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Study on Friction and Wear Characteristics of Aluminum Alloy Hydraulic Valve Body and Its Antiwear Mechanism

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Abstract

In order for the working status of the aluminum alloyed hydraulic valve body to be controlled in actual conditions, a new friction and wear design device was designed for the cast iron and aluminum alloyed valve bodies comparison under the same conditions. The results displayed that: (1) The oil leakage of the aluminum alloyed hydraulic valve body was higher than the corresponding oil leakage of the iron body during the initial running stage. Besides during a later running stage, the oil leakage of the aluminum alloyed body was lower than corresponding oil leakage of the iron body; (2) The actual oil leakage of different materials consisted of two parts: the foundation leakage that was the leakage of the valve without wear and wear leakage that was caused by the worn valve body; (3) The aluminum alloyed valve could rely on the dust filling furrow and melting mechanism that led the body surface to retain dynamic balance, resulting in the valve leakage preservation at a low level. The aluminum alloy modified valve body can meet the requirements of hydraulic leakage under pressure, possibly constituting this alloy suitable for hydraulic valve body manufacturing.

Keywords: Aluminum alloy, Hydraulic valve body, Oil leakage, Friction and wear

1. Introduction

Aluminum alloyed material are light and corrosion resistant, whereas the corresponding strength is normal [1,2]. Therefore these materials are normally utilized for certain unimportant parts [3,4]. Consequently, hydraulic valve body manufacturing by aluminum alloys is proven rare, whereas most hydraulic valves are made of iron. As technology has displayed progress, high performance aluminum products have displayed a superior performance [5,6,7]. Moreover, based on high performance aluminum alloys for hydraulic valve body manufacturing, a new method has been discovered for certain complicated valves in engineering machinery. Currently, complicated multi-valves are made of cast iron. This material presents an adequate strength and self-lubricating properties being widely utilized in hydraulic valve bodies, whereas certain problems exist, such as the multi-valve inner flow channels being significantly complicated and the sand core coheres in the channels under the liquefied iron exceeding

1300° C. These coherent sands could not be completely cleaned and subsequently pollute the hydraulic system, finally resulting in device failure. The casting temperature of aluminum alloyed materials is lower than the corresponding iron casting temperature and the sand core could easily be cleaned by vibration. The flow channels of multi-valve of aluminum alloys can be cleaned, providing a manufacturing possibility for complicated hydraulic multi-valves. This large valve group made by aluminum alloys also can be utilized in the automotive or aerospace fields, by a possible contribution in weight reduction of the corresponding parts.

A friction and wear device was designed for oil leakage measurements of valves from various materials at the same conditions. Also, by oil leakage measurements, both friction and wear of various materials can be characterized. This research demonstrates the performance of aluminum alloyed materials during the actual running condition and the theoretical support for multi-valve manufacturing is provided.

2. Experimental Procedure

2.1. Experimental device

The experimental device is presented in Fig.1. This device can convert the motor rotating motion into a reciprocating linear motion of a valve stem through the cam. The actual working procedure is presented: the cam rotation is driven by a motor and following the top rod moves linearly. The cam seat is provided with a spring, constituting the push rod to be always adjacent to the cam. The push rod drives the valve rod to reciprocate within the hole of the valve body. In this procedure the valve actual running simulation is demonstrated. A counting sensor is arranged on the bracket at the bottom of the cam and the counting sensor is connected to the counter in the electric control box. The reciprocating times of the valve rod during running can be recorded. Moreover, the valve body is provided with a thermocouple and a heating rod, therefore the valve body is heated by the heating rod. The valve body temperature can be measured by a thermocouple for the effects of temperature on friction and wear to be tested for the valve body. The valve body is connected to the hydraulic system, whereas both ends of the valve body are provided with a sealing ring and the valve body wear is determined by oil leakage observation through the sealing.

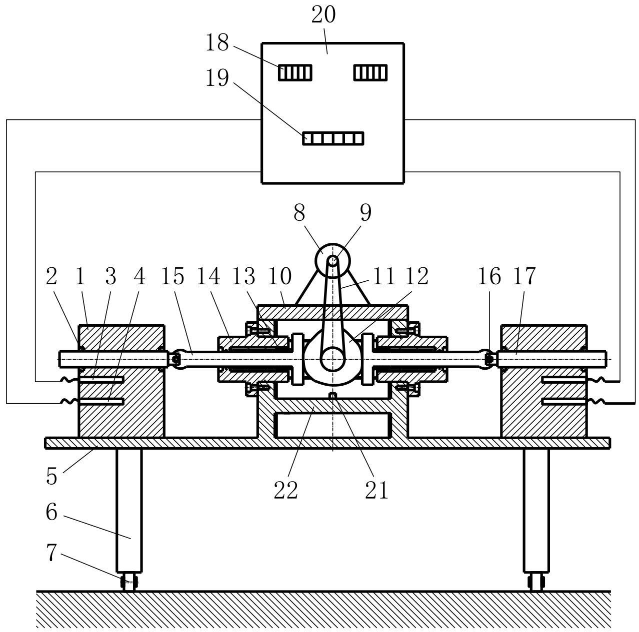


Fig.1 Experimental apparatus of valve body wearing
1-body, 2-sealing, 3- thermocouple, 4-heater, 5-plane, 6-leg, 7-wheel, 8-motor, 9-shaft, 10-frame, 11-belt, 12-cam, 13-spring, 14-cam seat, 15-push rod, 16-bolt, 17-valve rod, 18- monitor, 19- counting, 20- electric control box, 21- counting sensor, 22-frame

2.2. Experiment execution

(1) Valve body and valve rod preparation

A 201HT aluminum alloy was utilized for the valve body production and a 201HT -CR (abbreviated CR) was utilized for the valve rod preparation. The valve body was made of the QT500 alloy, whereas the 45# steel alloy was utilized for the valve rod manufacturing. The wear material couple scheme of the valve manifold is presented in Table 1.

Table 1.
Wear material couple of valve group

Valve body	Valve rod
201HT	CR
QT500	45#

(2) Valve group wear test settings

Following the installation of the valve body and rod, the experiment could be initiated. Each 50,000 cycles' times, the hydraulic system was pressurized to 15MPa and this pressure was retained for 1 minute. The valve group oil leakage and temperature were measured and recorded. Each group of experimental measurements described measurements conducted 600,000 cycles' times.

(3) Surface topography analysis

The FEI-Quanta 400 FEG tester was utilized for valve surface topography examination following wearing.

3. Experimental results

3.1. Valve group leakage analysis of various materials

In Fig.2 the valve group leakage of various materials is presented. During various wearing cycles' times, the leakage was different. As presented in Fig.2, the cast iron leakage was significantly lower than the aluminum alloy valve leakage at the beginning of wear, whereas the leakage rate increased slowly as the number of times increased. Besides, a cast iron leakage alteration following 300 thousand wear times was apparent, and therefore the leakage sustained a substantial increase. Consequently, the cast iron valve leakage increased slowly. The leakage of the aluminum alloy valve increased faster than the cast iron leakage. Whereas following 150 thousand wear times, the leakage decreased significantly and at 250 thousand times the first low leakage value was apparent. As the valve run continuously, the corresponding minimum leakage was apparent at 350 thousand wear times. Subsequently, the leakage gradually increased, whereas the leakage curve was parallel to the cast iron curve, even though aluminum alloy valve group leakage rate was lower than the rate of cast iron.

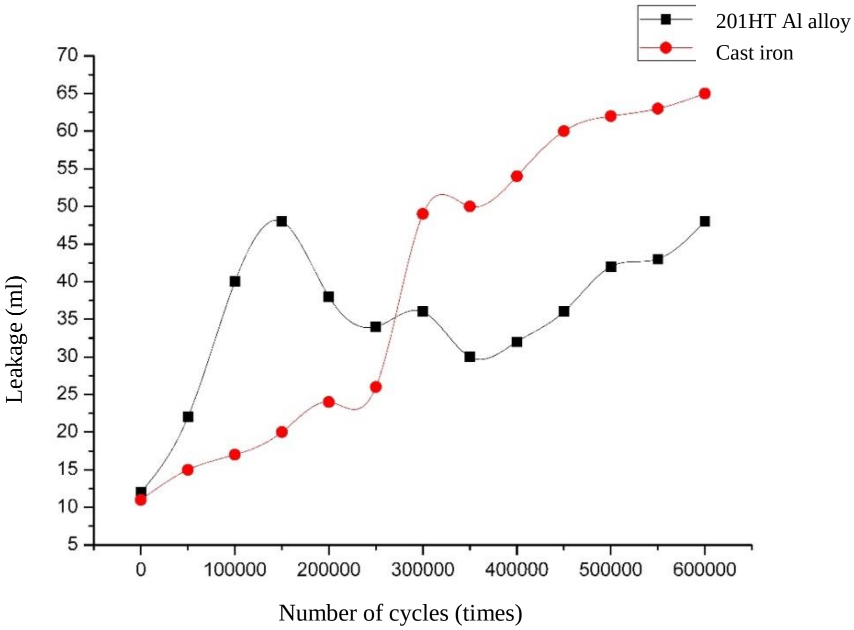


Fig. 2. Leakage curve of different material

3.2. Valve body temperature of various materials

In Fig.3 the temperature curves of two types of materials are presented. It can be observed, that in addition to initial temperature, the subsequent temperature of the aluminum alloy was lower than the corresponding cast iron temperature. The thermal conductivity of the aluminum alloy valve group was improved than the cast iron conductivity.

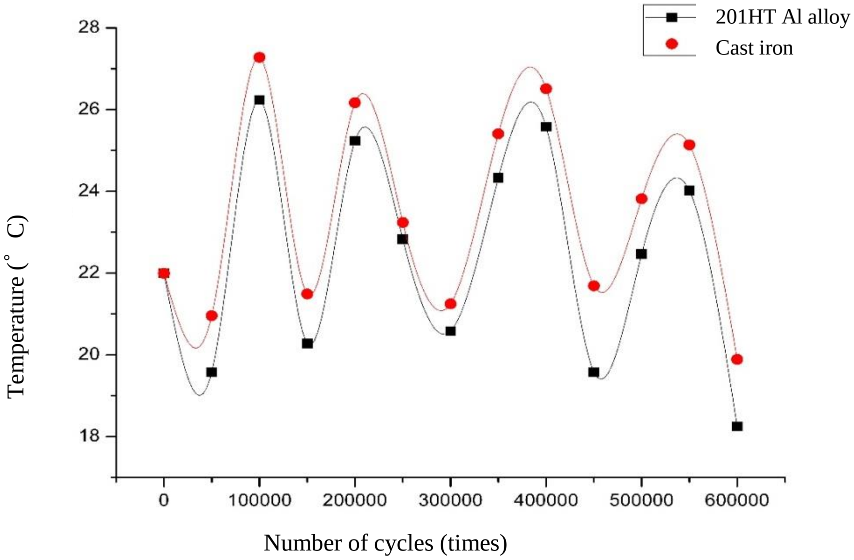
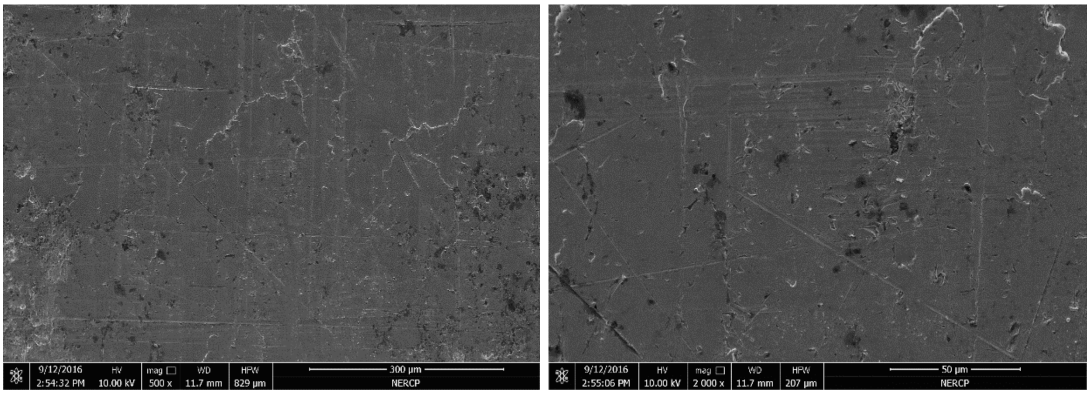


Fig. 3. Temperature curves of different materials

3.3. Micro Morphology

The valve body samples were observed following the 300,000 cycles' times and 600,000 cycles' times of wear and the corresponding inner surface was analyzed, as presented in Figs.4-7.

From the low magnification presented in Fig. 4, it can be observed that the cast iron valve body inner surface was quite smooth. Also, plastic deformation was the main friction result, along with the partial furrow. During magnification, the small pits could be observed being distributed on the surface and also the slip morphology of the materials following plastic deformation was apparent.

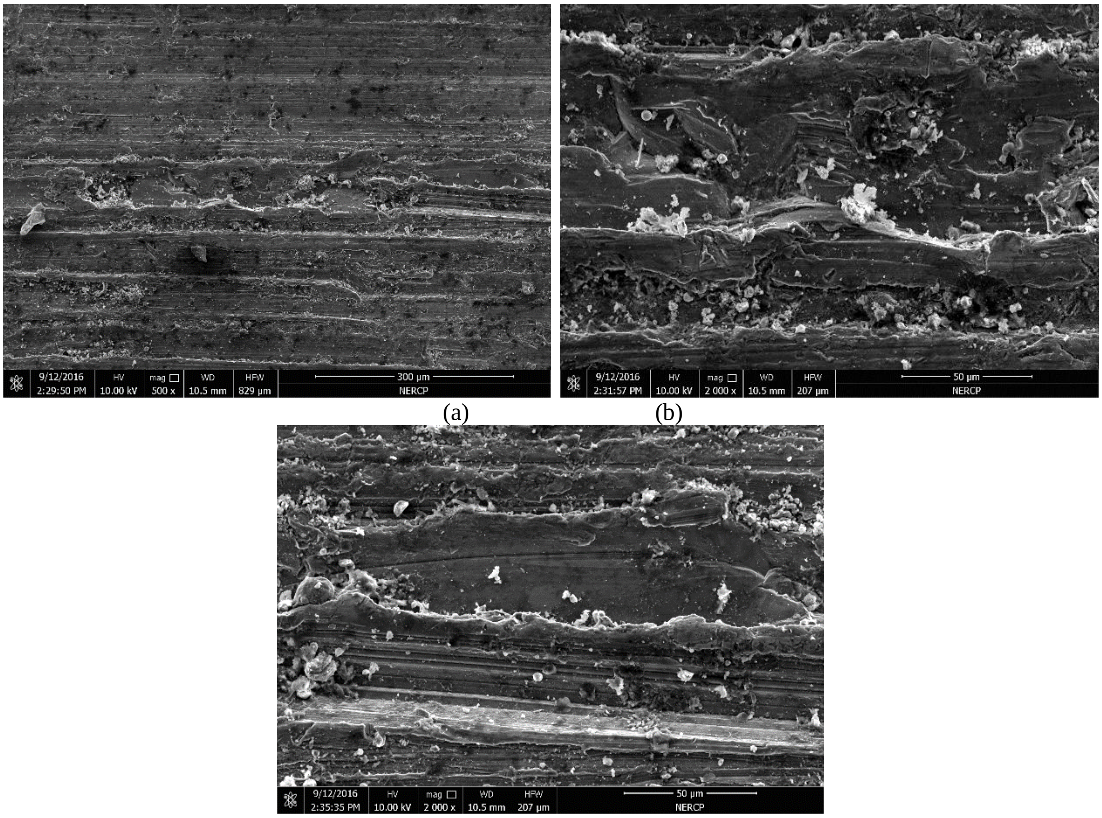


(a) (b)

Fig. 4. Cast iron valve following a 300,000 cycles' times wear

In Fig.5 the inner surface morphology of the 201HT valve body following a 300, 000 cycles' times wear is presented. From Fig.5 (a) it can be observed that friction consisted of large furrows mainly and appeared with a significantly layered slip, also attributing a local melting point. During amplification, the local plastic deformation and micro lamellar slips could be observed. In addition, apparent material tear morphology existed, whereas in the micro pits a high amount of aluminum chips were concentrated, as presented in Fig.5 (b). Moreover, another slip band area demonstrated that broad furrows and slip band morphology existed. Also, in these slip bands low sized furrows were apparent, possibly caused by the second cutting of aluminum scrap during running.

Compared to the 300, 000 cycles' times of cast iron and aluminum alloy body wear it can be observed, that the cast iron valve body surface damage was lower than the aluminum alloy body damage, being also significantly cleaner. The aluminum alloy valve body surface was consisted of a high number of furrows and plastic slips whereas in these furrow or slip bands a high amount of aluminum scrap was concentrated.



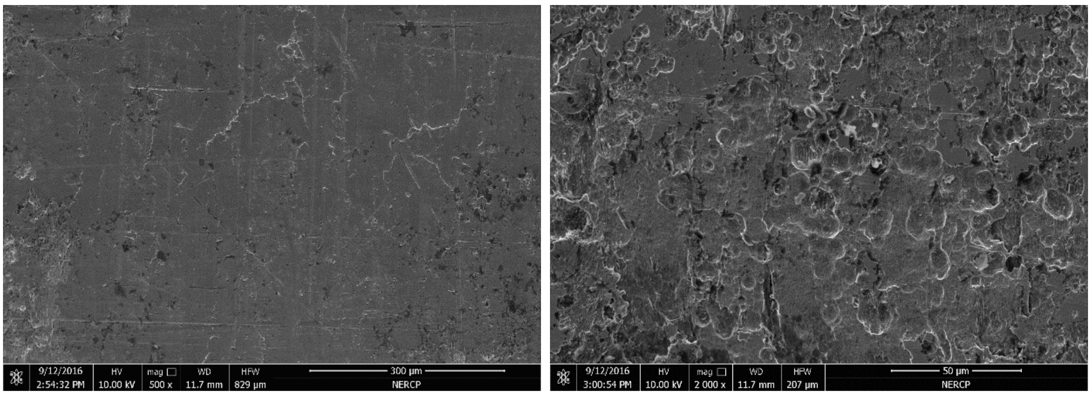
(a) (b)

(c)

Fig. 5. 201HT valve body micrograph following 300,000 cycles' times of wear

In Fig.6 the cast iron valve body surface morphology is presented, whereas in Fig.7 the aluminum alloy body morphology of following a 600,000 cycles' times running of wear is presented.

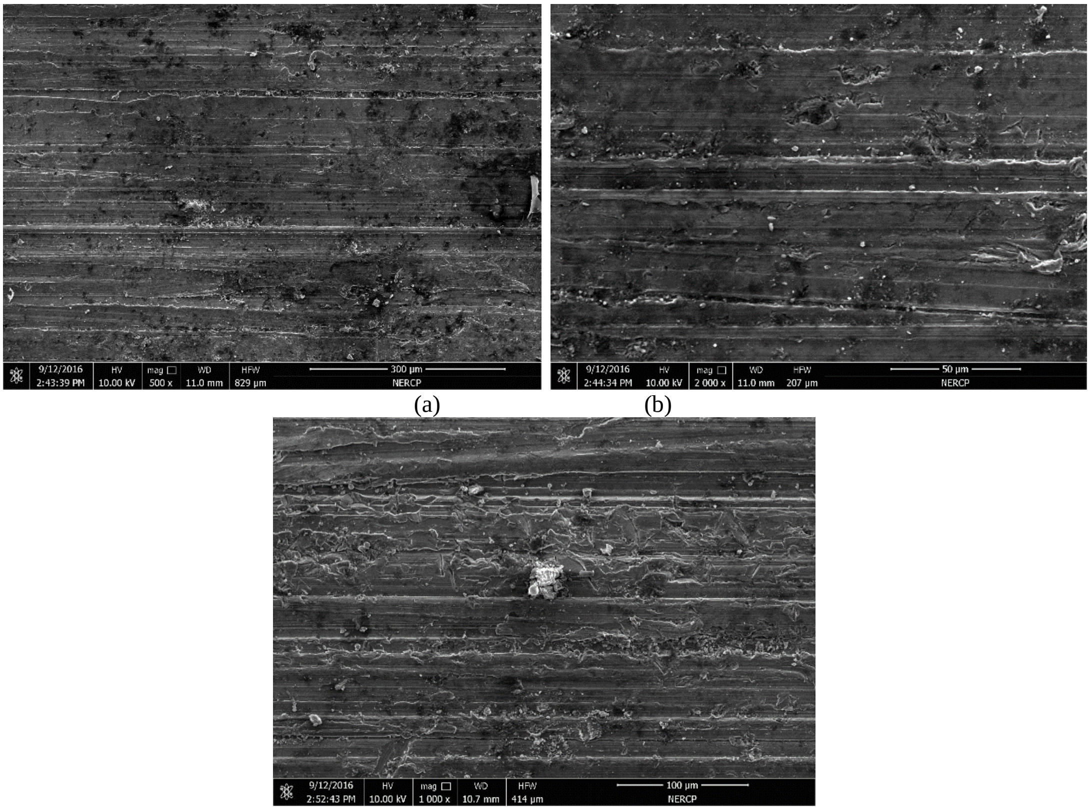
It can be observed from Fig.6 that the internal surface of the cast iron valve body displayed certain pits as wear times increased. The corresponding magnification is presented in Fig.6 (b). It can be observed that a high number of honeycomb pits were formed, whereas certain pits were polished. These pits would result in the valve group oil leakage during the hydraulic operation, whereas the subsequent result would be a system pressure loss.



(a) (b)

Fig. 6. Cast iron valve after 600,000 cycles' times

In Fig.7 the morphology of the aluminum alloyed body following 600,000 times of wear. It slip zone and furrow topography can be observed from Fig.7 (a) on the valve body surface. Besides, following 600,000 cycles' wear times, the sliding zone tended to be flat and uniform, whereas a high amount of the original pits were filled and only a low sized furrow remained, as presented in Fig.7 (b). In addition, due to continuously repeated rolling, a certain amount of surface material of the aluminum alloy valve body became thin and consequently formed a high number of fragments during the 600,000 cycles' times of wear, as presented in Figure 7 (c). The surface fatigue micro-cracks were formed by continuous rolling. These cracks were expanded due to stress alternation, continuing the valve body surface material exfoliation.



(a) (b)

(c)

Fig. 7. 201HT valve body micrograph following 600,000 cycles' times of wear

4. Results and Discussion

4.1. Relationship between valve body leakage and wear times and effects mechanism

This relationship between the valve body leakage and wear times is significantly different in valve leakage between different materials. Besides, in Fig.8 the three parallel lines (AB, CD and EF) are presented, which describe different materials and different times demonstrating the same line slope. Therefore, a linear relationship existed between the number of wear times and the leakage amount of different materials.

The three-segment curves are presented in Fig. 8 and the slope of the straight line is:

$K = \tan\alpha$ = Leakage / time = $\tan 30^\circ = 0.577$ (ml / time).

Therefore, the linear equation is:

$$y=0.577x+Q \quad (1)$$

where Q is the foundation leakage, representing the leakage of the valve without wear (system internal discharge).

In Equation (1) a linear relationship between the number of wear times and the amount of leakage of all materials is presented. The differences in materials or times are the forces on the Q values, demonstrating that different materials or different zones of the non-wear leakage base value varied. This indicated that the actual amount of leakage during the actual running procedure was composed by the non-wear base leakage value and the leakage of valve body and rod addition following wear.

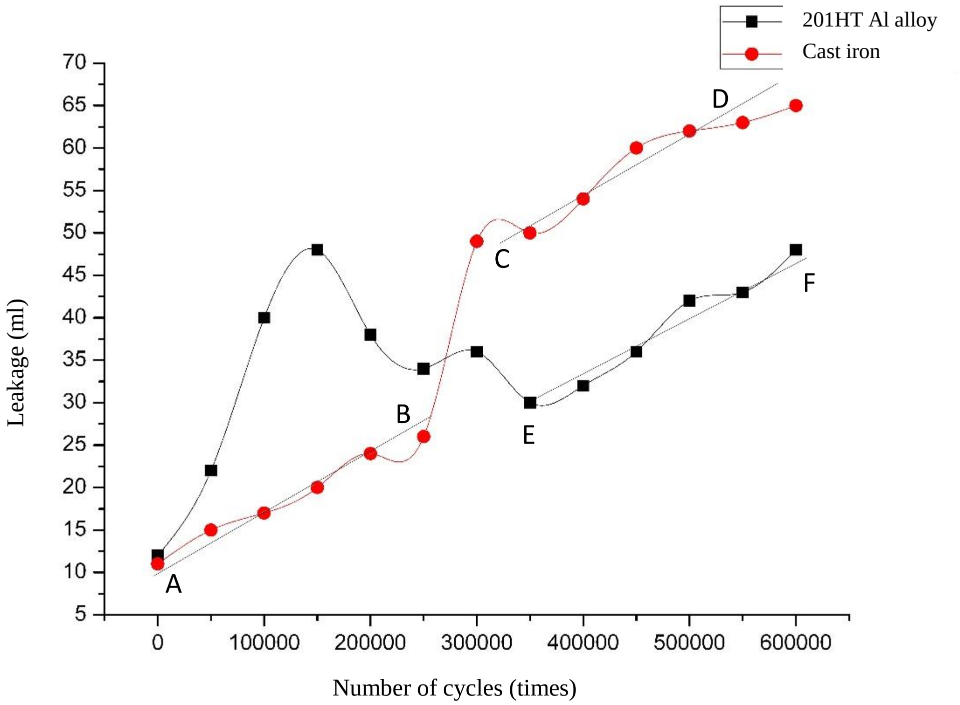


Fig. 8. Leakage and times linear fitting

Compared to the leakage curves of cast iron and aluminum alloys, various alterations existed in various stages on the leakage curves. At 300,000 cycles' times of wear, the curves of cast iron displayed a change: the curves slope of leakage presented an abrupt sudden increase, mainly due to the inner surface morphology alterations of iron (internal material surface peeling). It resulted in the valve group internal leakage and slopes increase. At this time, the system leakage performance for the wear process leakage. As running continued (exceeding 300,000 cycles' times), the valve body adapted to the new surface, therefore the valve leakage mechanism returned to the leakage value, composed by the foundation leakage value, friction and wear, resulting in a leakage value increase. Besides, due to internal morphology alterations, the foundation leakage amount increased, therefore the straight line moved upwards.

Regarding the aluminum alloy softness, a high surface deformation occurred under the applied force in the beginning of running. Therefore, the initial procedure leakage curve slopes and leakage performance for the wear process leakage. Regarding the internal friction and wear of the valve body and aluminum scraps melting, the valve body and rod gaps decreased continuously, leading to a continuous decline in leakage. Also, some leakage peaks of valve body will form.

As running continued (exceeding 300,000 cycles' times), the friction surface gradually adapted to the valve rod and body gaps, whereas system was driven into a normal wear stage, as presented in the EF straight line area of Fig.8. Consequently, the aluminum alloy valve leakage became similar to the leakage mechanism: composed of foundation leakage values and friction and wear resulting in the leakage value increase.

4.2. Friction and wear mechanism analysis

Due to the valve group being mainly a longitudinal sliding during actual running, unavoidable non-parallel or offsets appeared between the rod and valve body, as presented in Fig.9. It led the valve rod shovel the internal surface of the valve body, causing the formation of surface furrows and plastic slips on the material surfaces.

Regarding the cast iron body, the inner surface of the valve body was basically not deformed in the initial stage, whereas the only surface damage was the surface shallow furrows and slight plastic deformation slips. This occurred due to the hardness of cast iron and the absence of the valve rod furrow or the shovel valve body effects. Therefore, the damaging effects of the rod to the body were limited, whereas a plough wear was apparent in the micro morphology.

In addition, the cast iron body contained spherical graphite, which could constitute a solid lubricant for the valve body during running. It could slow down friction and wear of both the valve rod and body. As the wear times increased, the micro-cracks on the inner surface of the valve body were continuously subjected to an alternating stress, the fatigue was exacerbated and the micro-cracks expanded. These extended micro-cracks caused the surface material to be squeezed, slipped, thinned and peeled off from the surface of the valve body, whereas finally forming micro-pits.

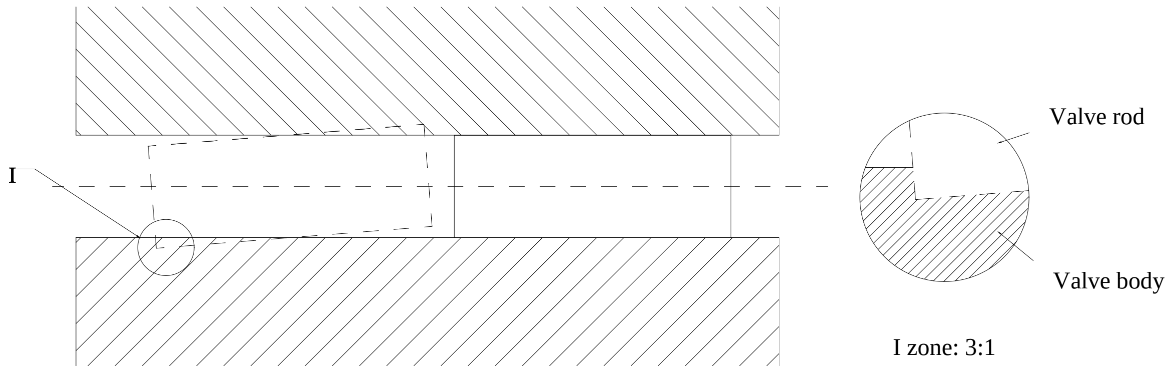


Fig. 9. Valve body and rod actual position

Furthermore, due cast iron to poor thermal conductivity, the temperature of the valve body surface gradually increased during the continuous running. The graphite oxidized under high temperatures [8], exacerbating graphite peeling of the valve body inner surface. During this procedure o high amount of pits formed on the surface also as presented in Fig. 6.

Due to the valve body surface alterations, the leakage mechanism of the body also changed, whereas the curve slopes also changed. As running continued, the rod and body adapted to the new gap and relapsed to the previous leakage mechanism, consisting of both leakage values that resulted in linear leakage along with wear times. That difference is the foundation value: later foundation value is more than the before.

Regarding the aluminum alloy body, friction and wear occurred in two main stages.

Firstly, the inner surface of the valve body formed a number of plastic deformations and furrows: because the aluminum material was soft compared to cast iron. The CR valve rod presented hardness exceeding the 201HT and shoveling effects increased significantly. It resulted to a high deformation in plastic sliding and high sized furrow morphology. This morphology led to a valve group increased leakage, which was also explained in Fig. 2 where a high amount of leakage was apparent during early running.

Secondly, as the tests continued, due to debris filling furrows and melting constituting the surface area smooth, the alternating stress led certain zones to present fatigue wear. Due to the relatively soft aluminum alloy surface, the local high temperature and high pressure during running led the surface temperature to an instantaneously increase. This energy allowed the aluminum alloy to reach the melting point and melt onto the substrate surface. The high sized furrows were filled by debris and melted with substrate surface, the rod and valve body gaps were drastically reduced, whereas the leakage minimum points are presented in Fig.2. As the system continued to run, the valve rod shoveling effect continued to produce furrows and debris. Also, the aluminum debris were continuously filled with furrows and consequently melted again under a high temperature and high pressure during running, therefore procedure led the valve body inner surface to retain a dynamic equilibrium. This dynamic balance could retain the foundation leakage value of non-wear at a lower level. Therefore, the leakage level of the aluminum alloy valve was lower than the cast iron leakage level, as presented from the EF line in Fig.8.

5. Conclusions

From the analysis of the aforementioned test results, the following conclusions were drawn:

(1) The alteration of the valve internal surface morphology affected the valve leakage: the cast iron leakage increased gradually as the number of wear times increased firstly. Also, the leakage curves sustained an alteration, whereas following leakage gradually increased as the wear times increased again. Besides, the aluminum alloy leakage increases rapidly at the beginning of running and acquired several minimum values. Following, the leakage curves increased linearly.

(2) Both aluminum alloy and cast iron valves follow a similar leakage mechanism: actual leakage consisted of the foundation leakage value of non-wear and the increased valve group leakage value during running, formed gaps.

(3) The expansion of micro-cracks and high-temperature graphite oxide peelings led to a cast iron valve body gap increase and eventually led to leakage curve alteration occurrence. Because the aluminum alloy body was soft, it led to the initial wear increase and the initial valve group displayed a large amount of leakage. Besides, since the debris filled the furrows, a high temperature melting was utilized for valve body internal surface dynamic balance to be retained, leading to a number of aluminum alloy valve leakages minimization. Due to the dynamic balance, the aluminum alloy body sustained a lower leakage finally.

Through the study of the 201HT material friction and wear, it was indicated that this alloy could meet the requirements of the existing valve group during friction and wear.

Acknowledgments

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