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Evaluation of the Plateau Honing on the Friction and Wear Cylinder Liners in Agricultural Tractors

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Abstract

To enhance the fuel efficiency of the engines of agricultural tractors, the optimal control of interacting surfaces for improving engine performance becomes extremely significant, especially in developing the surface of cylinder liners. Therefore, plateau honing technology was designed on the cylinder liner of automotive and tractor engines. A substantially flat or plateau is left on the sliding surfaces along with more bearing areas, although a cross hatch model of valleys is kept for retaining oil. On the contrary, the created valley by honing functions as an oil repository can negatively affect creating fluid dynamic pressure on the surfaces. Accordingly, a better understanding of generated surfaces during plateau honing is essential for optimizing process. To this end, some experiments were performed on a cylinder liner of the Perkins 4-248 engine (related to the Massey Ferguson 285 tractor) which was manufactured by Keyhan Sanat Ghaem Company. Then, friction and wear tests with reciprocating motions were conducted to compare the lubricity of sliding cylinder liner surfaces with each different mark of plateau honing. Then, a comparison was made between the friction and wear of the surfaces including various depth of profiles, which were used as the honing mark of the agricultural tractors diesel engine, and those which had randomly ground surfaces. Based on this study results, higher amounts of wear volumes were produced by creating more interactions from asperity contacts and relatively thin films, compared to the test with the shallow-grooved honing marks.

Keywords: Cylinder liner, Friction, Plateau honing, Tractor engine, Wear

Introduction

Nowadays, the process of mechanization development highlights that an increase in the application of tractors in agriculture and the share of mechanical power in operations improves production (Khodabakhshian, 2013; Keshvari and Marzban, 2019). However, improved engine performance and reduced fuel and oil consumptions are among the requirements which challenge the agricultural tractor industry. In agricultural tractors, nearly 11.5% of the energy is utilized for the actual power while the remaining energy is lost. In addition, 18% of the energy loss occurs in mechanical parts, and the energy waste is related to friction losses. Fuel and oil consumption may be reduced by 2% when a 10% reduction occurs in friction losses. According to Khodabakhshian and Shakeri (2011), piston assembly and interface between piston rings and cylinder liners are considered as the most losses in the tractor engine.

Recently, controlling interacting surfaces optimally for increasing the engine performance has been highlighted, especially in designing the surface of cylinder liners to enhance the fuel efficiency related to the agricultural tractor engine. Recent approaches in improving high-speed engines necessitate having an engine with lighter weight, higher

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performance, lower exhaust gasifiers, as well as less fuel consumption compared to previous ones (Grabon *et al.*, 2018). Further such engines should have the ability for severe loading, which necessitates a reduction in the amount of wear. The process of making some grooves on the surface for lubricating purposes and controlling contact surfaces are considered as one of such methods in this regard. Thus, plateau honing technology was designed on the cylinder liner related to the tractor and automotive engines (Tomanik *et al*., 2018). A plateau honing results in producing flat or plateau finishes on sliding surfaces with a more bearing area while maintaining a cross hatch model of valleys for retaining oil (Kim *et al*., 2018a; Sadizade *et al*., 2020).

Texturing surface is considered as one of the most useful technologies for handling the friction between cylinder liners and piston rings. Some studies focused on a multi-stage honing operation and texturing laser surface on cylinder liners for reducing the friction (e.g., Kligerman *et al*., 2005; Anderberg *et al*. 2018). Ramadan *et al*. (2009) indicated that the honing process enhances the geometric shape of the cylinder liner in terms of its geometric properties, including ovality and roundness. The ovality of the cylinder increases frictions in the engine and the wear between the ring and the cylinder liner wall since it establishes an asymmetric contact surface between rings and pistons with the cylinder liner wall. This phenomenon leads to an increase in fuel consumption while it decreases the output power of the engine and thus the service life of engine parts through time, with additional wear between the ring and piston with the cylinder wall (Kim *et al*., 2018b). Accordingly, tractor manufacturing companies now employ more rigid standards with tight tolerances in the permitted level of cylinder liner roughness although these standards differ relying on the type of the engine and the diameter of the cylinder and piston.

To the best of our knowledge, no study has evaluated the influence of honing or plateau honing on friction and wear of tribological cylinder liner surfaces in agricultural tractors, as well as the effect of honing parameters on the functional parameters of the engine. Most studies in this area predicted the maintenance and repair costs of agricultural tractors and estimated the economic life of tractors (e.g., Almasi and Yeganeh, 2000; Khodabakhshian and Shakeri, 2011; Rohani *et al*., 2011). Furthermore, some studies investigated the application of the preventive net in maintenance and repair programs of agricultural machines (e.g., Khodabakhshian and Shakeri, 2011; Khodabakhshian, 2013). Contrarily, various studies evaluated honing and plateau honing technology on the cylinder liner of automotive and ship engines. For example, Buj-Corral *et al*. (2015) designed several models for optimizing the honing equipment of the driving liner by comparing the obtained data from the surface roughness test device in the laboratory and the existing Honing machine. Additionally, Cabanettes *et al*. (2015) obtained data regarding the surface roughness of the cylinder liner and its related wear. In addition, Yousfi *et al*. (2015) studied the effect of plateau honing parameters on the surface roughness of the driving cylinder liner. In another study, Kim *et al*. (2018b) examined the effect of the parameters related to plateau honing on creating friction and wear for the driving cylinder liner.

Considering the above-mentioned explanations, the present study attempted to assess the impact of plateau honing on creating the tribological cylinder liner surfaces for friction and wear in agricultural tractors. A change occurred in profile depth from 0.05 μm to 0.8 μm in R_a, which often uses the honing mark related to the agricultural tractor engine. Further, a comparison was made between these surfaces and the randomly ground surface with a surface roughness of 0.15 and 0.25 μm in R_a. To this end, a cylinder liner of the Perkins 4-248 engine (related to the Massey Ferguson 285 tractor and manufactured by Keyhan Sanat Ghaem Company) was applied to perform the test.

Materials and Methods

The spatial and temporal domain of the study

Keyhan Sanat Ghaem Company, as one of the largest manufacturers of cylinder liners in Iran and the Middle East, was selected as the case study. The current study was conducted in 2017 in this company. Given the aim of the present study regarding evaluating the cylinder liner of the agricultural tractor, the cylinder liner of the Perkins 4-248 engine was selected, which was associated with the Massey Ferguson 285 tractor. Fig. 1 depicts a sample of this cylinder liner.

Tribological tests

A reciprocating ring-liner tribometer driven by a slider-crank mechanism with a stroke length of 80 mm (Fig. 4) was implemented for evaluating the friction and wear characteristics of cylinder liner surfaces with different honing marks against piston ring surfaces with 27±2 $^{\circ}$C temperature. Then, the contact surface was lubricated by using a 10W40 semi-synthetic oil (μ_D equal to 0.08 Pas at 40 $^{\circ}$C). It should be noted that the total wear test took 120 min in which extra amounts of lubricant were summed (2-3 mL) every 20 min. In addition, the normal force and engine velocity used for these tests were 100 N and 120 rpm, respectively (Yousfi *et al*., 2015; Kim *et al*., 2018b).

Fig.1. A sample of the cylinder liner

The measured cylinder liner material involves high-quality cast iron (GG 25) which has a 101 mm bore diameter and 233 length. The chemical compositions of the grey cast iron are shown in Table 1. The inner surface of cylinder liners has a hardness of 225-272 HB. The metallography (ASTM A247) results indicated that the liner consists of cast iron along with the pearlite matrix and an insignificant amount of the steadite (iron phosphide eutectic network). Further, the form of graphite is type I, graphite distribution is pattern A, E, and graphite size is 4.5.

Table 1– Cylinder liner material specifications

Element*	Cr%	S%	P%	%Mn	%Si	%C
% By weight	0.5	0.1	0.4	0.9	2.4	3.35

**Note*. Cr: Chrome; S: Sulfur; P: Phosphorus; Mn: Manganese; C: Carbon.

Sample preparation

First, the honing process from cylinder liners in the Perkins 4-248 engine block honing station was used for producing specimens by utilizing a mono spindle vertical honing machine by a developed instrument (NAGEL no. 28-8470) (Fig. 2). Cylinder blocks are delivered to the honing station after pressing and boring liners in the machining line. Then, liner specimens were prepared with varied honing depths, representing a surface roughness of 0.05, 0.15, 0.25, 0.5, and 0.8 µm in Ra (Fig. 3). In addition, five honing marks were produced to assess the impact of the honing mark on the wear and friction related to the contacting surfaces. The final surface of engine liners in plateau honing should become 0.8 µm in R_a (in other words R_k 3.712, R_{pk} 0.895, and R_{vk} 2.321 values should be seen on the final surface) on the surface processed by long-stroke honing. Additionally, two surfaces were created by random grinding without any honing marks, and the surface roughness of which were 0.15 and 0.25 µm in Ra. Next, all liner specimens were mounted on a reciprocating tester along with cleaning with acetone. Finally, scanning electron and optical microscopes were utilized to examine worn tracks on surfaces.

Friction tests undertake a load level of 100 N and reciprocating velocity of 120 rpm (Yousfi *et al*, 2015; Kim *et al*., 2018b). The contact pressure is high and can reach up to 50 MPa thanks to a small contact surface between the liner and ring surface (nearly 2-3 mm^2). Then, the friction was measured after 0, 15, 30, 60, and 120 min. Finally, the friction coefficient was calculated by applying the ratio between the average normal force (F_N) over the mean tangential force (F_T) assessed by strain gauges. The Rtec Multi-Function Tribometer software was used. A balanced Wheatstone bridge has been constructed by mounting four strain gauges over F_T. Two strain gauges have been mounted over the outer surface (for F_N), while rests are placed at the inner surface.

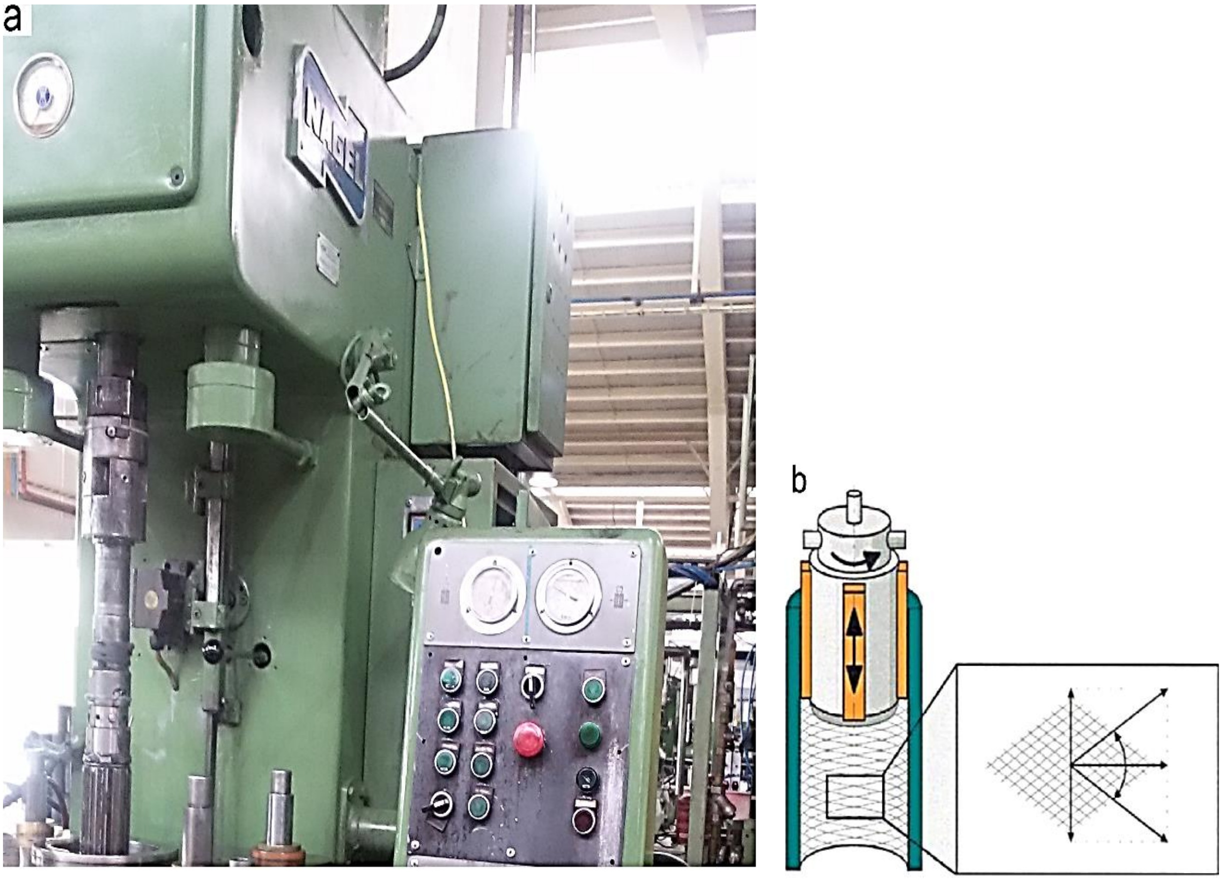

Fig.2. (a) Vertical honing machine with an expansible tool and (b) Schematic representation of a honing head and its motion

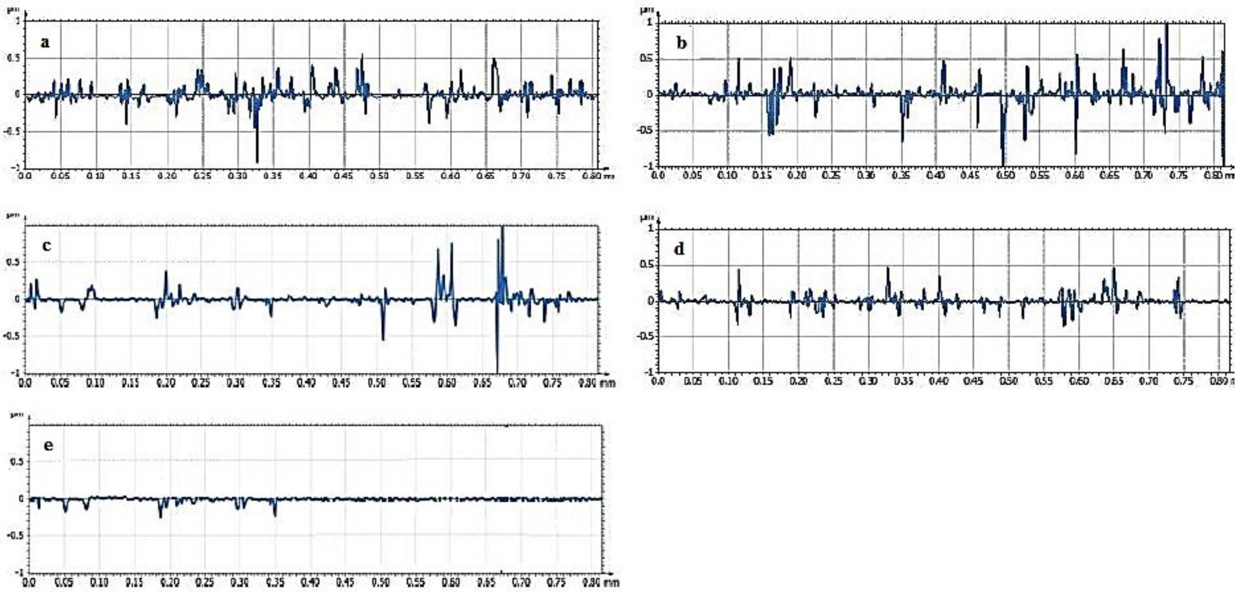

Fig.3. Honing processed surface roughness: (a) R_a 0.8 μm, (b) R_a 0.5 μm 5, (c) R_a 0.25 μm, (d) R_a 0.15 μm, and (e) R_a 0.05 μm– polishing processed surface

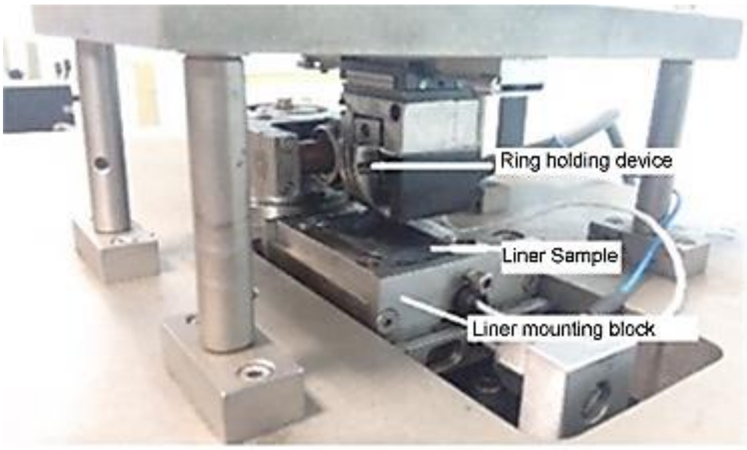

Fig.4. Reciprocating ring-liner tribometer

Results and Discussion

Running-in friction dependence on surface

Fig. 5 illustrates the specimen friction coefficient made by utilizing different surface processes. As displayed, compared to the surfaces with a grinding process with similar surface roughness, honing processed surfaces involve the coefficients with lower friction. Based on the results, no difference was observed in the friction performance related to the surface roughness of 0.8 μm in R_a in comparison to those of smoother surfaces. However, the highest friction coefficient was reported for polishing processed surfaces which confirmed some numerical results in the mixed lubrication regime (Mezghani *et al*., 2013; Yousfi *et al*., 2014). However, these findings should be approved by firing engine experiments that consider real engine conditions. These findings corroborate with those of Yousfi *et al*. (2015), Kim *et al*. (2018b), Anderberg *et al*. (2018), and Grabon *et al*. (2018).

Wear evolution during running-in

The evaluation method related to the wear volume of the cylinder liner during the plateau honing process compares the surface bearing as a curve of the original and plateau honed surface (Kumar *et al.*, 2000; Srivastava *et al.*, 2007). Further, this method represents that original surface depth is not eliminated when there is a negligible amount of wear. Fig. 6 illustrates the wear volumes related to cylinder liners with different roughness of the surface. The least volume of wear is created by the surfaces with the honing marks of 0.1-0.2 µm in R_a.

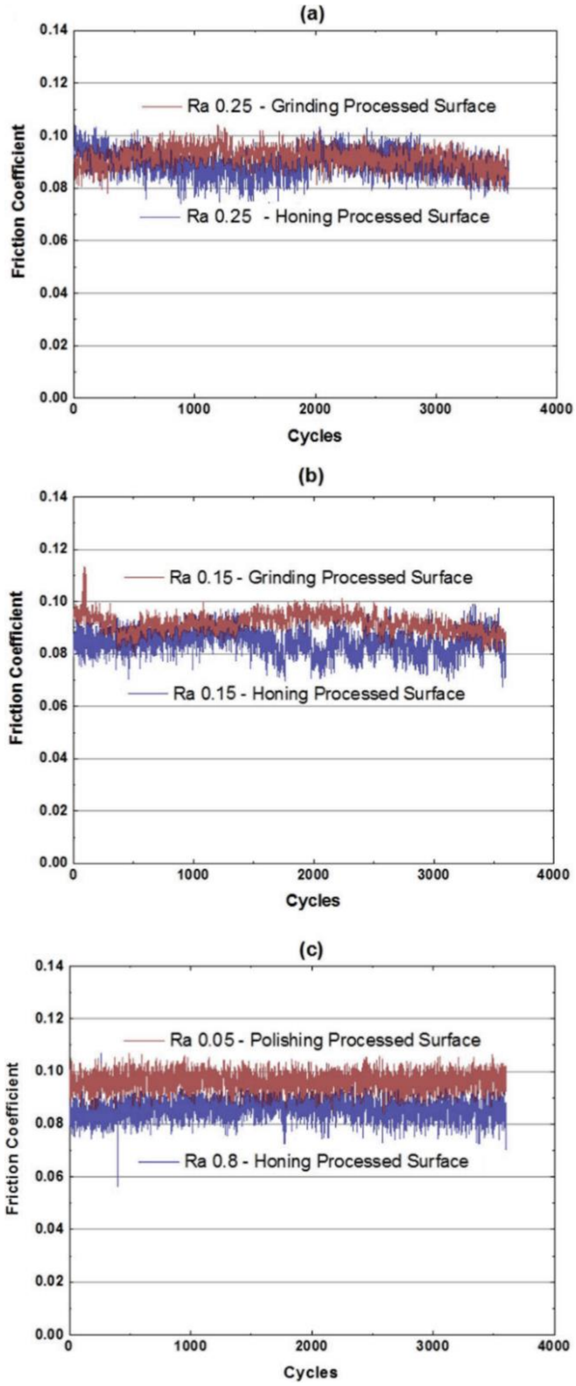

Fig.5. The friction coefficient related to surface roughness: (a) R_a 0.25 µm, (b) R_a 0.15 µm, and (c) R_a 0.8 and 0.05 µm

However, the highest wear volume was observed in the surface roughness of 0.8 μm in R_a. Based on the results, the volumes of wear increased by enhancing the surface roughness from 0.2 μm since colliding jagged asperities resulted in increasing in polishing effects. Contrarily, a decrease in the surface roughness from 0.1 μm led to an increase in the volumes of the wear by considering the fact that an increase in the real contact area between steel ball and cylinder liner results in creating more severe wear by adhesion. Other studies such as Yousfi *et al.* (2015) and Kim *et al.* (2018b) reported a similar trend for the wear volumes related to cylinder liners with different surface roughness.

In addition, the randomly ground surface indicated identical or better wear resistance after comparing the wear volumes related to the two machined surfaces, in comparison to the honing processed surface. It is worth noting that the surface valleys interrupt the maintaining hydrodynamic pressure of the lubricant film which results in creating partially metal-to-metal contact and plastic deformations by interacting asperities.

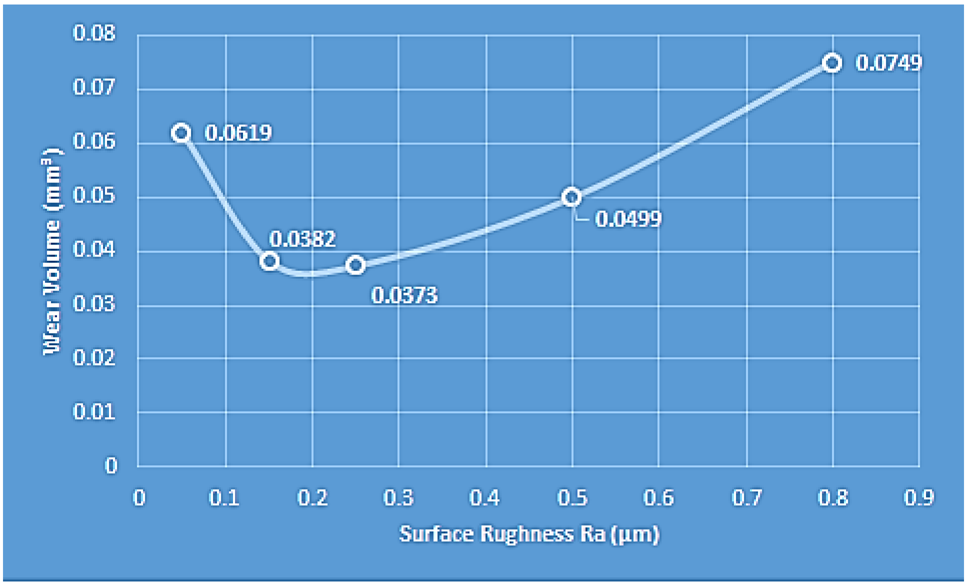

Fig.6. Wear volume of the cylinder liner

Scanning electron microscope (SEM) observations

To evaluate the effect of the honing mark on the wear, the honed surfaces with different surface roughness were considered for comparison. As shown in Fig. 7, the rough surface with 0.8 μm in R_a is rather damaged due to its plowing action and deep valley. In addition, the polished surface indicated a deep wear depth and higher plowing, while the wear mark related to the surface roughness of 0.5 μm in R_a is less than those of other surfaces.

As shown in Fig. 8, the surface with R_a 0.8 μm, which involves deeper grooves and a less contact area, demonstrates severe plastic deformations due to the interaction existing in colliding asperities. Based on the results, the grooves smeared by sliding surface and plastic deformations became smooth. Kim *et al.* (2012) evaluated the effect of reserving oils on grooves as well. The results of the current study further represented that surfaces with R_a 0.25 and 0.15 μm still indicate several groove patterns after the sliding test. Furthermore, adhesive wear was observed by the smoothest surface with polishing, which produced higher volumes of wear (Fig. 6). Thus, there is an optimum range of surface roughness to reduce the wear amount of the plateau honing process ranged between 0.15 and 0.25 µm in R_a.

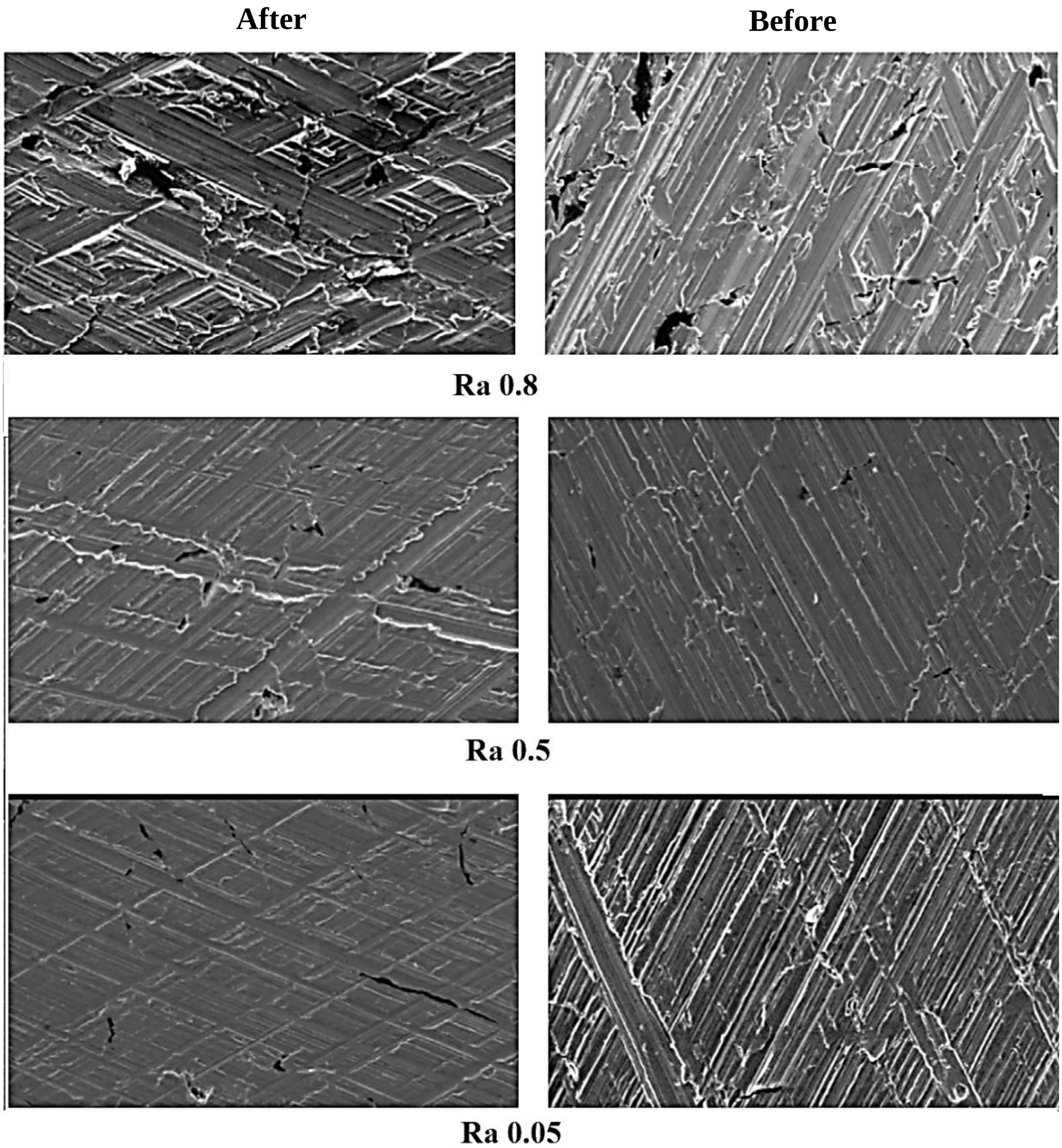

Fig.7. Microscopic images before and after the experiment

Fig. 9 depicts SEM images measured by ground surfaces without any honing process. The amounts of the wear were almost similar in comparison to similar surfaces with honing. Although the optimum groove depth of plateau honing is available for reducing the amounts of wear, the effect of the groove by using the plateau honing process which is considered as an oil reservoir is insufficient for reducing the wear compared to using only the grinding process.

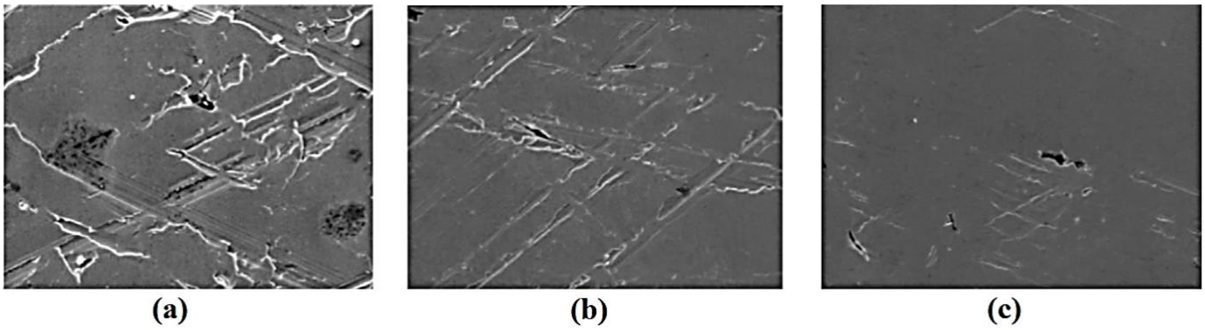

Fig.8. SEM images analysis of honing processed surface: (a) R_a 0.8 μm, (b) R_a 0.25 μm, and (c) R_a 0.15 μm

Note. SEM: Scanning electron microscope.

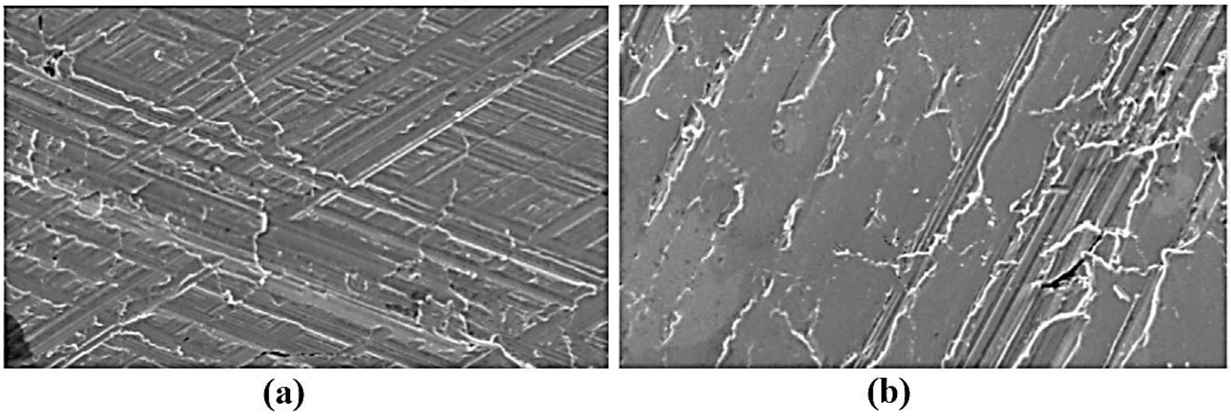

Fig.9. SEM images analysis of grinding processed surface: (a) Ra 0.25 μm and (b) Ra 0.15 μm

Note. SEM: Scanning electron microscope.

Conclusion

In general, increasing the fuel efficiency of the agricultural tractor engine requires a better understanding of the generated surfaces during the honing of cylinder liners. Therefore, the present study evaluated the impact of plateau honing marks on the cylinder liner of the Perkins 4-248 engine (related to the Massey Ferguson 285 tractor). To this end, five types of honing marks (with the surface roughness of 0.05, 0.15, 0.25, 0.5, and 0.8 μm in R_a) and two randomly ground surfaces including 0.15 and 0.25 μm in R_a for the surface roughness were used for testing friction and wear. The tests were performed under the load level of 100 N and reciprocating velocity of 120 rpm with a 10W40 semi-synthetic oil. The main findings of the present study are as follows.

1. Based on the results of deep-grooved honing marks, higher amounts of wear volumes were created after severe interactions due to asperity contacts and the formation of relatively thin films in comparison to the test related to shallow-grooved honing marks.

2. The least volume of wear occurred for the surface with the honing mark ranged 0.15 and 0.25 μm in R_a.

3. Similar amounts of wear were observed for the tests without honing with a similar R_a of 0.25 μm in comparison to the wear test with the honed surface.

4. Lubricant films were not enough for decreasing the surface interaction resulting from deep grooves regarding surfaces with the honing mark, which resulted in disrupting fluid film formation.

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مقاله پژوهشی

جلد ۱۲، شماره ۱، بهار ۱۴۰۱، ص ۶۶-۵۵

بررسی تاثیر هونینگ پلاتو بر روی اصطکاک و سایش بوش سیلندر در تراکتورهای کشاورزی

رسول خدابخشیان کارگر[1*]، ستایش سجادی[2]

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تاریخ پذیرش: ۱۳۹۹/۰۹/۰۴

چکیده

به‌منظور افزایش بازده سوخت موتورهای تراکتورهای کشاورزی، کنترل بهینه سطوح برهم‌کنش برای بهبود عملکرد موتور به‌ویژه در توسعه سطح بوش سیلندر بسیار چشمگیر می‌شود. از این رو، فن‌آوری هونینگ پلاتو بر روی بوش سیلندر موتورهای خودرو و تراکتور طراحی شد. یک سطح صاف یا پلاتو در واقع به‌جا گذاشتن سطوح لغزشی همراه با مناطق تنش پسماند بالا می‌باشد، اگرچه یک مدل هاشور متقاطع از شیارهای سطح برای نگهداری روغن نگهداری وجود دارد. در مقابل، شیارهای سطح ایجاد شده از طریق عملیات هونینگ به‌عنوان مخزن روغن می‌تواند بر ایجاد فشار دینامیکی سیال بر روی سطوح، تأثیر منفی بگذارد. بر این اساس، درک بهتری از سطوح تولید شده در طی فرآیند هونینگ پلاتو برای بهینه‌سازی فرآیند ضروری است. بدین منظور، برخی آزمایش‌های روی یک بوش سیلندر موتور پرکینز ۴/۲۴۸ (مربوط به تراکتور مسی فرگوسن ۲۸۵) تولیدی شرکت کیهان صنعت قائم انجام شد. سپس، آزمون‌های اصطکاک و سایش با حرکات رفت و برگشتی برای مقایسه روانکاری سطوح بوش سیلندر با تیمارهای مختلف هونینگ پلاتو انجام شد. درنهایت، مقایسه‌ای بین اصطکاک و ساییدگی سطوح از جمله عمق‌های مختلف پروفیل‌ها، که به‌عنوان تیمارهای مختلف هونینگ موتور دیزل دریایی استفاده شده و آن‌هایی که دارای سطوح تصادفی بوده انجام گردید. بر اساس نتایج، مقادیر بالای سایش با ایجاد فعل و انفعالات بیشتر از تماس‌های زبری و فیلم‌های نسبتاً نازک، در مقایسه با آزمون با تیمارهای هونینگ شیار کم عمق تولید شد.

واژه‌های کلیدی: اصطکاک، بوش سیلندر، سایش، موتور تراکتور، هونینگ پلاتو

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