

# DRY SLIDING WEAR STUDY OF AISI HNY3 EXHAUST VALVE MATERIAL<sup>+</sup>

دراسة البلى الانزلاقي الجاف لمعدن صمامات العادم AISI HNY3

Jamal N. Sultan\*  
Adil M. Ali\*\*\*

George M. Hannoush\*\*  
Hussain A. Al- Kareem\*\*\*\*

## Abstract:

The effects of bearing pressure, sliding time, and sliding speed on dry sliding wear properties of AISI HNY3 internal combustion engine exhaust valve material were investigated. Experimental tests were performed by using a pin-on-disc apparatus. For all tests, pin was rubbed against silicon carbide emery paper of ASTM grit 180, which was mounted on rotary disc with varying speed 7.5 - 235.5 m/min, under varying bearing pressure 48.75 - 292.75 KN/m<sup>2</sup>.

Experimental results, revealed that wear rates increased with increasing bearing pressure, in three linear regions separated by transition points. In the first region, wear rate were low , and increased slightly up to the first transition point, and the wear process was mainly controlled by formation of fine dark oxide debris particles, with smooth and flat wear tracks. This region falls in mild wear process. Beyond this point in the second region , wear rates were increased and debris particles became both metallic and oxidative, with rough wear track surfaces, and this region represents the transition zone from mild to severe wear. In the third region, wear rates were largely increased, and large metallic wear debris had been delaminated from the sliding surfaces, with rough and deep wear tracks in which severe wear had been formed. It was also concluded, that wear rates decreased with increasing sliding speeds.

## المستخلص:

تم اختبار تأثير كل من زمن الانزلاق (Sliding Time)، سرعة الانزلاق (Sliding Speed)، و ضغط التحميل ( Bearing Pressure ) على خواص البلى الانزلاقي الجاف لمعدن صمامات محركات الاحتراق الداخلي نوع AISI HNY3. اجريت التجارب العملية باستخدام جهاز المسمار على القرص ( Pin-On-Disc ) وذلك بانزلاق عينات الاختبار على ورق تجليخ من كاربيد السيليكون ( ASTM grit 180 ) مثبت على قرص دوار متغير السرعة من ٧,٥-٢٣٥,٥ م/دقيقة تحت ضغط تحميل من ٤٨,٧٥-٢٩٢,٥ كيلونيوتن/م<sup>٢</sup>. اظهرت نتائج

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\* Ass. Prof. / Technical College/ Mosul

\*\* Ass. Lecturer/ Technical Institute/ Mosul

\*\*\* Chief Eng. /Technical Institute/ Mosul

\*\*\*\* Eng / Technical Institute/ Mosul

الاختبارات ان معدلات البلى (Wear Rates) تزداد خطيا مع ضغط التحميل عبر ثلاثة مناطق تفصلها نقاط تحول (Transition Points). في المنطقة الاولى ، معدلات البلى (wear rates) كانت واطنة ثم ازدادت تدريجيا لغاية نقطة التحول الاولى، حيث تكون حطام البلى (wear debris) من جزيئات اوكسيدية كانت هي المسيطرة على عملية البلى في هذه المنطقة ، كما ان اثار البلى (wear track) على اسطح العينات في منطقة الانزلاق كانت ناعمة ومسطحة. ثم ازداد معدل البلى في المنطقة الثانية واصبح ناتج حطام البلى جزيئات معدنية واوكسيدية، وآثار البلى على سطح العينة كان خشنا . هذه المنطقة تمثل تحول البلى المعتدل الى البلى العالي. معدلات البلى ازدادت خطيا في المنطقة الثالثة مع ظهور جزيئات معدنية ذات حجم كبير من حطام البلى والمنفصلة من اسطح الانزلاق ، كما ان آثار البلى على اسطح الانزلاق كانت خشنة وعميقة ومعدلات البلى كانت ذات قيم عالية. كما استنتج ايضا ان معدلات البلى انخفضت مع زيادة سرعة الانزلاق ولجميع حالات الاختبار.

## **Introduction:**

Engine valves control the flow of gases in and out of engine cylinders. When intake valve opens, air and fuel flow into cylinder. After the intake valve closes, combustion occurs and the exhaust valve opens and the burned gases flow out of the cylinder. During valve closing, a combination act of impact and sliding can lead to valve seat wear, causing the valve to sink or recede into the seat insert [1]. This wear leads to loss of compression, reduces engine efficiency, and affects engine performance. Therefore, the common goal for engine manufacturers is to improve quality, efficiency, and the life of those valves, as well as reducing emission by increasing material wear resistance of the engine exhaust valves [2, 3,4 ]. Due to higher performance demands, as well as increasing usage of alternative fuels, engine valves are challenged with greater wear problems than in the past [5, 6 ]. Valve recession occurs when wear of valve or seat inserts, has caused the valve to sink or recede into the seat insert. Excessive recession leads to incorrect valve seating, causing cylinder pressure loss. Leaking hot combustion gases can also cause valve guttering or torching, which accelerates valve failure. It was showed that valve recession was strongly dependent on valve closing velocity, combustion load, and valve/ seat insert misalignment [5].

Wear of X45Cr9Si3 and X53Cr22Mn9Ni4N valve steels showed that for 30N load and 5Hz frequency, had been improved by 15.2% and 10.3% respectively due to shallow treatment compared to that of the conventional heat treatment [7]. It was also found that wear resistance of En52 and 21-4N valve steel had been improved by 81.15% and 13.49% respectively, due to shallow cryogenic treatment [8]. Valve head prepared by Ni76Cr19AlTi alloy coated by Cobalt base alloy was studied for promoting its wear resistance, and found that the grains are coarsened in the side of Ni76Cr19AlTi alloy in the welds, with a dendritic structure in Cobalt base alloy [9]. Seating faces wear of exhaust valve and its seat , was studied for  $2 \times 10^6$  to  $8 \times 10^6$ , 10 – 15 Hz test speeds, 350°C temperature, and 1960N load. It was shown that the tribo-chemical reaction products covered the base metals of the valve and seat insert, preventing wear of base metals [10]. Engine valve and seat insert wear, depending on speed changes was investigated by a simulator to generate and control high temperature up to 900°C, and various frequencies up to 80Hz during motion. The results showed that a great degree of wear was caused by a higher frequency than lower frequency under identical test conditions: temperature, valve displacement, number of cycles, and test loads [11]. The temperature effects up to 400°C, on impact/sliding of valve/seat contacts had been studied, and the seat surface was subjected to repetitive impact action of the valve, with small amplitude sliding in the surface. The material behavior under the impact sliding up to 400°C temperature helped giving better understanding of failure mechanisms and established

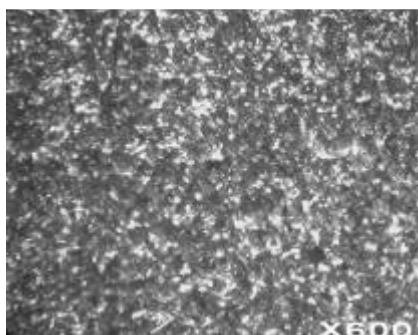
guidelines for future improvements, namely concerning surface treatment [12]. Diesel engine inlet valve/seat insert wear was studied to establish the effect of engine operating parameters on its inlet valve recession, and to screen potential new seat materials. The result showed an increase in the valve recession with: combustion loading, valve closing velocity, and valve misalignment [13]. Also, engine valve /seat insert wear had been studied to evaluate the compatibility and wear of valve and seat insert. Intake valves made from SiL1 material were treated with nitride salt bath and were tested against six different insert materials, and wear resistance of these combinations were ranked and compared to SiL1 valve material without nitriding. It was concluded that nitriding improved valve seat wear resistance [14]. Wear mechanism of engine exhaust valve seat have been studied. Four exhaust valve materials: 23 – 8N, 21- 4N Mod, Pyromet 31, and Stellite 6 (hard-facing), were tested with insert material made of SiLXB at 538°C temperature. Running tests for three millions cycles showed that Pyromet 31 had the lowest wear rate while 21 - 4N had the highest wear rate [15]. The aim of the present work, was measuring and evaluating sliding wear parameters of AISI HNY3 exhaust valve engine material. A specially designed pin – on disc apparatus was constructed to carry out wear parameter experiments, and wear rates data for material characteristics were then collected and analyzed.

### **Experimental Work:**

The experimental work was carried out to investigate the influence of wear testing parameters on abrasive wear test samples. For all experiments, the samples used in the present study, were prepared from AISI HNY3 which is equivalent to DINX45CrSi9 3 exhaust valve automobile engine material. Its chemical composition and mechanical properties are given in Table 1. Fig.1, shows the microstructure of the material. All test samples were machined 25mm long and 9mm in diameter. Abrasive wear tests were carried out using pin-on-disc test apparatus shown in Fig.2, which was designed then fabricated according to ASTM specification (G99-05).

**Table 1: Properties of Exhaust Valve Material**

Chemical Composition	0.46% C, 9.0% Cr, 3.0% Si & Fe balance
Hardness	297HV
Material Designation	AISI HNY3
Micro-Structure	Mixed Carbides in Ferrite Matrix



**Fig1: Microstructure of Exhaust valve Material , mixed carbides ( dark) in ferritic matrix ( light area), X600**



**Fig.2: Pin – On - Disc Apparatus**

Tested samples were slide against Silicon Carbide (SiC) emery paper of ASTM grit 180. Emery paper was fixed on rotary steel disc, performing single test per new abrasive paper. For each test, test sample was fixed on loading arm of the apparatus, then loaded against the abrasive medium with precise known weight. Dry wear experiment, was run for each test at room temperature at sliding speeds: (7.5 - 235.5) m/min, under bearing pressure of (48.75 - 292.5) KN/m<sup>2</sup> for sliding time ( 2 – 10) min to cover all parameter ranges of sliding speed, bearing pressure, and sliding time that the exhaust valve operate in the engine [12 ]. For all experiments, each sample was weighed before and after the test using Metler balance with 0.1mg sensitivity. Mass loss was then recorded at the end of each test, then converted to wear rate using the equation [16, 17]:

$$\text{Wear Rate} = \Delta W / 2\pi r N t \quad \text{gm / cm}$$

Where:

$\Delta w$ , mass loss of the sample, gm.

r, track radius, mm.

N , sliding speed, rpm.

t, sliding time, min.

Wear rate values were then plotted against sliding time, bearing pressure, and sliding speeds.

### Results and Discussion:

Fig.3 shows the variation of weight loss against sliding time, under 292.5KN/m<sup>2</sup> bearing pressure. The figure indicates that weight loss increases with sliding time and decreases with sliding speed. Increase in weight loss with sliding time is due to sub-surface cracks that initiated by fatigue process because of stick – slip action (i.e. loading and unloading) between the mating asperities of both pin and counter-face material. Upon repeated sliding, fatigue wear was noticed, causing fine cracks to form on or below the surface regions, and a surface damage occurs. Fine cracks were associated and propagated with sliding time , as a result of sub-surface fracture formation, which grown up towards pin surface and detached as wear debris.

According to the model presented by investigators [18] on steel and other metals, cracks that are vertical to the direction of sliding , will meet together with line of weariness, and showed that rate of adhesion wear was directly proportional with time, sliding speed, and load. So, the present work results do agree with previous results obtained [19].

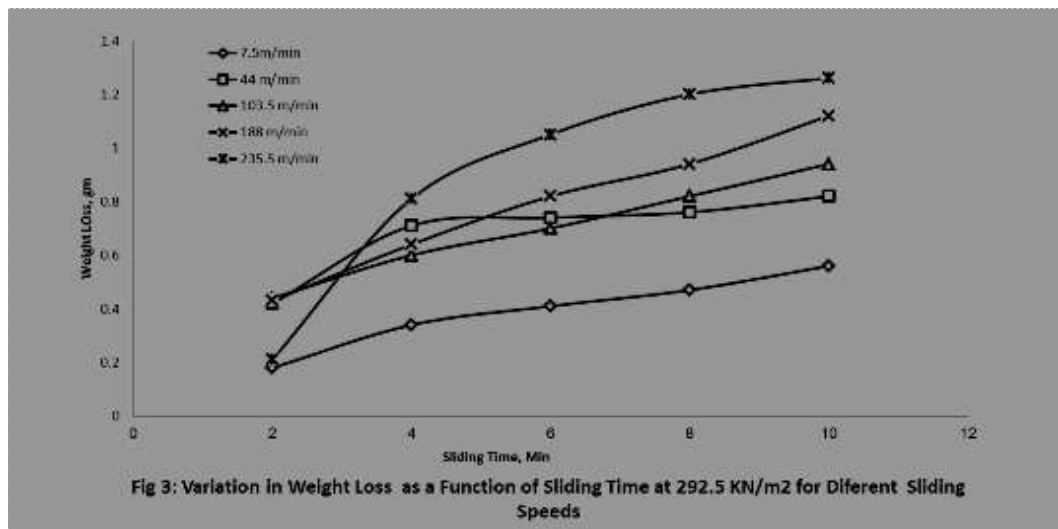
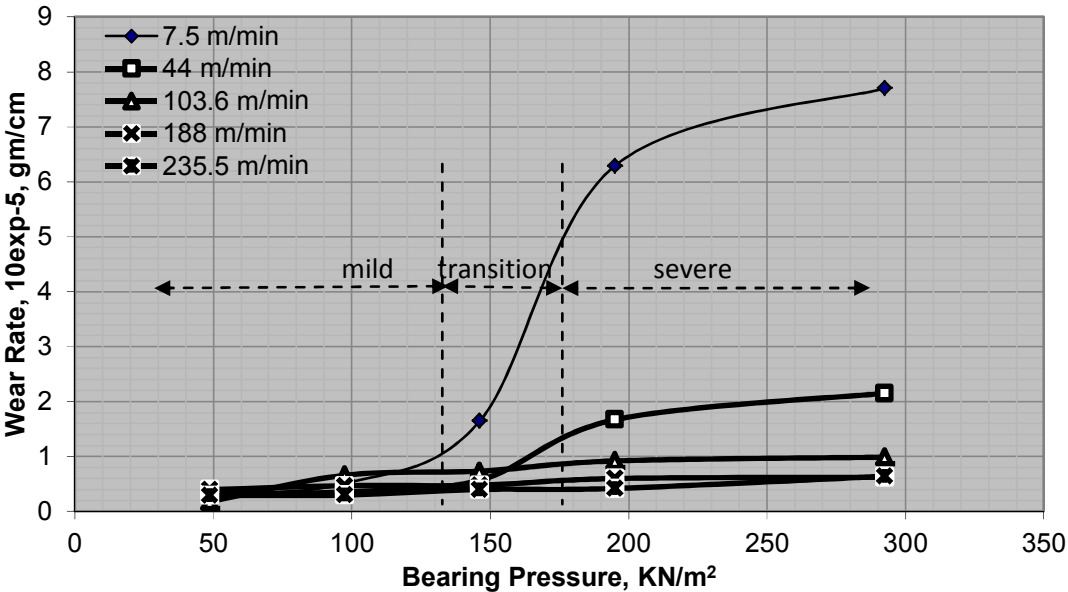
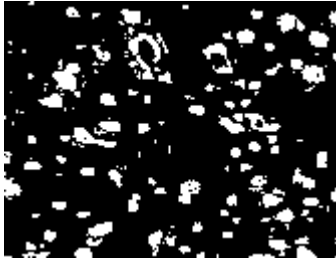


Fig 4 shows the variation between bearing pressure as a function of wear rate for different sliding speeds. The curves in the figure reveal that the wear rate has been increased slightly with an increase in bearing pressure at high sliding speeds, especially at 103.6, 188, and 235.5 m/min speeds. The curve also indicates higher wear rates with an increase in bearing pressure for specimens slid at low speeds: 7.5 and 44 m/min, with tow transition points, i.e. the curves show three stages of wear. Initially, wear rates were low in magnitude but increased slightly until the first transition point. This increase in wear rates can be attributed to an increase in local plastic deformation at asperity tips of specimen surface [20], which led to an increase in dislocation density. These dislocations agglomerate and develop fine micro-cracks [21]. This region falls in mild wear process. Wear rates at this region were mainly controlled by oxide layer formation, where fine dark debris particles were generated as shown in fig.5, with nearly flat regions of worn pin surfaces that are shown in fig.6.

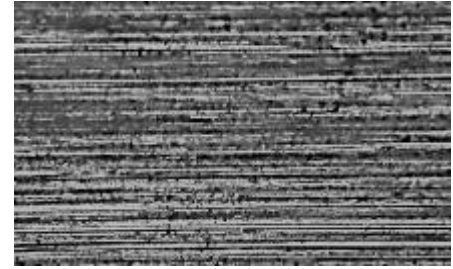


**Fig 4: Variation of Wear Rate as a Function of Bearing Pressure for 10 Minutes Sliding Time and Different Sliding Speeds**

As bearing pressure was increased beyond first transition point, micro-cracks were associated, developing fine cracks, which result in a large increase in wear rates, especially at 7.5 m/min sliding speed, and debris particles generated were both metallic and oxidative as shown in fig. 7, while worn track pin surfaces are rough as shown in fig.8. This region represents a transition from mild to severe wear. As the bearing pressure was increased beyond the second transition point, fine cracks were propagated, and subsurface fracture occurred. As a result, delamination of large metallic debris were generated as shown in fig. 9, and deep rough wear tracks were formed at pin sliding surfaces as shown in fig. 10, which led to large increase in wear rates. This region of wear is accompanied with seizure event due to severe wear, where material was transformed from pin surface to the adjacent surface [22], and this region falls in severe wear process.



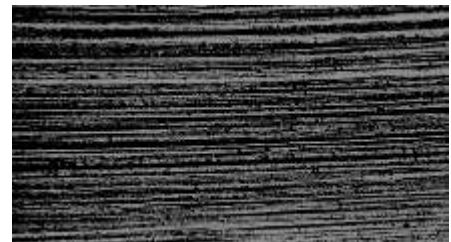
**Fig 5: Wear Debris as Fine Oxidative Particles, at 7.5 m/min 97.5KN/m<sup>2</sup>& 2 minutes X20**



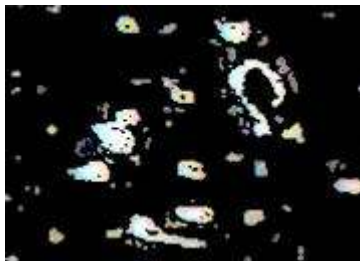
**Fig 6: Mild Wear Pattern, Smooth & Flat Wear Track at 7.5 m/min,97.5 KN/m<sup>2</sup> & 2 minutes X150**



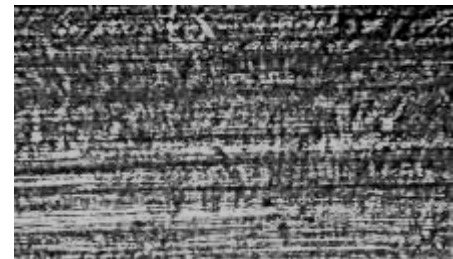
**Fig 7:Wear Debris as Metallic and Oxidative Particles at 7.5 m/min, 195 KN/m<sup>2</sup> & 6 minutes X20**



**Fig 8: Transition Wear Pattern, Rough Wear Track, at 7.5 m/min 195KN/m<sup>2</sup> & 6 minutes X150**



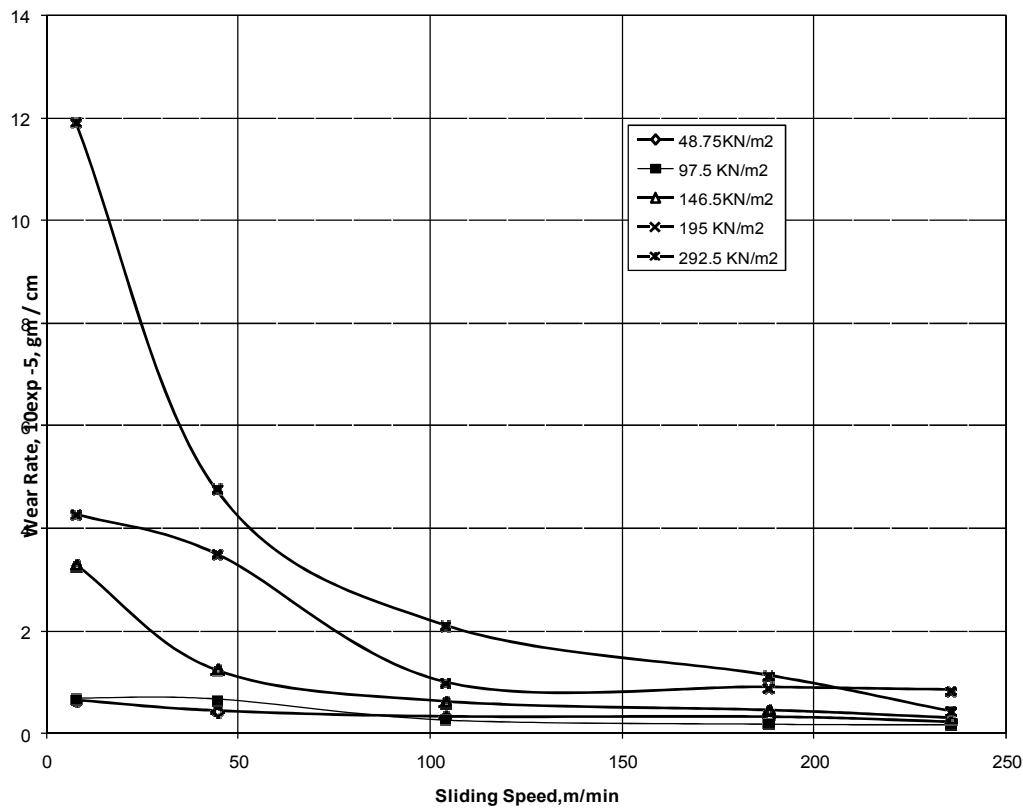
**Fig 9: Wear Debris as Large Metallic Particles at 7.5 m/min, 292.5 KN/m<sup>2</sup> & 10 minutes X20**



**Fig 10: Severe Wear Pattern, Rough and Deep Wear Track, at 7.5 m/min, 292.5 KN/m<sup>2</sup> & 10 minutes X150**

Fig.11 , represents variation of wear rates against sliding speeds for different bearing pressures. It can be concluded from the figure that wear rates decrease sharply with sliding speeds, especially at higher bearing pressure values, i.e. up to 44 m/min and then remain nearly constant. Decrease in wear rate values with increasing sliding speeds, can be explained by formation of iron oxide layer that was generated at high sliding speeds, due to frictional heating of contacting asperity tips of pin surface with counter-face material which acted as a lubricant layer. Stott F.H and Wood G.C [23], concluded that wear surfaces exhibit an oxide film layer by oxidation – ploughing – compacting process. As the load was increased additional oxide layer was formed due to higher frictional heating, which led to an increase in sliding surface temperature [24]. Glasscott et al [25], observed oxide debris formation during wear process which was build up progressively at wear track, as contact pressure increased.

During sliding, more oxides were produced, which led to reduction of metal to metal contact, thus lowering wear rate [26].



**Fig11: Variation of Wear Rate as a Function of Sliding Speeds for 10 Minutes Sliding Time Different Bearing Pressure**

### Conclusions:

Dry sliding wear process conducted on AISI HNY3 exhaust valve automobile engine material samples slid against silicon carbide emery paper ASTM grit 180, using pin-on-disc wear apparatus, under bearing pressures ranging from 48.75 to 292.5KN/m<sup>2</sup>, and sliding speeds ranging from 7.5 to 235.5 m/min, led to the following conclusions:

- 1- For all cases, weight loss values were increased with increased both sliding time and sliding speeds.
- 2- For all cases wear rate values were increased with bearing pressure and decreased with sliding speeds. Wear rate relationship exhibit three regions separated by transition points, especially at 7.5 and 44 m/min sliding speeds.
- 3- At first region, wear rates were low in magnitude, then increased with nearly constant manner, and fine dark oxide debris particles were generated, with smooth and flat wear tracks. Wear process in this region is mild wear.
- 4- At second region, wear rate values were increased with bearing pressure, and wear debris were both metallic and oxide particles, while worn surface tracks, were nearly rough. Wear rate in this region represents a transition from mild to severe wear.

5- At third region, wear rates were largely increased and severe wear rates were found. Wear debris were large in size and composed of metallic particles. Wear tracks were rough and deep.

6- For all cases, wear rate values were decreased with increasing sliding speeds and increased with increasing bearing pressure.

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