SR EN ISO 20623 - A standard for tribological evaluation of lubricants that may bust innovation

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Abstract. This paper presents the opportunities offered for research by using the four ball machine and the procedures included in SR ISO 20623:2018. There are presented results of research studies that are started from the procedures and parameters included in standard, but also wear and friction parameters that derived from recording friction and wear scar dimensions and texture parameters.

1. Introduction
Testing devices for assessing the tribological behavior of lubricants could be classified into two categories [1-4]:
   a) laboratory systems that try to model the friction and wear processes from actual tribosystems or realize friction and wear in well determined conditions;
   b) actual tribosystems used in test or under actual working conditions.

Figure 1. Four-ball machine (“LubriTest” Laboratory from “Dunarea de Jos” University of Galati).
For given test conditions (load, sliding speed, lubricant temperature), the smaller the wear scar, the better the anti-wear characteristics of the lubricant.

In our university, studies on four ball tribotester started with research grant CEEX-M4-C2-452: Adoption and implementation of test methods for lubricants conformity assessment, financed by Ministry of Education and Research – National Agency for Scientific Research, in the frame of the Research for Excellence Program (CEEX) that allowed for funding the acquisition of a four ball machine (European conditions), designed and fabricated by Shaeffer, in 2008 (see figure 1).

The four-ball machine had been proposed till 1933, by Boerlage for determining the tribological properties of liquid lubricants. Due to its simple geometry (figure 2), it is used for ranking the lubricants, for assessing the quality of additives and their influence on friction and wear.

The standard was elaborated for the first time by ISO in 2003 and reviewed in 2017. In Romania, it was adopted in 2004 and, then, in 2018, due to the interest manifested by academic media, but also the lubricants’ producers and their clients.

Table 1 presents several studies did on the four-ball machine at „Dunarea de Jos” University of Galati, but similar studies were done at Politehnica Bucharest, by Ilie and his co-workers [6], Nazare and Paleu at Technical University of Iasi [7].

The capability of a lubricant to face extreme pressure regime is pointed out by the load wear index (LWI). Three measurements go into determining the LWI. Nye Company proposed an evaluation comparing this test to a traffic light [14]. The last non-seizure load (LNSL) is the highest applied load that exists when there is still lubrication between the 4 balls, or the “green light”. The load is increased until the lubricant film no longer exists and there is metal to metal contact and the seizure regime occurs, or the “yellow light” (not recommended passing as in traffic). Finally, the load is increased until welding occurs, or the “red light” (this implies damaging not only the contact, but also other components of the system). Taking into account that, the four-ball machine are designed to be protected when the balls weld. Seizure and welding may be detected if one or more of the following events are noticed:

- the friction coefficient undergoes a sharp increase,
increased noise level of the machine (motor, but also in the four-ball cup),
smoke from the ball cup,
oscillation(s) of the lever load arm,
a WSD greater than 4 mm.

Using the values of the parameters determined on the four-ball machine, the Load-Wear Index can
be calculated, which gives a numerical value to compare a lubricant capability to prevent wear at
applied loads. Based on this value, new formulated lubricants can be compared to others, already
being on the market [14], [15].

Table 1. Research studies elaborated by using the four-ball machine, at „Dunarea de Jos” University
of Galati.

| Year | Authors                  | Title                                                                 |
|------|--------------------------|----------------------------------------------------------------------|
| 2007 | C Spanu, I Stefanescu, M Ripa | Comparative study of the testing methods using four ball machine [8] |
| 2013 | L C Solea                | Contributions on studying the rheological and tribological behavior of biodegradable lubricants based on vegetal oils [9] |
| 2015 | C Georgescu              | Using vegetal oils for formulating ecological lubricants [10]         |
| 2017 | G C Cristea              | Tribological characterization of soybean oil additivated with nano materials based on carbon (black carbon, graphite and graphene) [11] |
| 2019 | T F Ionescu, D Guglea, D Dima, C Georgescu, L Deleanu | Influence of ZnO concentration in rapeseed oil on tribological behavior [12] |
| 2019 | D Guglea, T F Ionescu, D Dima, C Georgescu, L Deleanu | Tribological behavior of rapeseed oil additivated with boron nitride [13] |

2. Tests using the four ball tribotester
The balls recommended by the standard have 12.7 mm ± 0.0005 mm in diameter, with a hardness of
60...66 HRC and a surface roughness Ra = 0.032 μm, a deviation from spherical form of 0.5 μm. In
the previous standard, the steel grade was given in ISO 683-17:1999, but now the steel grade for balls is
ISO 3290-1, grade 20, equivalent to chromium steel AISI 52100 — EN 10027 100CR6 (1.3505).
One of the suppliers for the balls, with high quality as concerning the surface texture, hardness and
tolerances is SKF [16].

There are studies using other steel grades for manufacturing the balls or even using balls made of
ceramics, hard polymers or composites in order to assess the tribological characteristics of such rarely
used materials.

Xiao et al. [17] studied the performances on different coatings on the balls, using the same
lubricant (GL-5 heavy-duty extreme pressure gear oil 85W/90). AISI 52100 steel balls were selected
because of their appropriate hardness (a diameter of 12.7 mm, hardness of 61–66 HRC, and surface
roughness Ra of 0.014 μm), according to the standard IP-239. The motor was driven at 1200...750 rpm
with a test duration of 1200 s, in accordance with ASTM D4172. The applied loads were 785 N, 981
N, 1569 N and 6076 N. This is also an example of how researchers could combine procedures and
requirements of related standards.

Lesniewski and Krawiece [18] studied the effect of ball hardness, the test balls being made of
100Cr6 steel with a hardness of 24–62 HRC. A mixed lubrication model correlating the hardness of
the steel sliding surfaces, the magnitude of the friction and the wear of the surfaces in a defined range
of parameters (pressure \( p_{Hertz} \) and sliding velocity \( v \)) for lubrication with oil Transol 150, has been
developed. Hardness has been found to have a significant influence on wear. The top ball rotated at
1450 rpm. The first test was performed under applied load $F = 800$ N. The load was stepped up (in accordance with the standard) in next tests until the balls welded. An analysis of WSD (wear scar diameter) indicates that, in the range of applied Hertz pressure ($p_{\text{Hertz}} = 2600–4000$ MPa), speed ($v = 0.12 – 0.68$ m/s) and surface hardness ($H = 24–62$ HRC), there is a relationship between wear scar diameter on the fixed balls and their hardness $H$ (figure 3).

![Figure 3. 3D diagram for the relationship $d = f(v, H)$, at $p_{\text{Hertz}} = 3800$ MPa [18].](image)

In 2012, Dongare and Vikhe Patil [19] applied ASTM-D-2783, the standard test method for measurement of Extreme Pressure (EP) properties of lubricating oils. By using four ball extreme pressure oil testing, the machine plays an important role in selecting a lubricating fluid. Lubricating oils are needed to reduce frictional losses as well as to support working load and avoid metal to metal contact between the components working together, for obtaining the desired functions in machines.

### Table 2. Standard parameters and new parameters that could be discussed, based on the same test.

| Standard parameters                                                                 | Other parameters for evaluating the tribological behavior                                                                 |
|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|
| • the weld load to the nearest 100 N, for 10 s or 60 s;                            | • evolution of friction coefficient in time or/and for different periods of testing time, for mild and/or severe regimes, with different speeds and loads; |
| • the mean Hertz load to the nearest 10 N for 10 s or 60 s;                          | • 2D and 3D profilometry of the wear scars;                                                                               |
| • the initial seizure load to the nearest 50 N, for 10 s or 60 s;                    | • same parameters, but evaluated for longer periods;                                                                        |
| • the flash temperature parameter for 10 s or 60 s;                                 | • wear rate of the WSD;                                                                                                |
| • the average WSD to the nearest 0.01 mm;                                           |                                                                                                                          |
| • the wear-load curve.                                                              |                                                                                                                          |

A brief comparison among the standard methods for determining the extreme-pressure and anti-wear properties of technical fluids are presented in Table 3. There are standards using the same tribotester and similar, but not precisely identical, procedures.

ASTM has standardized several procedures, based on the use of the four-ball machine:
- ASTM D2266; (for greases) [20],
- ASTM D4172; WP tests for lubricating fluids [21],
- ASTM D2783 EP test for lubricating fluids [22],
- ASTM D2596 for grease [23],
- ASTM D5183: Coefficient of friction of lubricants [24].

The Energy Institute has standardized IP 239 EP and AW tests for lubricants [25].
DIN has standardized DIN 51350, Extreme pressure properties test for liquid lubricants, divided into five parts:
- Part 1: General working principles [26],
- Part 2: Determination of the welding load of liquid lubricants [27],
- Part 3: Determination of the wearing characteristics of liquid lubricants [28],
- Part 4: Determination of the welding load of consistent lubricants [29],
- Part 5: Determination of the wearing characteristics of consistent lubricants [30].

DIN, ASTM and Energy Institute test methods stipulate different rotational speeds. Table 3 summarizes the test conditions for these standards.

Table 3. Test parameters for different standards using four ball tribotester [5] (EP - extreme pressure).

| Standard     | Lubricant       | Type of test | Load (N)               | Duration     | Rotational speed (rpm) | Temperature °C |
|--------------|-----------------|--------------|------------------------|--------------|------------------------|----------------|
| SR EN ISO 20623:2018 | Liquid lubricants and greases | Test A | 60 to 8000 (some machines can support up to 12000) | 60 min | 1450 to 1500 | any |
| STAS 8618_79 (not withdrawn) | Oils | Test B | 60...1200 | 60±5 s | 1425 ± 50 | 20 ± 5 |
| ASTM D2266 | Grease | Test C | 392 | 60 min | 1200 | 75 |
| ASTM D4172 | Oil | Wear | 147 (A), 392 (B) | 60 min | 1200 ± 60 | 75 |
| ASTM D2596 | Grease | EP | 59 to 7848 | 10 s | 1770 | 19 to 35 |
| ASTM D2783 | Oil | EP | 59 to 7848 | 10 s | 1760 ± 40 | 18 to 35 |
| IP 239 | Grease, oil | EP + wear | 60 to 7940 | wear: 60 min EP:10 or 60 s | 1450 | Not specified |
| DIN 51350-2 | Oil | Weld load | 2000 to 12000 | 60 s | 1450 | 18 to 40 |
| DIN 51350-3 | Oil | Wear | 150 (A), 300 (B) | 60 min | 1450 | 18 to 40 |
| DIN 51350-4 | Consistent lubricant | Weld load | 2000 to 12000 | 60 s | 1450 | 18 to 40 |
| DIN 51350-5 | Consistent lubricant | Wear | 150 (C), 300 (D), 1000 (E) | 60 min, 60 min, 10 s | 1450 | 18 to 40 |

A comparing analysis of these tests points out:
- the rotational speeds, meaning also the sliding speeds, are different. The lowest value is recommended in ASTM D4172. The sliding speed influences the regime that is generated in contact, the local flash temperature, but also the temperature in the bath oil, thus, all the commanding parameters of the test have to be mentioned and the standard procedure that was applied;
- SR EN ISO 20623:2004 [31] did not required a certain temperature, and the same is for the standard reviewed in 2018, thus, becoming more flexible for testing procedure. But it gives a calculus for the flash temperature of each test, using a relationship that depends on load and scar diameter after seizure;
- the time of testing is now specified for mild regime (1 h) and severe one (till seizure), the same for ASTM D2783 and SR EN ISO 20623:2018, but different for STAS 8618_79 [32], now withdrawn.
- loads are identical for the standards ASTM D2783, SR EN ISO 20623:2004 and STAS 8618_79; the standard ASTM D4172 imposes two loads, but much lower than the other ones (15 kgf or 40 kgf).

SR EN ISO 20623:2018 [5] proposed three different test conditions:
• test A for the load-wear index (LWI);
• test B for the wear-load curve;
• test C for the wear.

As concerning the number of measured parameters, the standard SR EN ISO 20623:2018 proposes the following the lubricants' properties to be reported:

• initial seizure load (ISL);
• weld load (WL);
• wear-load curve;
• load-wear index (LWI);
• anti-wear characteristics short duration (MWSD) (10 s or 60 s) and long duration (60 min).

3. Discussions

Some testing methodologies are standardized, there are also original variants, applicable for only a research study, but the tendency in the research field is to use both or even a combination. For instance, one may adopt the test rig, but different parameters to be recorded. Thus, comparison among results has to be carefully done, as differentiation in test procedure could change the final results. For instance, making the test lasting for more than 1 hour could be of interest for specialists, but results have not to be compared to tests of other durations, even if the other test conditions are the same.

Concerning the measurement of time required by experiments, ASTM 2783, ASTM 4172 and SR EN ISO 20623 standards indicate timers with various accuracies. STAS 8618 made use of a chronometer.

For the measurement of the wear scar diameters, all the standards, except for STAS 8618, suggest removing or not removing the balls from the cup. An optical bifocal microscope of low magnification (as in figure 1) is more productive, as it could be kept near the machine, but now, measurements are done with optical or electronic microscope, the advantage of the last ones being that texture quality, seizure and material modifications could be more easy observed (figure 4).

![Image of wear scar](image)

**Figure 4.** Images of wear scar.

The anti-wear and extreme-pressure properties are reflected by measuring the friction moment among the triboelements and by the friction coefficient calculated by the help of the friction moment, and by the magnitude of the scar diameters, generated on the fixed balls.

New revision of standard SR ISO 20623, in 2018, becomes more versatile, introducing the following major changes as compared to the previous edition:

• test procedure extended to liquid lubricants and greases, but specifying them ("liquid lubricants (categories C, D, F, G, H, M, P of ISO 6743-9), lubricating greases (ISO 6743-9, category X) and other consistent lubricants" [5]). The test conditions are not intended to simulate particular service conditions, but to provide information over a range of standard
conditions for the purpose of research, development, quality control and fluid ranking. The output is used in lubricant specifications to the nearest 0.2 s;

- the procedures have been revised, but the test principle was kept;
- the test balls have been better specified;
- calculations for wear parameter test have been included;
- the calibration procedure of the friction recorder springs has been deleted and reference is now done to the manufacturer's instructions.

Usually, wear parameters could include the volume or mass loss of the ball (as average of the three values obtained for each fixed ball). In four ball tests, a characteristic wear parameter is the wear scar diameter (WSD). Many authors give the results of wear using this parameter. WSD is the arithmetic mean of the six measurements, two on each of the three fixed balls of a test. For each ball, the wear diameter was measured in the direction of sliding and perpendicular to it.

Many tests are done with 1 h duration, with different rotational speeds, but the sliding distance is different, depending on time. For instance, Georgescu [10], Solea [9] Cristea [11], Ionescu et al. [12] and Guglea et al. [13] used different speeds and the calculated sliding distances for 1 h are: \( L_{1000} = 1378.8 \text{ m} (v = 0.38 \text{ m/s or 1000 rpm}) \); \( L_{1400} = 1933.2 \text{ m} (v = 0.53 \text{ m/s or 1400 rpm}) \); \( L_{1800} = 2487 \text{ m} (v = 0.69 \text{ m/s or 1800 rpm}) \). It is possible that the graph of the WSD dependence on test parameter is not relevant due to the difference in the sliding distances, and so, on the basis of the literature [35], the wear can be also evaluated by another parameter, called the wear rate, where:

\[
\frac{\Delta V}{F \cdot L} = \text{wear rate}
\]

where \( \Delta V \) – variation in sample volume (volume of removed material), \( F \) – loading force; \( L \) – sliding distance.
The product $F\cdot L$ is the mechanical work done by the tribosystem, in other words, the wear rate shows the loss of material volume or mass for the mechanical work unit performed by the system. The wear rate of WSD (wear scar diameter) is:

$$w(\text{WSD}) = \frac{\text{WSD}}{F \cdot L} \text{ [mm/Nâ€¢m]}$$  \hspace{1cm} (2)$$

where WSD is the wear scar diameter average for a test, $F$ – the load applied on the four balls, $L$ – the sliding distance.

Based on literature, but also on their own research studies, the authors consider that the lubricating capability of a lubricant could be characterized by supplementary investigation on the wear scars, bath lubricant temperature, changes in tested fluids etc. Wear scars could be scanned with a laser profilometer and 2D and 3D texture parameters could give information about the wear progress, the quality of worn surfaces, seizure spots and so on [10], [34].

Figure 5 gives the images of the wear scars and the dependence on load and speed could be qualitatively noticed.

Figure 6 presents the evolution of the friction coefficient (here, the moving average of 100 values, with 7200 values for 1 hour test). These graphs are useful for establish if this parameter becomes stable, how high are its peaks etc. For longer test duration, oscillations of COF may indicate the presence of wear debris or additive agglomerations.

![Figure 6](image)

**Figure 6.** Evolution of friction coefficient (COF) in 1 h of test, for rapeseed oil.

An interesting discussion may be done with the help of figure 7, presenting wear scar diameter (WSD) and wear rate of WSD, $w(\text{WSD})$.

![Figure 7](image)

**Figure 7.** A comparison of WSD and $w(\text{WSD})$ diagram.
A jump of the WSD (as it is from 100 N to 200 N, at \( v = 0.69 \) m/s) could emphasis a change of the working regime, from one with full film (at 100 N) to a mixt or boundary regime (at 200 N) as wear is more intensive in a mixt or boundary regime. For the other two tested speeds (0.38 m/s and 0.53 m/s), WSD increases with load, without any obvious jump. If the wear rate of WSD is calculated according to relationship (2), the best regimes for reducing wear rate are those of higher speed as this parameter influence more the generation of a fluid film [36].

Repeatability (intradetermination accuracy) and bias (difference between measurements) was achieved because each set of parameters (load, speed, additive concentration) was repeated twice and figure 8 [11] shows the evolution of the friction coefficient (COF) over time for two tests performed with the same parameters to evaluate the repeatability. Few researchers reported three tests under similar conditions of sliding.

![Figure 8. Evolution of COF in time for two tests done with the same parameters [11].](image)

Figure 9 presents how the stable regime could be evaluated. The average values of COF for 1 hour (the entire duration of a test) (a) are higher than the same values calculated for the last 10 minutes (b), meaning that the surfaces in contact accommodate (or run in) at the beginning of the test.

![Figure 9. Average of recorded values for the friction coefficient, rapeseed oil.](image)

Figure 10 presents the virtual reconstruction of the wear scars, for two tests, as obtained by the help of a dedicated soft [33], for the rapeseed oil tested 1 hour under different conditions. Studies on wear scar profilometry were done initially by Georgescu et al. [34] and revealed how much the regime parameters influence the quality of worn surfaces.
Figure 10. Virtual reconstruction of the wear scar texture by the help of a non-contact profilometer, for one of the three balls, tested in rapeseed oil (plan levelling from initial spherical shape).

4. Conclusions
SR ISO 20623:2018 is a very versatile standard for evaluating the tribological behavior of liquid lubricants and it will continue to be used for this purpose, both for ranking the already existing lubricants on market and for new formulated ones.

This new standard allows for testing liquid lubricants and grease, a step forward in comparing the large diversity of lubricants on the global market. One may notice that before reviewing this standard, ASTM 2783 and ASTM 4172 indicating as materials – fluid lubricants, EN ISO 20623 – lubricating oils and fluids and STAS 8618 - mineral oils.

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