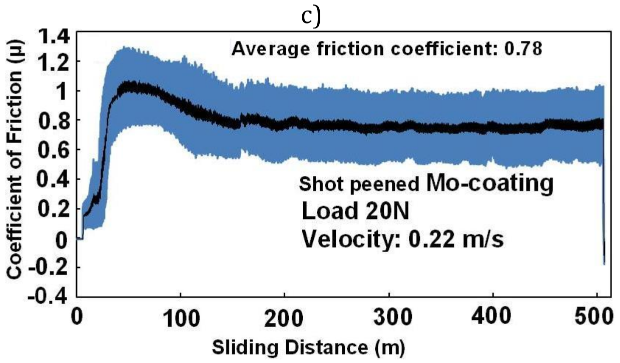
a)



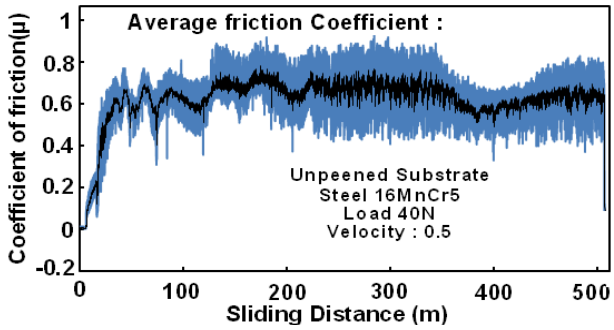
b)



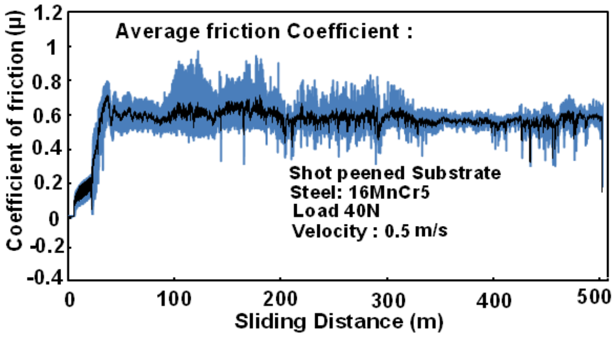
c)



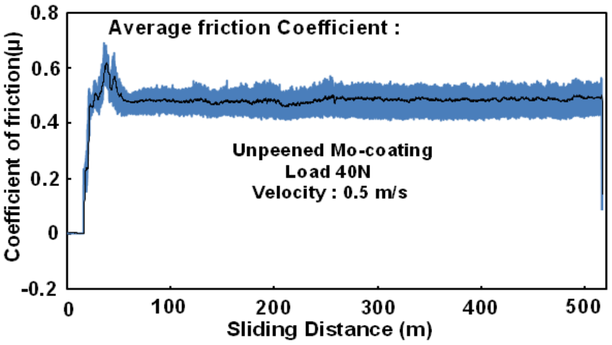
d)



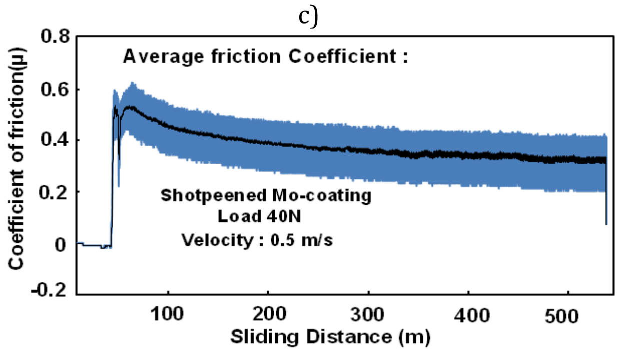
a)



b)



c)



d)

Fig. 8. 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.

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 in dry sliding conditions against steel pins in pin-on-disc is shown in Fig. 10. The tribological tests were performed using the pin-on-disk testing, according to ASTM G-99 [27- 28].

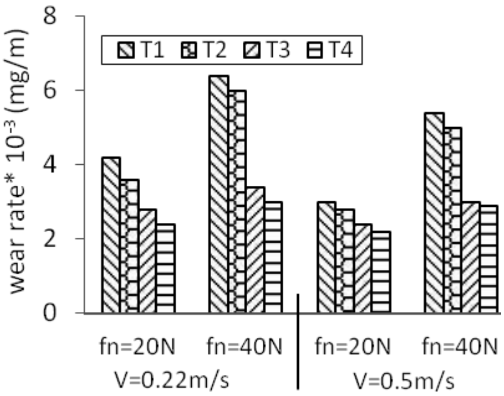


Fig. 9. Variations of the percentage wear for different treatment in the different conditions of applied loads and sliding speeds in dry sliding conditions.

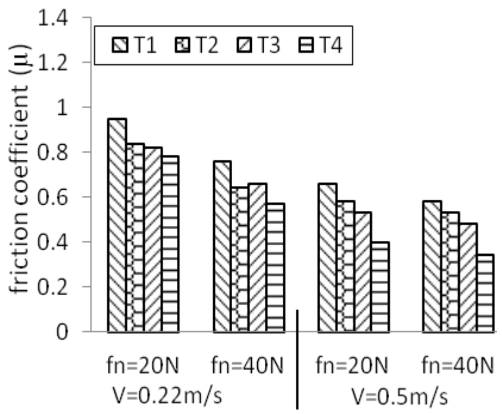


Fig. 10. Variations of the friction coefficient for different treatment in the different conditions of applied loads and sliding speeds in dry sliding conditions.

As can be seen, in the steady-state friction stage, shot peened Mo-coating presented much lower friction coefficient and the changing range of this coefficient is limited as compared with other ones. Moreover, the friction coefficient values were generally lower for the peened Mo-coating specimens than for the corresponding unpeened Mo-coating ones. These two factors about substrate steel specimens are more sever than unpeened Mo-coating ones. 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 [6,29].

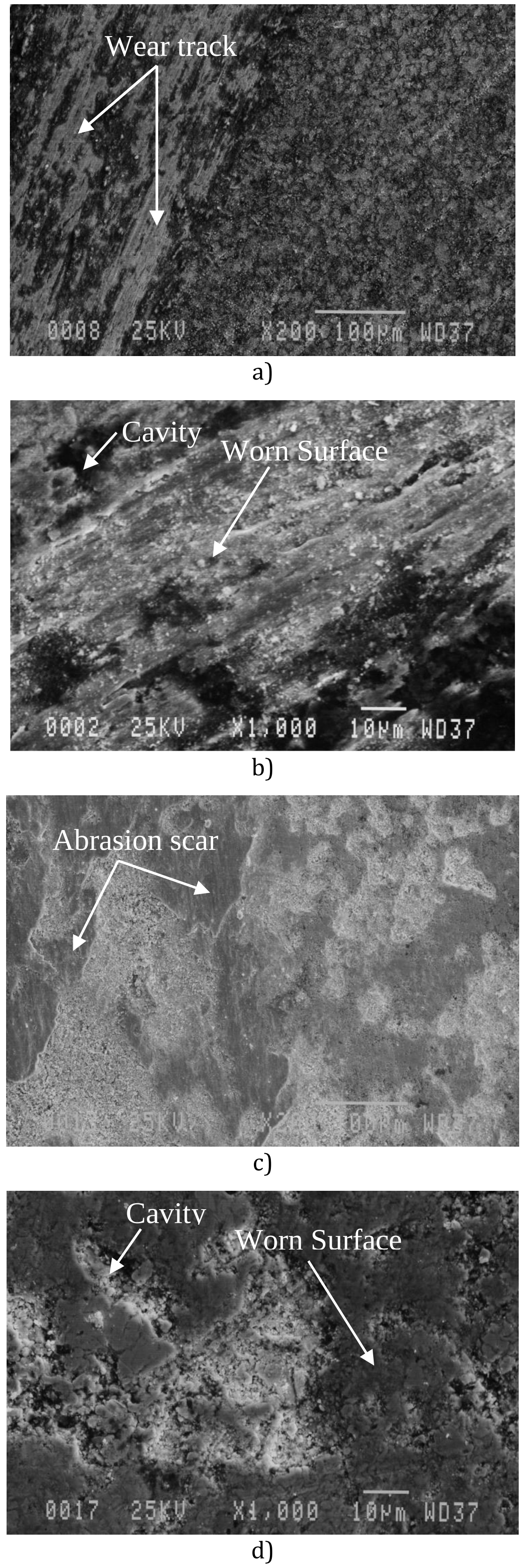


Fig. 11. wear surface morphology by SEM of Mo-coating and substrate steel specimens in the dry sliding conditions for 20 N of applied load and 0.22 m/s of sliding speed for different surface treatment a) T1 b) T2 c) T3 and d) T4 state.

3.4 Morphology of worn surface

The surface morphology and wear mechanism of the specimens were observed by a JEOL, jxa-840 model, Japan, scanning electron microscope (SEM). Display of wear tracks of tested specimens in the dry sliding conditions for 20 N of applied load and 0.22 m/s of sliding speed are shown in Fig. 11. When sliding against steel pins, the behaviour of the material was highly influenced by the differences in hardness between the pin and the coating [9]. As can be seen in Fig. 11d, the steel pin were severely worn by Mo-coating with high hardness, The non distinct parallel and continuous grooves are formed in shot peened Mo-coating specimen can be observed from the (Fig. 11d), while in case of unpeened Mo-coating specimen large distinct grooves will reduce to fine scratches as shown in (Fig. 11c). In the present study, as can be seen in afore-mentioned figure the worn surface doesn't show adhesive deformation; instead by considering the two sides of the wear track which show the not-worn parts, the flattening of the coating is predominant. It seems that because of the high hardness of the coating, the slider abrades and leads to mechanical damage of both the pin on the coating.

From (Fig. 11 b 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 (Fig. 11d). In the case of the wear track produced in unpeened Mo-coating, an abrasion scar was clearly seen (Fig. 11c). the large distinct parallel and continuous grooves are formed on the substrate specimens can be observed from the (Fig. 11a and b), while in the case of unpeened Mo-coating specimens large distinct grooves will reduced to fine scratches as shown in (Fig. 11c).

4. CONCLUSION

- 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.
- 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.
- From friction behaviour point of view, T4 specimen showed stable friction behaviour as compared with other specimens in the same condition.
- The amount of micro hardness is increased by 1.15 and 1.07 times for substrate and Mo-coating, respectively.
- Range of wear rate achieved in dry sliding of Mo-coating, as well as the worn surface morphology indicate mild wear regime.

Acknowledgment

The research study was financed by Iran Gear Research Center, Charkheshgar Company, Tabriz, Iran.

Referencs

[1] H.A. Ameen and K.S. Hassan, 'Effect of nitro-carburizing on corrosion resistance of carbon steel', *American Journal of Scientific and Industrial Research*, Vol. 1, no. 2, pp. 320-325, 2010.

[2] DIN EN 657 Standard for Thermal Spray–Begriffe, Einteilung; Beuth- Verlag, 1994.

[3] SULZER Metco, an introduction to thermal spray, available at: https://www.sulzer.com/, accessed: 2013.

[4] H.D. Steffens and J. Wilden, *Materials and Corrosion*. Moderne Beschichtungsverfahren, Oberursel, Wiley, 1996.

[5] Metal Improvement Company, Shot Peening Applications Guide, available at: https://cwst.com/, accessed: 2005.

[6] B. Bhushan, *Modern Tribology Handbook*. NEW YORK: CRC Press, 2001.

[7] E. Martínez, U. Wiklund, J. Esteve, F. Montalà and L.L. Carreras, 'Tribological performance of TiN supported molybdenum and tantalum car-bide coatings in abrasion and sliding contact', *Wear*, vol. 253, pp. 1182-1187, 2002.

[8] D. Kirk, 'Review of Shot Peened Surface Properties', *the Shot Peener*, vol. 21, no. 4, pp. 24-30, 2007.

[9] M. Babic, D. Adamovic, S. Mitrovic, F. Zivic, D. Dzunic and M. Pantic, 'Wear properties of shot peened surfaces of 36NiCrMo16 alloyed steels under lubricated condition', *Journal of the Balkan Tribological Association*, vol. 18, no. 4, pp. 566-576, 2012.

[10] M.C. Sharma and S.C. Modi, 'Effect of metal-spraying and shot peening on abrasive wear of carbon steel', in *9th International Conference on Shot peening*, ICSP-9, Paris, France, 2005, p. 75-80.

[11] AMSS13165 Standard for Shot-peening of Metal Parts, 1997.

[12] A. Niku-lary, 'An Overview of Shot peening Process', in *International Conference on Shot Peening and Blast Cleaning*, Bhopal, India, 1996.

[13] SAE H-84 Standard for SAE Manual on Shot Peening, 2001.

[14] SAE J443 Standard for Procedures for Using Standard Shot peening Test Strip, 2003,

[15] SAE J442 Standard for Strip, Holder and Gage for Shot peening, 2001.

[16] SAE J2277 Standard for Shot Peening Coverage, 2003.

[17] S. Mitrovic, D. Adamovic, F. Zivic, D. Dzunic, M. Pantic, 'Friction and wear behaviours of shot peened surfaces of 36CrNiMo4 and 36NiCrMo16 Alloyed Steels under dry and Lubricated contact conditions', *Applied Surface Science*, vol. 290, pp. 223-232, 2014.

[18] A. Burton et al., Thermal Spray Coating, in metals Handbooks, 10th Ed, Friction, lubrication, and Wear, Technology, ASM international, p. 829, 1992.

[19] R.B. Massad, 'Diamond wheel grinding of Thermal Spray Materials', in *Thermal Spray Coatings: New Materials*, processes and application Conference, OH, USA, 1985, p.139.

[20] J.H. Clare, D.E. Crawmer, Thermal Spray Coatings, in metals Handbook, in *9th Ed: surface cleaning, finishing and coating*, ASM International, p. 361, 1982.

[21] DIN EN657 standard for thermal spray, 1994.

[22] N.M. Vaxevanidis, D.E. Manolakos, A. Koutsomichalis, G. Petropoulos, A. Panagotas, I. Sideris, A. Mourlas and S.S. Antoniou, 'The Effect of Shot peening on Surface Integrity and Tribological Behavior of Tool Steels', in *International Conference on Tribology*, Parma, Italy, 2006, p. 1.

[23] D. Adamović, M. Stefanović, M. Živković, S. Mitrović, J. Živković and F. Živić, 'Influence of the Lubricant Type on the Surface Quality of Steel Parts Obtained by Ironing', *Tribology in Industry*, vol. 37, no. 2, pp. 215-224, 2015.

[24] U. Zupanc, J. Grum and S. Vestnik, 'Surface Integrity of Shot peened Aluminium Alloy 7075-T651', *Jornal of Mechanical Engineering*, vol. 57, no. 5, pp. 379-384, 2011.

[25] M.S. Priyan and P. Hariharan, 'Wear and Corrosion Resistance of Fe Based Coatings by HVOF Sprayed on Gray Cast-Iron for Automotive Application', *Tribology in Industry*, vol. 36, no. 4, pp. 394-405, 2014.

[26] M. Ovundur, F. Muhaffel and H. Cimenoglu, 'Characterization and Tribological Properties of Hard Anodized and Micro Arc Oxidized 5754 Quality Aluminum Alloy', *Tribology in Industry*, vol. 37, no. 1 , pp. 55-59, 2015.

[27] R.M. Castro, L.C.C. Cavaler, F.M. Marques, V.M. Bristot and A.S. Rocha, 'Comparative of the Tribological Performance of Hydraulic Cylinders Coated by the Process of Thermal Spray HVOF and Hard Chrome Plating', *Tribology in Industry*, vol. 36, no. 1, pp. 79-89, 2014.

[28] B.M. Viswanatha, M.P. Kumar, S. Basavarajappa and T.S. Kiran, 'Effect of Ageing on Dry Sliding Wear Behaviour of Al-MMC for Disc Brake', *Tribology in Industry*, vol. 36, no. 1, pp. 40-48, 2014.

[29] M. Babić and D. Adamović, 'Tribological Effect of Shot peening Surface Treatment', in *3rd International Conference on Manufacturing Engineering*, Greece, Chalkidiki, 2008, p. 657-664.