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REDUCING WEAR OF PISTON RINGS USING ZERO FLOW NITRIDING

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Abstract

This article presents new method of controlled gas nitriding called ZeroFlow, which is used for nitriding of internal combustion engine parts. Increasing efficiency of internal combustion engines means that engines are working under high thermal and mechanical loads, which is the unfavourable phenomenon – especially for elements of engine power train such as crankshaft or piston rings. Due to the high temperature and pressure in cylinder during combustion, piston rings are working under limit loads, which mean that lengthened fatigue life and wear resistant are of critical importance. Heat treatment is the most common way used for improving tribological properties of piston rings; one of the methods of heat treatment using in automotive industry, which meets with growing interest, is nitriding, especially controlled gas nitriding. The main aim of nitriding is to obtain layer with higher surface hardness, improved fatigue life and corrosion resistance, increased wear resistant and antigallic properties. According to that, this layer increase durability of nitrided parts, and as a result – durability of machines and vehicles. Steel nitriding using the ZeroFlow method allows precise forming of nitrided layers with respect to the phase structure, zone thicknesses and hardness distribution, which means that the ZeroFlow nitriding enable maintenance of full control over the kinetics of the nitrided layer growth. Kinetics of nitrided layer growth allows developing the especially dedicated process with specific parameters, which ensure obtaining on piston rings nitrided layer with strictly defined, required properties.

Keywords: *piston rings, controlled gas nitriding, nitrided layer, diffusion zone, hardness distribution*

1. Introduction

Nowadays, the development of internal combustion engines is aimed at the realization of the key requirements such as reduction in fuel consumption by reducing friction losses and the weight of the motor, reduction of noise and exhaust emission and increasing of operating parameters. Increase of the efficiency of internal combustion engines means that engines work under high thermal and mechanical loads. This is an adverse phenomenon, especially for the elements from engine power train/piston-cylinder pair, like piston rings [8].

We can recognize two types of piston rings used in internal combustion engines:

– compression rings,
– scraping rings.

Both types of piston rings are placed in their grooves within the piston, which is connected with labyrinth seal. Gas produced during combustion floats through the piston rings (the links of labyrinth), reduces its pressure, and thereby – reduces its speed and amount of blow-by into the crankcase. However, blow-by is impossible to avoid, even with efficiently working piston rings.

The losses of the working medium caused by leakage have negative influence over indicators of engine's work; in particular, they lead to a loss of power, higher fuel consumption, overheating of piston and piston rings, increased wear of the cylinder and piston rings, coking, and consequently – piston rings can be stopped. In addition, exhaust fumes getting into the crankcase contaminate the engine oil and impair its lubricating properties. Moreover, at the same time increases oil consumption, caused by overpressure in the crankcase [9].

On account of high temperatures and pressures in the cylinder during combustion, piston rings work under the conditions of limit load; therefore, the main assumption in their construction and structure is to ensure high strength and abrasive wear resistance [1]. Heat treatment is one of the most common method for improving tribological properties. High surface hardness, improved fatigue life and corrosion resistance, increased wear resistant and antigallic properties can be obtained using ZeroFlow – a new method of controlled gas nitriding.

Technology of nitriding using ZeroFlow method has been developed, among others, for crankshafts assembled in sports car engines. The main purpose of nitriding of crankshafts is to obtain high surface hardness of journals and it concerns to carbon steels of higher quality or alloy steels [2]. ZeroFlow nitriding is also used for parts of machines and vehicles such as: toothed wheels for wind power plants, plates for casting glass bulbs for lamps, inlet sleeves with the pushing piston used in molds for aluminum pressure die casting, camshafts, piston rings, poppet valve springs and discs, piston pins or nozzles for unit injectors. Many examples of industrial applications of nitriding processes using ZeroFlow method can be found in the literature [2-5, 7].

With appropriately selected parameters, all technologies allow to obtain similar depth of nitrogen penetration and similar wear characteristic. In ZeroFlow nitriding selection of parameters is much simpler than in other currently used methods; therefor, models of the kinetics of nitrided layer growth are used, which enable to carry out the simulations of the process and to predict its results – the growth of the nitrided layer thickness and particular phases that will occur in it, effective case depth and hardness distribution – both graphical and computational as a function of process parameters: time, temperature and nitriding potential of the atmosphere. In practice it means that by using models of the kinetics of nitrided layer growth, it is possible to form the nitrided layer precisely and as a result – to obtain nitrided layer with strictly defined, required properties. Moreover, models of the kinetics of nitrided layer growth also enable to optimize the process parameters, so the required nitrided layer is formed in the shortest possible time and with the lowest energy and gases consumption [2, 3].

Due to this advantages and its economical and environmentally friendly character, ZeroFlow method is especially suitable for piston rings nitriding and currently it is applied worldwide.

2. Characteristics of ZeroFlow method

ZeroFlow is a new method of controlled gas nitriding, developed at the Poznan University of Technology, which enables precise forming of nitrided layers using nitriding kinetics. It is characterized by much lower consumption of gases, as well as simplification of the nitriding furnace and of the process itself, while full control over the kinetics of the growth of nitrided layer is still maintained. The same as in the traditional process, ZeroFlow method assumes the use of atmosphere consisting only raw ammonia. However, unlike to the traditional method, kinetics can be controlled by adjusting the chemical composition of the atmosphere in the furnace retort (by adjusting the nitriding potential) through the regulation of ammonia flow rate, or more precisely – through the regulation of ammonia inflow rate by stopping and reactivating ammonia feeding into the furnace retort. It is significant that in ZeroFlow method ammonia inflow rate is temporarily reduced to zero, which makes much easier to control the chemical composition of the atmosphere. To sum up, using a unary atmosphere makes the ZeroFlow method simpler than currently popular methods based on binary atmospheres, but simultaneously it allows controlling the kinetics of nitrided layer growth by regulating of ammonia inflow rate [3, 6, 7].

Gathered experience shows that ZeroFlow method enables forming of nitrided layers with respect to the required phase structure, zone thicknesses, and hardness distribution [3-5, 7]. Using phenomenological models layers are produced in the shortest possible time, which is connected with the lowest energy consumption. Mathematical models of the kinetics of nitrided layer growth additionally allow determining nitrided layer phase structure and thickness of each zone that occurs in it as a function of process parameters: time, temperature and nitriding potential of the atmosphere. Layer obtained this way does not need costly and time-consuming grinding of iron nitrides, which leads to lower consumption of energy and materials. Several times, lower consumption of gases in comparison with its consumption in another currently used nitriding processes, and as a result – much lower emission of post-process gases, also indicates on economical and environmentally friendly character of ZeroFlow method [2].

Until now, ZeroFlow nitriding method has been introduced in 26 industrial plants in Poland and many other countries worldwide, such as Italy, Great Britain, Canada, Sweden, Singapore, South Korea, Germany, Czech Republic, Belarus, Russia, India, Pakistan, Switzerland. 36-industrial installations have been constructed and implemented so far, another 4 are launched. Several thousands of nitriding processes for various parts of machines and vehicles have been conducted with positive results, which is the best verification of this method rightness.

3. Nitriding of piston rings

Due to the wear of bearing surface, nitrided layer is made as thick as it is possible; thus, tooling after nitriding cannot lead to significant dimensional changes. All piston rings, which can be tooled before nitriding, should have polished bearing surfaces to avoid separation of roughness peaks and scratching during piston ring – cylinder pair is lapping. Because the fatigue life of piston rings decreases if the nitrided layer depth is increasing, there is a limit of maximum thickness of nitrided layer. However, the compromise between case depth and piston ring strength is still possible, even with relatively large reserve of layer thickness intended for wear.

The minimum thickness of nitrided layer for compression rings in spark-ignition engines is of approximately 0.05 mm, whereas in compression-ignition engines is a tendency to enlarge this thickness (to provide longer durability) by 30-50%. For piston rings with the axial width, over 3 mm there is no problem with layers of 0.08mm thickness. In compression-ignition engines, thicknesses of above 0.20 mm sometimes result in piston rings cracking [9]. Research on the piston rings with use of devices for the evaluation of material fatigue is continued; they are aimed to determine the extent in which dynamic strength is reduced as a function of nitrided layer depth. The results of this research will provide information necessary for practical application.

4. Example of piston rings nitriding using ZeroFlow method

Nitriding processes of piston rings using ZeroFlow method were conducted on behalf of one of the companies producing piston rings. Nitrided details were made of steel consisting 0.5-0.75% C, 11-15% Cr, max 1% Si, max 1% Mn, max 0.6% Mo, max 0.1% V, max 0.03% P and max 0.03% S. Major requirements connected with nitrided layer included:

- a 0,01mm (for the side surface of piston ring) to 0.03mm (for the working surface of piston ring) thick nitrided layer,
- nitrided layer hardness minimum 1000 HV0.2.

Hardness test conducted before nitriding process shows that minimum hardness of discussed piston rings is 380 HV0.1, and maximum – 430 HV0.1.

To determine the optimal parameters of the nitriding process, which allow obtaining required nitrided layers, the number of nitriding processes had been carried out at the Poznan University of Technology, using VTR horizontal retort furnace (VTR-5022/24). Parameters of conducted nitriding processes are shown in Tab. 1. They vary only in duration of second stage; it is worth noting that depth of nitrided layer is dependent on total time of nitriding process. Duration of first stage is equal for all piston rings and it lasts 1 hour. Temperatures of first and second stage are the same (490°C). Nitriding potential of the atmosphere in first stage is several times higher than in second stage ($N_p^I >> N_p^{II}$). In practice, all piston rings were nitrided simultaneously and then they were pulled out from furnace at various intervals. This procedure allows to research into the kinetics of nitrided layer growth on the nitrided piston rings.

Tab. 1. Parameters of nitriding processes for piston rings

piston ring no.	parameters of nitriding using ZeroFlow method					
	I stage			II stage		
	temperature [°C]	time [h]	nitriding potential	temperature [°C]	time [h]	nitriding potential
1-2	490	1	N_p^I	490	2	N_p^{II}
1-8	490	1	N_p^I	490	8	N_p^{II}
1-24	490	1	N_p^I	490	24	N_p^{II}
1-32	490	1	N_p^I	490	32	N_p^{II}

After nitriding, all piston rings have been examined. As the criterion was taken hardness distribution on the cross section of piston ring and the criterion of diffusion zone, HVC+50 (layer effective thickness with core hardness of +50HV). Polished sections were etched twice due to the differences between shades of the nitrided layer depending on the time of etching. Complete analysis of the nitrided layer depth was made after determining hardness distribution on the cross-section of piston rings. Results of metallographic tests are shown on Fig. 1-4.

For piston ring no. 1-2 (Fig. 1), with total time of nitriding 3 hours, diffusion zone depth is of approximately 100 µm. Maximum value of nitrided layer hardness is 1390 HV0.1.

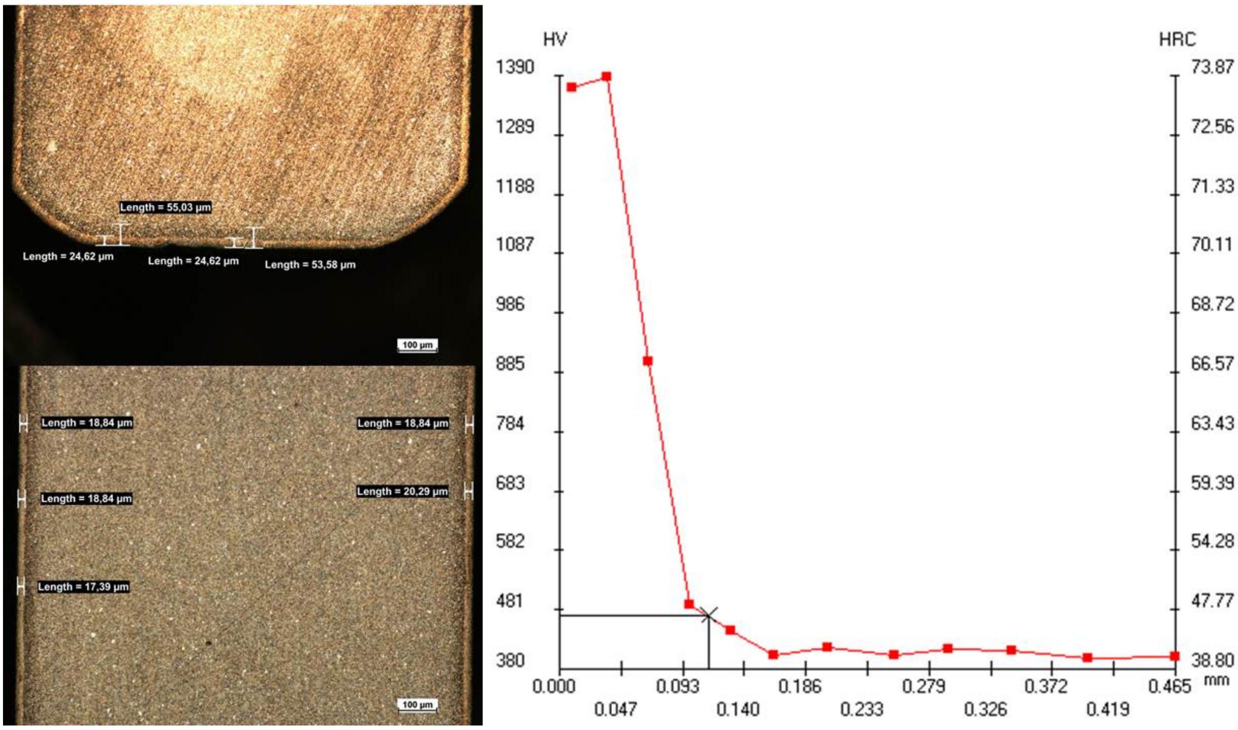

Fig. 1. Microstructure of nitrided piston ring 1-2, x100 (on the left side) and hardness distribution HV0.1 from surface to core (on the right side)

For piston ring no. 1-8 (Fig. 2), with total time of nitriding 9 hours, diffusion zone depth is of approximately 200 µm. Maximum value of nitrided layer hardness is 1500 HV0.1.

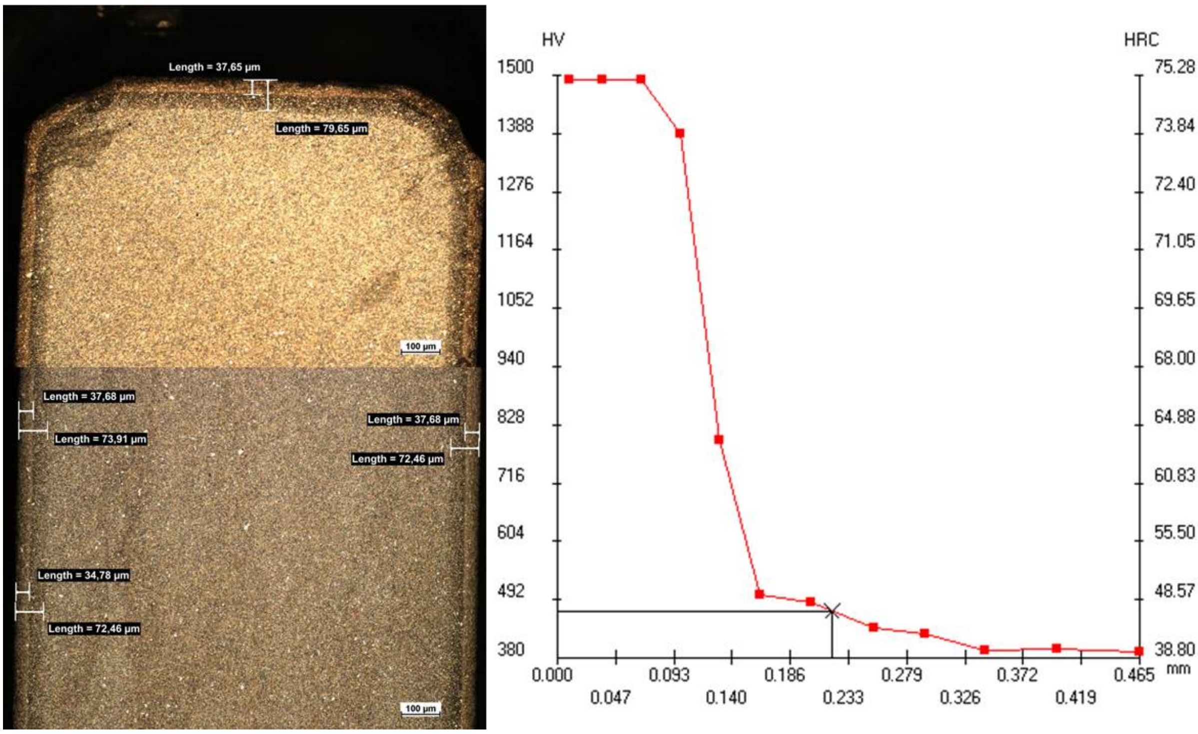

Fig. 2. Microstructure of nitrided piston ring 1-8, x100 (on the left side) and hardness distribution HV0.1 from surface to core (on the right side)

For piston ring no. 1-24 (Fig. 3), with total time of nitriding 25 hours, diffusion zone depth is of approximately 300 µm. Maximum value of nitrided layer hardness is 1390 HV0.1.

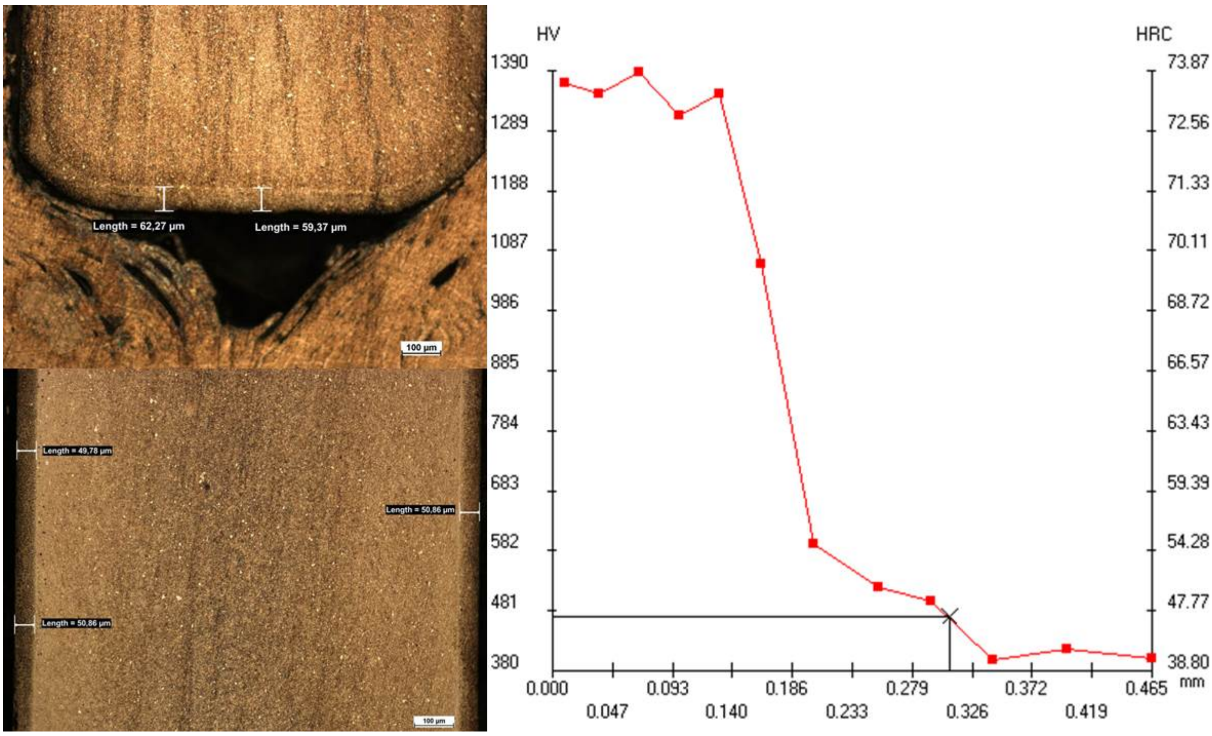

Fig. 3. Microstructure of nitrided piston ring 1-24, x100 (on the left side) and hardness distribution HV0.1 from surface to core (on the right side)

For piston ring no. 1-32 (Fig. 4), with total time of nitriding 33 hours, diffusion zone depth is of approximately 300 µm. Maximum value of nitrided layer hardness is 1370 HV0.1.

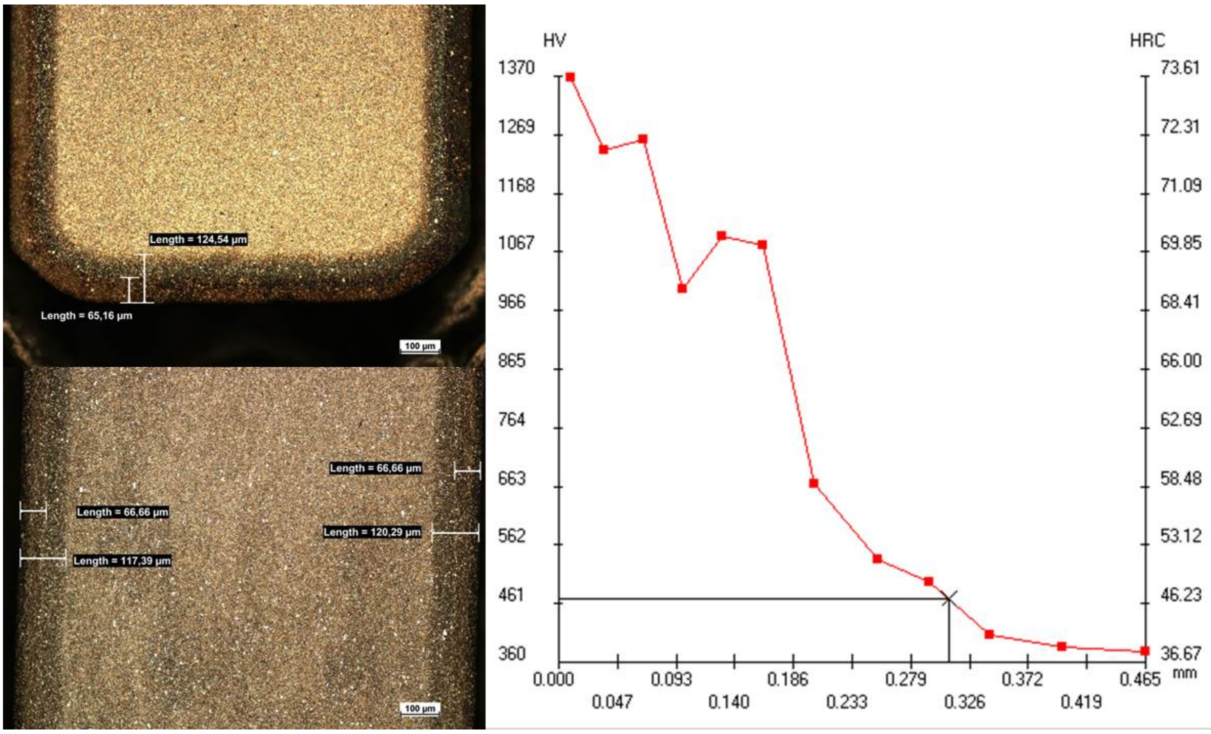

Fig. 4. Microstructure of nitrided piston ring 1-32, x100 (on the left side) and hardness distribution HV0.1 from surface to core (on the right side)

5. Summary

The results from conducted processes of nitriding allow concluding that:

- hardness of nitrided layer on each of the nitrided piston rings has met the requirements (minimum 1000 HV0.2),
- despite the use of bigger load, obtained hardness of nitrided layer at the surface is included in the range from 1300 HV0.1 to 1500 HV0.1,
- due to the dispersed alignment of the batch in furnace, there are no differences between diffusion zone depth on side surface and working surface of the piston ring,
- diffusion zone depth of 0.3mm was obtained for piston rings with a total time of nitriding 33 hours (1-32) and 25 hours (1-24),
- diffusion zone depth of 0.1 mm was obtained for piston rings after all processes of nitriding.

The experimental and industrial experience gained so far confirmed the effectiveness and precision of ZeroFlow method. According to that, ZeroFlow method can be successfully applied in nitriding of internal combustion engine parts (like piston rings for example); it allows forming nitrided layers which fulfil the requirements imposed on them, and as a consequence – it allows to achieve the appropriate durability of each part.

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