ISSN 2179-3956

CORRELATION AMONG ABRASIVE WEAR TESTS[1]

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Abstract

The study of wear has focused much effort on reproducing, in laboratory, micromechanisms identified on industrial applications. To do so, many tribometers were developed, but not much attention has been given to correlation among such variety of abrasive wear tests results. This study aims to compare the behavior of four different wear tests, three of them classified as severe abrasive wear tests (pin-on-disk, single pass pendulum and scratch test) and one as a non severe abrasive wear test (LTM test). High chromium white cast irons alloys and Al-Si alloys (the latter collected from the literature) were used in different tribological conditions (contact pressure, interface fluid, velocity, abrasive size and shape). It was observed that the wear resistance classification offered by the single pass pendulum and the LTM test were the same and was inversed with the classification offered by the scratch and pin on disk test. The single pass pendulum and the scratch test offered less data dispersion and faster results, therefore, these tests should be more attractive. The wear rate behavior corroborates the models presented by Zum Gahr regarding the force transferred on the contact region named: constant depth and constant load. For the constant load system, the product K*q, proprieties of the material presented by U. BRYGGMAN et al., explains better the wear rate behavior when compared to the indentation hardness.

Key words: Tribometer; Wear rate; Correlation.

[1] *Technical contribution to the First International Brazilian Conference on Tribology – TriboBr-2010, November, 24th-26th, 2010, Rio de Janeiro, RJ, Brazil.*
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ISSN 2179-3956

1 INTRODUCTION

Tribology's history is strongly related to the transportation technologies. The relative movement among parts lead to wear, friction and lubrications needs. Understanding transportation as a broader term, e.g. transportation of grains, ores, metals, people and fuels shows the importance of the science.
Kragelskii[1] pointed out that the systemic characteristic of wear was firstly reported more than half a century ago by Zaitsev, Konvisarov, Khrushov and Schapov by saying that the wear resistance of materials depends in great part on the usage conditions. Wear is, therefore, an answer of the tribosystem and not a material propriety.
Peter Blau[2] said that the study of wear is usually conducted for one of the following reasons:

1. Understand the behavior of a family of materials under wear;
2. Improve the materials selection method for a specific application;
3. Understand the effect of some variables on a specific tribosystem;
4. Support theoretical models for wear rates prediction;

Most of the efforts related to the study of wear are focused on the developing or improving methods to obtain an accurate selection of materials for a specific application. Consequently, a material selection starts with a micromechanism analysis and ends with laboratory testing.
Through out the development of materials selections techniques many laboratory tests were develop and referred as tribometers. Few tribometers became very popular, e.g. pin-on-disk test and rubber wheel test, and there is still a great variety of tribometers developed to reproduce a very specific tribosystem.
Just a few papers, e.g. Misra and Finnie[3] e Hawk et al.,[4] tried to correlate the results of wear rates of different tribometers. They aimed to select materials that were under mixed micromechanisms of wear. However understanding the combined effect of tribometers' constructive variables and the wear rate measured brings light to a discussion about the selecting materials technique which is supported on the tribometers selection.

2 MATERIALS AND METHODS

2.1 Materials

2.1.1 Aluminum-Silicon alloys

The Table 1 presents the chemical compositions and indentation hardness values of the Al-Si alloys used in the study. This data was collected from the literature.[5]

Table 1 - Al-Si alloys' chemical composition and indentation hardness. Data collected from the literature[5]

Material	%Si	Hardness [HV]
D	0	21
E	5	43
F	9	51
G	12	56
H	16	63
I	21	63

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2.1.2 High chromium white cast irons alloys (HCWCI)

The Table 2 shows the chemical composition and Table 3 shows the indentation hardness values of the alloys.

Table 2 - Chemical composition of high chromium white cast irons alloys

Material	%C	%Cr	%Si	%Ti	%V	%Mo	%P	%S	%Mn
C	1,7-1,8	25-27	0,5-0,7	0,12-0,18	0,15-0,25	0,3-0,5	0	0,03	0,7-0,9
J	1,4-1,6	25-28	1,25	-	-	-	0	0,02	0,8

Table 3 - Indentation hardness of high chromium white cast irons alloys

Material	Hardness [$HV_{0.2}$]
C0	450,6
J0	426,6
J4	381,4

The alloys C0 and J0 are presented as cast. The alloy J4 is presented after operating 3.5 years in a service temperature of 450°C in average.

2.2 Methods

2.2.1 LTM test

The LTM test is a non standardized tribometers developed at Uberlandia's Federal University. Usually it simulates a non severe abrasive wear. It's accepted by the scientific community[6,7] and has a low cycle time and high reproducibility.[8]

The Figure 1 presents an illustration of the LTM test. Three samples are pressed against a spinning grey cast iron plate. The rotation movement of the plate and the constructive system of the machine creates a relative motion between the samples and the plate. The wear rate is measured at steady state by the mass loss.

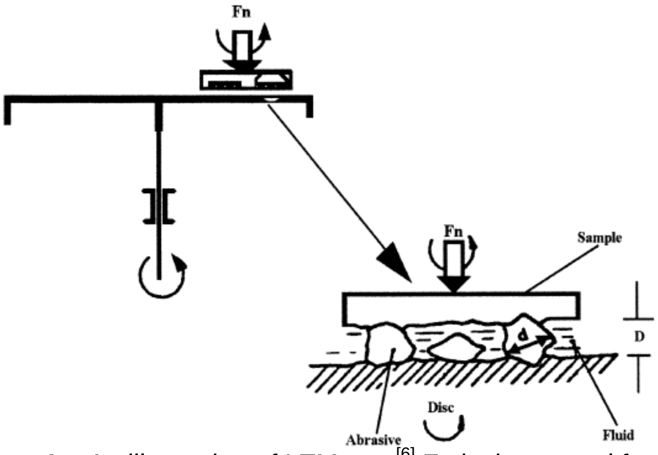

Figure 1 – An illustration of LTM test.[6] Fn is the normal force.

The Table 4 presents de parameters used in the test.

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Table 4 - LTM test parameters. Al-Si data collected from the literatur [5]

Test Parameters	Materials	
	HCWCI	Al-Si
Normal pressure (KPa)	30,37	408,28
Abrasive	SiO_2	Al_2O_3
Abrasive size [µm]	150 a 300	7 ± 3,4
Fluid	Air	Oil

2.2.2 Pin-on-disk

The pin-on-disk test is a standardized test[9] and widely used by the scientific community. It simulates a severe abrasive wear. Although there is a standard related to this tribometers many adjustments are usually made to reproduce a specific micromechanism.

Uberlandia's Federal University has a pin-on-disk test developed by Pacca, Raslan e Mello.[10] It's a multiple tribometers once it can simulate two or three bodies tests depending on the configuration.

For this study a two body test was chosen. The pin travels on an abrasive paper and spins around its own axial. The normal force is given by a dead weight. The Figure 2 presents an illustration of the pin-on-disk test developed.

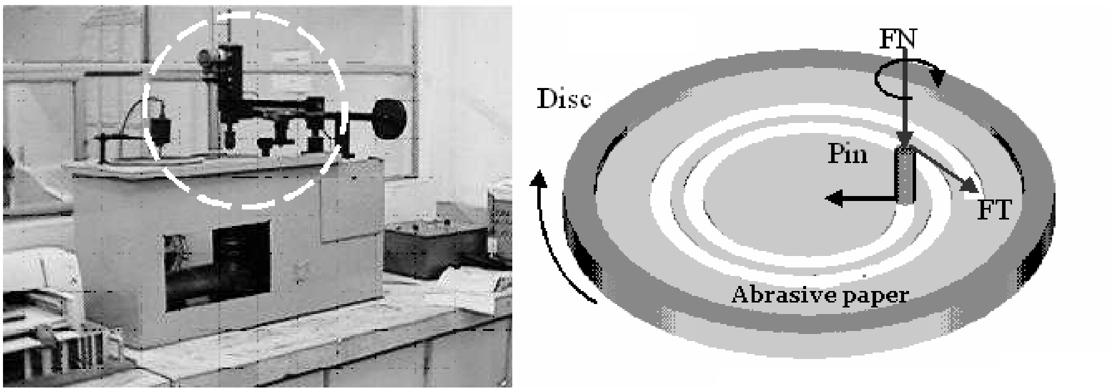

Figure 2 – An illustration of pin-on-disk test.[11]

The Table 5 presents the parameters used in this test.

Table 5 – Pin-on-disk test parameters. Al-Si data collected from the literature[5]

Test parameters	Materials	
	HCWCI	Al-Si
Disc velocity [rpm]	25	25
Sample velocity [rpm]	25	20
Distance [m]	3,2	3,2
Duration [s]	22	32
Abrasive	Al_2O_3	Al_2O_3
Abrasive size [µm]	14,1 ± 8,5	14,1 ± 8,5

2.2.3 Single pass pendulum test

This technique was developed by Vingsbo and Hogmark at Uppsala University in Sweden. It has been used to investigate the wear behavior of many materials such

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as Al-Si alloys,[5,12] grey cast irons[13] and a wide variety of steels.[14] Del Piero, Mello and Scandian(15) and Del Piero[16] investigated the wear behavior of white cast irons under high service temperatures.
A single pass pendulum test is basically a Charpy test modified. At the bottom of the pendulum an indenter is installed. The pendulum or the sample is adjusted in a position that allows the indenter to produce a single and precise grove in the sample, the Figure 3 illustrate a single pass pendulum test. The energy dissipated, measured by the pendulum's position before and after, is used to calculate the wear rate.

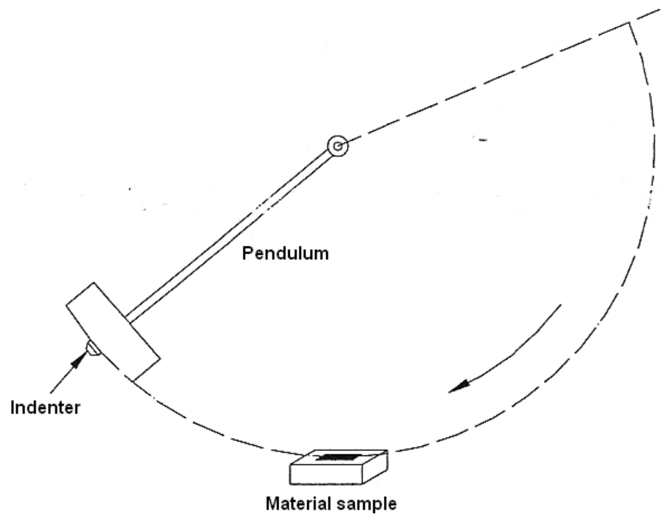

Figure 3 – Illustration of a single pass pendulum test.[16]

Although it's not a very known tribometer, it has a high reproducibility, low data dispersion and very low cycle time.[17]
For all test the pendulum energy was 50 J and the Table 6 presents the parameters used in this test.

Table 6 – Single pass pendulum test parameter. Data collected from the literature (Al-Si[5] and White cast irons[16])

Material	W(mg)
C0	2,40
J0	2,50
J4	2,20
D	0,80
E	0,80
F	0,80
G	0,80
H	0,80
I	0,80

2.2.4 Scratch test
The scratch test is a mono event of grooving. One of the first studies regarding the ability of one material perform a grove in another was developed by Mohs[18] in 1824.
The scratch hardness and the indentation hardness are different proprieties. The indentation hardness has been adopted as a general rule for designs[19] and the scratch hardness has been normally used as a quality control technique.[19]

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The scratch test consists of an indenter, used in indentation hardness tests, which sustain a normal load and assume a translation motion, see Figure 4. The wear rate is measure by the grove size (d).

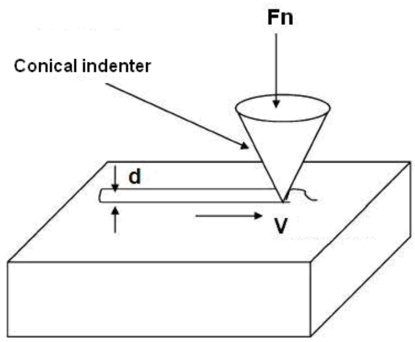

Figure 4 – An illustration of a scratch test. Fn is the normal load, d is the size of the grove and V is the velocity of the translation motion.[20]

For the white cast iron alloys it was used a Vickers pyramidal indenter with a 136° angle. The Table 7 presents the test parameters used in this test.

Table 7 – Scratch test parameter. Al-Si data were collected from the literature[5]

Test parameters	Materials	
	HCWCI	Al-Si
Scratch velocity [mm s-1]	0,1	0,6
Normal load [N]	10	0,27

3 RESULTS

The wear rate behavior of the LTM, pin-on-disk, single pass pendulum and scratch test are presented as a function of the indentation hardness in the Figure 5 for the white cast irons alloys and in the Figure 6 for the Al-Si alloys.

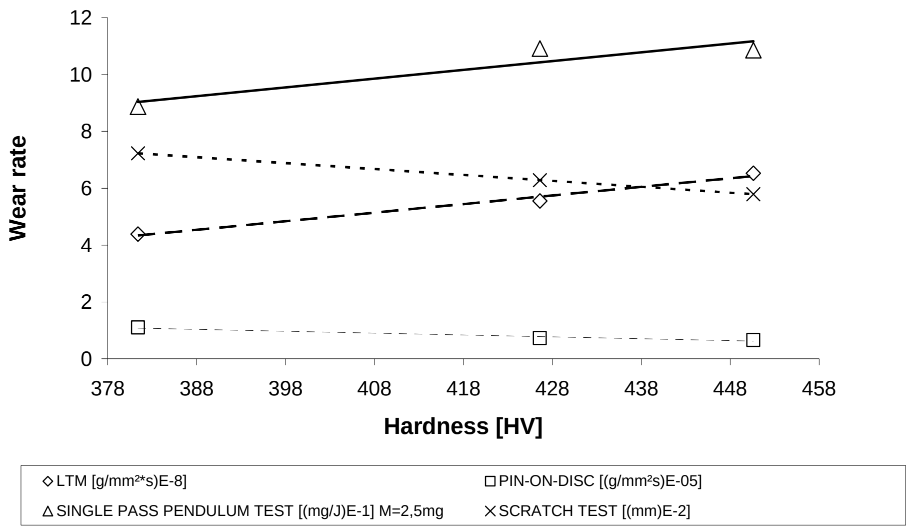

Figure 5 – Wear rate behavior comparison among pin-on-disk, LTM, single pass pendulum and scratch test for white cast irons alloys.

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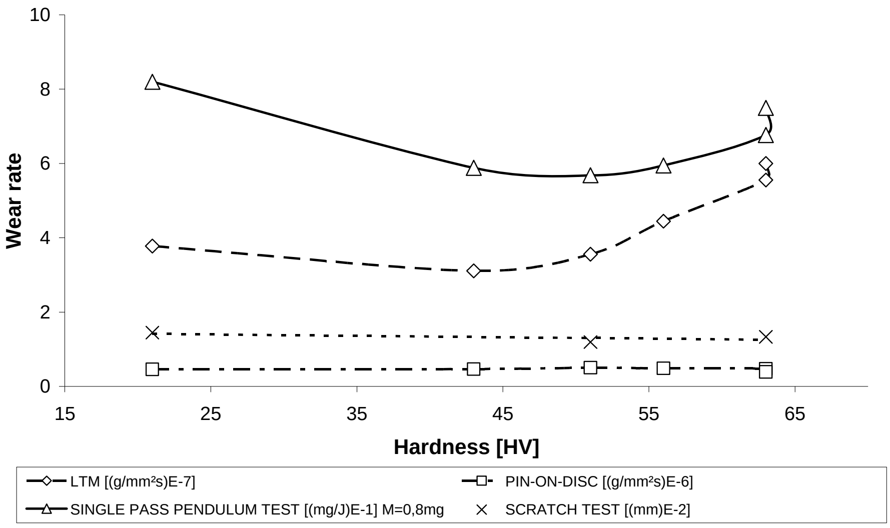

Figure 6 - Wear rate behavior comparison among pin-on-disk, LTM, single pass pendulum and scratch test for Al-Si alloys.

It can be observed that the wear rate measured in the pin-on-disk and on the scratch test follow the same behavior. A similar observation can be seen in the wear rate measured in the LTM and single pass pendulum test.
It can also be observed that the wear resistance classification offered by the pin-on-disk and scratch test is inverted when compared to the classification offered by the LTM and the single pass pendulum.
It must be highlighted that even modifying the tribosystem (materials, pressure on the contact, abrasive size and shape, velocity and interface fluid) the wear rate behavior remains the same. This suggests that the variable responsible for this phenomenon is related to the constructive characteristics of the tribometers.

4 DISCUSSION

This phenomenon can be explained by Zum Gahr's study[21] where he correlated the constructive characteristics of a tribometer with the response of the simulated tribosystem.
The Figure 7 shows two hypothetical system named System I and System II. It also makes reference to two different materials named A and B. For the system I, the penetration depth, h, remains constant (constant depth) even after a material change. Therefore, the material with the highest deformation capability, which is a property defined by Zum Gahr as the maximum plastic deformation that a material can absorb, will achieve the lower wear rate. In the system II, the normal load remains constant (constant load), usually related to the gravity, it follows that the indentation depth varies as a function of the yield stress. So, the material with the highest yield stress and work hardening will have a lower indentation depth and consequently a lower wear rate.
It must be observed that for the system I (constant depth) the propriety of material that interfere the most is the capability of deformation. Differently, in the system II (constant load), a combination of the indentation hardness and work hardening are the most important proprieties.

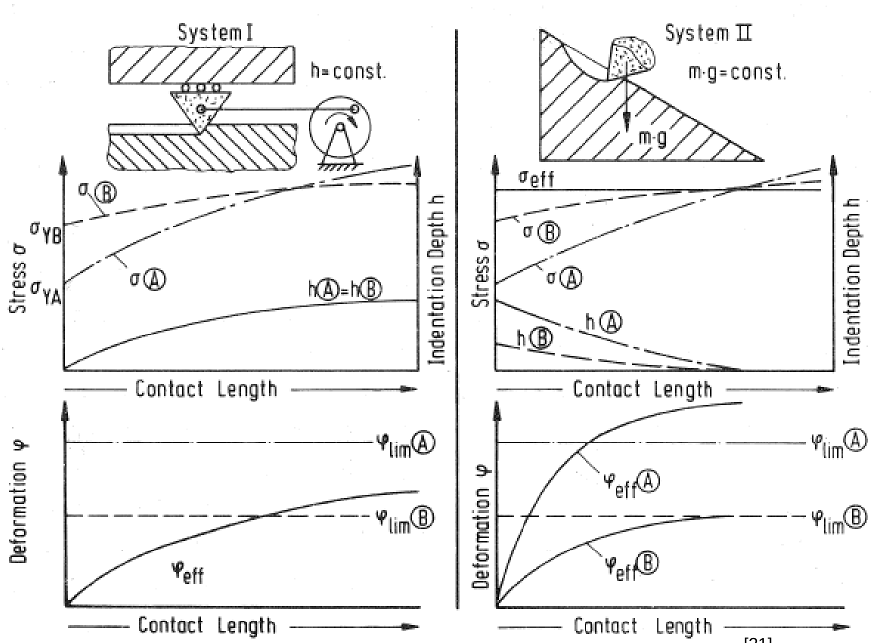

Figure 7 – Hypothetic systems proposed by Zum Gahr.[21]

After analyzing the constructive characteristic of the tribometers tested in this article, we can consider that the pin-on-disk and the scratch test as similar to the system I (constant depth) and the single pass pendulum and the LTM test are similar to the system II (constant load). Then, it is not expected a strong correlation between the indentation hardness and the wear rate measured on the system I, once the main property is the capability of deformation. This behavior is observed in the Figure 5 and Figure 6 for the pin-on-disk and scratch test.

While analyzing the results regarding the system II, a positive correlation between the hardness and the wear rate is observed. This misunderstanding was also verified by Liang et al.[22] "It suggests that in pendulum scratching wear resistance depends on both hardness and capability of elastic and plastic deformation". According to Zum Gahr's theory, the wear rate in the system II, varies as a function of the indentation hardness and the work hardening. So, there is still another property that must be considered.

The parameters k and q, obtained through the single pass pendulum test, are related to the material properties as reported by Brygmman, Hogmark and Vingsbo.[23]. k is related to cutting resistance and q, to the capacity of a material recover a established deformation. Therefore, we could assume that k is related to the yield stress and q to the work hardening.

The correlation among the k and q parameters and the wear rate, measured on the tribometers similar to the system II, is presented in the Figure 8 and Figure 9.

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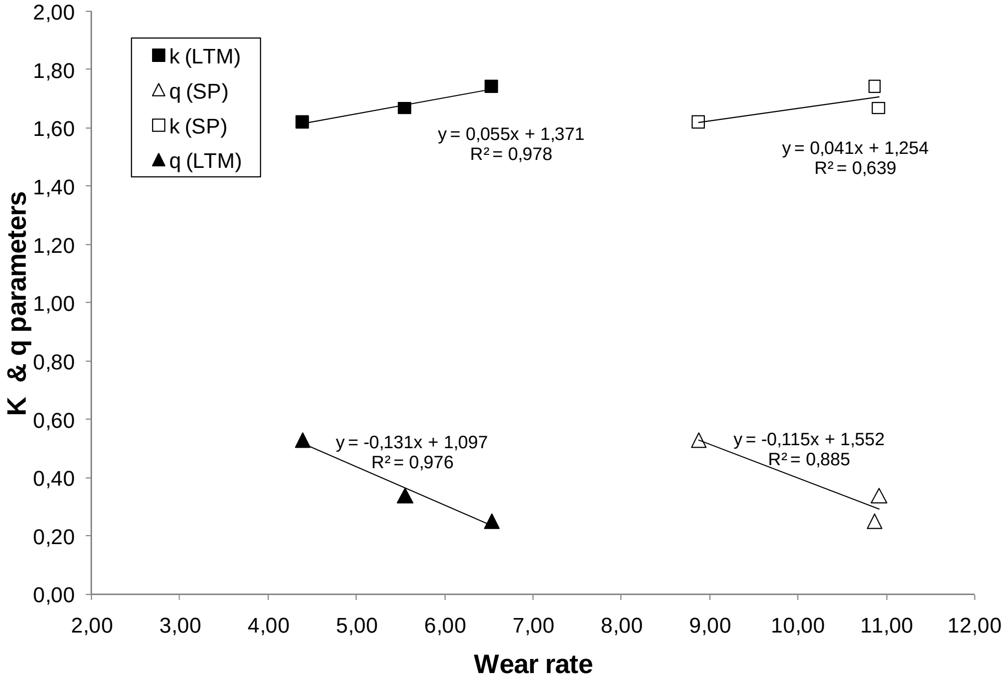

Figure 8 – Correlation among k and q parameter for the HCWCI alloys.

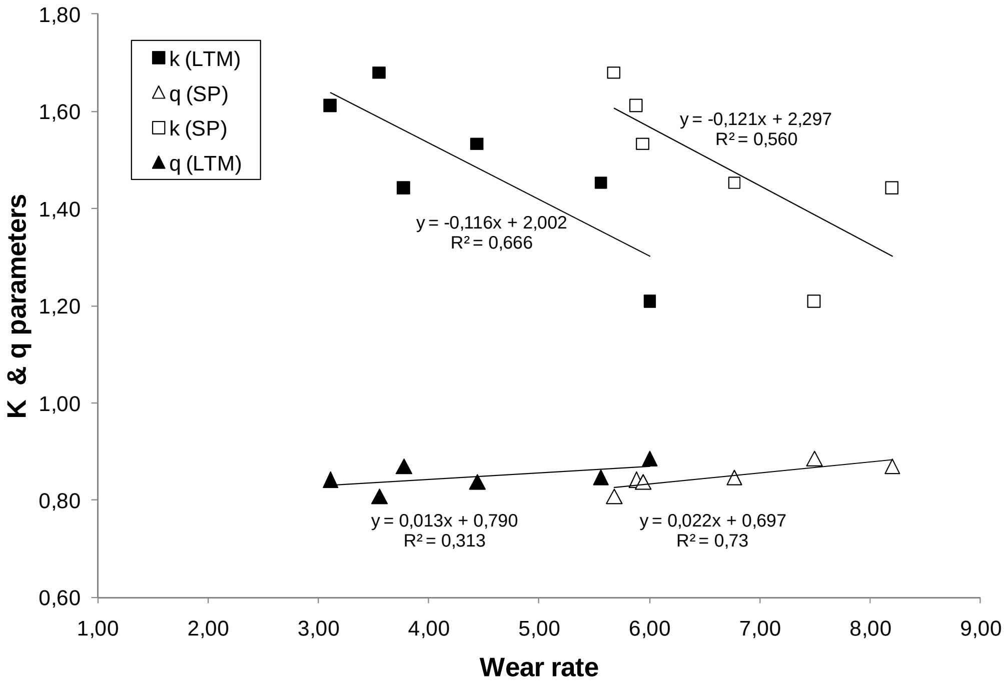

Figure 9 - Correlation among k and q parameter for the Al-Si alloys.

It can be observed that for the HCWCI alloys the parameter that most interfer in the wear rate behavior is the q parameter (work hardening). For the Al-Si alloys, this the k parameter is the most important (yield stress). This phenomenon could be related with the size of the abrasive.

Therefore a combination of both parameters is necessary to understand the system II. The correlation between the product k*q and the wear rate of the system II, considering the Al-Si and HCWCI alloys, are presented in the Figure 10.

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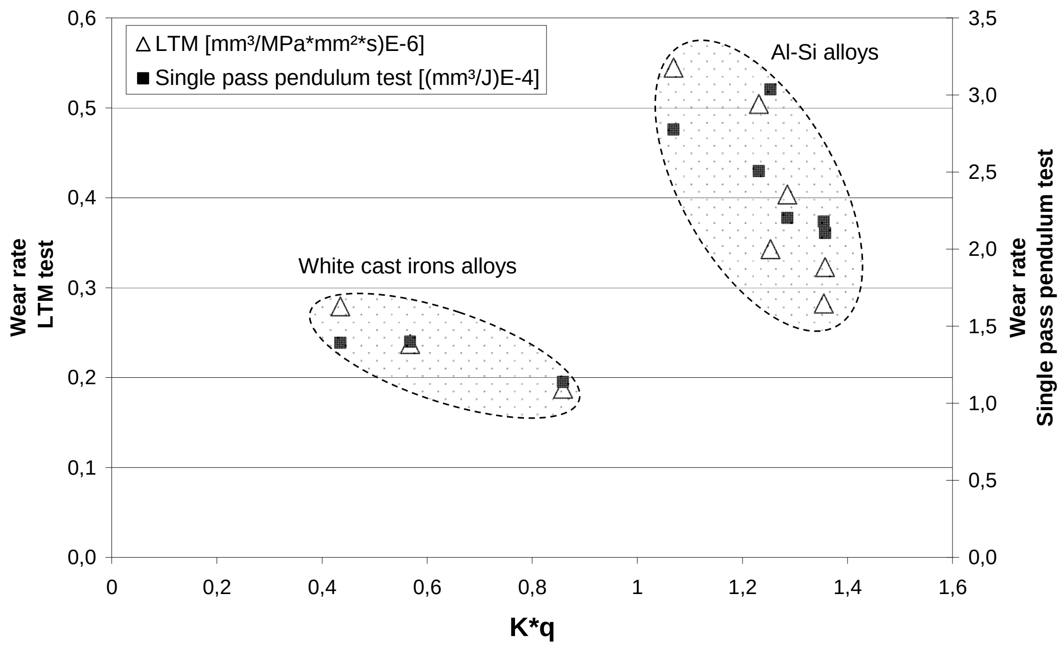

Figure 10 – Wear rate behavior of single pass pendulum and LTM test as a function of the k*q product.

It can be observed a negative correlation tendency between de wear rate and the k*q parameter. Therefore it is clear the combined action of yield stress and work hardening as proposed by Zum Gahr for the system II.

5 CONCLUSION

1. The wear rate behavior as a function of the constructive characteristics of the tribometer corroborates the model presented by Zum Gahr (constant depth and constant load).
2. For the constant load system, the product k*q explains better the wear rate behavior when compared to the indentation hardness.

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